EPSC Abstracts
Vol. 12, EPSC2018-1203, 2018
European Planetary Science Congress 2018

Titan's interior structure after Cassini/Huygens

Christophe Sotin (1), Nicolas Rambaux (2), Ondrej Cadek (3), Klara Kalousova (3), Adrien Neri (4) and Bruno Reynard (4)
(1) Jet Propulsion Laboratory–California Institute of Technology, Pasadena, CA, USA, (2) IMCCE, Observatoire de Paris – PSL Research University, Sorbonne Université, 77 Avenue Denfert-Rochereau, 75014 Paris, France, (3) Charles University, Faculty of Mathematics and Physics, Department of Geophysics, V Holešovickách 2, 180 00 Praha 8, Czech Republic, (4) Laboratoire de Géologie de Lyon: Terre, Planète, Environnement, Campus de la Doua, 2 rue Raphaël Dubois, 69622 Villeurbanne Cedex, France (christophe.sotin@jpl.nasa.gov)

Abstract

Several data sets acquired by the Cassini-Huygens mission are combined with petrological models of hydrated silicates and numerical simulations of heat transfer through the different layers to provide a model of Titan's interior structure. The gravity data are interpreted for different models of mass distribution to explain the topography. The preferred model has a moment of inertia 3% smaller than that predicted by the Radau-Darwin equation. This study suggests that Titan's moment of inertia is 3% smaller than predicted by the Radau-Darwin equation. The interior structure would be composed on an inner silicate core of 1885 km overlaid by a 690 km thick hydrosphere composed of a convective high-pressure ice layer, a salty ocean, and a convective icy crust that includes a thin outer layer made of ethane-clathrates at the poles.

1. Introduction

Titan is the only large icy moon with a dense atmosphere, organic molecules, and liquid reservoirs at the surface. The Cassini mission has revealed Titan as being a complex world with a methane cycle that requires exchange processes between the interior and the atmosphere. It is also an ocean world with the presence of a salty water ocean below an icy crust [1]. The combined analysis of gravity and topography data can help constrain its interior structure and dynamics (section 2). Implications for the size and density of the silicate core are then described in section 3 before describing the different layers of the hydrosphere in section 4 and the potential for transport of surface organics to the ocean and the transport of salts and volatiles from the deep interior to the surface.

2. Interior models

Titan's shape has been measured by radar altimetry, synthetic-aperture radar topography and stereo radargrammetry [1]. It is turned into a topographic map by substracting an ellipsoid that contains the rotational and tidal potentials. The difference between this ellipsoid and an equipotential surface calculated with the gravity coefficients up to degree 4 [3] is less than 25 m. The data are inverted into a spherical harmonics model up to degree 8 (Fig. 1). The inversion puts more weight on the altimetry data which have a better precision. The topographic map shows a strong degree (2,0) corresponding to the polar depressions, but no obvious equatorial degree (2,2).

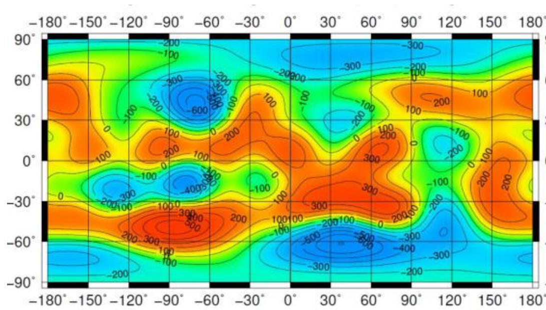

Figure 1: Titan's topography obtained from the spherical harmonics decomposition up to degree 8.

The interior model consists of four nested shells characterized by their density and outer and inner radius: icy crust, ocean, high-pressure ice layer, and silicate core. The position of each interface is calculated by solving the Clairaut equations. The ratio of J_2 to $C_{2,2}$ is close to 10/3, suggesting hydrostatic equilibrium. However, surface topography generates mass anomalies at the surface whose influence on the values of the degree 2 gravity coefficients can be large [4]. We assess the effect of topography by using a 3D spherical code where lateral mass anomalies can be included at each of the four interfaces. The effect of topography at the pole is investigated for both Airy and Pratt models based on geodynamical processes [5, 6, 7]. We also investigate the effect of non-compensated equatorial topography.

Results are summarized in Fig. 2 for the J_2 gravity coefficient. The nominal model assumes that both the polar depressions and the equatorial topography are compensated. For 100% compensation of the equatorial topography the Pratt model and the Airy model explaining the polar depressions provide slightly different values of J2 because the Airy model is compensated at the icy crust / ocean interface whereas the Pratt model is compensated within a few kilometres below the surface. The value of J_2 decreases very rapidly with decreasing degree of compensation. On the other hand, a non-compensated equatorial topography (red points and curves) increases the value of J_2 suggesting that non-compensated polar topography could be hidden by non-compensated equatorial topography. Another possibility would be to have a smaller value of the moment of inertia (smaller value of J2). The parameter space of interior models is large but however bounded as we cannot change these three parameters independently from each other. In addition, the value of $C_{2,2}$, not shown here, provides additional constraints.

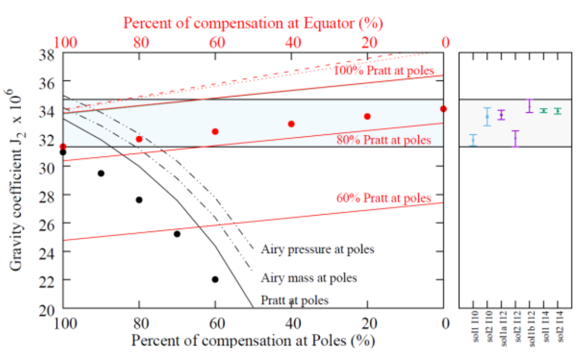

Figure 2: Value of the J_2 gravity coefficient for different degrees of compensation at the pole and at the equator. The right panel shows the values of J_2 inferred from different inversions [2, 3].

3. Implications for the composition of the silicate core

The nominal isostatic model leads to a large silicate core with a low density that corresponds to that of Mg-antigorite. It would imply that there is no iron in the silicate core. This seems difficult to accept. So a model with a smaller and denser core (smaller value of J_2) is appealing. This is possible with a non-compensated equatorial topography which leads to a silicate core 125 km smaller and 270 kg/m3 denser leading to a Fe# much closer that that of carbonaceous chondrites.

4. Structure of the hydrosphere

The present structure is very simple with constant density for each layer. Ongoing work is investigating the effect of more realistic equations of state (EoS) on the value of the MoI. With the present model, the thicknesses of the icy crust, ocean, and HP ice layer are 75, 250, and 365 km, respectively. The HP-ice would be convecting in a regime that allows for the transfer of volatiles from the silicate core to the ocean [8].

5. Summary and Conclusions

Now that the Cassini mission ended, it is possible to use the available data sets to infer the most probable interior structure. However, major questions remain such as the size of the silicate core, the thickness of the HP ice layer, and the dynamics of the icy crust. Future landed missions equipped with seismometers and orbiter missions acquiring more precise topography and gravity fields would provide the missing data to understand the interior structure and dynamics of this complex organic world.

Acknowledgements

This work has been performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA.

References

[1] P. Corlies et al. (2018) GRL, 44, 11,754-11,761. [2] Iess L. et al. (2010) Science, 327, 1367. [3] Iess L. et al. (2012) Science 337, 457. [4] P. Gao and D.J. Stevenson (2013) Icarus, 226, 1185–1191. [5] F. Nimmo and B.G. Bills (2010) Icarus 208, 896–904 [6] J. Kvorka et al. (2018) Icarus, in revision [7] Choukroun M. and Sotin C. (2012) GRL, 39, L04201. [8] Kalousova K. et al. (2018) Icarus, 299, 133-147.