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Tidal Dissipation and Forced Libration in Enceladus

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Abstract

The estimations of the heat dissipated in Enceladus based on the observations with Cassini support the idea of a non-stationary process in which an increase in temperature decreases the viscosity and consequently increases the heat dissipation and so on, cyclically. This could favor the existence of an internal ocean, consistent with the plumes and the large physical libration around the observed synchronous rotation. The new version of the creep tide theory allows us to reconcile all measurements and construct internal models constrained by the set of all observational parameters of Enceladus determined by the Cassini mission.

1. Introduction

One of the puzzling phenomena discovered by the Cassini mission is the existence of strong geysers ejecting plumes of water near the South Pole of Enceladus. These plumes evidence the existence of heat sources in the interior of the satellite, much more strong than the 1 GW indicated by classical tidal theories when the Kelvin's formula for k_2 and arbitrarily fixed values for the rigidity are used. If more realistic values of k_2 (and Q), is used [1], the dissipation obtained with classical models is of the order of the observed values, estimated at 5-16 GW. The creep tide theory [2],[3] and [4], indicates that the observed heat flow is simply due to the low viscosity of the outer layers (ice near the melting point). The comparison with Mimas, with no tectonic activity due to internal heating and viscosity at least one order of magnitude larger (ice at temperatures well below the melting point) are a clue for the existence, in Enceladus, of a non-stationary process in which an increase in temperature decreases the viscosity and consequently increases the heat dissipation, and so on cyclically (see Fig. 1). Such a process may have been triggered by some transitory event enhancing the eccentricity of Enceladus and may have been progressing slowly, subsisting even after the eccentricity was damped to its current value. On the other hand, Enceladus presents a forced libration of $0.120° \pm 0.014°$ [9] that cannot be explained with a tidal theory for homogeneous bodies. Consequently with the proposed non-stationary process, the presence of an internal ocean may decouple rotationally the crust from the interior, allowing a greater amplitude of libration.

Figure 1: Scheme of the cyclical non-stationary process possibly taking place in Enceladus.

2. Tidal Dissipation

2.1. Dissipation vs. Viscosity

A new formulation of the creep tide theory has been developed [4] to cope with the case of bodies whose rotation is not synchronous but is oscillating with a forced oscillation around the synchronous state (physical libration). The new model was used to calculate the tidal dissipation in several satellites. The result is shown in Fig. 1. The result for Enceladus corresponds to a viscosity $0.6 - 1.9 \times 10^{14}$ Pa s, of the order of the viscosity of melting ice. At variance, the absence of current tectonic activity in Mimas is evidence of a small dissipation (<1 GW), that corresponds to a viscosity $> 10^{16}$ Pa s, which corresponds to a low temperature ice.

2.2. Non-stationary scenario

Because of ice's low conductivity (2-6 W/mK), the crust ability to transfer heat produced in the interior is of some 10^{-2} W/m, i.e. the order of the observed values. The surface temperature measurements [8] show

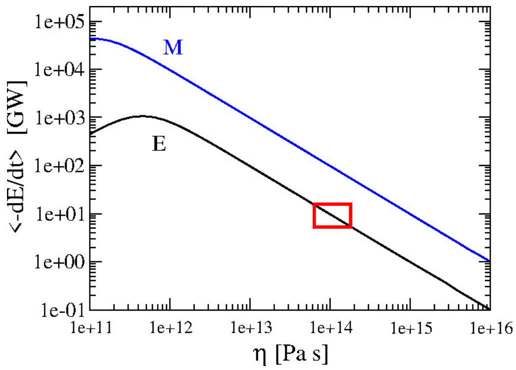

Figure 2: Dissipation curves of Enceladus (black line, labelled E) and Mimas (blue line, labelled E). The red box shows the observed dissipation in Enceladus [4].

the inability of the crust ice to fully transfer the produced heat. Most of the internally produced heat is flowing through the faults existing in the South Pole. The accumulation of heat below the crust allows the existence of a wide liquid layer with lower viscosity and enhances the tidal heat production. Once triggered by some resonance crossing [7], the satellite heating may become self-sustained and lasts for a long time.

3. Forced Libration

3.1 Crust thickness and density

The forced libration obtained with the creep tide theory for homogeneous bodies, in the case of Enceladus, is 3.1 times smaller than the libration amplitude obtained from Cassini's observations. However, the extension of the creep tide theory to the case of differentiated bodies with an ocean between the crust and the inner parts by Folonier et al. [5] allows us to construct models constrained by the set of all observational parameters of Enceladus determined by the Cassini mission. The results are shown in Fig. 3. If the crust viscosity is $\geq 0.3 \times 10^{14}$ Pa s, the range for the crust thickness is $18.5 - 22.0$ km and its density is ≥ 960 kg/m^3, depending on the crust viscosity value.

3.2 Interior model

The gravity harmonic coefficient $C_{22} = (1549.8 \pm 15.6) \times 10^{-6}$ [6], beside the total mass and the mean radius of Enceladus allows us to determine the rest of the internal parameters. For the core, we obtain that the radius is in the range 195-197 km, the density is in the range 2295-2320 kg/m^3, and the ocean thickness

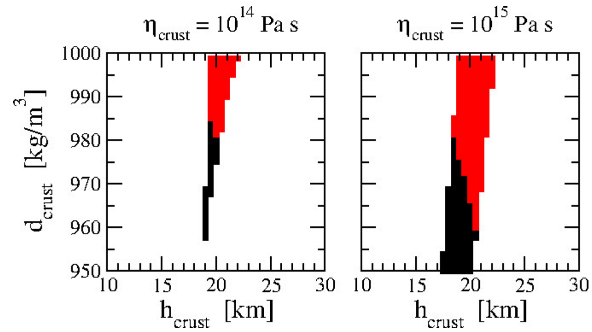

Figure 3: Values of the density, thickness and viscosity of the crust for which the physical libration and the dissipation have the observed values (red). In the black points, we have the observed libration but not the observed dissipation.

is in the range 35-38 km (the ocean density is assumed as 1000 kg/m^3).

Acknowledgements

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