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Differentiation and melting of Rhea

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Abstract

Thermal history of Rhea from the beginning of accretion is investigated. Large scale melting of the satellite's matter and gravitational differentiation of silicates from ices are considered. The results indicate that the partial differentiation of the matter of the satellite's interior is possible only for narrow range of parameter.

1. Introduction

Rhea is a medium sized icy satellite (MIS) of Saturn. It is built of mixtures of rocks and ices. The rocky component is believed to be of chondritic composition. The main component of ices is frozen H_2O. Initially the interior was built from homogenous mixture of both components. The separation of rocky component from the ices is known as differentiation. It is possible if the icy component is molten in the large part of the satellite interior. During this differentiation the high density silicate grains sink in the liquid eventually forming the central core. The low density matter forms an upper layer.

Analysis of the Doppler data acquired by the Cassini spacecraft on November 26, 2005 yields the mass of Rhea and its gravity field with unprecedented accuracy [3]. It was found that Rhea is in hydrostatic equilibrium. Moreover, models with a constant silicate mass fraction throughout the body cannot account for the determined quadrupole coefficients of the gravity. Eventually, [3] conclude: "The one model that fits the gravity data and is self-consistent […] is an "almost undifferentiated" Rhea, in which a very large uniform core is surrounded by a relatively thin ice shell containing no rock at all".

In the present paper we try to find conditions necessary for this partial differentiation.

2. Description of the model

The parameterized theory of convection combined with FDM (Finite Difference Method) approach is chosen for the present research [1, 2]. The approach is based on the 1 dimensional equation of the heat transfer in spherical coordinates:

$$\rho c_p \frac{\partial T(r,t)}{\partial t} = \mathrm{div}(k(r,T)\,\mathrm{grad}\,T(r,t)) + Q(r,T) \quad , (1)$$

where r is the radial distance (spherical coordinate), ρ is the density [kg m^{-3}], c_p [J kg^{-1} K^{-1}] is the specific heat, Q [W kg^{-1}] is the heat rate, and k [W m^{-1} K^{-1}] is the thermal conductivity. Note that Q(r, t) includes sources and sinks of the heat: radiogenic heat resulting from the decay of isotopes, latent heat of melting and latent heat of solidification. The heat of accretion is included as initial temperature of the accreted layer.

The heat transported by convection is included by multiplying the coefficient of the heat conduction in the considered layer by the Nusselt number Nu:

$$k_{conv} = Nu\ k, \quad (2)$$

where for Nu we use the formula given by [4] for temperature dependent viscosity and for the medium viscosity contrast.

3. Basic results of the model

We found that partial differentiation followed by uprising of light component is consistent with observations of gravity and surface of Rhea. Our calculations indicate that partial melting is possible only for narrow range of parameters. It makes possible to determine approximately the time of accretion of Rhea. The time from forming CAI to the end of accretion is probably from 2.9 to 4.1 My.

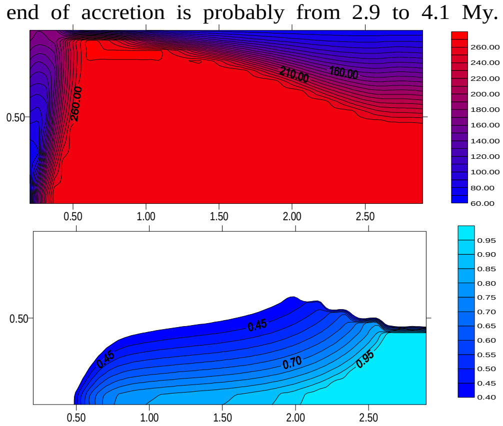

Figure 1. Thermal and melting history in Rhea according to our model for accretion starting 0.4 My after formation of CAI and lasting for 1 My. The reference viscosity of ice at melting temperature is $\eta_m=10^{12}$ Pa s. The vertical axis gives r/R_{sat}, the horizontal axis gives $\log_{10}$(t [My]), where t is the time from the beginning of accretion. The upper panel presents isotherms in Kelvin, the isolines in lower panel give supplied fraction of latent heat of melting (1 means fully molten matter). Note substantial phase shift between temperature distribution and melting distribution and that the melting starts after 100 My only [2].

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