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Coupling satellite thermal and orbital evolution: application to Enceladus and Dione.

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Abstract

We develop a numerical tool which couples satellite thermal and orbital evolution. The thermal evolution is based on 1D conductive code while the orbital evolution uses an N-body approach. As a first example we study the evolution of Enceladus and Dione. Our preliminary results show that their eccentricity evolution is different from a case using constant tidal parameters.

1. Introduction

With few exceptions, the thermal and orbital evolution of Saturn's icy satellite have been studied as separate problems. On the one hand thermal evolution studies do not take into account aspects of long-term orbital evolution such as resonance crossings [1, 7], while on the other hand orbital evolution studies generally assume constant tidal parameters [6, 10]. One exception is an analytical study of Enceladus' coupled thermal-orbital evolution [6]; several studies of the Galilean satellites have included thermal-orbital feedbacks [8, 3].
The multiple orbital resonances present among the saturnian satellites suggest that their orbital parameters and so the tidal dissipation have evolved over time. Similarly, the non-steady-state heat production at Enceladus suggests its eccentricity has evolved [4]. We are currently developing a coupled simulation of satellite thermal and orbital evolution. As a preliminary work we study the evolution of two saturnian satellites: Enceladus and Dione.

2. Model

The thermal evolution of the satellite is determined in a spherical geometry and the energy equation is solved radially (1D code) with a predictor-corrector method. The numerical domain extends from the center to the surface with a resolution of few kilometers. For differentiated bodies (as we assume here), the heat conducted out of the silicate core may result in melting of the overlying ice. We track the subsequent evolution of any subsurface evolution, assuming that the heat coming out from the core is instantaneously transmitted to the base of the ice shell.
Two different viscoelastic linear rheologies are considered in order to compute the love number k_2 and the dissipation factor Q: (i) a Maxwell model and a Burgers model. k_2 and Q are then transmitted to the orbital evolution code.

The detail of our orbital model has been published in the appendix of [10]. The core of the orbital code is a variable-order Bulirsch-Stoer integrator. Saturn and the satellites are treated as point masses with corrections from tidal and rotational deformation. Secular interactions among the satellites are automatically handled using the N-body approach. Tidally-deformed planet/satellites are modeled as ellipsoidal bodies and their potentials are expanded out to the fifth-order in R/r, where R is the radius of the tidal-raising body, and r is the separation between Saturn and the satellite. The strength of tidal deformation is parametrized by two quantities: the tidal quality factor Q, and the second degree Love number k_2. Because these two quantities are both controlled by the satellite's internal structure, the thermal and orbital evolution are hence coupled.

3. Results

As a first example we chose to study the coupling between Enceladus and Dione. Their coupling has already been studied by previous works [5, 6, 10] making our results easier to compare. As long as we study the resonance with constant tidal parameters the start time of the simulation doesn't matter. But the internal structure (and thus the tidal parameters) of Dione and Enceladus differ significantly depending on whether we begin during the first tens of millions year of their evolution or in the last billion years. For our preliminary simulation, we use initial parameters in our thermal model such that the tidal parameters will evolve

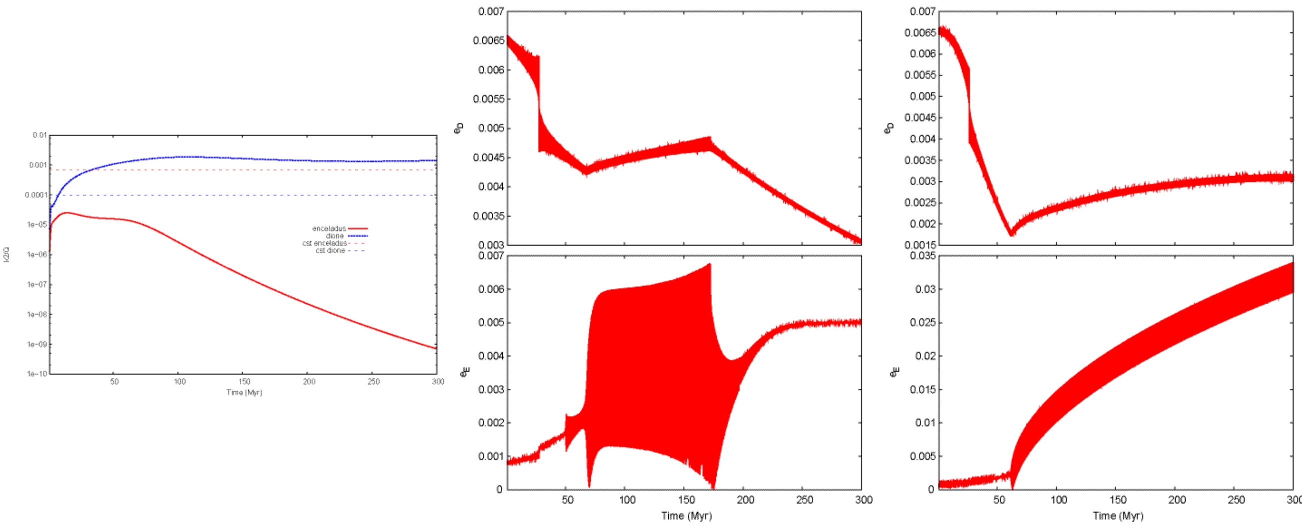

Figure 1: Enceladus-Dione eccentricity and k_2/Q evolution. a) k_2/Q for simulations coupling thermal and orbital evolution. Values used in the constant case are also plotted. b) and c) Eccentricity evolution for Dione and Enceladus (respectively e_D and e_E) using constant k_2/Q shown on a). d) and e) Eccentricity evolution for Dione and Enceladus with k_2/Q consistent with thermal evolution.

in few tens of millions years. Thus an initial temperature profile of 200 K was assumed, and we begin our simulation 5 Myr after CAI (Calcium-Aluminum rich inclusion) formation. Each body is assumed to be differentiated into a silicate core and icy mantle. Density and radius are following [9].

Figure 1 shows the evolution of k_2/Q and the eccentricity for this preliminary simulation coupling thermal and orbital evolution. Figure 1a shows that k_2/Q for Enceladus decreases as it cools, while for Dione k_2/Q remains more constant, owing to Dione's greater radius and higher silicate mass fraction. Figures 1b and 1c show the eccentricity evolution of Dione and Enceladus with constant k_2/Q and reproduce very well the results from [10]. Figures 1d and 1e show the same evolution with a time-variable k_2/Q (Figure 1a). The eccentricity evolution is totally different for both bodies. The two orbits encounter the e_D resonance (see [10] for further details) at $\sim$ 25 Myr as their k_2/Q values are not so different from the values used in the constant case. But after $\sim$ 70 Myr as Enceladus cools its k_2/Q decreases and the eccentricity evolution changes radically so that later resonances are not encountered.

4. Summary and Conclusions

Our preliminary results show that satellite orbital and thermal evolution should be studied together in order to better understand their evolution.

References

[1] Běhounková, M., Tobie, G., Choblet, G., and Ondrej, Čadek. Coupling mantle convection and tidal dissipation: Applications to Enceladus and Earth-like planets. J. Geophys. Res., 115, E09011, 2010.

[2] Carslaw, H. and Jaeger, J.: Conduction of heat in solids, Oxford University Press, 1959.

[3] Hussmann, H. and Spohn, T. Thermal-orbital evolution of Io and Europa Icarus, 171, 391-410, 2004.

[4] Meyer, J. and Wisdom, J. Tidal heating in Enceladus Icarus, 188, 535-539, 2007.

[5] Meyer, J. and Wisdom, J. Episodic volcanism on enceladus: Application of the ojakangas-stevenson model. Icarus, 198, 178-180, 2008a.

[6] Meyer, J. and Wisdom, J. Tidal evolution of Mimas, Enceladus, and Dione. Icarus, 193, 213-223, 2008b.

[7] Roberts, J.H. and Nimmo, F. Tidal heating and the long-term stability of a subsurface ocean on Enceladus. Icarus, 194, 675-689, 2008.

[8] Showman, A. P., Stevenson, D. J. and Malhotra, R. Coupled orbital and thermal evolution of Ganymede Icarus, 129, 367-383, 1997.

[9] Thomas, P. Sizes, shapes, and derived properties of the saturnian satellites after the Cassini nominal mission Icarus, 208, 395-401, 2010.

[10] Zhang, K. and Nimmo, F. Recent orbital evolution and the internal structures of Enceladus and Dione. Icarus, 204, 597-609, 2009.