**Librational response of Enceladus to its interior structure** Nicolas Rambaux, Julie C. Castillo-Rogez, James G. Williams, and Ozgur Karatekin.

**Introduction**

The physical librations of Enceladus might play a significant role in its geophysical structure and plume events. Therefore, it is important to investigate the physical libration response of Enceladus to Saturnian torque. We determined in [2] that the largest librational responses are oscillations at 11 and 4 years periods related to the orbital perturbation of Enceladus by a 2:1 resonance with Dione. These long period librations have amplitudes almost independent of the triaxiality of the body. However, the third main libration is an oscillation at 1.37 days period related to the eccentricity of Enceladus’ orbit and its amplitude is dependent on the triaxiality of the body because of the short period [2]. Thus, the libration in longitude at the orbital period might provide information on the distribution of mass inside Enceladus.

Our objective in this study is to give a possible relationship between the interior structure and the librational response of Enceladus. In addition, we investigate the impact of tidal coupling on the librational motion of Enceladus by varying possible viscoelastic structures. For this study we assumed that Enceladus does not include an ocean, the presence of which at the global scale is a matter of discussion [3,4].

**Interior models**

We constructed two-layer interior models of Enceladus constrained by its mass and radius. For given core and mantle densities, total moment of inertia of the body is determined. Then, by using the fact that the body is in synchronous spin-orbit resonance, we calculated the surface triaxiality by the method of [5]. The triaxiality parameter $\sigma$ is equal to $(B - A)/C$, where $(A < B < C)$ are the unnormalized moments of inertia.

**Librational response**

The Enceladus physical librations in longitude are driven by any departure of its orbit from a circle. The librational response of Enceladus at the orbital period is of the form

$$\gamma = \frac{6e\sigma}{3\sigma - 1} \sin(nt + \phi) \tag{1}$$

where $\gamma$ is the libration in longitude at the orbital period, $e$ the eccentricity, $n$ the orbital frequency, $t$ the time, and $\phi$ is the mean anomaly at $t = 0$ (the libration argument is the mean anomaly and the libration in longitude is equal to zero at the pericenter). Therefore, the libration angle $\gamma$ depends on the magnitude of the eccentricity but also on the proximity of the forcing frequency $n$ to the proper frequency $n\sqrt{3\sigma}$ (also called free libration frequency) resulting from the spin-orbit resonance. Periods are inversely related to frequencies and for all models of the interior the proper period of Enceladus is about 6~7 days, i.e. different from the orbital period (1.37 days).

The librational response of Enceladus as a function of its interior is shown in Figure 1. Depending on the radius of the core, the amplitude of the libration in longitude at the orbital period varies between 113 and 139 m on the equator.

The behavior of the curves of Fig. 1 can be interpreted by using the density jump $\Delta \rho$ between the core (characterized by faint black lines) and the ice shell (in colored lines). For a homogeneous body (not shown here), the density jump is zero and the triaxiality is maximum, $\sigma = 0.0231$ [2]. For interior models with a large core the density jump is smaller than for models with a small core by conservation of the mass. Therefore, the triaxiality is higher for models with a large core resulting in larger librational amplitudes (the restoring torque from Saturn is therefore stronger). Similarly, models
with a higher ice shell density present larger libration amplitudes due to the fact that the mean density of Enceladus is about 1600 kg/m$^3$ and thus models with higher ice shell density tend toward a homogeneous body (small density jump) and the triaxiality becomes larger implying a larger libration amplitude.

**Dissipation effects**

We estimate the impact of tides on the libration and orientation of Enceladus. The viscoelastic behavior of Enceladus is characterized by using the Andrade model [6]. The change in the nonrigid body libration amplitudes due to tidal coupling are negligible. Nevertheless, tidal dissipation induces a small phase shift up to 0.6° corresponding to a displacement of Enceladus’ figure of a few meters, 1.3 meters, along the moon’s equator at the mean anomaly period.

**Conclusion**

The librational amplitude for two-layer solid models ranges between 113 and 139 meters depending essentially on the core radius for plausible interior scenarios. Such libration amplitudes can be determined by measuring the influence of the gravity field on the dynamics of a low orbiter on Enceladus as suggested for Europa by [7]. We note also that the presence of a global ocean as a third layer, still in debate, could decouple the icy shell from the interior freeing the shell for possible larger libration amplitude [8,9]. We will quantify this situation and compare it against the models presented in Fig. 1 in order to evaluate whether a deep ocean could be inferred from libration measurements.

The libration displacement of the surface may be inferred from gravity measurements, tracking of surface landmarks, and/or altimeter measurements. However such a determination requires several close flybys for different positions of Enceladus along its orbit, as may be achievable with a dedicated orbiter [10]. In the meantime, we hope that upcoming flybys by the Cassini orbiter will help to better constrain the orientation of Enceladus’ figure axis.

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