EPSC Abstracts
Vol. 6, EPSC-DPS2011-516, 2011
EPSC-DPS Joint Meeting 2011

Rotational signature of Mimas' interior

B. Noyelles (1,2), Ö. Karatekin (3) and N. Rambaux (4,2)
(1) NAmur Center for Complex SYStems (NAXYS), FUNDP-The University of Namur, Belgium
(2) IMCCE - Paris Observatory, France (3) Royal Observatory of Belgium (4) Université Pierre & Marie Curie (UPMC), France (benoit.noyelles@fundp.ac.be)

Abstract

The Cassini space mission gives the opportunity to have a better knowledge of the properties of the main Saturnian satellites. Among them, Mimas is up to now poorly known, and was considered as a cold rigid body until Cassini observed surface temperature inhomogeneities. The scope of this study is to model the rotation of Mimas with different interior models, based on compaction experiments by Yasui et al. 2009 [6], allowing to consider Mimas as a rigid body composed of 2 solid layers. We also considered 2 different hypotheses for the interior model: a model based on Mimas' observed shape, and another one based on the hydrostatic approximation. The rotation has been numerically computed using the 3 degree of freedom model of rigid rotation of Henrard. Physical longitudinal librations of ≈ 4 km are to be expected, and an obliquity of ≈ 2 arcmin, while the deviation of the equilibrium position because of tides is expected to be negligible.

1 Introduction

As most of the main Solar System satellites, the Saturnian satellite Mimas is assumed to be in synchronous rotation. The period of the free librations and the amplitudes of the forced ones around the exact spin-orbit resonance are known to be signatures of the internal structure (see e.g. [3],[4]), that is the reason why we here propose a theoretical study of its rotation, based on a modern view of Mimas on the light of Cassini data and recent compaction experiments.

We first model the internal structure of Mimas, in assuming the hydrostatic equilibrium, or not. Then we estimate the dynamical signature of this internal structure, before estimating the influence of tides.

2 Internal structure

Modeling the rotation of a body requires to estimate its moments of inertia. Laboratory compaction experiments support the hypothesis of a 2-layer rigid Mimas [6], this differentiation being due to variations of porosity. Due to the lack of contraints for Mimas, we built two interior models. The first one is an hydrostatic equilibrium model whereas the second one contains non-hydrostatic anomalies as suggested by Johnson et al. 2006 [2] based on shape model.

For a two layer interior model the core radius R_c can be determined if the densities of the rocky core ρ_c and the icy mantle ρ_s are known, i.e. $R_c = R\left(\frac{\rho-\rho_s}{\rho_c-\rho_s}\right)^{1/3}$. The moment of Inertia factor ($MOI = I_p/(MR^2)$) is given as $MOI = \frac{2}{5}\left(\frac{(\rho-\rho_s)^{5/3}}{\rho(\rho_c-\rho_s)^{2/3}} + \frac{\rho_s}{\rho}\right)$. Once the MOI and R_c are determined, we can either use hydrostatic approximation or the observed shape to calculate the moment of inertia differences.

MOI is related to the fluid Love number k_f which describes the reaction of the satellite to a perturbing potential after all viscous stresses have relaxed: $MOI = \frac{2}{3}\left[1 - \frac{2}{5}\sqrt{\frac{4-k_f}{1+k_f}}\right]$, and the gravity coefficients C_{22} and J_2 are determined from $C_{22} = \frac{k_f}{4}q_r$ and $J_2 = \frac{5k_f}{6}q_r$, where $q_r = \Omega^2R^3/(Gm)$, Ω being the spin velocity of Mimas, equal to its mean motion n since Mimas is in synchronous rotation.

The differences between the three principal moments of inertia $A < B < C$ are determined from the definitions of C_{22} and J_2, i.e. $B - A = 4C_{22}MR^2$, $C - A = (J_2 + 2C_{22})MR^2$, and $C - B = (J_2 - 2C_{22})MR^2$. The relationship between the mean moment of inertia $I = \frac{A+B+C}{3}$ and the polar moment of inertia C is $C = I + \frac{2}{3}J_2MR^2$, so we can then calculate all the three moment of inertia A, B and C.

From all these calculations, we get 23 models of interior, 22 being based on the hydrostatic approximation with different densities and sizes of the core, and the last one being based on the shape of Mimas.

3 The rotation

We use the model extensively presented in [1]. It consists in considering a 3 degree of freedom rotation of Mimas, modeled by the following Hamiltonian $\mathcal{H}$:

$$
\begin{aligned}
\mathcal{H} \quad = \quad & \frac{nP^2}{2} + \frac{n}{8}\left[4P - \xi_q^2 - \eta_q^2\right] \\
& \times \left[\frac{\gamma_1 + \gamma_2}{1 - \gamma_1 - \gamma_2}\xi_q^2 + \frac{\gamma_1 - \gamma_2}{1 - \gamma_1 + \gamma_2}\eta_q^2\right] \\
& - \frac{3}{2n}\frac{\mathcal{G}M_{\saturn}}{d_{\saturn}^3}\left[\gamma_1(x_{\saturn}^2 + y_{\saturn}^2) + \gamma_2(x_{\saturn}^2 - y_{\saturn}^2)\right],
\end{aligned}
$$

in which P is the norm of the angular momentum normalized to 1, ξ_q and η_q are canonical variables related to the polar motion of Mimas, and $\gamma_{1,2}$ are related to the differences of the moments of inertia. $x_{\saturn}$ and $y_{\saturn}$ are the first 2 coordinates of the perturber, here Saturn ($\saturn$), in a reference frame bound to the principal axes of inertia of Mimas. These coordinates have been obtained thanks to TASS1.6 ephemerides [5] and 5 rotations containing the other degrees of freedom, especially the longitudinal motion and the obliquity of Mimas.

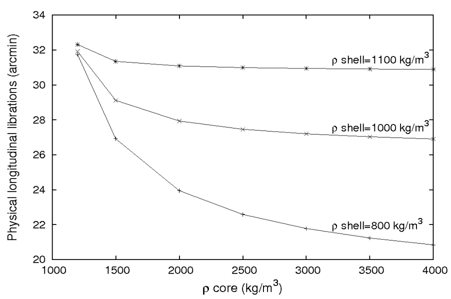

Figure 1: Physical librations of Mimas.

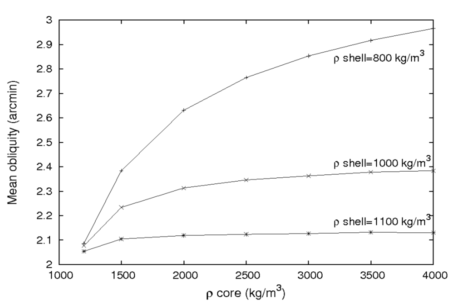

Figure 2: Obliquity of Mimas.

The Fig.1 & 2 give the amplitude the physical librations of Mimas associated with the orbital period, and the mean obliquity, with respect to the densities of the core, for a hydrostatic Mimas. For the physical librations, this represents a motion of ≈ 4 km. This quantity has to be compared with the deviation of the equilibrium position due to tidal dissipation. A study similar to the one performed by Rambaux et al.[3] for Enceladus gives a deviation smaller than 1 meter.

4 Conclusion

Physical longitudinal librations have already been observed for the Moon, for the Martian satellite Phobos, and for the small Saturnian satellite Janus. 4 km librations of Mimas should be able to be detected. Inverting them to improve our knowledge of the interior is challenging.

Acknowledgements

Numerical simulations were made on the local computing ressources (Cluster URBM-SYSDYN) at the University of Namur. This work has been supported by EMERGENCE-UPMC grant (contract number: EME0911). BN is F.R.S.-FNRS post-doctoral research fellow.

References

[1] Henrard, J.: The rotation of Io, Icarus, 178, 144-153 (2005)

[2] Johnson, T.V., Castillo-Rogez, J., and Matson, D.L.: Mimas' interior models, prospects for constraining Enceladus' thermal evolution, DPS Meeting 38, 69.03, BAAS, 38, 621 (2006)

[3] Rambaux, N., Castillo-Rogez, J., Williams, J.G., and Karatekin, Ö.: Librational response of Enceladus, GRL, 37, L04202 (2010)

[4] Rambaux, N., van Hoolst, T., Karatekin, Ö.: Librational response of Europa, Ganymede, and Callisto with an ocean for a non-Keplerian orbit, Astronomy and Astrophysics, 527, A118 (2011)

[5] Vienne, A. and Duriez, L.: TASS1.6: Ephemerides of the major Saturnian satellites, Astronomy and Astrophysics, 297, 588-605 (1995)

[6] Yasui, M., and Arakawa, M.: Compaction experiments on ice-silica particle mixtures: Implication for residual porosity of small icy bodies, J. Geophys. Res., 114, E09004 (2009)