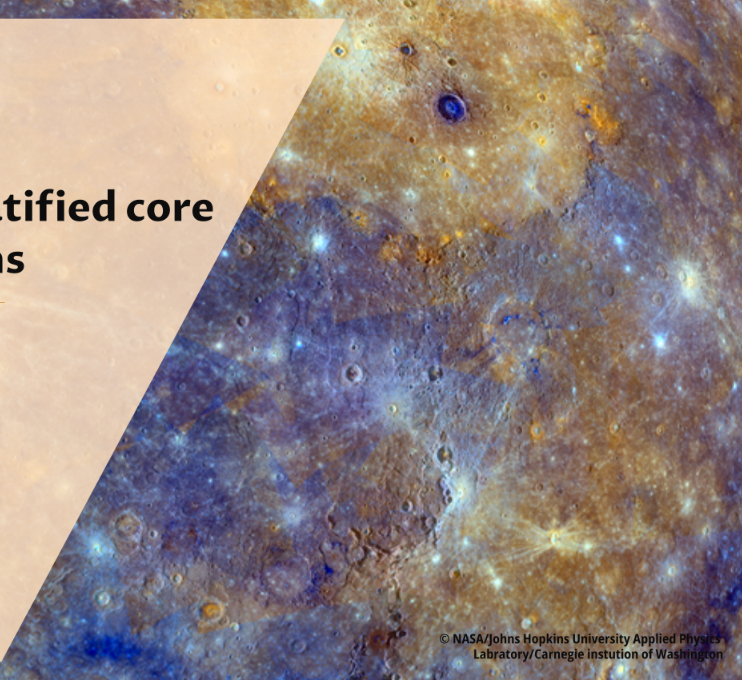
The influence of a stratified core on Mercury's librations

Fleur Seuren[1,2]

S.A. Triana[1]
J. Rekier[1]
T. Van Hoolst[1,2]
V. Dehant[1]

[1]Royal Observatory of Belgium, Uccle, Belgium
[2]Institute of Astronomy, Celestijnenlaan 200D, 3000, Leuven, Belgium



Libration

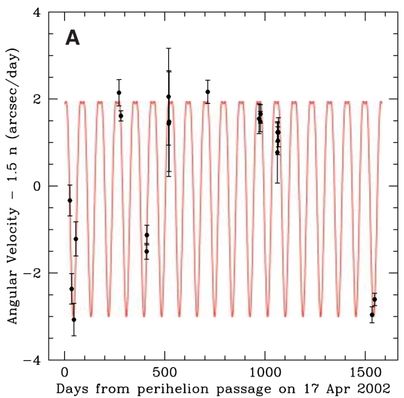


Figure 1. Observed and numerically computed spin rate deviations. Figure taken from Margot et al. (2007).

What type of flows does libration excite in Mercury's stratified core...

Stratification

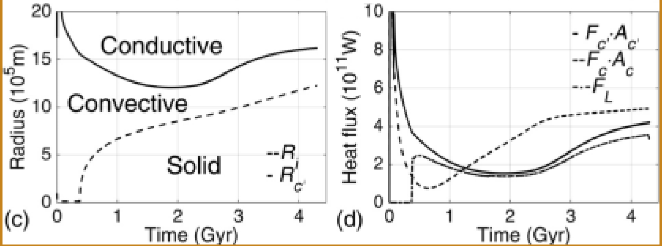


Figure 2. Archetype interior evolution of Mercury. Figure taken from Knibbe & Van Westrenen (2018).

...and can these flows influence the rotation of the mantle?

1. steadily rotating frame
2. viscous, Boussinesq, incompressible fluid
3. density as a function of temperature
4. constant heat flux through boundary
5. no-slip boundary conditions

$$\vec{\mathbf{u}}|_s = \vec{\mathbf{u}}_s \tag{1}$$

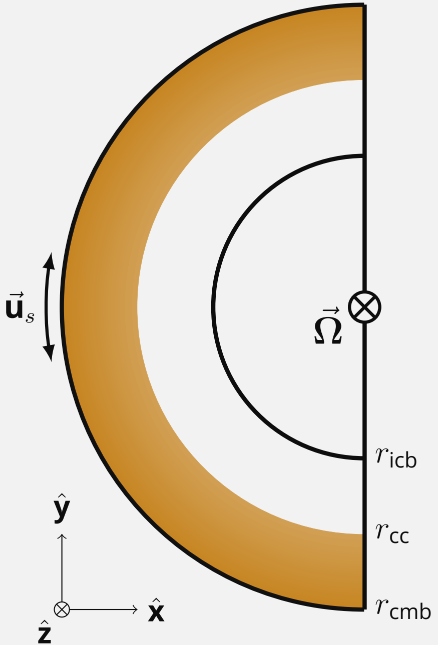


Figure 3. A simple model for the librationally induced flow inside Mercury's core.

Numerical method.

Dimensionless equations

$$\partial_t \vec{\mathbf{u}} = -2\hat{\mathbf{z}} \times \vec{\mathbf{u}} - \nabla p + r\Theta\hat{\mathbf{r}} + \mathrm{Ek}\nabla^2\vec{\mathbf{u}}\,, \tag{2}$$

$$\partial_t \Theta = -N^2(r)\vec{\mathbf{u}} \cdot \hat{\mathbf{r}} + (\mathrm{Ek}/\mathrm{Pr})\nabla^2\Theta\,. \tag{3}$$

Fully spectral decomposition

Velocity $\vec{\mathbf{u}}$ and temperature Θ perturbations expanded on spherical harmonics (tangential) and Chebyshev polynomials (radial).

Kore

https://bitbucket.org/repepo/kore/src/master/

Stratification

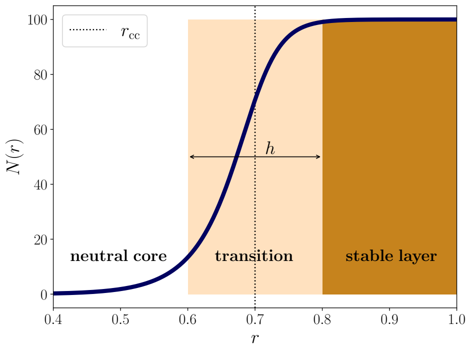
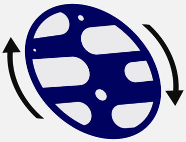


Figure 4. Buoyancy profile of the stratified case, characterized by $r_{\text{icb}} = 0.4$, $r_{\text{cc}} = 0.7$, $h = 0.2$ and $N_{\text{cmb}} \equiv N(r_{\text{cmb}}) = 100$.

Libration forcing as a boundary condition.

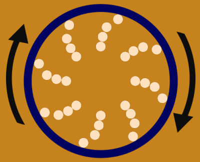
From Rekier et al. (2019) the oscillating librating motion ($\phi \rightarrow \phi + \epsilon \cos(\omega_f t)$) can be represented as the superposition of three decoupled motions of the outer boundary.



$=$

$m = 0$

tangential displacement due to viscous drag

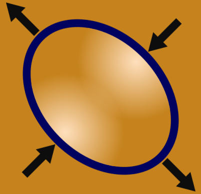


$$\vec{\mathbf{u}}|_s = \epsilon \omega_f Y_1^0 \sin(\omega_f t) \quad (5)$$

$+$

$m = \pm 2$

radial displacement due to small triaxiality



$$\vec{\mathbf{u}}|_s = 2\alpha_2 \epsilon \omega_f Y_2^{\pm 2} \sin(\omega_f t) \quad (6)$$

How can libration change the core angular momentum?

Change of core angular momentum in the model

$$\frac{d\mathbf{L}}{dt} = -2\int_V \rho_0 \mathbf{r} \times (\hat{\mathbf{z}} \times \mathbf{u})\, dV + \mathrm{Ek} \int_V \rho_0 \mathbf{r} \times \nabla^2 \mathbf{u} dV - \int_V \rho_0 (\mathbf{r} \times \nabla p)\, dV$$
$$+ \int_V \rho_0 r \Theta\, (\mathbf{r} \times \hat{\mathbf{r}})\, dV + \int_S \rho_0 (\mathbf{r} \times \mathbf{u})(\mathbf{u}_s \cdot \hat{\mathbf{n}}) dS\,. \quad (7)$$

How can the flow in the core influence the mantle rotation?

“Coffee cup lemma”

Core-mantle coupling mechanism

- viscous torque
- ~~electromagnetic torque~~
- ~~topographic torque~~
- ~~pressure torque~~

Small contribution of the viscous torque.

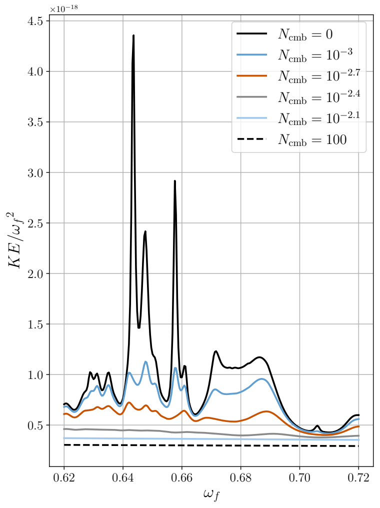


Figure 5. Kinetic energy ($m = 0$) of the core flow given various N_{CMB}.

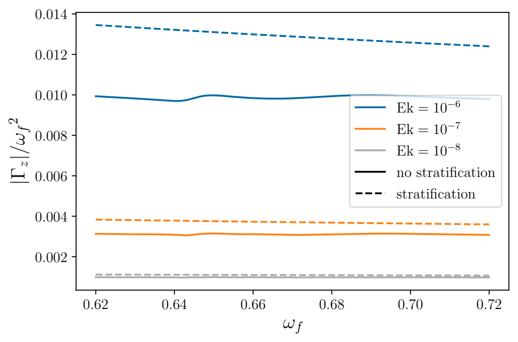


Figure 6. Total axial viscous torque exerted on the mantle by the flow in the core.

Estimated total torque $\Gamma_{\mathrm{tot}} \approx 0.6$.

For the stratified case:
Increase of kinetic energy in response to the radial forcing.

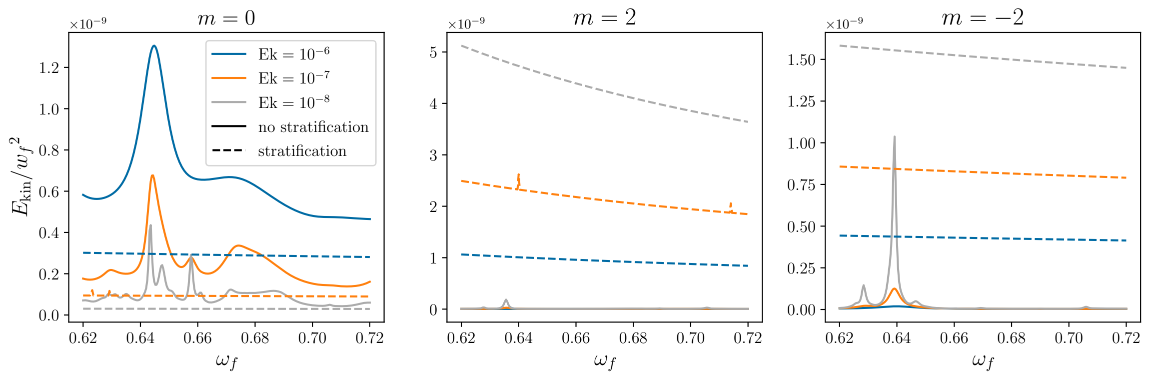


Figure 7. Kinetic energy of the core flow in response to the three types of libration forcing.

Large horizontal flow under the core-mantle boundary.

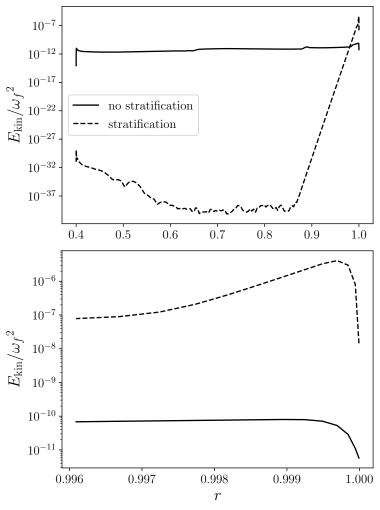


Figure 8. Radial kinetic energy profiles for Ek $= 10^{-8}$.

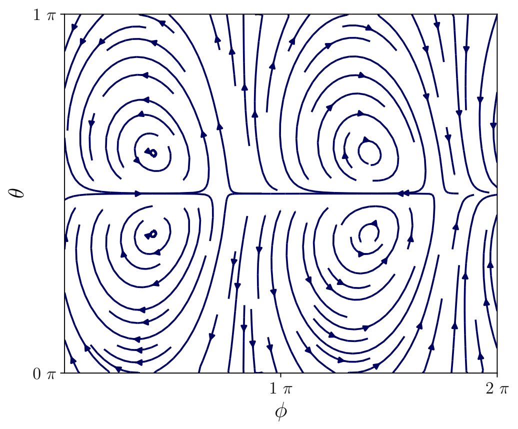
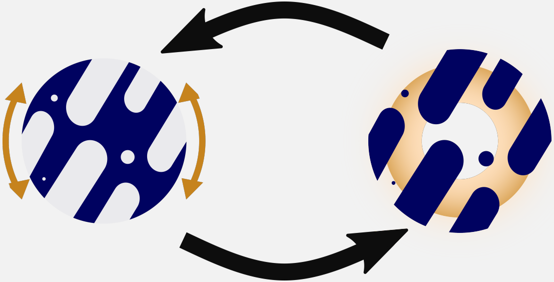


Figure 9. Tangential flow at $r = 0.9996$.

Summary.

1. the viscous torque resulting from the flow in the core most likely has no significant contribution to the librating motions;



2. the stratified layer can affect the flows excited from libration in different ways:
   - by shielding the motion of the mantle from that of the bulk flow;
   - by inducing a large horizontal flow under the core-mantle boundary.

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