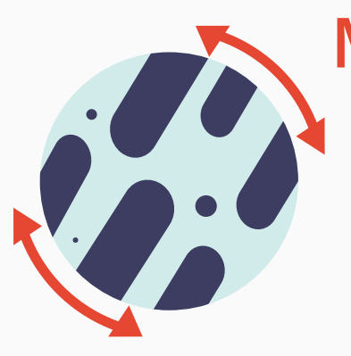
The core flow induced by Mercury's libration: density stratification and magnetic fields

Fleur Seuren[1,2] *(fleur.seuren@ksb-orb.be)*, Santiago Andrés Triana[1], Jérémy Rekier[1], Tim Van Hoolst[1,2]

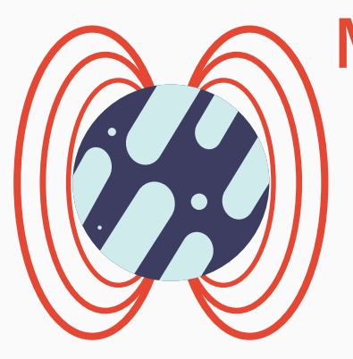
[1]Royal Observatory of Belgium, Ringlaan 3, 1180, Uccle, Belgium; [2]Institute of Astronomy, Celestijnenlaan 200D, 3000, Leuven, Belgium

1. INTRODUCTION

Background



Mercury experiences small periodic variations in its rotation rate called librations. Precise measurements of these librations can be used to infer the internal structure[a].



Mercury has a magnetic field that is mostly axisymmetric and dipolar, aligned with the rotation axis and that has a very weak intensity[b].

The top part of Mercury's fluid outer core is most likely stably stratified as suggested by thermal evolution models[c] and numerical dynamo models[d].

Question

As a result of core-mantle coupling mechanisms such as the viscous and electromagnetic torque the librating motion of Mercury's mantle generates a flow in the core fluid. We have investigated how a stably stratified layer near the outer boundary can influence this librationally induced core flow and what the potential consequences are for the induced magnetic field.

Assumptions

We describe the flow in Mercury's fluid outer core as the motion of a **homogeneous, viscous, conductive, incompressible** fluid contained within a spherical shell, assuming:

① **Steadily rotating frame of reference** rotating with the planet's average rotation rate Ω of 59 days;

② **Dipolar** background magnetic field;

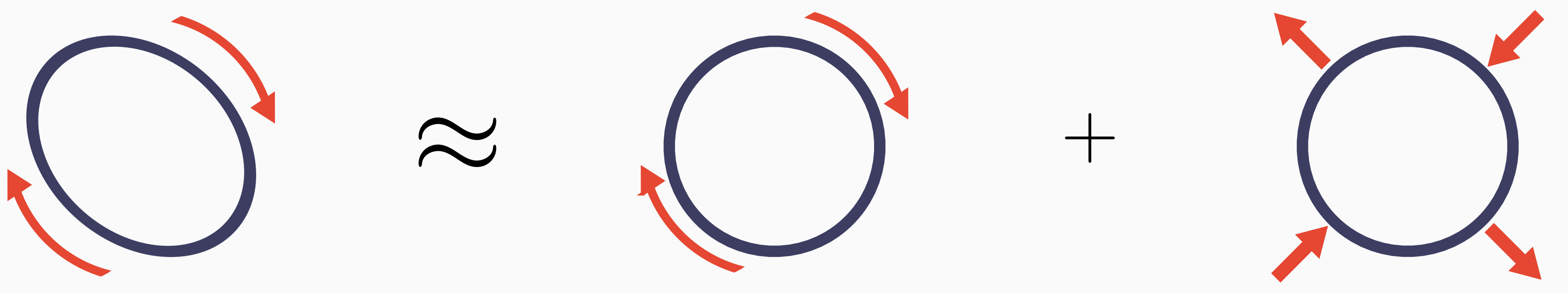
③ **Boussinesq approximation**;

④ Background **thermal stratification** as a function of the Brunt-Väisala frequency governing a top stably stratified layer smoothly transitioning in a neutrally stratified deeper fluid core.

2. METHOD

Forcing libration at the outer boundary

Up to first order we can represent the libration, with frequency ω and amplitude ε, of a triaxial ellipsoid, with equatorial flattening α_2, as a superposition of three independent oscillations in the sphere[e]:



Azimuthal displacement of the triaxial boundary.

Tangential (m=0) forcing
Azimuthal displacement of the spherical boundary.

$$v_\phi = \mathrm{i} r_{\mathrm{CMB}} \sin\theta\, \omega \frac{\epsilon}{2} \left(e^{\mathrm{i}\omega t} - e^{-\mathrm{i}\omega t}\right). \quad (1)$$

Radial (m=±2) forcing
Radial in- and outflow at the spherical boundary.

$$v_r = -r_{\mathrm{CMB}} \alpha_2 \omega \epsilon\, \mathrm{Y}_2^{\pm 2}(\theta, \phi) \mathrm{e}^{i\omega t} + \mathrm{c.c.} \quad (2)$$

Numerically computing the resultant core flow

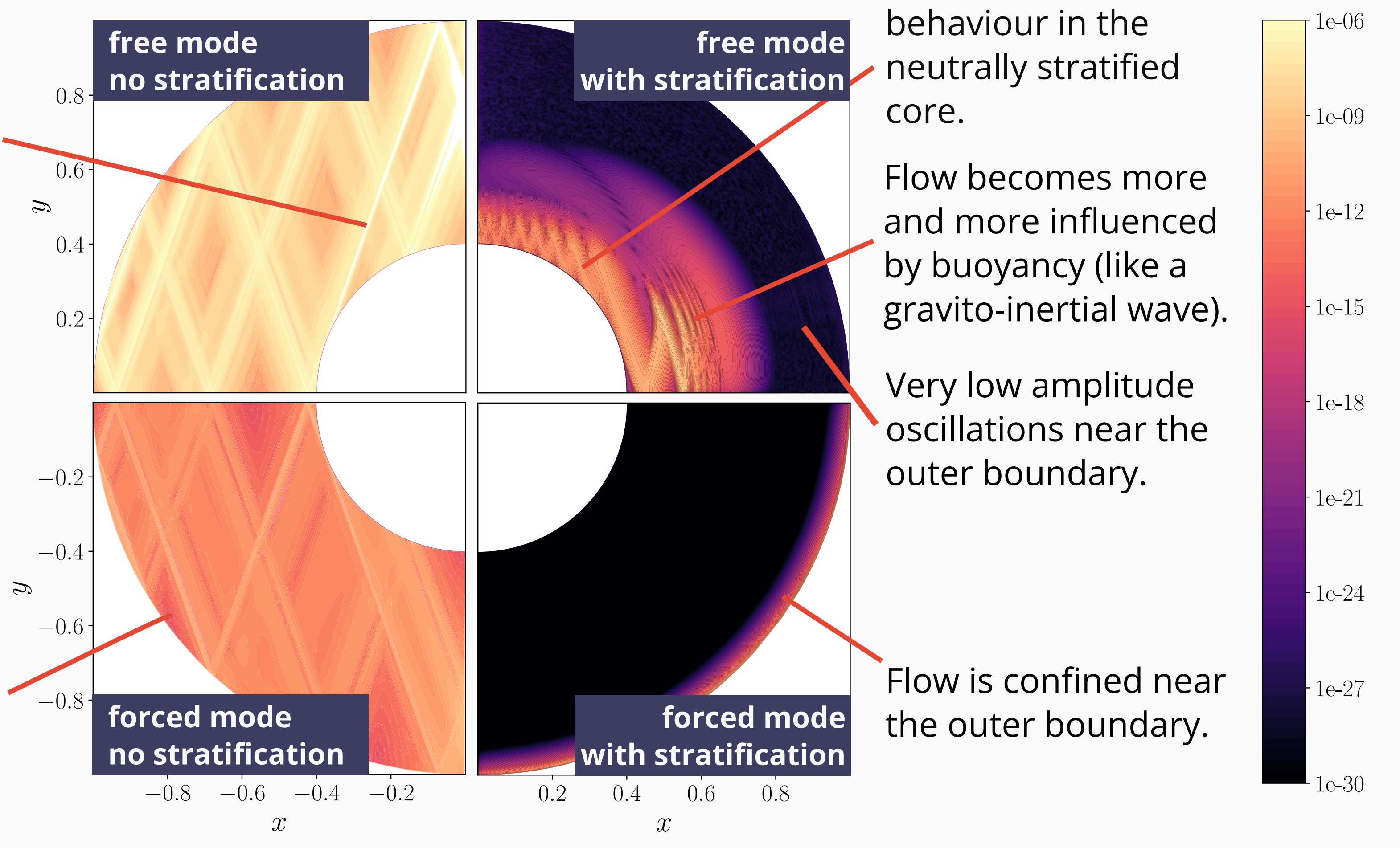
Starting from the standard non-dimensional **Boussinesq MHD equations**, we use a **fully spectral decomposition** of the velocity, magnetic field and temperature and solve the resulting algebraic equations with the numerical code Kore.

KORE

3. RESULTS

Tangential (m=0) forcing

Meridional cuts (φ = 0) of the kinetic energy density in a simple model of Mercury's fluid outer core with Ekman number $E = 10^{-8}$ show the following:



Shear layers indicative of an inertial wave.

Libration at the outer boundary excites a similar inertial wave.

Inertial wave behaviour in the neutrally stratified core.

Flow becomes more and more influenced by buoyancy (like a gravito-inertial wave).

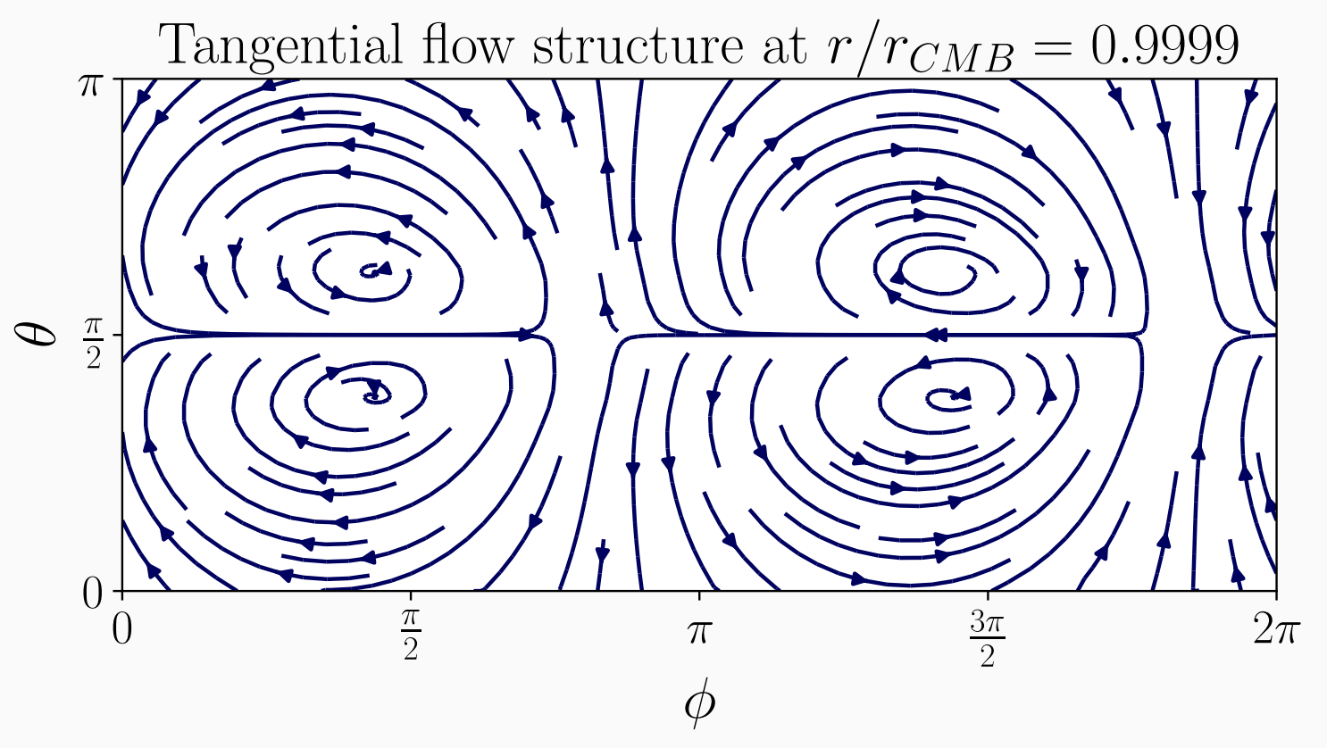
Very low amplitude oscillations near the outer boundary.

Flow is confined near the outer boundary.

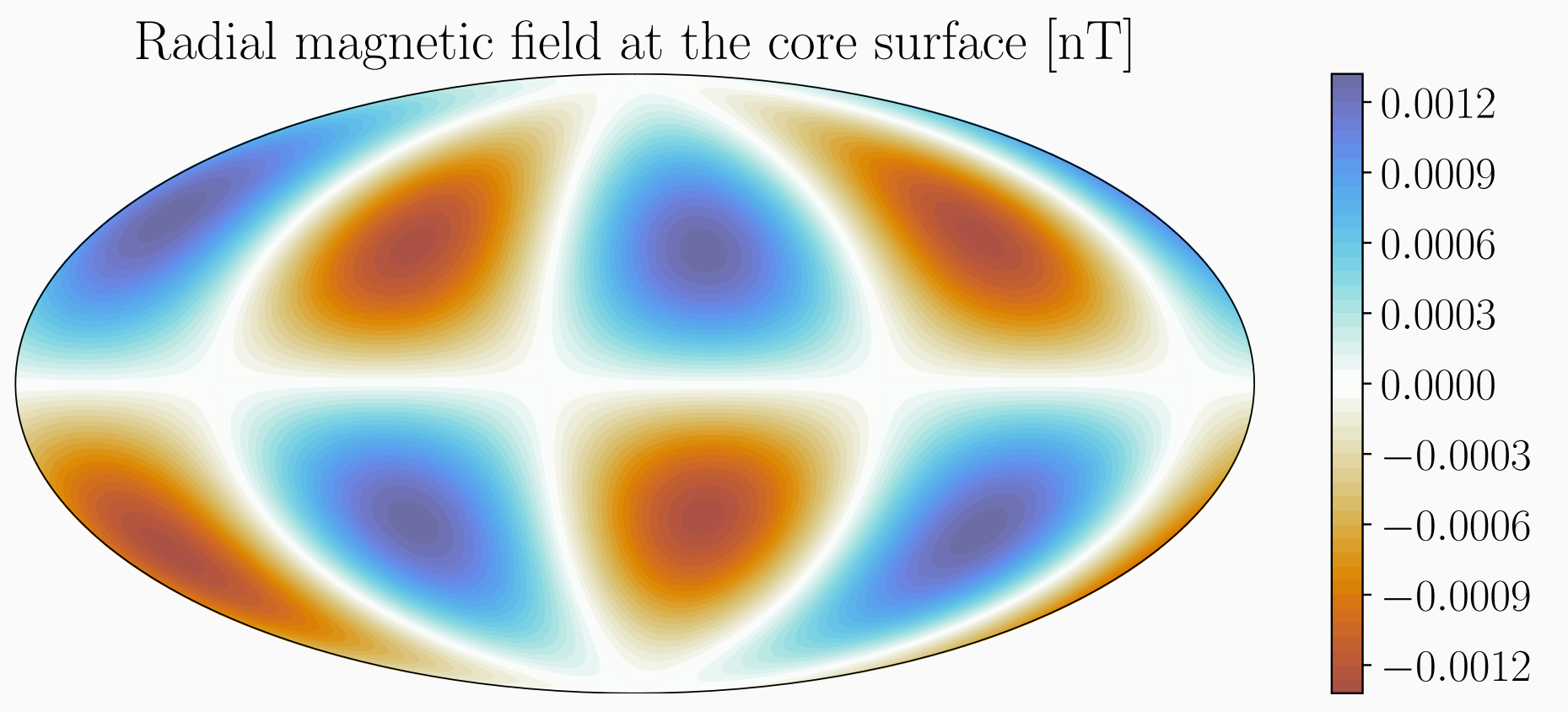
Free mode: eigensolution with frequency closest to the libration frequency of $\omega = 0.67\Omega$.
Forced mode: core flow in response to a tangential forcing at the outer boundary with frequency $\omega = 0.67\Omega$.
No stratification: without a background thermal stratification.
With stratification: an outer stably stratified layer with Brunt-Väisälä frequency $N_0 = 100\Omega$ at the top of the core.

Radial (m=±2) forcing

Radial forcing and a stably stratified outer layer generate a **strong tangential flow** near the outer boundary. When the Ekman number (the ratio of viscous vs. rotating forces) decreases this flow becomes even stronger. For $E = 10^{-10}$:



This type of flow induces a **non-axisymmetric (m=2) magnetic field** that has a stronger intensity when the Ekman number decreases. For $E = 10^{-10}$:



4. CONCLUSION

Tangential (m=0) forcing

Stong stratification near the core-mantle boundary suppresses radial flow which prevents fluid motions to travel from the outer boundary to the bulk of the core and vice versa. Additionally (gravito-)inertial waves with frequencies close to the libration frequency have very low amplitude in the stratified layer, and can therefore not be excited by libration forcing if a stratified layer is present.

Radial (m=±2) forcing

A radial forcing from the outer boundary will be converted into a strong (mainly) horizontal flow by the stratified layer. This pumping mechanism becomes stronger with lower viscosity and the resulting flow induces a non-axisymmetric magnetic field structure that could potentially be observed at Mercurial conditions.

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Abstract information: