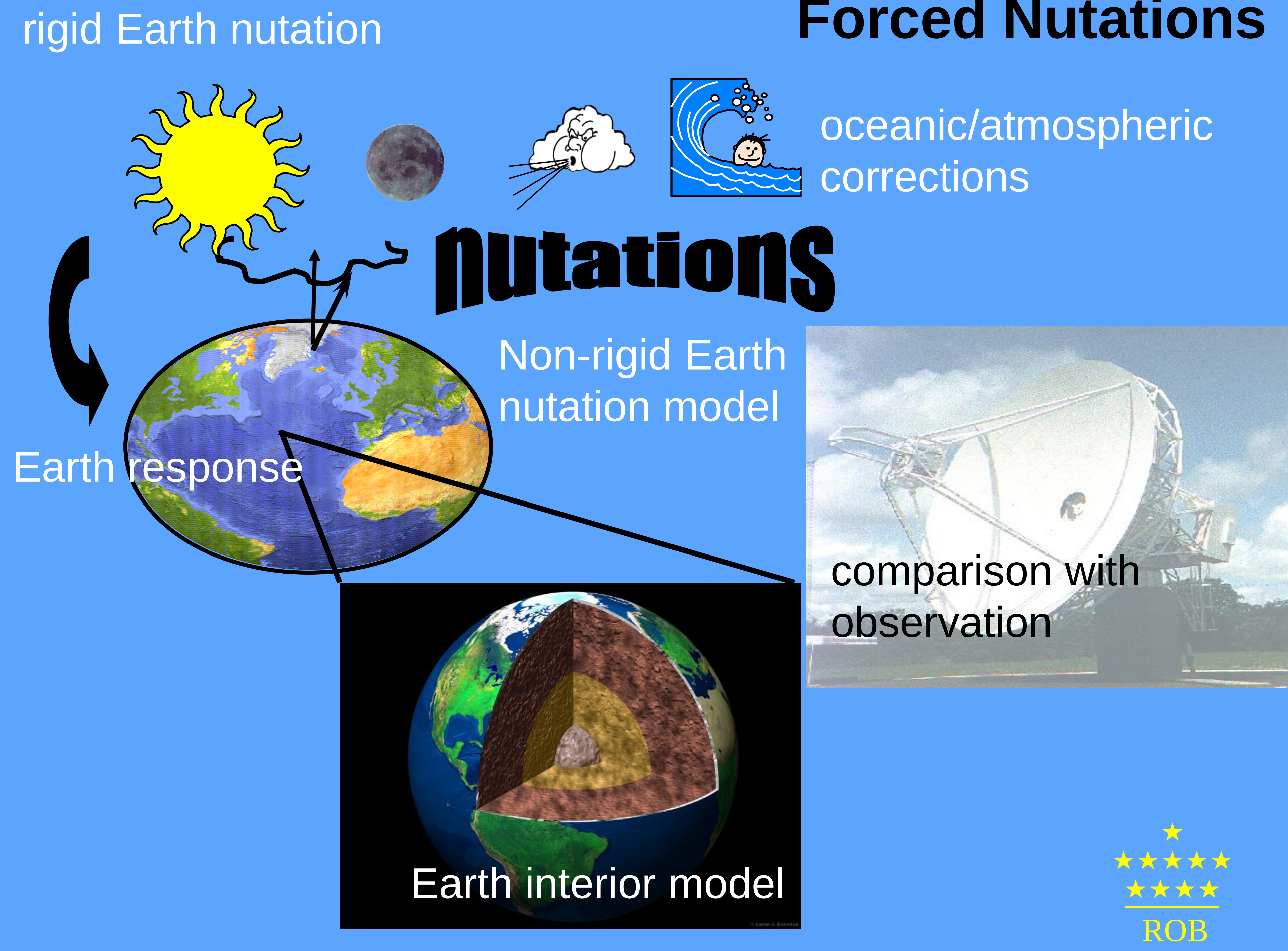
Refinements on precession, Nutation, and Wobble of the Earth

Véronique Dehant,

Royal Observatory of Belgium

ROB

Forced Nutations



Earth rotation changes due to the core; core-mantle coupling

→ coupling mechanisms:

- ☞ topographic torque
- ☞ gravitational torque
- ☞ viscous torque
- ☞ electromagnetic torque

classically

this talk

ROB

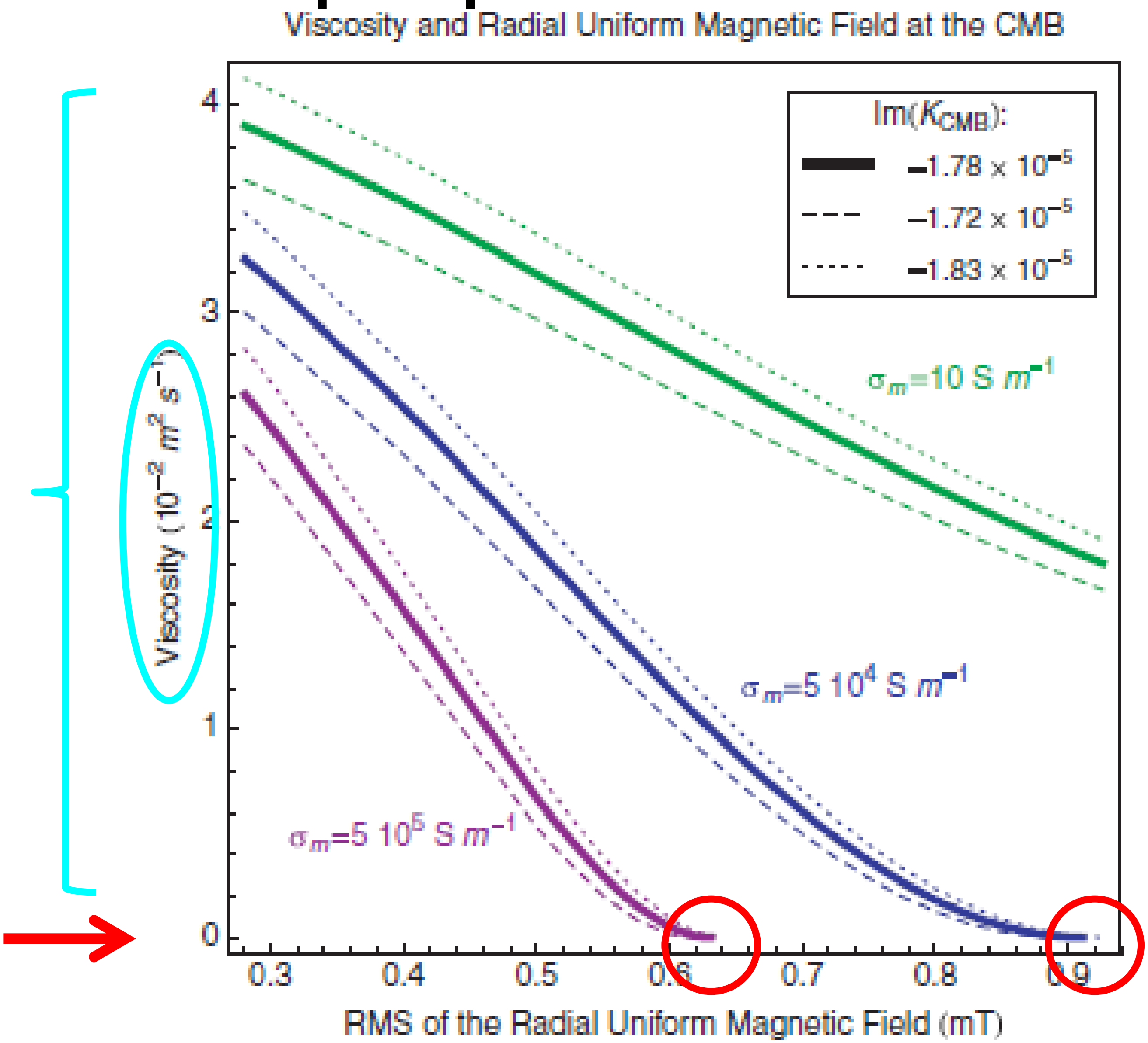
Electromagnetic torque + viscous torque: dissipative

- Outer core electrical conductivity: known from laboratory experiments: **$5\ 10^5$ S m^{-1}** (Stacey & Anderson 2001).
- Lowermost mantle electrical conductivity (~200 m layer at the base of the mantle): unknown but has to be lower than that of the core.

  σ_m= 10 S m^{-1}, $5\ 10^4$ S m^{-1}, $5\ 10^5$ S m^{-1}

- RMS of the radial magnetic field at the CMB: from surface magnetic field measurements: > 0.3 mT.
- Viscosity of the outer core fluid close to the CMB:
  - molecular viscosity: ~10^{-6} m^2 s^{-1} (laboratory experiments and ab initio computations).
  - eddy viscosity: < 10^{-4} m^2 s^{-1} (Buffett & Christensen 2007).

Constraints on the physical properties of the CMB



Coupling model used: Buffet et al. 2002 for EM and Mathews & Guo 2005 for viscomagnetic

From Koot et al. 2010

ROB

Earth rotation changes due to the core; core-mantle coupling

→ coupling mechanisms:

- ☞ topographic torque
- ☞ gravitational torque
- ☞ viscous torque
- ☞ electromagnetic torque

adopted model

negligible

How to explain high magnetic field?

ROB

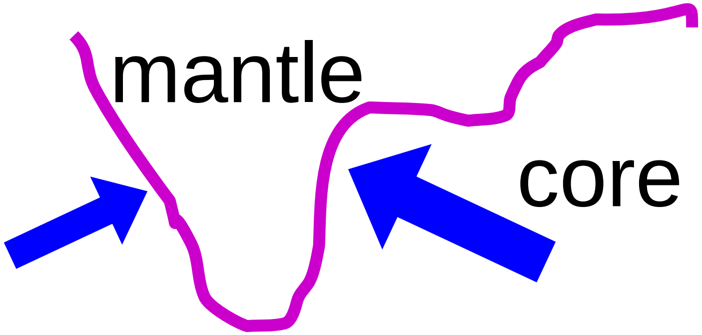
Core Angular Momentum exchange due to **topographic** torque at CMB

☞ pressure at CMB

☞ **core-mantle boundary topography (<2km)**

Difficult, challenging

but cannot be ruled out



e.g. Hide 1977

ROB

Topographic torque computation

- Aim at obtaining torque and associated effects on nutation
- Strategy:
  - Establish the motion equations and boundary conditions in the fluid;
  - Compute analytically the solutions;
  - Obtain the dynamic pressure as a function of the physical parameters;
  - Determine the topographic torque.
- Assessment: Comparison with Wu and Wahr (1997) who used a numerical technique

ROB

Differential equations and boundary conditions

- Linearized Navier-Stokes equation:

$$\frac{\partial \vec{V}}{\partial t} = -\frac{1}{\rho_f}\nabla P + \vec{b} - \vec{\omega}\times(\vec{\omega}\times\vec{r}) - 2\vec{\omega}\times\vec{V} - \frac{\partial\vec{\omega}}{\partial t}\times\vec{r}$$

velocity — pressure — gravitational force (equilibrium+mass redistribution+tides) — Rotation

forcing

- Boundary conditions:

$$\hat{n}\,.\vec{V} = 0 \qquad \nabla\,.\vec{V} = 0 \qquad \vec{V} = \vec{v} + \vec{u} \qquad \vec{q} = \frac{\vec{u}}{\Omega L}$$

$$\begin{cases} \frac{\partial\vec{v}}{\partial t} + 2\vec{\Omega}\times\vec{v} + +\Omega\frac{\partial\vec{m}}{\partial t}\times\vec{r} - \nabla\phi_m = \nabla\chi \\ \nabla\cdot\vec{v} = 0 \end{cases}$$

χ for nutations

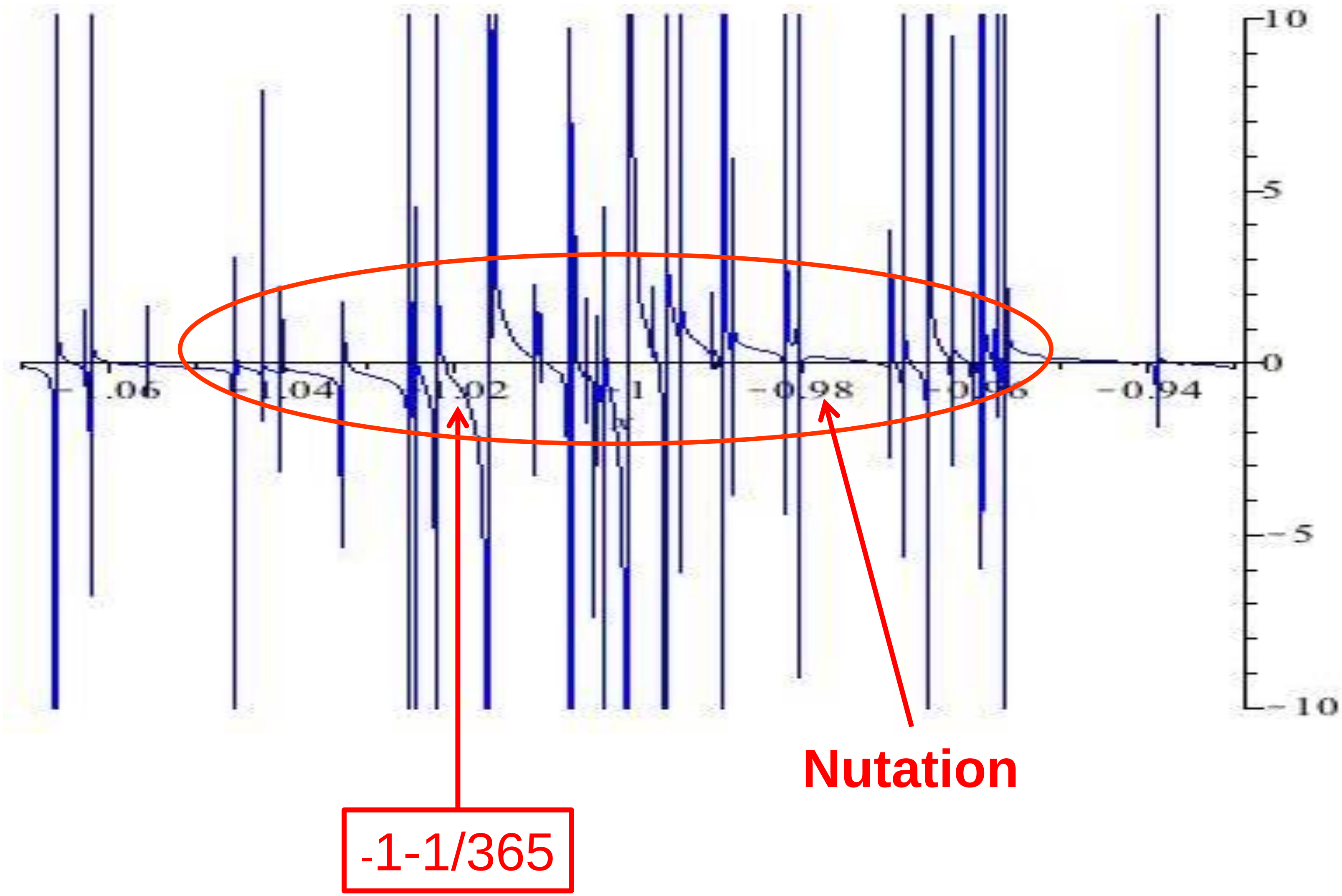
$$\chi = \Omega^2\left(m_1^f\, xz + m_2^f\, yz\right)$$

$$\begin{cases} i\,\sigma_m\,\vec{q} + 2\vec{\hat{z}}\times\vec{q} + \nabla\Phi = 0 \\ \nabla\cdot\vec{q} = 0 \\ \vec{n}\cdot\vec{q} + \Omega^{-1}L^{-1}\vec{n}\cdot\vec{v} = 0 \end{cases}$$

Coriolis

where $\Phi = \frac{\phi}{\Omega^2 L^2}$ and $\phi = \frac{p}{\rho_f} + \chi$.

ROB



10
5
0
−5
−10
−1.06
−1.04
−1.02
−1
−0.98
−0.96
−0.94
Nutation
-1-1/365

Earth rotation changes due to the core; core-mantle coupling

+ Core stratification

→ coupling mechanisms:

- ☞ topographic torque
- ☞ gravitational torque
- ☞ viscous torque
- ☞ electromagnetic torque

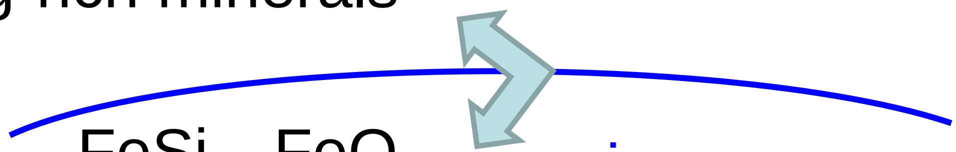
adopted model

ROB

Buffett EPSL (2011)

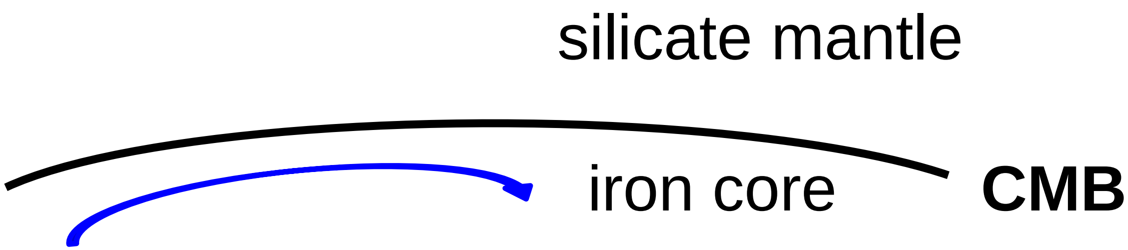
Topography, stratification, and magnetism

- chemical interactions between the core and the mantle



Buffett EPSL (2011)

Stratification and magnetism

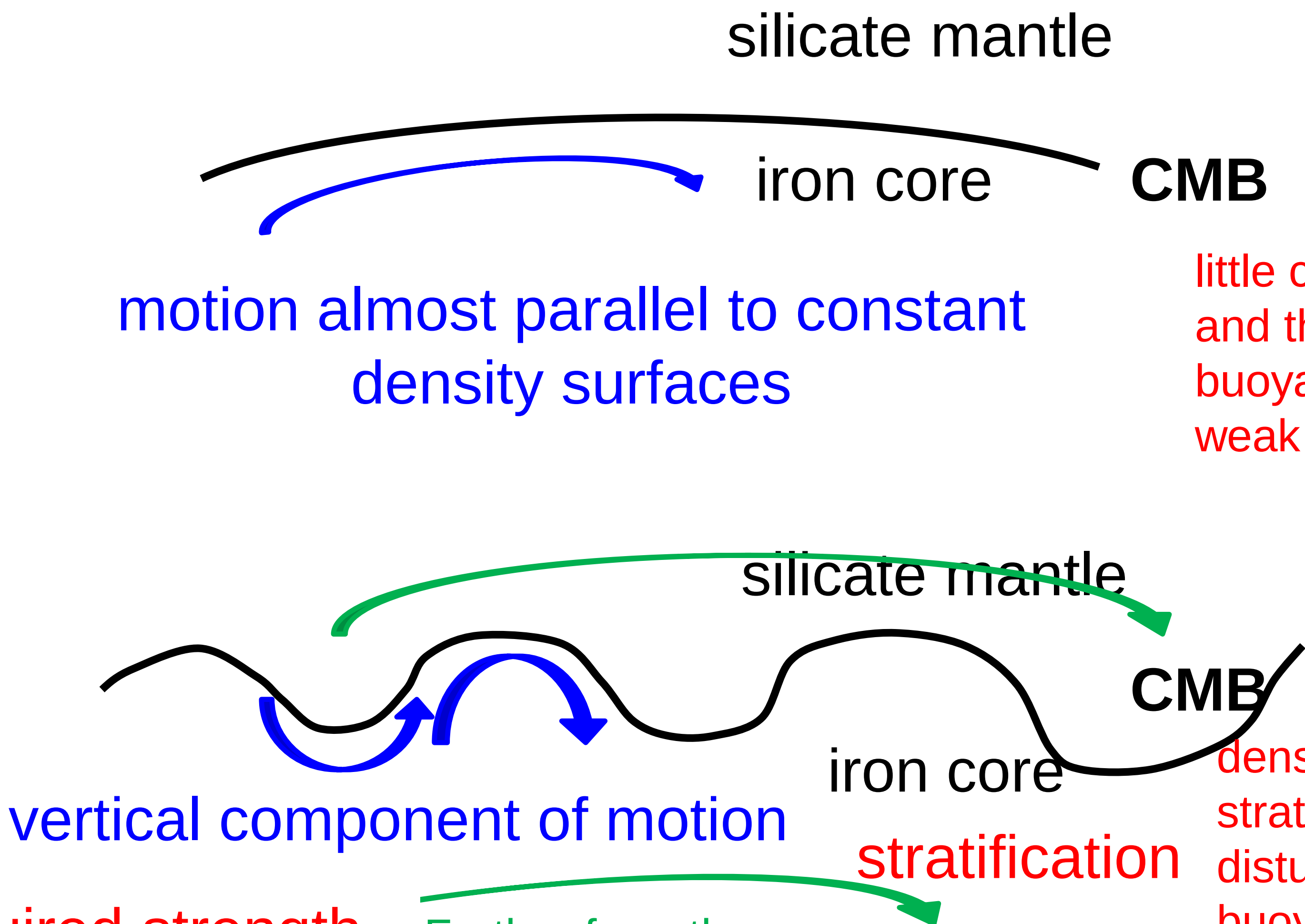


motion almost parallel to constant density surfaces

little change in density and the resulting buoyancy forces are weak

Buffett EPSL (2011)

Topography, stratification, and magnetism

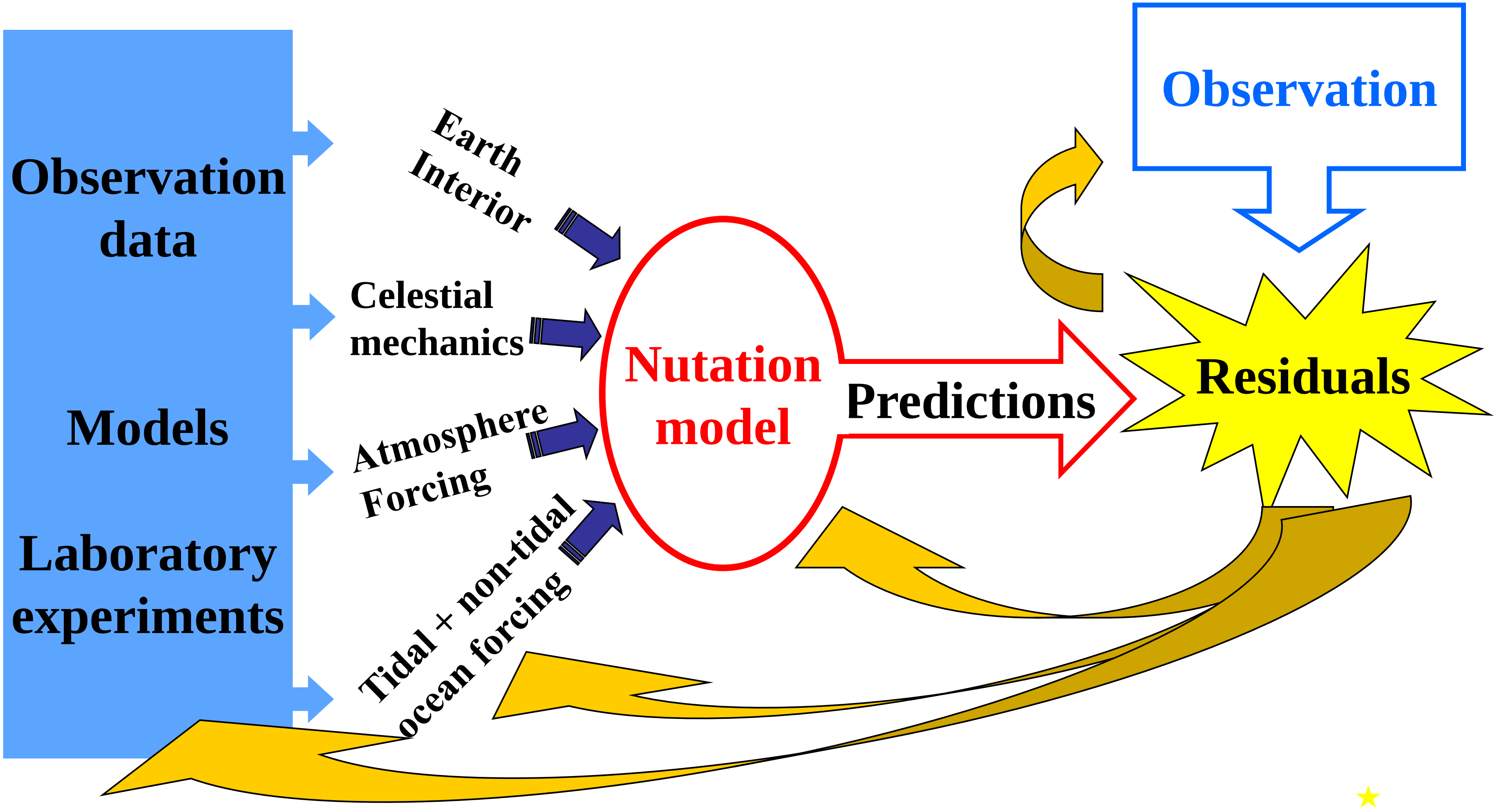


little change in density and the resulting buoyancy forces are weak

density field in a stratified fluid is disturbed and a buoyancy force arises

Required strength of the radial magnetic field can be lowered.

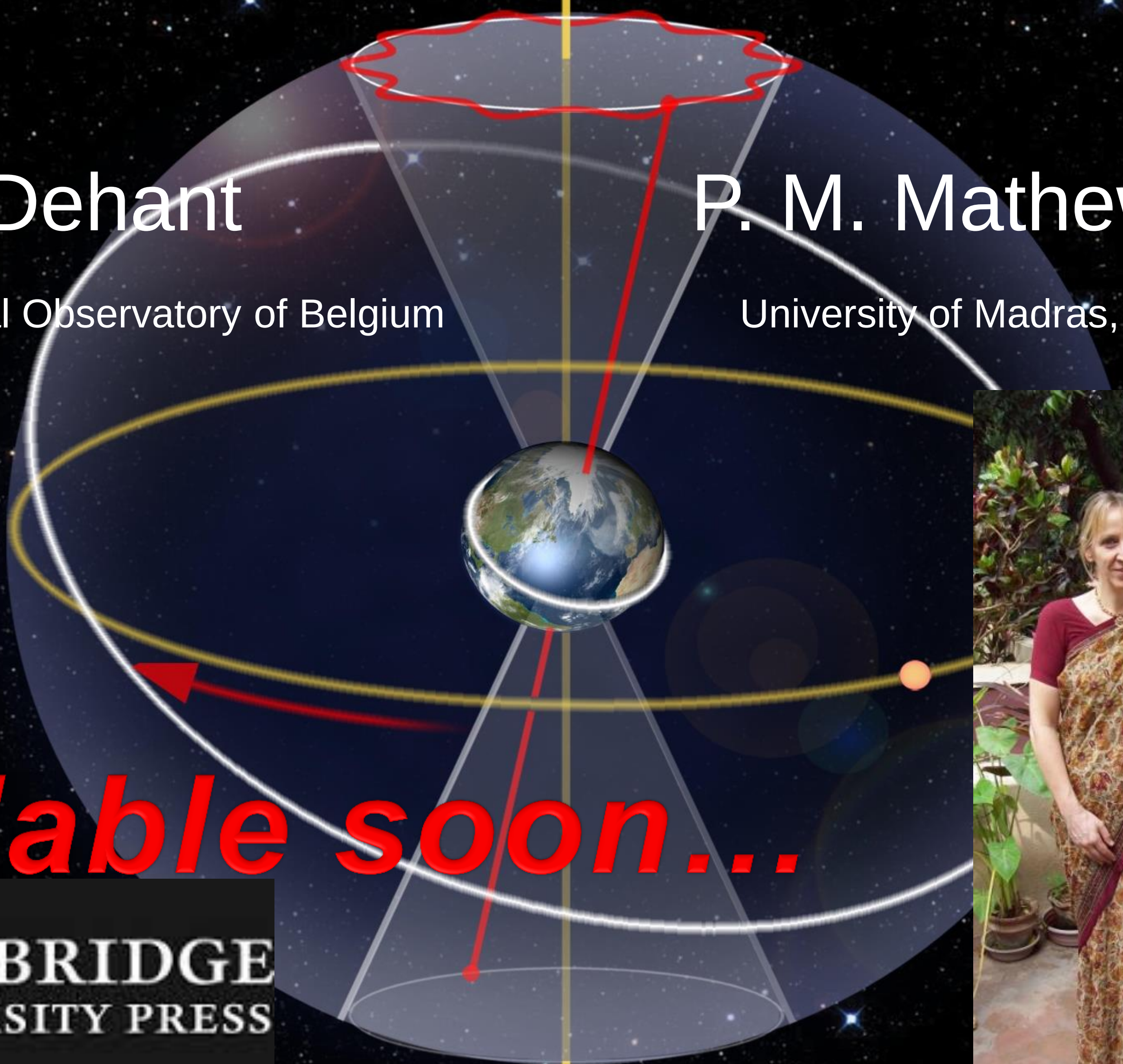
Further from the boundary the stratified fluid is swept past the mantle with the underlying tidal flow



Better understanding of the Earth interior!

ROB

Precession, nutation, and wobble of the Earth



V. Dehant

Royal Observatory of Belgium

P. M. Mathews

University of Madras, India

Available soon...

CAMBRIDGE UNIVERSITY PRESS

THANK YOU FOR YOUR ATTENTION