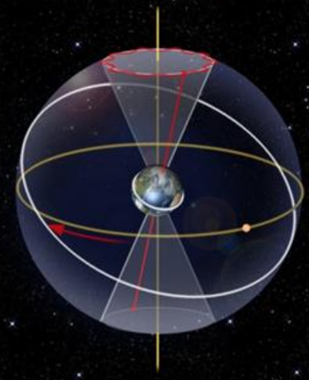
Progress in understanding nutations

RotaNut – Rotation and Nutation of a wobbly Earth

Véronique Dehant and the RotaNut team:
R. Laguerre, J. Rekier, S.A. Triana, A. Trinh, T. Van Hoolst, P. Zhu, A. Houliez

Royal Observatory of Belgium

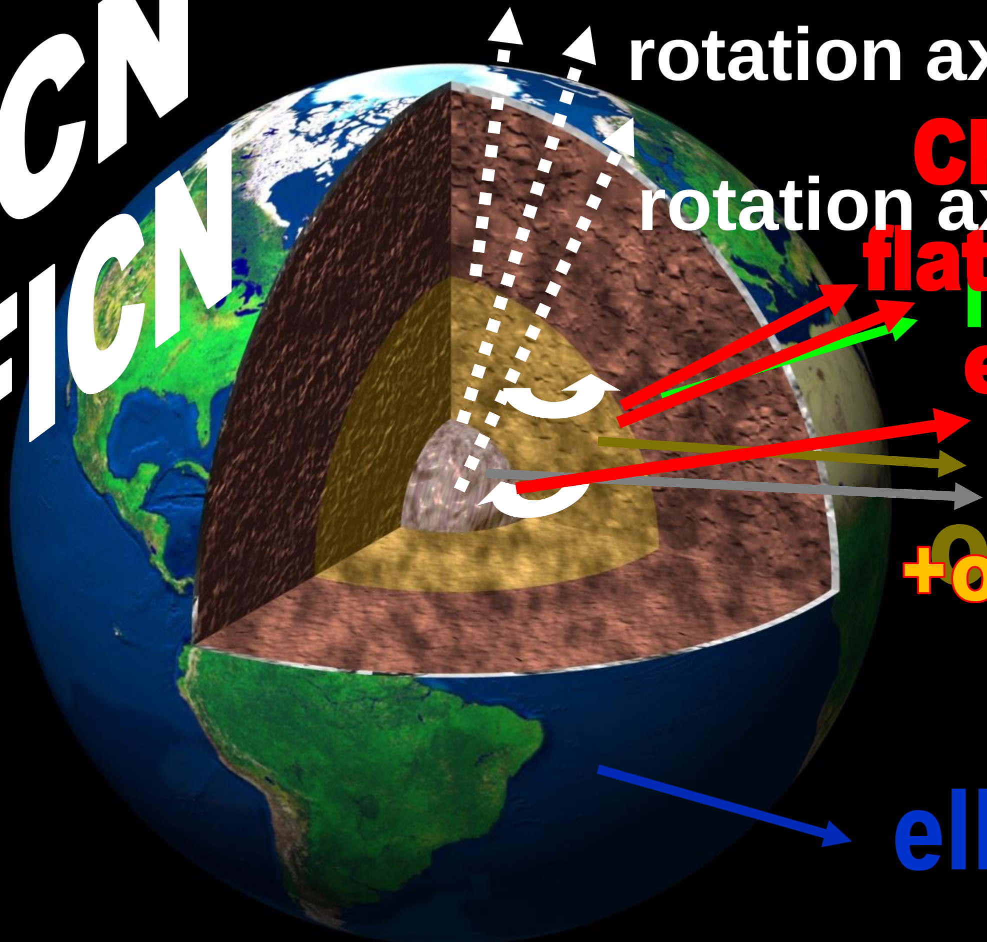
RotaNut
Rotation and Nutation of a wobbly Earth

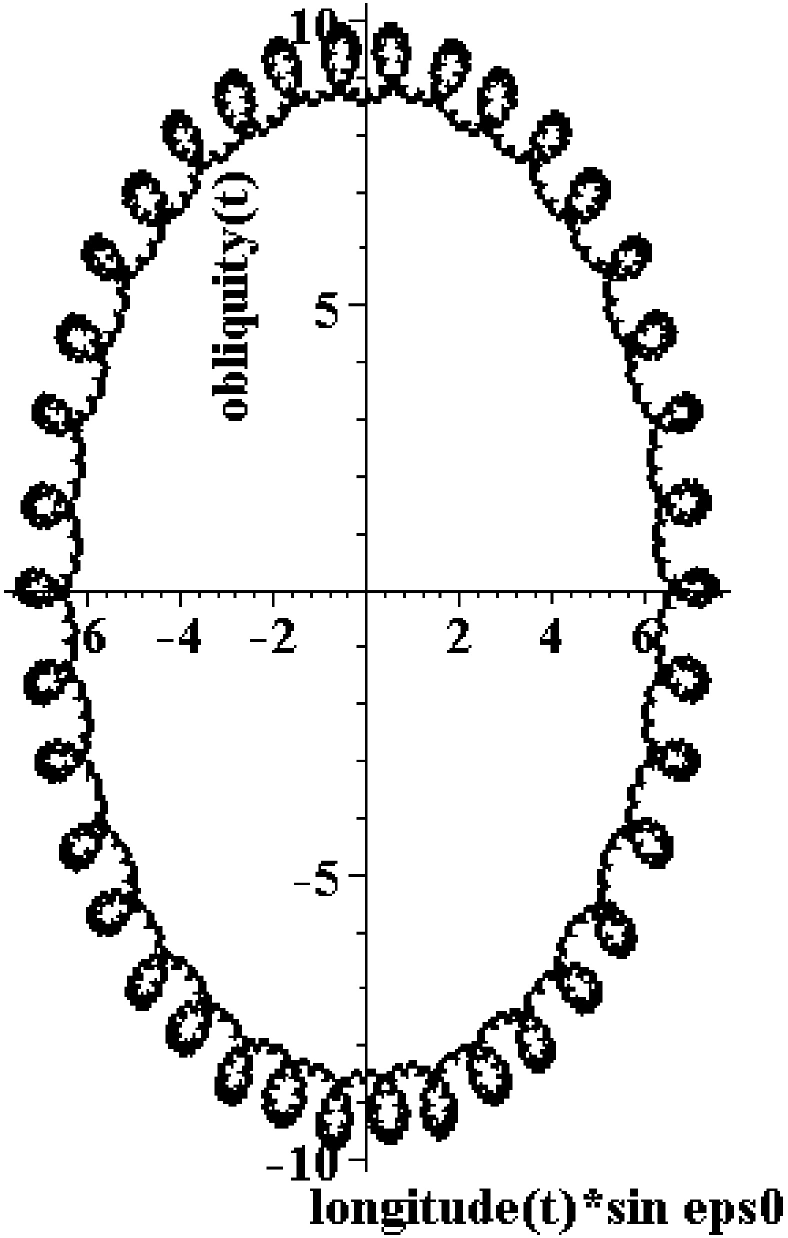


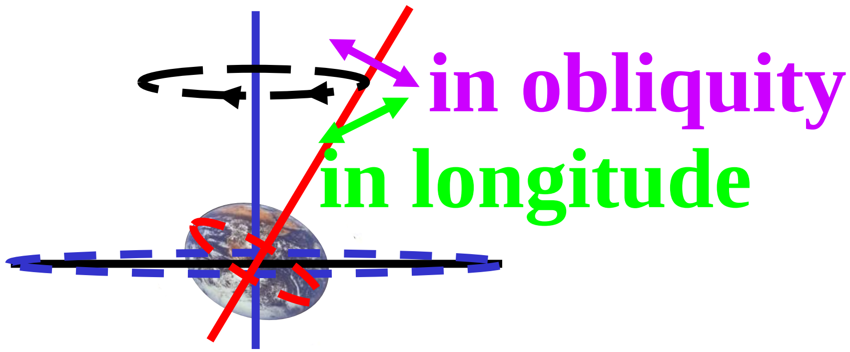
European Research Council
Established by the European Commission

ERC Advanced Grant 2014
Action number: 670874

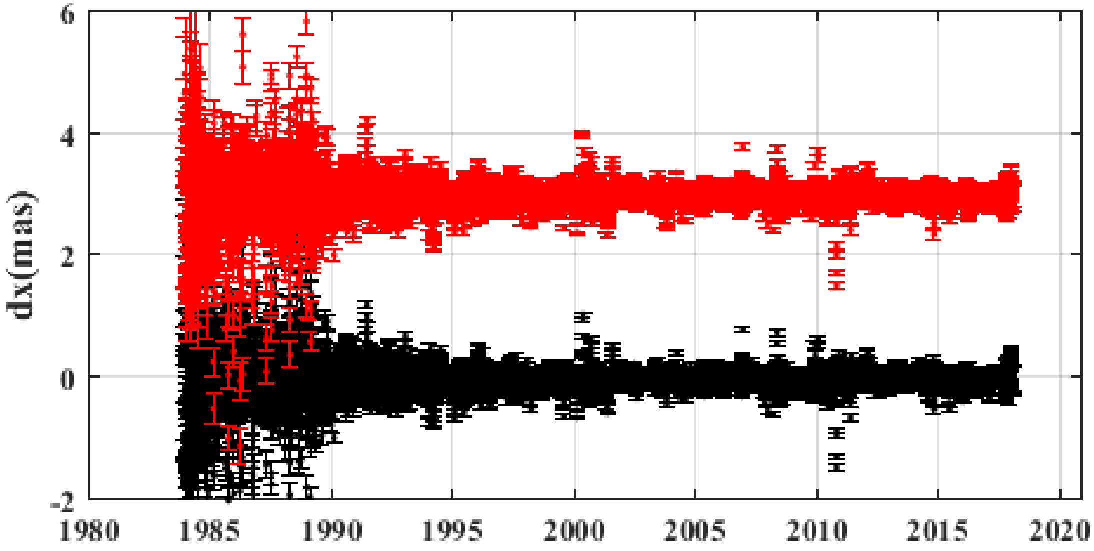
Adopted model of the Earth's interior for nutation

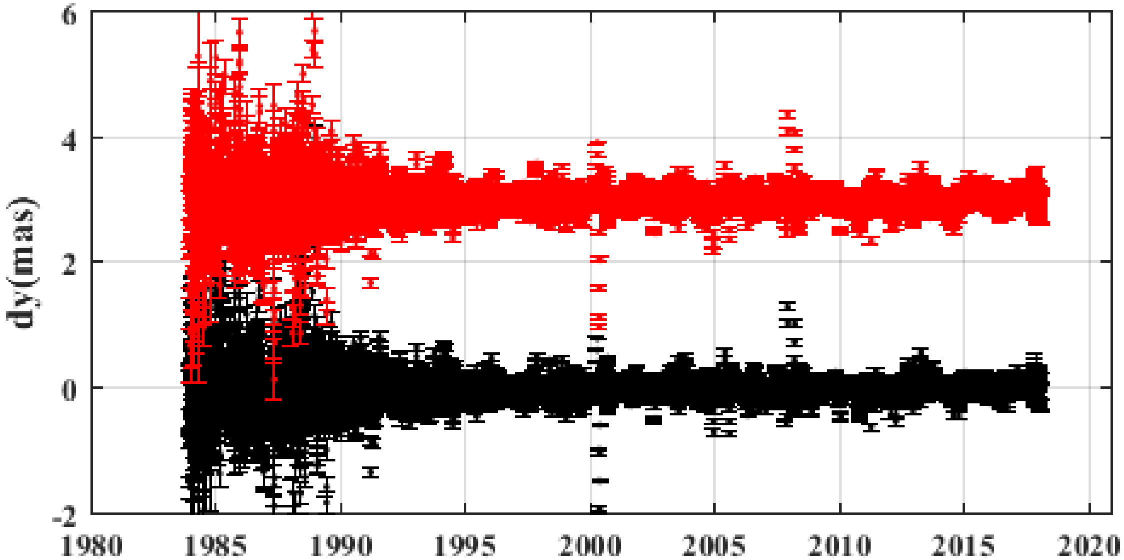






Better understanding of the core => New nutation model





Black, IERS 14C04 nutation residuals with respect to IAU2000/IAU2006 procession-nutation model.

Red, Nutation residuals with respect to the series obtained by fitting 350 terms on VLBI observations.

The RMS between the nutation series obtained by fitting the 350 terms on VLBI observations and the IAU2000/IAU2006 mode is 0.9 mas in dX and 0.8 mas in dY, respectively.

BEPs Basic Earth Prameters from VLBI

Our work

BEPs	MHB2000(1979-2001)[a]	1979-2015[a1]	1979-2010[b]	1979-2015[b1]
$10^3 \times e$	3.2845479 ± 12	3.2845474 ± 2	3.2845481 ± 7	3.2845474 ± 8
$10^3 \times (e_f + ReK^{CMB})$	2.6681 ± 20	2.6752 ± 15	2.6753 ± 7	$\boxed{2.6760 \pm 8}$
$10^3 \times ImK^{CMB}$	-0.0185 ± 14	-0.0186 ± 5	-0.0178 ± 4	$\boxed{-0.0188 \pm 5}$
$10^3 \times ReK^{ICB}$	1.11 ± 10	0.98 ± 6	1.01 ± 3	$\boxed{1.01 \pm 4}$
$10^3 \times ImK^{ICB}$	-0.78 ± 13	-0.87 ± 22	-1.09 ± 4	$\boxed{-1.11 \pm 4}$
κ	0.0010340 ± 92	0.0010360 ± 43	0.001038 ± 2	0.0010368 ± 10
γ	0.0019662 ± 14	0.0019659 ± 6	0.0019649 ± 3	0.0019651 ± 2
Precession rate	$-2.960 mas/yr$	$-2.963 \pm 2 mas/yr$	-	-
$d\epsilon/dt$	-	-	$-0.2585 mas/yr \pm 4$	$-0.2529 mas/yr \pm 3$

Koot et.al. 2010

Zhu et al. 2016

Summary/ranges

1

2

CMB($\times 10^3$)

$e_f + ReK^{CMB}$ → [2.67   2.68]

ImK^{CMB} → [-0.019   -0.018]

ICB($\times 10^3$)

ReK^{ICB} → [0.98   1.11]

ImK^{ICB} → [-1.11   -0.78]

Coupling Constant at the CMB

1

Radial magnetic field at the CMB

Dipolar ：B_{Dr}= 0.21 mT

Uniform ：B_{NDr}=0.28 mT

(CHAOS-2s,Olsen *et al.* 2009
From magnetic feld observation)

CMB($\times 10^3$)

$e_f + ReK^{CMB}$ → [2.67 2.68]

ImK^{CMB} → [-0.019 -0.018]

Updated [-0.018 -0.017]

Uniform：(VLBI） 0.62-0.64 mT

Coupling Constant at the ICB

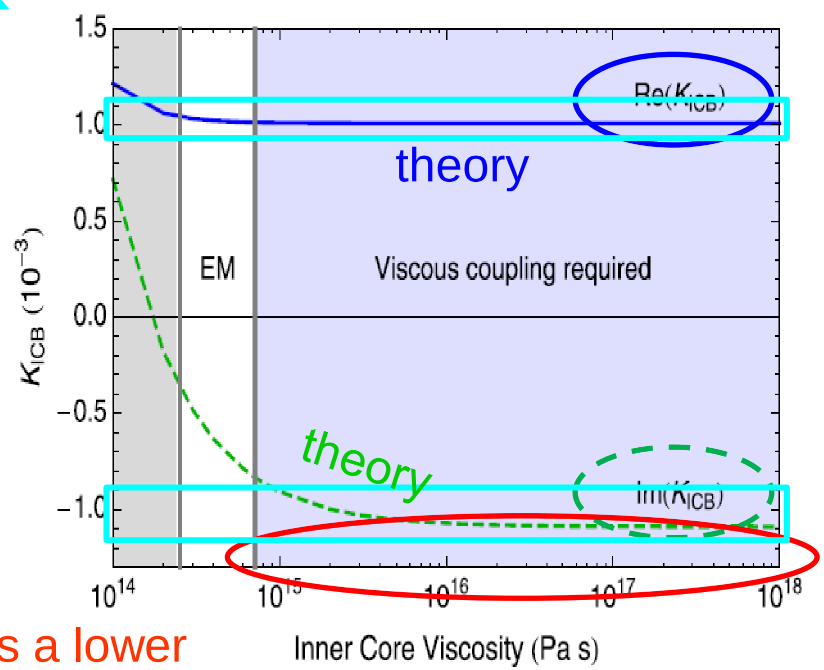
2

ICB($\times 10^3$)

$ReK^{ICB} \rightarrow$ [0.98   1.11]

$ImK^{ICB} \rightarrow$ [-1.11   -0.78]

observation



gives a lower bound on inner core viscosity

Koot and Dumberry, 2011

too much energy is dissipated by inner core deformation

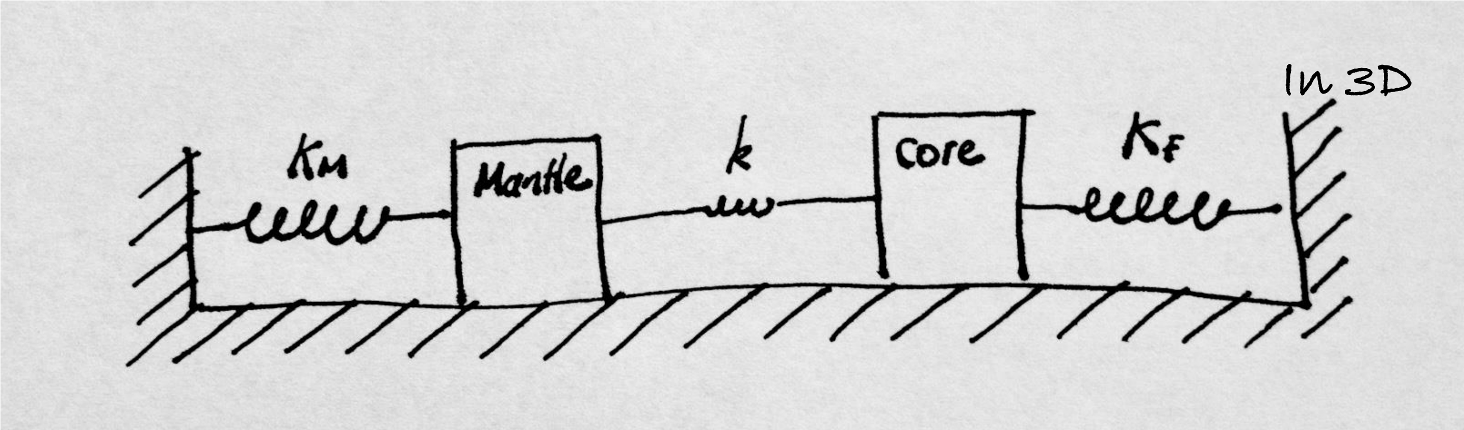
Coupling constants cannot be explained when EM coupling alone participates in surface stresses at the ICB.

+ New effects from the core flow itself!

- Inertial waves in the core
- Rotational modes in the core
- Dissipation mechanism (not only at core-mantle boundary)
- Electromagnetic field

RotaNut: Rotation and nutation of a wobbly Earth

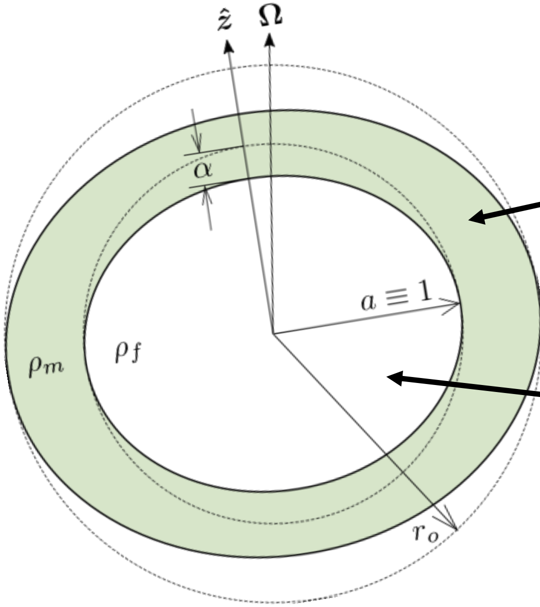
Concept



A fully coupled, self-consistent, core-mantle model (numerical, fully 3-D)

→ much better suited to compare with observations

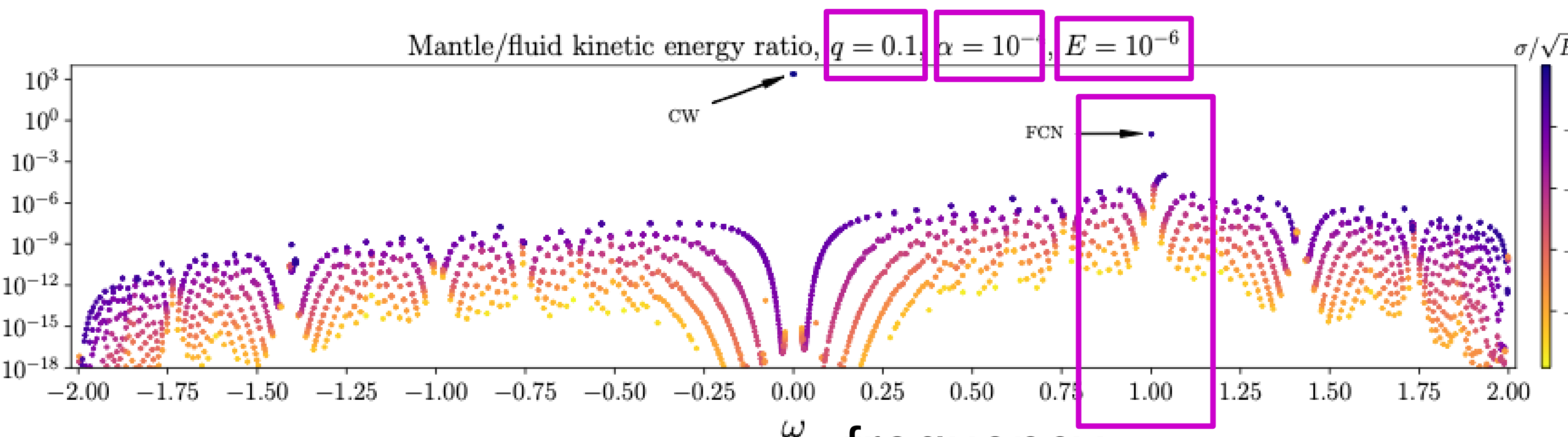
Kinetic energy of the mantle / of the fluid



Rigid mantle:
Euler equations

Fluid core:
Navier-Stokes equation

coupled via
viscous and pressure
torques



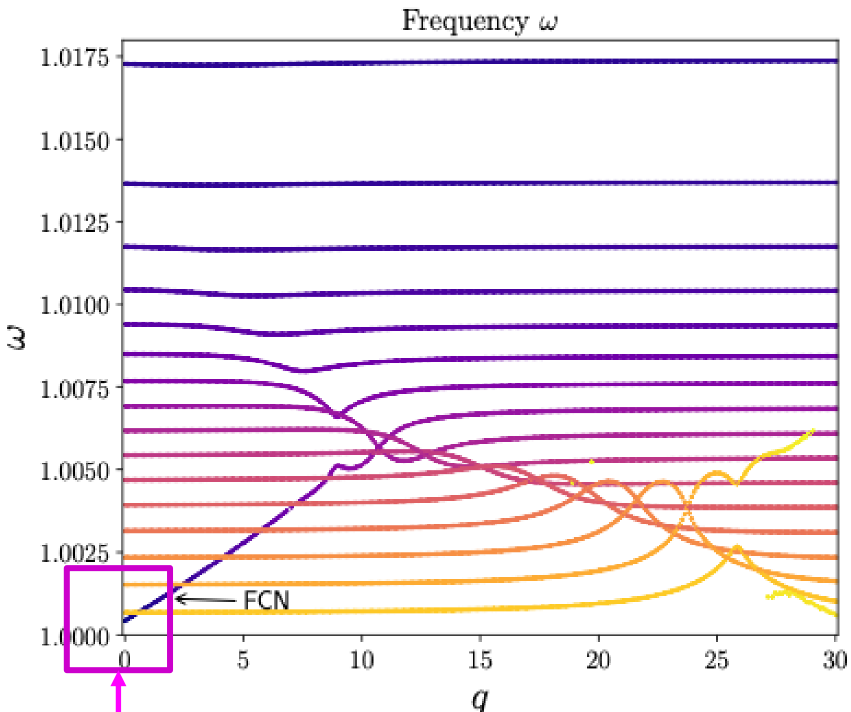
frequency

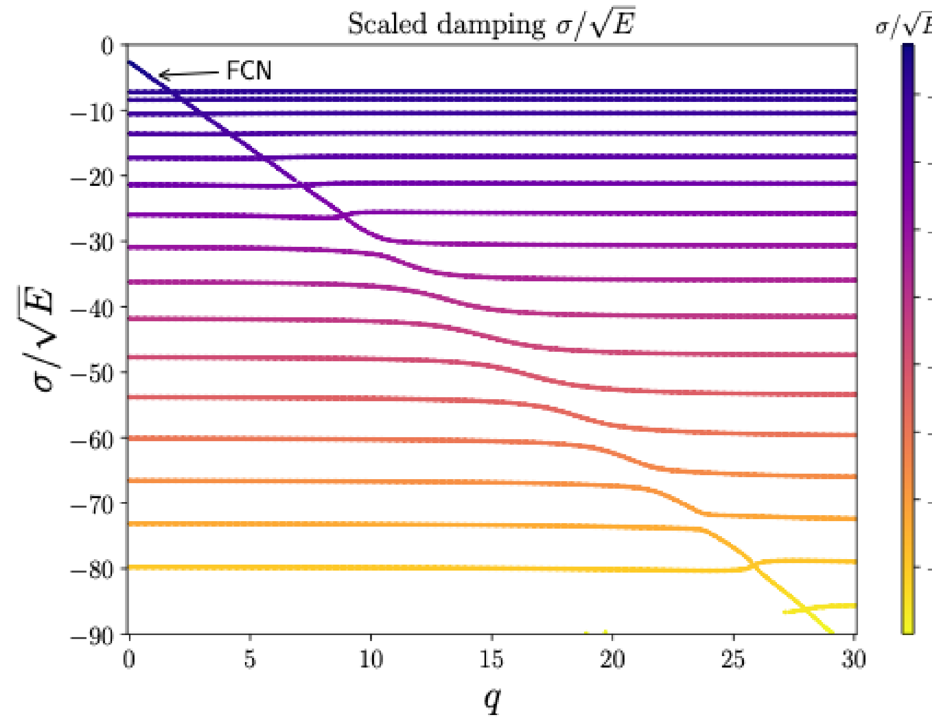
Moment of inertia $q = \dfrac{1}{(r_o^5 - 1)} \dfrac{\rho_f}{\rho_m}$

Ekman number $E = \dfrac{\nu}{\Omega_0 a^2}$

The color scale indicates the damping, very dark are less damped.

$$\text{Eigenvalue} = \sigma + i\omega$$





Earth's mantle	$q \sim 0.026$
Mercury's mantle	$q \sim 0.27$
Enceladus' icy crust	$q \sim 1.6$

In this 2-layer planet model, the FCN interacts with nearby inertial modes for ***q>>1*** mainly through viscous torques.

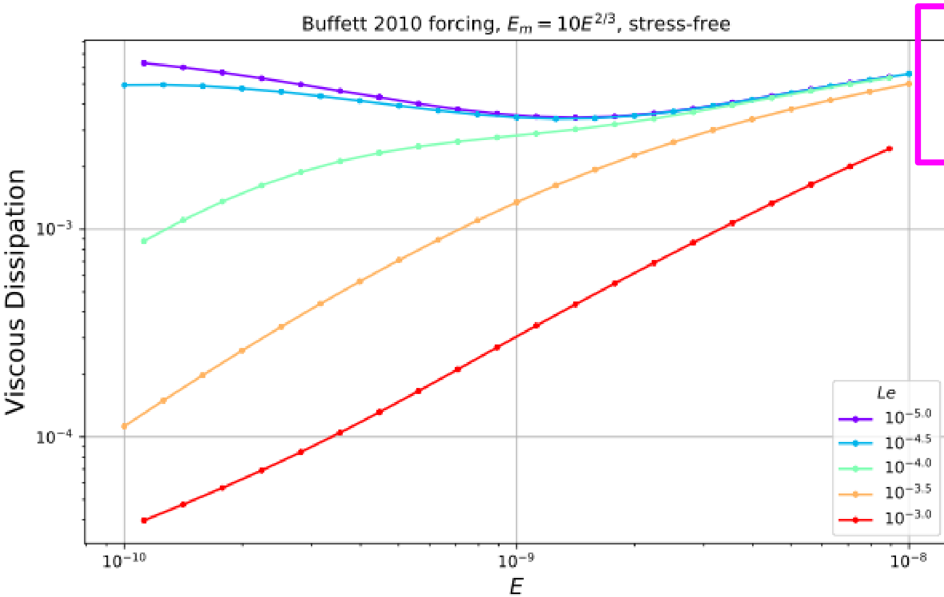
Earth's FCN might be affected if magnetic torques are taken into account.

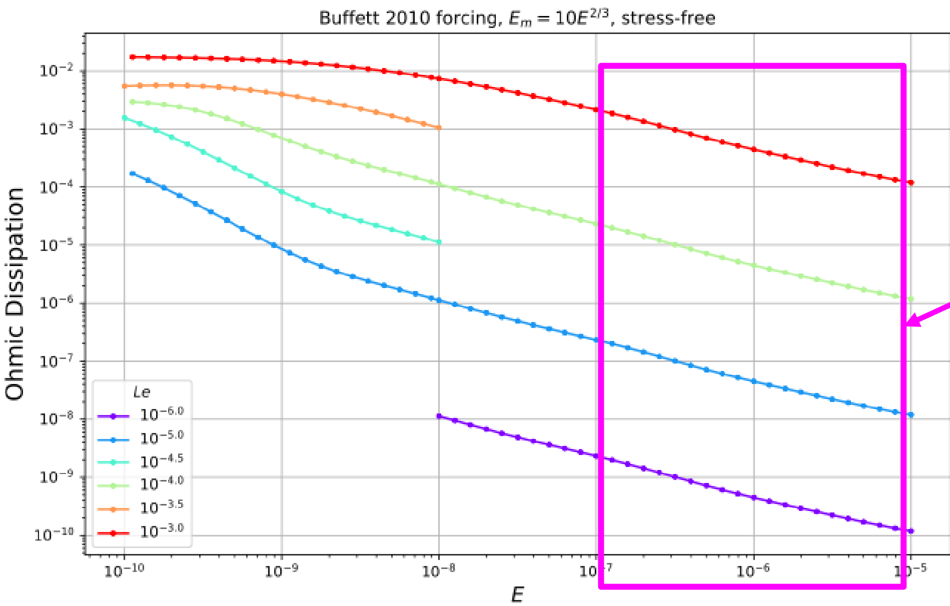
The color scale indicates the damping, very dark are less damped.

S.A. Triana, J. Rekier, A. Trinh & V. Dehant
The coupling between inertial and rotational eigenmodes in planets with liquid cores.
GJI.

Imposing a magnetic field and mimicking the FICN as an ICB forced flow

The color scale indicates the intensity of the magnetic field

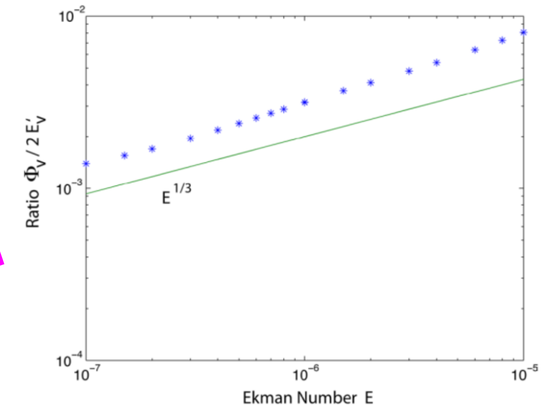


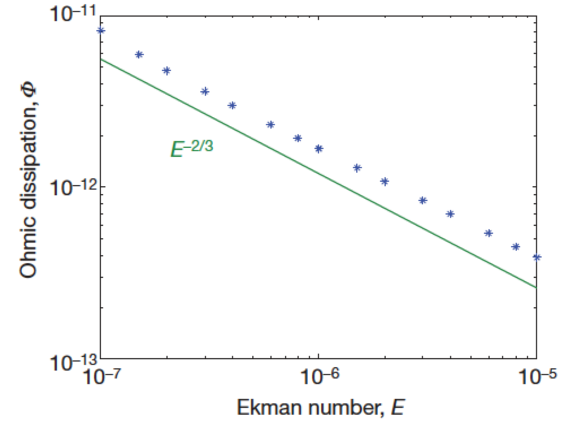


$$Le = \frac{B_0}{\Omega R\sqrt{\rho\mu_0}}$$

$Le = 10^{-4}$ is about 3 mT

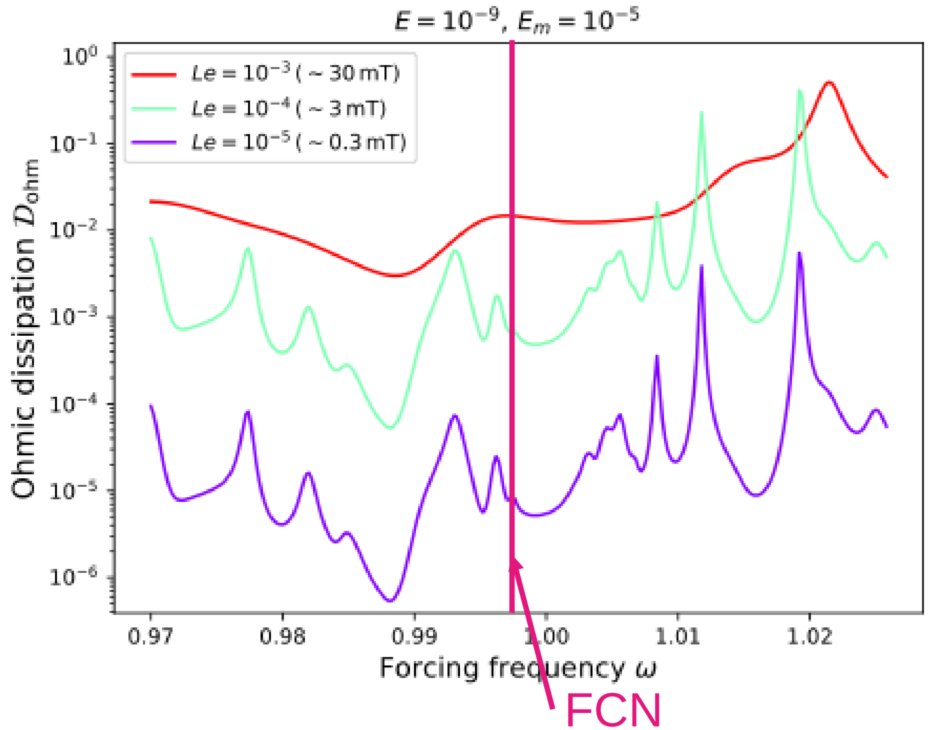
$Le = 10^{-5}$ is about 0.3 mT





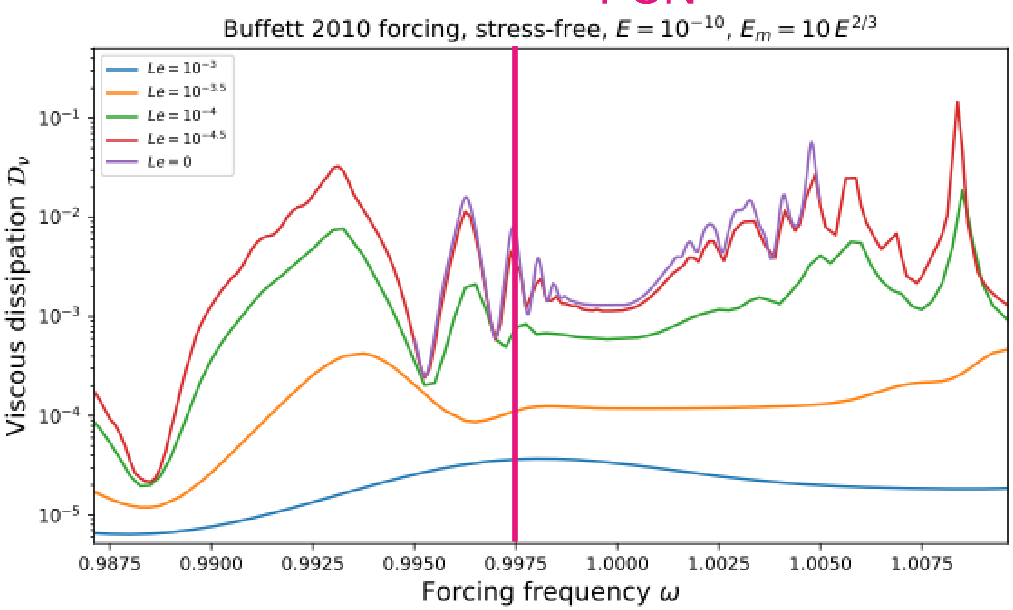
Tidal dissipation and the strength of the Earth's magnetic field

Buffett, 2010



As the magnetic field intensity increases, the inertial mode resonances become smoother.

Earth



But at moderate fields (like in the Earth's core) inertial mode peaks might persist and the total energy dissipation will depend on how close the forcing frequency is close to a resonance.

Conclusions

- Inertial waves and global nutation in the fluid core interact.
- The FCN can be influenced
- Associated with viscosity and electromagnetic field, there are internal dissipations
- The frequencies and damping of the inertial modes and global rotation mode change with the core flattening, Ekman number, and mantle moment of inertia
- A magnetic field changes also the inertial waves and global rotation inside the fluid core
- Numerical codes have been developed
- First results as part of the complete puzzle
- Stay tuned for further results soon

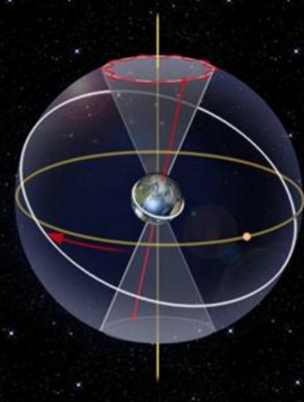
THANK YOU FOR YOUR ATTENTION!

ACKNOWLEDGEMENT:

The research leading to these results has received funding from the European Research Council under ERC advanced grant 670874.

RotaNut

Rotation and Nutation of a wobbly Earth



European Research Council

Established by the European Commission

ERC Advanced Grant 2014

Action number: 670874