Convection Modelling

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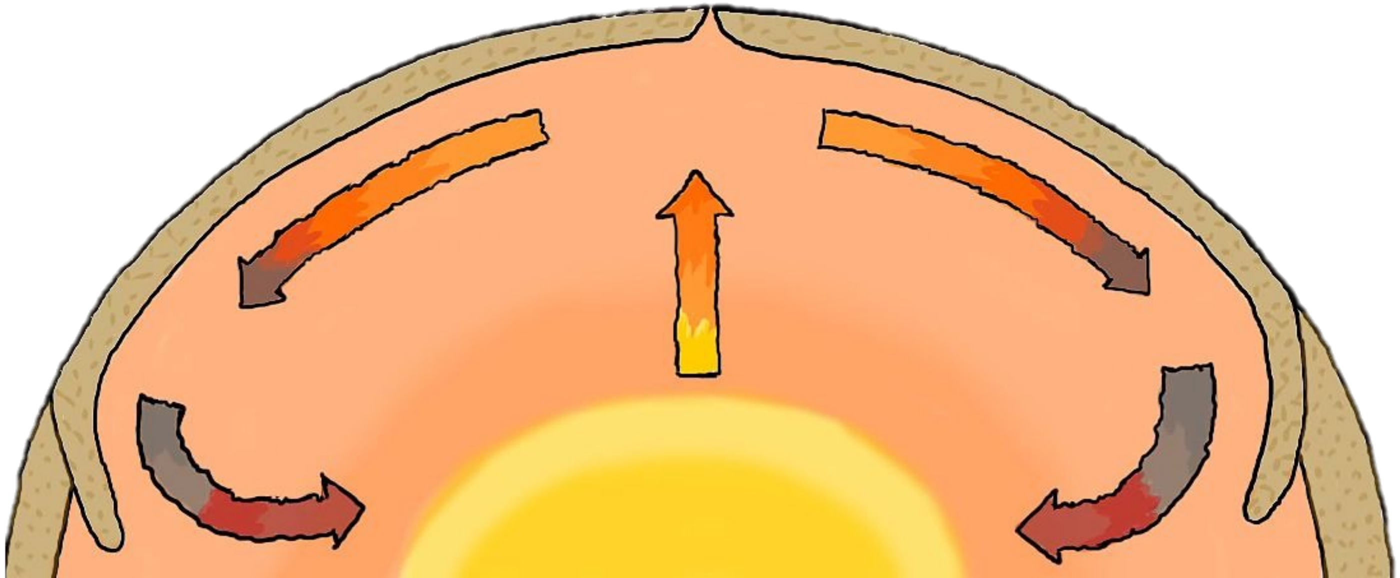

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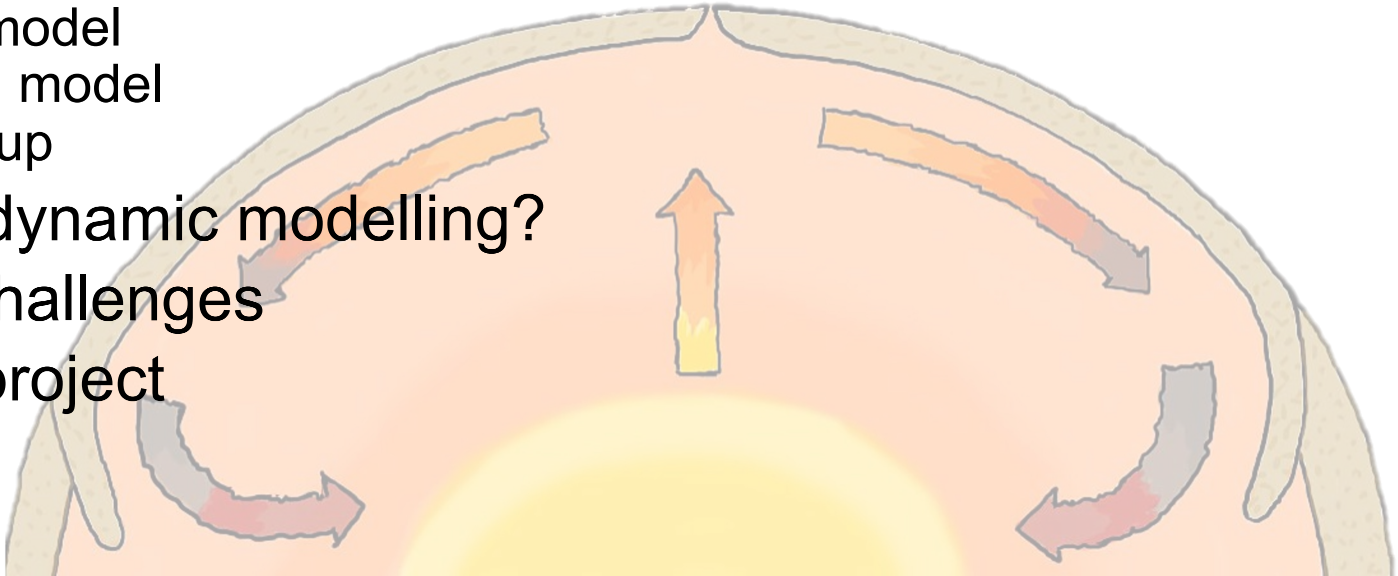
Outline

1. What is convection?
2. Convection in system Earth
    - Outer Core Convection
    - Mantle Convection
3. Link to lithosphere & asthenosphere
4. Convection Modelling Methods
    - Geodynamic modelling
    - Physical model
    - Numerical model
    - Model setup
5. Why geodynamic modelling?
6. Gaps & challenges
7. My PhD project



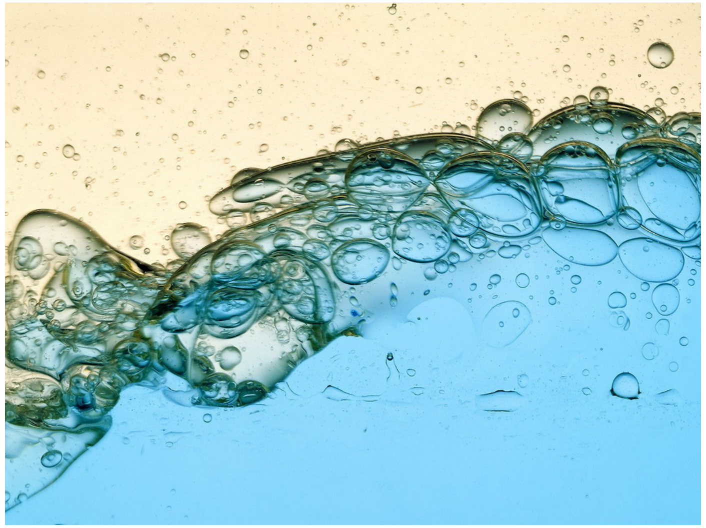
What is convection?

e.g. density

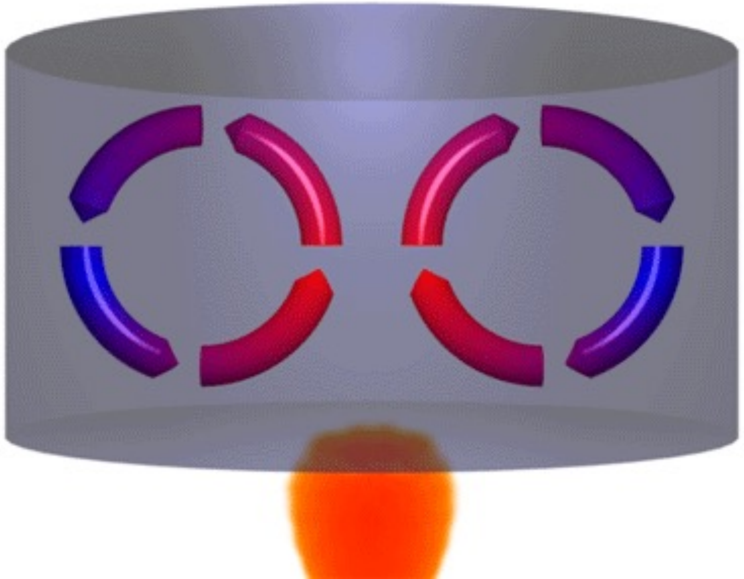
= *motion of fluid driven by* ***material property heterogeneity***
combined with ***body forces acting on the fluid***

e.g. gravity (buoyancy)

transient



steady-state

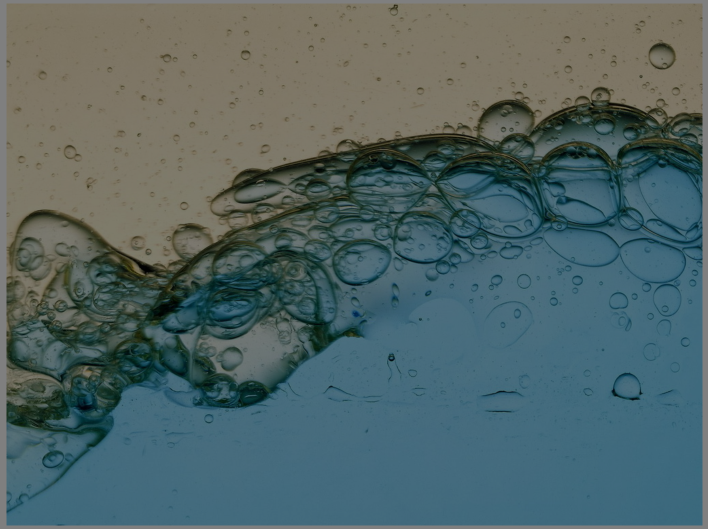


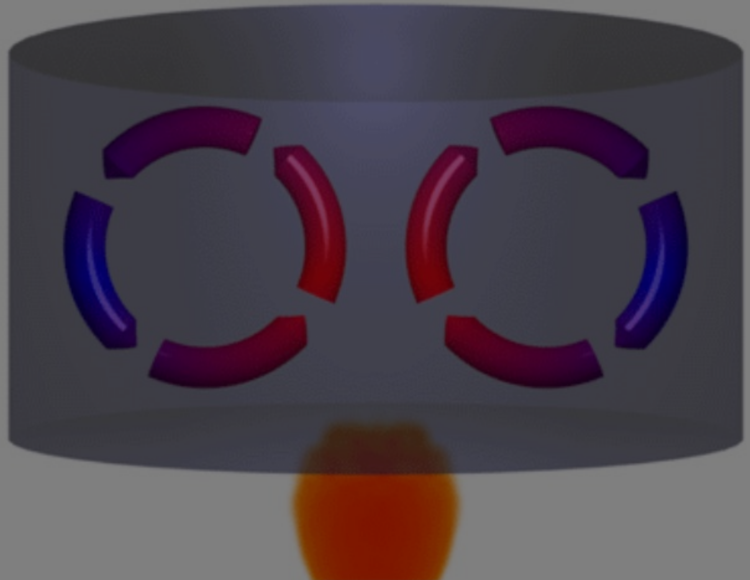
What is convection?

e.g. density

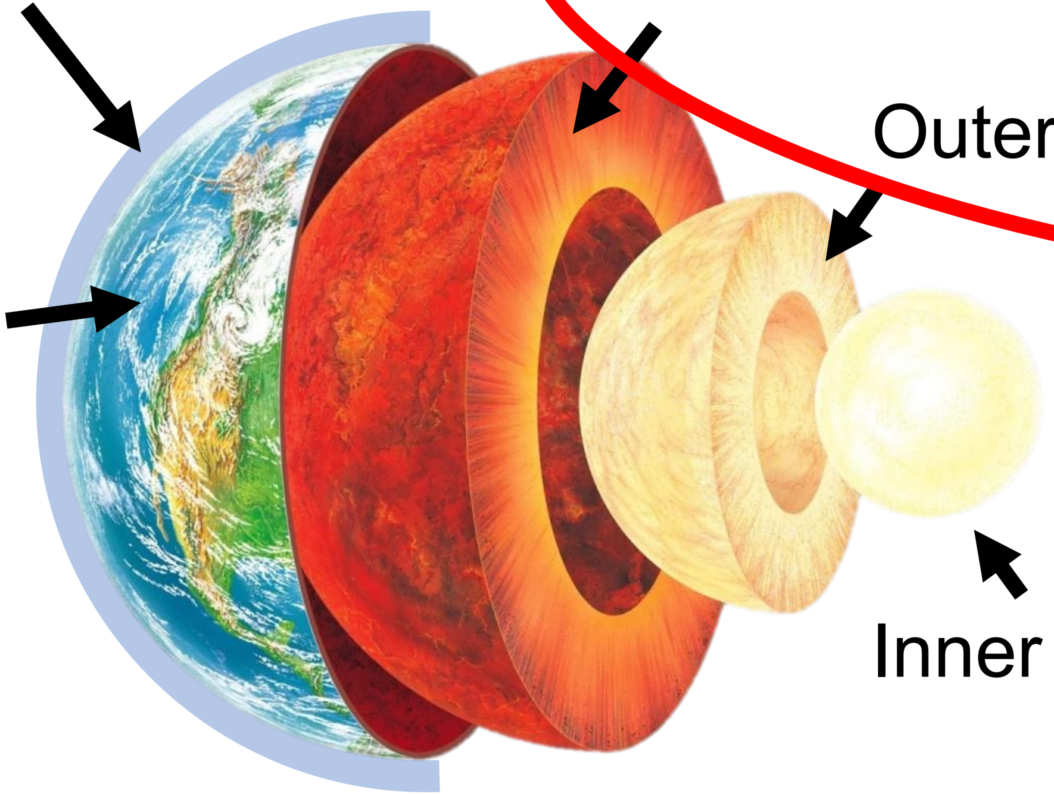
= *motion of fluid driven by* ***material property heterogeneity***
combined

Natural convection (no external driver)



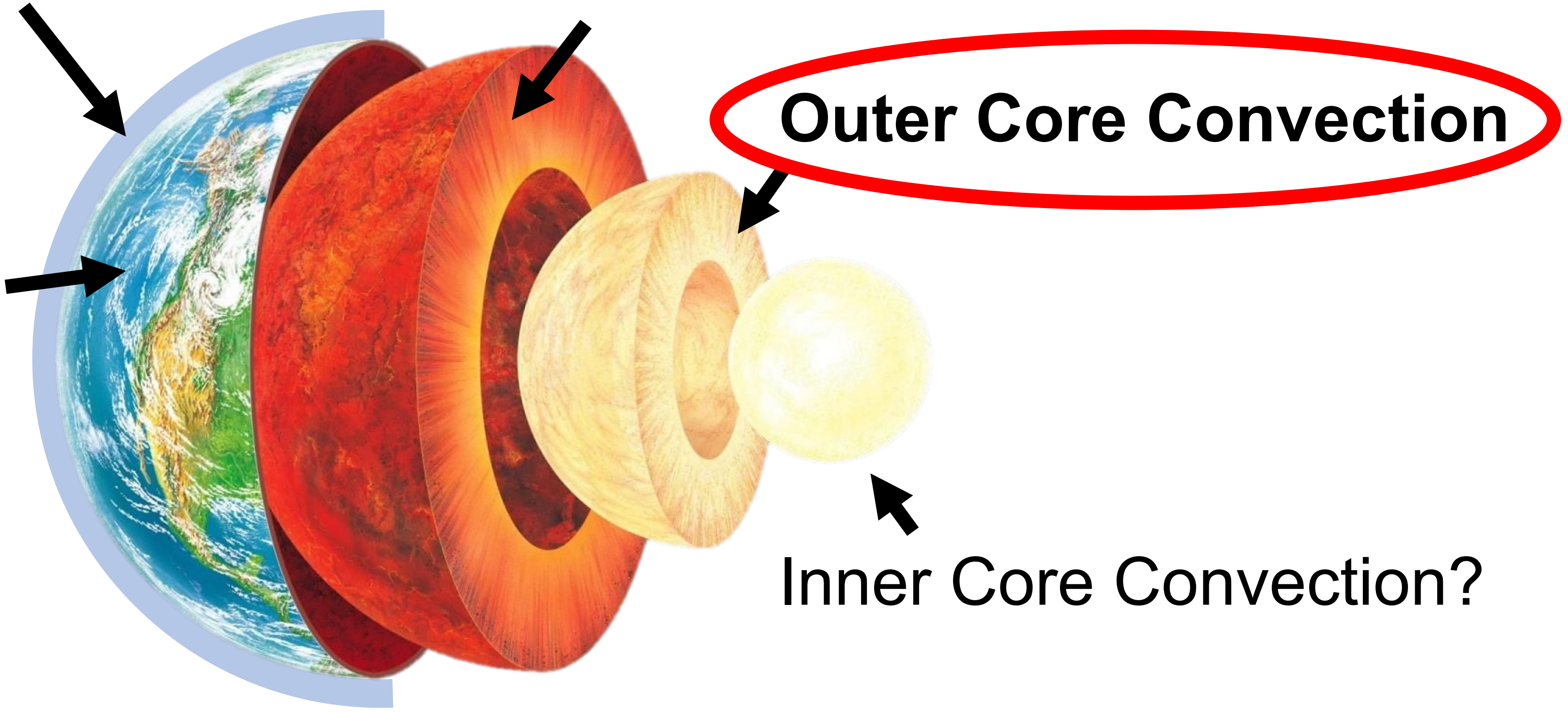


Convection in system Earth



Credits: Fabio Crameri

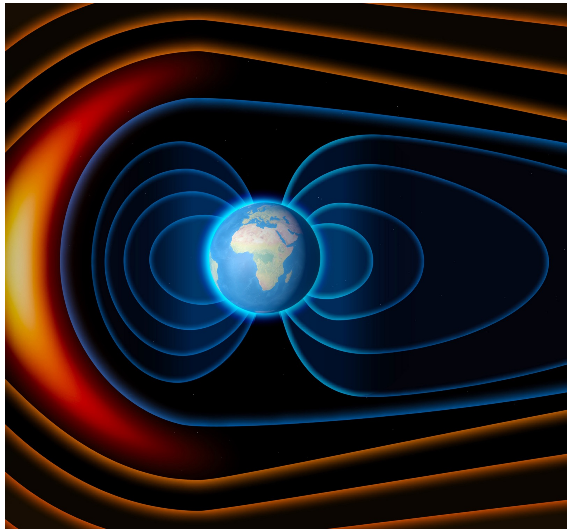
Convection in system Earth

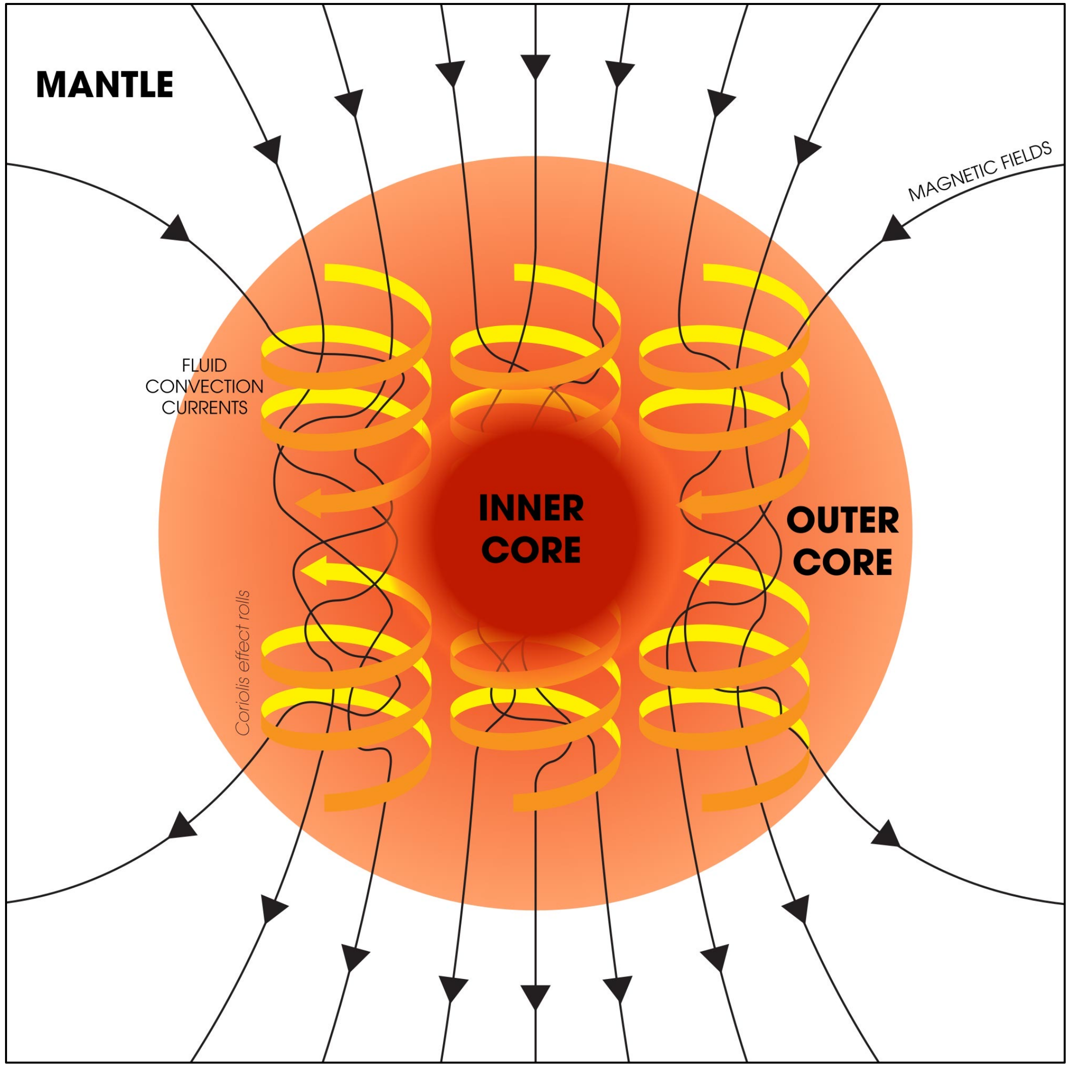


Credits: Fabio Crameri

Outer Core Convection

- Fluid iron-nickel
- Parameters: Ekman, Prandtl, magnetic Prandlt, Rayleigh
- Electromagnetic field generation (geodynamo)





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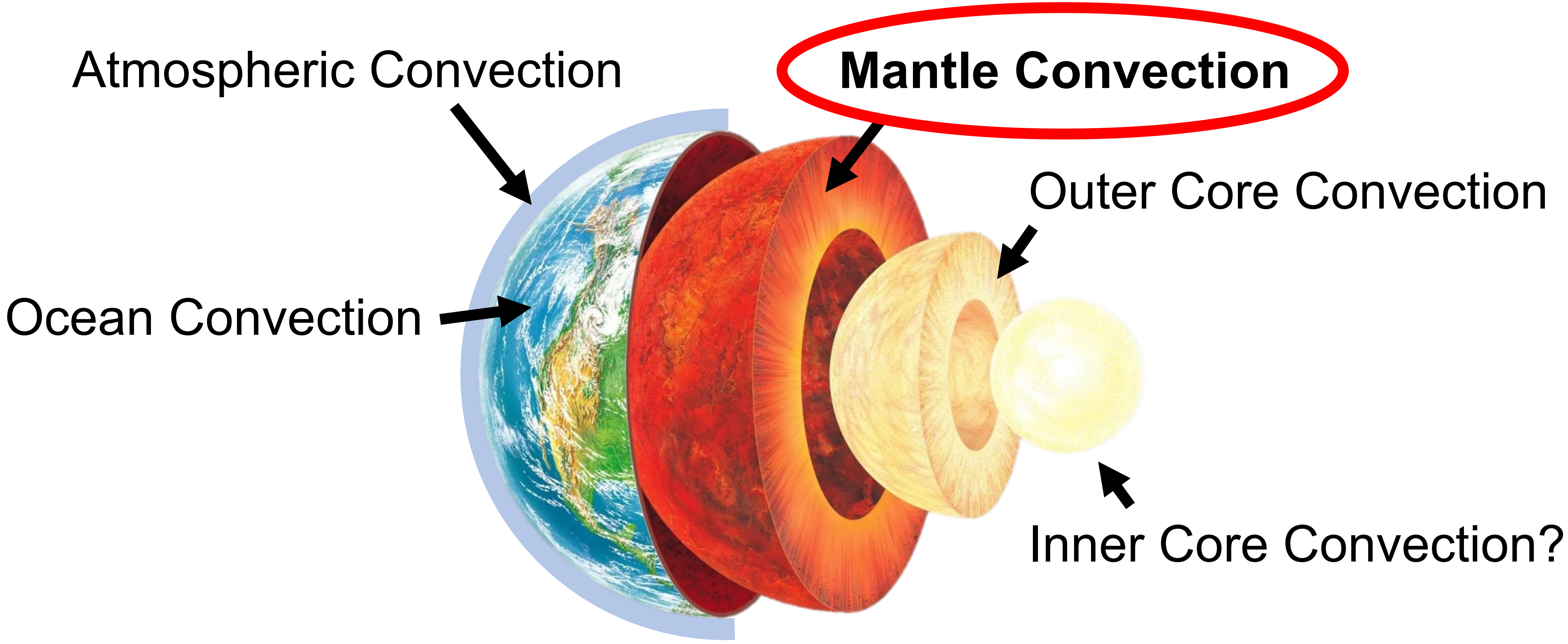
Convection in system Earth



Credits: *Fabio Crameri*

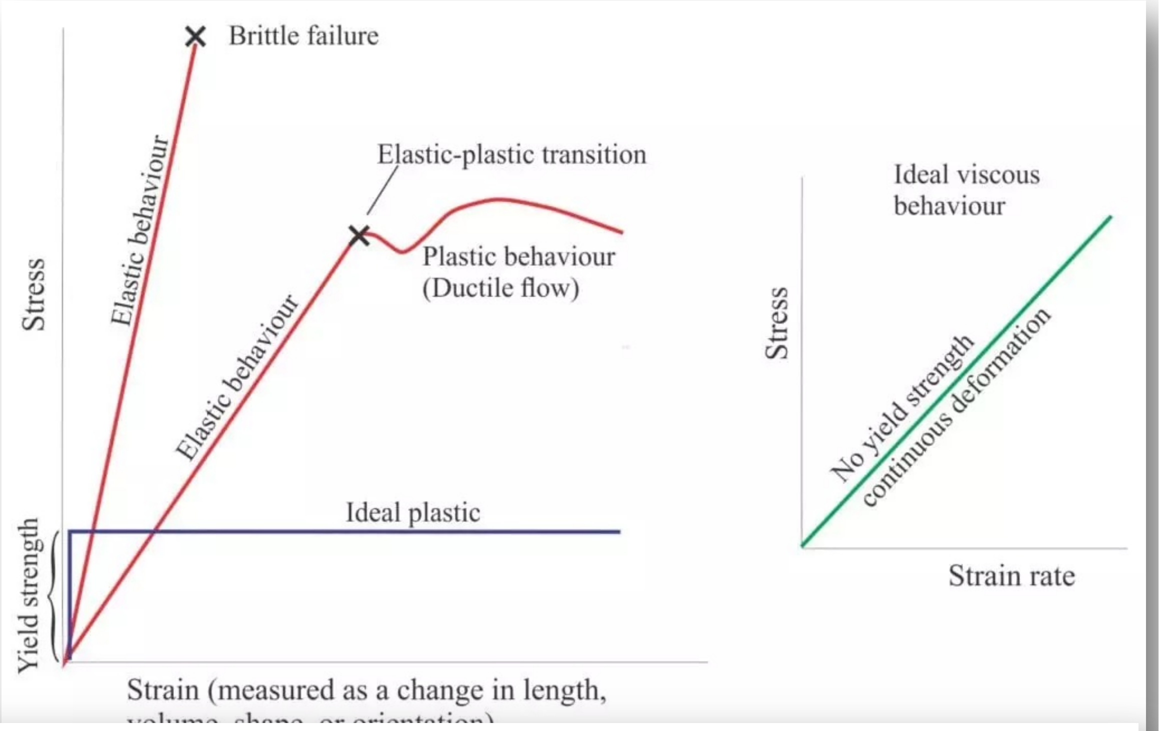
Mantle Convection

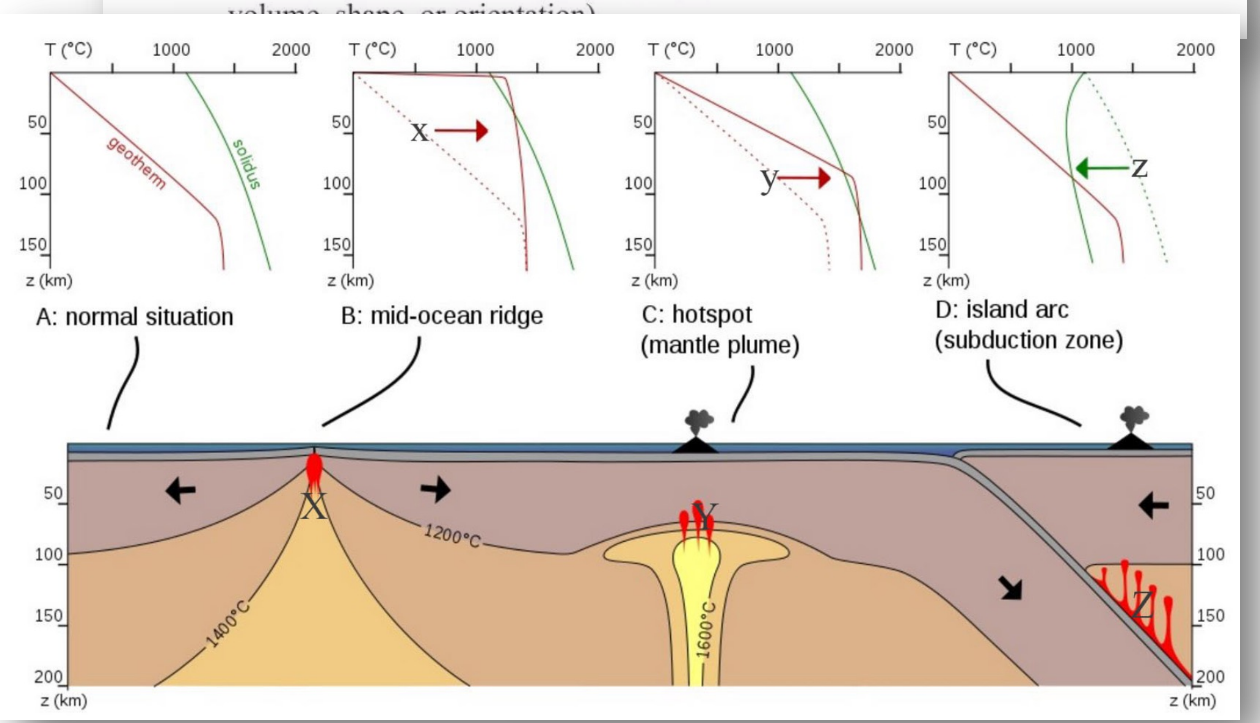
= viscous rock that flows over geological time scales

Affected by:

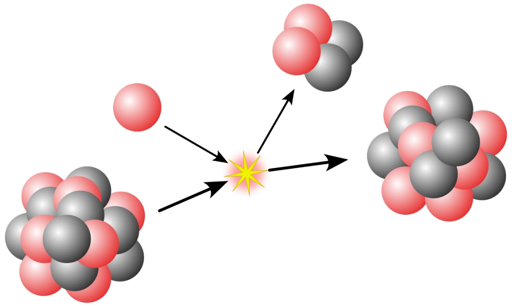
- Rheology
- Melting
- Compressibility
- Solid phase changes

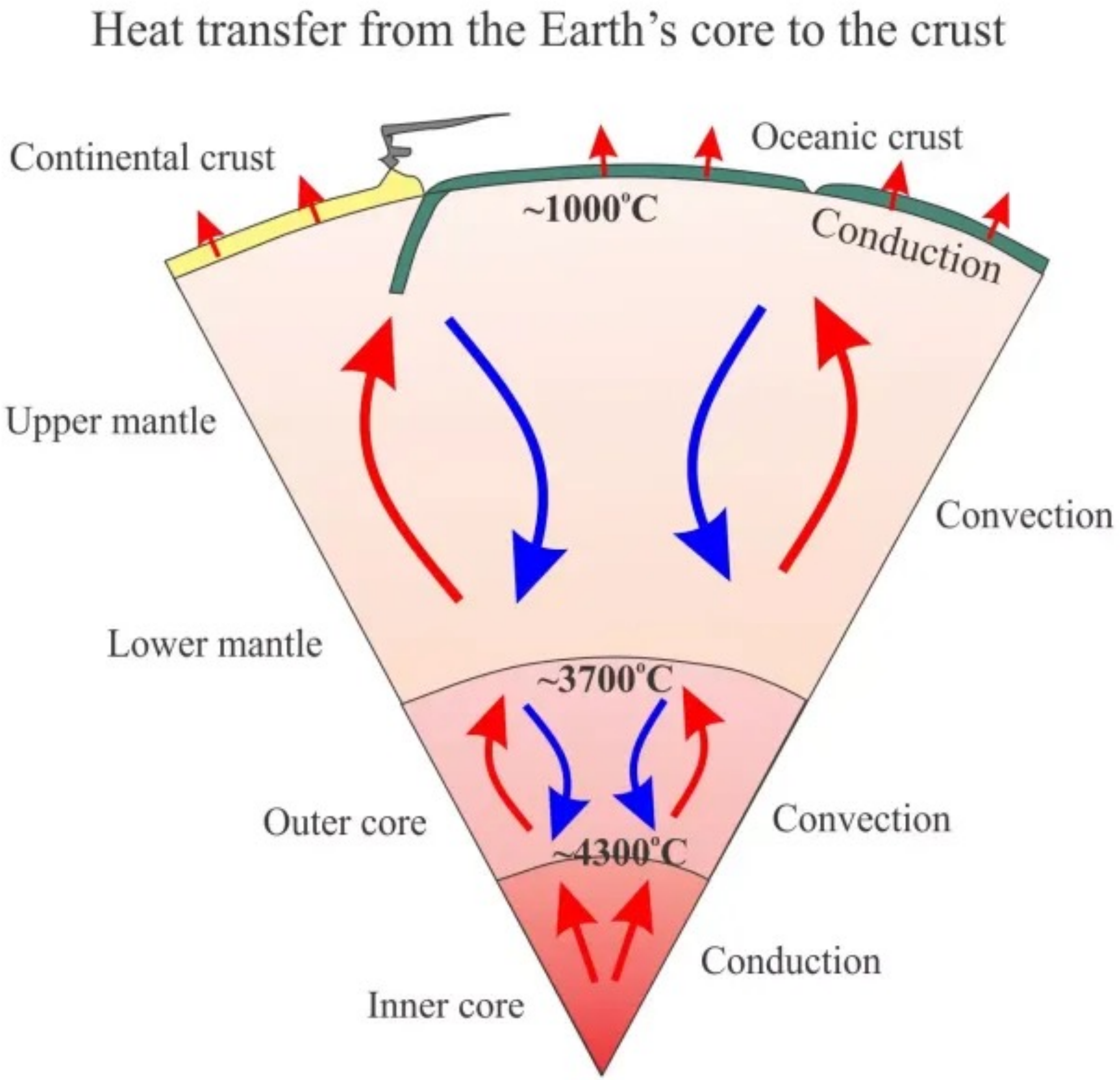
→ Major mode of heat transfer!





Mantle Convection - heat transfer





Release of heat through lithosphere through conduction

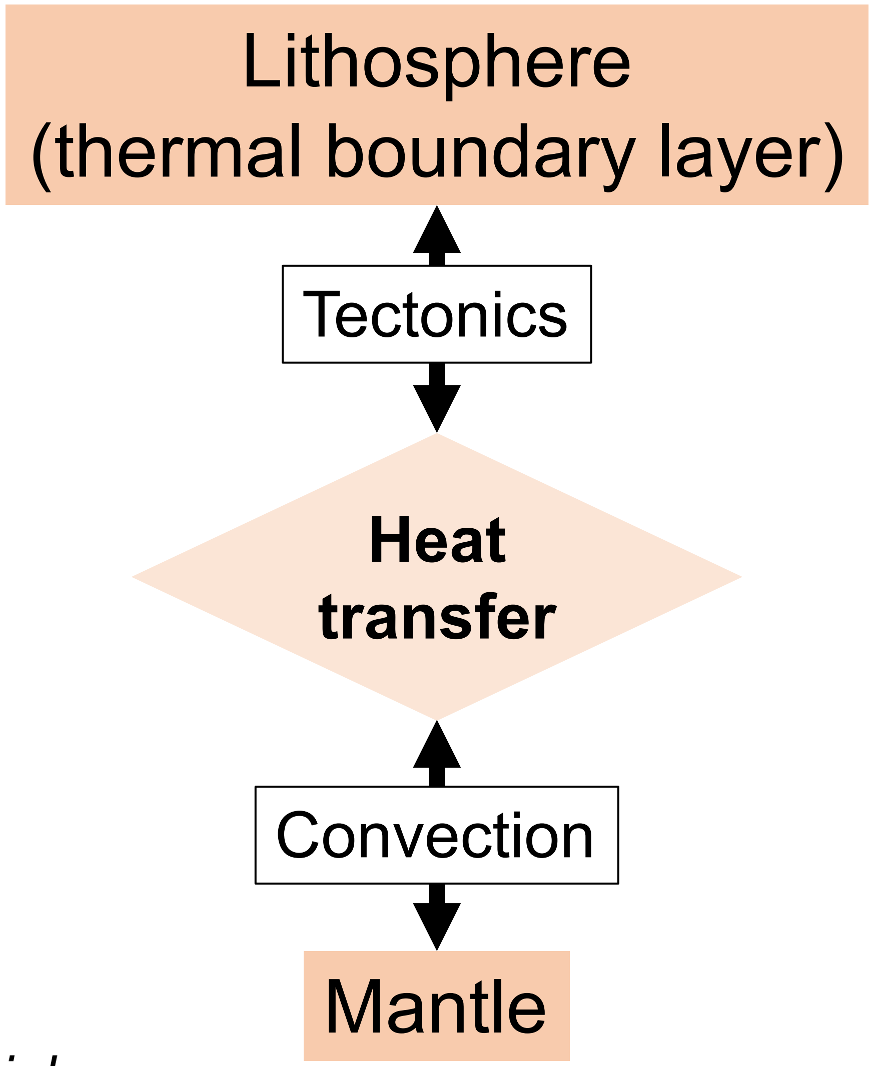
↑

+ internal heating (radioactive decay)

↑

Mantle heated from below (core cooling)

Link to lithosphere

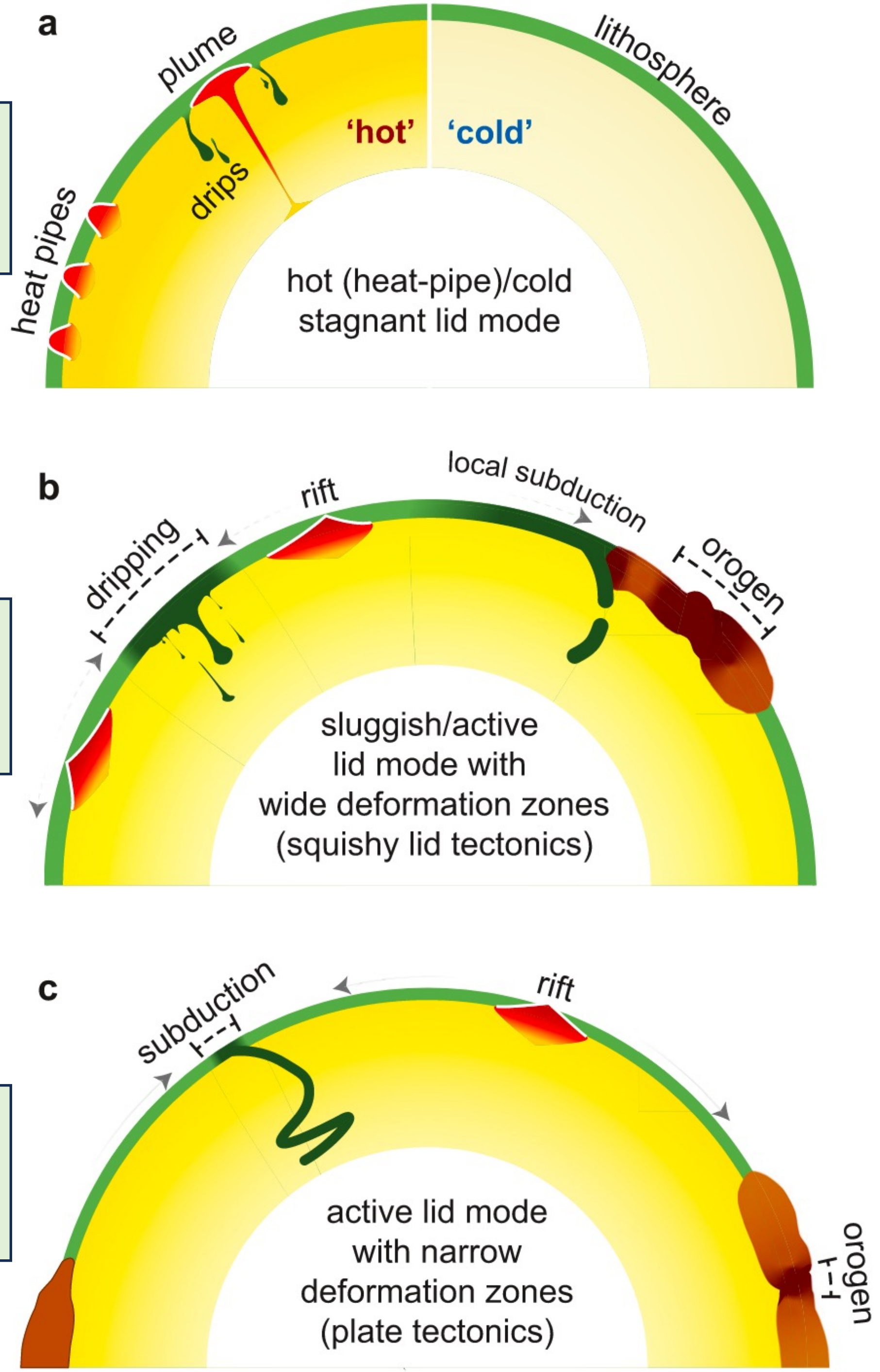


Cawood et al. (2022)

Stagnant lid mode

Sluggish lid mode

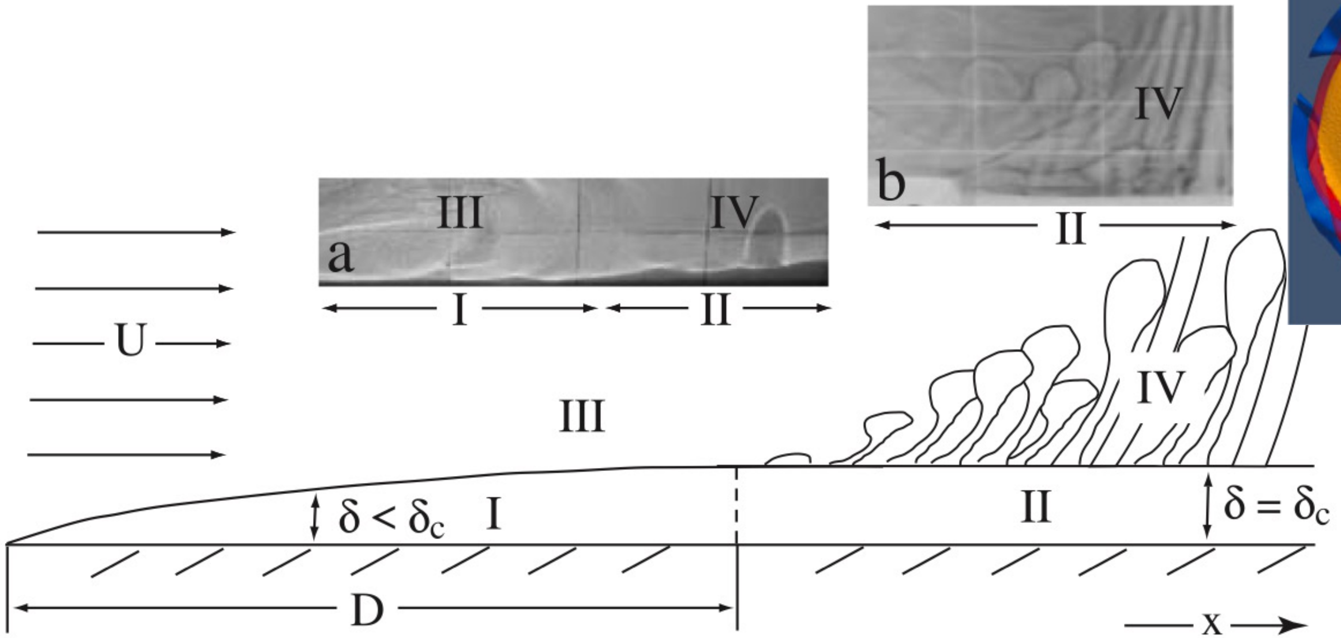
Active lid mode



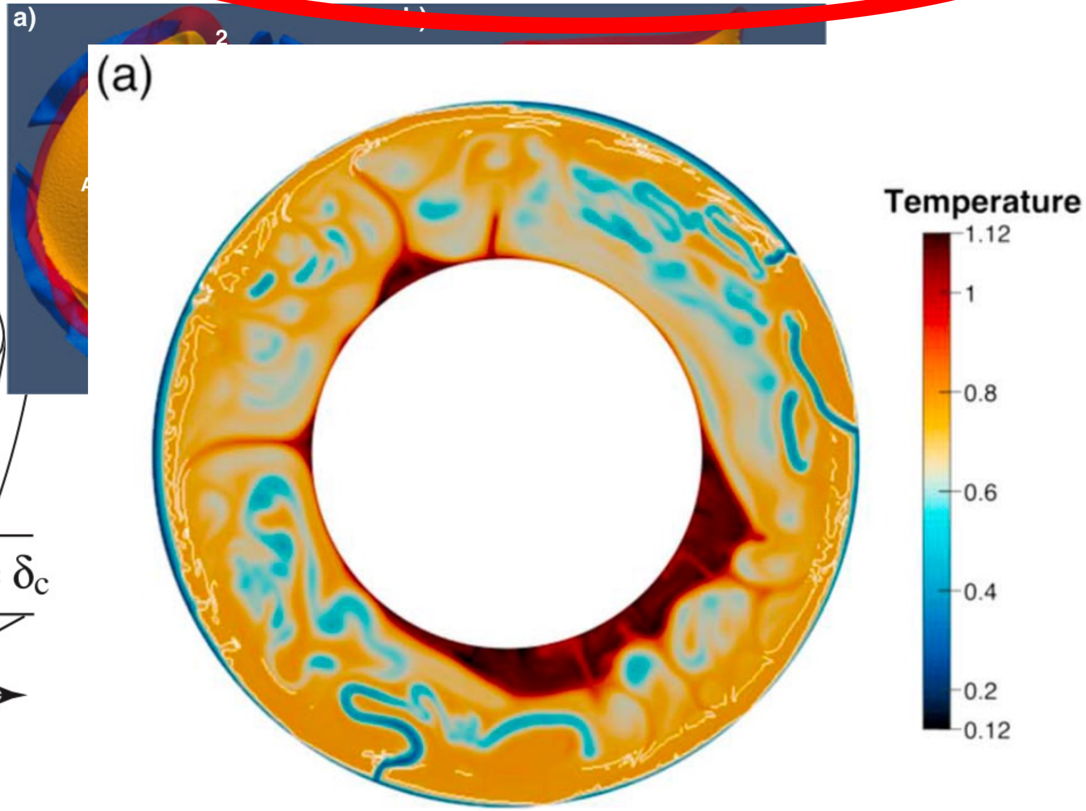
Convection Modelling Methods

Laboratory experiments

Computational methods

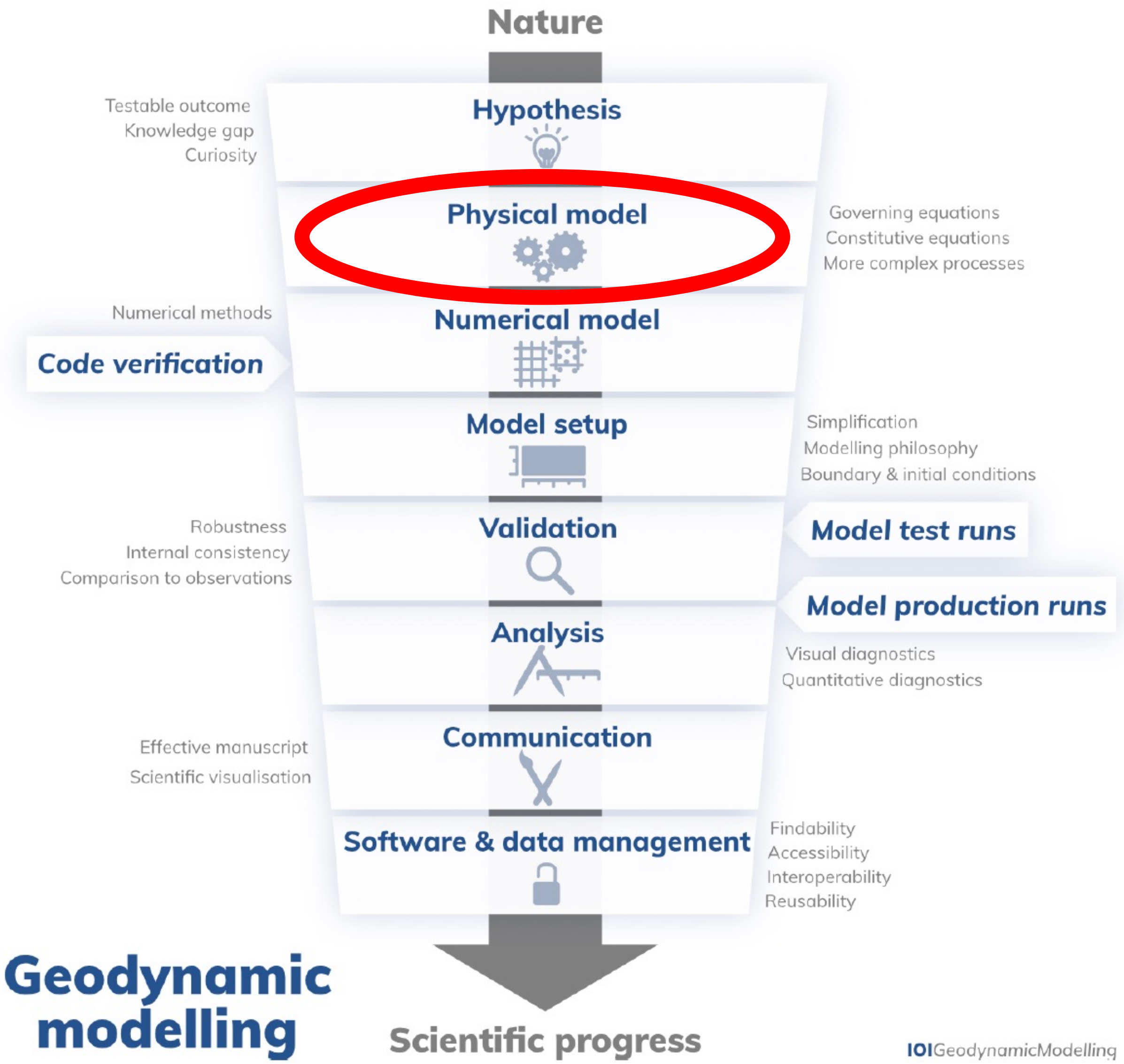


Gonnermann et al. (2005)



https://www.youtube.com/watch?v=t_d35KYh6aI
http://earth.uni-muenster.de/~wiesehof/convection/#

Geodynamic modelling



by Fabio Crameri from van Zelst et al. (2021)

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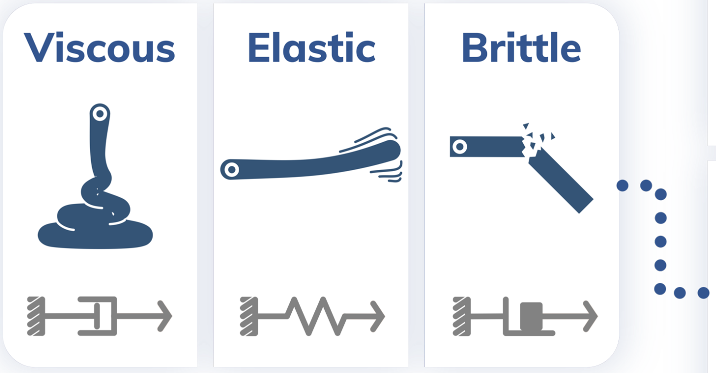
The physical model

Rheology



Conservation equations

Mass

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{v}) = 0$$

Local changes in mass over time — Influx/outflux of mass

Momentum

$$\nabla \cdot \boldsymbol{\sigma} + \rho \boldsymbol{g} = 0$$

Surface forces per unit volume — Body forces per unit volume (gravity)

Energy

$$\rho C_p \left(\frac{\partial T}{\partial t} + \boldsymbol{v} \cdot \nabla T \right) - \nabla \cdot (k \nabla T) = \rho H + S$$

Changes in thermal energy over time — Advection — Conduction — Internal heat production — Other heating processes

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Rayleigh number (vigour of flow)

$$Ra = \frac{\rho g \alpha \Delta T d^3}{\mu \kappa}$$

Earth's mantle:
Ra = 5e6 – 5e7

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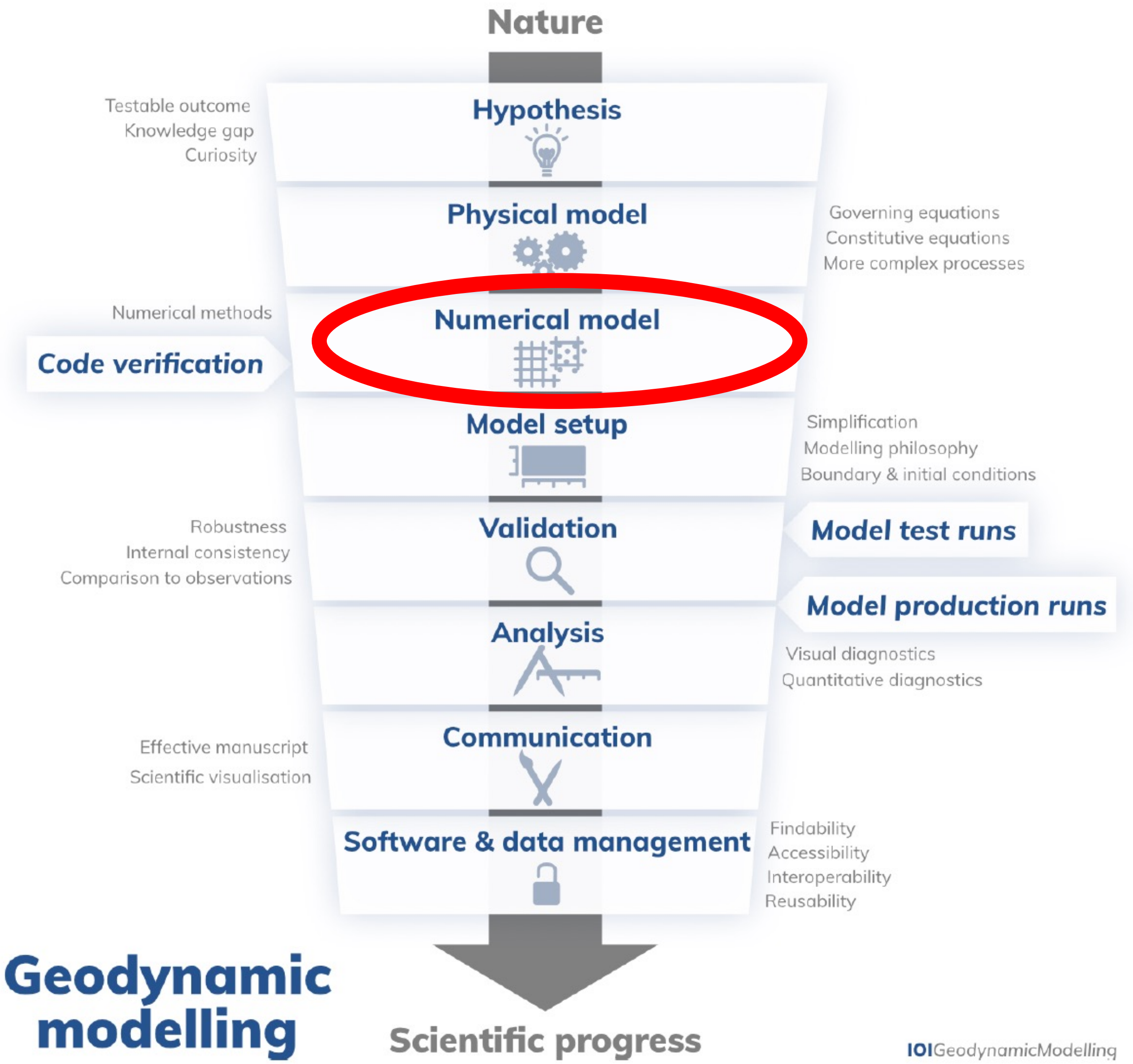
Geodynamic modelling



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The numerical model

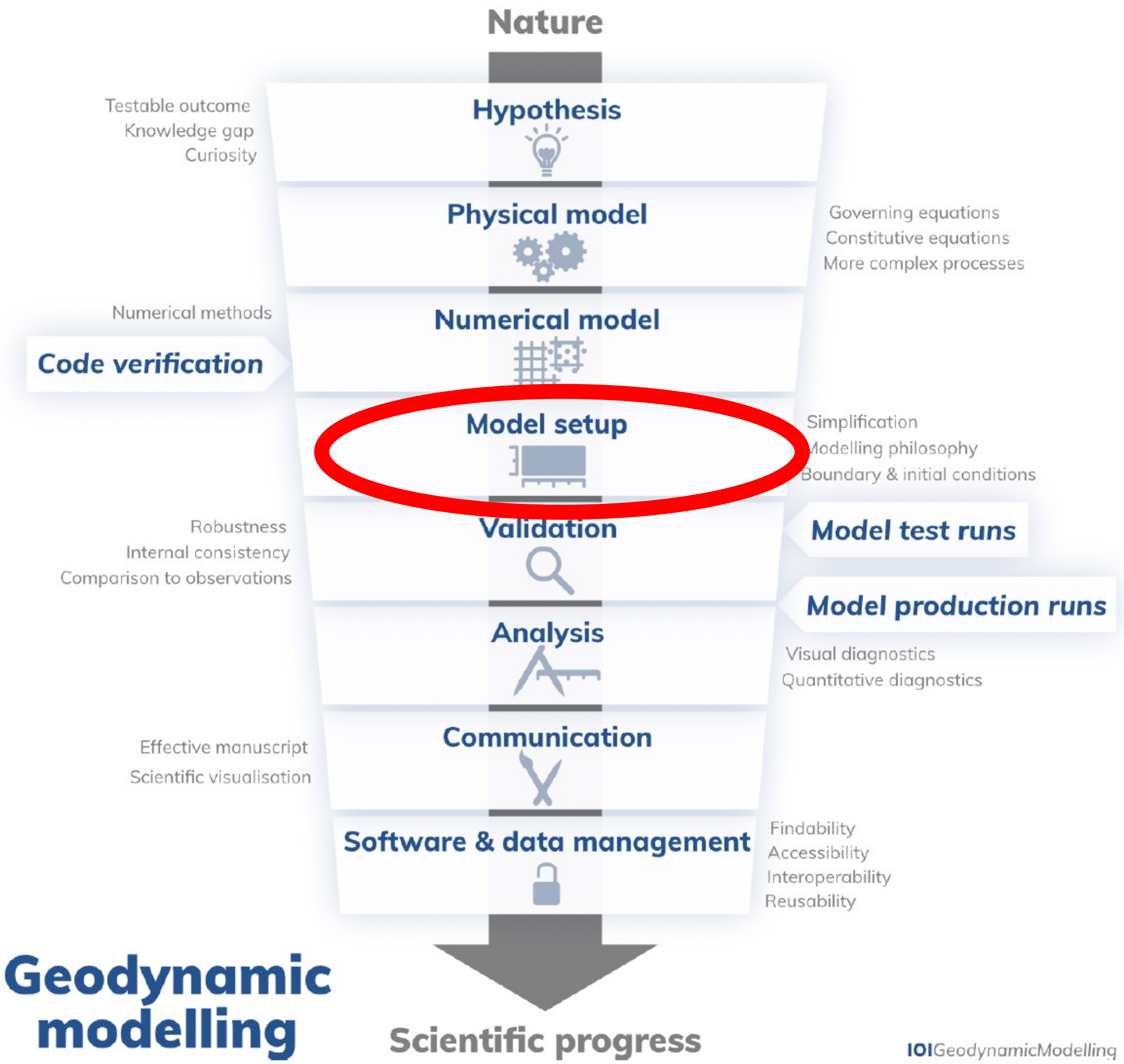
Discretisation:

- Finite Element
- Finite Difference
- Finite Volume

Some numerical convection codes:

- StagYY (*Tackley, 2008 & many others*)
- ASPECT (*Heister et al., 2017 & many others*)
- CitcomS (*Moresi et al., 2014 & many others*)

Geodynamic modelling



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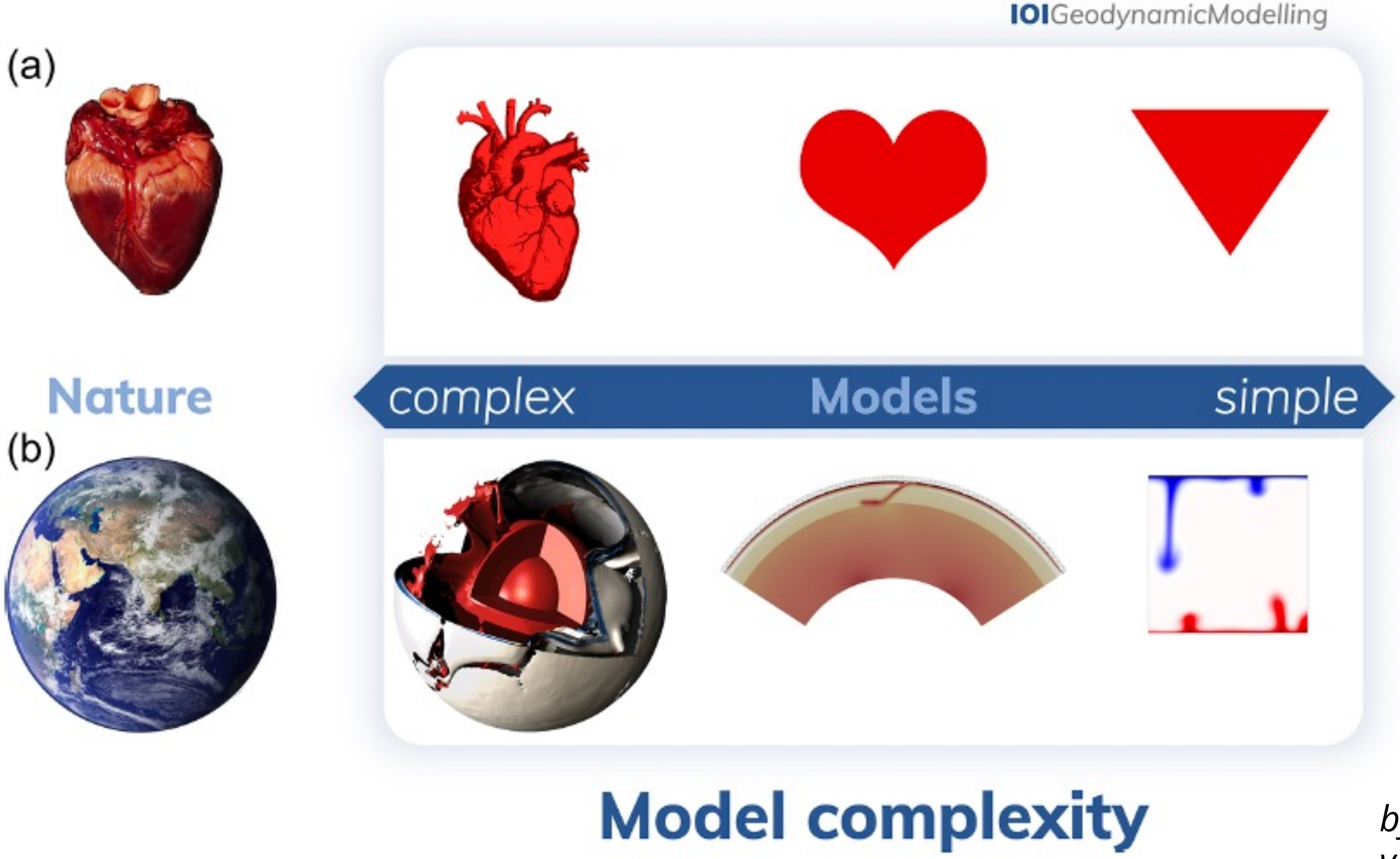
Model setup - different levels of complexity



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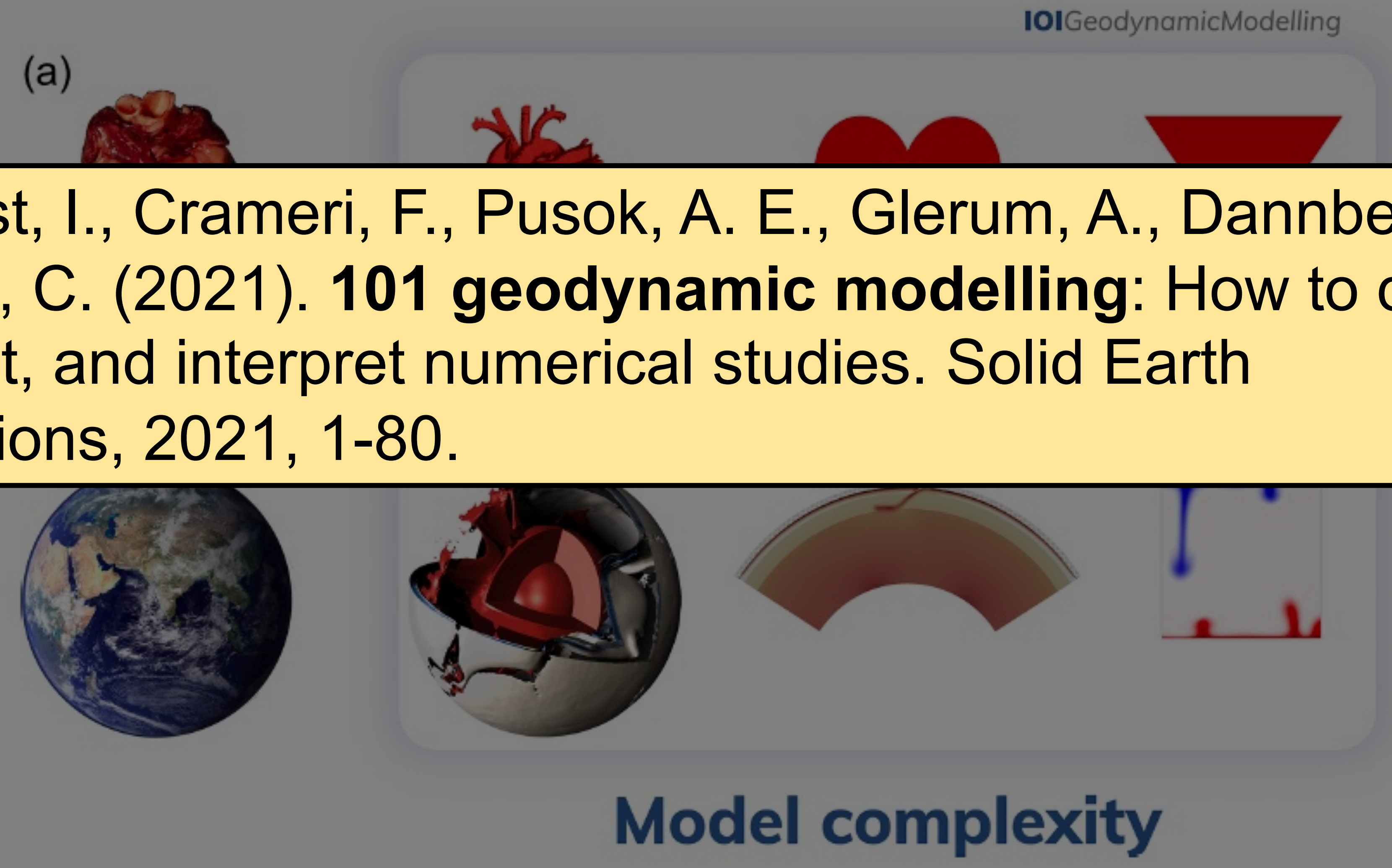
Model setup - different levels of complexity

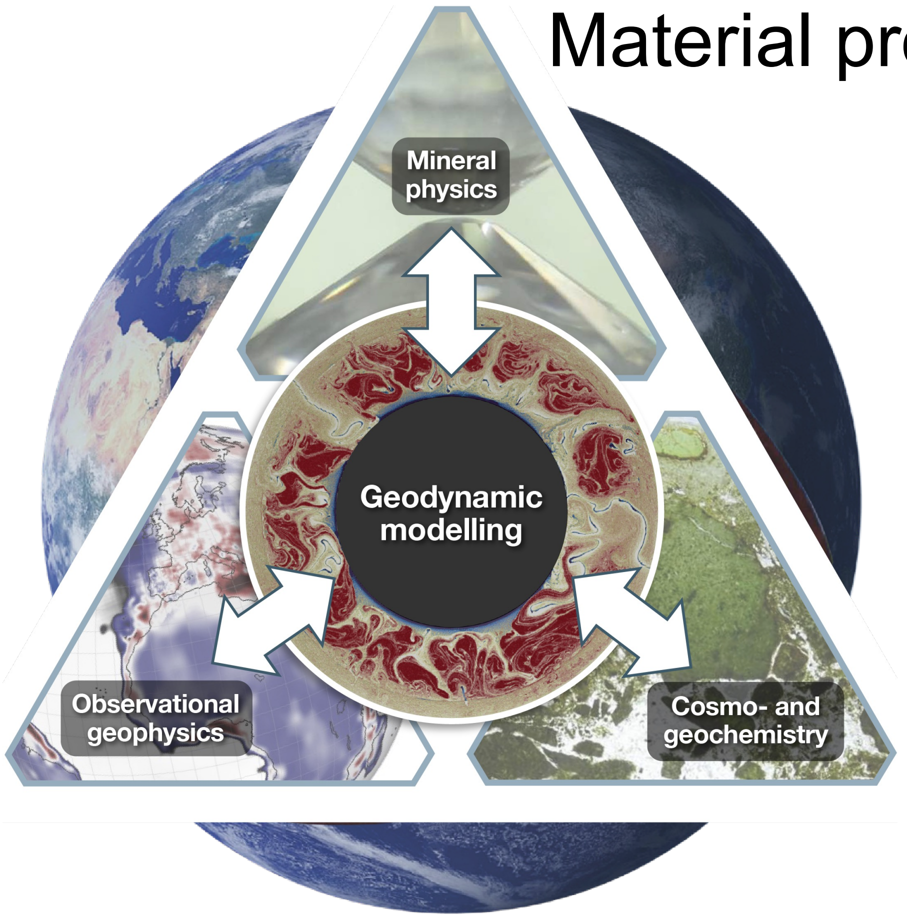


van Zelst, I., Crameri, F., Pusok, A. E., Glerum, A., Dannberg, J., & Thieulot, C. (2021). **101 geodynamic modelling**: How to design, carry out, and interpret numerical studies. Solid Earth Discussions, 2021, 1-80.

by Fabio Crameri from van Zelst et al. (2021)

Why geodynamic modelling?

Equations-of-state
Phase changes
Material properties



Seismology
Tomography
Geodesy

Bulk composition
Isotopic ratios

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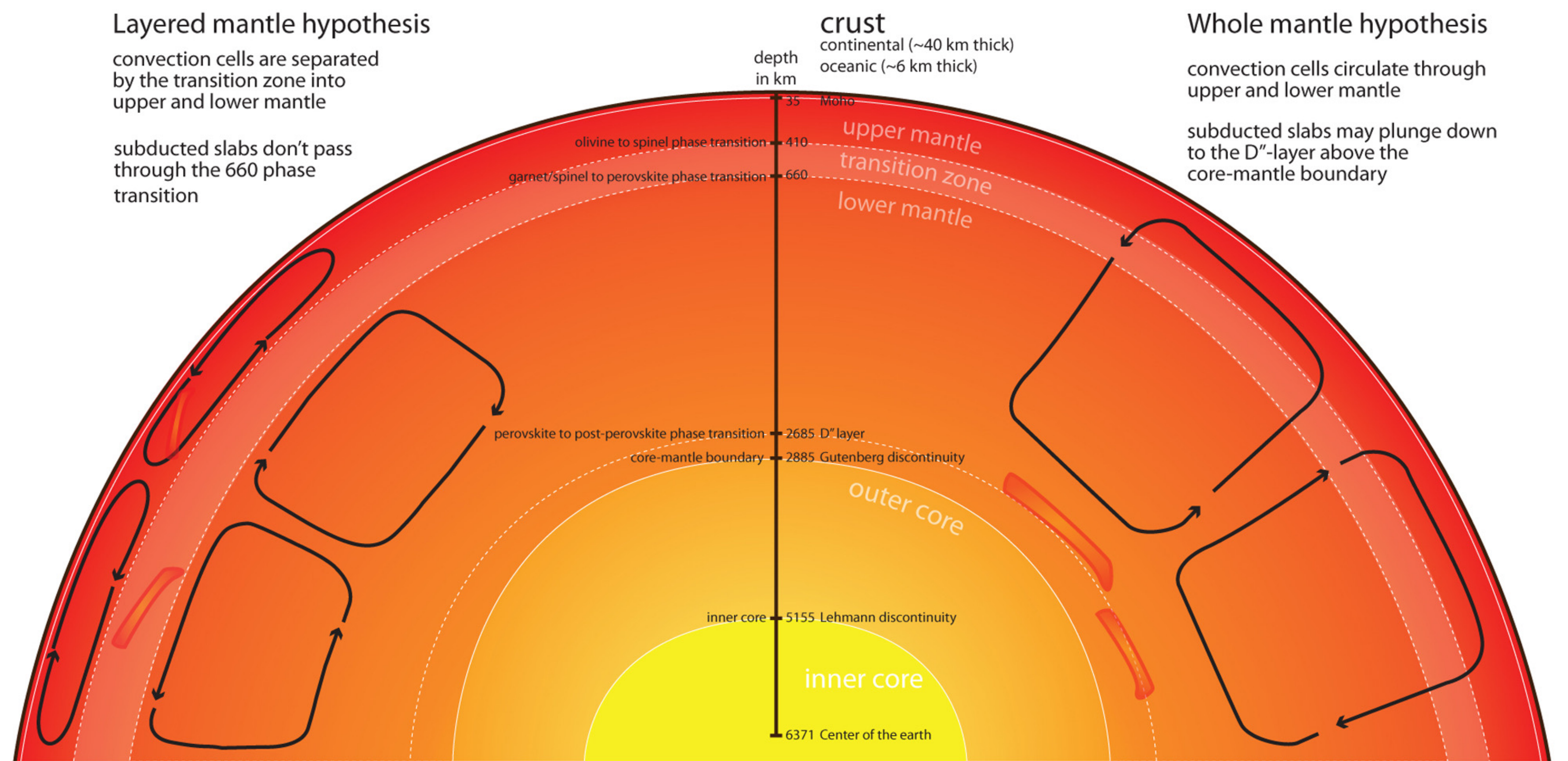
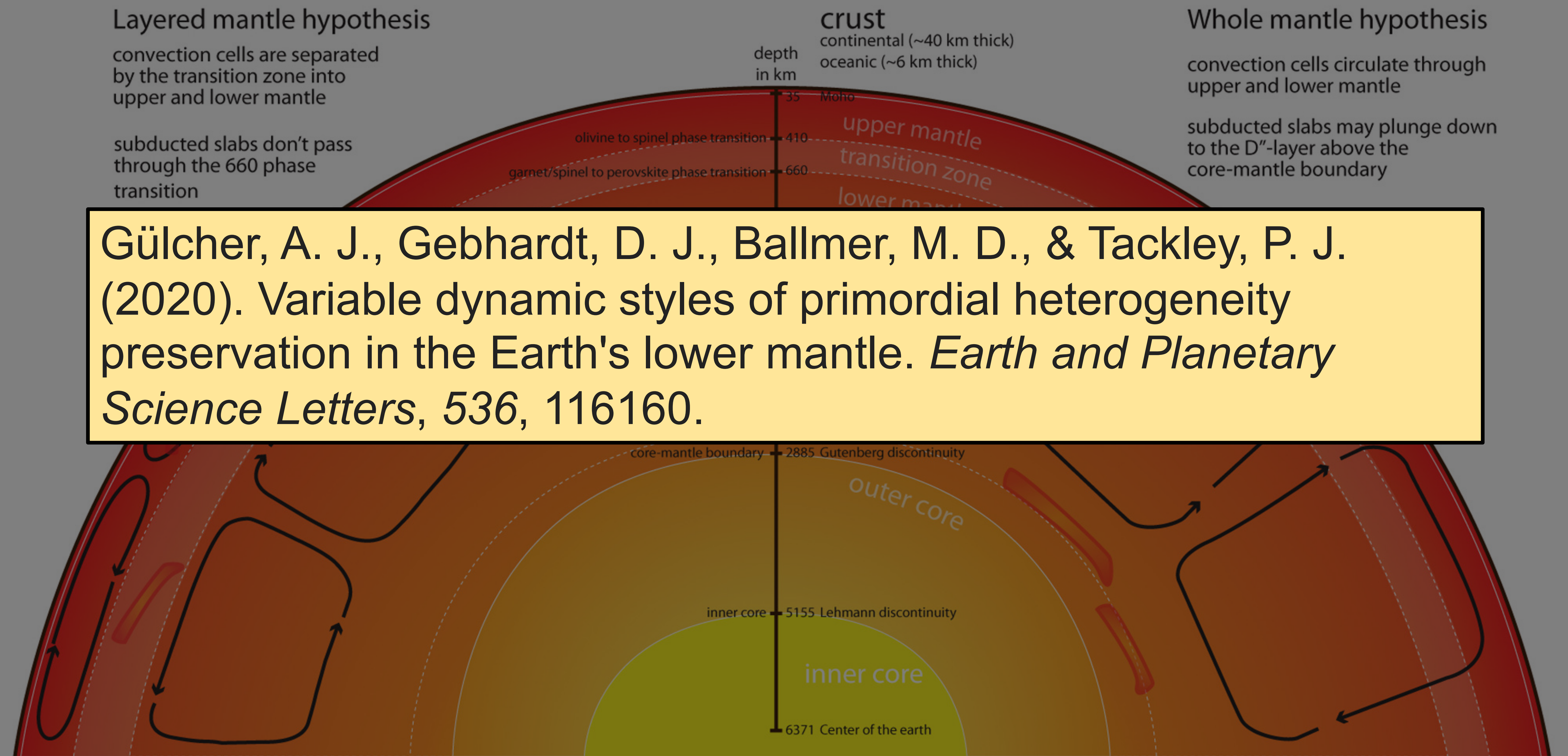
Credits: Anna Gülcher

Gaps & challenges

- Exact relation between mantle and plates
- Rheological behaviour
- Plate tectonics initiation
- **Mantle convection mode**
- Deep mantle processes
- Modelling 2-phase flow
- Interaction with carbon cycle, climate & biosphere
- & so many more…

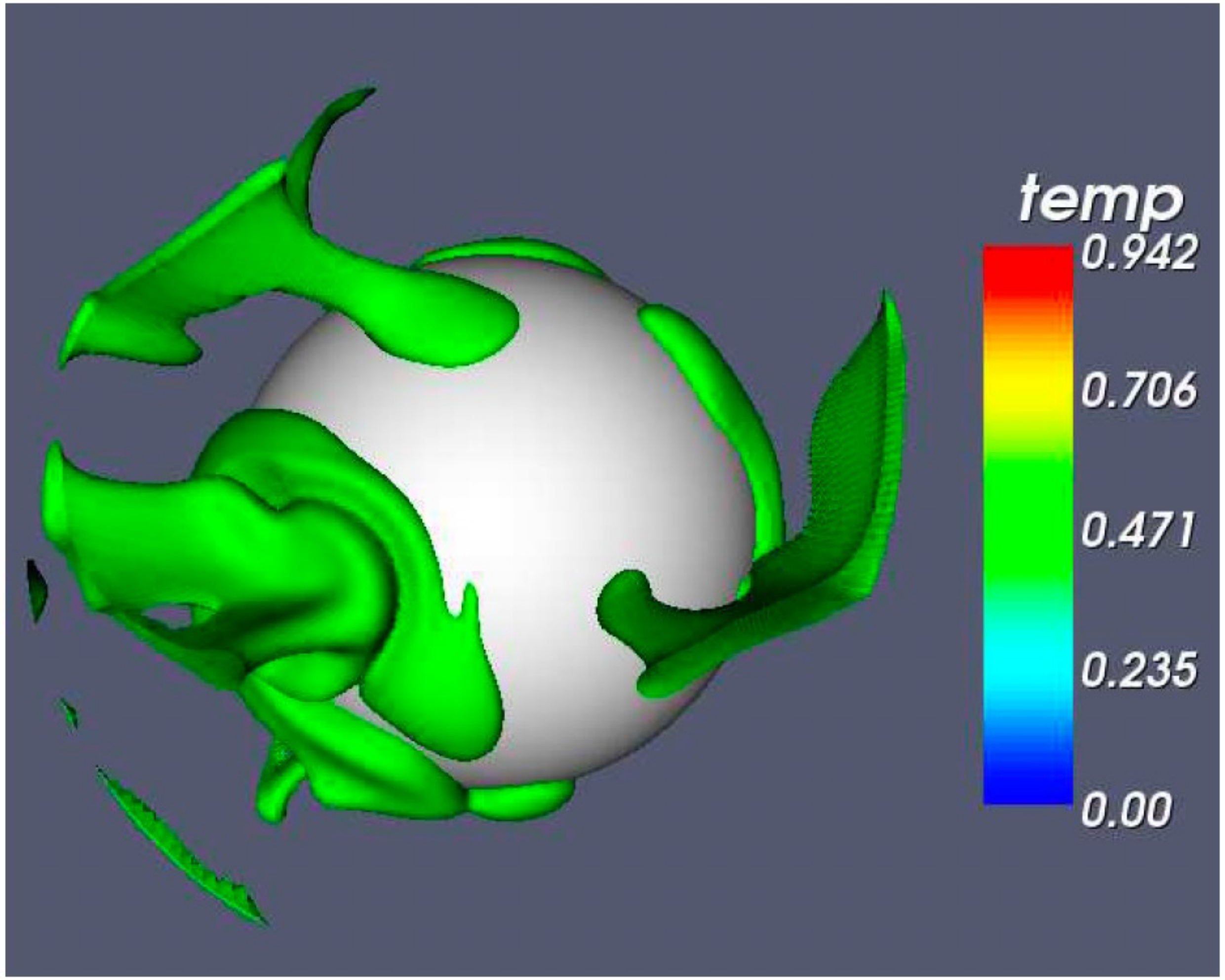

Layered mantle hypothesis
convection cells are separated by the transition zone into upper and lower mantle
subducted slabs don't pass through the 660 phase transition
crust
continental (~40 km thick)
oceanic (~6 km thick)
depth in km
35 Moho
upper mantle
olivine to spinel phase transition 410
transition zone
garnet/spinel to perovskite phase transition 660
lower mantle
perovskite to post-perovskite phase transition 2685 D" layer
core-mantle boundary 2885 Gutenberg discontinuity
outer core
inner core 5155 Lehmann discontinuity
inner core
6371 Center of the earth
Whole mantle hypothesis
convection cells circulate through upper and lower mantle
subducted slabs may plunge down to the D"-layer above the core-mantle boundary

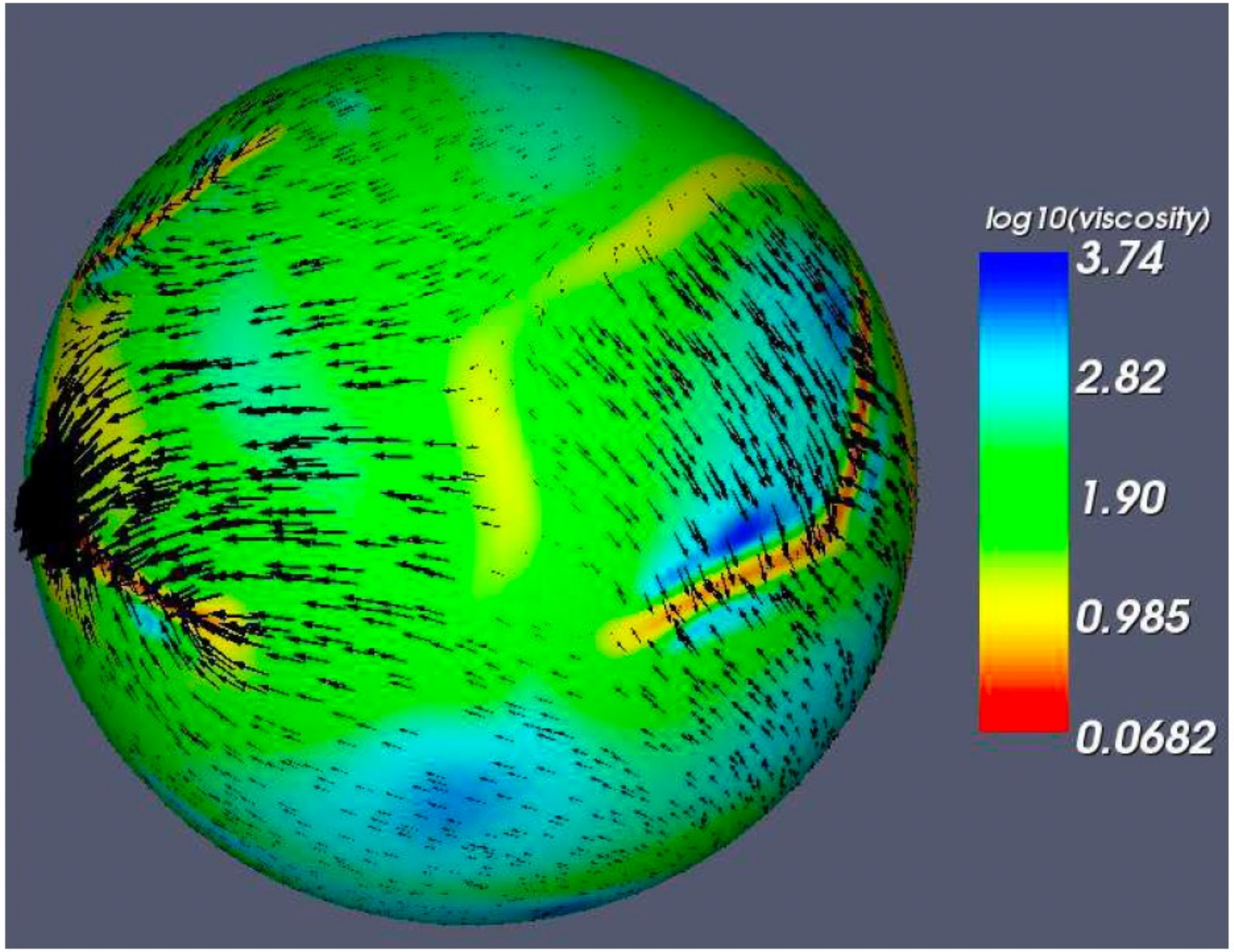


Gülcher, A. J., Gebhardt, D. J., Ballmer, M. D., & Tackley, P. J. (2020). Variable dynamic styles of primordial heterogeneity preservation in the Earth's lower mantle. *Earth and Planetary Science Letters*, *536*, 116160.

My PhD project

Swiss National Science Foundation





Foley and Becker (2009)