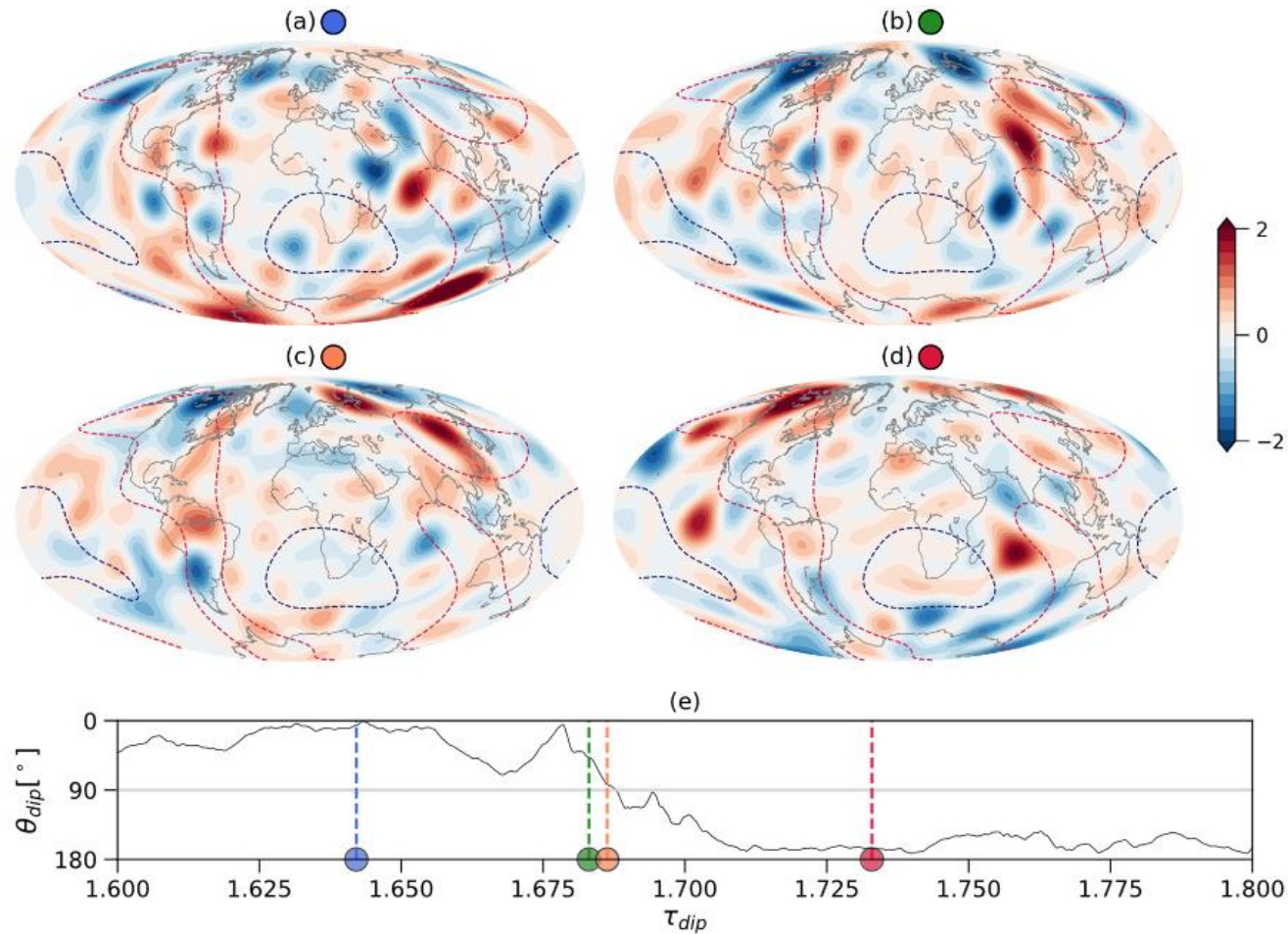# Regionally-triggered geomagnetic reversals

Filipe Terra-Nova and Hagay Amit
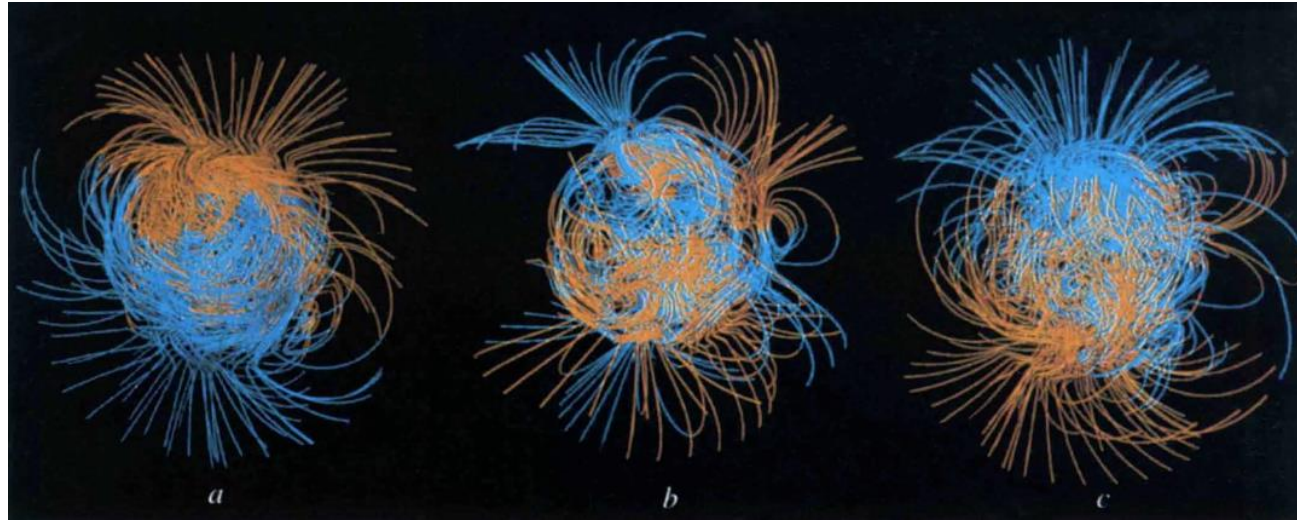

Terra-Nova, F., Amit, H., 2024. Regionally-triggered geomagnetic reversals. Sci. Rep., 14, 9639.

ANR DYRE-COMB annual meeting 2024
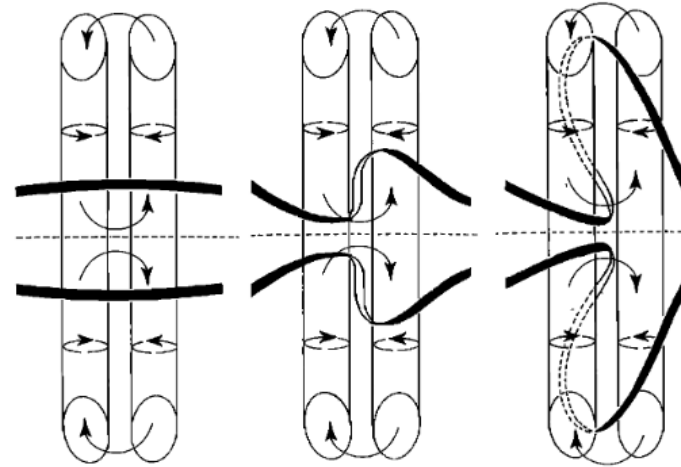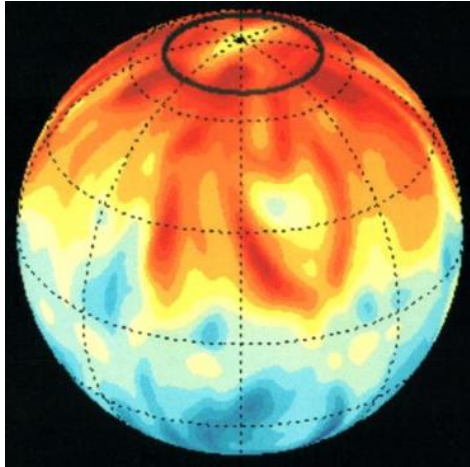
30 years of numerical dynamo models

- Glatzmaier and Roberts (1995) – first numerical dynamos, including a reversal

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- Olson et al. (1999) – dipole dominance recovered and explained by dynamo generation mechanisms

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GEODYNAMO SIMULATIONS—HOW REALISTIC ARE THEY?
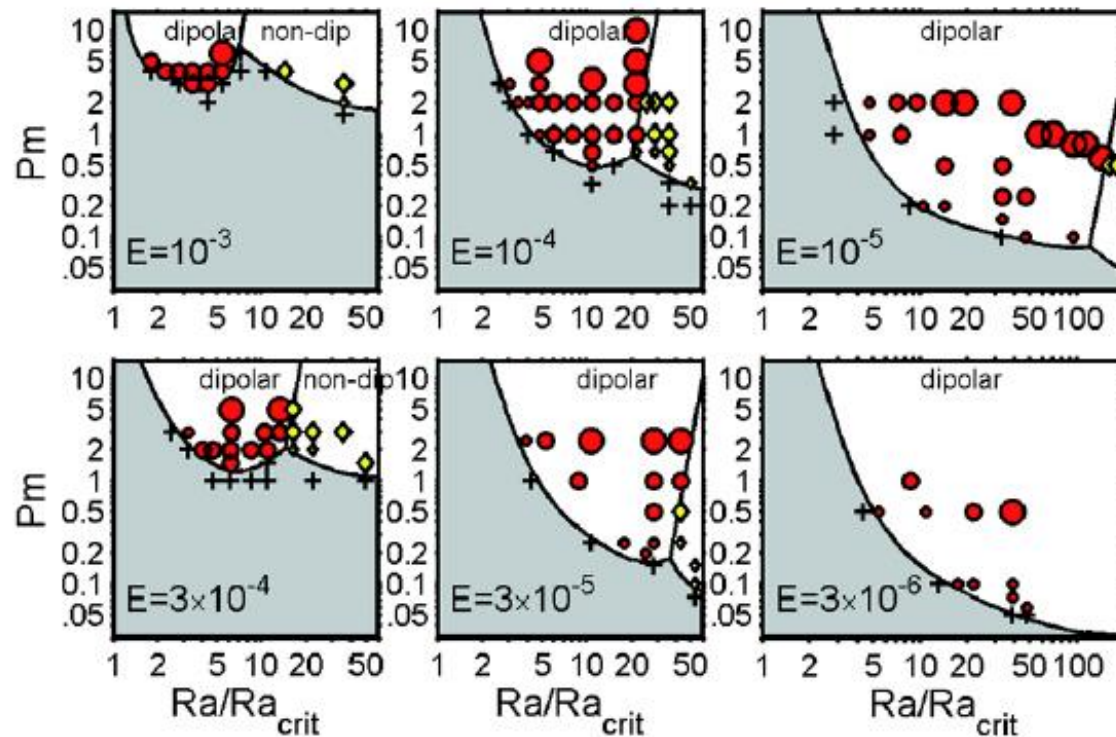
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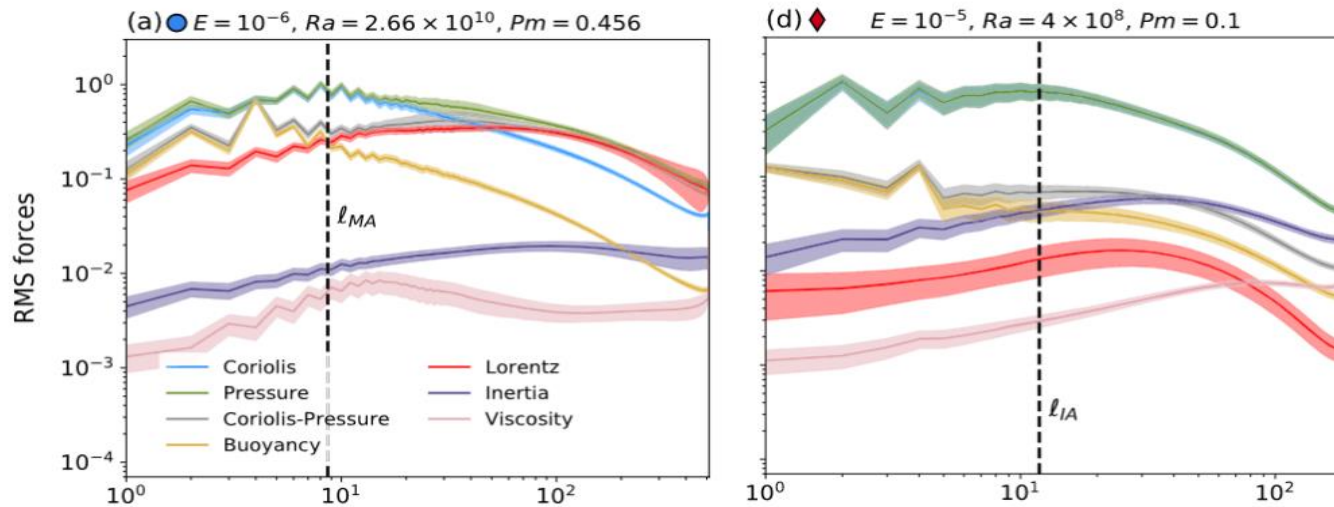
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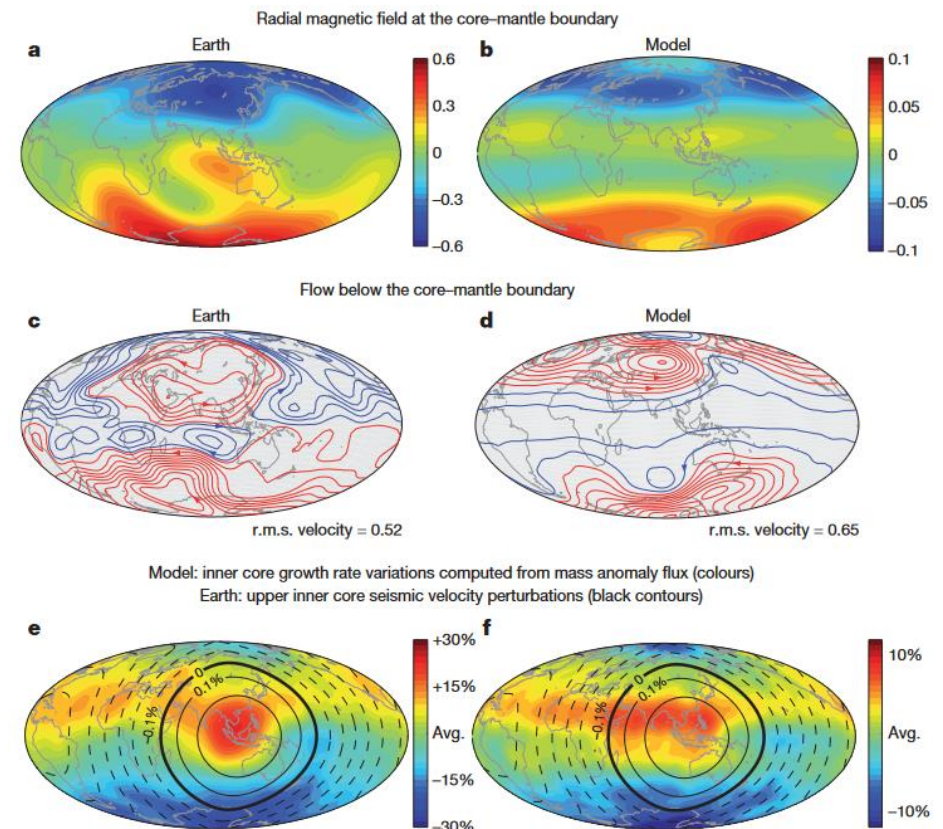
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- Aubert et al. (2008) – CMB heat flux heterogeneity may explain numerous geodynamo related observations

Radial magnetic field at the core–mantle boundary

a Earth   b Model

Flow below the core–mantle boundary

c Earth   d Model

r.m.s. velocity = 0.52   r.m.s. velocity = 0.65

Model: inner core growth rate variations computed from mass anomaly flux (colours)
Earth: upper inner core seismic velocity perturbations (black contours)

e   f

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Can CMB heat flux heterogeneity recover inertia-free reversals?

Magnetic field reversibility vs. amplitude of CMB heat flux heterogeneity

- Homogeneous case not reversing

- Increasing q* leads to reversals

- For q*>1 reversibility decreases
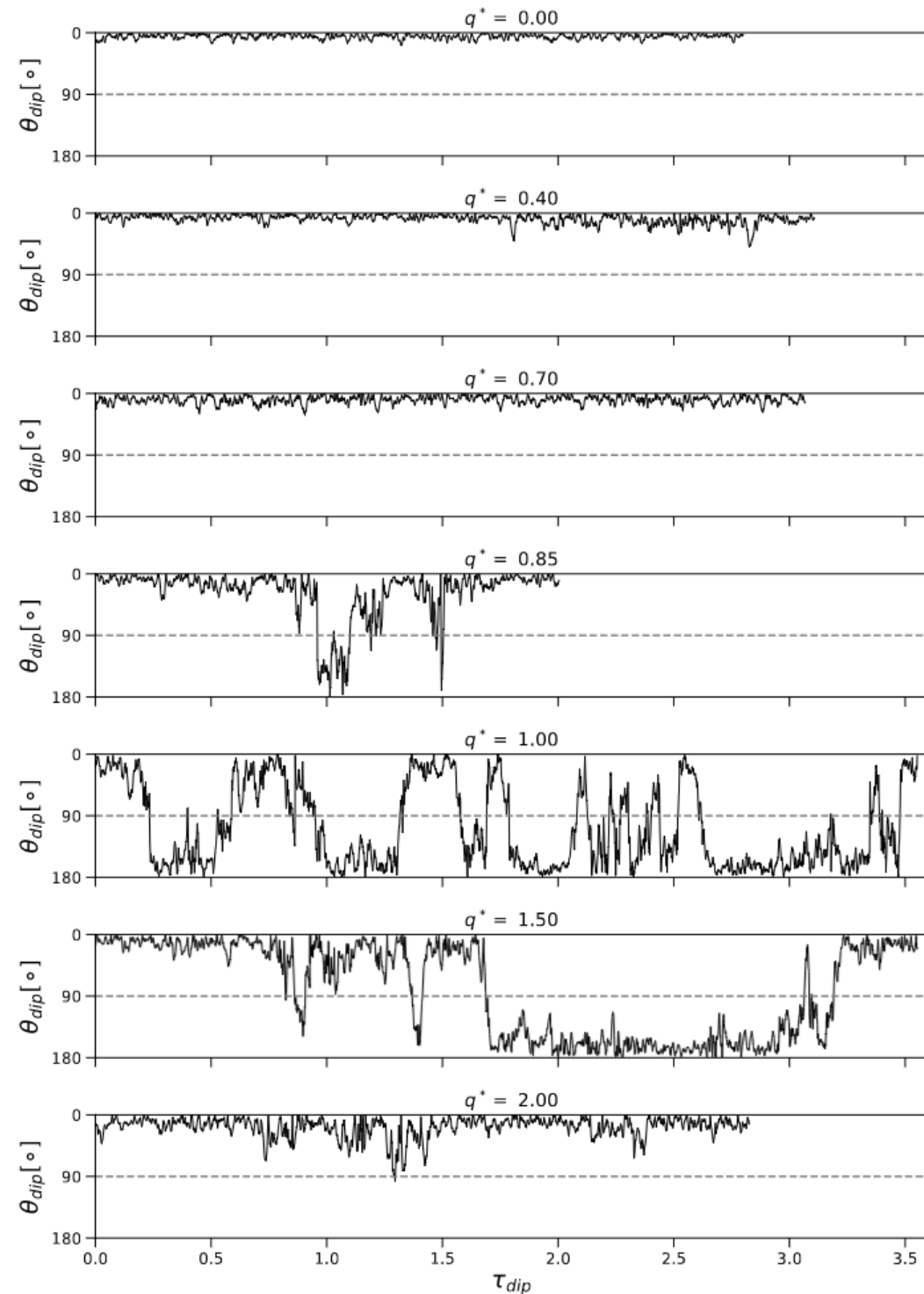
Dipole tilt as a function of time for all dynamo models

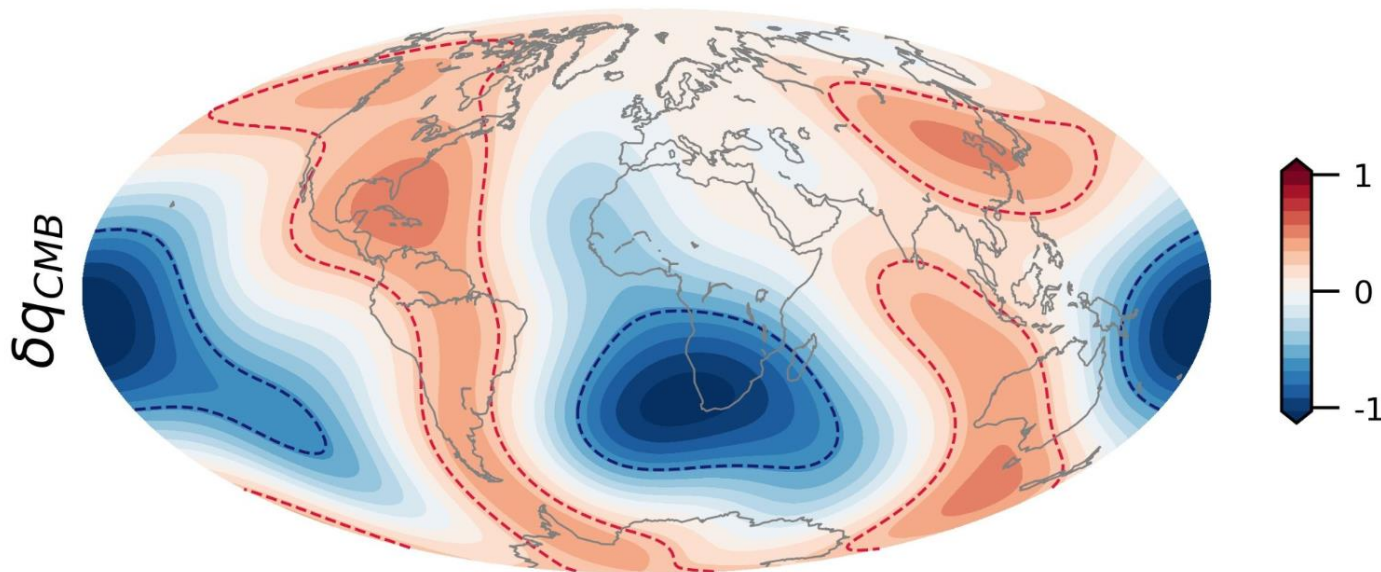# Regional measures of boundary control

Inertia force (out/q⁺)	Radial flow (q⁻/out)

$$< I_{q^+} > = < \sqrt{\frac{\int_{q^+} I_\phi^2 dS}{\int_{q^+} dS}} >$$

$$< u_{r\,q^-} > = < \sqrt{\frac{\int_{q^-} u_r^2 dS}{\int_{q^-} dS}} >$$

$$< I_{q_{out}} > = < \sqrt{\frac{\int_{q_{out}} I_\phi^2 dS}{\int_{q_{out}} dS}} >$$

$$< u_{r\,q_{out}} > = < \sqrt{\frac{\int_{q_{out}} u_r^2 dS}{\int_{q_{out}} dS}} >$$

δq_{CMB}

Lowermost mantle seismic shear velocity anomaly (Masters et al., 2000)
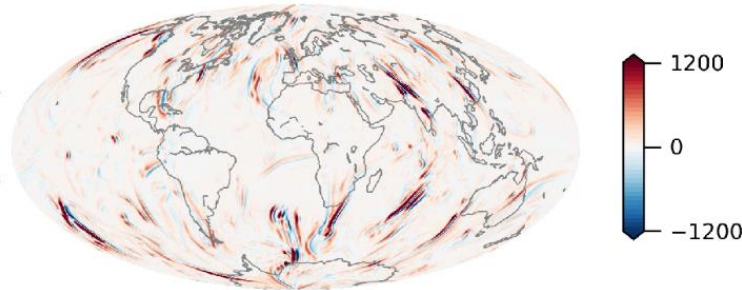
Regional triggering of reversals

q*=0.4

(a)
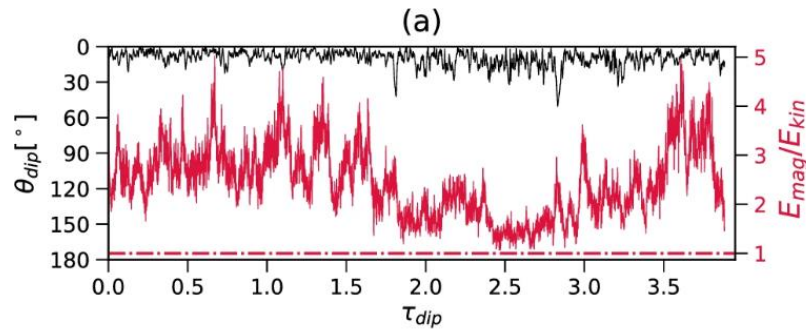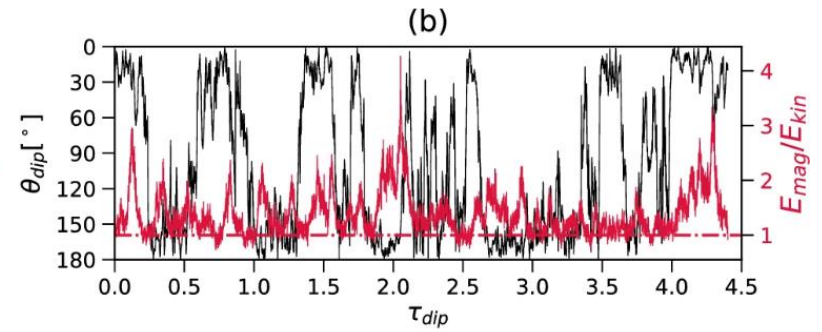
(c)

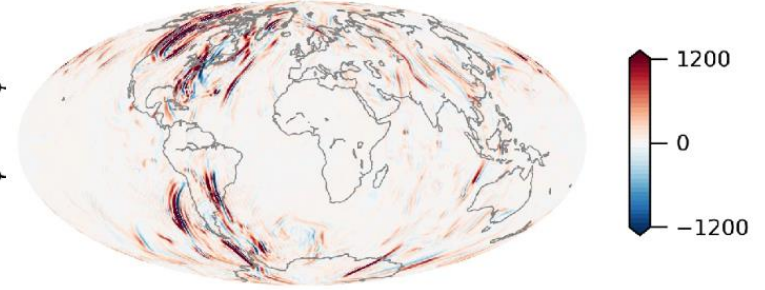Ageostrophic Coriolis

$\mathcal{P}_\phi - \mathcal{C}_\phi$

Inertia

$\mathcal{I}_\phi$

q*=1.0

(b)
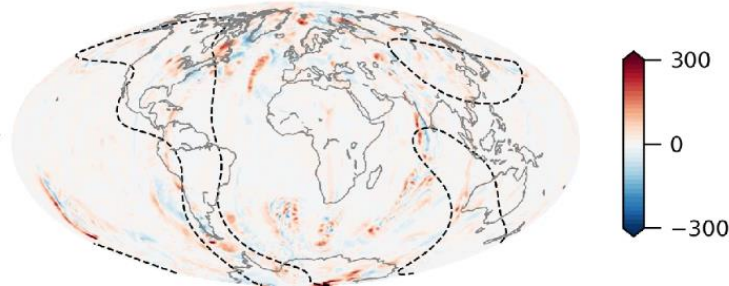
(d)

$\mathcal{P}_\phi - \mathcal{C}_\phi$

$\mathcal{I}_\phi$
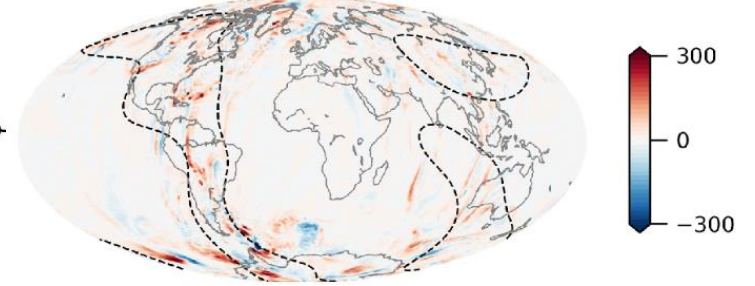
- Ekin > Emag => reversals

- **Localized inertial** force below regions of **large CMB heat flux**

δq_{CMB}
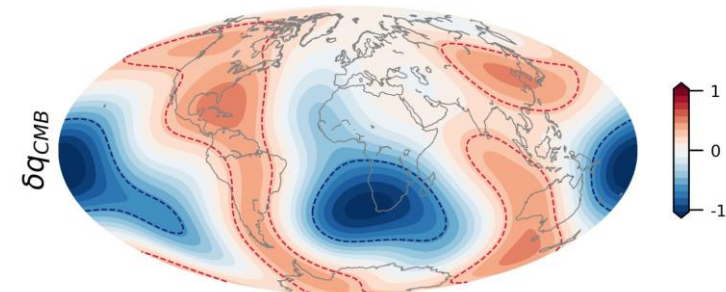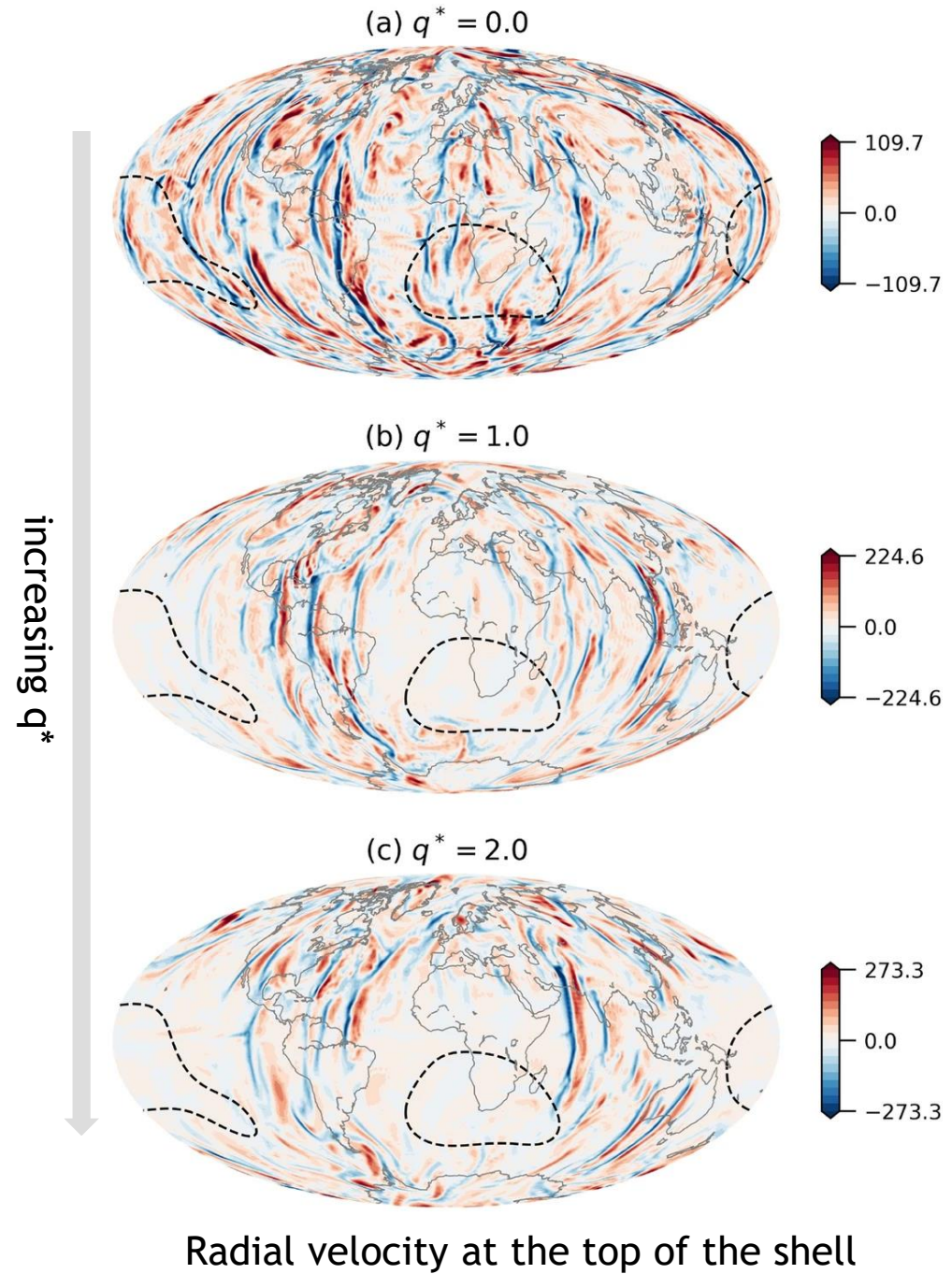
Regional suppression of reversals

Partial stratification below regions
of **weak CMB heat flux**

⬇

Diffusion of small-scale field

⬇

Suppression of reversals

increasing q*

(a) $q^* = 0.0$

109.7

0.0

−109.7

(b) $q^* = 1.0$

224.6

0.0

−224.6

(c) $q^* = 2.0$

273.3

0.0

−273.3

δq_{CMB}

1

0

−1

Radial velocity at the top of the shell
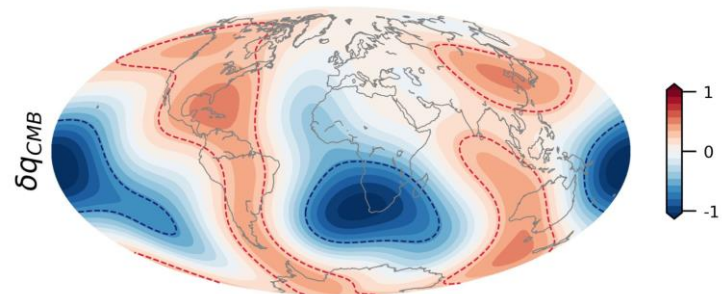
# Global dynamics diagnostics vs. amplitude of CMB heat flux heterogeneity
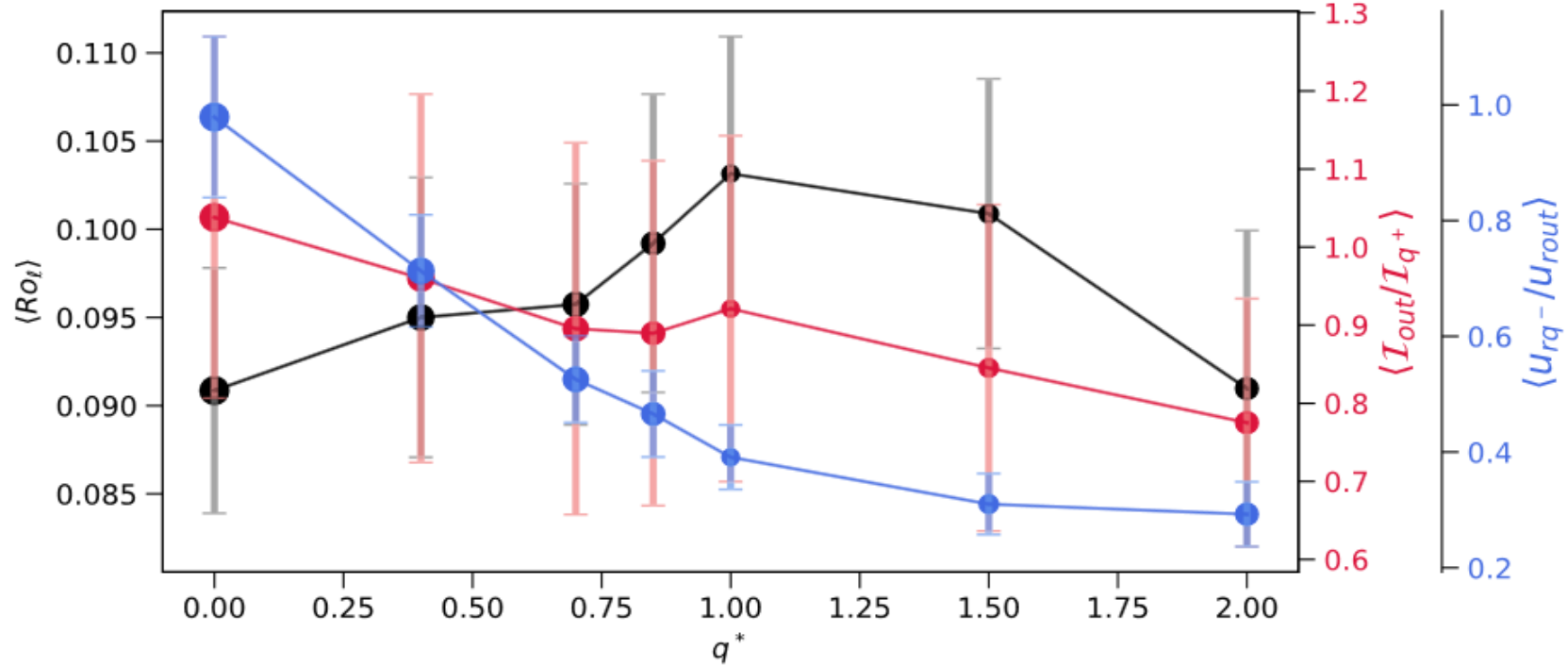
- Reversibility increases/decreases => Increasing/decreasing convection and inertia (black)

- Reversibility increases/decreases => Decreasing/increasing dipolarity (circles sizes)

- **Increasing reversibility** at q*<1 => Enhanced **inertia** at **large CMB heat flux** regions (red)

- **Decreasing reversibility** at q*>1 => Partial **stratification** at **low CMB heat flux** regions (blue)
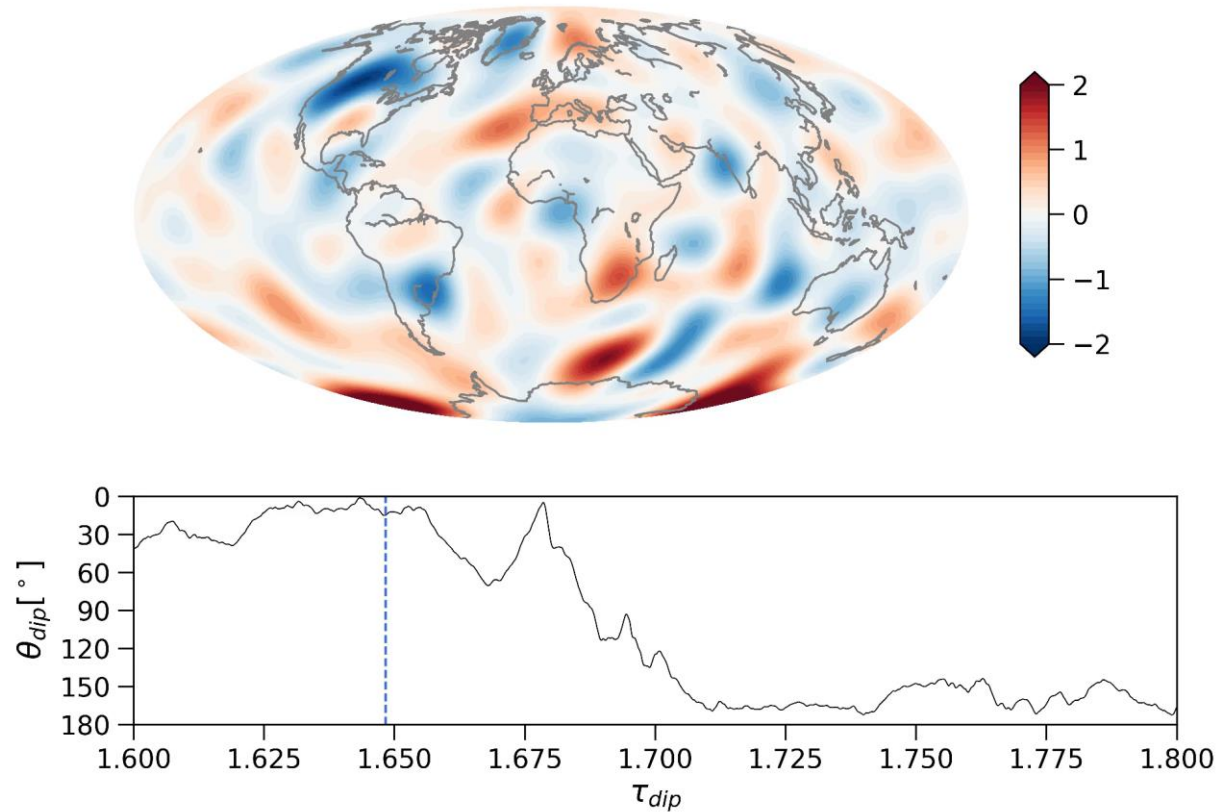
Force balance in a reversing dynamo model

In the shell **volume**
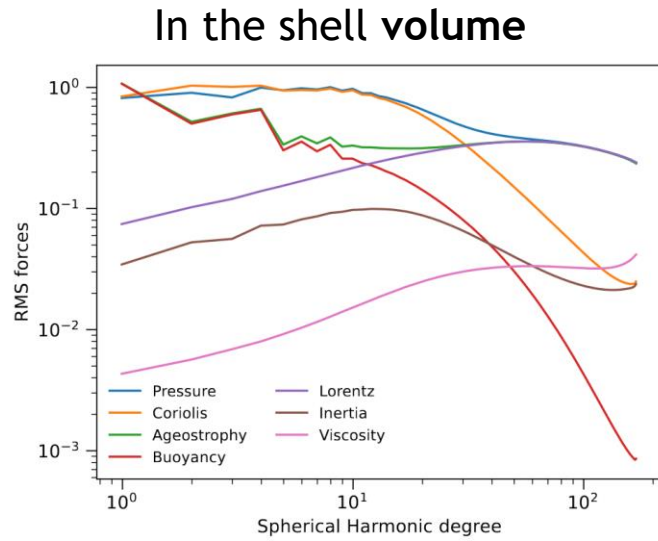
QG-MAC as in e.g. Schwaiger et al. (2019)
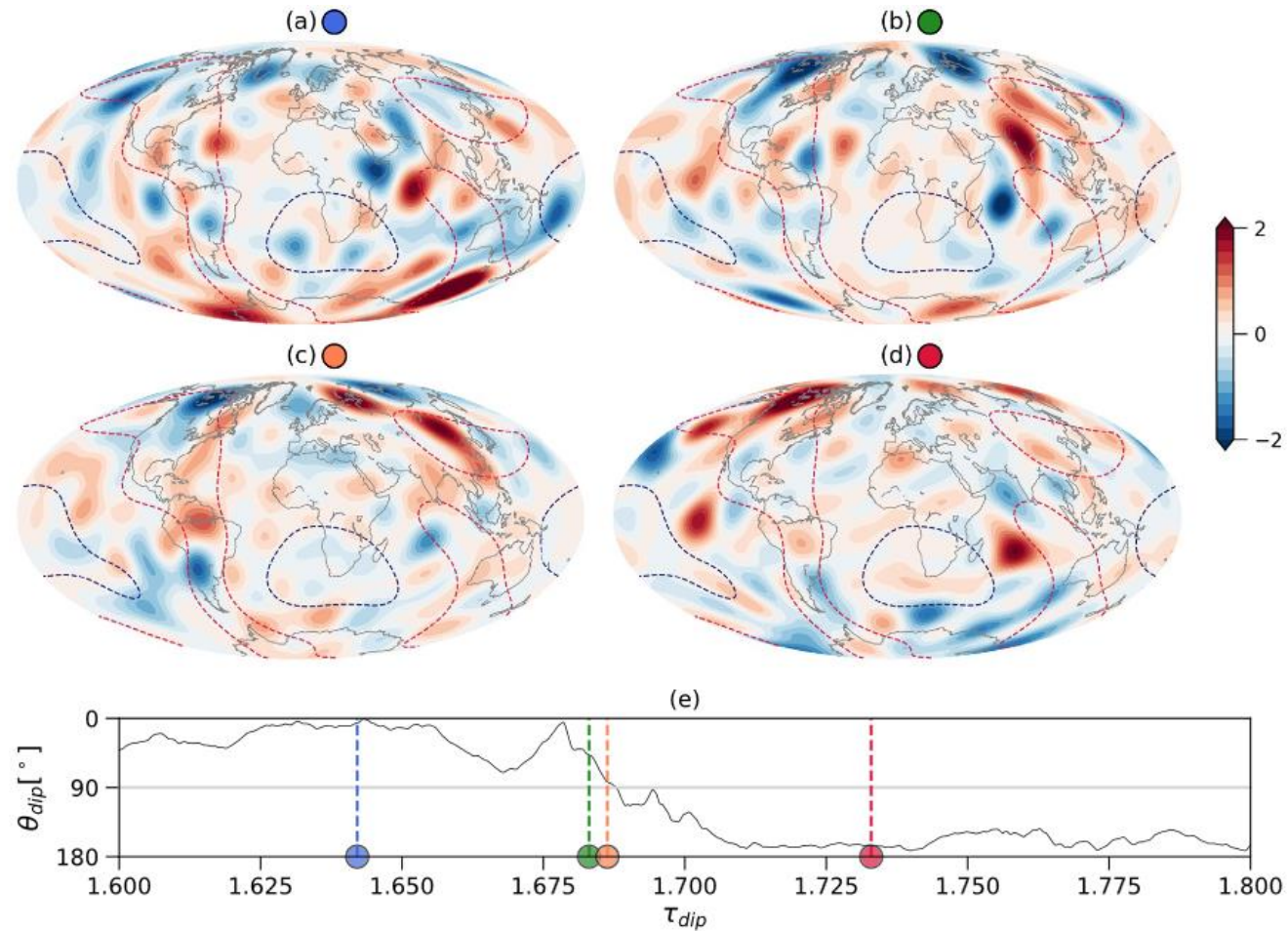
At the **top of the free stream**
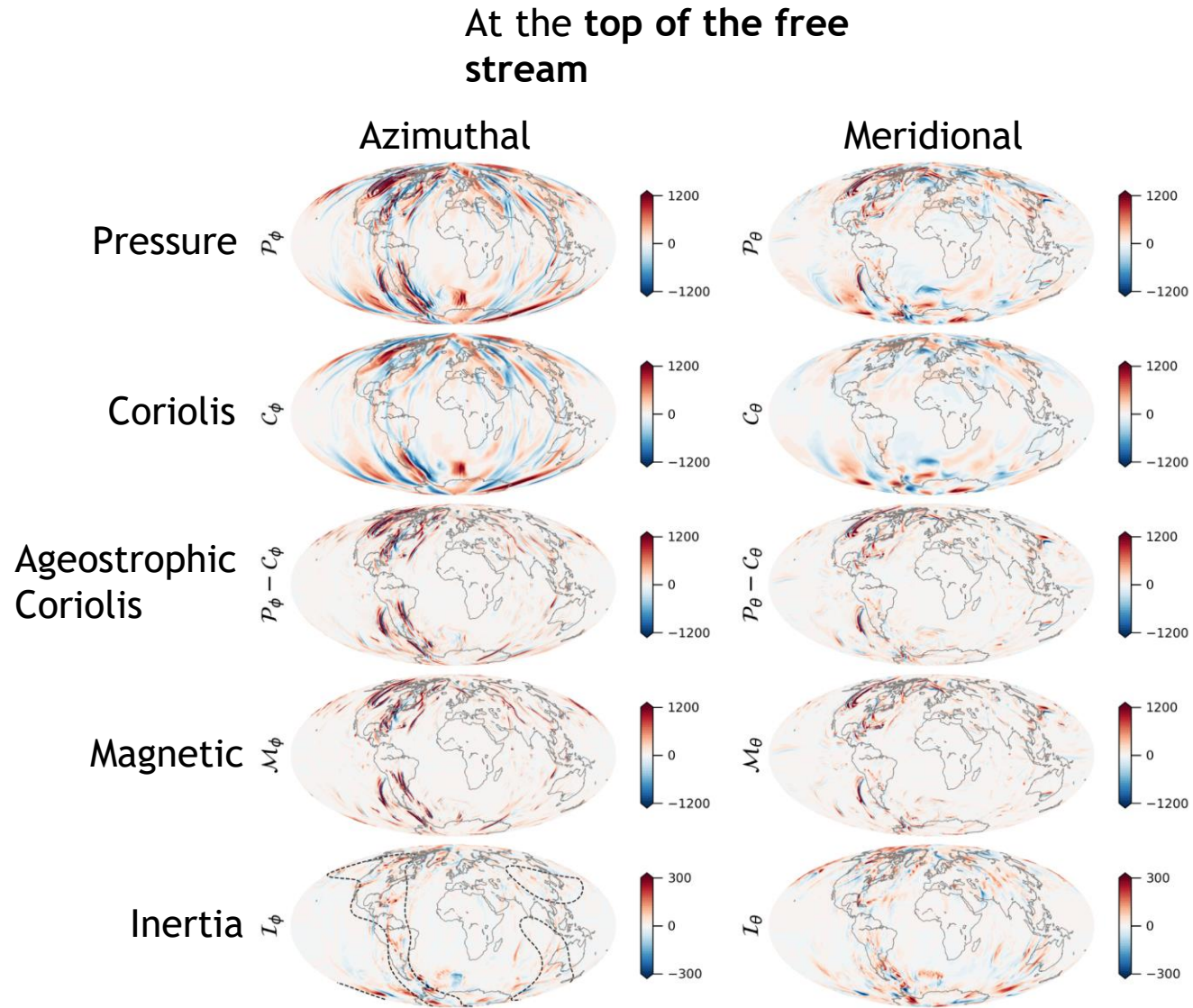
Localized **inertial** force balances **ageostrophic Coriolis** below regions of **large CMB heat flux**

A simulated reversal

- **Magnetic flux** is **concentrated** below regions of **large CMB heat flux** (Americas and East Asia)

- **Magnetic flux** is **absent** below regions of **low CMB heat flux** (Africa and mid-Pacific)
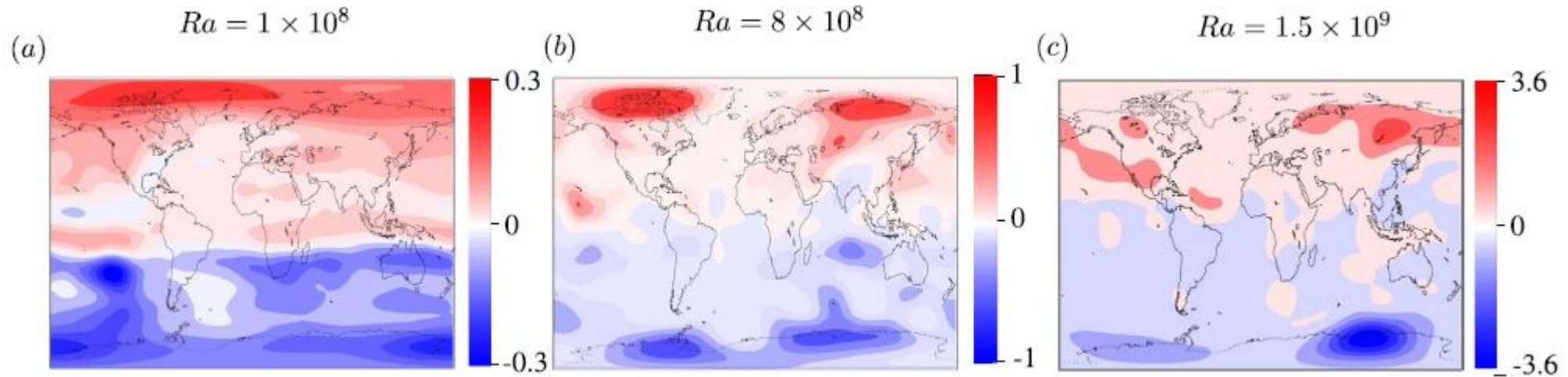
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Discussion

Large CMB heat flux may cause fragmentation of intense magnetic flux patches (Sahoo and Sreenivasan, 2020)
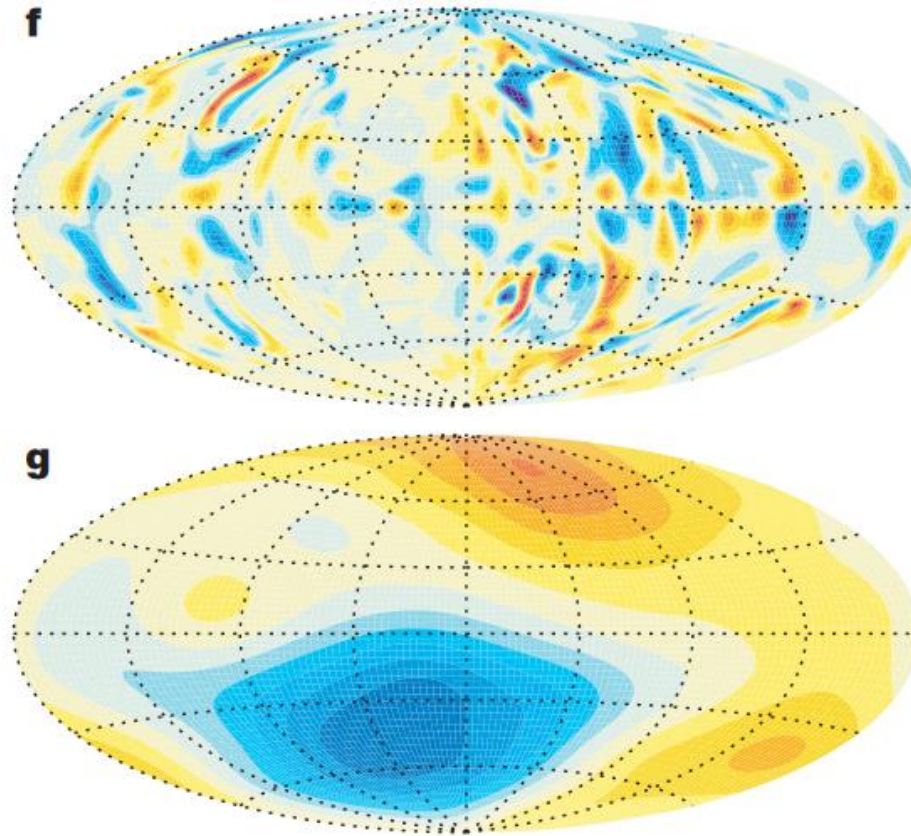

Radial magnetic field on the CMB at tomographic dynamo models with increasing convection strength.

Similar **fragmentation** may eventually lead to **reversals**.

Discussion – skin effects

Stratification diffuses small-scale magnetic field (Christensen, 2006)

Radial magnetic field at depth (f) and at Mercury's surface (g) in a dynamo model with stratification at the top of the shell.
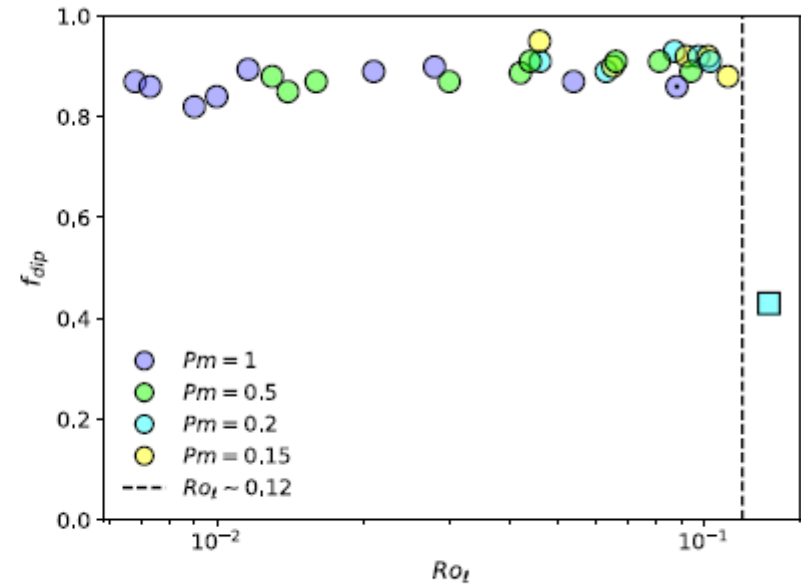
Similarly **regional skin effects** may **stabilize** the **dipole**.

Discussion – Critical local Rossby number

Strong field dynamos give non-reversing models at large Rol > 0.1 (Menu et al., 2020).
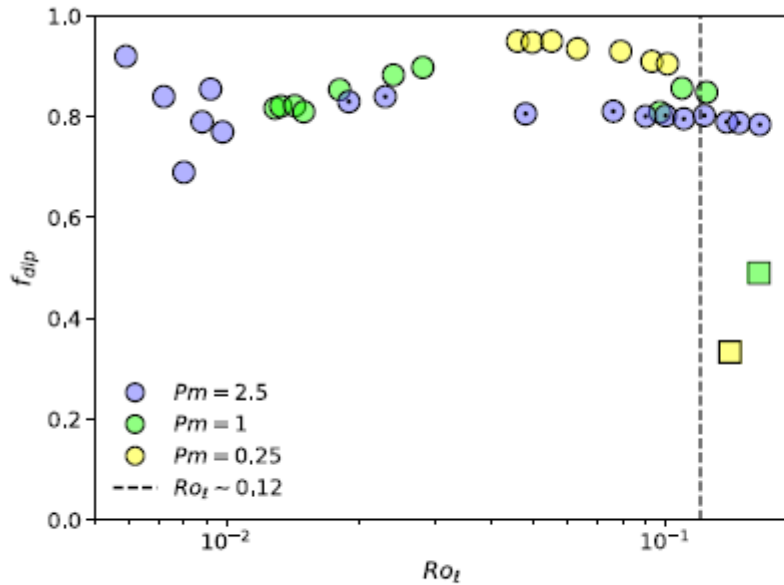
(c) $E = 3 \times 10^{-5}$.

(d) $E = 10^{-5}$.

Dipolarity (>0.5 non-reversing) vs. local Rossby number in dynamo models with decreasing Pm.

CMB heat flux heterogeneity may give **reversing dynamos** at **low Rol < 0.1.**

Conclusions

- CMB heat flux heterogeneity triggers **reversals** with **globally weak inertia**

- **Reversals** are triggered below regions **of large CMB heat flux** where **inertia is locally large**

- Further increase of amplitude of CMB heat flux heterogeneity leads to **partial stratification** which **suppresses reversals**

Aubert (SEDI 2024): Reversals are triggered by decrease (not increase) in convection strength!