# F-layer

## Dynamics and implications for the Earth's core

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# What the F-layer?

## Seismic observations

| Year | Event |
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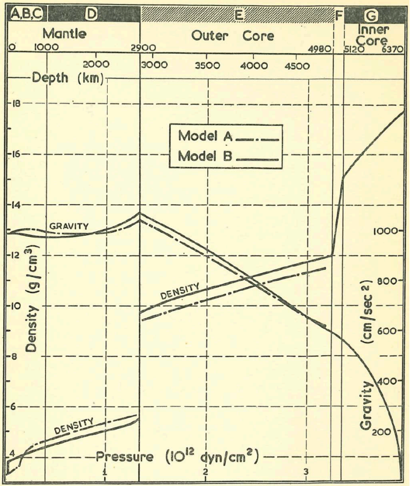


Fig. 13. Pressure, density and gravity in the Earth Models A and B

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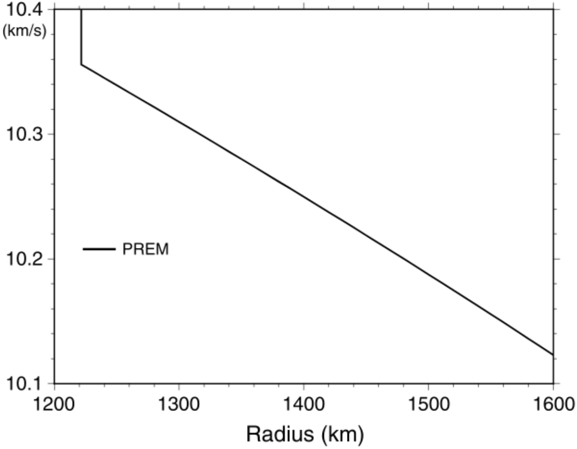


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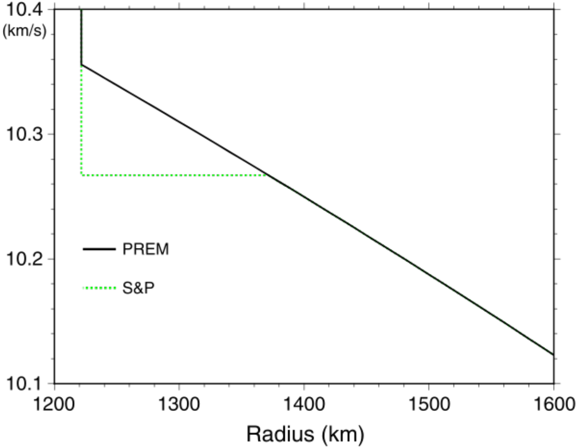


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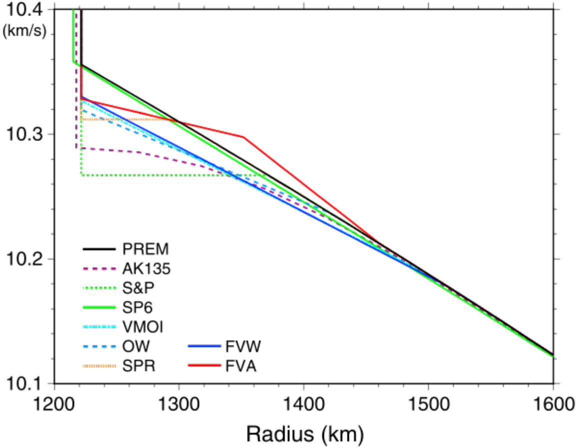


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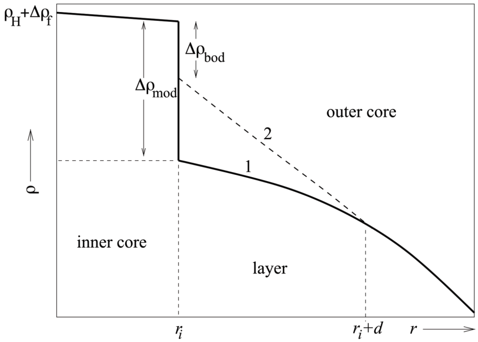


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## Density structure

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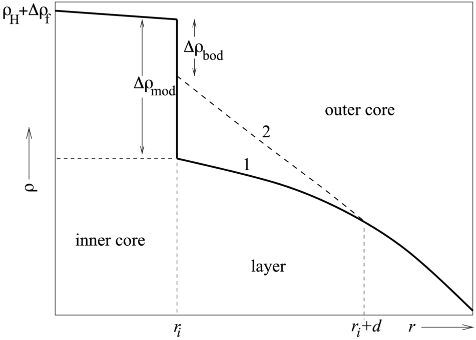


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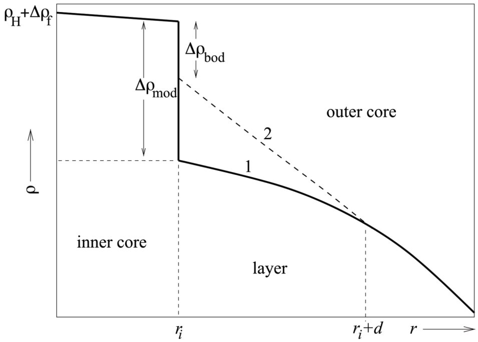


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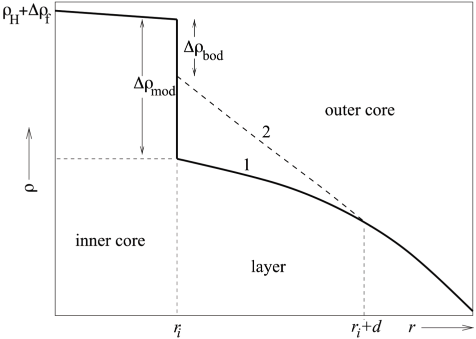


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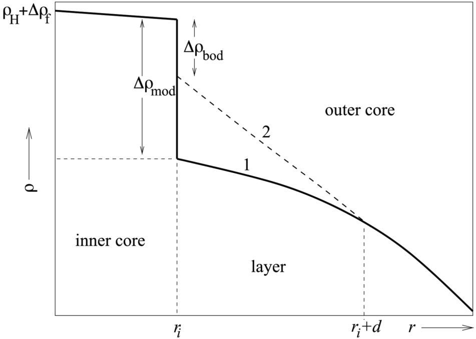
- Layer cannot be a thermal boundary layer

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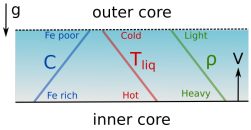


Figure:
Thermochemical layer on the liquidus
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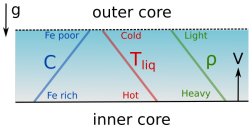


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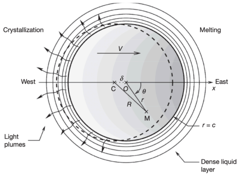


Figure: Convective translation (Alboussière *et al.* 2010)

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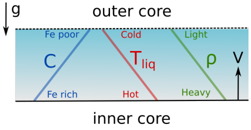


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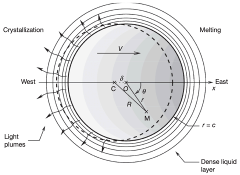


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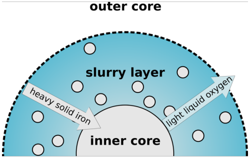
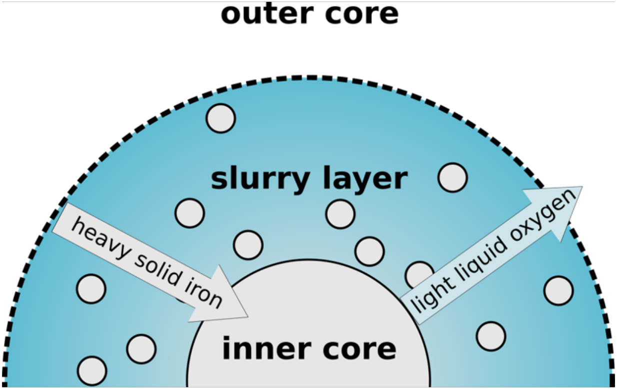



Figure: Slurry layer (Loper & Roberts 1978, Wong *et al.* 2018)

# Slurry layer

## Model details

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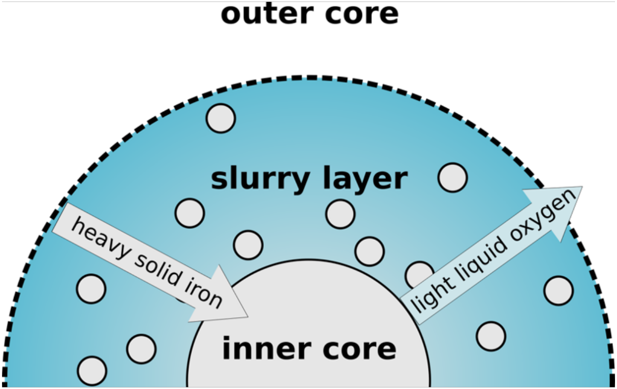


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- Formation and transport of solid phase provides a way for light elements to pass through a stably-stratified layer

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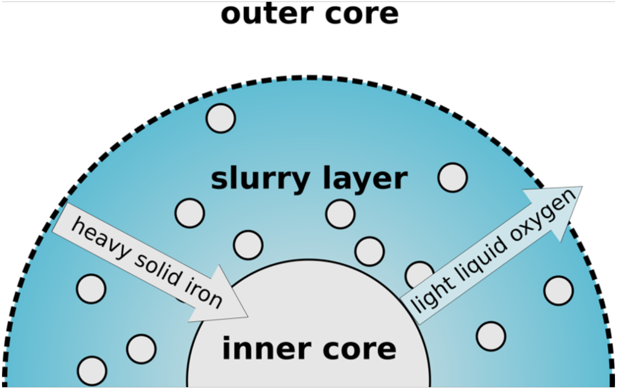



- Two component (iron and oxygen) two phase (solid and liquid) system
- Formation and transport of solid phase provides a way for light elements to pass through a stably-stratified layer
- Solid fraction is small

# Slurry layer

## Governing equations

$$-\hat{v}\frac{\partial\hat{\xi}}{\partial\hat{r}} = -\frac{1}{\hat{r}^2}\frac{\partial}{\partial\hat{r}}\left(\frac{Li_p R_\rho}{Li_\xi Pe St R_v}\frac{\hat{g}\hat{\rho}\hat{r}^2}{\hat{T}}\exp\left[\frac{F\left(r_{sl}\hat{r}-r_i\right)}{d}\right]\right) + \hat{\xi}\frac{\partial\hat{\jmath}}{\partial\hat{r}} + \hat{\jmath}\frac{\partial\hat{\xi}}{\partial\hat{r}} + \frac{2}{\hat{r}}\hat{\xi}\hat{\jmath}, \tag{1}$$

$$-\hat{v}\frac{\partial\hat{T}}{\partial\hat{r}} = \frac{Le}{Pe}\left(\frac{\partial^2\hat{T}}{\partial\hat{r}^2} + \frac{2}{r}\frac{\partial\hat{T}}{\partial\hat{r}}\right) + \frac{1}{St}\left(\frac{\partial\hat{\jmath}}{\partial\hat{r}} + \frac{2}{\hat{r}}\hat{\jmath}\right), \tag{2}$$

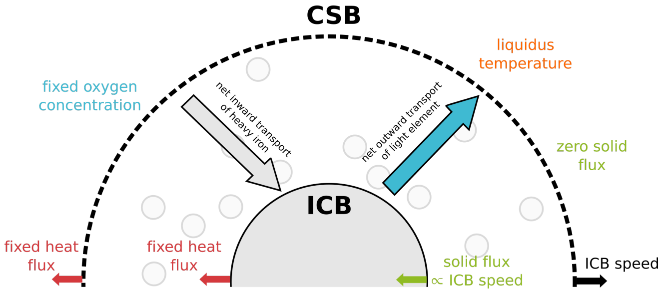
$$\frac{\partial\hat{T}}{\partial\hat{r}} = -Li_p\hat{g}\hat{\rho}\hat{T} - \frac{Li_\xi St}{R_\rho}\hat{T}^2\frac{\partial\hat{\xi}}{\partial\hat{r}}. \tag{3}$$

where the dimensionless numbers are defined as

$$R_\rho = \frac{\rho_{sl}}{\bar{\rho_s}}, \quad R_v = \frac{\Delta V^{s,l}_{Fe}}{\Delta V^{s,l}_{Fe,O}}, \quad Li_p \equiv \frac{\Delta V^{s,l}_{Fe} g_{sl}\rho_{sl} r_{sl}}{L}, \quad Li_\xi \equiv \frac{1000R\xi_{sl}}{a_O c_p},$$
$$Pe \equiv \frac{v_f r_{sl}}{D_O}, \quad St \equiv \frac{q_{sl}}{\rho_s v_f L}, \quad Le \equiv \frac{k}{\rho_{sl} c_p D_O}. \tag{4}$$

# Slurry layer

## Boundary conditions




$$\hat{T}(1) = \frac{T_{sl} c_p R_\rho}{StL},$$

$$\left.\frac{\partial \hat{T}}{\partial \hat{r}}\right|_{\hat{r}=\frac{r_i}{r_{sl}}} = -\frac{Pe}{StLe},$$

$$\left.\frac{\partial \hat{T}}{\partial \hat{r}}\right|_{\hat{r}=1} = -\frac{Pe}{Le},$$

$$\hat{\xi}(1) = 1,$$

$$\hat{\jmath}\left(\frac{r_i}{r_{sl}}\right) = -\hat{v},$$

$$\hat{\jmath}(1) = 0.$$

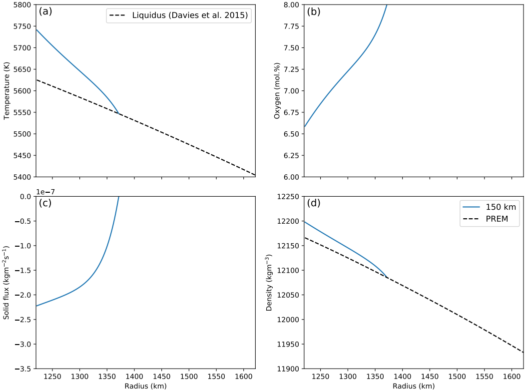
# Slurry layer

## Geophysical constraints

| | $\Delta\rho_{mod}$ $(\mathrm{kgm}^{-3})$ | $\Delta\rho_{bod}$ $(\mathrm{kgm}^{-3})$ | $Q_c$ (TW) | $Q_i$ (TW) |
|---|---|---|---|---|
| Maximum | $1000$ | $1100$ | $15$ | $2$ |
| | (Masters & Gubbins 2003) | (Tkalčić *et al.* 2009) | (Lay *et al.* 2008) | (Pozzo *et al.* 2014) |
| Minimum | $600$ | $520 \pm 240$ | $5$ | $> 0$ |
| | (PREM) | (Koper & Dombrovskya 2005) | (Lay *et al.* 2008) | |

# Slurry layer

## Results



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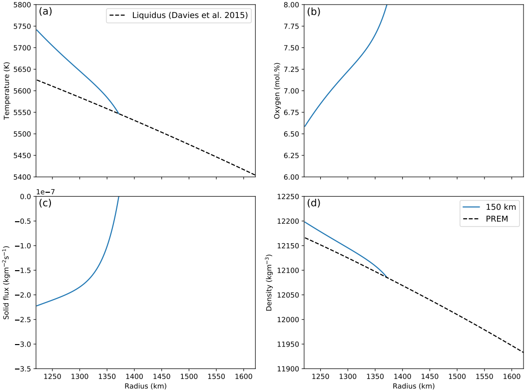

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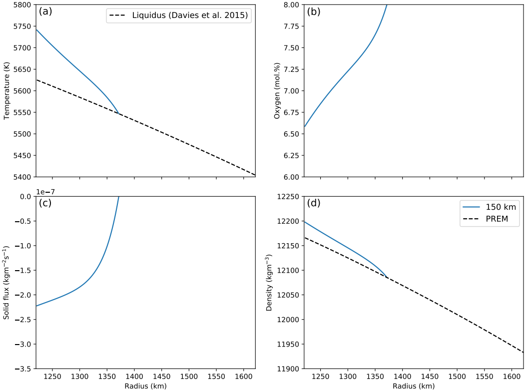

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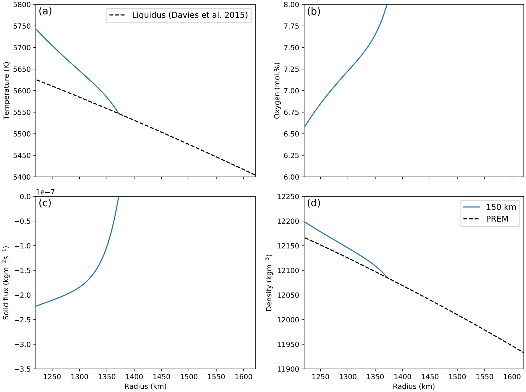

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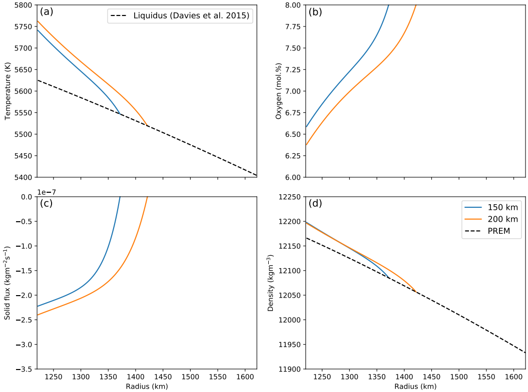

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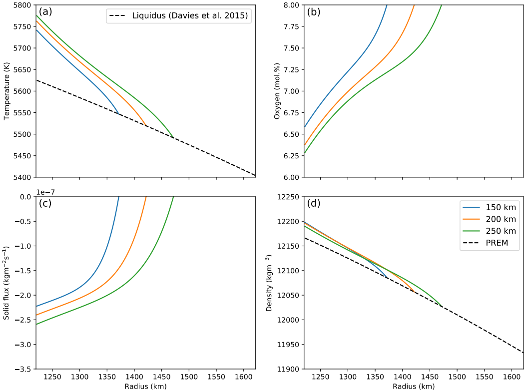

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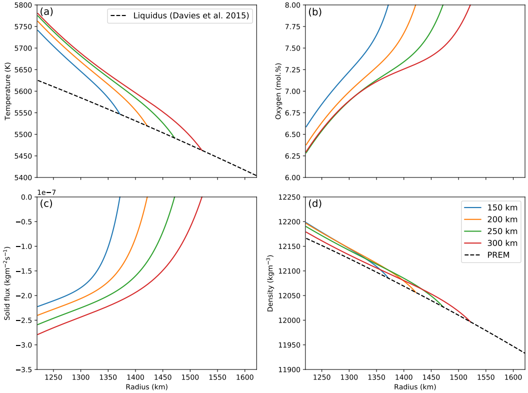

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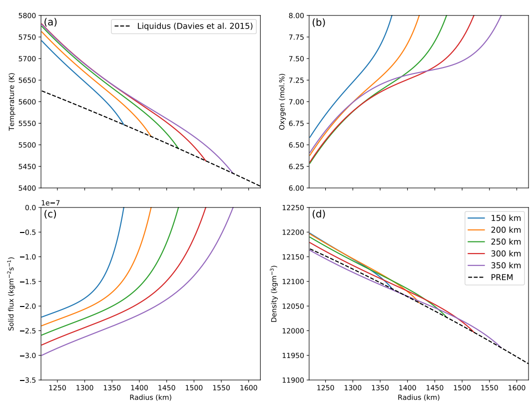

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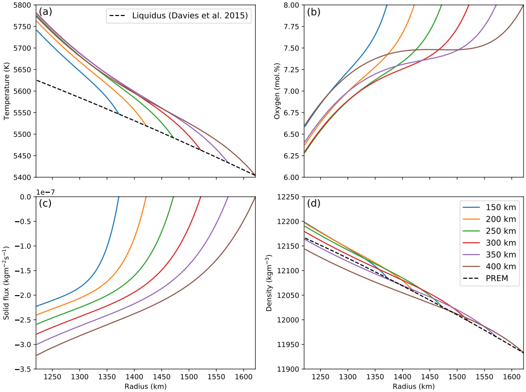

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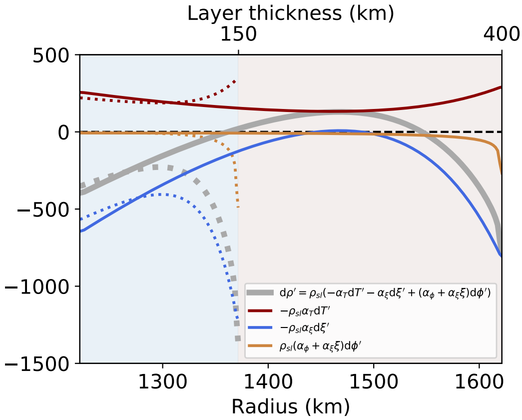

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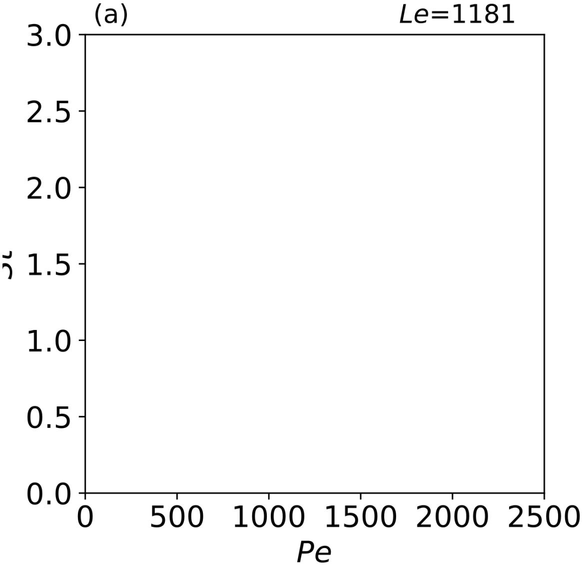

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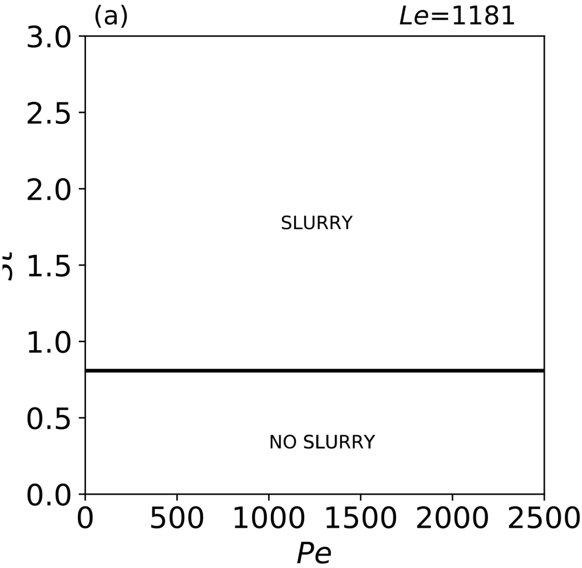

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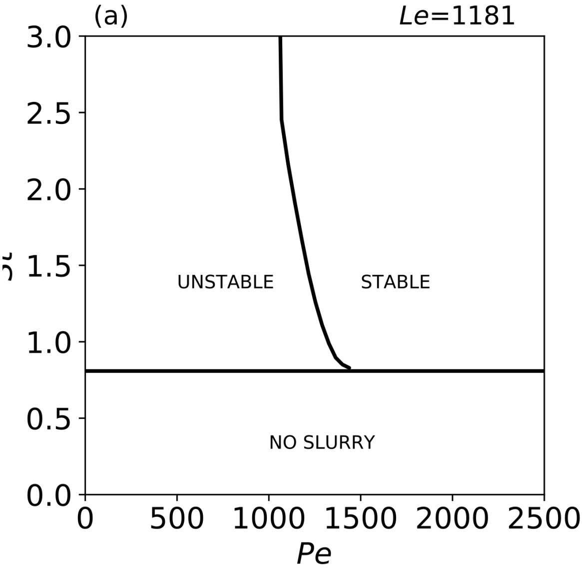

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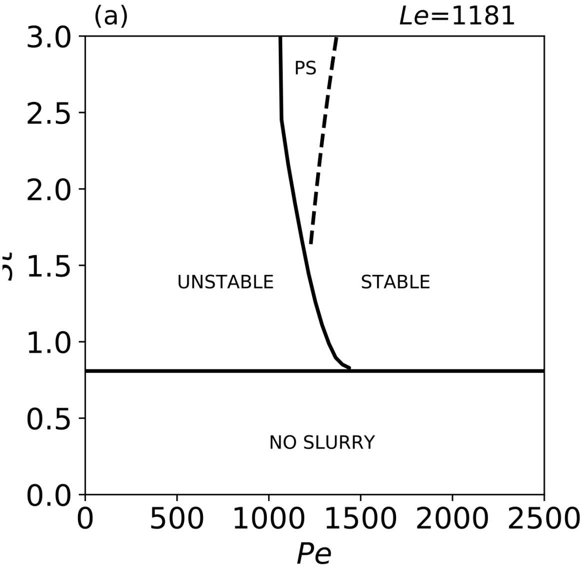

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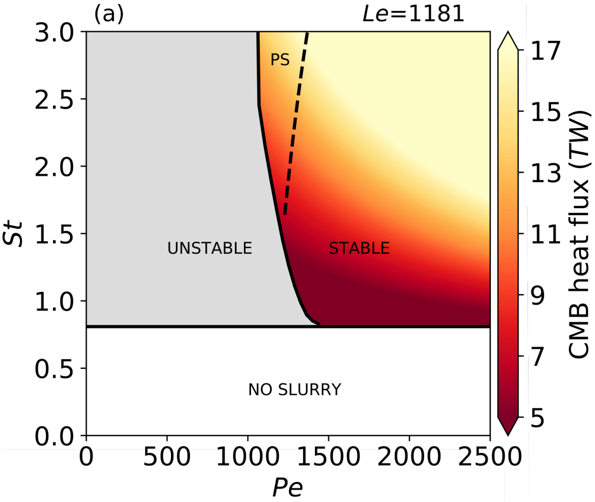

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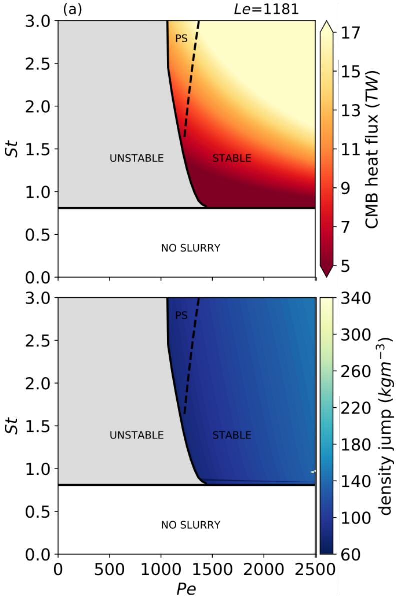

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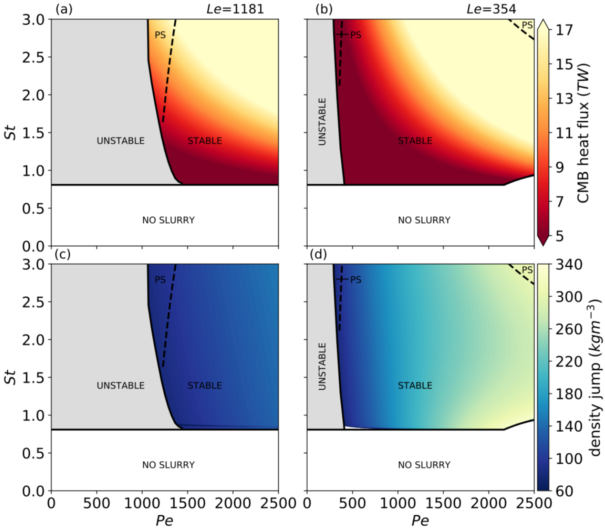

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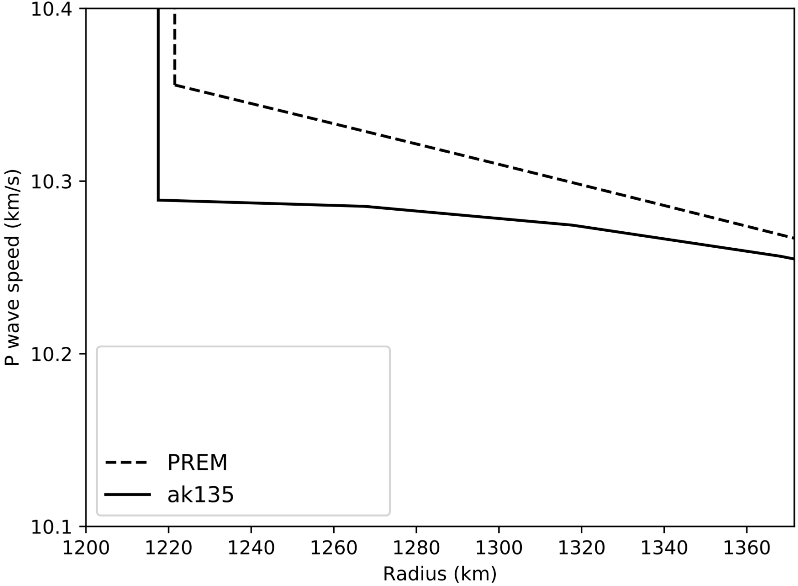

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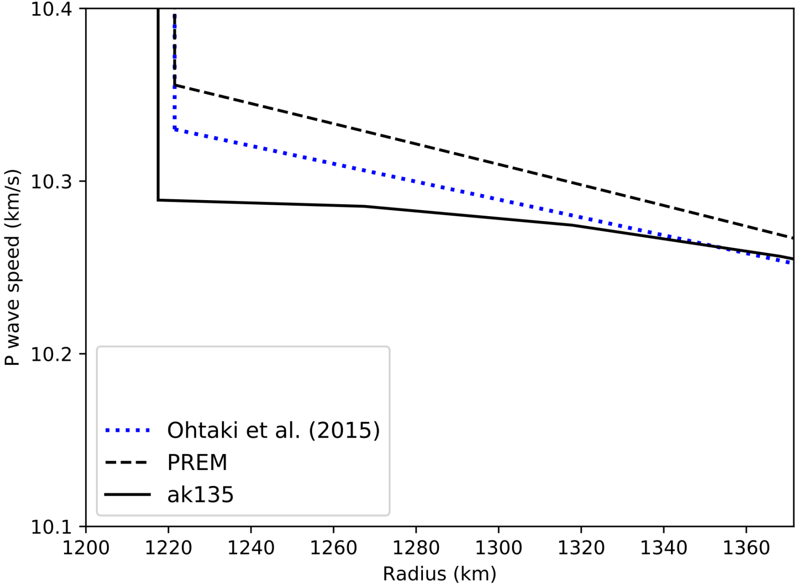

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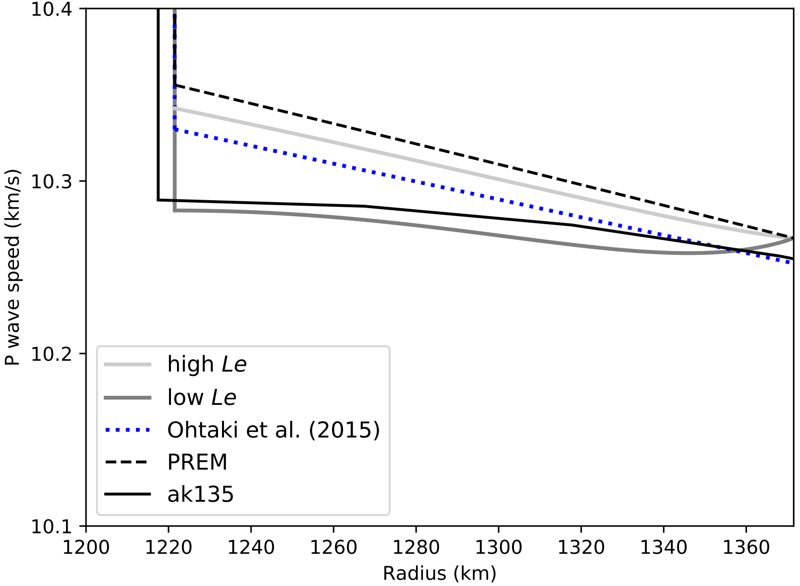

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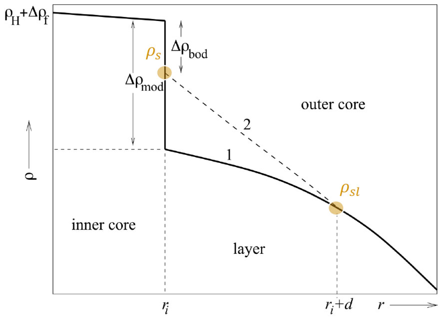
## ICB density jump

| $(\mathrm{kgm}^{-3})$ | High *Le* | Low *Le* |
|---|---|---|
| $\rho_s - \rho_{sl}$ | $< 140$ | $< 330$ |
| $\Delta\rho_{bod}^{sl}$ | $> 460$ | $> 269$ |
| $\Delta\rho_{bod}^{obs}$ | $280 - 1100$ | |



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- Fix $d = 360\ \mathrm{km}$ and vary $0 < N/\Omega < 14.7$

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- Fix $d = 360\ \mathrm{km}$ and vary $0 < N/\Omega < 14.7$
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Table: Simulation parameters $E = 3 \times 10^{-5}$, $Ra_F \equiv RaE^3Pr^{-1} = 2.7 \times 10^{-5}$, $Pr = 1$ and $Pm = 2.5$

| $d_s$ | $a_r$ | $f_i$ | $N/\Omega$ | $\lvert\overline{\Gamma}/\Gamma_{\max}\rvert$ | $Rm$ | $\Lambda$ | $R_{\mathrm{NP}}$ | $R_{\mathrm{SP}}$ | $t_{\mathrm{run}}$ |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.35 | – | 0 | $0.6 \times 10^{-2}$ | 965 | 19.2 | 86% | 72% | 1.07 |
| 360 | 0.35 | −200 | 14.7 | $10.3 \times 10^{-2}$ | 810 | 19.9 | 74% | 79% | 1.15 |

# Geomagnetic implications

## Meridional cuts

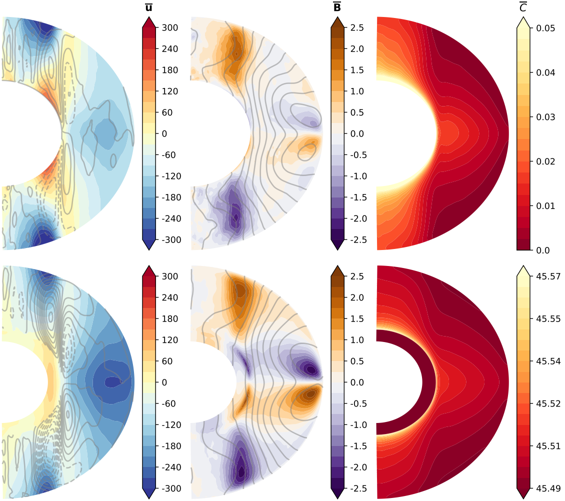


Figure: Top - reference case, bottom - F-layer case

# Geomagnetic implications

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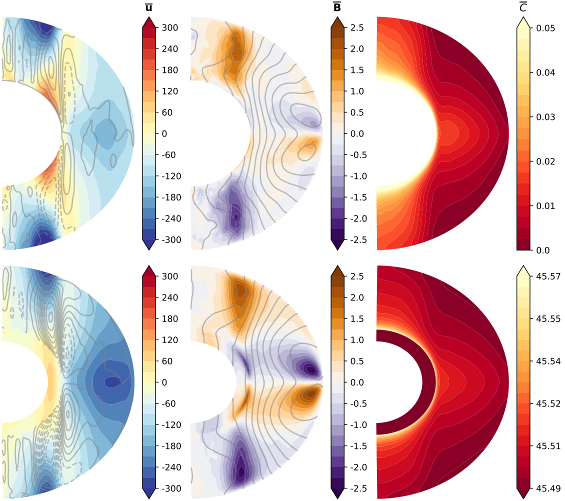
- Distinct zonal flow structures and jet detachment

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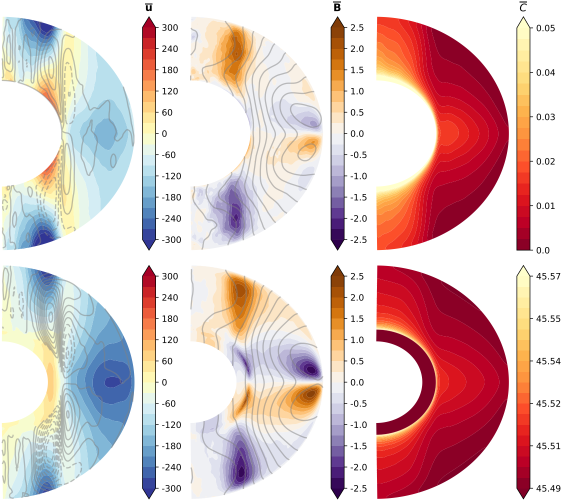


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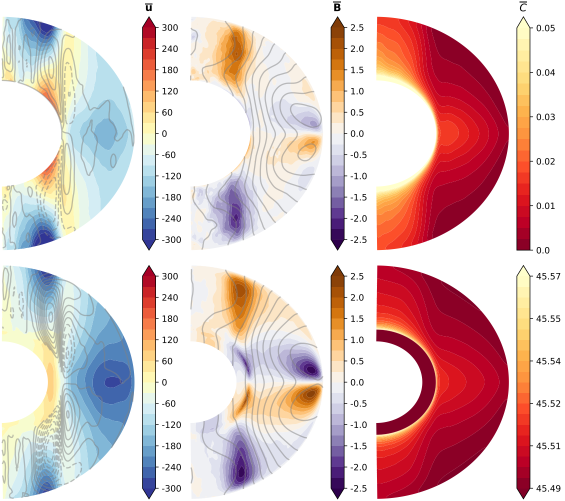


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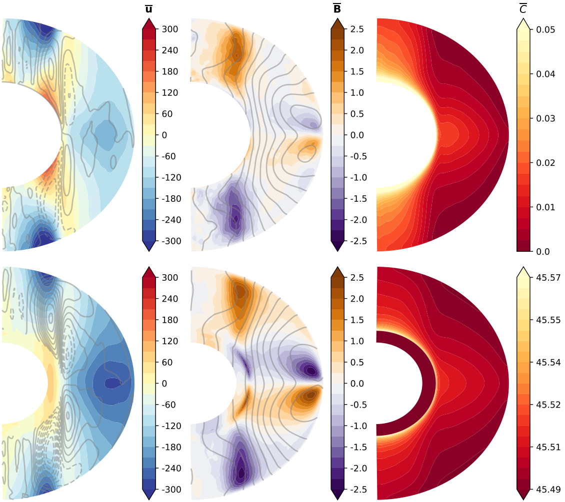
- F-layer reduces local shear at the ICB ⇒ conservation of angular momentum increases westward flow at CMB

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# Geomagnetic implications

$B_r$ at the core surface

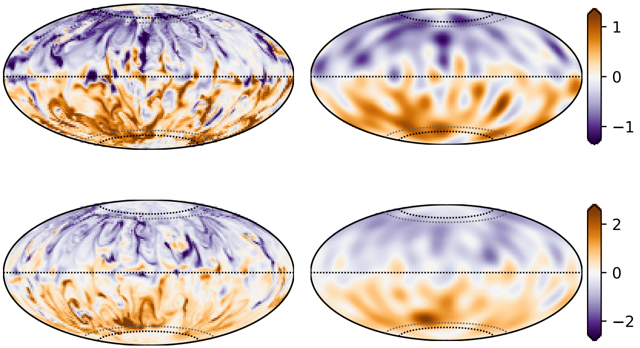


Figure: Top: reference case, bottom: F-layer case, left: full resolution, right: truncated to $\ell \leq 13$. Latitude of $B_r^{\max}$ is shifted by $10^\circ \approx 1,000$ km at the Earth's surface, and with larger $B_{surf}/B_{deep}$

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Thanks for listening!