SEDI 2020
Session 7 – Inner Core

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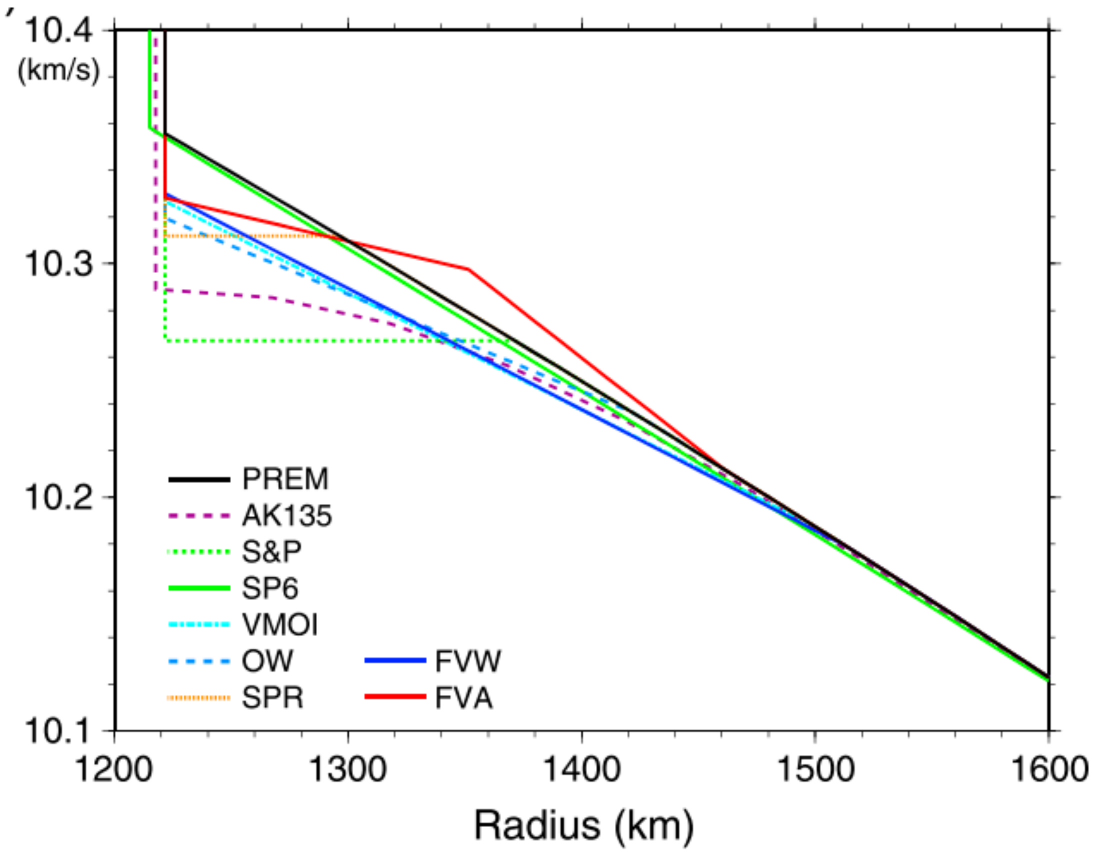
Introduction

- Present day radius is 1220 km
- First crystallised approximately 1 billion years ago (debated)
- Composed of solid iron containing light element impurities
- Continuously freezing and growing as the planet cools over time
- Latent heat release and partitioning of light elements into the liquid core is an important power source for the geodynamo

Seismic observations

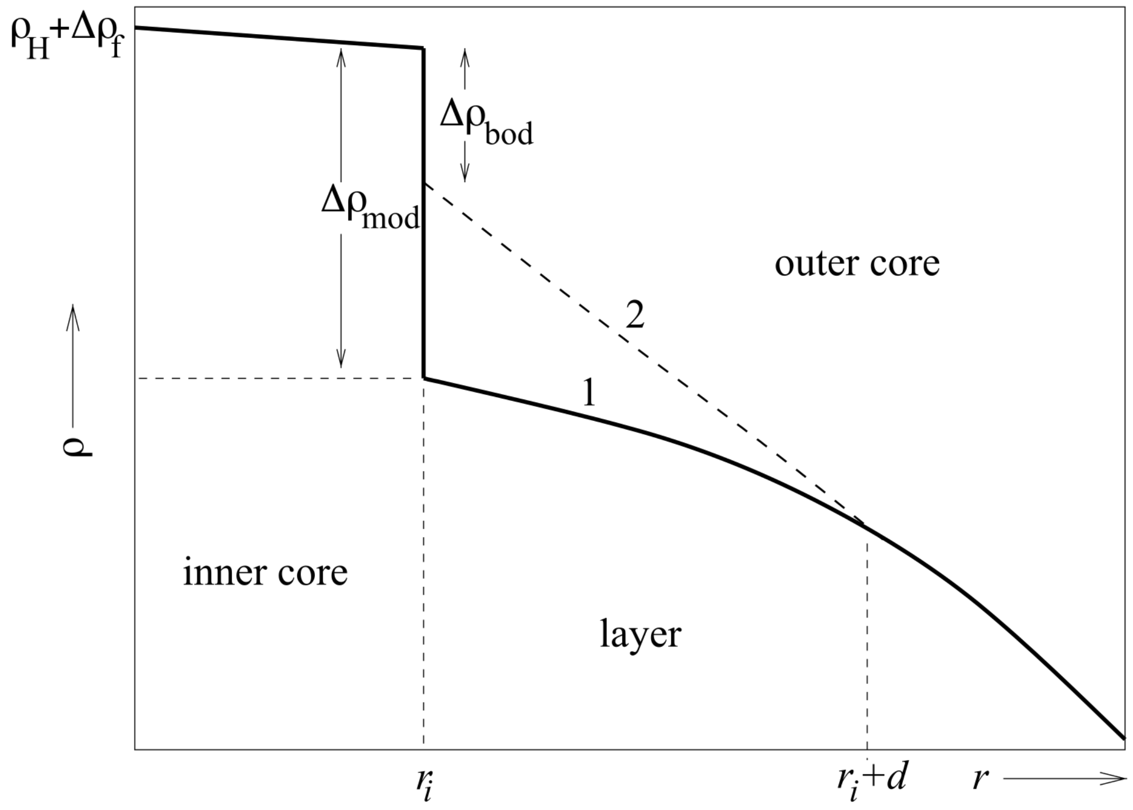
Year	Event
1953	Bullen alphabetises the structure of the Earth and names "shell F"
1972-73	Cleary & Haddon, King et al. debunk the early F-layer
1981	Dziewonski et al. publish PREM
1991	Souriau & Poupinet detect the modern F-layer with $d = 150\ km$
onwards	Many studies support this observation with $d = 150$ to $400\ km$



Ohtaki et al. (2018)

Density structure

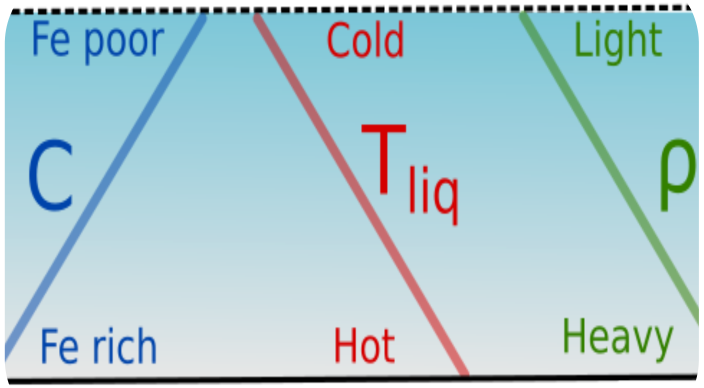
- Detectable by Slichter modes?
- Also have a discrepancy between $\Delta\rho_{mod}$ and $\Delta\rho_{bod}$
- This infers that a stably stratified layer indeed exists
- How can light elements pass through the F-layer and out into the bulk of the liquid core?
- Layer cannot be a thermal boundary layer



Gubbins et al. (2008)

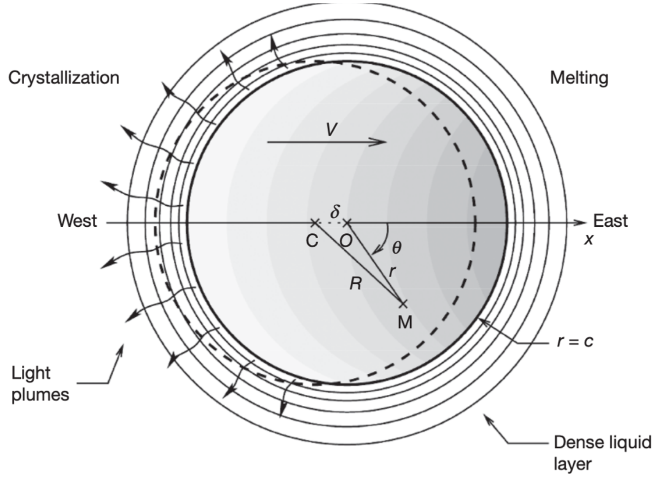
Possible scenarios

Gubbins et al. (2008)



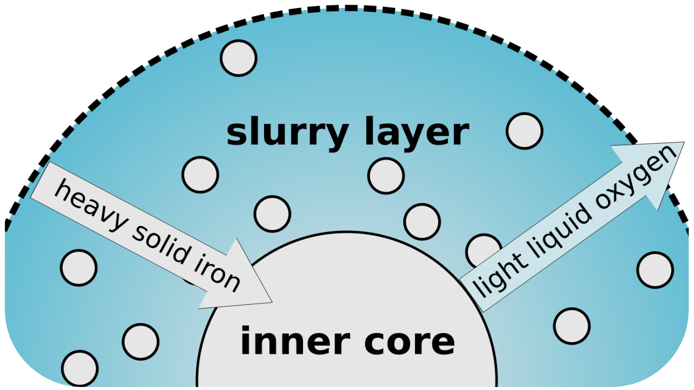
Thermochemical layer on the liquidus

Alboussière et al. (2010)



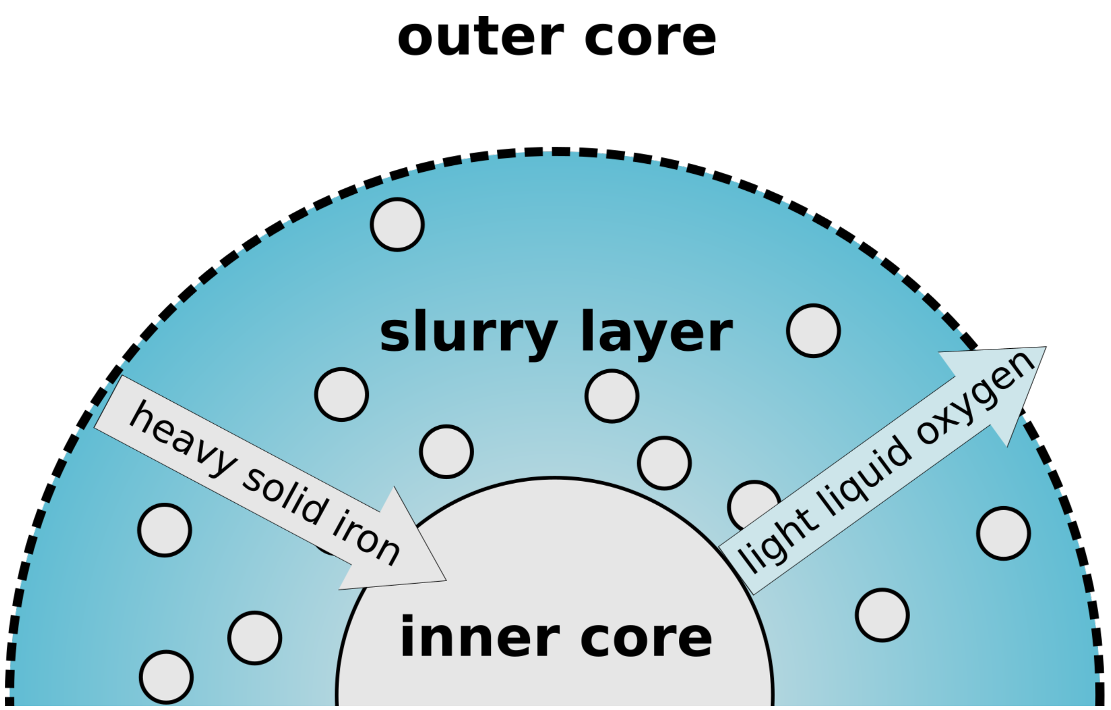
Convective translation

Loper and Roberts (1977), Wong et al. (2018)



Slurry layer

Model details



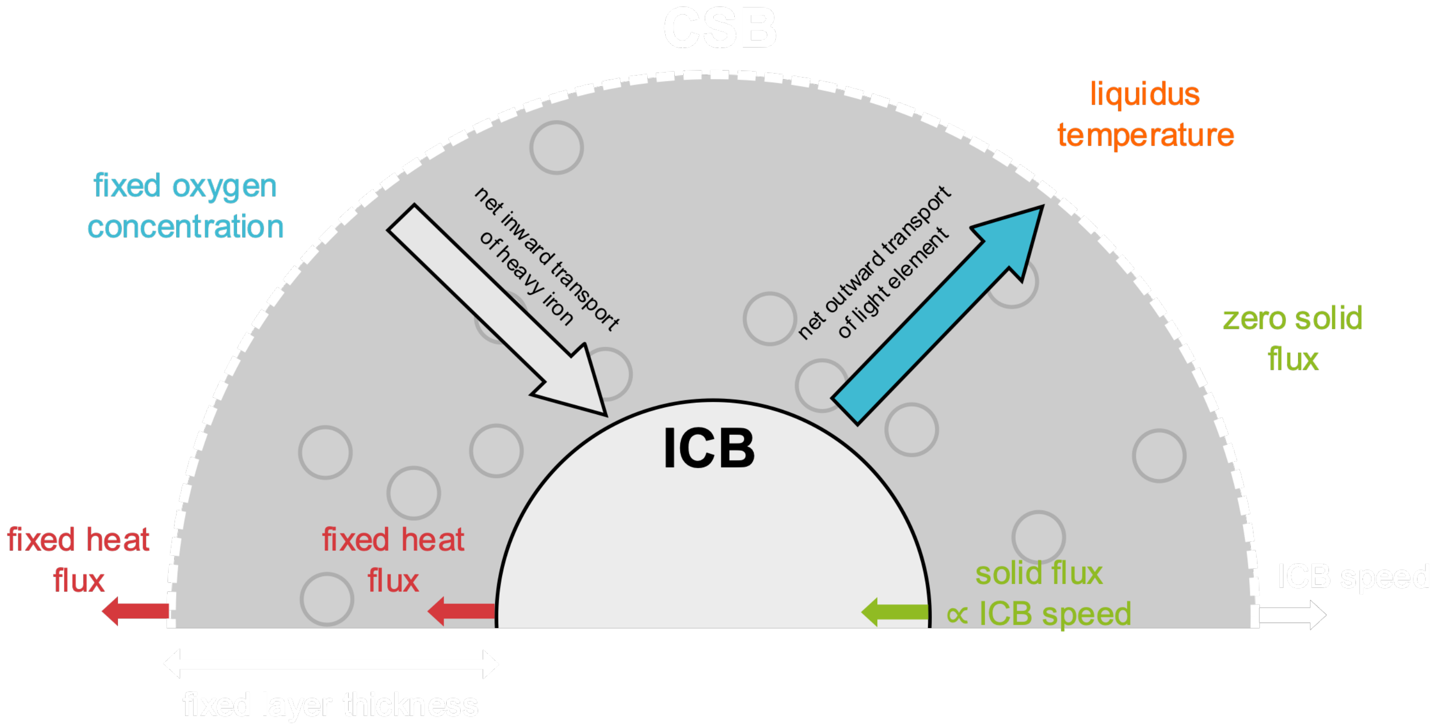
- Two component (iron and oxygen), two phase (solid and liquid) system
- Formation and transport of solid phase provides a way for light elements to pass through a stably-stratified layer
- Solid fraction is small

For full details please see Wong *et al.* (2018)
https://doi.org/10.1093/gji/ggy245

Model details

Dimensionless parameters:

Péclet $\sim Q_i$ Stefan $\sim \frac{Q_{sl}}{Q_i}$ Lewis $\sim k$



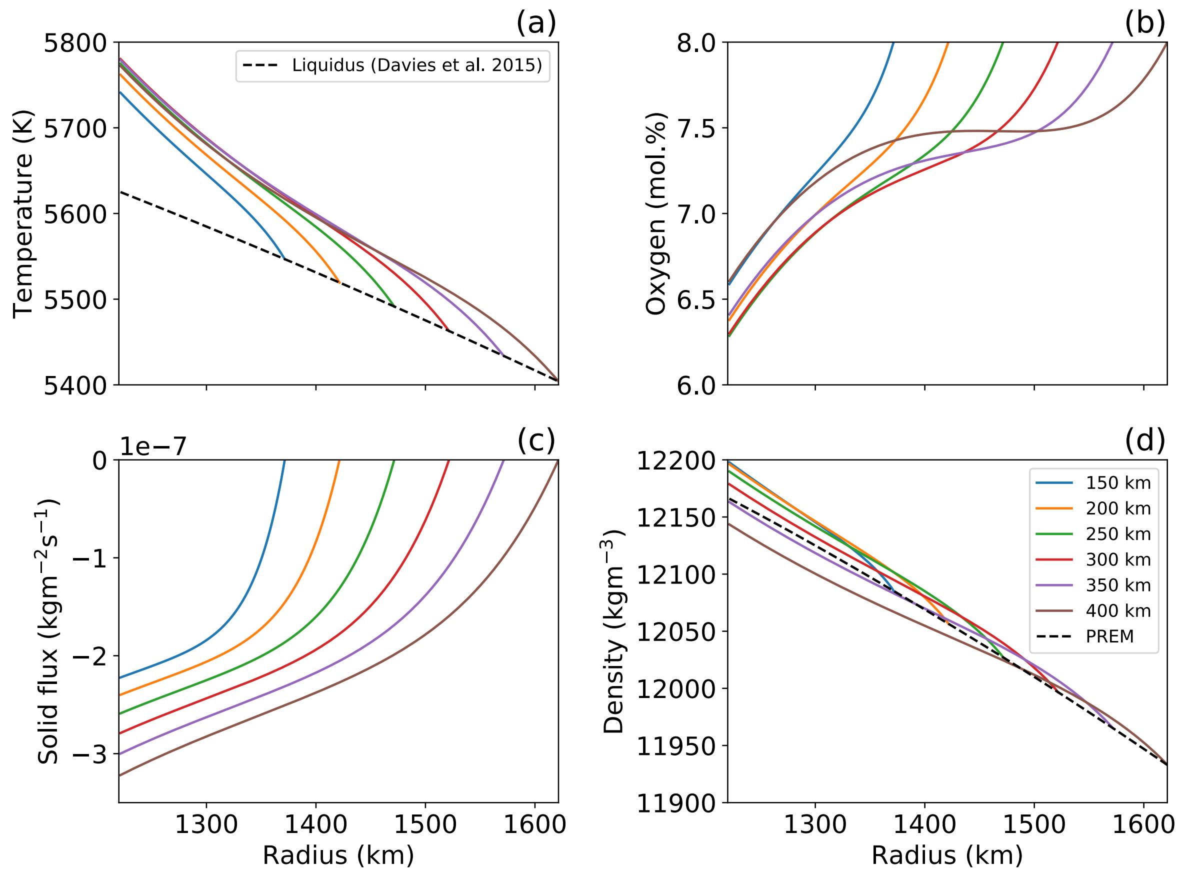
- Governing equations:
  - Liquidus
  - Conservation of oxygen
  - Conservation of energy
- Steady slurry, 1D and spherical geometry
- Reference frame of fixed layer thickness moving at IC growth rate

Geophysical constraints

	$\Delta\rho_{mod}\ (kg\ m^{-3})$	$\Delta\rho_{bod}\ (kg\ m^{-3})$	**CMB heat flow** (TW)	**ICB heat flow** (TW)
Maximum	1000 (Masters & Gubbins 2003)	1100 (Tkalčić et al. 2009)	15 (Lay et al. 2008)	2 (Pozzo et al. 2014)
Minimum	600 (PREM)	520 ± 240 (Koper and Dombrovskya 2005)	5 (Lay et al. 2008)	> 0

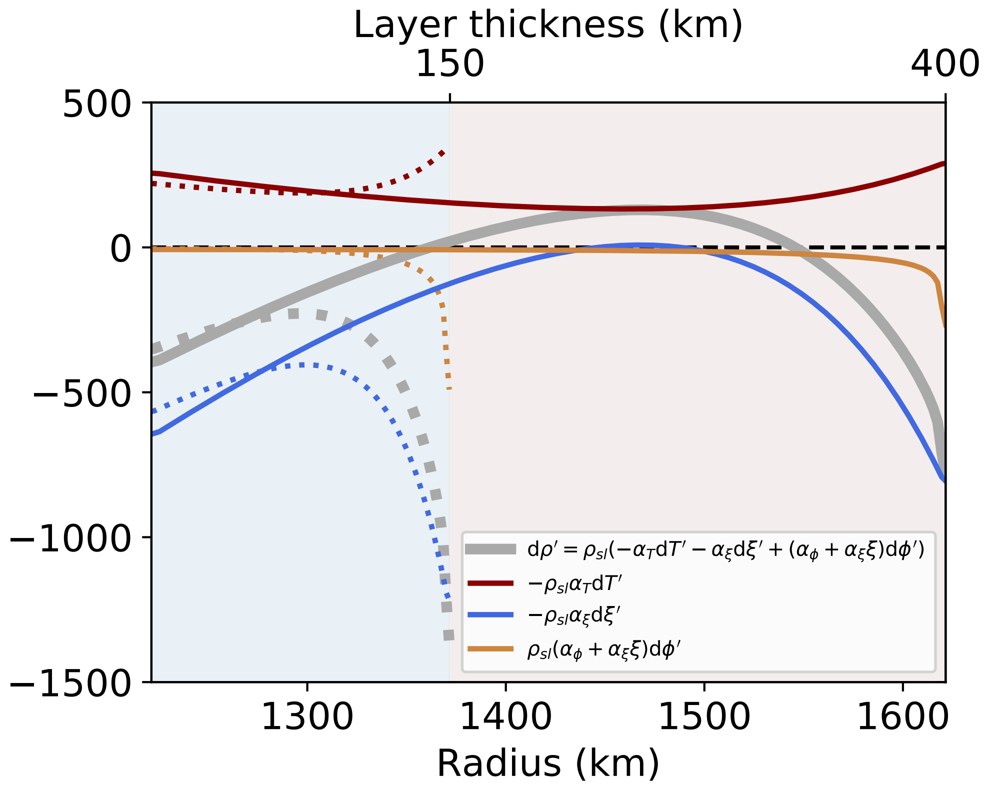
Model solution

- Temperature gradient is "locked" to the oxygen gradient via the liquidus
- Solid flux is negative downward towards ICB
- Increasing layer thickness destabilises the layer



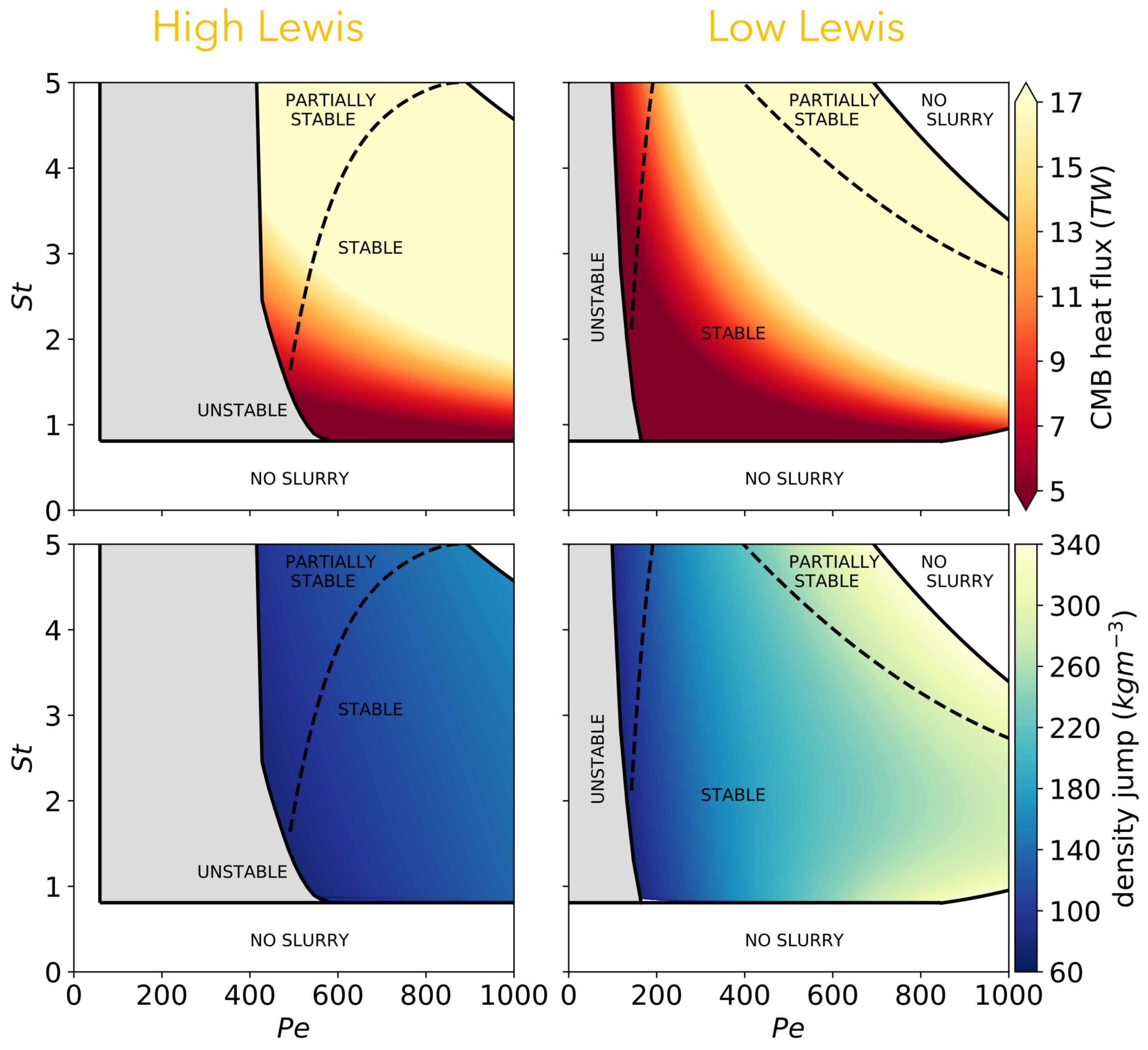
Model solution

- Temperature gradient is "locked" to the oxygen gradient via the liquidus
- Solid flux is negative downward towards ICB
- Increasing layer thickness destabilises the layer
- Temperature, oxygen and solid flux contribute to density anomaly

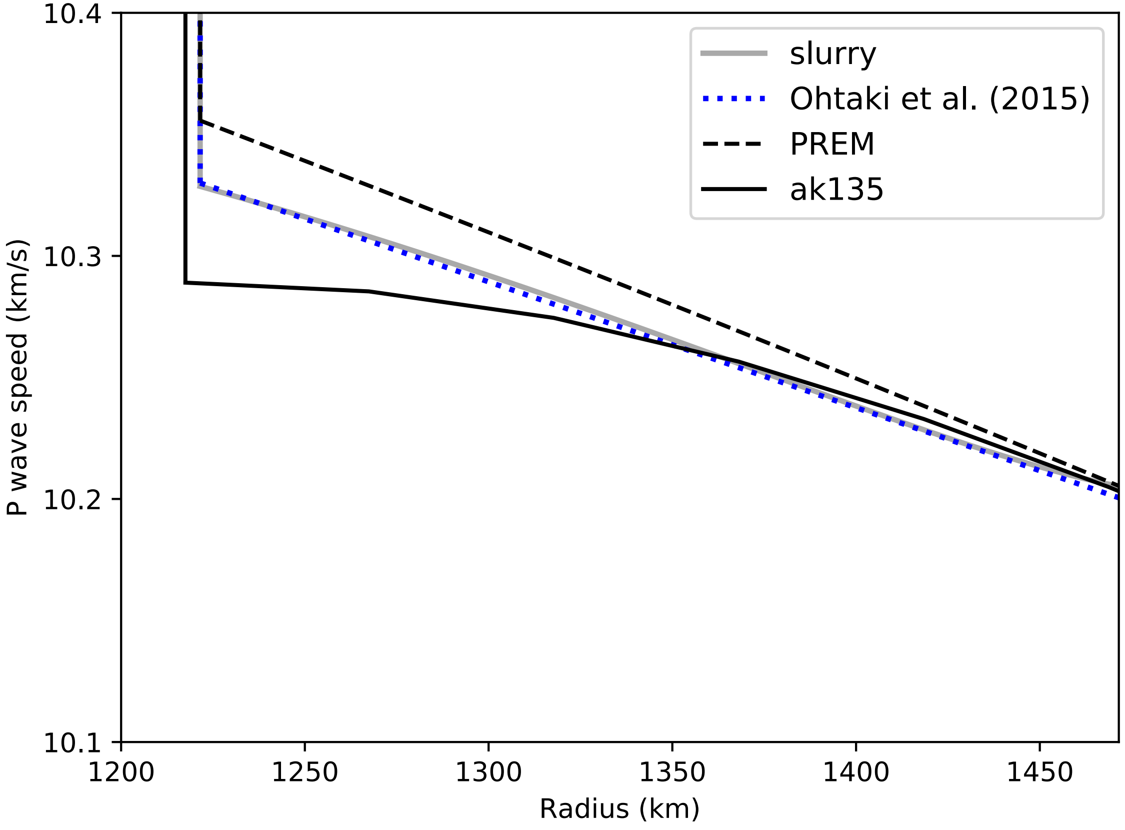


Regime diagram

- Perform parameter search over Pe, St, Le space (fixed layer thickness)
- Determine which parameter combinations give
  - a STABLE slurry
  - a PARTIALLY STABLE slurry
  - an UNSTABLE slurry
  - NO slurry
- Apply geophysical constraints to narrow solution space
  - Density jump ($\rho_s - \rho_{sl}$)
  - CMB heat flow



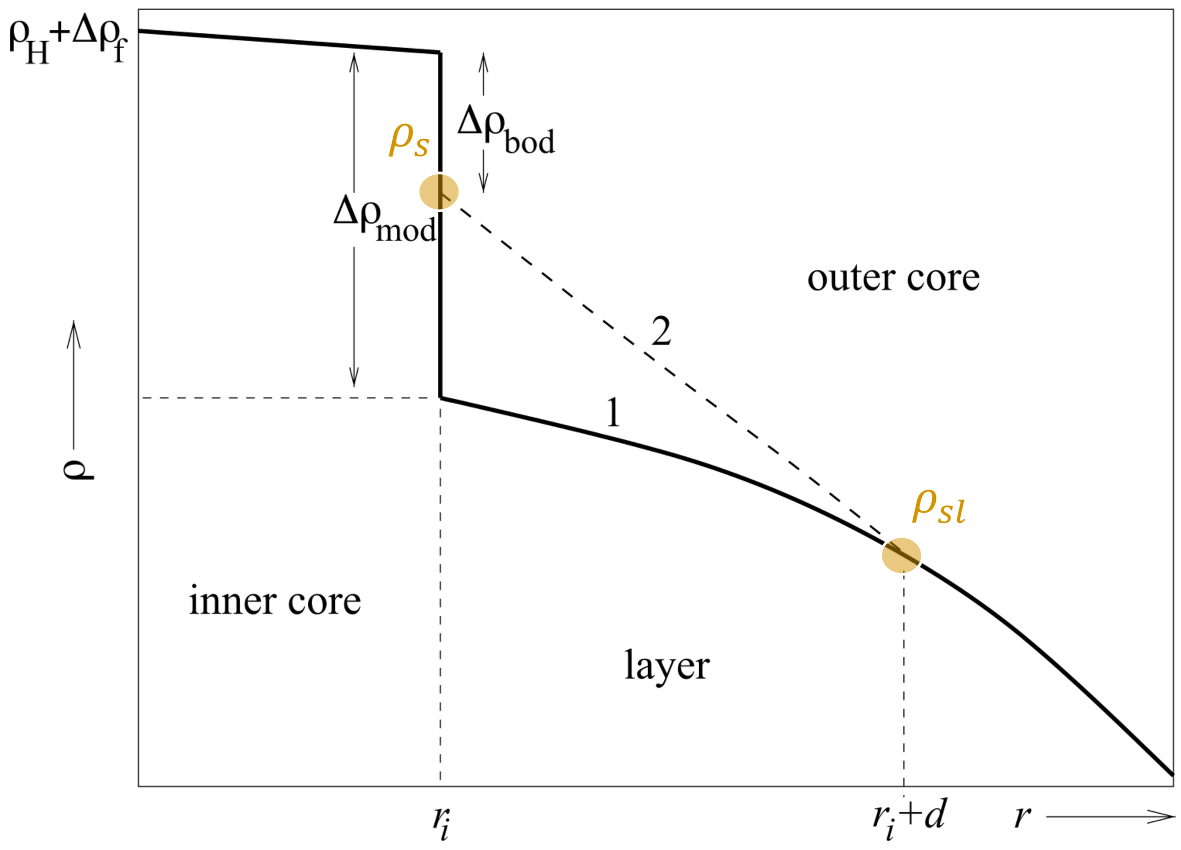
Geophysical implications



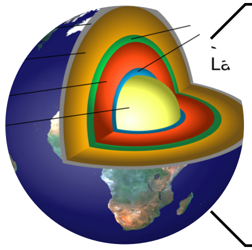
$$v_p^2 = \frac{K}{\rho}$$

$d = 250\ km$
$k = 100\ W\ m^{-1}K^{-1}$
$Q_i = 3.5\ TW$
$Q_{sl} = 6\ TW$

Geophysical implications

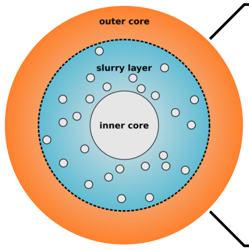


	High Lewis	Low Lewis
$\rho_s - \rho_{sl}$ (kgm^{-3})	<140	<331
$\Delta\rho_{bod}^{sl}$ (kgm^{-3})	>460	>269
$\Delta\rho_{bod}^{obs}$ (kgm^{-3})	280 - 1100	



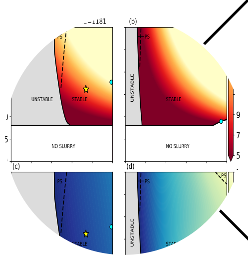
Motivation

Consensus on slowdown in P-wave speed at the base of the core.



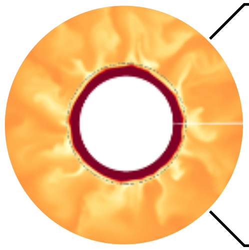
Slurry (iron snow) layer

A slurry provides an explanation of how the stably-stratified F-layer is maintained.



Regime diagram

Stable slurry is likely when $Pe \gtrsim Le$. Agrees with available geophysical constraints.



Ongoing work

How does a stably-stratified F-layer impact core dynamics and the dynamo?

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Special thanks to:

Séverine Rosat	*Université de Strasbourg*
Chris Davies	*University of Leeds*
Chris Jones	*University of Leeds*
Julien Aubert	*IPGP*
Renaud Deguen	*ISTerre*

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