# Inferences on Transition Zone Anisotropy From Higher Mode Surface Waves

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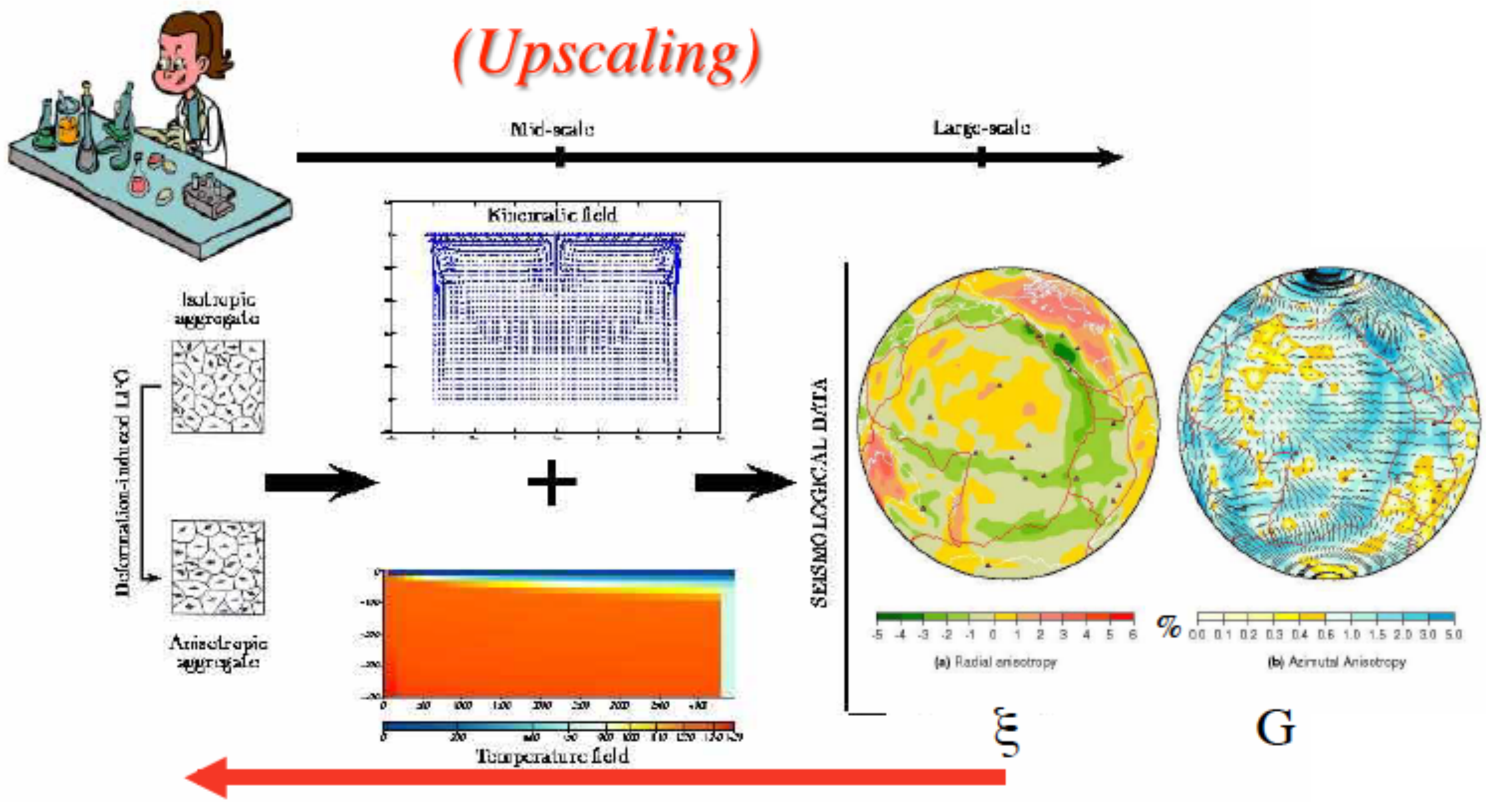
Acknowledgements: Kaiqing Yuan (UCBerkeley), Karin Visser & Jeannot Trampert (Utrecht University)

Micro LPO (strain) Macro

*(Upscaling)*



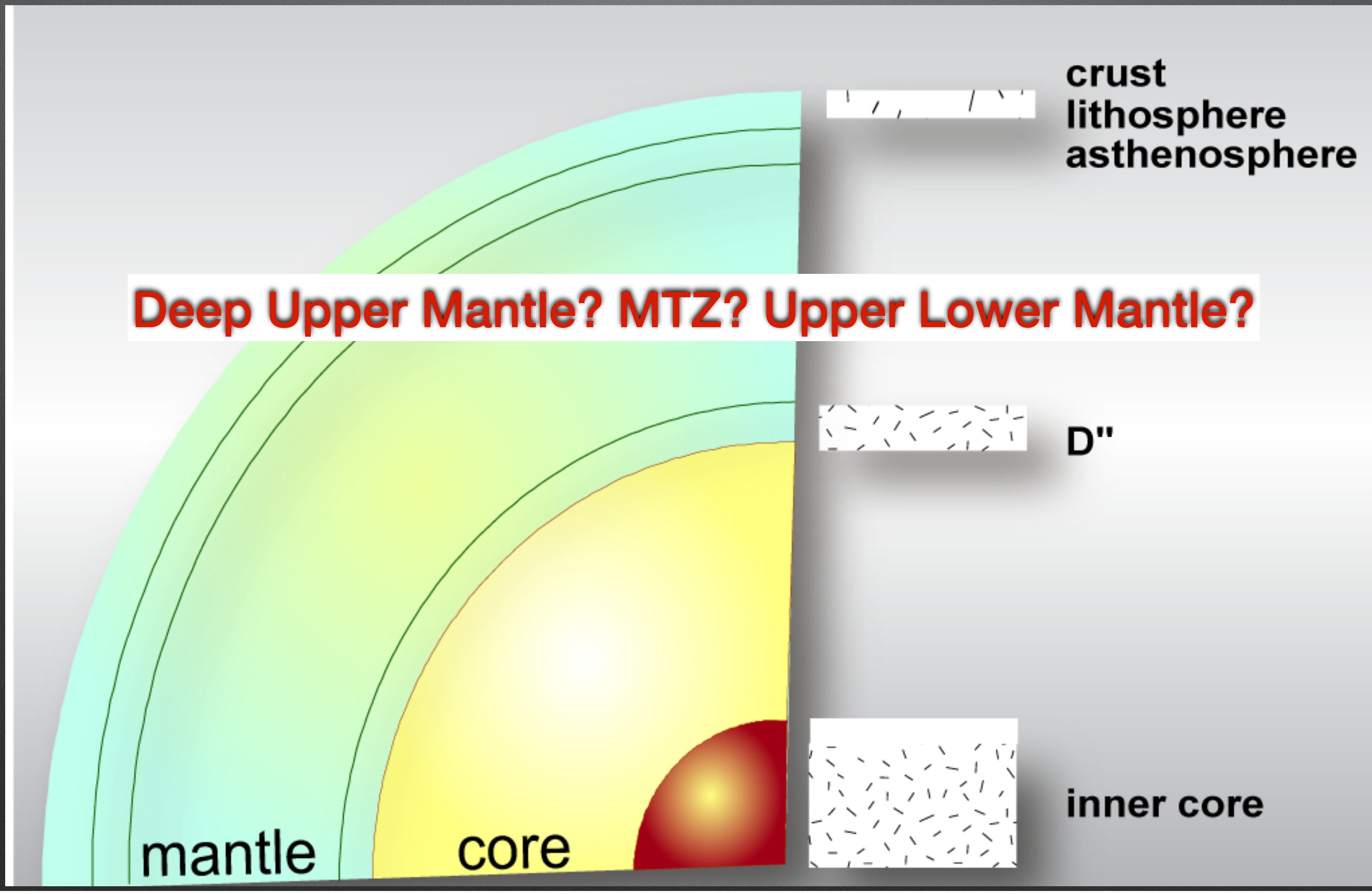

Mineralogical composition

Mapping convection

*(Downscaling)*

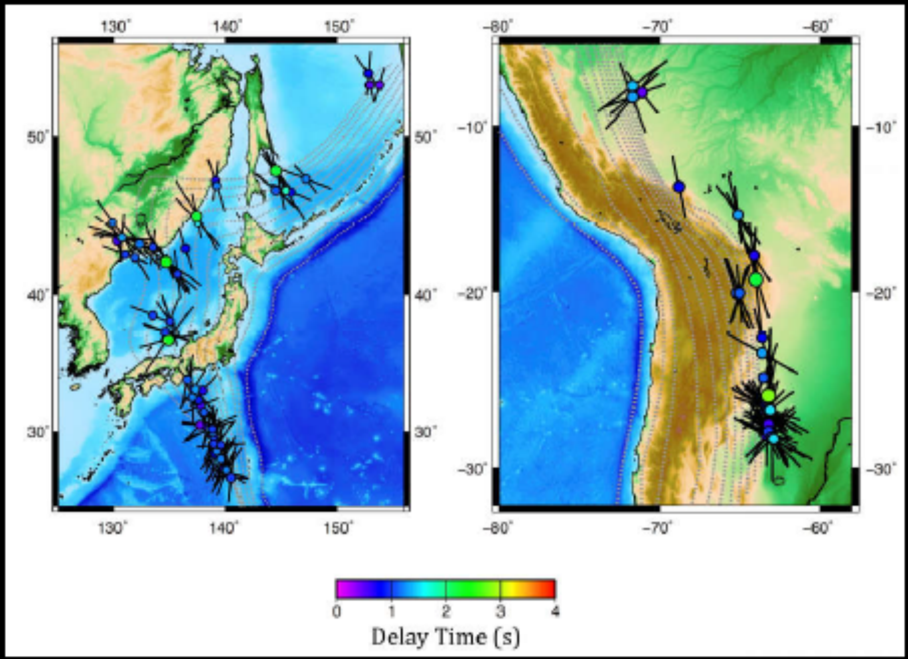
Slide from Jean-Paul Montagner

# Where is the Seismic Anisotropy?

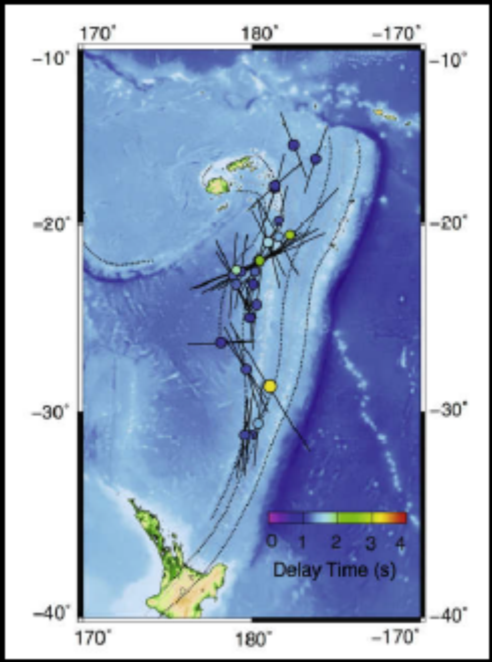



Modified from Garnero

# Transition zone and uppermost lower mantle anisotropy: splitting from deep earthquakes




*Lynner and Long, GJI*, 2015

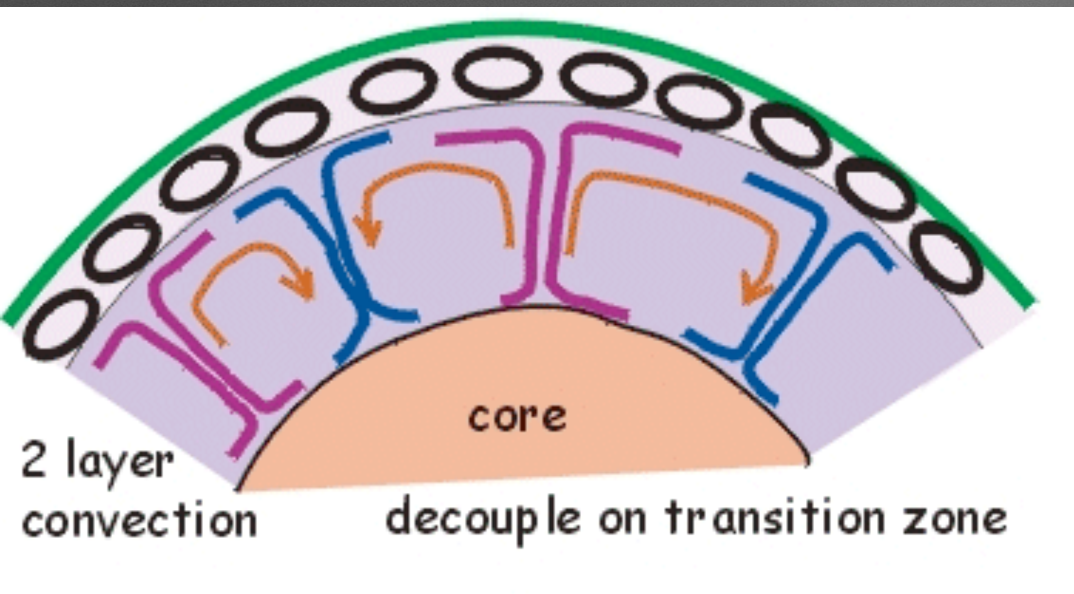



*Mohiuddin et al., PEPI*, 2015

BOTTOM LINE: Substantial shear wave splitting associated with mid-mantle anisotropy. Splitting from deepest events (~660 km) requires contribution from uppermost lower mantle. Patterns are complex…

**Slide from Maureen Long**

# Plate Tectonic and Mantle Convection



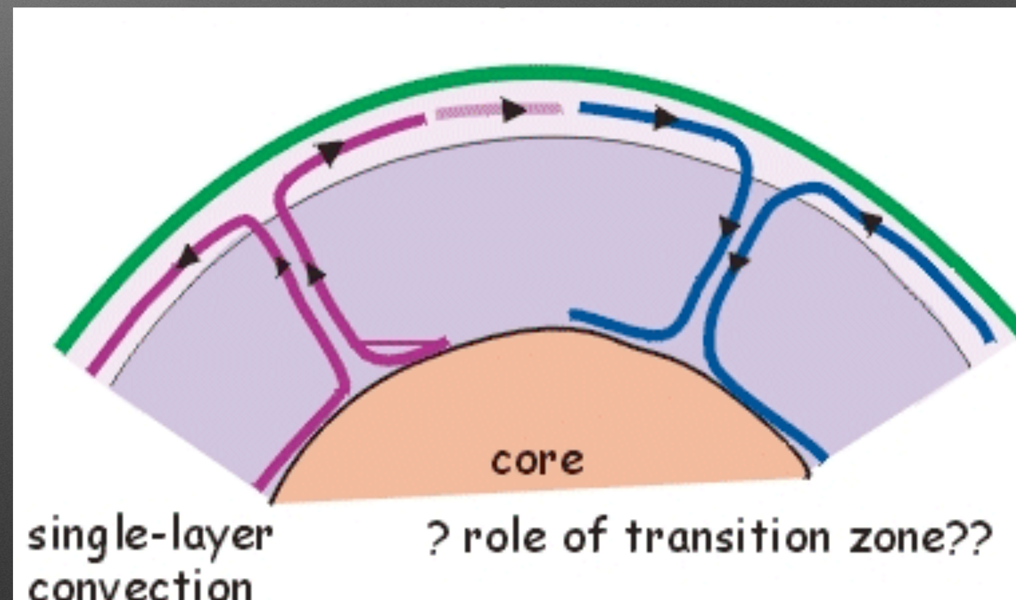



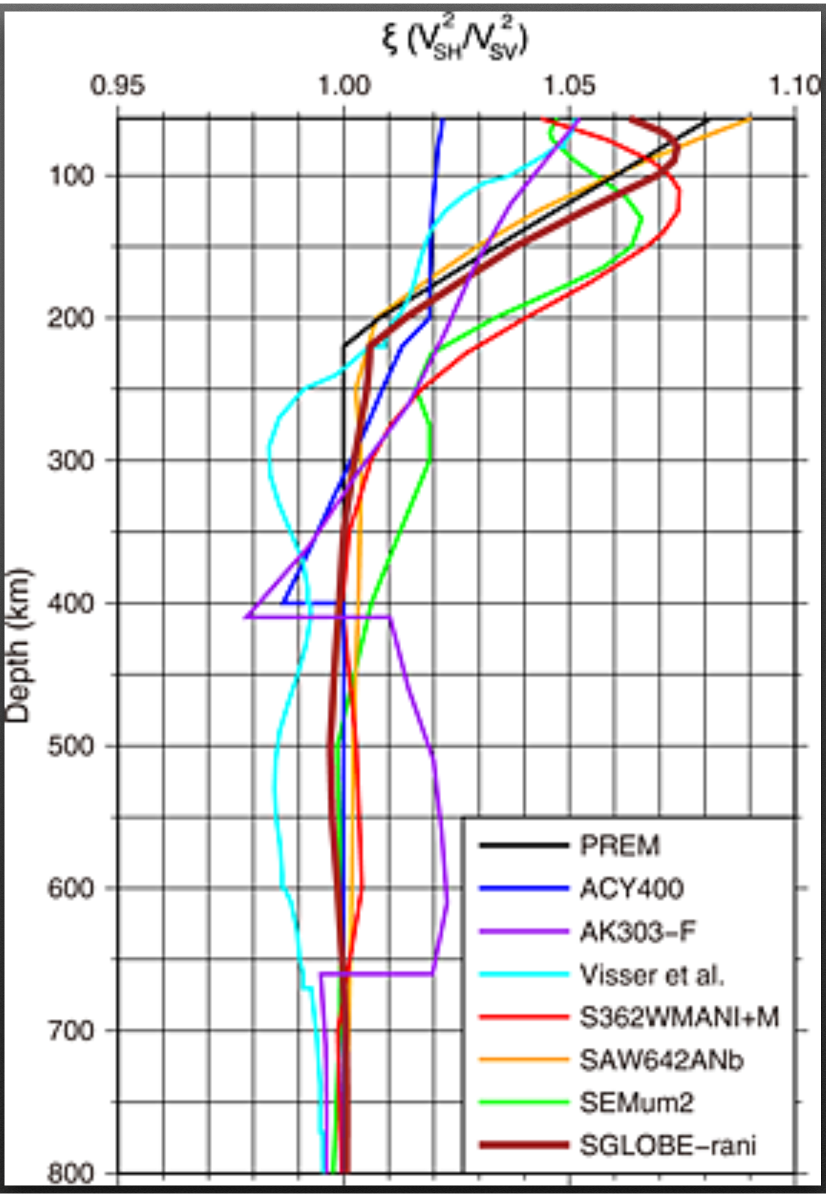

Fig: http://www.see.leeds.ac.uk/structure/dynamicearth/convection/models.htm

# Anisotropy in Reference Seismic Models

1-2% radial anisotropy in the mantle transition zone

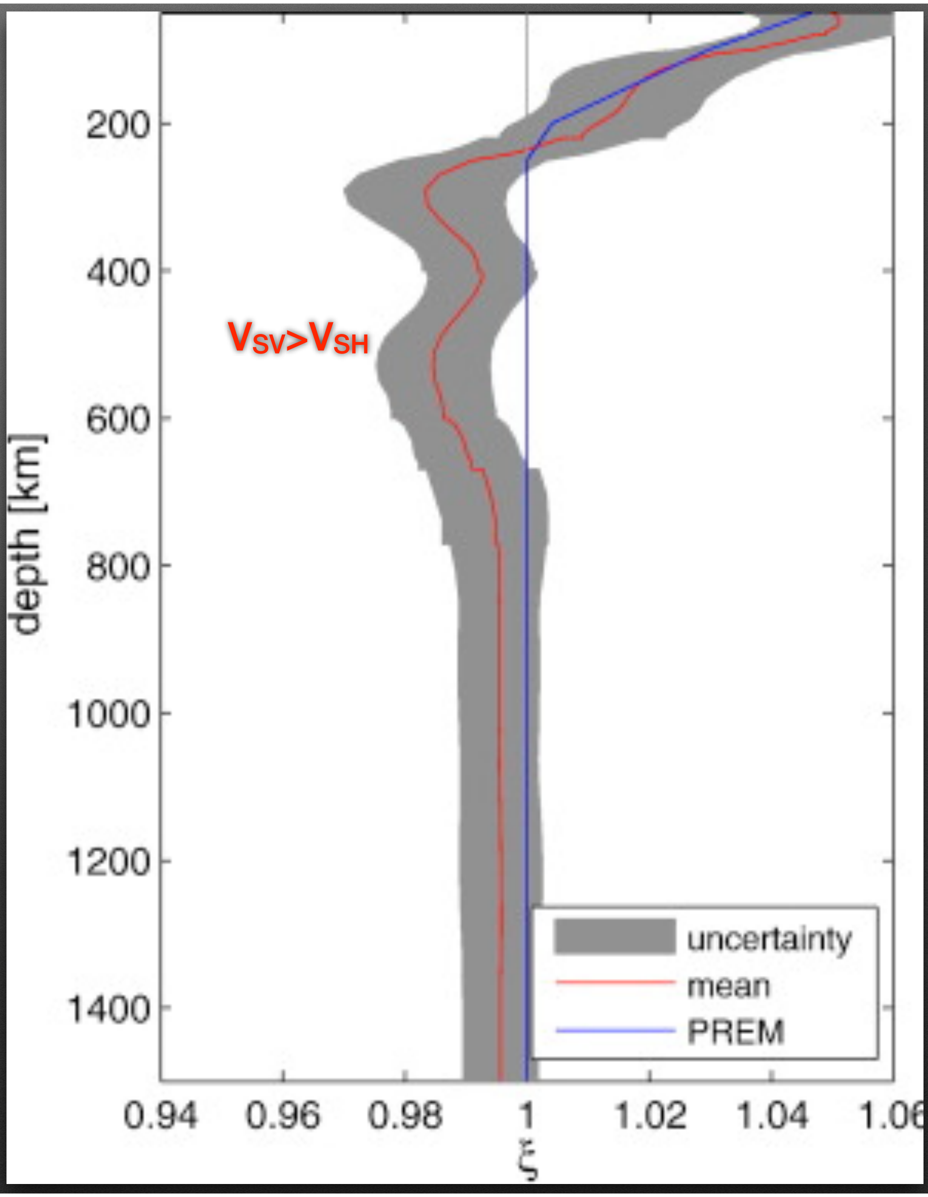
$V_{SH}>V_{SV}$ or $V_{SV}>V_{SH}$?

Chang et al. (2015)



# Anisotropy in Reference Seismic Models

Model space search using Love and Rayleigh wave fundamental and higher modes separately, with prior assumptions on $V_P$, $\Phi$, $\eta$, and $\rho$

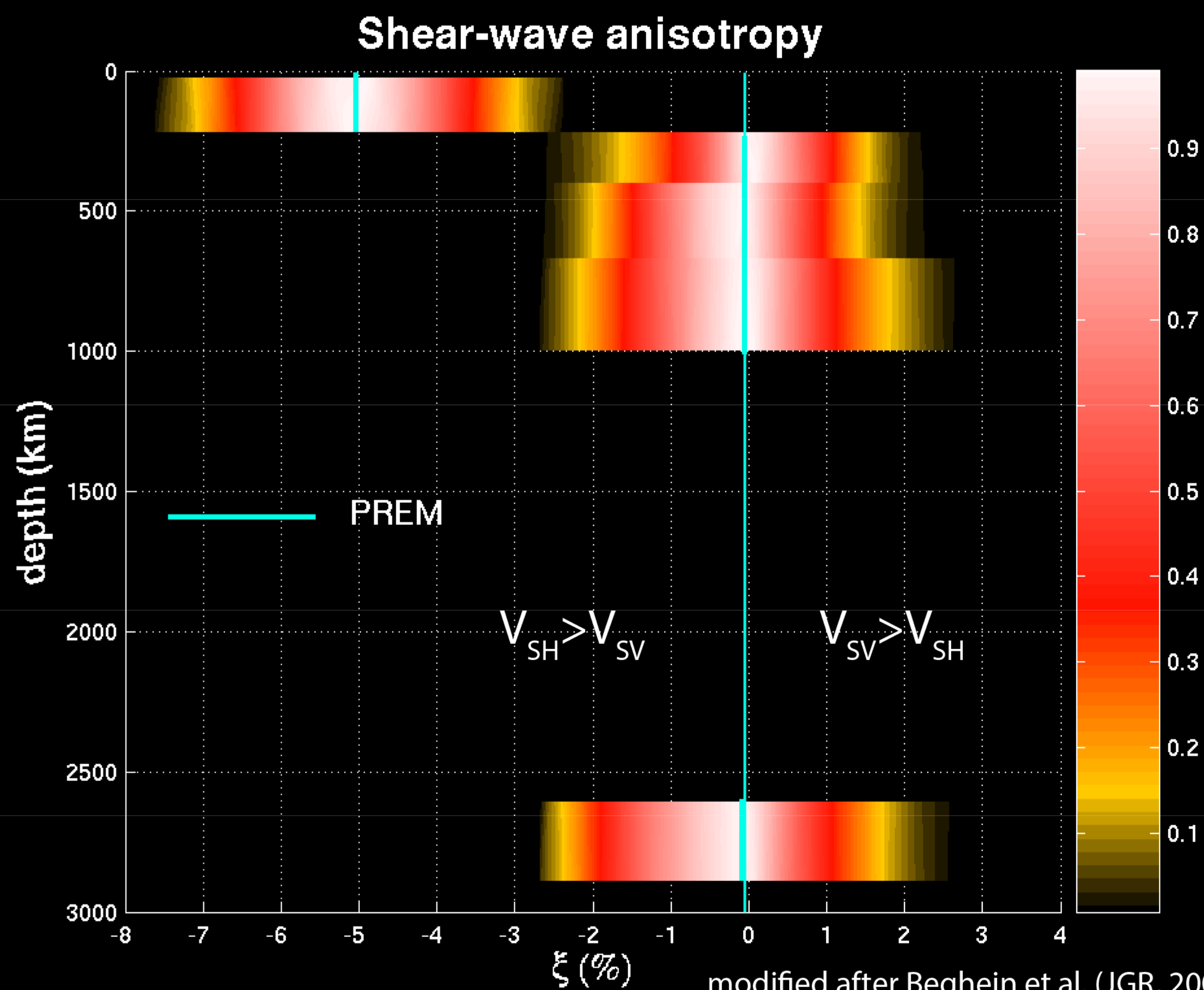



Visser et al. (2008)

# Anisotropy in Reference Seismic Models

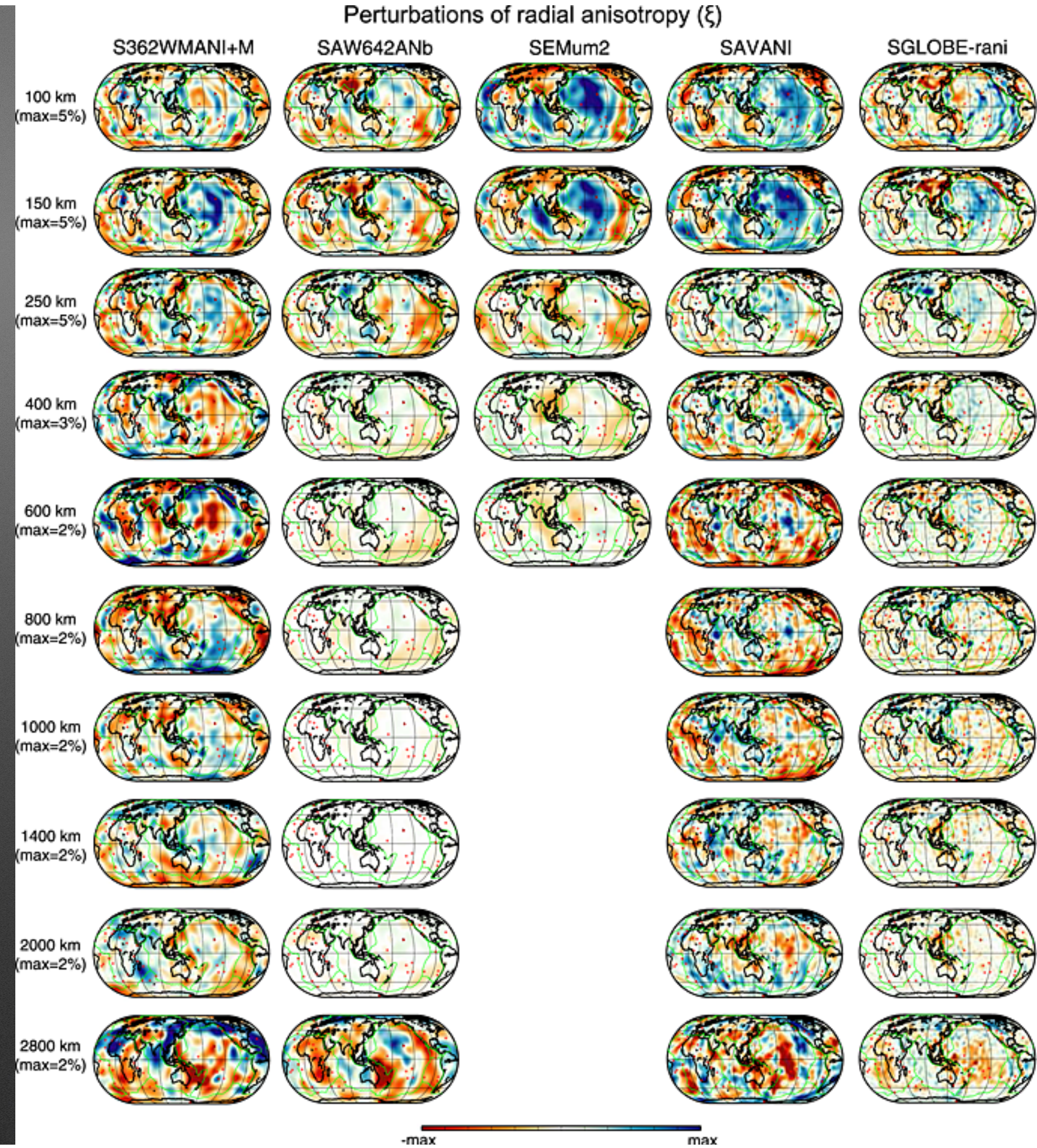
Model space search
- using Love and Rayleigh wave fundamental and higher modes together
- looking for 5 radial anisotropy parameters + density
- assuming no anisotropy in mid-mantle

⇒ yields large model error bars but most likely $V_{SH}>V_{SV}$ in MTZ

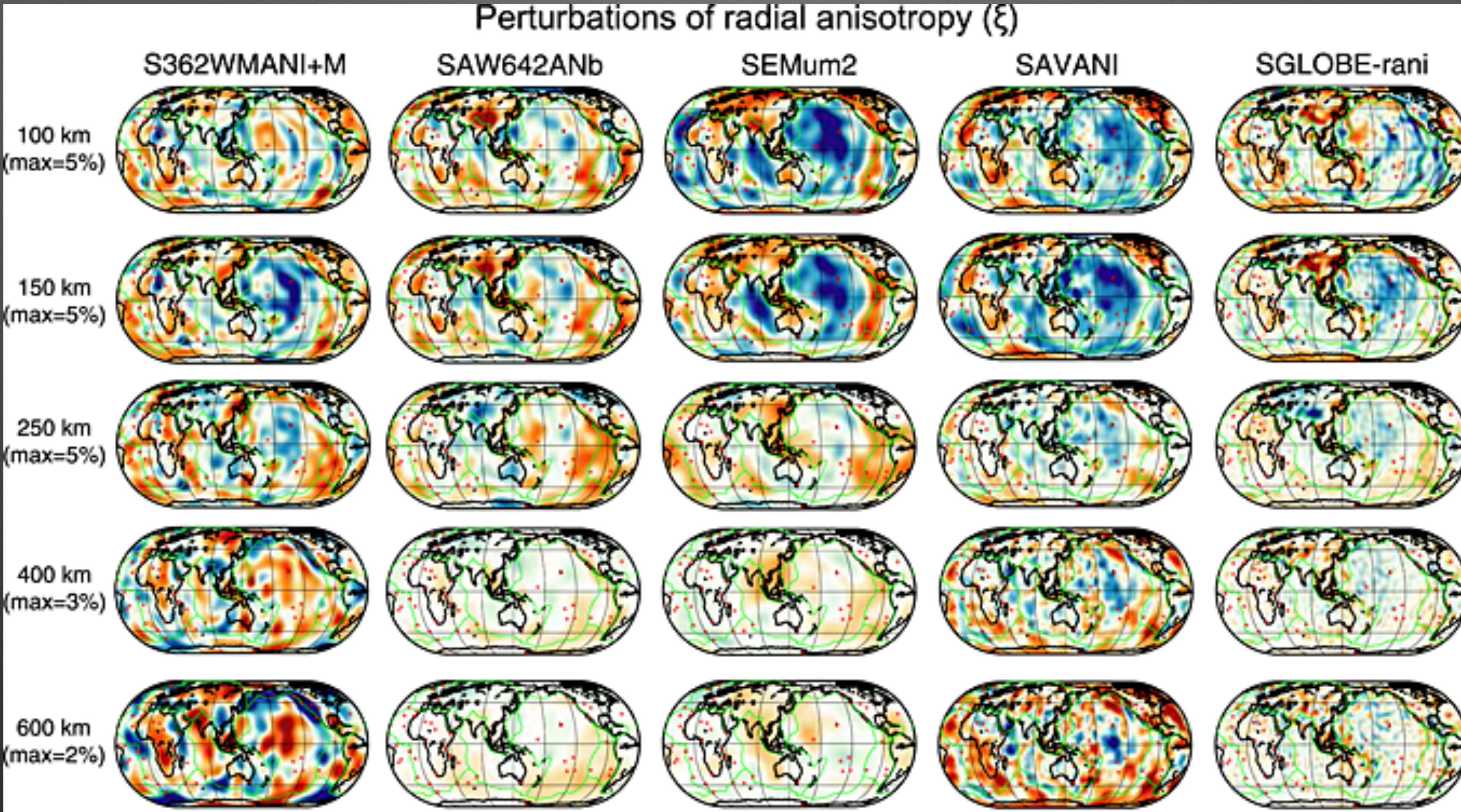


modified after Beghein et al. (JGR, 2006)

# 3-D Radial Anisotropy Models




Chang et al. (2015)
blue is $V_{SH}>V_{SV}$




Chang et al. (2015); blue is $V_{SH}>V_{SV}$

# Azimuthal Anisotropy from Surface Waves

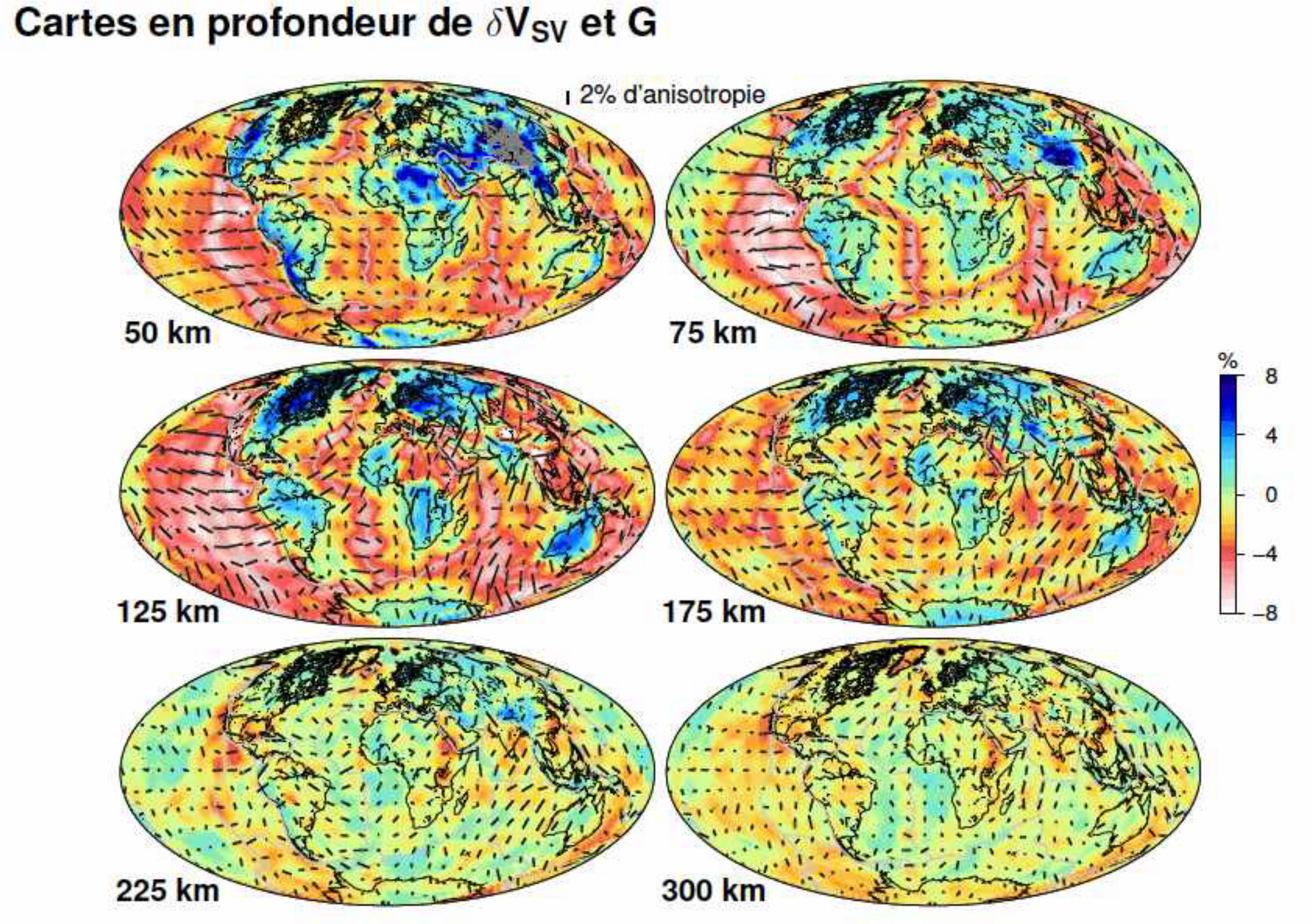
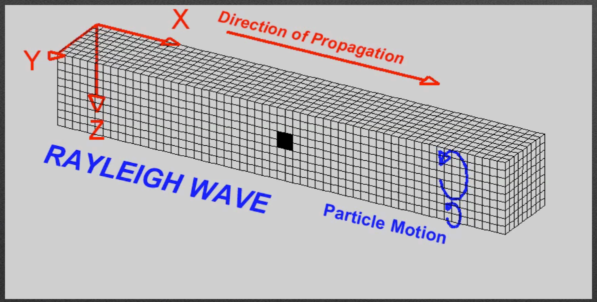
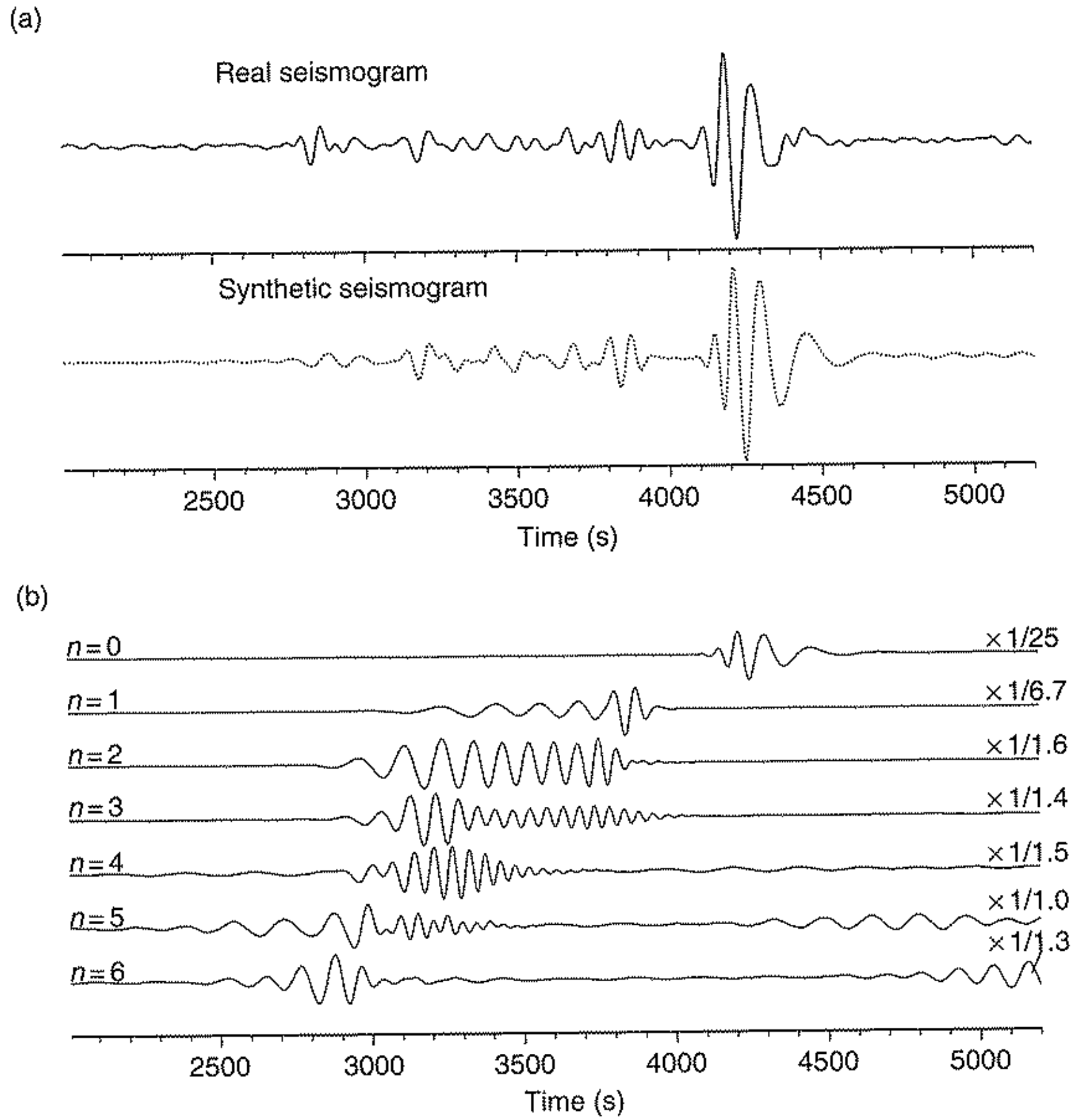



Fig: Jean-Paul Montagner

# Fundamental and Higher Mode Surface Waves




Beucler et al. (2003)

# Fundamental and Higher Mode Surface Waves

Synthetic seismogram calculation by adding higher modes

Visser (PhD thesis (2008)

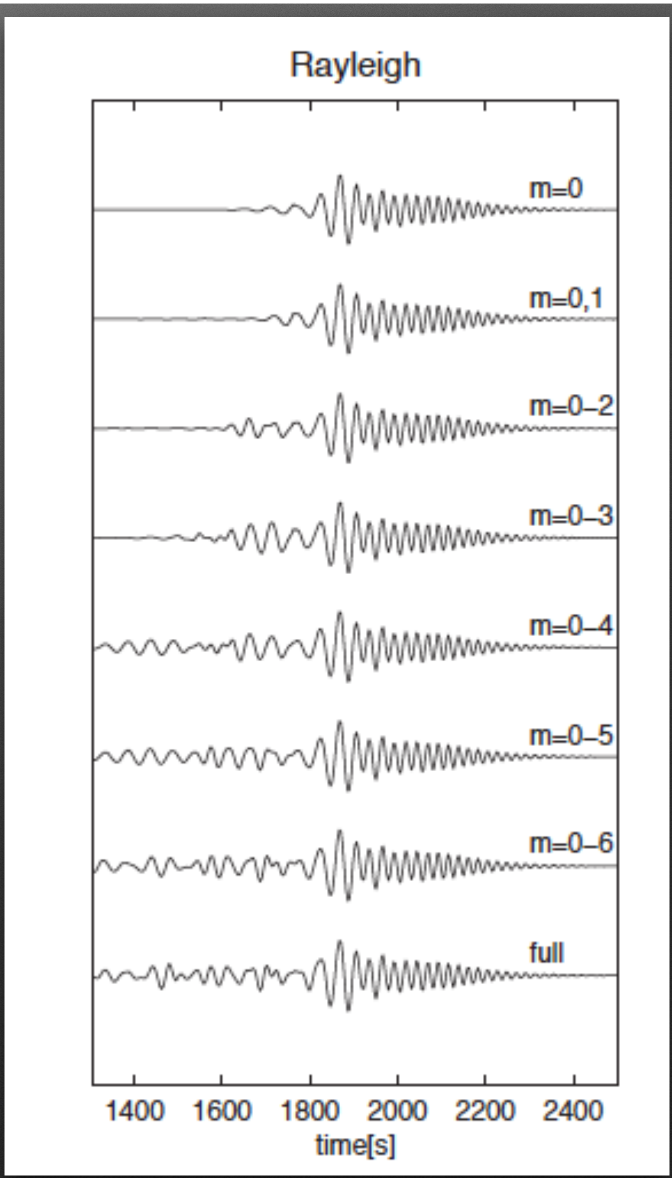
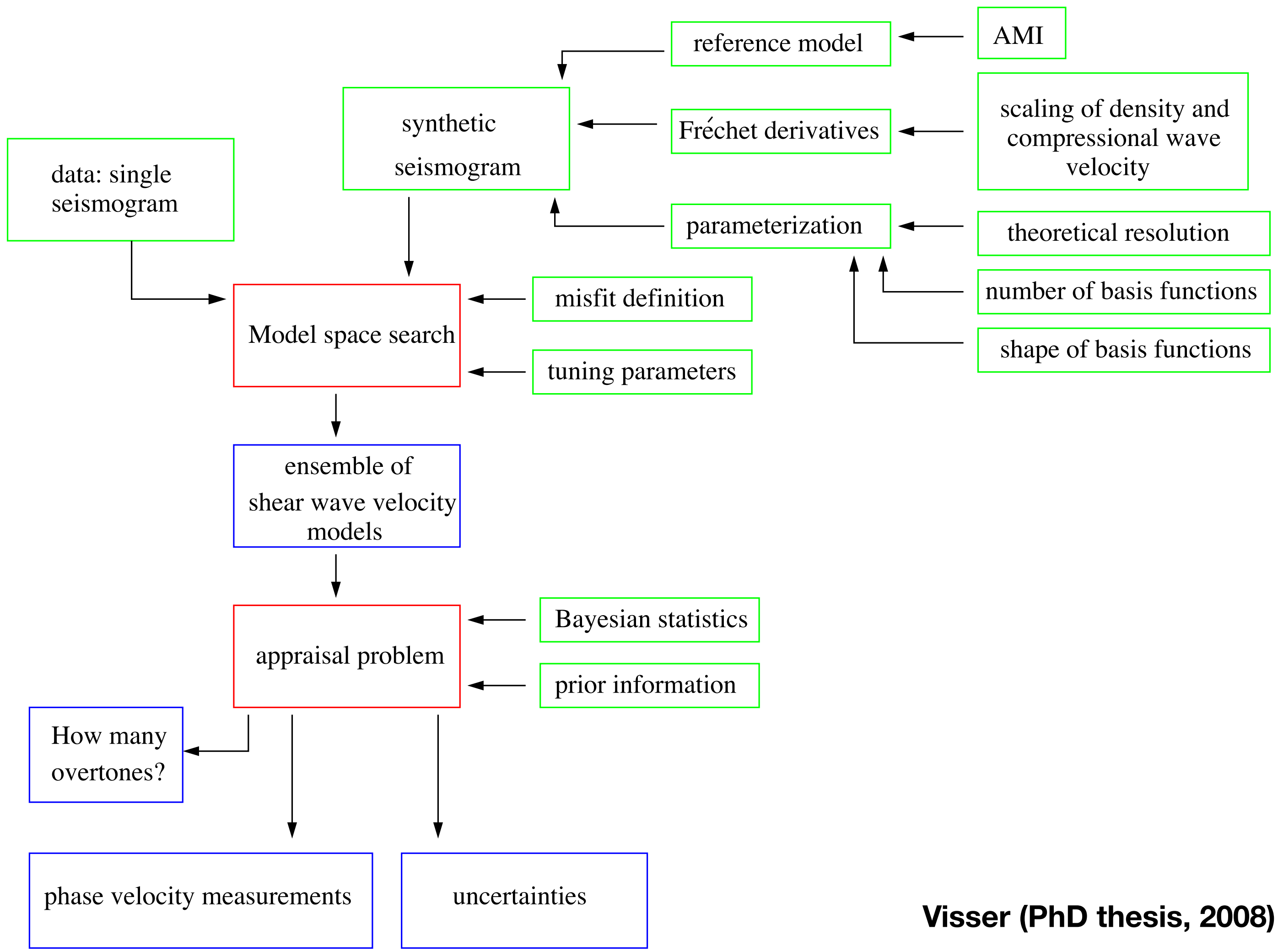


Figure 2.3: *flowchart of the method. Red block correspond to main programs, green to input blocks and blue blocks correspond to measurements.*




**Visser (PhD thesis, 2008)**

| | Number of measurements | |
|---|---|---|
| | Rayleigh | Love |
| fundamental mode | 63,628 | 45,179 |
| first higher mode | 54,035 | 34,859 |
| second higher mode | 52,457 | 31,704 |
| third higher mode | 48,762 | 24,102 |
| fourth higher mode | 40,606 | 15,065 |
| fifth higher mode | 31,637 | 8,514 |
| sixth higher mode | 21,626 | |

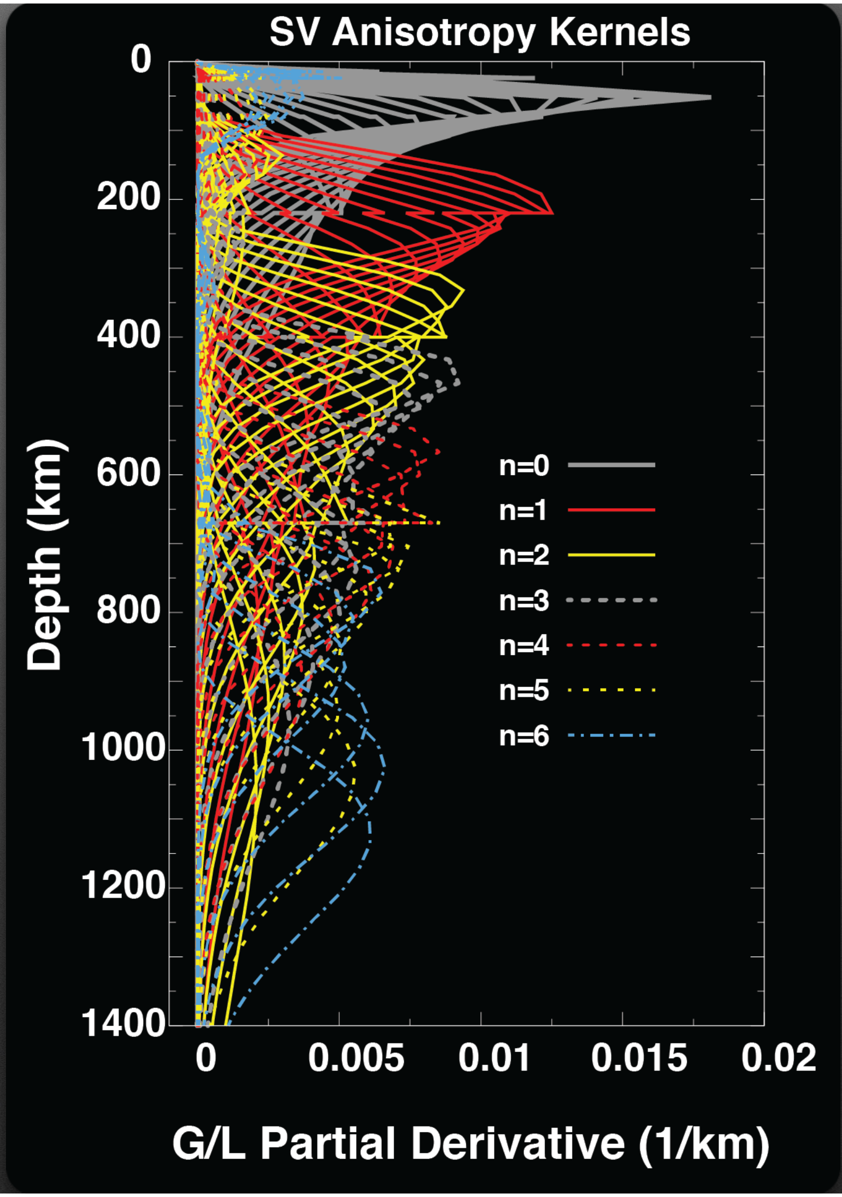
Visser et al. (2008)

# Sensitivity Kernels

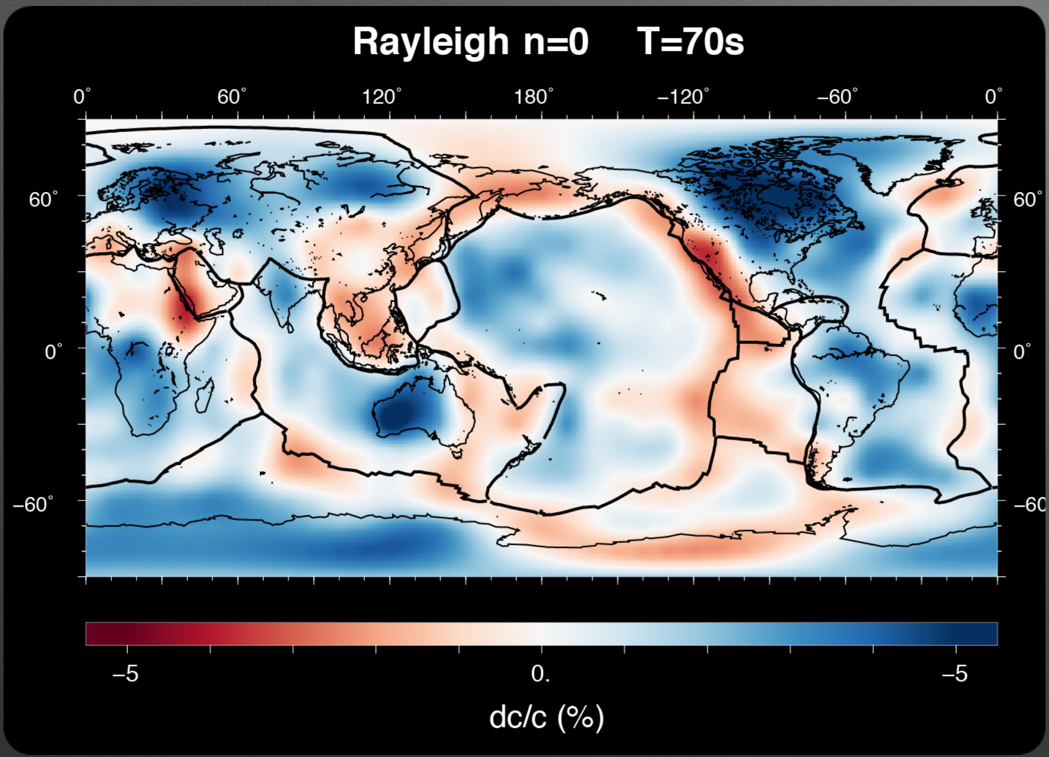
Higher modes provide sensitivity to structure at greater depth than fundamental modes

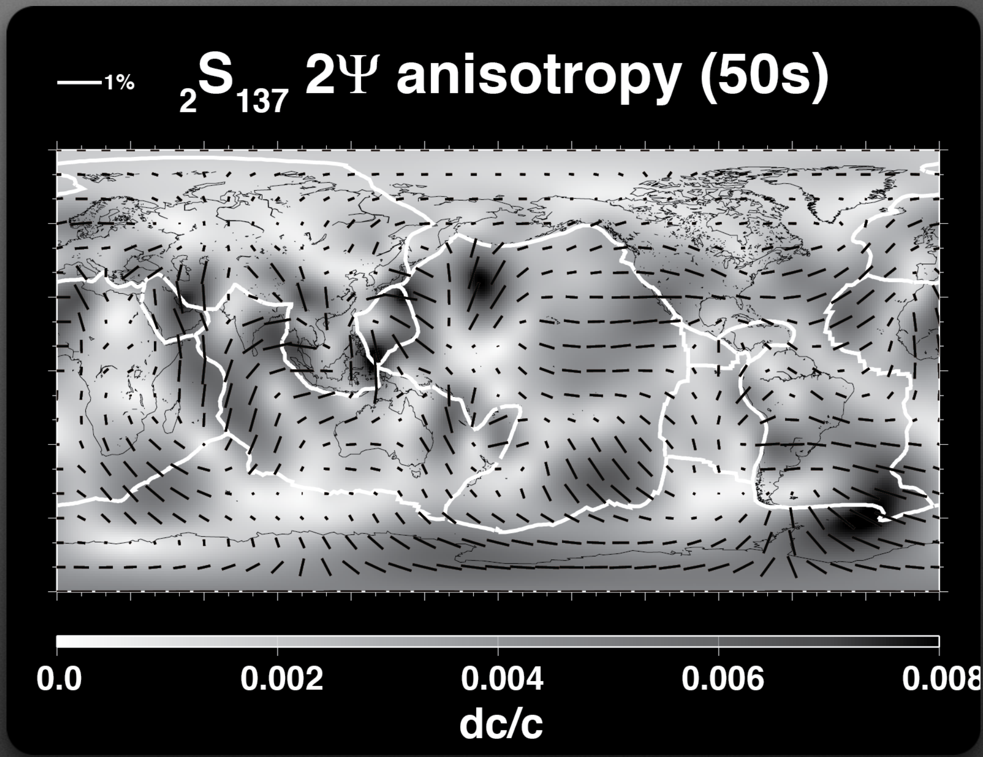
They also improve sensitivity to upper mantle

Yuan & Beghein (2013)



# Phase Velocity Maps



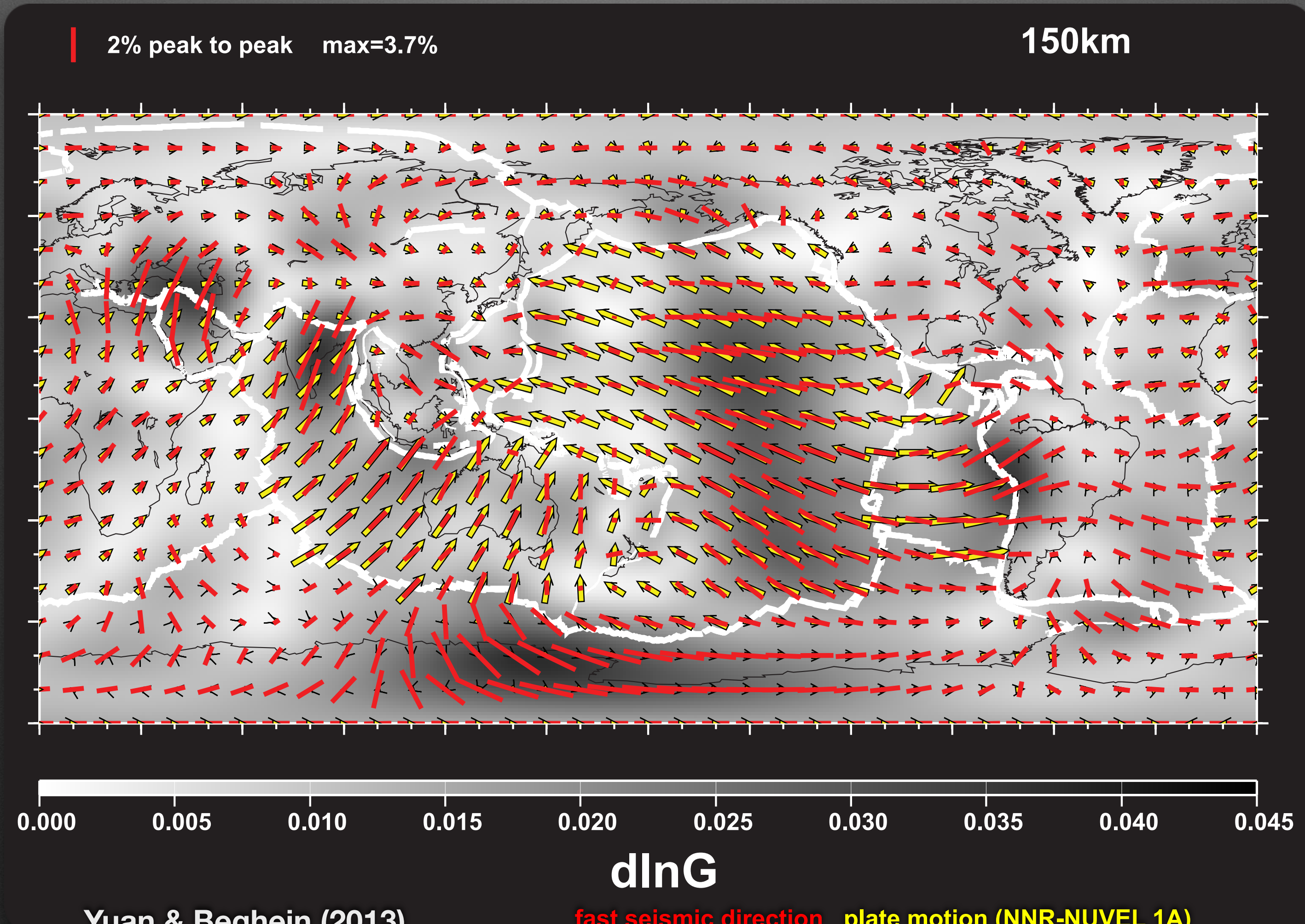




Visser et al. (2008)

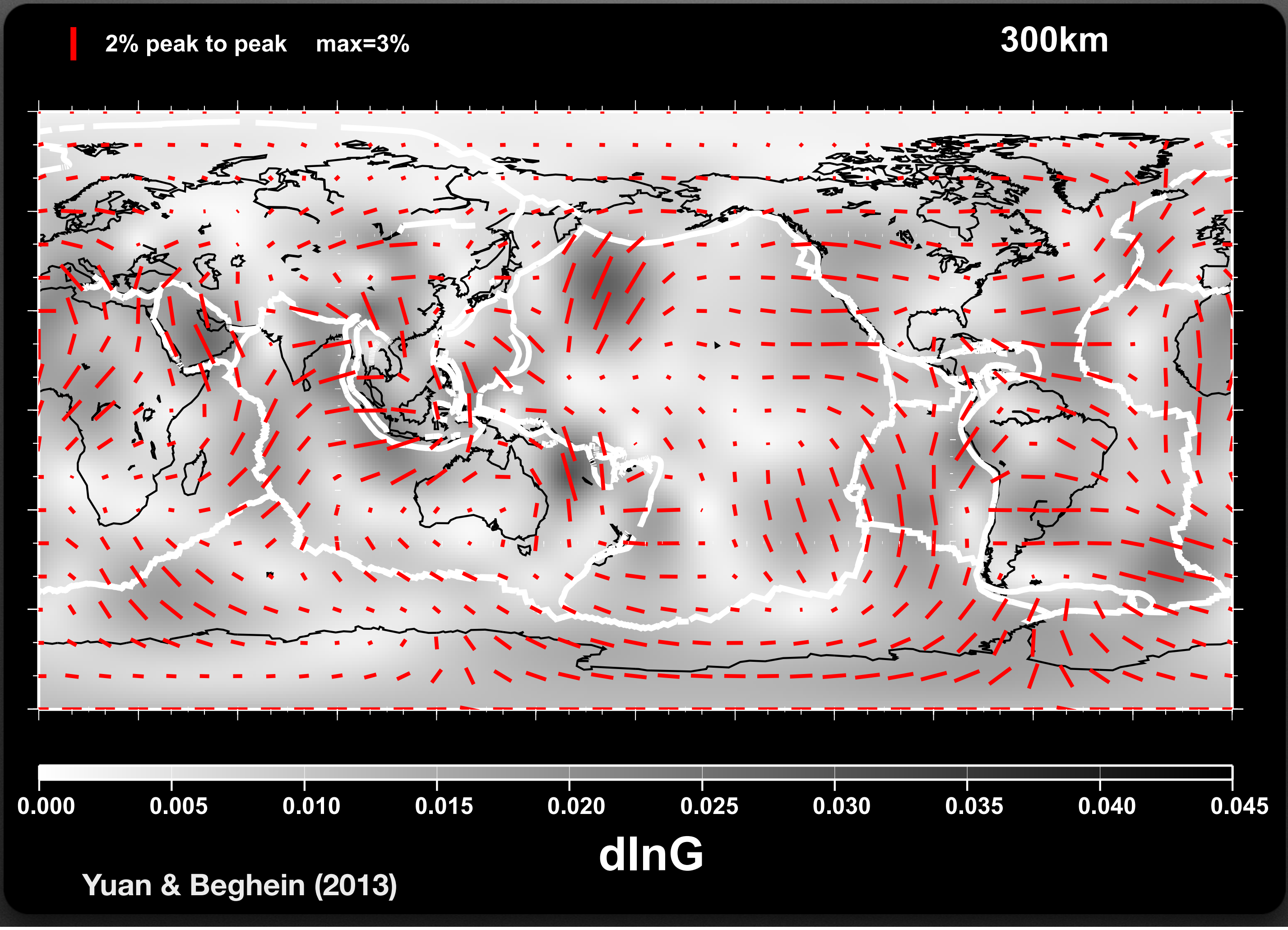
Depth inversions of isotropic phase velocity data ⇒ 3-D model for Vs

Depth inversion of anisotropic component of map ⇒ 3-D model of $V_{SV}$ anisotropy

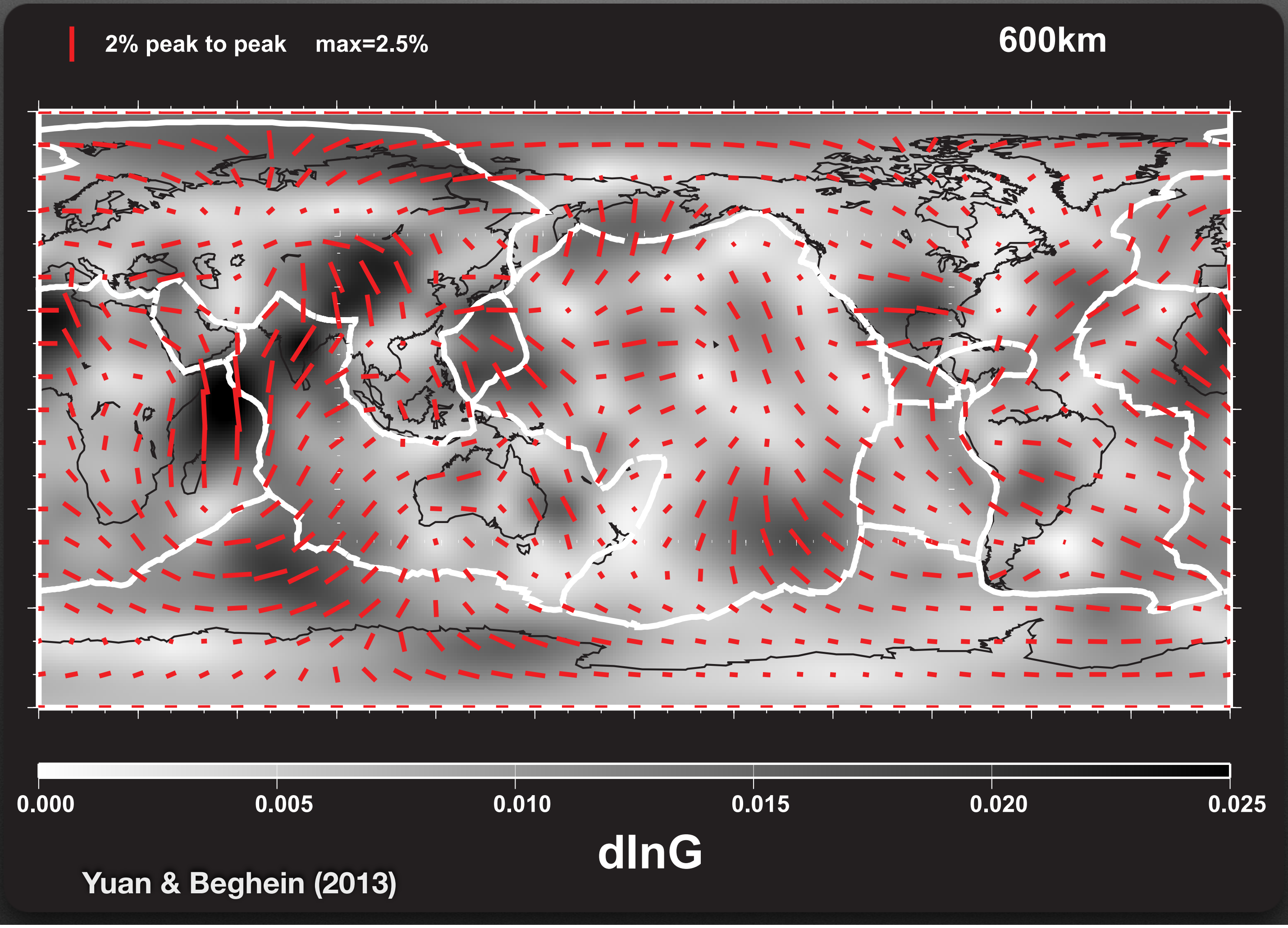
# 3-D SV Anisotropy Model

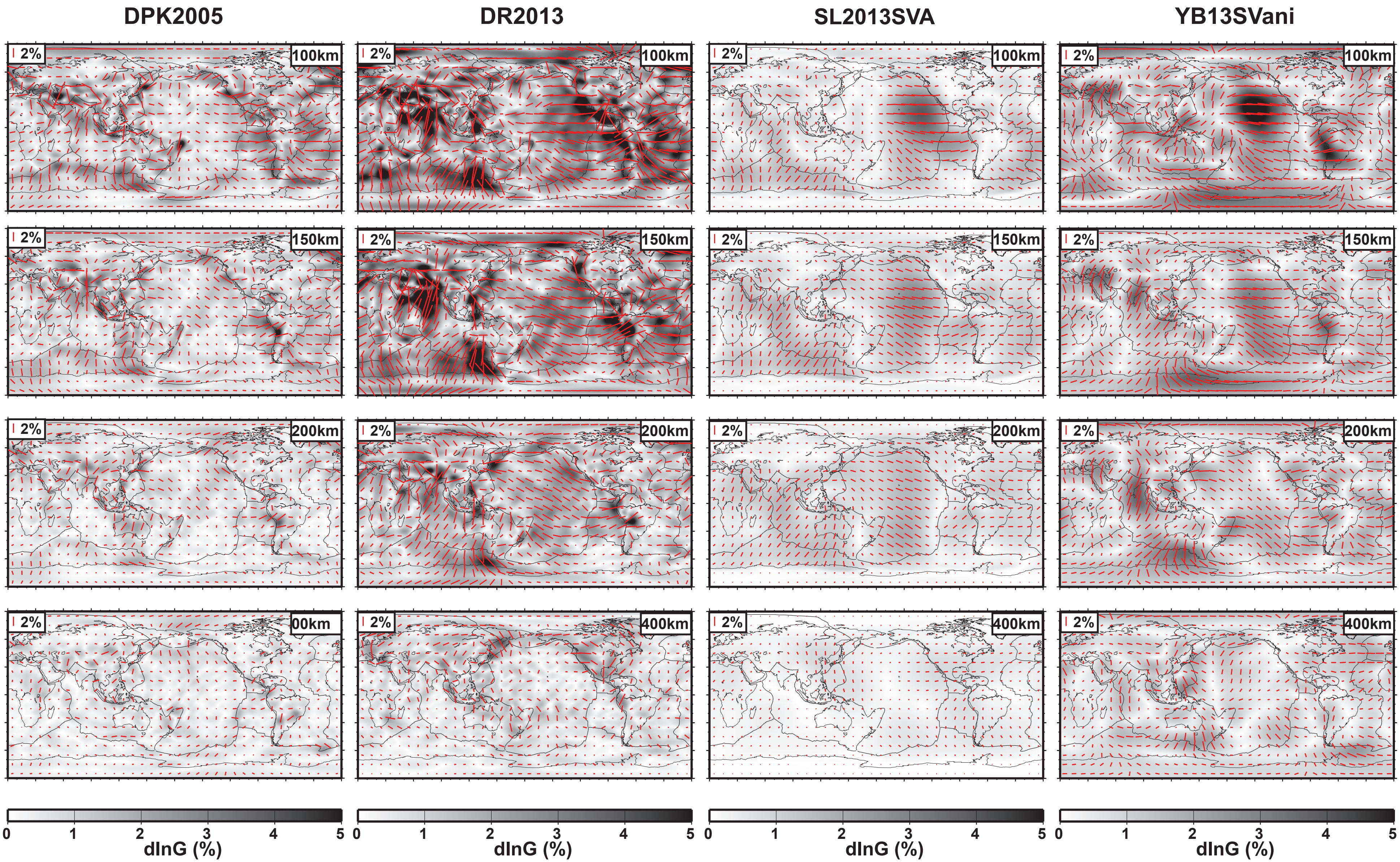


# 3-D SV Anisotropy Model



# 3-D SV Anisotropy Model



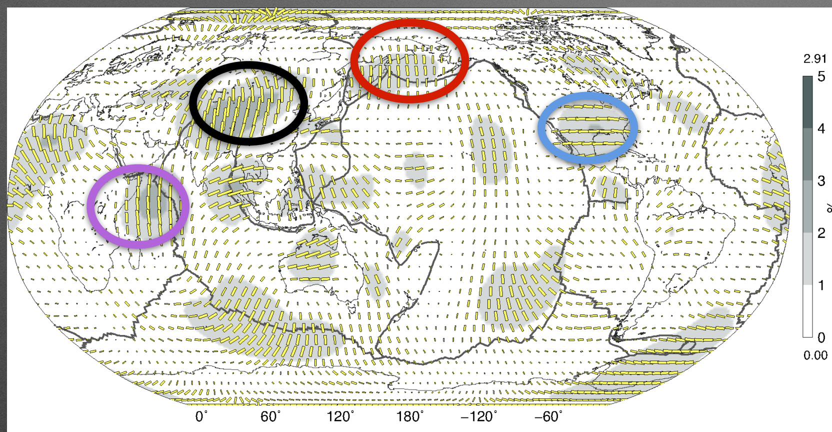

DPK2005
DR2013
SL2013SVA
YB13SVani
2%
100km
150km
200km
00km
400km
0 1 2 3 4 5
dlnG (%)

# Anisotropic Transition zone Structure: 650 km

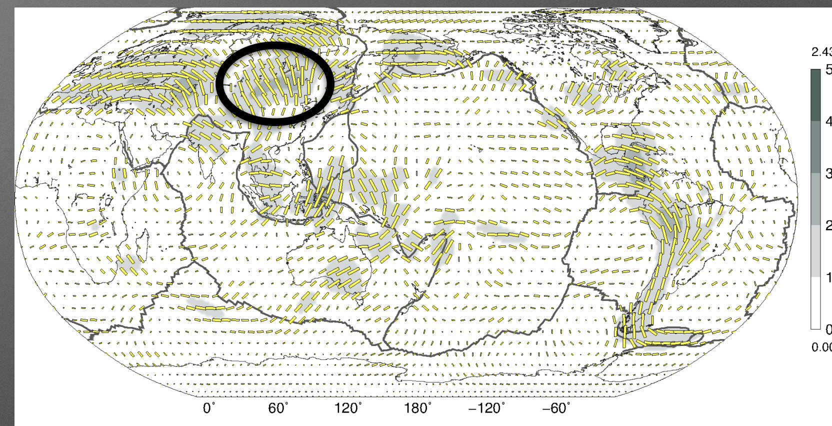
Yuan & Beghein, 2013
Lebedev & van der Hilst, 2008; Becker et al, 2010
Schaeffer & Lebedev, 2013;
Becker et al, 2014
Debayle & Ricard, 2013

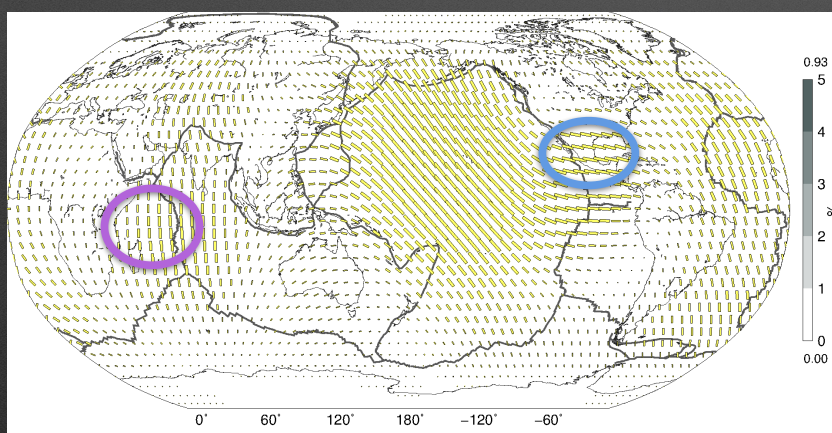
Slide modified from Schaeffer & Lebedev (AGU2014)

YB13SVani

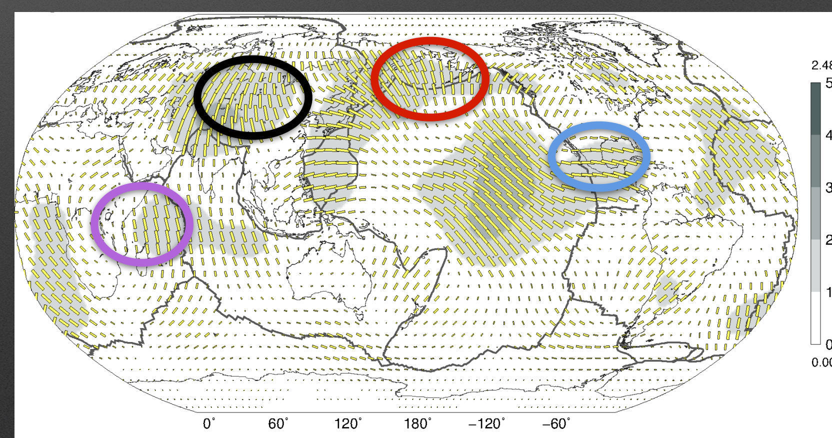



DR2012a



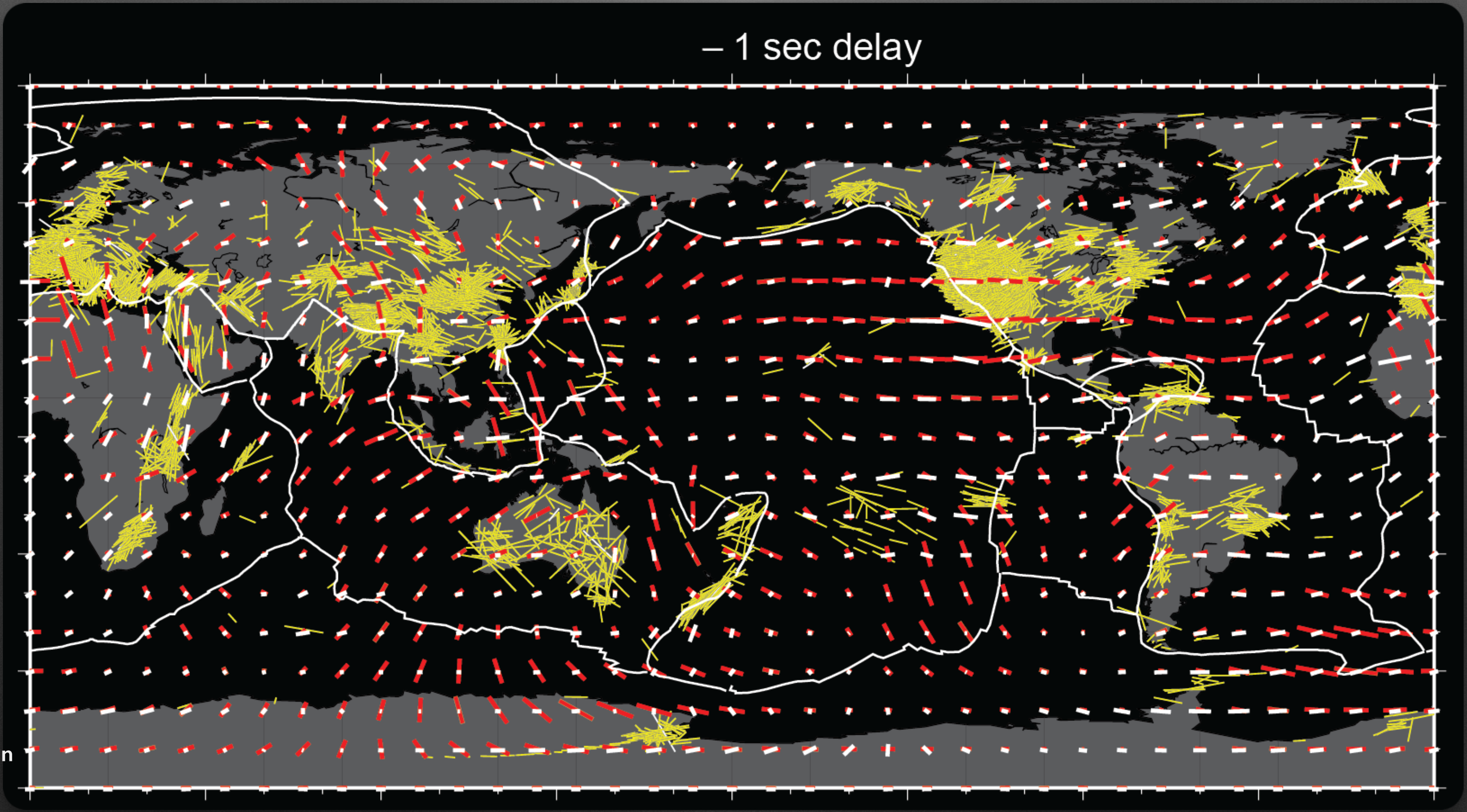




SL2013svA




SL2013svAr

# SKS Splitting Data & Predictions




Yuan & Beghein (2013)

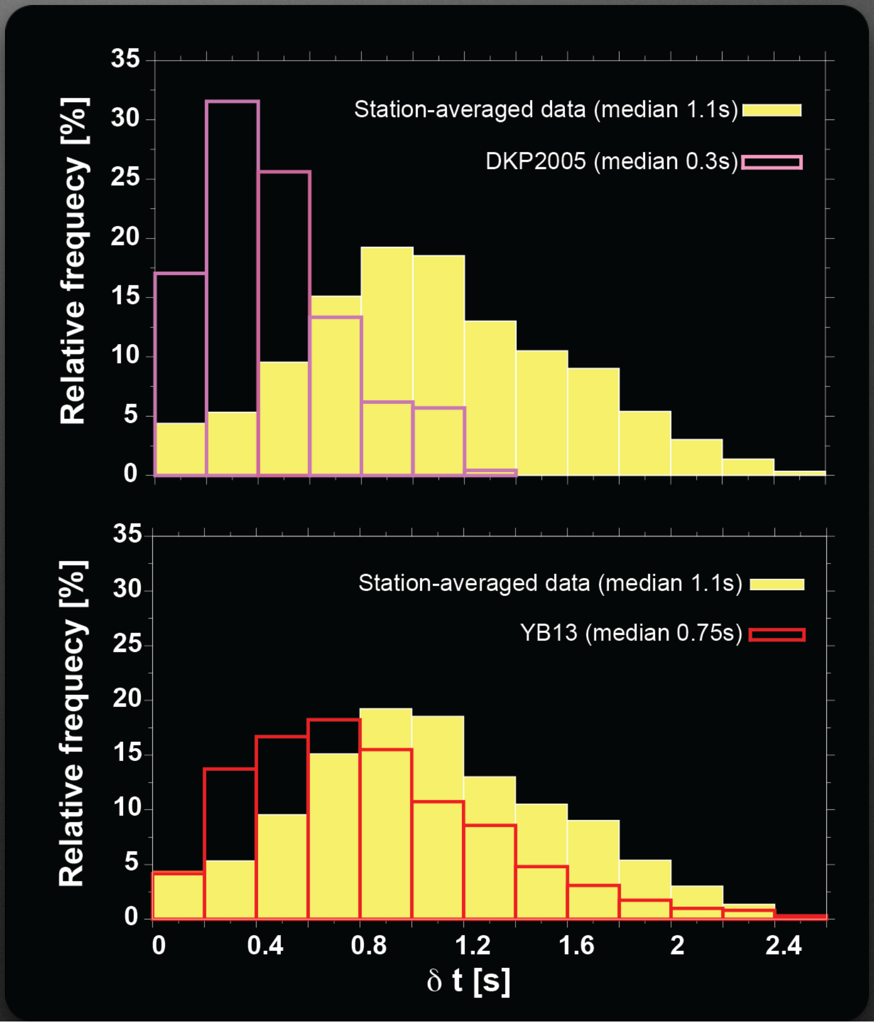
# SKS Splitting Amplitudes

- Long-standing issue:

  SKS predictions based on surface wave models of azimuthal anisotropy underestimate delay times (Becker et al., 2012)

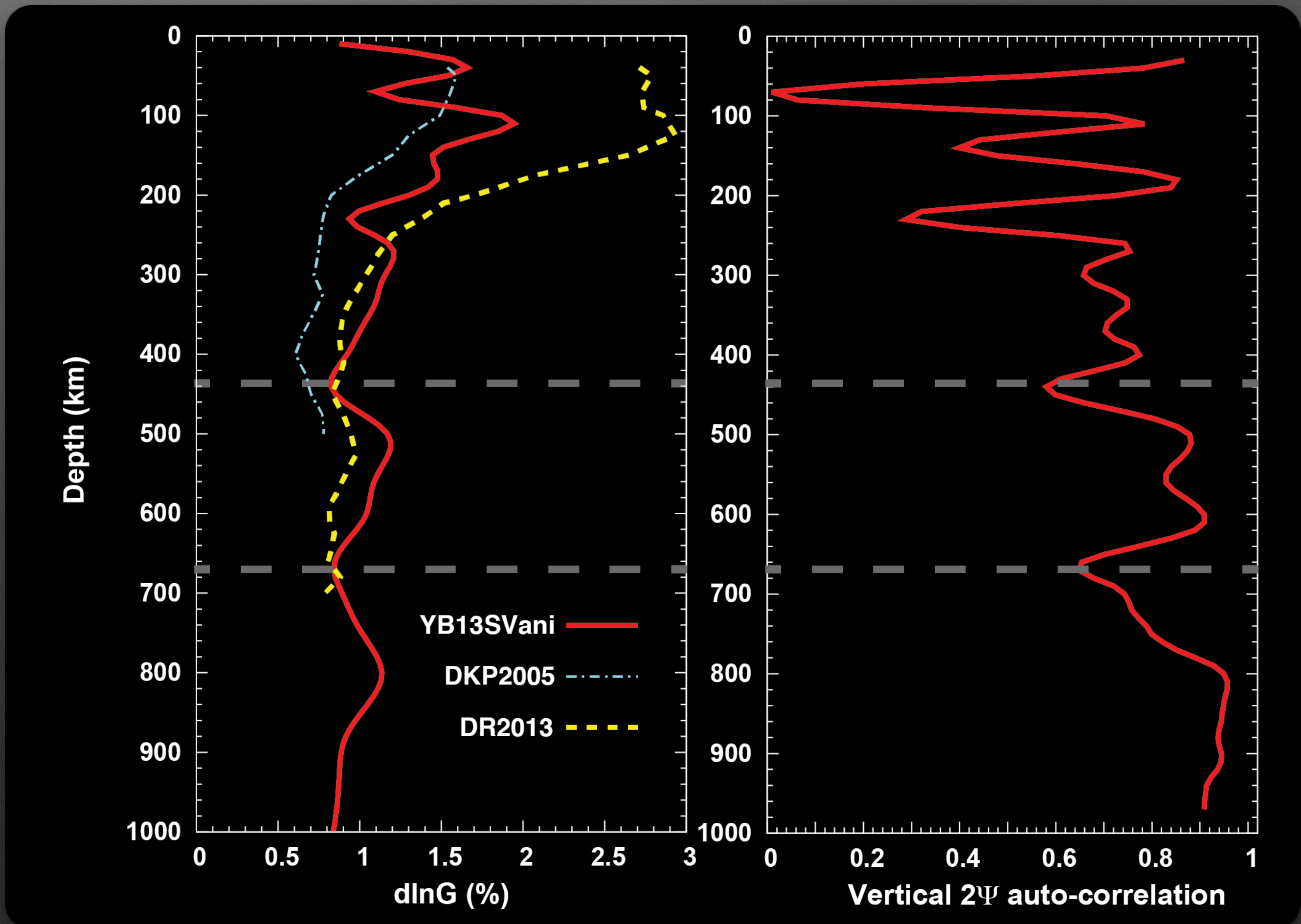
- Our model greatly improves delay time predictions

Yuan & Beghein (2013)



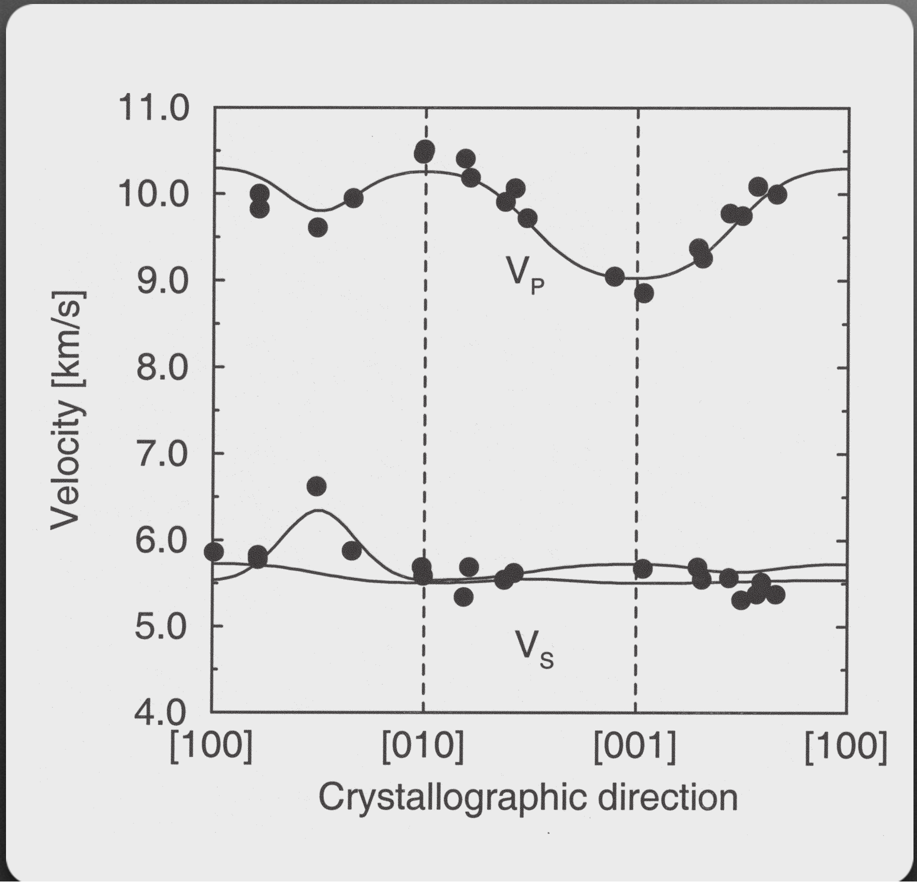
# SV Anisotropy on Average

- ~2% anisotropy at 100km depth - compatible with olivine LPO
- 1% anisotropy between 200 km and 900 km depth
- Changes in fast axes and amplitude minima coincide with transition zone boundaries!
- Also change in fast axes at ~520 km

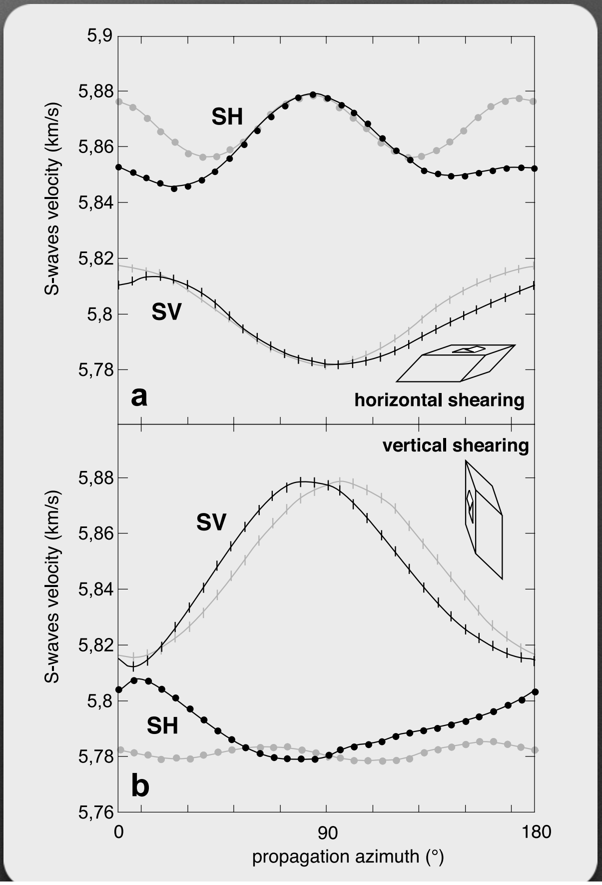



Yuan & Beghein (2013)

# Origin of MTZ Anisotropy?
# Wadsleyite Anisotropy?



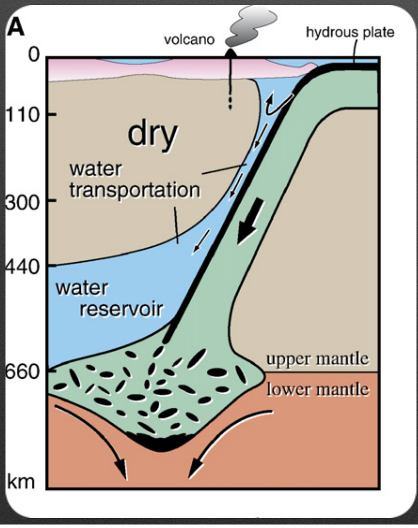

Kiefer et al. (2001)

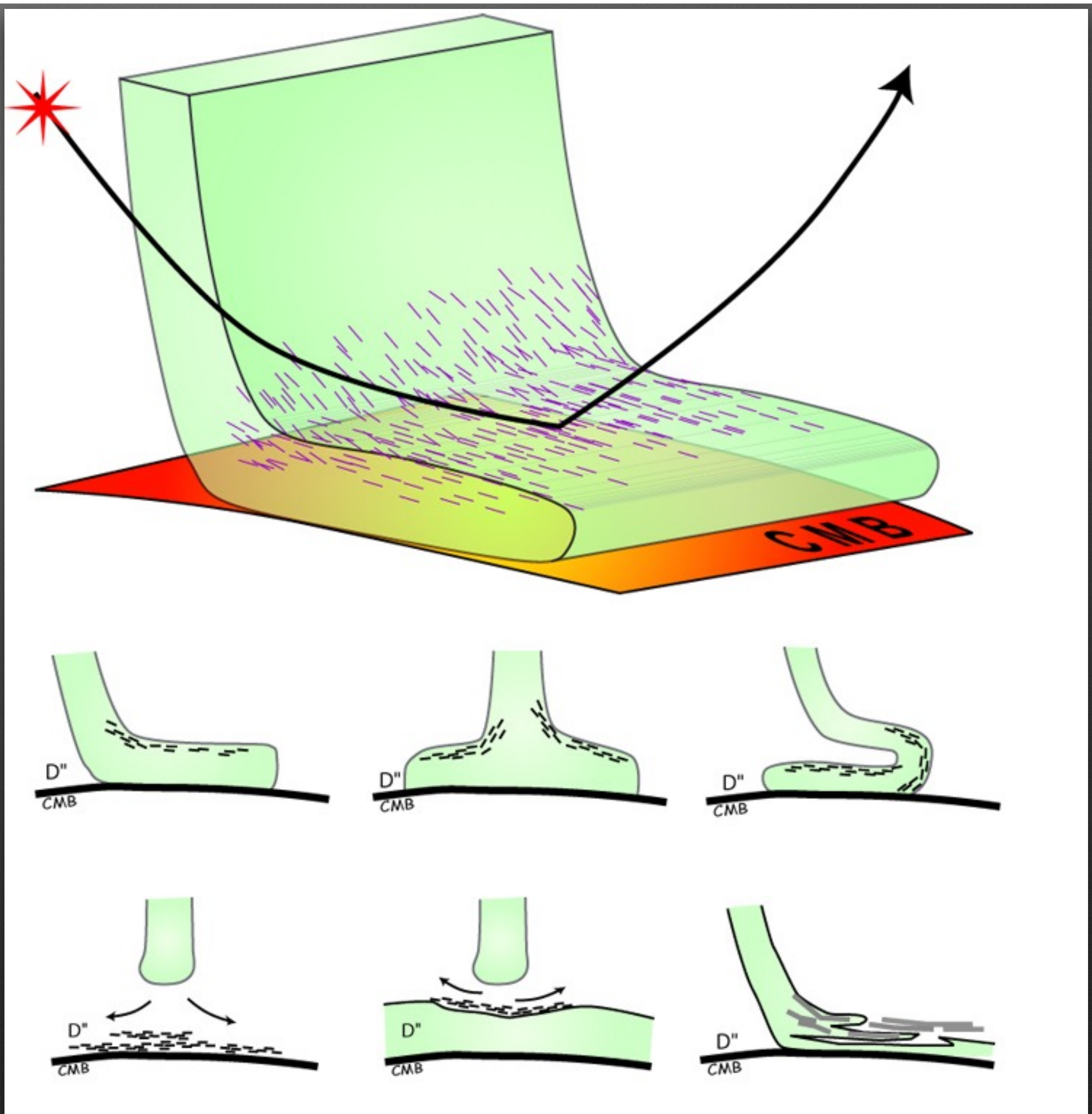



Tommasi et al. (2004)

# Origin of MTZ Anisotropy?

Similar mechanism as for slabs near CMB?




After Figure 15 (Garnero and Lay, 2003)

# Consequences for Geodynamics

- If changes in fast seismic axes  reflect flow direction at all depths ⇒Change in shear direction?
- Recrystallization during phase transition could induce or erase anisotropy signal at transition boundaries?
- Change in slip system due to effect of pressure, melt, or water?

# Conclusions

- Strong (2-3% on average) azimuthal anisotropy in upper 200 km and 1% seismic anisotropy in the MTZ
- MTZ boundaries associated with changes in azimuthal anisotropy in addition to velocity discontinuities
- What does it mean? This needs to be investigated further by mineral physicists and geodynamicists, and we need more MTZ studies including anisotropy by seismologists