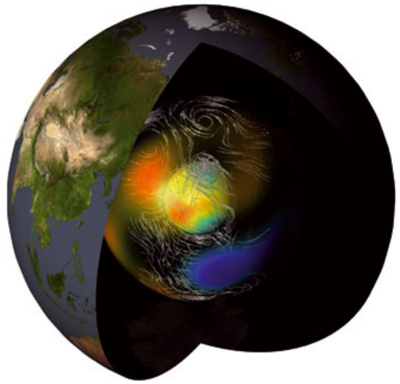
Is the inner core really translating?

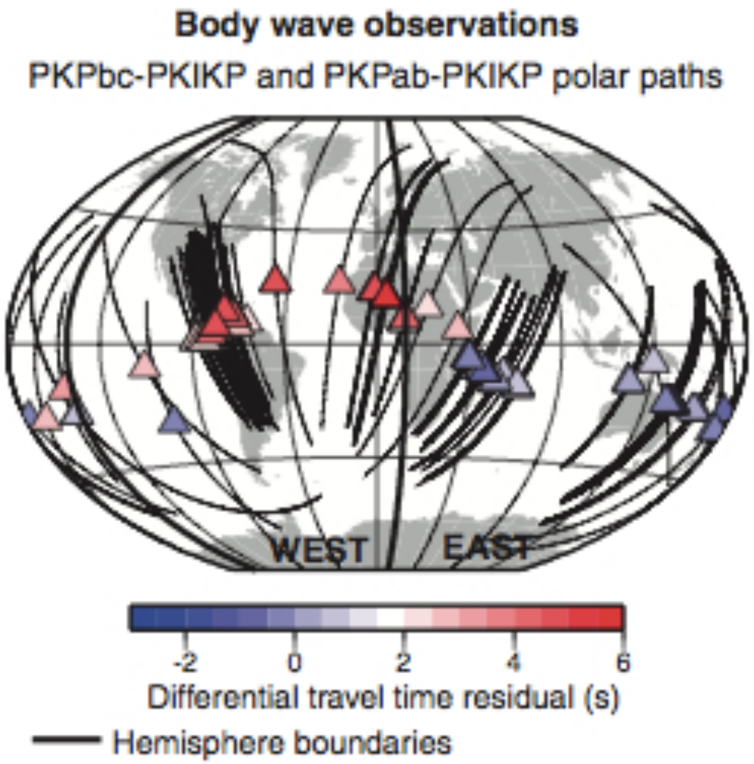


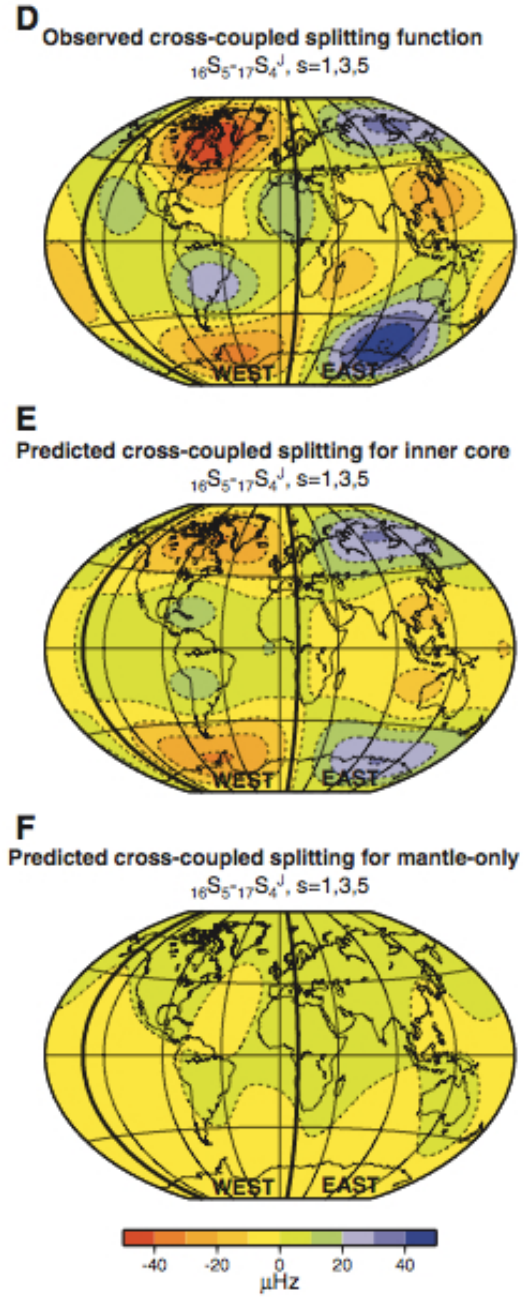
Vernon Cormier, Lizzie Day, Zach Geballe, Marine Lasbleis, Mohammad Youssof, Han Yue

“Deep time” & the “old fashioned” inner core

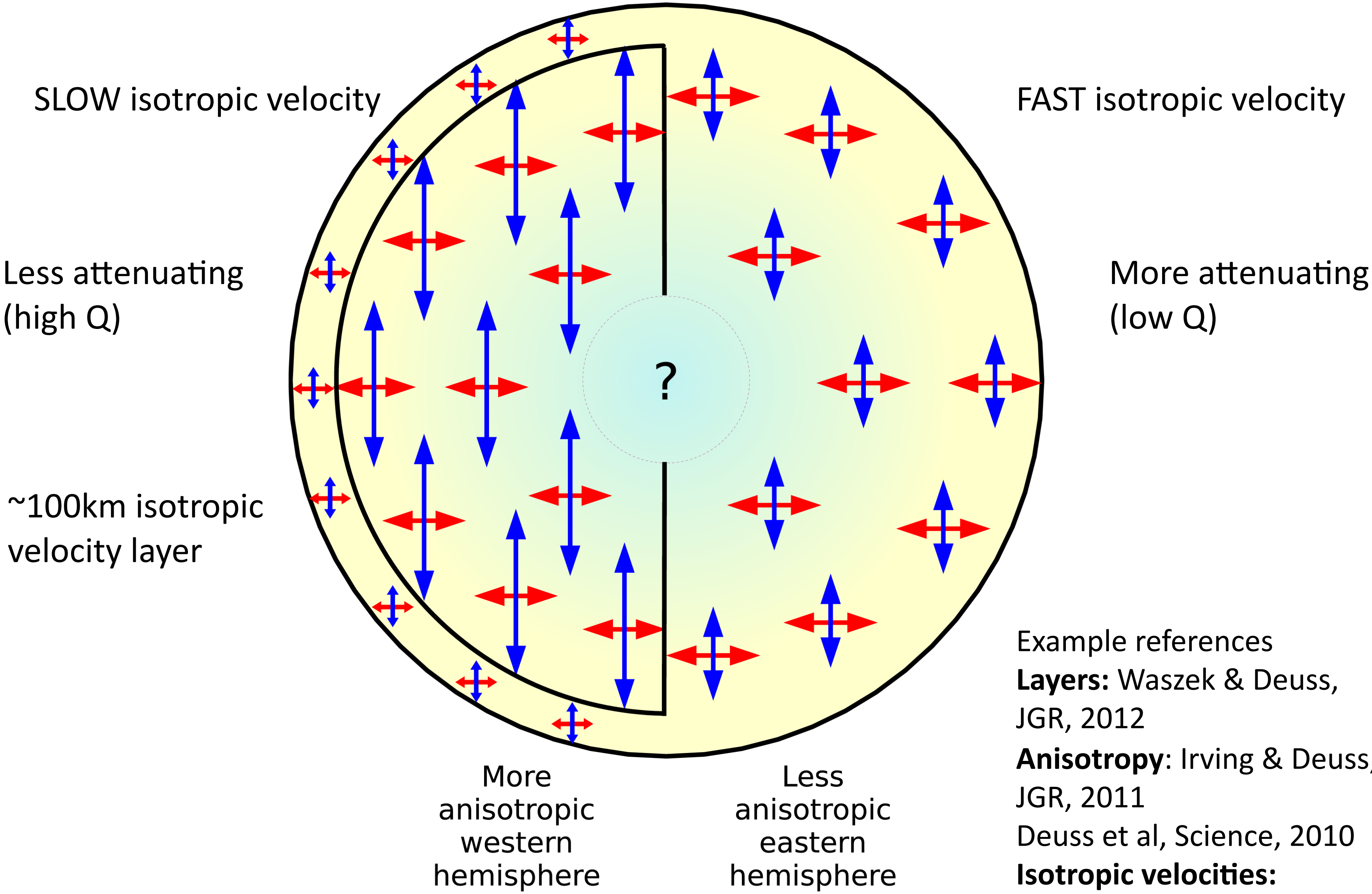
Velocity hemispheres

- Body waves
- Normal modes





Deuss, Irving & Woodhouse, Science, 2010

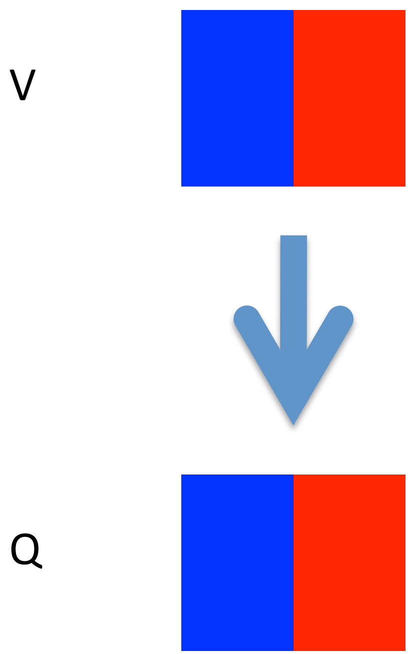


Modified from Jessica Irving, personal communication

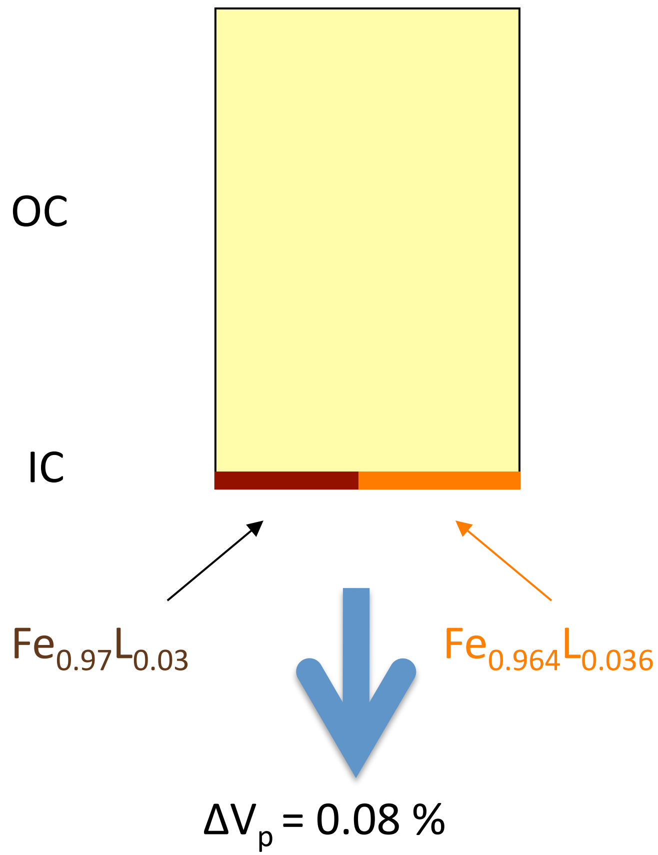
Example references
Layers: Waszek & Deuss, JGR, 2012
Anisotropy: Irving & Deuss, JGR, 2011
Deuss et al, Science, 2010
Isotropic velocities:
Waszek et al, NatGeo, 2011
Innermost inner core:
Li & Cormier, 2002

Possible sources of hemispherical differences?

Not Temperature:



Not [Light element]:



Geodynamics to the rescue!

Monnereau et al, Science, 2010

Lopsided Growth of Earth's Inner Core

Marc Monnereau,[1*] Marie Calvet,[1] Ludovic Margerin,[2] Annie Souriau[1]

Hemispherical asymmetry is a prominent feature of Earth's inner core, but how this asymmetry relates to core growth is unknown. Based on multiple-scattering modeling of seismic velocity and attenuation measurements sampling the whole uppermost inner core, we propose that the growth of the solid core implies an eastward drift of the material, driven by crystallization in the Western Hemisphere and melting in the Eastern Hemisphere. This self-sustained translational motion generates an asymmetric distribution of sizes of iron crystals, which grow during their translation. The invoked dynamical process is still active today, which supports the idea of a young inner core.

The inner core of Earth is one of the most enigmatic parts of our planet. This solid body at the center of Earth, with a radius of 1220 km, grows from the crystallization of the iron in the liquid outer core at a present rate of about 0.5 mm/year, a process that has been occurring for around 1 billion years (*1*). The structure of the inner core is mostly known from the propagation of seismic waves and from the normal modes that are excited after large earthquakes (*2*, *3*). The inner core is anisotropic, with faster propagation and stronger attenuation for seismic paths parallel to Earth's rotation axis than for paths parallel to the equatorial plane. However, the uppermost 100 km are nearly isotropic and strongly attenuating, with lower seismic *P*-wave velocity and attenuation in the Western Hemisphere than in the Eastern Hemisphere.

Previous studies report hemispherical anomalies for seismic *P* waves propagating through the uppermost isotropic inner core (called PKIKP waves), but these anomalies exhibit notable differences in their amplitude and spatial distribution (*4*–*7*). To resolve some of these in-

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LETTERS

Melting-induced stratification above the Earth's inner core due to convective translation

Thierry Alboussière[1,2], Renaud Deguen[1,3] & Mickaël Melzani[1]

In addition to its global North–South anisotropy[1], there are two other enigmatic seismological observations related to the Earth's inner core: asymmetry between its eastern and western hemispheres[2–6] and the presence of a layer of reduced seismic velocity at the base of the outer core[6–12]. This 250-km-thick layer has been interpreted as a stably stratified region of reduced composition in light elements[13]. Here we show that this layer can be generated by simultaneous crystallization and melting at the surface of the inner core, and that a translational mode of thermal convection in the inner core can produce enough melting and crystallization on each hemisphere respectively for the dense layer

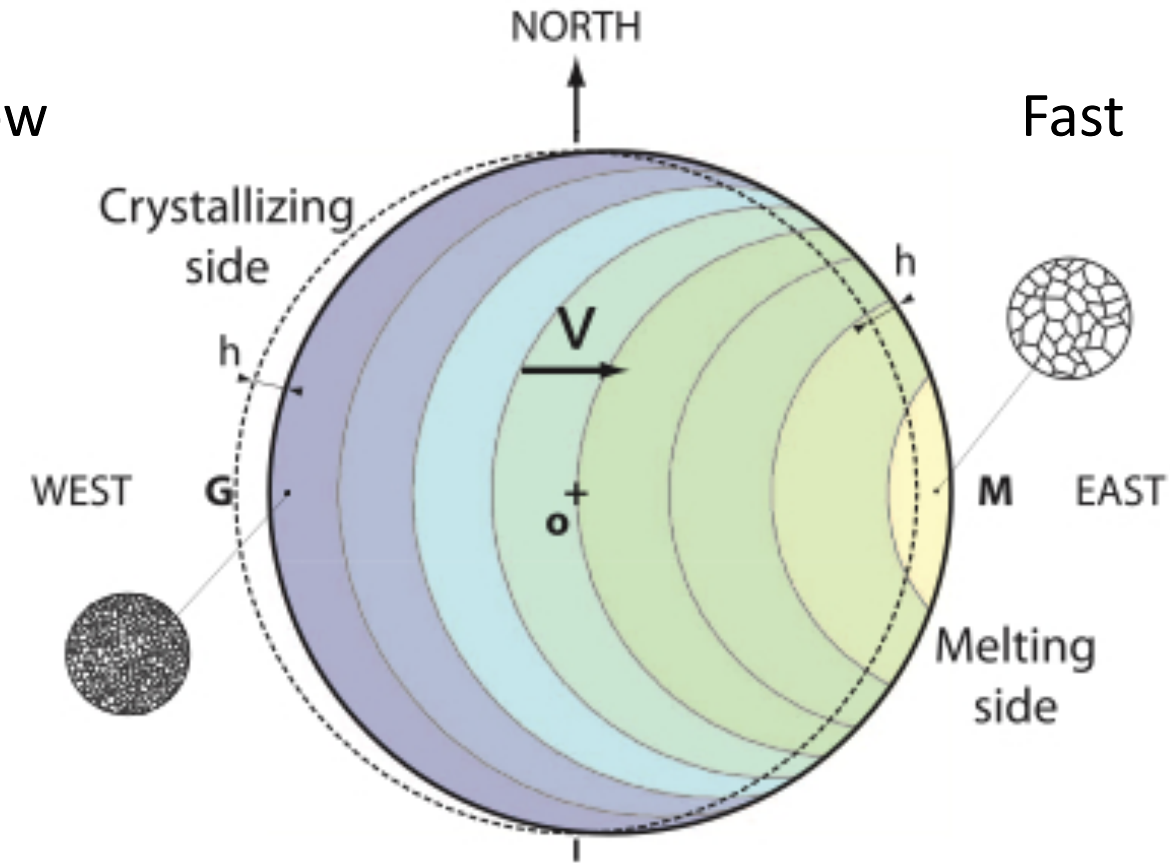
The experiments consist of simultaneously injecting constant fluxes of light and dense fluids at the bottom of a fluid cavity. The cavity is a box of perspex 20 cm high and with a 15 cm × 15 cm horizontal cross-section. It is initially filled with salted water (initial concentration χ_0, in wt% NaCl). At the bottom of the cavity, there is a porous layer (sponge) below which the cross-section is divided into two disconnected parts: on one side light fluid is injected ($\chi_l < \chi_0$) and on the other side heavy fluid is injected ($\chi_h > \chi_0$), where χ_l and χ_h are the salt concentrations of the light and heavy fluids in wt% NaCl. Both density differences $\chi_0 - \chi_l$ and $\chi_h - \chi_0$ and both flow rates are controlled and set to be constant during the experiment. The injec-

Alboussiere et al, Nature, 2010

Translation

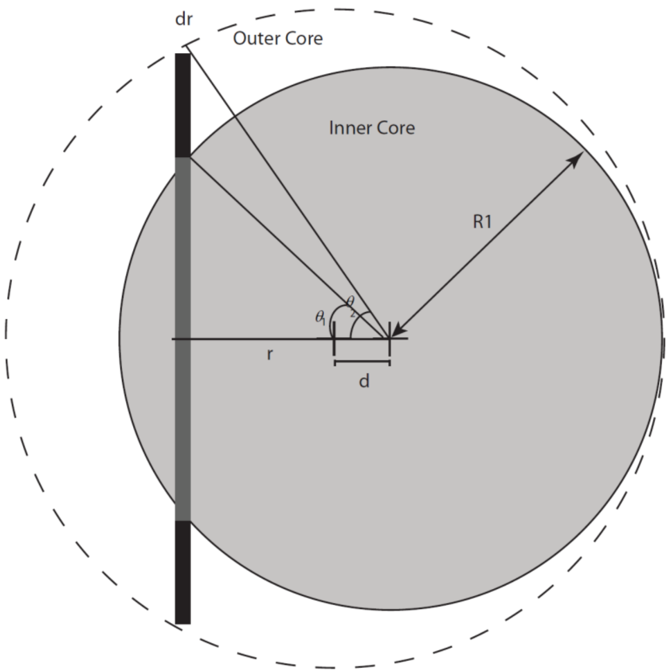
Slow

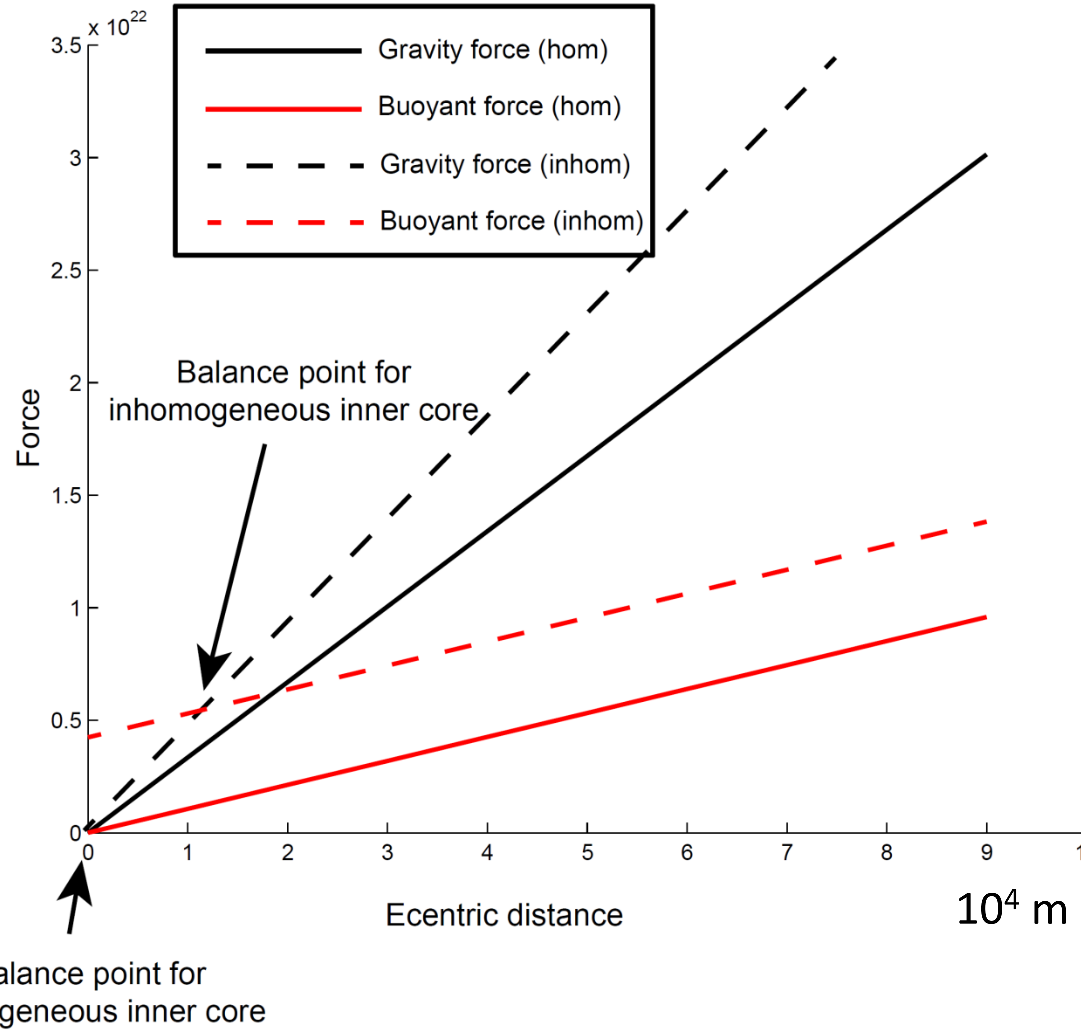
Fast



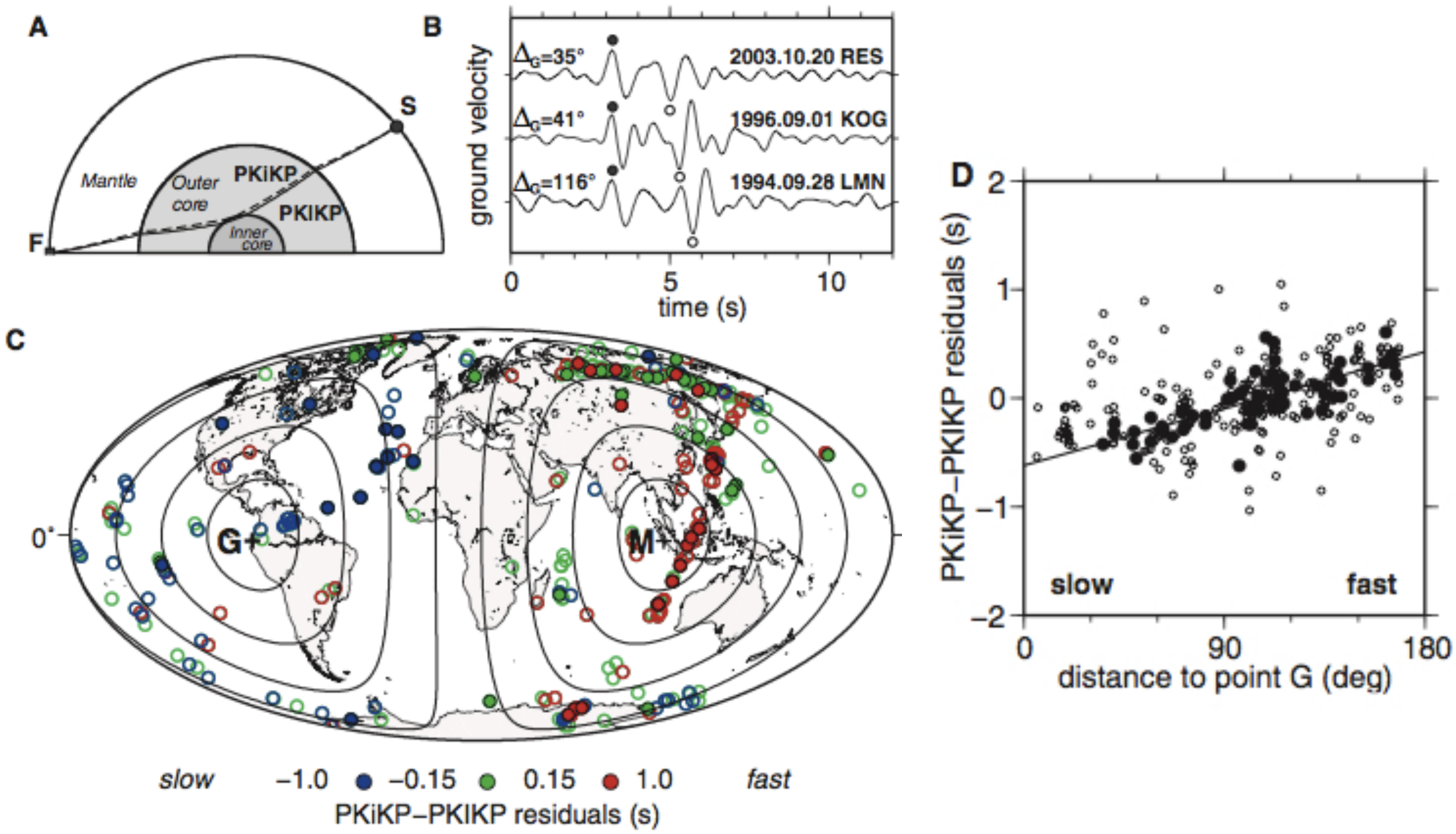
Monnereau et al, Science, 2010

Force balance of the inner core



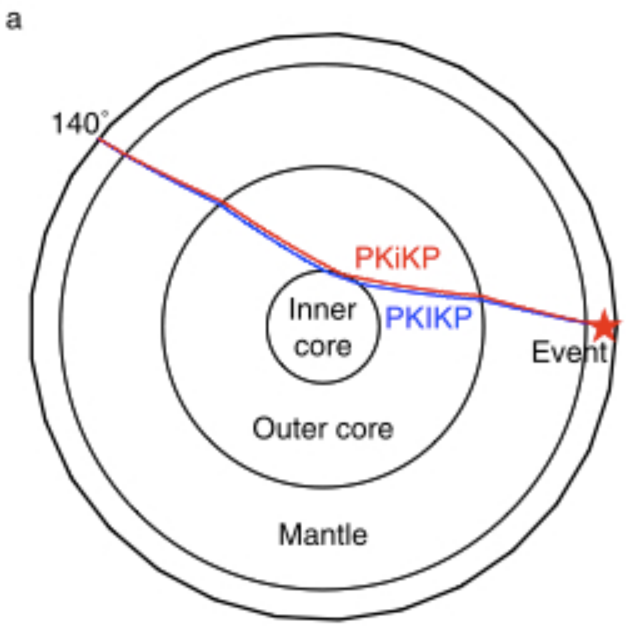


Translation model fits PKiKP-PKIKP differential travel times in Monnereau et al, 2010



Monnereau et al, Science, 2010

But the boundaries are sharp…?



Waszek & Deuss, JGR, 2012

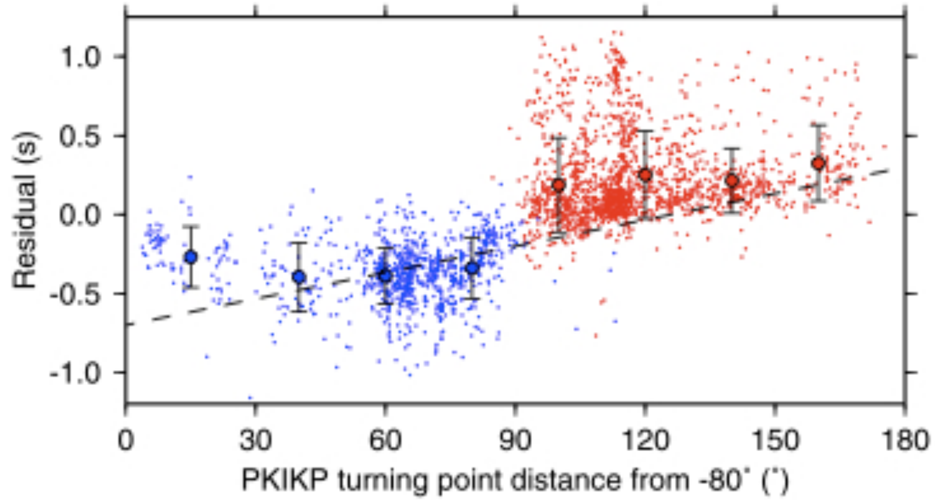
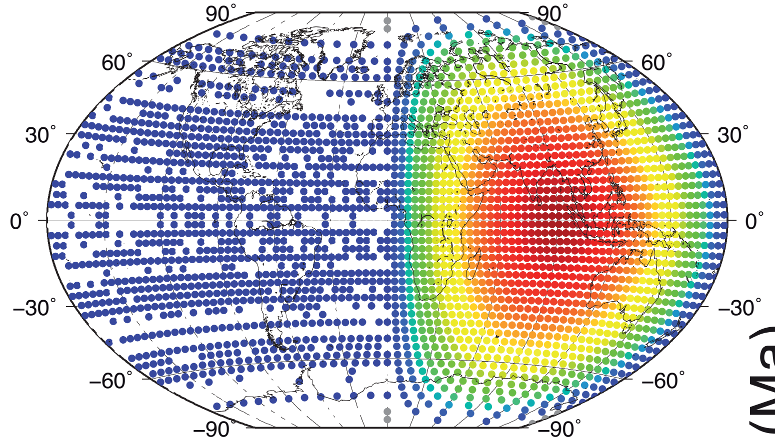


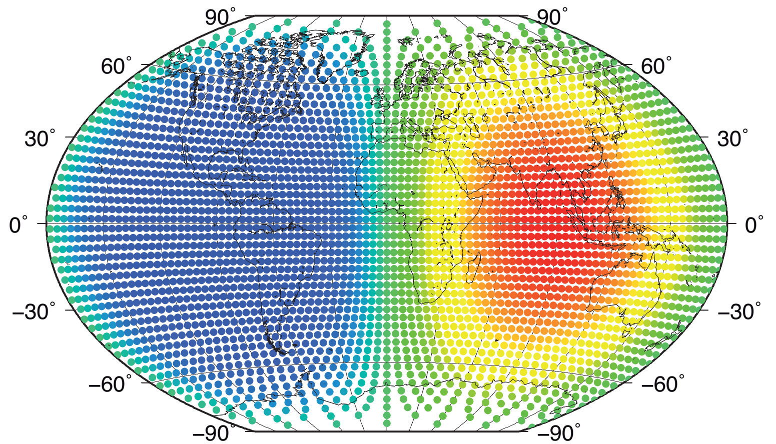
Figure 9. PKIKP-PKiKP residuals as a function of the distance between PKIKP turning point and the center of the west hemisphere (0°N, 80°W from *Monnereau et al.* [2010]). Data for the eastern hemisphere are shown in red, west are in blue; data in both hemispheres are binned (large circles). The positive correlation between travel time residual and distance from the center of the western hemisphere, taken from *Monnereau et al.* [2010], is indicated with a dashed line. Our data does not display this relationship.

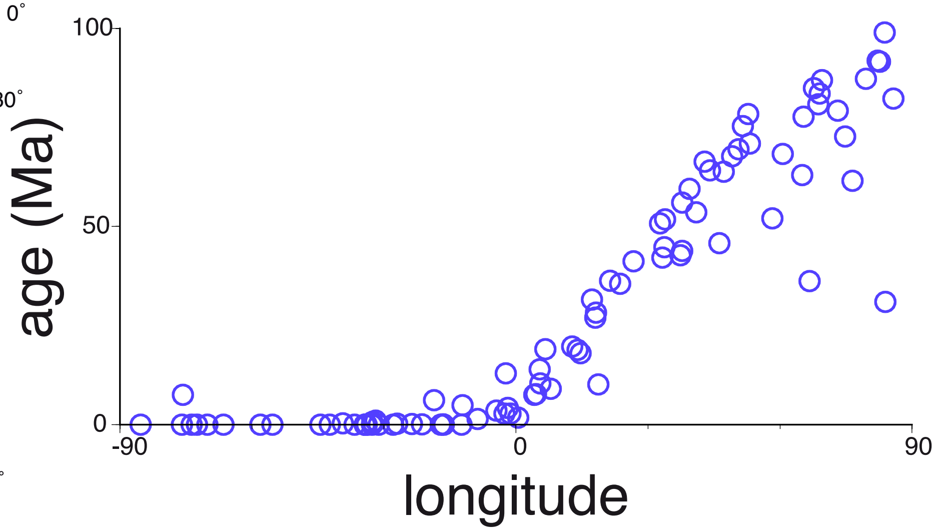
Age of the translating inner core

Depth= 0 km



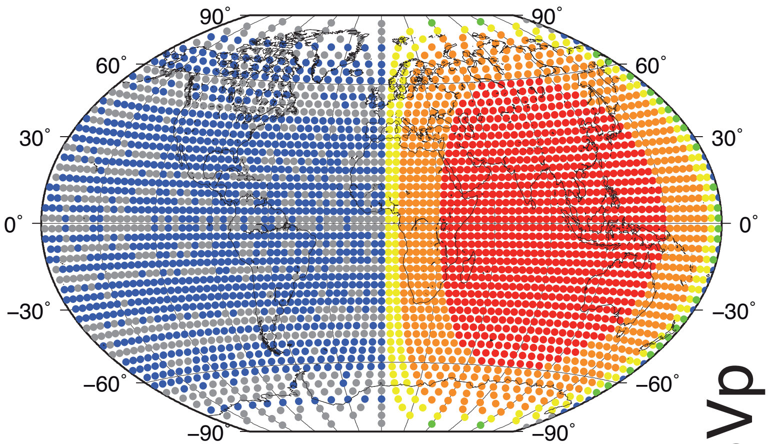
Depth= 245 km



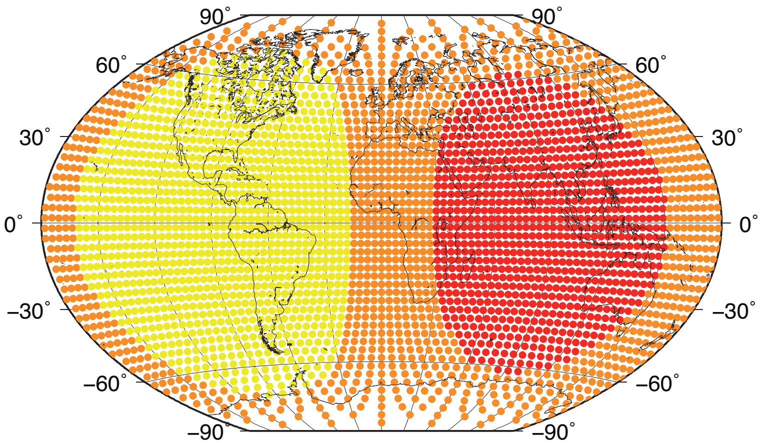


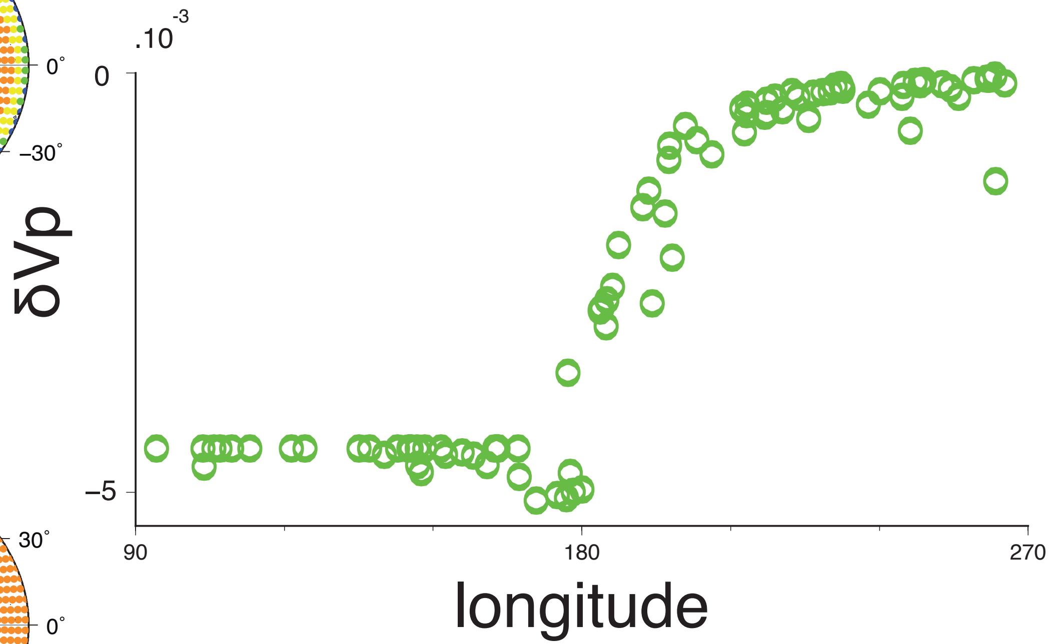
Vp in the translating inner core

Depth= 0 km



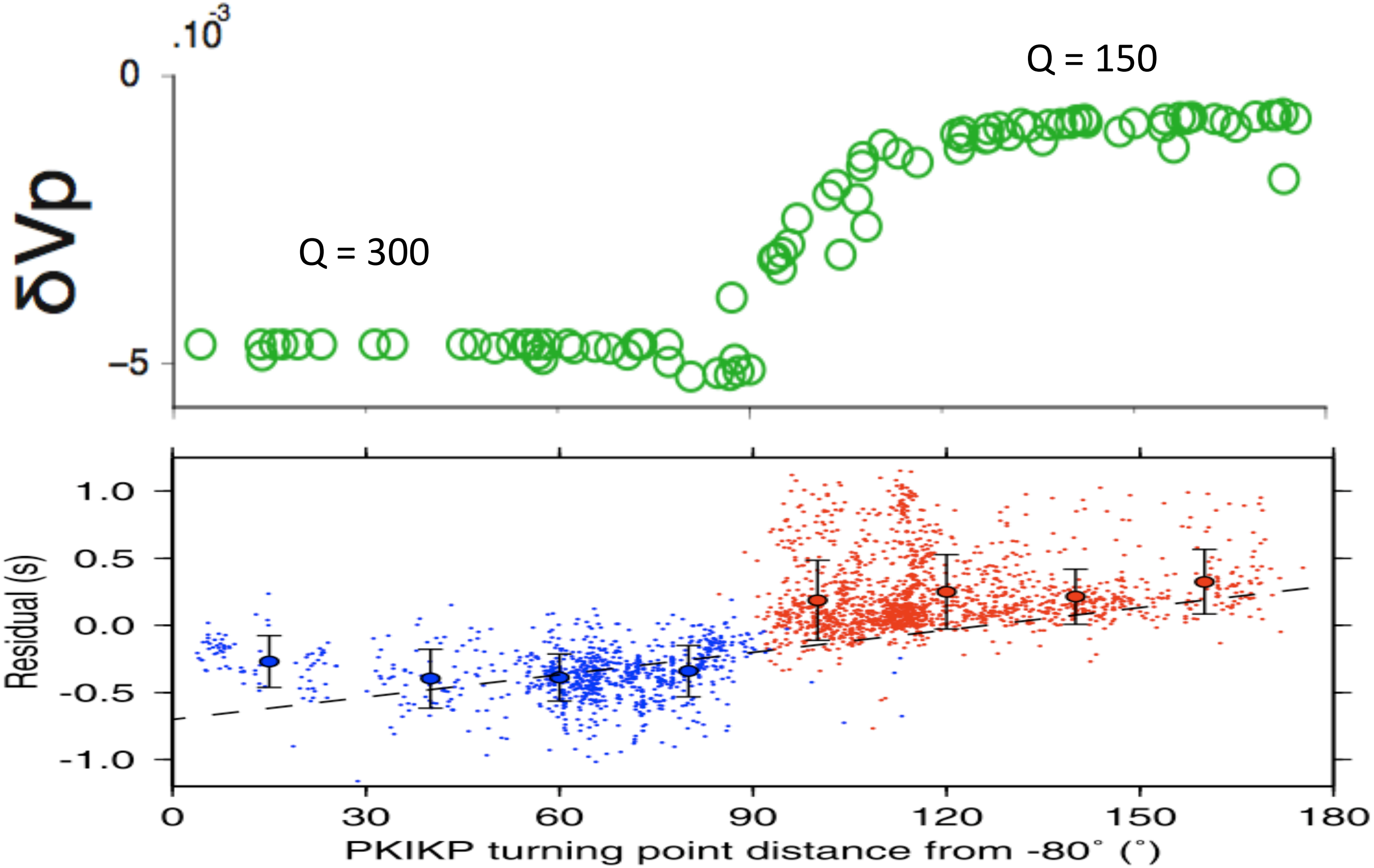
Depth= 245 km





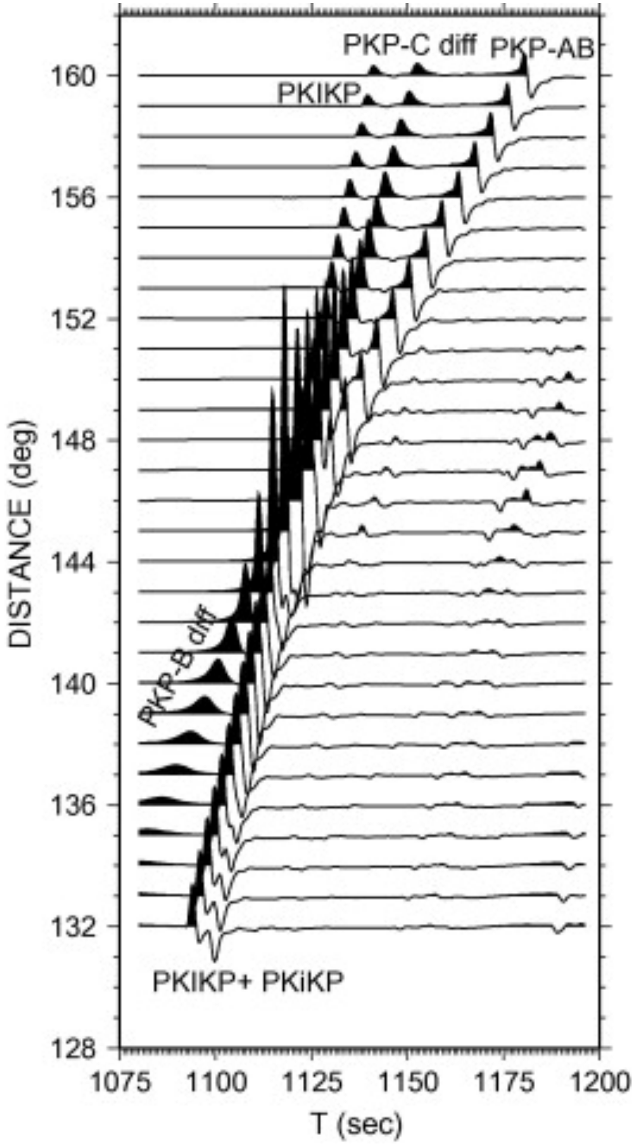
Patch size related to Vp via the Calvet & Margerin, 2008

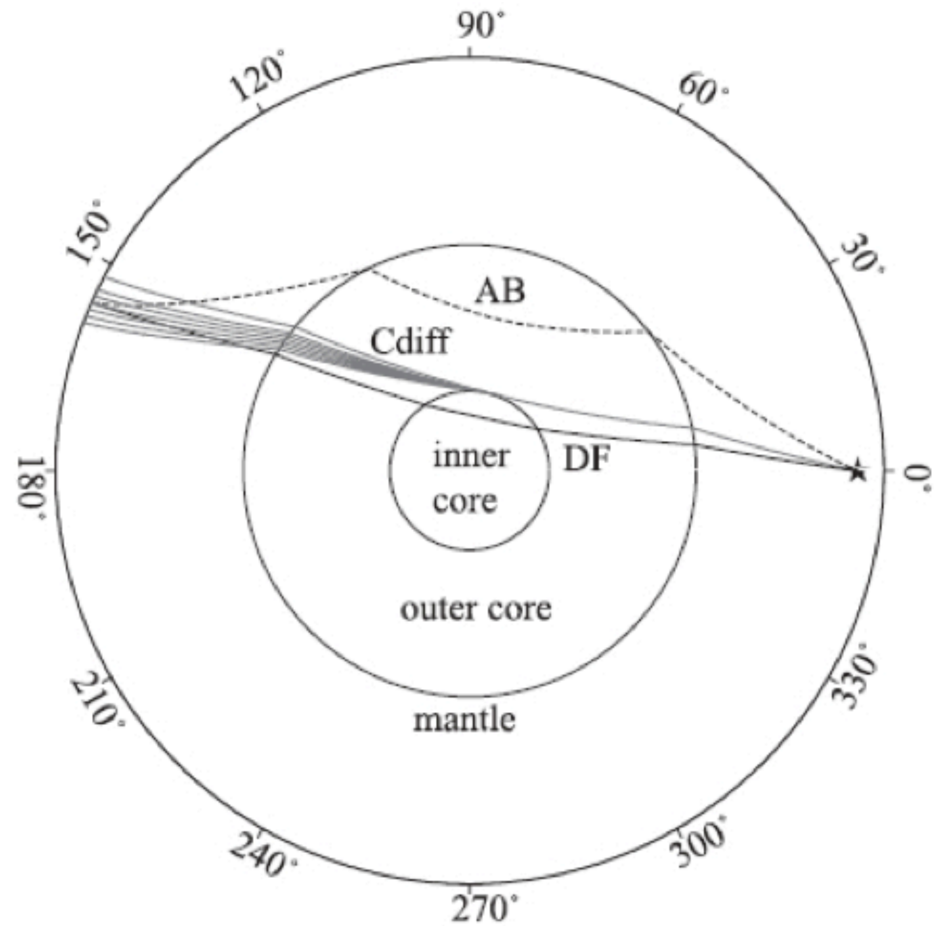
Sharp boundaries seem OK!



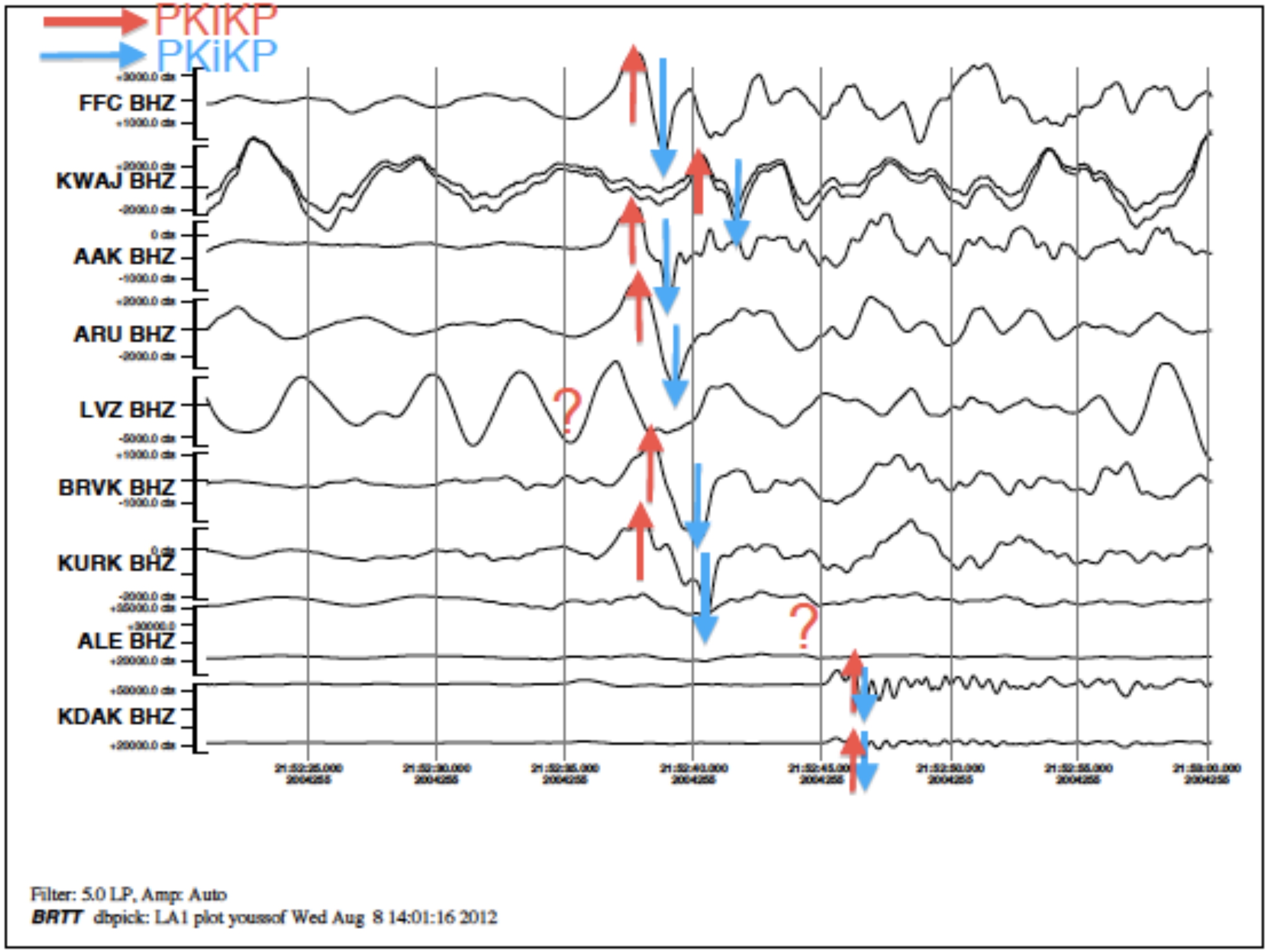
Seismic data figure from Waszek & Deuss, JGR, 2012

Examining the inner core boundary





Real data – PKiKP & PKIKP



Further work

- Look at melting and freezing regions with PKP-Cdiff
- Build a differential travel time data set that samples a range of depths and locations in the inner core (PKiKP-PKIKP, P’P’bc-P’P’df, PKP-PKIKP)
- Consider attenuation, dispersion, scatter and anisotropy in more detail.
- Worry more about the innermost inner core.

Conclusions

- Sharp hemisphere boundaries seem to be relatively compatible with translation
- For a simple model of grain size evolution over time we can produce shallow hemispheres with appropriate V_P and $Q_{P.}$
- This may be compatible with anisotropy in the younger hemisphere.

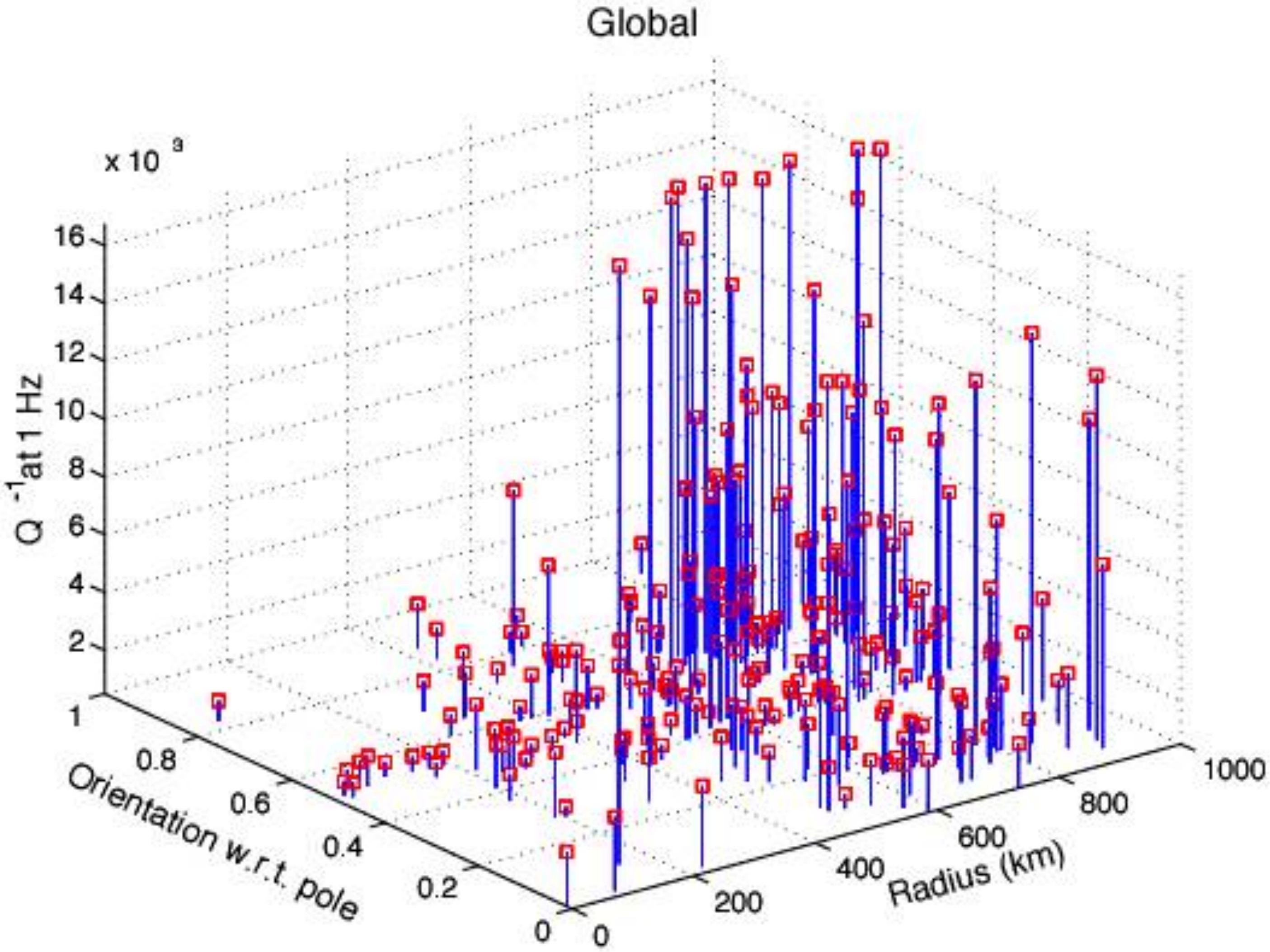
1475276	Ainhoa Lincot	Seismic anisotropy of the inner core deduced from geodynamical and mineralogical models
1476996	Rachel A Miller	Phonon Density of States and Sound Velocities of an Iron-Nickel Alloy at High Pressure
1477087	Januka Attanayake	Seismic Structure and Geodynamics of Earth's Upper Inner Core and the F Region
1478279	Marine Lasbleis	Growth of the inner core by snowfall
1479700	Elizabeth A Day	Investigating the translation of Earth's inner core
1481679	Zhicheng Jing	In-situ Ultrasonic Sound Velocity Measurements of Fe and Fe-Light Element Alloying Liquids at High Pressures with Implications to Planetary Cores
1482004	Tae-Gyu Yee	Regional variation of P-wave velocity in the uppermost inner core
1482413	Marc Monnereau	Translation and convection of Earth's inner core

Come and see us at AGU!

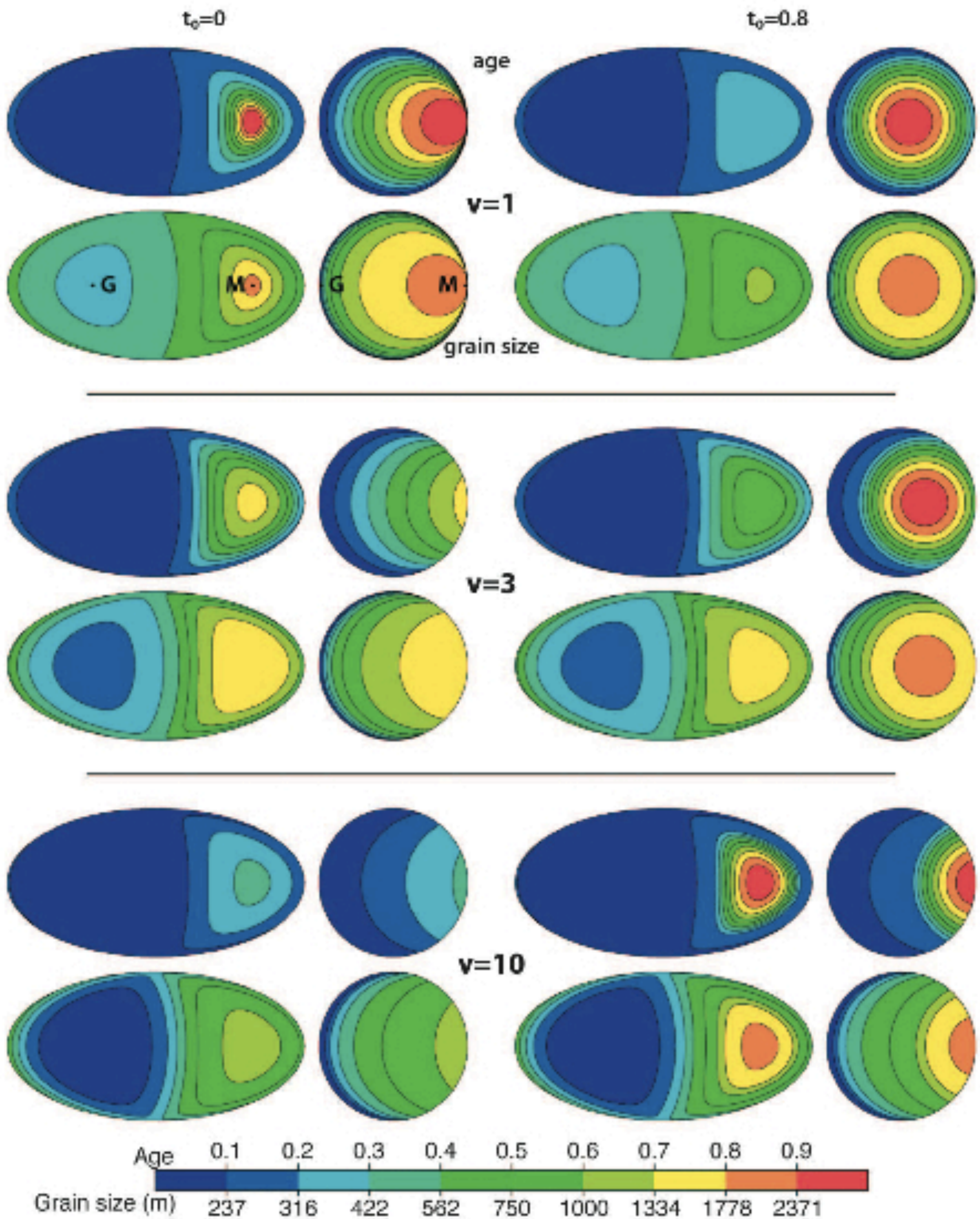
"Investigating the translation of Earth's inner core"

DI013: The Earth's Complex Core: Bridging our Understanding from Seismology to Mineral Physics and Beyond

Q inversion with a scattering model: Note signature of inner inner core at radius 500-600 km



Cormier & Li, JGR, 2002



t_0=0
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age
v=1
G
M
G
M
grain size
v=3
v=10
Age
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0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Grain size (m)
237
316
422
562
750
1000
1334
1778
2371

Anisotropy