School of Earth and Environment
FACULTY OF ENVIRONMENT

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# Seismic constraints on Earth's small-scale structure

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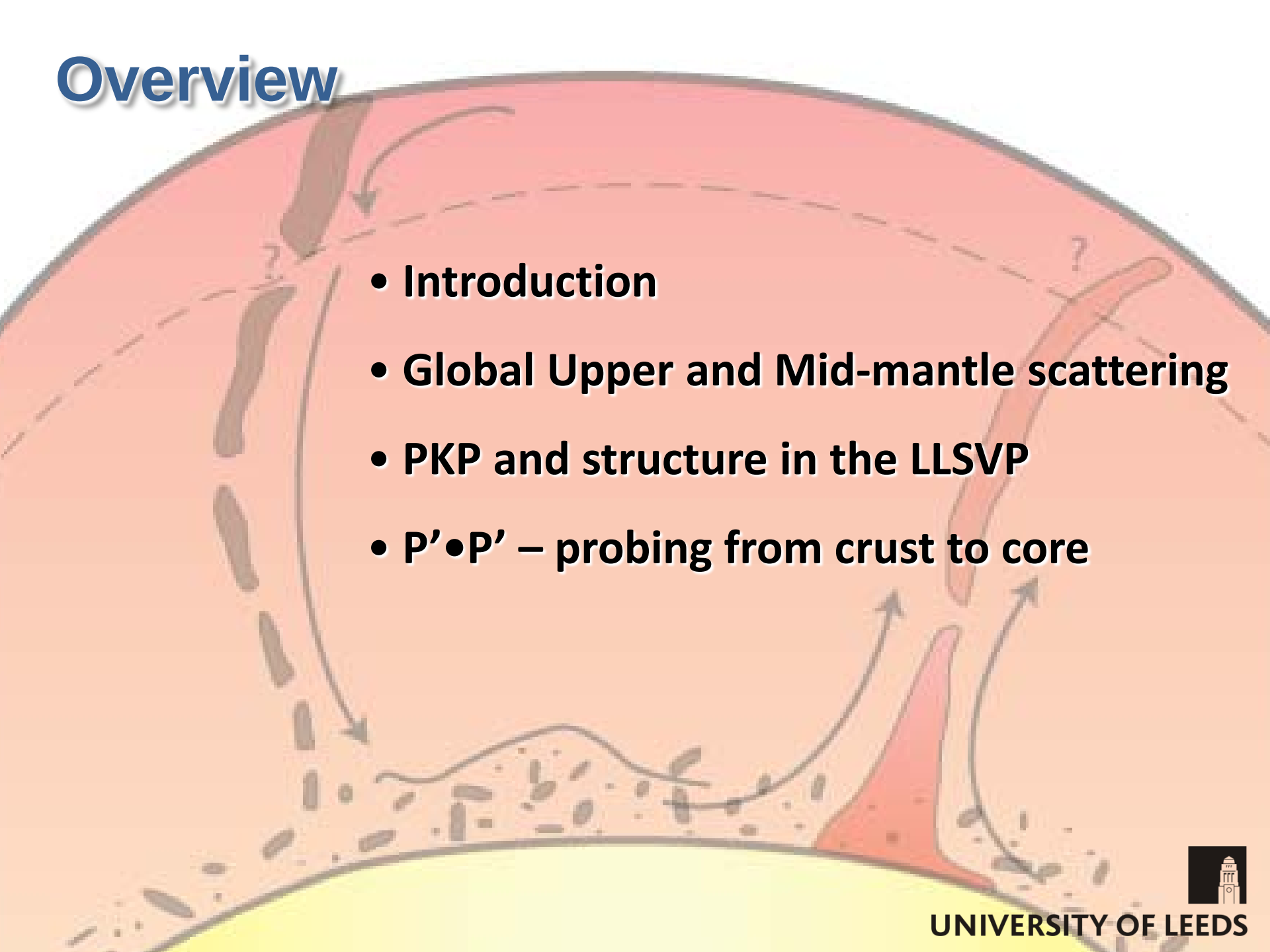
Paul S. Earle (USGS), Peter Shearer (UCSD),
Michael Thorne (Utah), Neil Selby (AWE Blacknest)

# Overview



- Introduction
- Global Upper and Mid-mantle scattering
- PKP and structure in the LLSVP
- P'•P' – probing from crust to core

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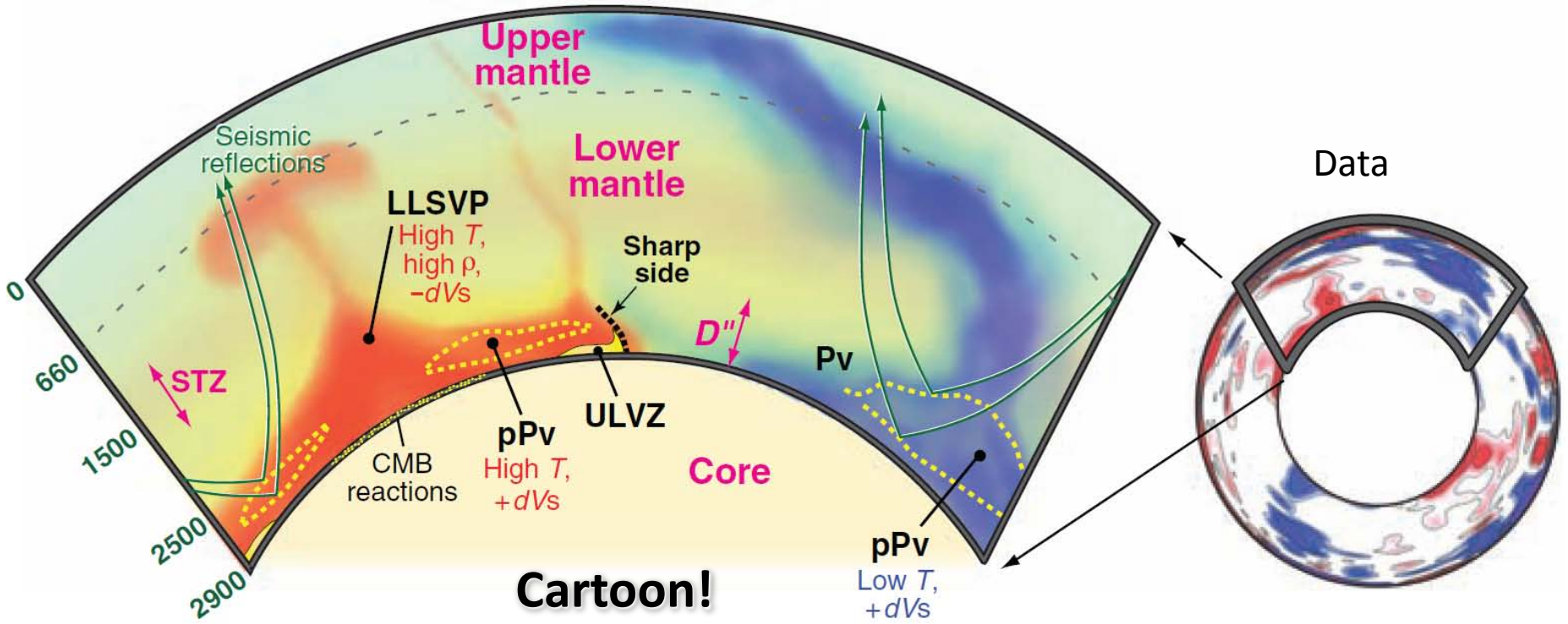
# Current Geophysical Cartoons

- Strong 3D heterogeneities on many scales
- Evidence for chemical heterogeneities
- Different behaviour of slabs and plumes in different areas
- Very small scale structure




Garnero & McNamara [2008]

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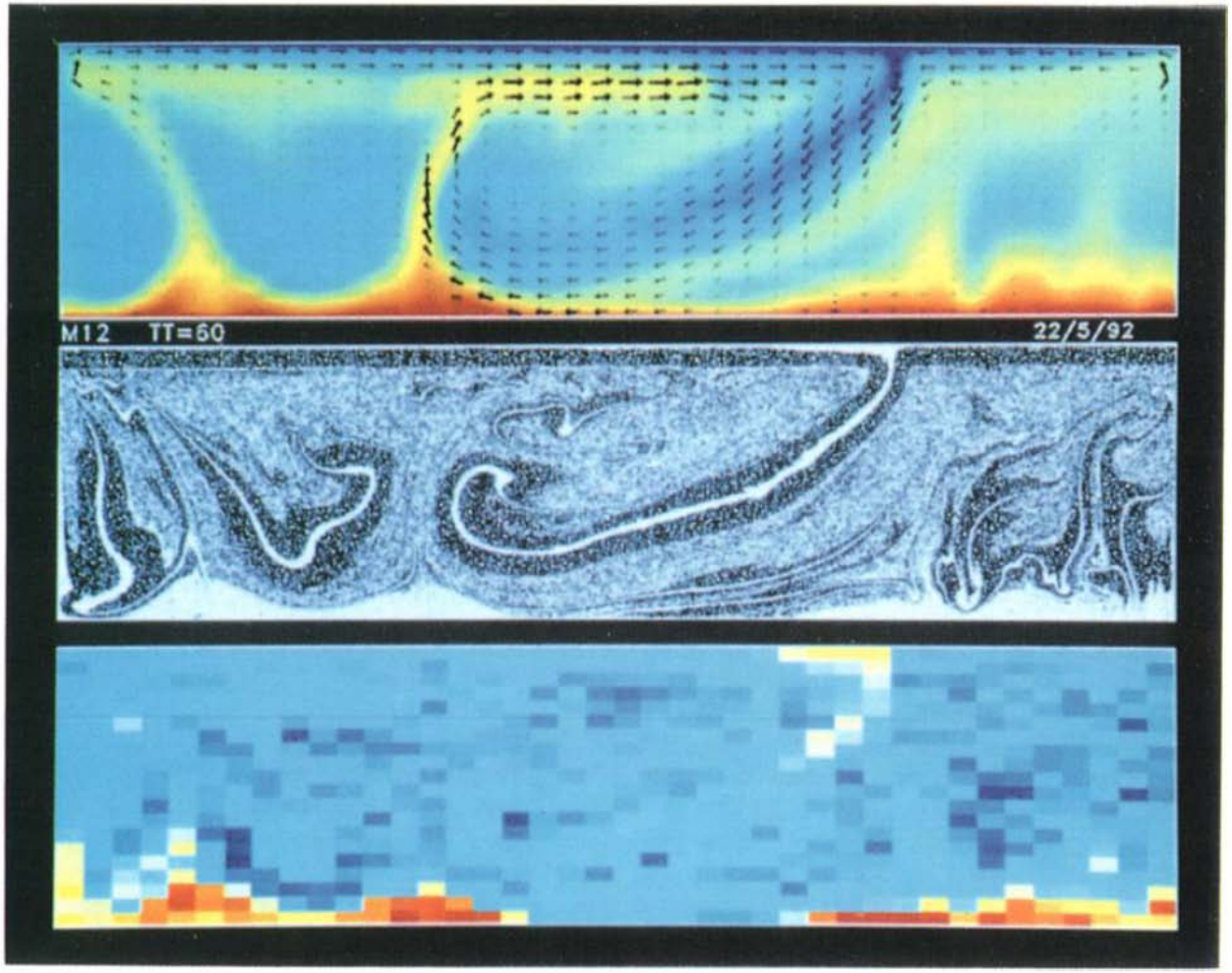
# Chemical Heterogeneities

Temp

Basalt tracer

Pb isotope ratio




- **Subduction major source for chemical heterogeneity**
- **Sedimentation of crustal material depends on density difference at the CMB**
- **Less entrainment for $\Delta\rho$ about 3%**

**[Christensen and Hofmann, 1994]**

- **Subduction – major source of chemical heterogeneity**
- **Mechanical mixing necessary to reintroduce heterogeneity into the mantle**
- **Density difference essential for dynamics of heterogeneities**
- **Details?**

ANNUAL REVIEWS
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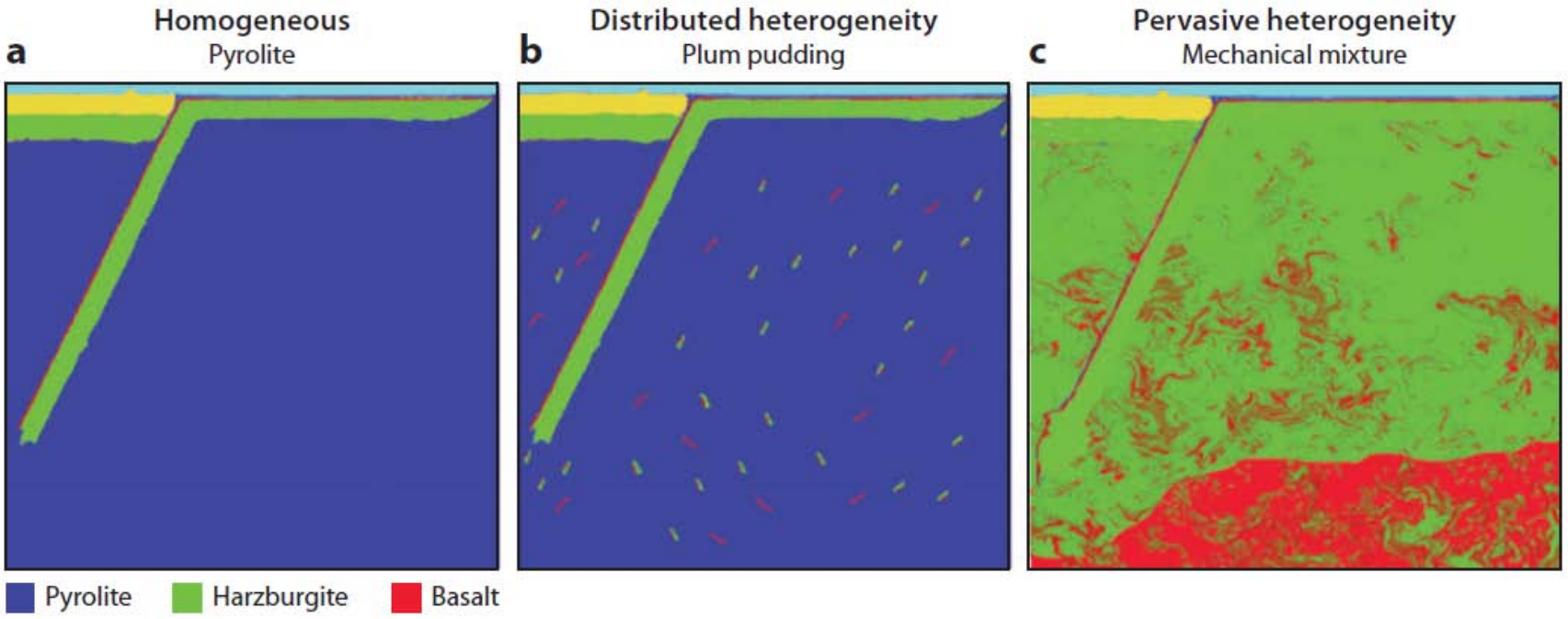
# Geophysics of Chemical Heterogeneity in the Mantle

Lars Stixrude and Carolina Lithgow-Bertelloni

Department of Earth Sciences, University College London, WC1E 6BT London, United Kingdom; email: l.stixrude@ucl.ac.uk, c.lithgow-bertelloni@ucl.ac.uk




Stixrude and Lithgow-Bertelloni, 2012

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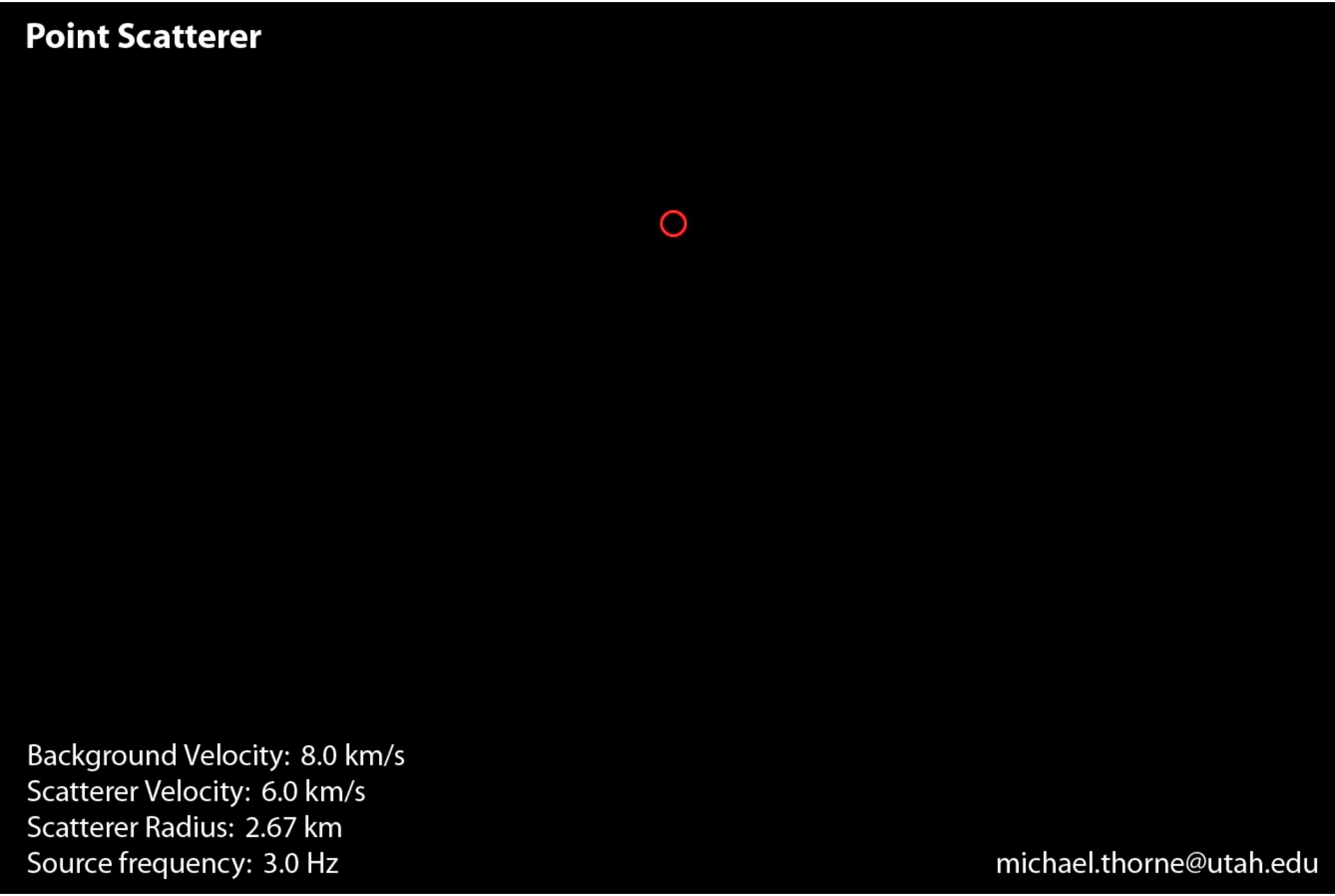
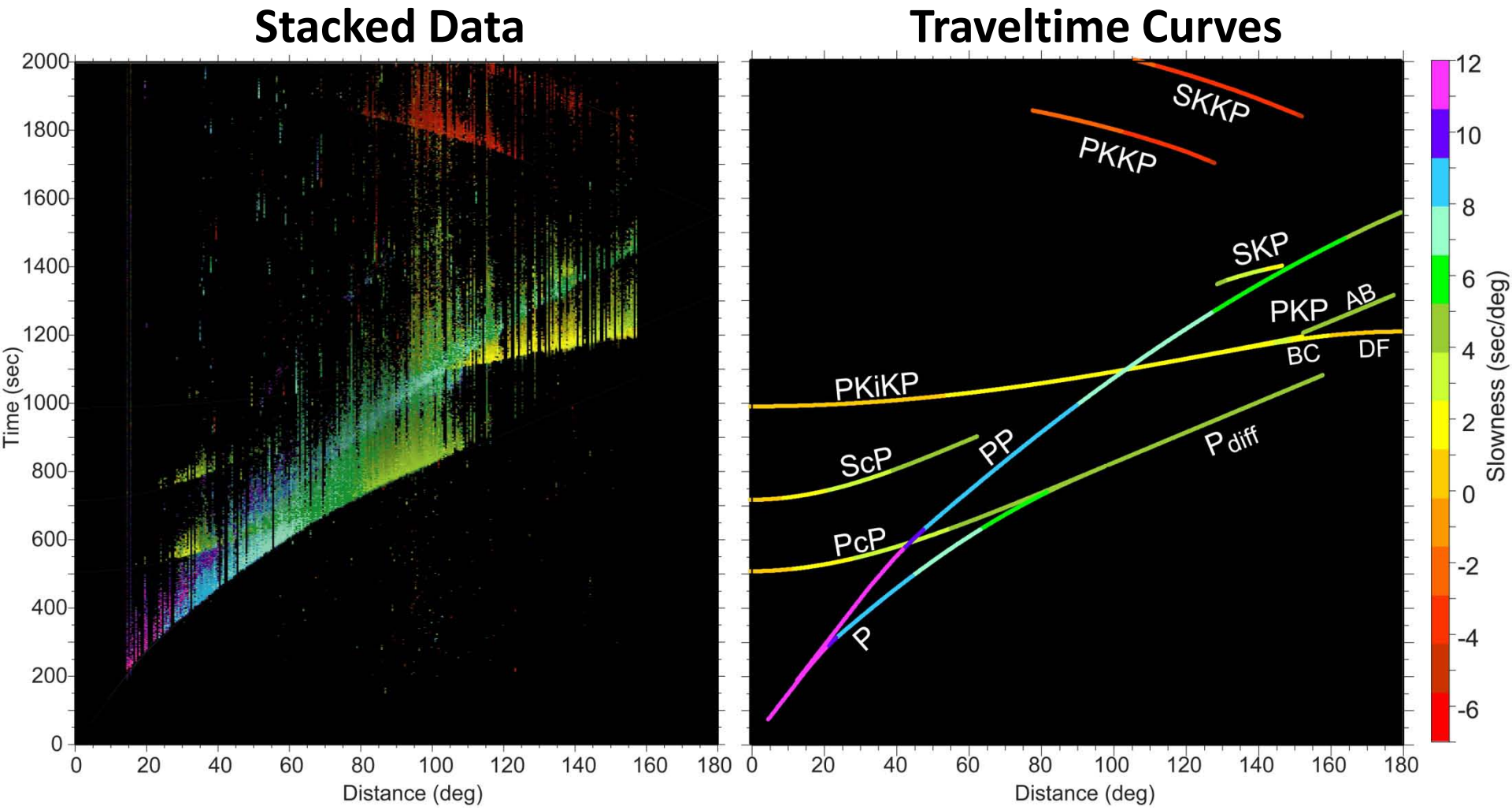
# Seismic Scattering



# Short-period seismic wavefield




- Stack of ~1200 array (YKA) recorded events
- Color = Slowness (vertical incidence angle)

Rost, Thorne, Garnero [SRL, 2005]

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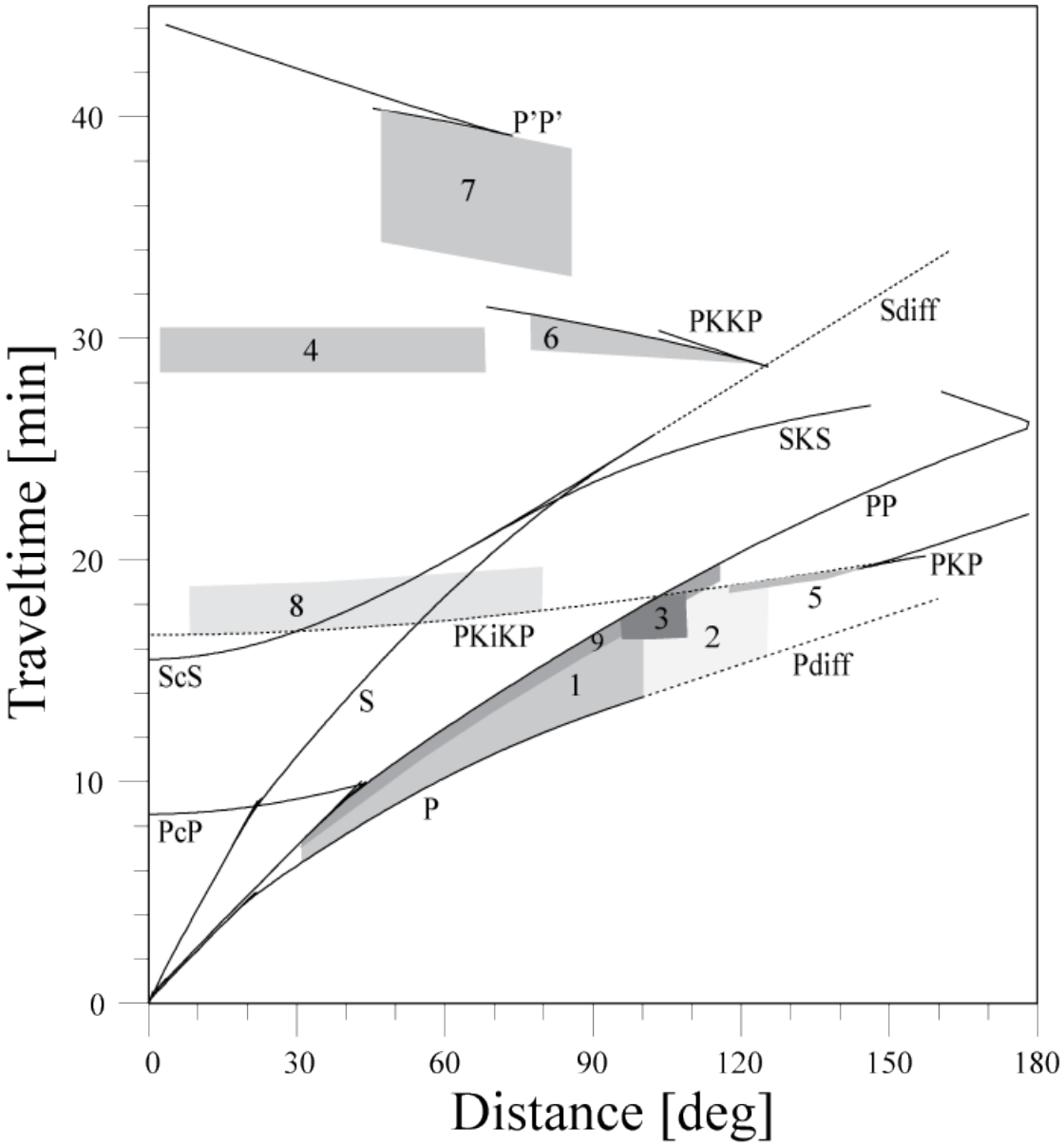
# Deep Earth Scattering Probes




1. P coda
2. $P_{diff}$ coda
3. Asymmetric PP precursors
4. PK•KP (precursors)
5. PKP precursors
6. PKKP precursors
7. P'P' precursors
8. PKiKP coda
9. Symmetric PP precursors

Rost et al. [2012]

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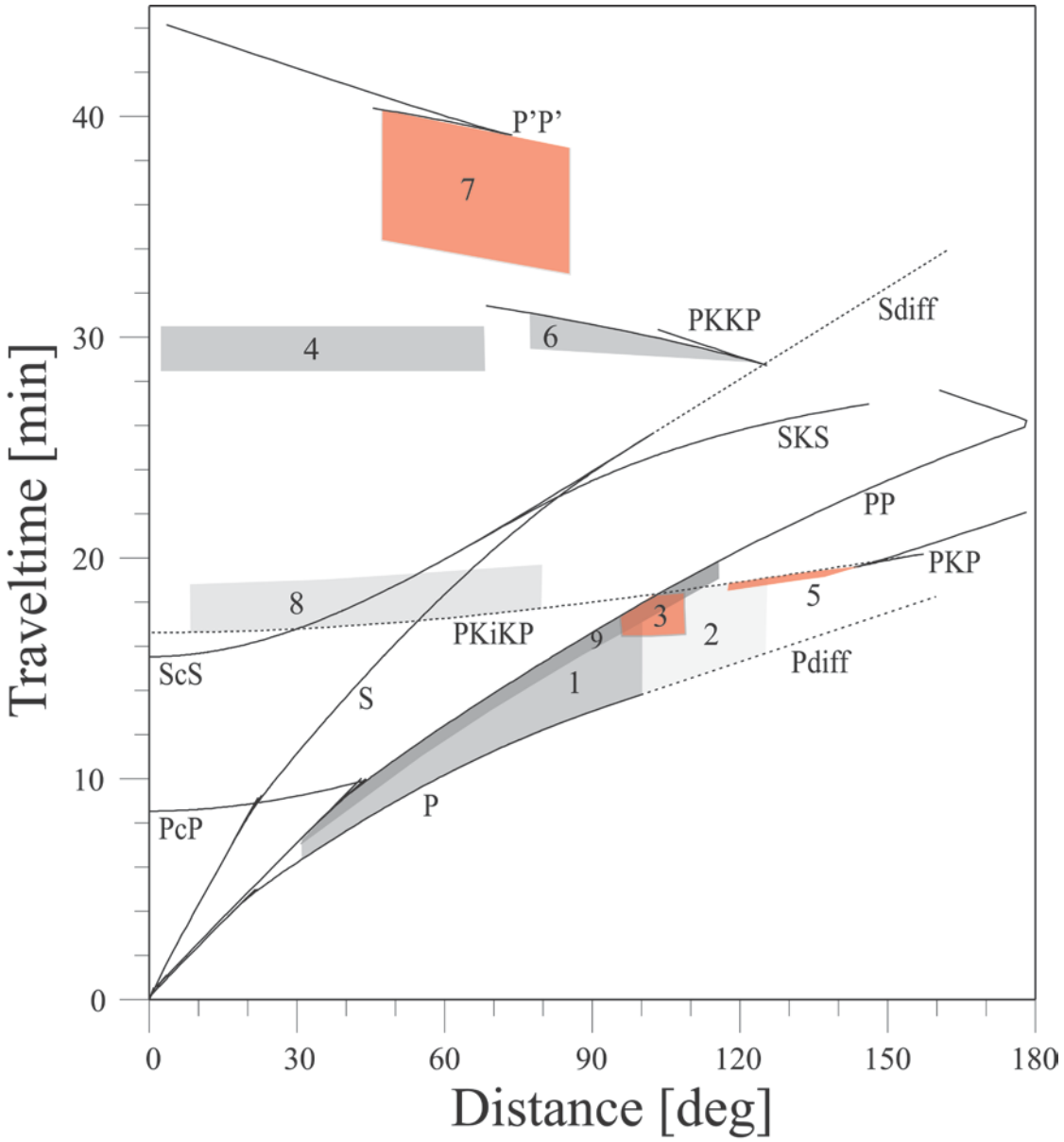
# Deep Earth Scattering Probes

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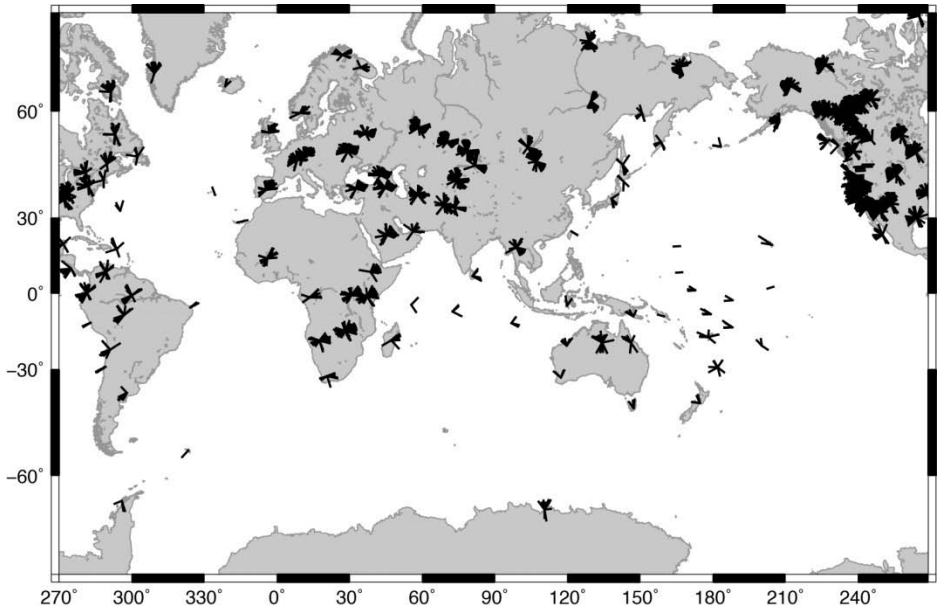
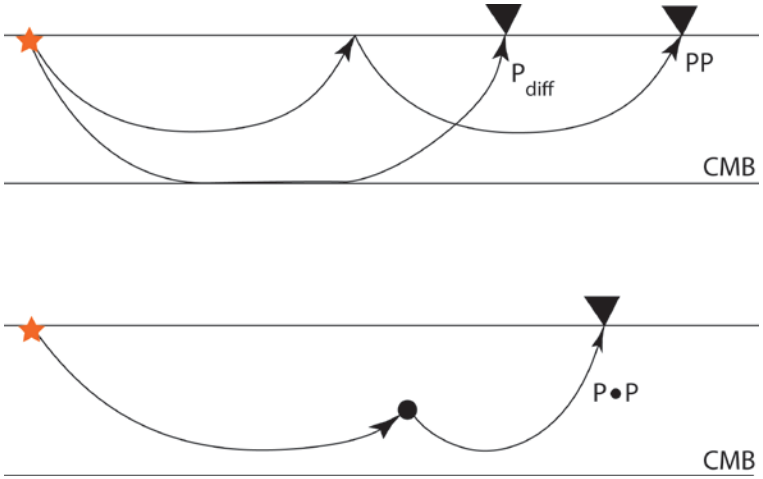
Rost et al. [2012]

# Dataset and Probe




- Global dataset of deep, M>6 events
- GSN stations
- Dataset augmented with CNSN stations
- Data aligned on PP
- Stacked in 5 deg distance bins

- Scattering related to PP
- PP as reference phase
- PP min-max phase
- Scattered energy arrives as precursor
- Probe most sensitive to structure at turning point depth




**Bentham, Rost and Thorne [2012]**

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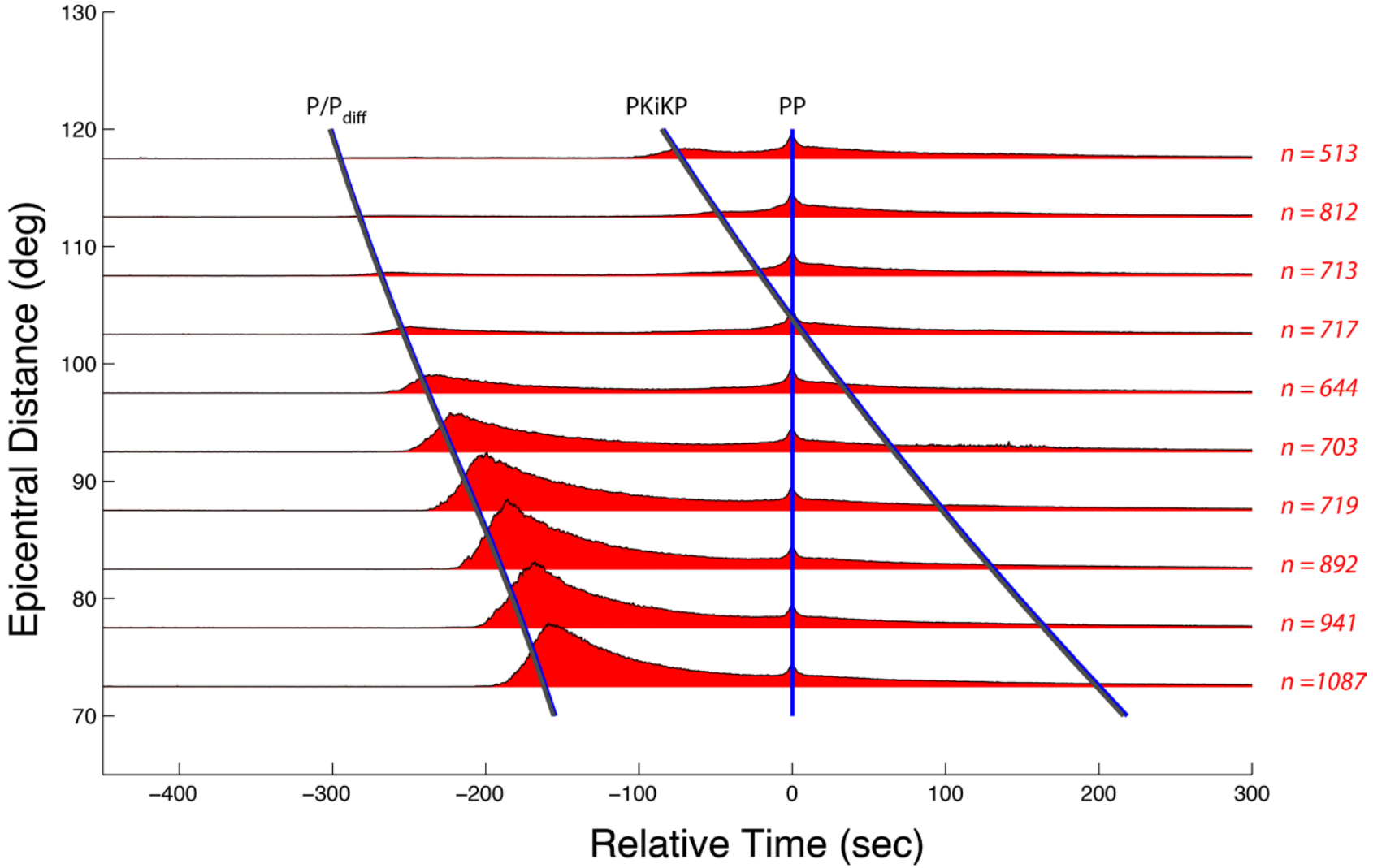
# Global Data Stack




- 7905 stacked traces
- Aligned and normalized on PP
- 5 deg distance bins
- Envelope stacks

- PP SNR > 5
- No weighting with SNR
- Not corrected for $P/P_{diff}$ moveout

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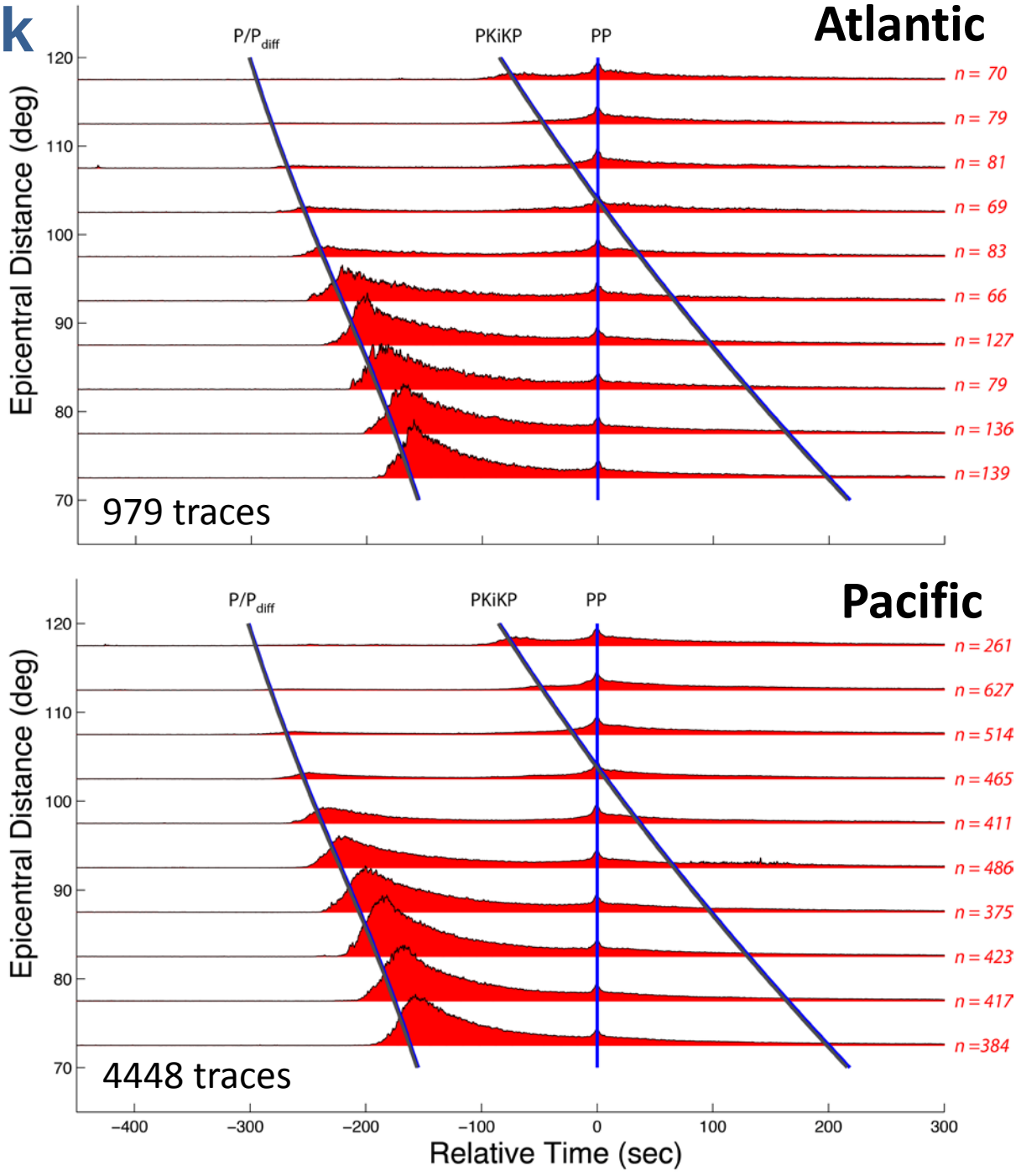
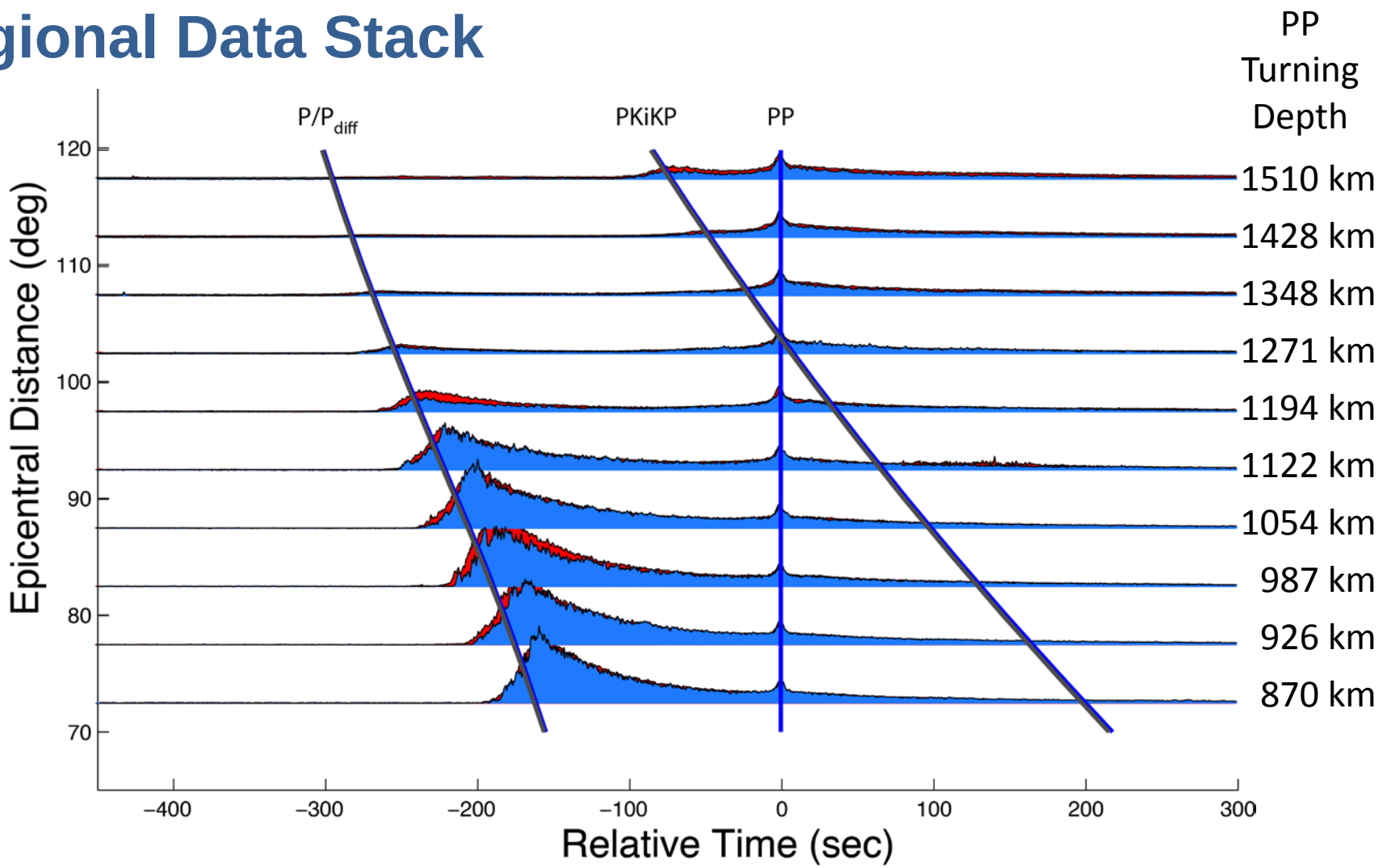
# Regional Data Stack

- Data divided into paths crossing the Pacific and the Atlantic
- Identical processing
- Fewer traces in Atlantic region
- Similar overall structure – stable stacking reached at about 50 traces
- $P/P_{diff}$ growth due to misaligned arrival within distance bin
- PKiKP cross over distance about 102 deg




**Bentham, Rost and Thorne [2012]**

# Regional Data Stack




- No dramatic differences in PP precursor coda
- No regional difference between region strongly affected by recent subduction
- Mid-mantle is generally well mixed and does not show strong evidence for imprint of surface tectonics
- Differences for large distances?

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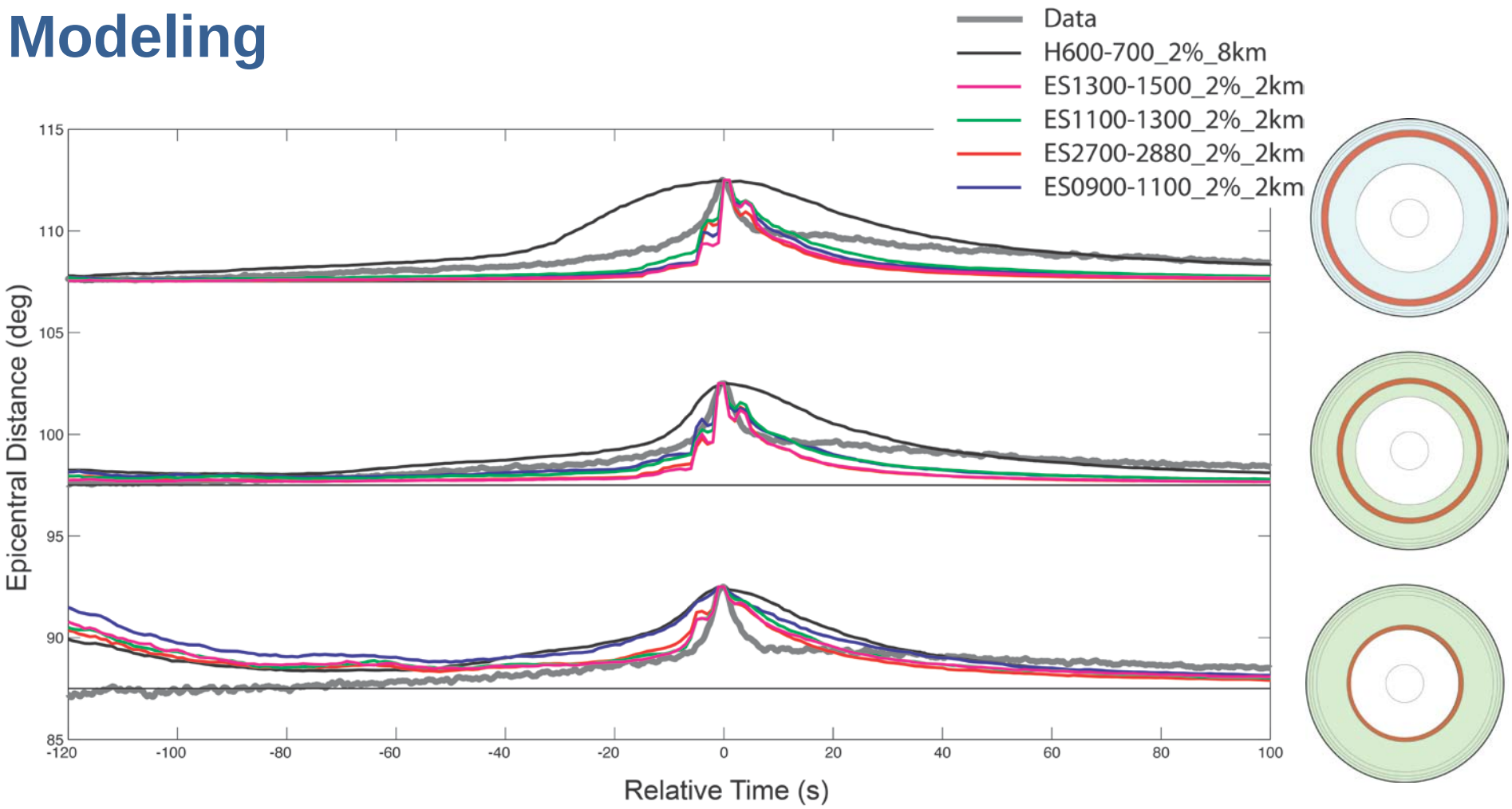
# Modeling




- Monte-Carlo Phonon Scattering algorithm
- No $P_{diff}$ modeling (ray based approach)
- Hedlin et al. (1997) or Earle/Shearer (2002) background model
- Variation in heterogeneities in spherical shells
- 3 distance bins –Synthetics processed as data
- Strong Moho arrival in synthetics

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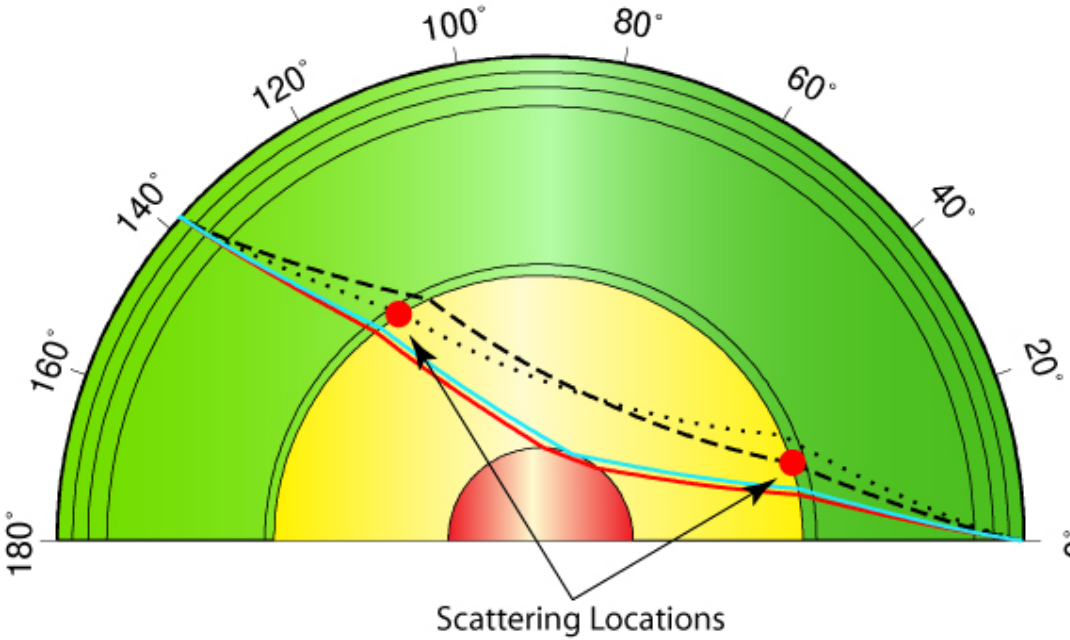
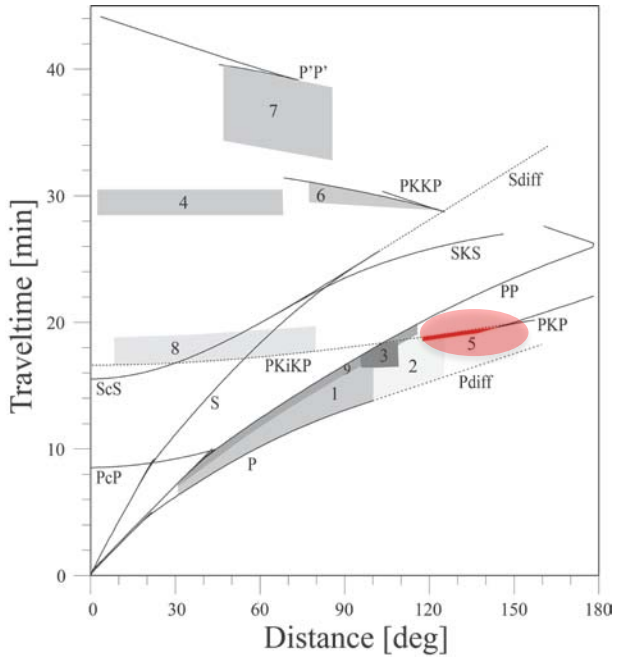
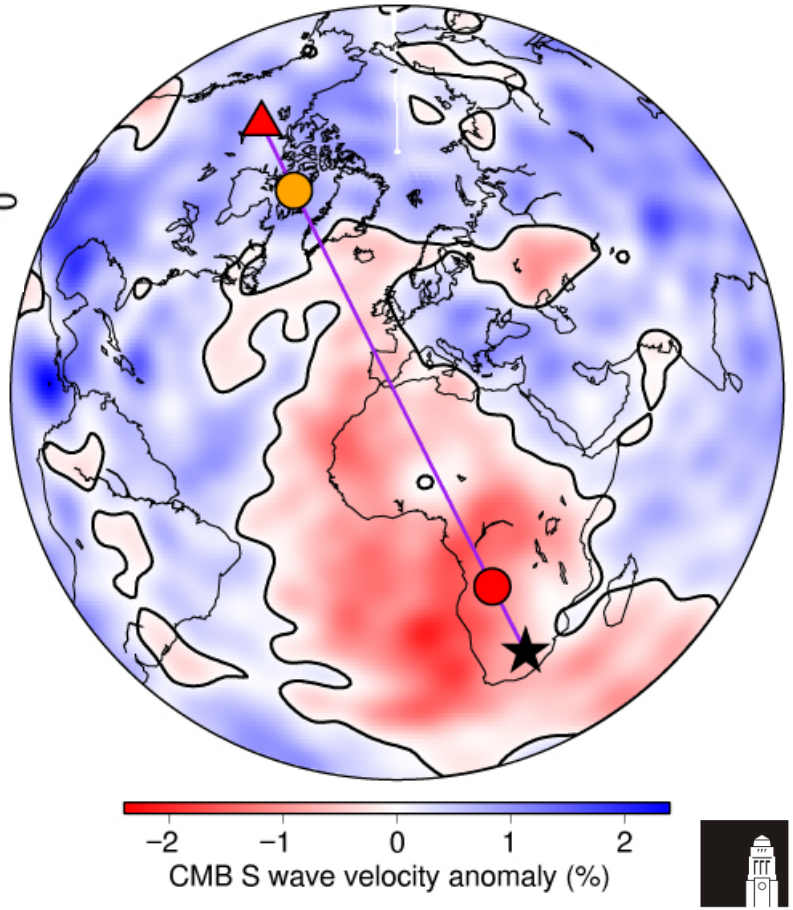
# PKP scattering




- Precursors to $PKP_{df}$
- Scattered energy from close the CMB
- Small events in SA recorded in Canada
- Yellowknife array (YKA)

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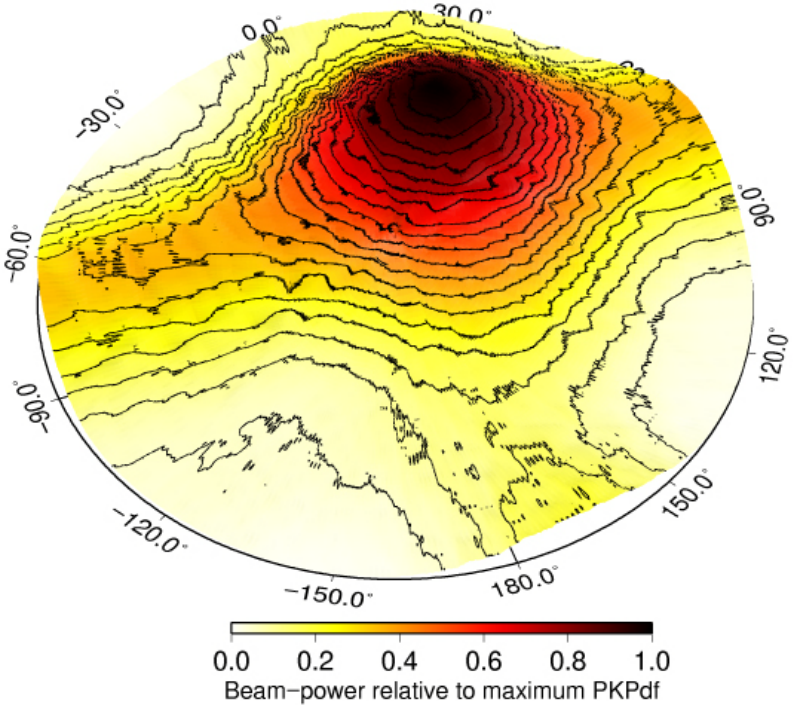
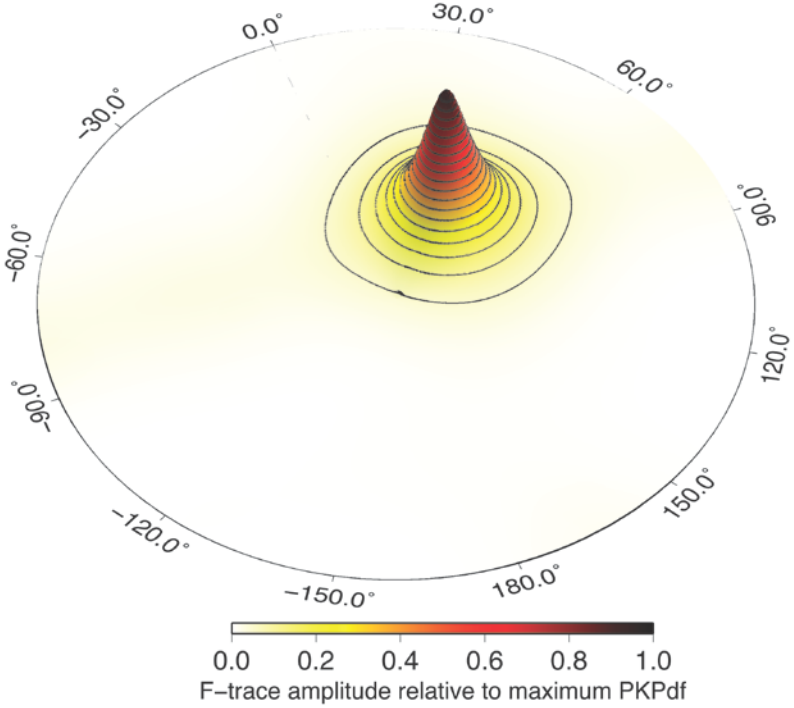
# PKP scattering array processing

**“Normal” array resolution**
**fk-analysis**




**High resolution Array Processing**
**F-statistic**




Frost et al. [2012]

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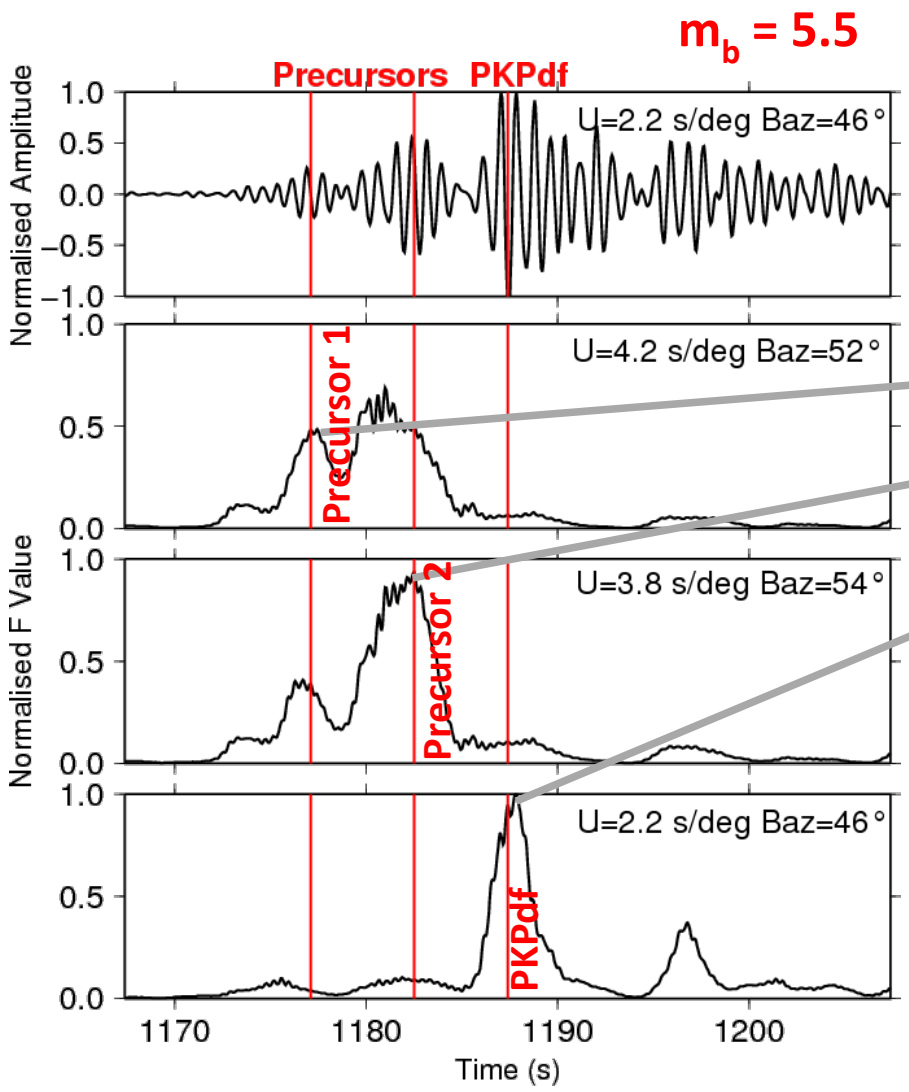
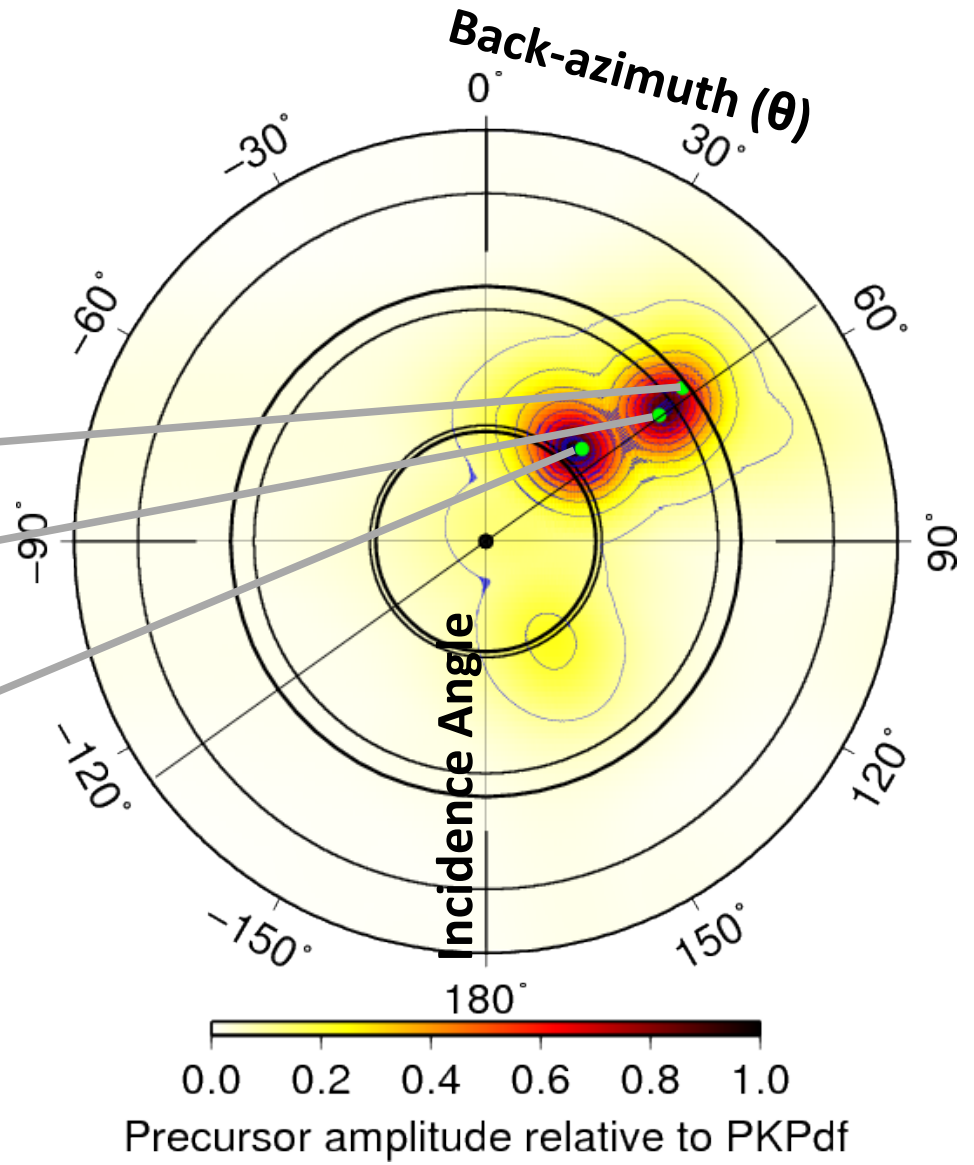
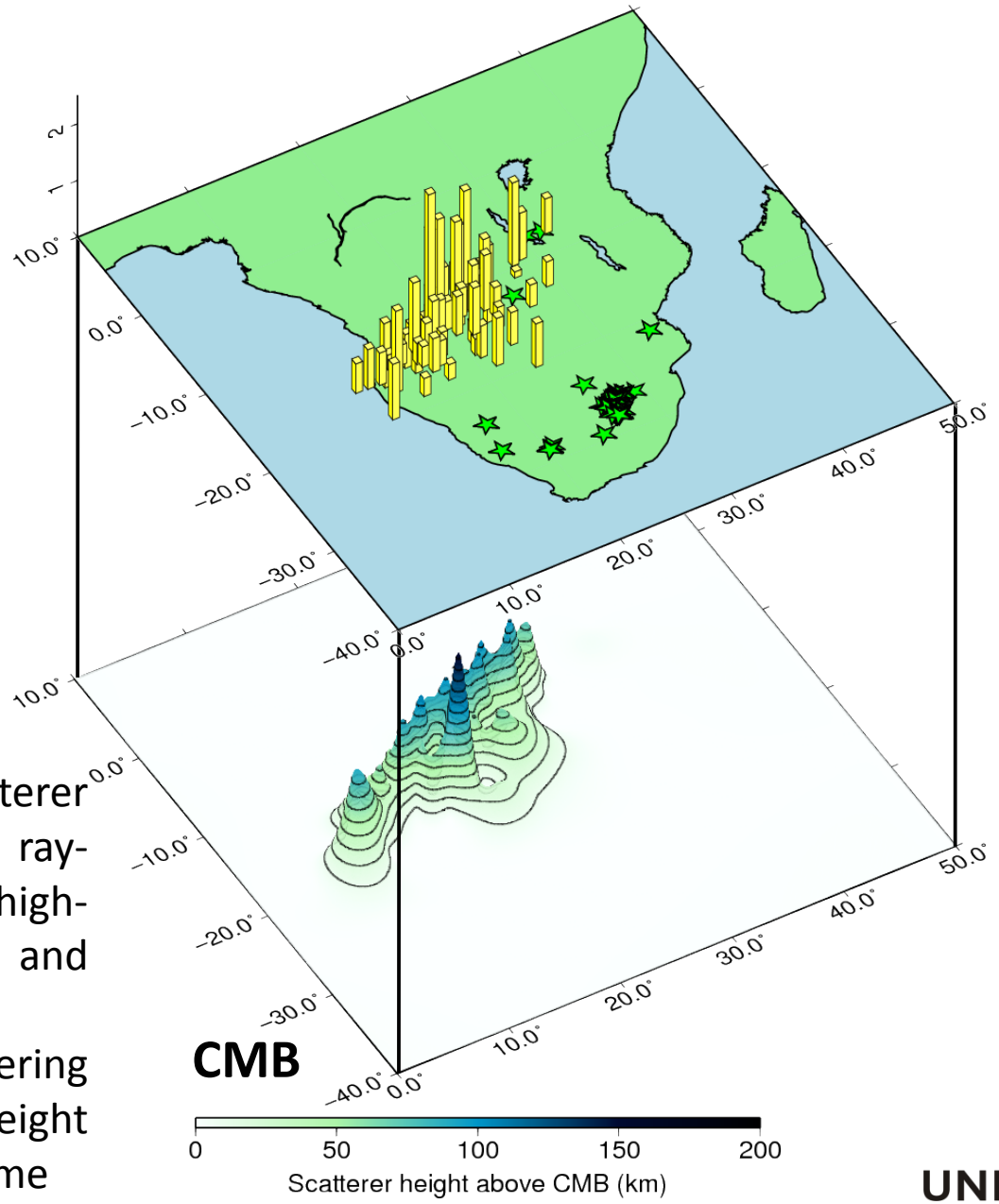
# South African Sources




Frost et al. [2012]

# Core-Mantle Boundary Structure




- Deterministic scatterer location through ray-tracing with high-precision slowness and backazimuth
- Variations in scattering strength and height above CMB in volume

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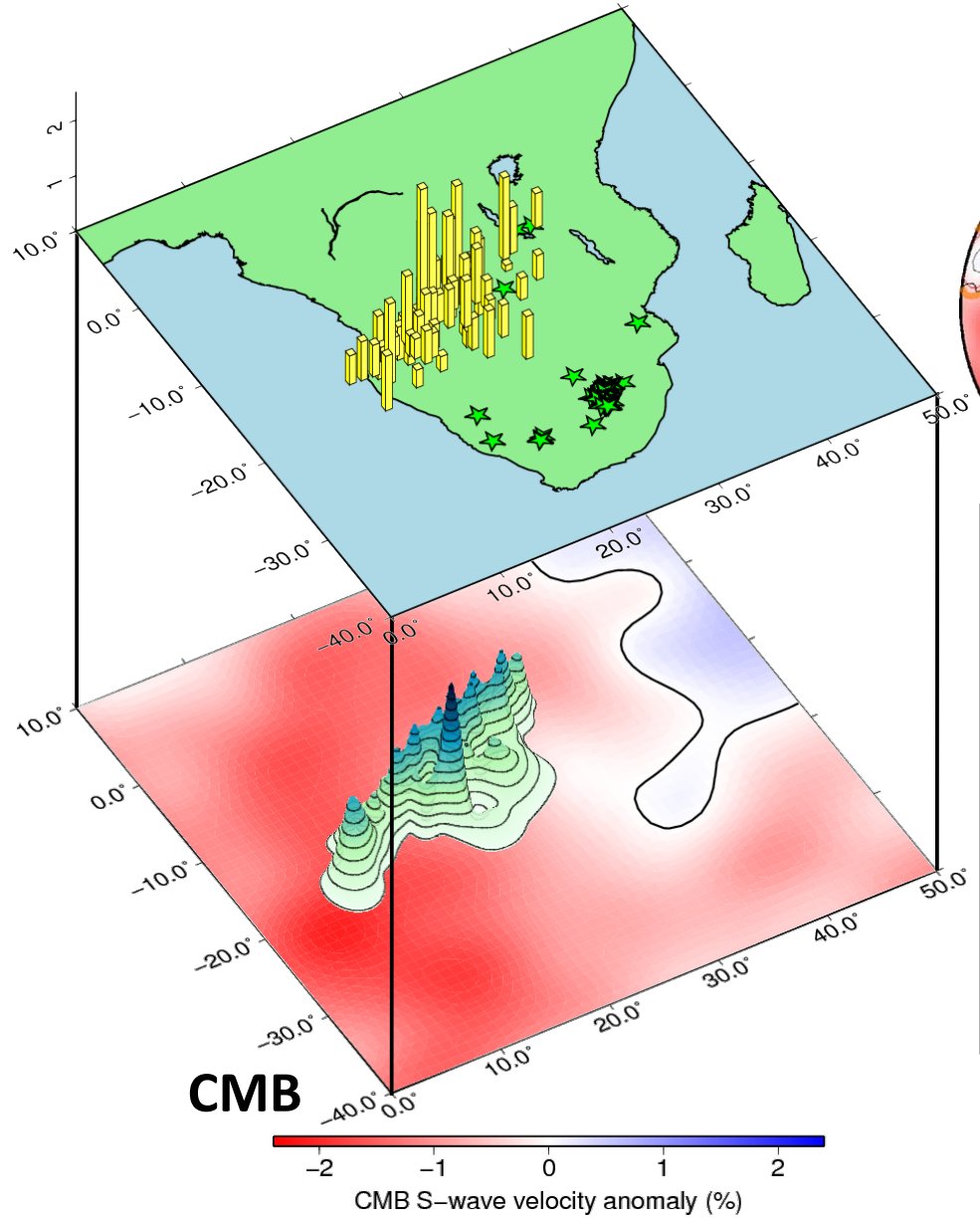
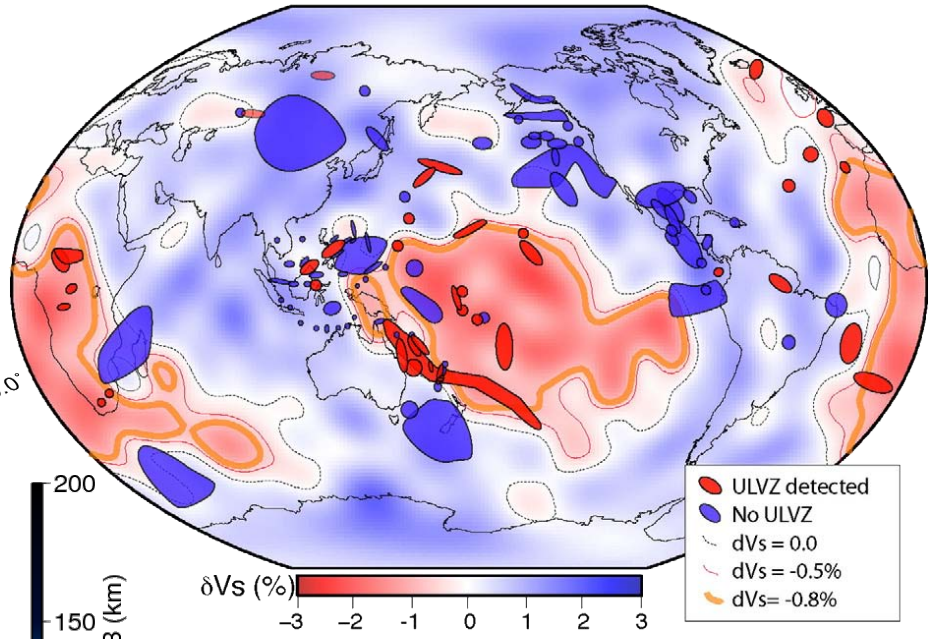
# Small and Large-scale structure




Frost et al [2012]




[McNamara et al, 2010]

- SE boundary well resolved
- NW boundary not resolved (*b*-caustic)
- SW/NE resolved through no scattering points
- Volume located at the edge of LLSVP
- Material in up-stream?

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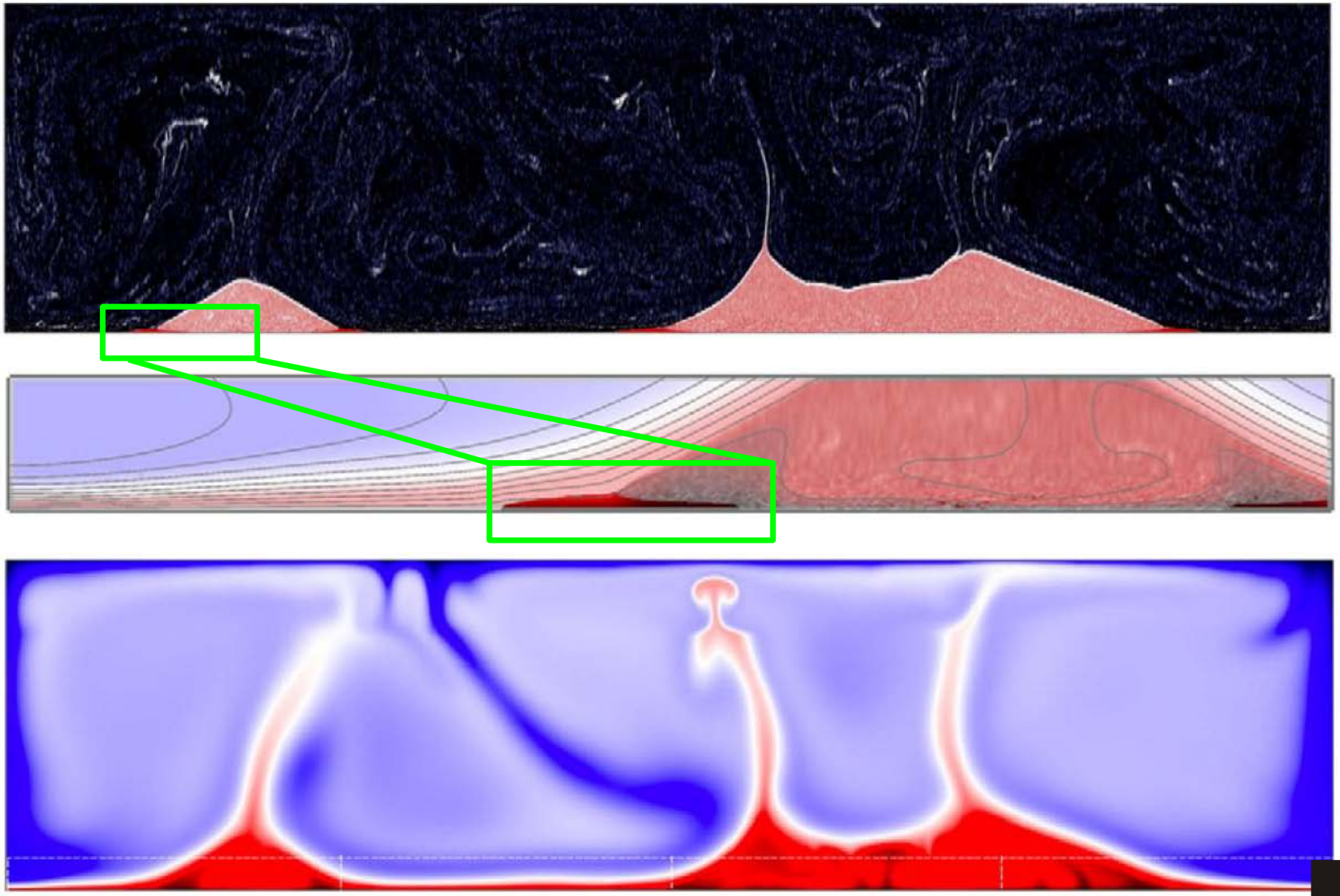
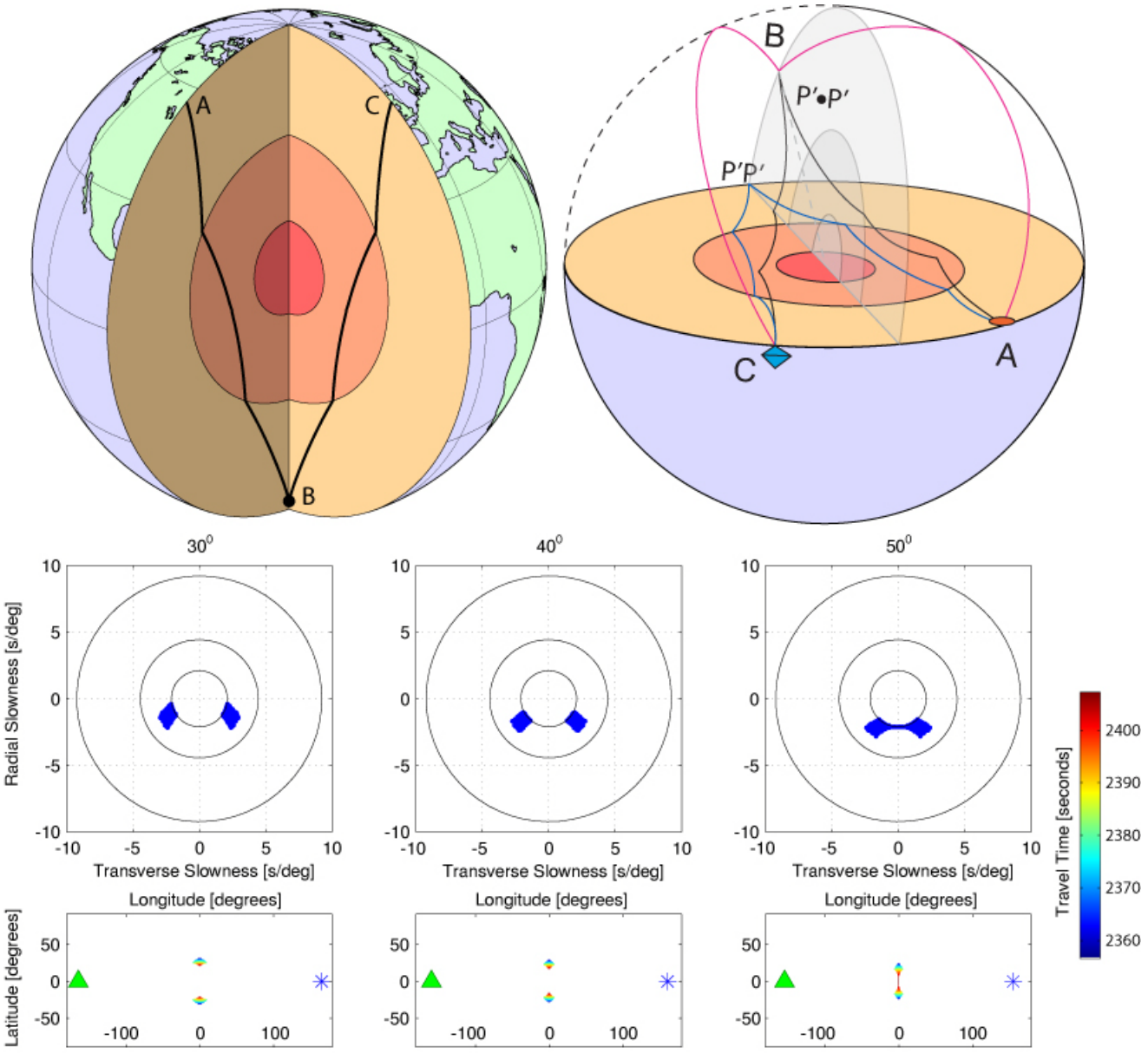
# Small and Large-scale structure



[McNamara et al, 2010]

# Scattering from Core to Crust - PKP•PKP




Earle et al., [2011]

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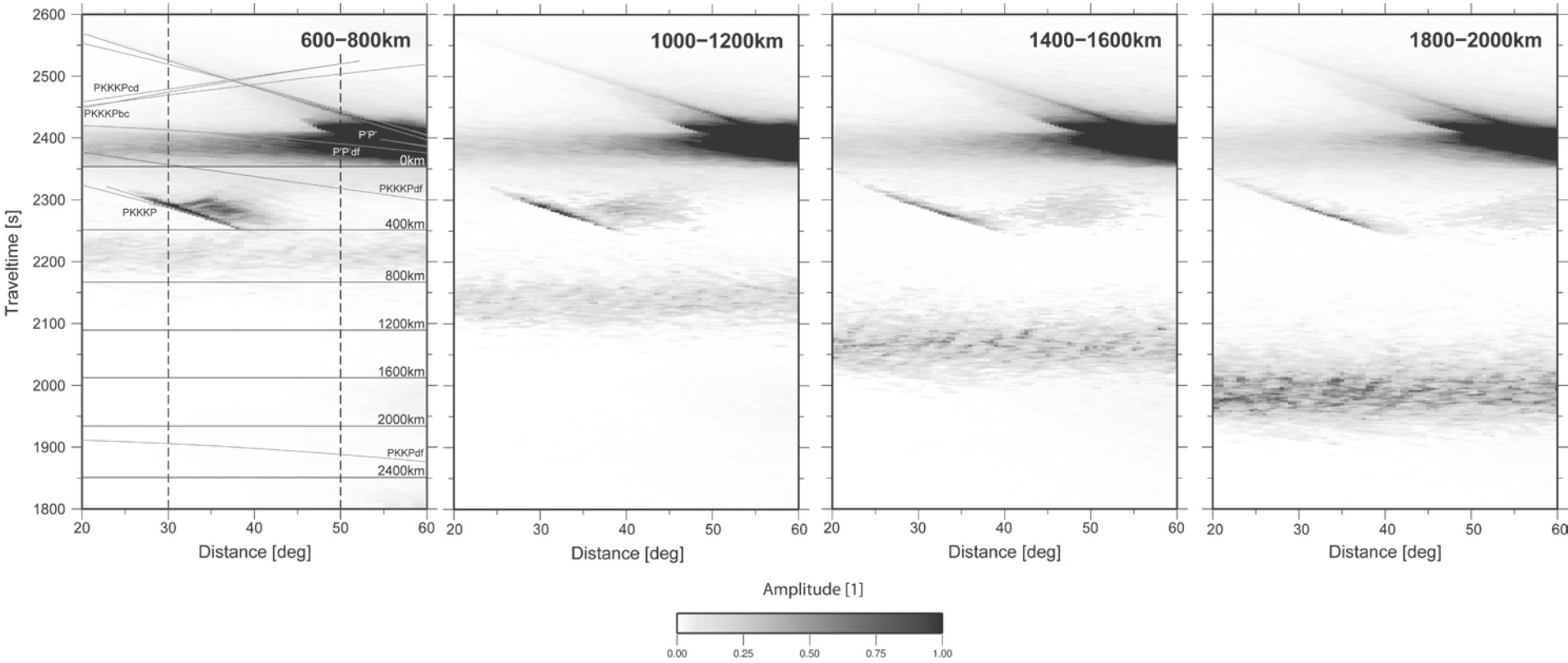
# PKP•PKP - P'P' Scattering




**Phonon Scattering Synthetics:**

| | |
|---|---|
| **Layer Thickness:** | **200 km** |
| **Correlation Length:** | **4km** |
| **RMS velocity Variation:** | **3%** |

**Earle et al. [2011]; Rost et al. [2012]**

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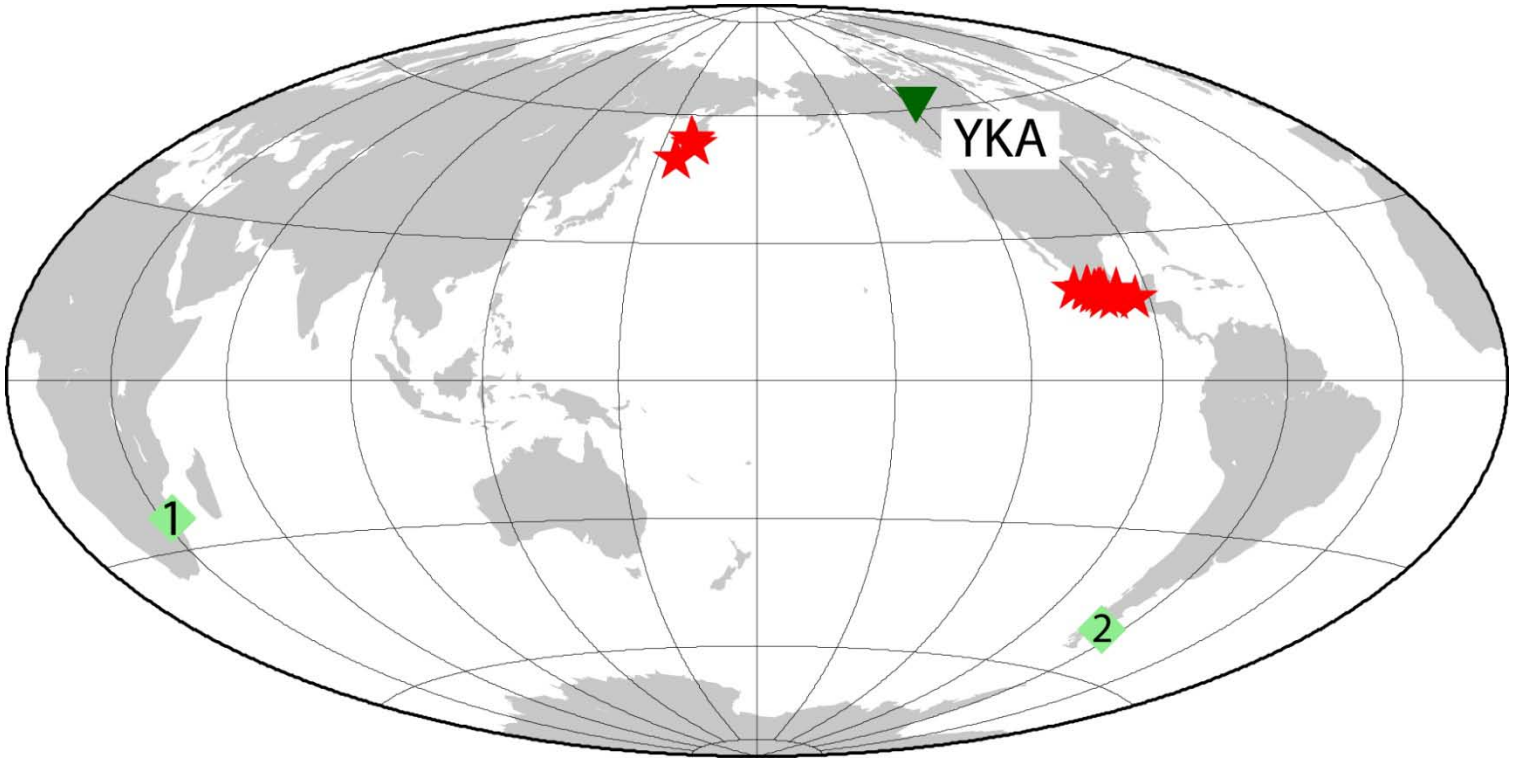
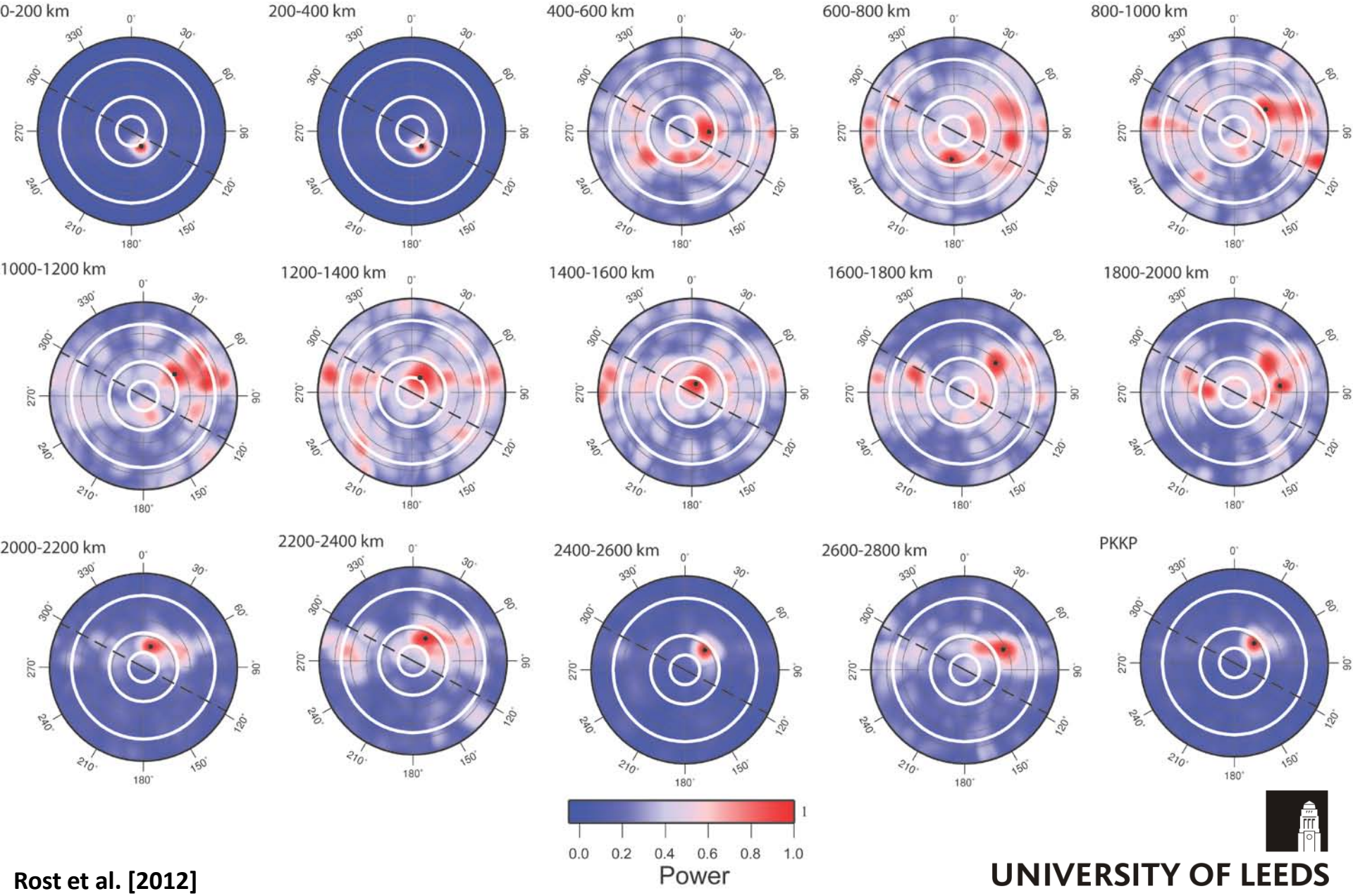
# Dataset




- Small dataset M > 6
- 20 – 40 deg distance
- Data recorded at Yellowknife Array – Northern Canada (YKA)
- Events dominantly in Kamchatka and Central America
- F-statistic approach in time slices equivalent to 200 km in depth (~50 s)

**Rost et al. [2012]**

# Kamchatka Event




Rost et al. [2012]

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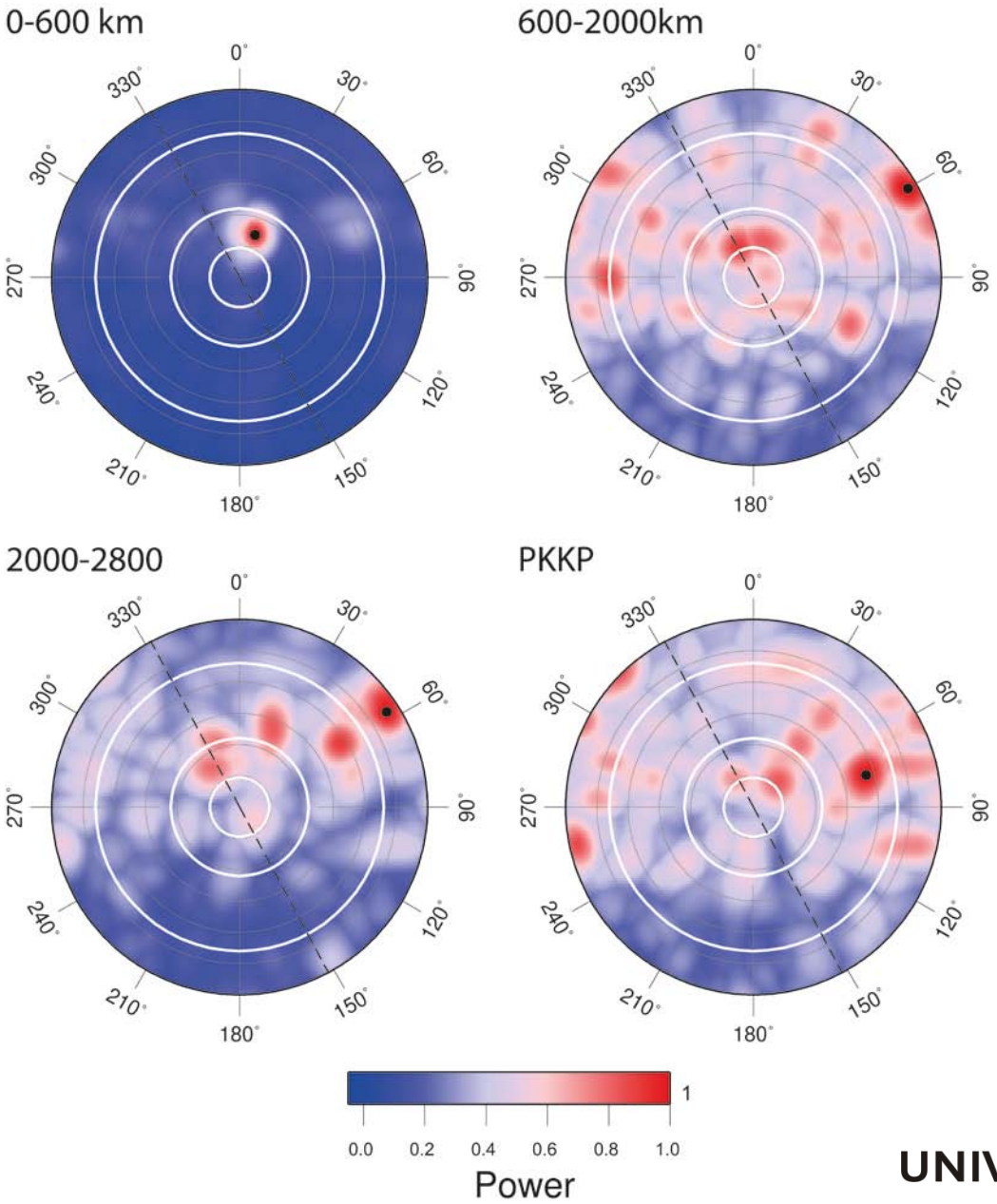
# Central American Event




Rost et al. [2012]

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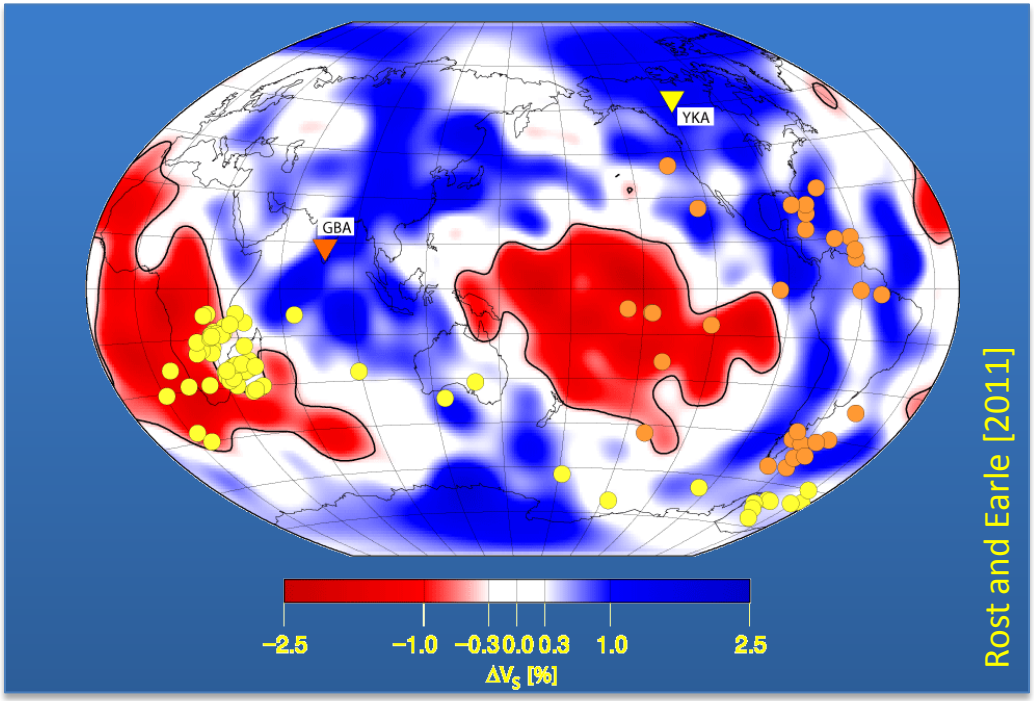
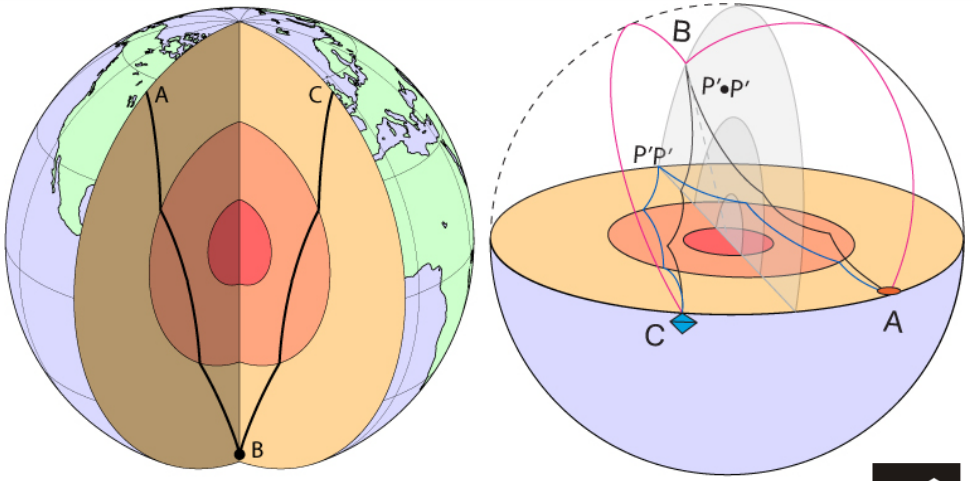
# Results

- P’•P’ offers the unique opportunity to sample the Earth for small-scale heterogeneity consistently from crust to core
- Kamchatka events consistently show upper mantle scattering from South American subduction zone region (2)
- Kamchatka events consistently show scattering from the edge of the African LLSVP (1)
- Central American events do not show evidence for lower mantle scattering
- Potential scattering points in the north western Pacific  dominated by fast velocities
- Upper mantle scattering in a subduction dominated upper mantle

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# Conclusions

- Small-scale heterogeneities are evident in many parts of the high-frequency seismic wavefield
- Using information contained in the scattered seismic wavefield allows probing the interior of the Earth for its fine-scale structure
- Many of the scattering areas seem to be connected to the tectonics of the surface or of the Earth's deep interior
- High thermal conductivity of mantle materials will likely lead to fast thermal equilibration of small-scale thermal anomalies
- Likely source for chemical heterogeneities is the subduction process, i.e. crustal material on the way to the CMB


- Several new probes for small-scale structure available
- Mechanical mixing ill-understood
- Better connection between geodynamical, mineral-physical and seismological modeling required

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