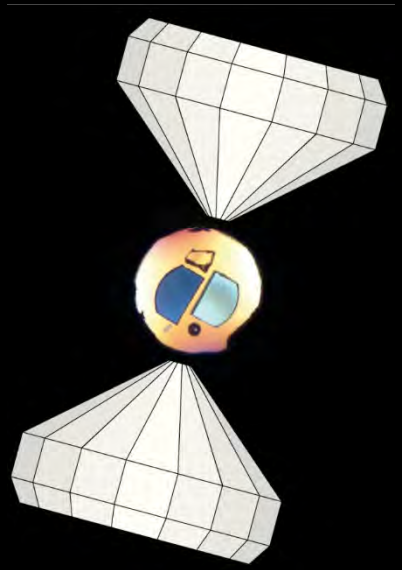
Earth's mantle seismic properties from laboratory experiments

Hauke Marquardt
hauke.marquardt@earth.ox.ac.uk



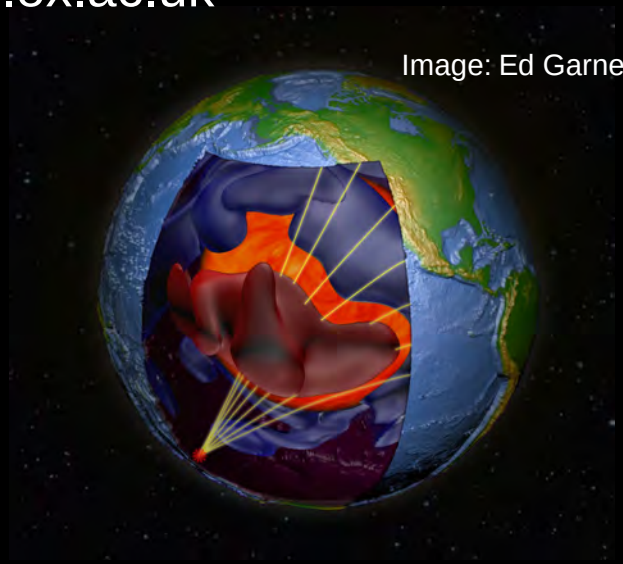


Image: Ed Garnero

Thanks to

Alba San Josè Méndez
Viktoria Trautner
Biao Wang

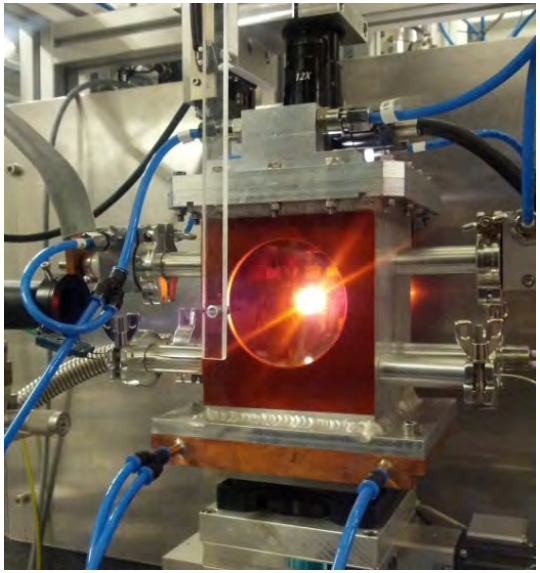
Stephen Stackhouse
Hanns-Peter Liermann
Niccolo Satta
Rachel Husband
Johannes Buchen

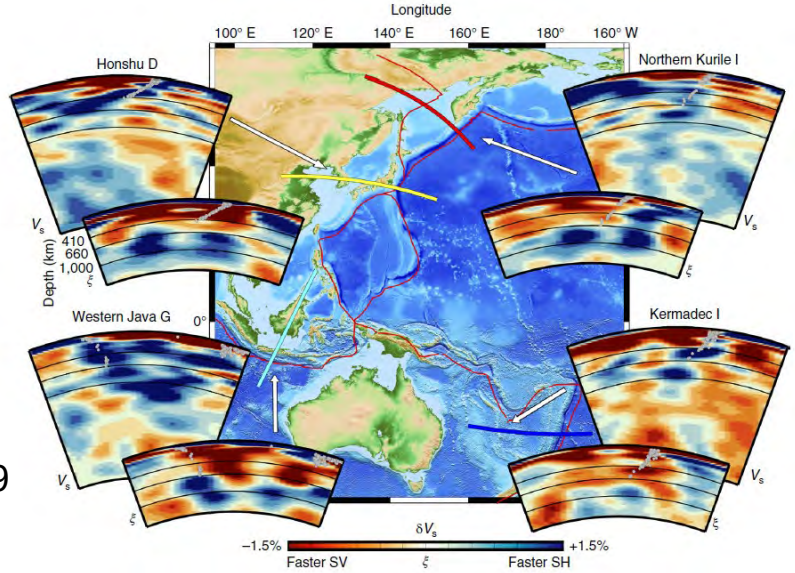
erc
DEEP-MAPS

UNIVERSITY OF OXFORD

DESY

Seismic properties from laboratory experiments





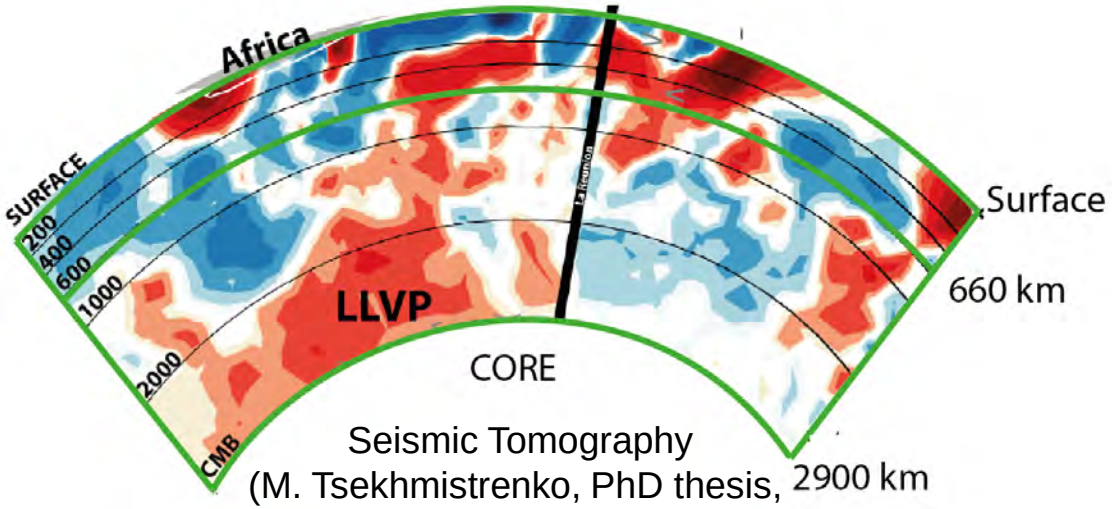
Ferreira,
Nature Geosc., 2019

$$V_p = [(K+4/3G)/\rho]^{0.5}$$

$$V_s = (G/\rho)^{0.5}$$

Anisotropy (c_{ij}s, CPO)

Attenuation (f-dependence)

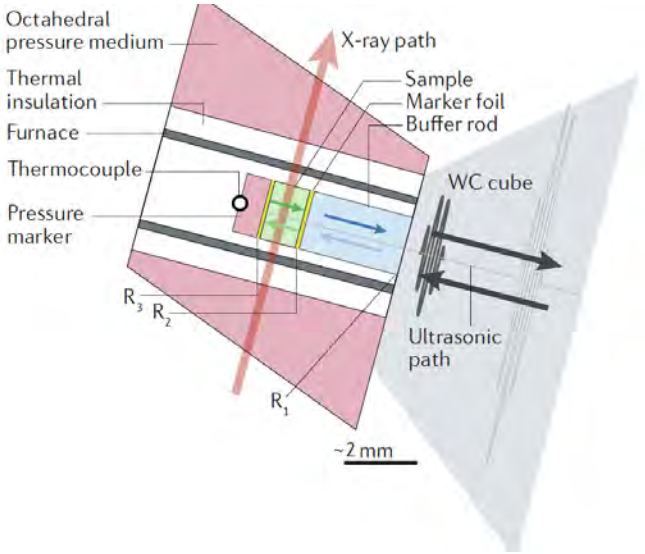


Seismic Tomography
(M. Tsekhmistrenko, PhD thesis, University of Oxford, 2019)

Experimental Elasticity of Earth's Mantle - Methods

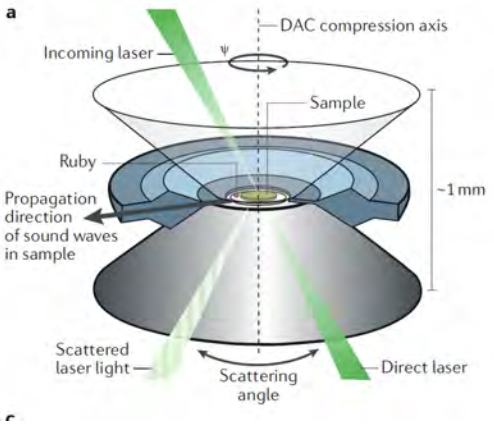
I. LVP Ultrasonics

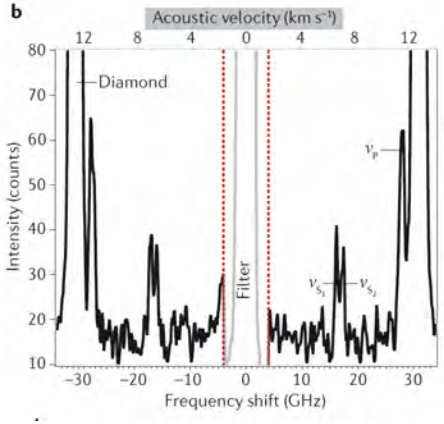
+ High-temperature
- Pressure limited to ~25 GPa
- Polycrystalline samples
- Only average wave velocities
- Ideally need Synchrotron

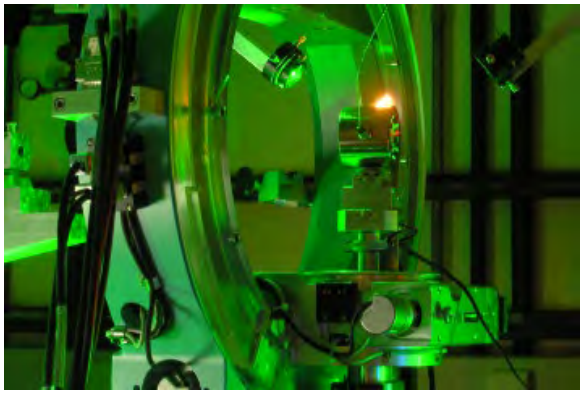


II. Light scattering techniques in DAC

+ High-pressure possible
+ Elastic anisotropy can be measured (Cijs)
- Temperature difficult (but possible)
- Polycrystalline sample measurements of unclear quality
- Non-transparent samples challenging



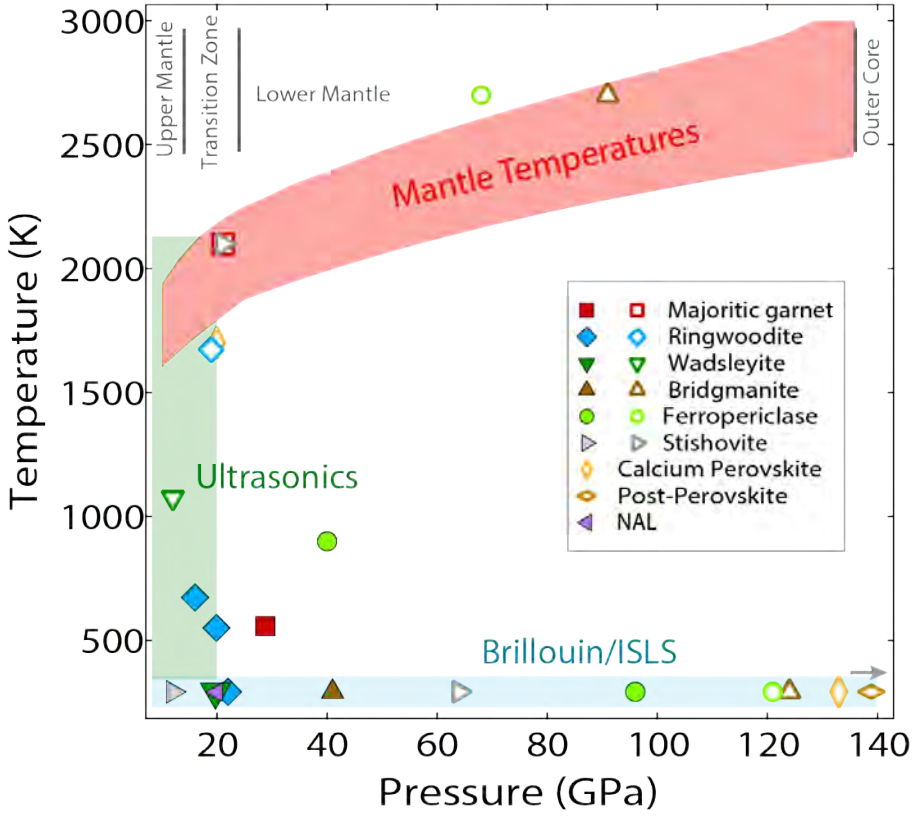




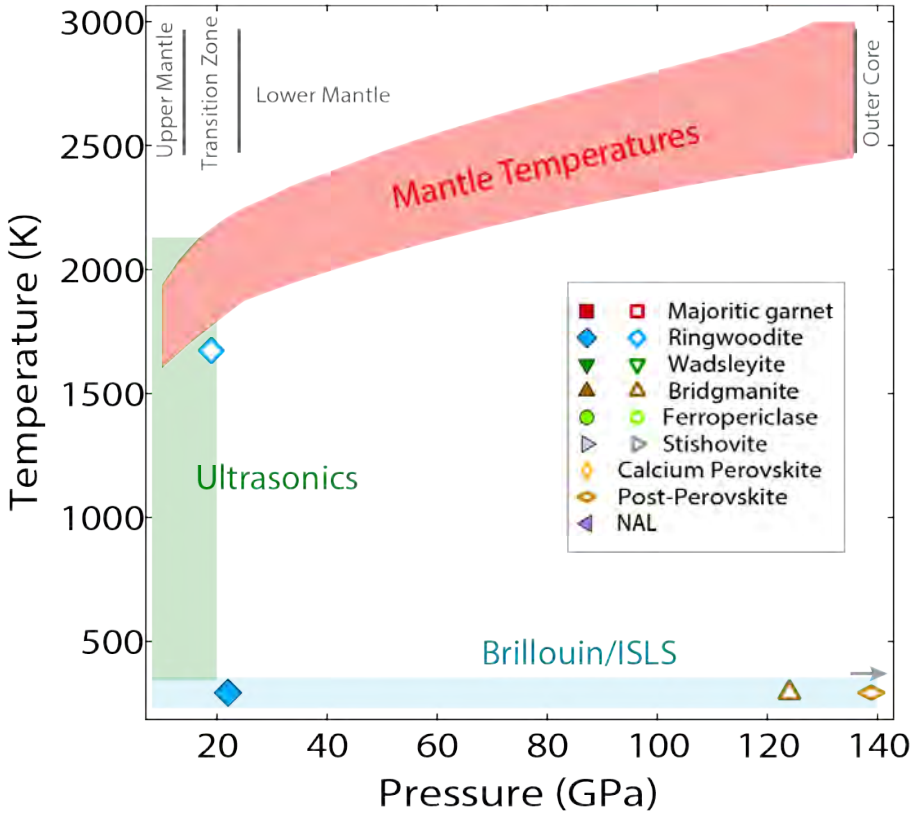
Experimental Elasticity of Earth‘s Mantle - Status

Marquardt & Thomson, *Nature Reviews Earth & Env.*, 2020

2020

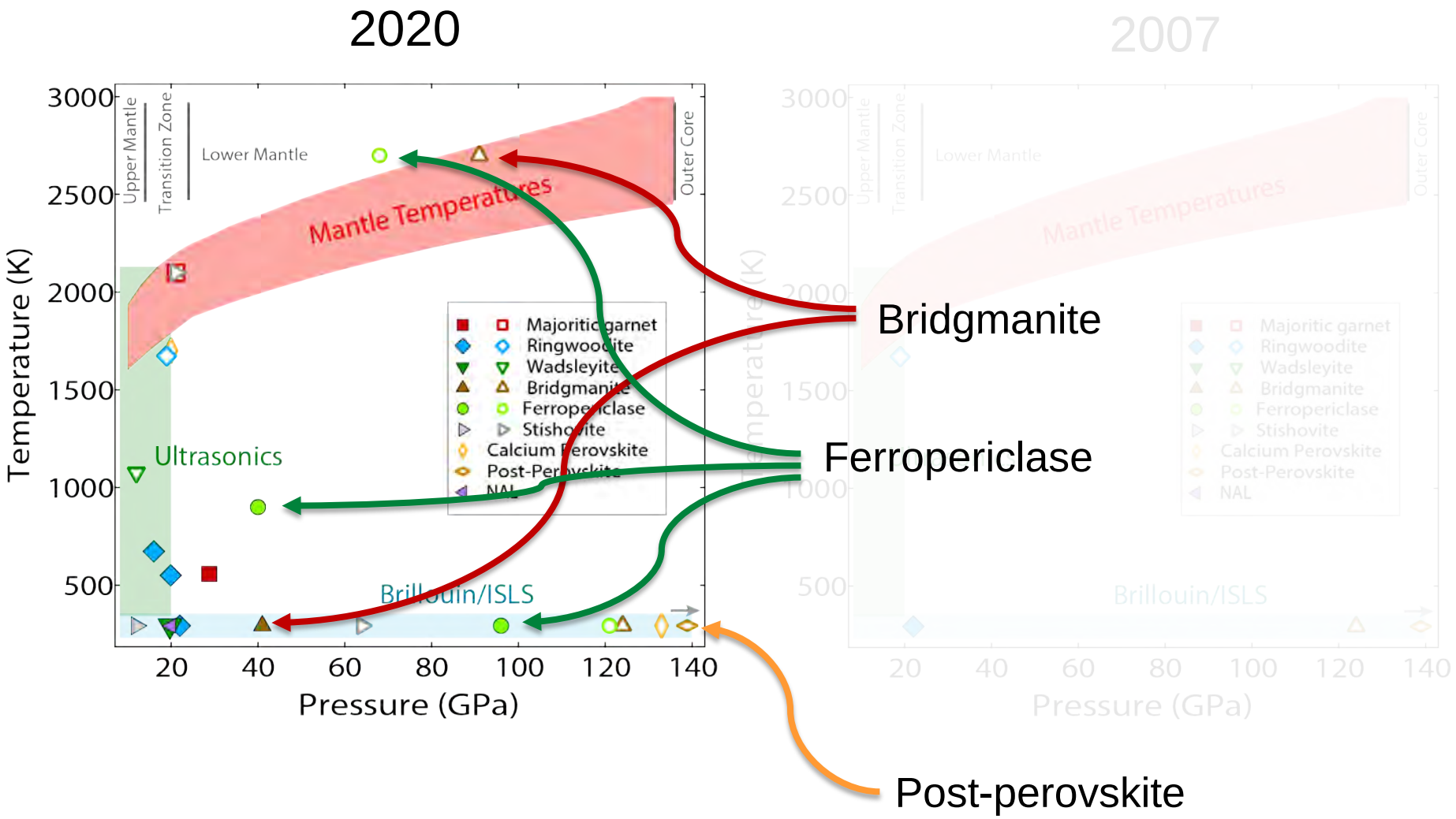


2007



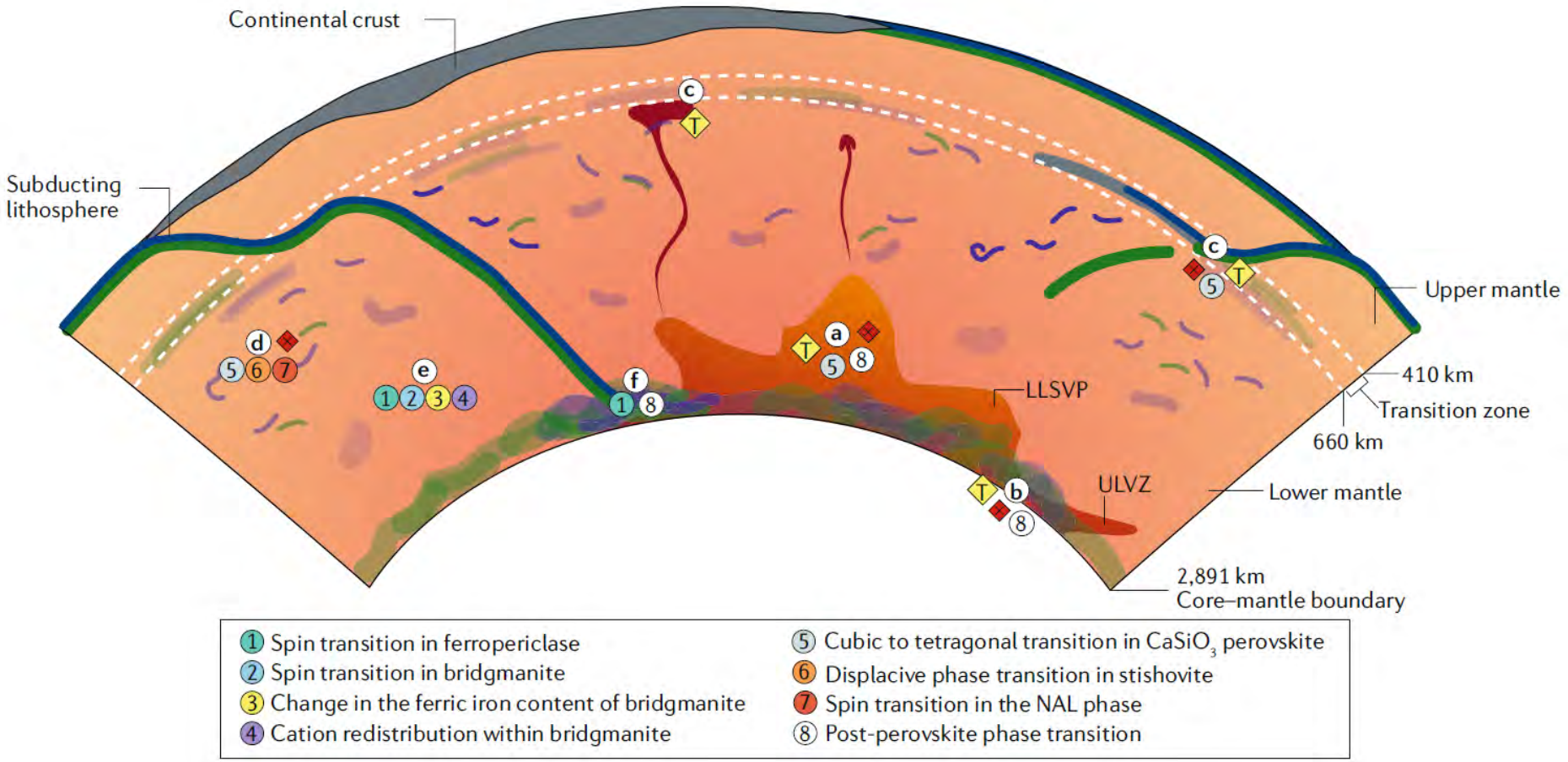
Experimental Elasticity of Earth's Mantle – Major gaps

Marquardt & Thomson, *Nature Reviews Earth & Env.*, 2020



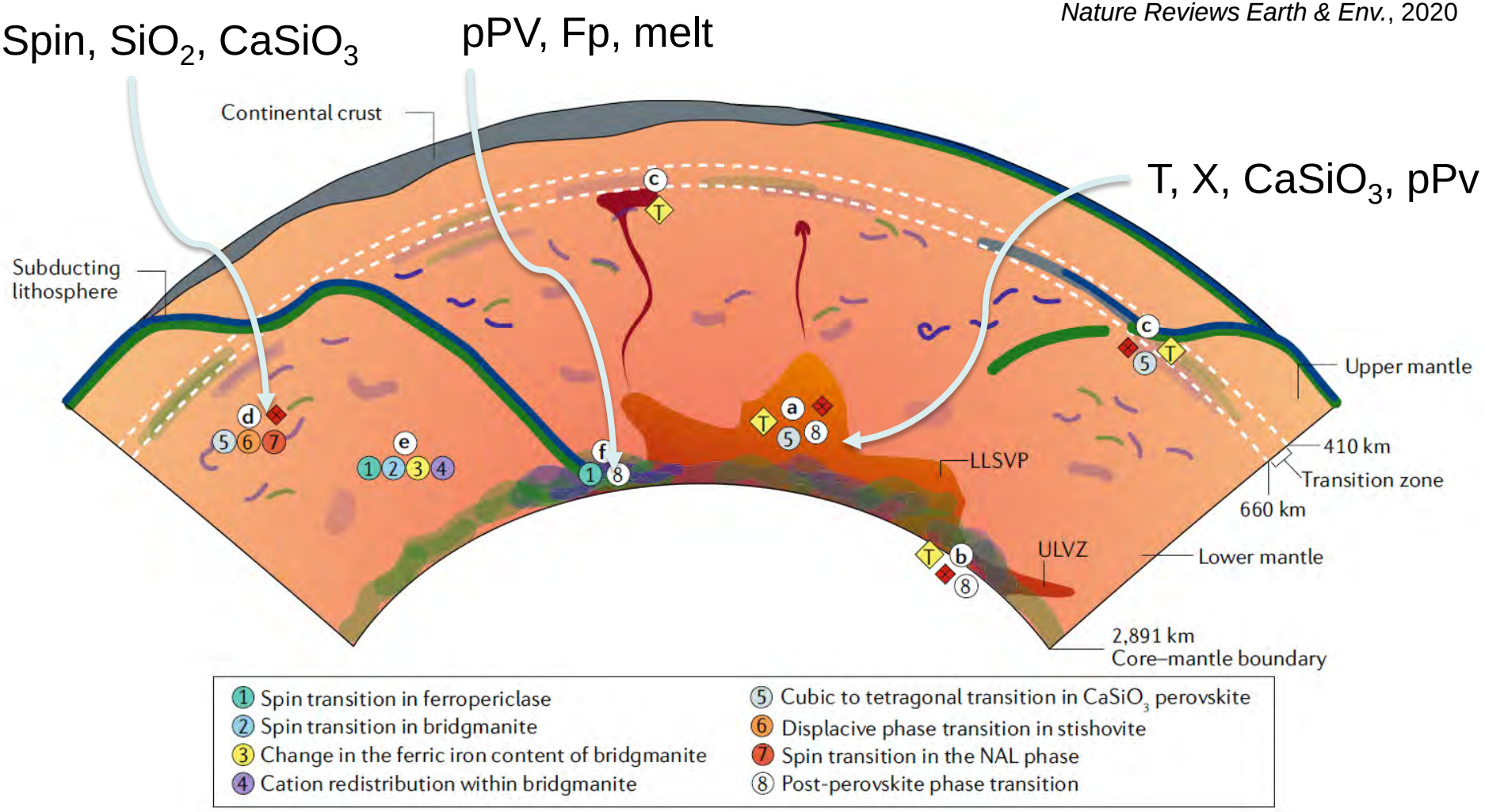
Interpretive Cartoon of Mantle Seismic Structures

Marquardt & Thomson,
Nature Reviews Earth & Env., 2020



Interpretive Cartoon of Mantle Seismic Structures

Marquardt & Thomson,
Nature Reviews Earth & Env., 2020



Experimental Elasticity of Earth's Mantle - Challenges

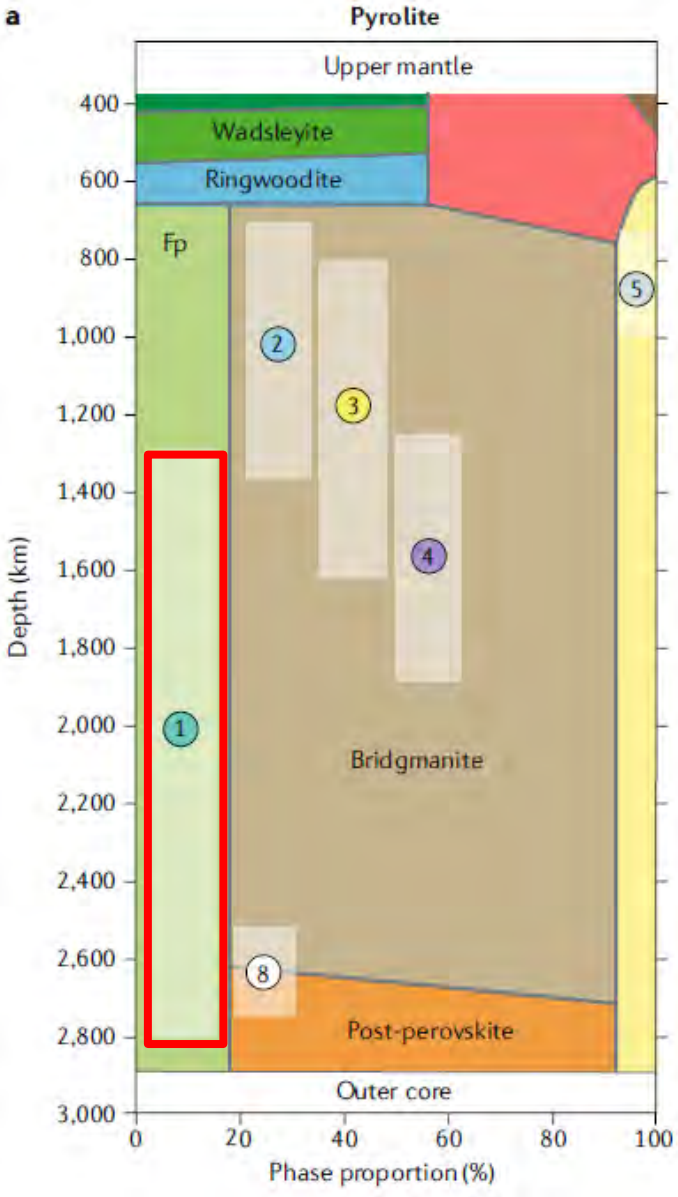
Can mostly be done by current methodology

- Systematic variations with chemistry
- Understanding measurements on polycrystals
- Statistics

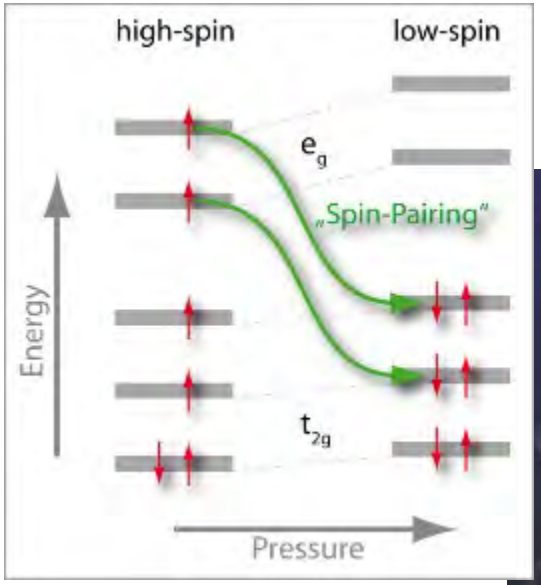
Can only partially (or not) be done

- High-temperature (particular in DAC)
- Time-dependence
- Signature of phase transitions

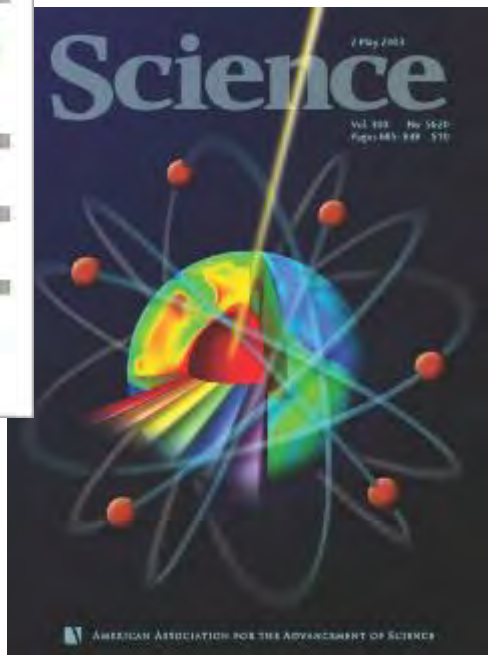
The Iron Spin Crossover in (Mg,Fe)O



Marquardt & Thomson,
Nature Reviews Earth & Env., 2020

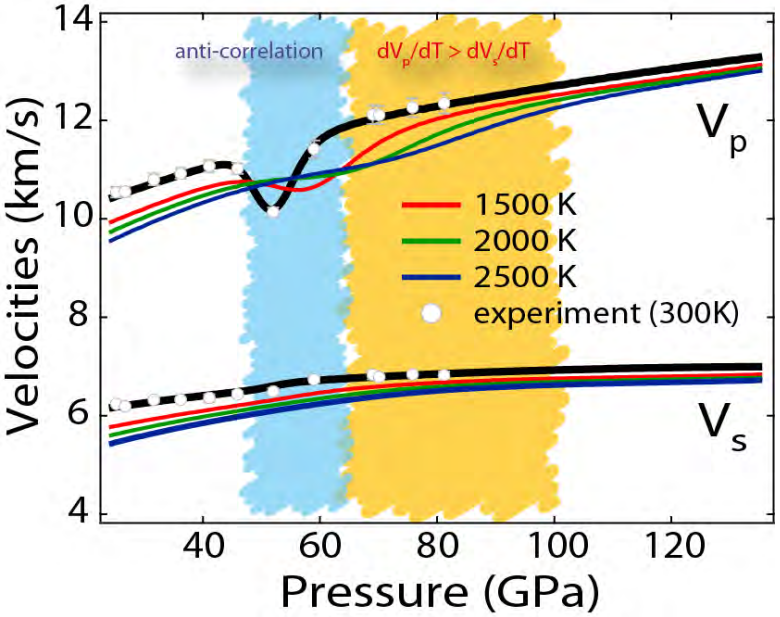


Badro et al.,
Science, 2003

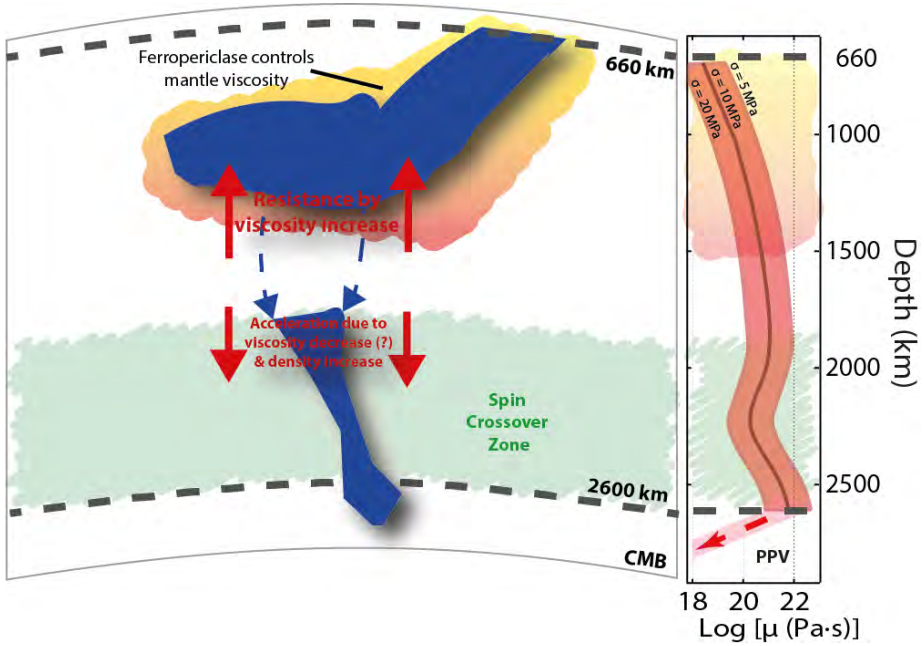


The Iron Spin Crossover in (Mg,Fe)O - Impact

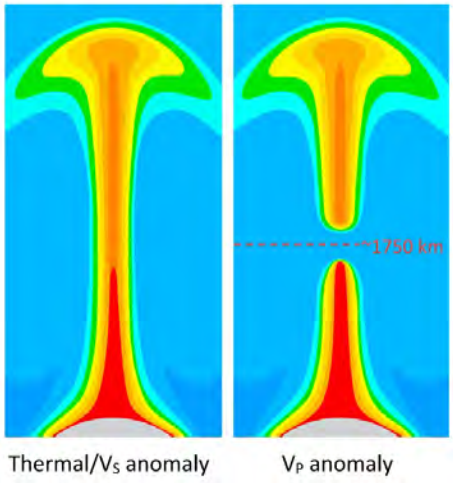
Marquardt et al.: *EPSL*, 2009



Marquardt & Miyagi (2015), Nature Geoscience 8, 311-314



Wu, *JGR*, 2016



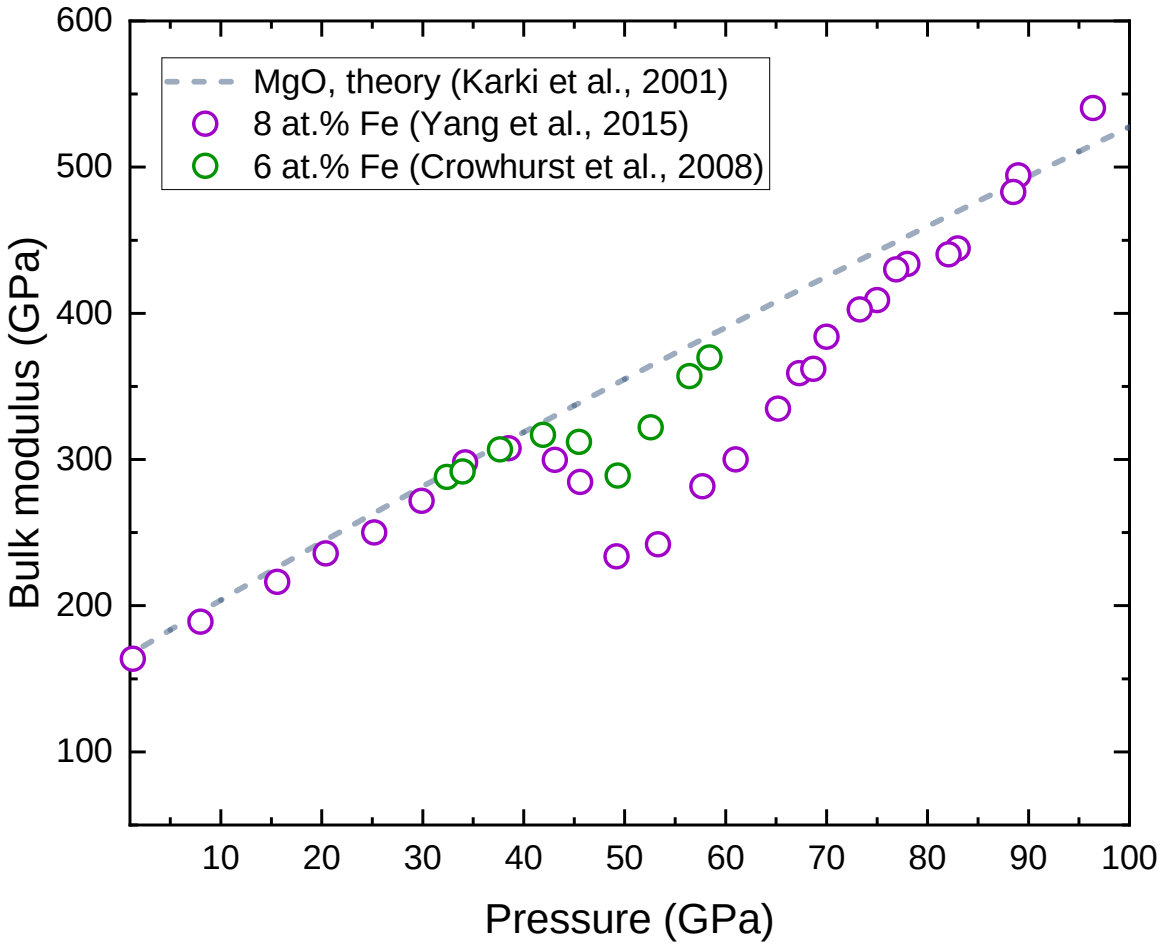
$Vp^2 = (\mathbf{K} + 4/3*G)/\rho$

The "mixed" spin state is markedly different from "pure" high or low spin

- Bulk modulus softens (~50%)
- Viscosity decreases (~10-100x)
- Thermal transport properties change
- Electrical conductivity increases
- Fe partitioning is affected

The Iron Spin Crossover in (Mg,Fe)O – Bulk modulus

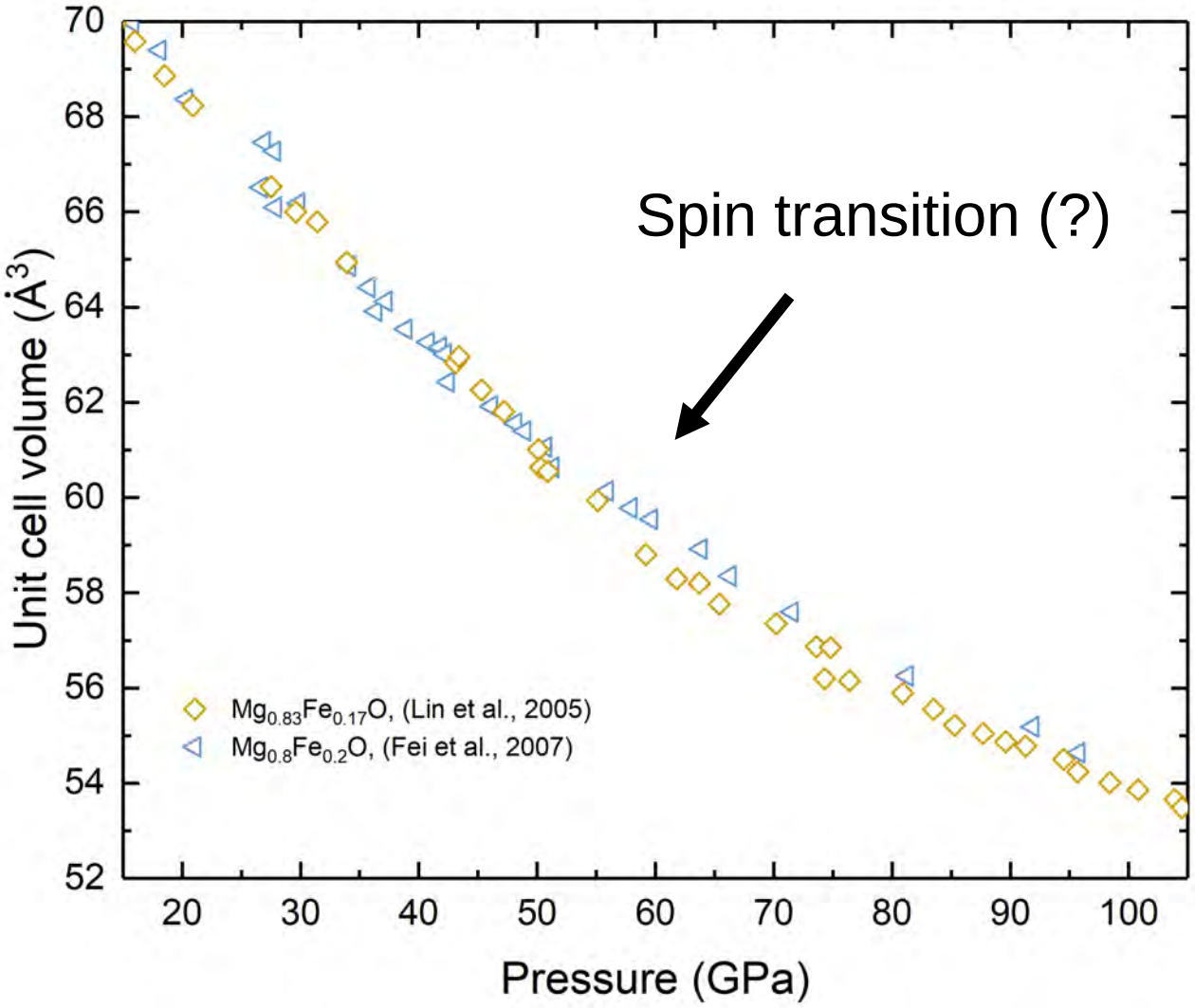
-> Bulk modulus is the key parameter!



Previous Light Scattering Studies

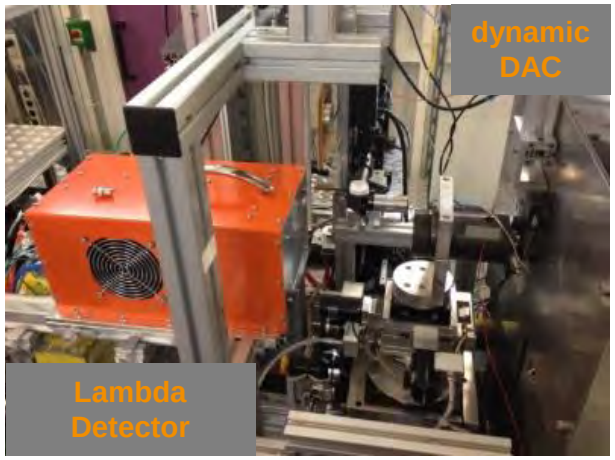
-> time-consuming
-> poor agreement
-> low Fe
-> NO high-temperature

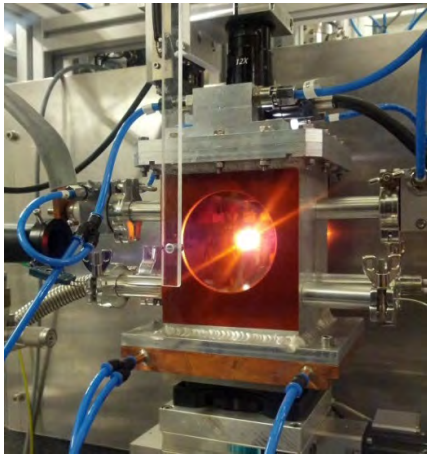
V(P) data from traditional (static) DAC experiments



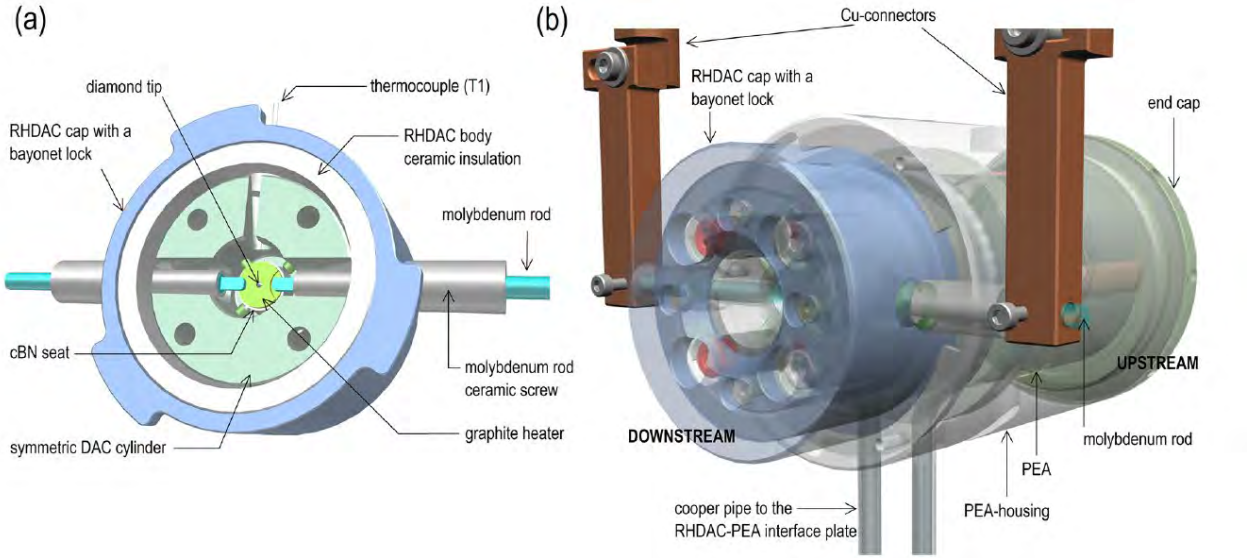
$K = -V\, dP/dV$

Time-resolved XRD in (dynamic) DAC





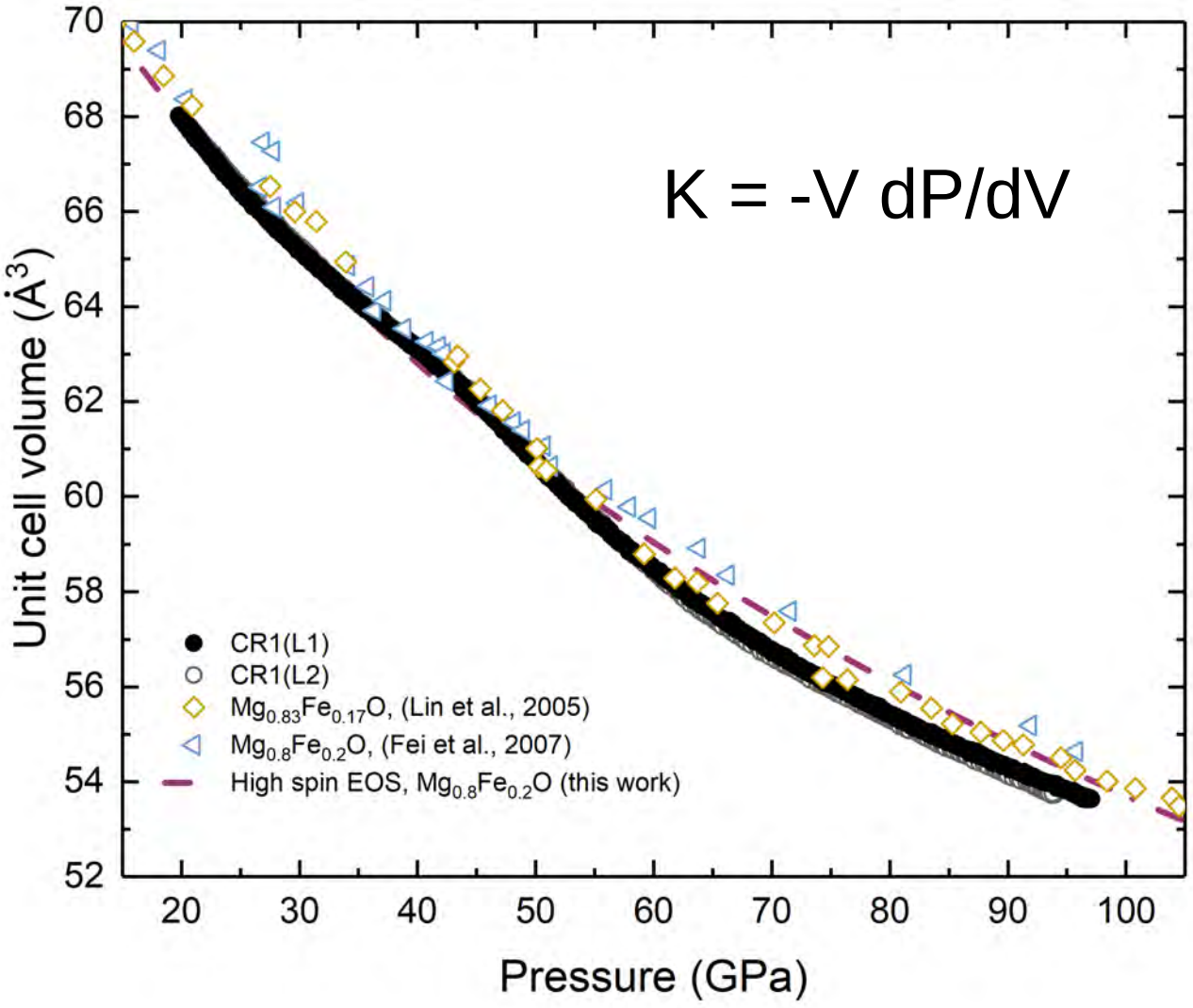
PhD work Alba San José Méndez



Jenei et al., RSI, 2019;

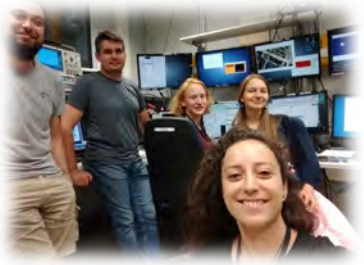
Mendez et al., RSI, 2020

V(P) data from time-resolved (dynamic) DAC experiments

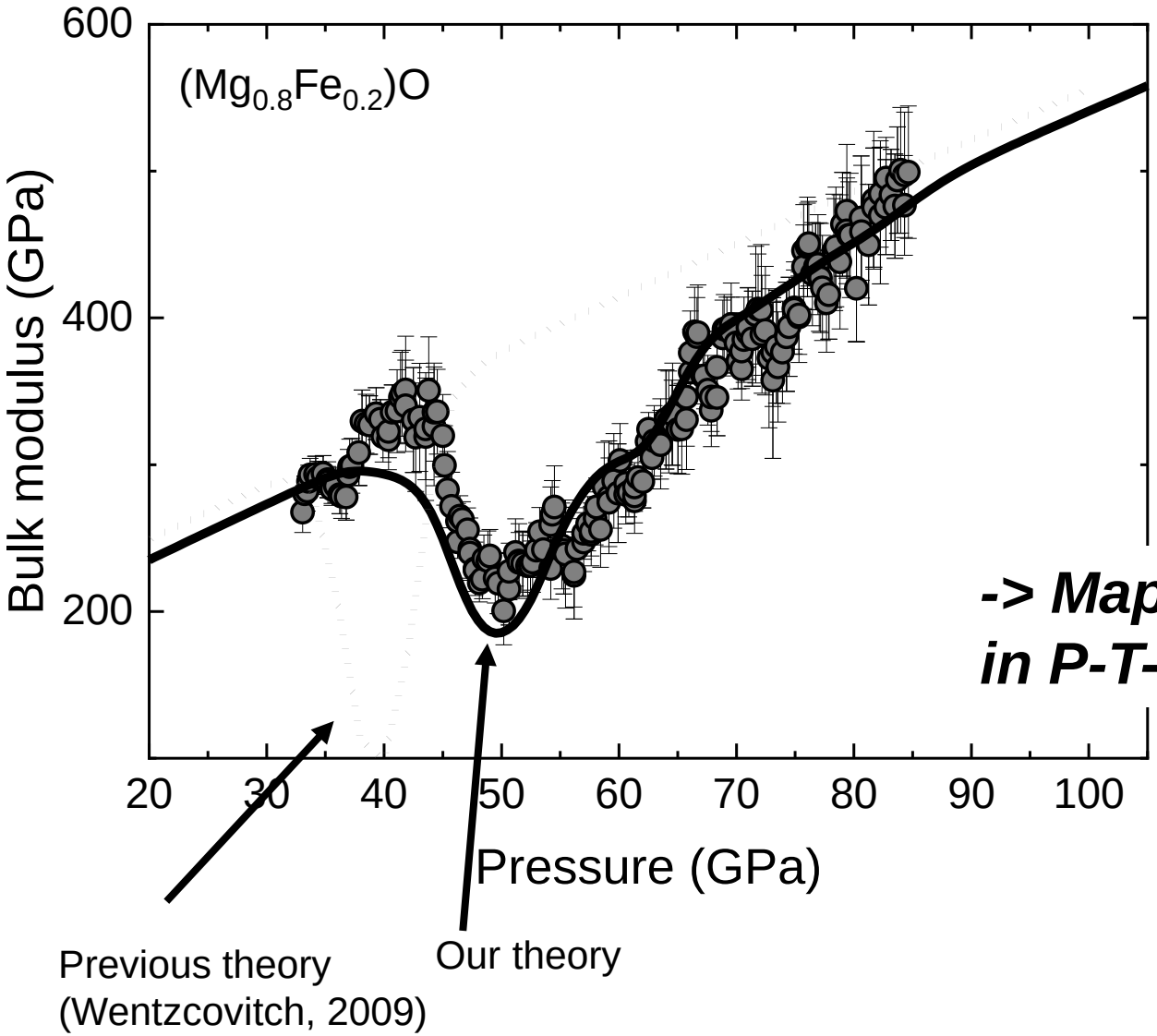


$K = -V\, dP/dV$

⇒ ***Seconds to Minutes***



Bulk modulus softening in $(Mg_{0.8}Fe_{0.2})O$

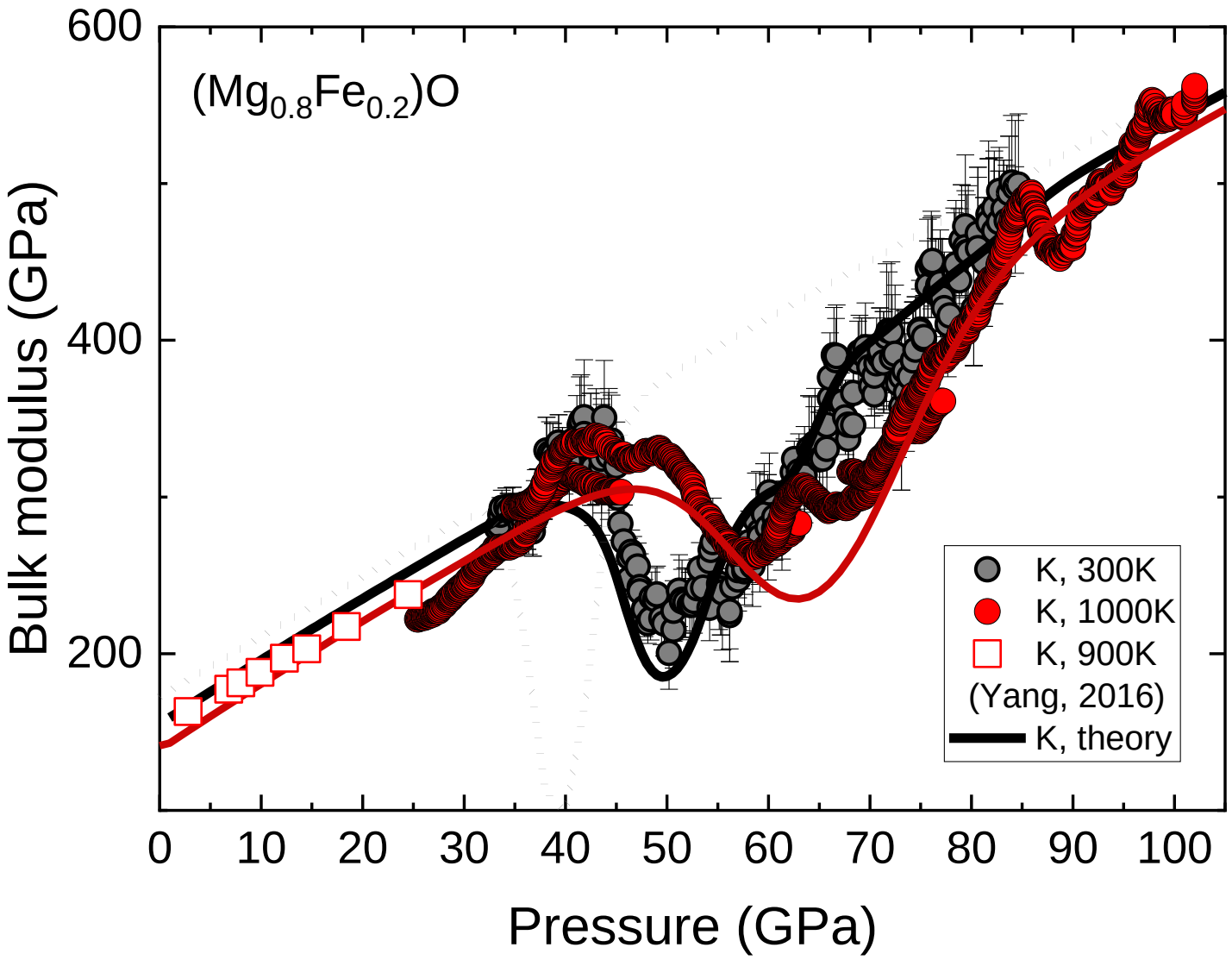


Theory in collaboration with
Stephen Stackhouse, Leeds

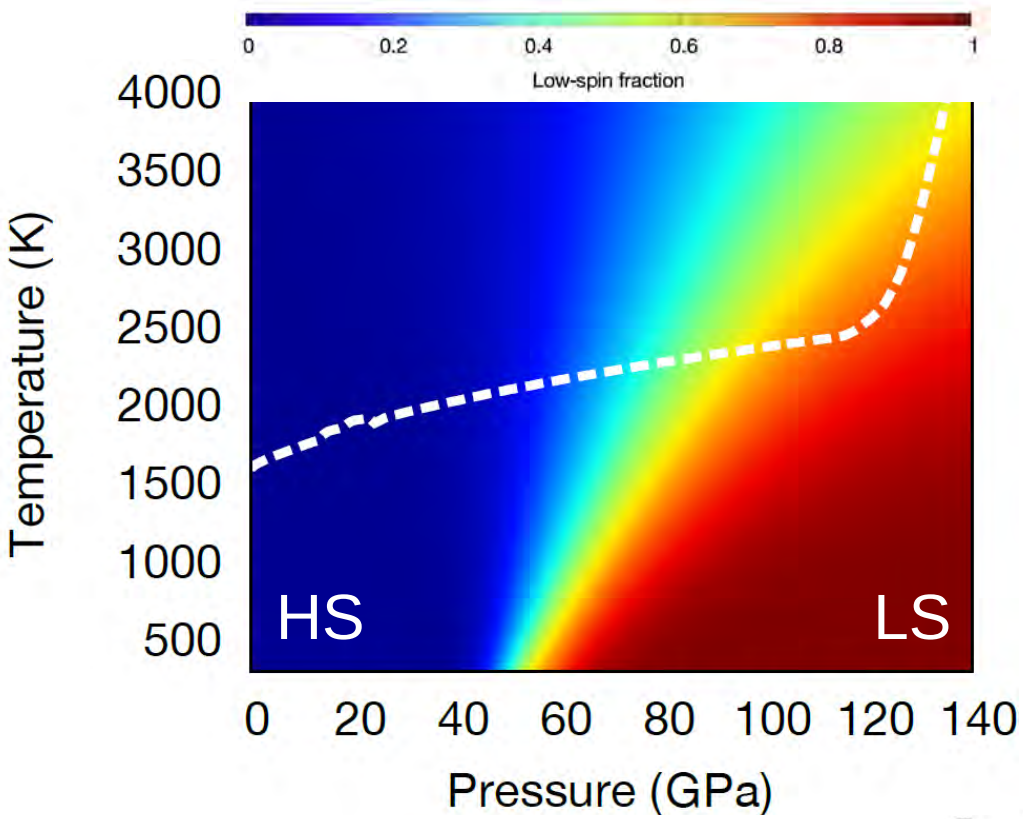
-> Mapping of K softening in P-T-X_{Fe}-space

Mendez et al., EPSL, in review

Bulk Modulus Softening in $(Mg_{0.8}Fe_{0.2})O$ at High Temperature

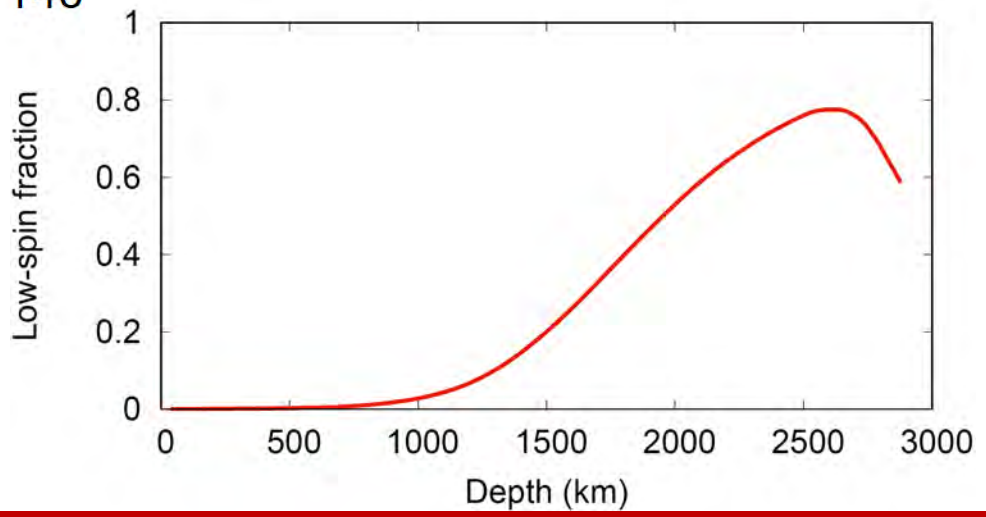


The iron spin crossover in Earth‘s lower mantle



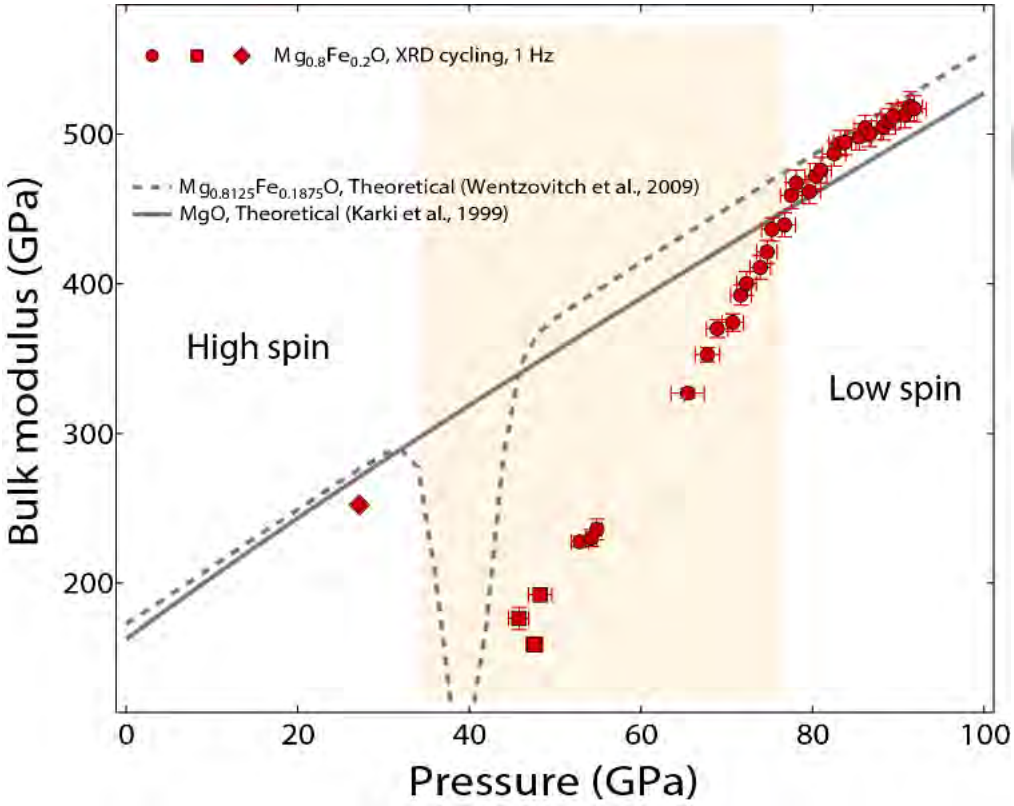
Mixed-spin dominant in LM

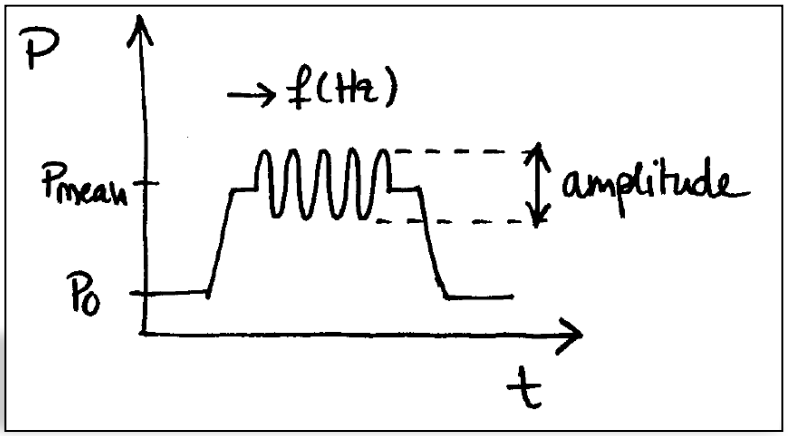
-> Bulk modulus
-> Viscosity
-> Thermal transport properties
-> Electrical conductivity
-> Fe partitioning



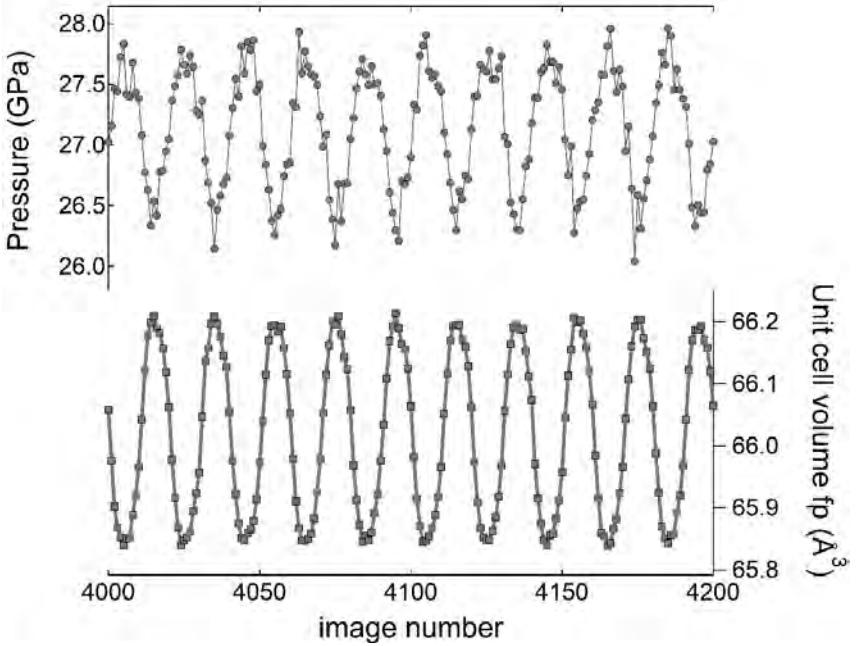
Mendez et al., *EPSL*, in review

Outlook: Stress Cycling Experiments





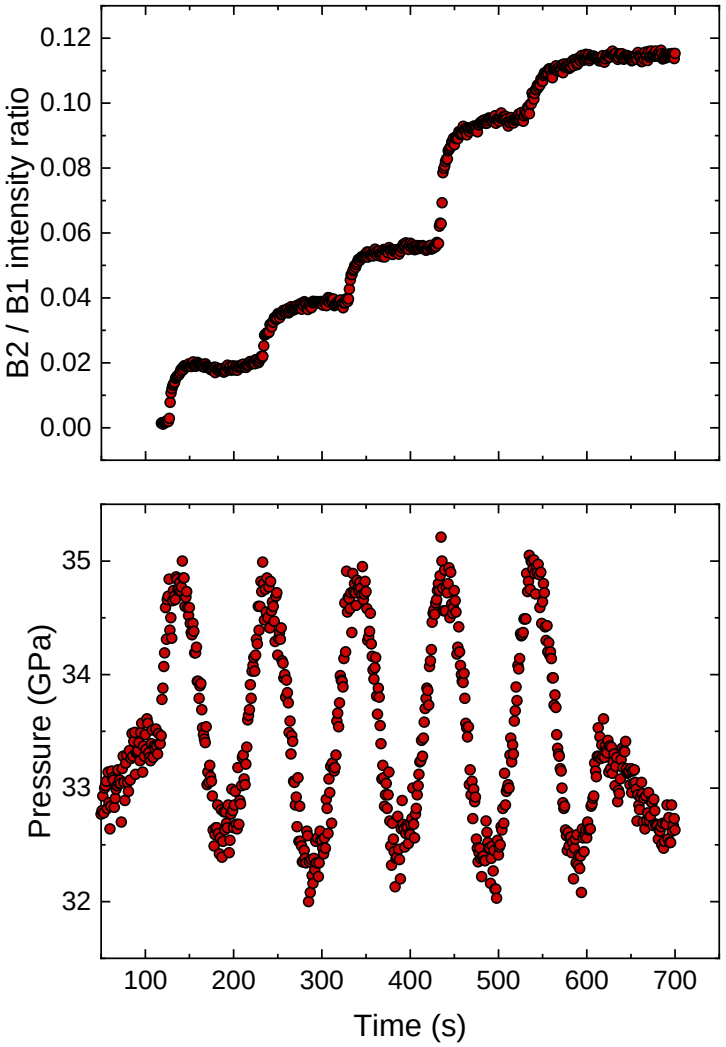
1 Hz cycling, single data point: 50ms



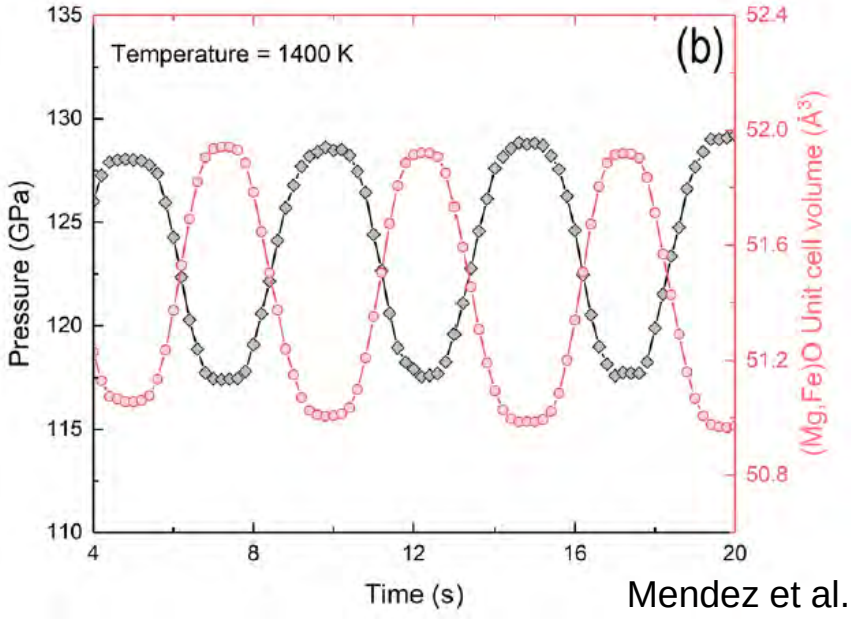
Marquardt et al., *GRL*, 2018

Outlook: Stress Cycling Experiments

B1-B2 transition in NaCl (work in progress)



Stress Cycling at 125 GPa and 1400 K



Mendez et al., *RSI*, 2020

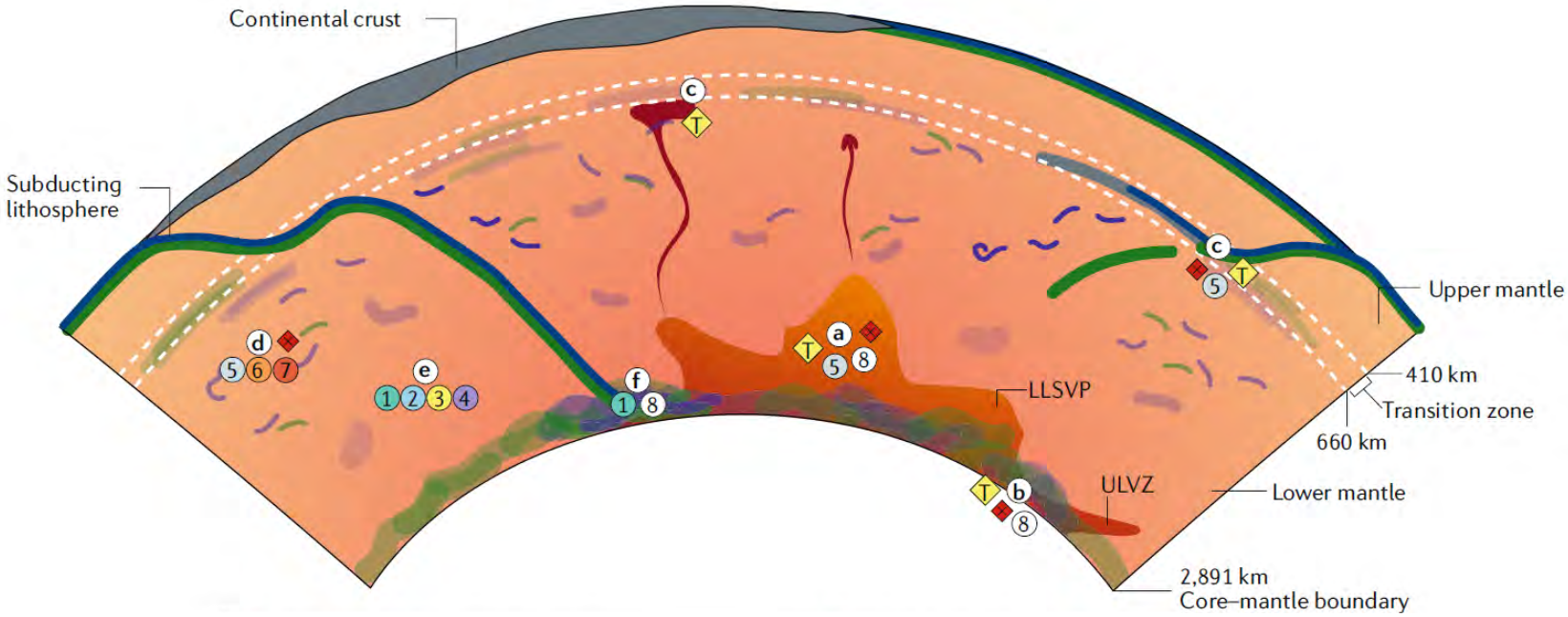
DEEP-MAPS

<u>Cycling experiments (outlook)</u>

-> *K* (*P*,*T*,*f*)
-> possibility to look for „resonant“ frequencies (e.g. coupling of seismic waves to phase transitions)

Towards Continuous Maps of Mantle Seismic Properties

Marquardt & Thomson, *Nature Reviews Earth & Env.*, 2020

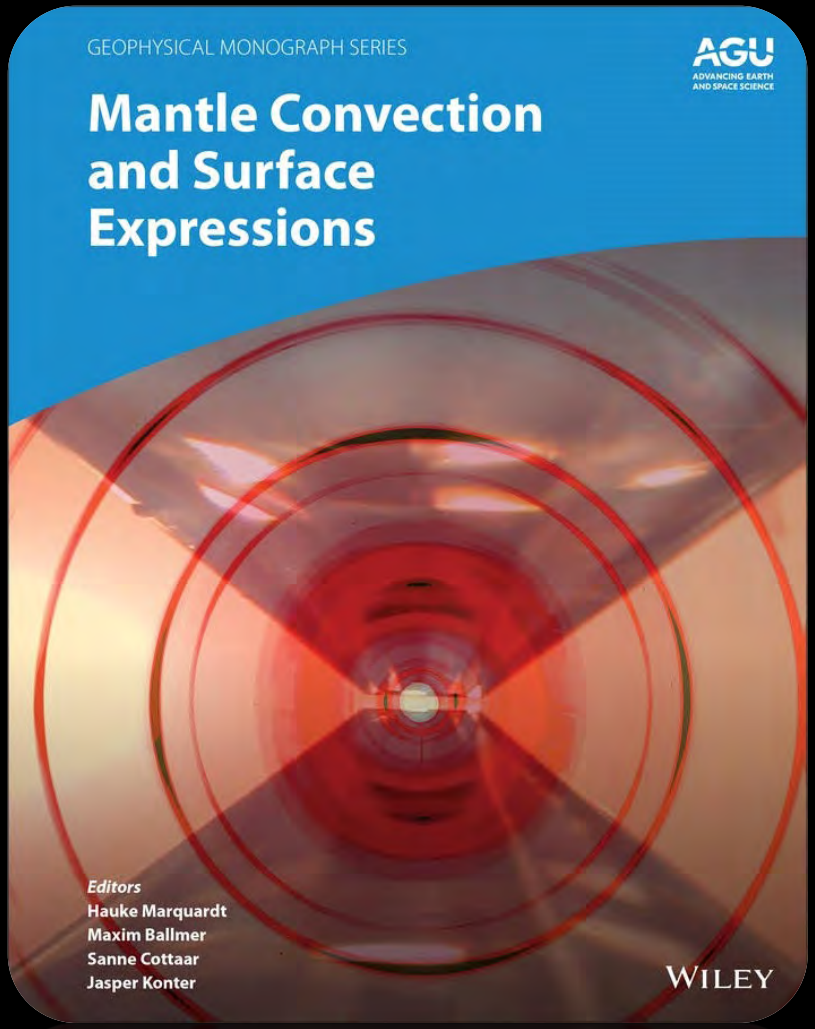


Potential of time-resolved XRD experiments:

- „Continuous“ maps of mantle seismic properties in *P*,*T*,*C*-space
- Direct monitoring of bulk modulus (and density) across phase transitions in *P*,*T*,*C*-space
- Time-/frequency-dependence of processes (e.g. phase transitions), „resonant frequencies“

erc

DEEP-MAPS



Thanks to

Alba San Josè Méndez
Viktoria Trautner
Biao Wang

Stephen Stackhouse
Hanns-Peter Liermann
Niccolo Satta
Rachel Husband
Johannes Buchen

erc

DEEP-MAPS

UNIVERSITY OF OXFORD

DESY