Abstract

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Characterization of ferropericlase under extreme condition using shock wave experiments carried out at European XFEL utilizing DiPOLE100-X drive laser

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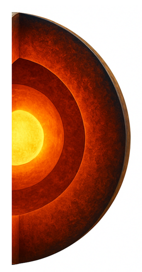
1 Motivation



- $(Fe,Mg)O$ is the second most abundant mineral in Earth's mantle.
- Spin transition information at high pressure obtained with shock experiments is still lacking.
- Information for $(Fe,Mg)O$ at conditions close to the CMB are still incomplete.

2 European XFEL Facility

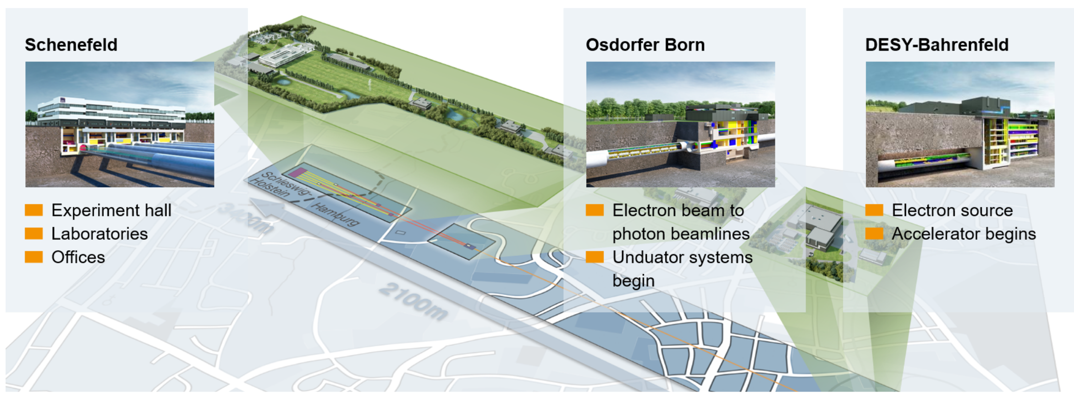


Fig 1.Facility overview

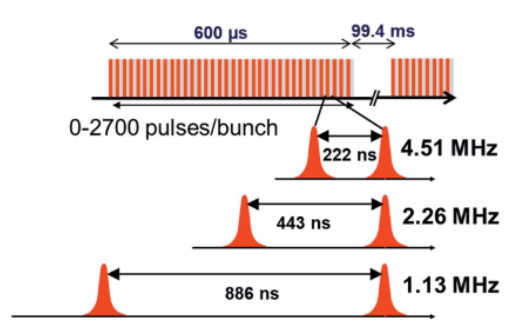
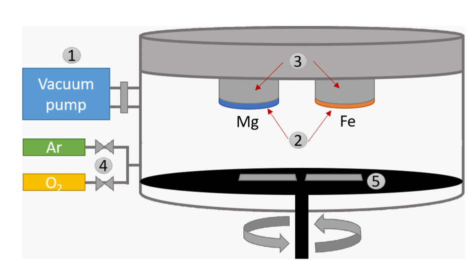


Fig 2.Bunch pattern of European XFEL (Zastrau et al. 2021)

- The European XFEL can produce 27 000 X-ray laser flashes per second
- Bunch trains: up to 4.5 MHz repetition rate
- 7 Instruments and three independent undulator systems that serve

3 Sample preparation and Characterization

- Sample synthesis using Physical Vapour Deposition (PVD)



(1) vacuum pump
(2) Fe and Mg cathodes
(3) magnetrons
(4) a gas injection system
(5) substrates on a rotating holder

Fig 3. Schematic diagram of the PVD system and the PVD machine at IMPMC: (credit to Buakor, K.).

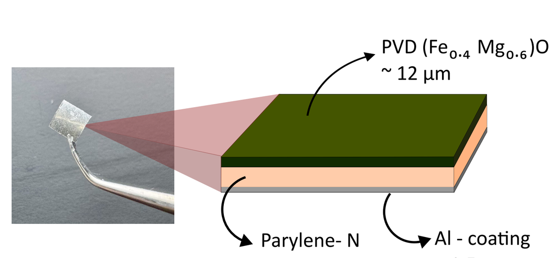


Fig 4. Ferropericlase PVD target layers.

- SEM- analysis

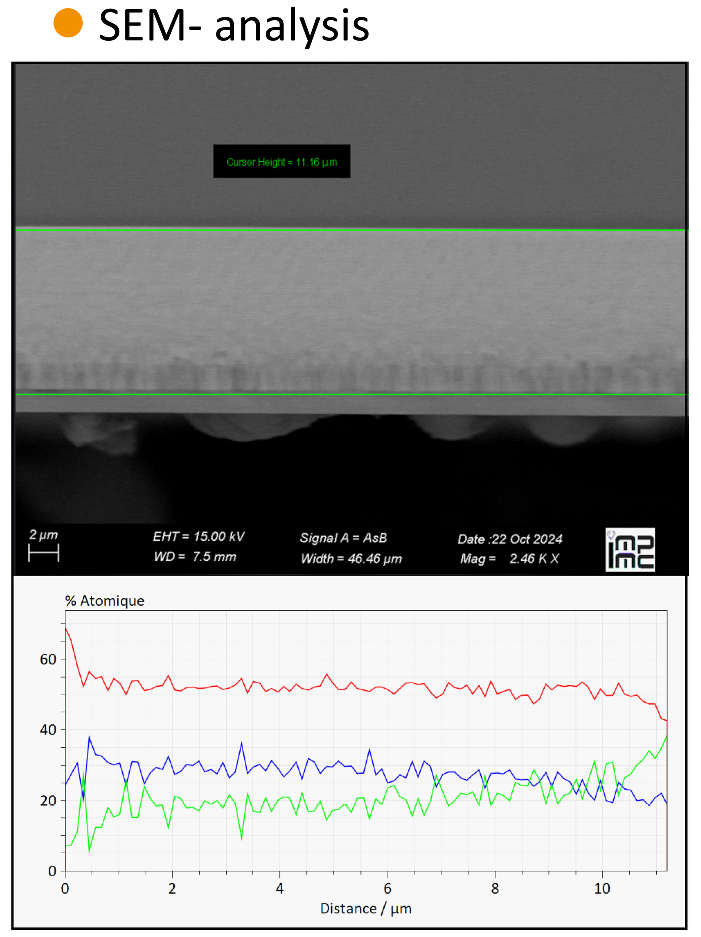


Fig 5. SEM analysis for PVD target, showing the composition for $(Fe,Mg)O$ and the thickness. (Red= Oxygen; Blue= Iron; Green= Magnesium)

4 Shock wave experiment

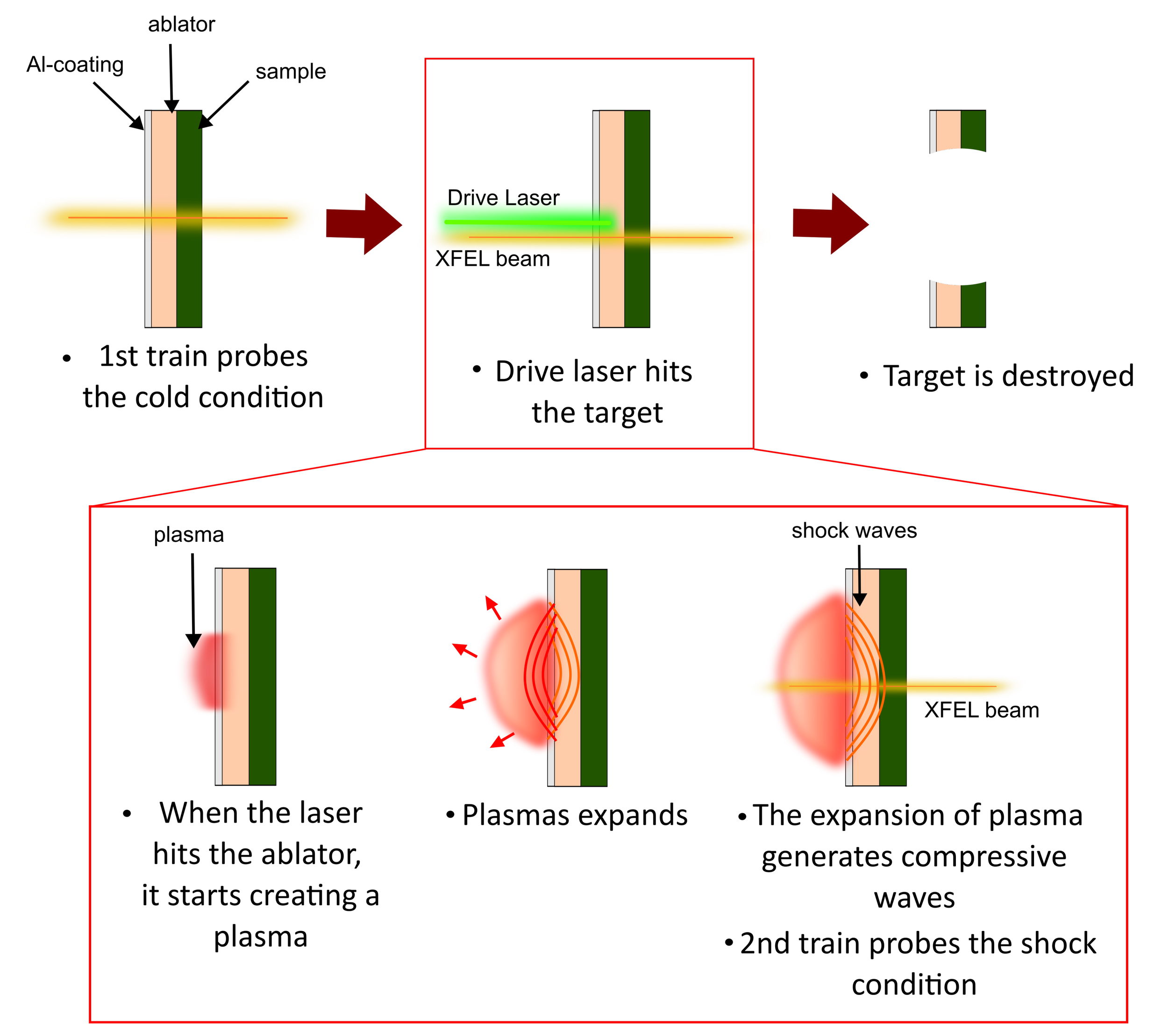


Fig 6. Schematic diagram illustrates the experiment: first, the DiPOLE laser drives the shock wave into the sample, and a few nanoseconds later, the X-ray beam probes the compressed material.

5 Setup: Time-resolved experiment

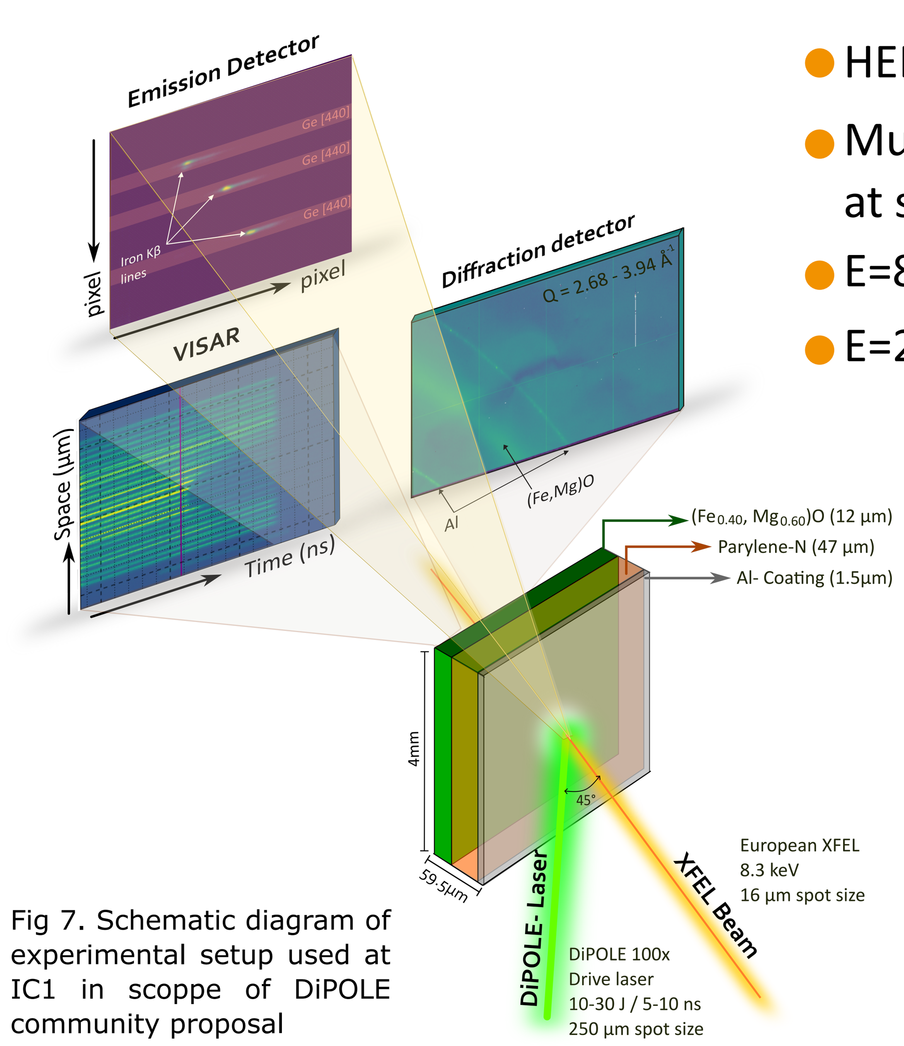


Fig 7. Schematic diagram of experimental setup used at IC1 in scoppe of DiPOLE community proposal

- HED Instrument
- Multiple diagnostics at same time
- E=8.3 keV (p.6656)
- E=24 keV (p.6746)

6 Velocity interferometer system for any reflector (VISAR)

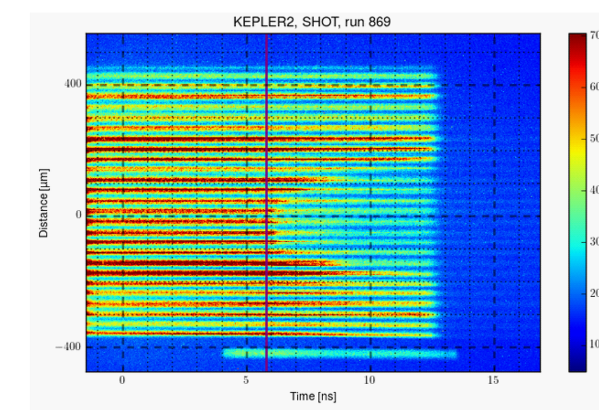


Fig 8. VISAR image from 6656 experiment (run 869). Laser energy was set at 28.4 J and with a 6.3 ns delay between the drive laser and X-ray probe. The purple line shows FEL X-rays probing time.

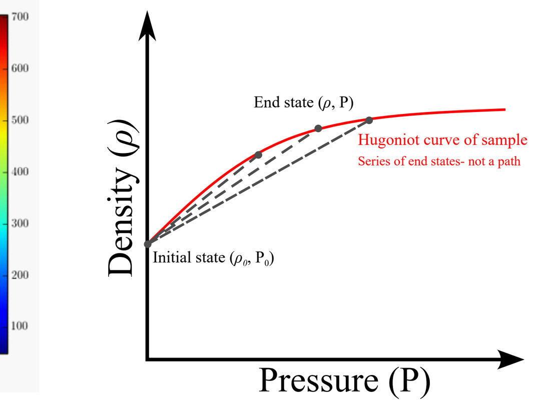


Fig 9. Example of Hugoniot curve showing the energy scan that we applied in this study. The Hugoniot curve can be calculated from VISAR analysis using shock velocity, particle velocity and breakout time.

7 X-ray Emission Spectroscopy (XES)

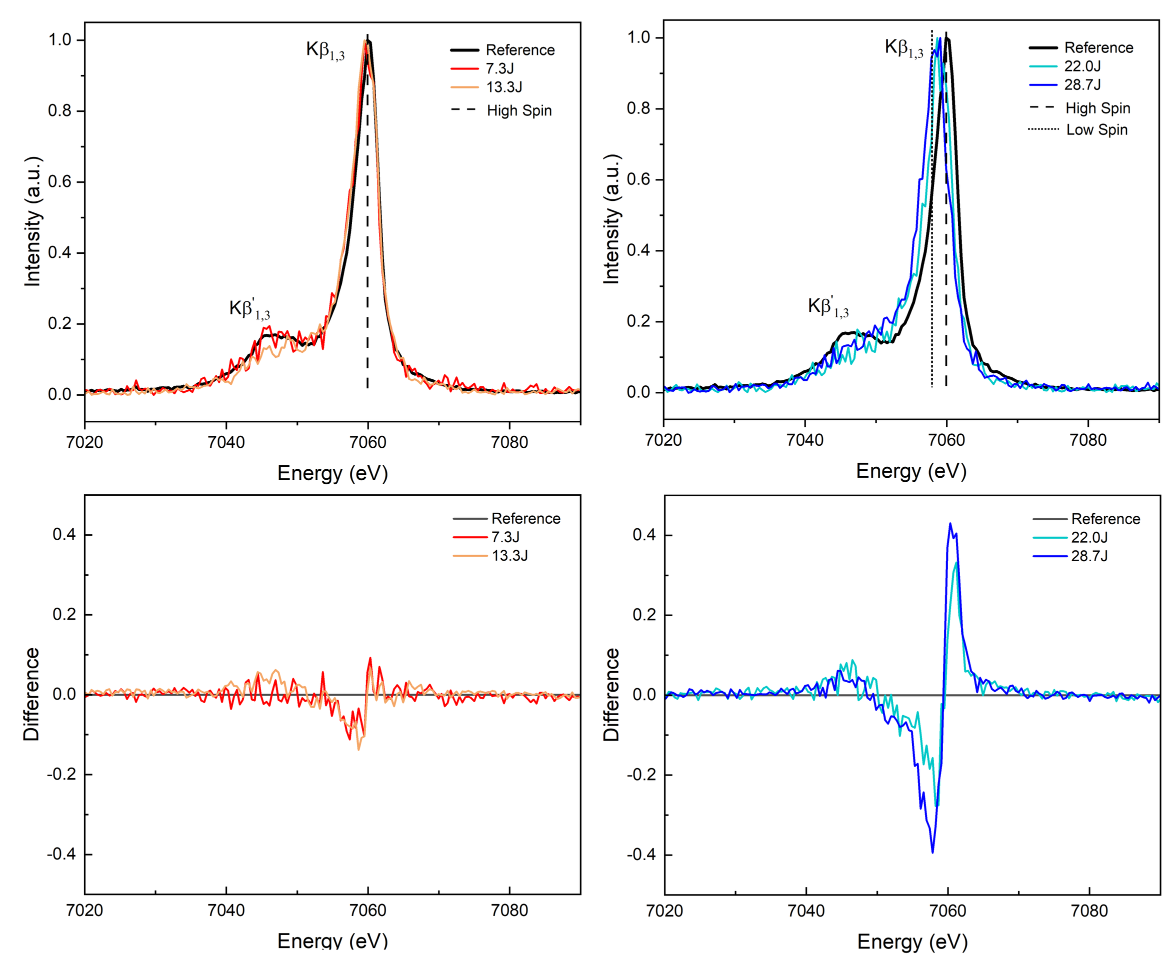


Fig 10. XES spectra showing the Fe-Kβ lines (upper insets) and the difference of the spectra (bottom insets). Left side shows the high spin state and right side shows the low spin state, which is indicated by the shift of Kβ towards low energies and the broadening of the Kβ'.

8 X-ray Diffraction (XRD)

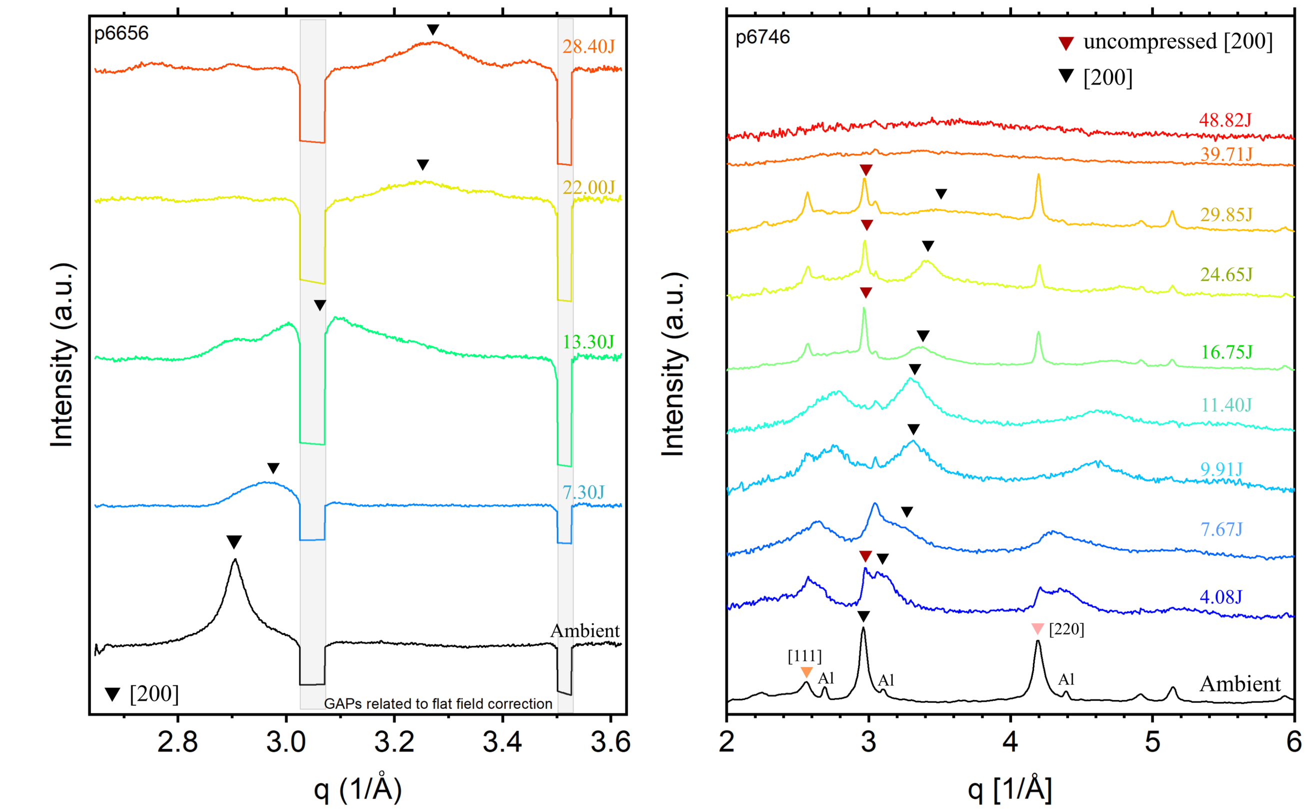


Fig 11. XRD energy scan patterns from two different experiments conducted at the HED instrument. Left: DiPOLE community proposal 6656; Right: Proposal 6746 (PI: Celine Crepisson). The patterns show the shift of the $(Fe,Mg)O$ peaks to high Q, while the energy increases up to 29.85 J. At higher energies, above 29.85 J, a possible liquid (or amorphous?) phase is observed. The structure of $(Fe,Mg)O$ remains cubic- B1 until the melt.

9 Preliminary Pressure Evaluation

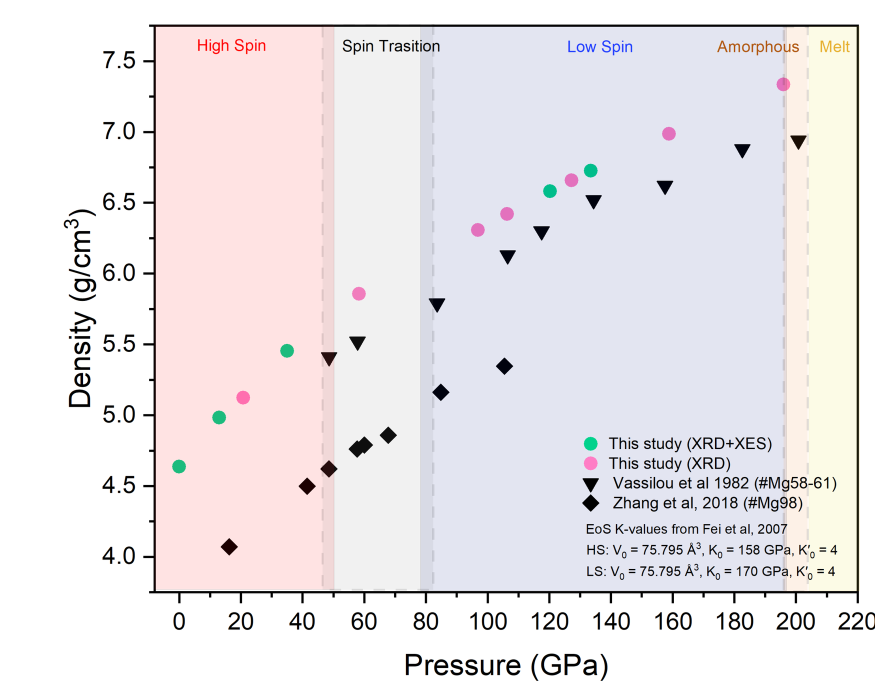


Fig 12. Based on our first results combined with EoS (Fei et al, 2007) we can estimate the pressure that we got for each shot conditions, as well get a curve of ρ X P, with information about the spin transition in the Earth's interior. This plot also shows the comparison between our data and others shock compression experiments (Vassilou et al 1982 and Zhang et al 2018).

10 Key points

- Ferropericlase is one of the most abundant minerals in the mantle. Understanding the properties of this material is crucial to unravel our planet dynamics
- Besides simulations, high pressure experiments are the only way to study lower mantle minerals.
- Spin state changes can justify the non-linear density curve.
- Density variation is directly related to seismic wave velocities, which could give deeper insights into for dynamics simulations
- Next step: Analyse VISAR and get the Hugoniot EoS and analyse the structure of the melt.

Reference: Zastrau et al, The HED Instrument a EUXFEL, J. Synchrotron Rad. 28, 1393–1416 (2021)
Fei et al. Spin transition and equations of state of (Mg, Fe)O solid solutions. Geophys. Res. Lett., 34, L17307 (2007)
Vassilou & Ahrens, The equation of state of Mg0.6Fe0.4O to 200 GPa, Geophys. Res. Lett., 9, (1982)
Zhang et al, Spin transition of ferropericlase undershock compression, AIP Advances 8, 075028 (2018)

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