



Single-shot XAS on laser shock compressed Fe-rich alloys: Fe-Ni, Fe-Si and Fe oxides

3rd DyCoMaX workshop 2021

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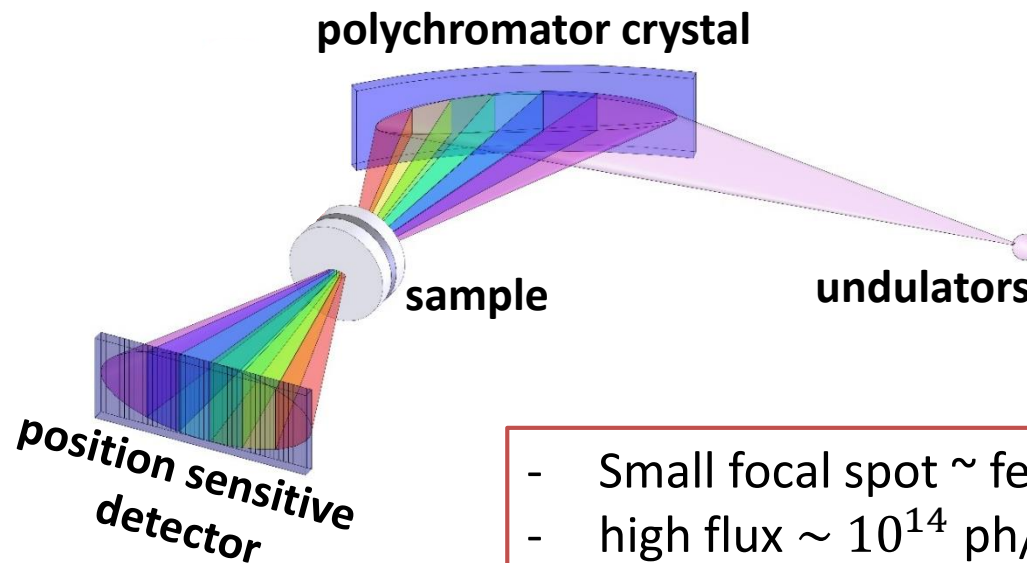
HZDR

 **IAMC**



High Power Laser Facility at ESRF: Timeline

ID 24: Energy dispersive beamline optimized for time-resolved and extreme conditions X-ray absorption spectroscopy

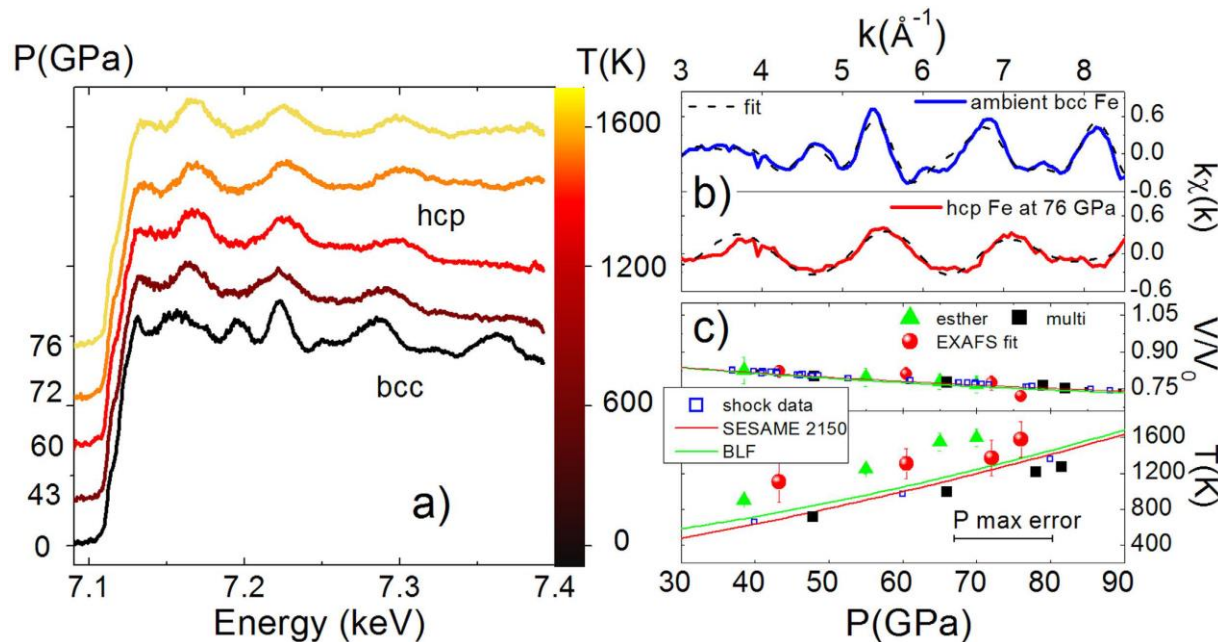


- Small focal spot \sim few μm
- high flux $\sim 10^{14}$ ph/s
- fast (single bunch) acquisition (100ps)

High Power Laser Facility at ESRF: Timeline

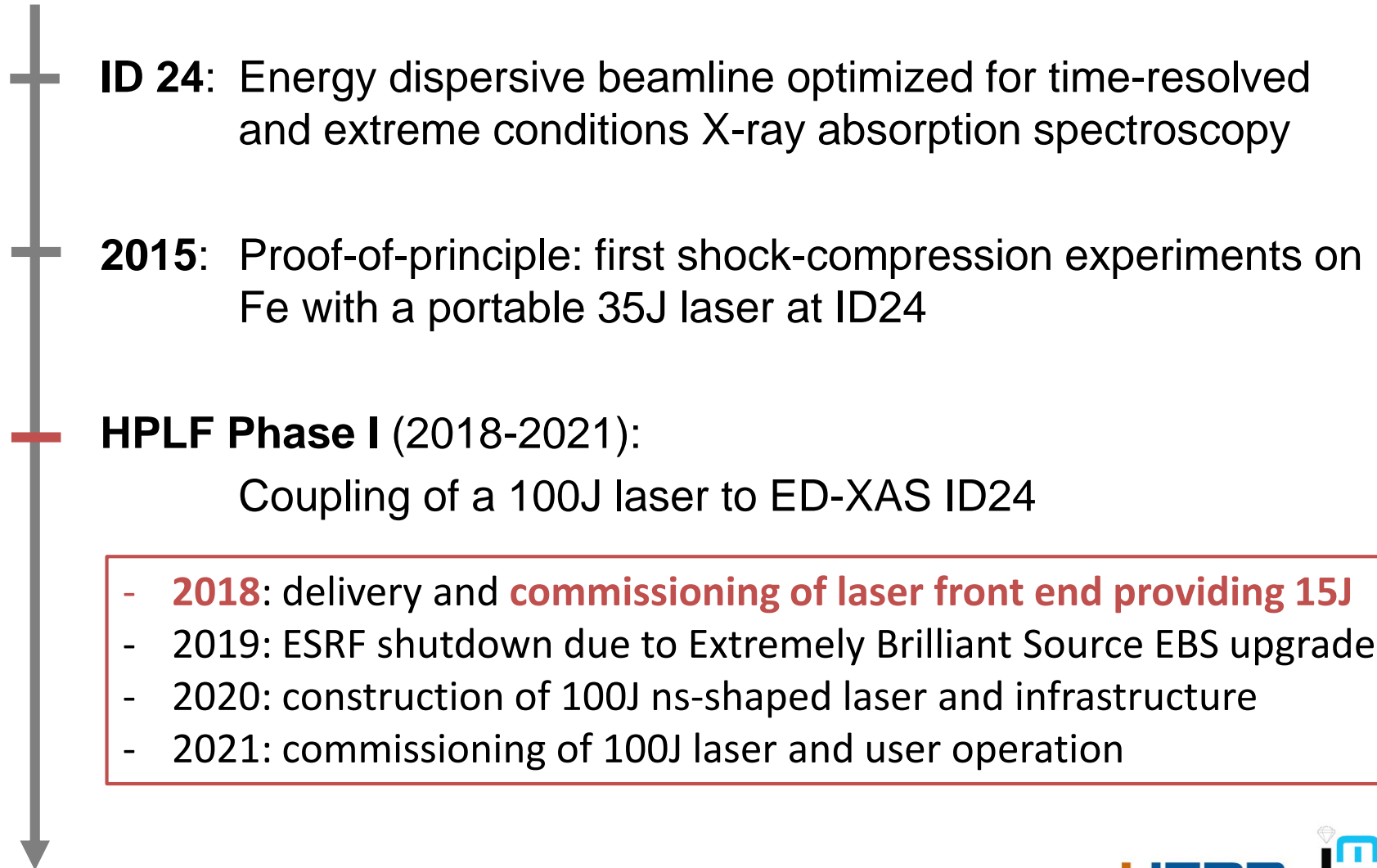
ID 24: Energy dispersive beamline optimized for time-resolved and extreme conditions X-ray absorption spectroscopy

2015: Proof-of-principle: first shock-compression experiments on Fe with a portable 35J laser at ID24

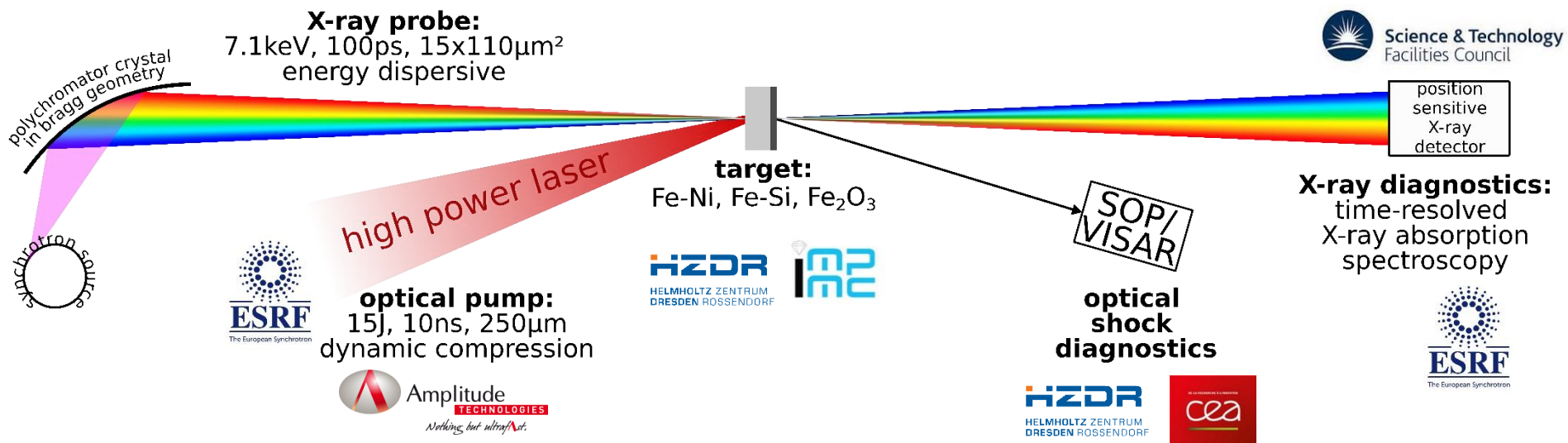


[Torchio, Raffaella, et al. "Probing local and electronic structure in Warm Dense Matter: single pulse synchrotron x-ray absorption spectroscopy on shocked Fe." *Scientific reports* 6 (2016): 26402.]

High Power Laser Facility at ESRF: Timeline



Commissioning Experiment



The Collaboration



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N.J. Hartley
J. Vorberger
D. Kraus

A. Amouretti
M. Harmand
A. Boury
F. Guyot
G. Fiquet



F. Occelli
C. Pepin
A. Sollier



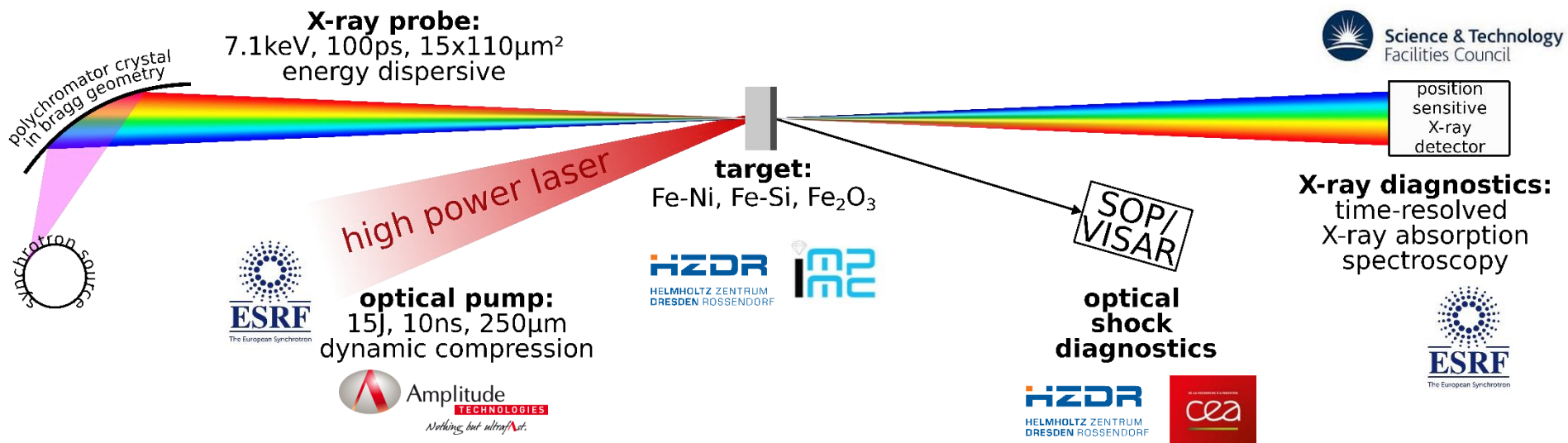
Science & Technology
Facilities Council

W. Helsby
J. Groove
M. Borri

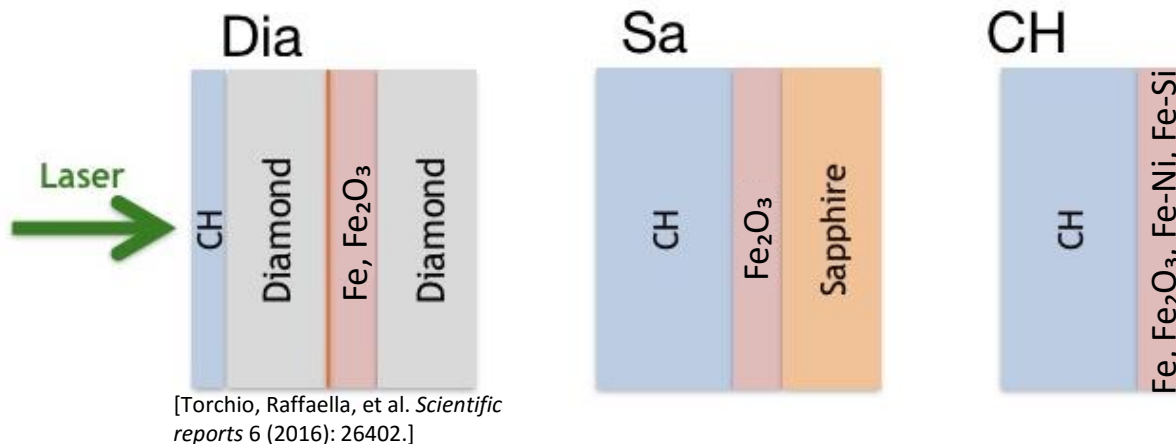
R. Torchio
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G. Berruyer
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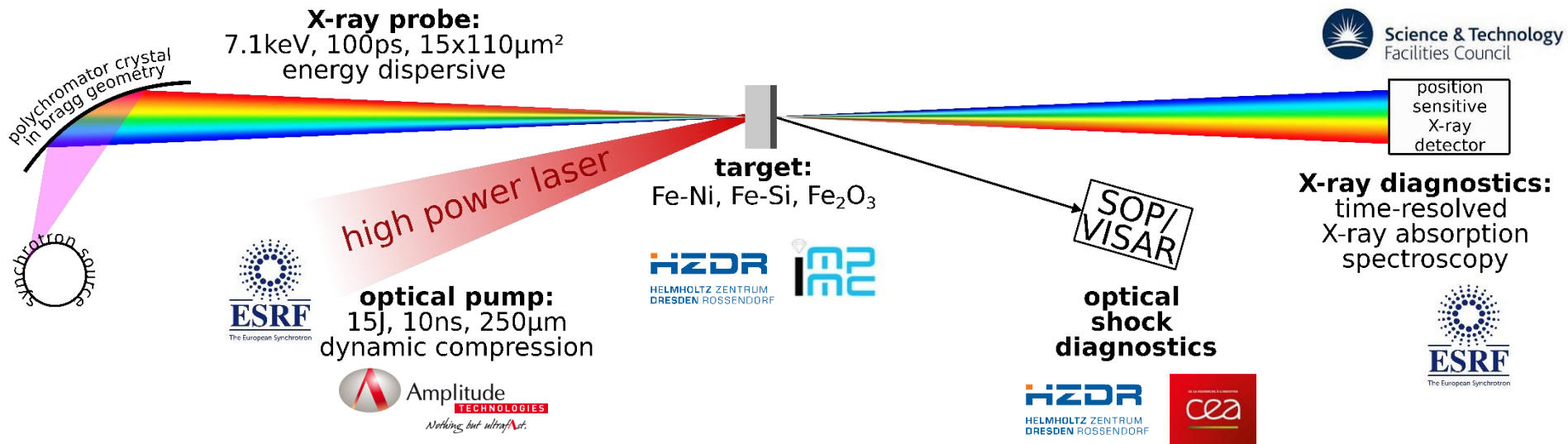
Commissioning Experiment



Targets



Commissioning Experiment



Shot Plan

September:

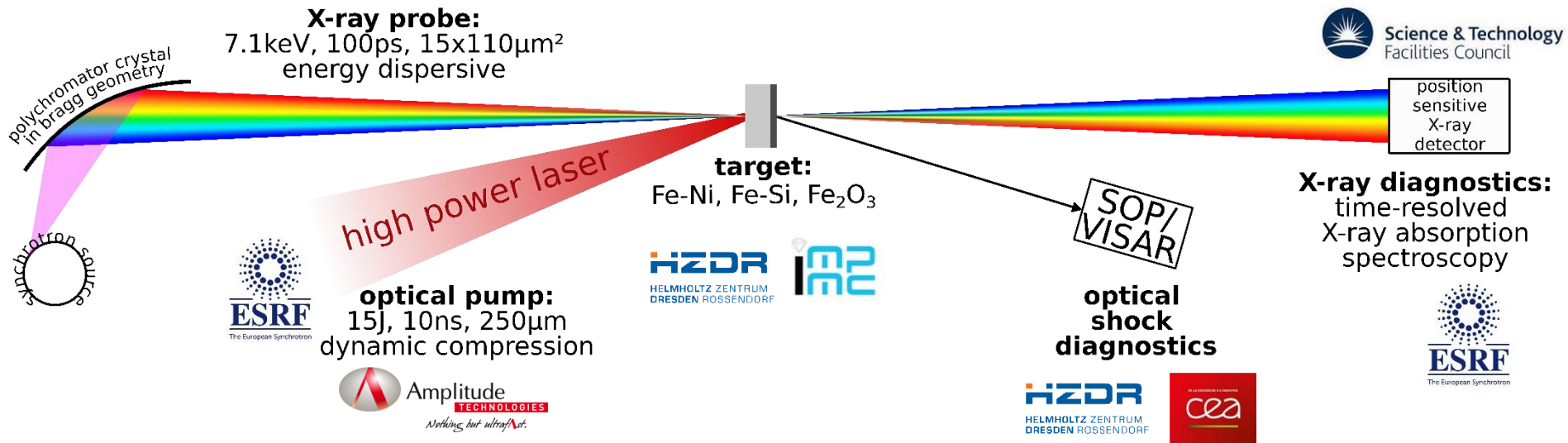
- 4-bunch-mode of synchrotron
- highest number of photons per pulse + largest separation between X-ray pulses
- laser alignment not perfect
-> lower pressure states
- Few shots on pure Fe, Fe-10wt%Ni, Fe-25wt%Ni and FeNiSi

November:

- 7/8+1-bunch-mode of synchrotron
- smaller separation between X-ray pulses
XH detector not at full performance -> lower signal-to-noise ratio
- Series of shots on Fe-3.5wt%Si and Fe_2O_3 for different time delays

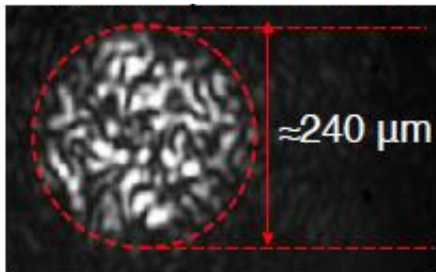


Commissioning Experiment

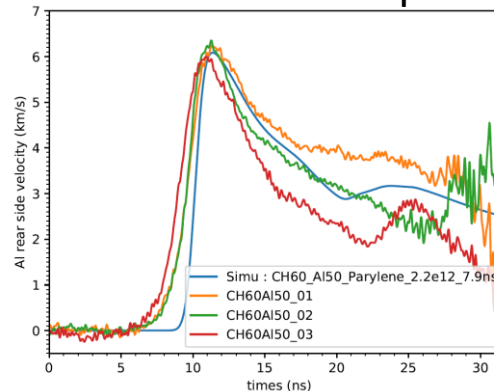


Pressure condition

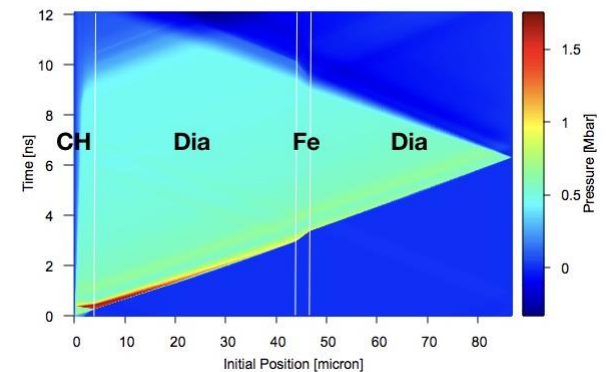
Focal spot of laser
(at 3-5 mJ)



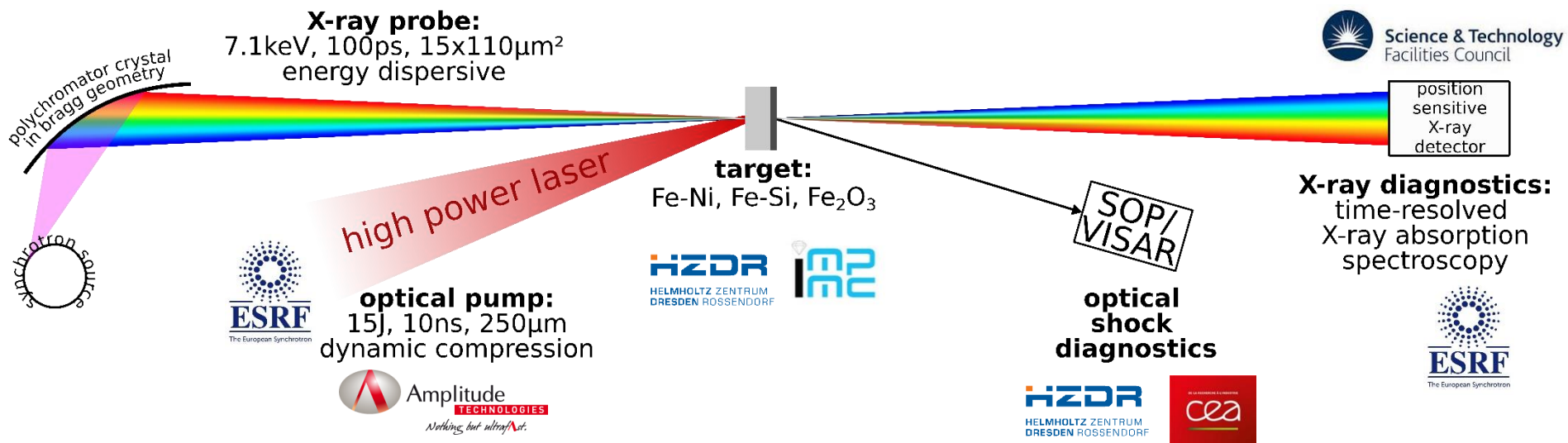
VISAR on Al samples



CH(4µm)/Diamond(40µm)/Fe(2.7µm)/Diamond(40µm)
 $I_{\text{num}} = 2.2 \times 10^{12} \text{W/cm}^2$

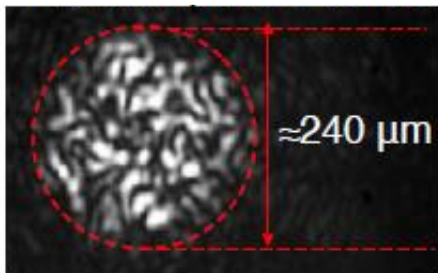


Commissioning Experiment

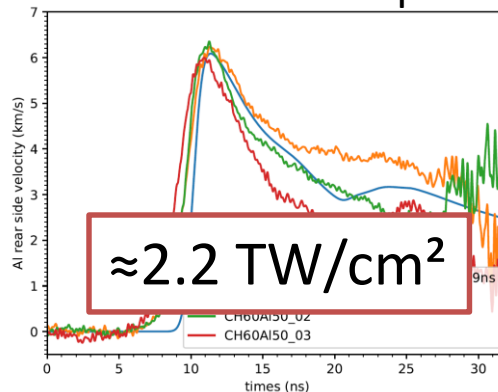


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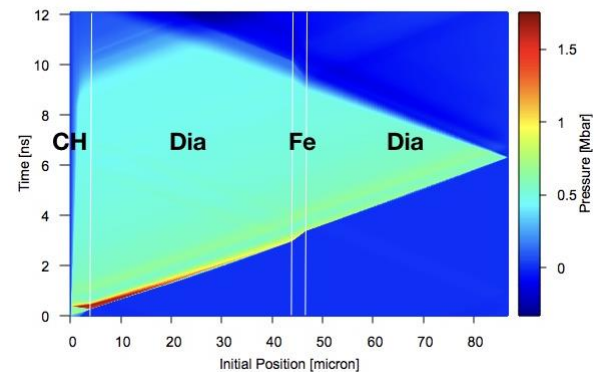
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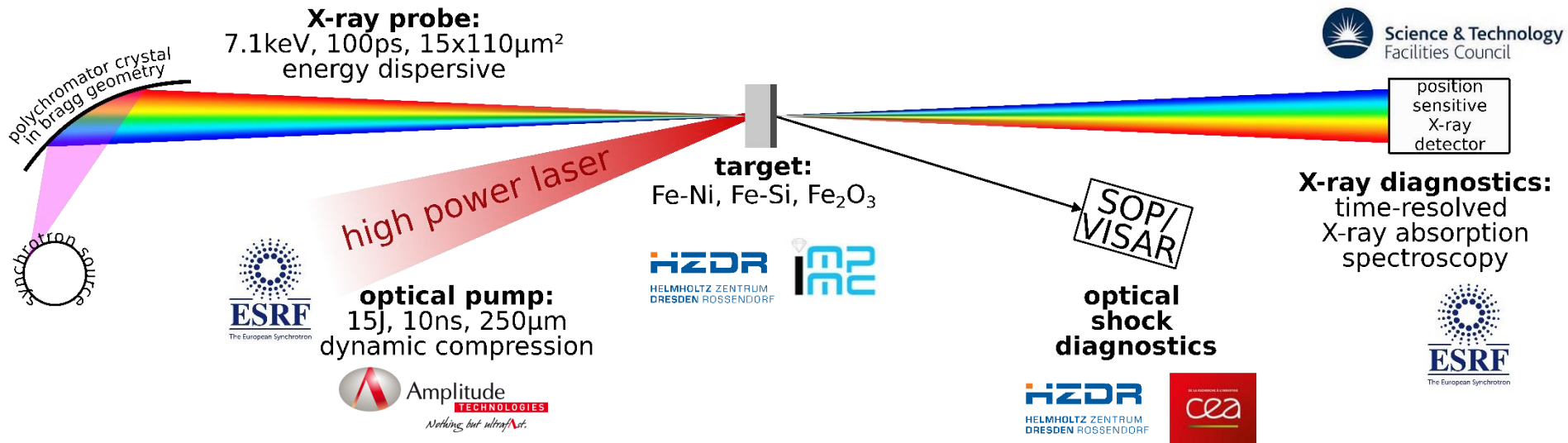
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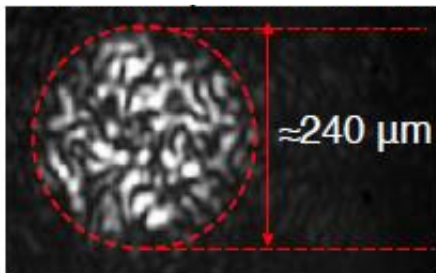


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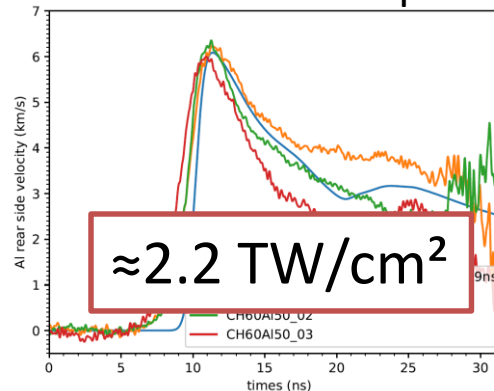


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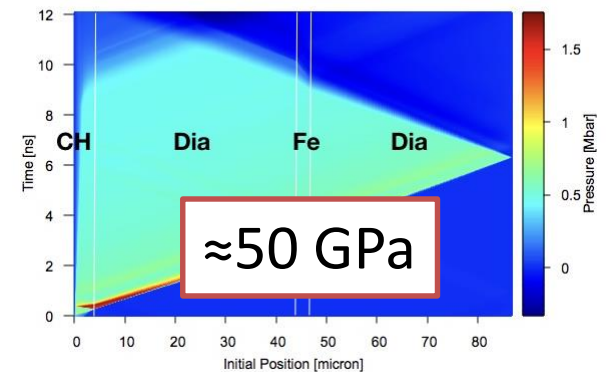
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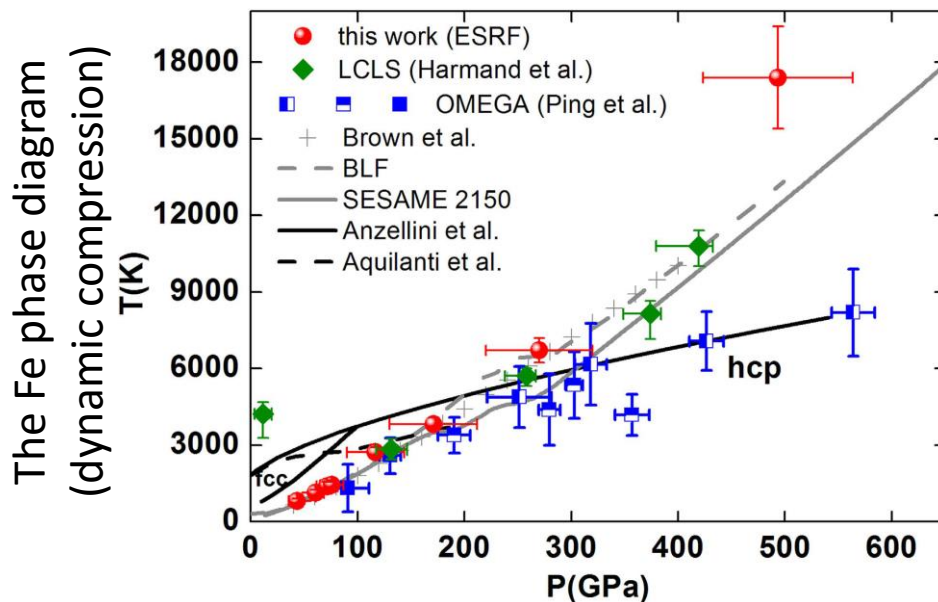
Investigation of bcc-to-hcp transition in Fe-Si and Fe-Ni alloys

hzdr

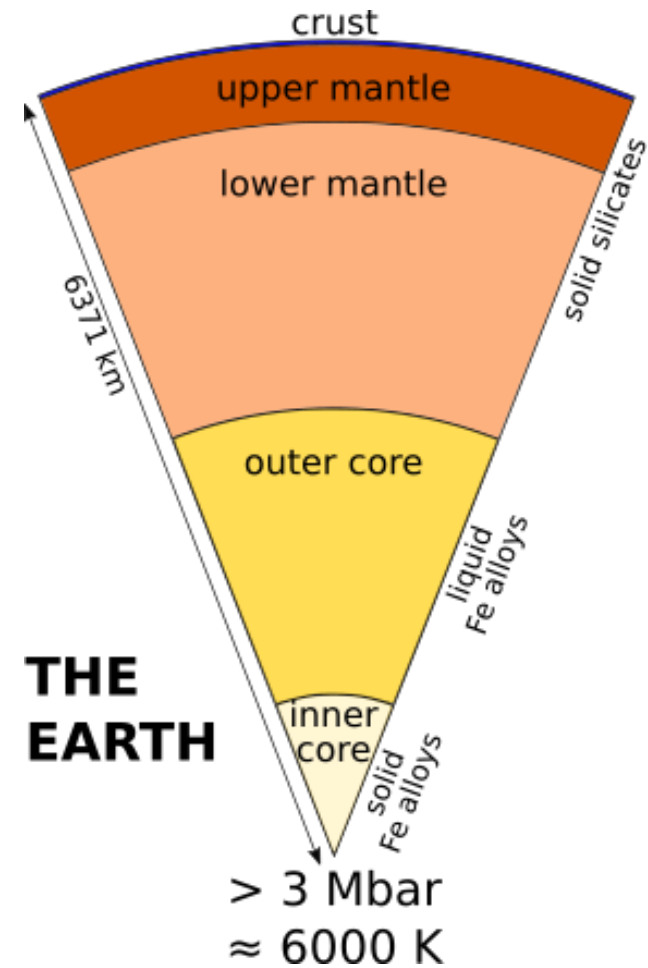
 HELMHOLTZ
ZENTRUM DRESDEN
ROSSENDORF

Fe and Fe rich alloys under extreme conditions

- Understanding of the Earth's and Earth-like exoplanet's core composition and evolution
- The Earth's core mostly consists of Fe, supposedly in an alloy with a substantial amount of Ni
- Seismological studies also suggest the presence of lighter elements (H, C, O, Si, S)
- Influence of minor elements on the Fe phase diagram still not fully understood



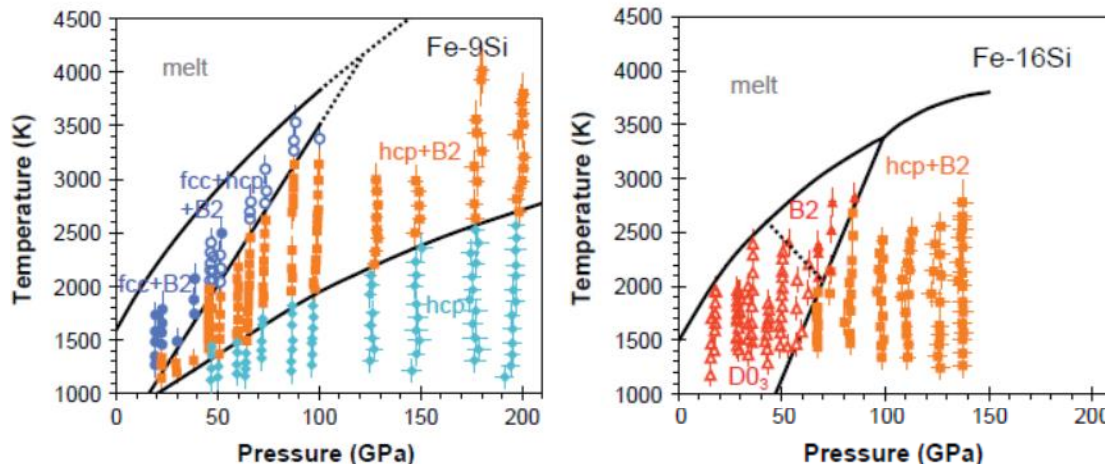
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Fe and Fe rich alloys under extreme conditions

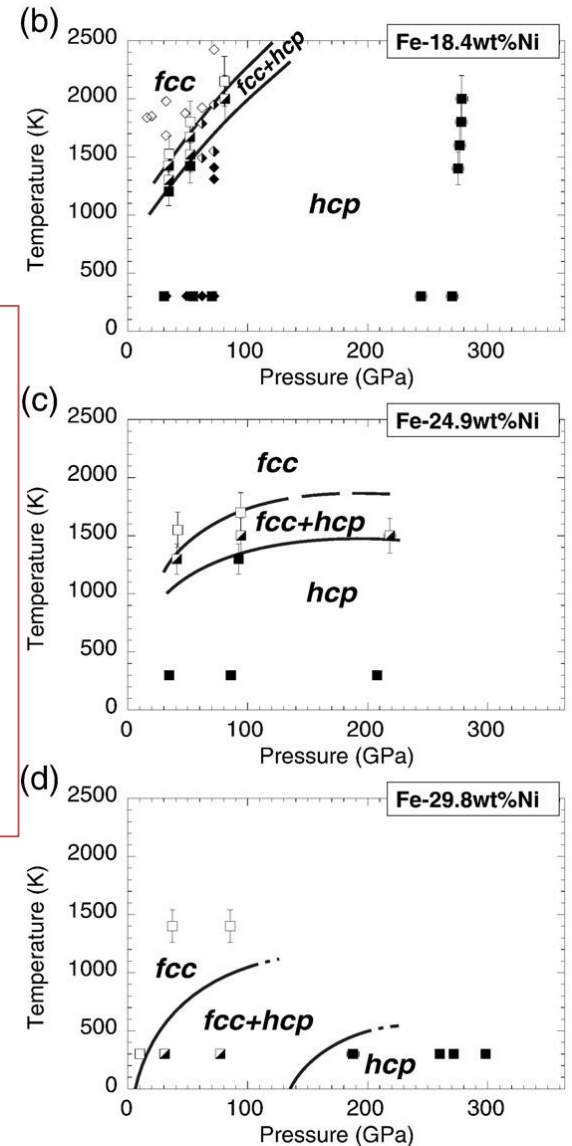
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Fe-Si (static compression)



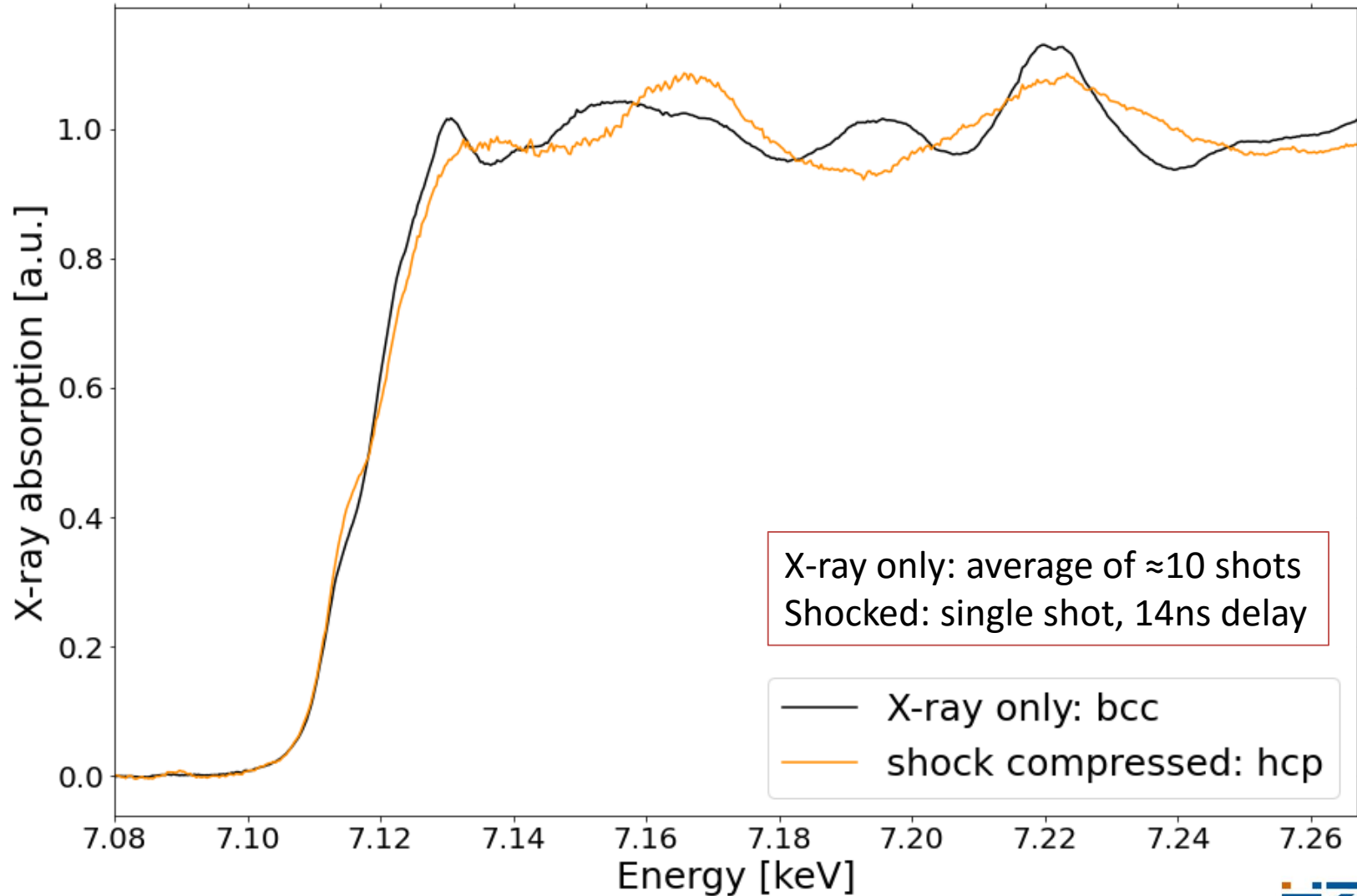
Fischer, R. A. et al. "Phase Relations in the Fe-FeSi System at High Pressures and Temperatures." *Earth and Planetary Science Letters* 373, 54–64 (2013)

Fe-Ni (static compression)

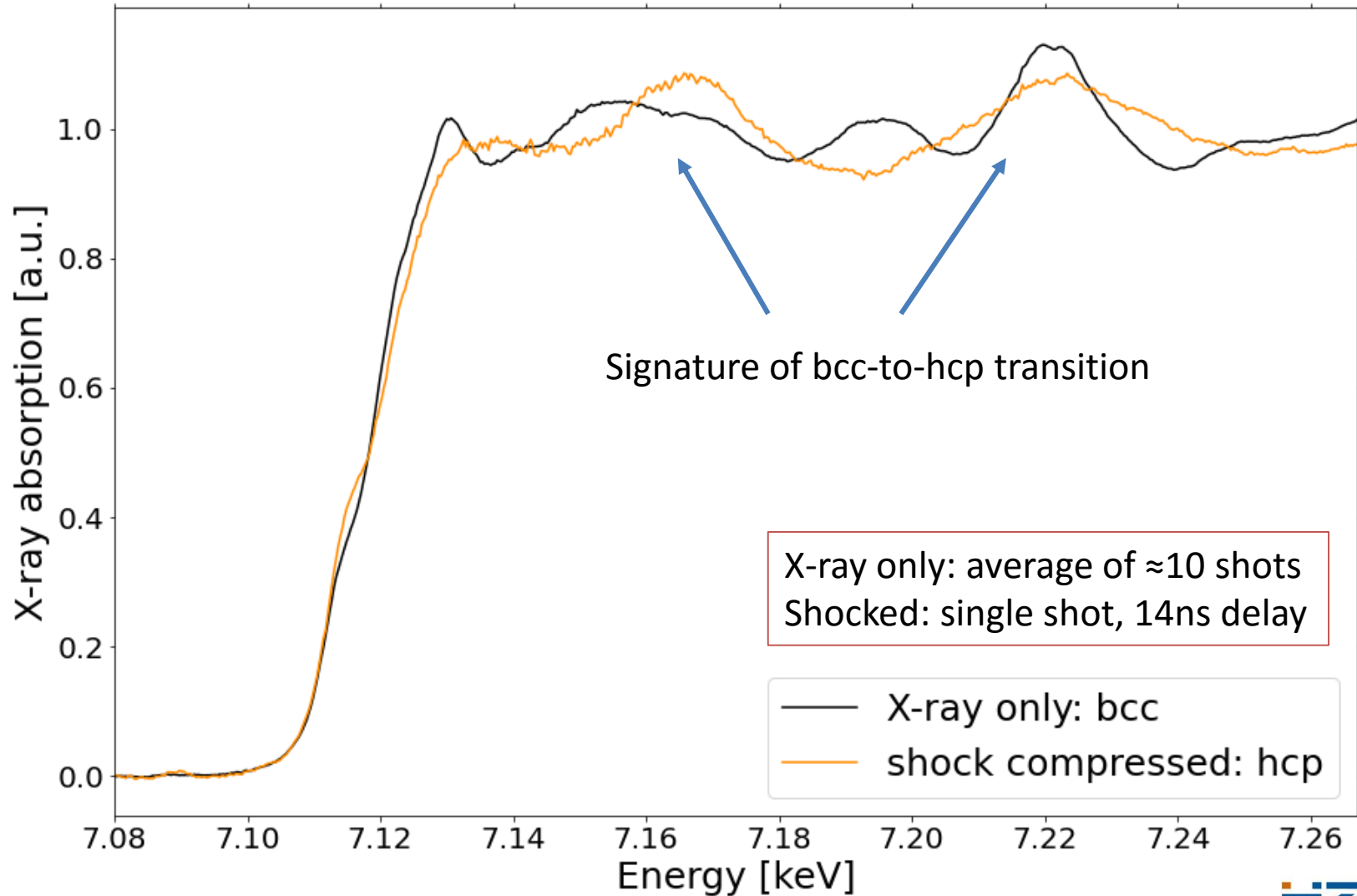


Kuwayama, Yasuhiro, et al. "Phase relations of iron and iron–nickel alloys up to 300 GPa: Implications for composition and structure of the Earth's inner core." *Earth and Planetary Science Letters* 273.3–4 (2008): 379–385.

Bcc-to-hcp transition in shocked Fe-10wt%Ni

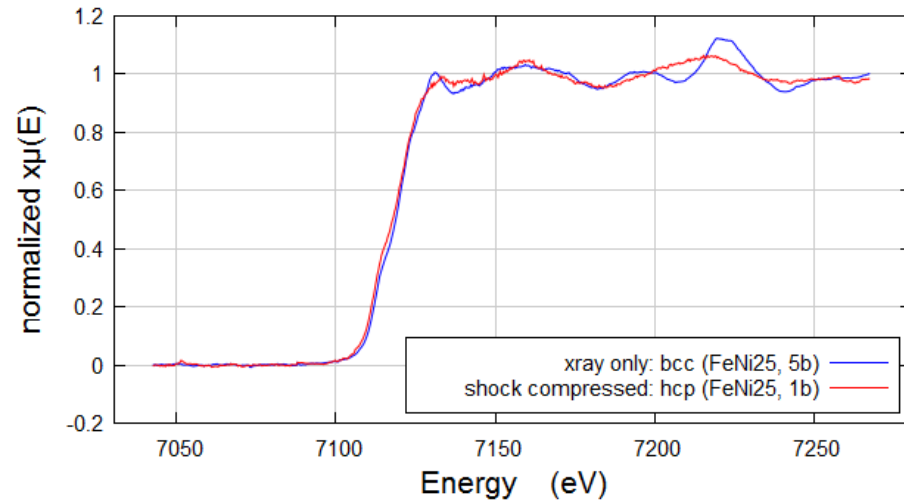


Bcc-to-hcp transition in shocked Fe-10wt%Ni

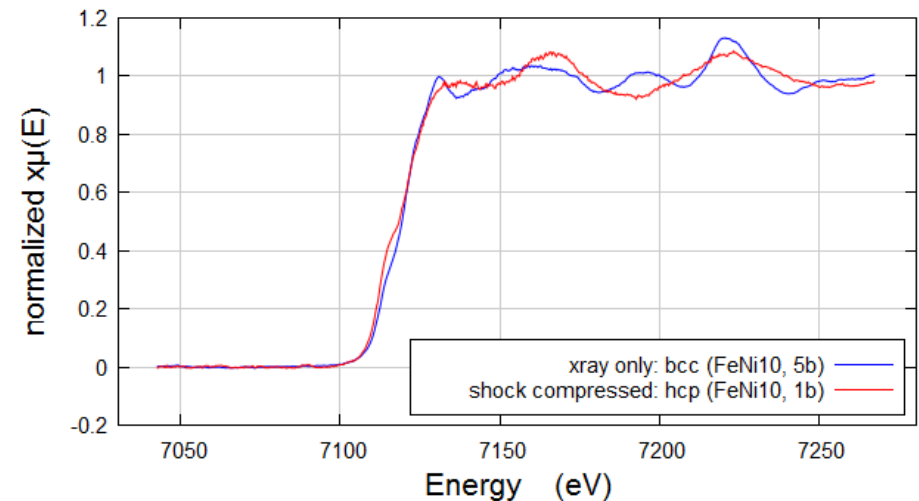


Single shot XAFS of FeNi and FeNiSi alloys

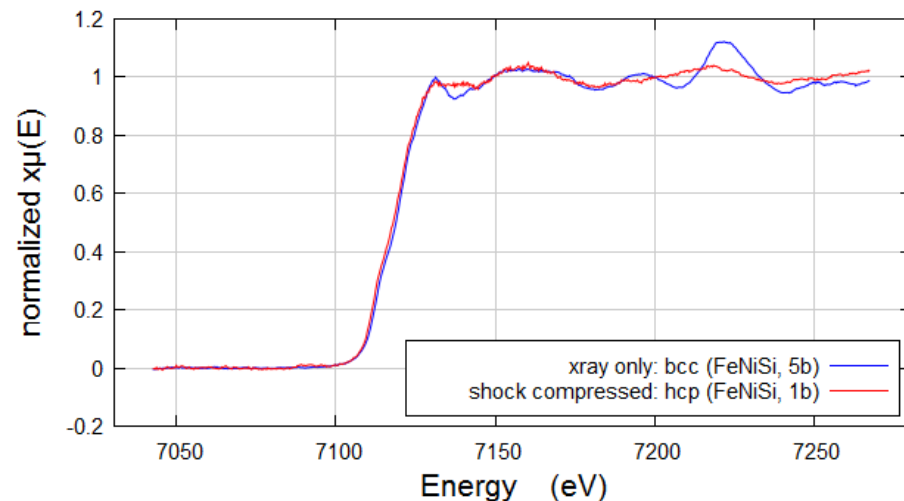
Fe25wt%Ni



Fe10wt%Ni

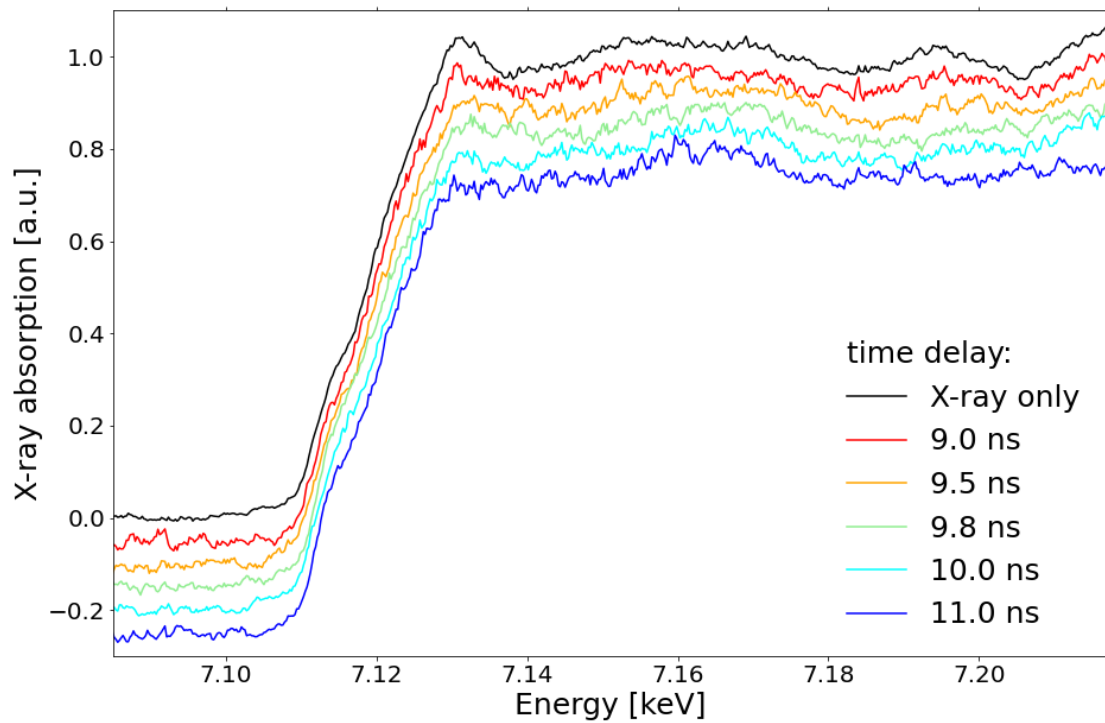


Fe10wt%Ni1.5wt%Si



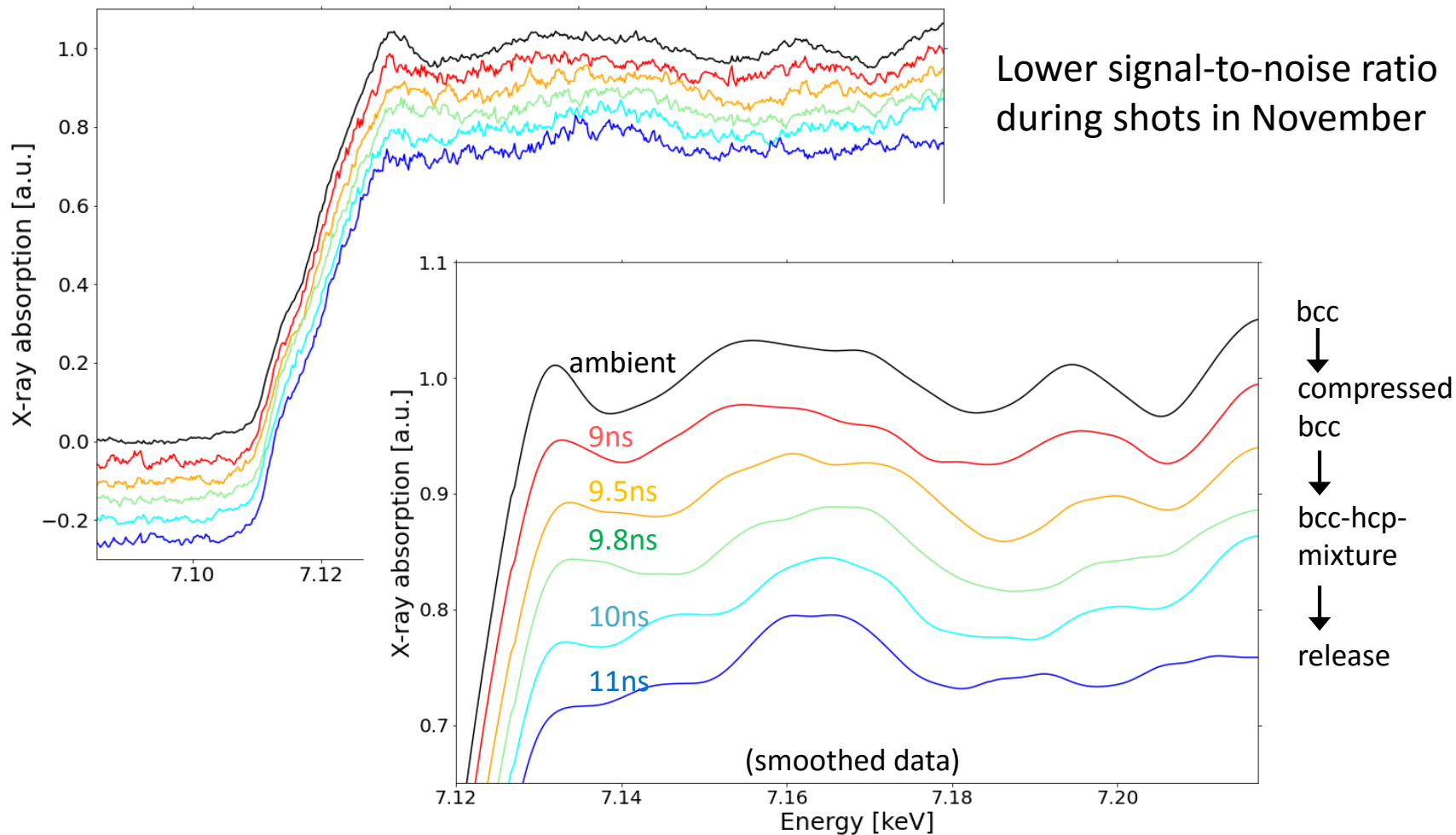
- Full bcc-to-hcp transition for Fe-10wt%Ni, Fe-20wt%Ni, Fe-Ni-Si at ≈ 50 GPa
- Proof of principle
- Very nice demonstration of high quality single bunch spectra in September

Single shot XAFS time delay scan of Fe-3.5%Si

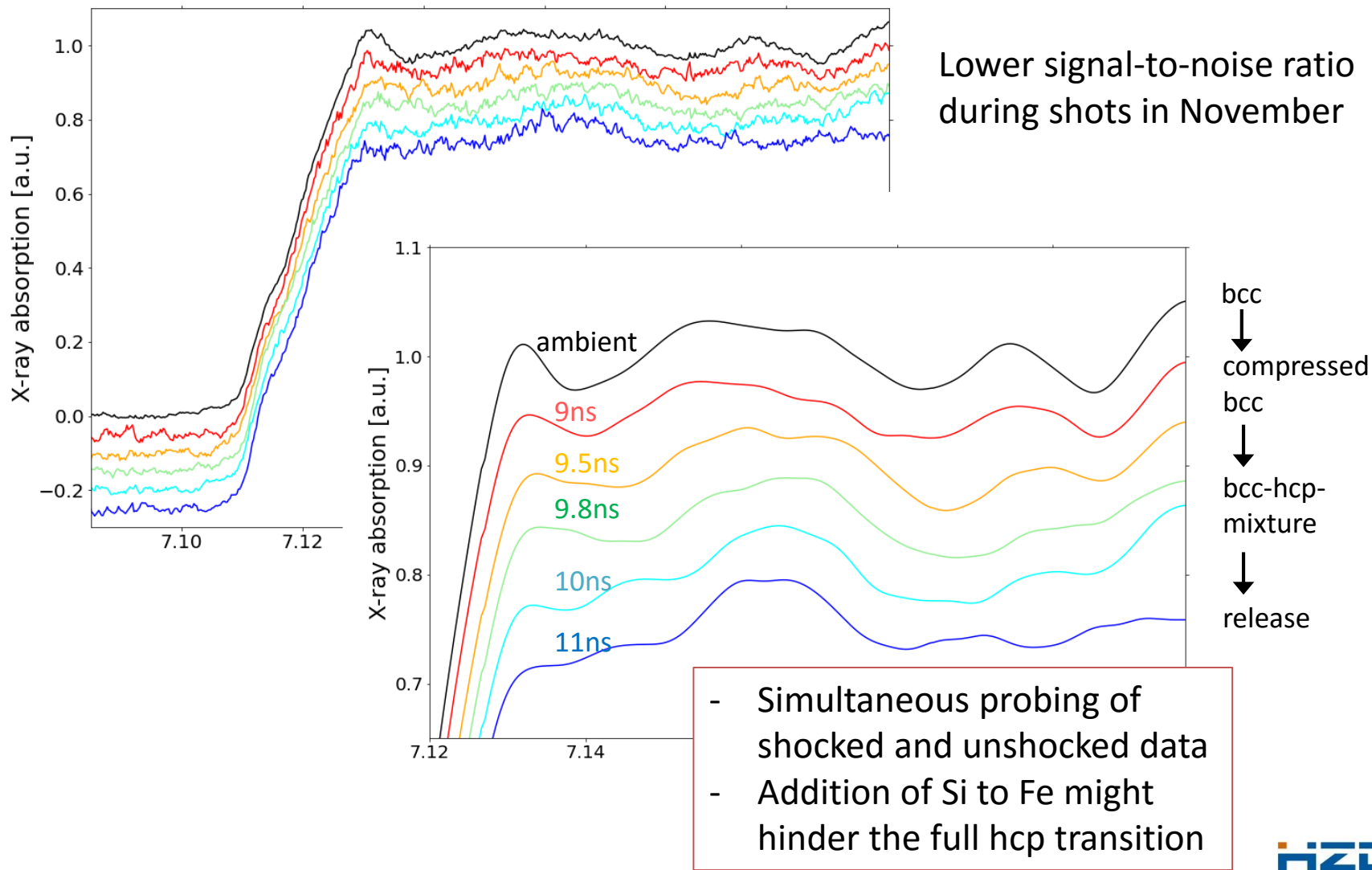


Lower signal-to-noise ratio during shots in November

Single shot XAFS time delay scan of Fe-3.5%Si



Single shot XAFS time delay scan of Fe-3.5%Si



FeNi and FeSi conclusions

- Very nice quality of single-shot XAS spectra in 4-bunch-mode
- Higher pressures reachable in future

- Investigation of Fe alloys similar to cores of telluric planets under WDM conditions
 - Simultaneous density and temperature measurements possible with XAFS
 - Off-Hugoniot states with double shock
 - Complementary Diagnostics of XRD, XRI and XES for complete characterization of WDM states