

***Insights into Earth's core from
vibrational studies of hot dense iron***

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Acknowledgements:

High resolution x-ray scattering group

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Laser-heating system setup

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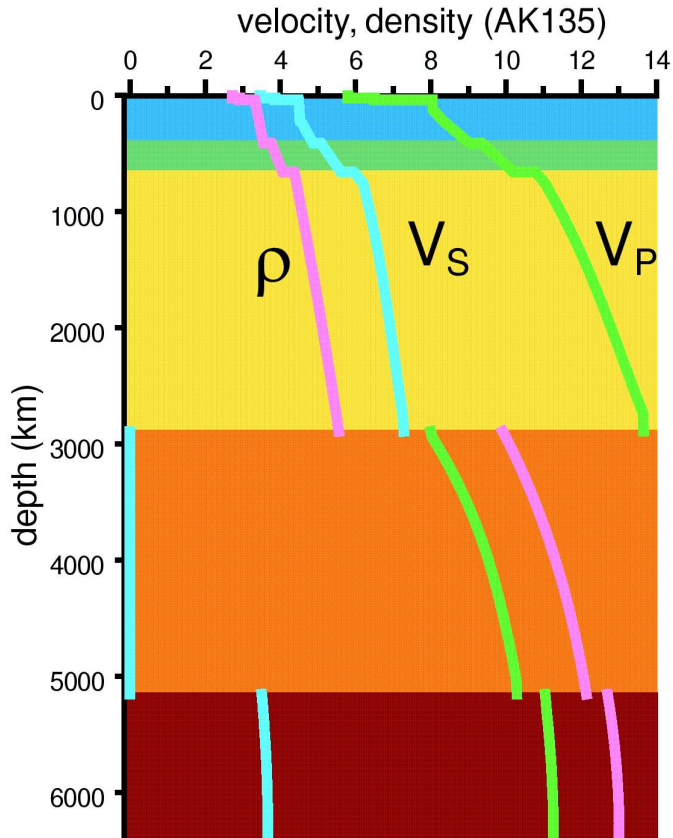
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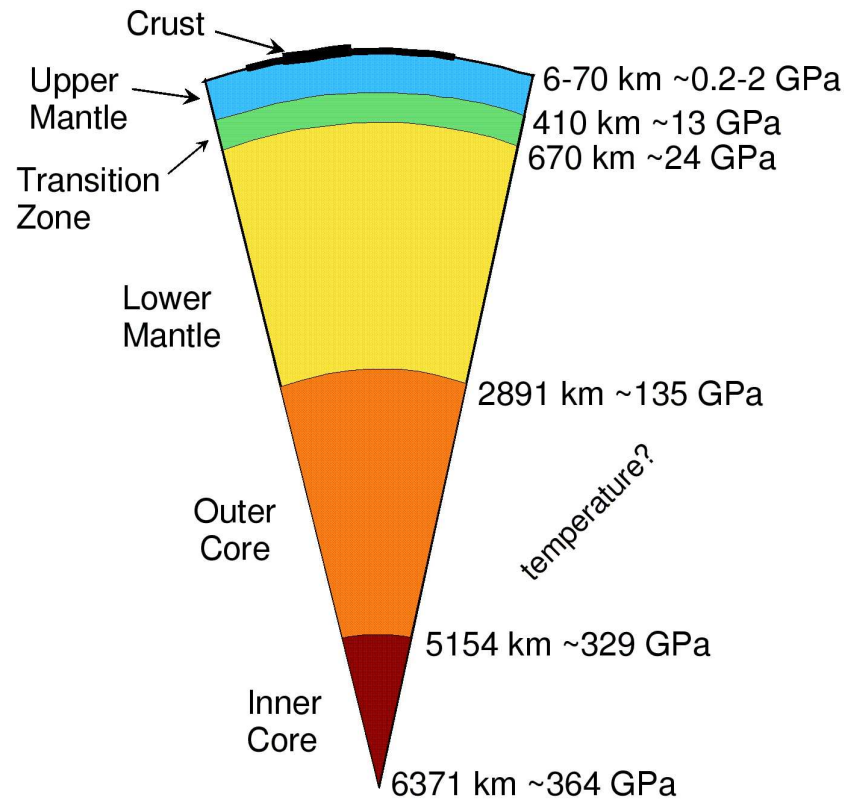
NSF & COMPRES Infrastructural Development

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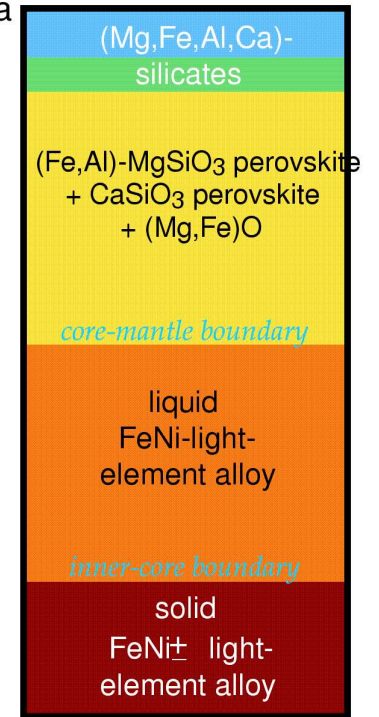
Earth's seismic structure



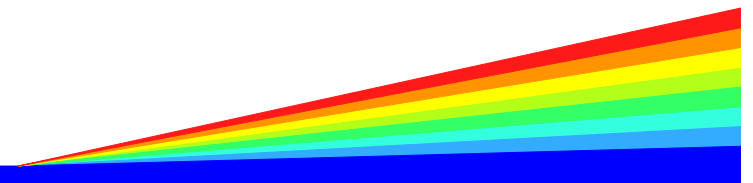
Earth's stratification



Earth's composition



- ☆ sound velocities and densities from seismic observations
- ☆ chemical, isotopic, and structural composition of meteorites





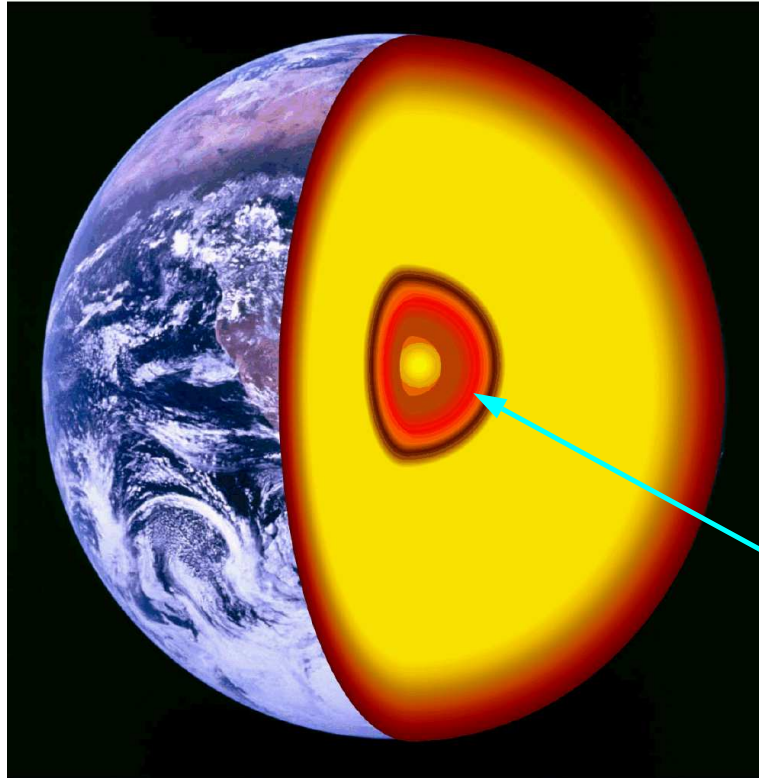
☆ Be gasket

☆ large opening

☆ a diamond anvil cell (DAC)
can create Mbar pressures

☆ DAC development by
*H.-K. Mao et al.,
Geophysical Laboratory,
Carnegie Institution of Washington*

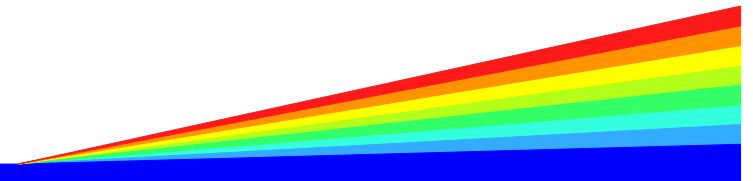
Why nuclear resonant scattering?



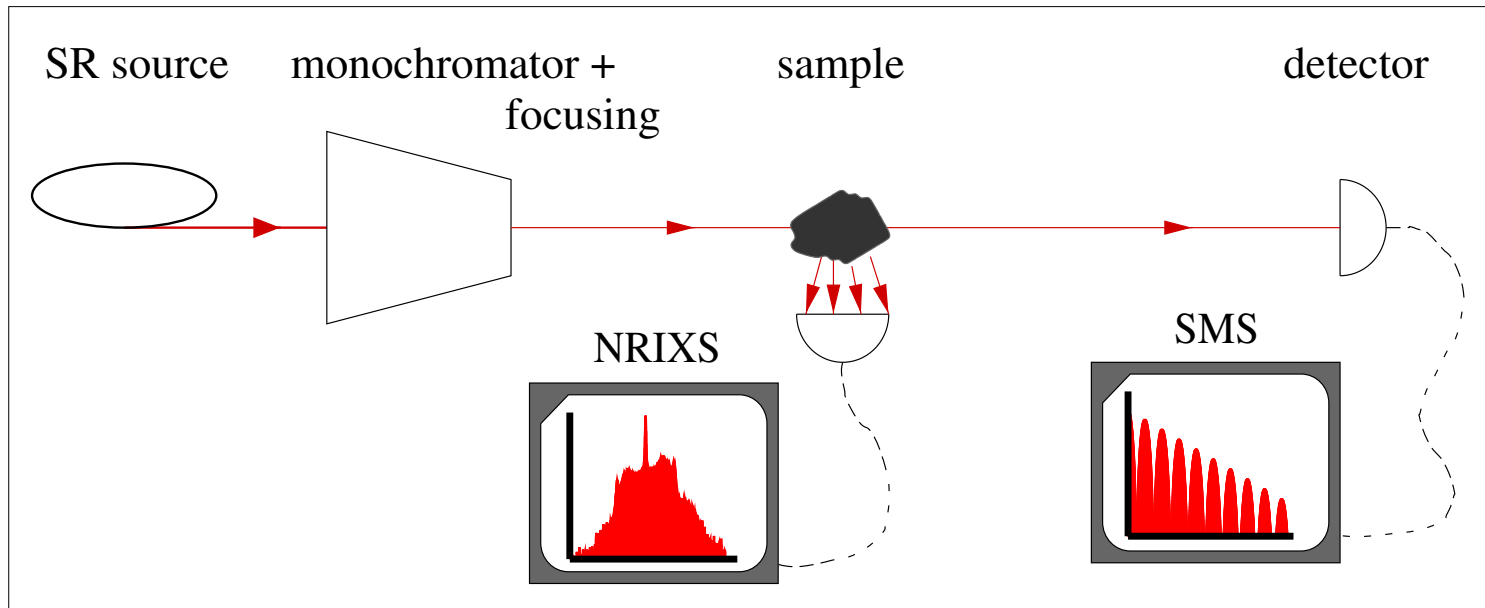
- ☆ high iron content in certain planets
- ☆ use the 14.4keV resonance in ^{57}Fe
- ☆ the microscopic material properties are needed to understand our planet's makeup.

pressure > 1Mbar
temp. > 2000K

- nuclear resonant scattering techniques offers a unique capability to measure iron-containing compounds under extreme conditions.



Synchrotron Mössbauer Spectroscopy (SMS) and Nuclear Resonant Inelastic X-ray Scattering (NRIXS)



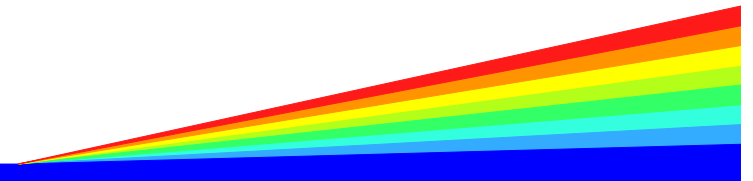
→ vibrational density of states,
sound velocities, Grüneisen parameter

W.Sturhahn et al., Phys.Rev.Lett. 74 (1995)
H.-K. Mao et al., Science 292 (2001)
J.-F. Lin et al., Science, 308 (2005)

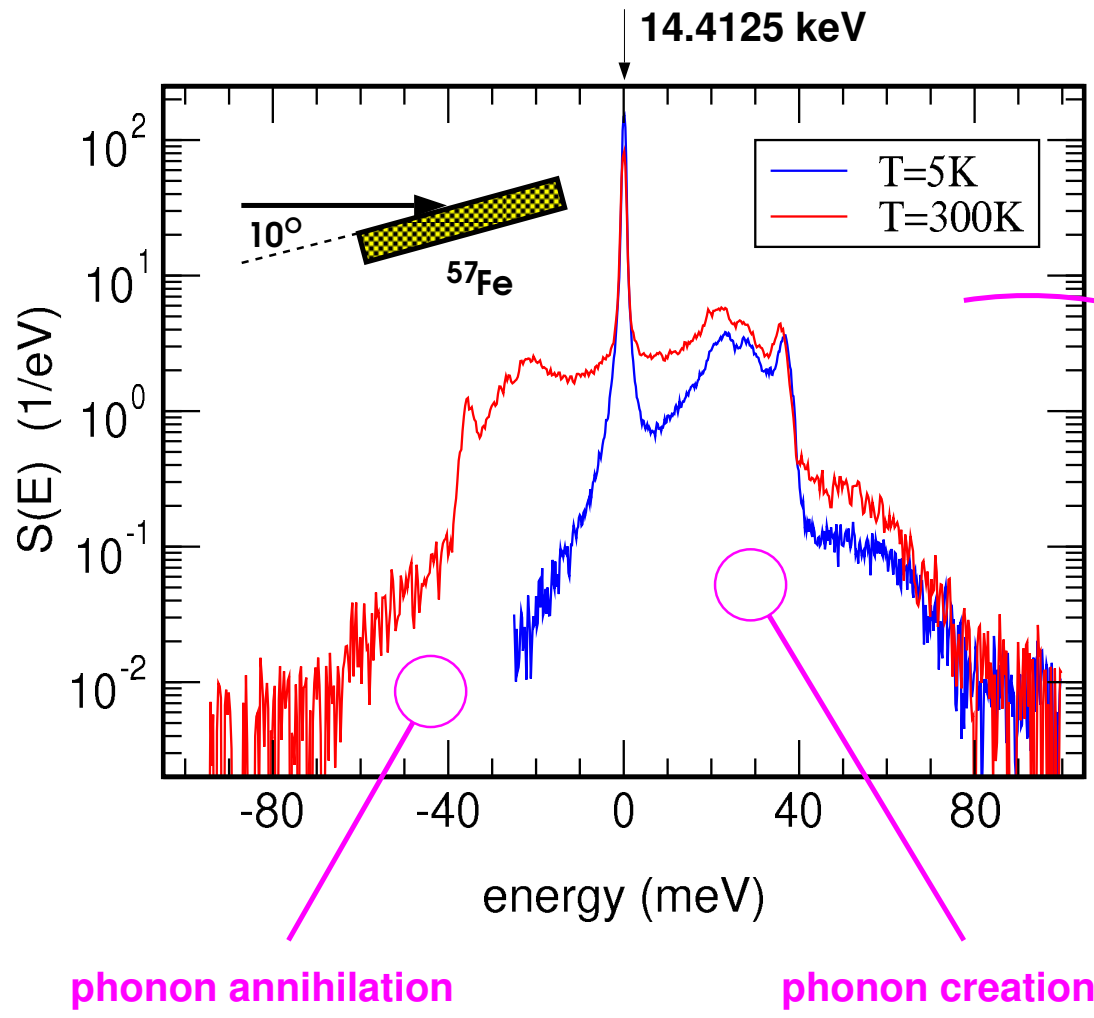
→ valence, magnetism, spin state

J.M.Jackson et al., Am. Min. 90 (2005)
J.-F. Lin et al., EPSL 226 (2004)

recent review of Nuclear Resonant Spectroscopy:
W.Sturhahn, J.Phys.: Cond.Matt., 16 (2004)



NRIXS on polycrystalline Fe (bcc):

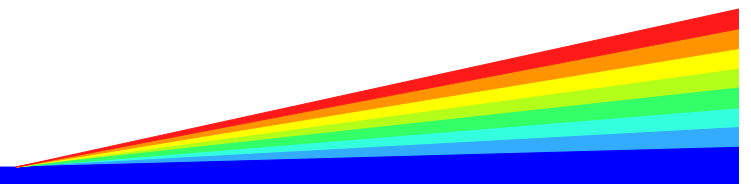
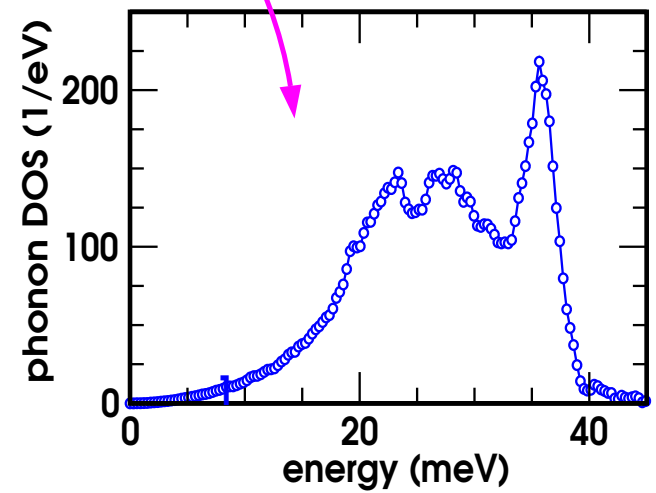


☆ the partial phonon DOS is extracted from the spectrum

V.G.Kohn et al.,
Phys.Rev. B 58 (1998)

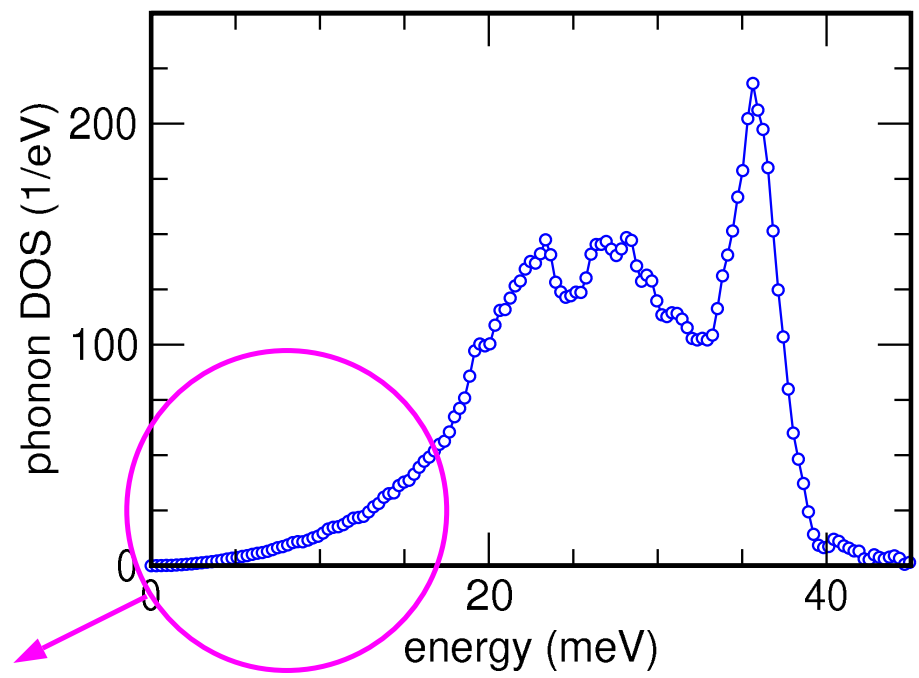
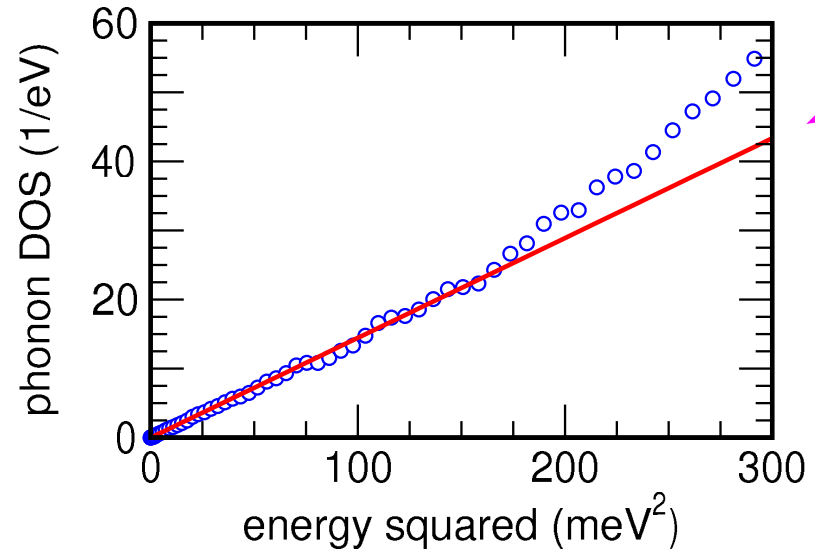
M.Hu et al.,
Nucl.Instrum.Meth. A 428 (1999)

W.Sturhahn,
Hyperfine Int. 125 (2000)



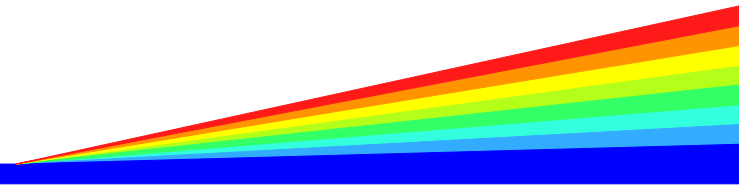
Extraction of sound velocities from DOS:

Apply a parabolic fit to the low-energy portion.

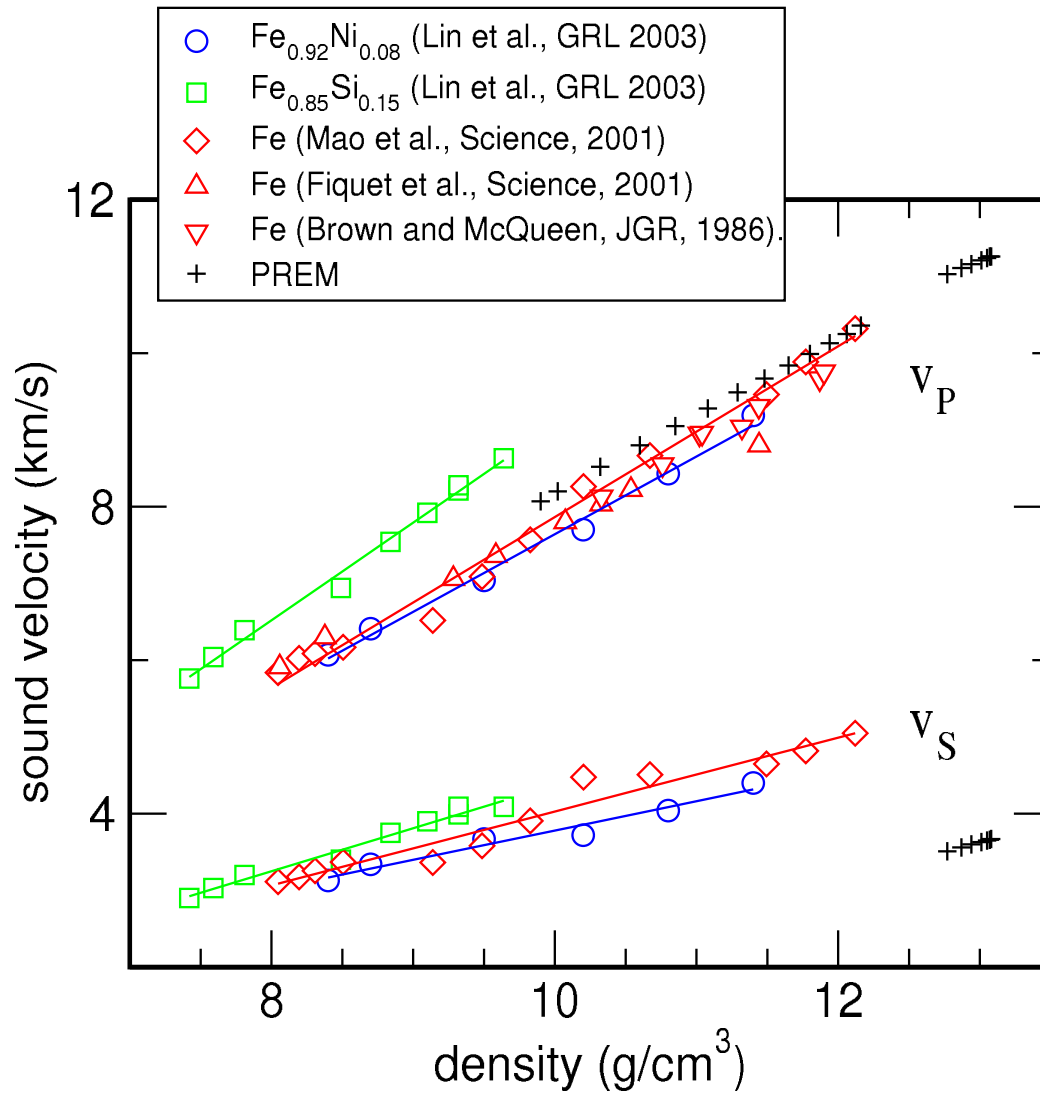


Obtain Debye sound velocity, even for compounds.

M.Y. Hu et al., Phys. Rev. B 67 (2003) 094304



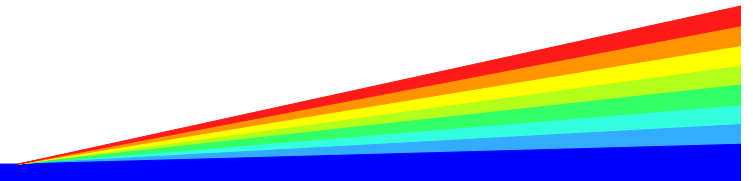
Pressure and shear wave velocities:



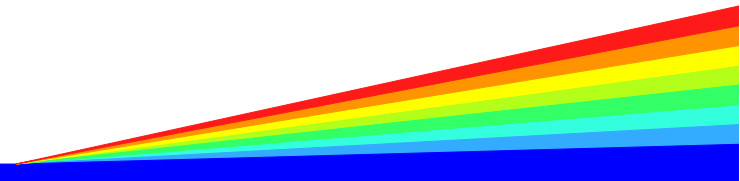
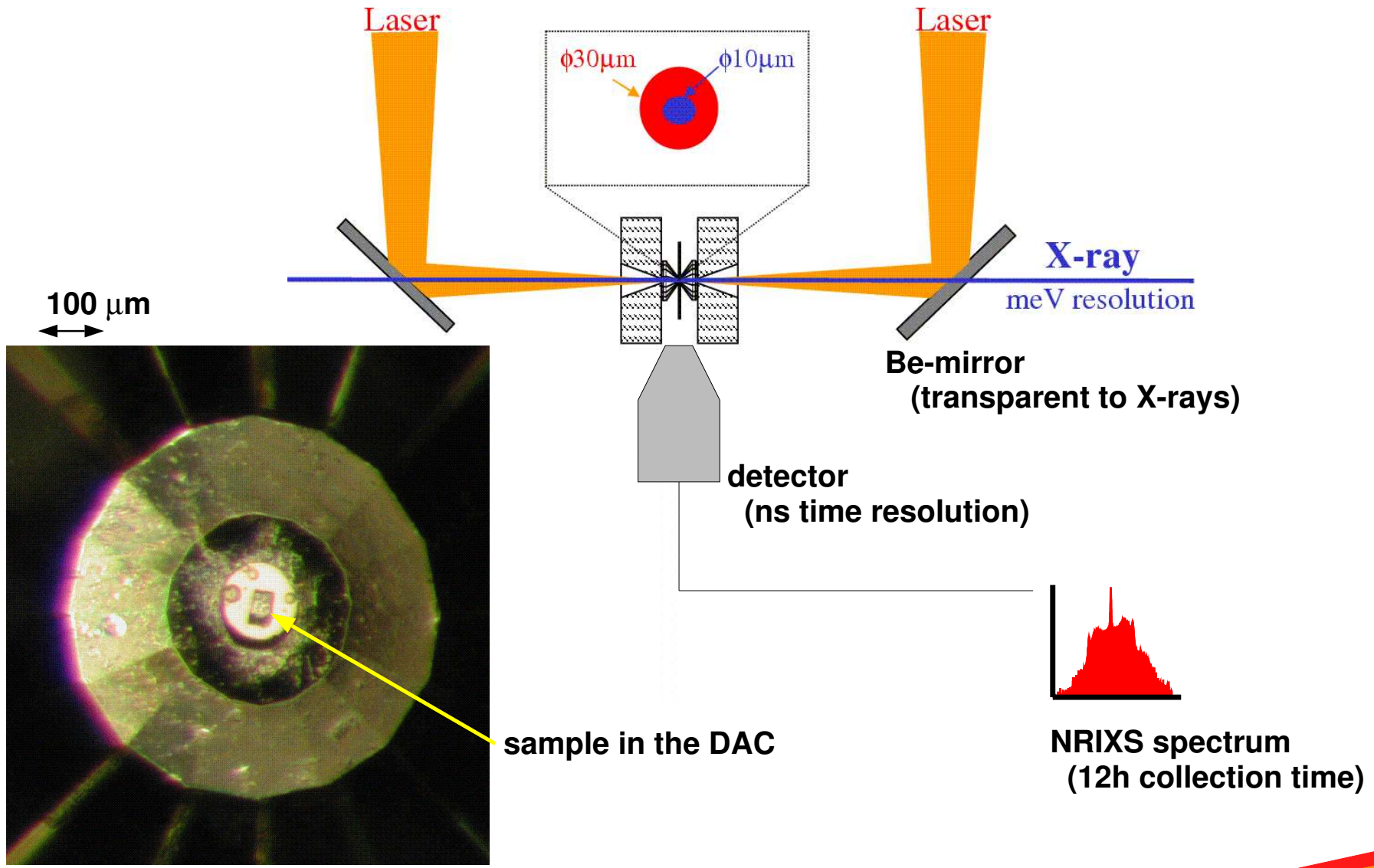
measure

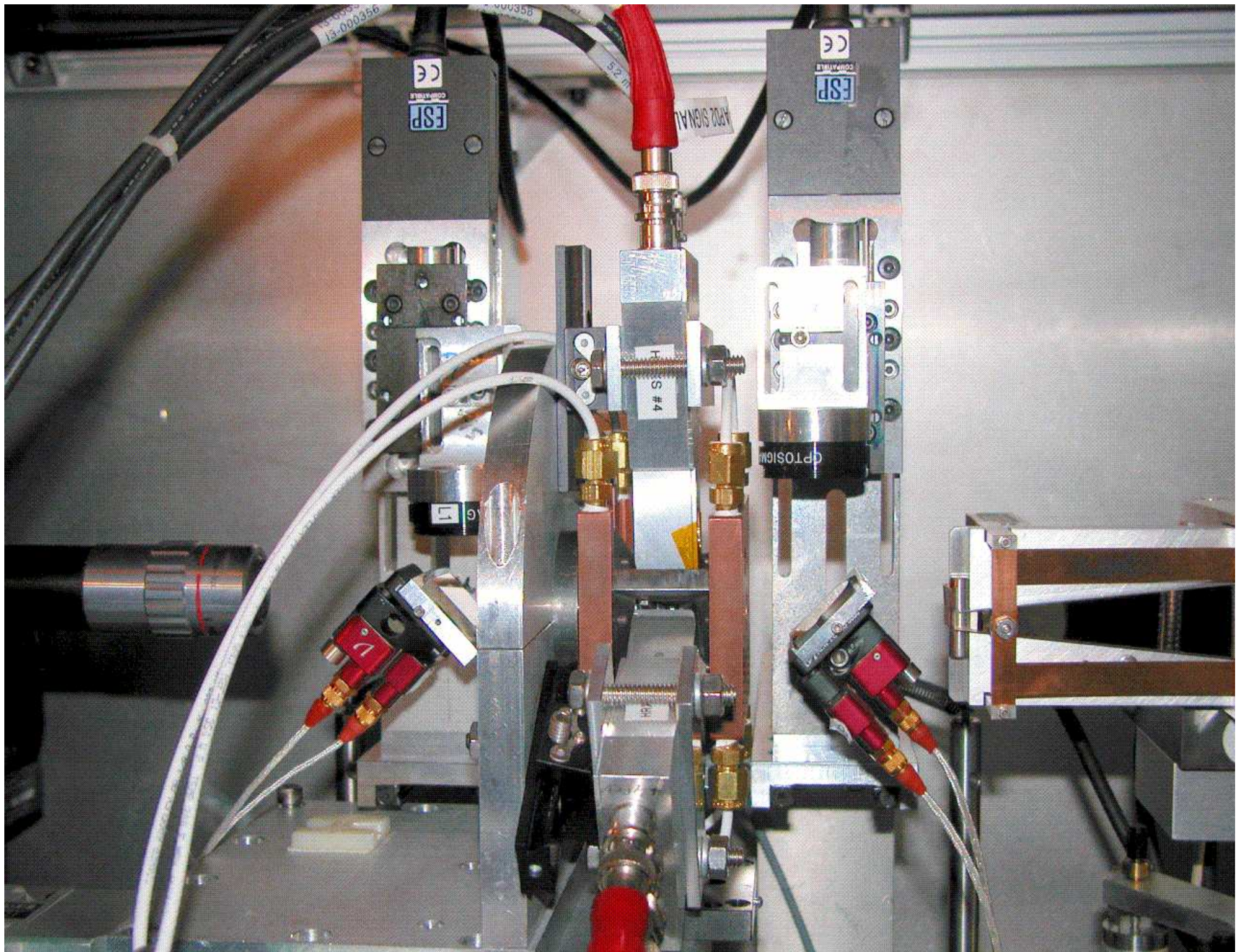
$$v_P^{-3} + 2v_S^{-3} = 3v_D^{-3}$$
$$v_P^2 - \frac{4}{3}v_S^2 = K/\rho$$

calculate

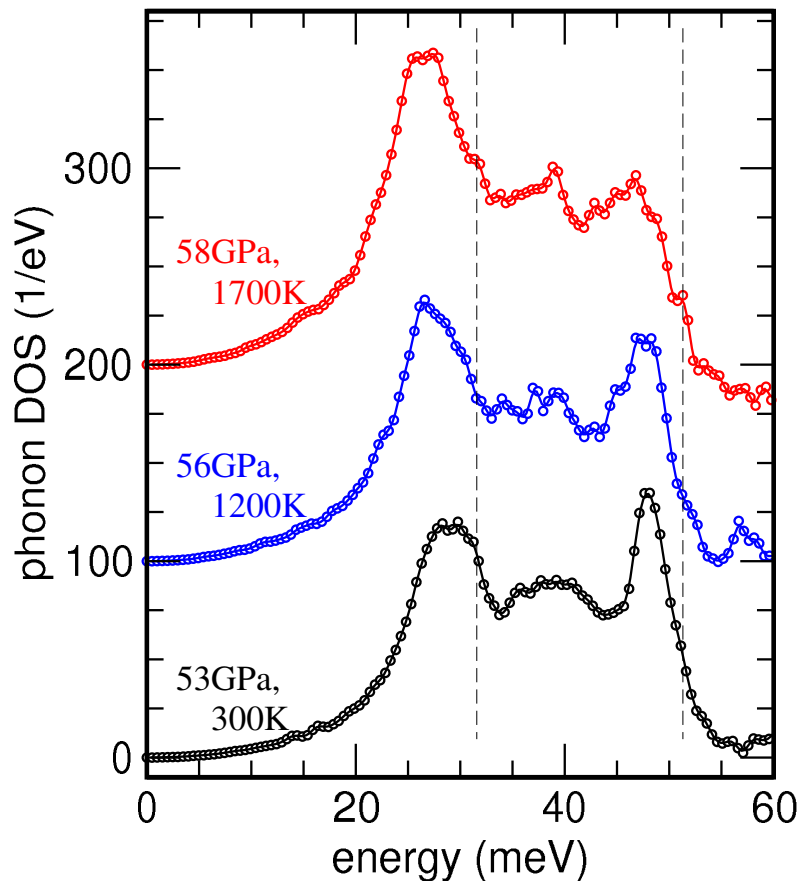


NRIXS in the DAC with Laser heating at sector 3-ID:

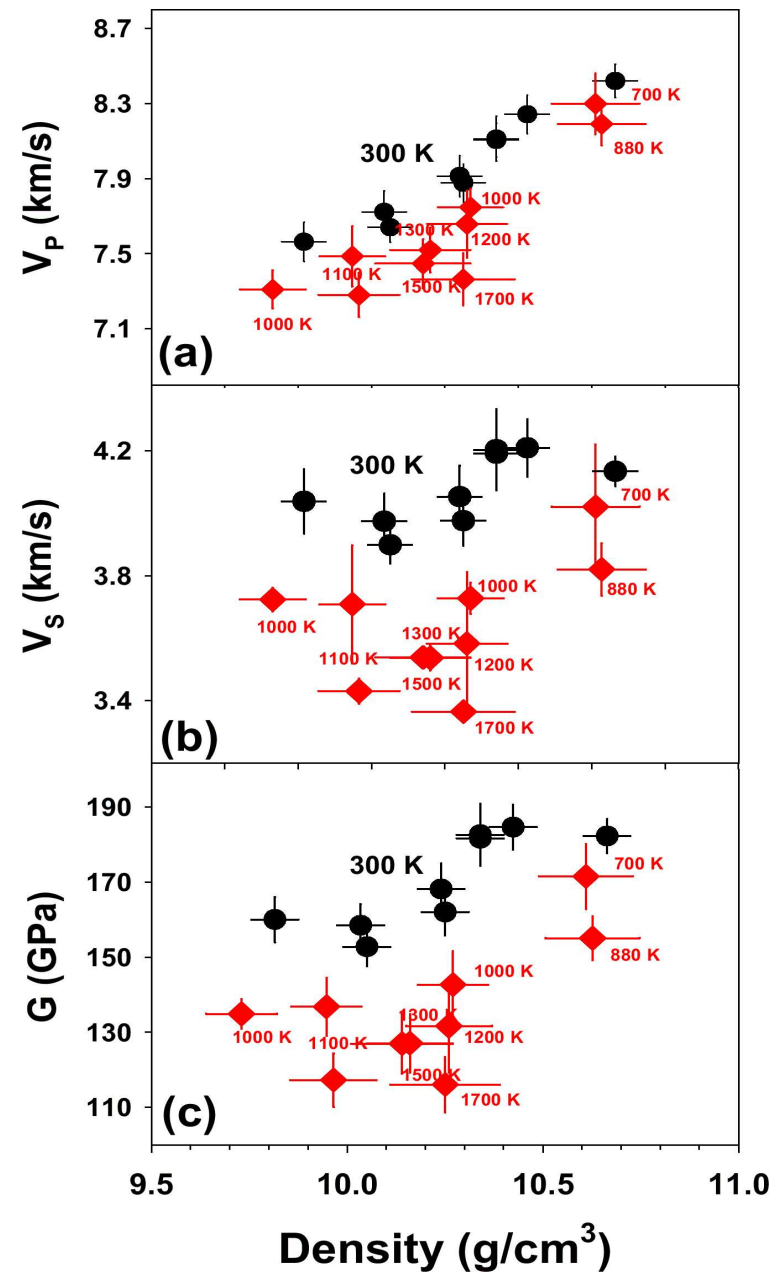




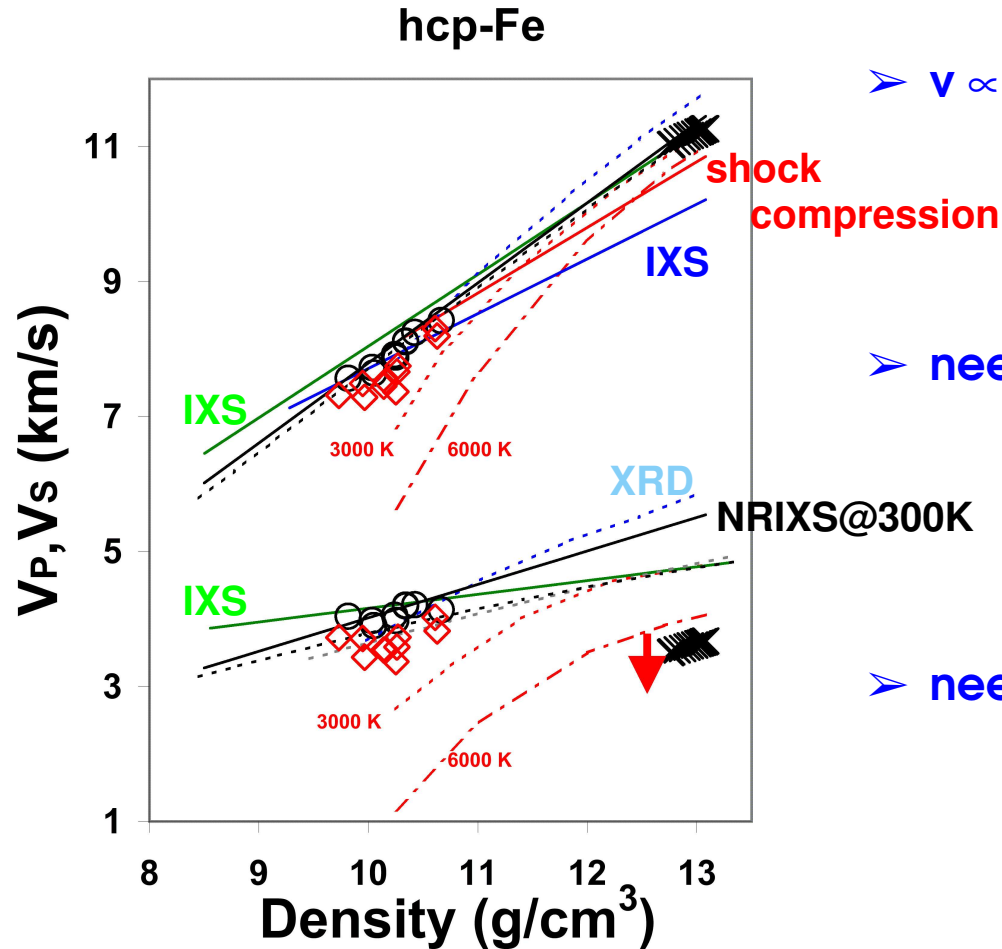
NRIXS results on hot, dense iron:



J.-F. Lin et al., Science, 308 (2005)

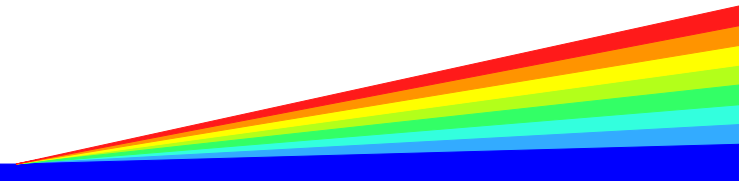


Sound velocity extrapolations:



- explicit temperature dependence
- $v \propto \rho$ rule (Birch's law) cannot be used
- need to increase v_p at core conditions
- need to decrease v_s at core conditions
- light elements need to be added

J.-F. Lin et al., Science, 308 (2005)



Where to go in the next 5 to 10 years?

➤ **technically**

- improve counting rates by factor of ten
- new IXS capabilities

➤ **methodologically**

- integration of diffraction capability with NRIXS
- IXS under high pressure
- viscosity in liquids under high pressure

➤ **scientifically**

- which light elements?
- anisotropy in Earth's core
- mantle-core coupling
- heat transfer and energy balance in planets