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Picosecond Acoustics : a way to Thermodynamical Properties of Solids and Liquids at Extreme Conditions

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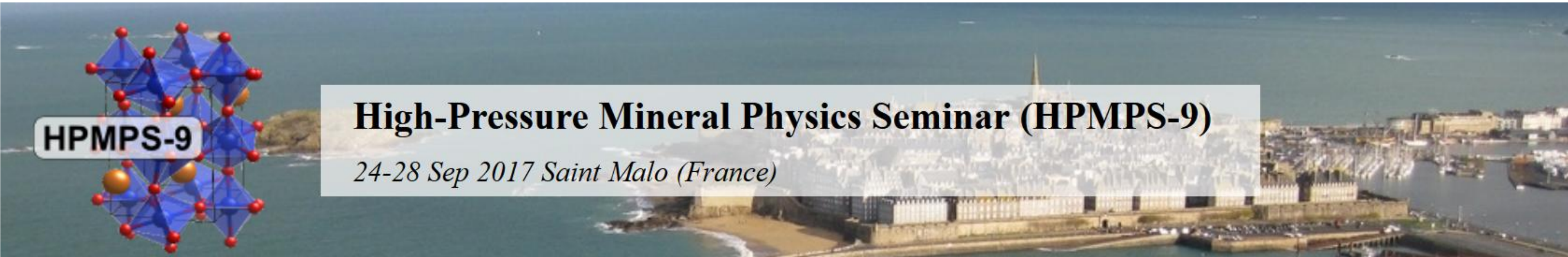

Outline

1. Experimental set-up
2. Some applications

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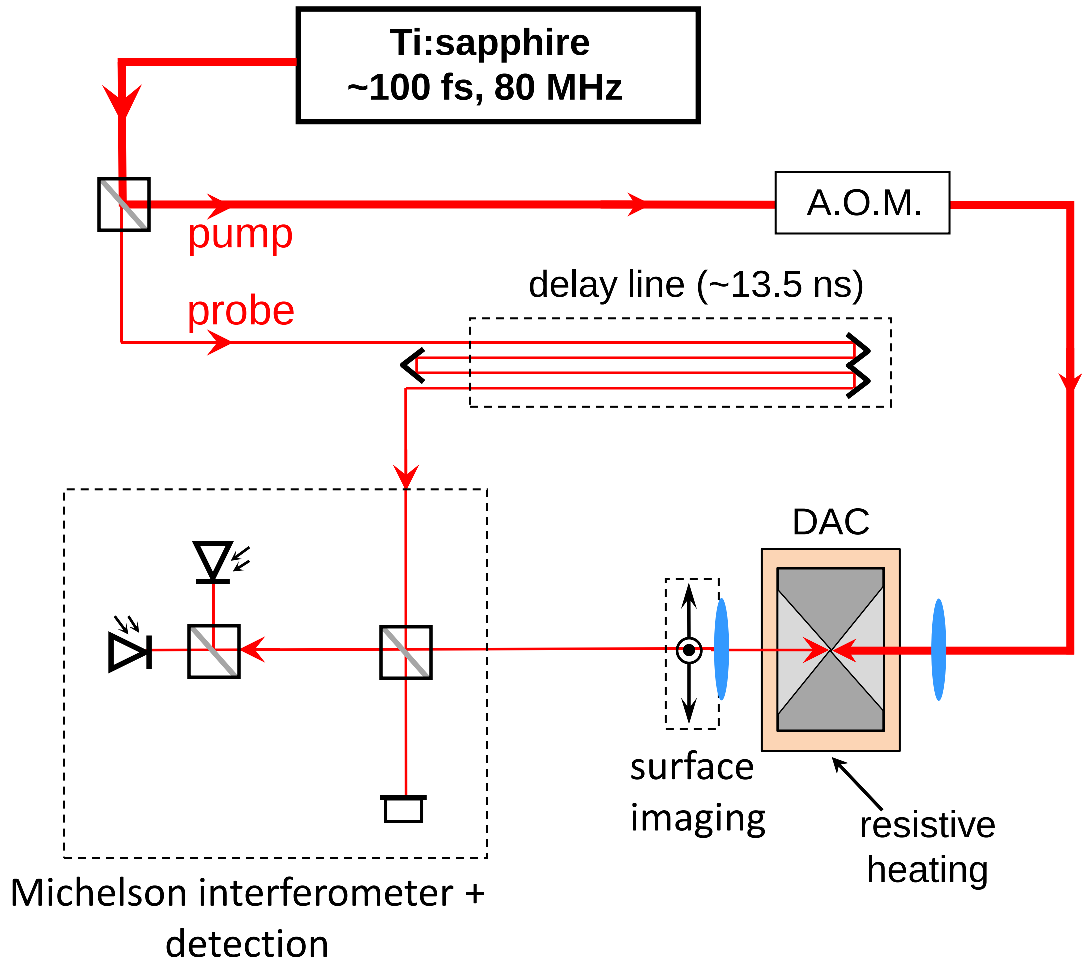
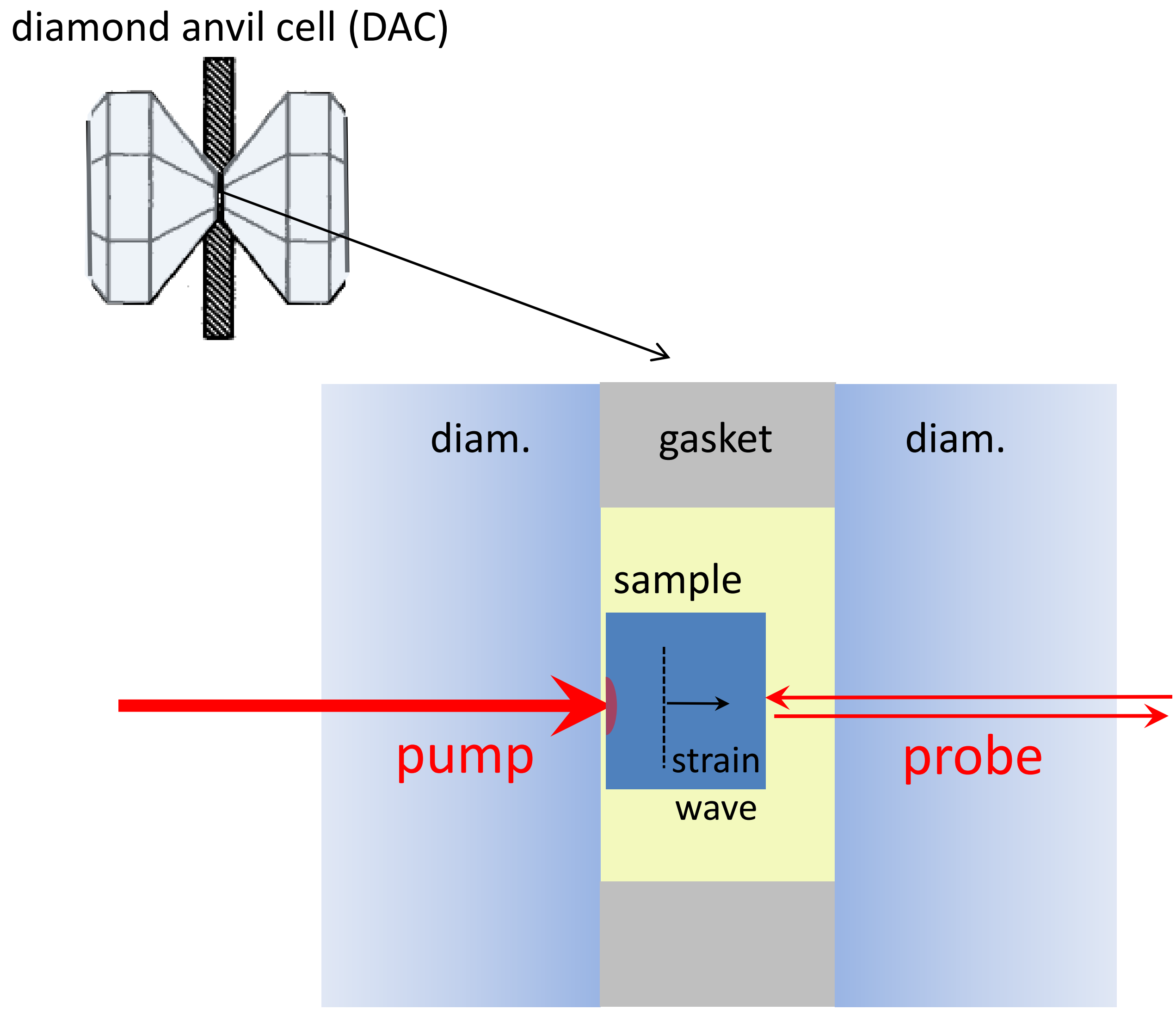
1. **Experimental set-up**
2. Some applications

Picosecond acoustics technique @IMPMC

C.Thomsen *et al*, PRB **34** 4129 (1986)
B.Perrin *et al*, Physica B **263** 571 (1999)
Y.Sugawara *et al*, Phys. Rev. Lett. **88,** 185504 (2002)
F.Decremps *et al*, PRL **100**, 3550 (2008)

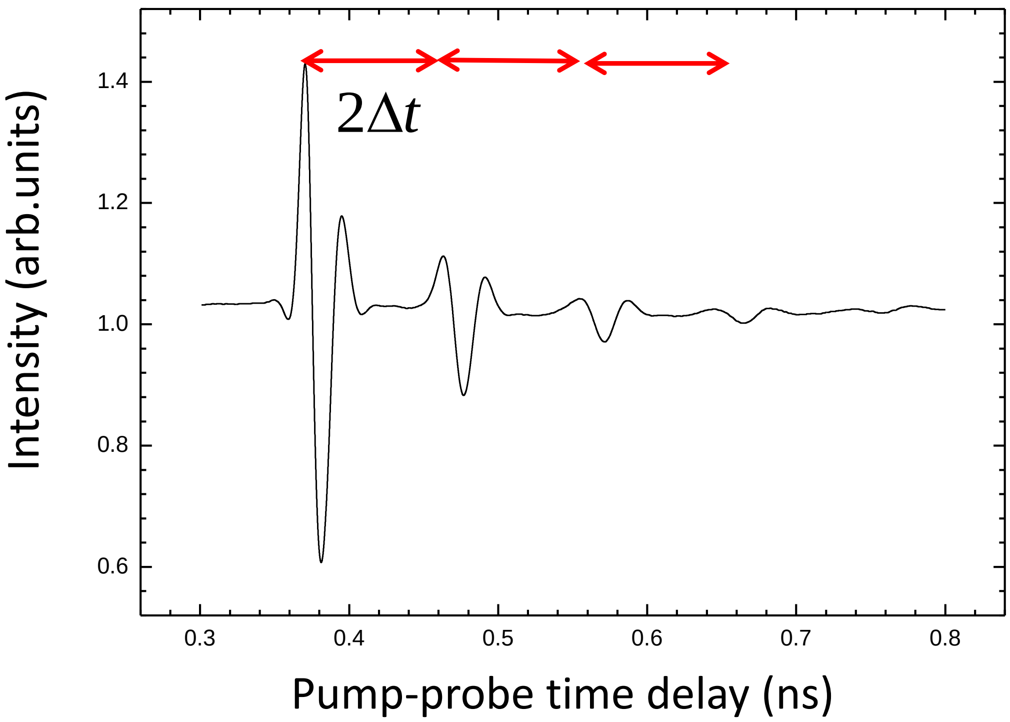


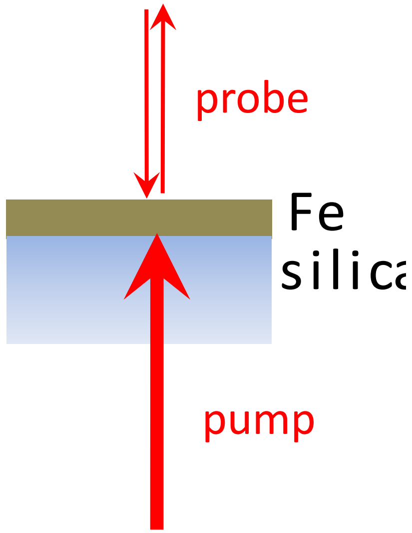
Picosecond acoustics technique @IMPMC



Picosecond acoustics technique @IMPMC

Typical signal





Time of flight → sound velocity

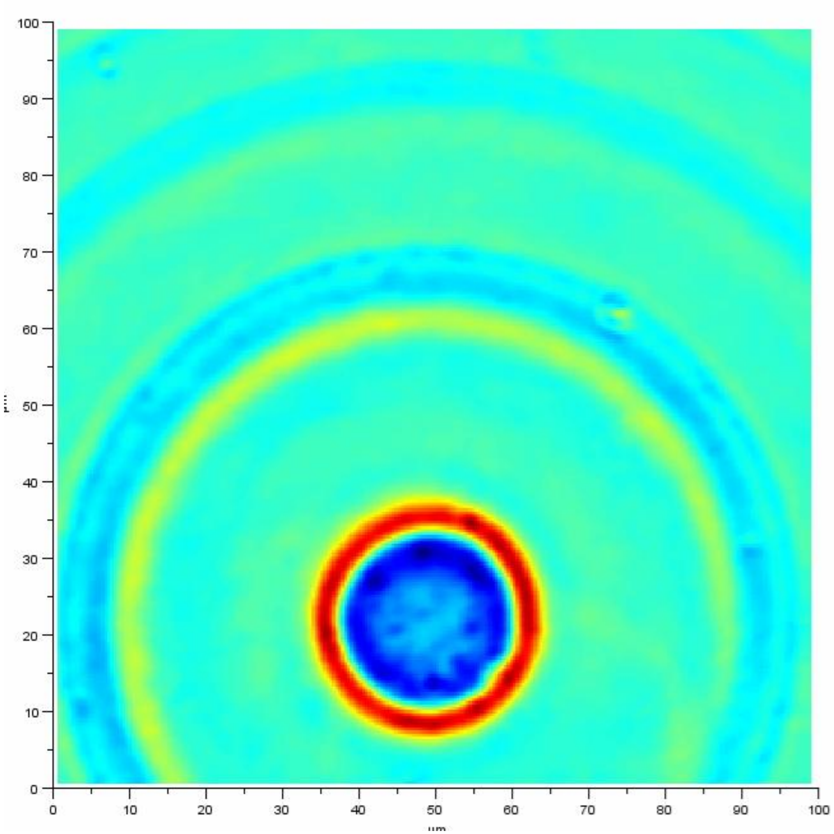
$$v = \frac{e_0}{\Delta t}$$

Surface imaging

Y. Sugawara *et al PRL* **88**, 185504 (2002)

in liquid Hg, at ambient

100 μm



100 μm

duration : 13.2 ns

f_{laser}=80MHz → T_{laser} =12.55 ns

→ parallel and undeformed culets

→ homogeneous sample

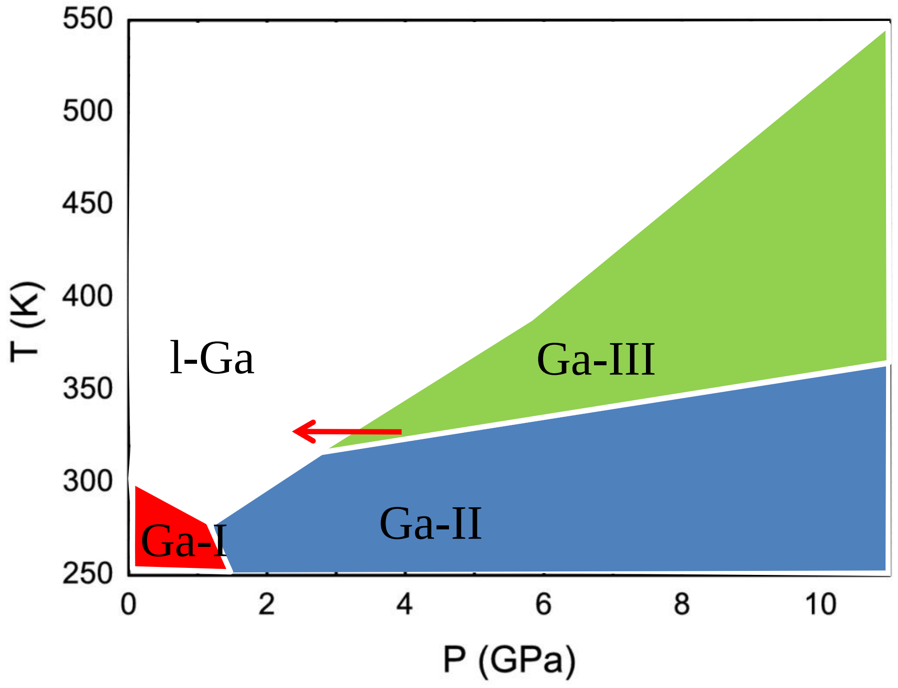
Movie analysis gives (independently) : v, e_0

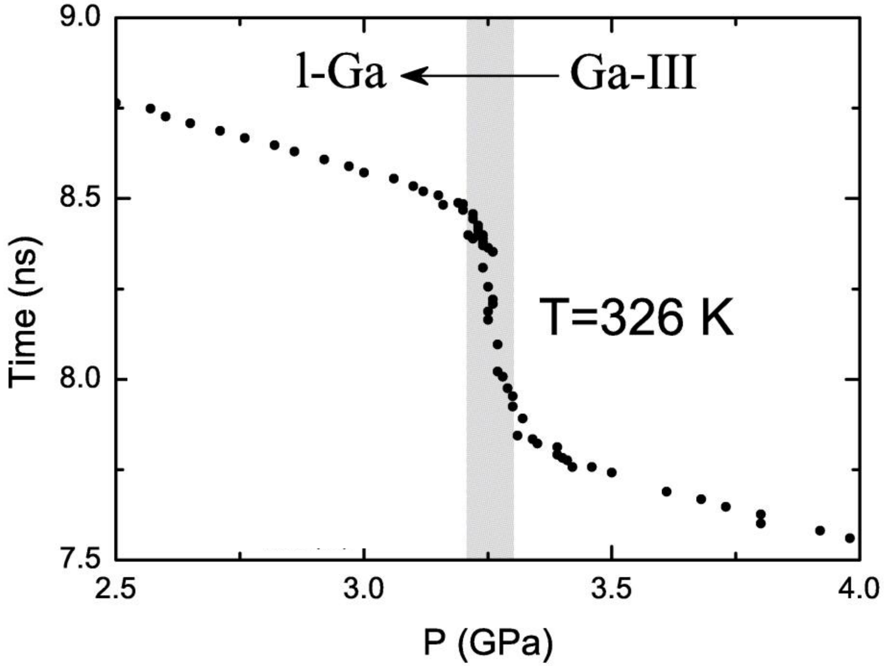
Outline

1. Experimental set-up
2. **Some applications**

First order phase transition

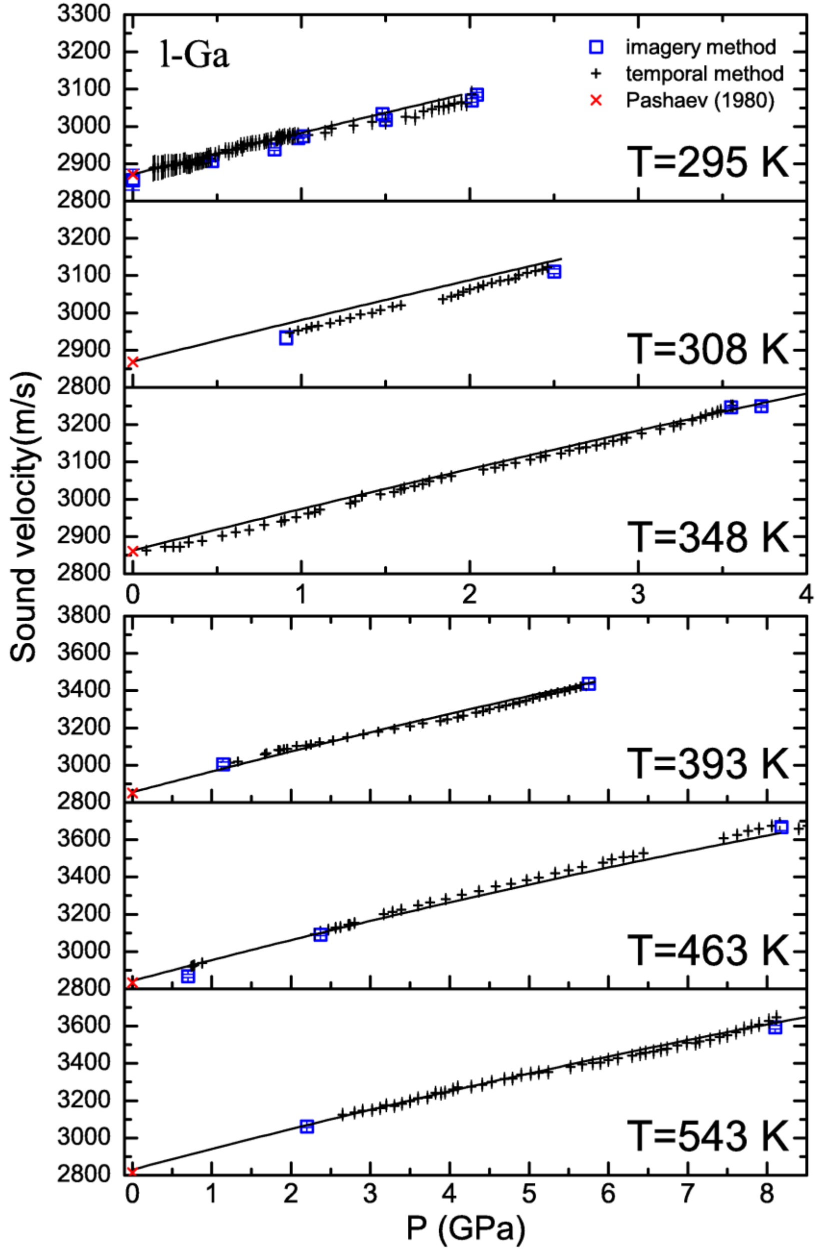
Example in liquid Ga





S. Ayrinhac *et al*, J. Phys.: Condens. Matter, **27,** 275103 (2015)

Adiabatic sound velocities



S. Ayrinhac *et al*, JPCM **27** 275103 (2015)

In liquid Ga

→ From adiabatic sound velocity to isothermal equation of state

→ Numerical procedure inspired by :

Davis & Gordon JCP **46** 2650 (1967)
Daridon *et al, International journal of thermophysics* **19** 145 (1998)

output

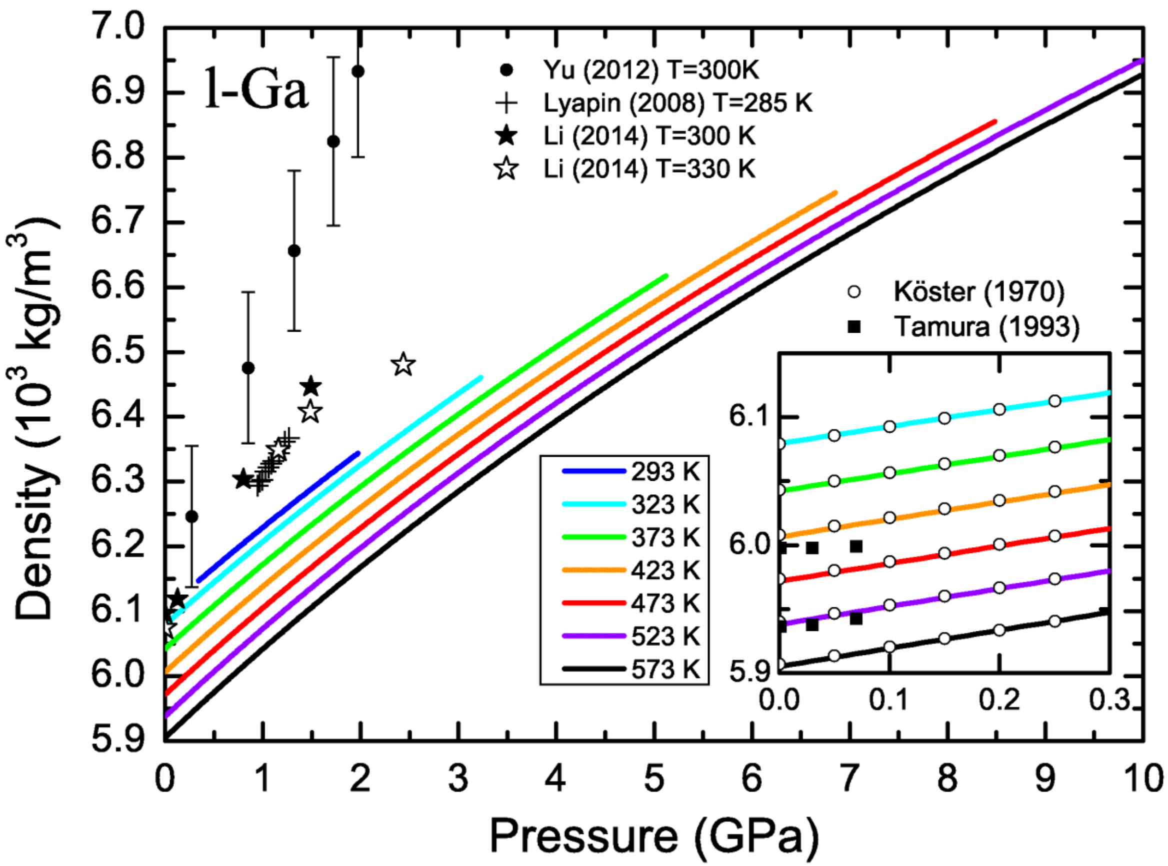
$\rho(P,T)$ $\quad B_T(P,T)$

$\alpha_P(P,T)$ $\quad C_V(P,T)$

$C_P(P,T)$ $\quad \gamma(P,T)$

…

Density of liquid Ga



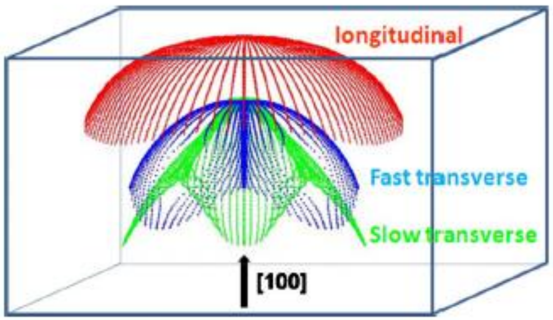
→ our data from sound velocity are in excellent agreement with Köster

→ other thermodynamic quantities in liquid gallium

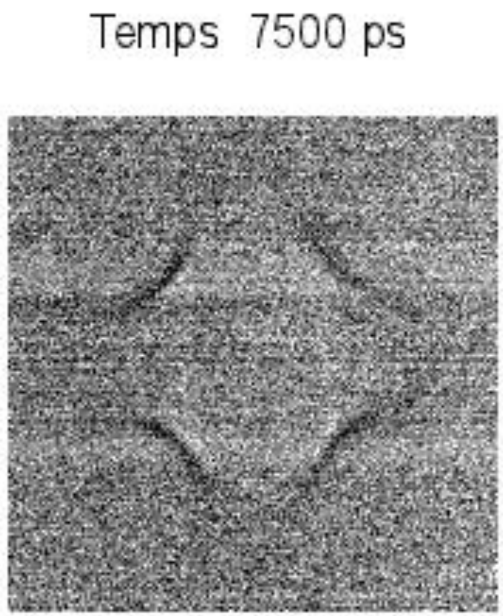
S. Ayrinhac *et al*, JPCM **27** 275103 (2015)

Anisotropic solid

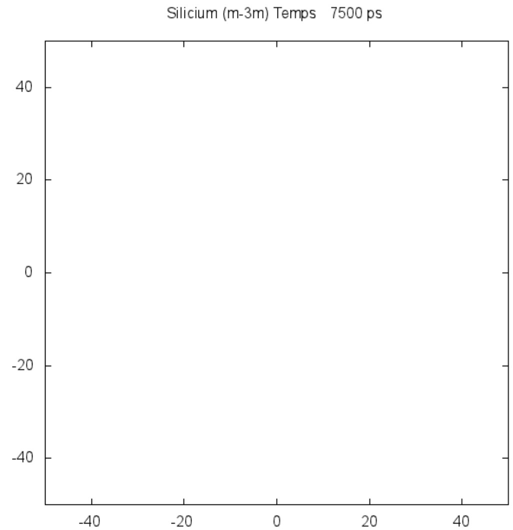
Example in Si



Experiment



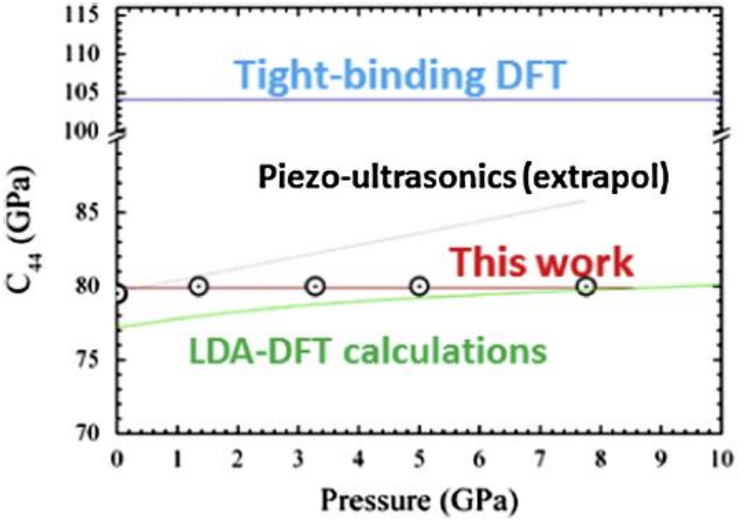
Simulation

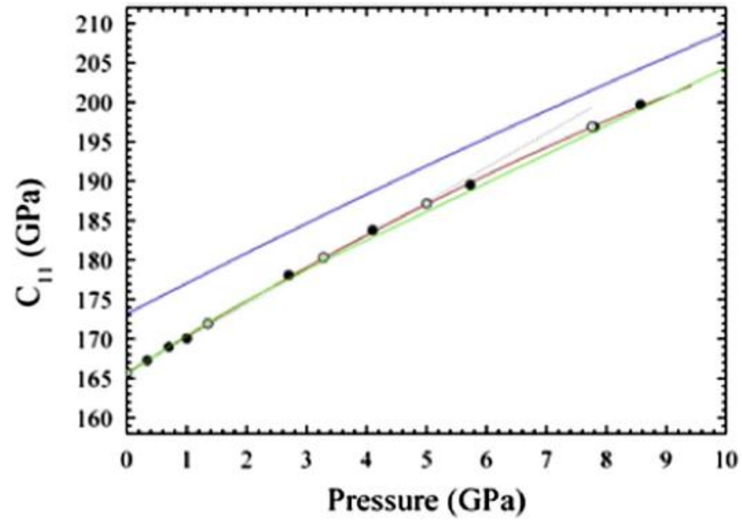


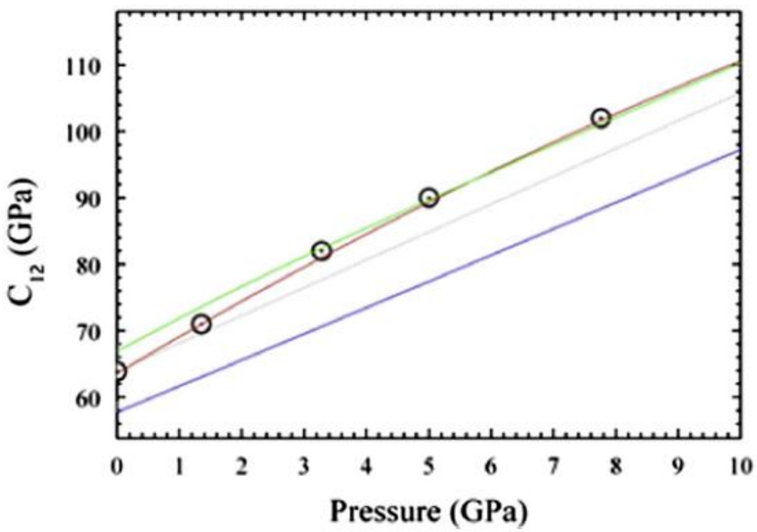
$$\rightarrow C_{ijkl}(P,T)$$

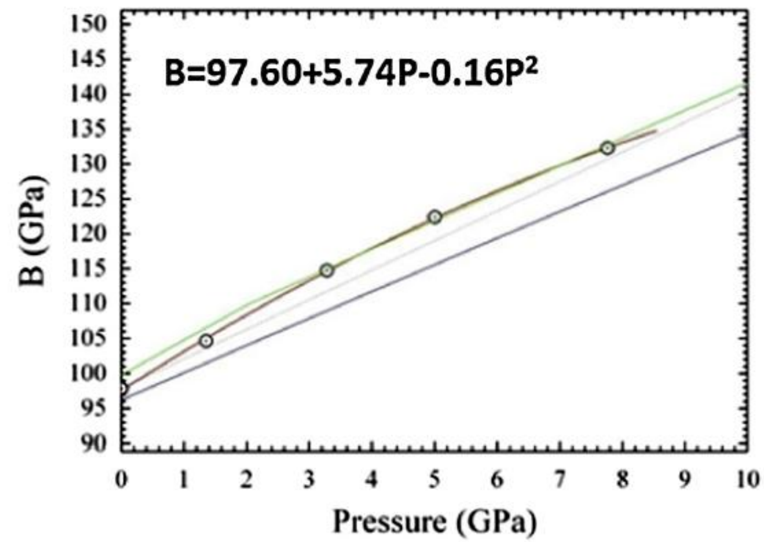
$$\rightarrow \beta = S_{iihh}\ (S = C^{-1})$$

F.Decremps *et al* PRB **82** 104119 (2010)









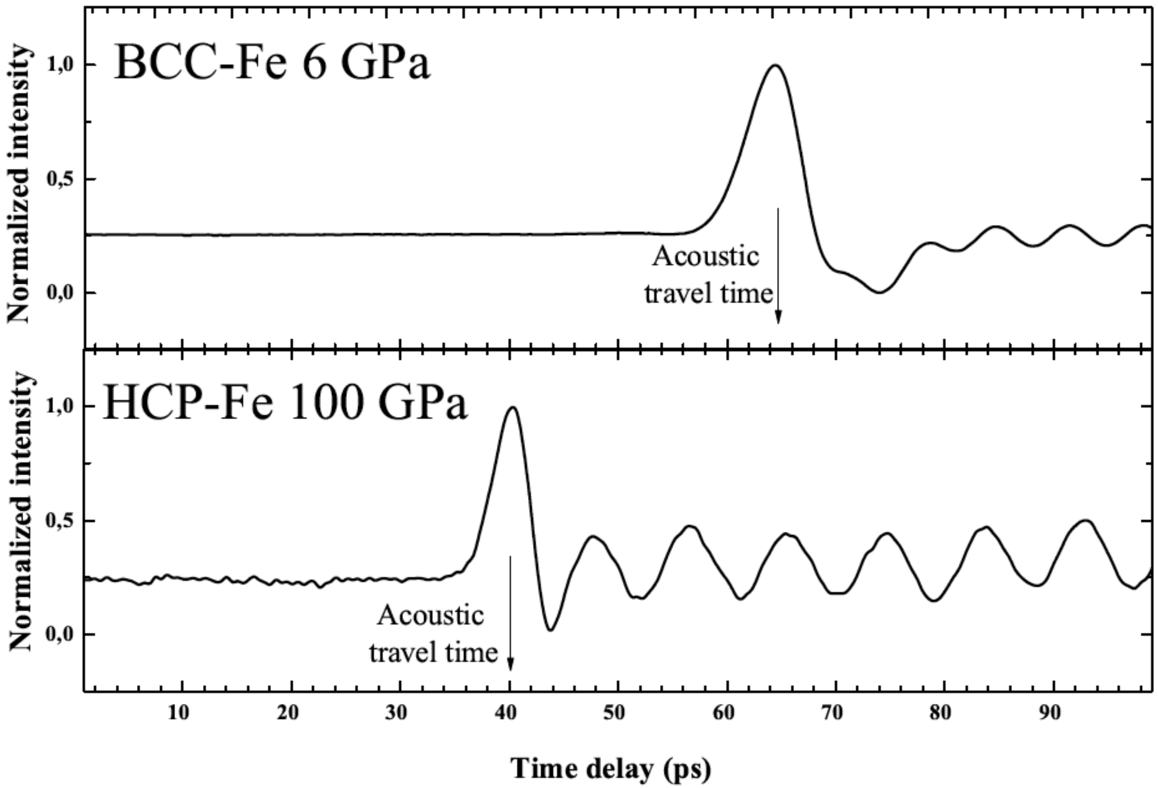
Equation of state :

$$B = \frac{C_{11} + 2C_{12}}{3}$$

Sound velocity in polycristalline Fe

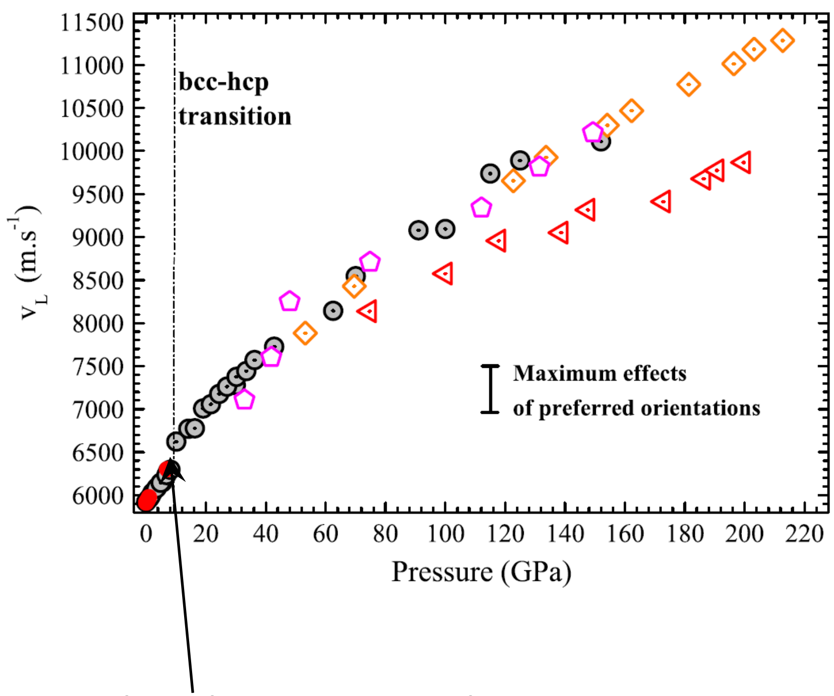
F.Decremps *et al* Geophys.Lett. **41** 1459 (2014)

Fe is the most abundant element in the Earth core

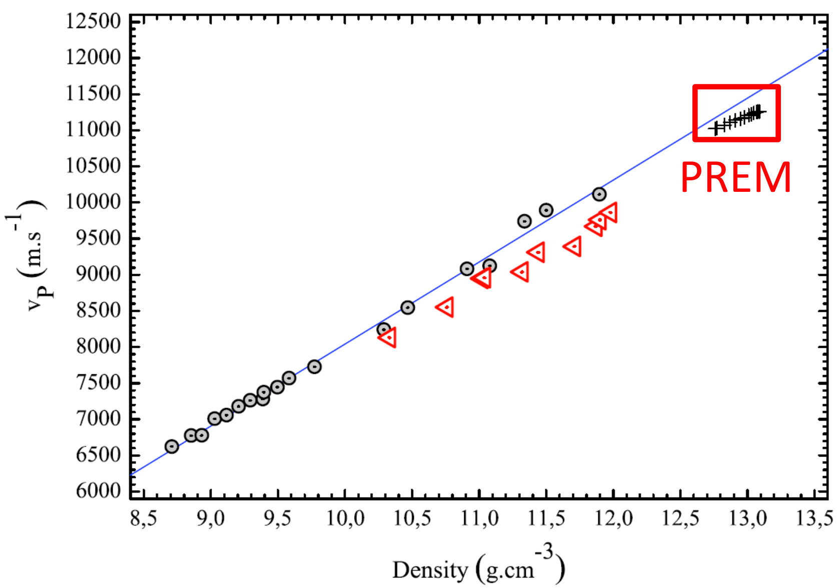


Sound velocity in polycristalline Fe

→ up to **152 GPa** (one order of magnitude higher than previously published ultrasonic data)



bcp-hcp structural transition

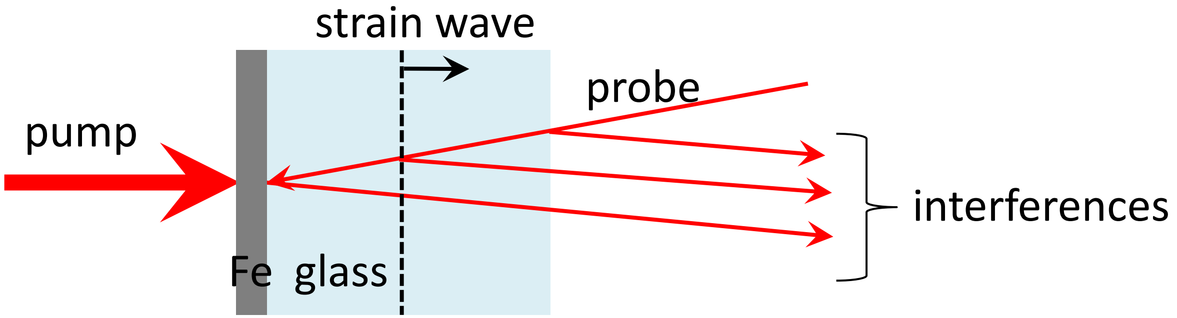


→ density is obtained with an EOS

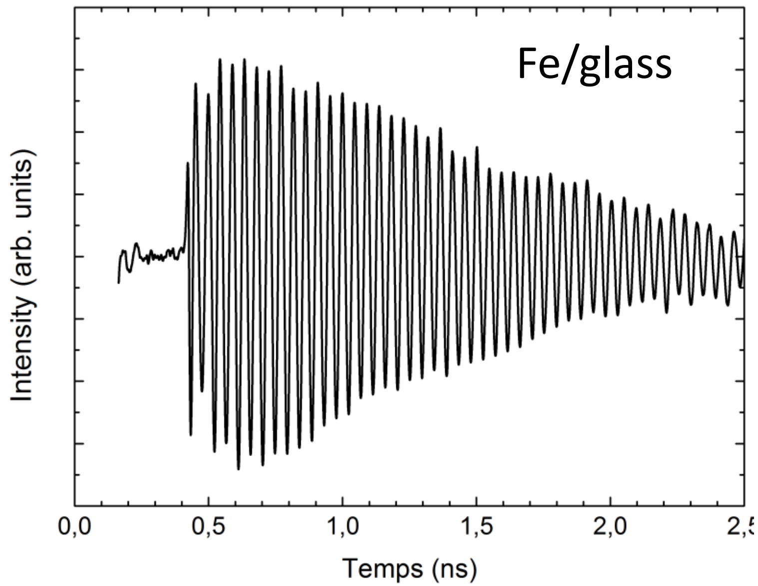
→ extrapolation and comparison with seismic model

F.Decremps *et al* Geophys.Lett. **41** 1459 (2014)

Transparent samples



Brillouin oscillations



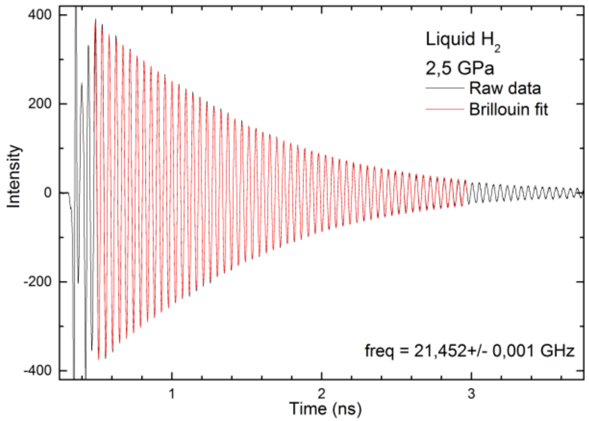
Period of oscillations

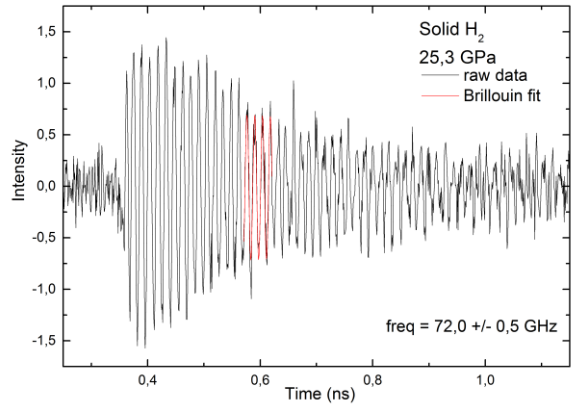
$$T = \frac{\lambda_{probe}}{2nv} = \frac{1}{f}$$

H_2 @ HP

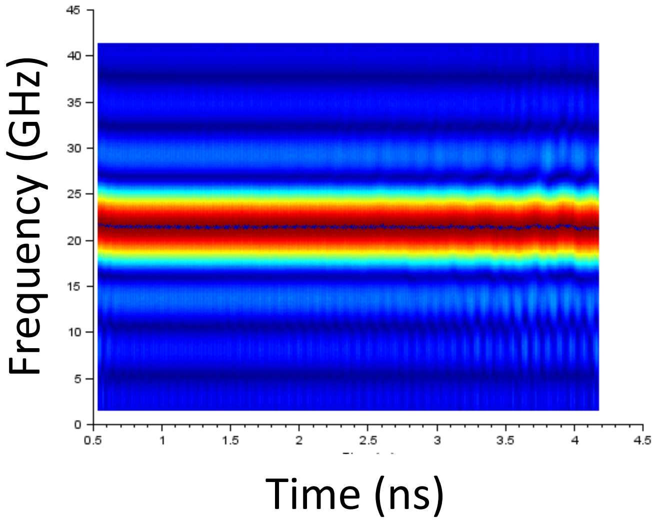
Liquid

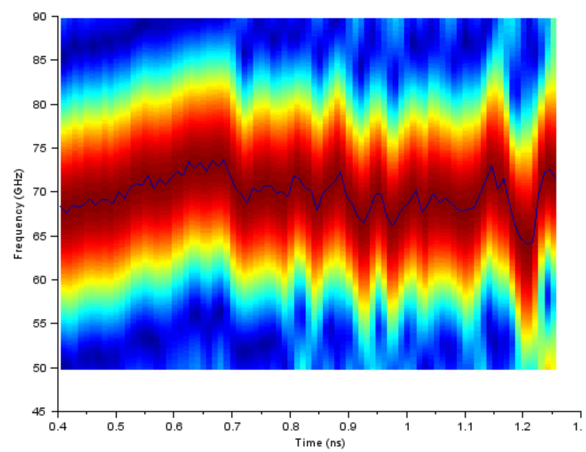
Solid

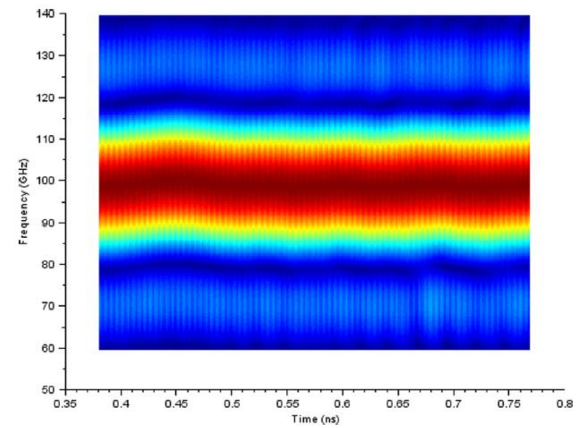




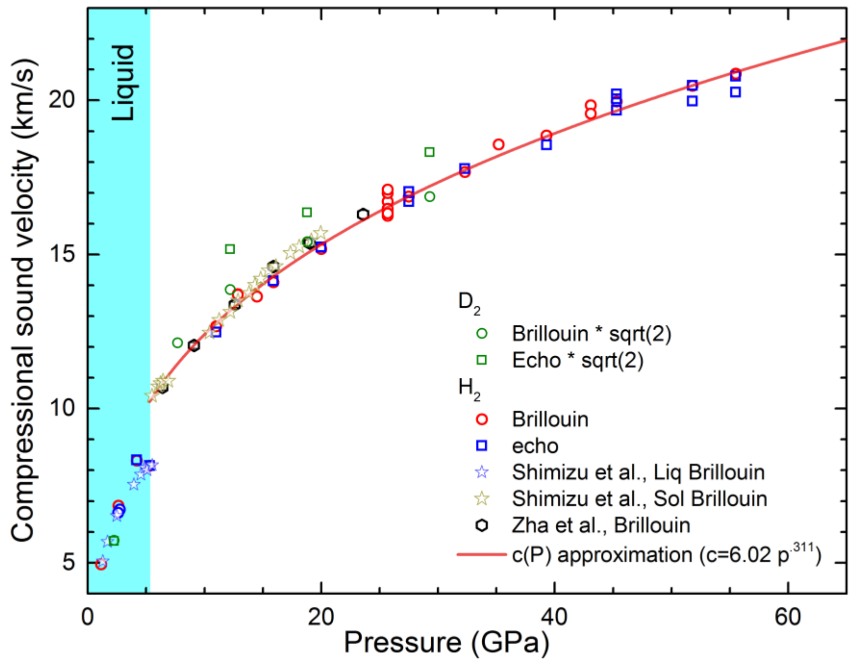
In-depth resolution in H_2



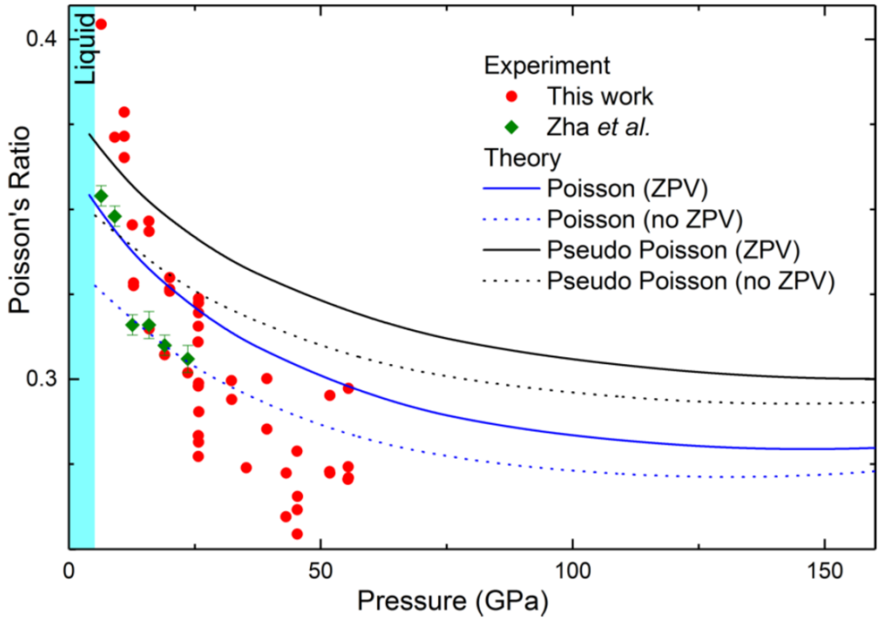




A. F. Goncharov *et al*, Phys. Rev. B, **95**, 214104 (2017)



(ZPV=zero-point vibration)



Brillouin osc. + echoes → v

→ Elastic properties over a large P range

A. F. Goncharov *et al*, Phys. Rev. B, **95**, 214104 (2017)

Conclusion & perspectives

- Picosecond acoustics is an useful technic to measure sound velocities, elastic properties, phase diagram, EOS @ HP in solids and liquids

- Review article : F. Decremps *et al* Ultrasonics **56** 129 (2015)

On-going developments

- Laser heating : 1000-5000 K, 0-200 GPa

- Thermal measurements (diffusivity) ?

THANK YOU FOR YOUR ATTENTION

See Eric Edmund *et al* poster <---------------------------

Velocity-Density Systematics in Fe-Si Alloys at Extreme Conditions