Synchrotron X-ray experiments for studying structure and properties of liquids and glasses at high-pressure and high-temperature conditions in large volume press

Yoshio Kono

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(formerly beamline scientist at HPCAT in Advanced Photon Source, USA)

Collaborators

Curtis Kenney-Benson, Changyong Park, Yanbin Wang, Guoyin Shen

Topics

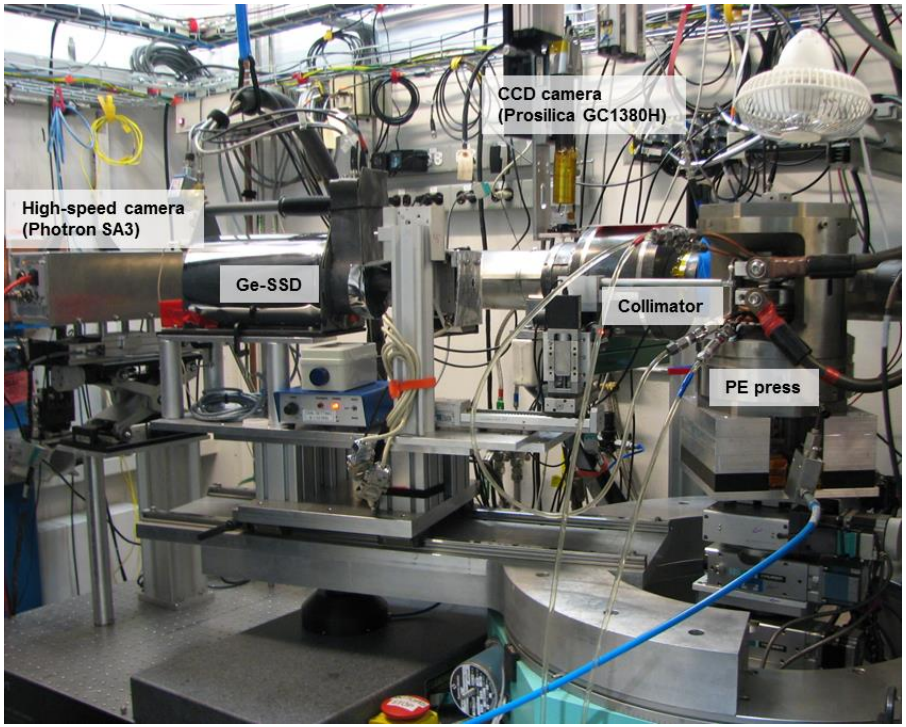
-High-pressure experiments using large volume press.

-High-pressure synchrotron X-ray experiments combined with large volume press.

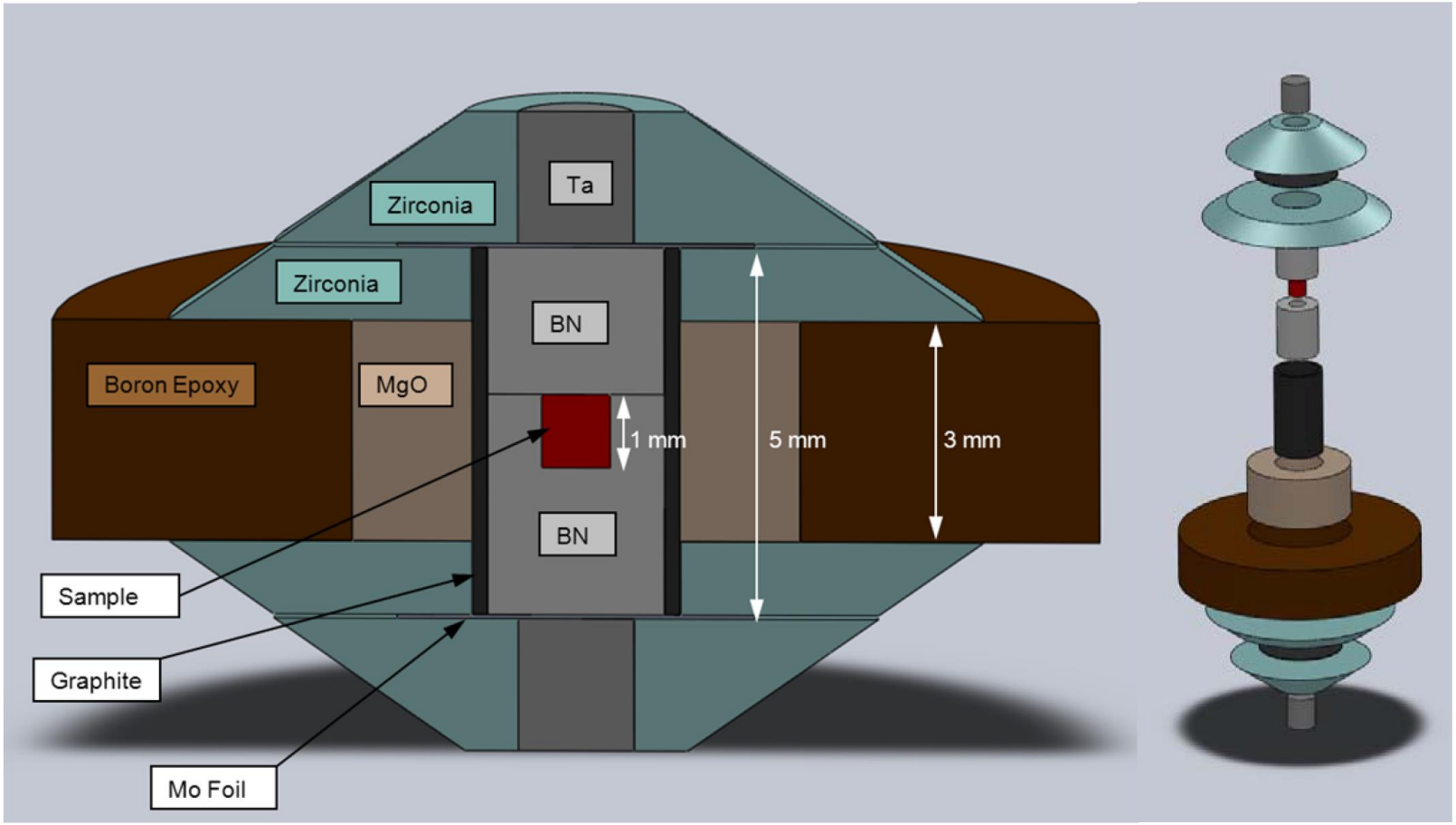
Large volume press

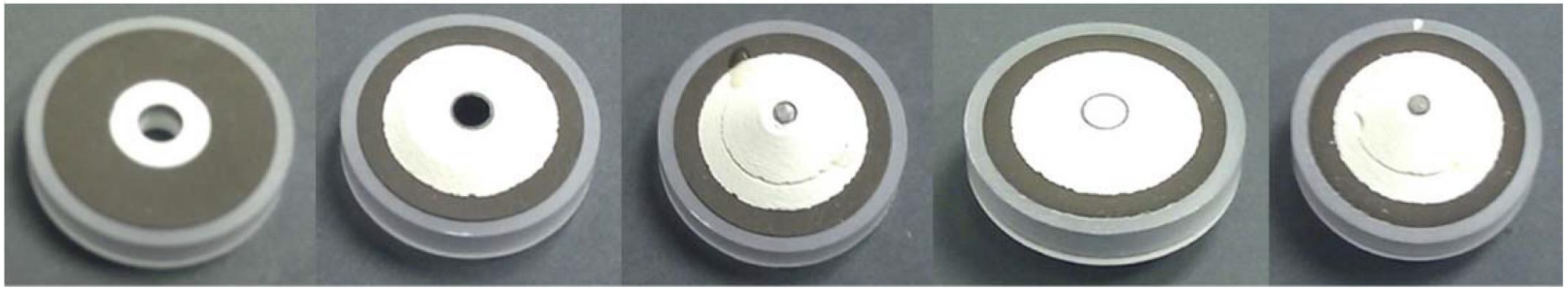
Multi-anvil press
at GRC, Ehime University, Japan

Paris-Edinburgh (PE) press
at HPCAT, Advanced Photon Source, USA



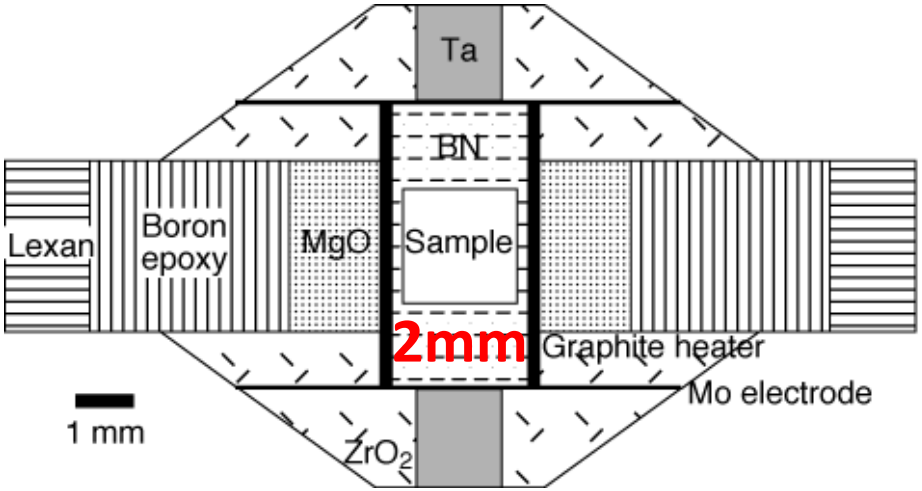
A standard PE cell at HPCAT



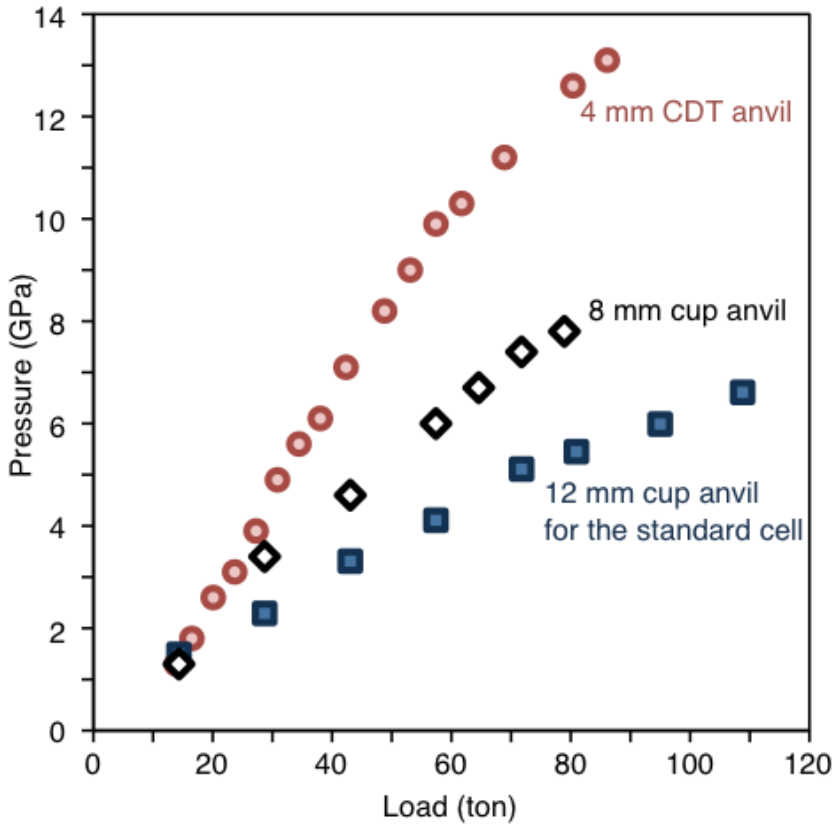


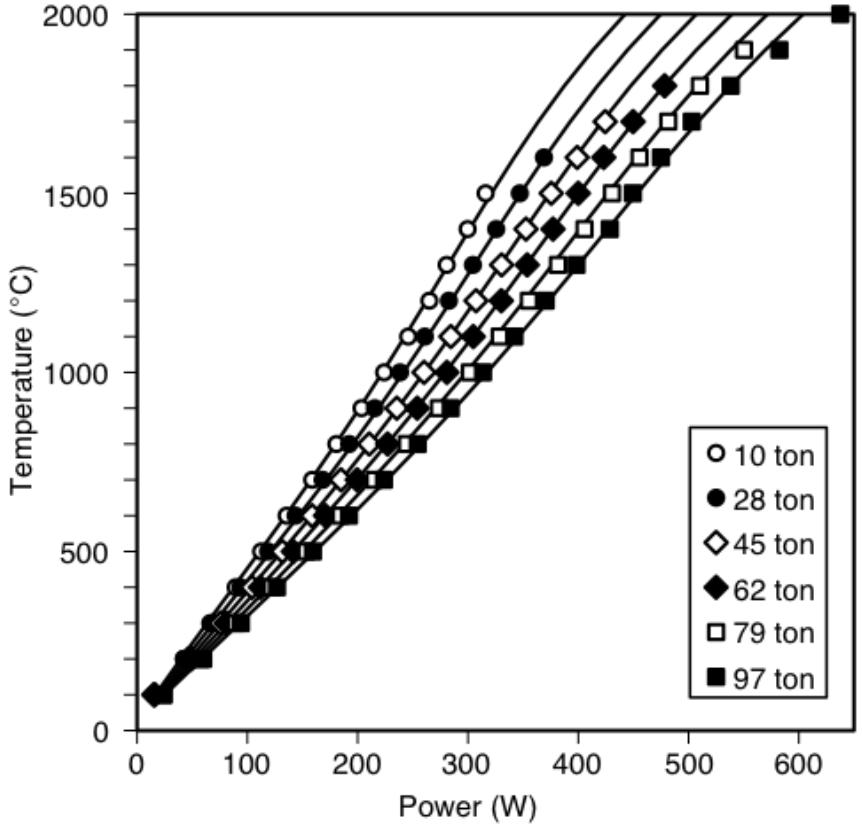
A standard PE cell at HPCAT

Large sample volume

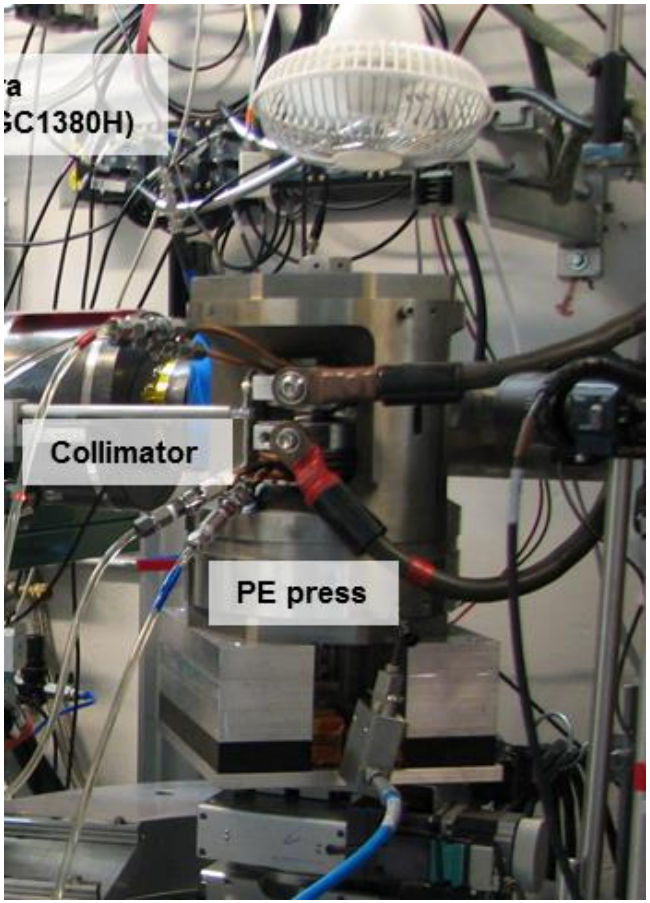


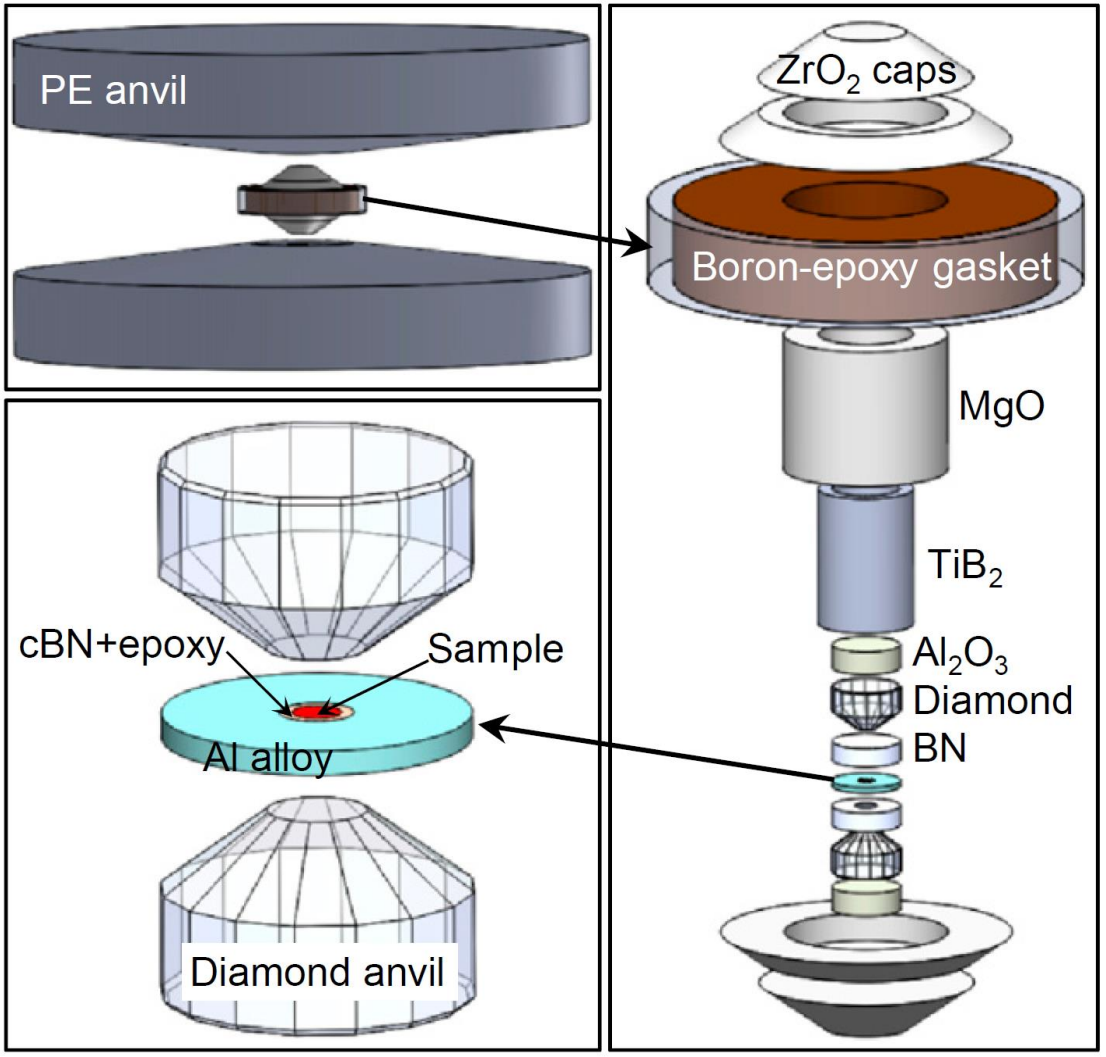
Kono et al. (2014), Phys. Earth Planet. Inter., 228, 269-280





New double-stage large volume cell (Kono et al., 2016)

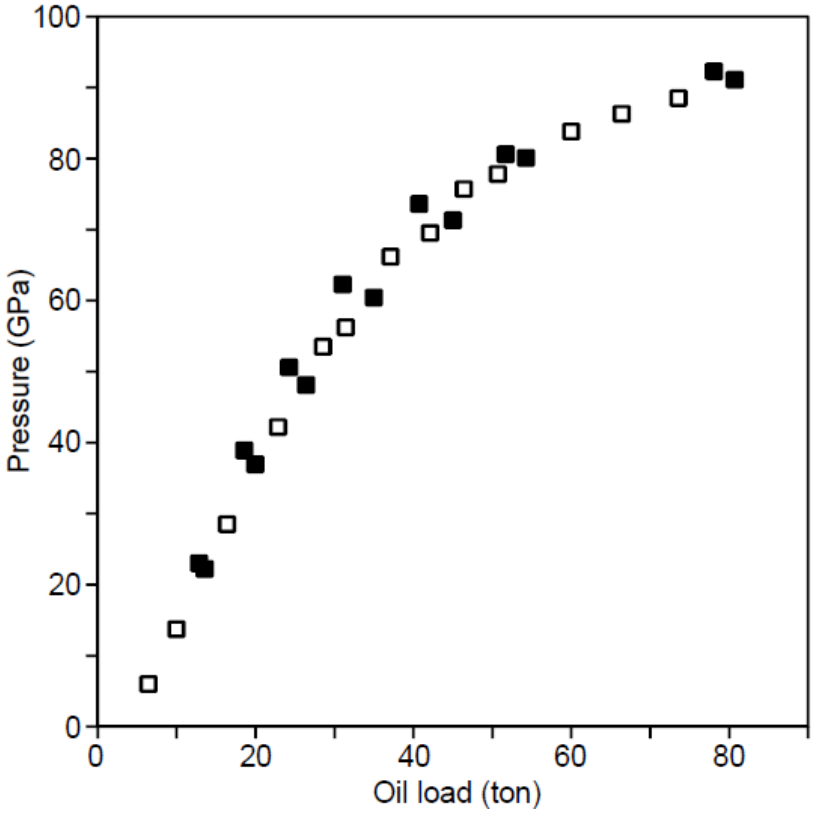




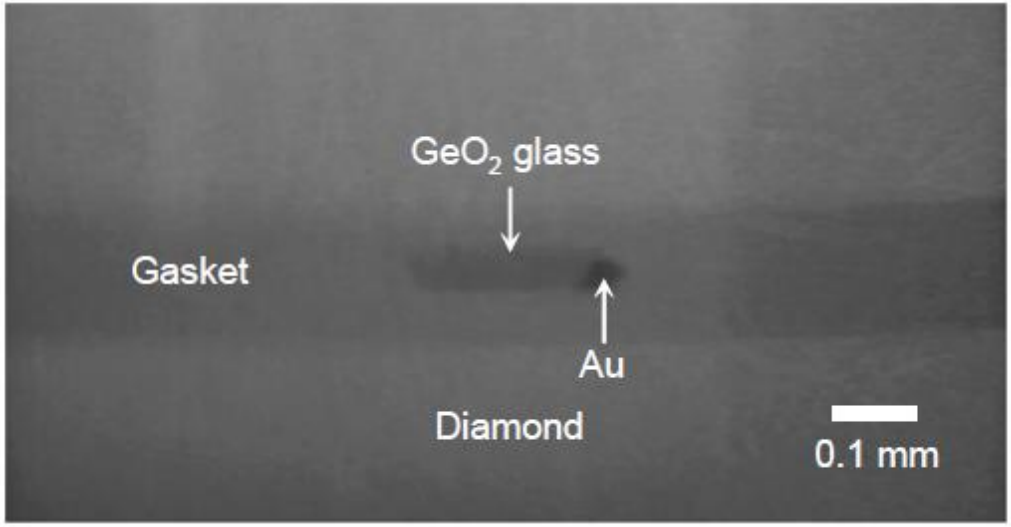
Kono et al. (2016)
PNAS, 113, 3436-3441

Sample size in 0.8 mm culet double-stage cell

Diamond anvil culet: 0.8 mm
Sample diameter: 0.3 mm
Sample thickness: 0.15 mm

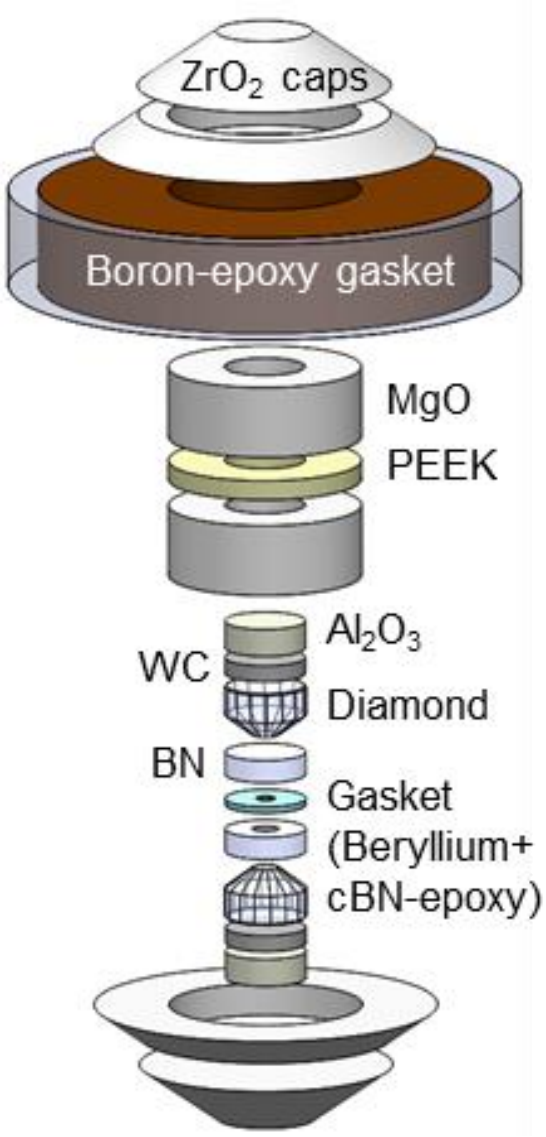


Radiography image at 92 GPa
Sample diameter: 0.24 mm
Sample thickness: 0.06 mm

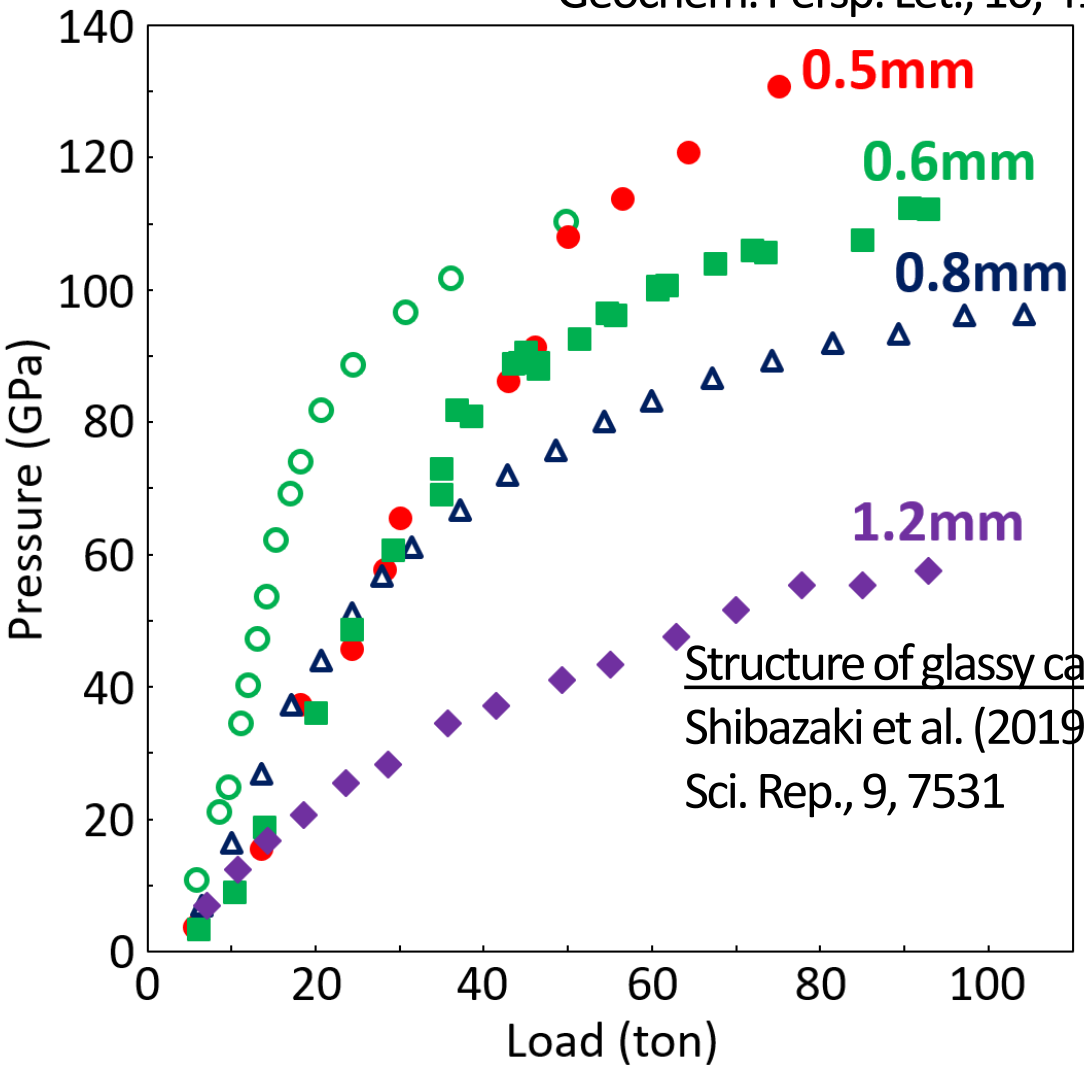


Kono et al. (2016)
PNAS, 113, 3436-3441

Latest advances in ultrahigh pressure generation with large volume sample



Ohira et al. (2019)
Geochem. Persp. Let., 10, 41-45



Structure of glassy carbon
Shibazaki et al. (2019)
Sci. Rep., 9, 7531

Topics

-High-pressure experiments using large volume press.

-High-pressure synchrotron X-ray experiments combined with large volume press.

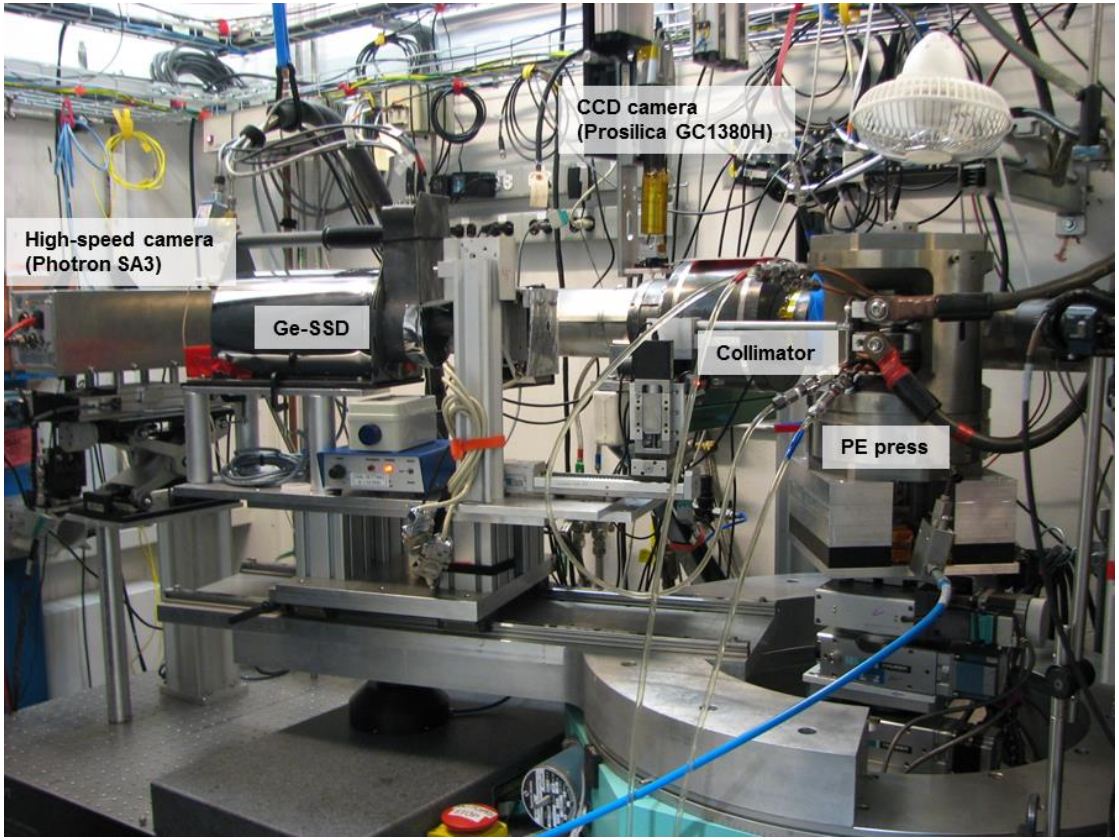
Synchrotron X-ray facilities

Couprie (2014)

APS 16BMB: unique beamline optimized for comprehensive study of liquids and glasses at high pressures using Paris-Edinburgh press

-Structure of liquids and glasses
-Elastic wave velocities
-Viscosity
-Imaging
of liquids

at high pressures and high temperatures using Paris-Edinburgh type large volume press.

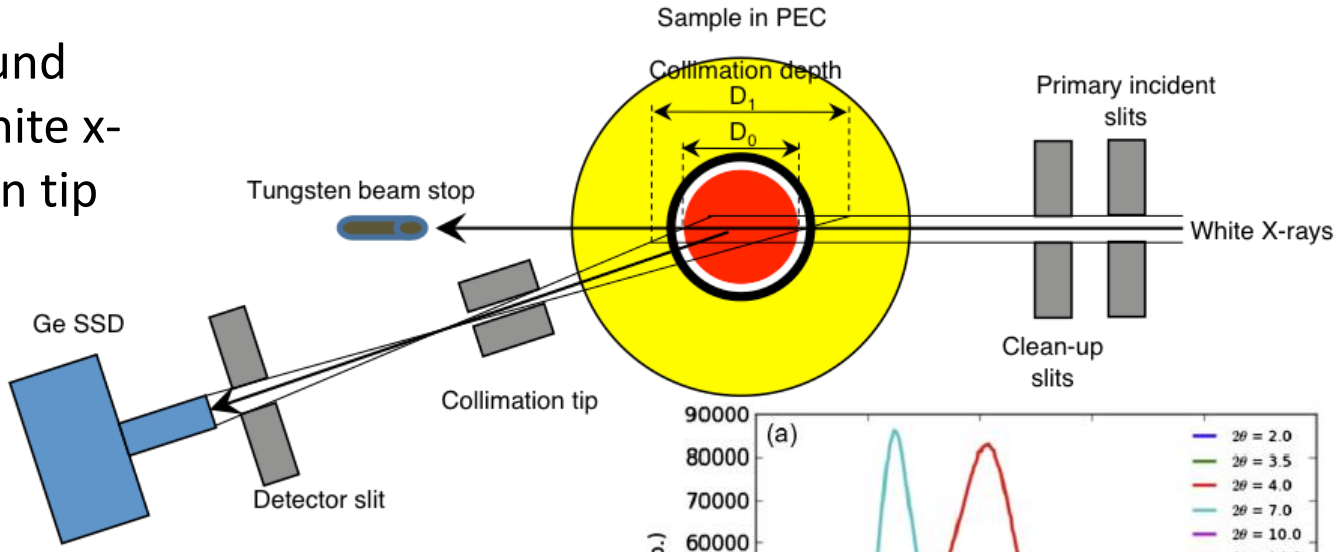


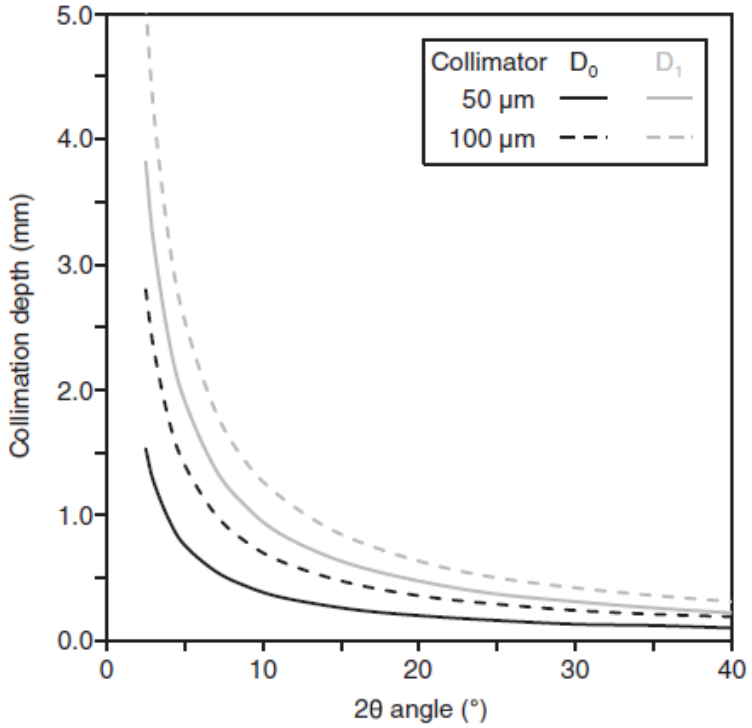
Kono et al. (2014), Phys. Earth Planet. Inter., 228, 269-280

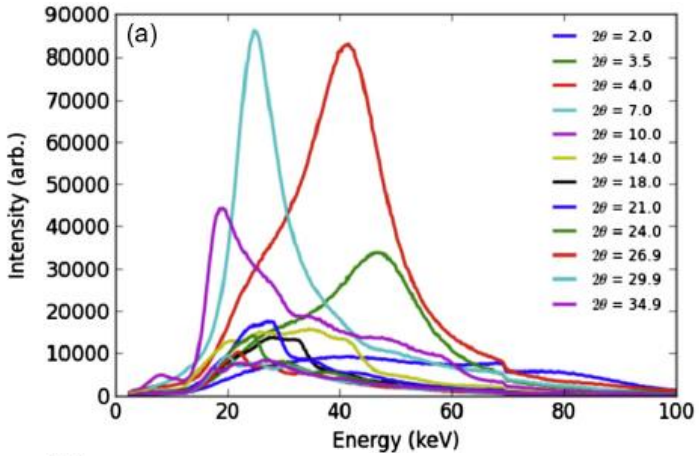
Structure measurement of liquids and amorphous materials

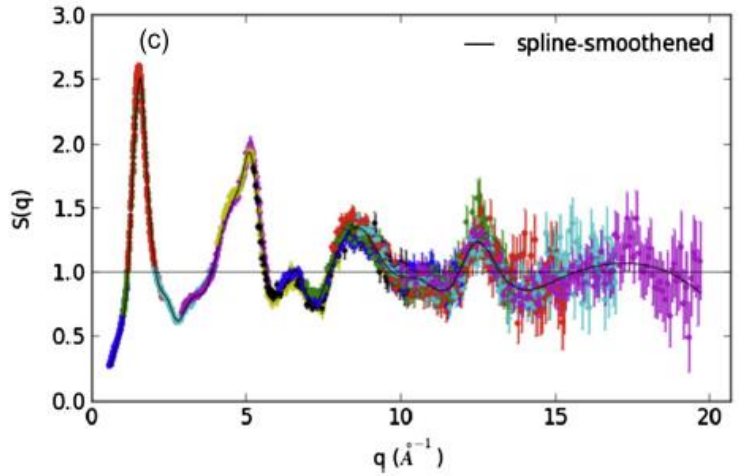
Reducing background signals by using white x-ray with collimation tip

Kono et al. (2014), Phys. Earth Planet. Inter., 228, 269-280









Discovery of ultrahigh pressure polyamorphism in GeO_2 glass with coordination number >6

PNAS

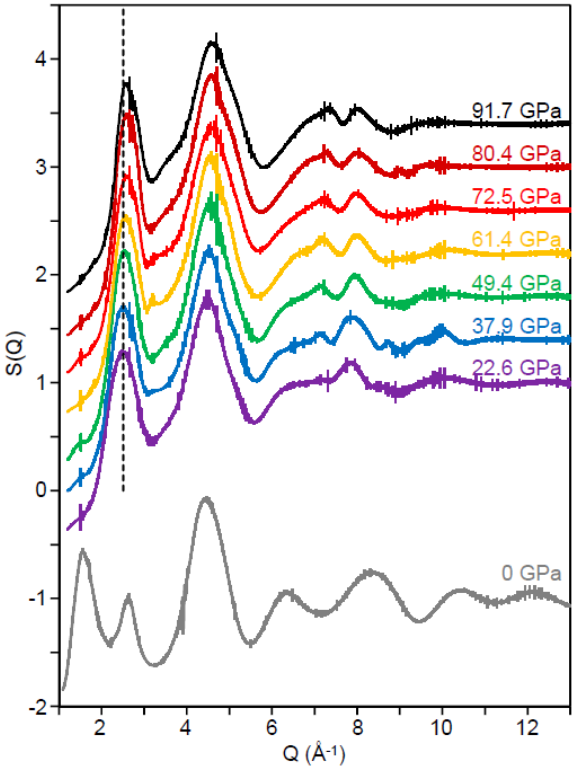
Ultrahigh-pressure polyamorphism in GeO_2 glass with coordination number >6

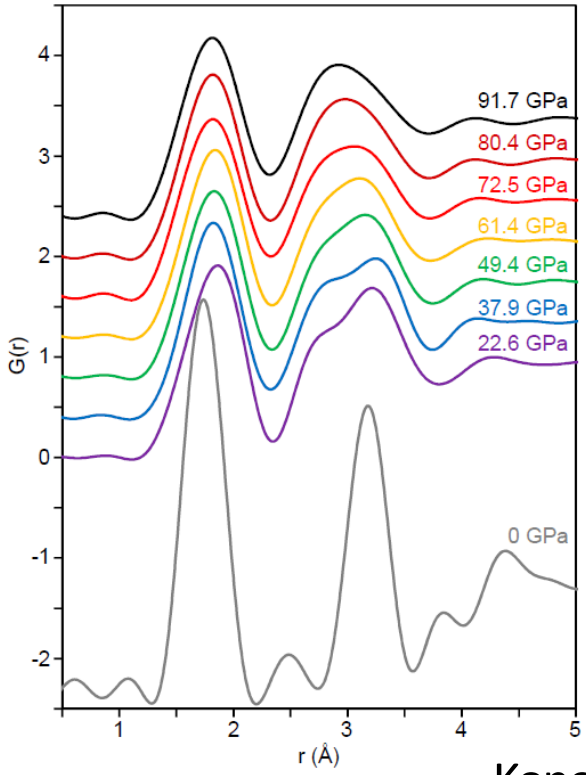
Yoshio Kono[a,1], Curtis Kenney-Benson[a], Daijo Ikuta[a], Yuki Shibazaki[b], Yanbin Wang[c], and Guoyin Shen[a]

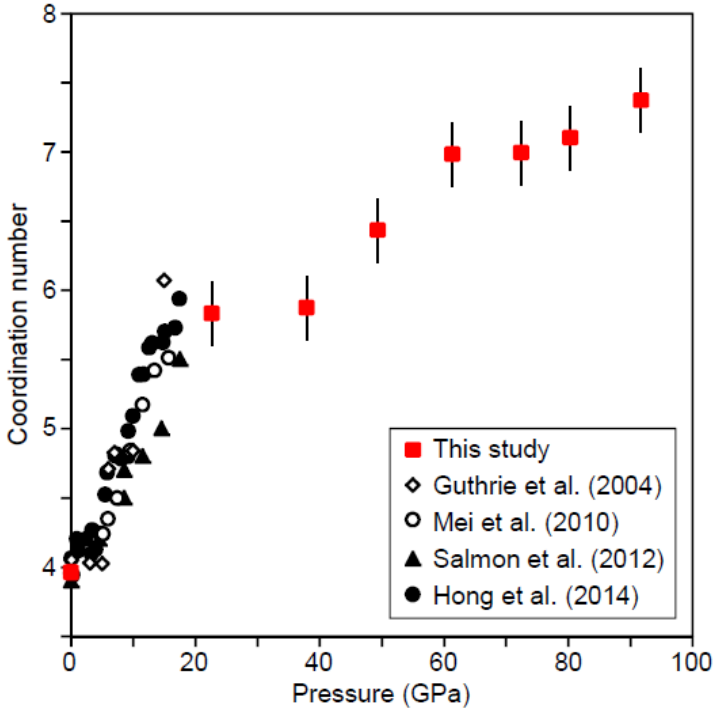
[a]High Pressure Collaborative Access Team, Geophysical Laboratory, Carnegie Institution of Washington, Argonne, IL 60439; [b]Frontier Research Institute for Interdisciplinary Sciences, Tohoku University, Aoba-ku, Sendai 980-8578, Japan; and [c]Center for Advanced Radiation Sources, The University of Chicago, Chicago, IL 60637

Edited by Alexandra Navrotsky, University of California, Davis, CA, and approved February 17, 2016 (received for review December 9, 2015)

Knowledge of pressure-induced structural changes in glasses is Brillouin scattering in a diamond anvil cell (DAC) showed a kink



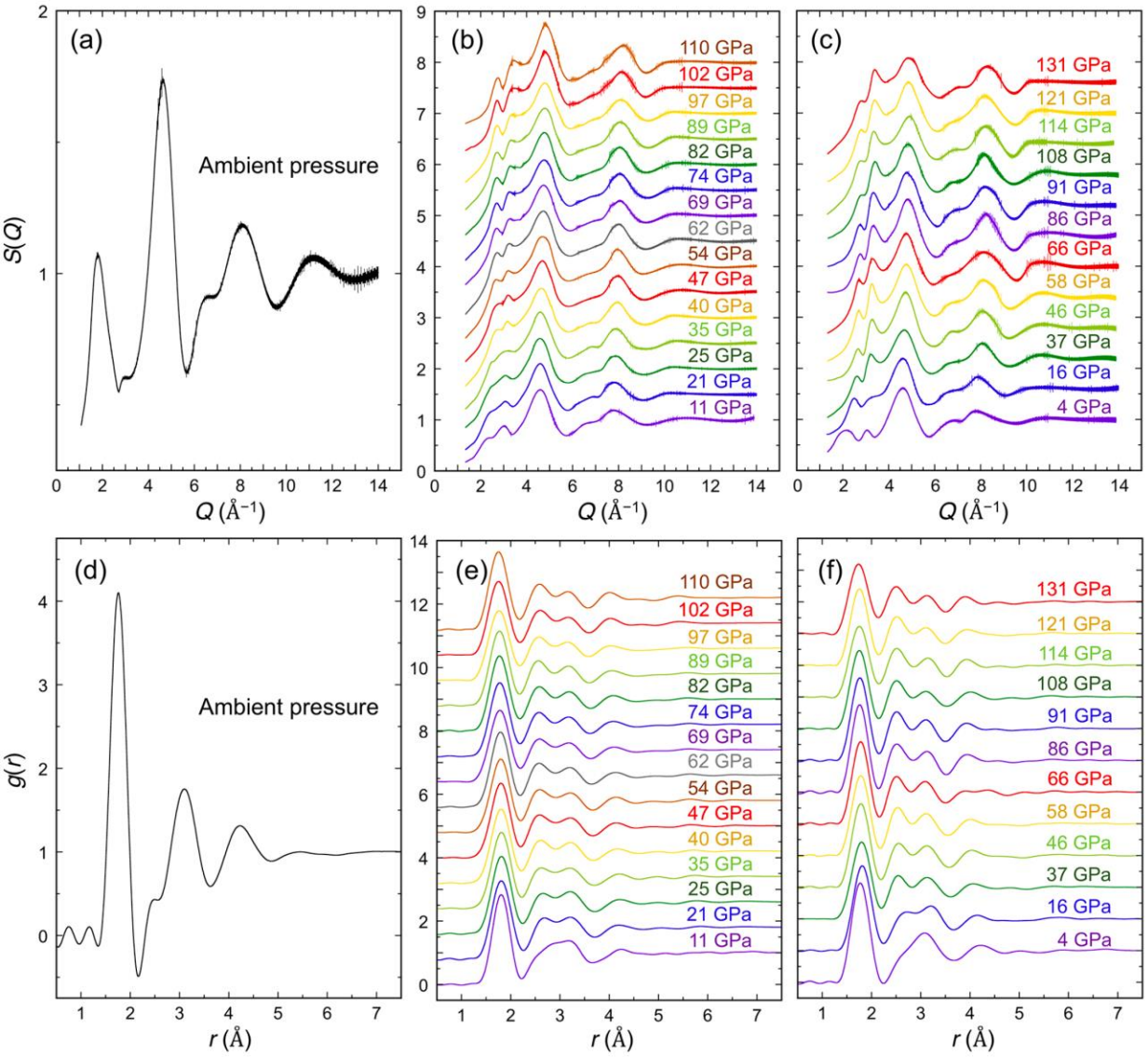




Kono et al. (2016), PNAS, 113, 3436-3441

Structure of Al_2O_3-SiO_2 glass near the pressure of CMB

Geochemical Perspectives Letters



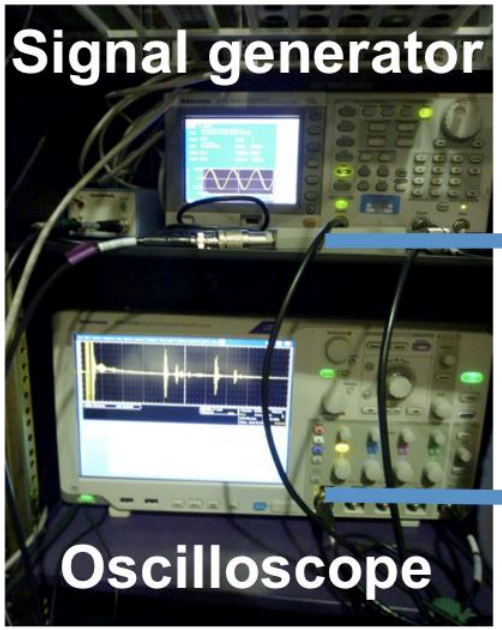
Ultrahigh pressure structural changes in a 60 mol. % Al_2O_3–40 mol. % SiO_2 glass

I. Ohira[1,2*], Y. Kono[1,3], Y. Shibazaki[4,5], C. Kenney-Benson[6], A. Masuno[7], G. Shen[6]

Ohira et al. (2019)
Geochem. Persp. Let., 10, 41-45

Ultrasonic measurement

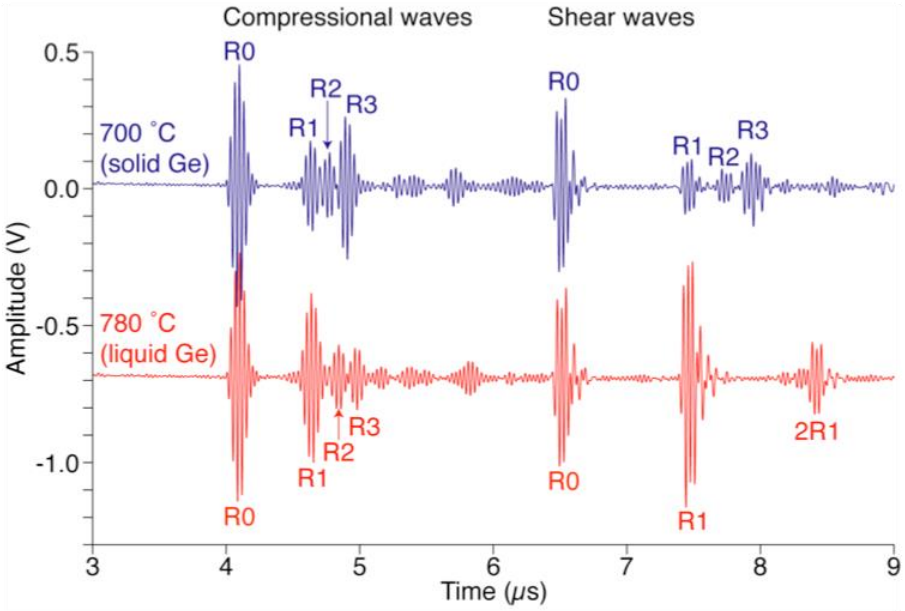
Kono et al. (2012), RSI, 83, 033905

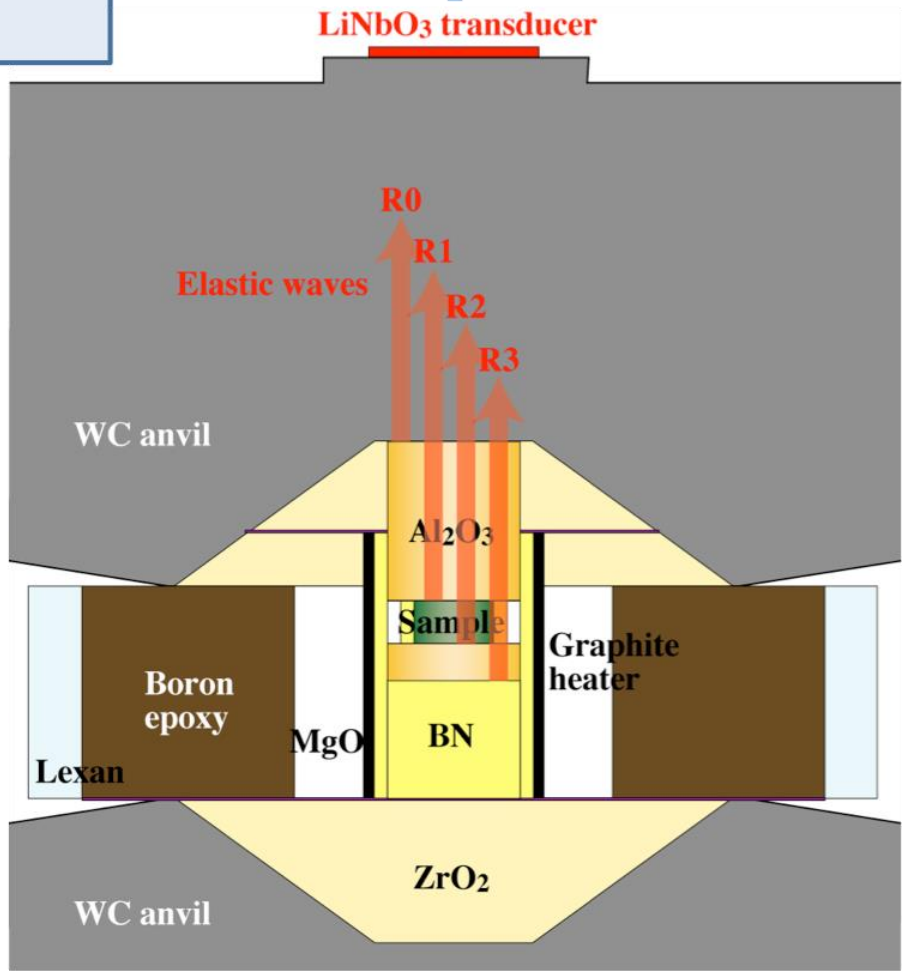


Directional bridge

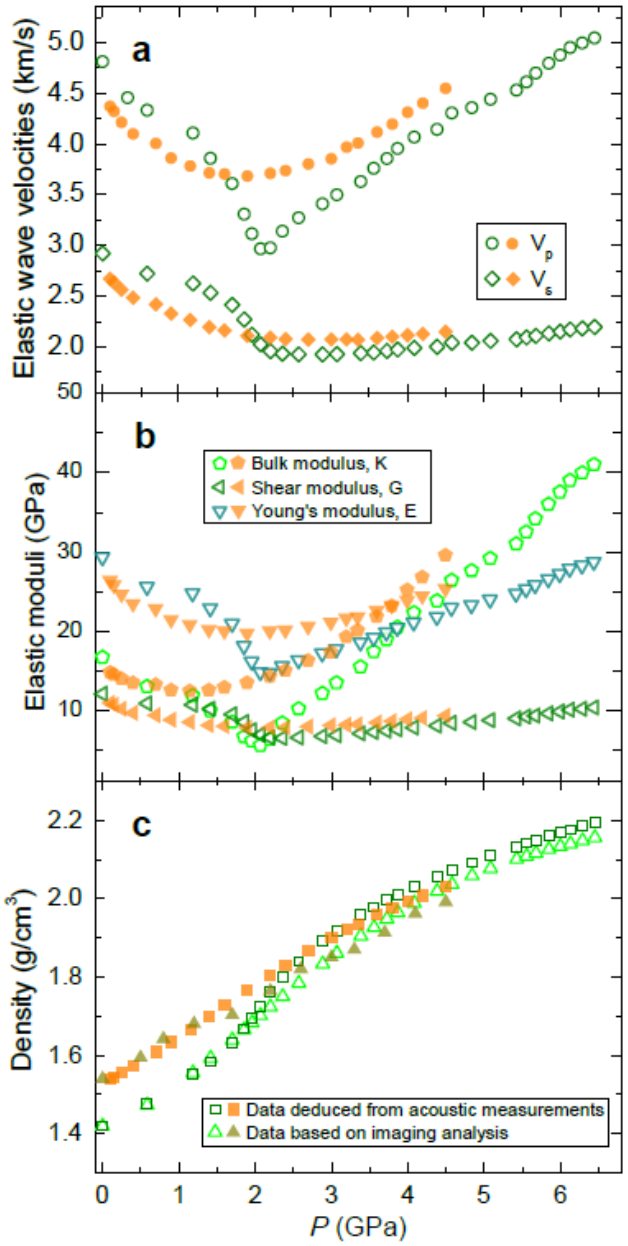
-40 dB

Amplifier (+40 dB)



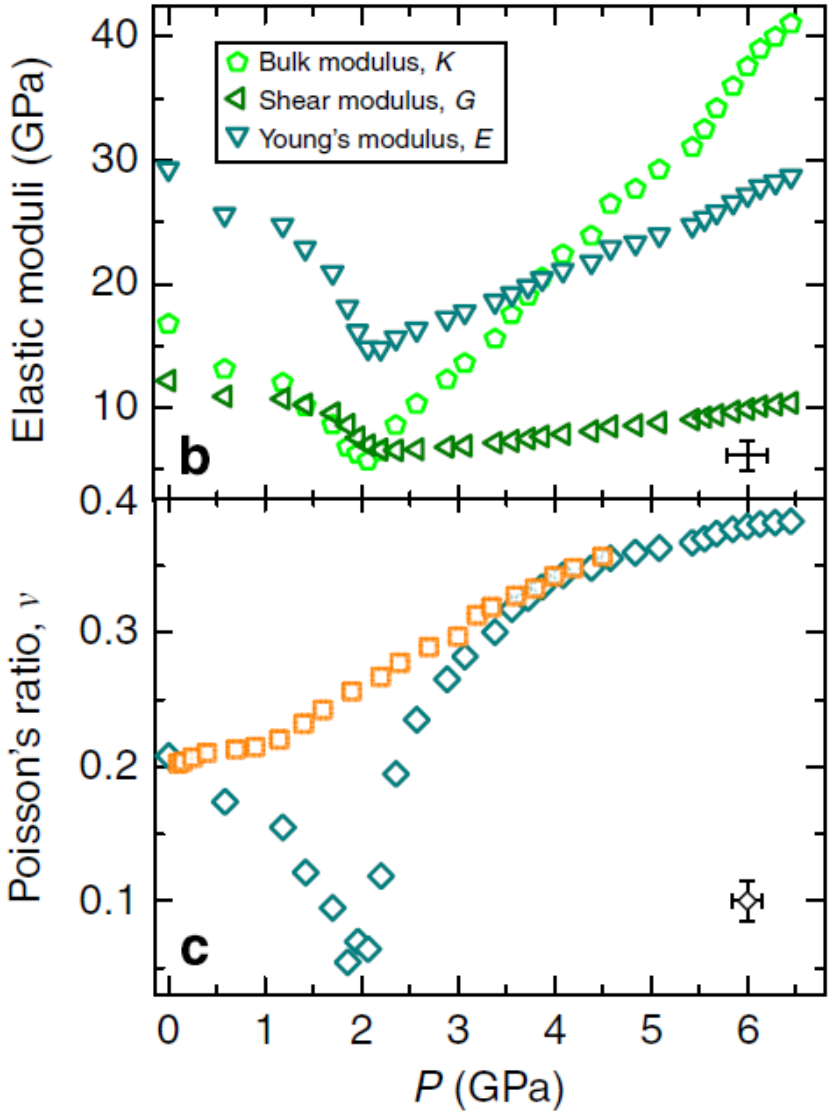


Anomaly in elastic properties in type-II grassy carbon



Type I

Type II



Zhao et al. (2015), Nature Communications, 6:6212

Combined elastic property and 3D tomography measurement at APS, 13BMD

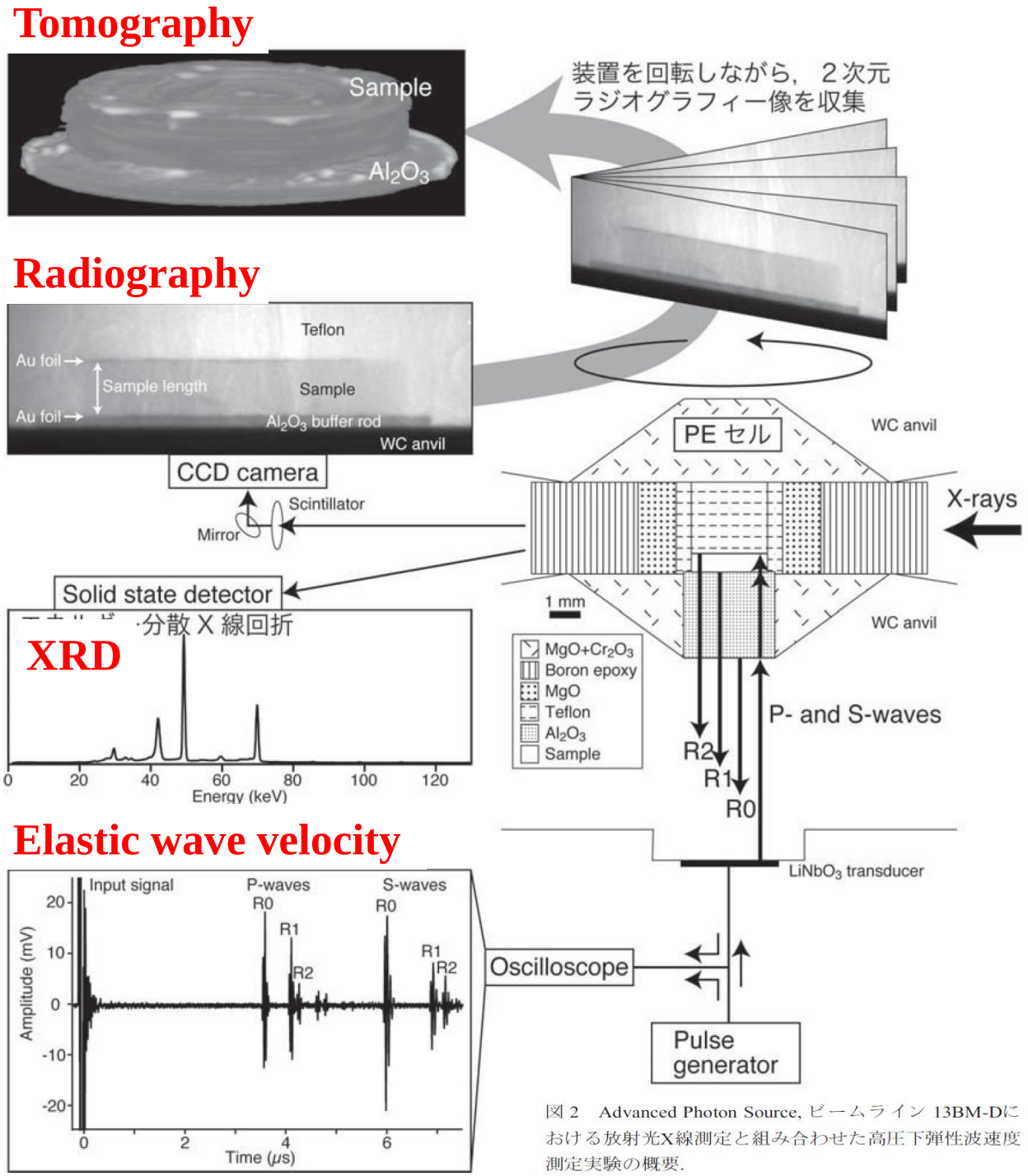
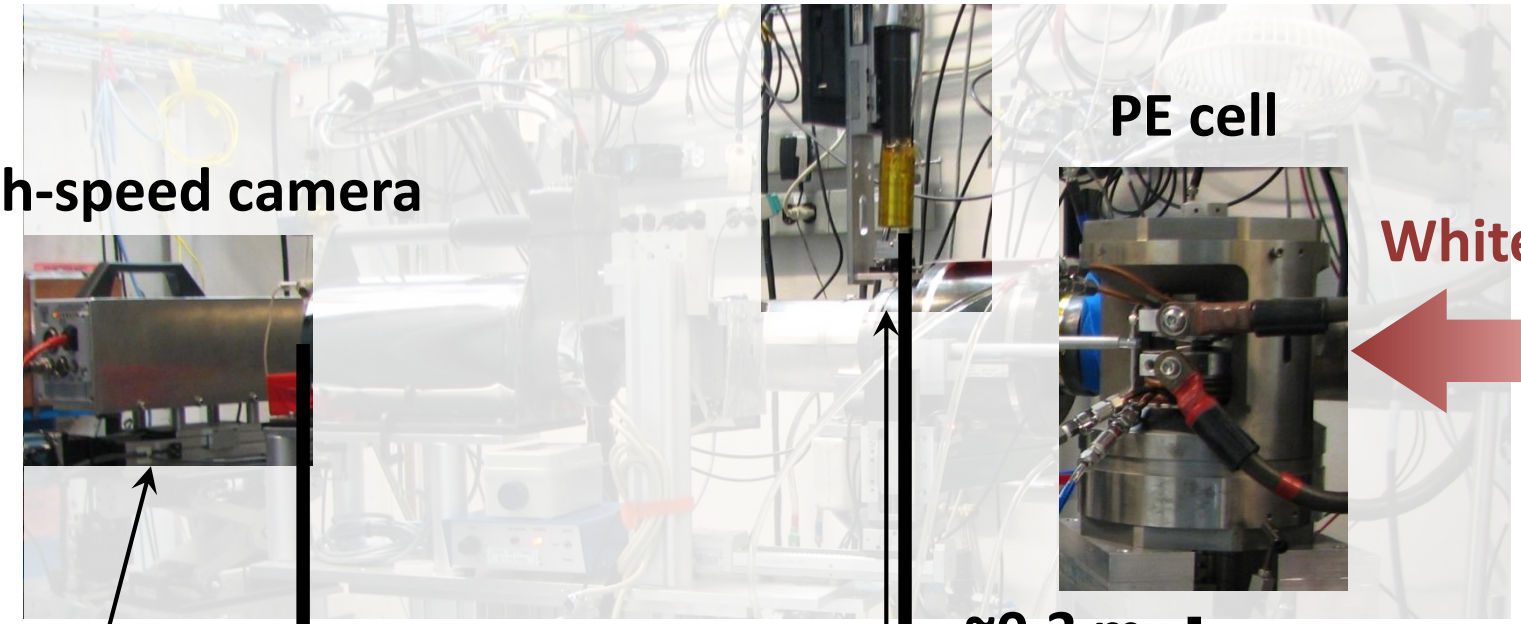


図２　Advanced Photon Source, ビームライン 13BM-Dにおける放射光X線測定と組み合わせた高圧下弾性波速度測定実験の概要.

Kono and Wang (2012), Chikyu

Kono et al. (2011) RSI, 82, 023906

White X-ray imaging



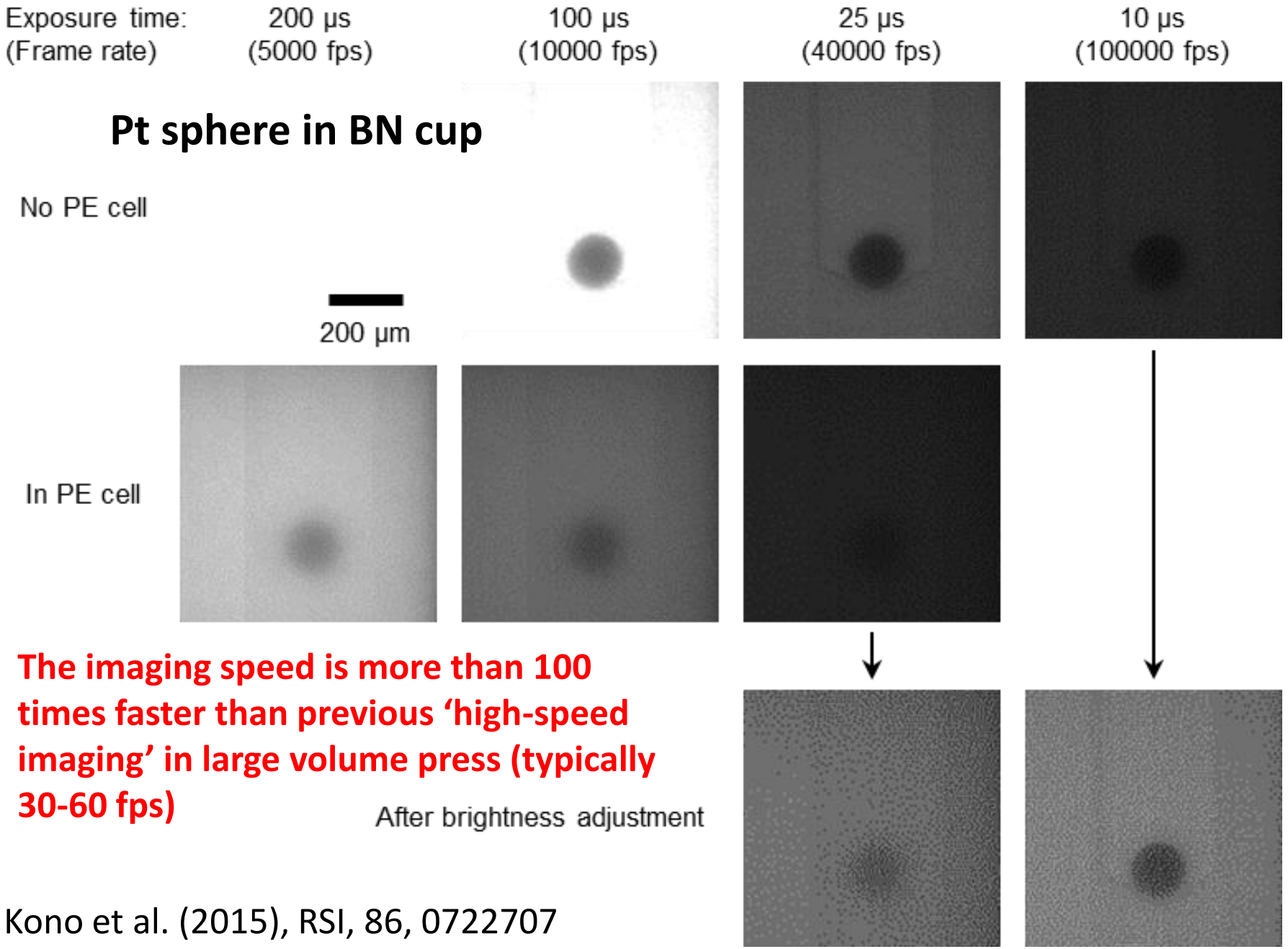
Photron SA3
- typically 2.5 or 5.0 µm/pixel
- up to120,000 frames/second

Purpose
-Fast imaging (e.g., viscosity)
-Phase contrast image

Prosilica GC1380H
- 0.95 µm/pixel
- <30 frames/second

Purpose
-Static and low speed imaging
-Sample shape determination

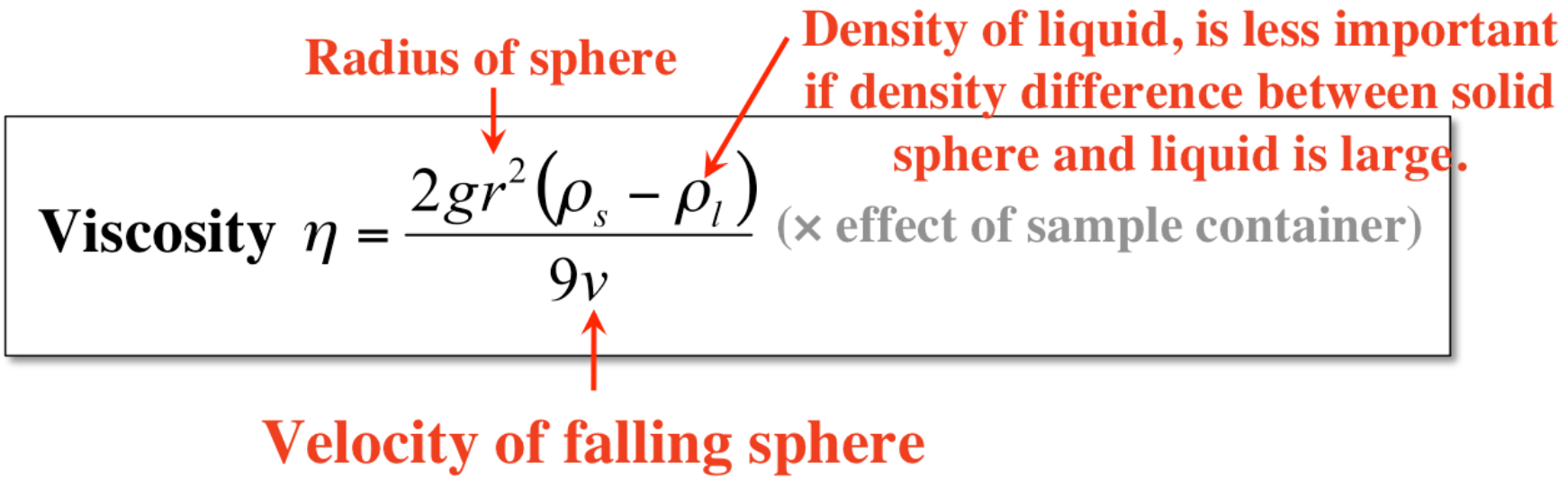
Fast imaging capability at 16-BM-B



The imaging speed is more than 100 times faster than previous 'high-speed imaging' in large volume press (typically 30-60 fps)

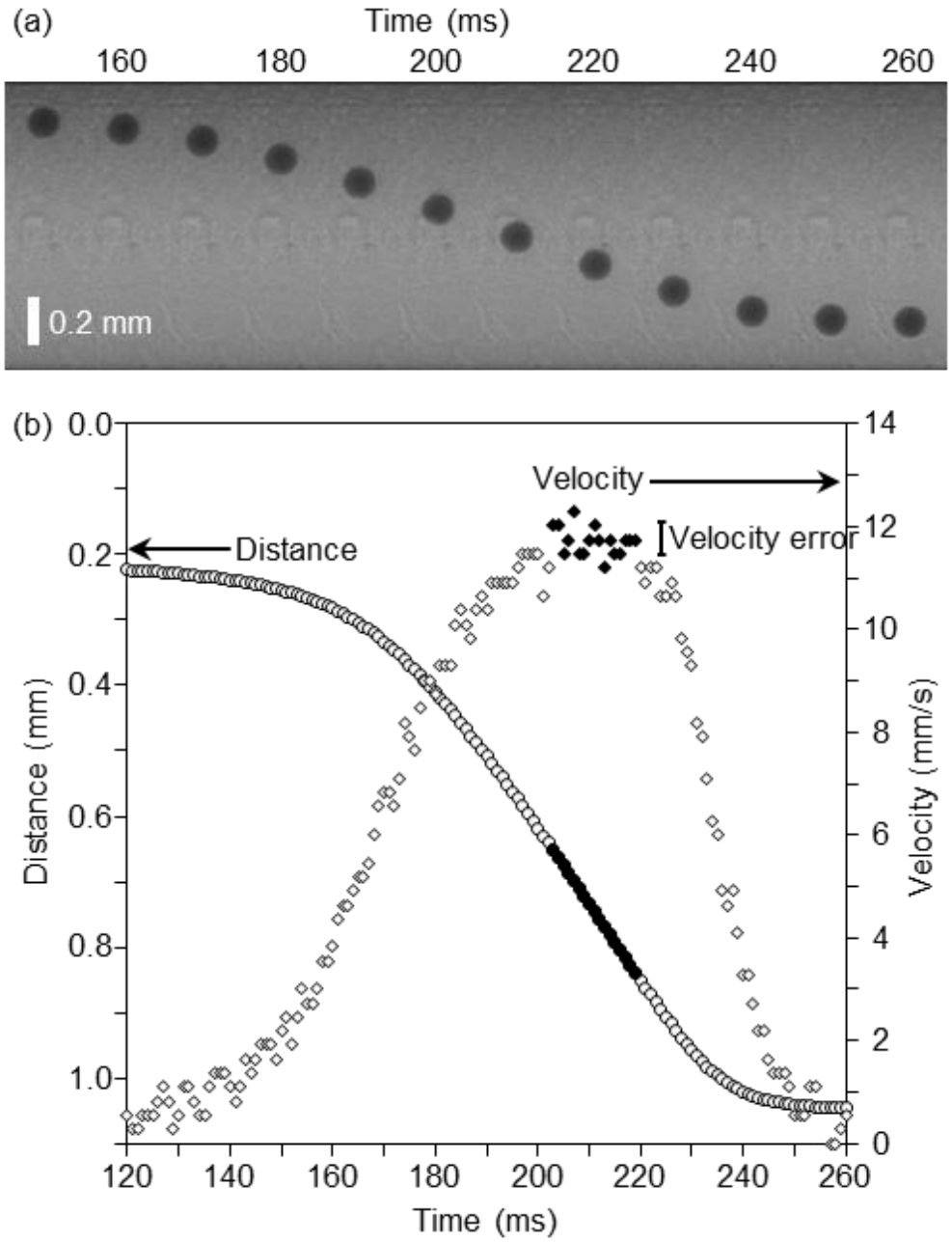
Kono et al. (2015), RSI, 86, 0722707

Falling sphere viscosity measurement



- Accurate determination of velocity of falling ball is essential to precisely determine viscosity of low-viscosity materials.

Analysis of falling sphere viscosity measurement



Kono et al. (2014)
Nature Comm., 5, 5091

Ultralow viscosisty of carbonate melt

Kono et al. (2014)
Nature Comm., 5, 5091

nature COMMUNICATIONS

ARTICLE

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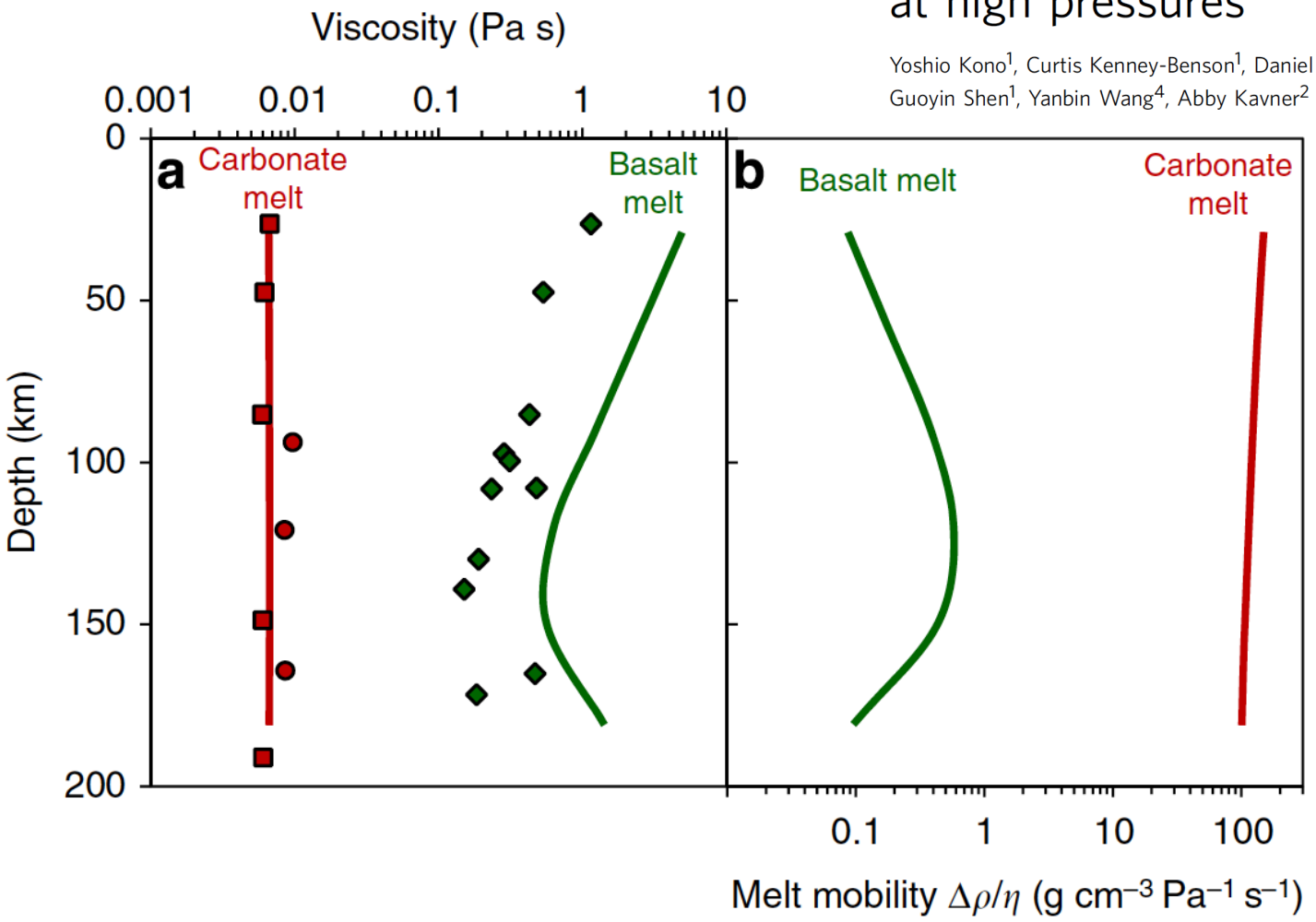
DOI: 10.1038/ncomms6091

Ultralow viscosity of carbonate melts at high pressures

Yoshio Kono[1], Curtis Kenney-Benson[1], Daniel Hummer[2], Hiroaki Ohfuji[3], Changyong Park[1], Guoyin Shen[1], Yanbin Wang[4], Abby Kavner[2] & Craig E. Manning[2]

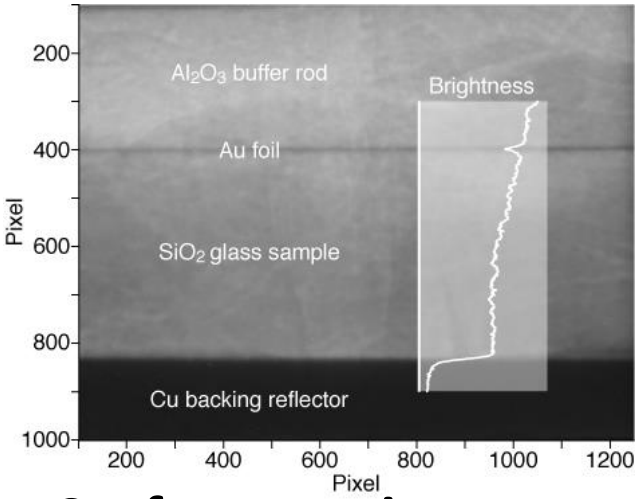


Other imaging experiments

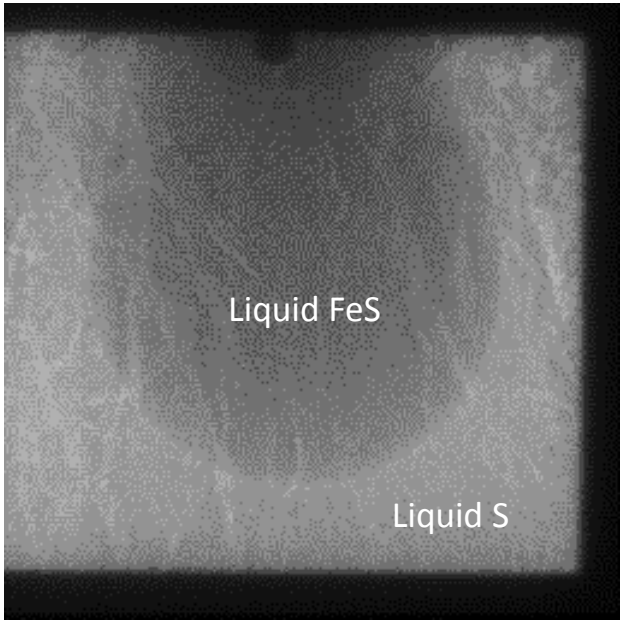
Kono et al. (2015), RSI, 86, 0722707

Sample shape

-Sample length

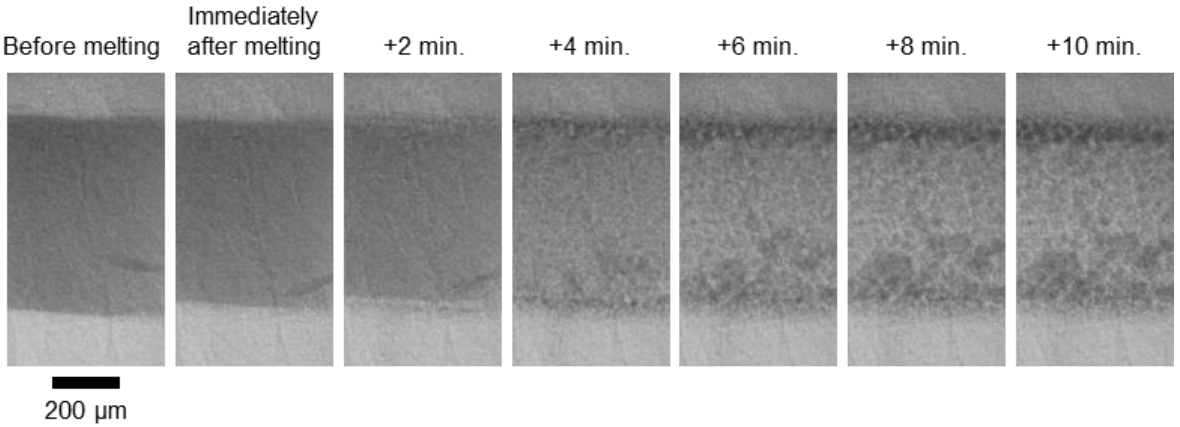


-Surface tension

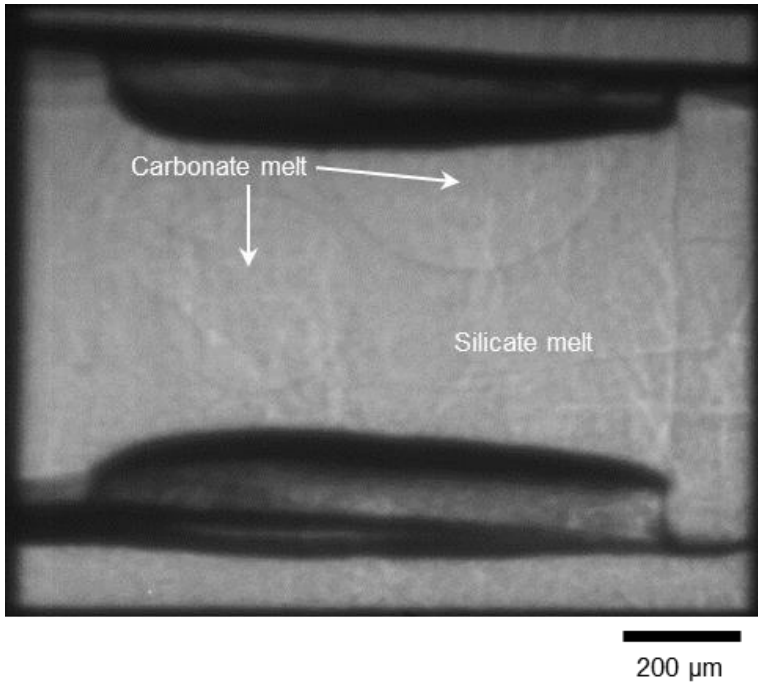


Liquid phase separation

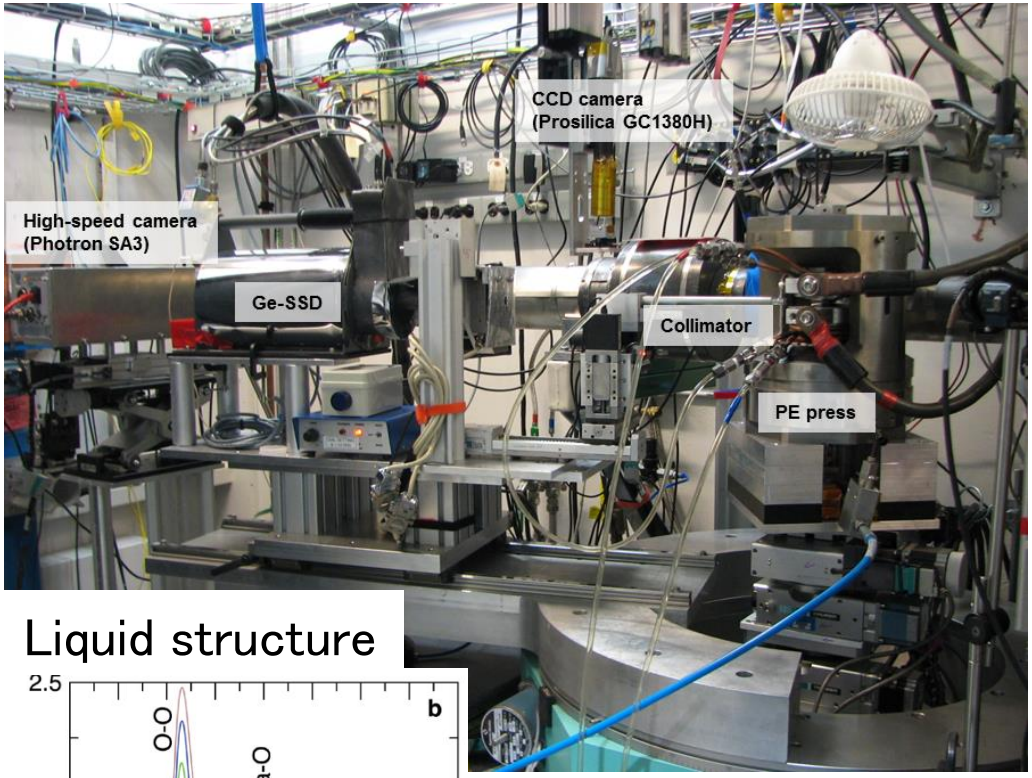
Sample: lithium germanate borate



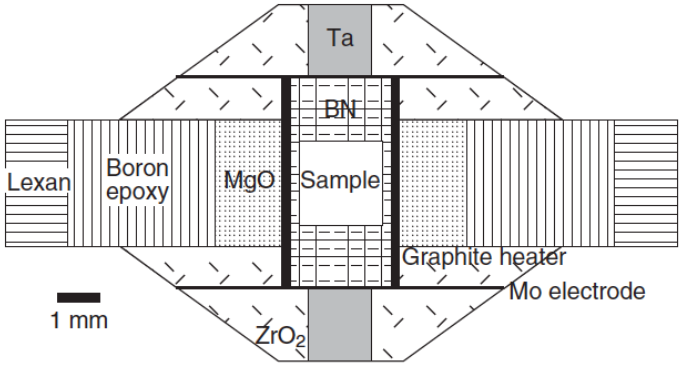
Silicate and carbonate melts immiscibility



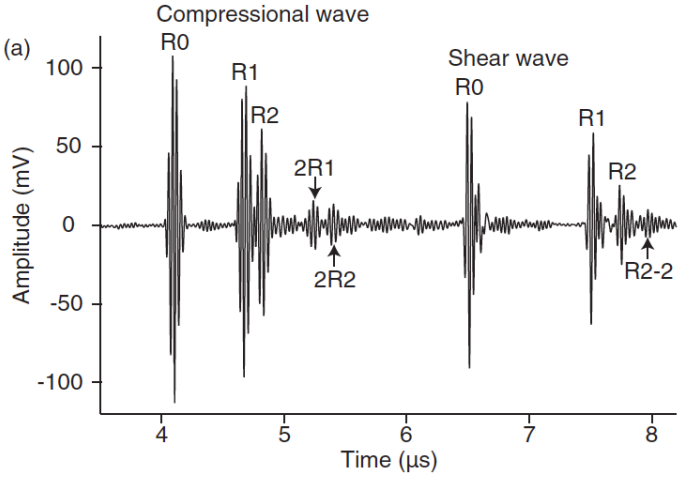
Comprehensive study of liquids under pressure



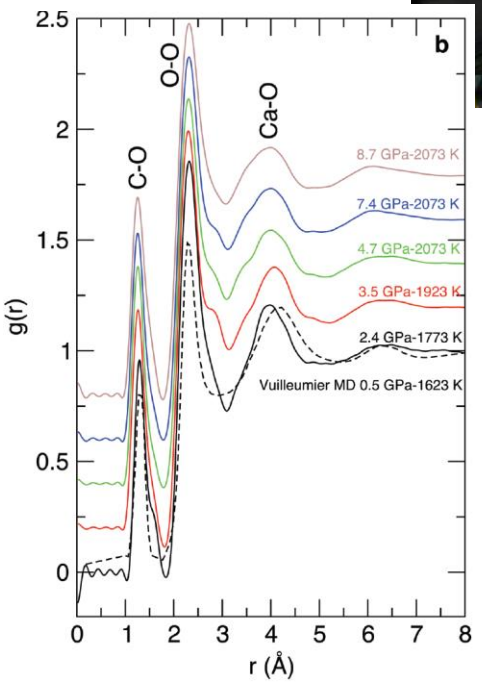
Large volume press experiment



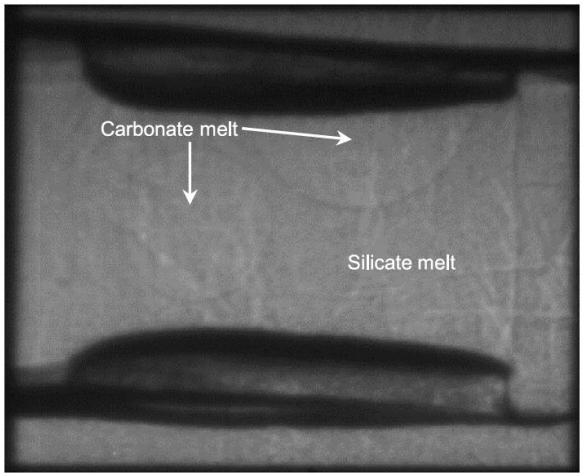
Ultrasonic measurement



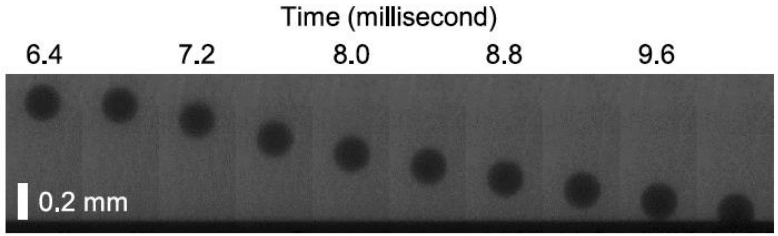
Liquid structure



Imaging of magmas

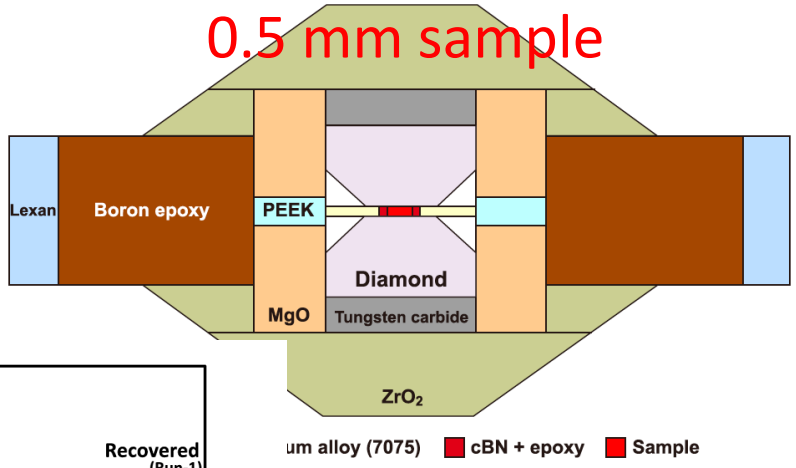


Viscosity of liquids

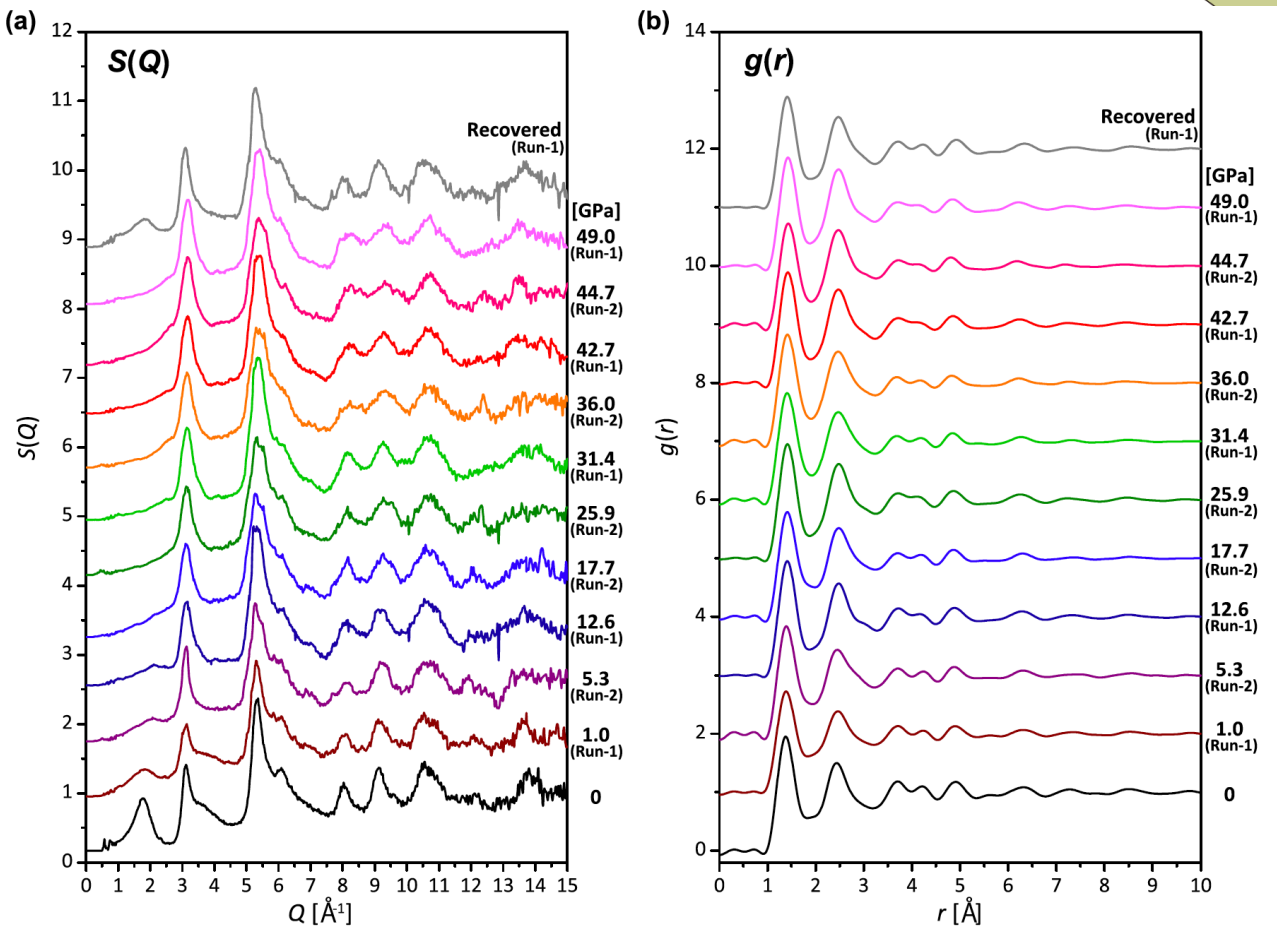


Measurement of structure of glassy carbon at 49 GPa

0.5 mm sample



9 hours acquisition time for 1 data point



Shibazaki et al. (2019)
Sci. Rep., 9, 7531

Measurement of structure of lower Z amorphous solids and liquids at higher pressures is challenge for the future.

Summary

-Combination of large volume press and synchrotron X-ray measurement is a powerful tool to investigate structure and properties of liquids and glasses at in situ high pressure and high temperature conditions.

-Study of structure of liquids and glasses under extreme conditions are still challenging due to weak X-ray scattering.

-High-brilliance X-ray after the upgrade of synchrotron X-ray facilities such as ESRF-EBS would open more opportunity to investigate liquids and glasses under extreme conditions.

References

[1] Y. Kono and C. Sanloup, Magmas Under Pressure: Advances in High-Pressure Experiments on Structure and Properties of Melts (2018).
[2] Y. Kono, C. Park, C. Kenney-Benson, G. Shen, and Y. Wang, Physics of the Earth and Planetary Interiors 228, 269-280 (2014).