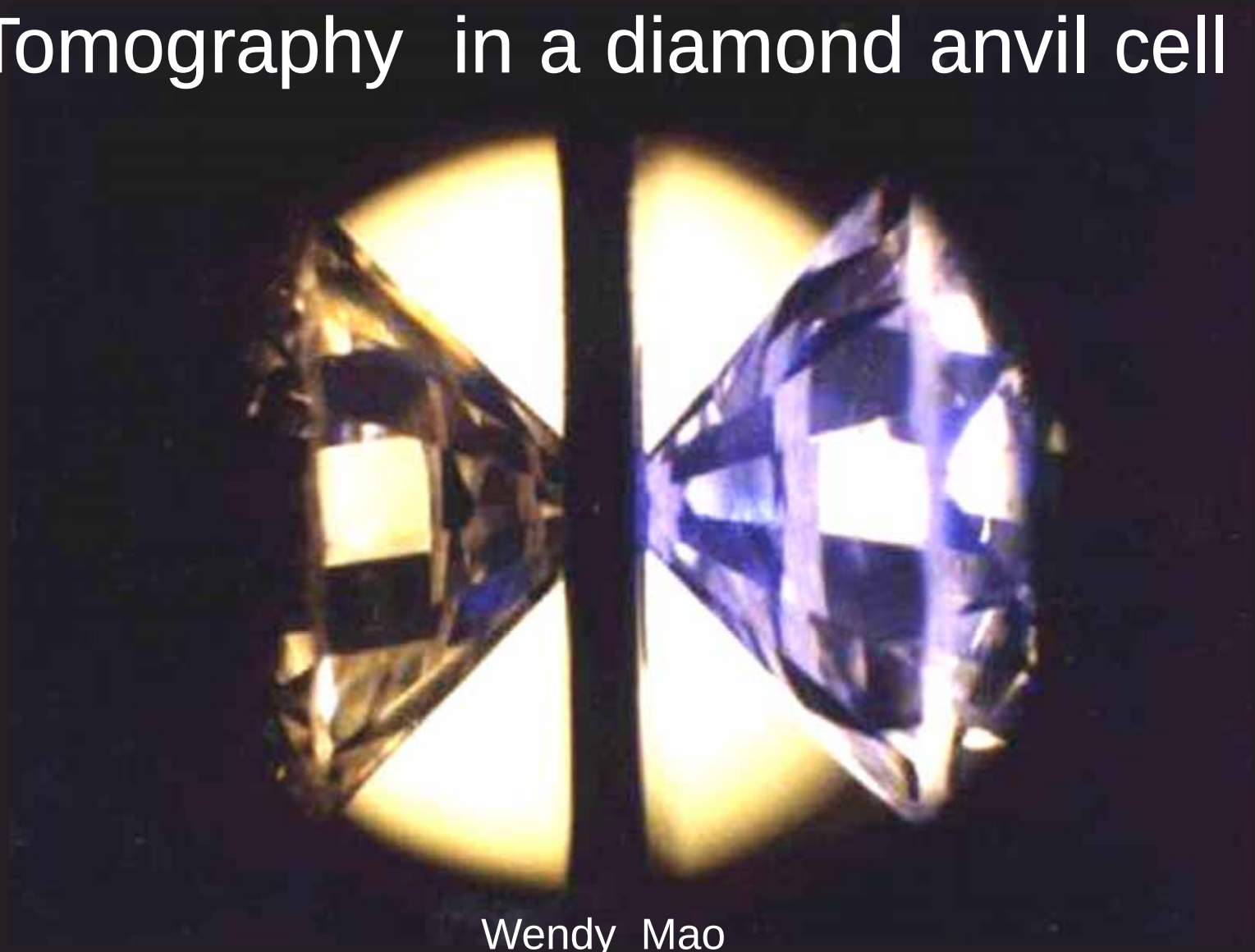
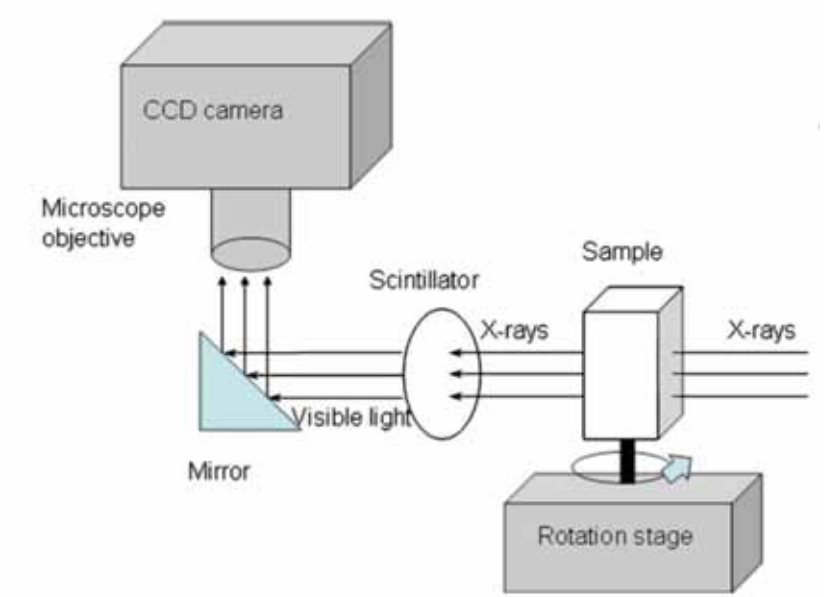
Tomography in a diamond anvil cell



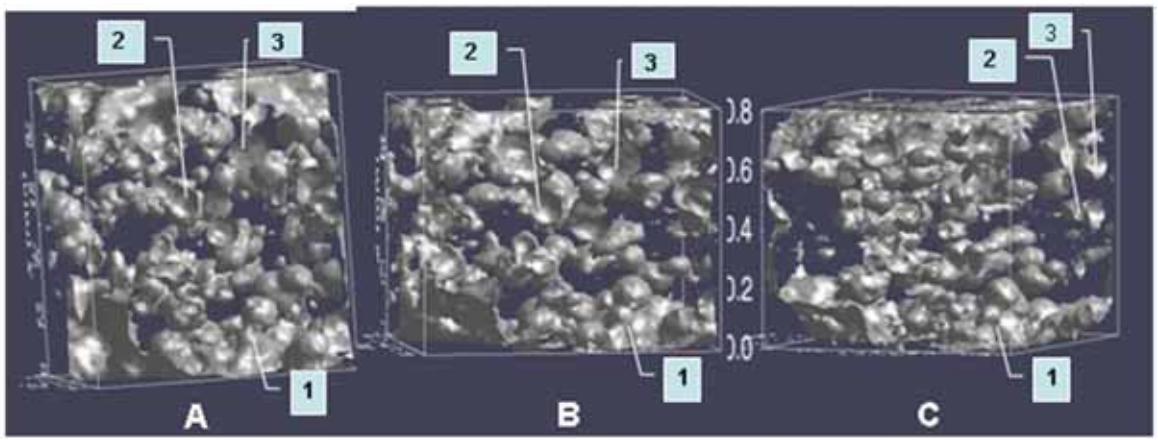
Wendy Mao
Geological and Environmental Sciences, Stanford University
& Photon Science, SLAC National Accelerator Laboratory

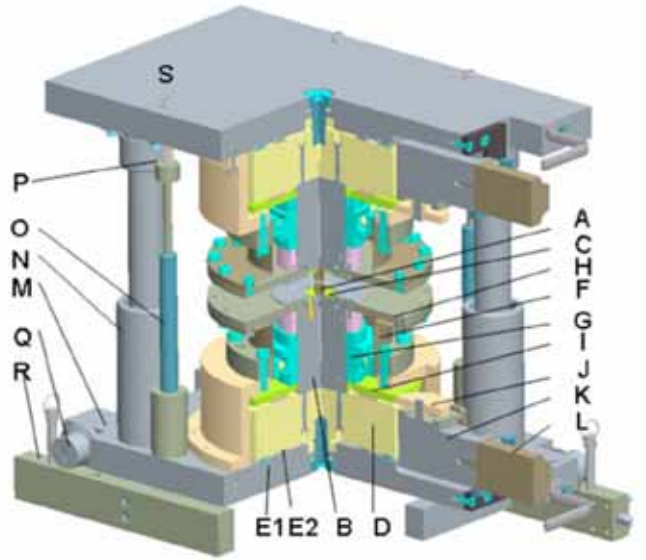
Current state of the art in high pressure x-ray imaging



Sector 13 GSECARS, APS

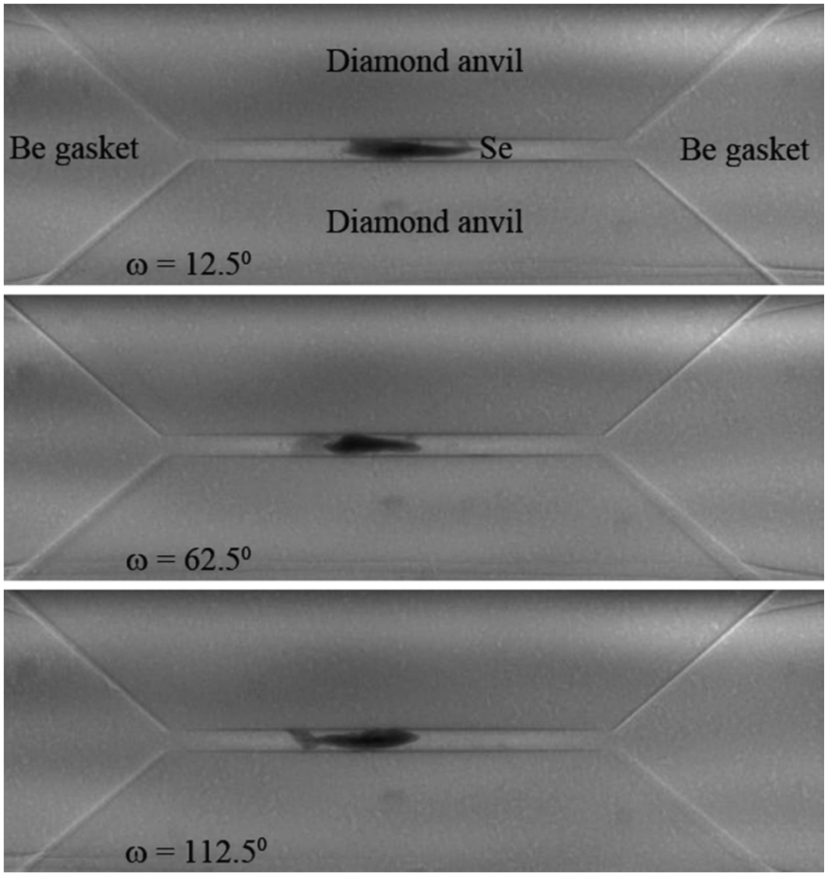
- Pressure < 10 GPa (Al ring)
- 35 keV
- micron resolution

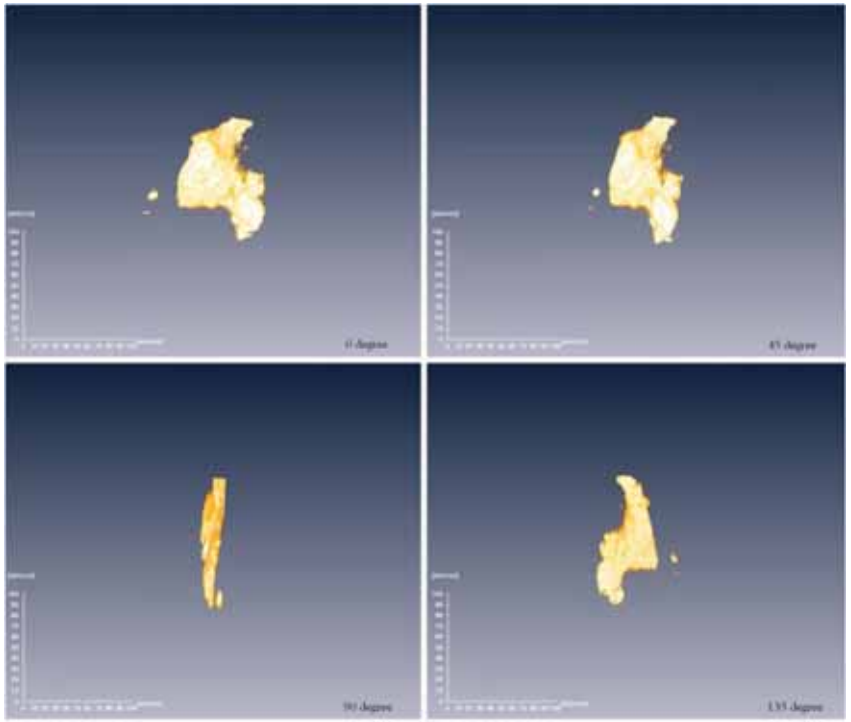




Y. Wang et al, RSI 2005

Microtomography of *a*-Se to 11 GPa





- Sector 2, APS
  - 1 micron resolution

H. Liu et al, PNAS 2008

nanoXCT

- Xradia instruments:
  - 6-2 SSRL & 32-IDC APS

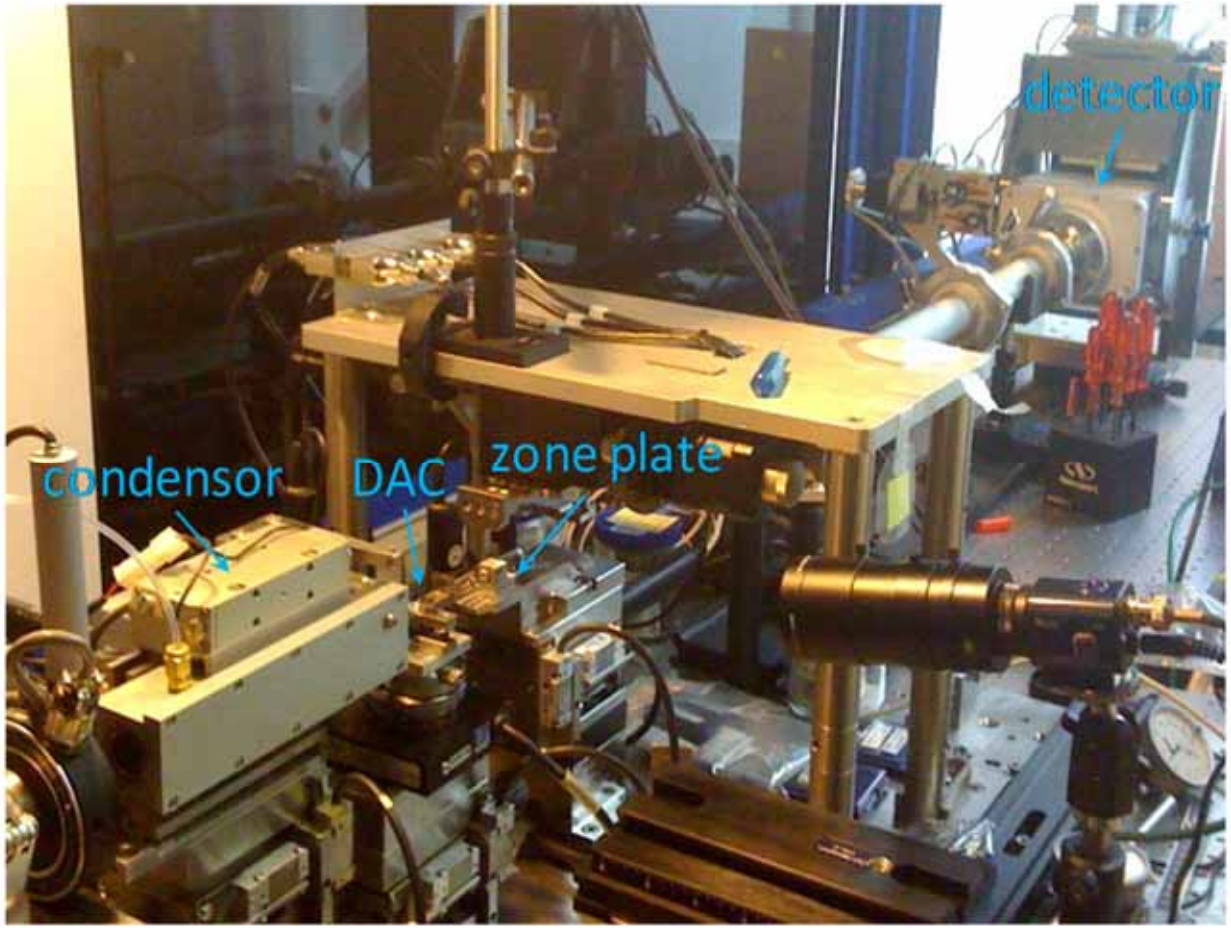
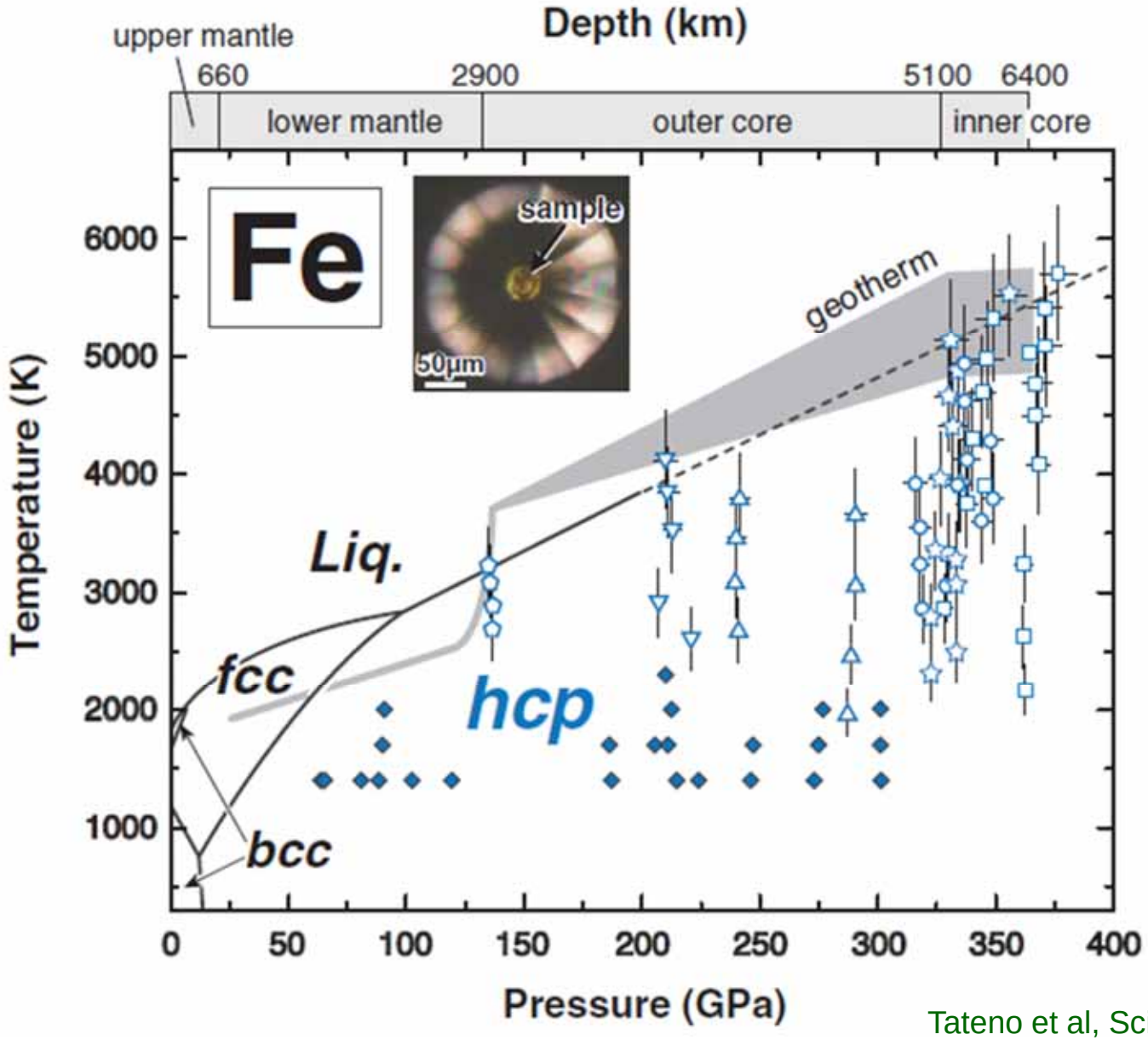


Image small samples

- Small domains
  - Resolve heterogeneity
- Higher *P-T*
  - Quenched samples
  - *in-situ* high *P*
  - *in-situ* high *P,* variable *T*

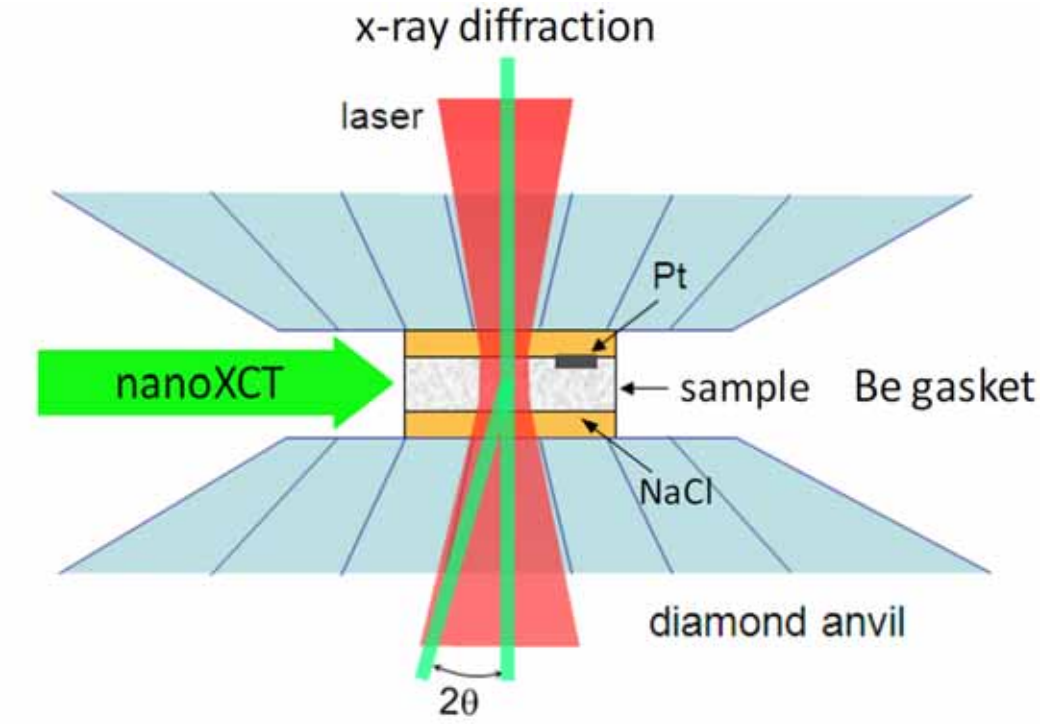
J. Andrews et al, J. Phys. 2009

Laser-heated Diamond Anvil Cell



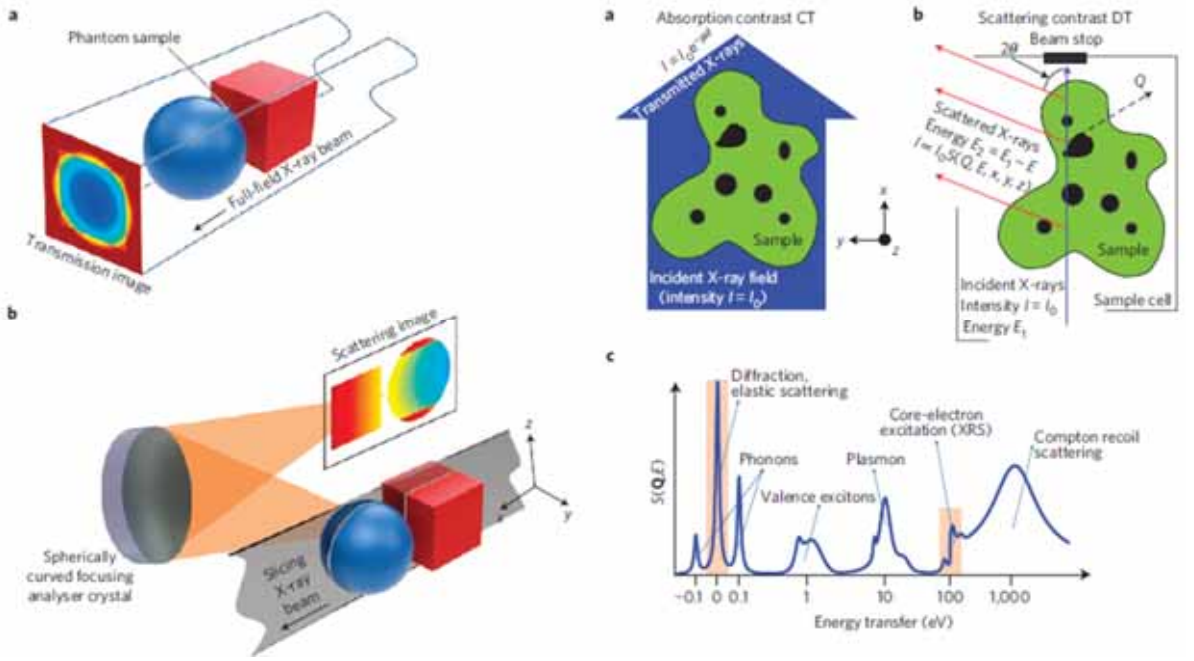
Tateno et al, Science 2010

Diamond anvil cells for tomography



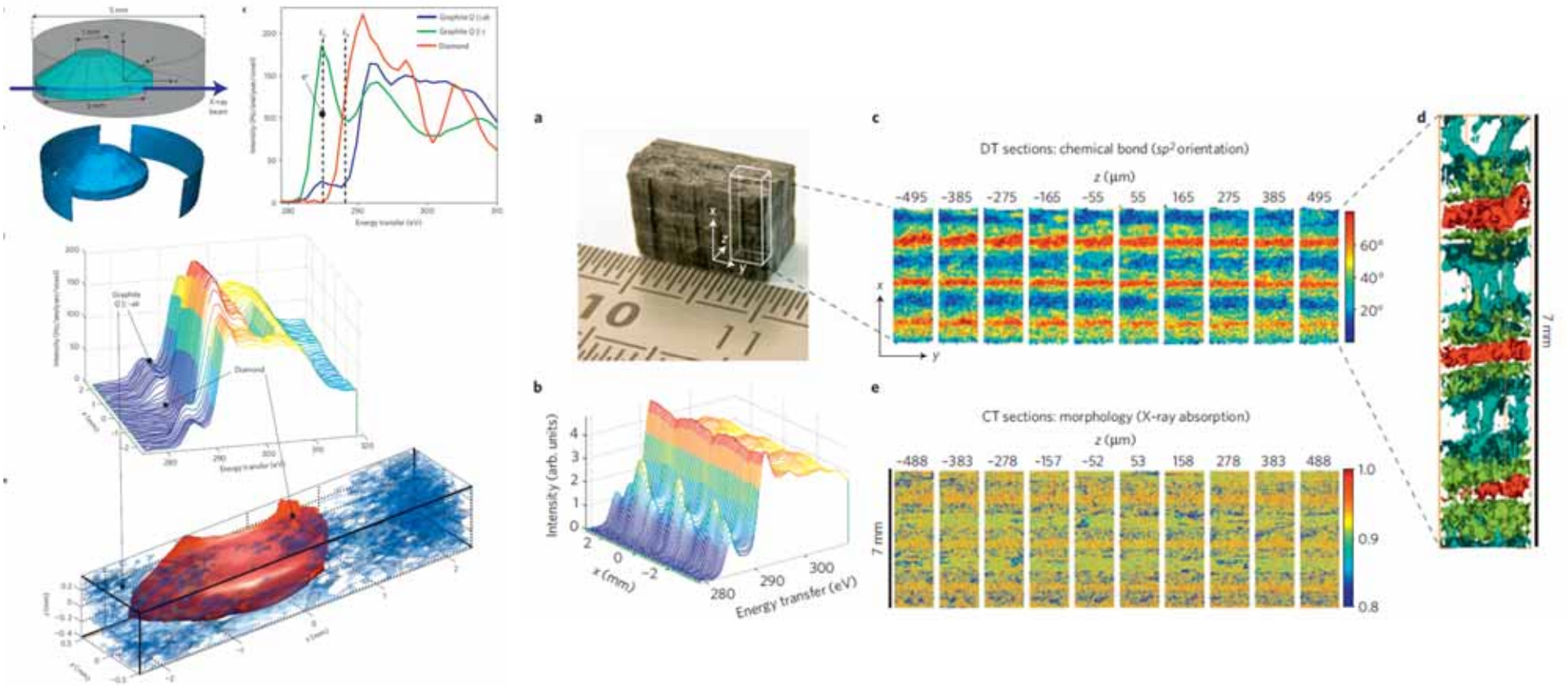
Contrast mechanisms

- Absorption
- Fluorescence
- Scattering
  - Diffraction
  - IXS



Huotari et al, Nature Mat. 2011

X-ray Raman



Huotari et al, *Nature Mat.* 2011

Many opportunities for extreme conditions research using tomography

- Texture and shapes of multi-phase assemblages
- Volume determination of amorphous materials
- Density of light element phases
- Morphology of nanomaterials
- Defects in materials
- Diffusion rate
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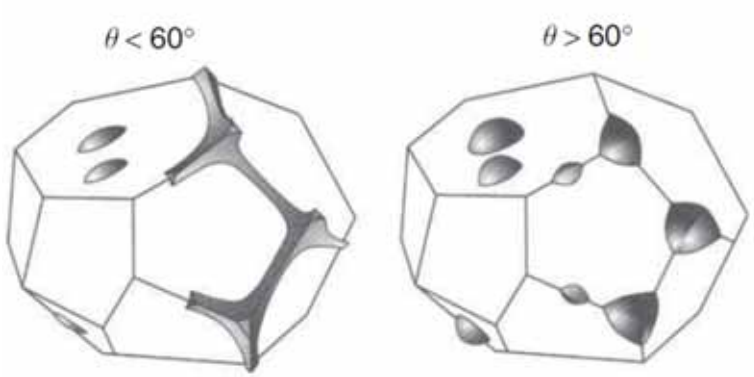
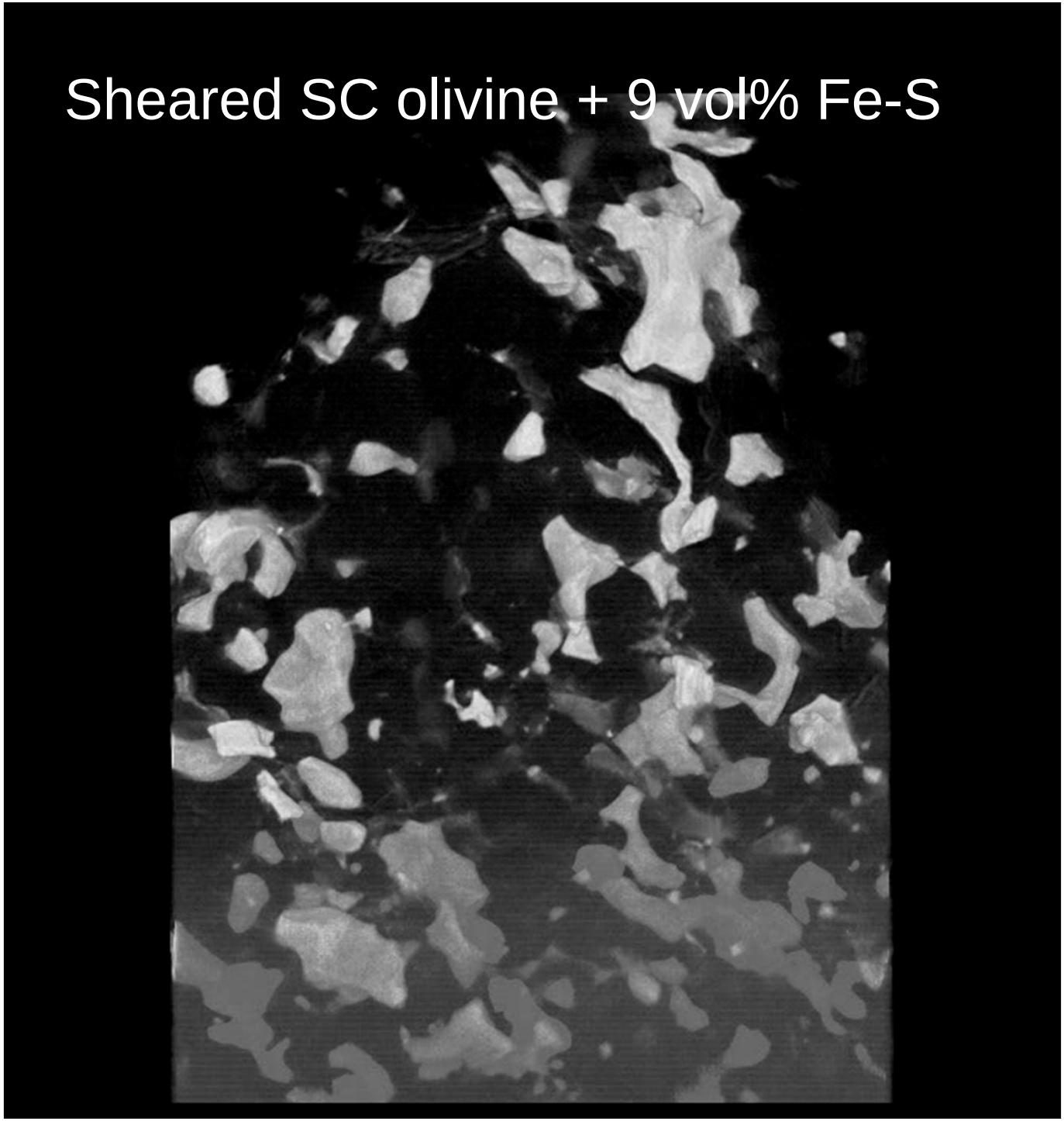
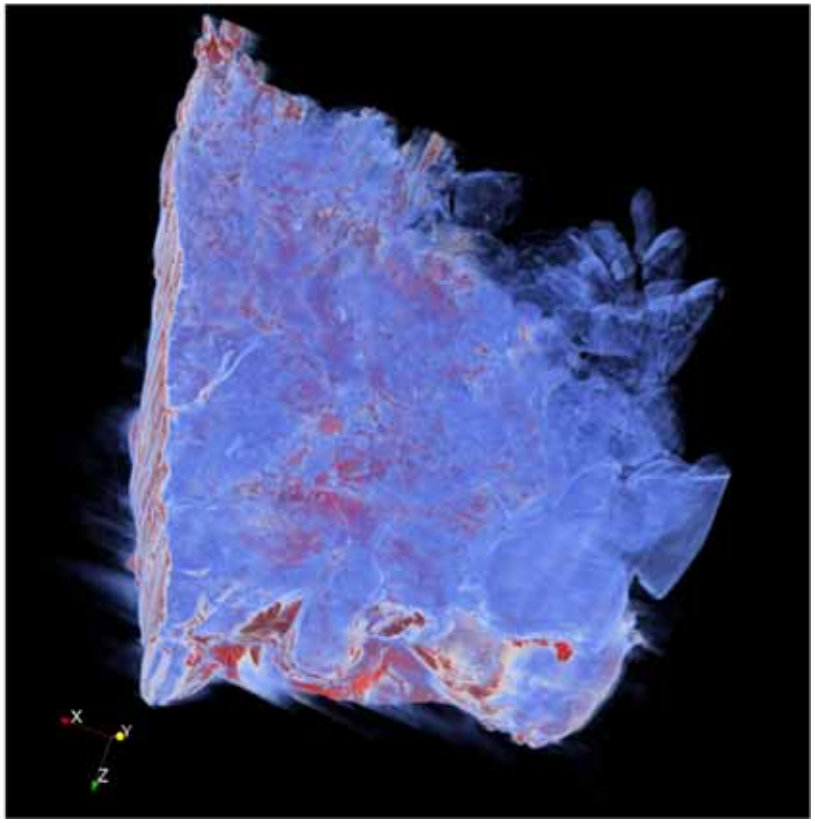


Planetary core formation

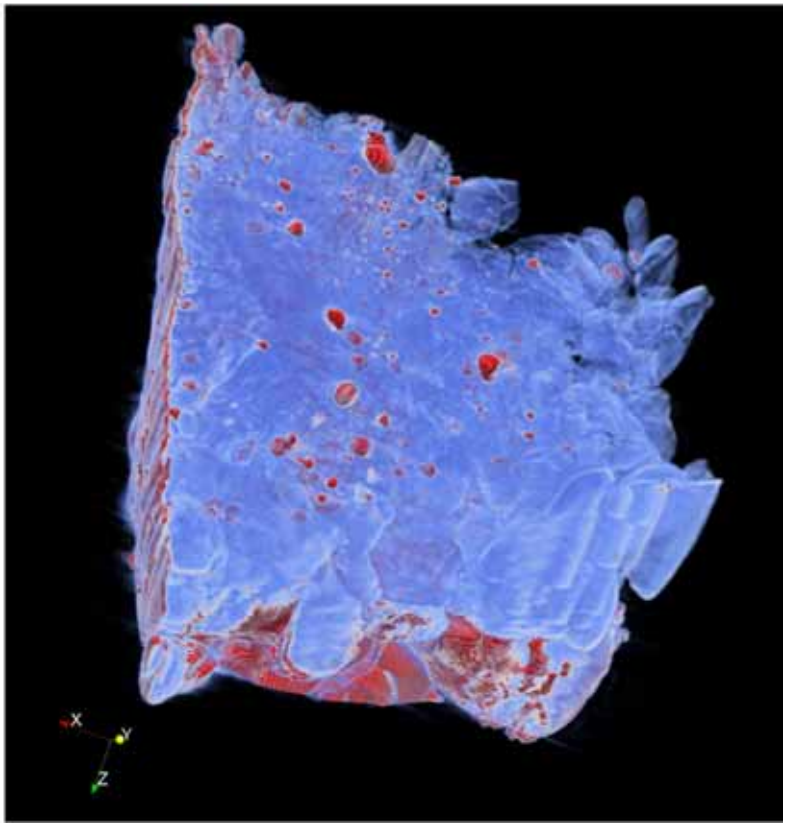

6 GPa, 2073 K
Fe+10wt%S spheres within a SC olivine, $(Mg_{0.88}Fe_{0.12})_2SiO_4$

Sheared SC olivine + 9 vol% Fe-S

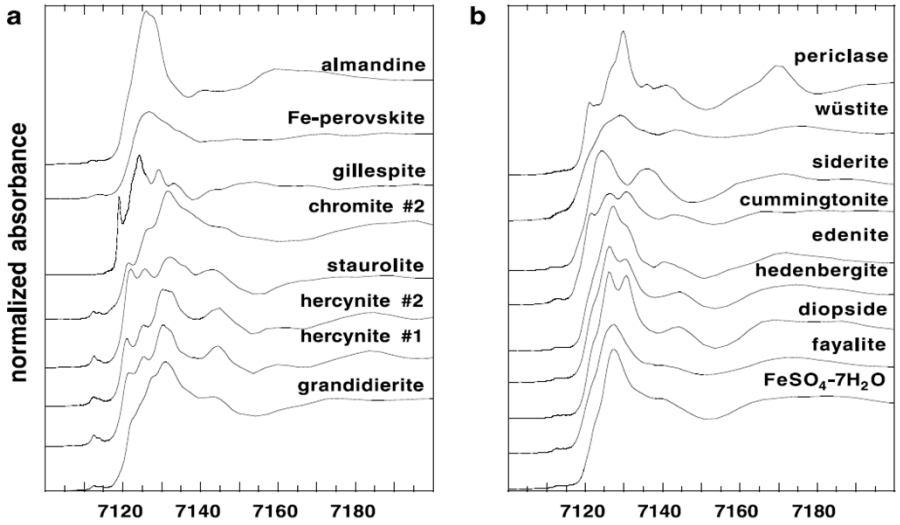




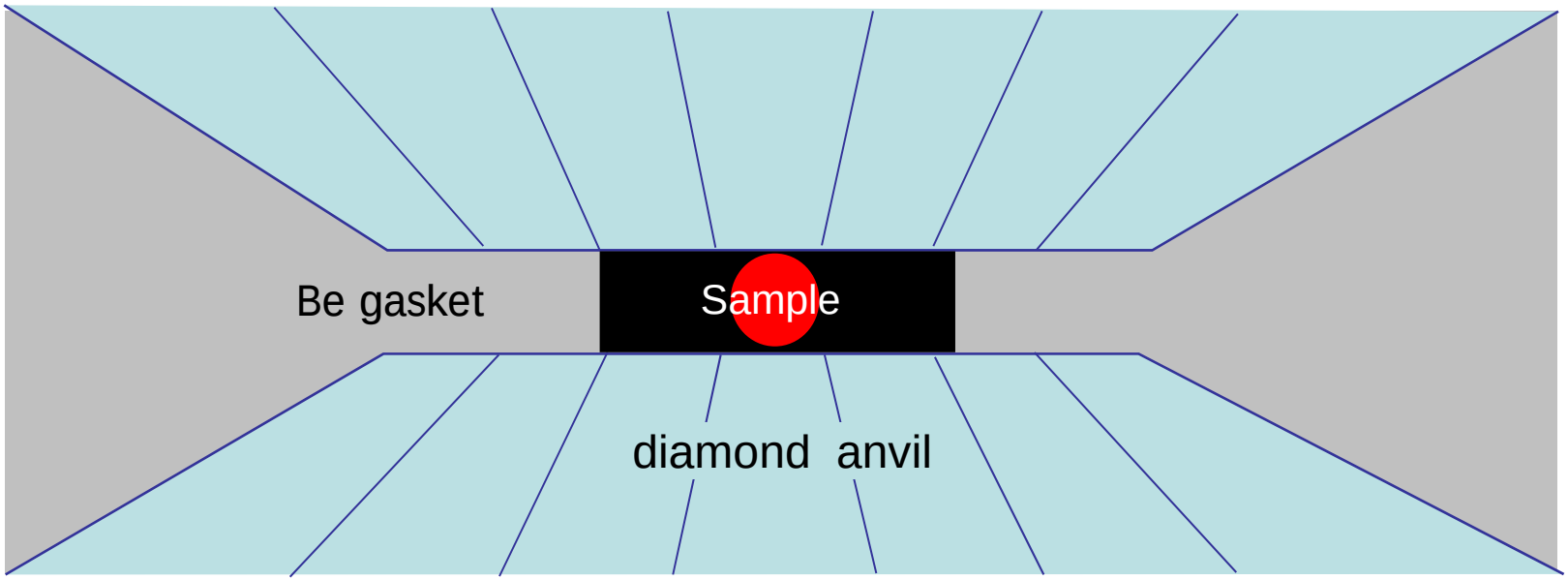
7080 eV

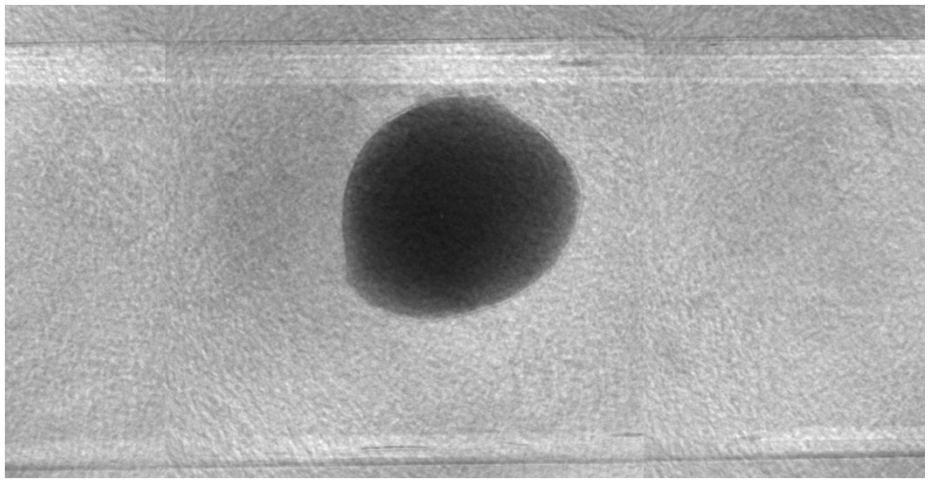


7220 eV



Volume determination within a DAC





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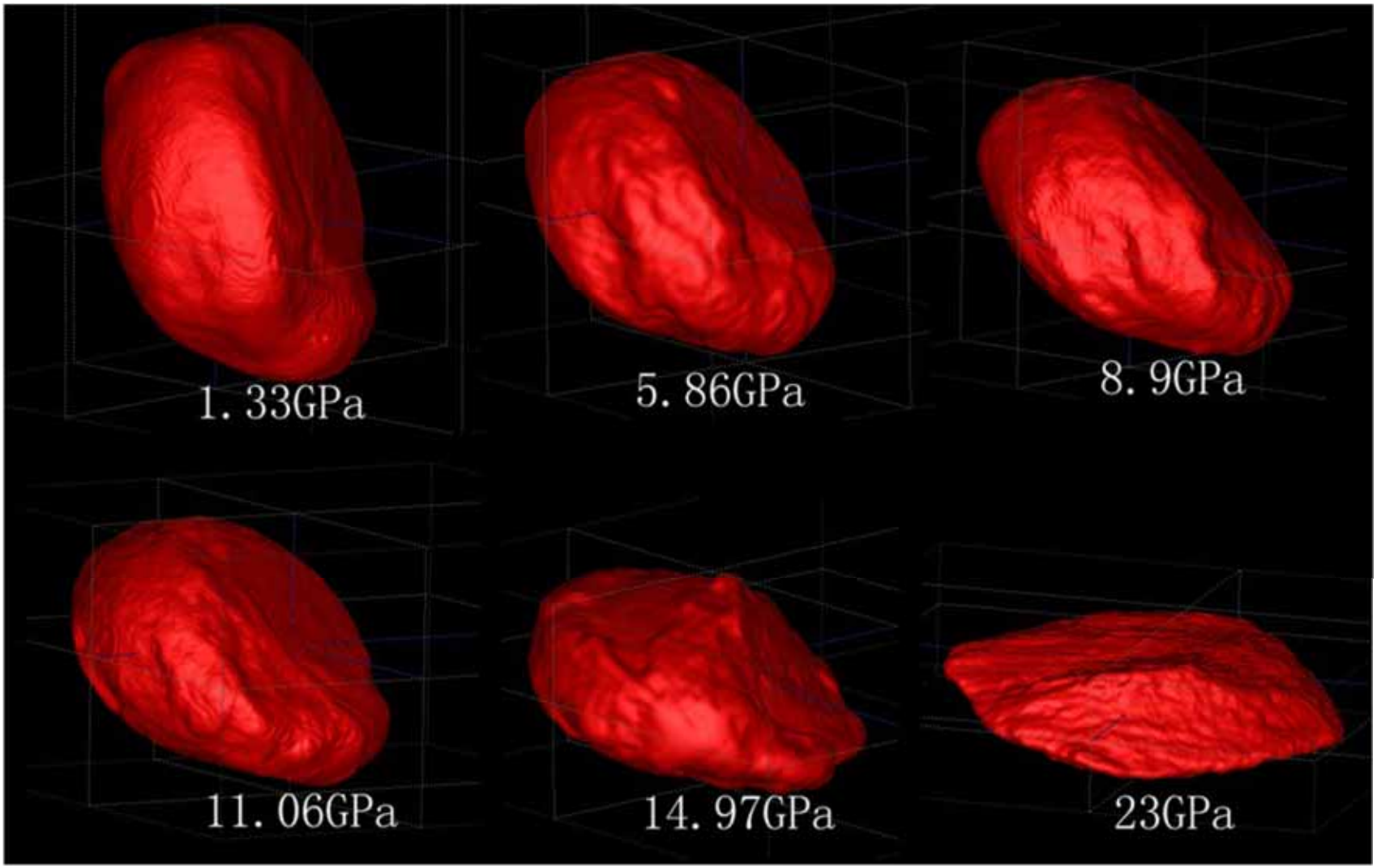
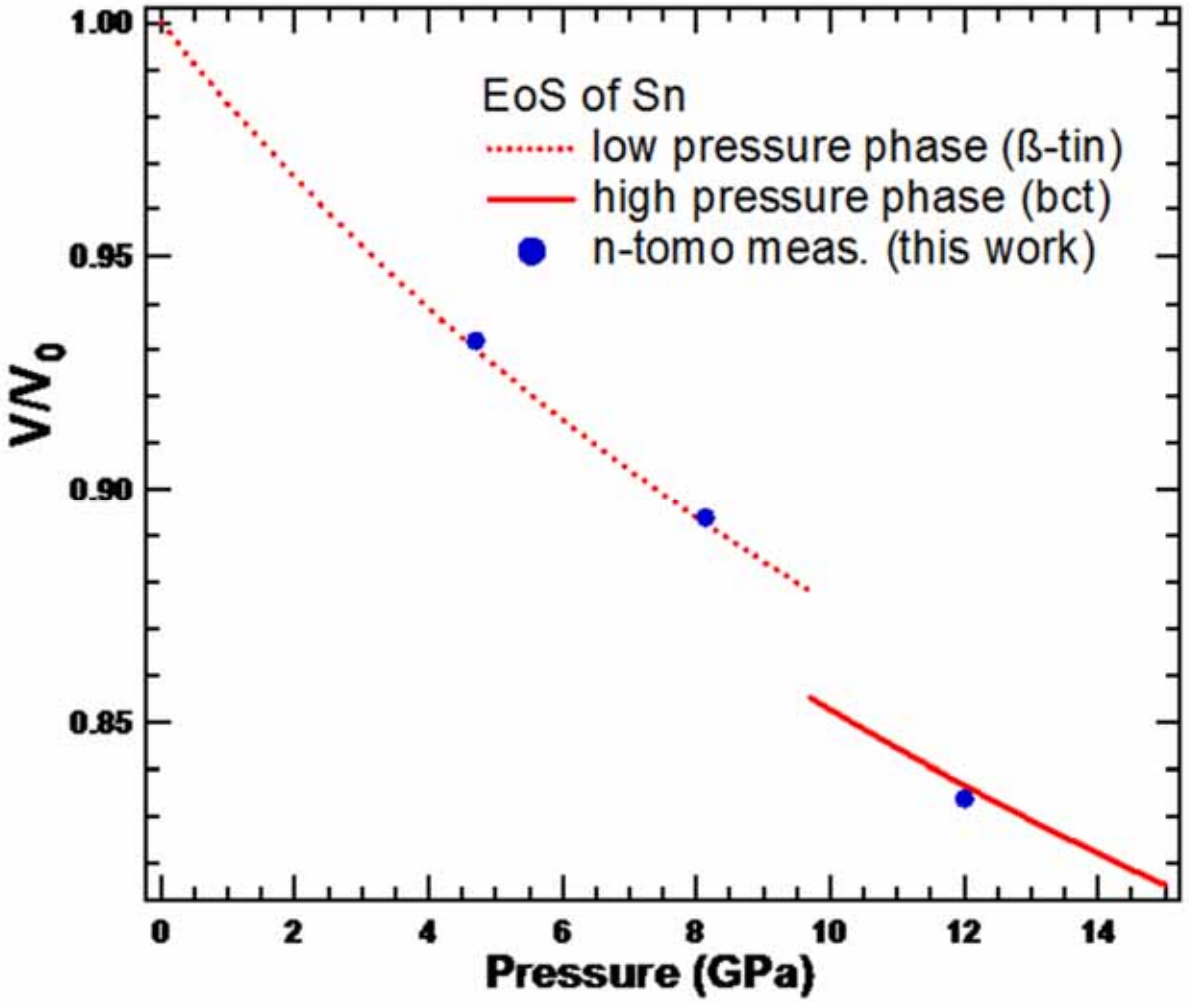
Sn sample



10 micron

HPCAT 16-IDE

J. Wang et al, *J. Appl. Phys.* submitted



J. Wang et al, *J. Appl. Phys.* submitted

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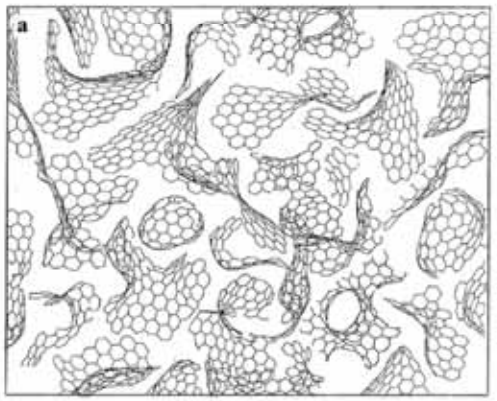
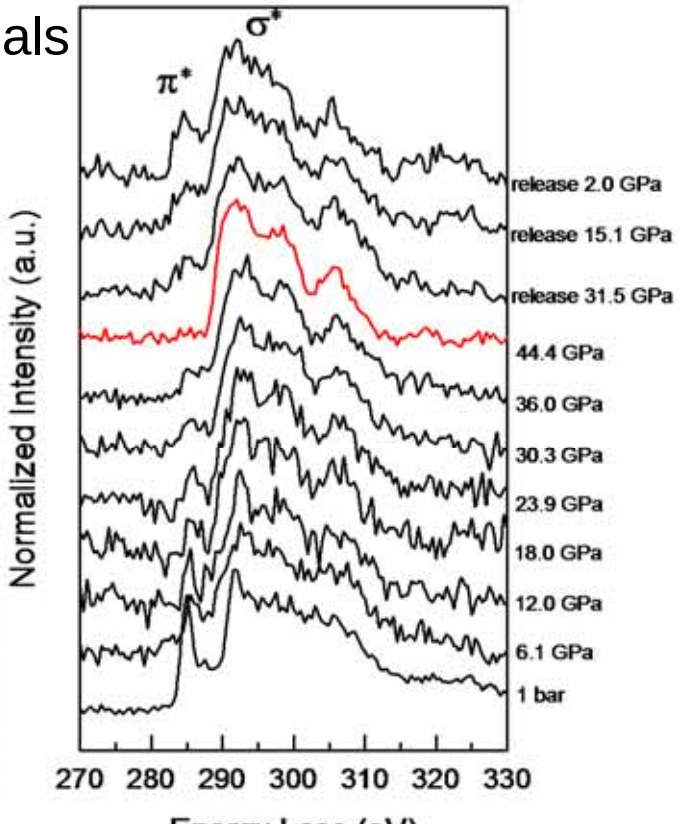
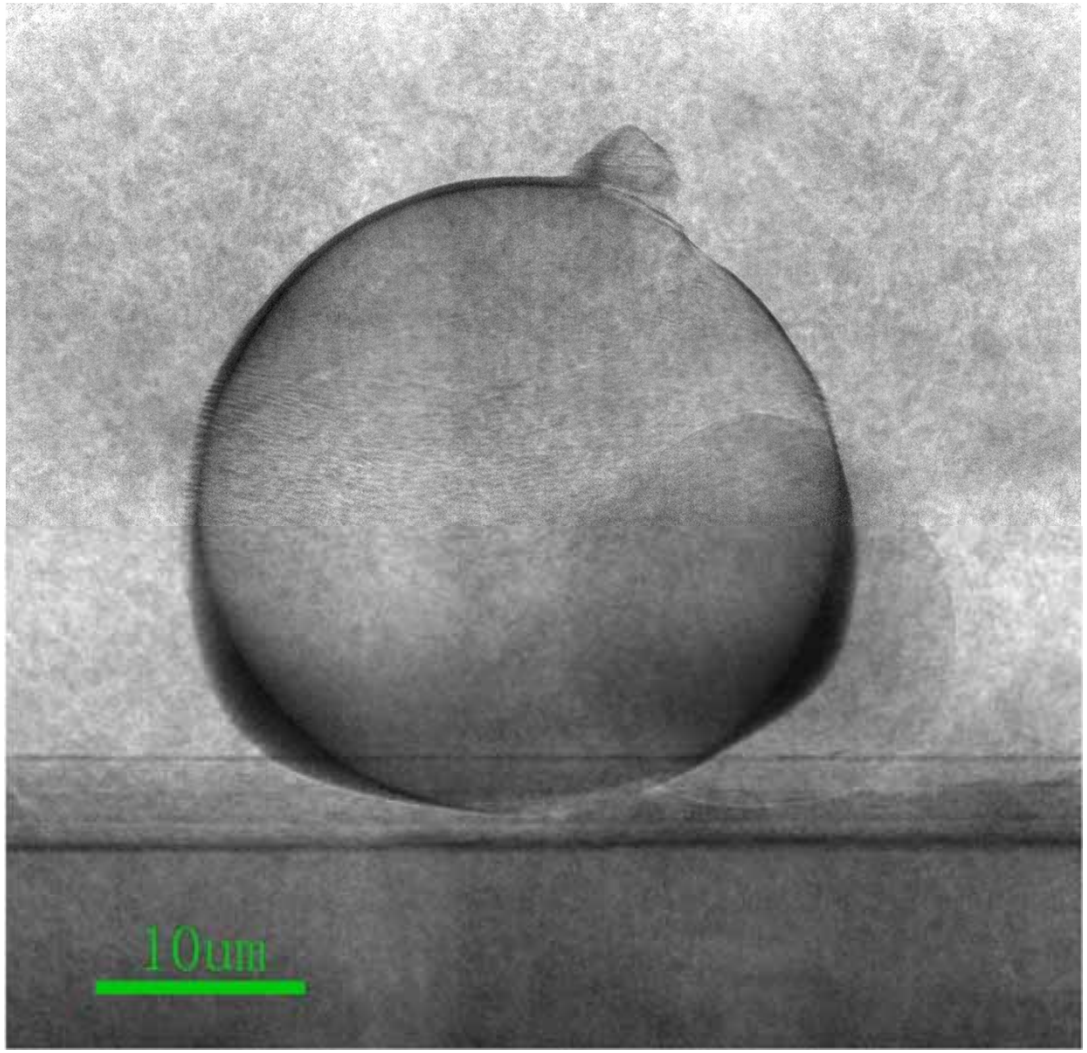


Harris, *Philos. Mag. 2004*



Y. Lin et al, submitted

Glassy carbon



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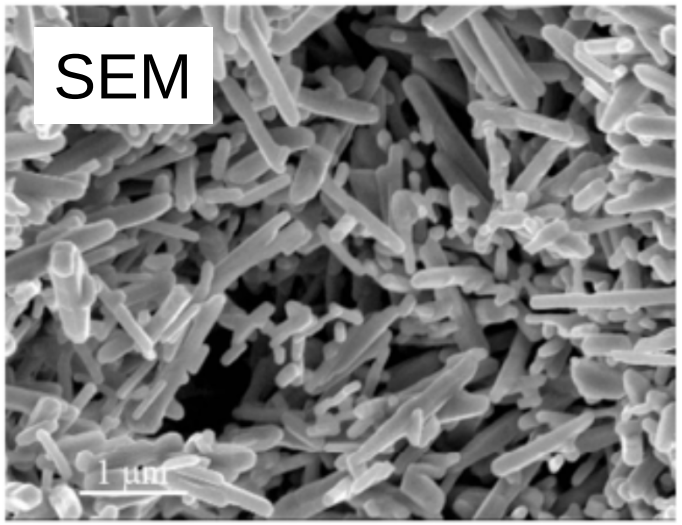
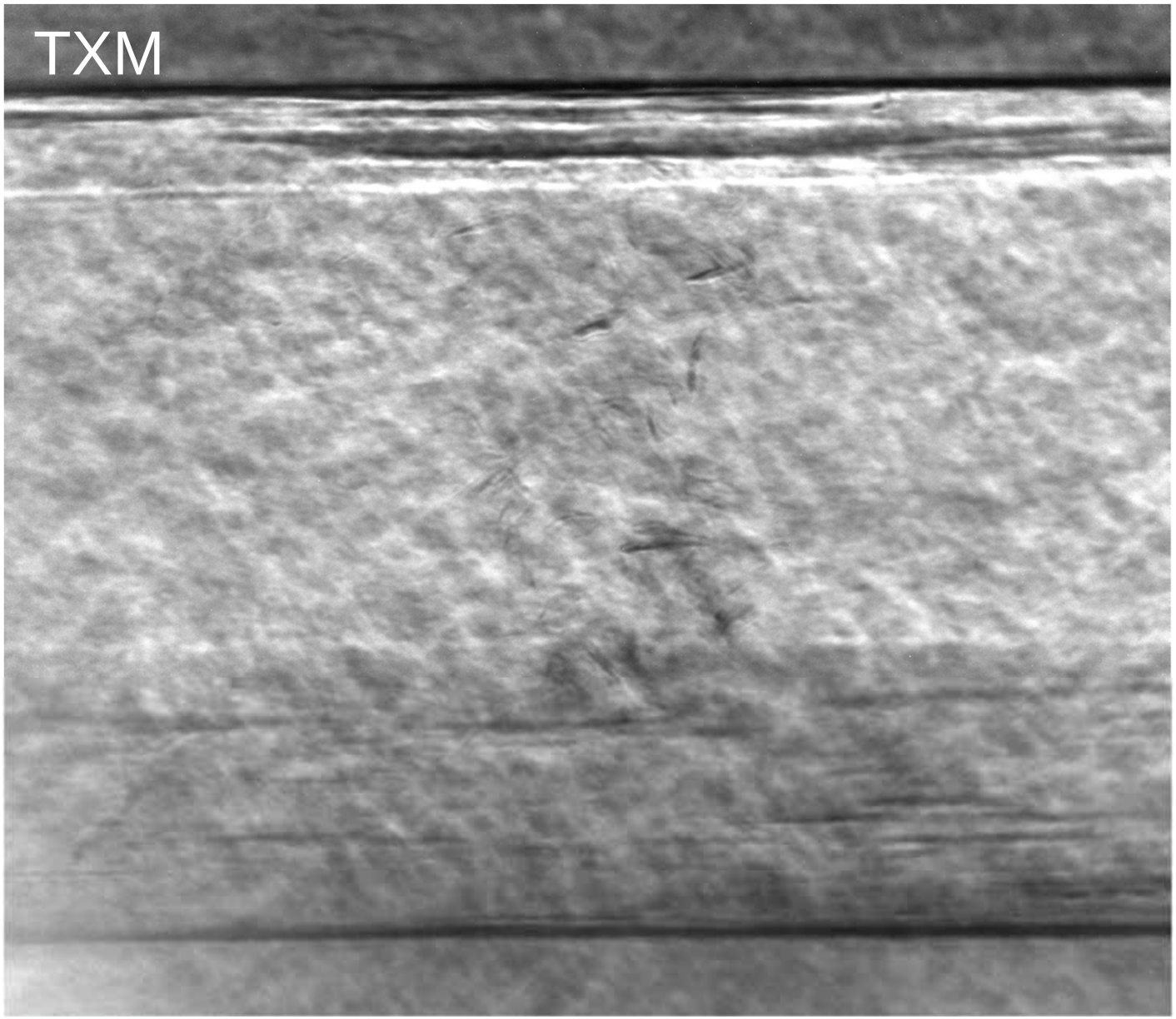


Lin et al, J. Phys. Chem. C 2011

$LiMn_2O_4$ nanorods



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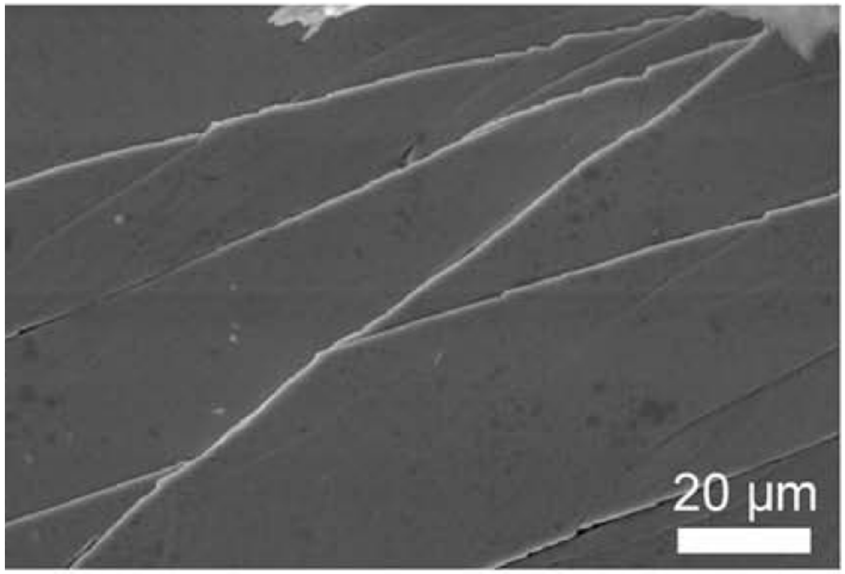
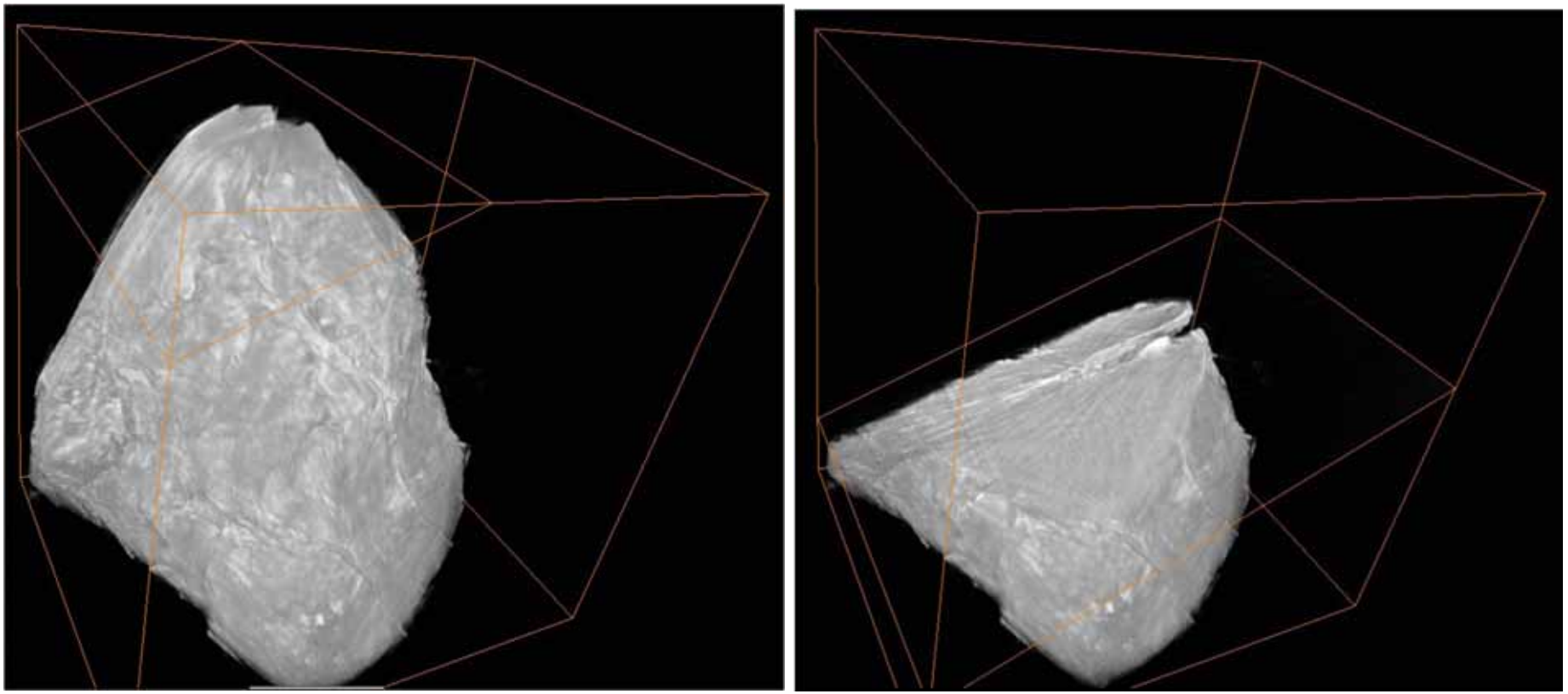


Cao et al, *Acta Mater.* 2010

Shear bands in bulk metallic glass



$Cu_{64}Zr_{36}$

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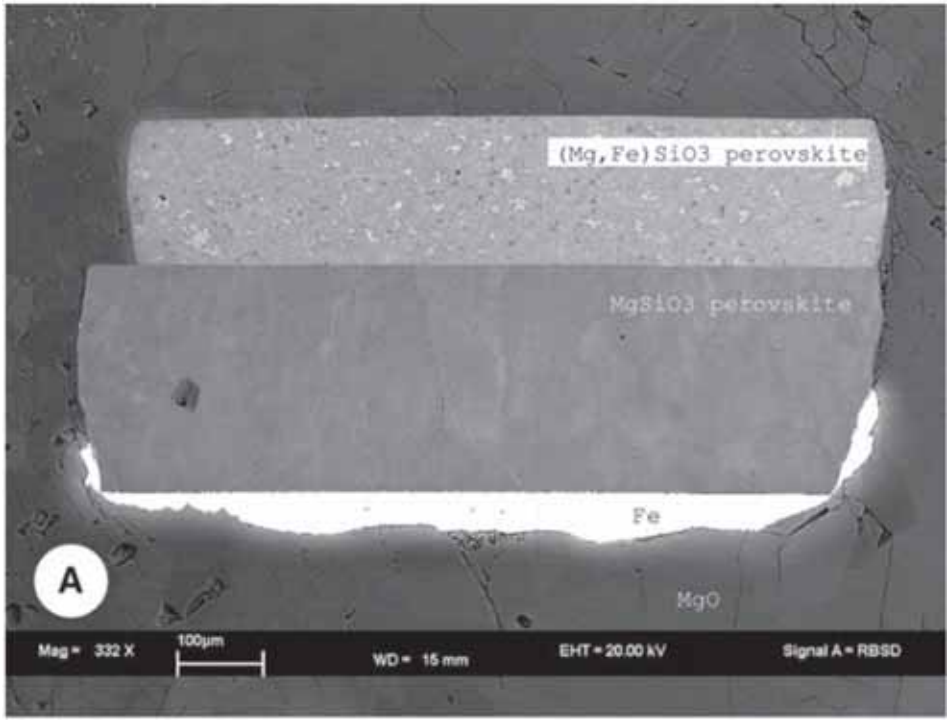
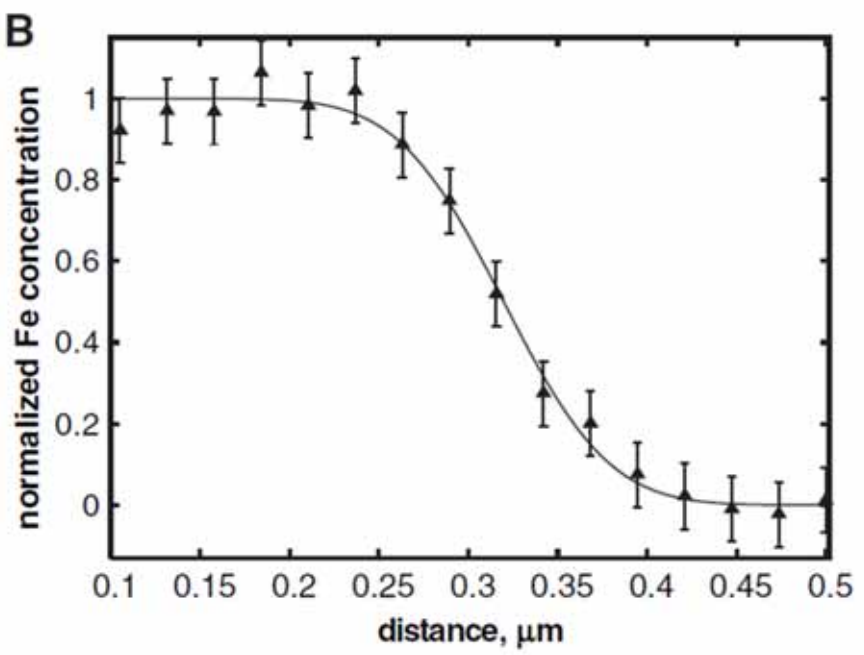
Diffusion





Holzapfel et al, *Science* 2005

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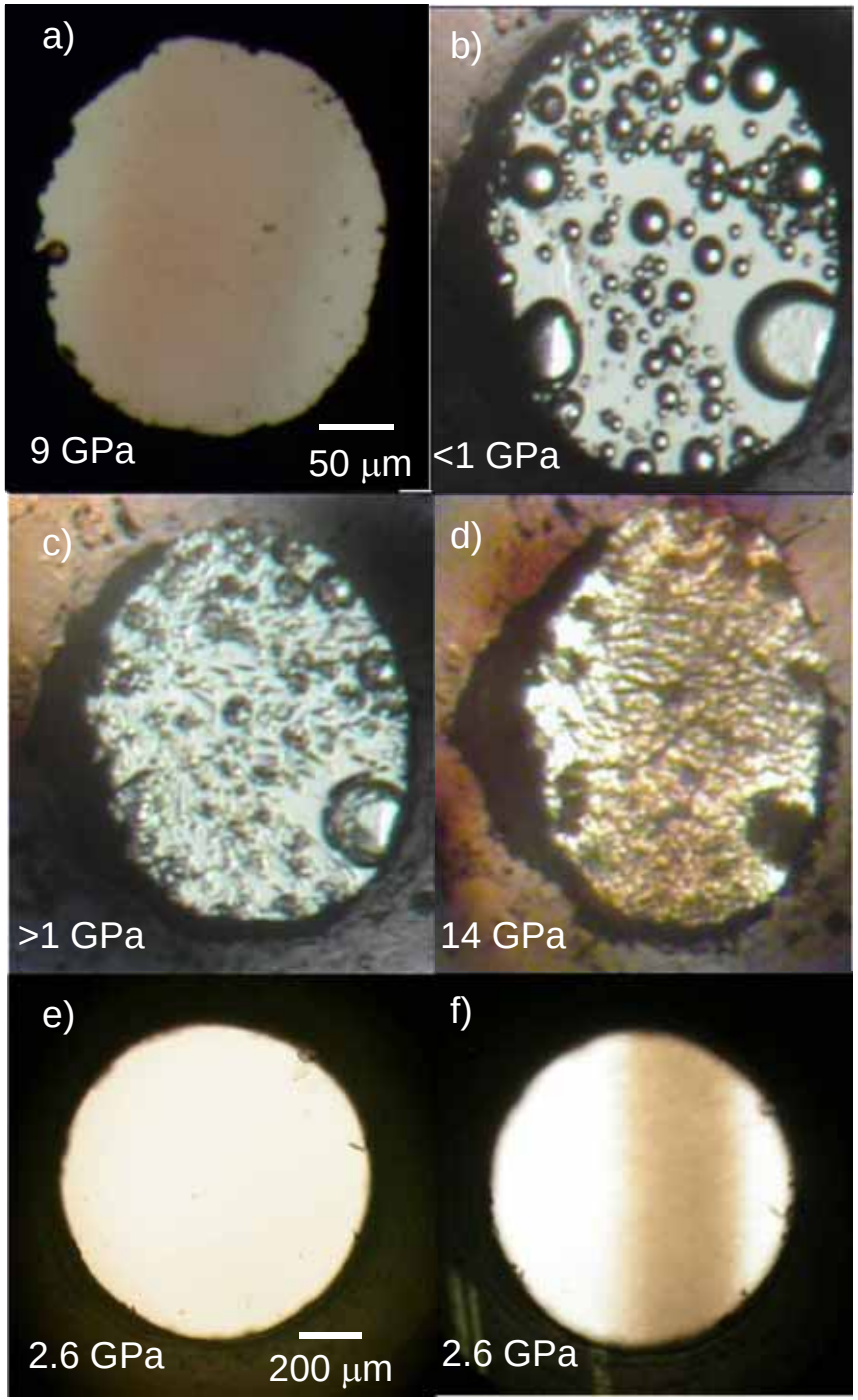
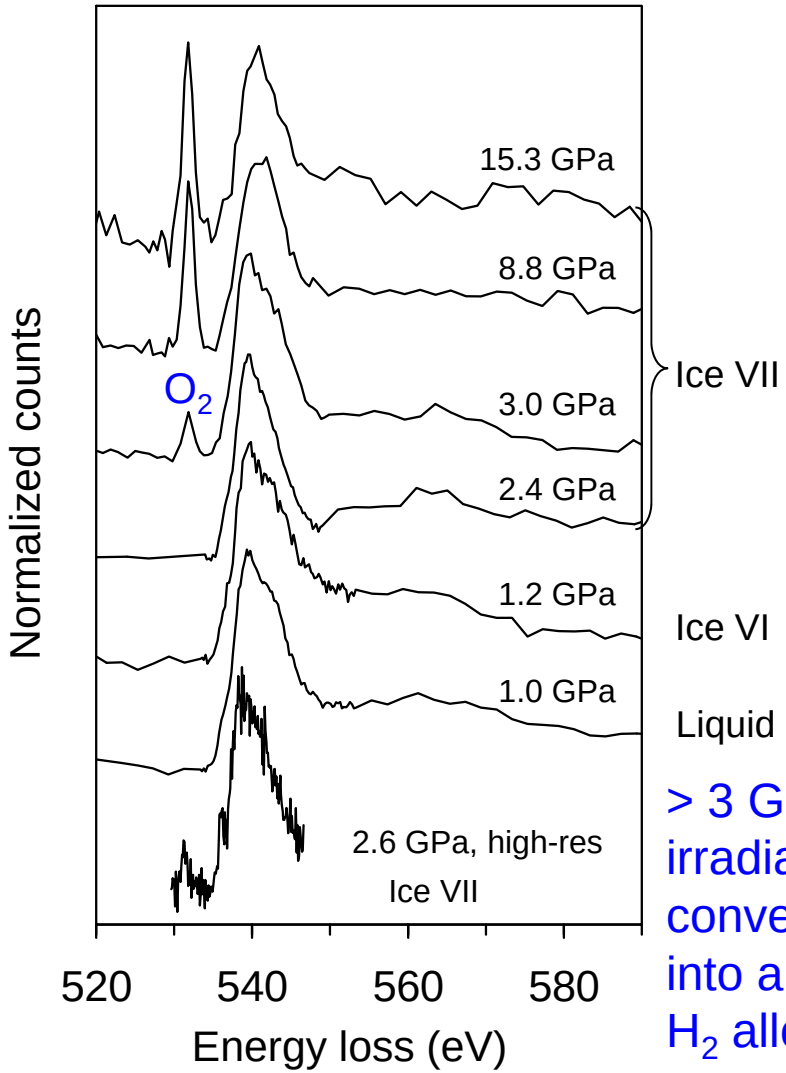
Radiation chemistry at high pressure





> 3 GPa, x-ray irradiation converts H_2O into a new O_2-H_2 alloy

W. Mao *et al*, *Science* 2006

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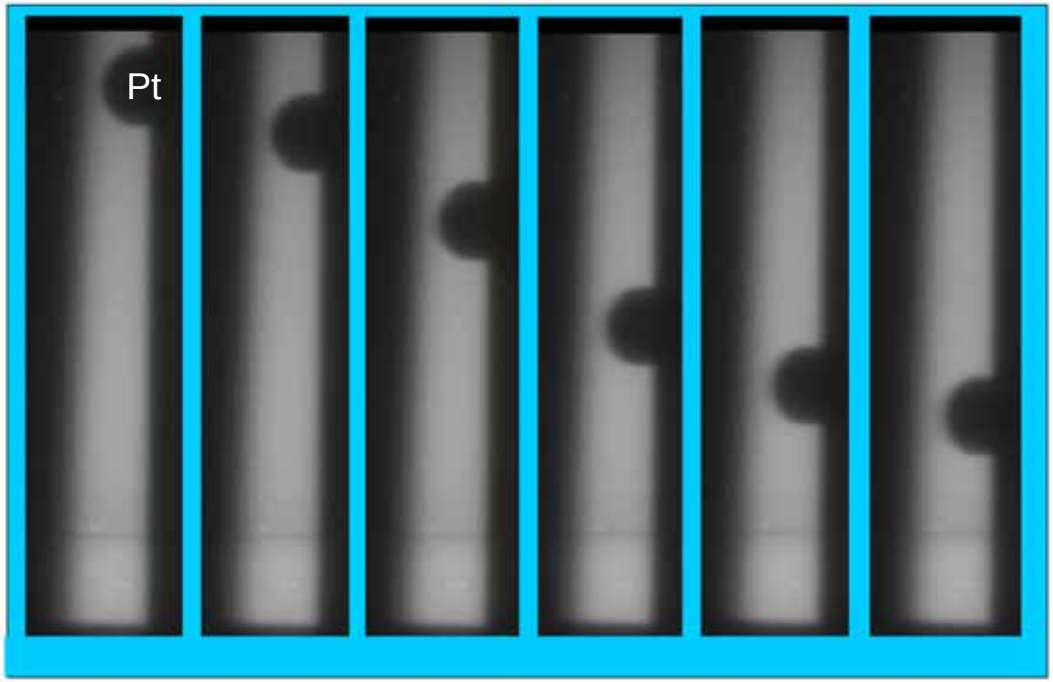
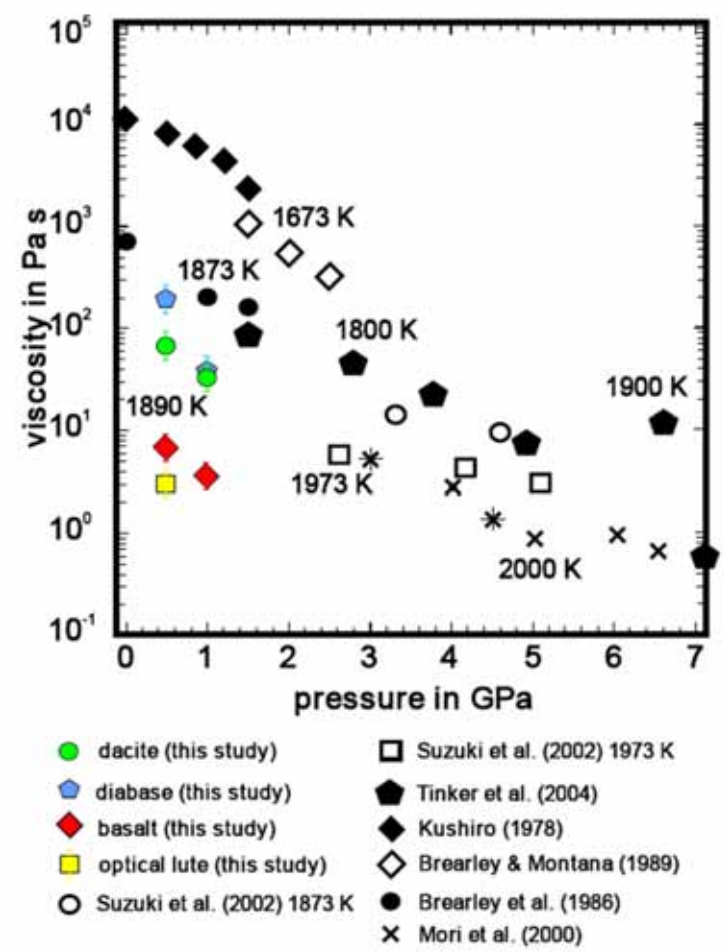
Falling sphere viscosity





Mueller et al, J. Phys.: Conf. Series 2010

Many opportunities for extreme conditions research using tomography

Texture and shapes of multi-phase assemblages: grain shape, intergrowth, orientation, and foliation

Direct determination of volume:

- *New crystalline phases:* when coupled with XRD to determine number of atoms per unit cell and stoichiometry
- *Amorphous materials*: accurate measurement of equations of state of non-crystalline phases
- *Density of light element phases*: determination of volume change by using negative contrast (putting low Z sample within higher Z surrounding medium).

Phase transition mechanism: Spatial relationship between original & new phase when crossing a phase boundary

First order liquid-liquid transitions: scan across phase boundaries to probe for discontinuous volume change and study near edge for electronic changes

Many opportunities for extreme conditions research using tomography

Morphology of nanomaterials: image changes in size and shape

Rheology: image changes in shape under applied stress

Defects in materials: development of shear bands in metallic glasses

Hardness and toughness: fracture development & propagation

Diffusion rate: probe changes in composition with time at interface between two materials

Chemistry: provide quantitative information on composition coordination, oxidation states, and spin states, etc.

Viscosity: imaging falling sphere experiments

and much more!

Acknowledgements

SLAC

Piero Pianetta

Joy Hayter

Yijin Liu

Florian Meirer (AIAU TI, Vienna)

Jie Chen (USTC, Hefei)

Stanford University

Yingxia Shi

Yu Lin

HPSynC

Junyue Wang

Wenge Yang

APS

Steve Wang

Geophysical Laboratory

Li Zhang

Yingwei Fei

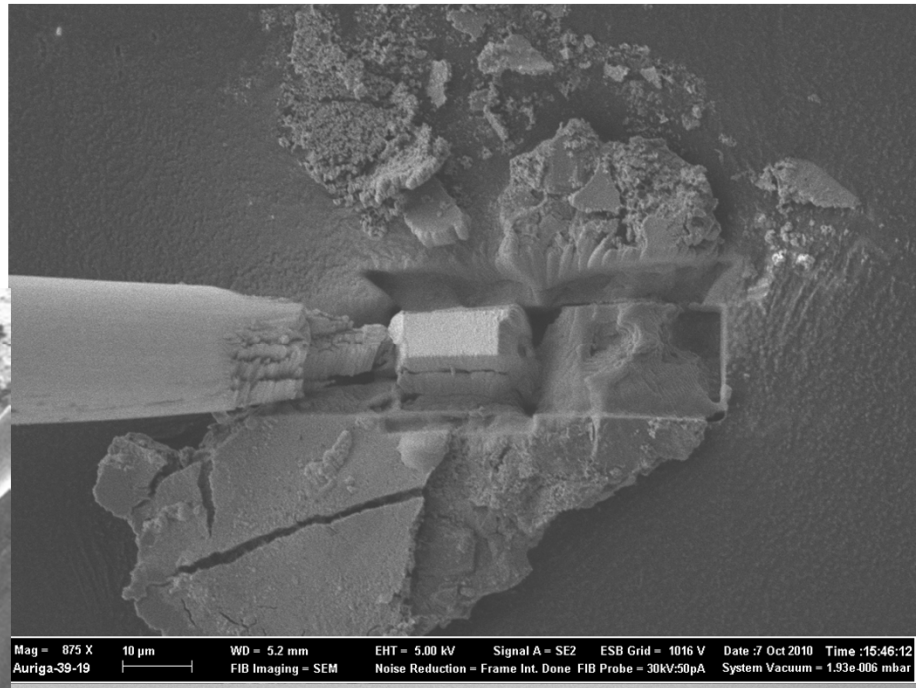
Ho-kwang Mao

U. Minnesota

David Kohlstedt

FIB


I-Beam
30.0 kV
Mag
500 X
Det
CDM-E
FWD
18.0
pA
46.0
Tilt
-0.0°
10/30/10
14:51:49
100 µm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WD = 5.2 mm
EHT = 5.00 kV
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ESB Grid = 1016 V
Date :7 Oct 2010
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Auriga-39-19
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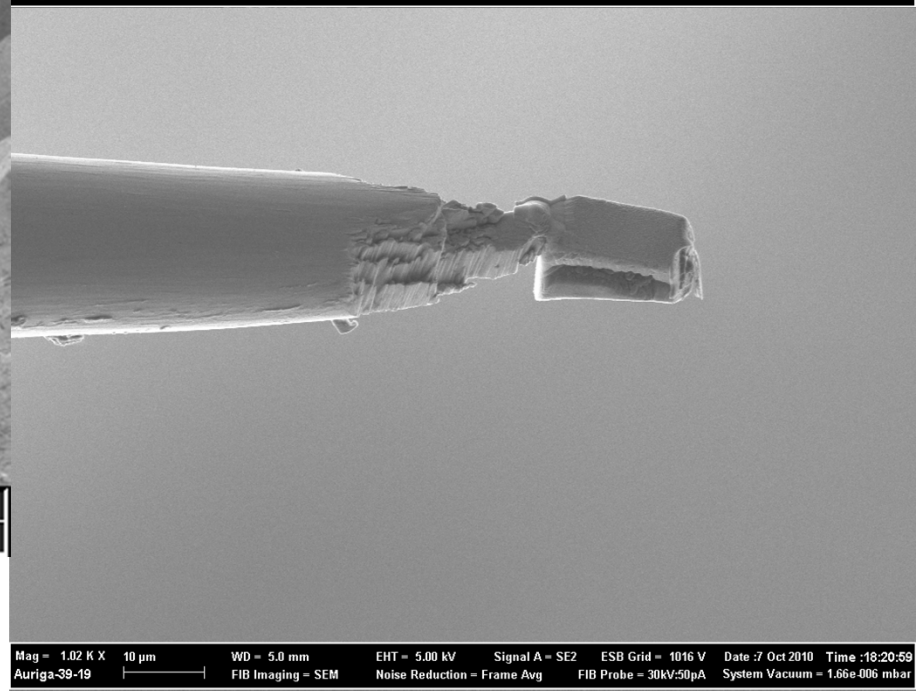
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10 µm
WD = 5.0 mm
EHT = 5.00 kV
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ESB Grid = 1016 V
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Time :18:20:59
Auriga-39-19
FIB Imaging = SEM
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FIB Probe = 30kV:50pA
System Vacuum = 1.66e-006 mbar