# Static material strength determined using a DAC

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# Outline:

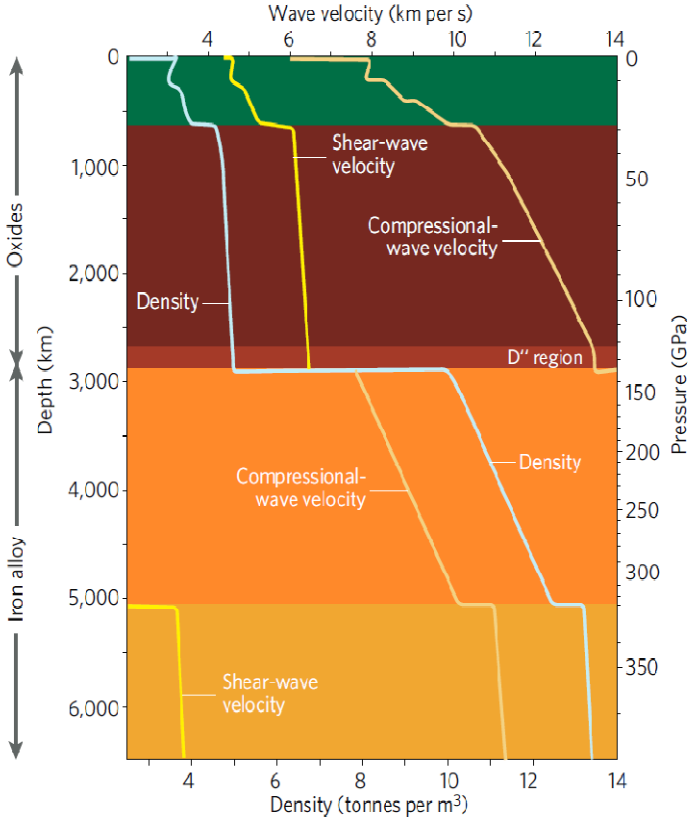
Introduction:

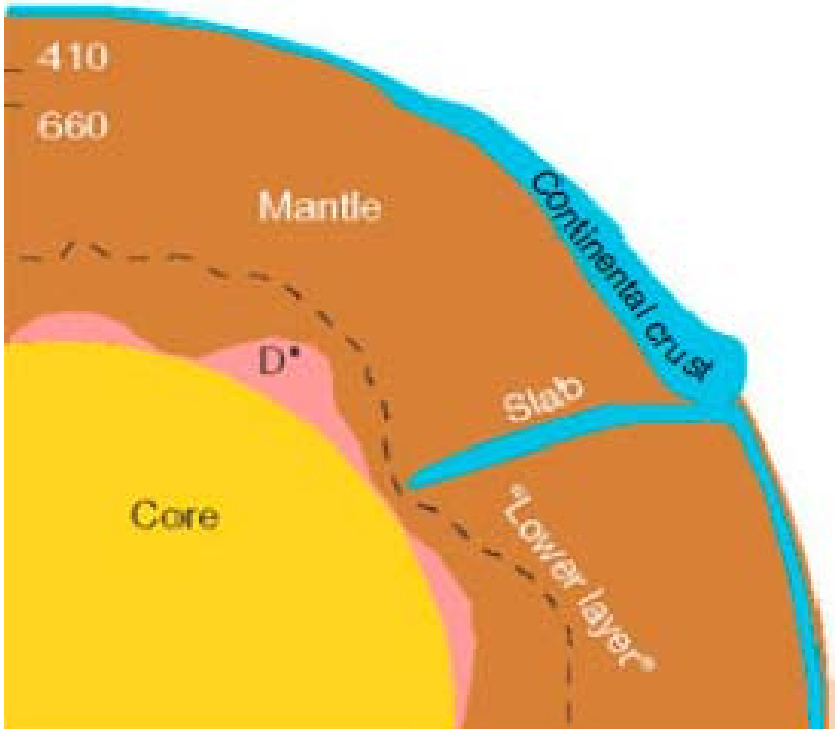
DAC - a tool to obtain accurate EOS
- also a tool to study deformation

Techniques
- Radial X-ray Diffraction
- Peak Width
- Pressure gradient * Absorption Measurement

Examples
- Au, Ag,Ta, V, Fe

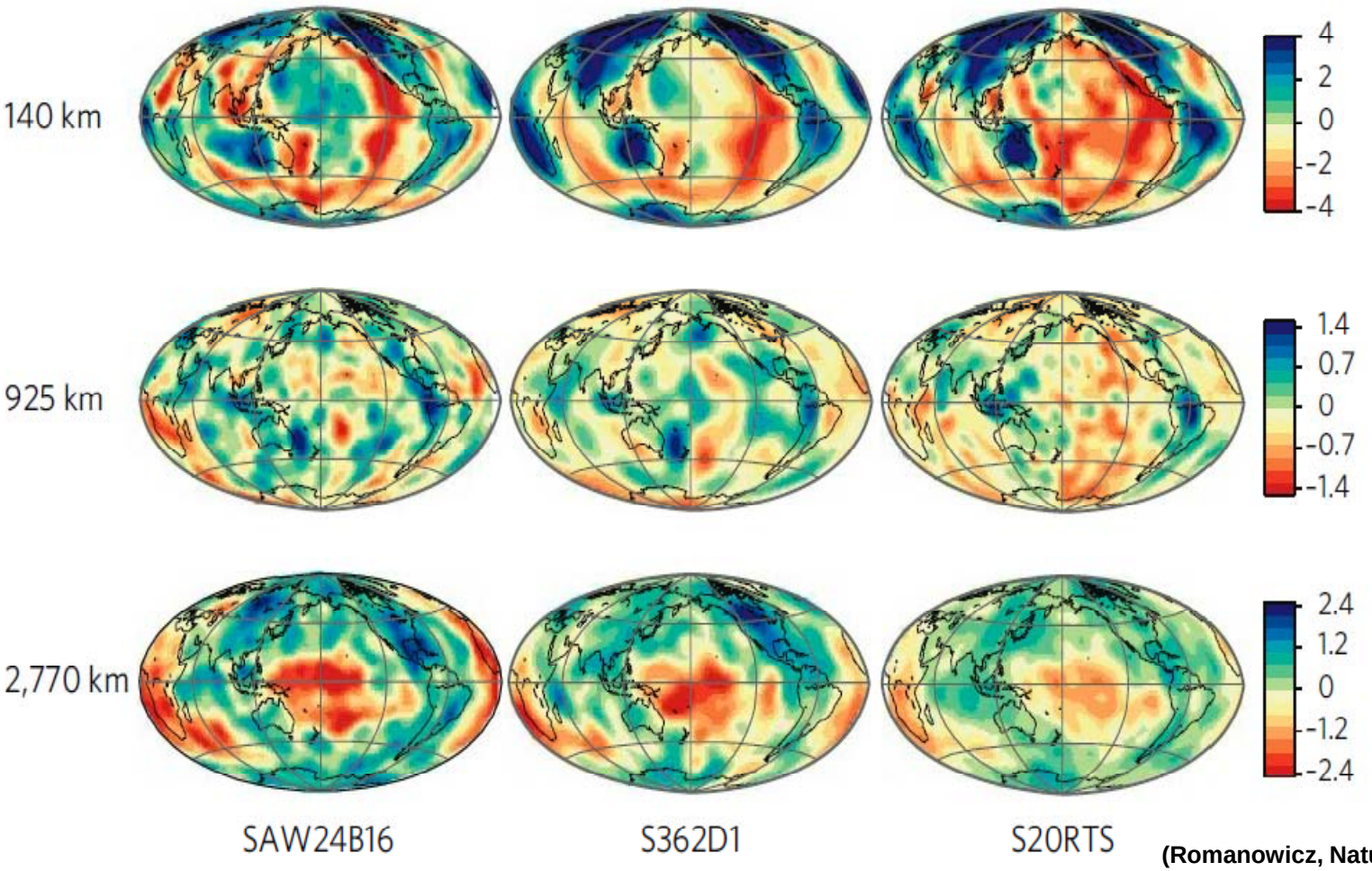
# Interpretation of the seismic structures of the Earth depends on mineral physics data




Mineral phases and chemical compositions help to interpret seismic structures

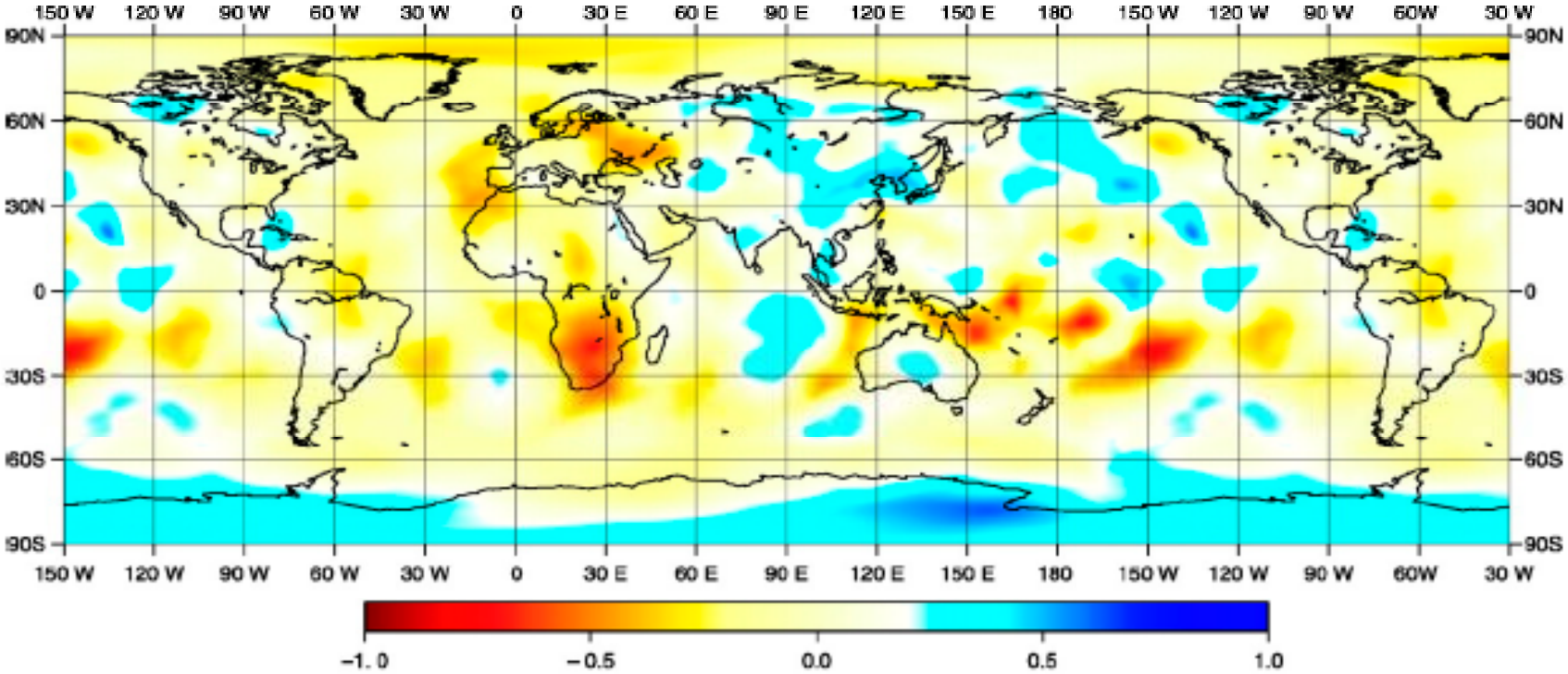
# 3-D Earth structure models inferred from mantle shear velocity




(Romanowicz, Nature, 2008)

Seismic anomalies are associated with geological structures

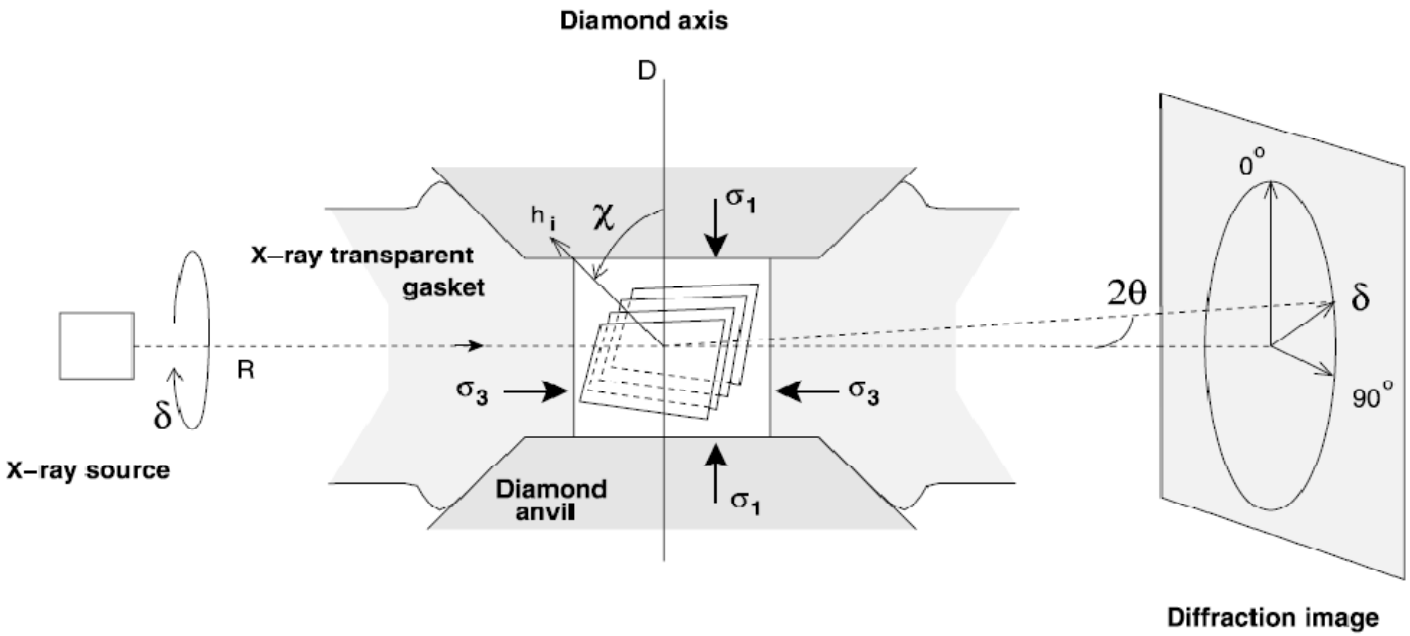
# Average P-wave velocity perturbation in the lowermost 1000 km




(Monteli et al., Science 2004)

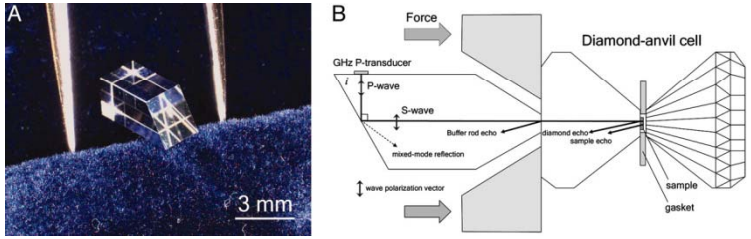
DAC and LVP coupled with modern synchrotron x-ray sources are crucial to examine the depth, slope, thickness and velocity contrast of the major seismic discontinuities under *in-situ* conditions

# DAC (Diamond Anvil Cell) has been a valuable tool to study Equation of State (EOS) of materials

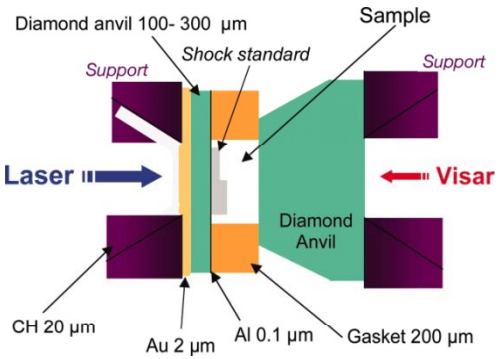



Study on texture (or Lattice Preferred Orientation) will help to determine deformation mechanism (slip system) and elastic properties: DAC is another tool to study Deformation of Materials at HP-HT

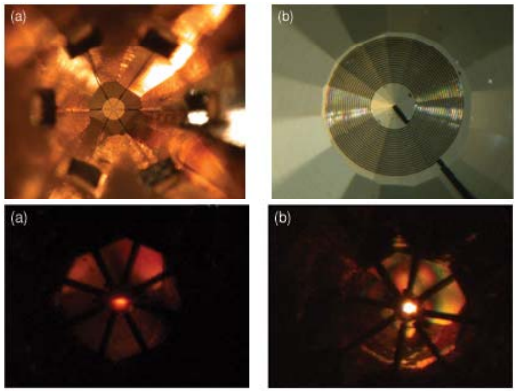
# New DAC experiments developed to study specific properties of materials quasi-hydrostatically



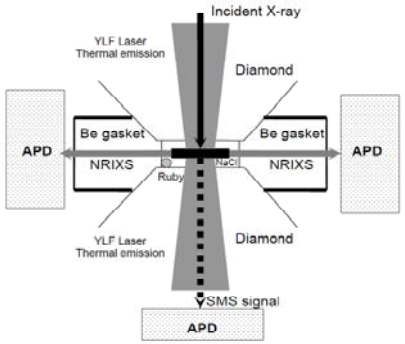

(Jacobsen et al., PNAS, 2004)




Laser driven shock



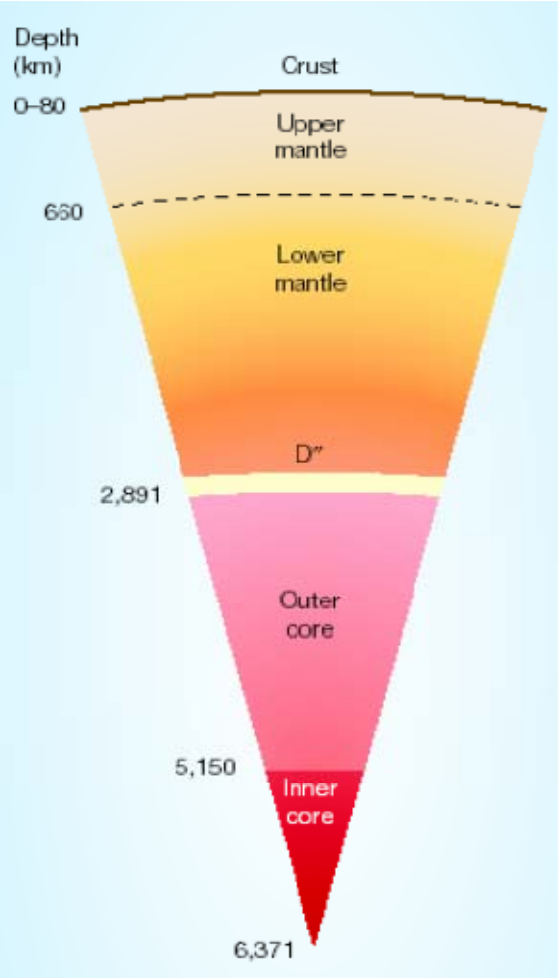

Designer anvil (Weir, S)

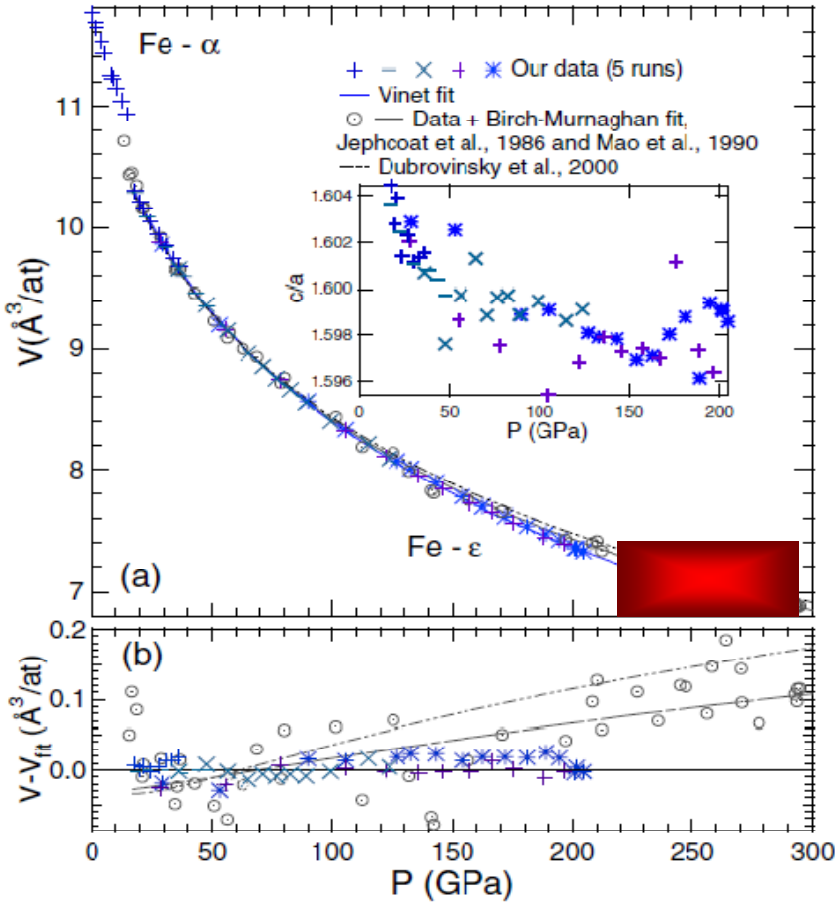



NRIXS, NFS

Many more….

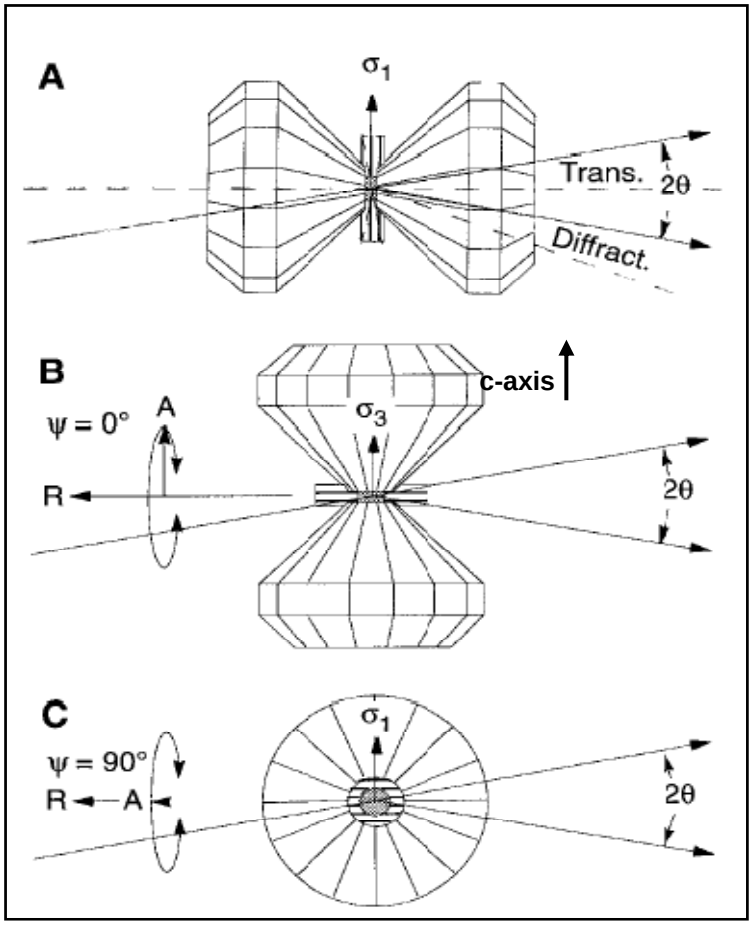
# Accurate EOS of materials are determined under quasi-hydrostatic compression: Fe

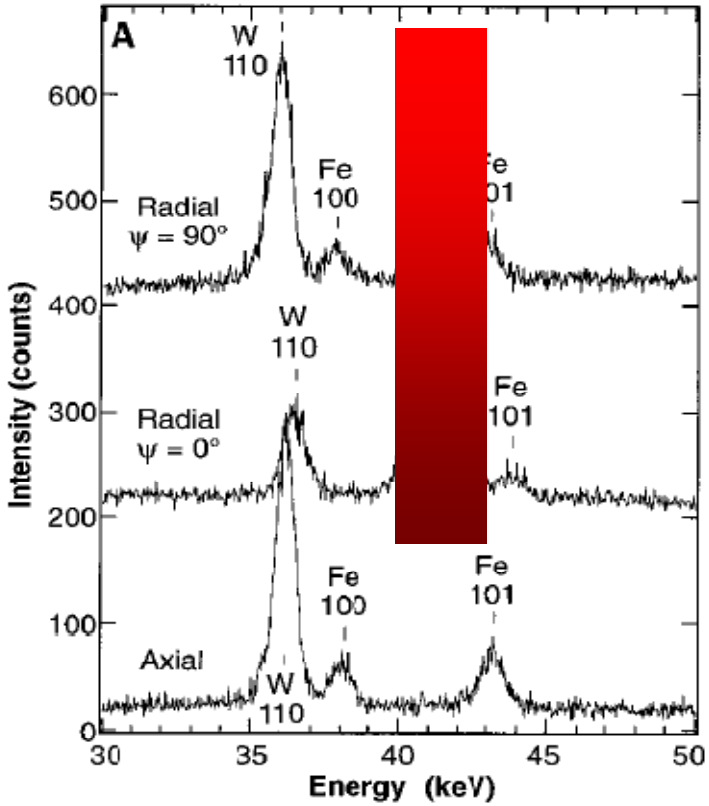



(Dewaele et al., PRL, 2006)

# Radial X-ray Diffraction (RXD) to determine yield strength of material at extreme conditions




Strong preferred orientation
Under uniaxial compression

($\sigma_P$(Fe)=290GPa; $\sigma_P$(W)=265GPa)

# Maximum uniaxial stress, *t* supported by a material: determined by its strength

Difference in *d-spacings*:

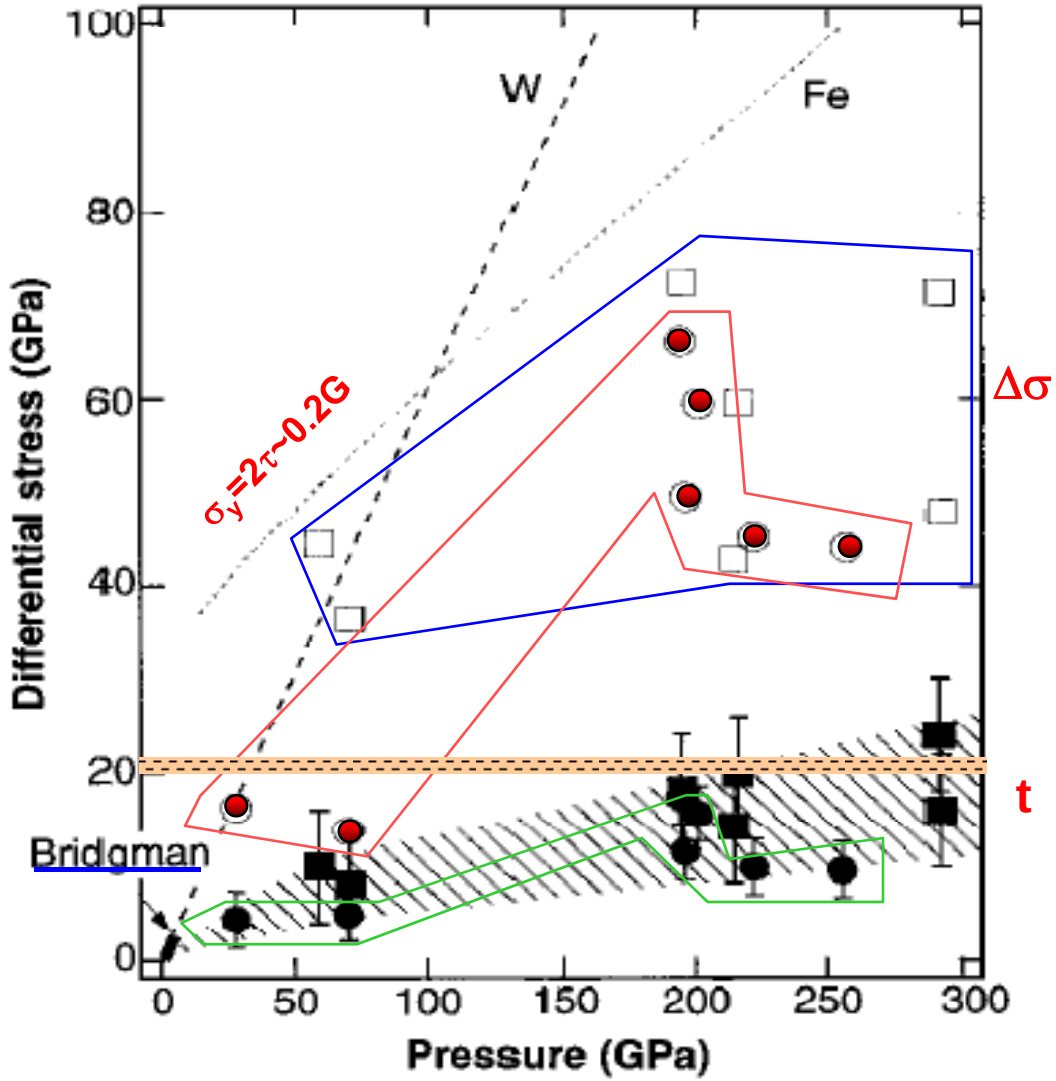
$Q = (d_{\psi 0}^{o} - d_{\psi 90}^{o})/3d_P$

$d_P = (d_{\psi 0}^{o} + 2d_{\psi 90}^{o})/3$

$t = \sigma_1 - \sigma_3 = 6G\langle Q(hkl)\rangle$

$t \leq \sigma_y = 2\tau$

- $\sigma_y$ : yield strength
- $\tau$ : shear strength
- $Q$ : deviatoric strain
- $t$ : differential stress or
  - deviatoric stress




(Hemley et al., Science, '97)

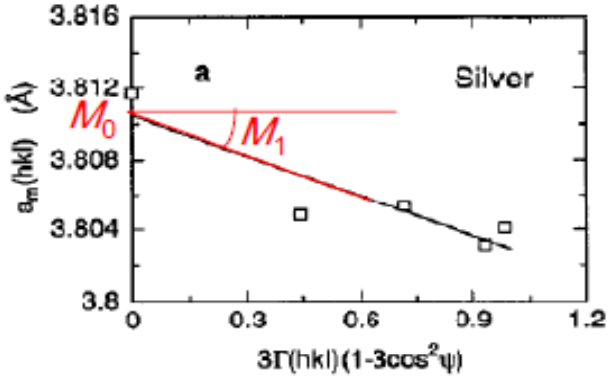
# How to estimate strength of materials when elastic anisotropy is known?

From theory/RXD/ISS/BS/IXS/NRIXS

Anisotropy $S$ allows measuring stress $t = \sigma_3 - \sigma_1$ above ~0.3 GPa using:

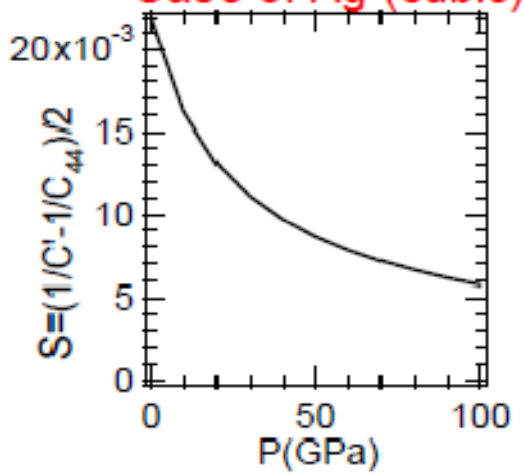
vertical radial

$$t = \sigma_3 - \sigma_1 \simeq -\frac{3M_1}{\alpha M_0 S}$$




[Akahama 2004]

Case of Ag (cubic):




$M_0$ and $M_1$ being defined by the « gamma-plot »

$$a_{\mathrm{hkl}} = M_0 + M_1 \times 3(1 - 3\sin^2\theta)\Gamma_{\mathrm{hkl}}$$

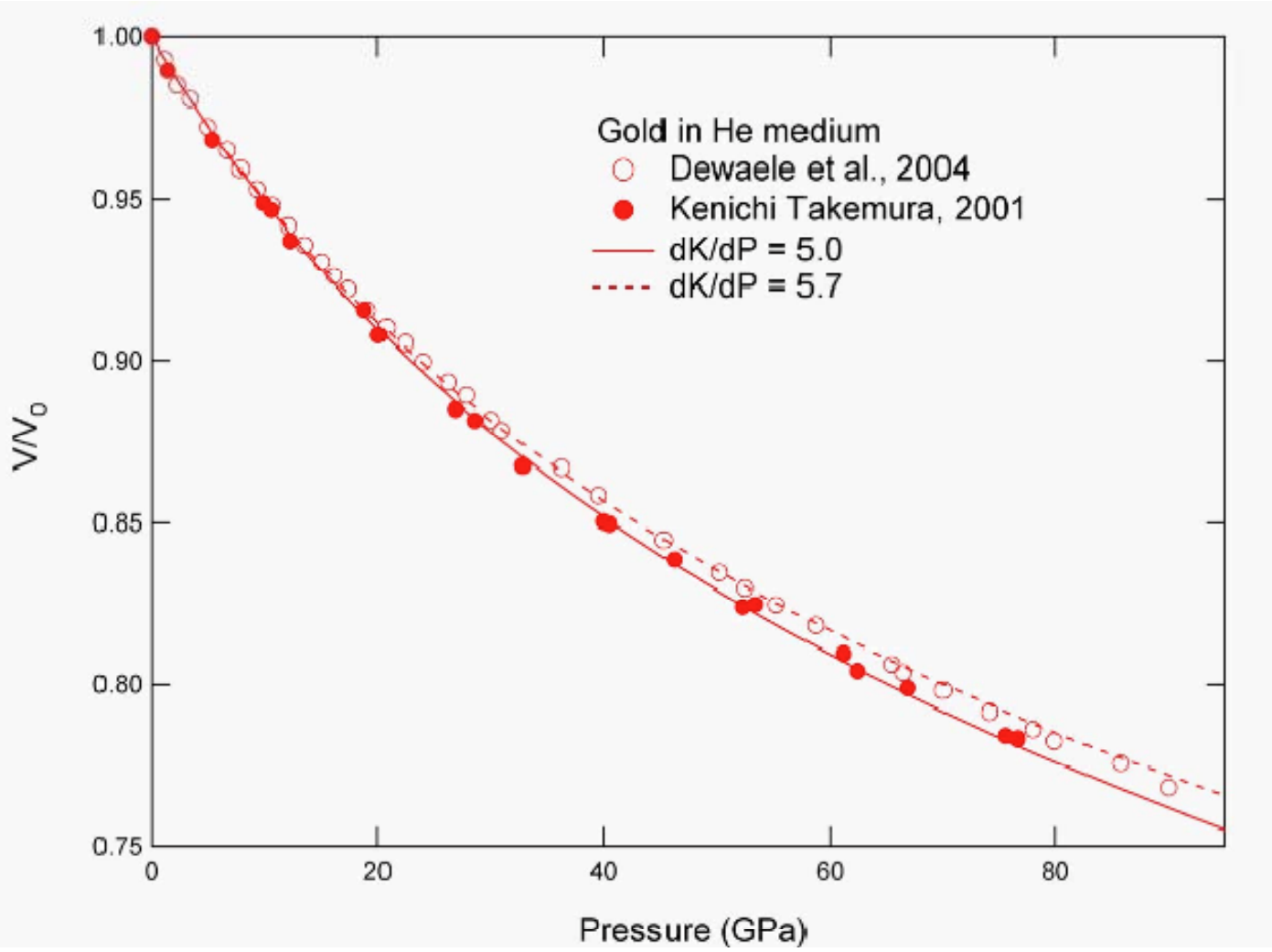
$$a_{\mathrm{hkl}} = d_{\mathrm{hkl}} \times \sqrt{(h^2 + k^2 + l^2)}$$

$d_{\mathrm{hkl}}$ distance between two ($hkl$) planes

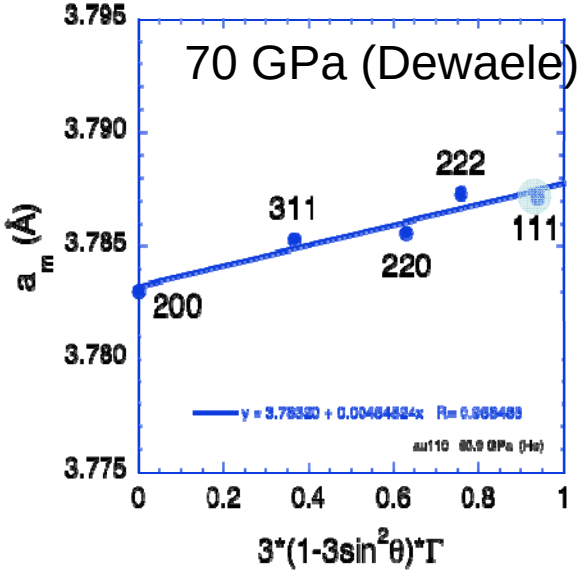
(2θ diffraction angle,

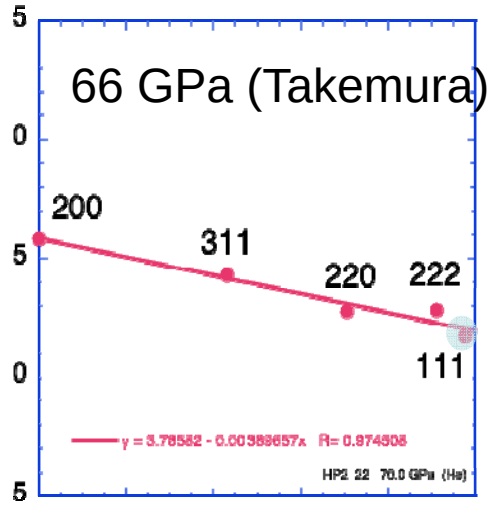
$$\Gamma_{\mathrm{hkl}} = (h^2k^2 + h^2l^2 + k^2l^2)/(h^2 + k^2 + l^2)^2$$

# EOS of Au


Gold in He medium
Dewaele et al., 2004
Kenichi Takemura, 2001
dK/dP = 5.0
dK/dP = 5.7
1.00
0.95
0.90
0.85
0.80
0.75
V/V0
0
20
40
60
80
Pressure (GPa)

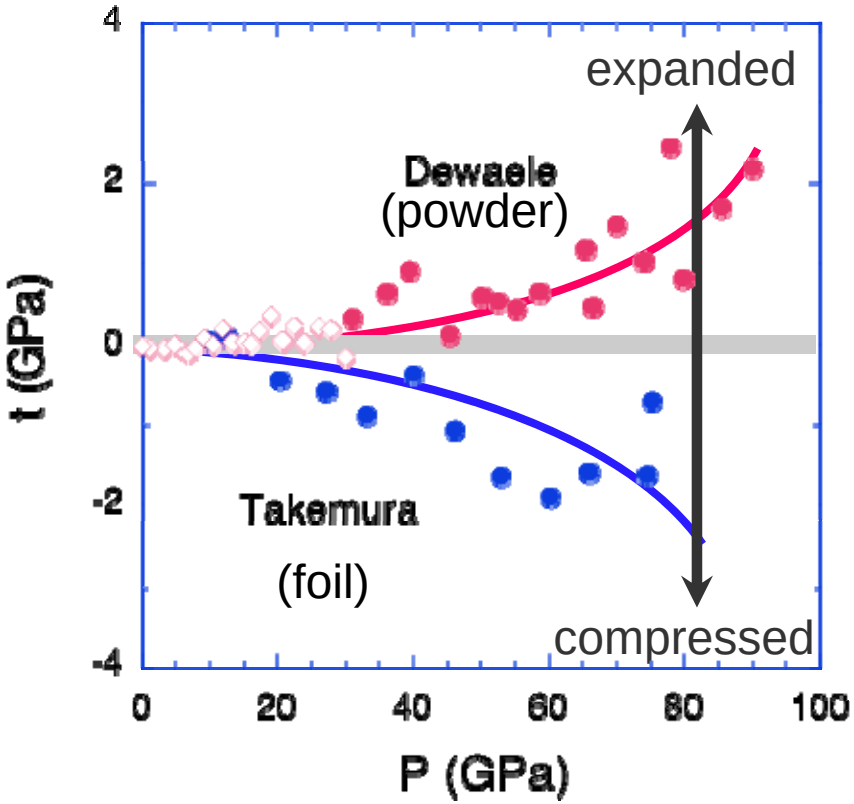
# Γ-plot & deviatoric stress of Gold




(Takemura, 2006)

t = ♦▤ - ♦▤ > ♦🗁
♦🗁 ♦▤ < ♦🗁



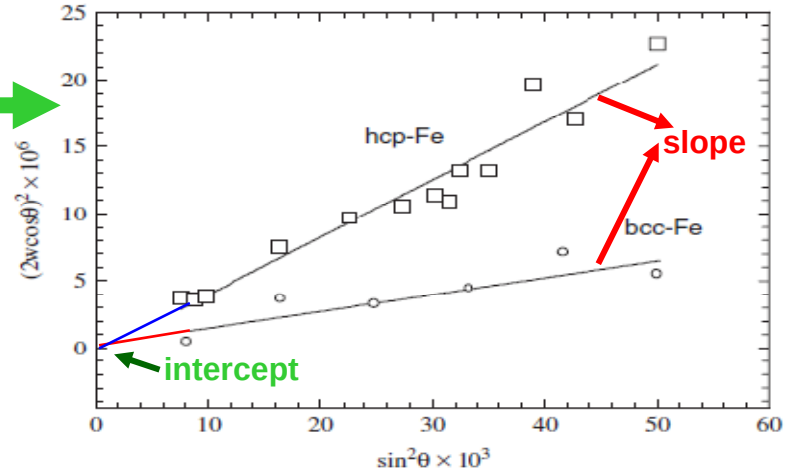

$t = -(3\,M_1)/(\Theta M_0\,S)$

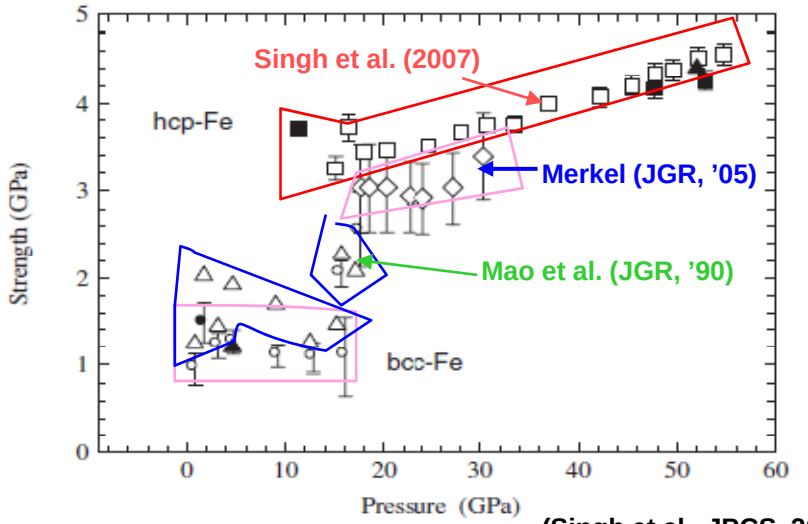
# Diffraction peak broadening due to deviatoric stress and grain size

$$(2w_{hkl}\cos\Theta_{hkl})^2 = (\lambda/d)^2 + \eta^2_{hkl}\sin^2\Theta_{hkl}$$

$2w_{hkl}$ : FWHM
d : grain size
$\lambda$ : x-ray wavelength
$\eta_{hkl}$ : microstrain

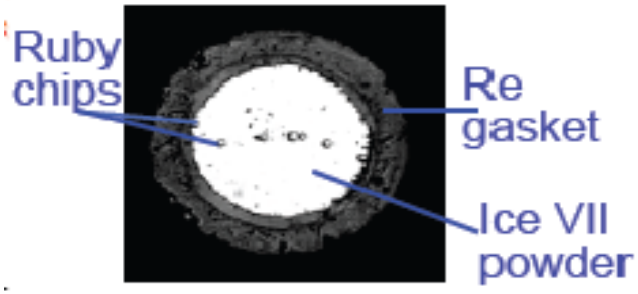
$$\eta^2_{hkl} = [(2w_{hkl}\cos\Theta_{hkl})^2 - (\lambda/d)^2] / \sin^2\Theta_{hkl}$$



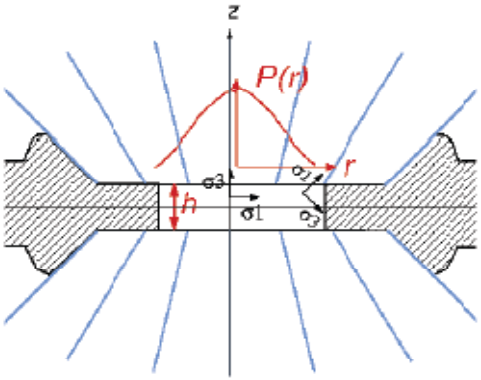




(Singh et al., JPCS, 2007)

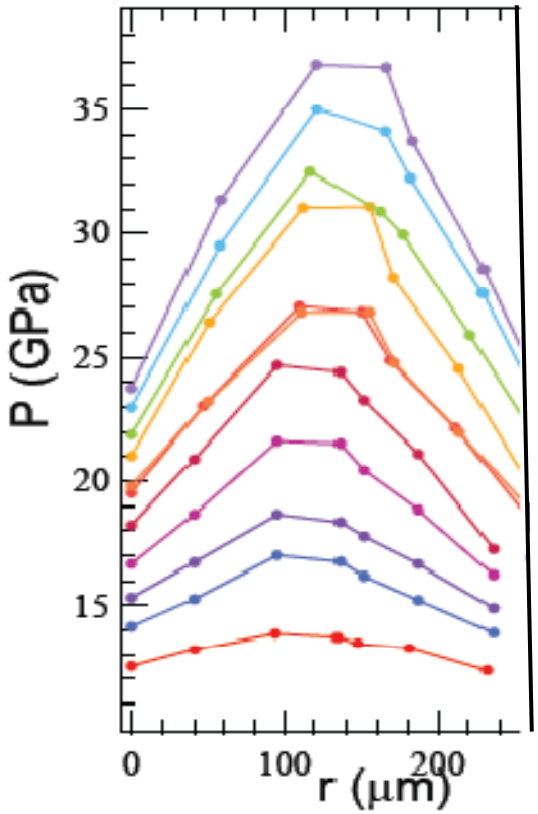
# Pressure gradient and sample thickness measurement provides yield strength of materials at high pressures




(Dewaele, 2006)

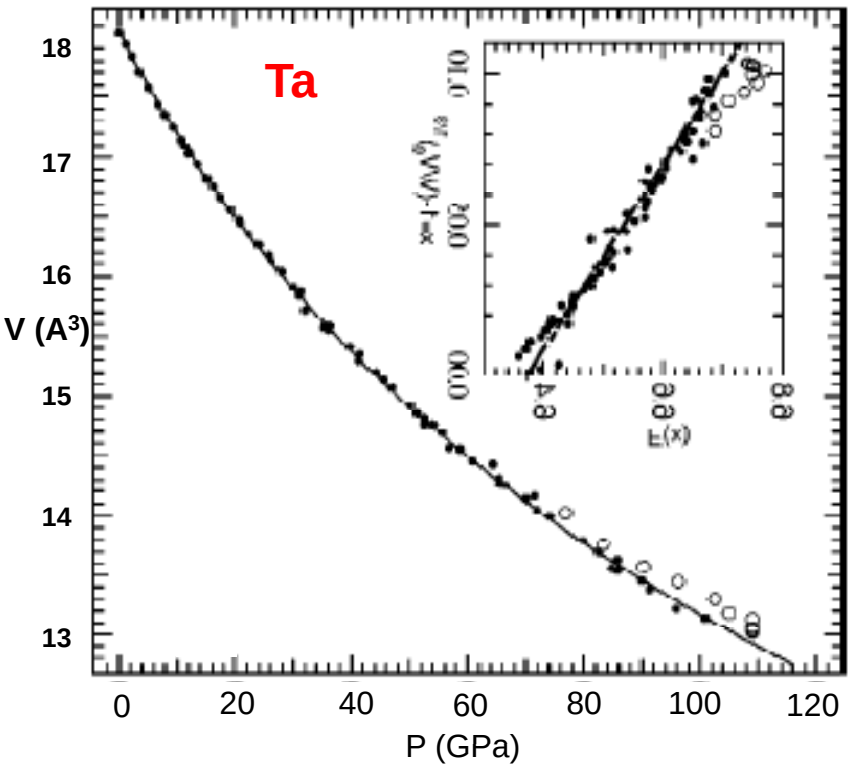



$t = (dP/dr)*2h$

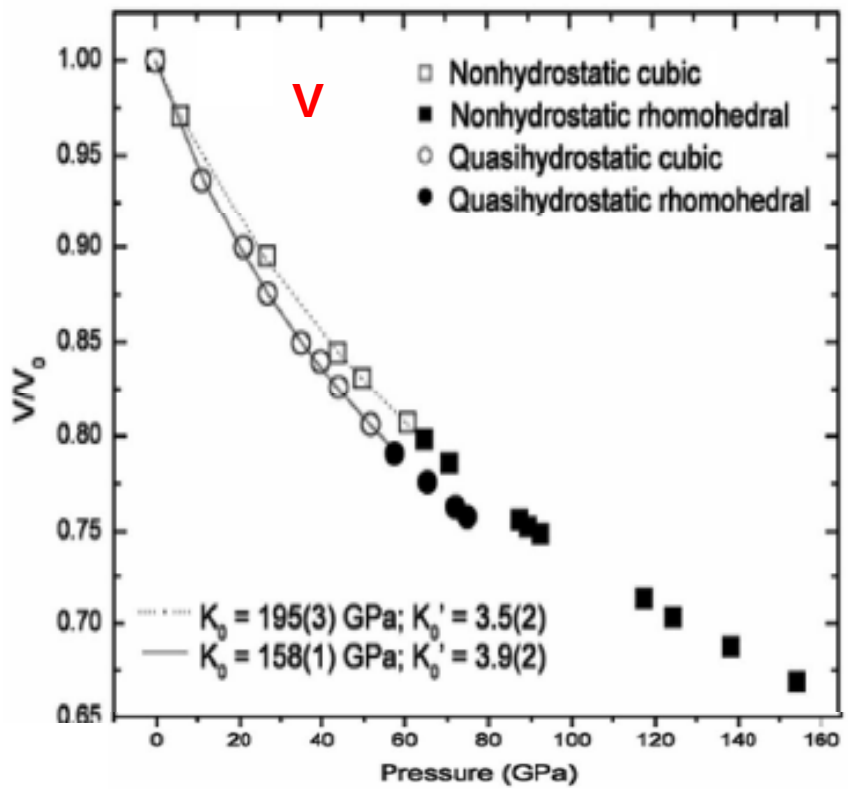



Accurate thickness measurement is crucial using *in-situ* x-ray absorption to determine precise material flow behavior

# Ta and V show drastically different non-hydrostatic behavior

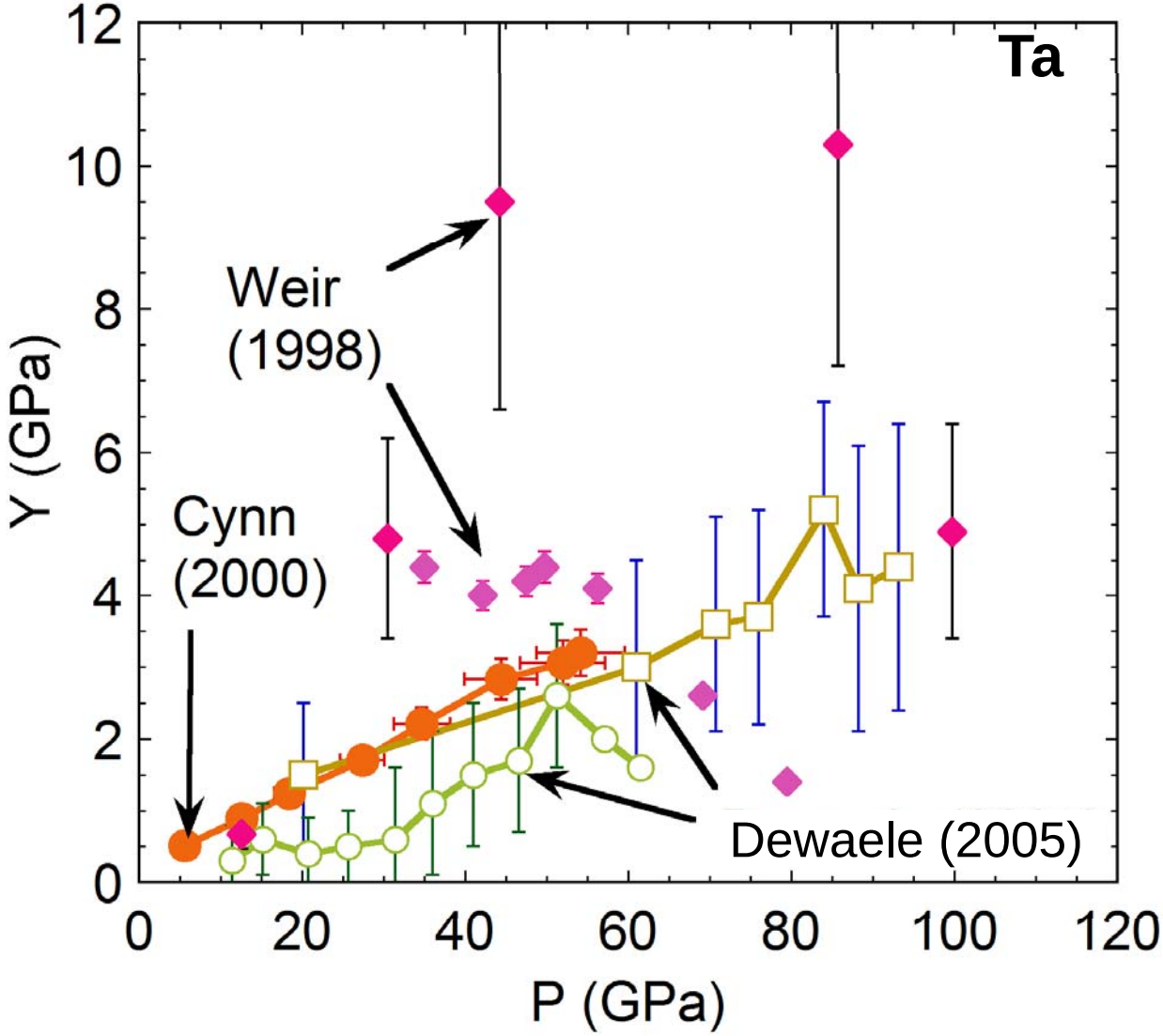


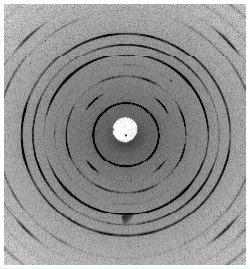

(Dewaele et al., PRB, 2006)



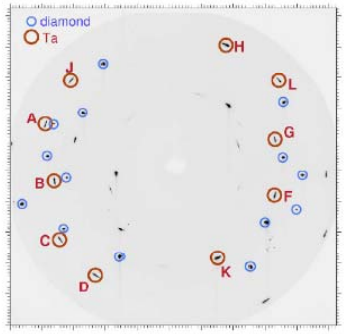

(Ding et al., PRL, 2006)

# Sample characterization is important to estimate mechanical properties

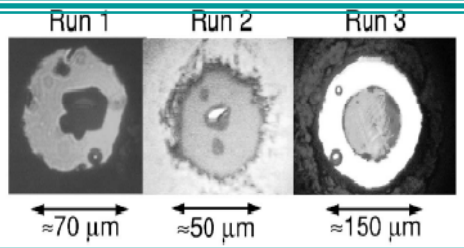


Ta foil showing texture

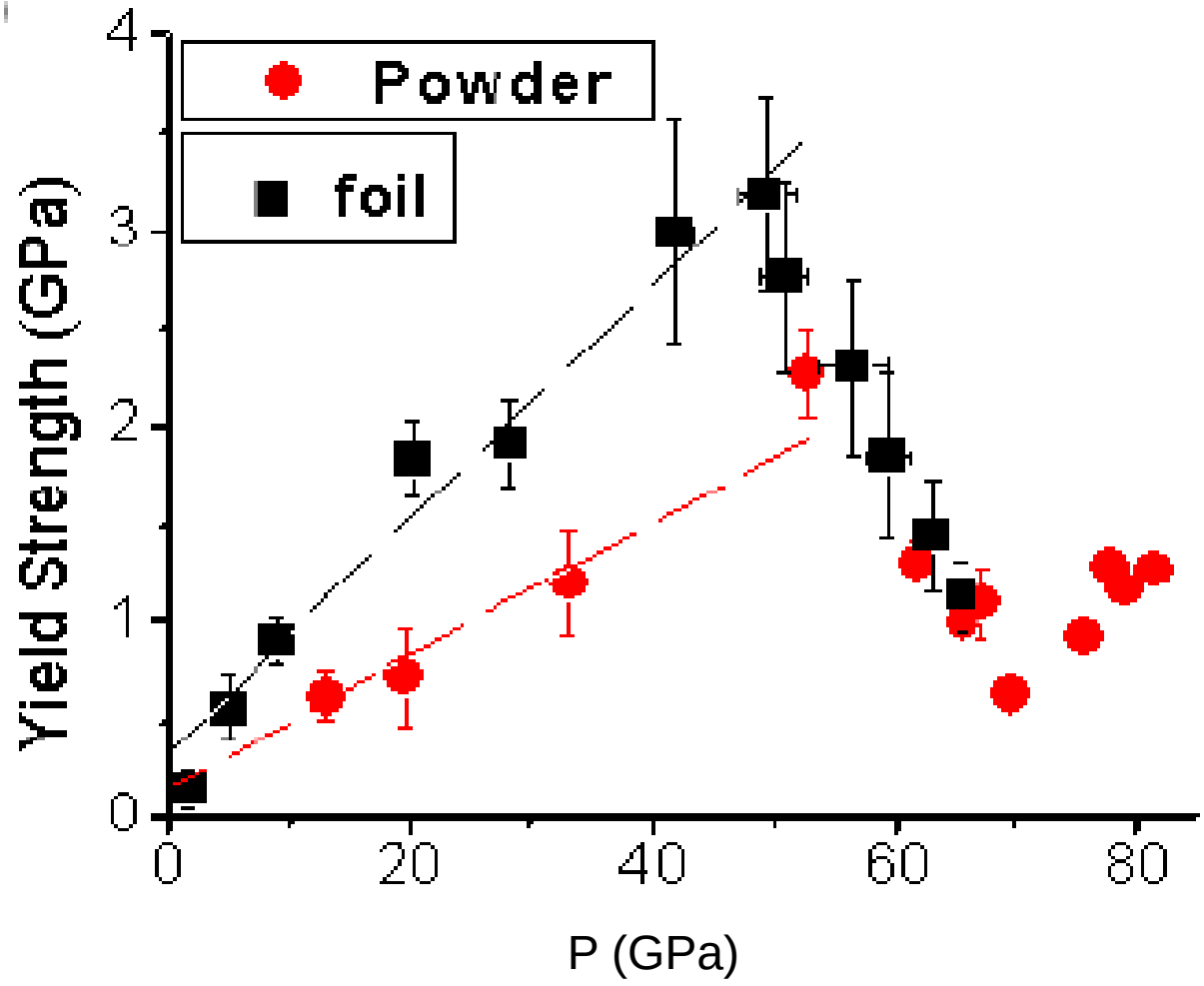



**Single crystal strain method**

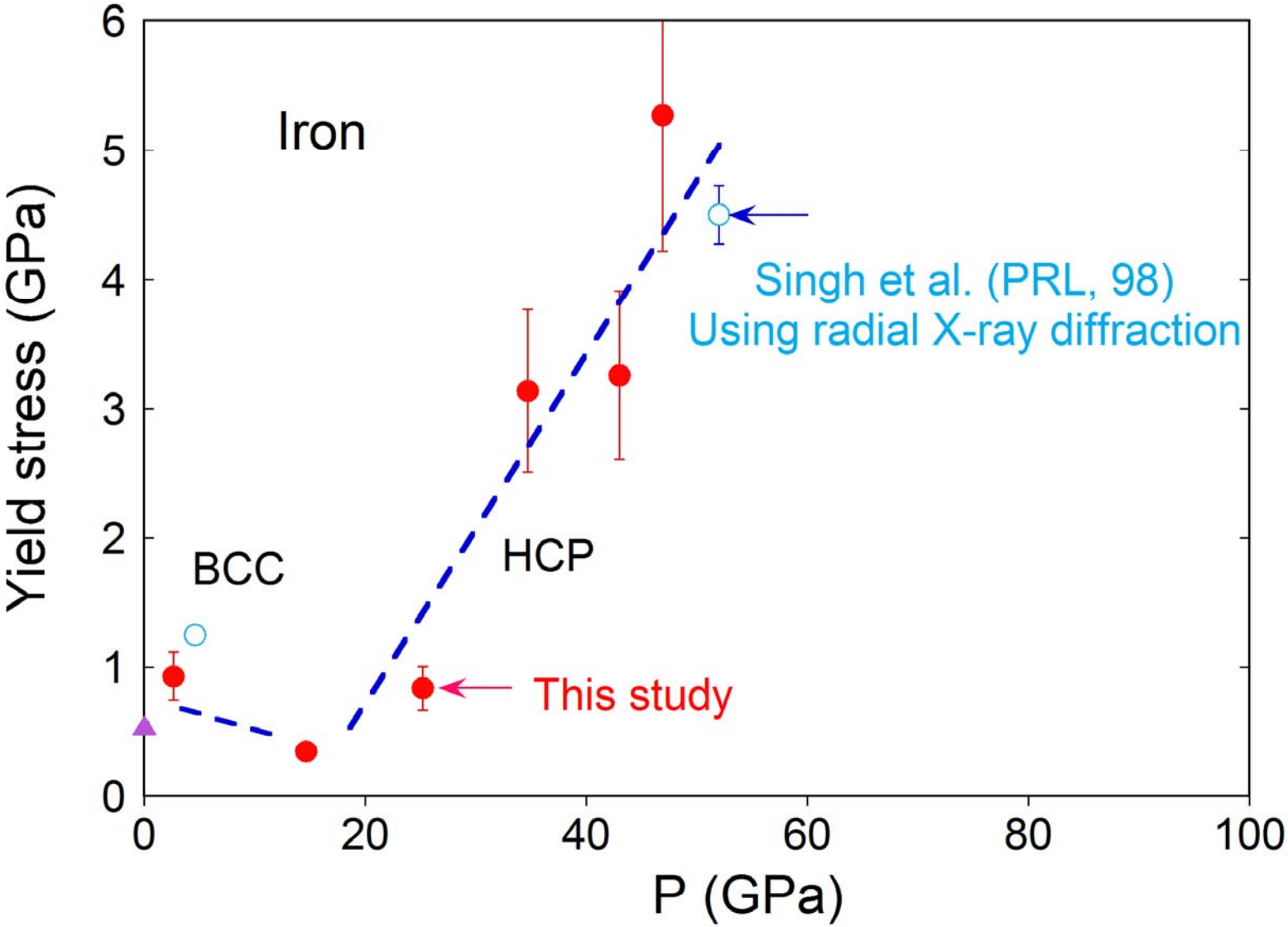



**(Dewaele & Loubyre, PRB, 2005)**

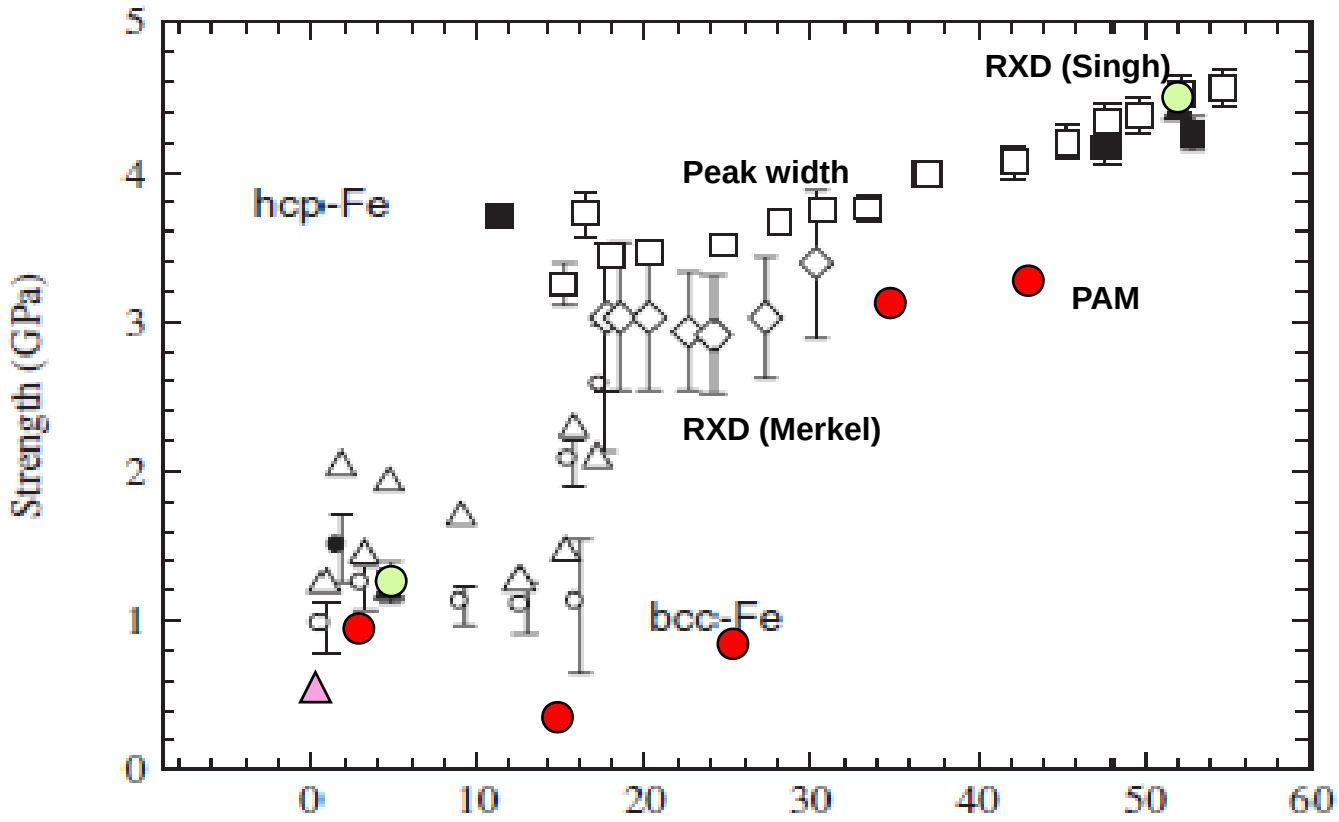
# Work in progress: Vanadium



# Yield strength of Fe determined using PAM

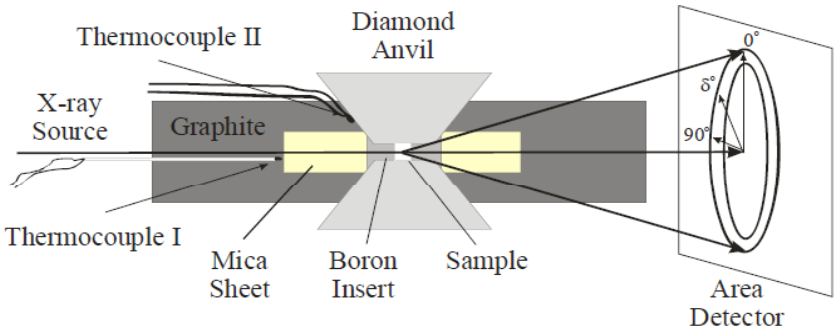


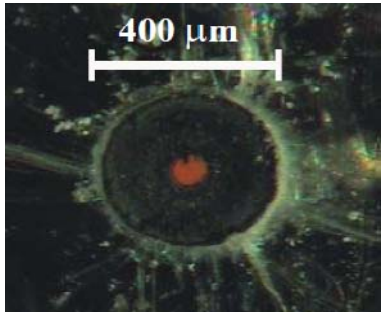
# Comparison of yield strength of Fe



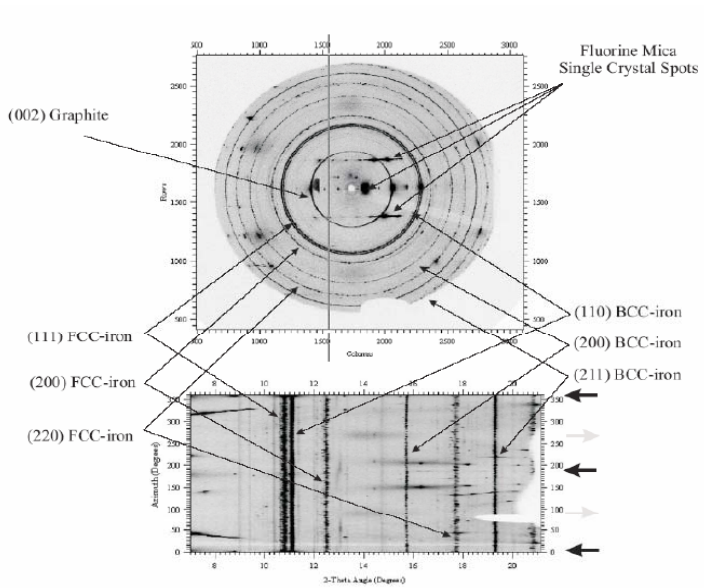

Lower yield strength determined using PAM compared to others

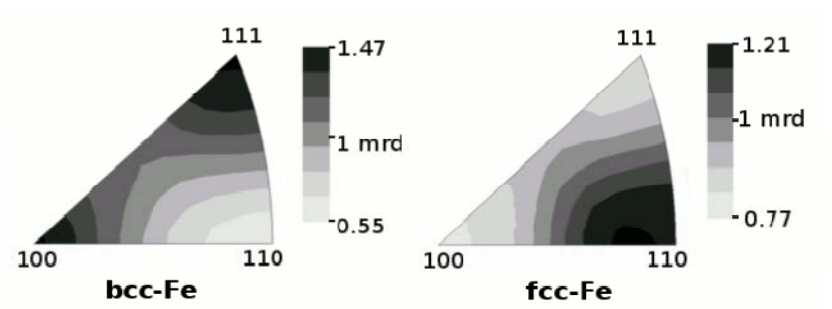
# Quantitative Rietveld texture analysis




B insert gasket




Inverse pole figure at ~1000 K, 9GPa

(Liermann et al., in preparation)

# Summary:

1. RXD – no knowledge about $\alpha$ : needs assumption

$$Q(hkl) = (t/3)\{\alpha[2G_R(hkl)^{-1} + (1-\alpha)(2G_V)^{-1}\}$$

If a=1, $t = 6GRQ(hkl)$

2. PAM – $t = (dP/dr)*2h$

3. Peak width – complication due to grain size effects

4. Texture analysis -