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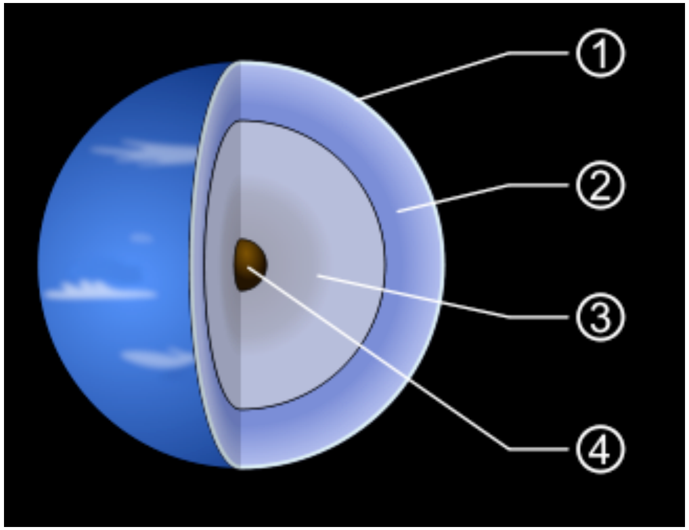
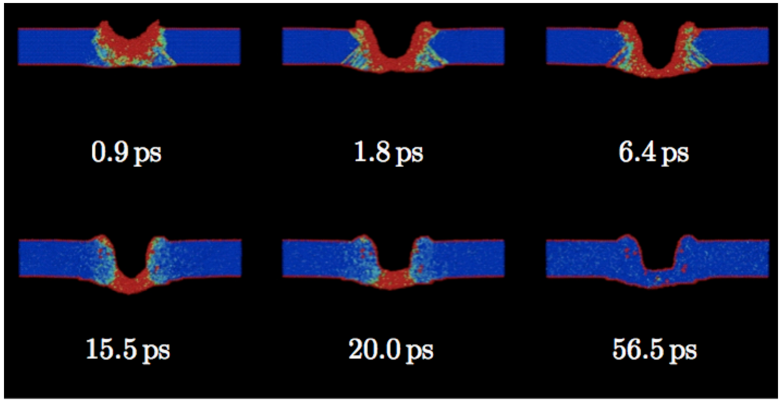
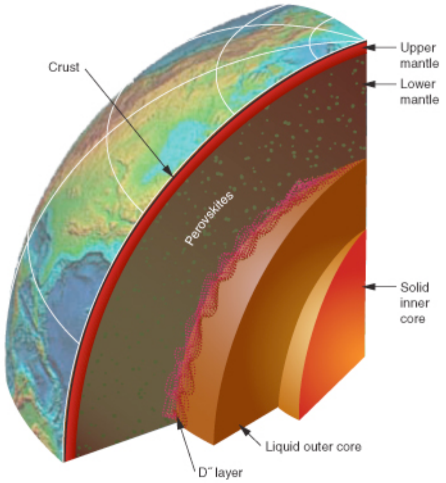
Frontiers of Dynamic Compression

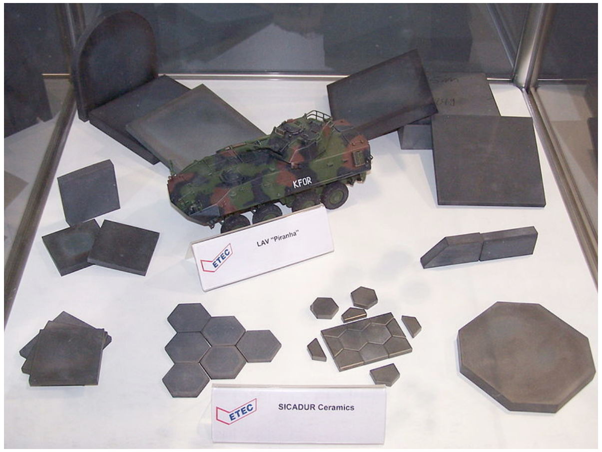
Andy Higginbotham

Why study HED Solids?



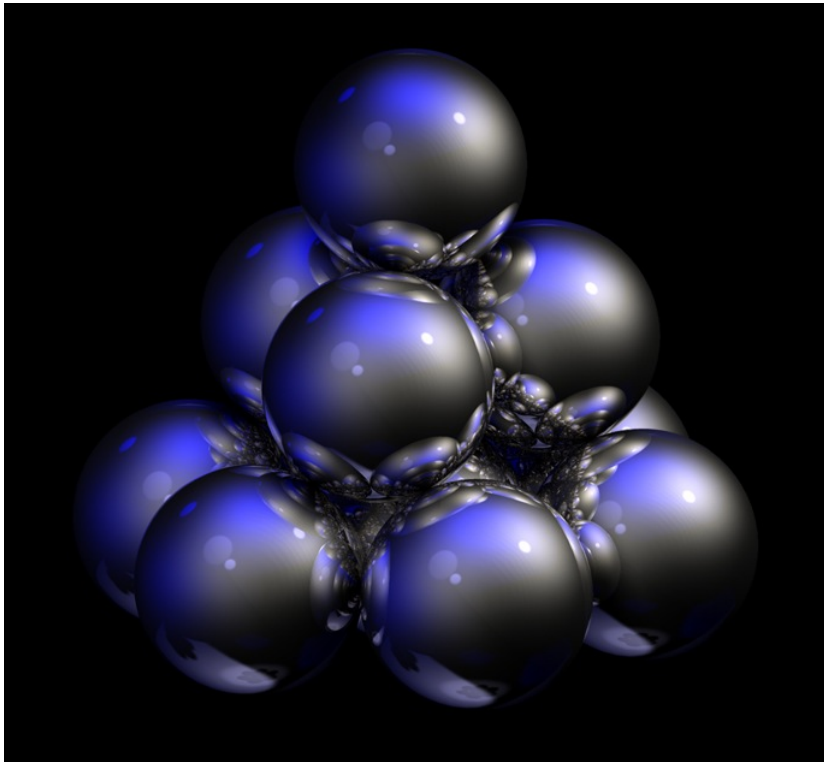


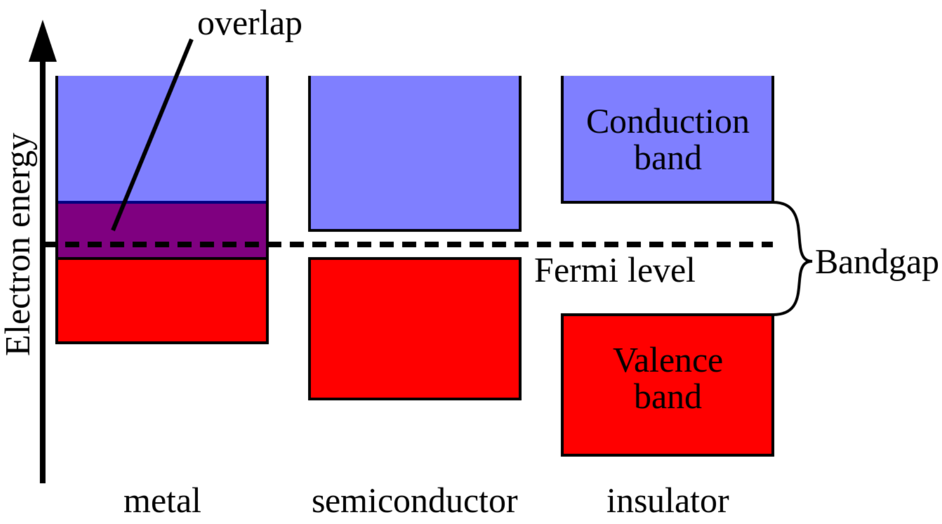




Are HED solids interesting?

Traditional picture





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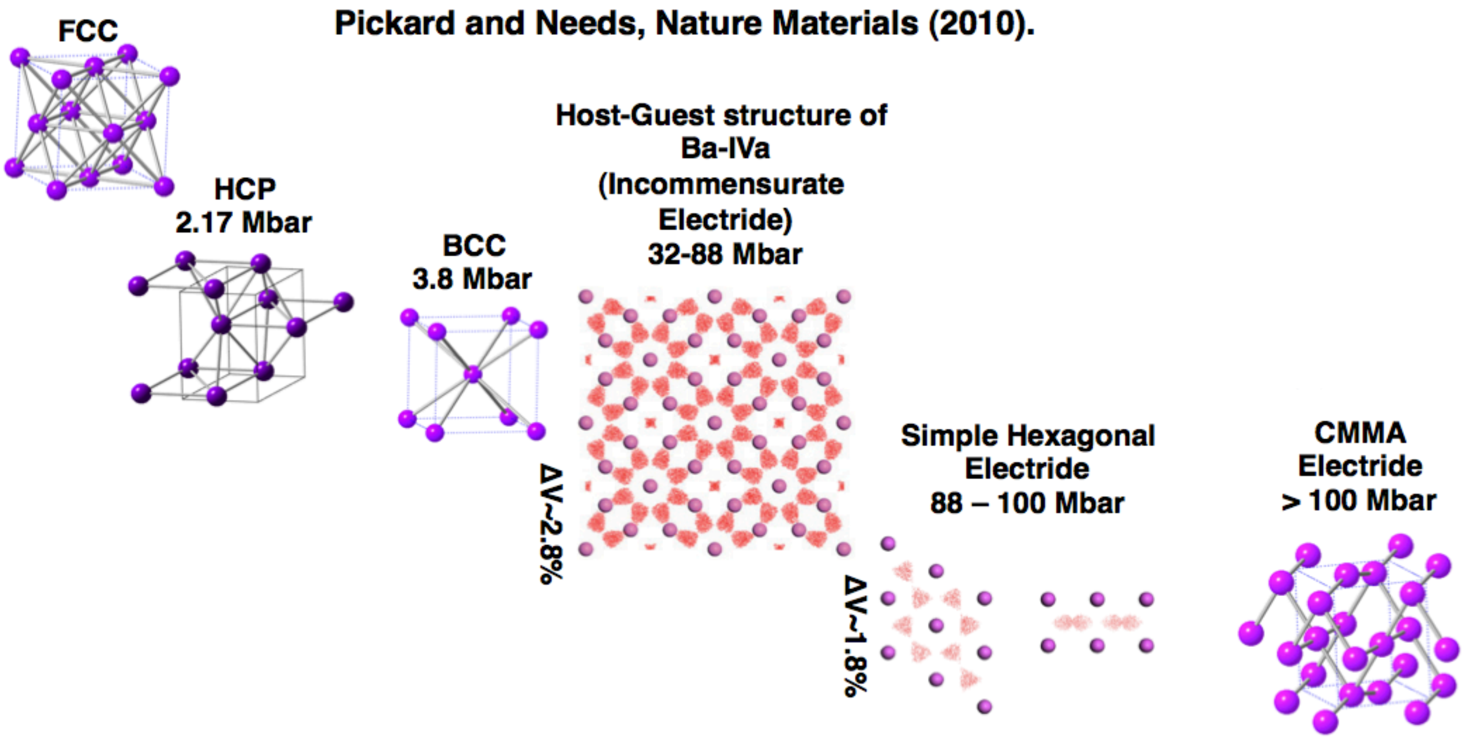
Are HED solids interesting?

“Chemical pressure”	1eV/Å^3 ≈ 100 GPa
“Atomic pressure”	1eV/a_0^3 ≈ 1 TPa

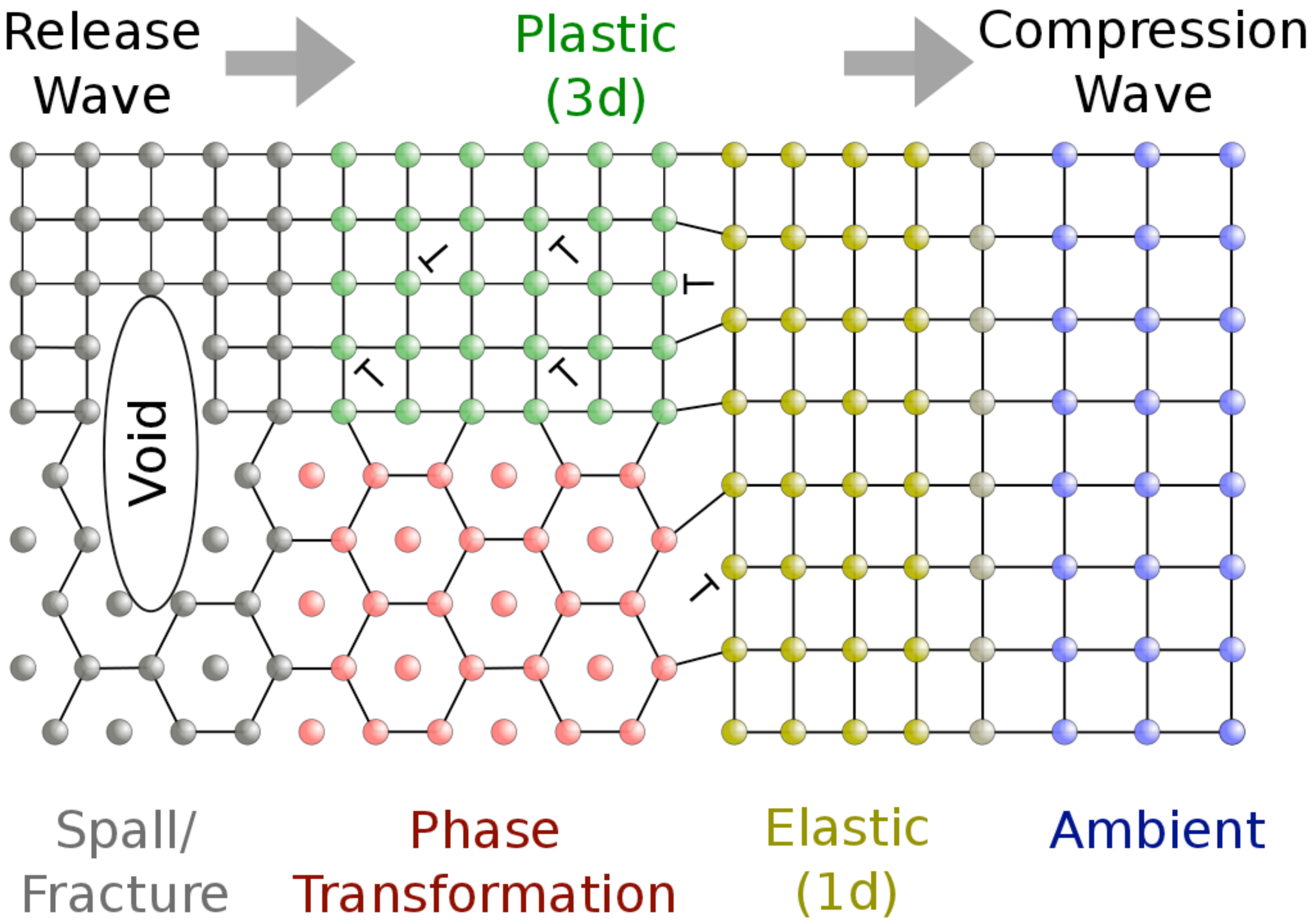
For HEDP, chemical energy density is equivalent to applied pdV work

Are HED solids interesting?

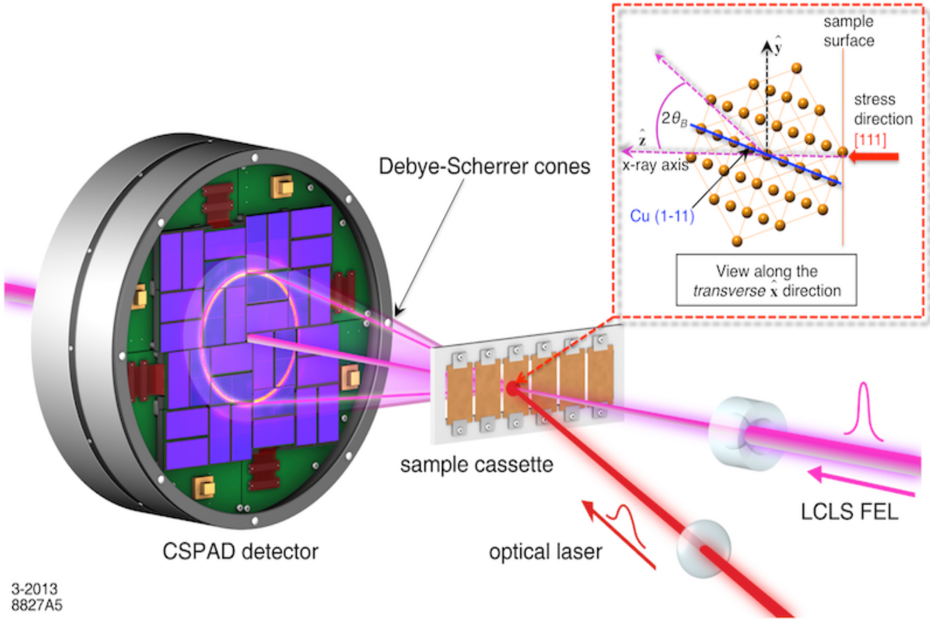
Al



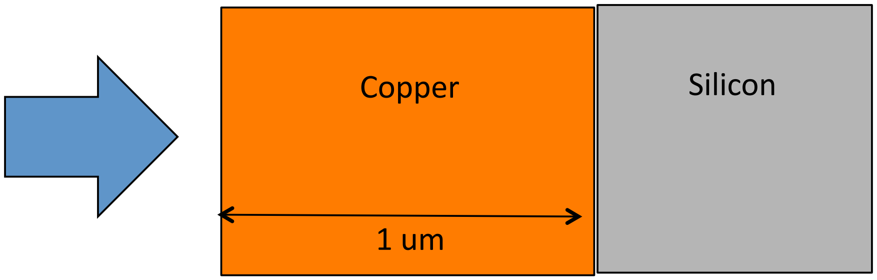
Planar Shock Waves



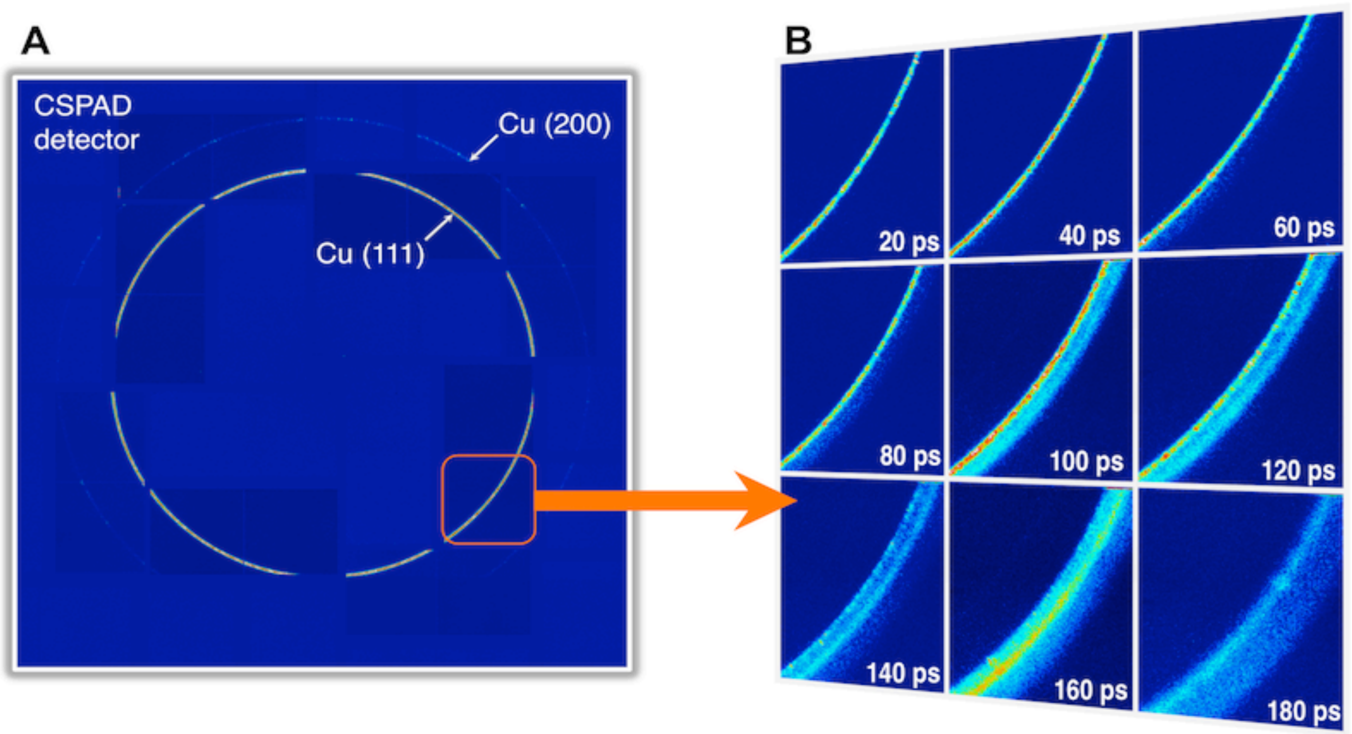
Cu Plasticity



$$\sigma_n = \sigma_0 t^2 \exp\left(-\frac{t}{T_0}\right)$$



Cu Plasticity



Milathianaki et al. Science 11 October 2013: 220-223.
Higginbotham & McGonegle, J Appl. Phys, **115**, 174906 (2014)

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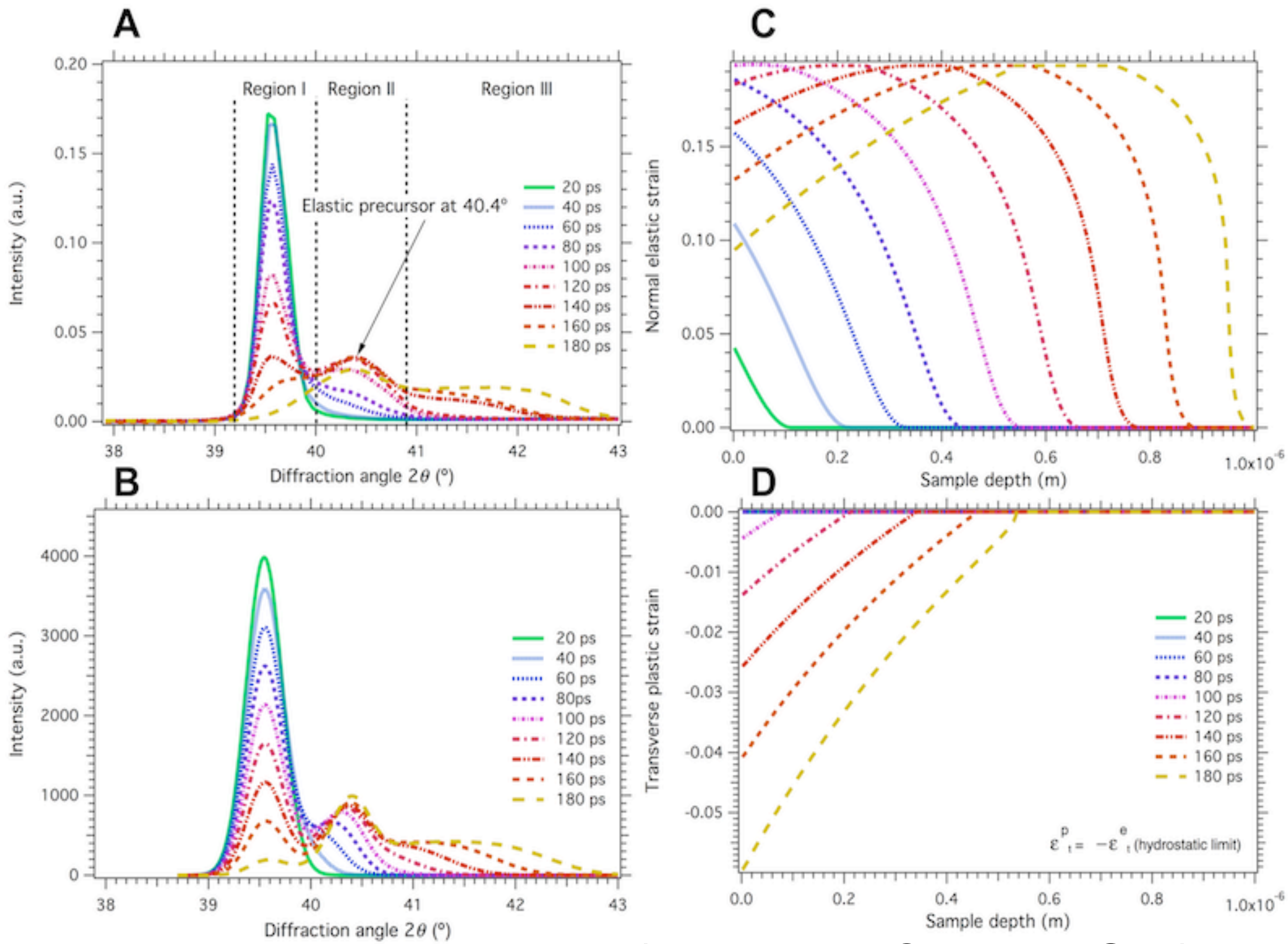
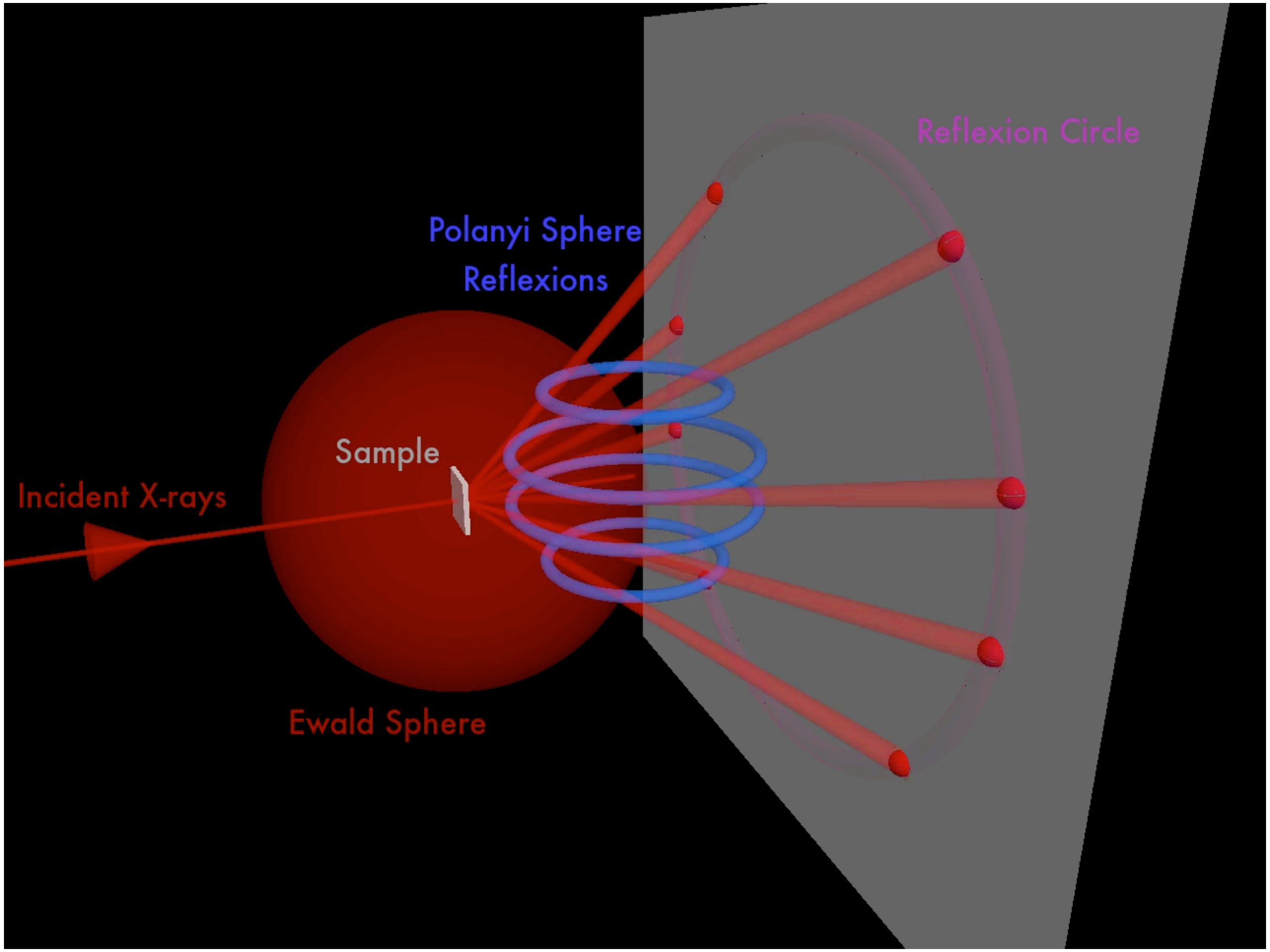
Cu Plasticity



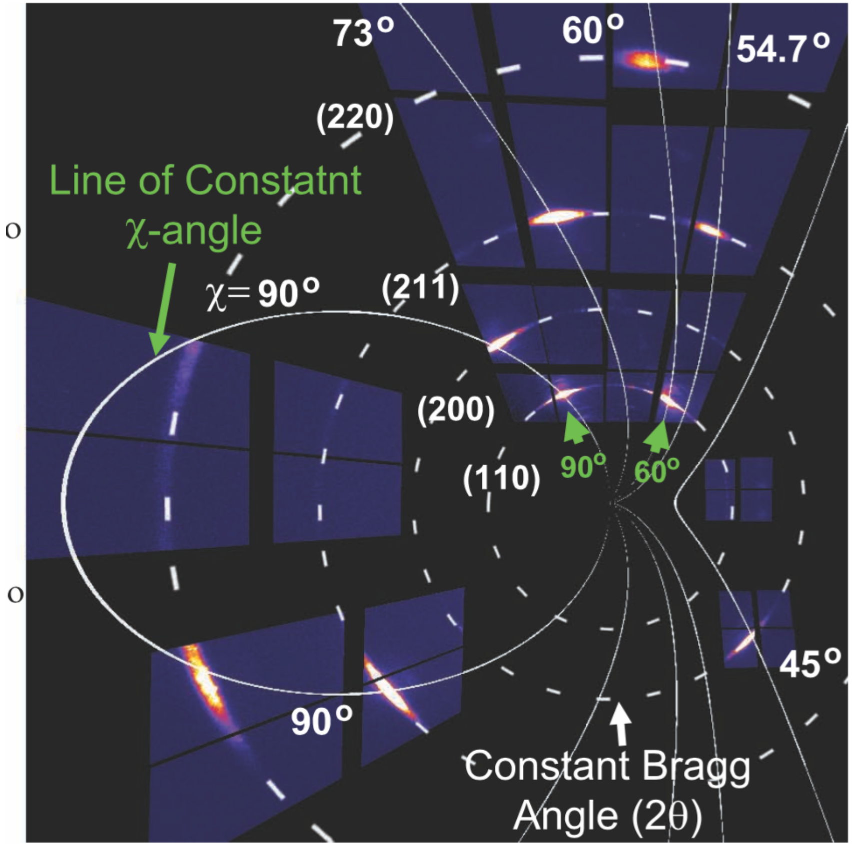
Milathianaki et al. Science 11 October 2013: 220-223.

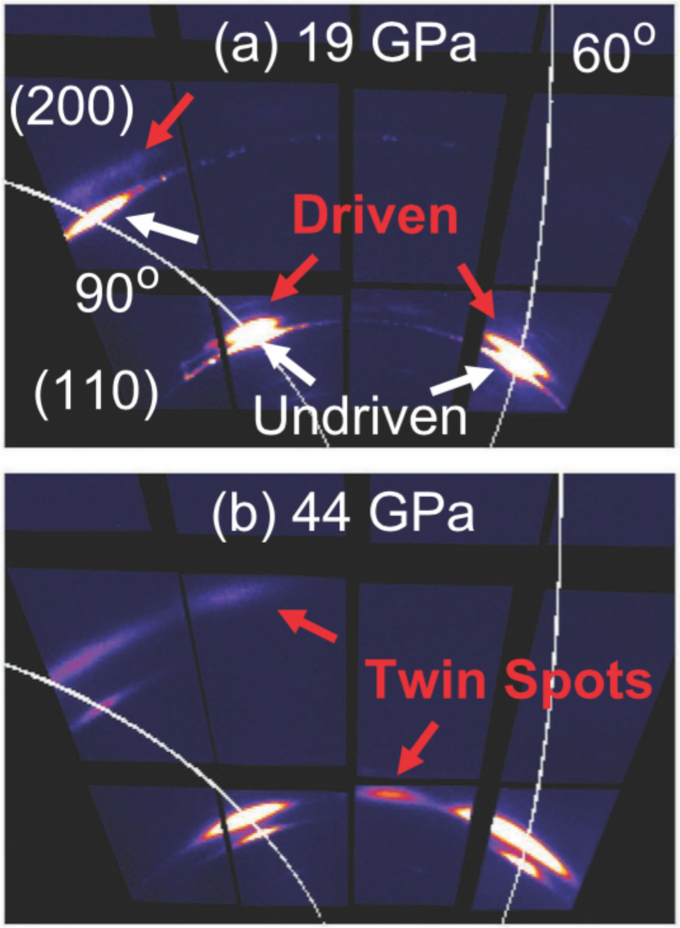
Higginbotham & McGonegle, J Appl. Phys, **115**, 174906 (2014)

Texture


Reflexion Circle
Polanyi Sphere
Reflexions
Sample
Incident X-rays
Ewald Sphere

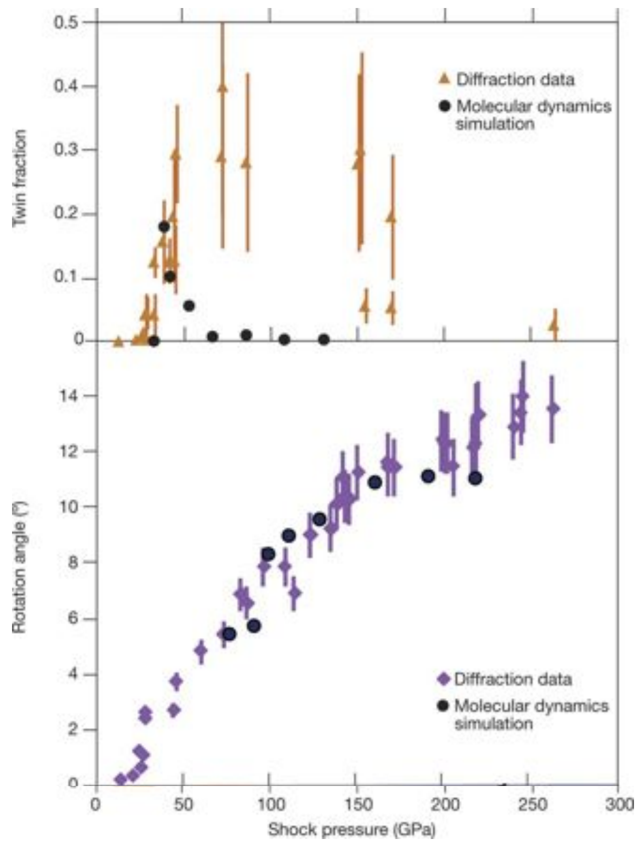
Ta Diffraction

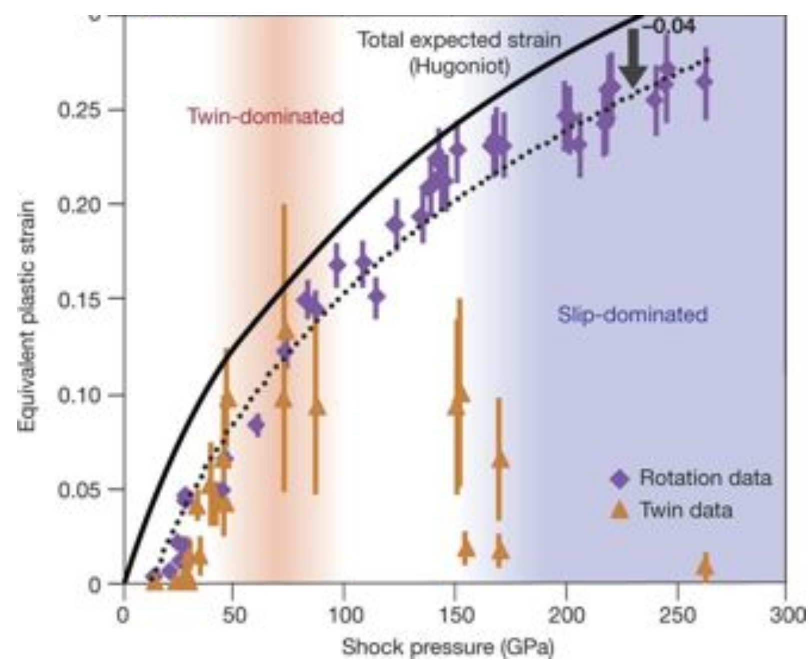




Wehrenberg et al. Nature, **550**, 496 (2017)

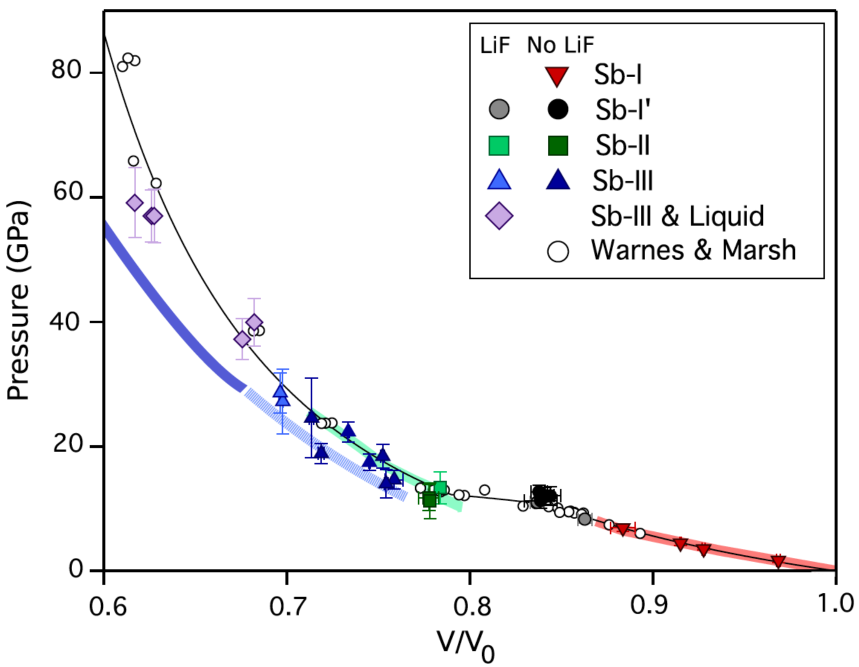
Ta Plasticity

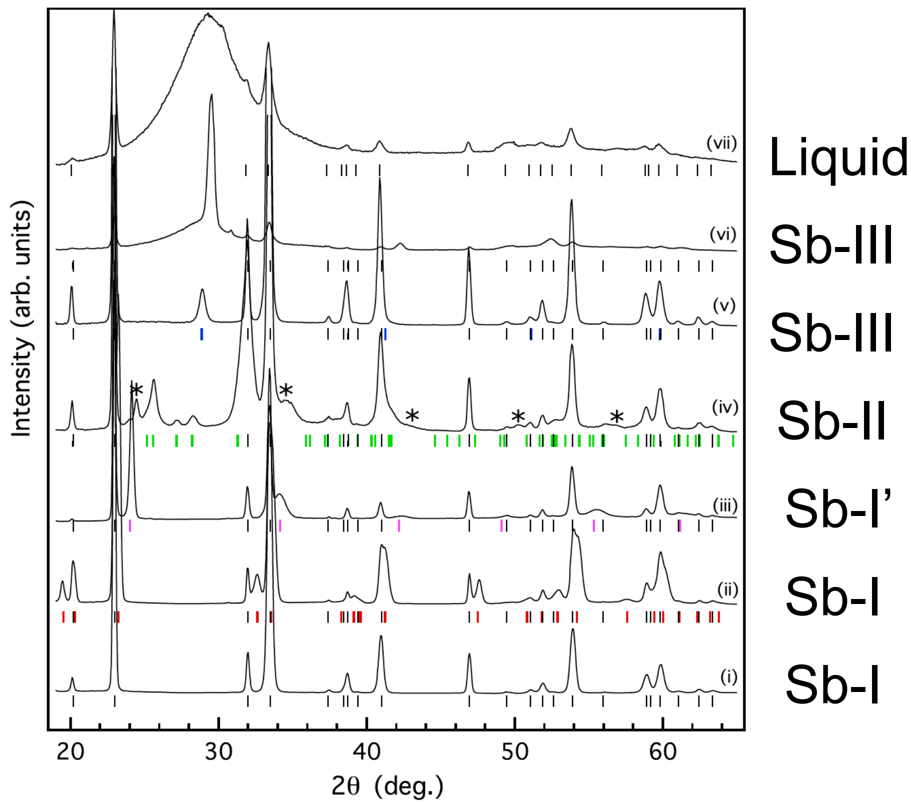




Wehrenberg et al. Nature, **550**, 496 (2017)

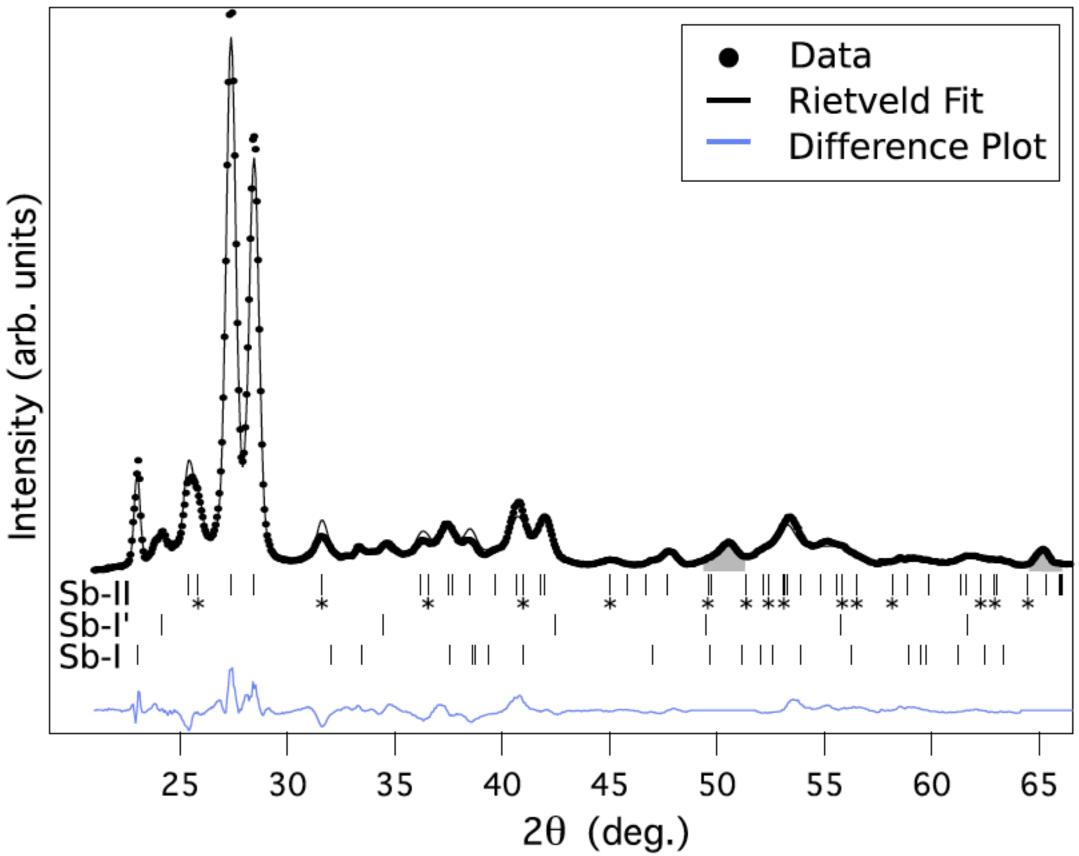
Antimony





Coleman et al. Phys. Rev. Lett., **122**, 255704 (2019)

Antimony - Rietveld Fit



Coleman et al. Phys. Rev. Lett., **122**, 255704 (2019)

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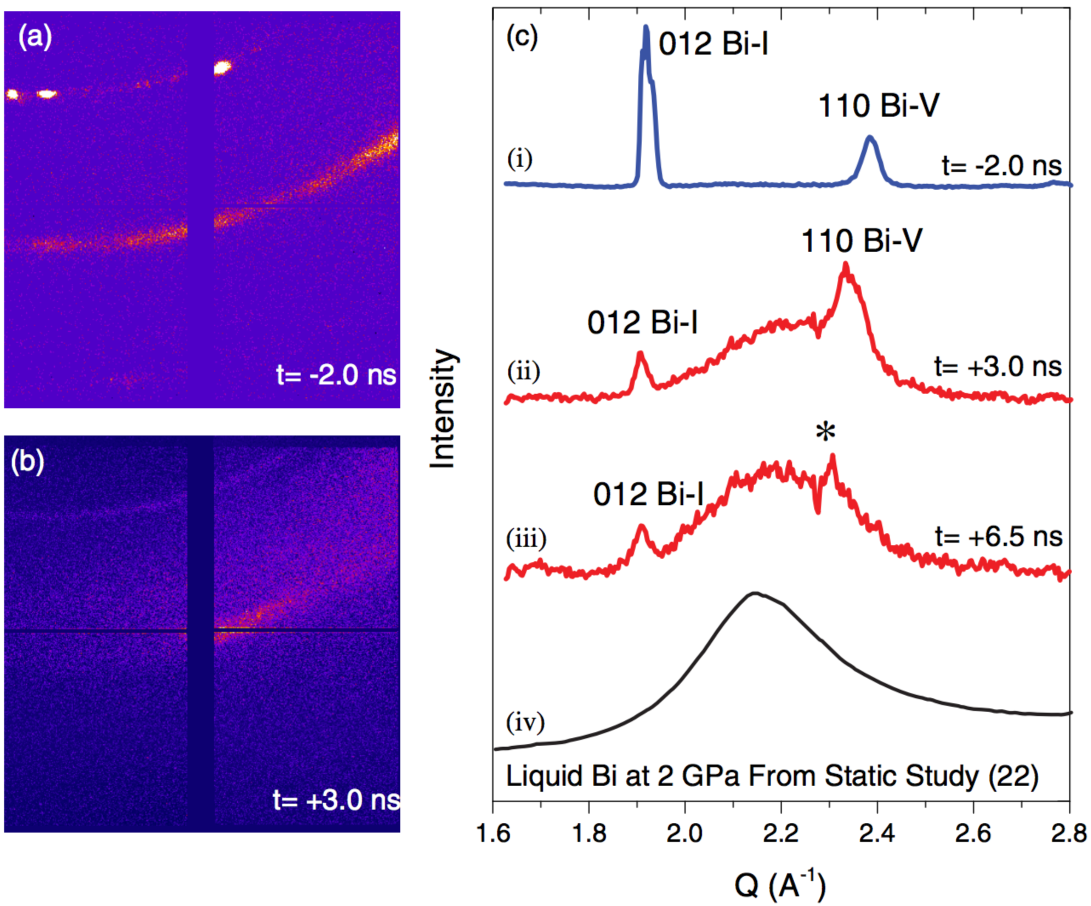
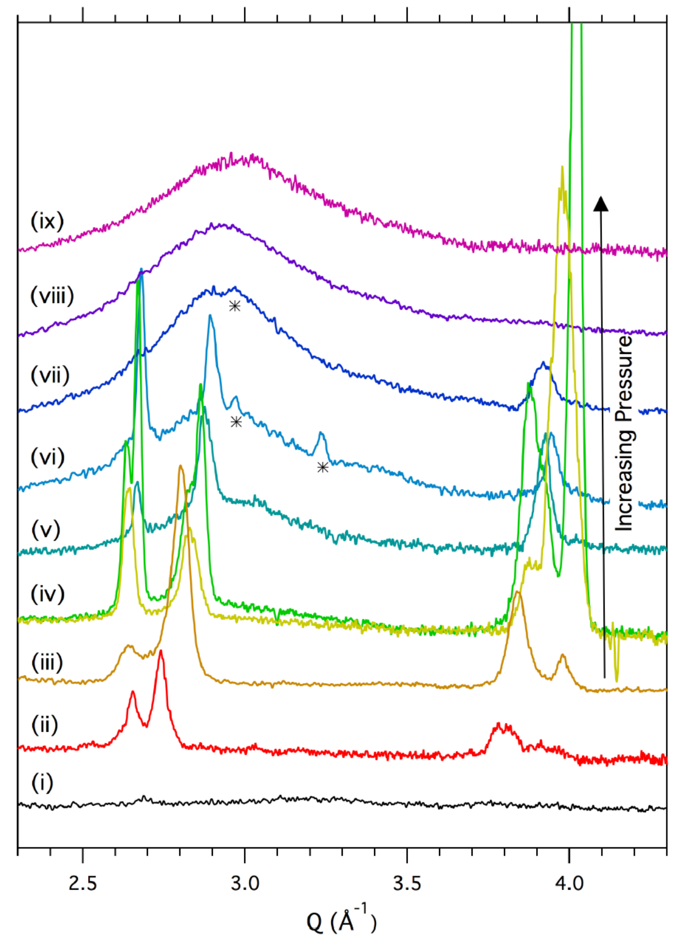
Solid-Liquid Transitions

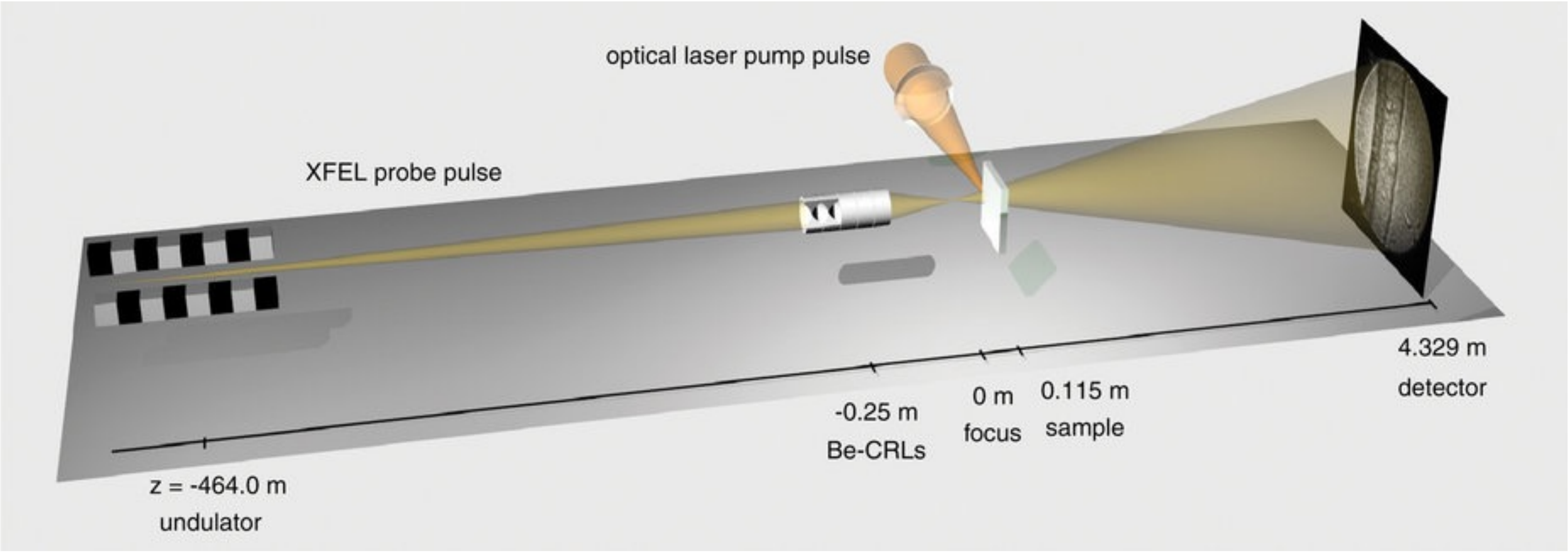


Gorman et al. Phys. Rev. Lett. 115, 095701 (2015)



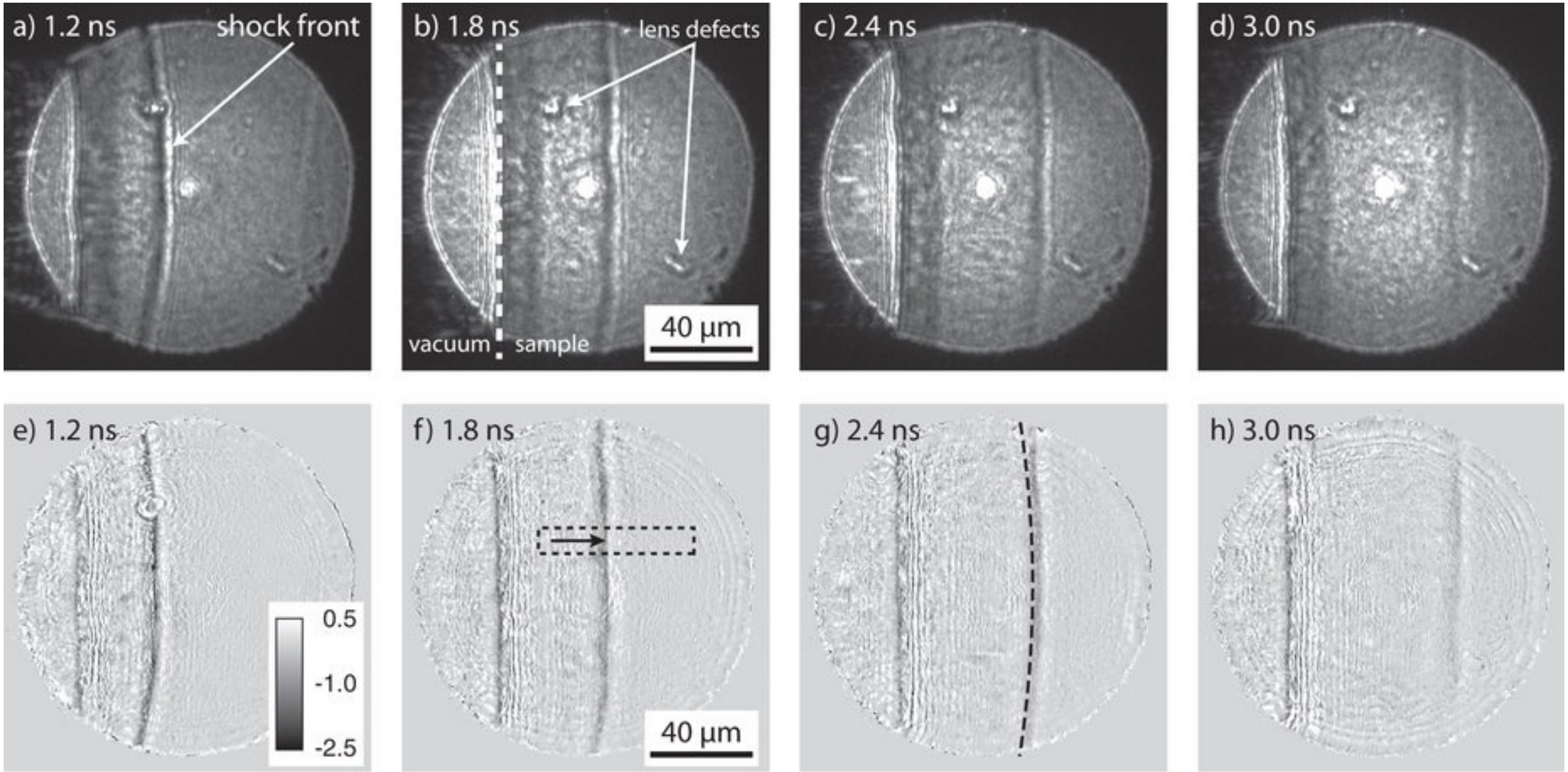
McBride et al., Nat. Phys. 15, 89–94 (2019)

Phase Contrast Imaging



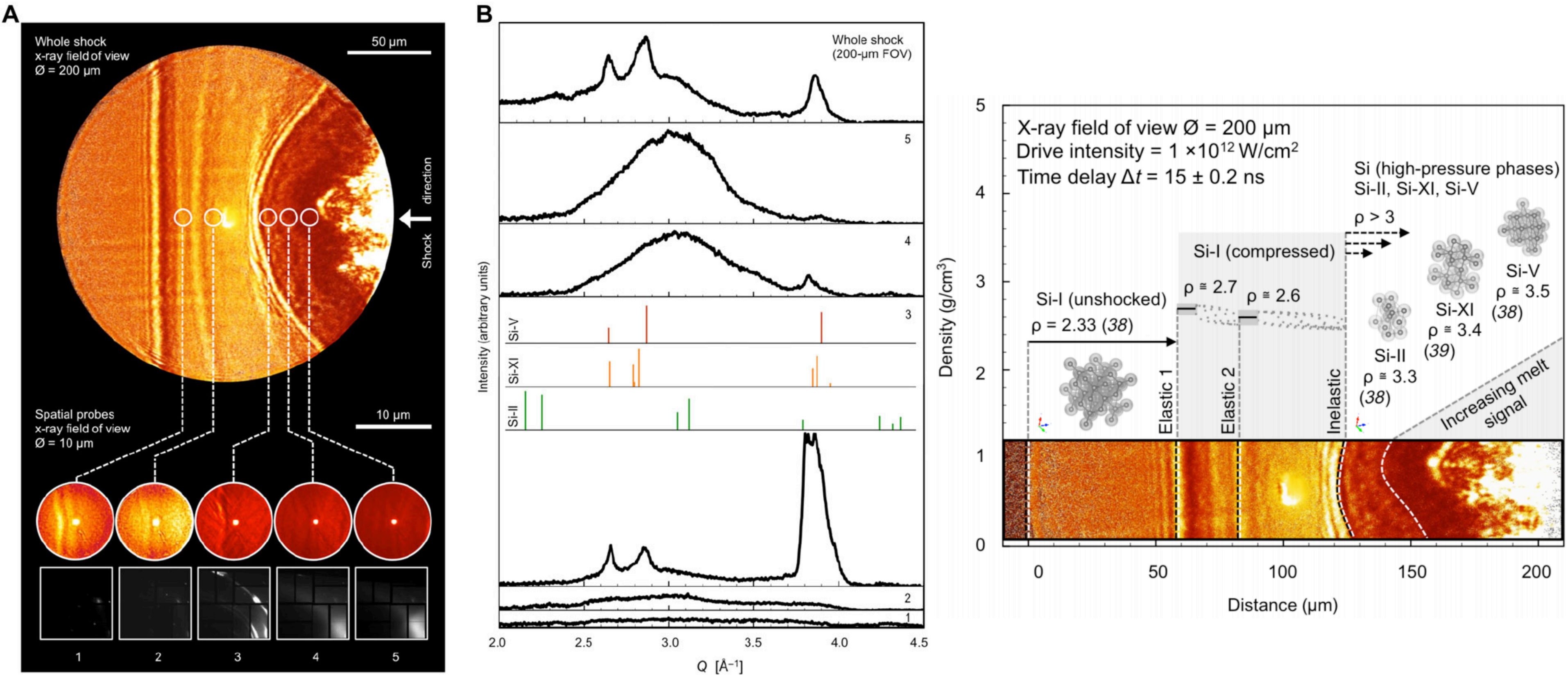
Schropp et al Scientific Reports 5, Article number: 11089 (2015)

Phase Contrast Imaging



Schropp et al Scientific Reports 5, Article number: 11089 (2015)

Imaging of shock waves



S. B. Brown et al., Science Advances, **5**, 3, eaau8044 (2019)

Other areas

Ultrafast X-Ray Diffraction Studies of the Phase Transitions and Equation of State of Scandium Shock Compressed to 82 GPa

R. Briggs, M. G. Gorman, A. L. Coleman, R. S. McWilliams, E. E. McBride, D. McGonegle, J. S. Wark, L. Peacock, S. Rothman, S. G. Macleod, C. A. Bolme, A. E. Gleason, G. W. Collins, J. H. Eggert, D. E. Fratanduono, R. F. Smith, E. Galtier, E. Granados, H. J. Lee, B. Nagler, I. Nam, Z. Xing, and M. I. McMahon

Phys. Rev. Lett. **118**, 025501 – Published 9 January 2017

ARTICLE

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DOI: 10.1038/ncomms9191

OPEN

Ultrafast visualization of crystallization and grain growth in shock-compressed SiO_2

A.E. Gleason[1,2], C.A. Bolme[1], H.J. Lee[3], B. Nagler[3], E. Galtier[3], D. Milathianaki[3], J. Hawreliak[4], R.G. Kraus[5], J.H. Eggert[5], D.E. Fratanduono[5], G.W. Collins[5], R. Sandberg[6], W. Yang[7,8] & W.L. Mao[2,9]

PRL **119**, 025701 (2017) PHYSICAL REVIEW LETTERS week ending 14 JULY 2017

Compression Freezing Kinetics of Water to Ice VII

A. E. Gleason,[1,2,*] C. A. Bolme,[1] E. Galtier,[3] H. J. Lee,[3] E. Granados,[3] D. H. Dolan,[4] C. T. Seagle,[4] T. Ao,[4] S. Ali,[5] A. Lazicki,[5] D. Swift,[5] P. Celliers,[5] and W. L. Mao[2,6]

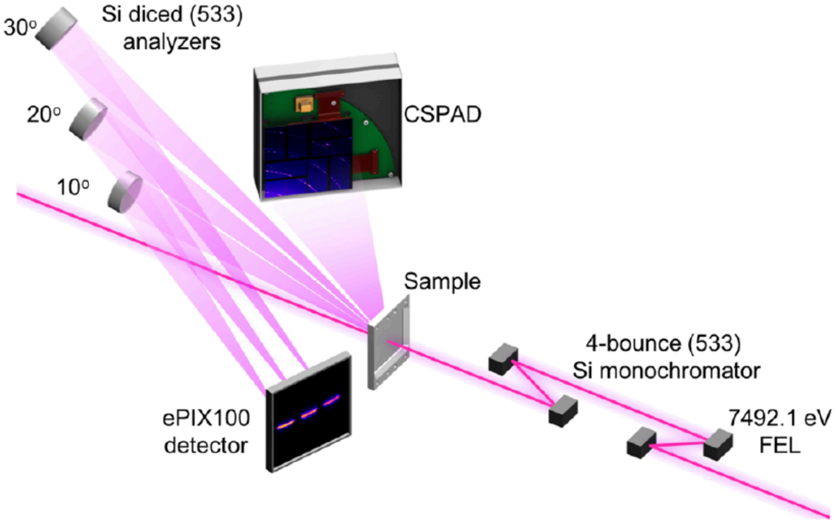
nature astronomy

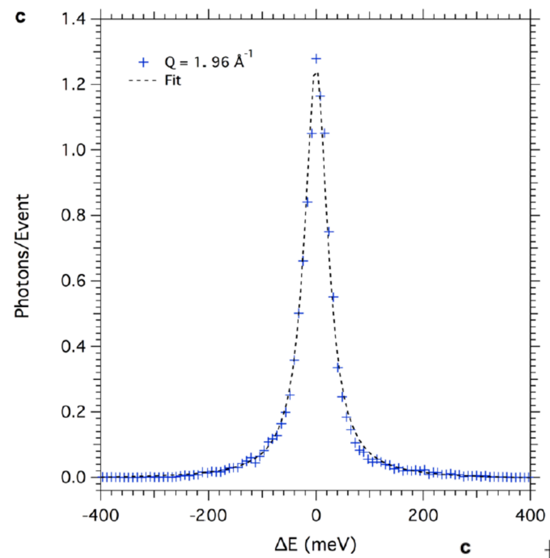
Letter | Published: 21 August 2017

Formation of diamonds in laser-compressed hydrocarbons at planetary interior conditions

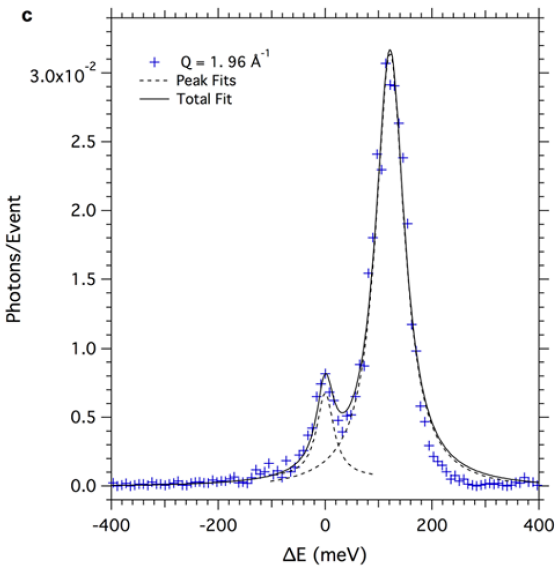
D. Kraus, J. Vorberger, A. Pak, N. J. Hartley, L. B. Fletcher, S. Frydrych, E. Galtier, E. J. Gamboa, D. O. Gericke, S. H. Glenzer, E. Granados, M. J. MacDonald, A. J. MacKinnon, E. E. McBride, I. Nam, P. Neumayer, M. Roth, A. M. Saunders, A. K. Schuster, P. Sun, T. van Driel, T. Döppner & R. W. Falcone

Inelastic X-ray Scattering



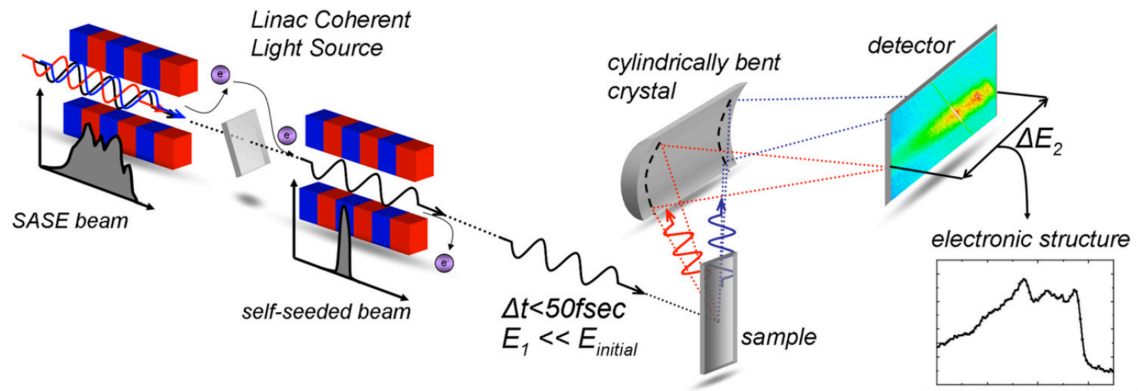


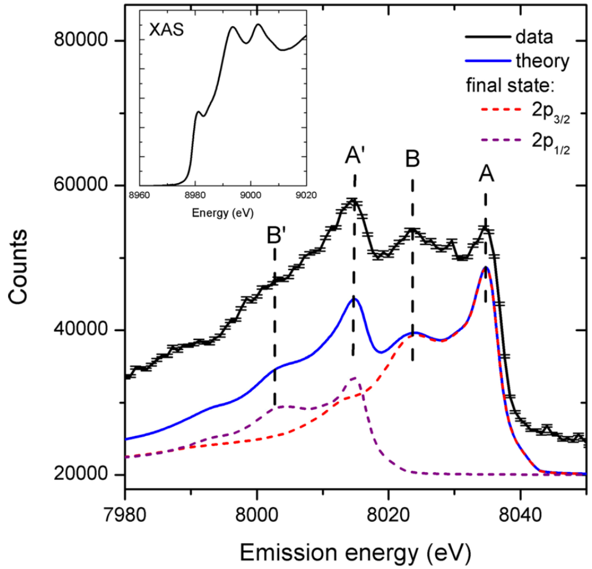
~1700 Shots
ΔE~50meV

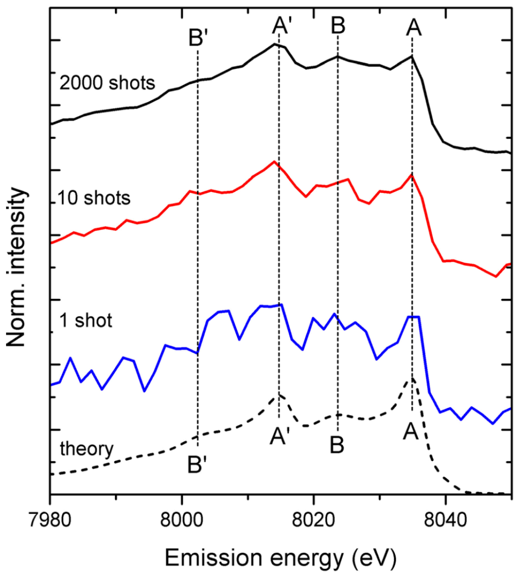


McBride et al. *Rev. Sci. Instr.* **89**, 10F104 (2018)

XAS HEROS

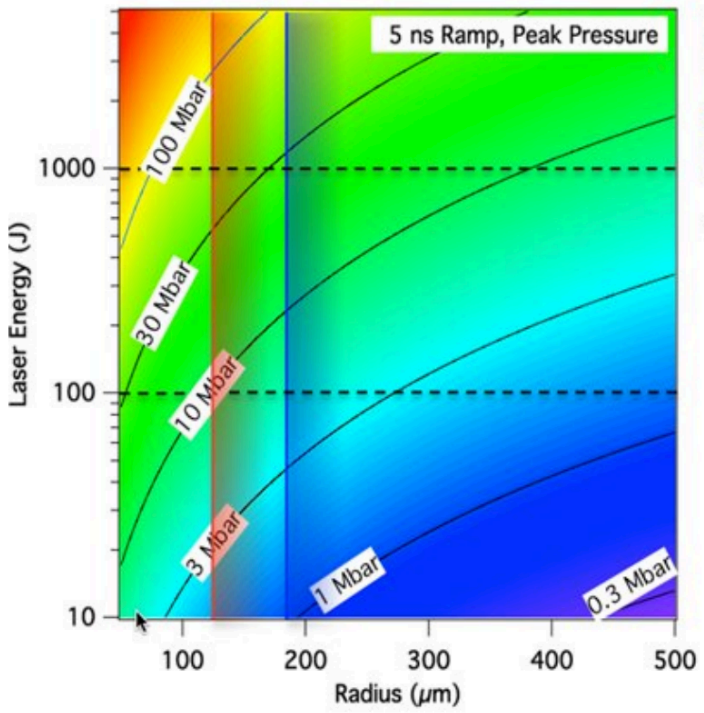






Szlachetko et al.
Struct. Dyn. **1**, 021101 (2014)

Attainable pressures at XFEL



5 ns ramped pulse:

Total Thickness ~ 60 μm

Shock: $R \geq 2d$ $R \geq 120$ μm

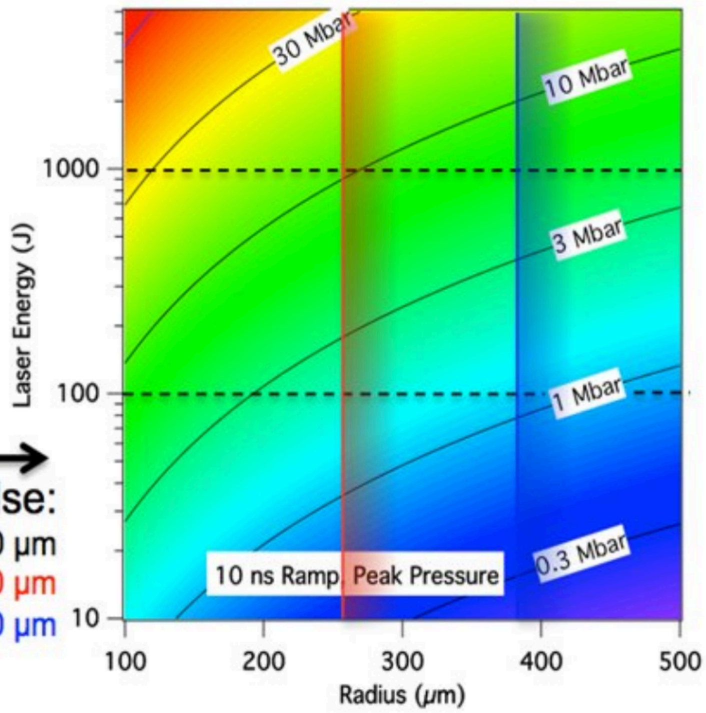
Ramp: $R \geq 3d$ $R \geq 180$ μm

10 ns ramped pulse:

Total Thickness ~ 120 μm

Shock: $R \geq 2d$ $R \geq 240$ μm

Ramp: $R \geq 3d$ $R \geq 360$ μm



Reproduced from HIBEF Dynamic Compression CDR

HED X-ray Properties

Photon energy	5 – 20 keV (3 – 25 keV *)
Pulse Duration	2–100 fs FWHM
Pulse Energy	of order 1 mJ in SASE mode
Beam size on sample	sub-µm foci to 1 mm
Bandwidth (ΔE/E)	10^{-3} (SASE) to 10^{-6} @ 7.5keV (Monochromated)
Special features	X-ray Split and delay Line (*BMBF contribution*)
	Standard 4-bounce Si monochromator (ΔE/E = 10^{-4})
	Pump–probe (mJ to 100 mJ class) short pulse (15 fs – 1 ps) laser
Laser	100J @ 1ω, 10Hz, shapable

Ideal XFEL Parameters (?)

Photon energy	Elastic	10 – 30 keV
	Inelastic	(0.5?)1.5 - 10keV
Pulse Duration		sub 50 fs
Pulse Energy	Elastic	mJ
	Inelastic	10mJ +
Beam size		sub-μm focus
Bandwidth (ΔE/E)	Elastic	10^{-3}-10^{-4}
	Inelastic	10^{-5} (10meV)
Special features		2 colour with both elastic and inelastic within 100ps.
Laser		1000J @ 3ω (minimum), 1 Hz minimum, on-the-fly arbitrary pulse shaping