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LAWRENCE LIVERMORE NATIONAL LABORATORY

Ramp Compression Experiments

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Ramp Compression Experiments

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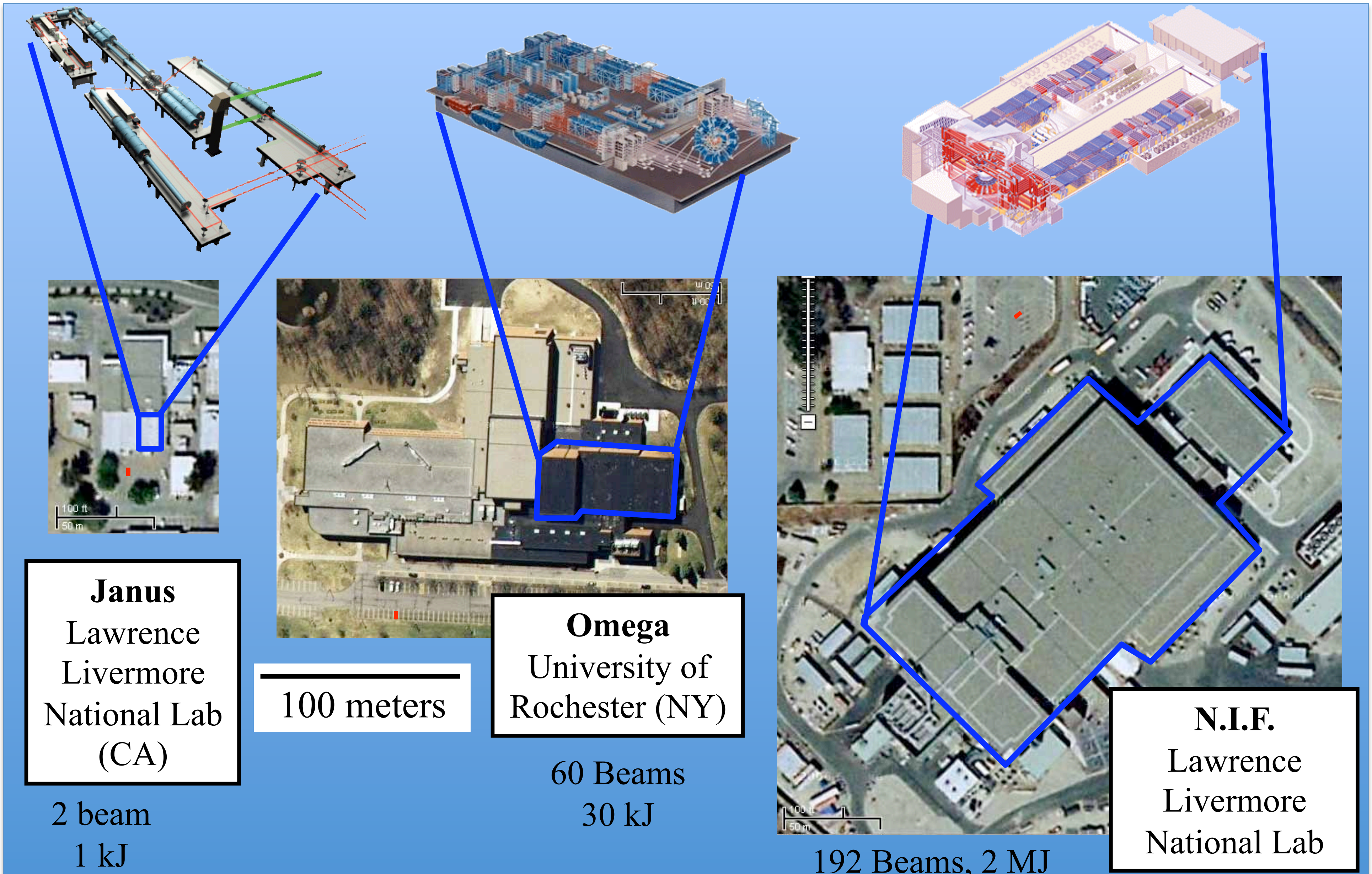
Outline

Laser-Driven Ramp Compression Experiments

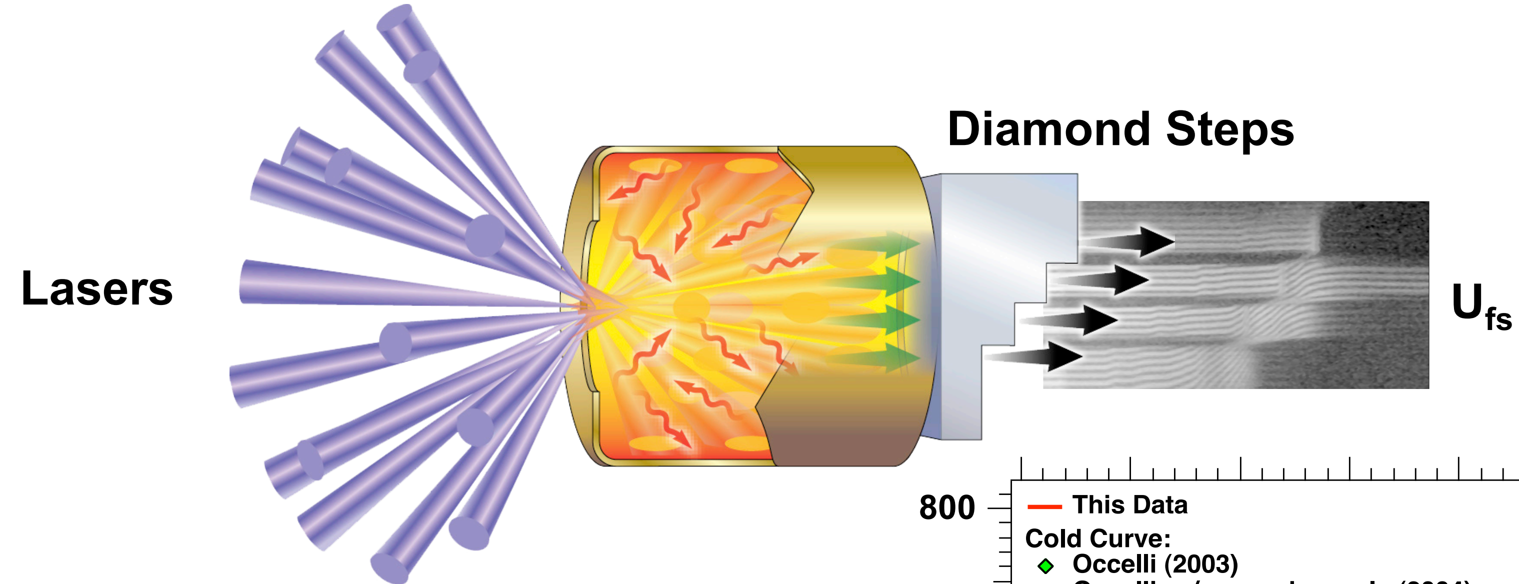
- **Ramp-Compression EOS on Tantalum to 320 GPa**
  - Cold Sample
  - Absolute Stress-Strain

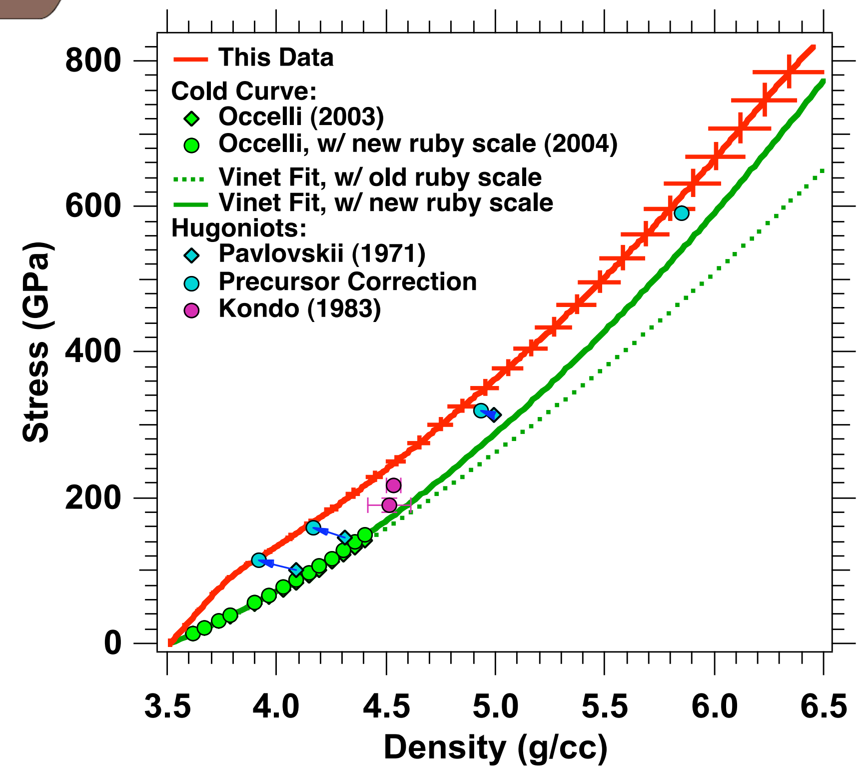
- **X-ray Diffraction on Iron to 470 GPa**
  - Far Above Shock Melting on Hugoniot
  - Still Solid
  - Consistent with HCP

Laser Facilities



We have ramp compressed diamond to 1500 GPa



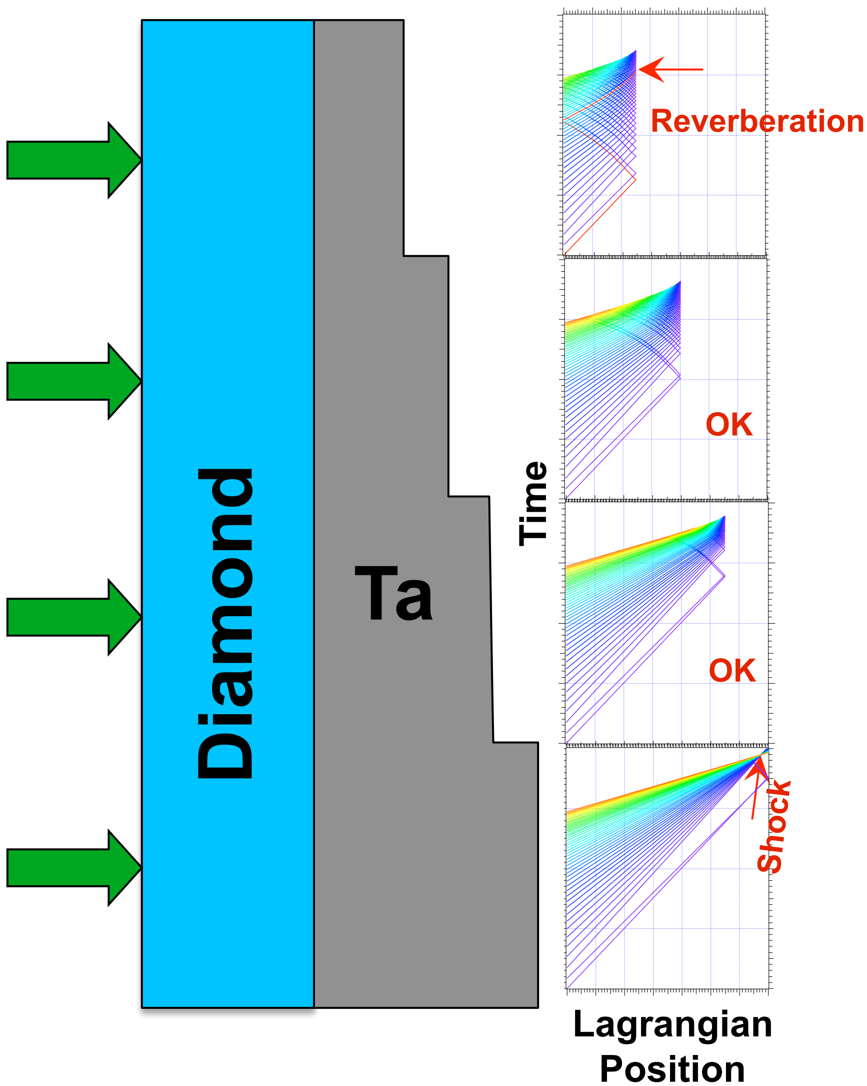


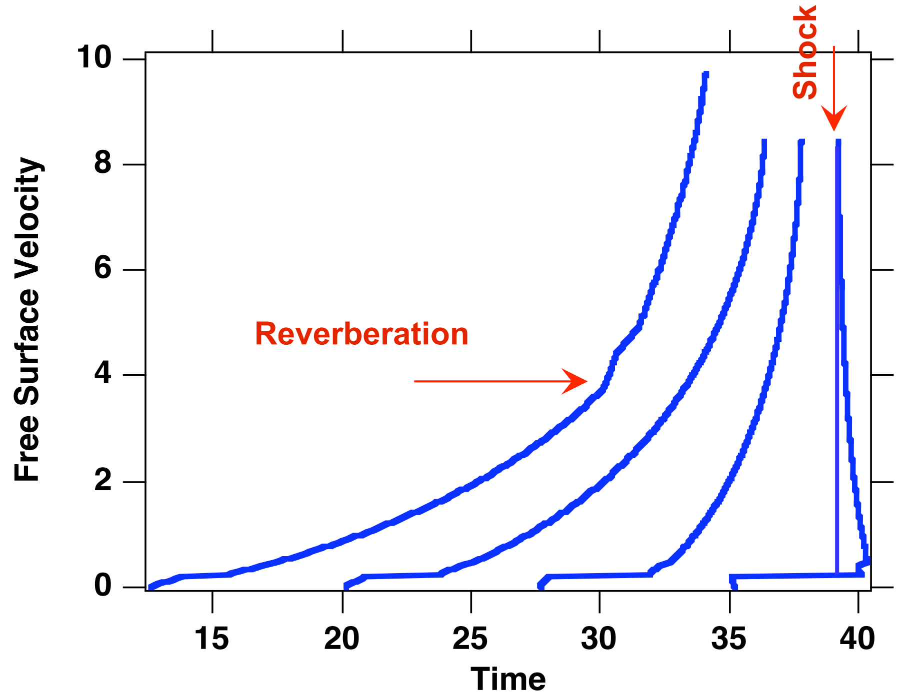
Ramp-compressed Stress-Density to 800 GPa.
(Bradley, et al., PRL 102, 07550, 2009)

Now we apply same technique to metals (Tantalum to 320 GPa)

Ramp-Wave EOS

--Design Requirements--





No reverberation

--and--

No Shock.

Iterative Analysis:

Correction for free-surface wave interactions.

Rothman, et al. J. Phys. D (2005)

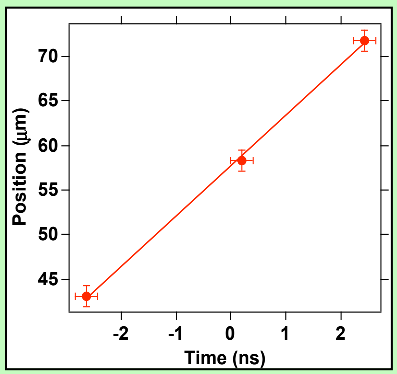
EOS, $C_L(U_{FS})$

Reverse propagate $U_{FS,j}(t)$ to find drive pressure, $P_j(t)$, for all steps, *j*

Forward propagate $P_j(t)$, *with no interface* to the step thickness d_j for all steps, *j*

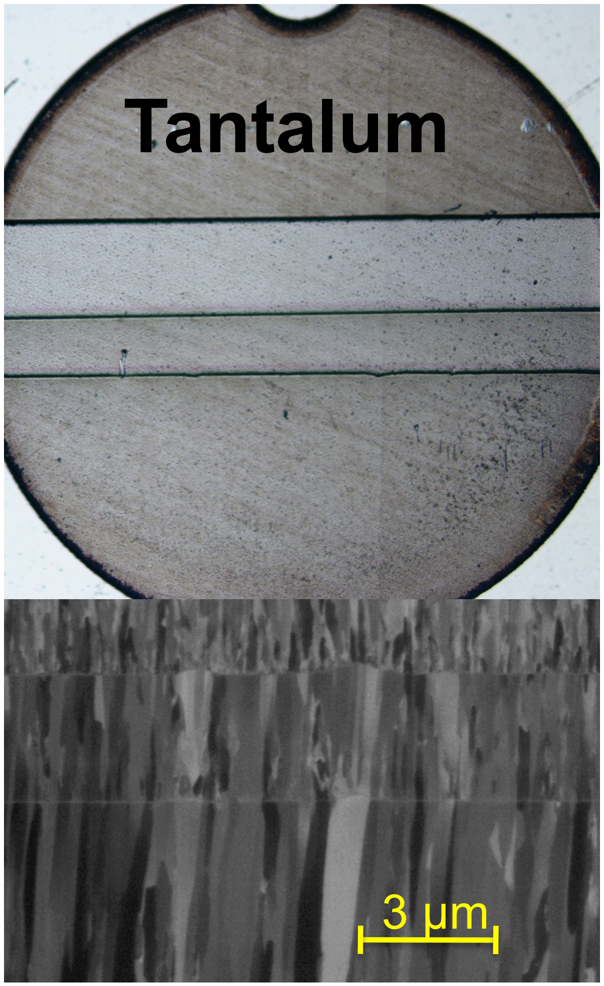
Update $C_L(U_{FS})$ by linearly fitting d_j vs. $t_{FS,j}$

Iterate to convergence

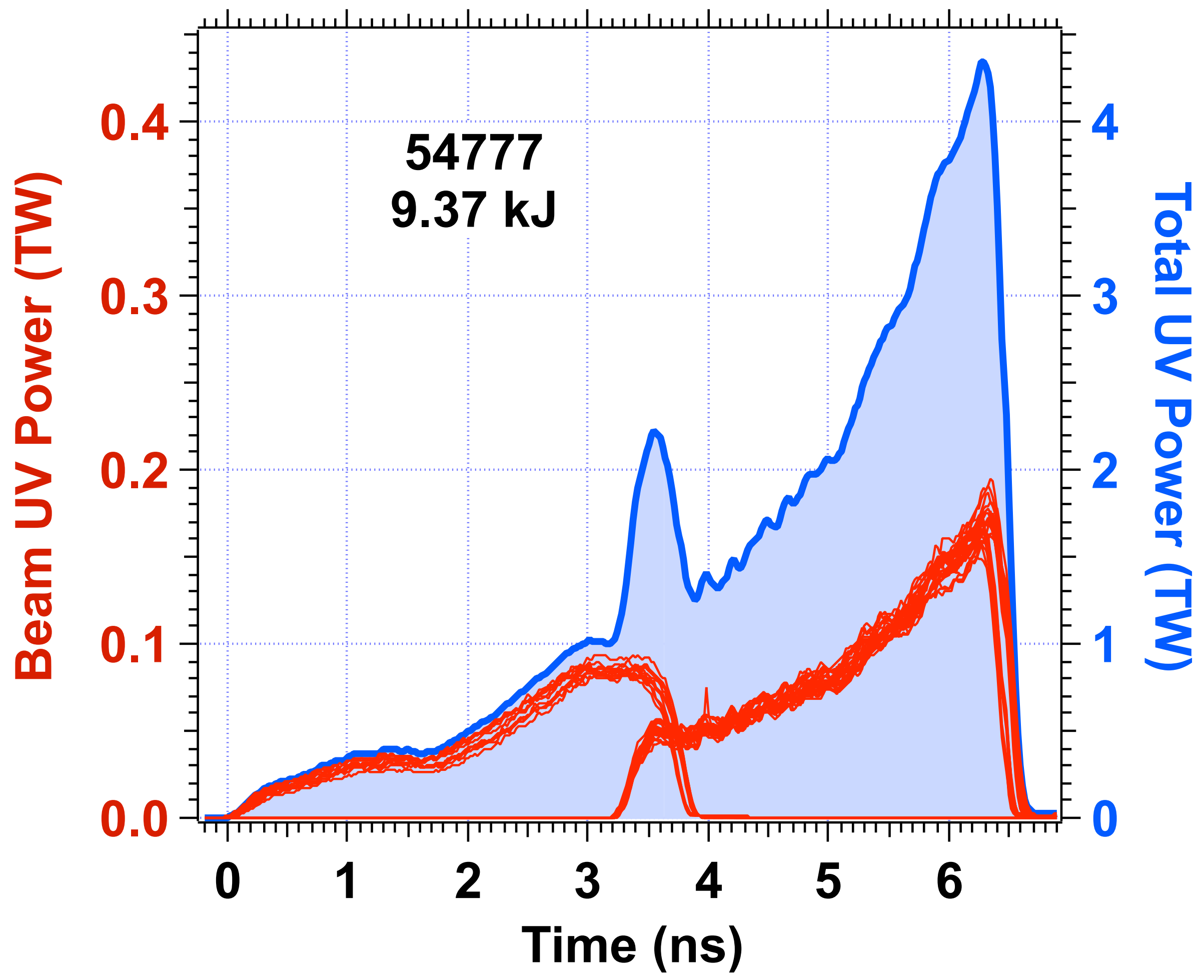


Absolute Stress-Density Measurement

Target Metrology and Pulse Shape



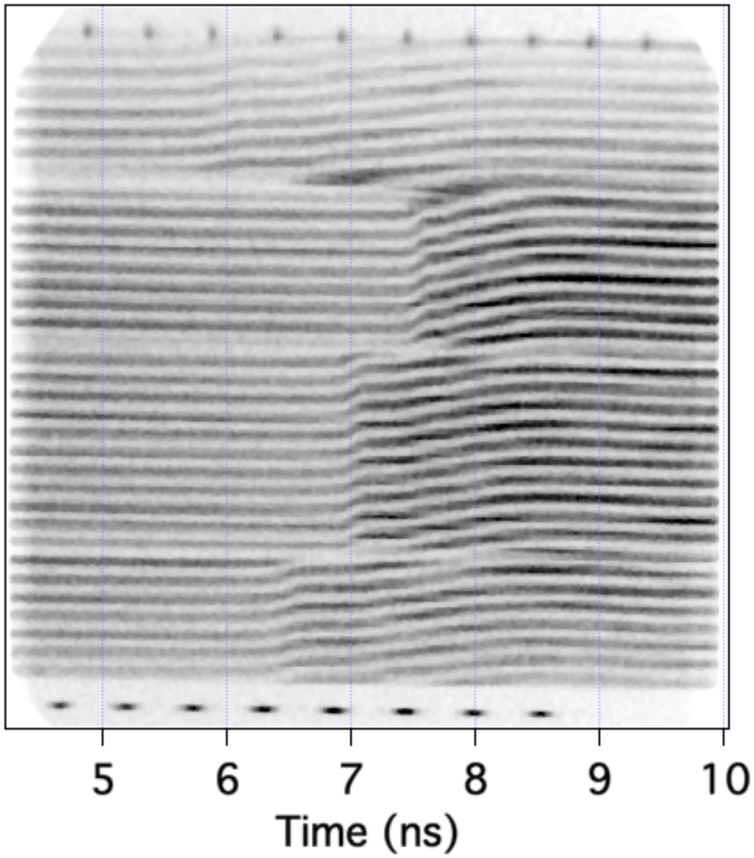
d_A=11.24±05 μm
– 2.59 μm
d_B=13.83±05 μm
– 2.71 μm
d_C=16.54±05 μm
– 2.81 μm
d_D=19.35±05 μm

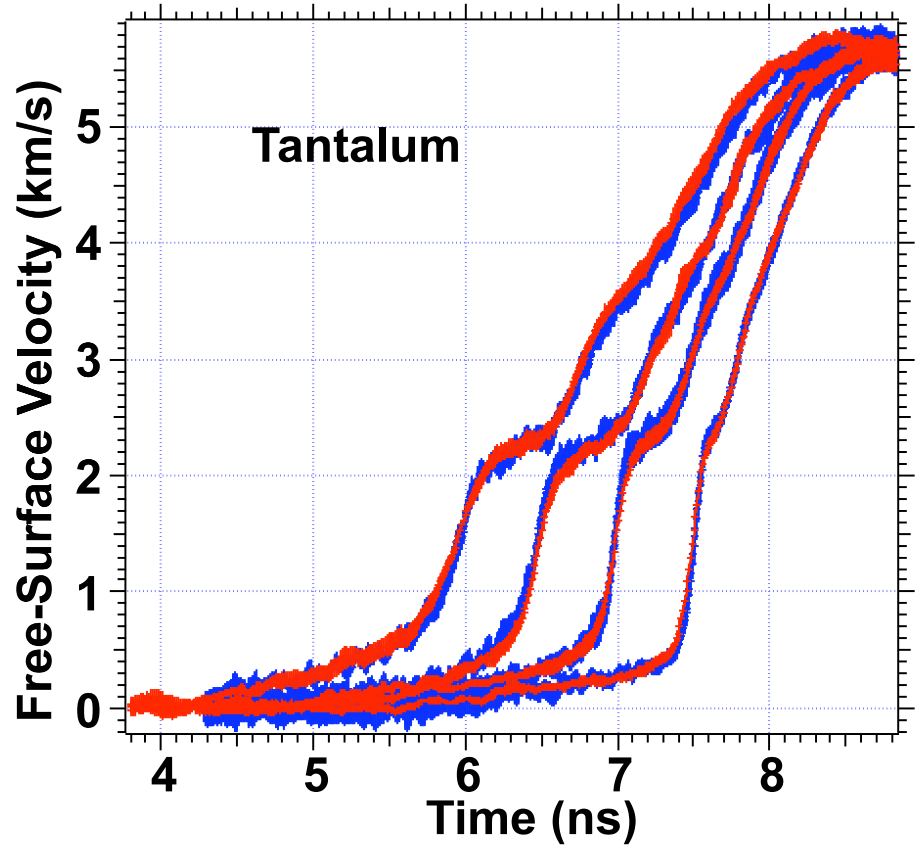


Omega Laser
University of Rochester

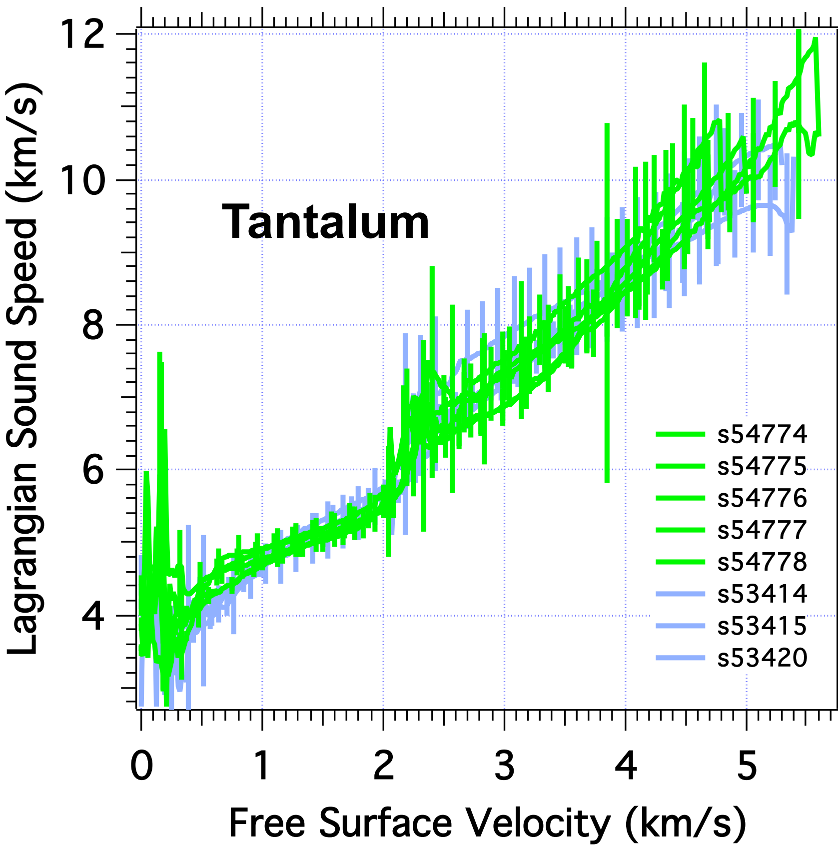
VISAR Wave Profiles

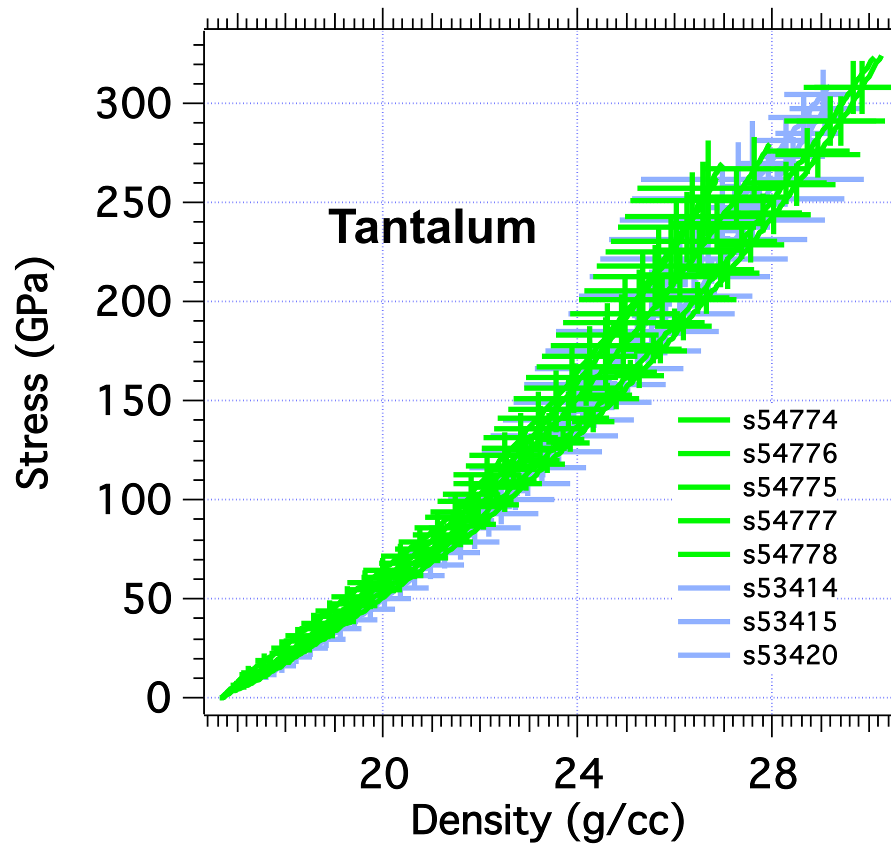
Shot 54777





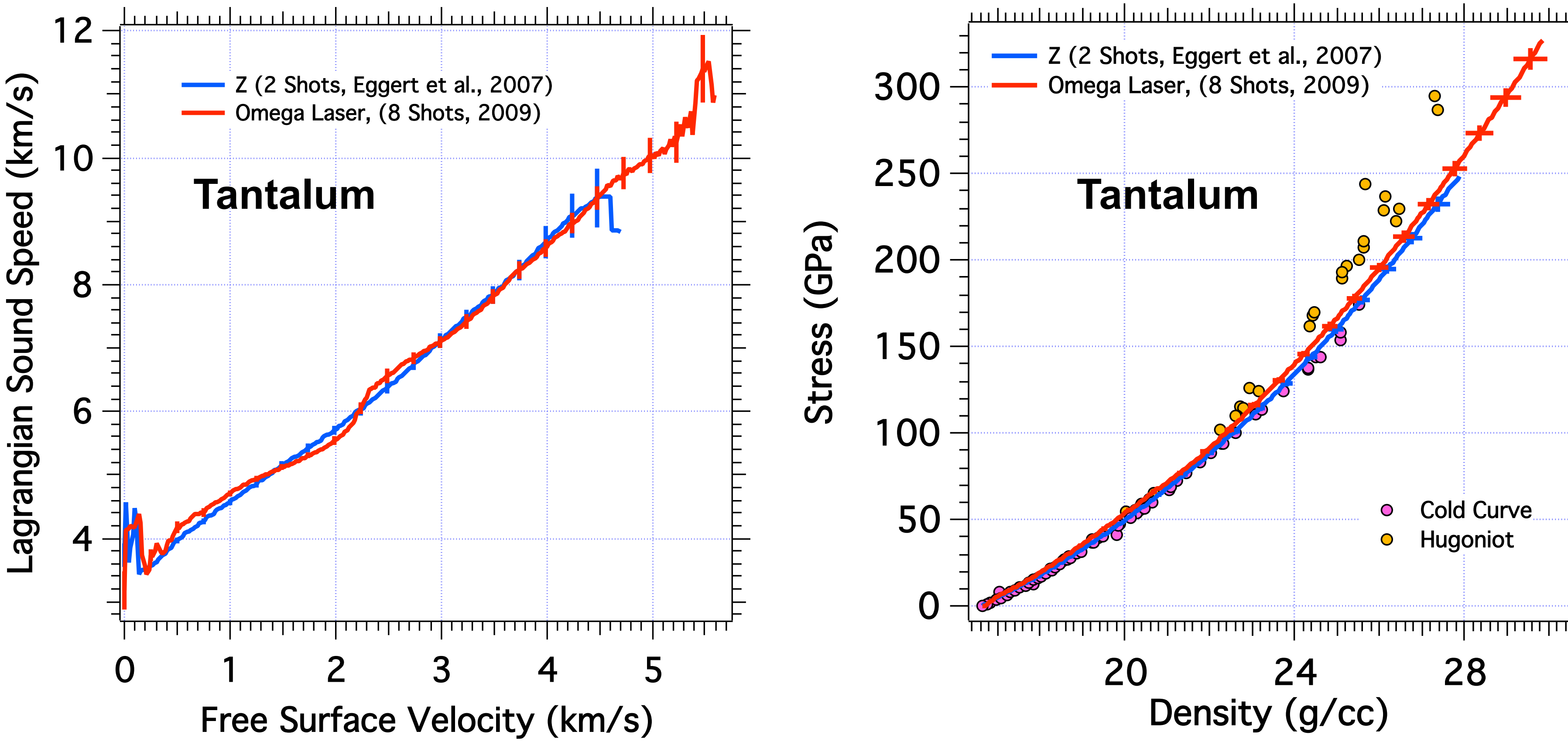
8 Shots—Highly Consistent Results





8 Shots on the Omega Laser in 2009
100% Data Return

Averaging All Laser Shots



Ramp Compression Tantalum Equation of State

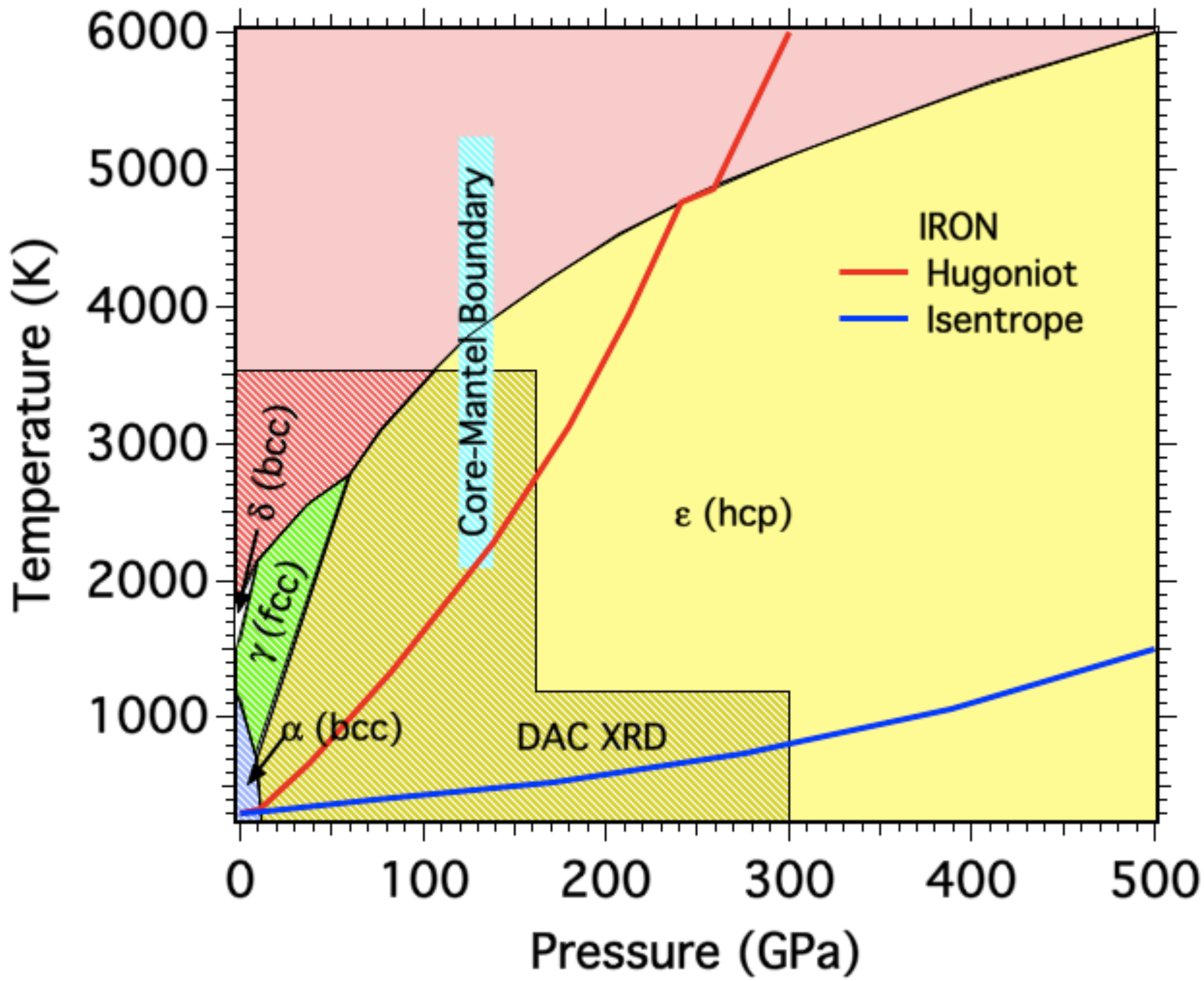
- **Stress-density on 8 shots to over 300 GPa.**
- **Very consistent with previous Z shots.**

Next Year: NIF experiments to 500 GPa and more . . .

X-Ray Diffraction

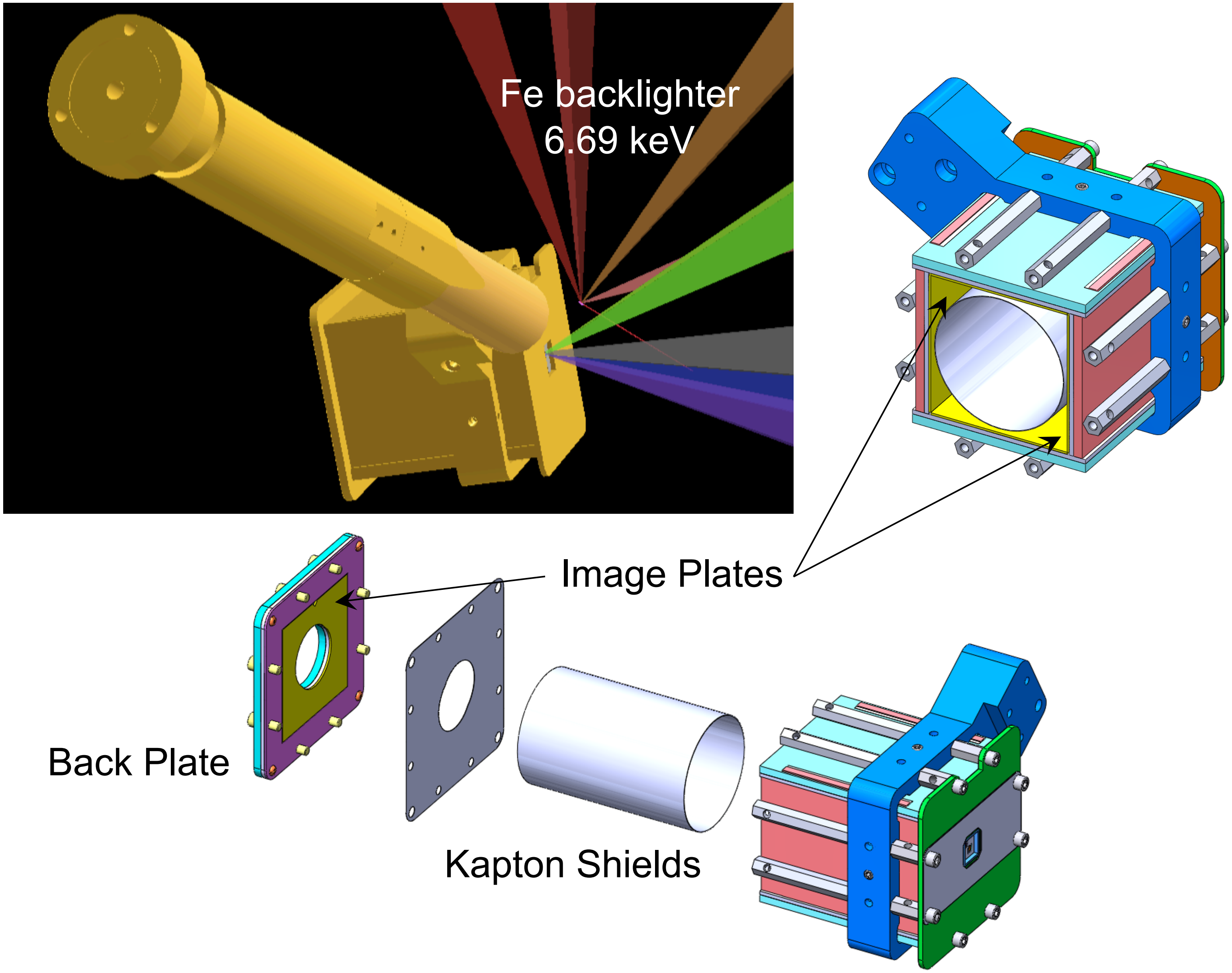
- **Diffraction -- Most direct way to determine crystal structure**
- **Laser Drive -- Ideal for X-ray diagnostics**
- **Ramp Compression -- limits shock heating, very high pressures in solid phase.**

Iron Phase Diagram

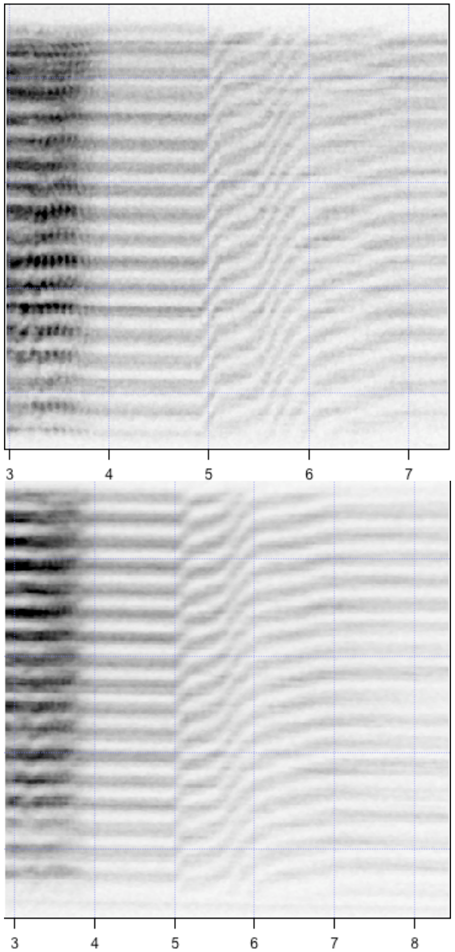


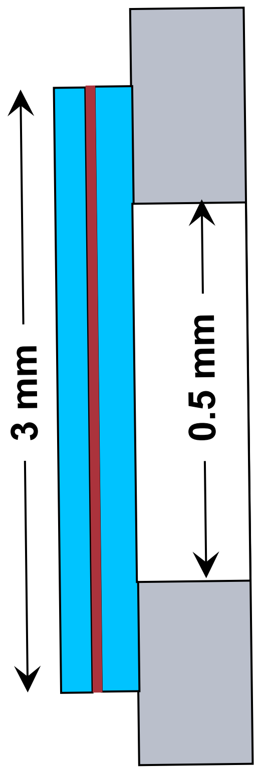
- **Diffraction above the shock melting pressure?**

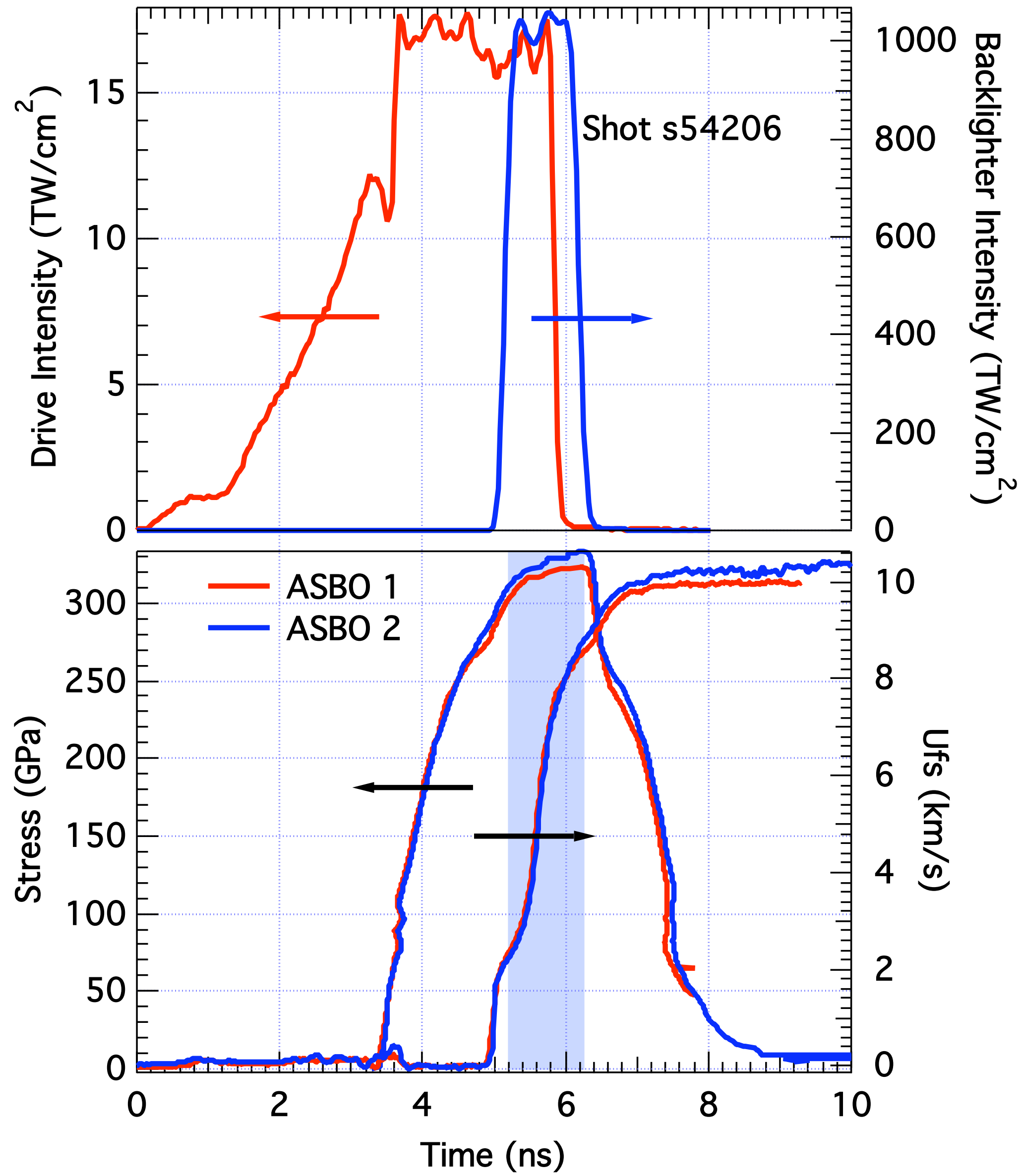
X-Ray Diffraction at Omega Laser



s54206, Fe



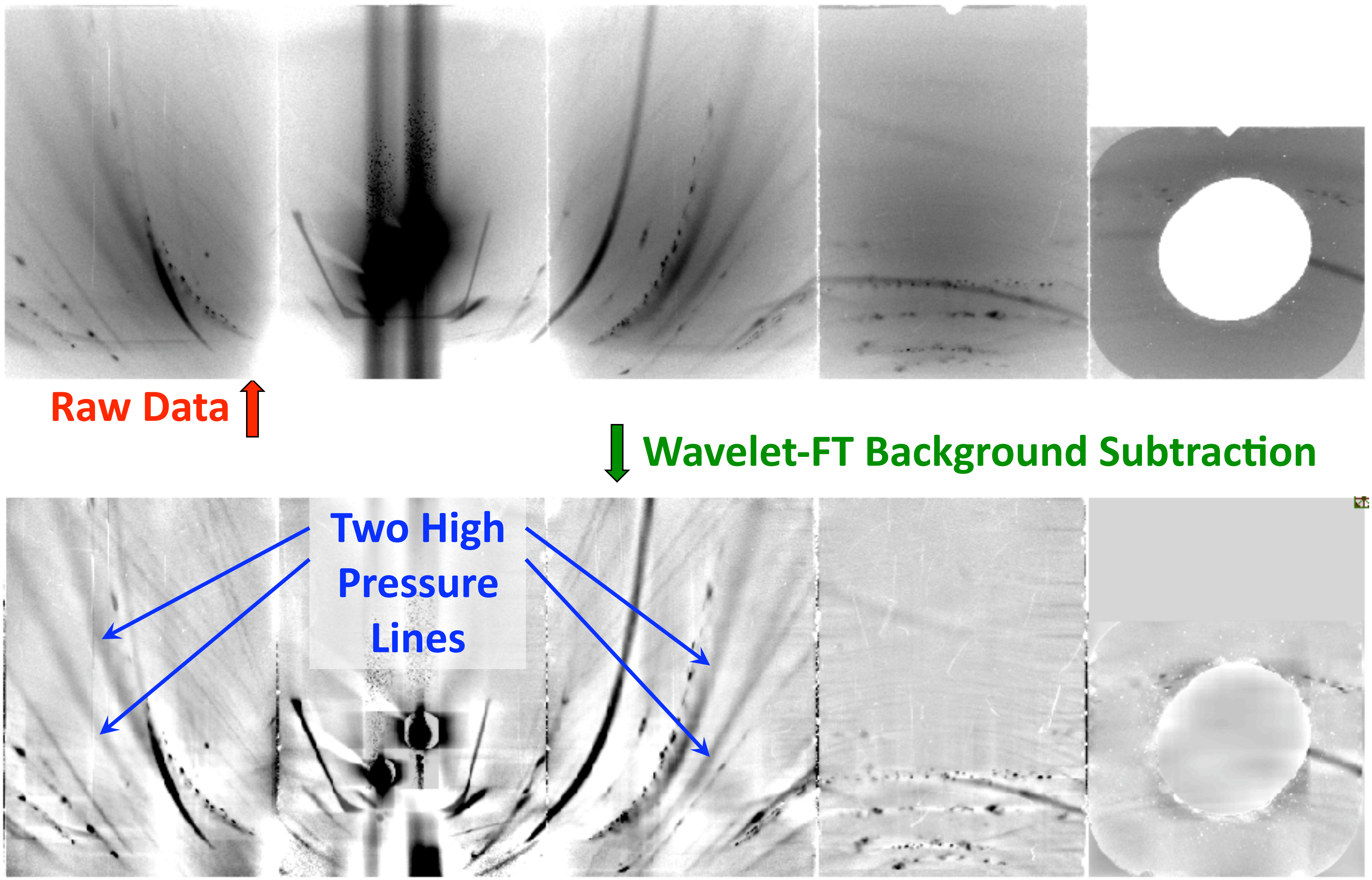




Strain rate is very high, ~10^8.
What does diffraction look like?

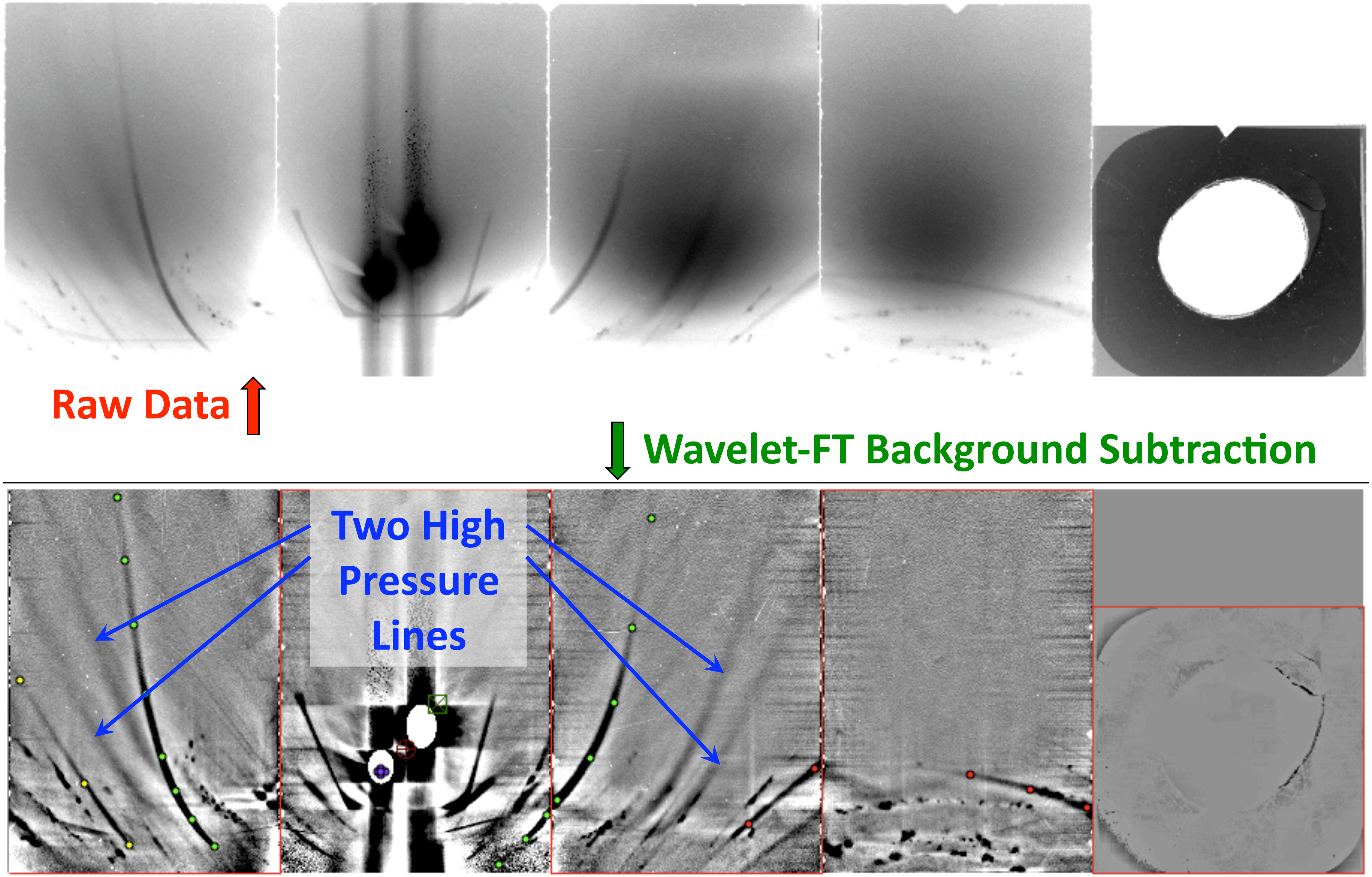
Shot 54203

$$P = 185^{+6}_{-17}\ \text{GPa}$$

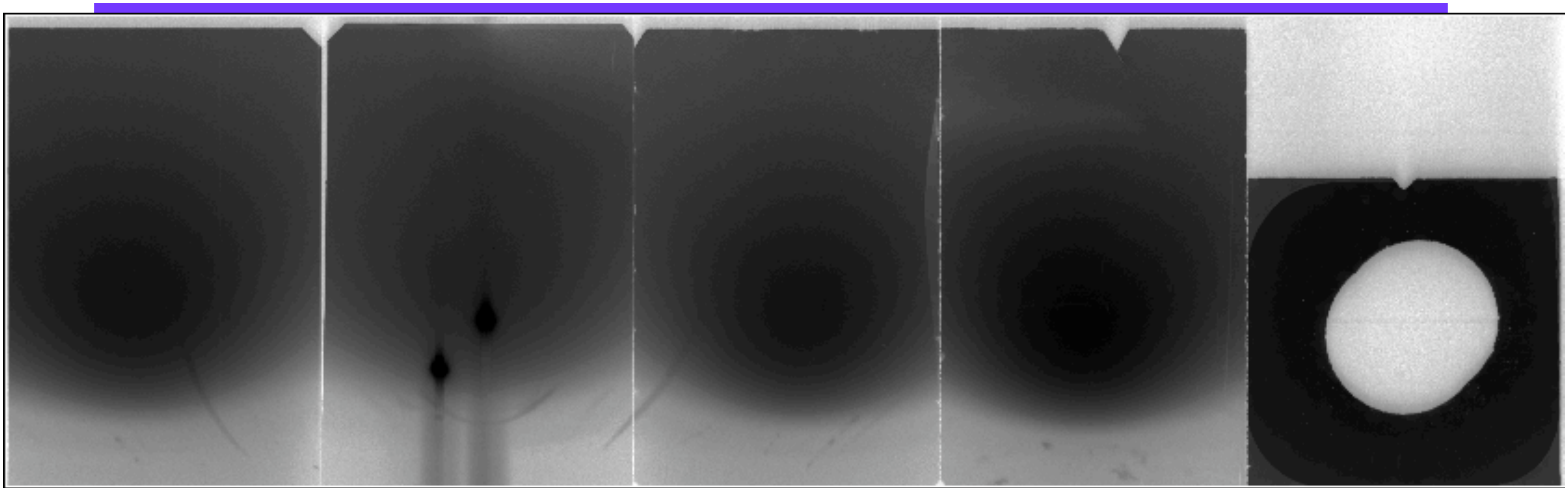


Shot 54206

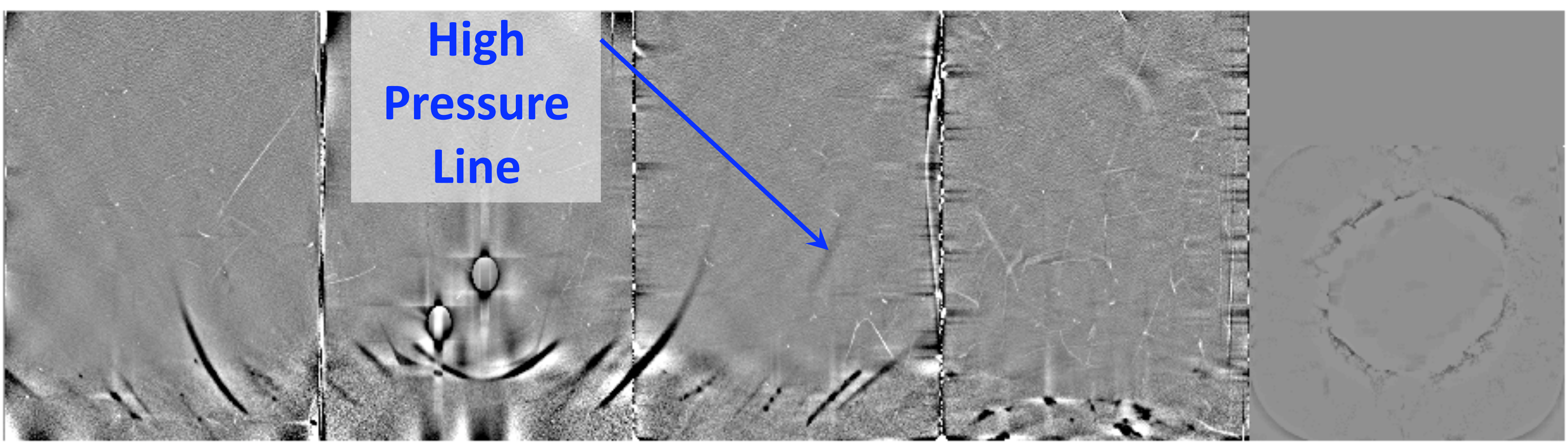
$$P = 324^{+9}_{-15}\ \text{GPa}$$



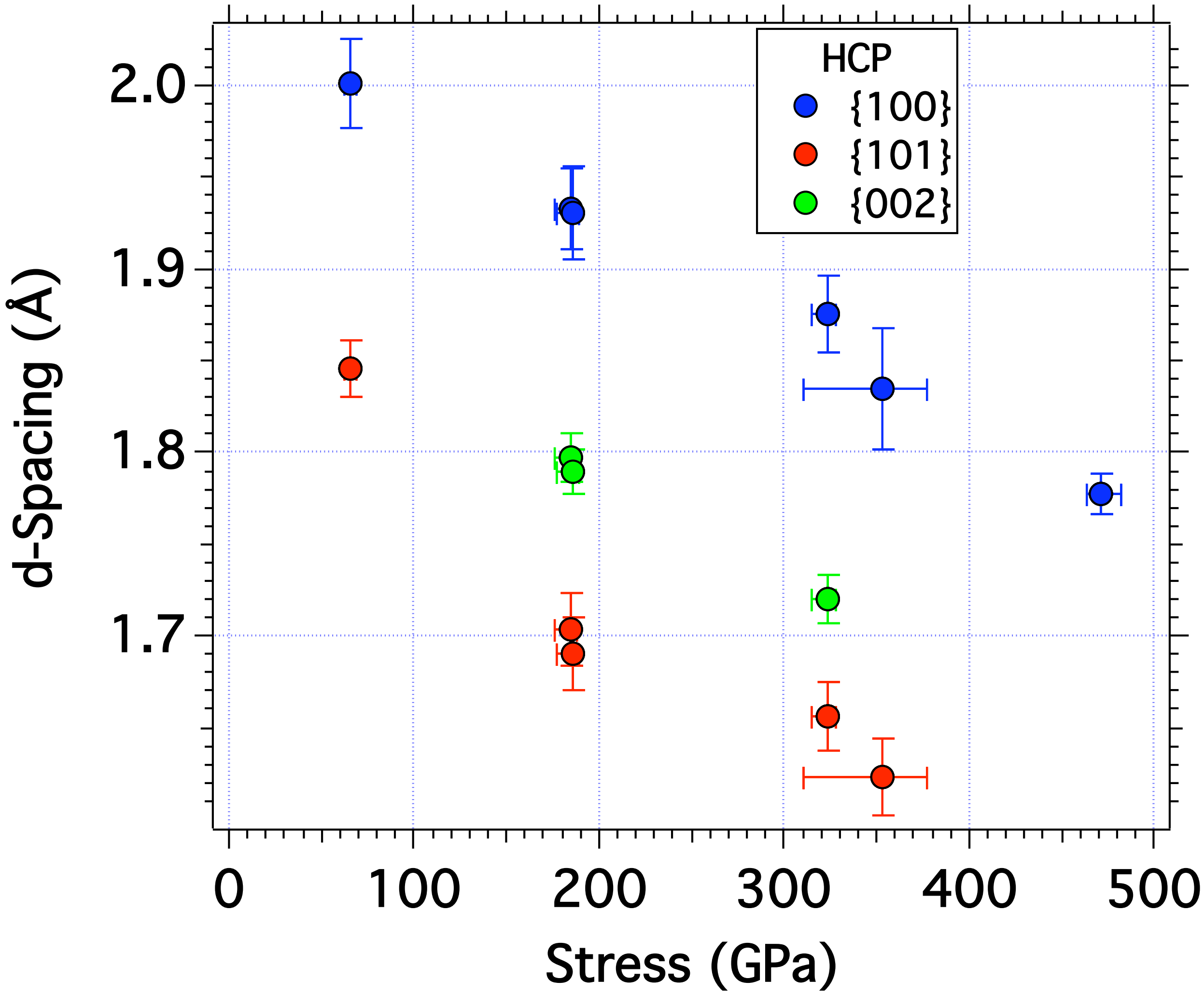
Shot 54200—"High" Pressure Iron,
$P = 471$ GPa



Raw Data ⬆ ⬇ Wavelet-FT Background Subtraction

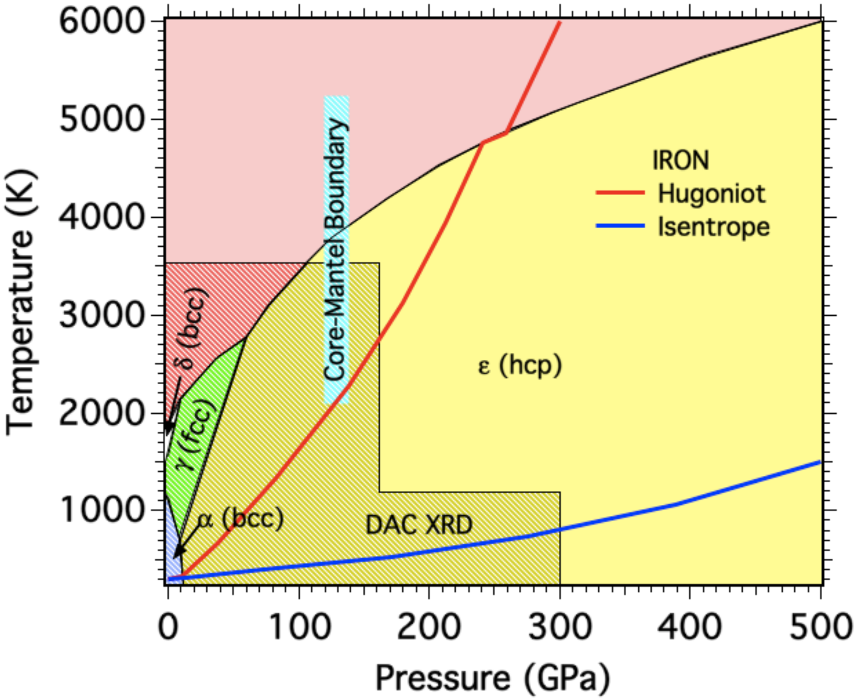


We see 2 strong, 1 weak reflections.



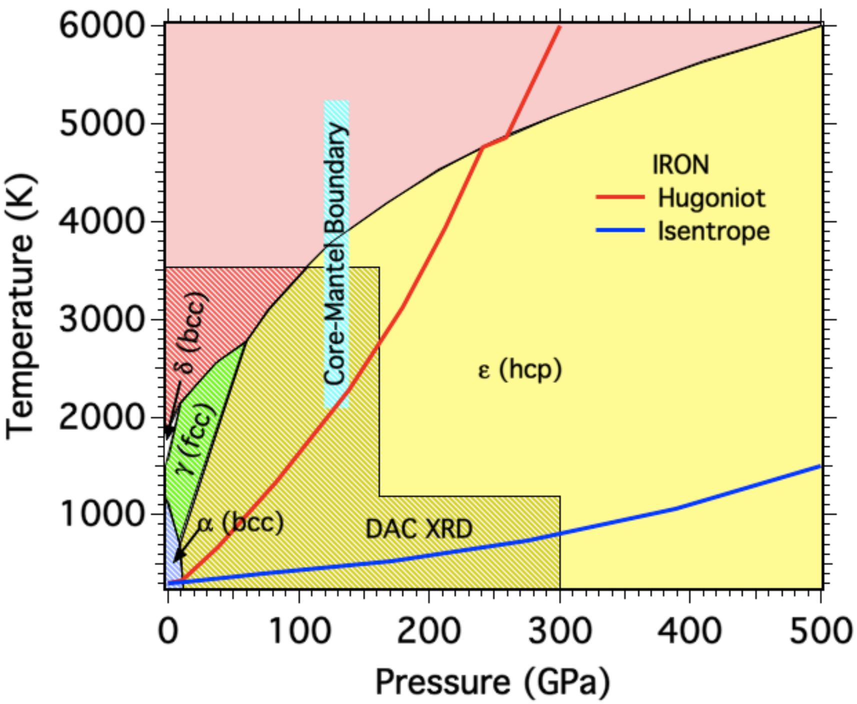
We will *assume* a structure and fit.

Likely Structures



Guided by static experiments, potential structures are hcp with *c/a*=1.61 and fcc. (Ma, et al. 2004)

Likely Structures



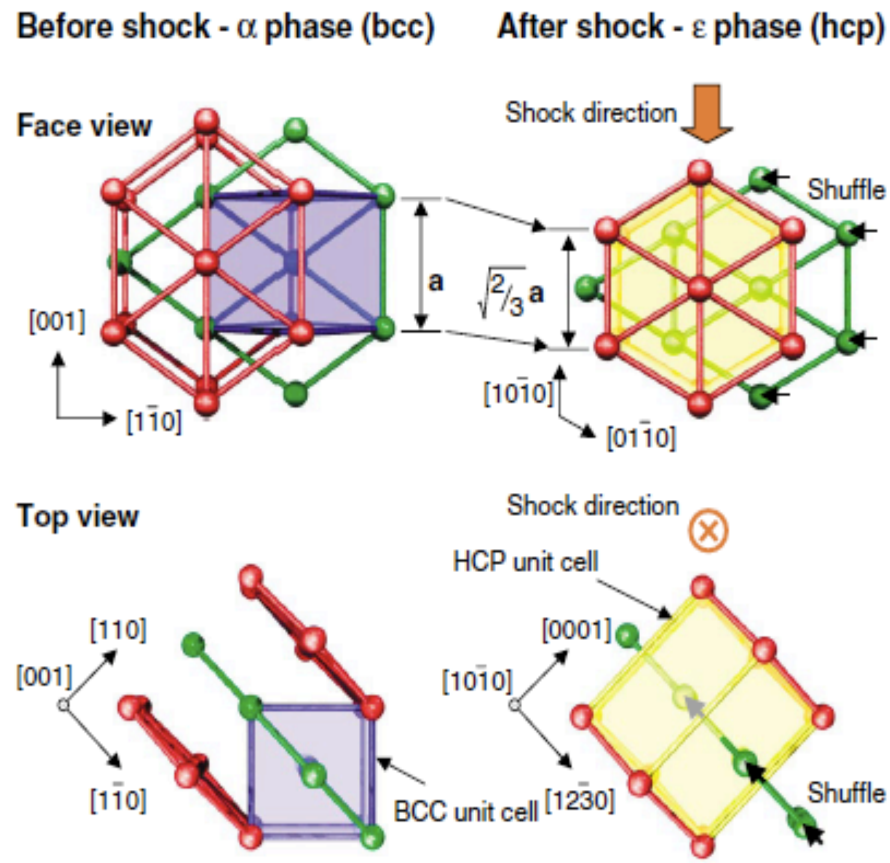


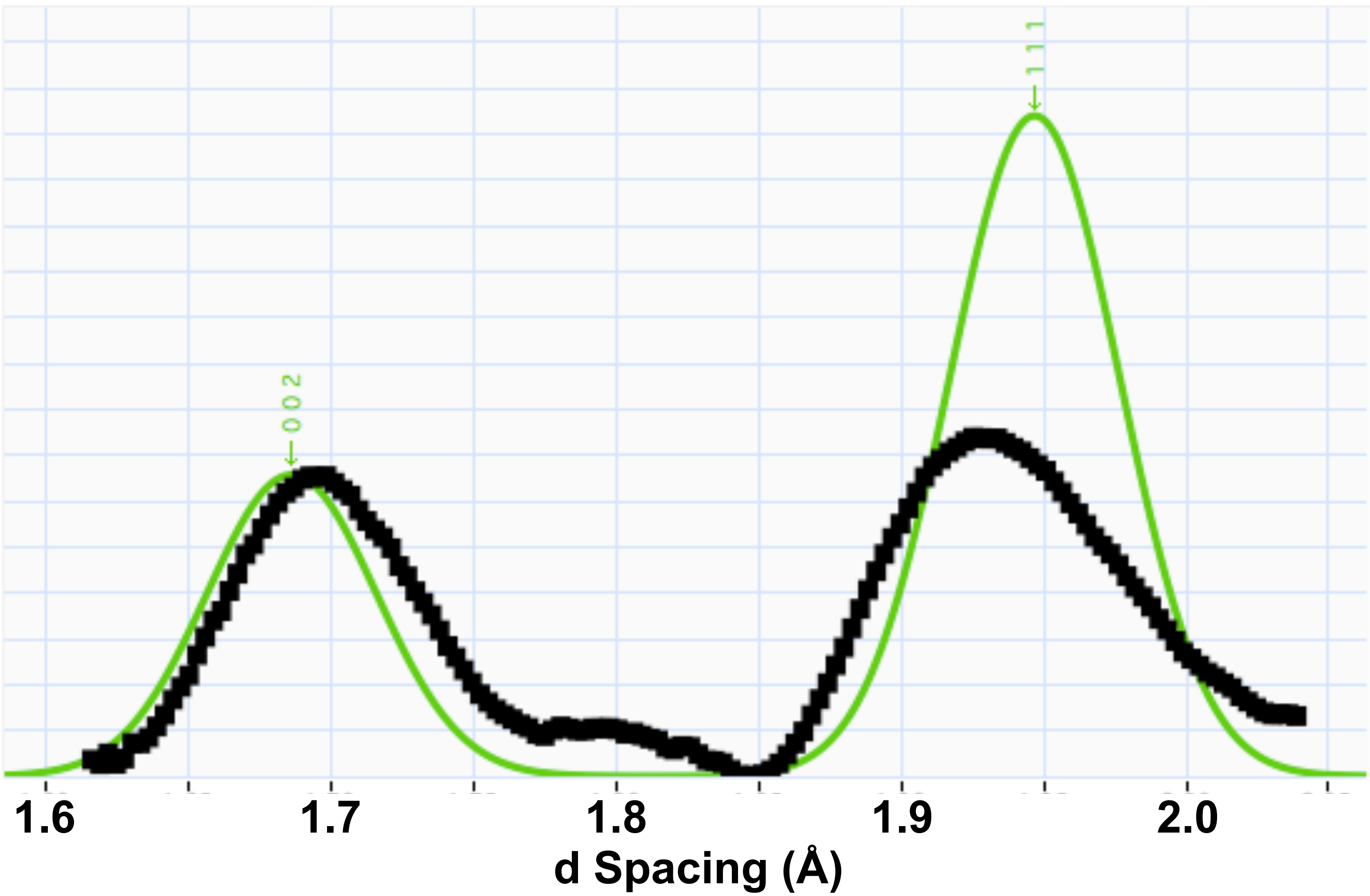
FIG. 1 (color). Schematic showing the lattice structure of the α and ε phases for iron. A pseudohexagonal structure results from 18.4% compression of the bcc lattice along [001]. Shuffling of alternate (110) planes creates the close-packed structure.

Kalantar, PRL **95, 075502 (2005)**. **$c/a=\sqrt{3}=1.73$**

Guided by static experiments, potential structures are hcp with *c/a*=1.61 and fcc. (Ma, et al. 2004)

Previous shock experiments on single crystals found hcp (c/a=1.73)

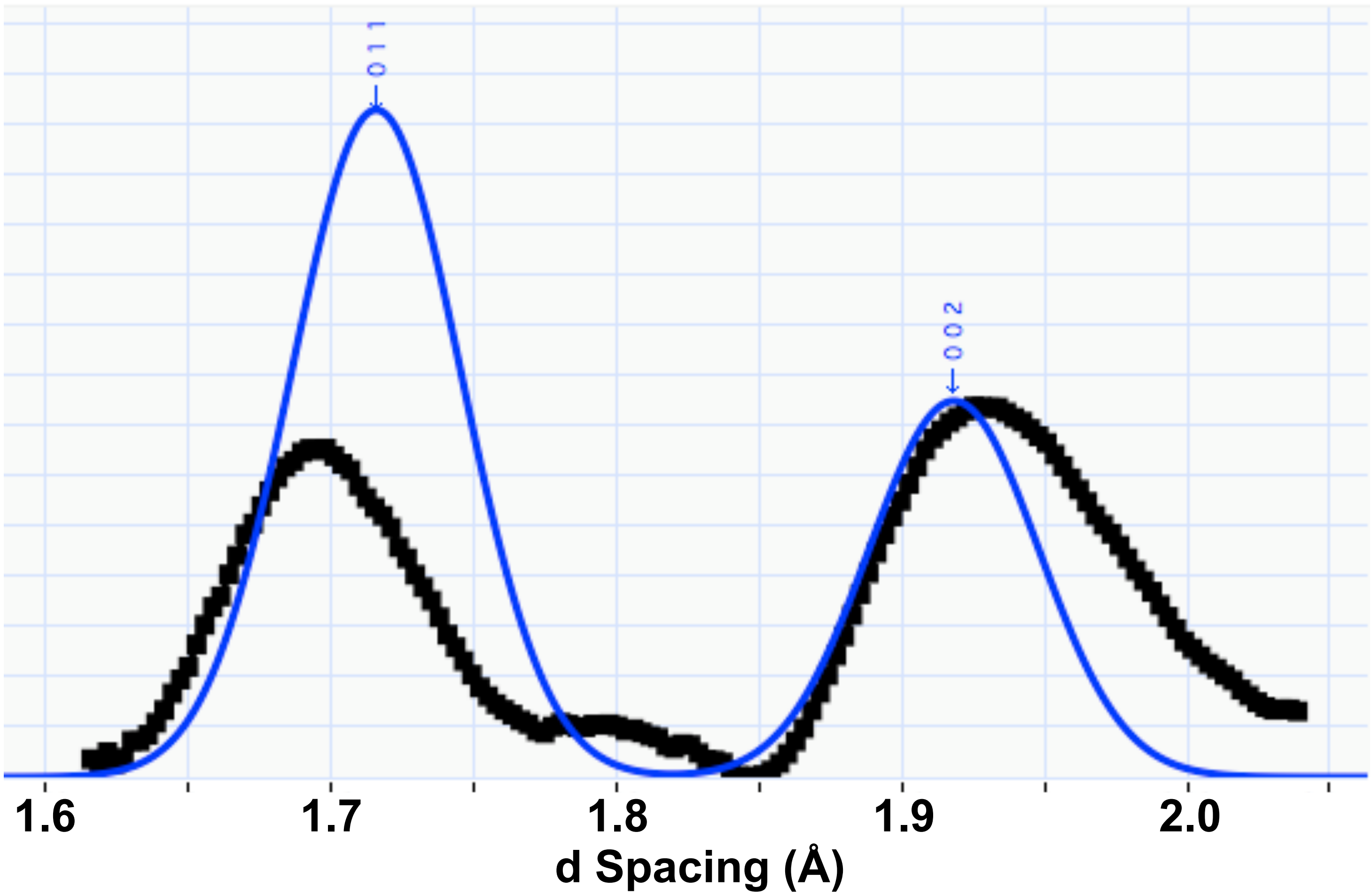
Best Fit Assuming FCC



Doublet, but not great fit to separation

Best Fit Assuming HCP, c/a = 1.732

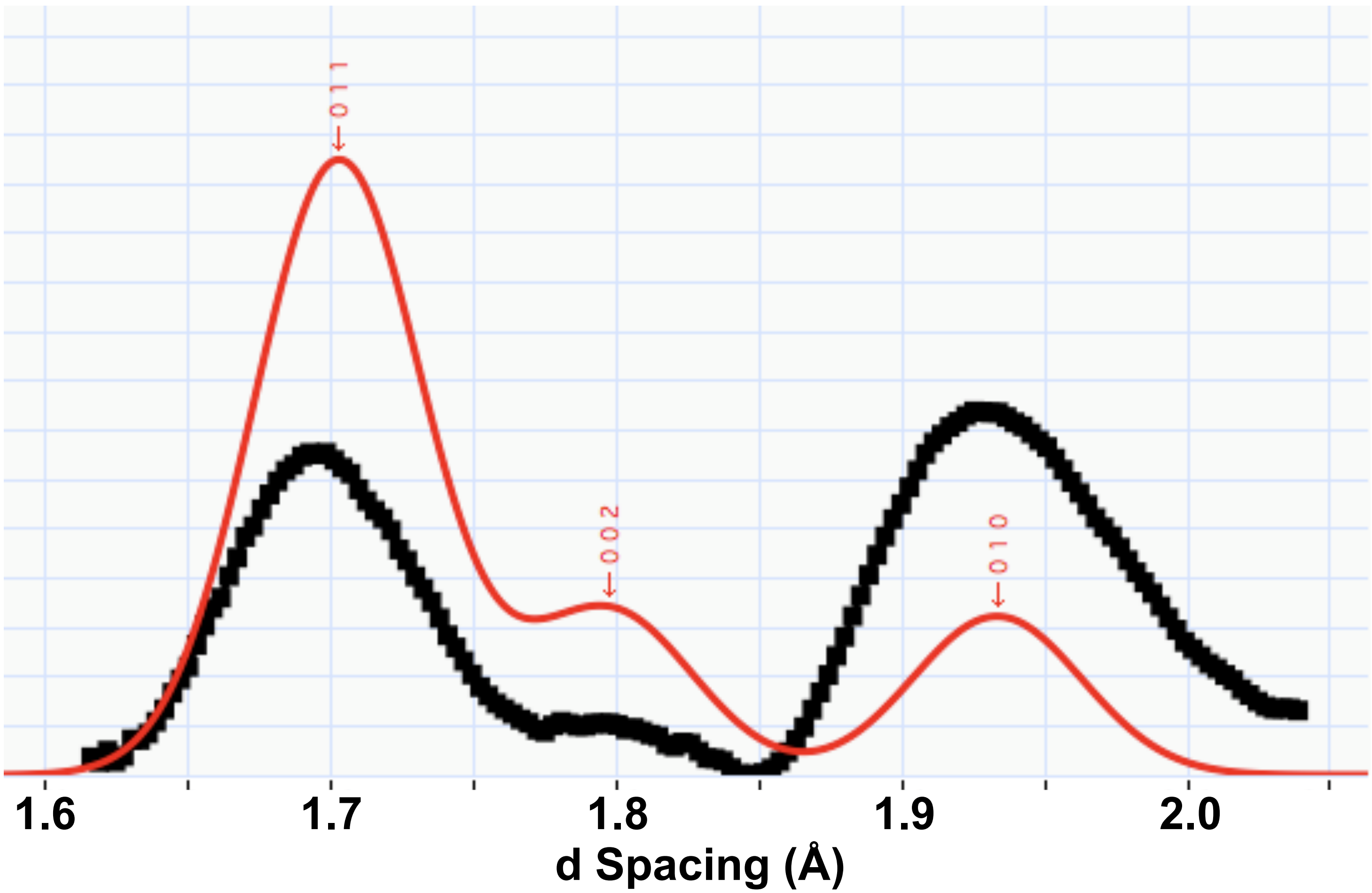
As observed in single crystal laser shock experiments



Doublet, but not great fit to separation

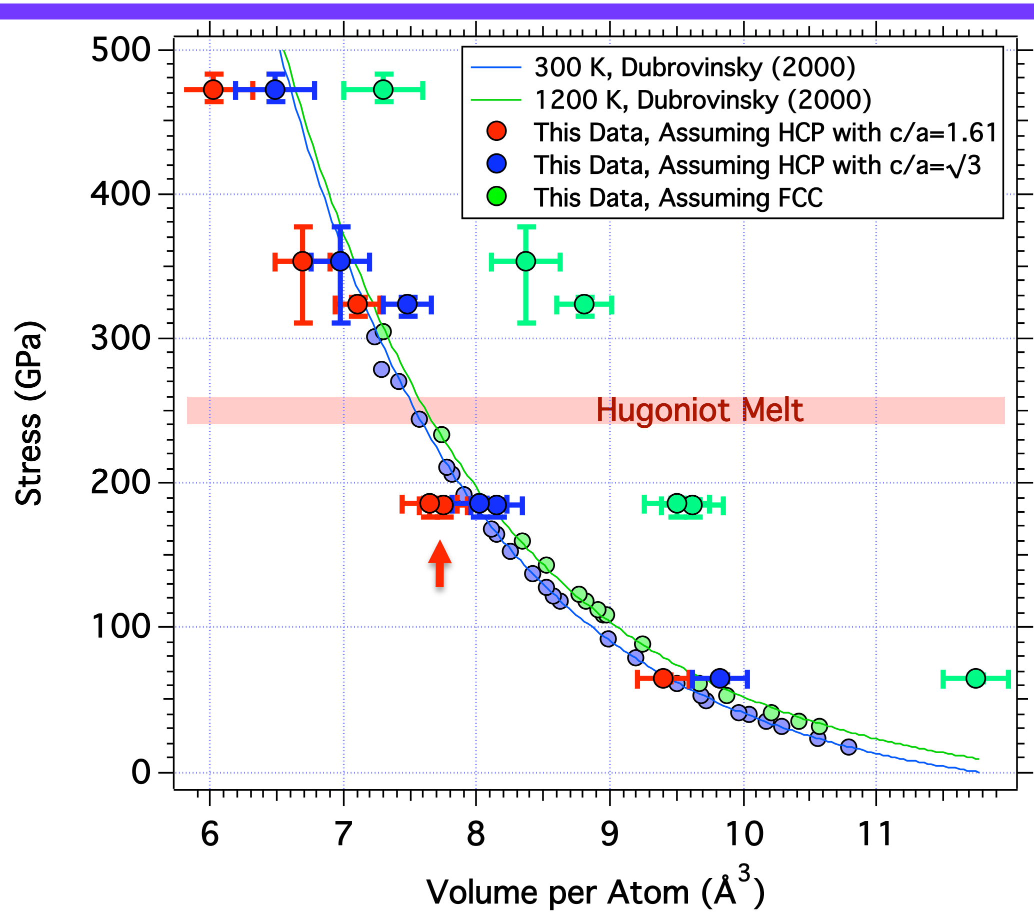
Best Fit Assuming HCP, c/a = 1.61

As observed in DAC experiments



Triplet, peak positions fit well for this shot, but significant basal texture required to get agreement with doublet structure observed.

Results and Comparison



Diffraction on *solid* Fe to 472 GPa

- **Highest pressure X-ray diffraction ever.**
- **Far above Hugoniot melt (~250 GPa).**
- **Structure appears to be HCP.**
- **More analyses / experiments still needed.**

Conclusions

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No obvious limit on pressure