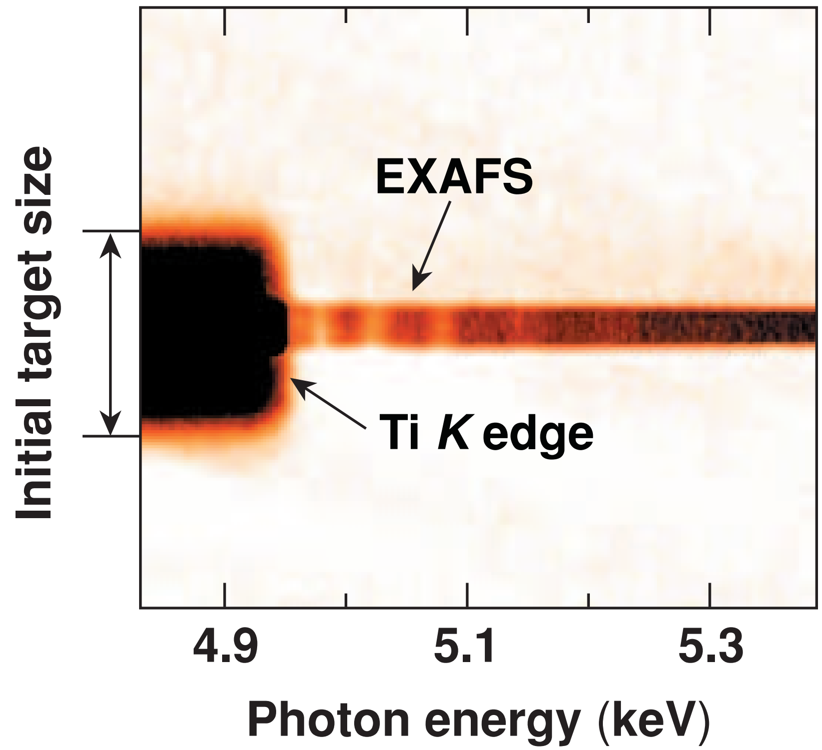
EXAFS Study of Laser Shocked Metals Below 1 Mbar

OMEGA shot 21238



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Summary

EXAFS is used to measure compression and temperature in shocked Ti and V and a phase transformation in Ti

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- V (z = 23): no phase transformation
  Ti (z = 22): α-Ti to ω-Ti phase transformation in μsec shocks

- An EXAFS spectrum from uncompressed and compressed V (~ 0.4 Mbar) was analyzed by FEFF EXAFS code and favorably compared with *LASNEX* simulations.

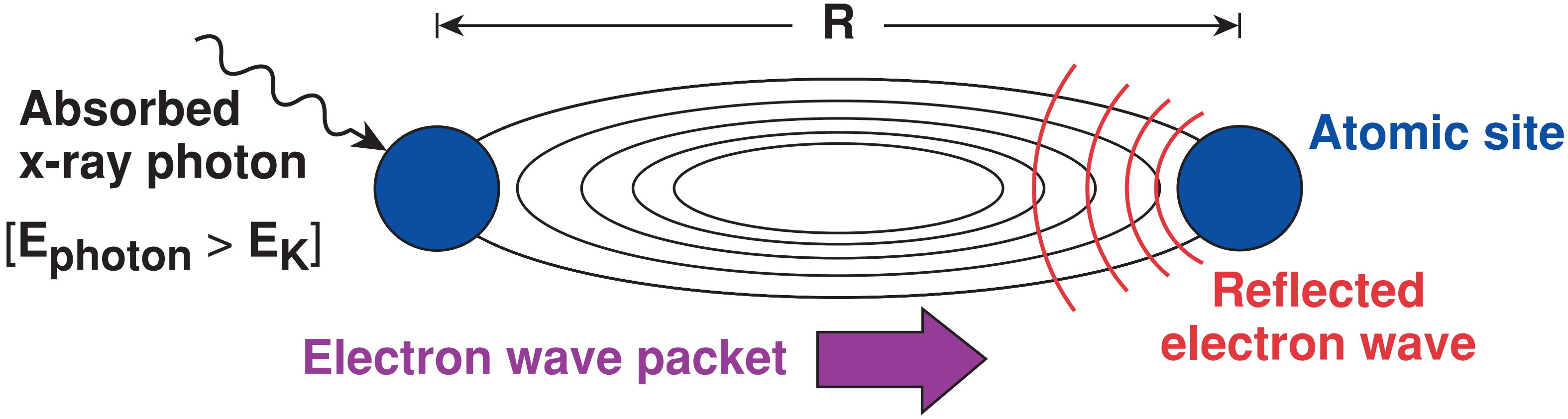
- Uncompressed Ti was successfully analyzed, but compressed Ti shows EXAFS of stronger damping than expected for the predicted temperature.

- FEFF analysis with the α-Ti and ω-Ti phases clearly shows that the expected transformation does take place.

- 1-D compression is ruled out as the reason for this discrepancy.

E12149a

EXAFS is modulations in x-ray absorption due to interference of the ejected electron wave function with reflections from neighboring atoms



$$\hbar^2 k^2_{electron} / 2m = E_{ph} - E_K$$

- Phase is $k_{electron}R$.
- Modulation frequency depends on R and, hence, on density.
- For higher temperatures, vibrations reduce coherence, leading to faster damping of modulation.

EXAFS modulations in the x-ray absorption coefficient depend on the density and temperature

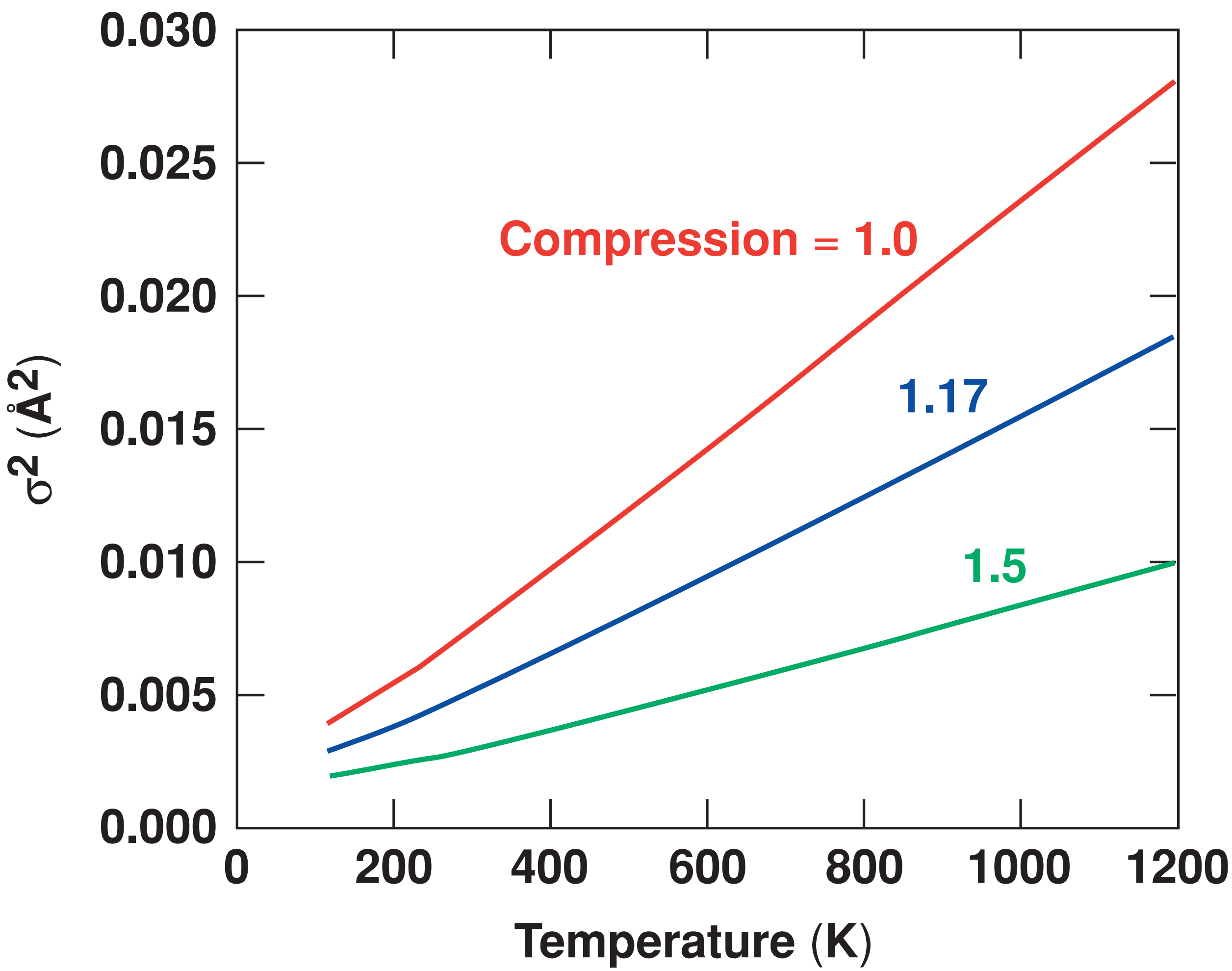
- Model for modulations in reduced x-ray absorption coefficient above the *K* edge:

$$\chi(k) = \Sigma_j N_j F_j(k) \exp\left[-2\sigma^2 k^2 - 2R_j/\lambda(k)\right] \sin\left[2kR_j + \phi_j(k)\right]/kR_j^2$$

- $-2\sigma^2 k^2$: Damping due to lattice vibrations, $\sigma^2 = f(T/\theta_D)$
- $2R_j/\lambda(k)$: Electron mean free path
- $2kR_j$: Modulations due to neighboring atoms

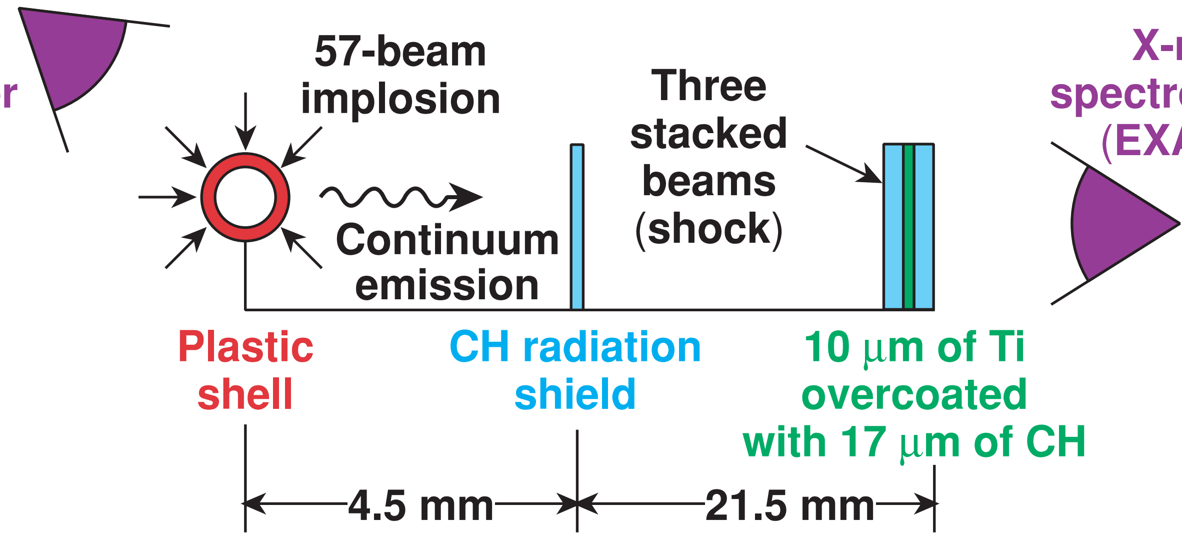
- For shock heating, compression increases $\theta_D \sim h\nu_m/k_B$ (ν_m, the maximum lattice frequency $\sim \rho^{1/3}$).

The Debye-Waller term, σ^2, depends on temperature and compression

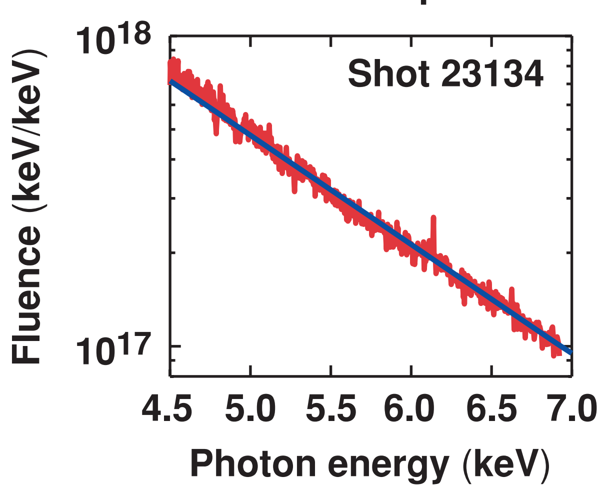


E. Sevillano, H. Meuth, and J. J. Rehr, Phys. Rev. B 20, 4908 (1979).

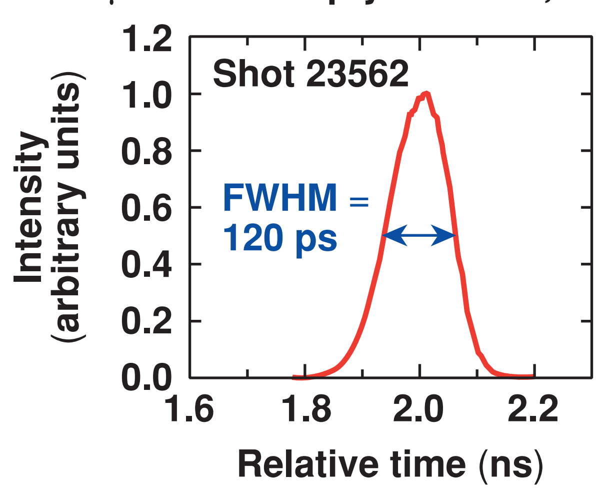
EXAFS is observed in thick metal foils backlit by a spherical target implosion



Featureless spectrum



18.5-μm-thick empty CH shell, 23 kJ



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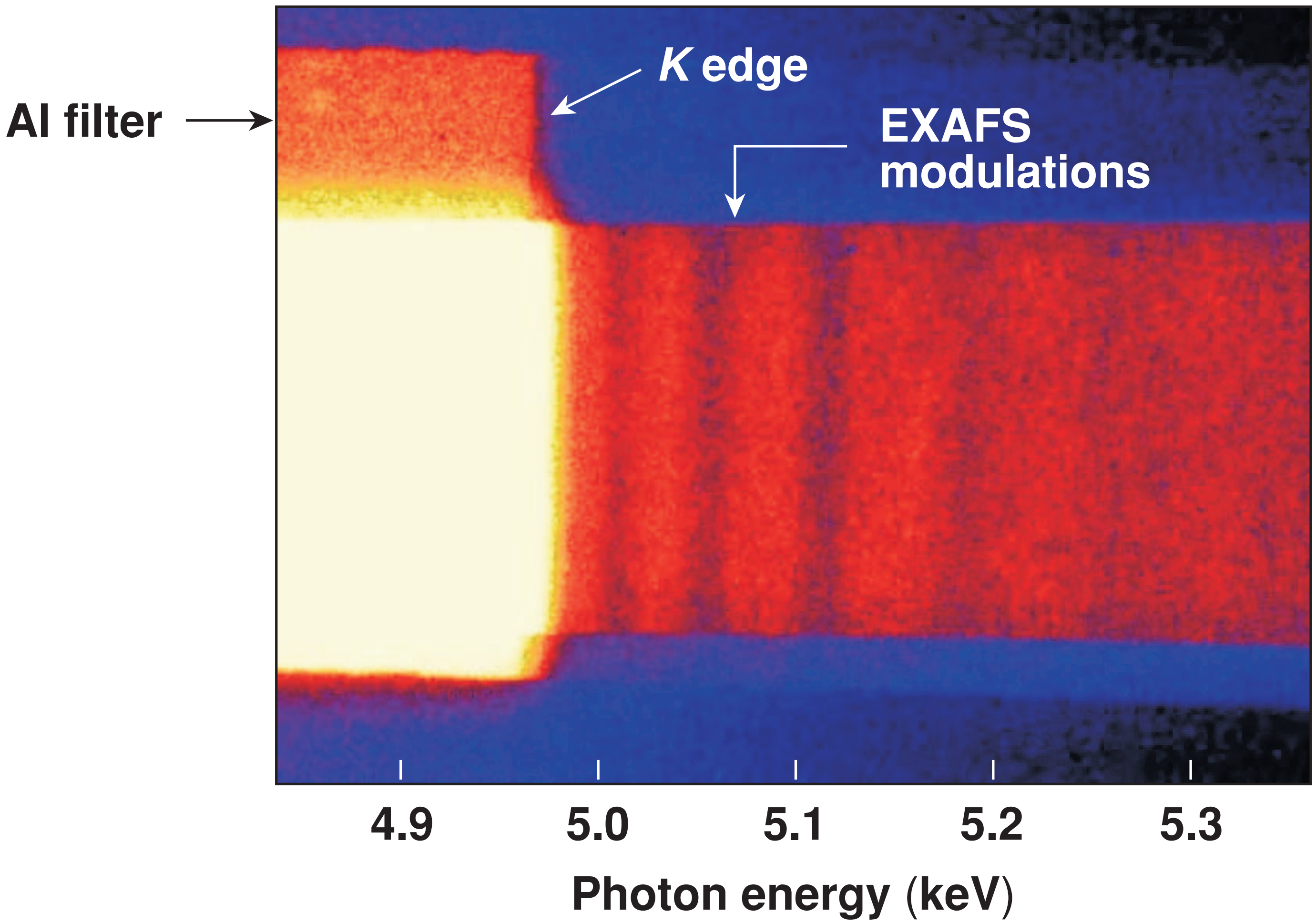
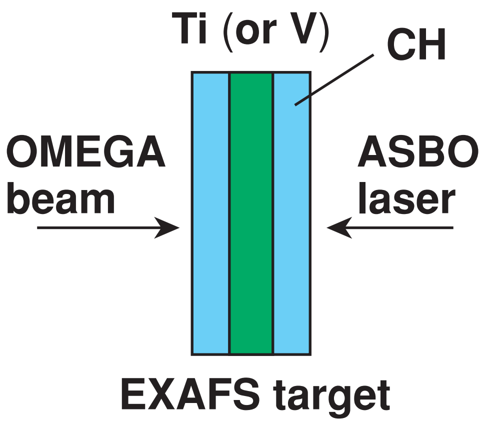
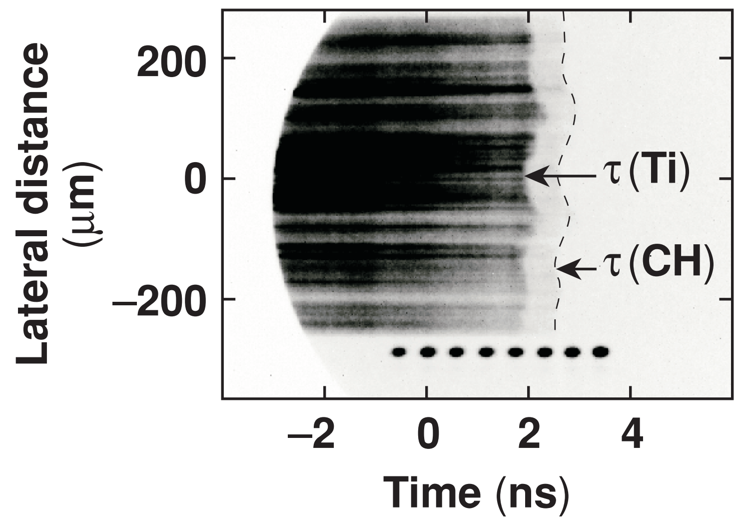
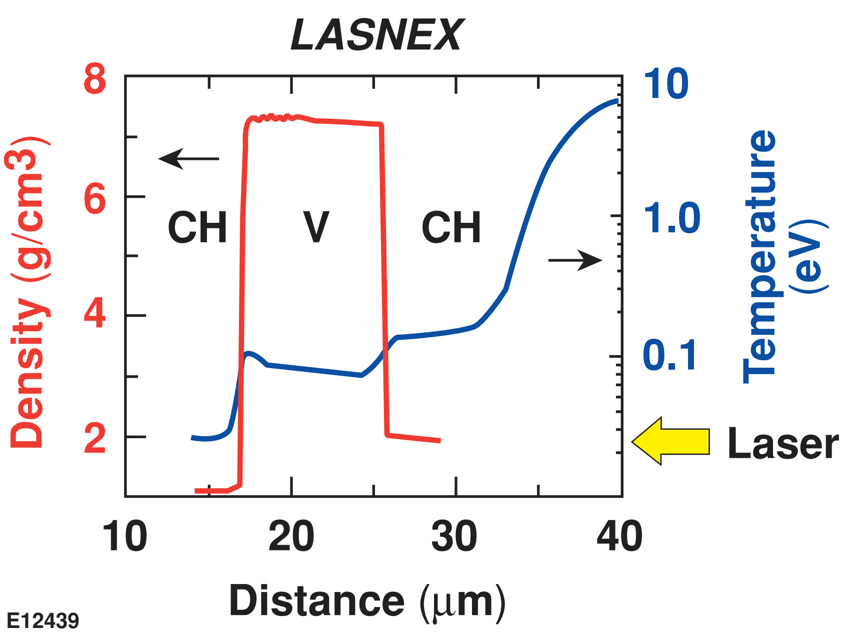
Raw EXAFS film image of unshocked Ti shows expected modulation (shot 27499)

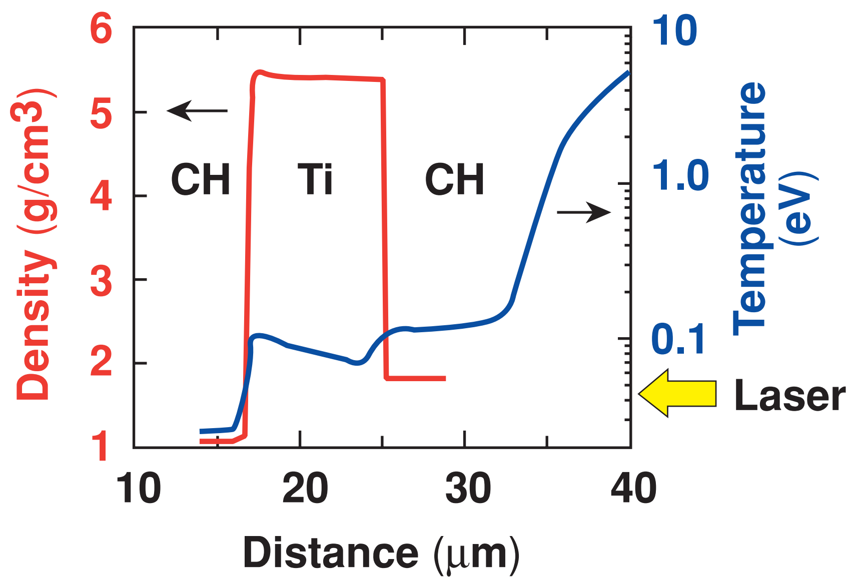


ASBO measures shock-arrival time at back of Ti; speed (through Hugoniot) confirms EXAFS compression



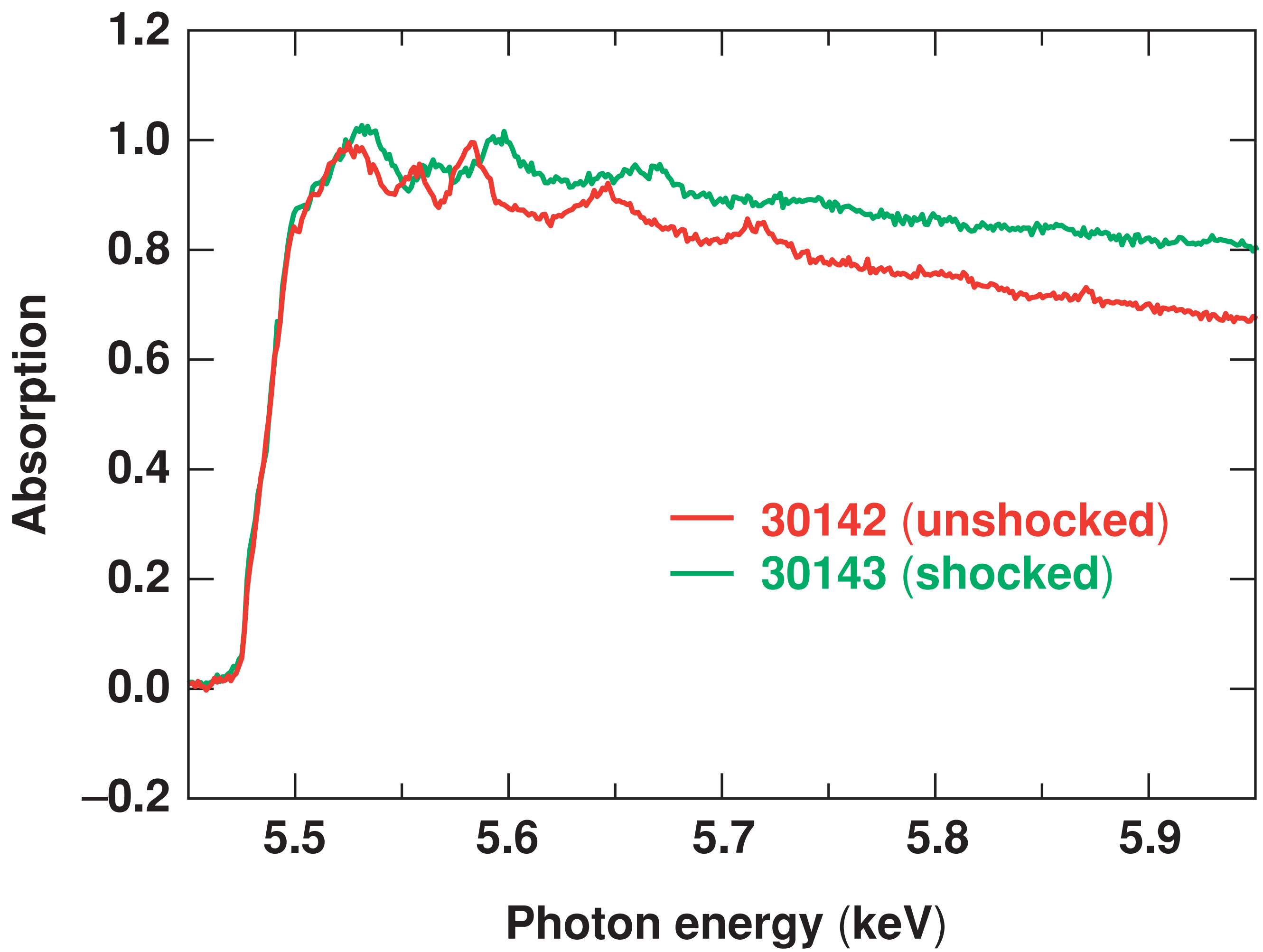






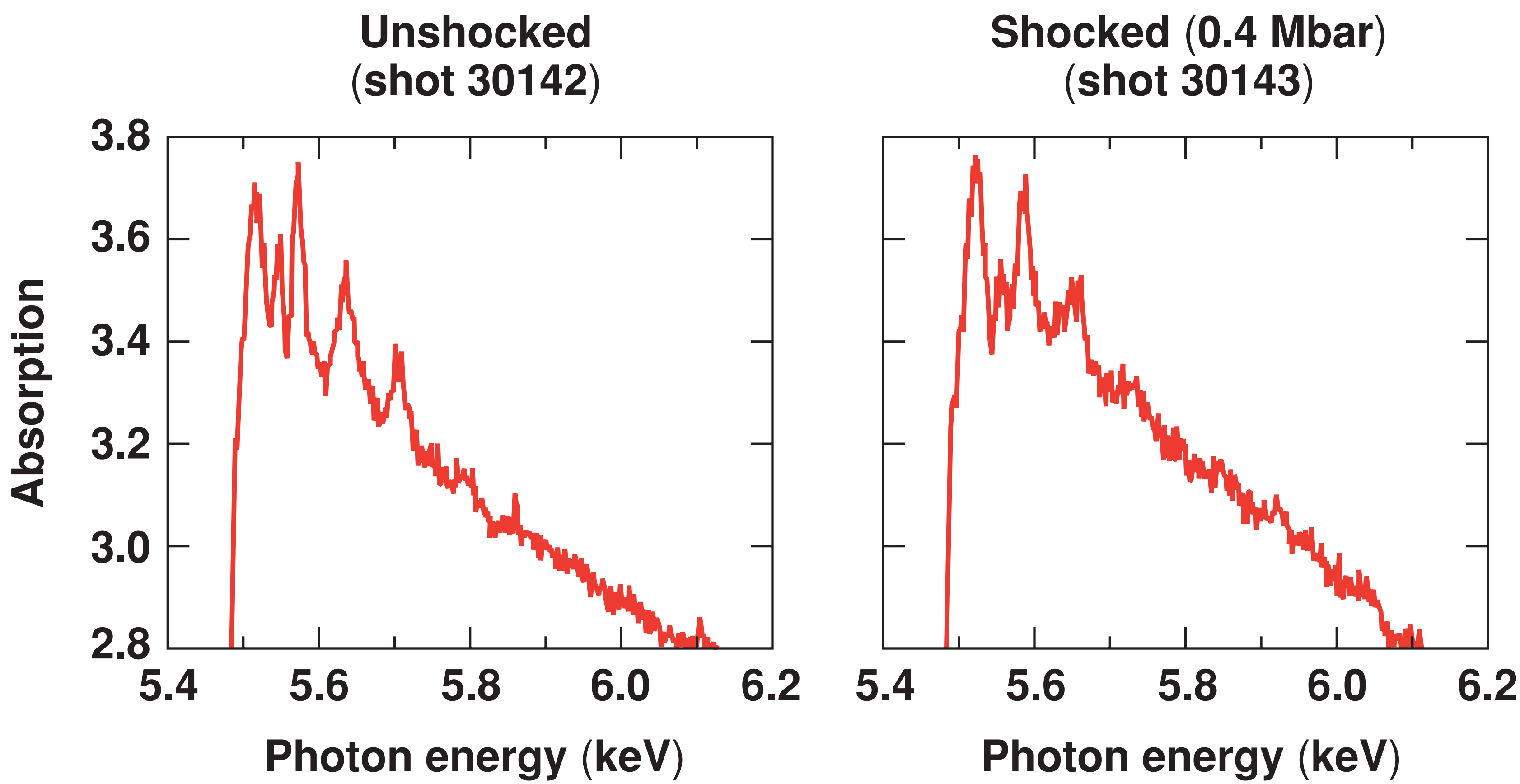
E12439

The increased modulation period indicates shock compression (0.4 Mbar) in V



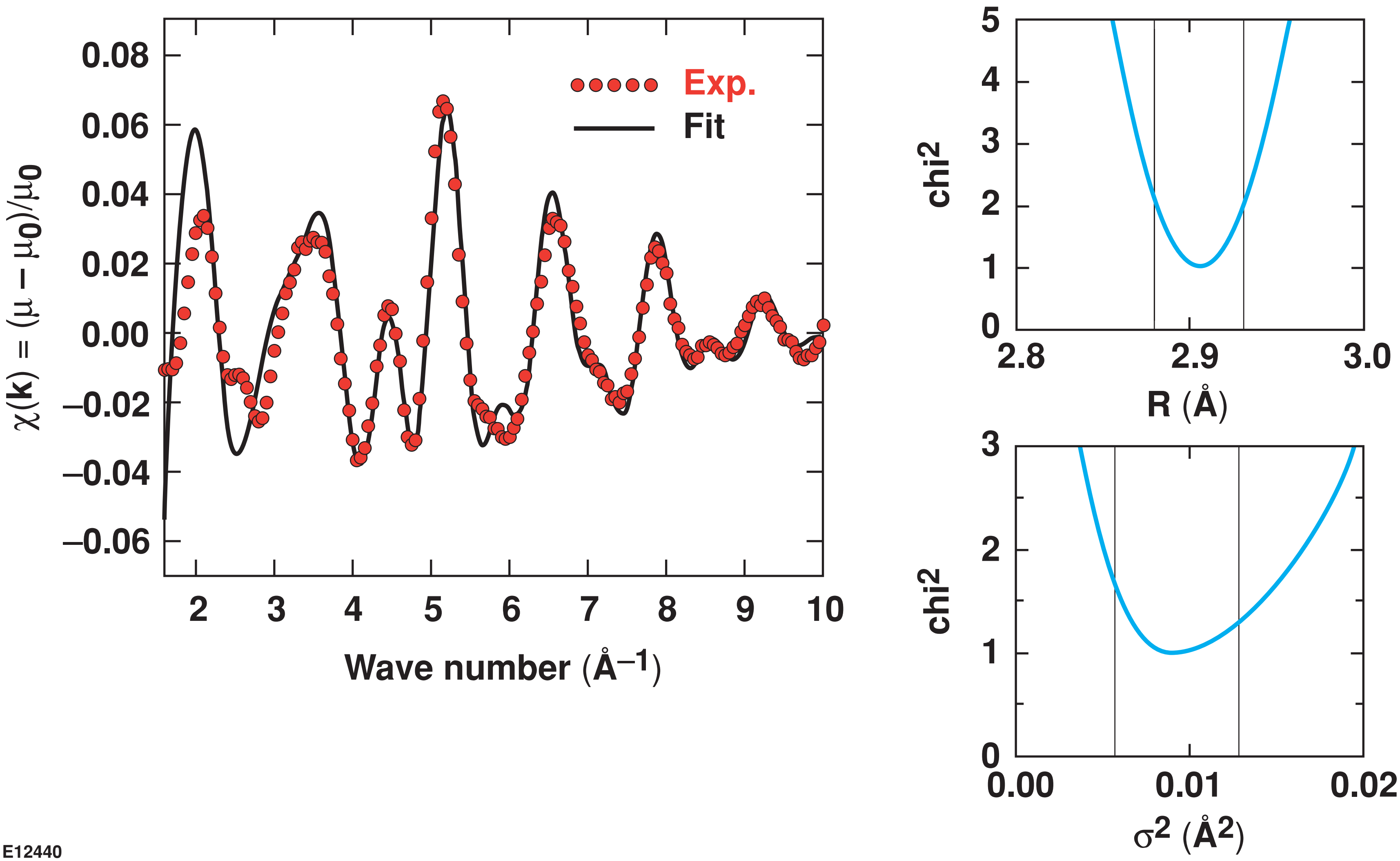
E12232a

EXAFS in shocked vanadium (0.4 Mbar) shows greater decay of modulations due to shock heating



E12154a

The FEFF fit of the EXAFS spectrum for unshocked vanadium shows solid density and T = 430 K



E12440

The FEFF fit of the EXAFS spectrum for shocked vanadium (0.4 Mbar) indicates ×1.14 compression, T = 770 K

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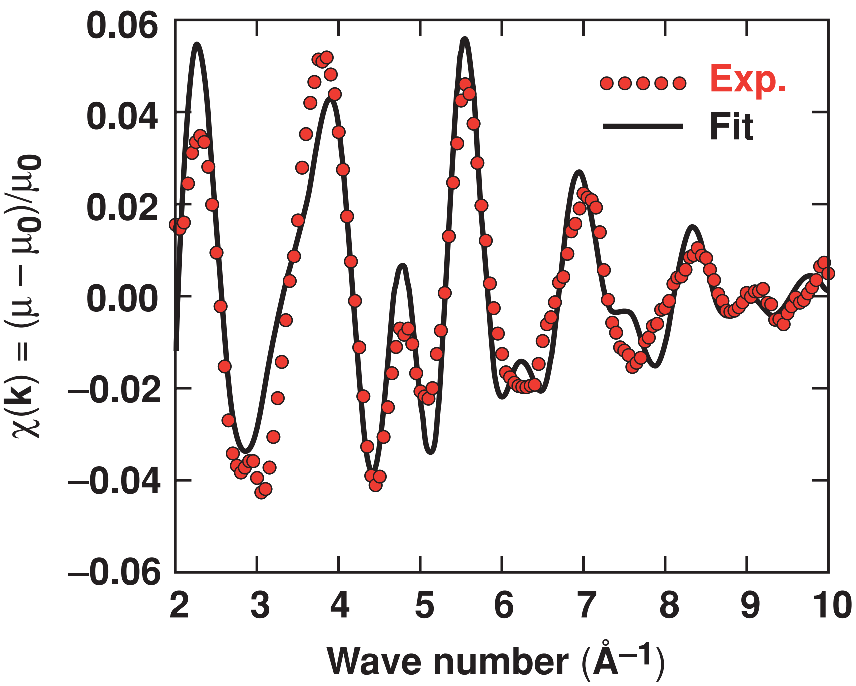


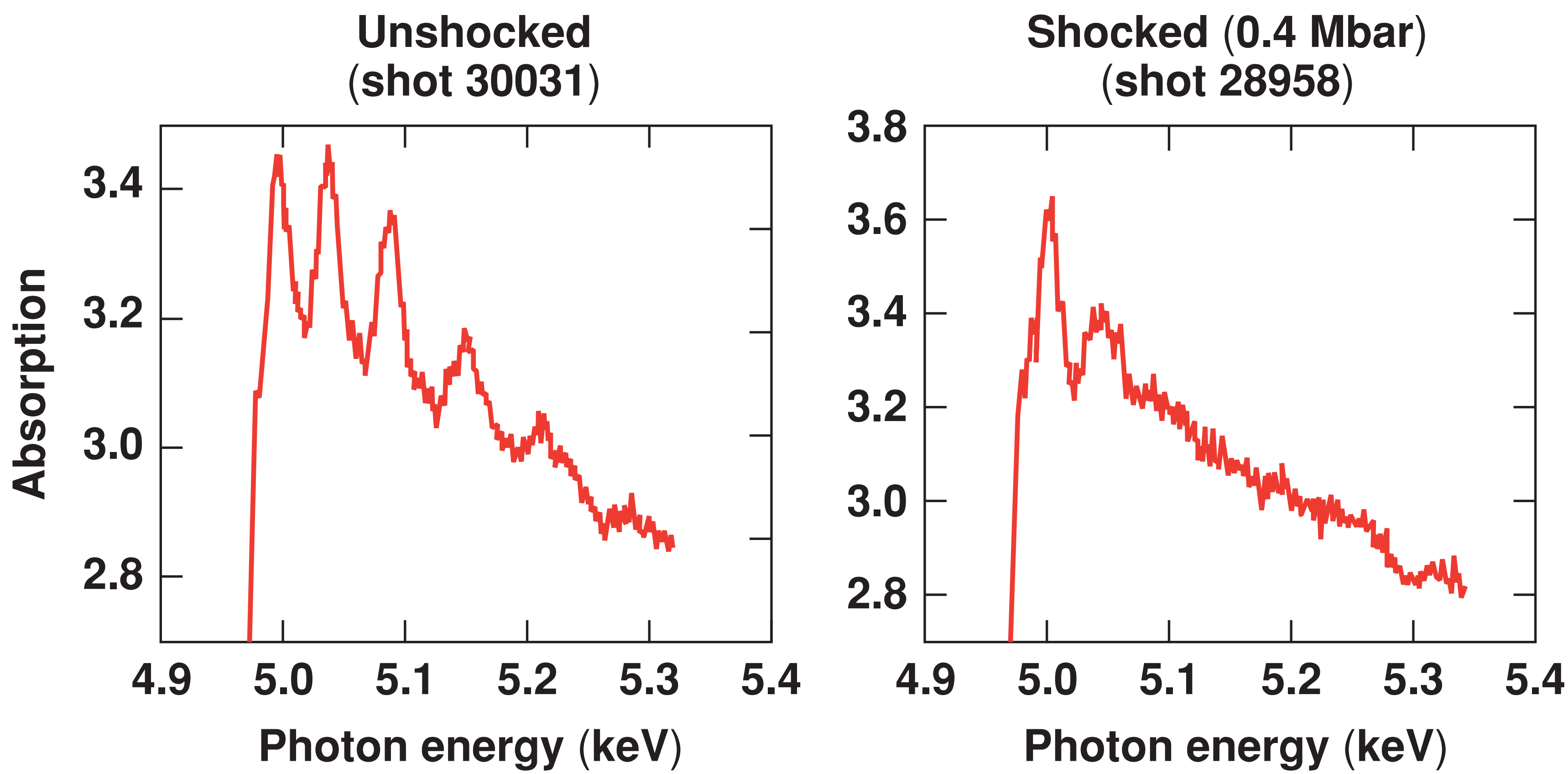
Calculated and measured parameters for shocked vanadium

Laser of intensity of 0.5 TW/cm^2 yielding a pressure of ~ 0.45 Mbar

LASNEX parameter ranges		EXAFS measurement		Shock-speed measurement
Compression	Temperature	Compression	Temperature	Compression
1.19±0.05	980±160 K	1.14±0.01	770±70 K	1.14±0.06

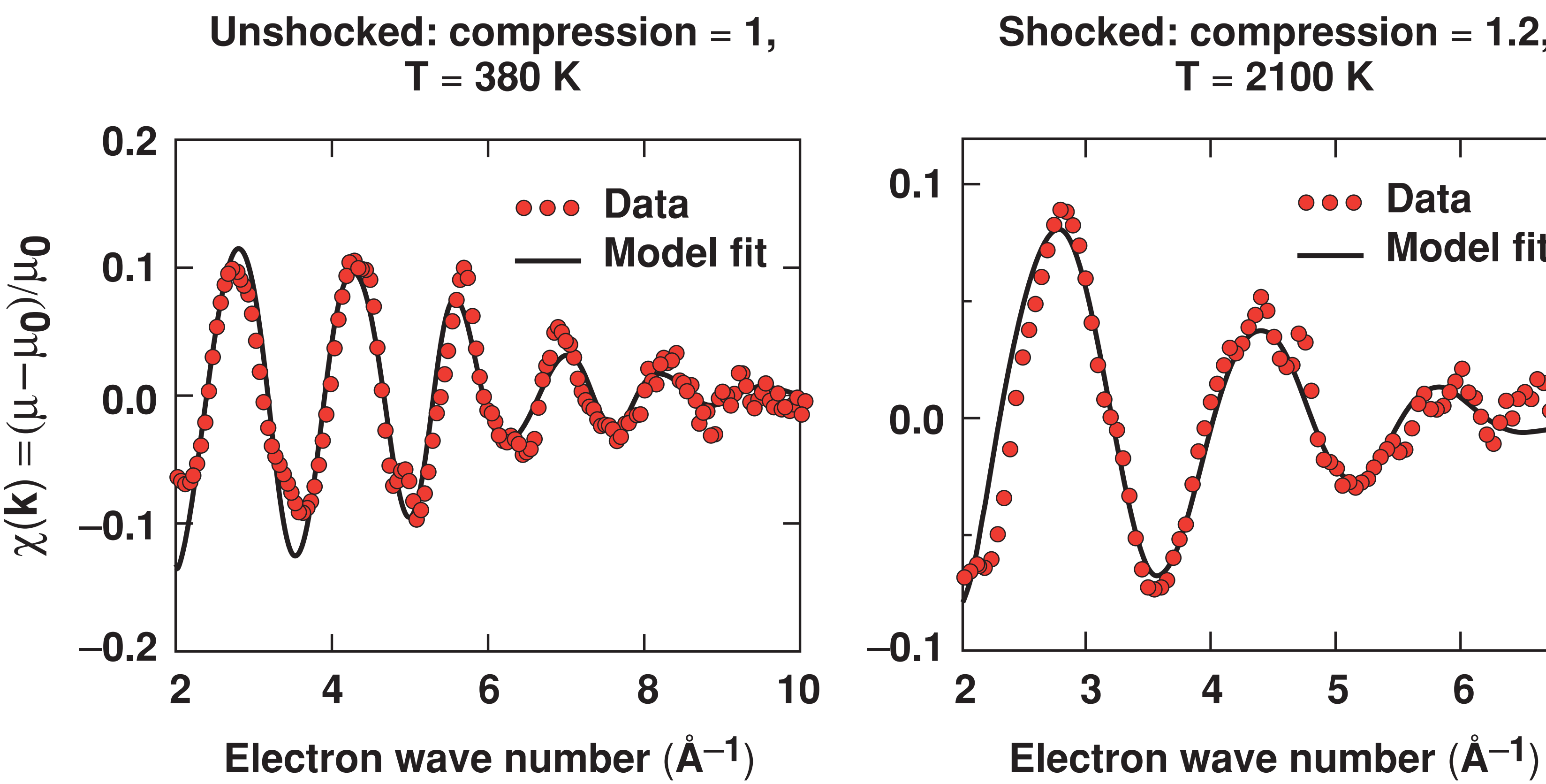
E12150a

A 0.4-Mbar shock in Ti reduces the EXAFS modulation dramatically



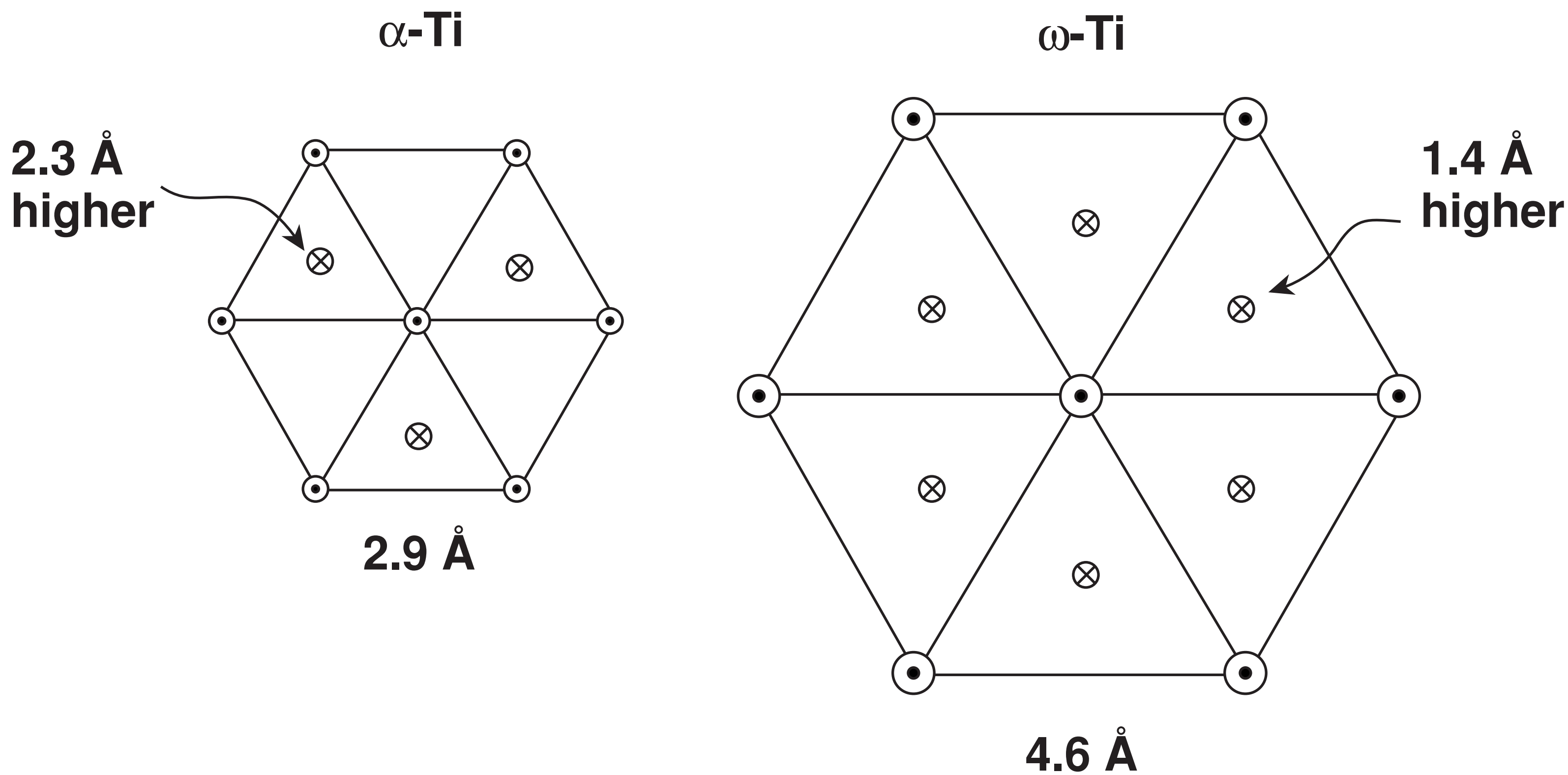
E12155

FEFF fits to the Ti EXAFS data show shock induced compression of ~1.2×



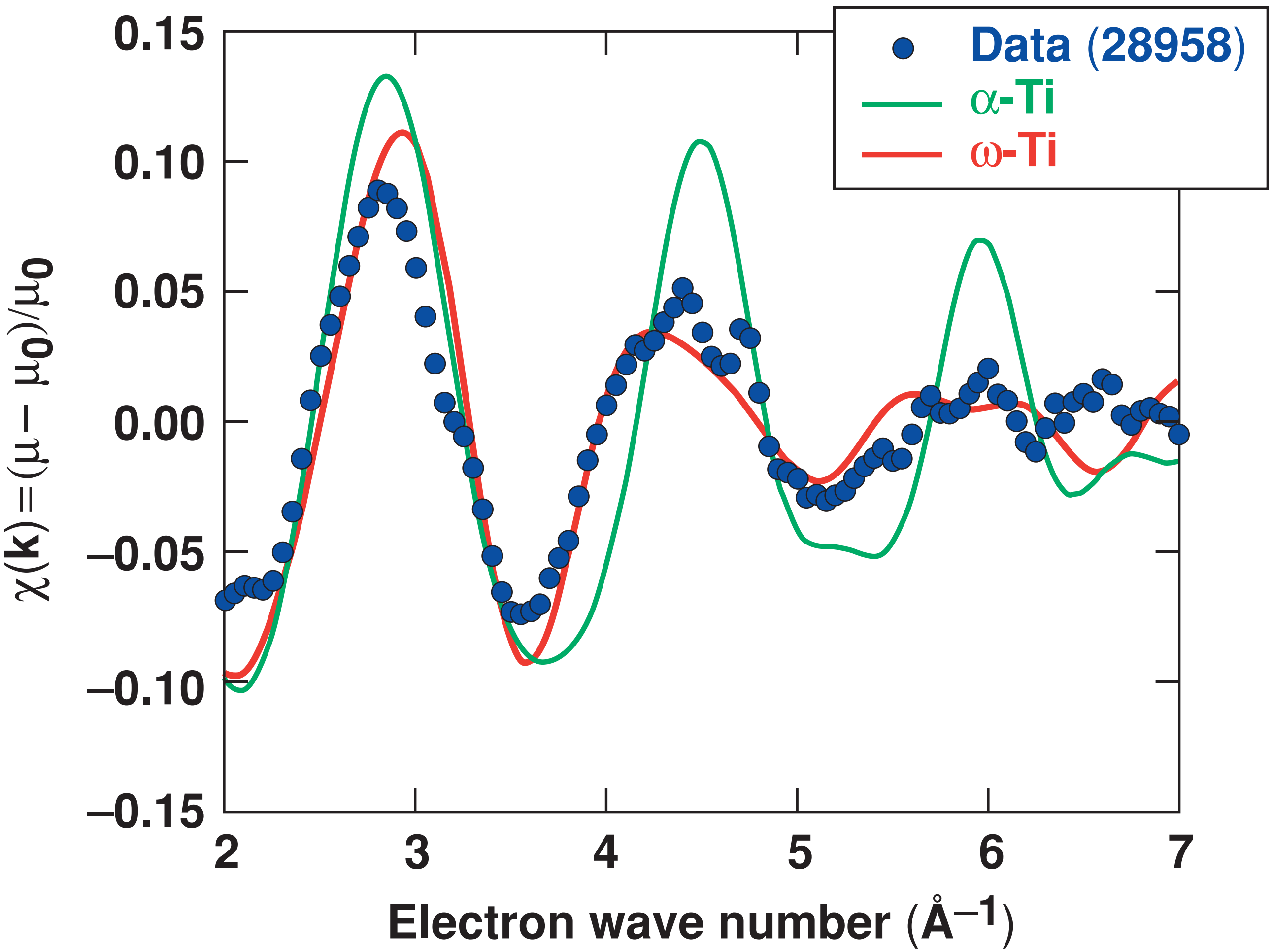
E12409a

At high pressures (0.02 to 0.1 Mbar) Ti undergoes an α-Ti to ω-Ti phase transformation



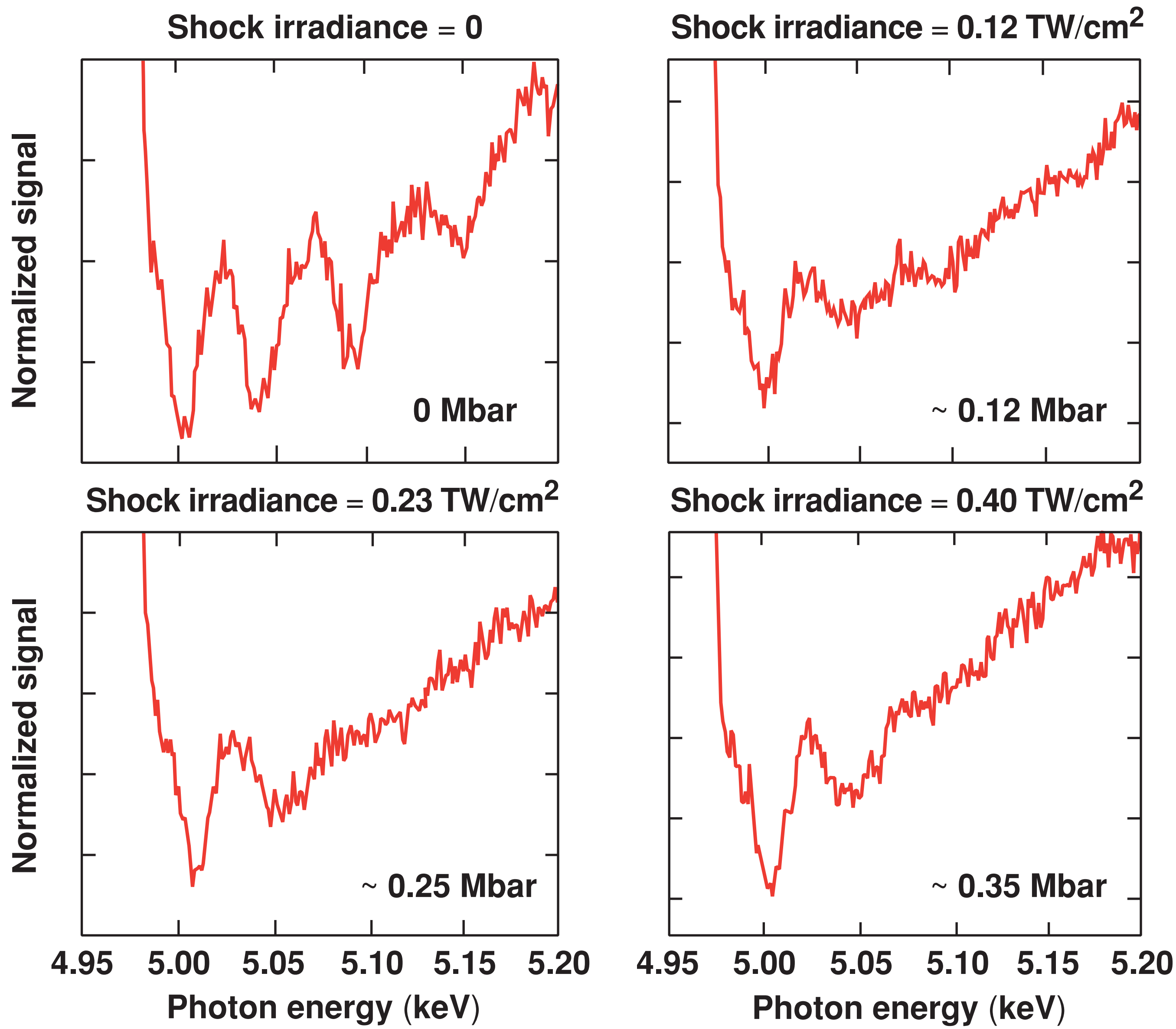
E12261

Evidence for α-Ti to ω-Ti phase transformation: fitting FEFF code to data, assuming T = 900 K



E12570

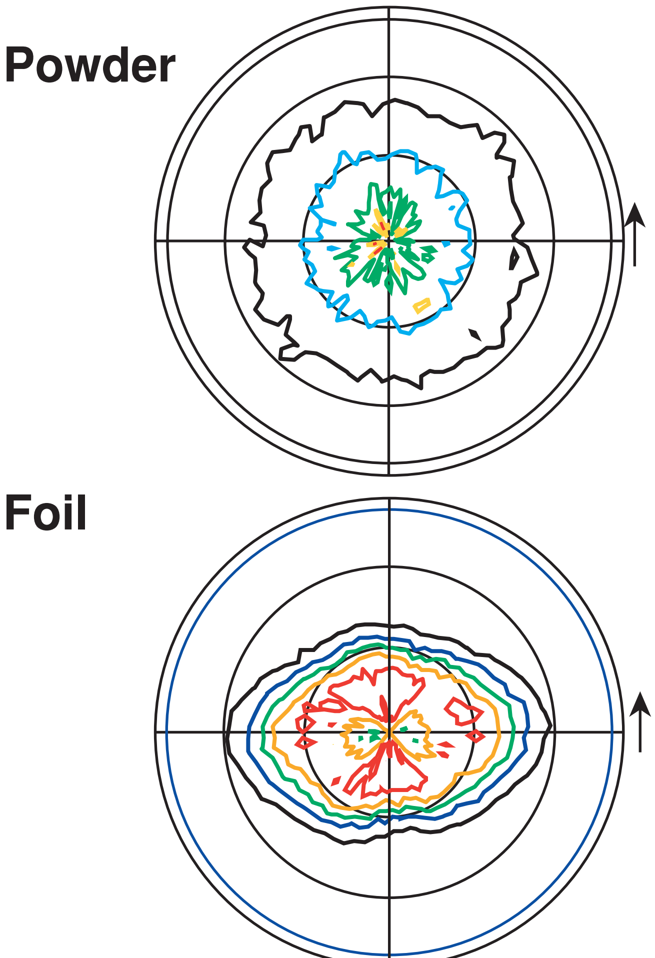
Ti EXAFS spectra at reduced irradiances support the observation of a phase transformation

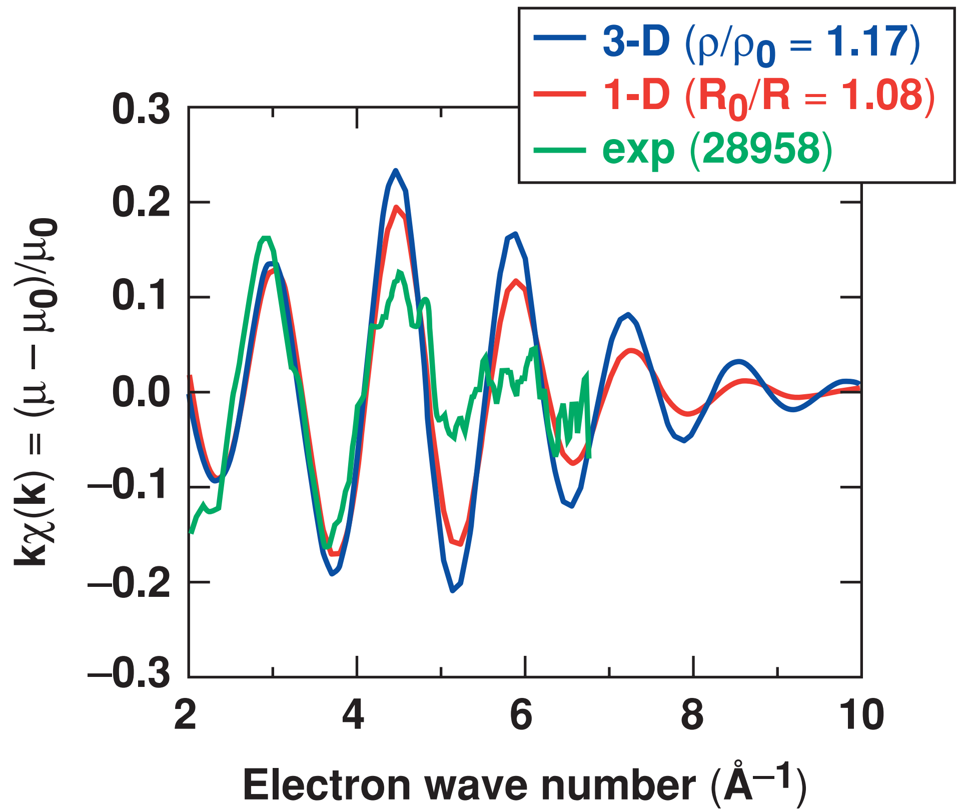


E12158

EXAFS of shocked Ti (0.4 Mbar) cannot be fitted with either 1-D (pole-figure-averaged) or 3-D compression at the predicted T = 0.09 eV

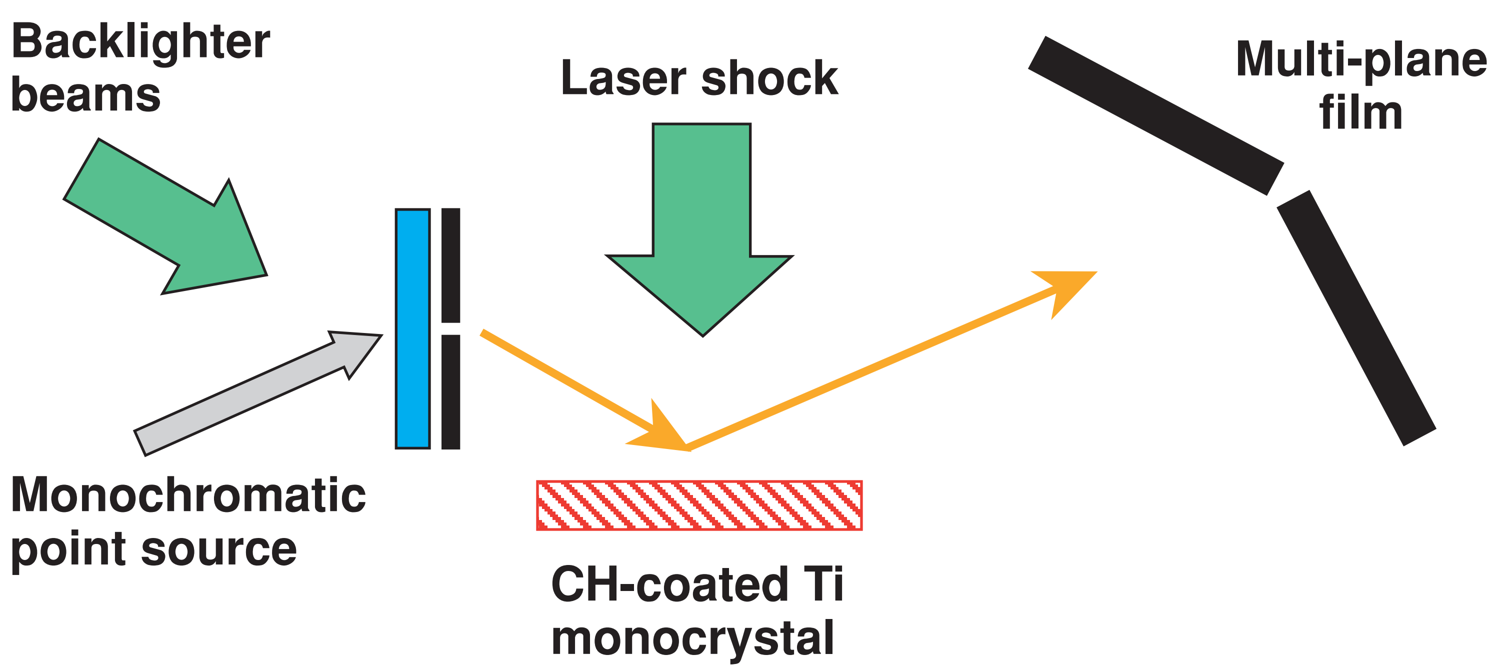
Pole figures of Ti powder and foil





E12163a

In-situ diffraction of shocked metals on OMEGA measures compression*

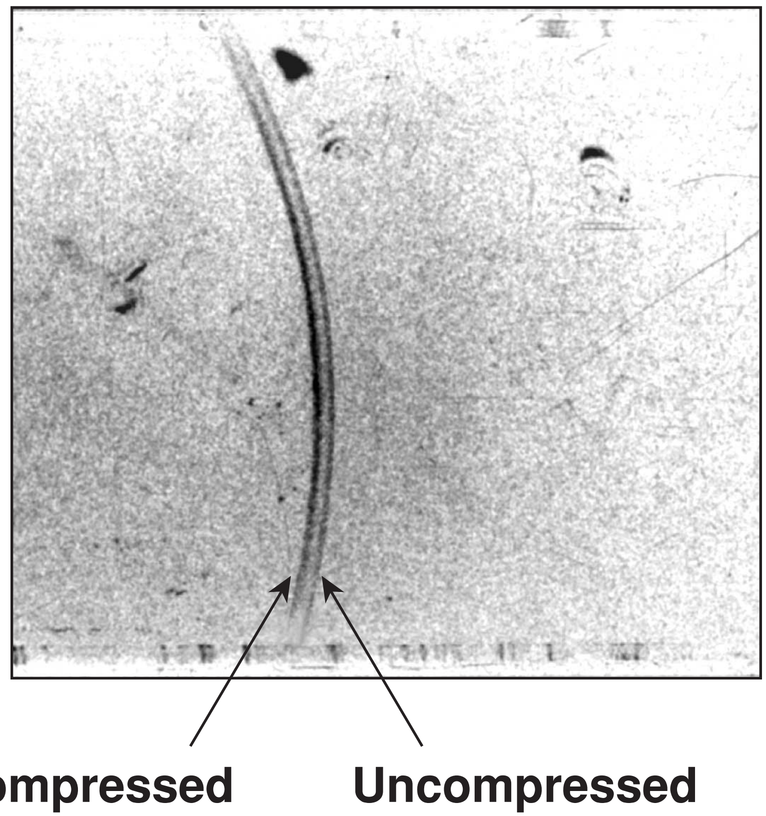


E12569

* D. H. Kalantar *et al.*, Phys. Plasmas 10, 1569 (2003).

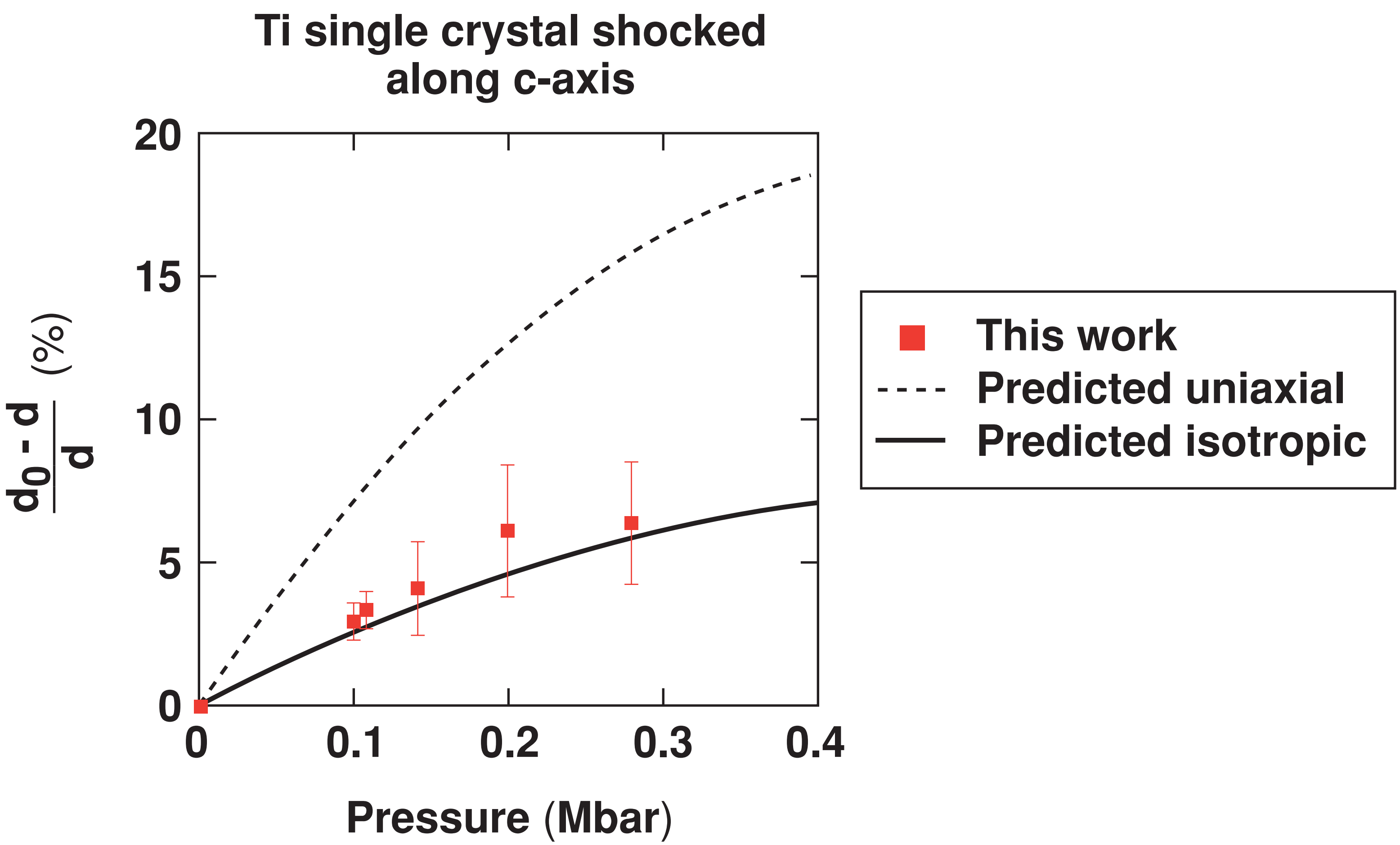
In-situ diffraction using monochromatic point source shows uniform compression

Single crystal Ti, 0.1 Mbar



E12683

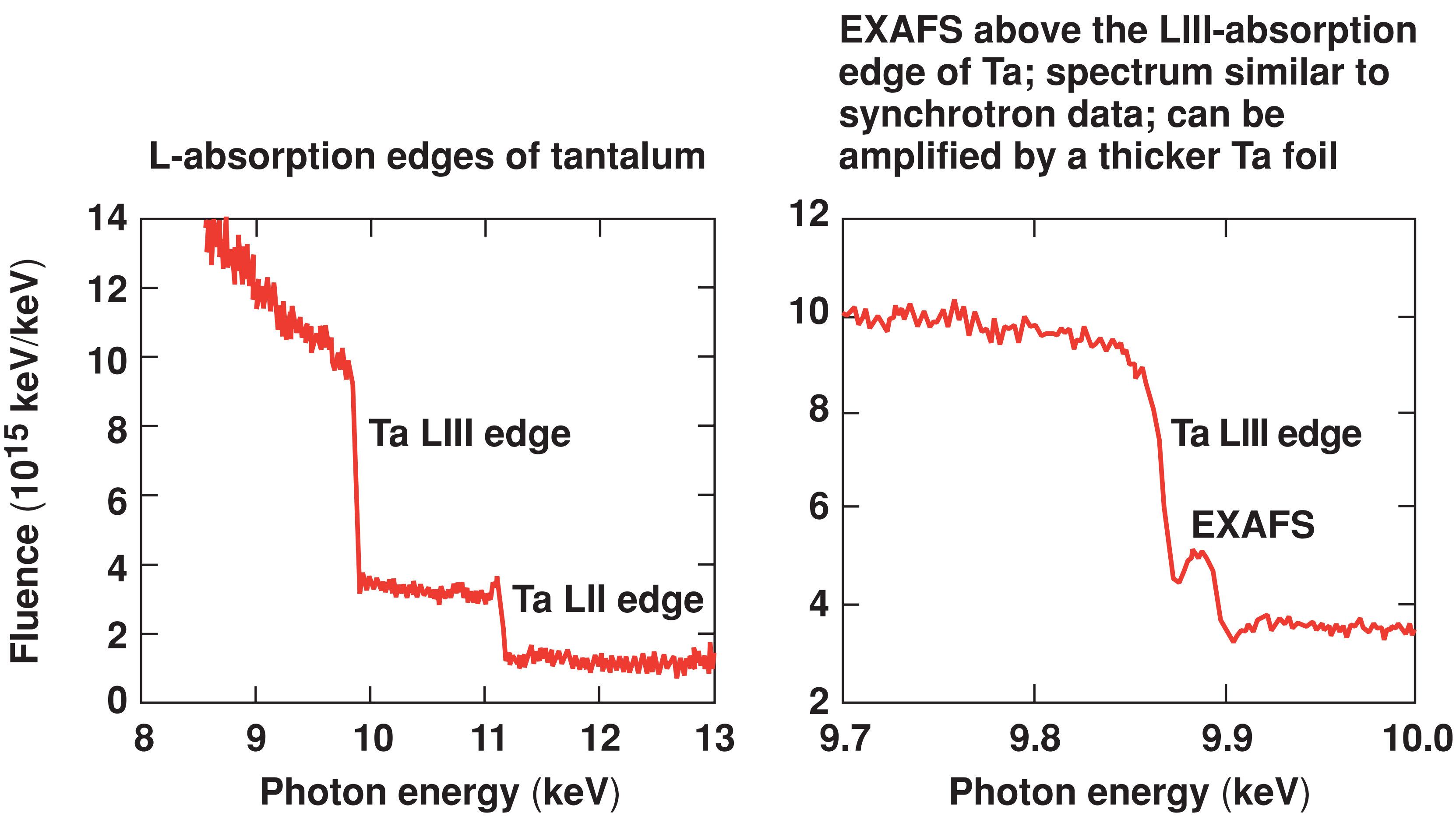
In-situ diffraction shows compression (a) increases with pressure, (b) is 3-dimensional



E12682

Initial L-shell EXAFS measurements are encouraging

OMEGA shot 29443, 5-μm Ta



E12225

Summary/Conclusions

EXAFS has been used to study shock compression in V and Ti and to demonstrate phase transformation in Ti

- *K*-shell EXAFS of shocked materials has been performed on OMEGA using an implosion as a backlighter.
- The measured compression and temperature of V (up to 0.4 Mbar) is in good agreement with predictions.
- The measured compression of Ti (up to 0.4 MBar) is in good agreement with predictions, but the damping can only be explained by assuming a transformation from the α to ω phase.
- In development:
  - Diffraction measurement of α- to ω-phase transformation in Ti
  - *L*-shell EXAFS measurements of very high-*Z* elements on OMEGA
  - EXAFS applied to isentropically compressed targets

E12258a