Temperature Diagnosis of Dynamically Compressed Matter

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Motivation

- Laser compression produces material properties of great interest to planetary science, inertial confinement fusion, and the larger materials community.
- Unfortunately there is a lack of capability in measuring the temperature of opaque solids in off-hugoniot states:

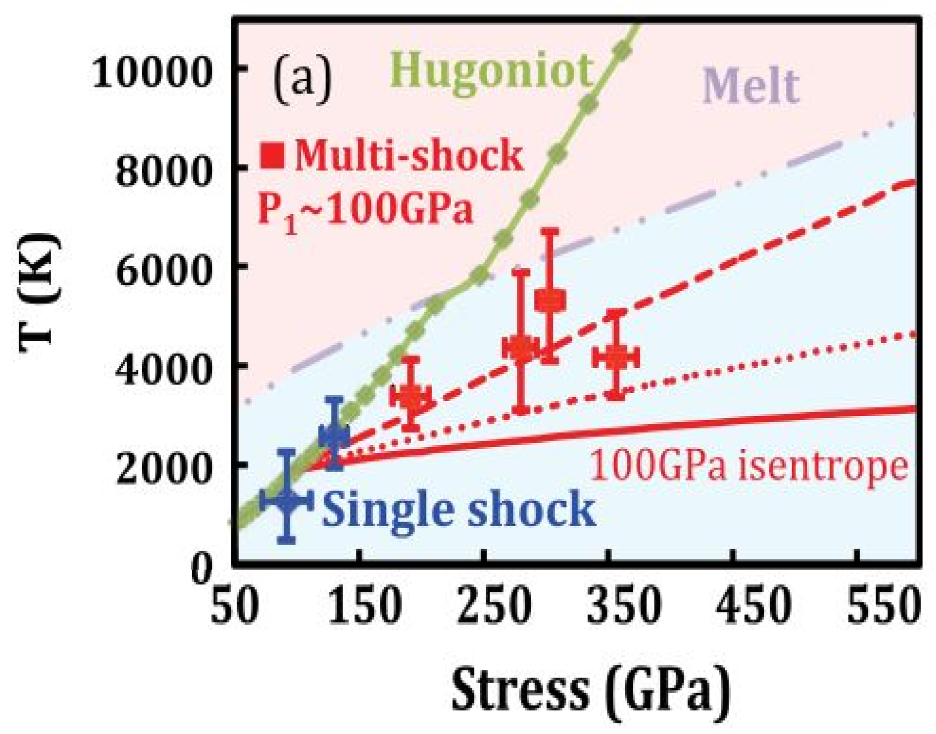

Fig. 1: Image taken from [1] to illustrate the large errors associated with currently used thermometry techniques (EXAFS).

- The use of well known and widely used x-ray diffraction techniques to measure the temperature of such states is proposed [2].

Debye-Waller Effect

- The normalised intensity of a diffraction peak, $I(T)$, is related to temperature by

$$I(T) = e^{-2M}$$

where

$$2M \propto |\mathbf{G}|^2 \frac{T}{\Theta^2}$$

and $\mathbf{G}$ is the reciprocal lattice vector of the peak, T is temperature, Θ is Debye temperature [3].

- Debye temperature is constrained by theory well enough to provide a temperature estimate that varies little with model used:

Model Type	Hydrostatic: Error in T	Static Uniaxial: Error in T	Shock (Up = 0.5 km/s): Error in T
Very Simple	+ 0.1 %	+ 5.7 %	+ 15.7 %
Perturbation theory	+ 0.1 %	+ 4.7 %	+ 14.3 %
Empirical	+ 0.1 %	+ 5.7 %	+ 15.7 %
Empirical + EOS	+ 0.1 %	+ 6.0 %	+ 16.0 %

Simulations of Single Crystal

- Cu has been simulated under a variety of conditions using a molecular dynamics code:

  - Static uncompressed.
  - Static uniaxially compressed.
  - Shock elastically compressed.

- By taking a Fourier transform of the atom positions, and using models for Debye temperature, an x-ray diffraction image can be simulated, from which we can glean intensities [4].

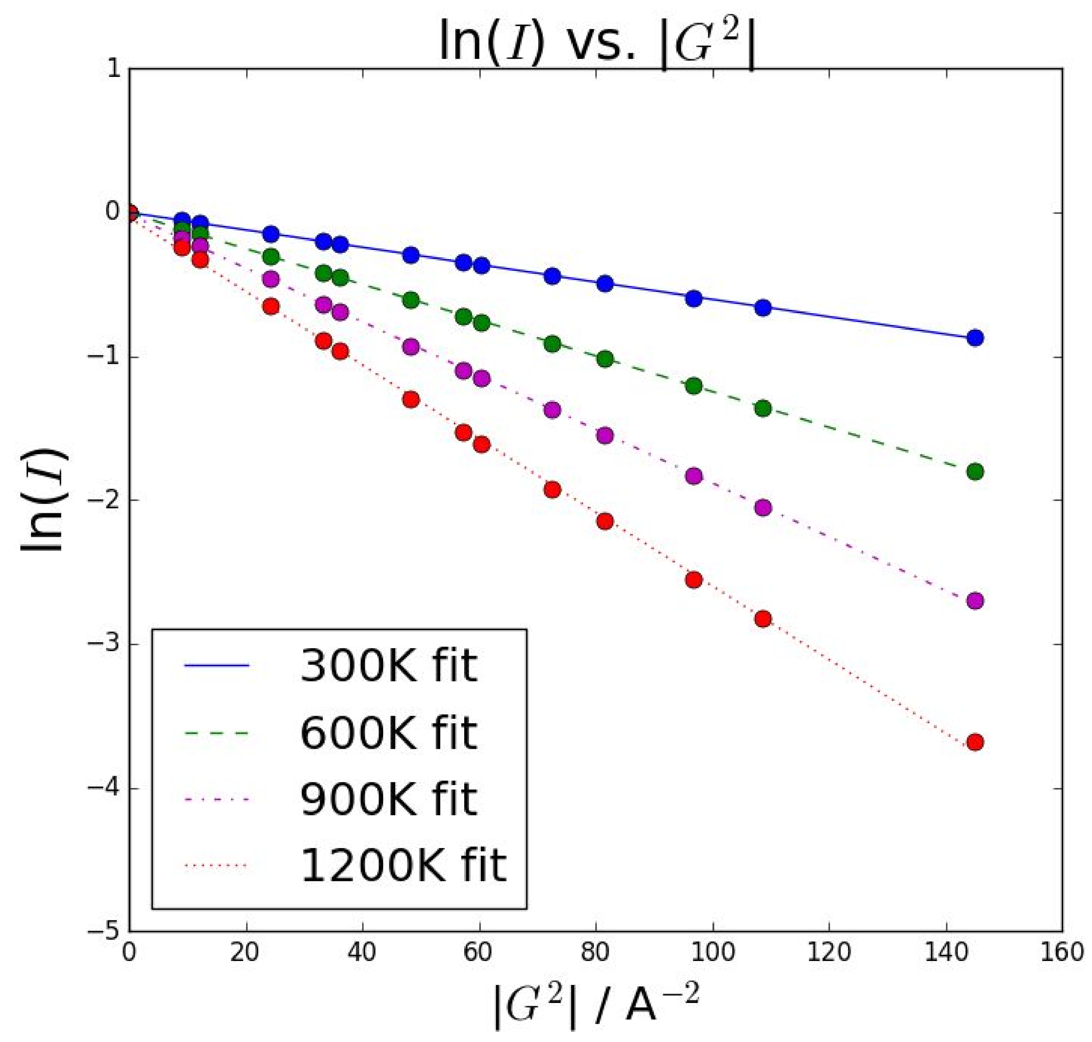

Fig. 2: Diffraction intensities from simulated copper at different temperatures, uncompressed. The slope of the lines can be used to measure temperatures.

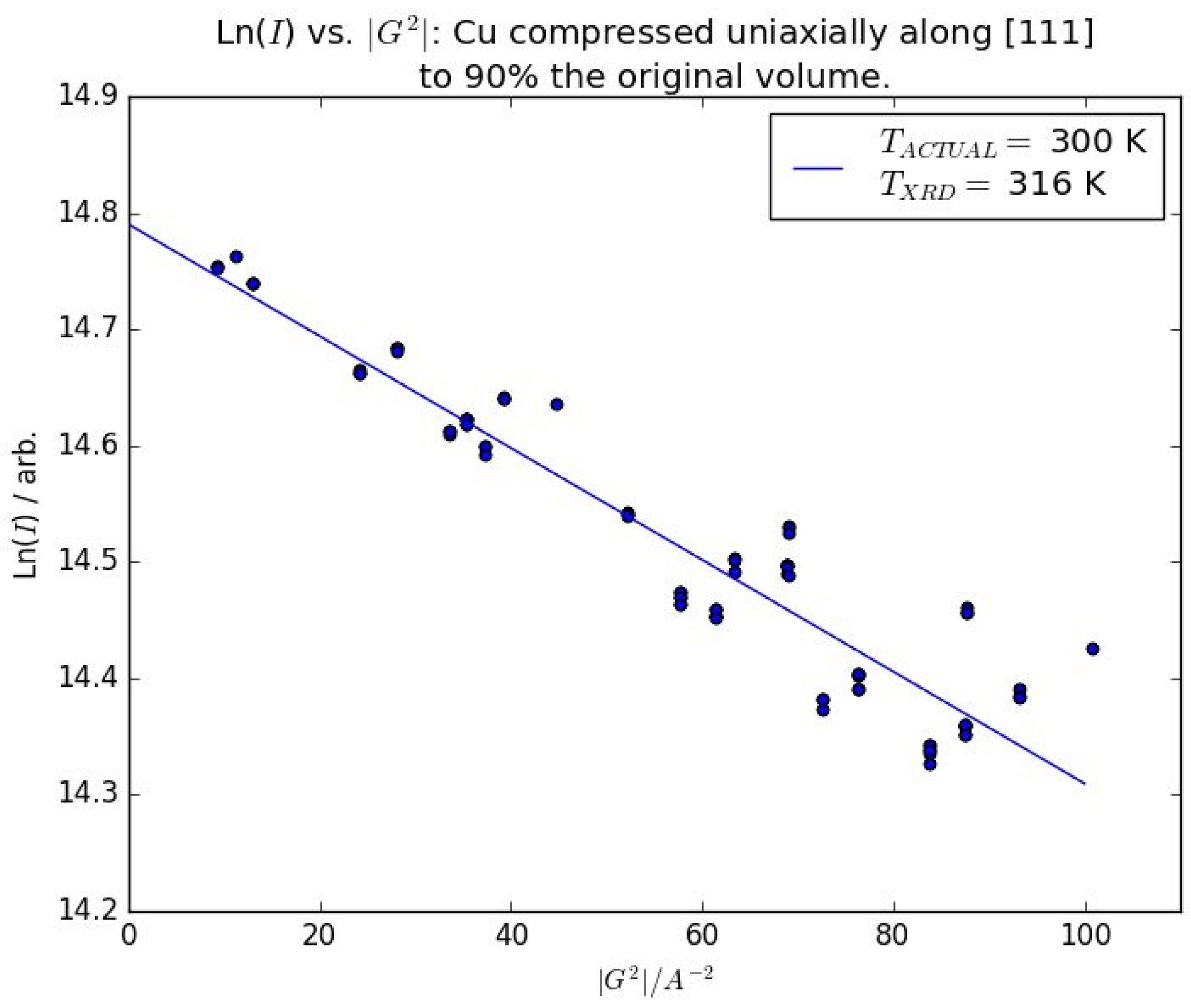

Fig. 3: Anisotropic compression causes the peaks to be dispersed in reciprocal space, but this still gives a reasonable measure of T. The thermometry capability of this scheme seems to be reasonably independent of material strength.

Dislocations and Polycrystals

- Wilkins' [5] line profile analysis techniques suggest that dislocations have little effect on the integrated diffraction intensity; simulations confirming this have yet to be completed.
- Polycrystals are not expected to interfere with the technique.
- A large simulation, with multiple grains, should be plastically shocked. This simulation will act as the closest approximation to experiment.

Future Work

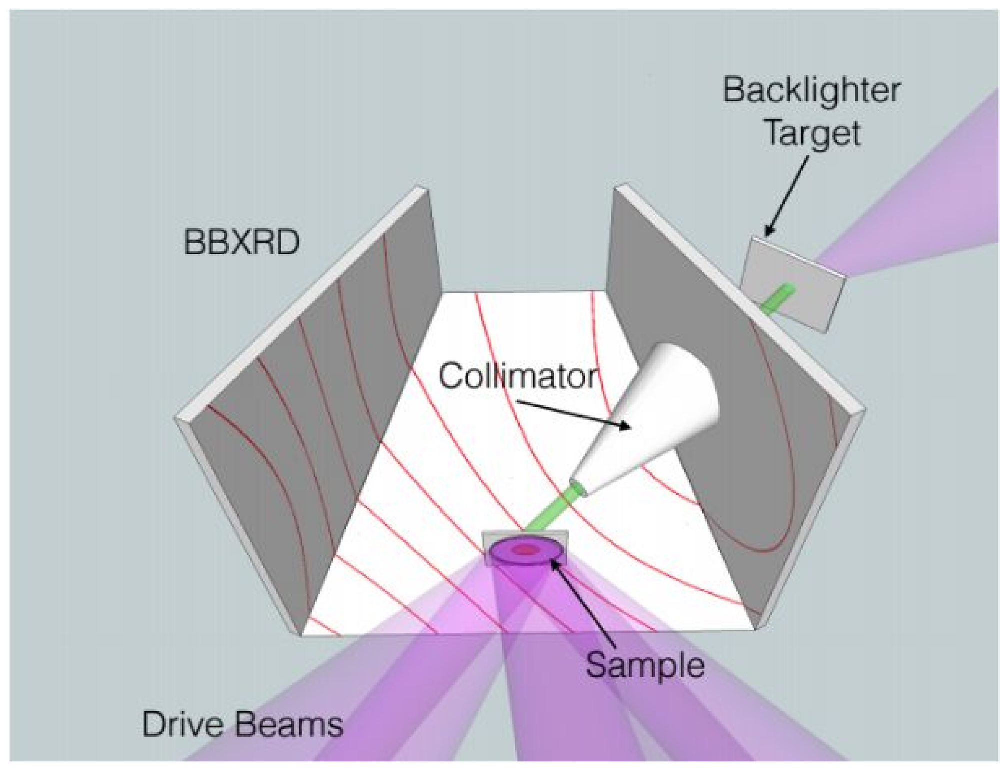

Fig. 4: Experimental geometry for future Orion experiment.

- *X-ray backlighter will be either Cu or Fe.*
- *Sample will be Nb.*
- *Scattered x-rays are collected on image packs which are placed in a geometry optimised for this experiment.*
- *This geometry allows for collection of photons from many locations around the diffraction rings.*

Acknowledgements

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