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Elucidating size effects on the yield strength of single-crystal Cu via the Richtmyer-Meshkov instability

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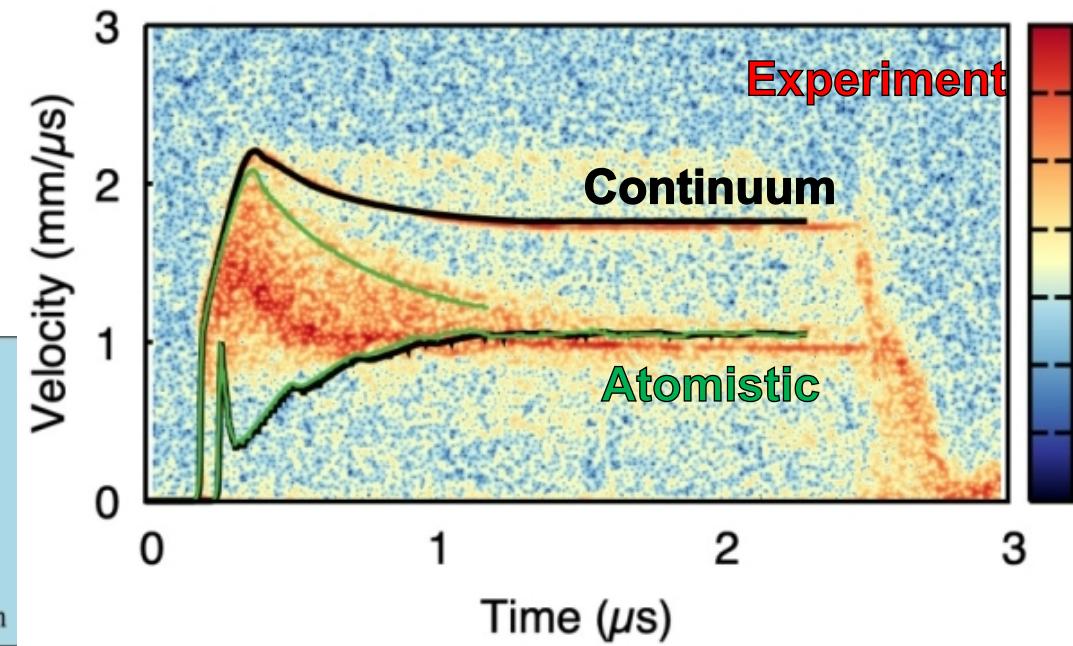
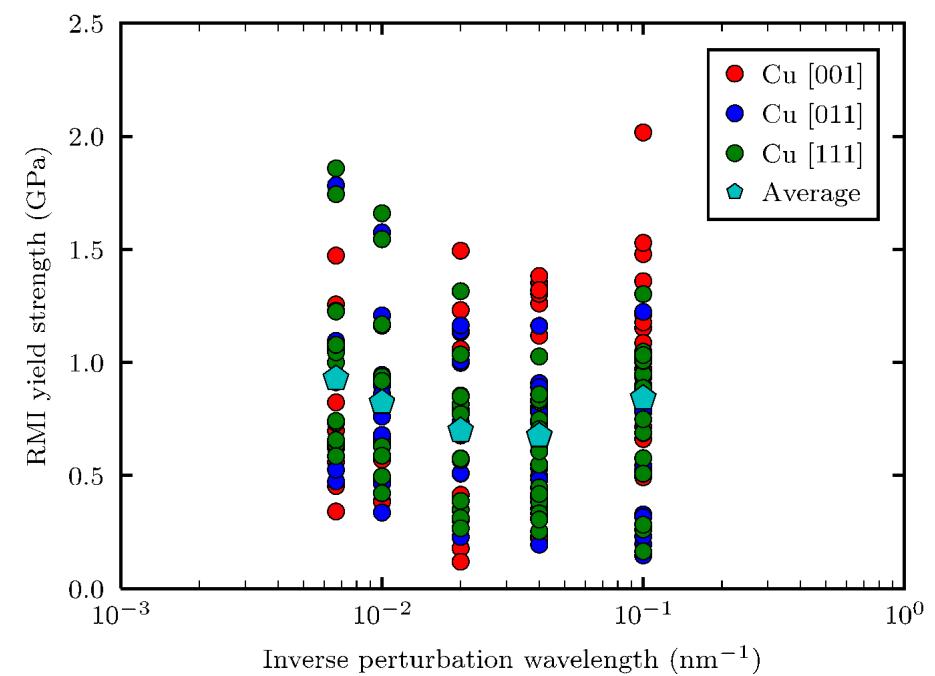
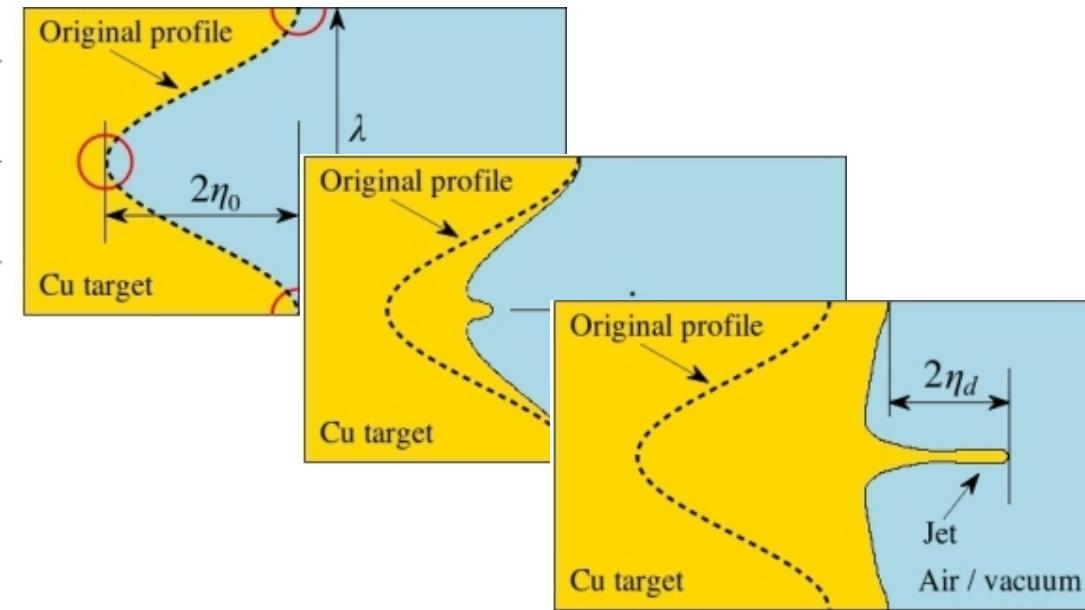
Material Strength at High Strain Rates

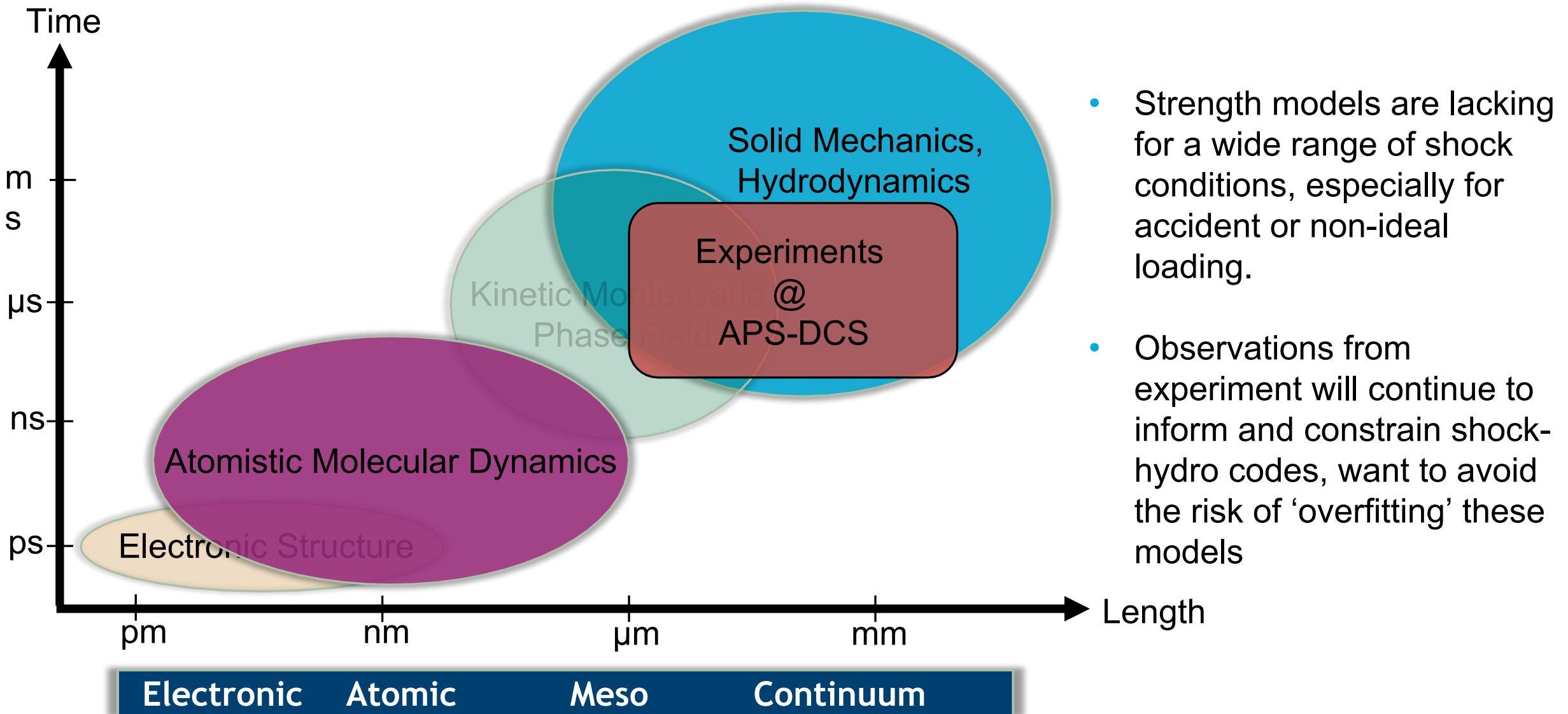


Bottom Line Up Front

- Measurements of yield strength from MD give:

$$Y_{MD} = 0.787 \pm 0.374 \text{ GPa}$$
- Single crystal geometry and size effects (higher strain rates) explain difference to experiments
- Complete map of RMI character generated from simulations, implemented in hydrodynamics code



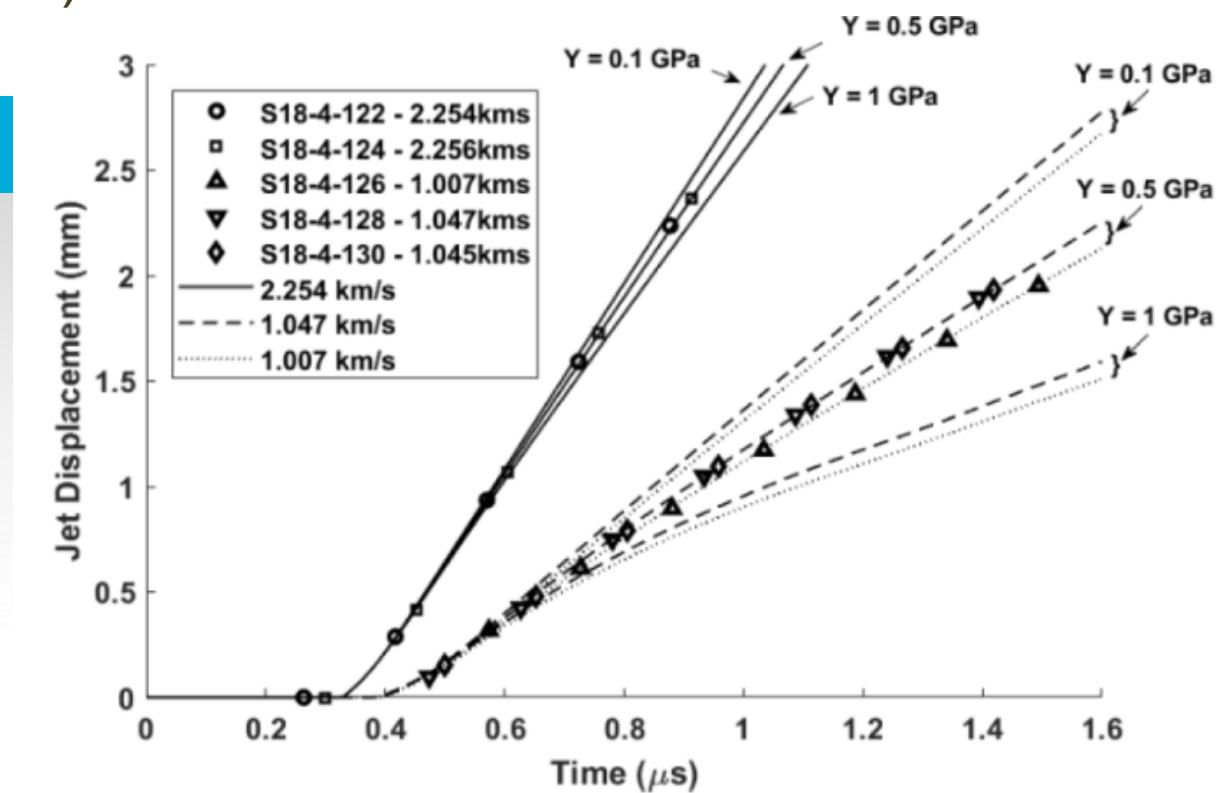
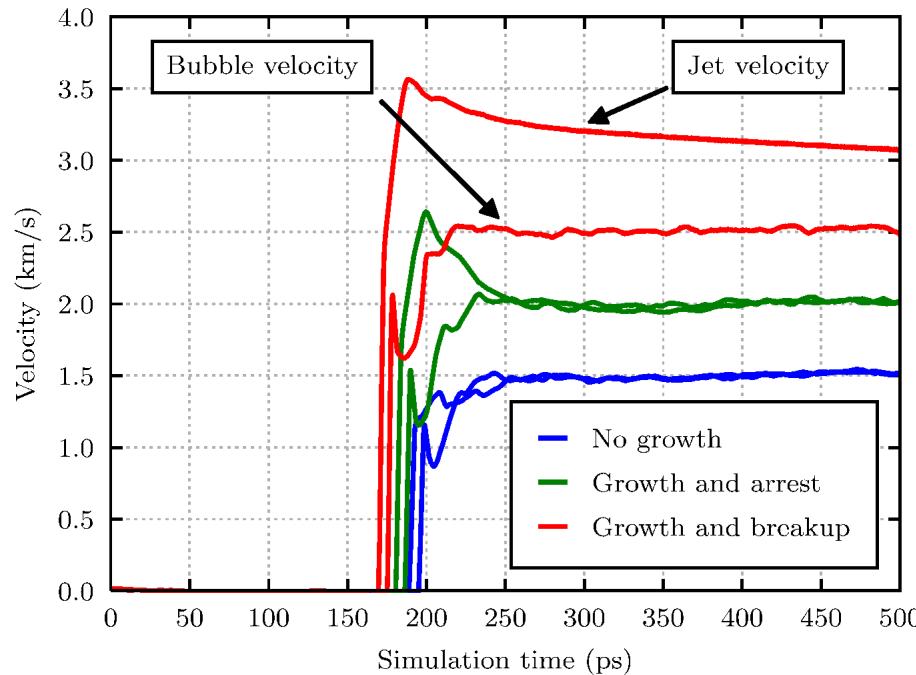


Richtmeyer-Meshkov Instability (RMI)

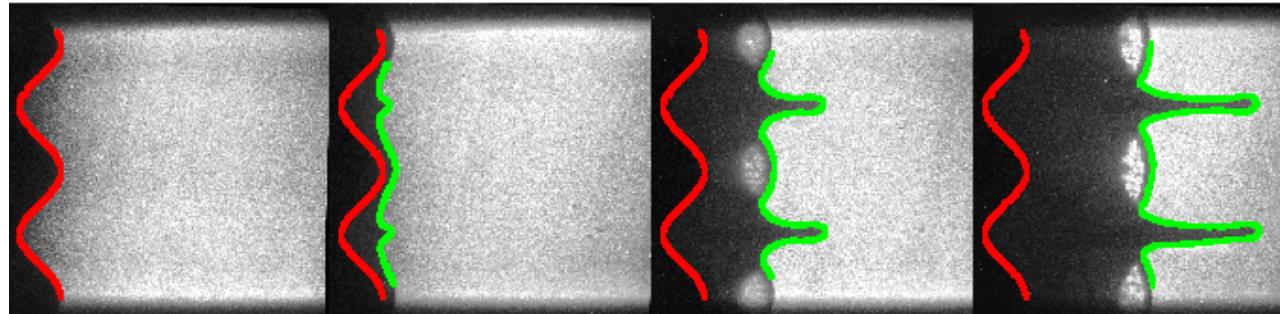


Shocked Metal/Air Interface

- General characteristics:
 - No Growth (weak shock)
 - Growth & Arrest (mid)
 - Growth & Breakup (strong)



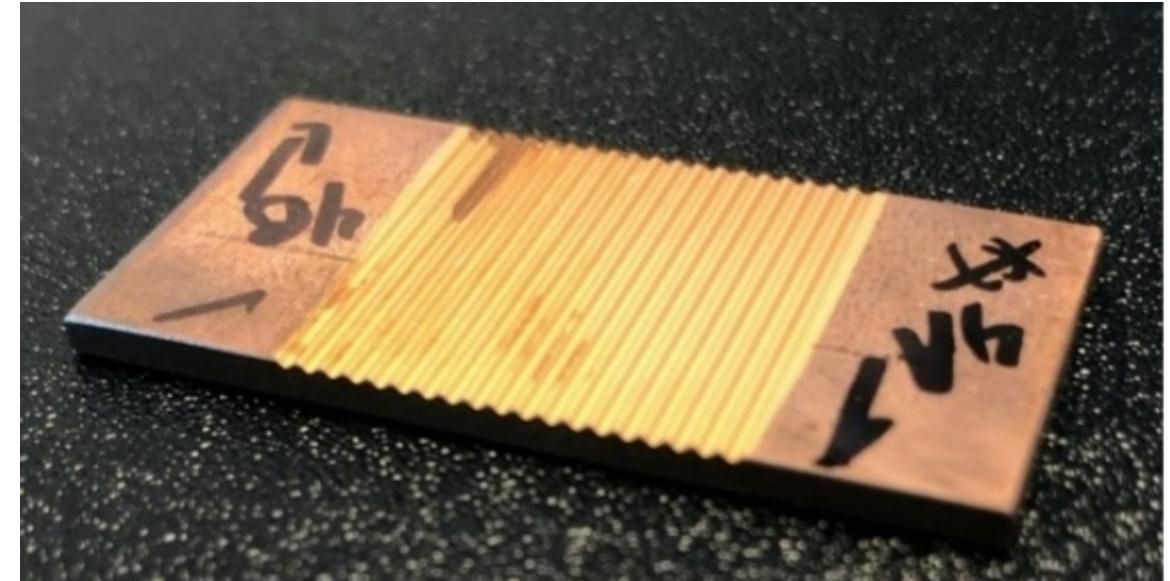
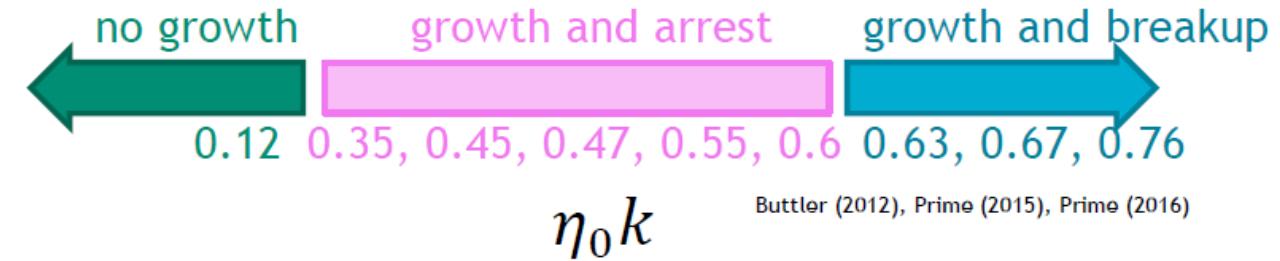
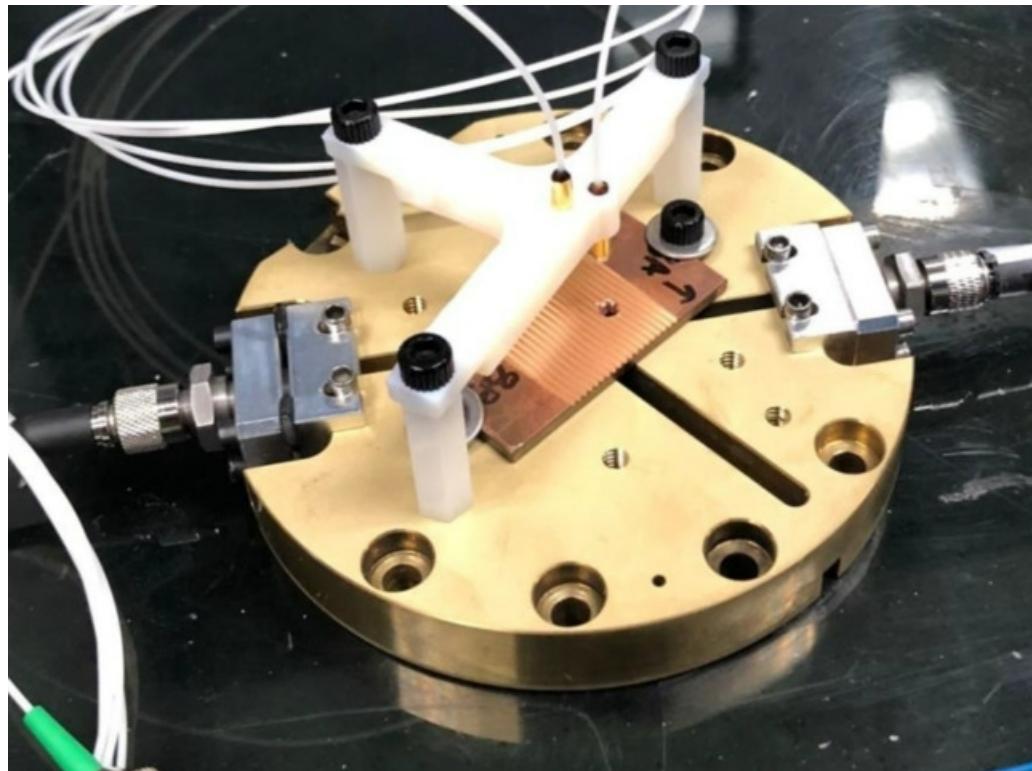
Experiment, strong shock Cu



Common Geometry For Both

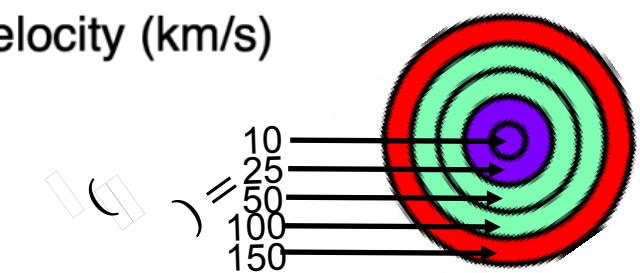
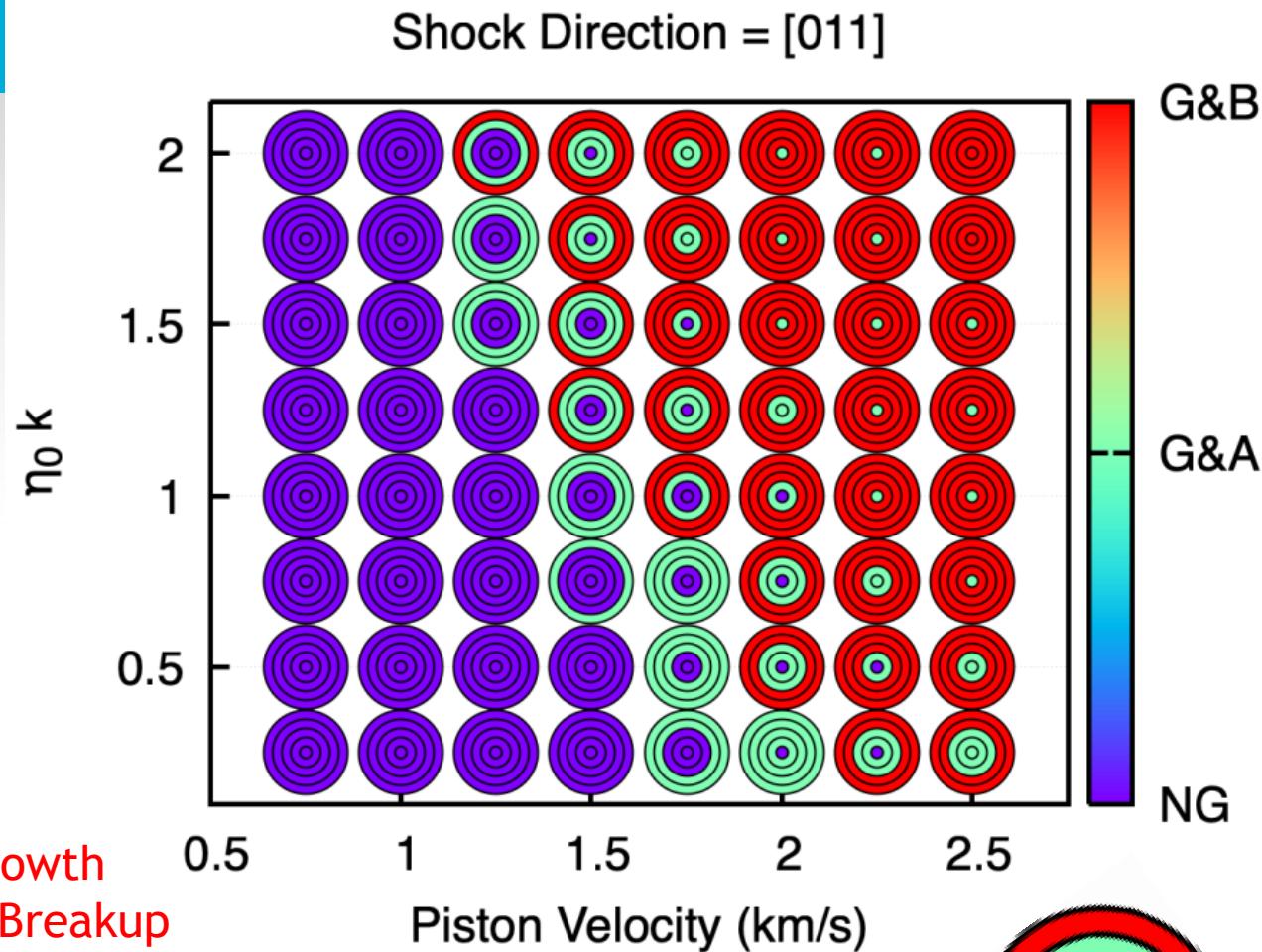
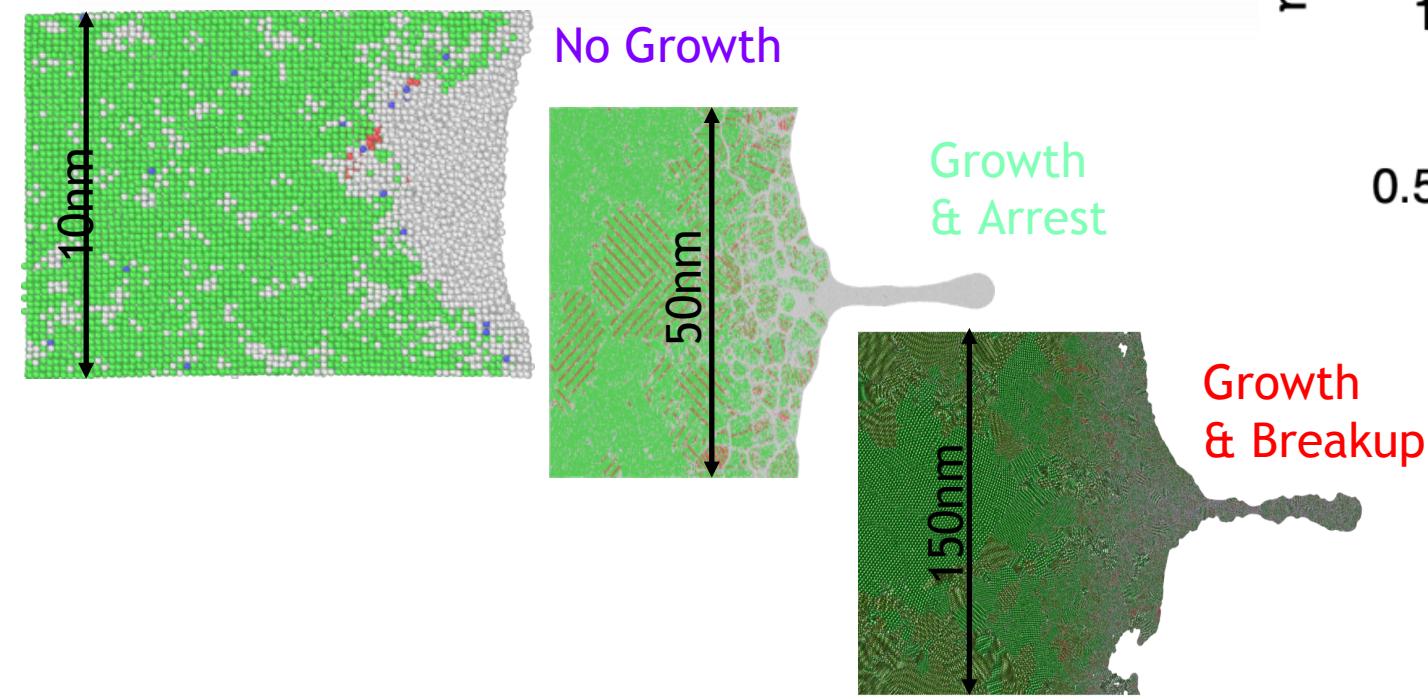


- Scalable experimental design to probe limits of material strength
- Projectile velocities ~ 1.0 km/s or 2.2 km/s which span sub-hydrodynamic up to fluid-like jetting
- **Non-dimensional wave number** $\eta_0 k = \frac{2\pi}{\lambda} \eta_0 \approx 1 \rightarrow$ growth and breakup
- **Atwood number** $At = \frac{\rho_1 - \rho_2}{\rho_1 + \rho_2} = -1$



Computational Discovery

- Under what conditions is there is size dependent response?
- Generated labels by hand to ensure accuracy
- [001], [011] and [111] tested



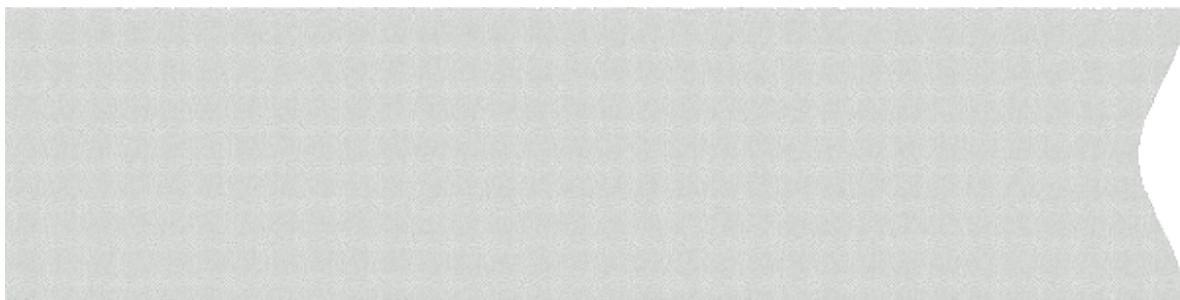
7 Predictions in Continuous Space



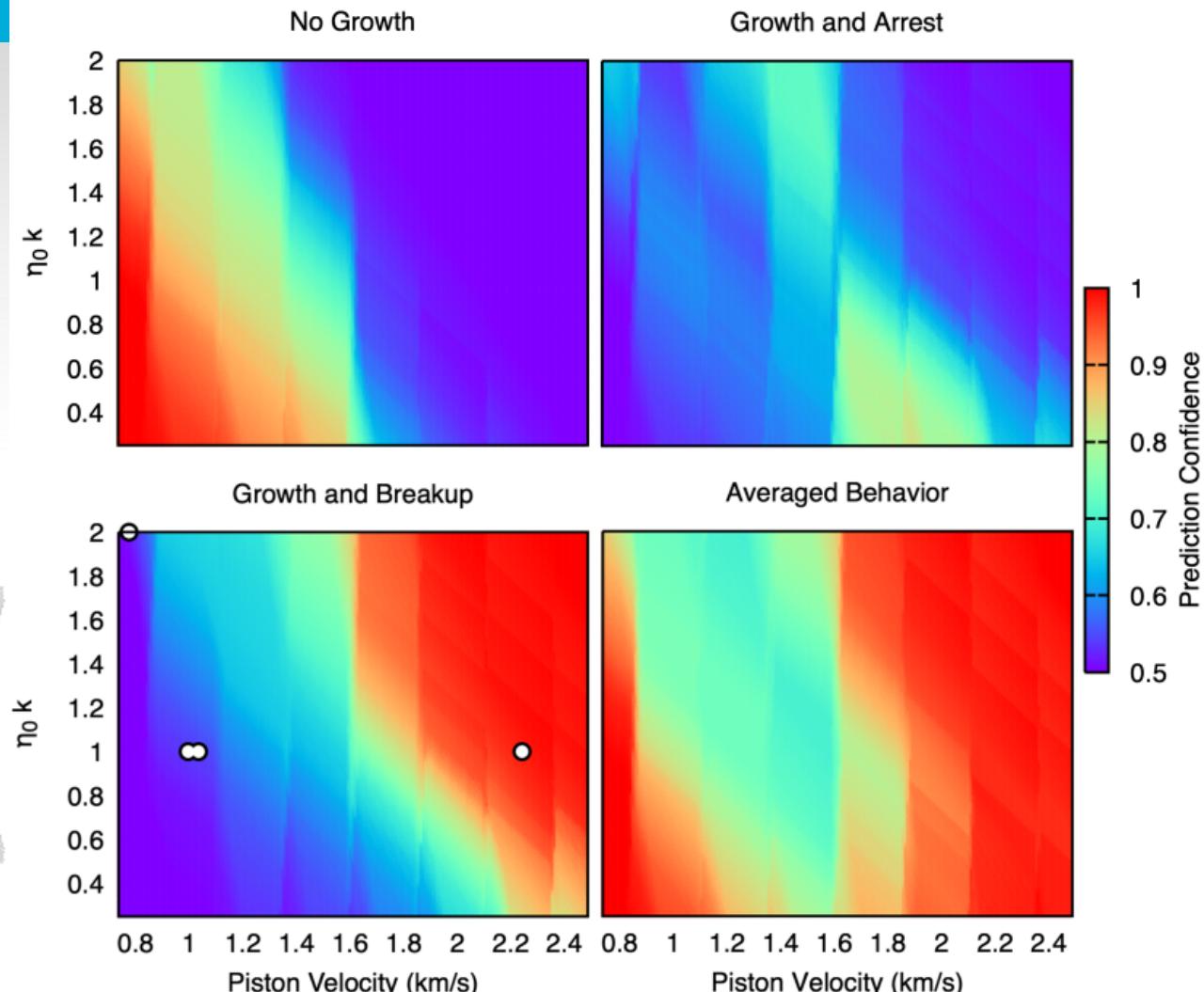
Excess Data

- How to plan future experiments?
- Neighborhood clustering of labeled responses, all orientations and sizes used.
- Known G&B response from experiments given as white circles

G&A wanted for strength estimates:



Compression  Tension



8 Atoms to Continuum



Assume Elastic-Perfectly-Plastic

- Following Dimonte *et. al.* PRL (2011) and Piriz *et. al.* PRE (2008);

$$2\eta_d k = A \rho_0 |\dot{\eta}_{max}|^2 / Y + b$$

- Fit to G&A where $\dot{\eta}_{max}$ is defined gives

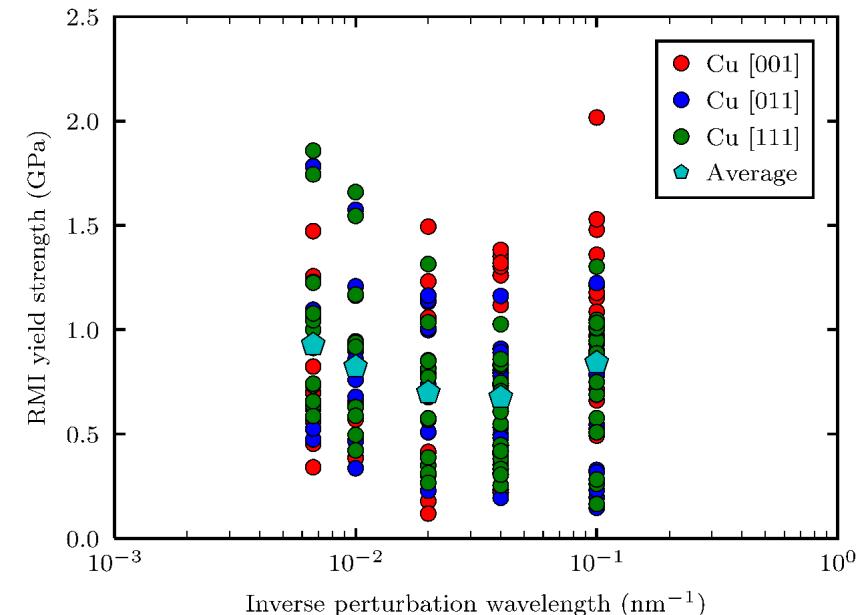
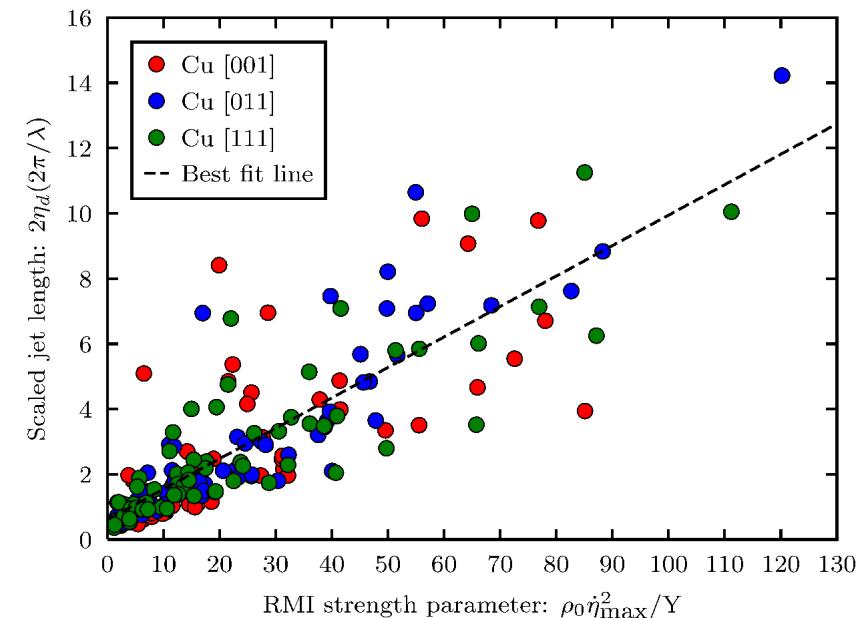
$$Y_{MD} \sim 0.09336 \rho_0 |\dot{\eta}_{max}|^2 / 2\eta_d k$$

- Averaging over all orientations and geometries;

$$\frac{\square}{\square} = 0.787 \pm 0.374 \frac{\square}{\square}$$

- Tuning of Y to match G&B from experiment;

$$\frac{\square}{\square} = 0.460 \frac{\square}{\square}$$

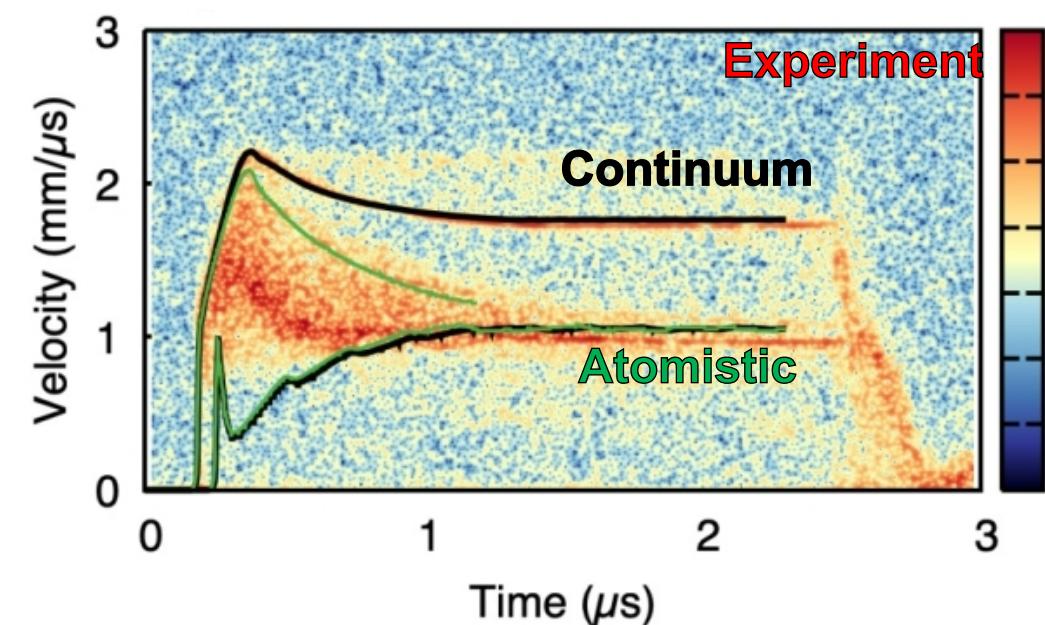
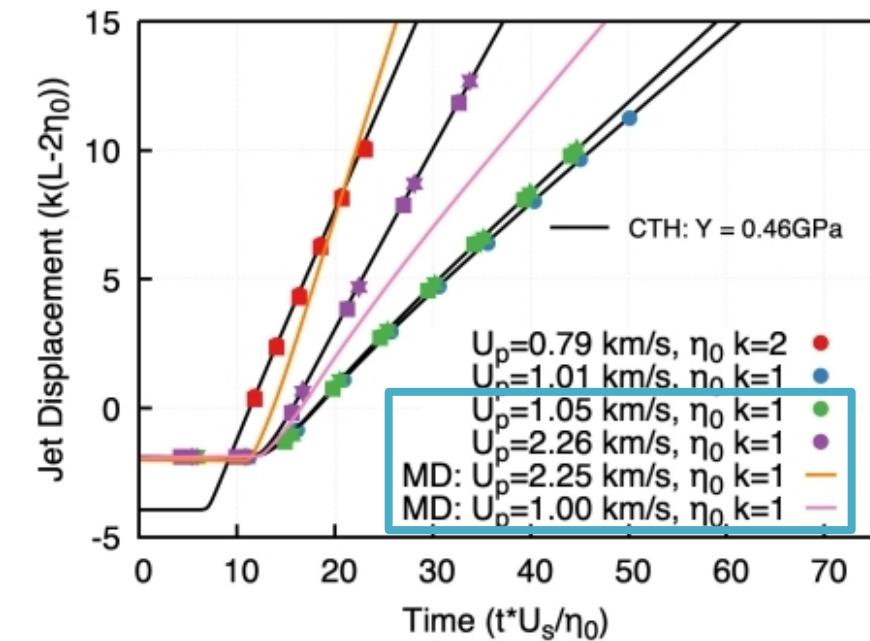
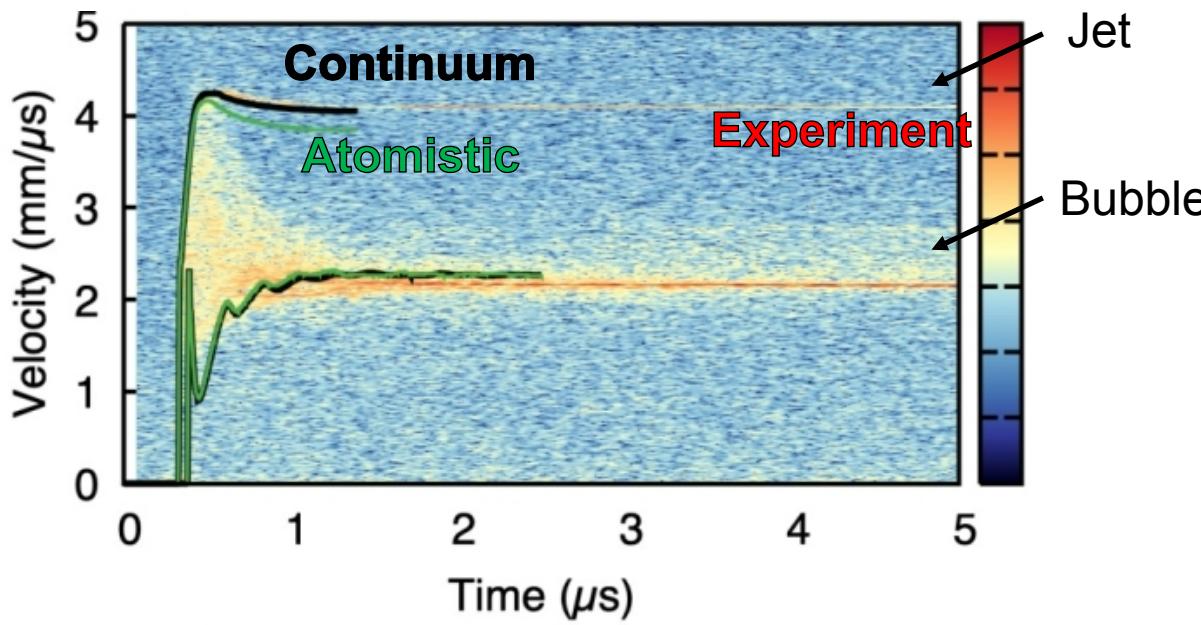


9 Scaling up Strength



Dimensionless Analysis

- Length $\sim k(L - 2\eta_0)$
 - Jet length scaled by initial peak height
- Time $\sim t \cdot U_s / \eta_0$
 - Shock wave transit across surface perturbation
- Implementing into CTH, no size dependence unless using a strain-rate dependent strength model





Results and Significance

- Observations from experiment will continue to inform and constrain shock-hydro codes, want to avoid the risk of 'overfitting' these models
- Map of RMI character for Cu can be reasonably transferred to other FCC metals of similar ductility (Al, Ni, etc.)
- MD parameterized strength resulted in velocity profiles of jet and bubble regions in close agreement with experiments without the need of user-driven tuning of yield strength.
- Small zones necessitate advanced strength and damage models



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COLLECTIONS

Paper published as part of the special topic on [Shock Behavior of Materials](#)



References:

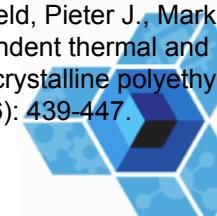
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LDRD

Laboratory Directed Research and Development

Internal Length Scale of Polymers

