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SAND2022-5550C

Grain Boundary Sliding and Low Friction in Metals

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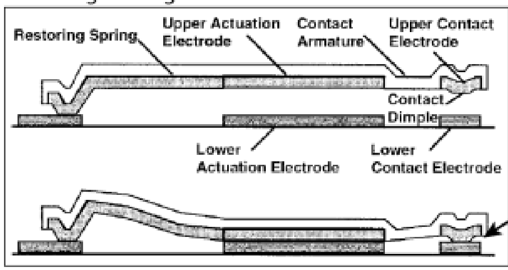
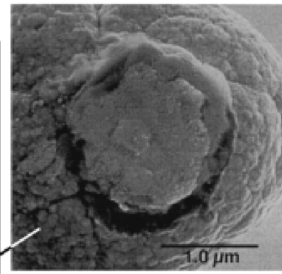
Electrical Contacts use Bare Metal

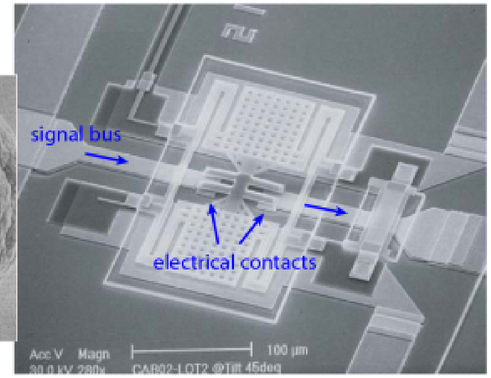
RF Micro Electromechanical Systems (MEMS)

switching GHz signals





Source: D. Hyman and M. Mehregany, IEEE Trans. & Pack. Tech. 22-3, 1999

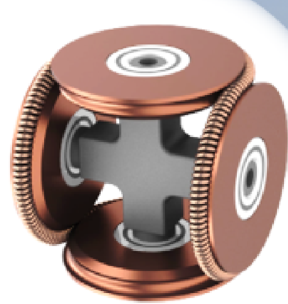


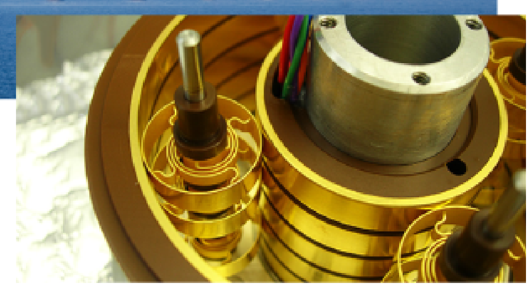
Source: Rockwell Scientific metal-metal switch

Phone Interconnects

Electronics (e.g. PCB blade connectors):
200 - 500 nm thick electroless hard gold

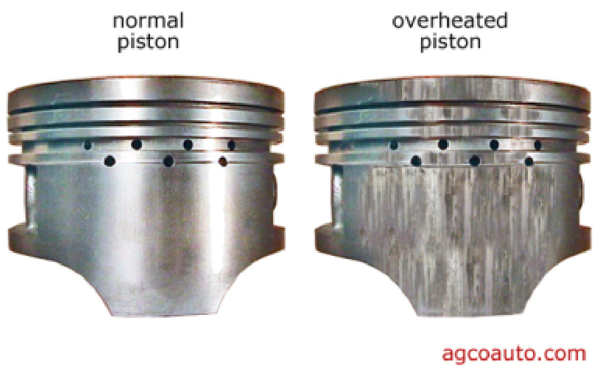
Aerospace and Energy





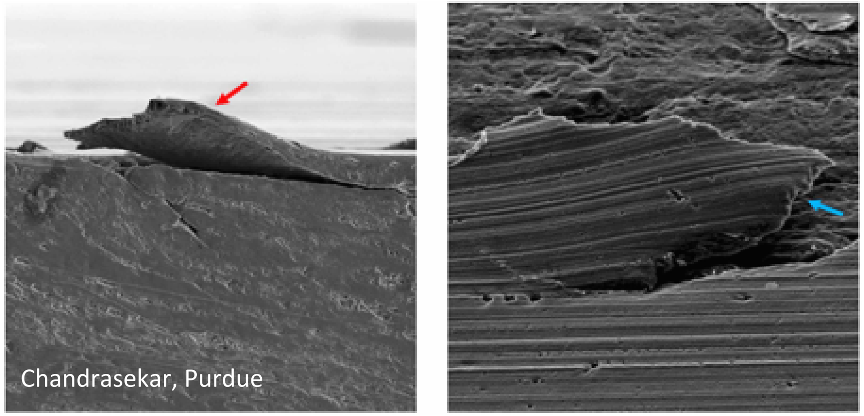
Source: Honeybee Robotics (http://www.honeybeerobotics.com/portfolio/rolling-contact-connector/)

Metals are Ductile and Sticky



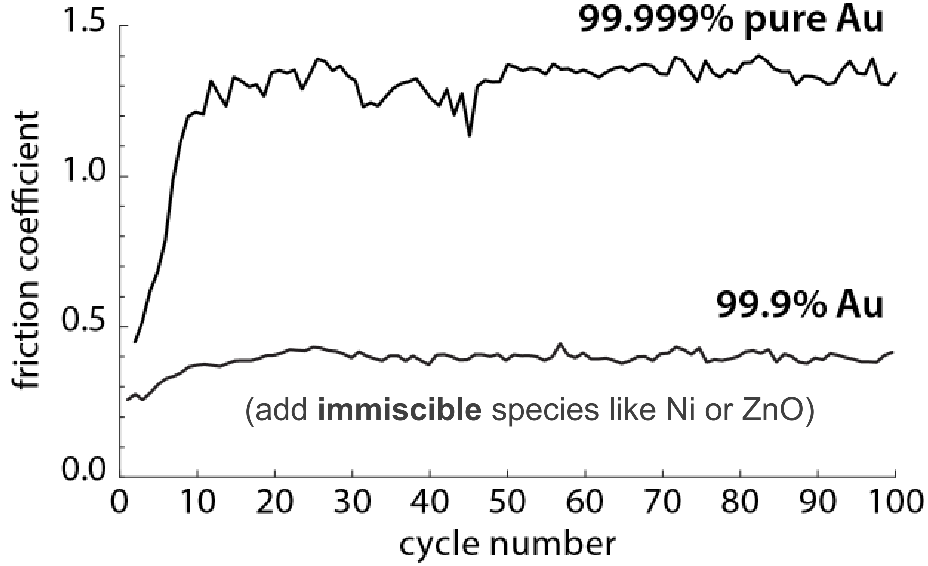
Materials	μ
Aluminum/Aluminum	1.2
Copper/Copper	1.0
Nickel/Nickel	0.9
Rubber/Asphalt	0.9
Waxed Ski/Snow (0° C)	0.05

- Sliding metal contacts are everywhere
  - Electrical interconnects
  - Wind turbines
  - Hip replacements
  - Car Engines (~12% loss)
- High adhesion and friction
- Lots of plasticity and wear



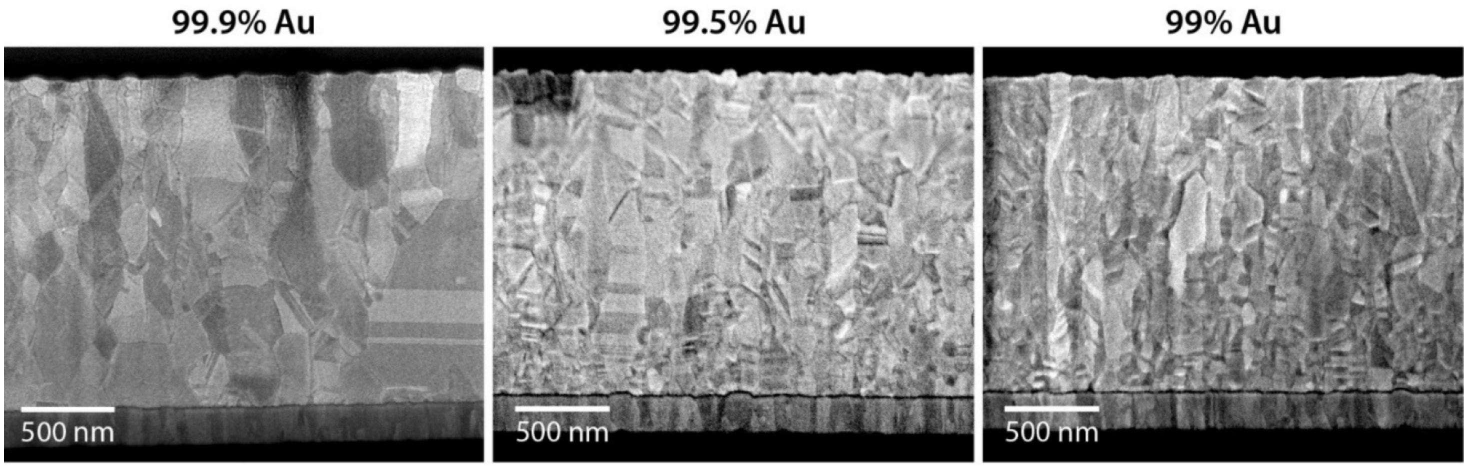
Reduced Friction and Wear of Nanocrystalline Metals

Alloying reduces friction coefficient:

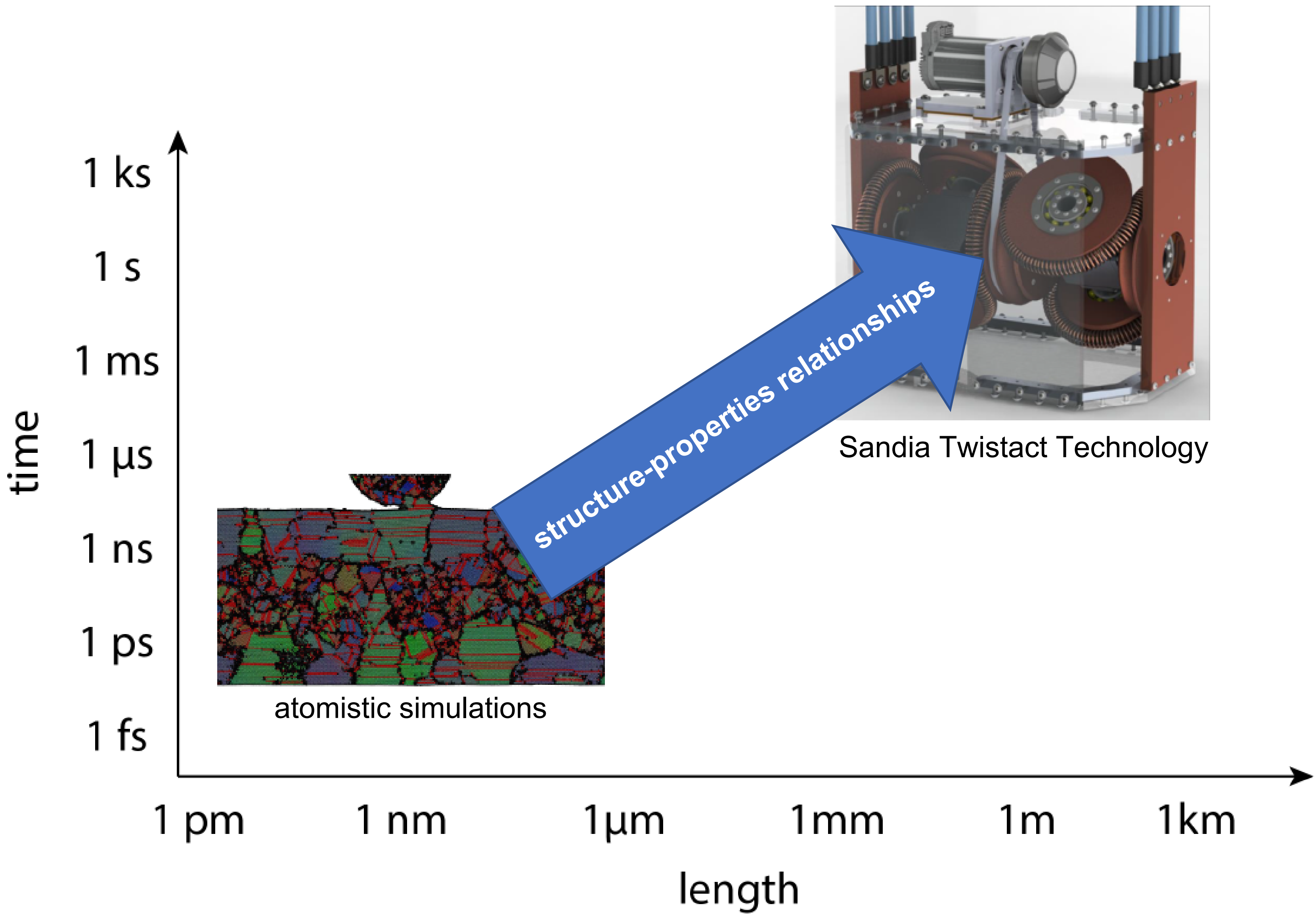


Alloying improves
friction & wear performance by reducing
and stabilizing grain size

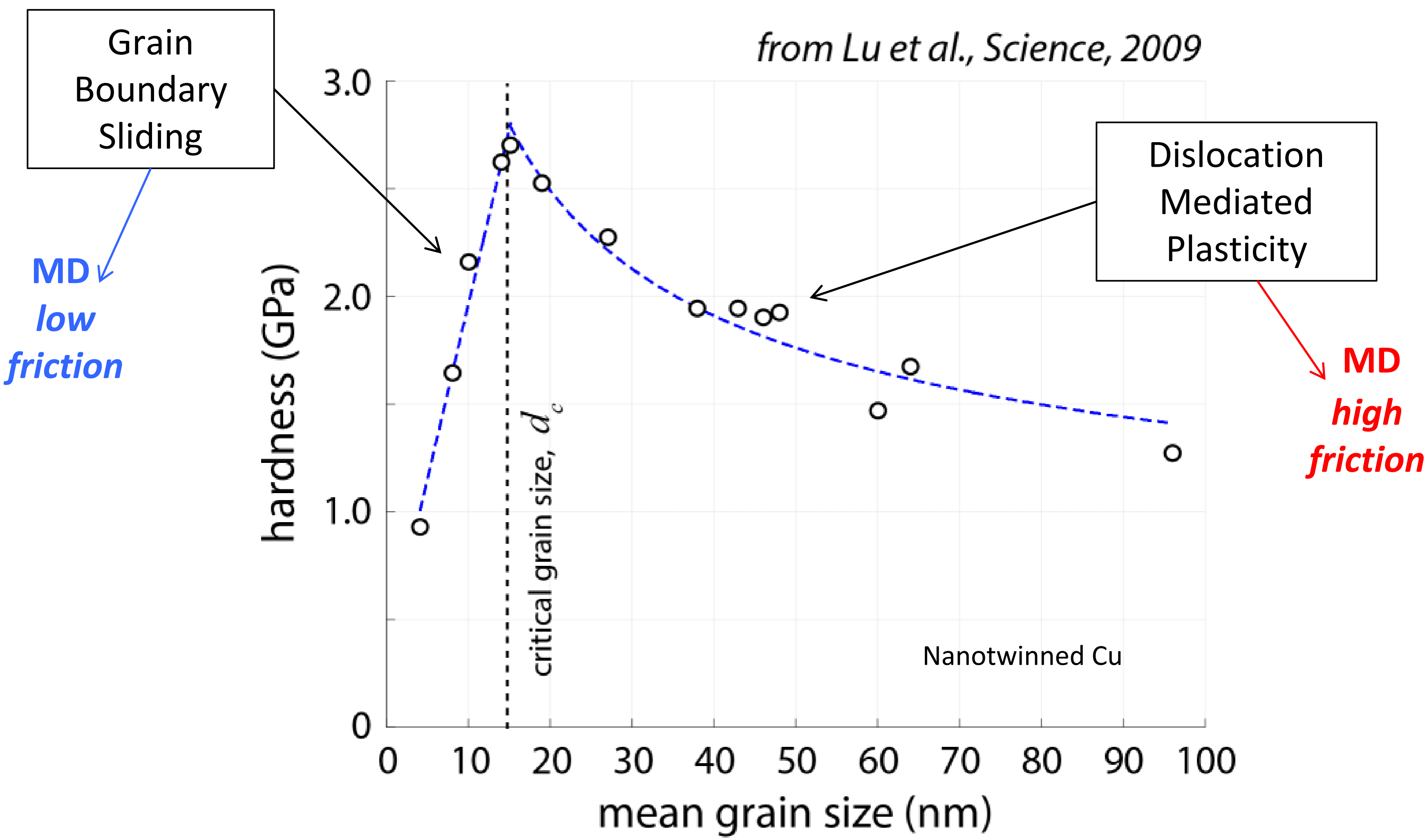
…by reducing grain size:



Bridging the Gap from Atomistic Modeling to Macroscale Applications

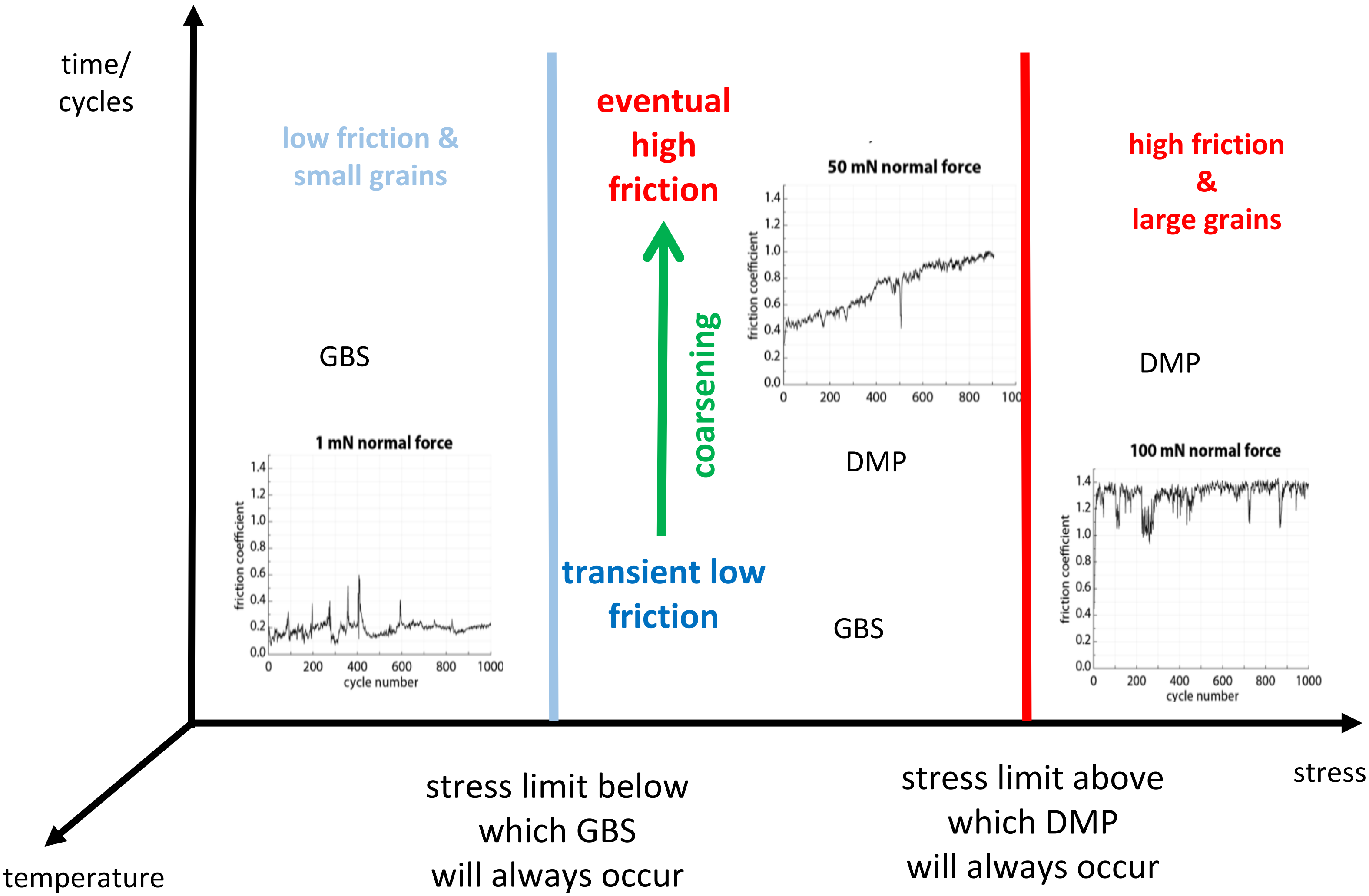


Grain size and Materials Properties

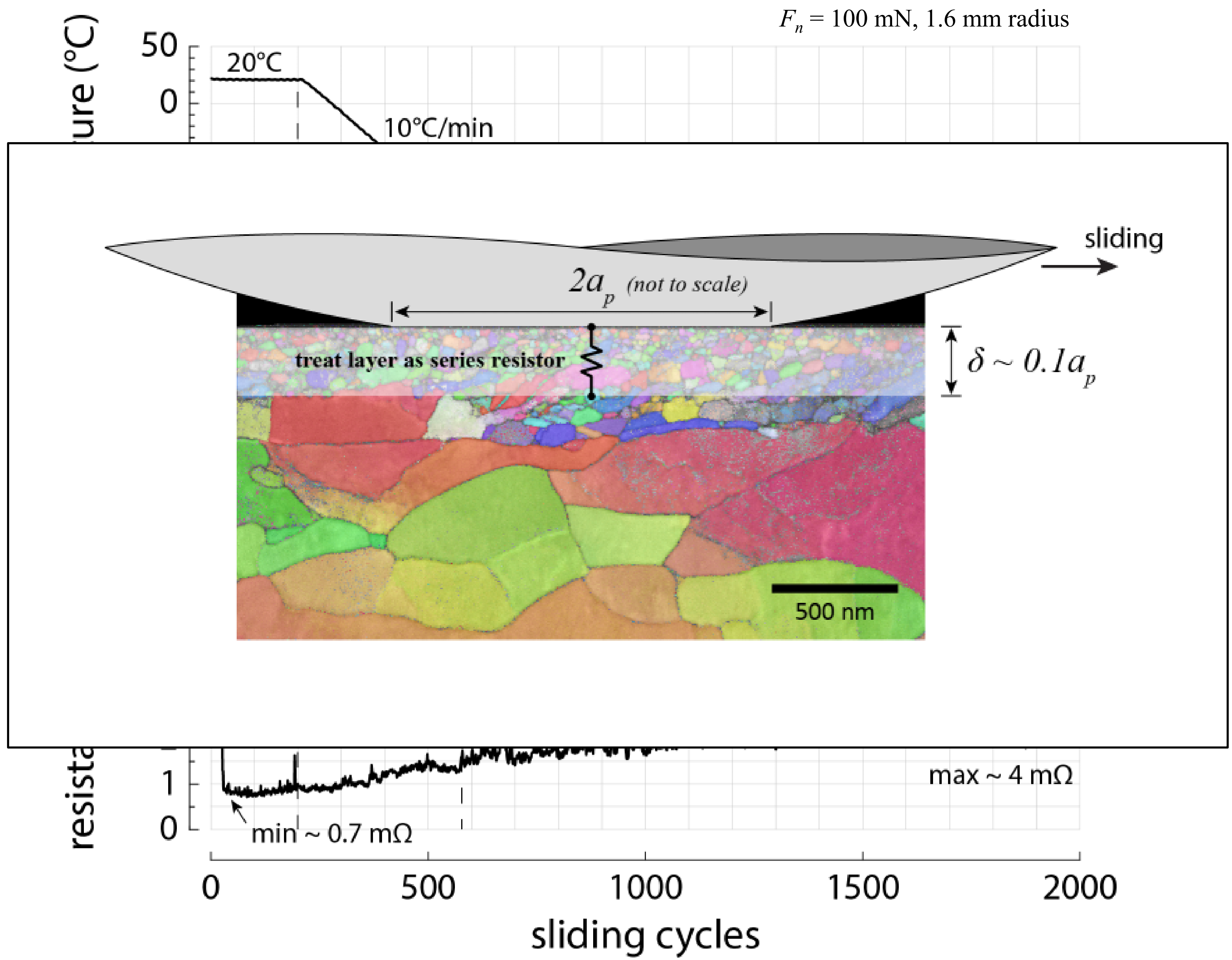


Generalized Friction Map for Metals

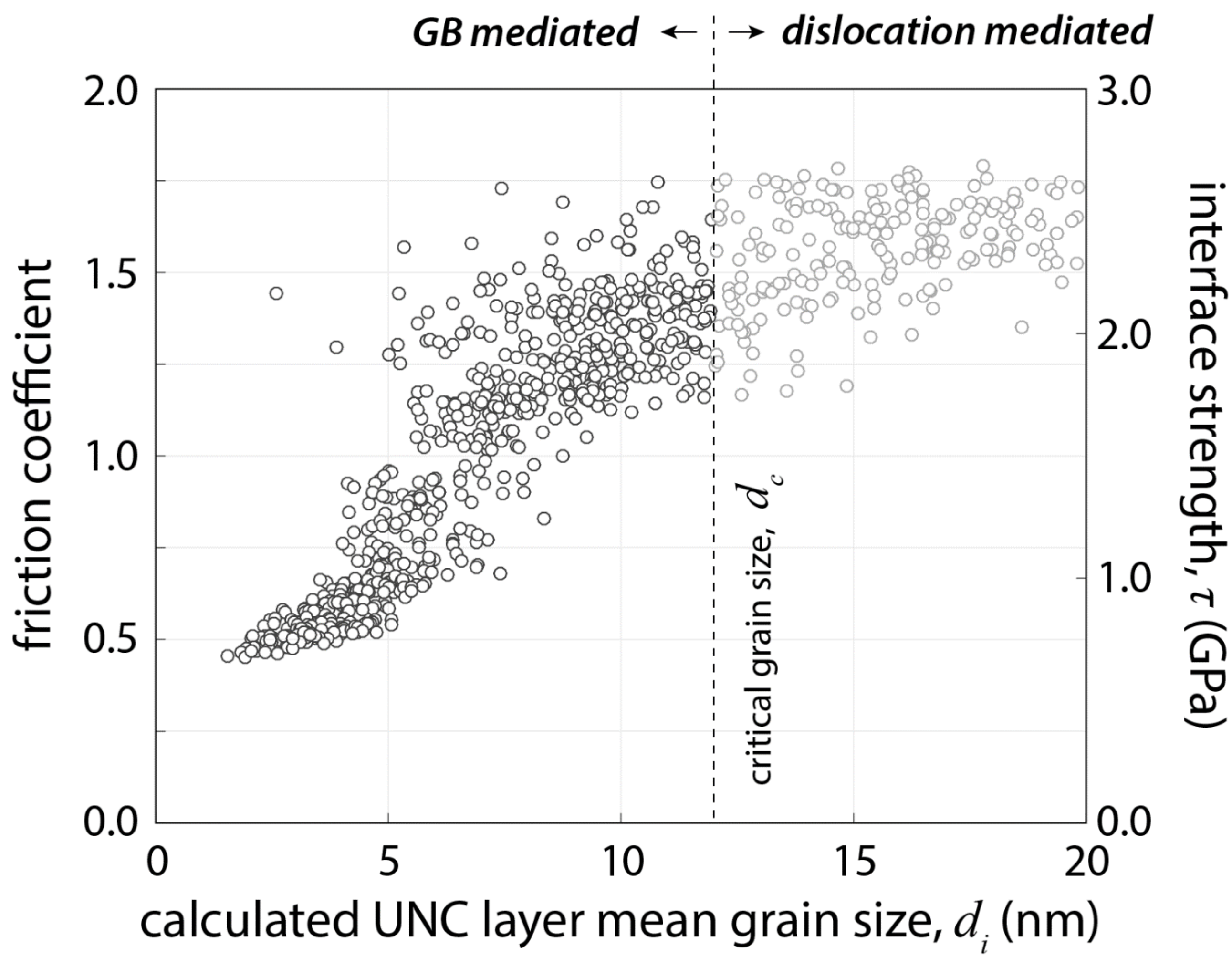
Argibay, Chandross, Cheng, Michael; J. Mater. Sci. (2017)



Evidence for GBS as a Low Friction Mechanism

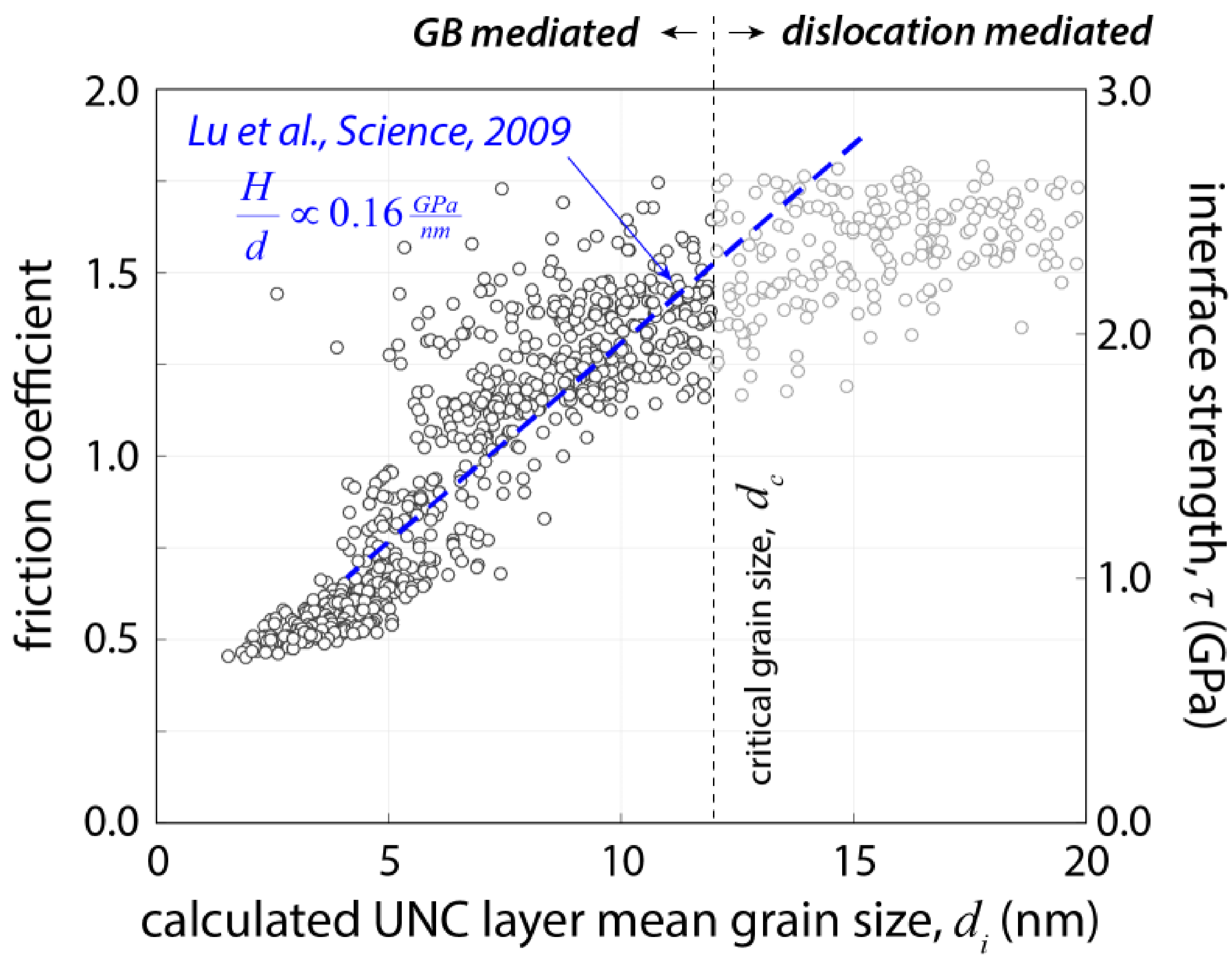


Direction Connection between Friction and Grain Size



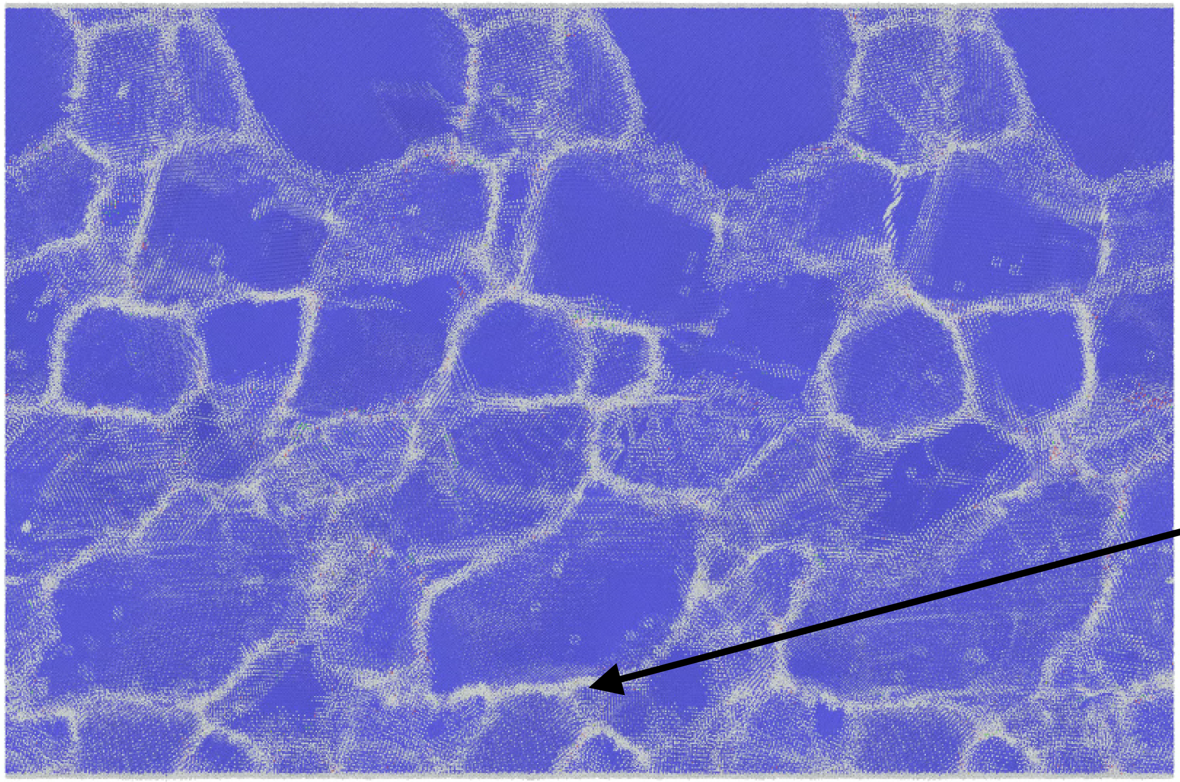
Direction Connection between Friction and Grain Size

Chandross, et al. *Scripta Mat* .(2017)



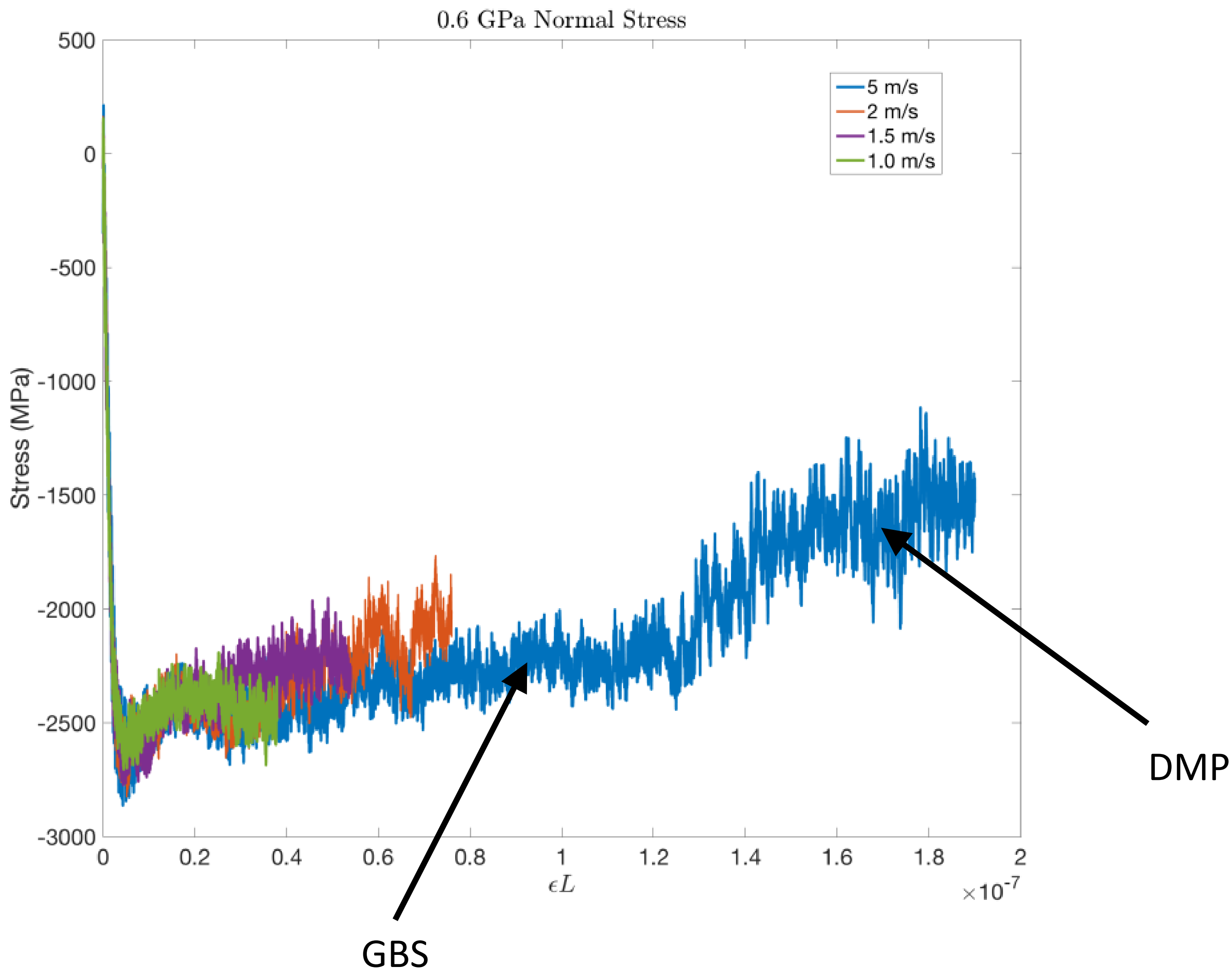
First evidence of (1) grain size dependent friction and (2) inverse H-P linked to low friction. Also, provides validation of inverse H-P behavior of metals.

Evidence of GBS in MD simulations (Ta)

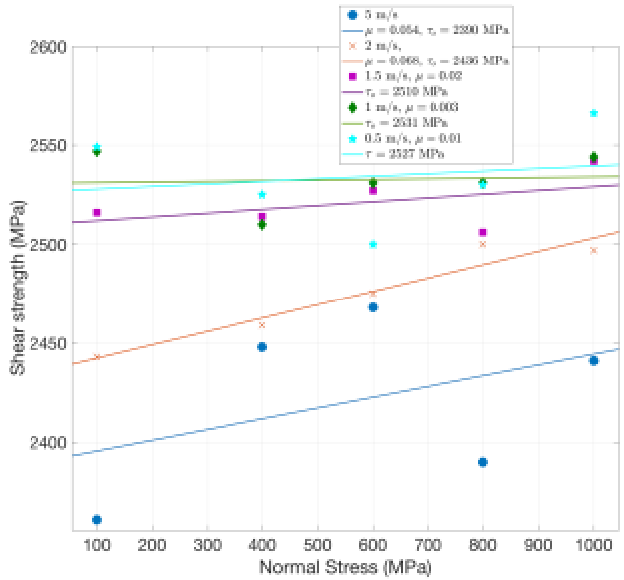


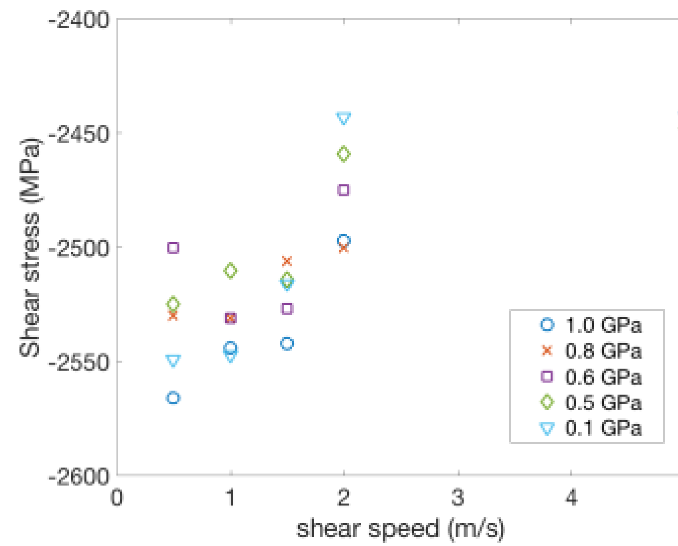
Grain boundary sliding here

Stress is different between GBS and DMP

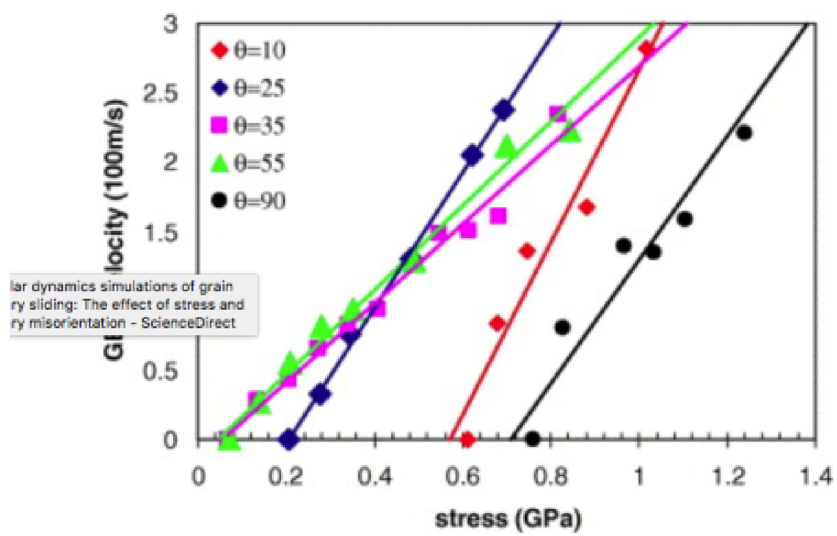


Link Between GBS and Friction



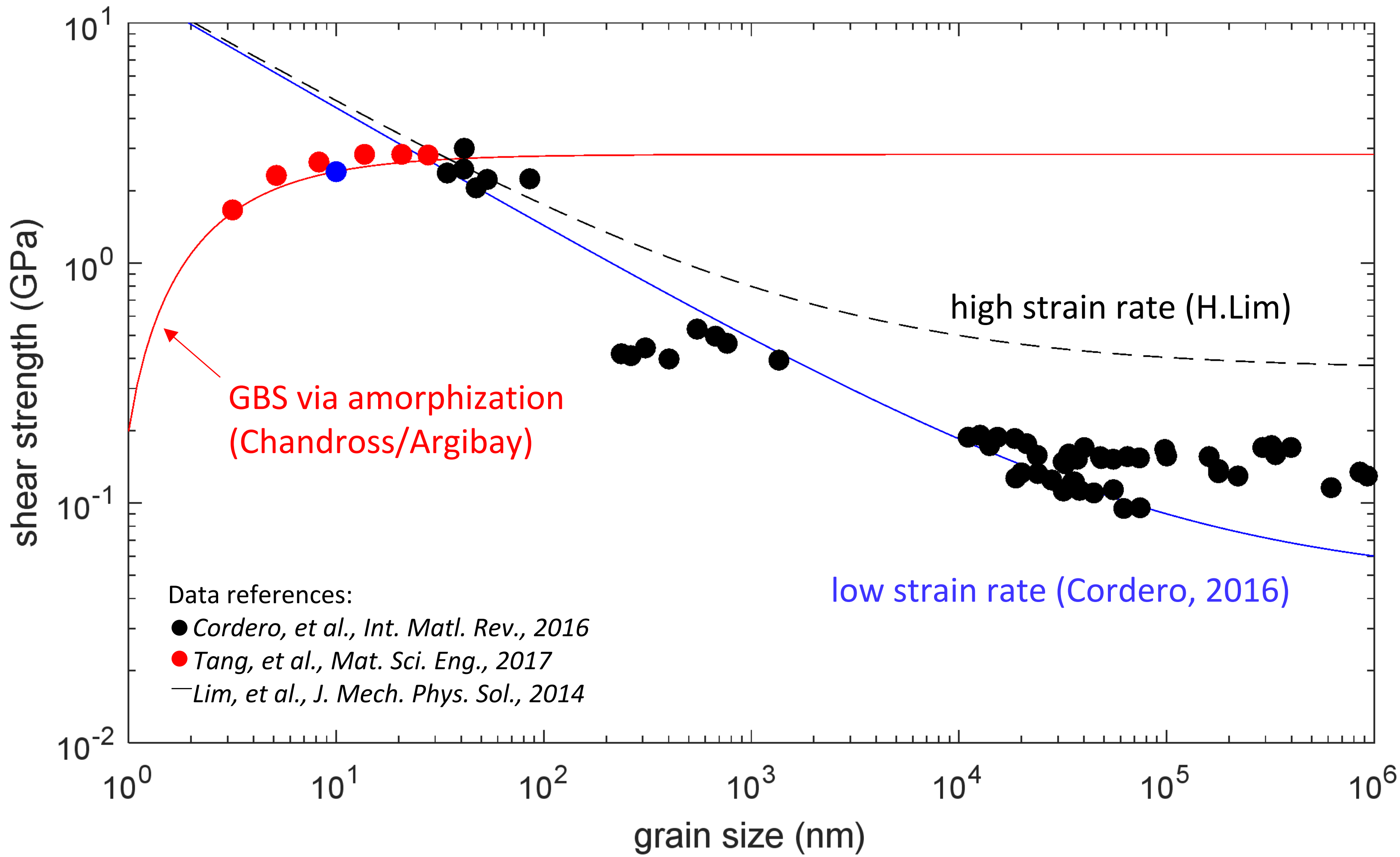


- Simulations clearly show GBS
- Linear dependence of shear strength on velocity or shear rate
- Also seen by other groups



Qi and Krajewski, Acta Mat. 2006

A New Model Predicts this behavior



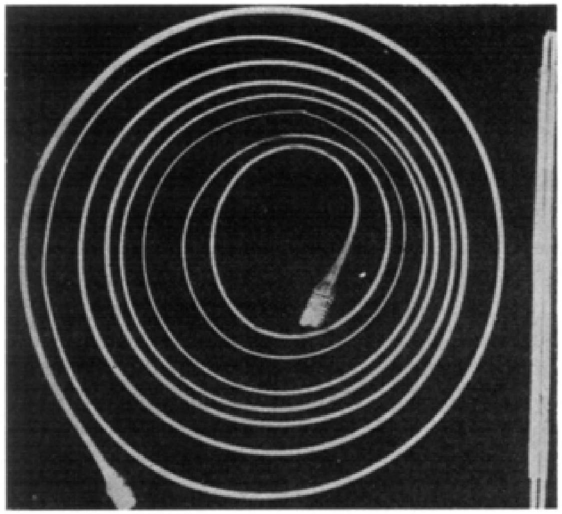
Conclusions

- GBS is linked to inverse H-P and low friction
  - Experiments @ cryogenic temperature
  - Experiments with stabilized boundaries
    - Pure metals
    - Stable NC alloys
  - Simulations on alloys w/ stable boundaries

- Tribological experiments maintain inverse H-P regime
  - High strain rates
  - Repeated contact

- Link to superplasticity
  - Linear strain rate dependence
  - Implies new potential for friction models

Link Between GBS and Superplasticity



Edington, J.W., K.N. Melton, and C.P. Cutler. "Superplasticity." Progress in Materials Science, 1976

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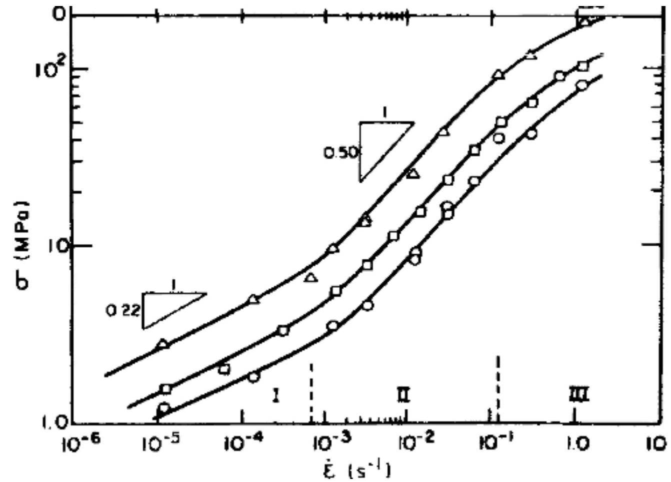
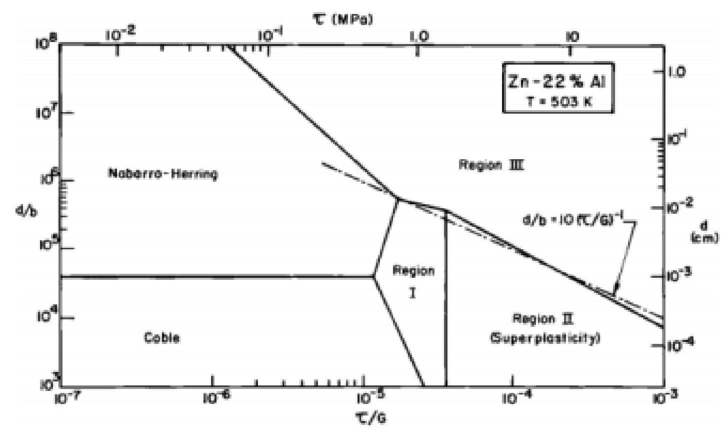


- General equation:
- When m=1, pure GBS $\dot{\varepsilon}^m = K(\sigma_f - \sigma_0)$
- Implies: $\varepsilon = \frac{\sigma_f - \sigma_0}{\eta}$ with η as a GB viscosity



Langdon, J. Mater Sci. 2006

Link Between Superplasticity and Friction?

$$F_f = \tau A$$ ← Classic Bowden & Tabor friction formula

Expand $\tau = \tau_0 + \alpha P + \beta \varepsilon^{\dot{m}}$

$$F_f = \tau_0 A + \alpha F_N + \beta A \dot{\varepsilon}^m$$

$$\tau_f = \tau_0 + \alpha \sigma_N + \beta \varepsilon^{\dot{m}}$$ ← fundamental shear strength of an interface

At $F_N = 0$

$$\tau_f = \tau_0 + \beta \dot{\varepsilon}^m$$

$Or: \dot{\varepsilon}^m = K(\tau_f - \tau_0)$ ← Superplasticity! (when m > 0.3)

- Extension of Bowden & Tabor's fundamental friction model
- Recovers superplasticity equations at $F_N=0$
- No refinement: all grain boundary sliding!