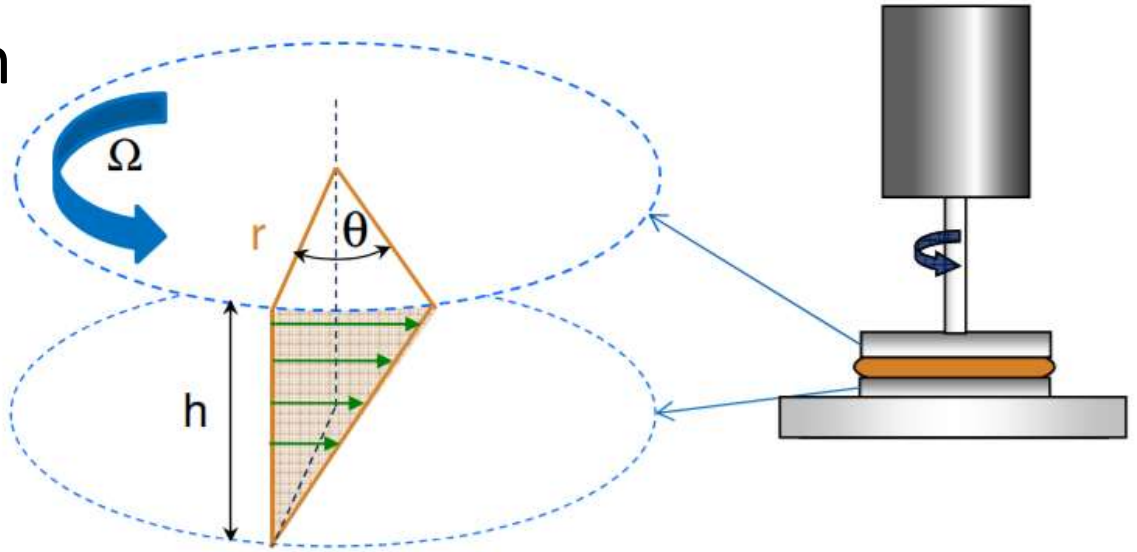
Measuring Local Shear Stresses in Wormlike Micelle Flow

Kevin Liu, Steven Hudson, and Paul Salipante

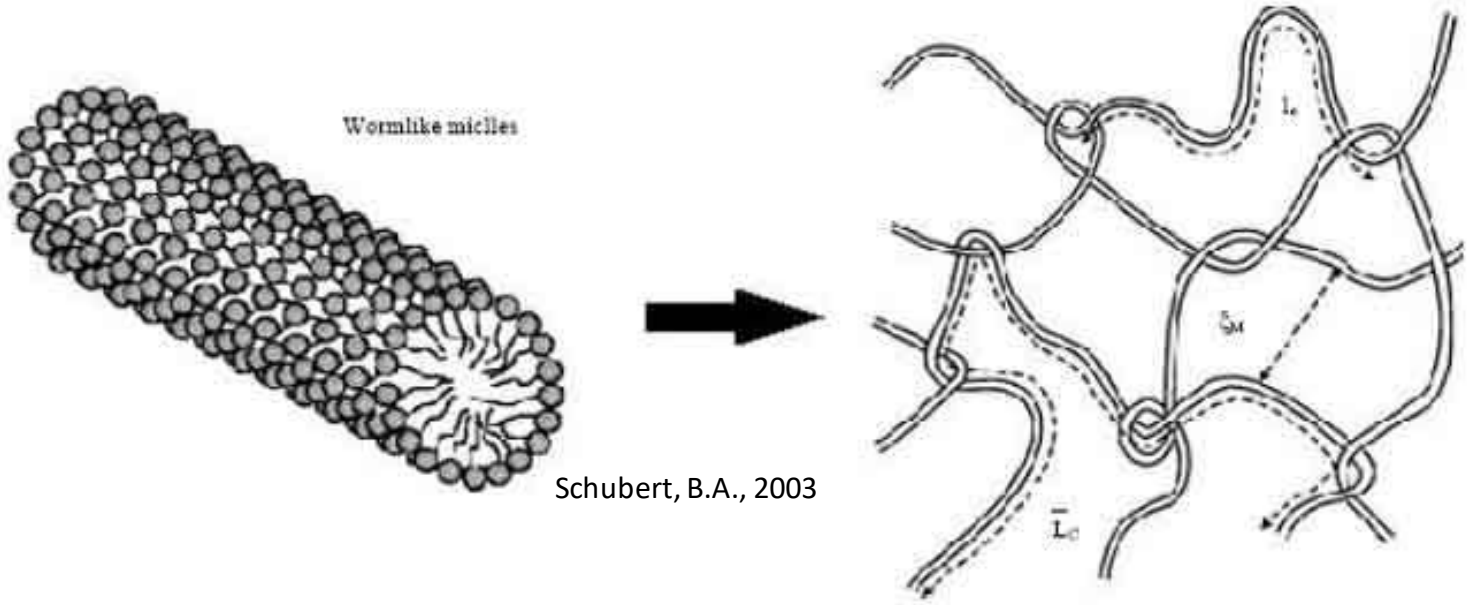
Fluid Flow

- Layers of fluid are sliding past each other
- Shear stress (Pa) is a function of torque (N·m)
- Shear rate (s^{-1}) is a function of Ω, the angular velocity ($rad \cdot s^{-1}$)
  - $\dot{\gamma} = K_{\dot{\gamma}} * \Omega$
  - Shear rate is NOT equivalent to flow rate



TA Instruments

Wormlike Micelles (WLM)

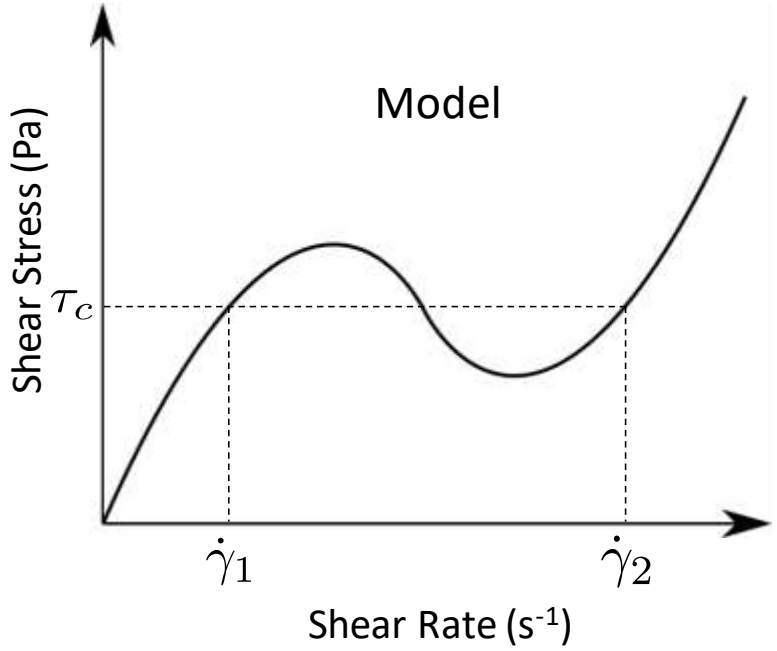


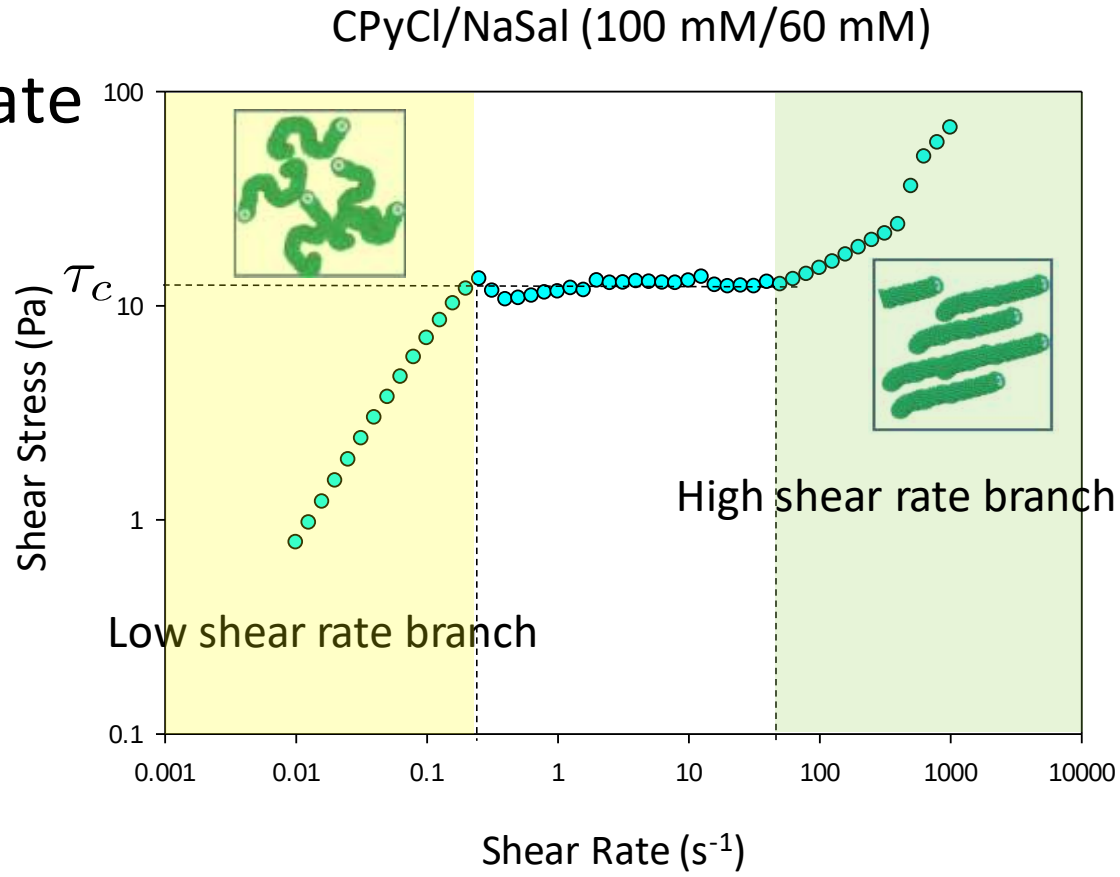
Schubert, B.A., 2003

- Self-assembled aggregates of surfactants
- Shampoo, skin care creams, drag-reducing agents
- WLM used was cetylpyridinium chloride-sodium salicylate (CPyCl-NaSal)
  - 100 mM CPyCl and 60 mM NaSal

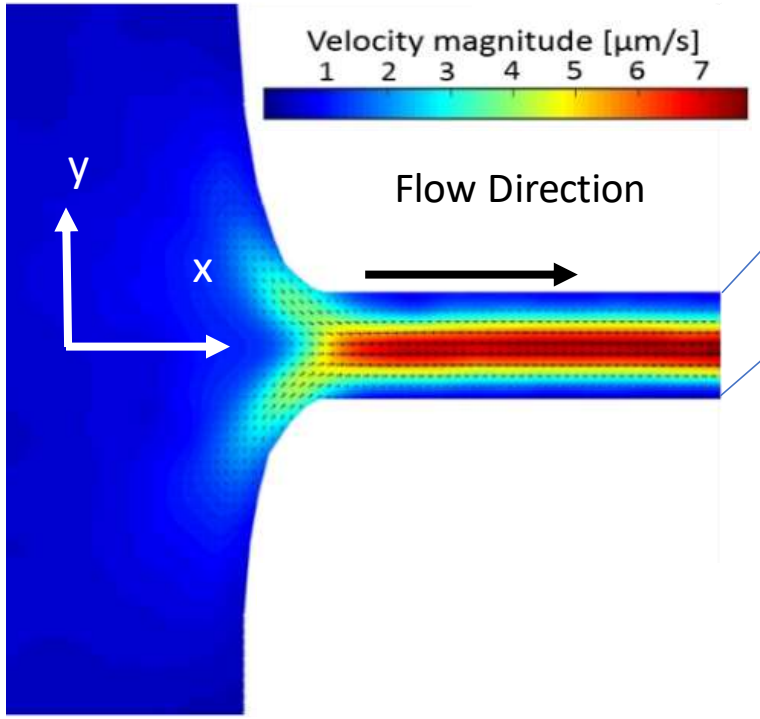
Wormlike Micelles (WLM)

- Non-monotonic stress curve
- Test conducted by increasing shear rate
- How can we see more of the model?

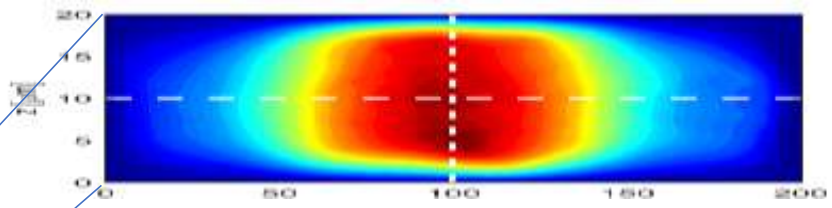




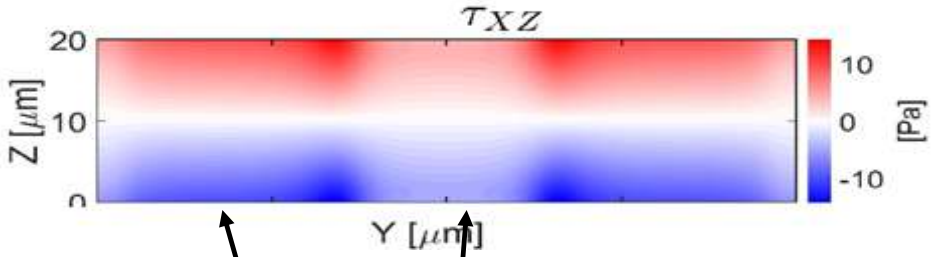
WLM Jetting



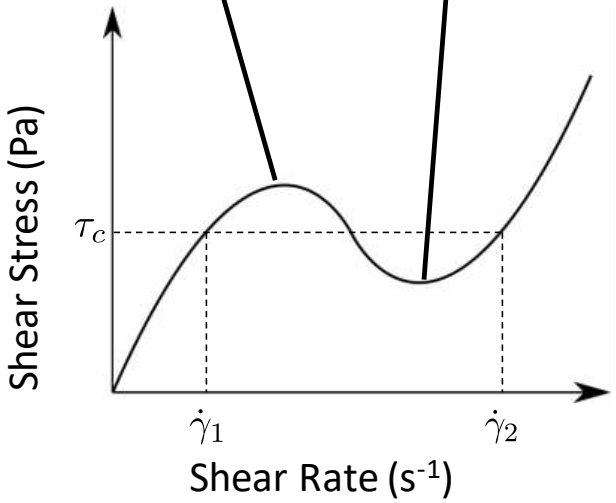
Salipante, Phys. Rev. Fluids



Channel Cross Section

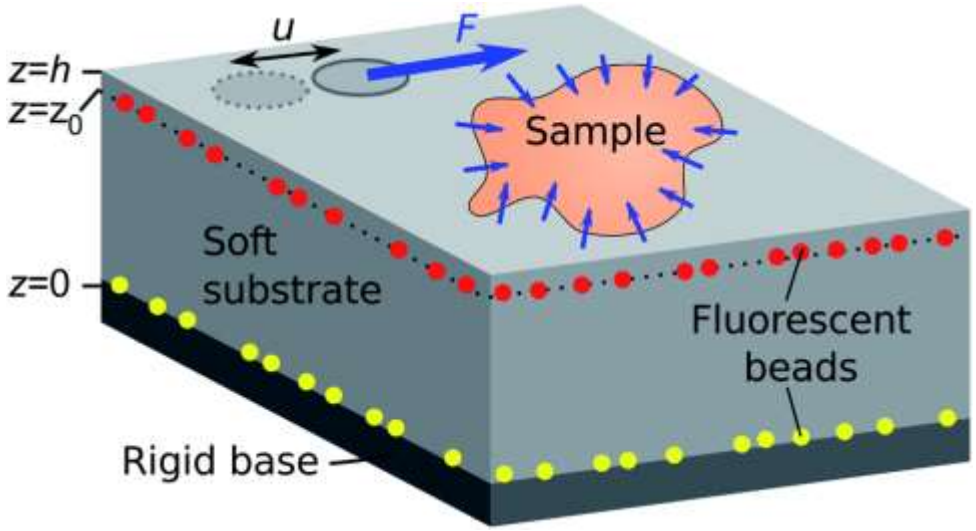


Simulation



Traction Force Microscopy

- Shear stress can be calculated from the displacement of fluorescent beads near the surface
- Similar to Hookes' Law: F = ku

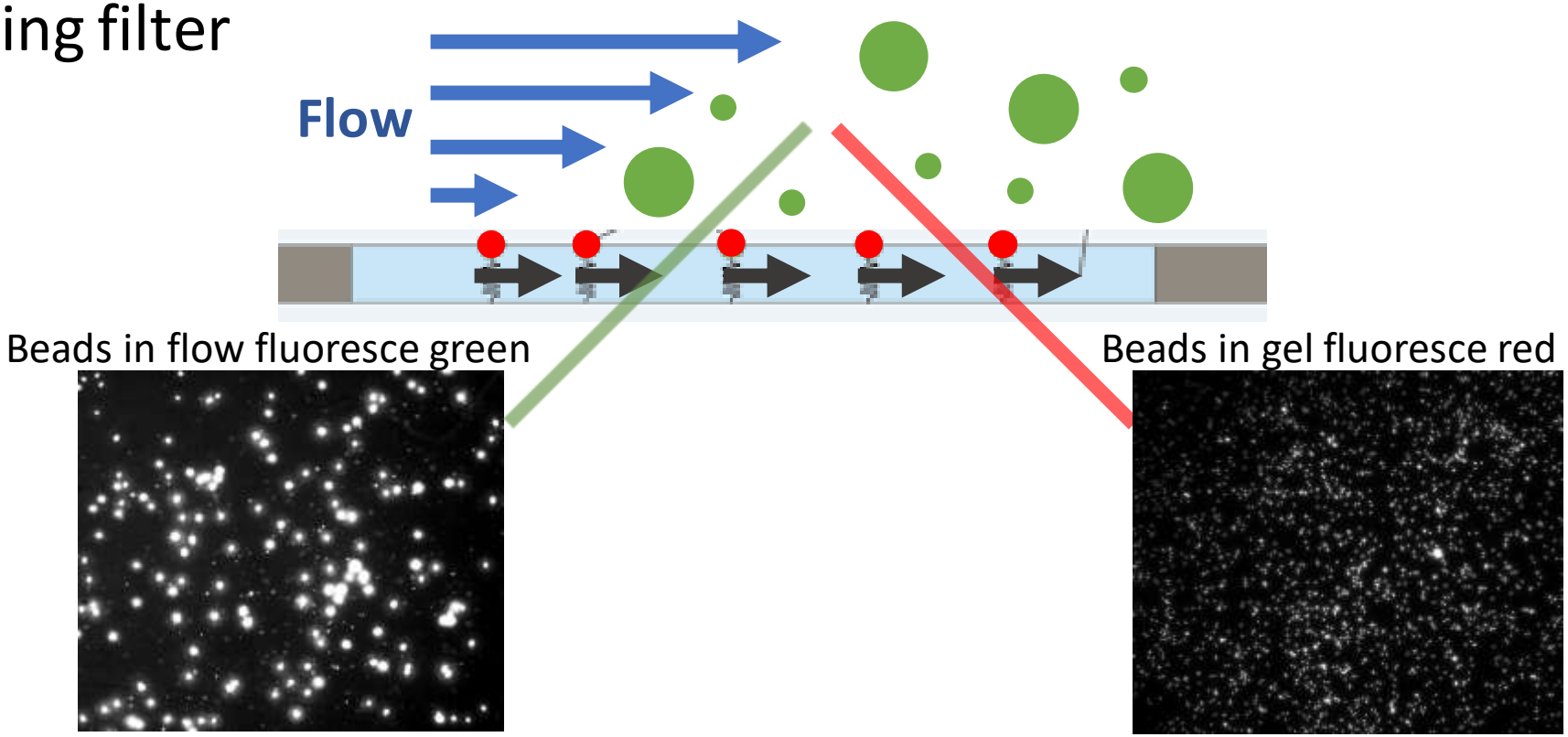


Soft Matter, 2014, **10**, 4047

Local Stress and Flow Measurements

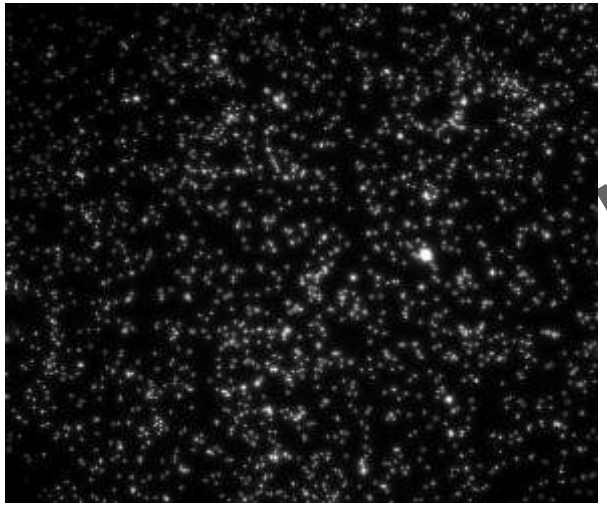
- Beads on surface are pulled by the flow stress
- Can quickly switch between tracers in flow and tracers in gel by changing filter

Bonakdar, 2014

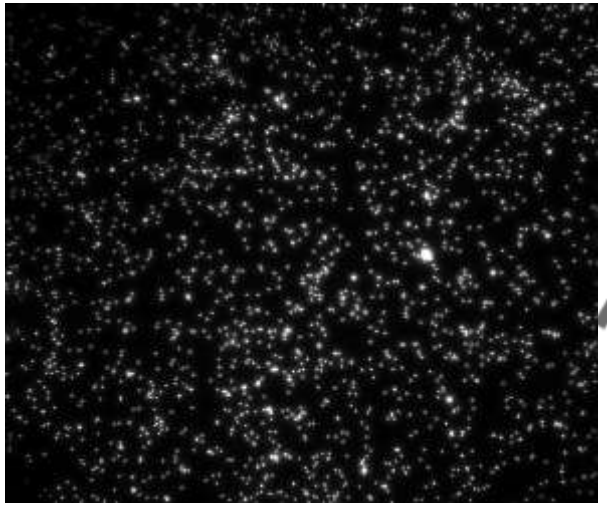


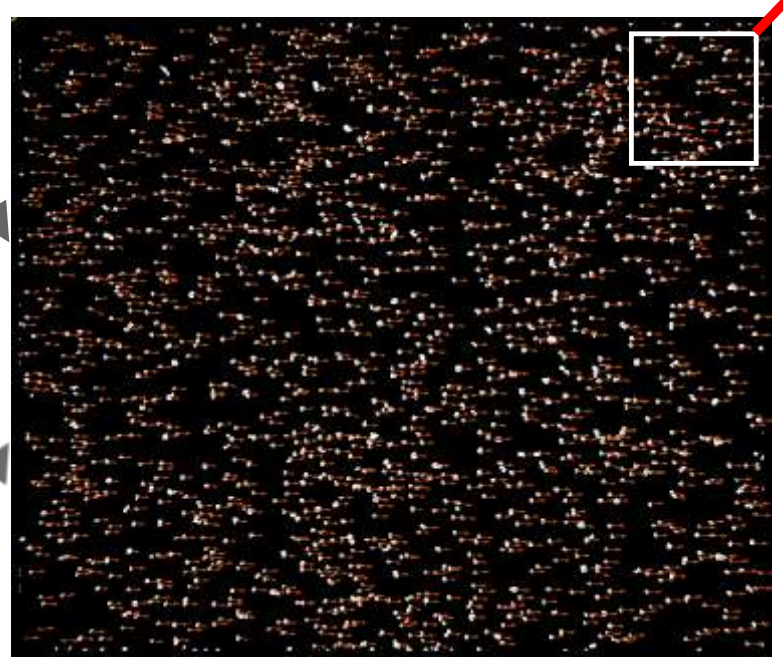
Bead Displacement Analysis

0 mbar

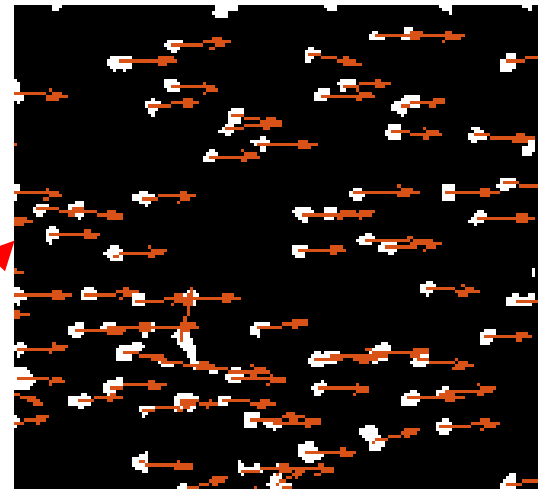


2400 mbar





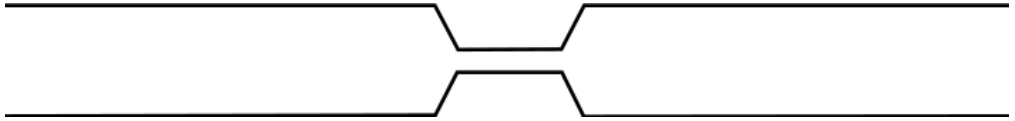
Displacement vectors mapped onto 0 mbar image



Stress map calculations

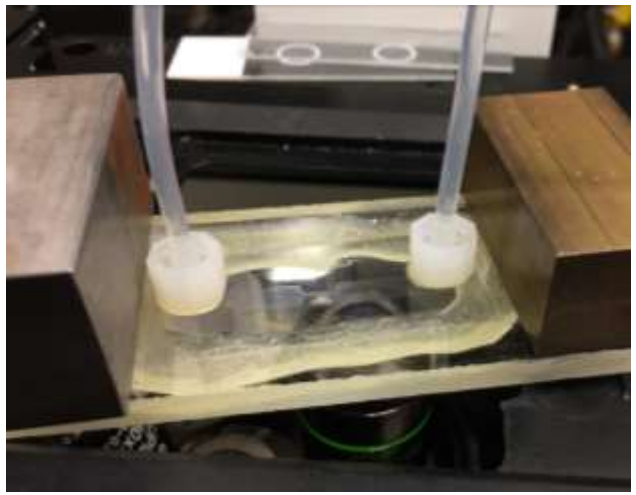
Final Channel Design

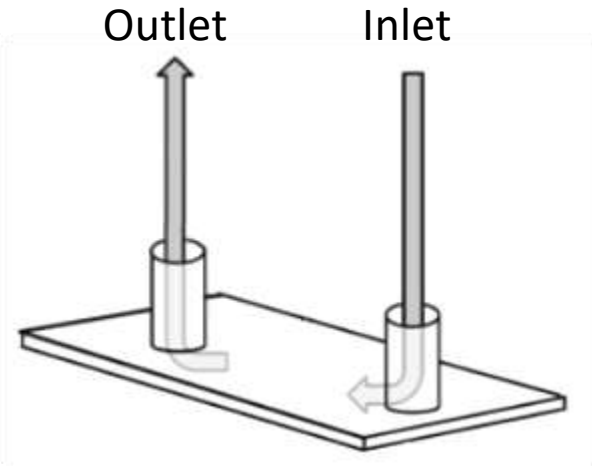
- Made out of double-sided sticky tape
- 50 microns thick
- Created jetting with WLM



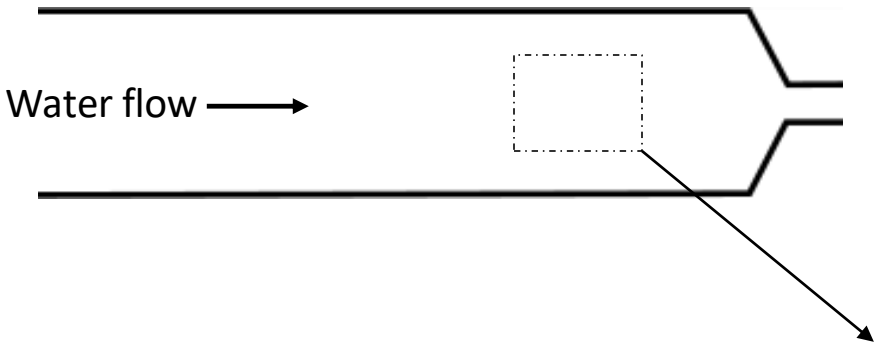
Channel Components

- Bottom: plexiglass base
- Middle: tape with channel shape
- Top: elastic PDMS gel
  - Seeded with evenly distributed fluorescent tracers on surface
  - Glass cover on very top
- Sealed with epoxy

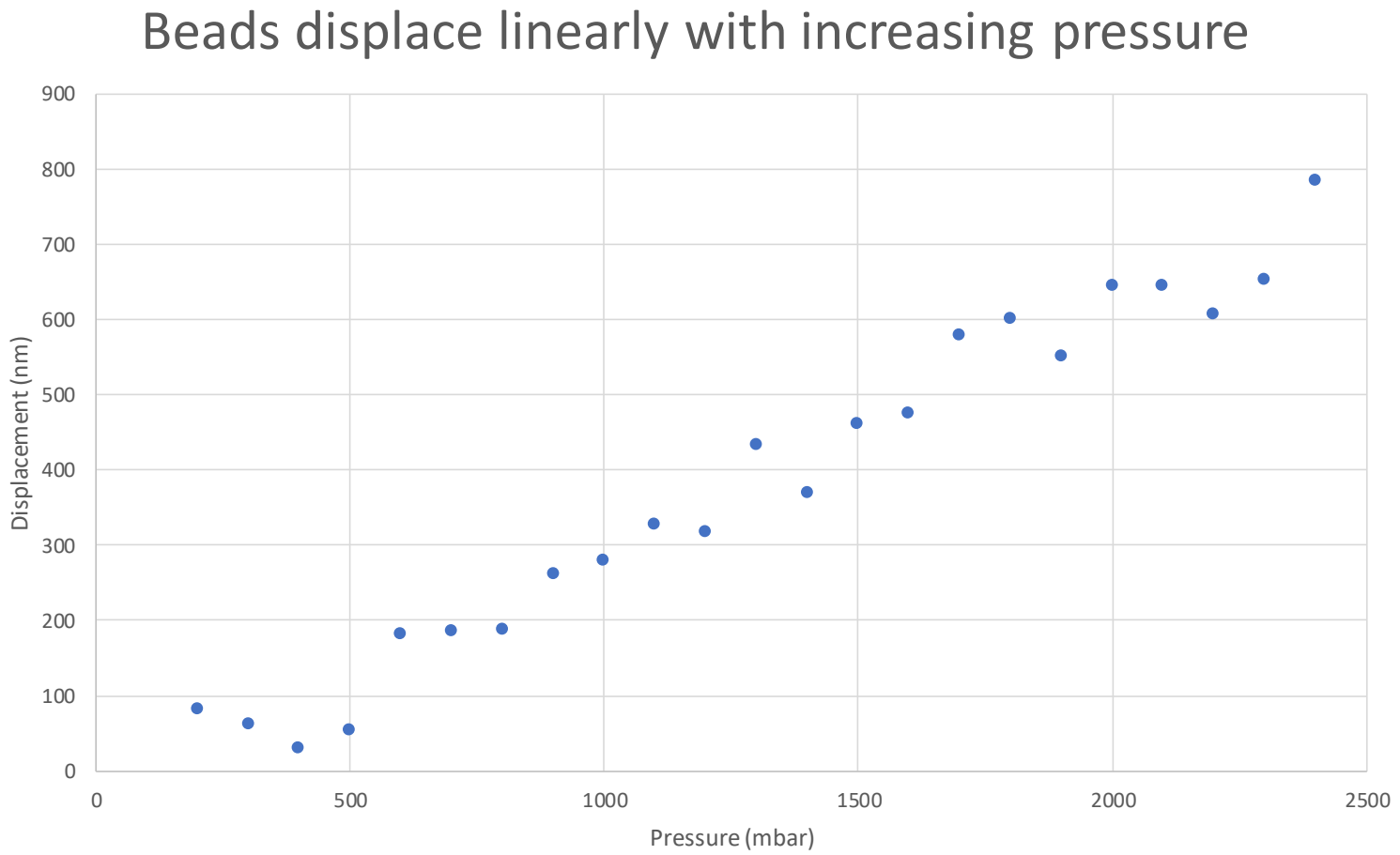




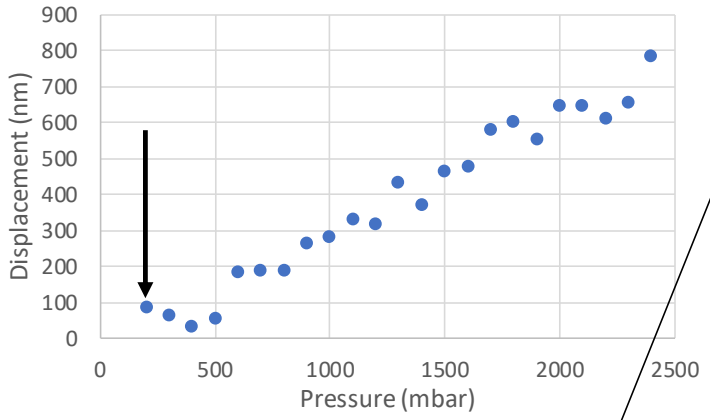
Validation Tests with Water (Newtonian)



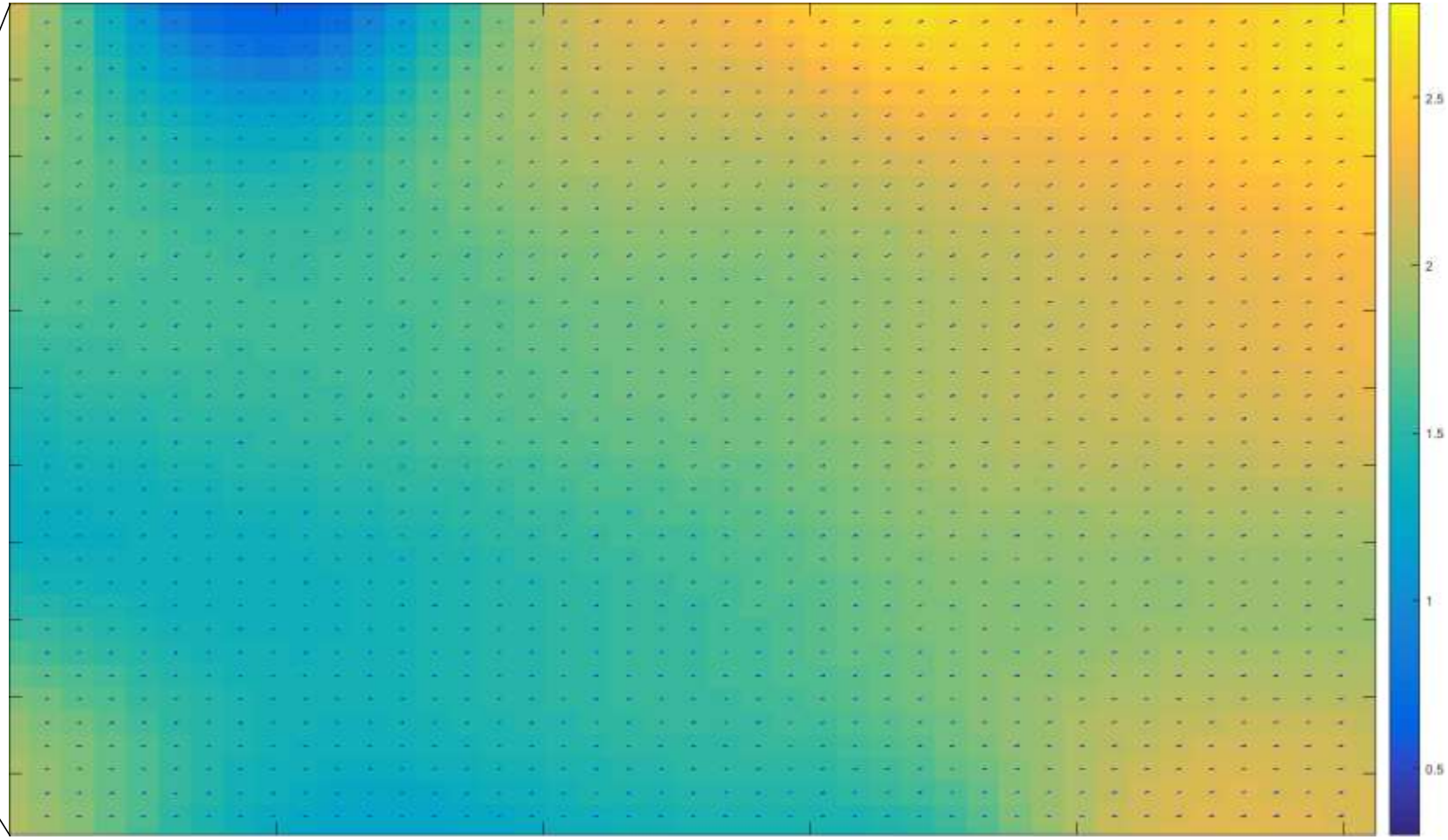
Area of interest is 0.8 mm by 0.8 mm



Water Shear Stress Maps

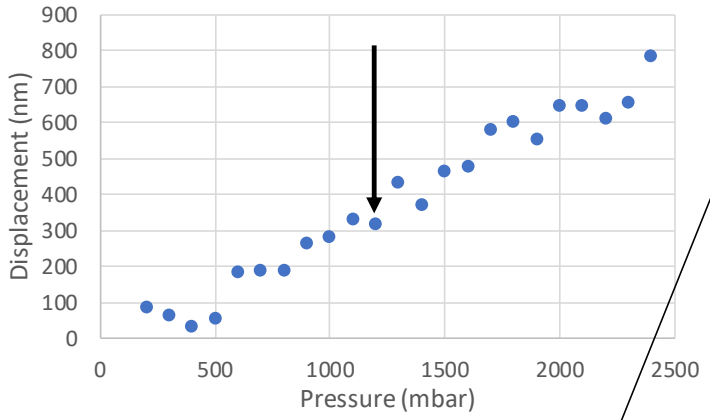


200 mbar

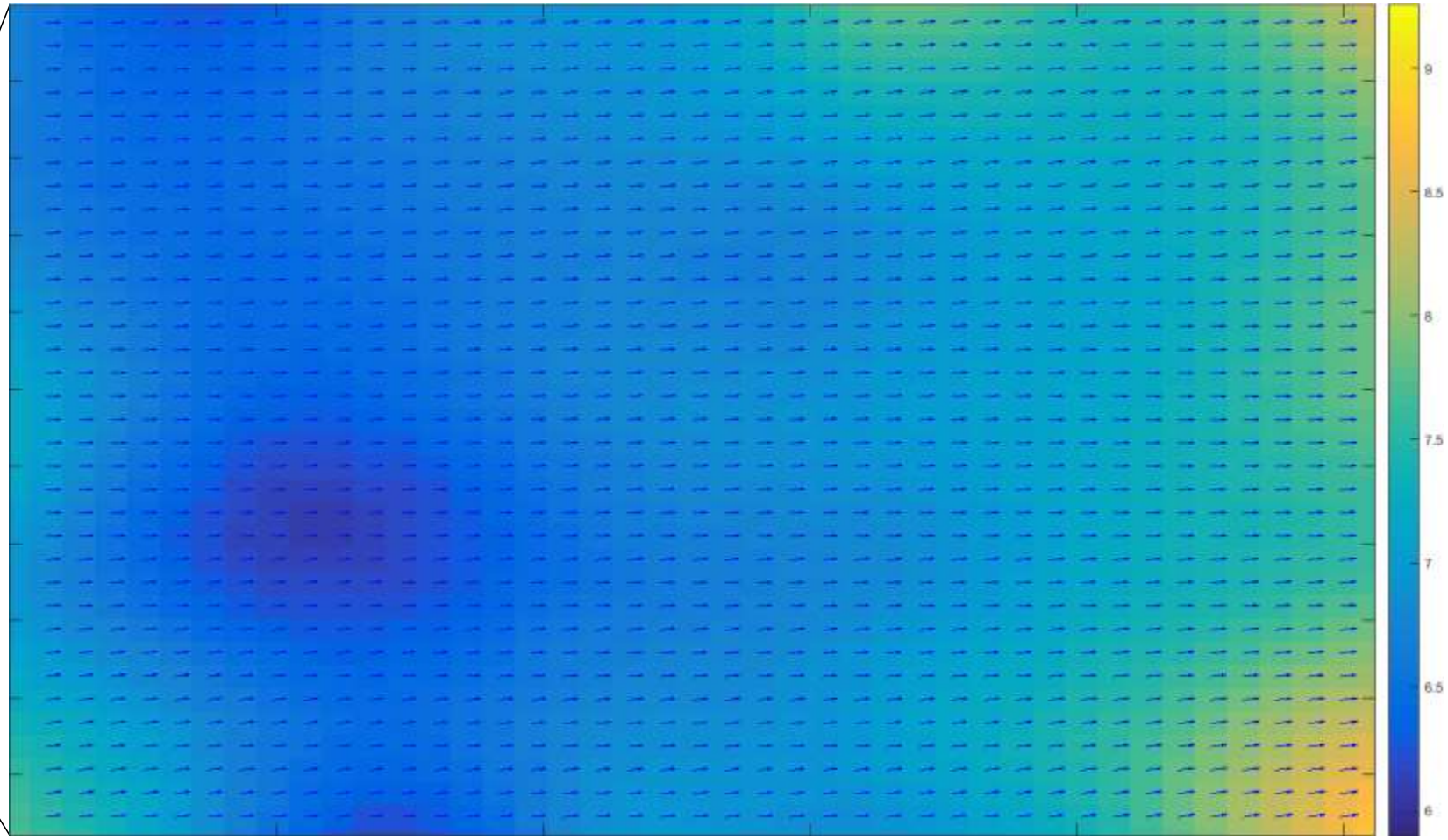


Microscope drift

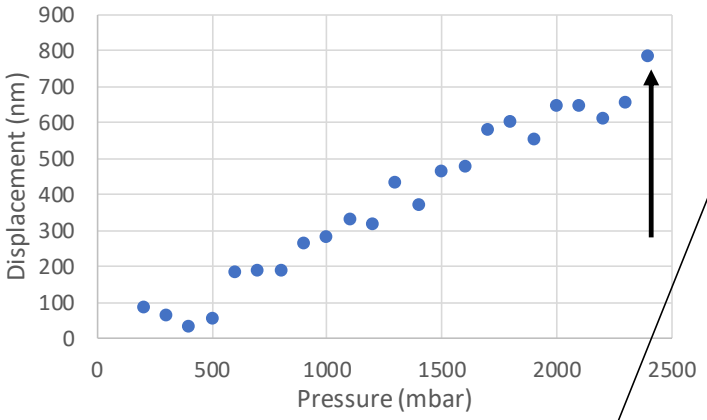
Water Shear Stress Maps



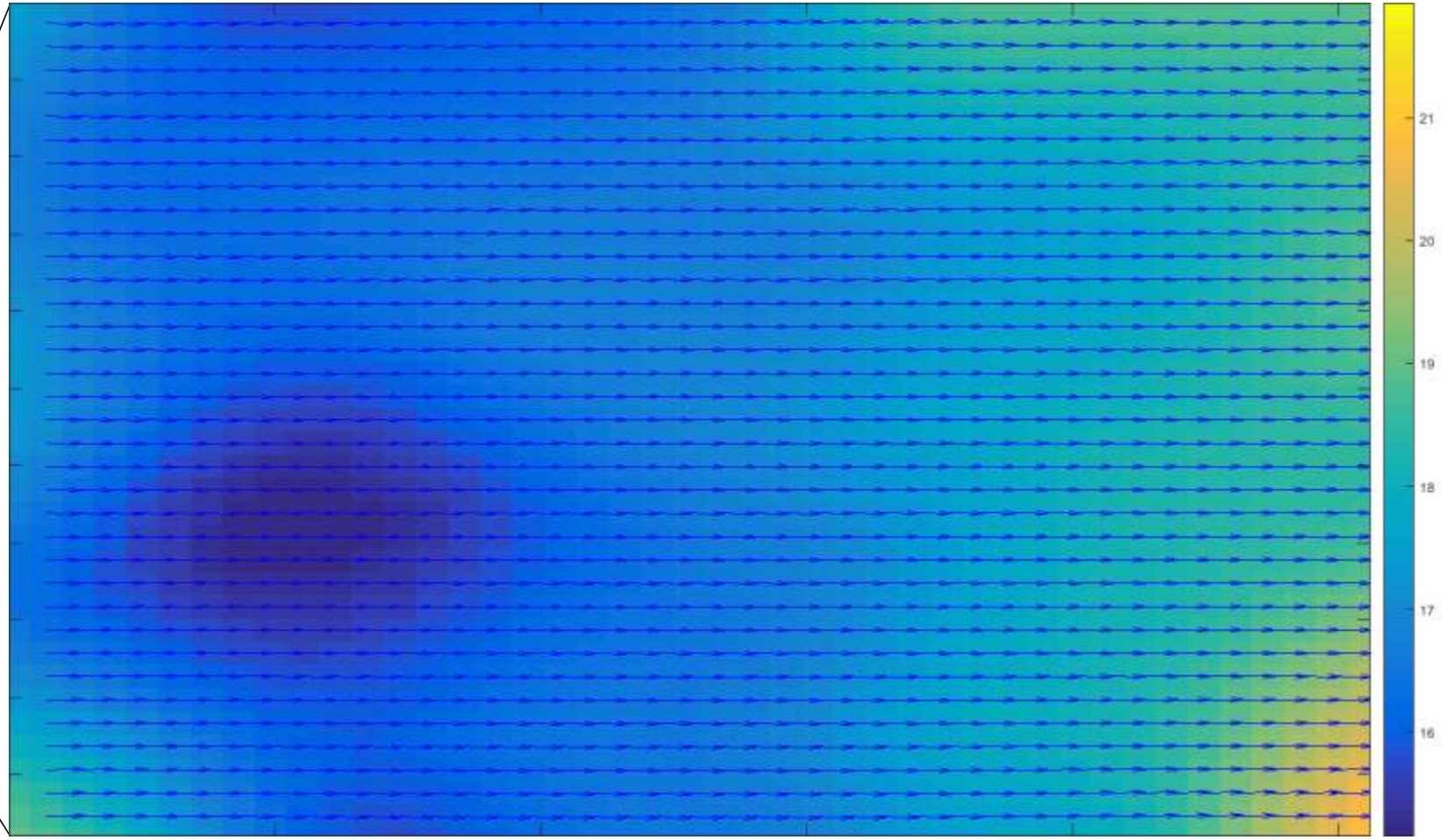
1200 mbar



Water Shear Stress Maps

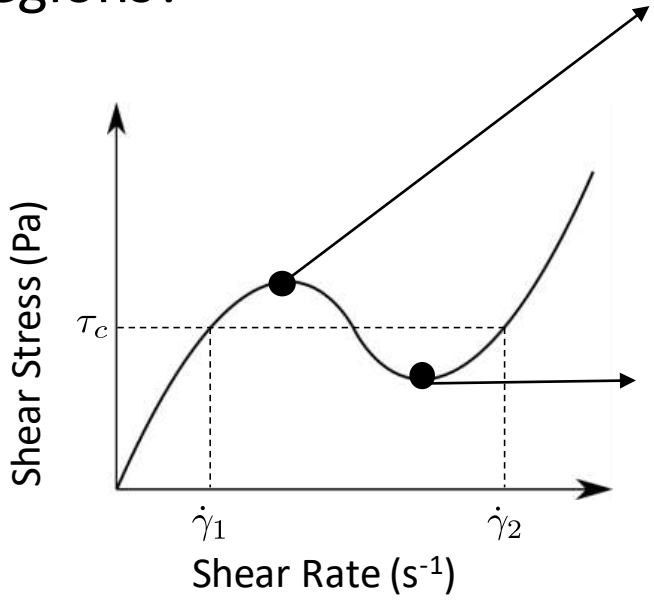


2300 mbar

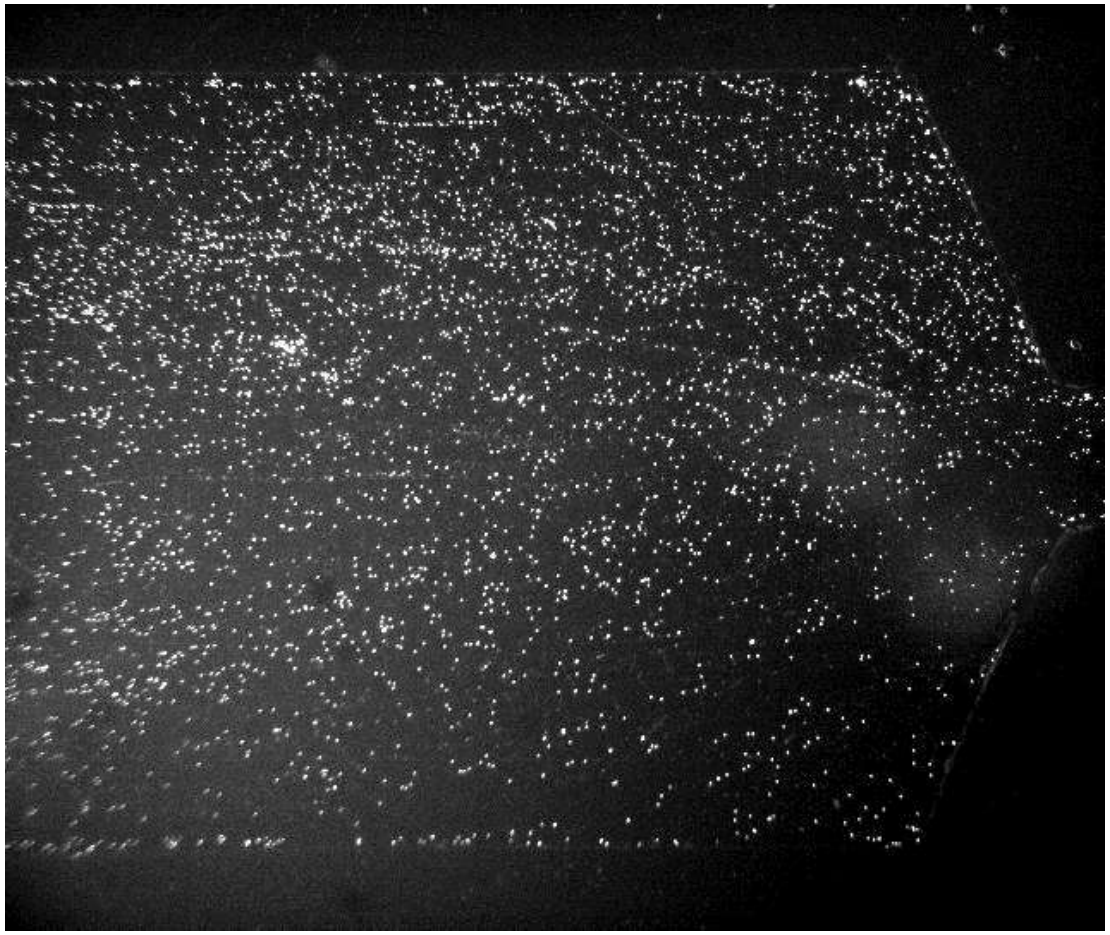


WLM Jetting

- Takes time before jet “settles” in a single location
- Is the stress different between jetting and non-jetting regions?

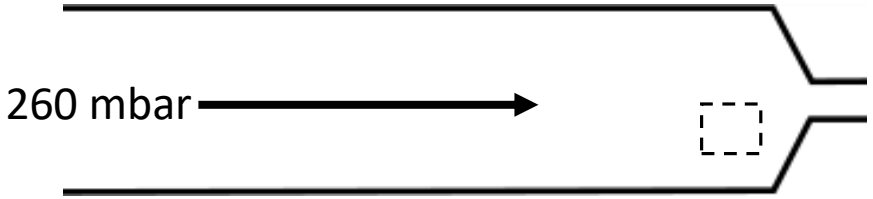


Tracers in flow

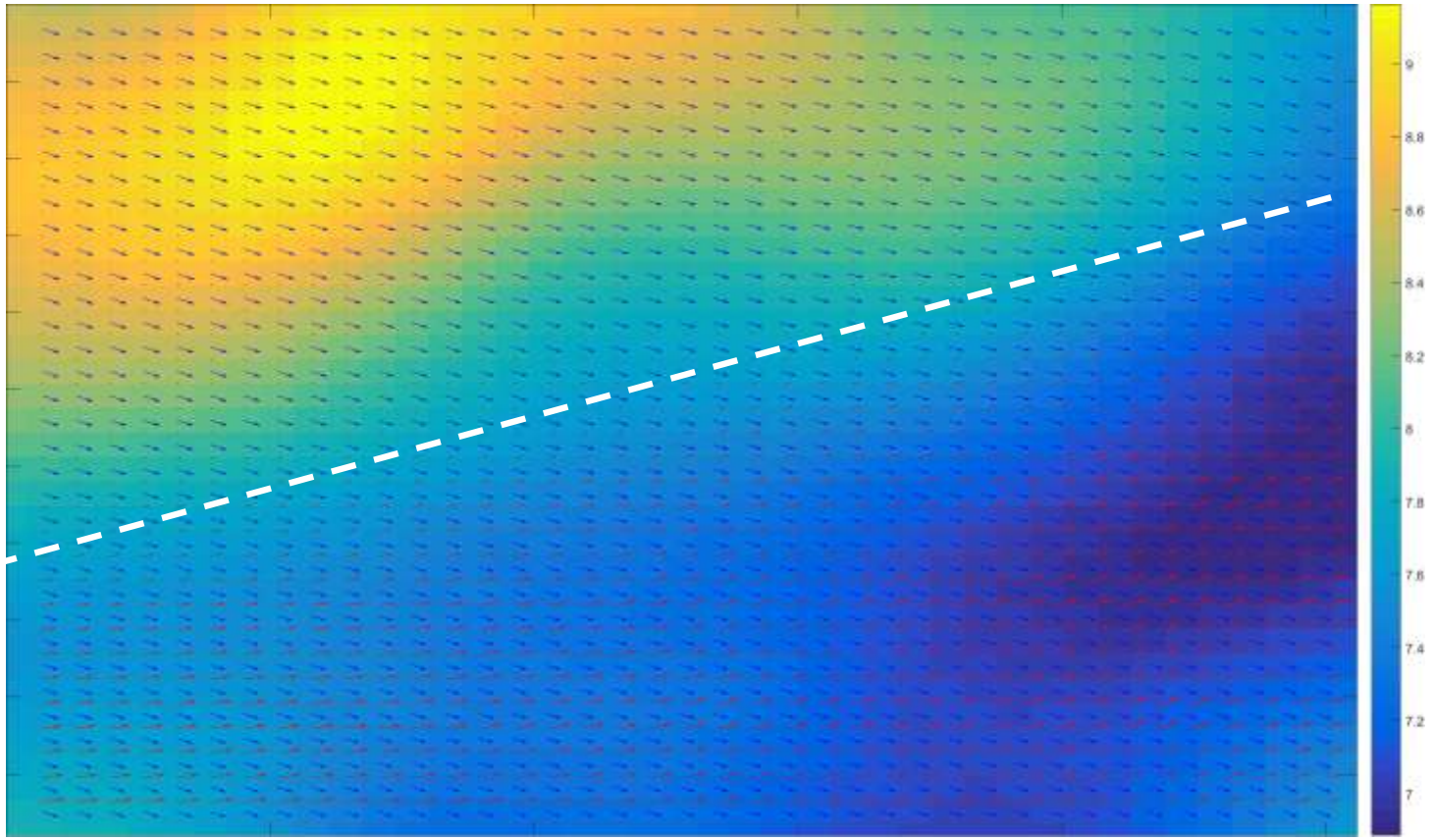


10 times actual speed

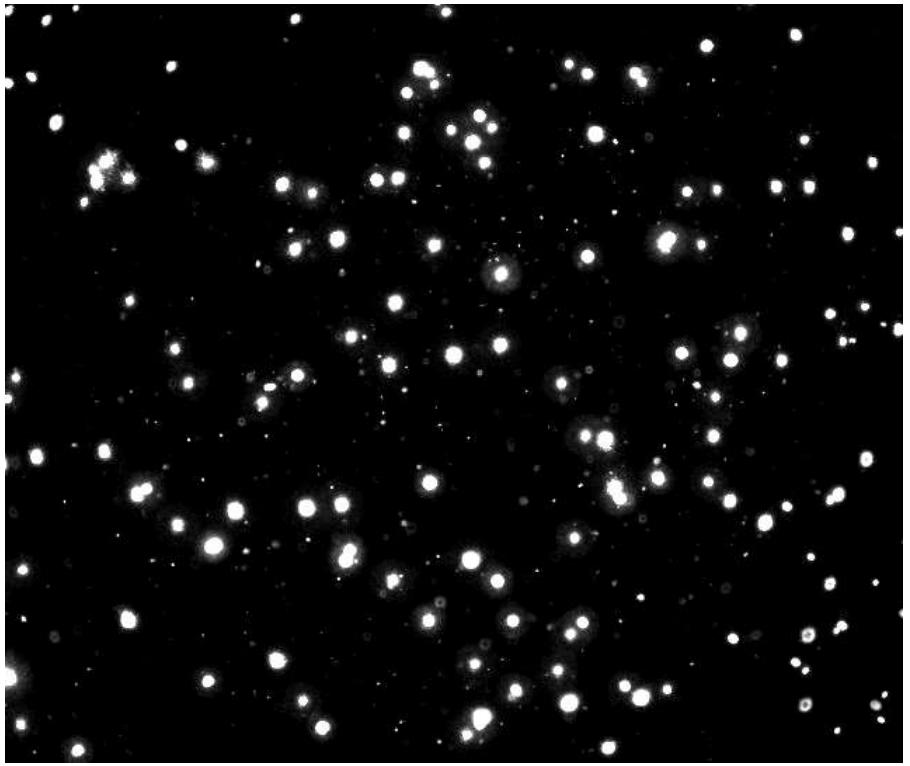
WLM Shear Stress Map



Stress map of gel surface



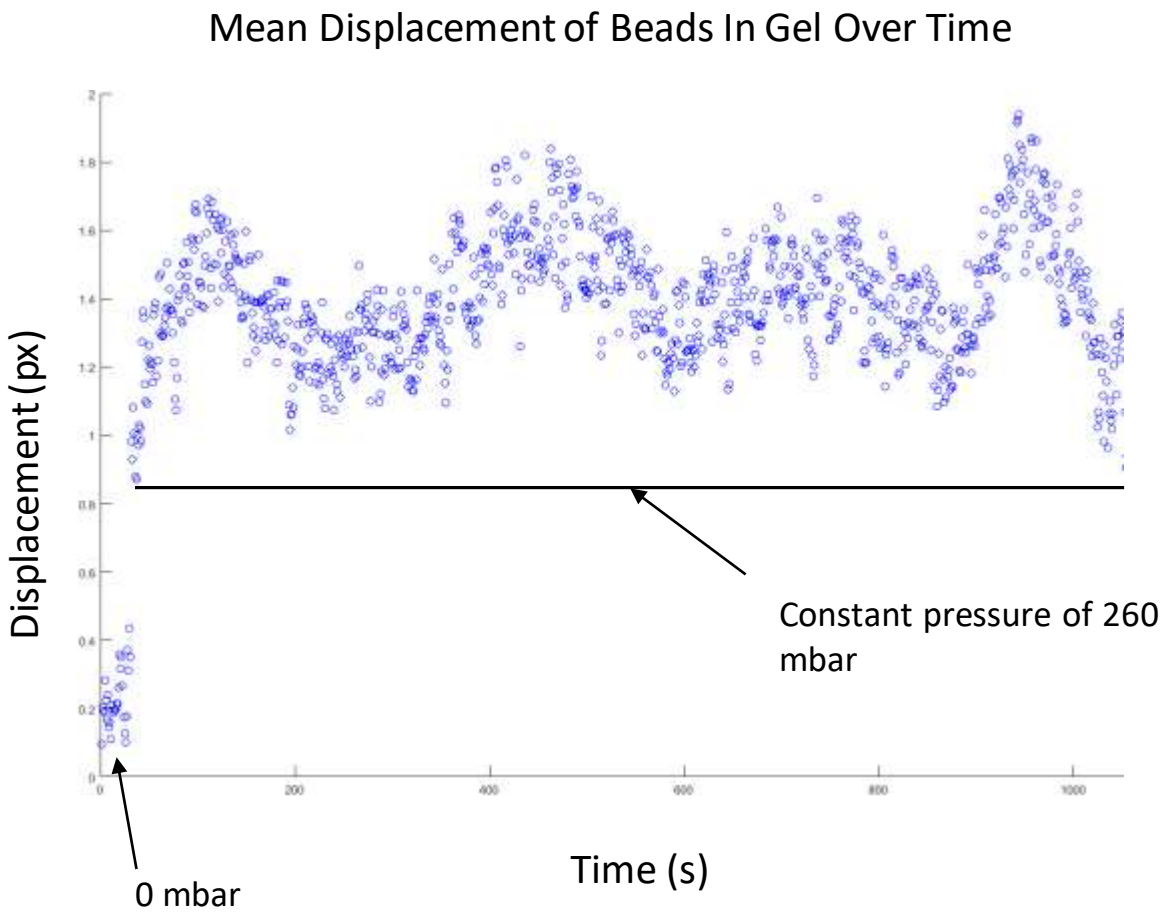
Tracers in flow



6 times actual speed

System Limitations

- Various measurement and analysis errors
  - Stage drift
  - Particle location
- How to identify jetting without looking at fluid flow?



Conclusion

- Developed working system for local shear stresses in rectangular channels
  - Reusable and durable channel
  - Can be easily adapted to other fluids
- Qualitatively, jetting region exhibits lower shear stresses compared to non-jetting region

Future Direction

- Improve local shear stress calculations and minimize error
- Quantitative understanding of local shear stresses

Acknowledgements

- Steven Hudson
- Paul Salipante
- SURF Program Directors