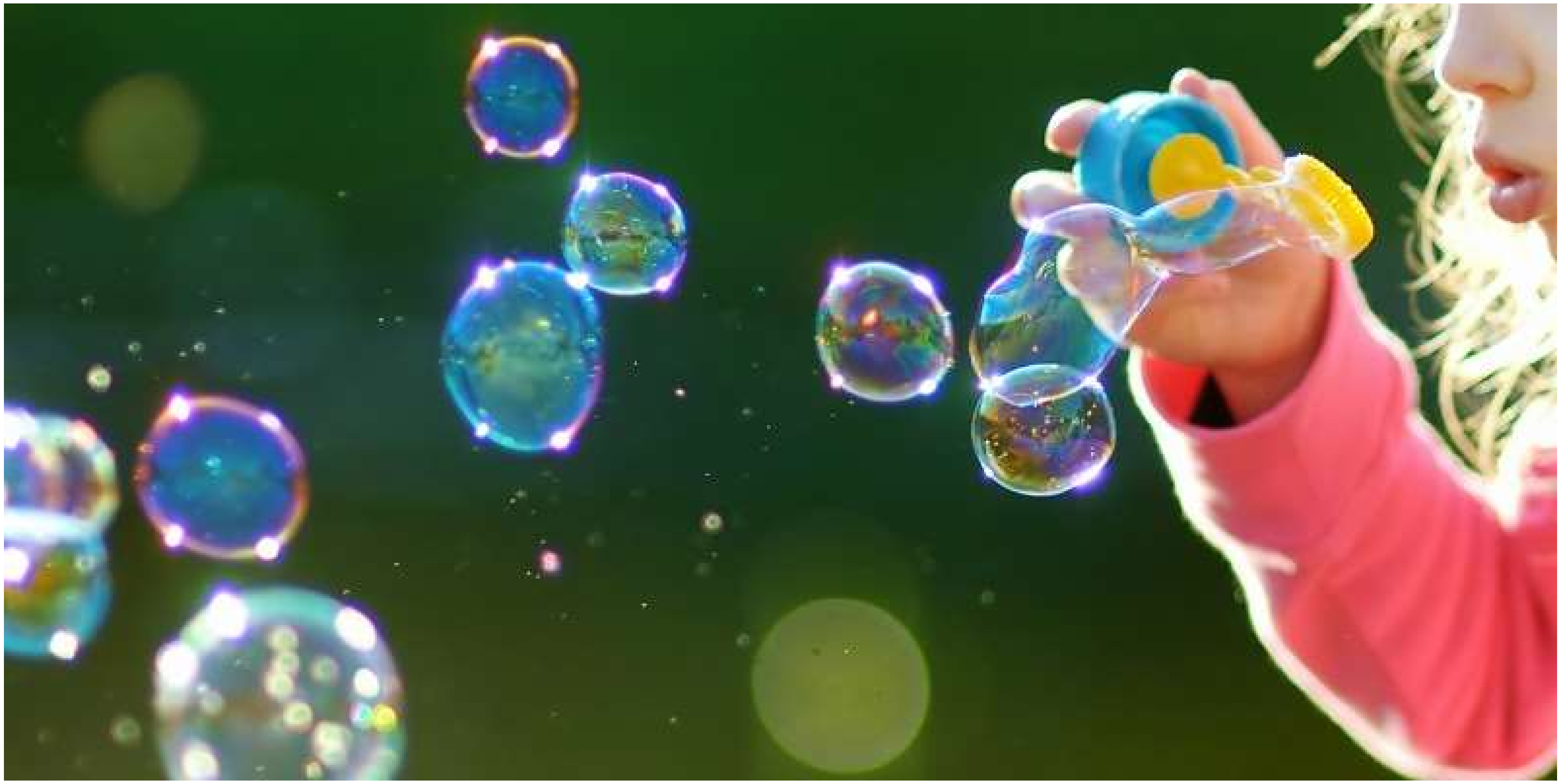
Understanding the physics of flowing soap films
: Why are soap films stable?

Ildoo Kim
Brown University

4:45pm-5:00pm, Sunday, March 4, 2018
KPS-AKPA Joint Symposium at Los Angeles, CA

Soap Films

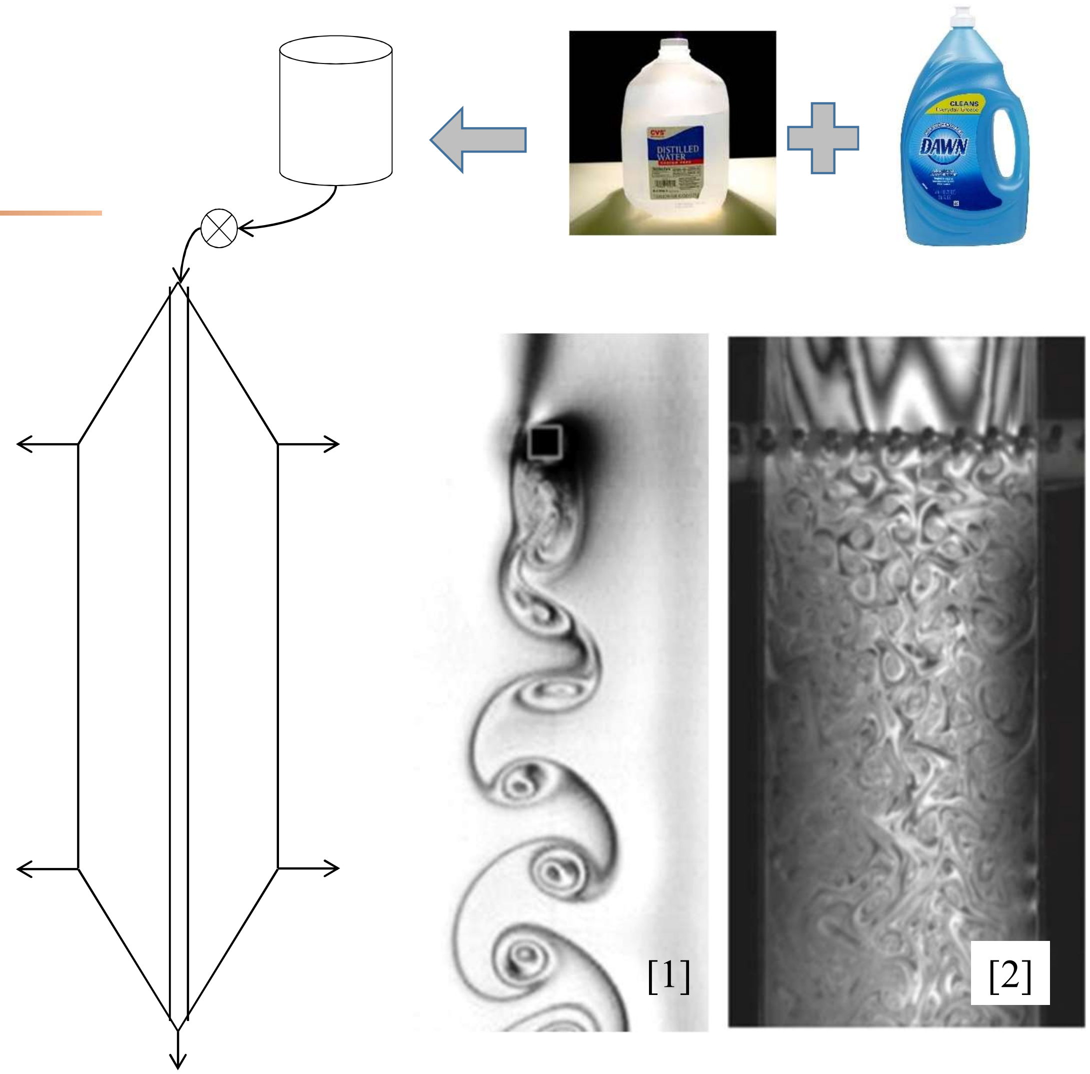


Flowing Soap Films

- Used for 2D hydrodynamics

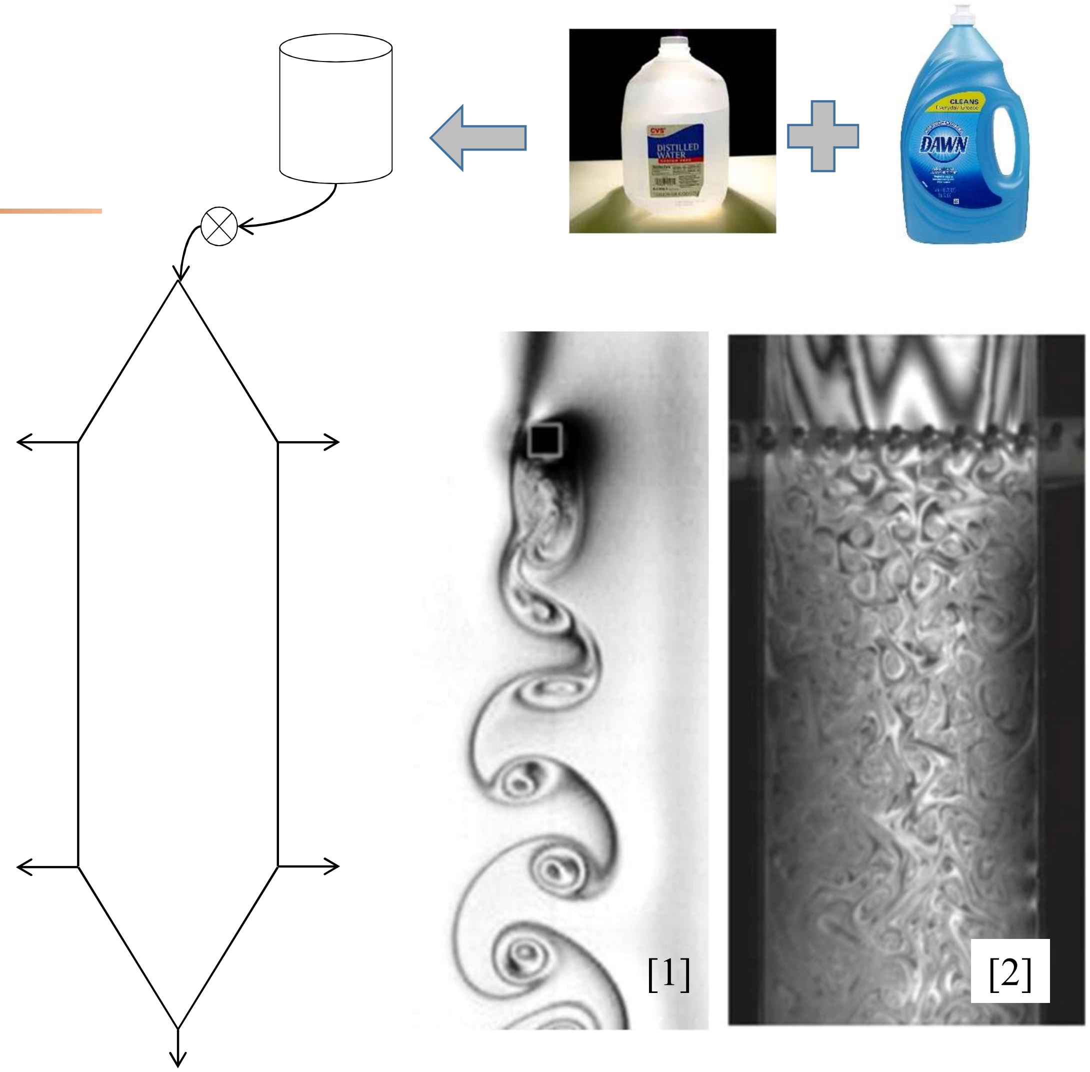
- How it is made:
  - ✓Soap solution
  - ✓Flow along two intact nylon wires
  - ✓Pull wires apart from each other

- Usage examples
  - [1] Kim and Wu, PRE 92, 043001 (2015)
  - [2] Tran et al. Nat. Phys. 6, 438 (2010)

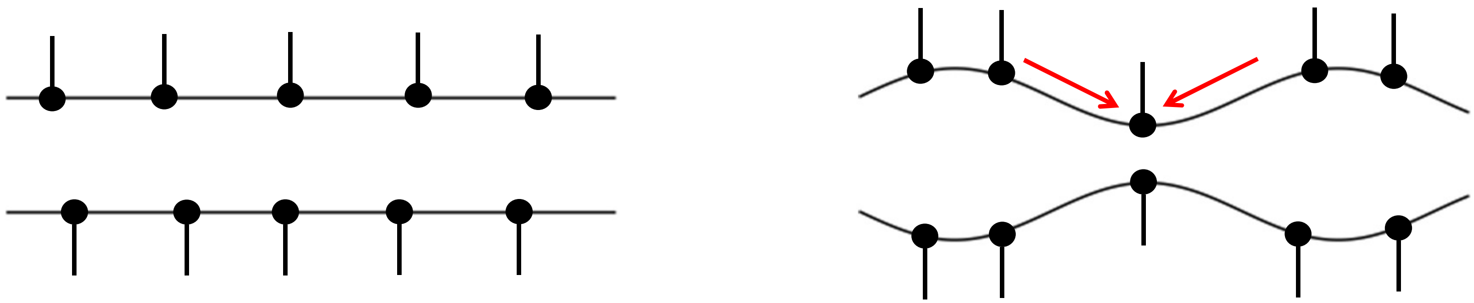


Problem Statement

- Why cannot make a flowing film of pure water?
- How do we make a long-standing soap films or bubbles?



Elasticity and Stability

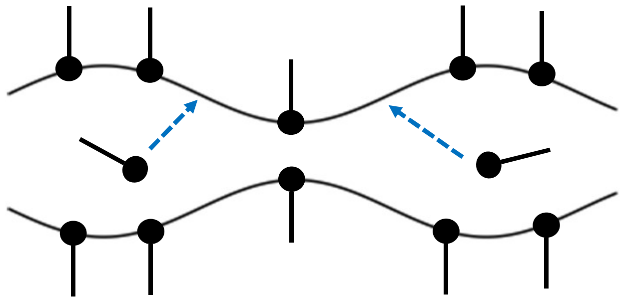


$$E = A\frac{d\sigma}{dA} = -h\frac{d\sigma}{dh}$$ [1]

[1] J. Lucassen et al., "Waves in thin liquid films", Proc. K. Ned. Akad. Wet. B 73, 109 (1970)

Elasticity and Equilibrium

- Equilibrium elasticity (Gibbs)
  - Zero if infinite supply of bulk surfactants
  - Nonzero if some surfactants exist
  - Zero if no bulk surfactants

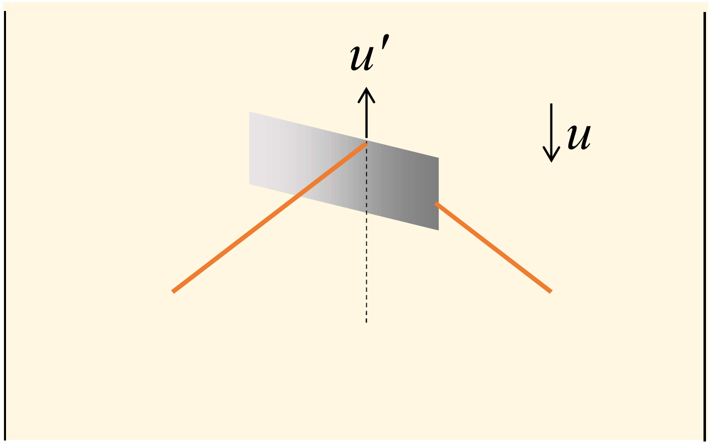


- Out-of-equilibrium elasticity (Marangoni)
  - Bulk surfactants become irrelevant.
  - Mechanical deformation equals the chemical deformation.

$$\tau_d \simeq 10\,\mathrm{ms}$$

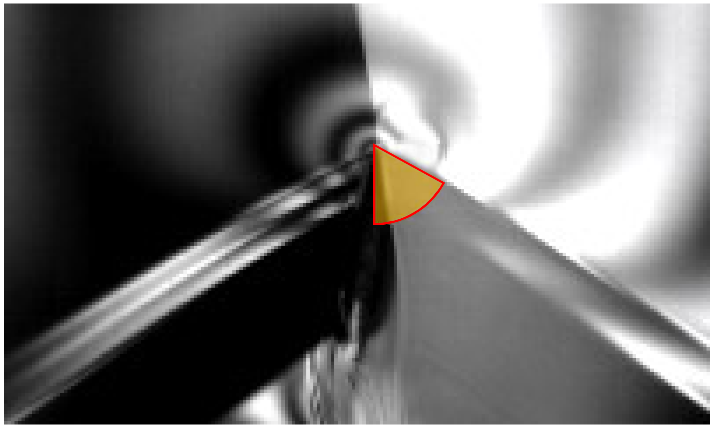
Marangoni Elasticity

- Out-of-equilibrium disturbance
  - Shock is approximately 1 mm thick.
  - The estimated shock formation time is much less than the diffusive time scale.



- Measurement of wave speed gives the out-of-equilibrium elasticity [1]

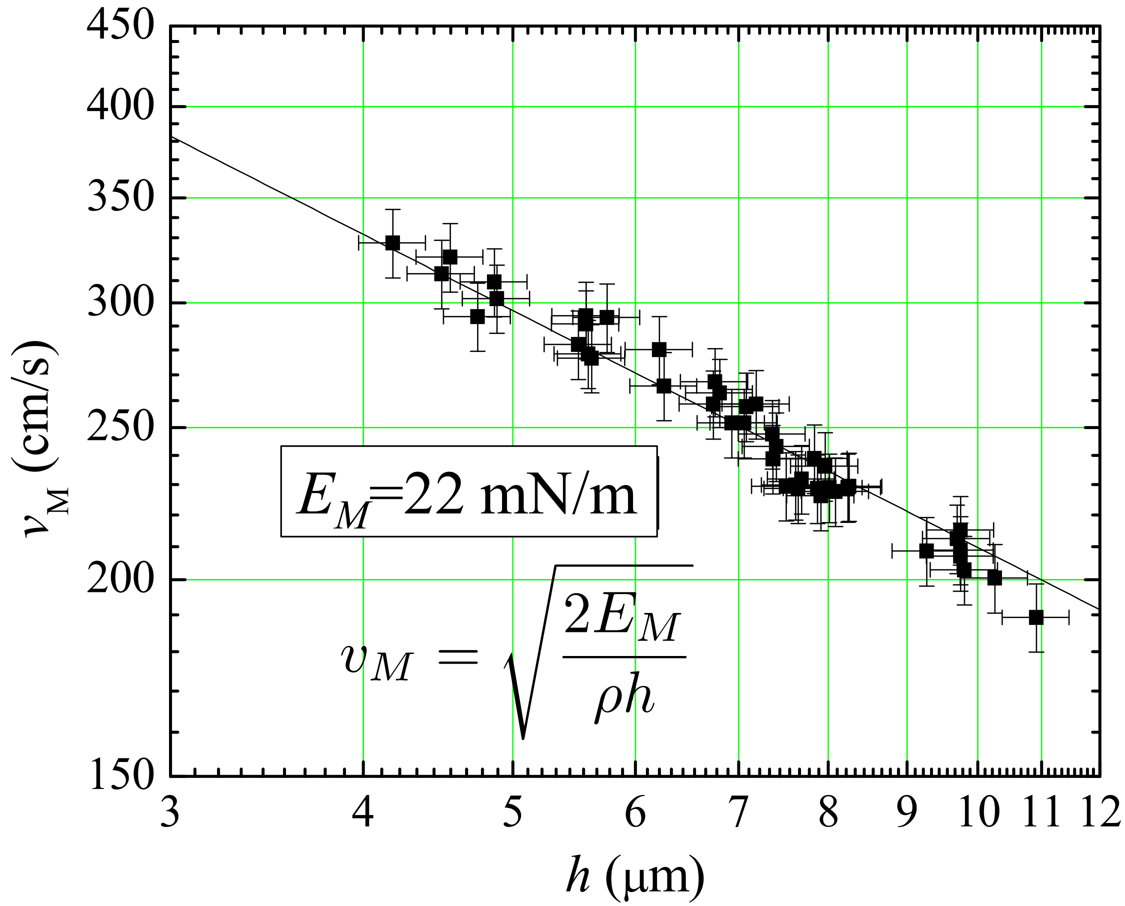
$$\sin\beta = \frac{v_M}{u+u'} \quad v_M = \sqrt{\frac{2E_M}{\rho h}}$$



[1] J Lucassen et al., "Waves in thin liquid films", Proc. K. Ned. Akad. Wet. B 73, 109 (1970)

Marangoni Elasticity

- Soap solution flux
  - 0.38 to 1.17 cm^3/s
- Film width
  - 3 to 6 cm
- Thickness
  - 4 to 11 microns
- Total soap concentration
  - 1%, 2%, 4%

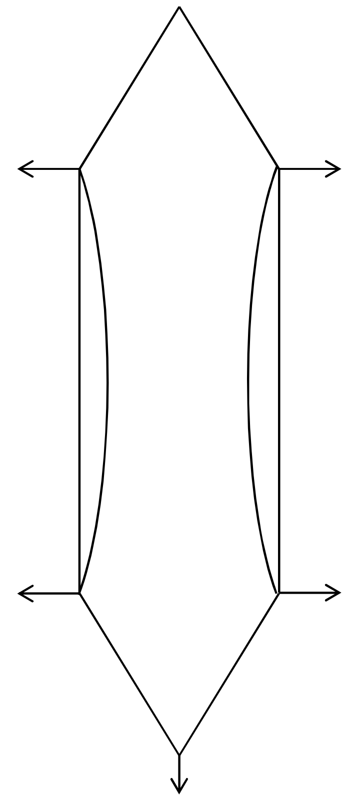


I. Kim and S. Mandre, "Marangoni Elasticity of Flowing Soap Films", Phys. Rev. Fluids 2, 082001 (2017)

Gibbs Elasticity

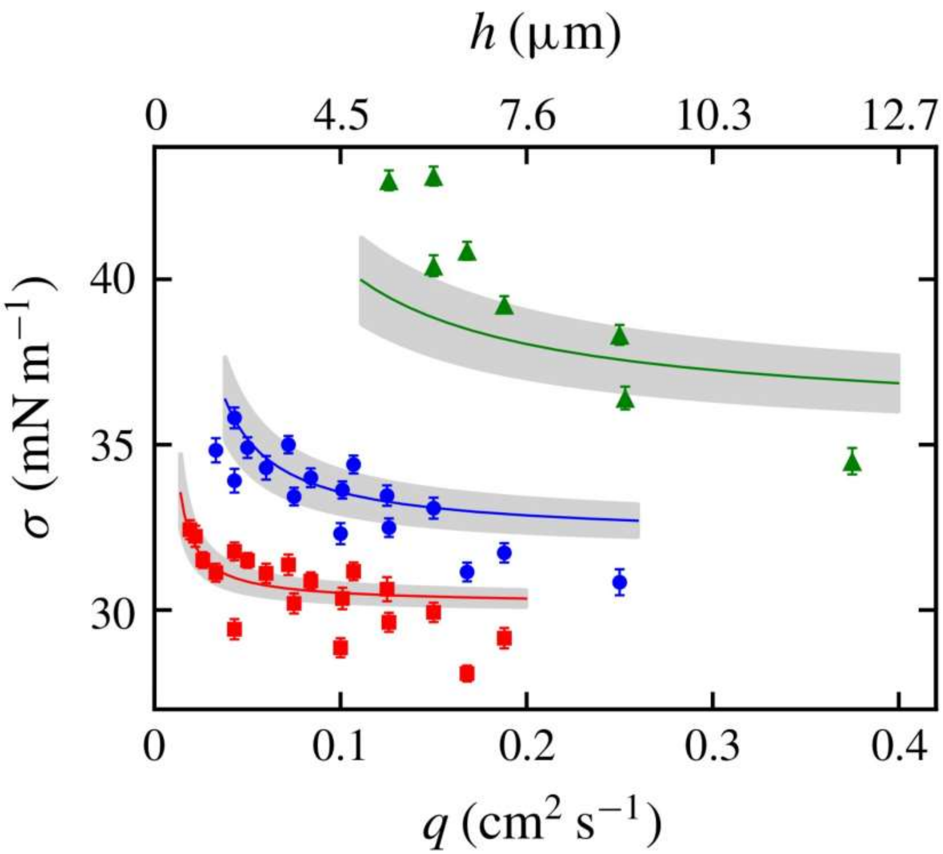
- Equilibrium disturbance
  - Increasing soap solution makes the film thicker.
  - The surface tension is measured using the bending of channel wall wires

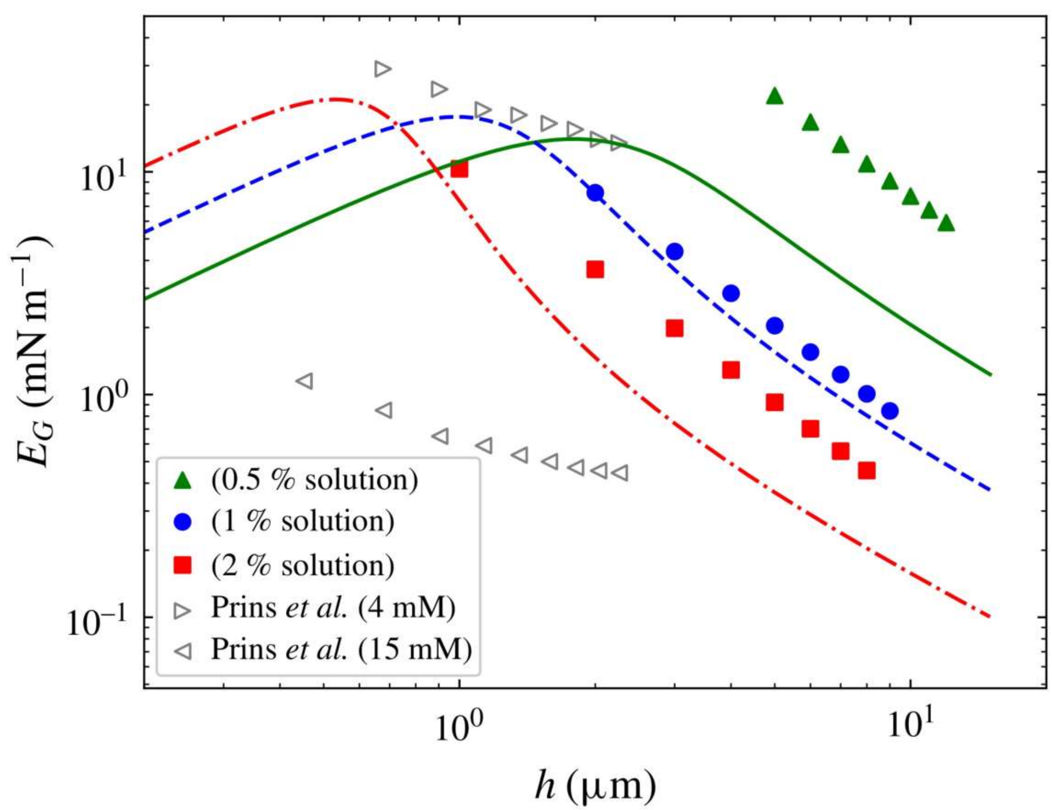
$$\sigma = \frac{\kappa T}{2}$$



A. Sane, S. Mandre, and I. Kim, Journal of Fluid Mechanics 860, R1 (2018)

Surface tension measurement





Take Home Messages

1. A soap film is stabilized because its surface tension can change when it undergoes the mechanical disturbance.

2. The Marangoni elasticity (out-of-equilibrium elasticity) is measured to be independent of the film thickness, from shock wave.

3. The Gibbs elasticity (in-equilibrium elasticity) depends on the film thickness and the soap concentration.