Elastocapillary effects in double dynamic networks

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Supervisors:
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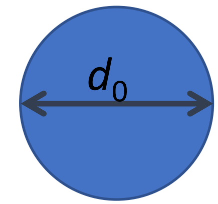
INITIAL TRAINING NETWORK

Elastocapillarity

- What is it ?

  Ability of capillary forces to deform a material



Bulk elasticity ⬌ Surface energy

$$\epsilon_{bulk} \sim d_0^3 E \qquad \epsilon_{surface} \sim d_0^2 \gamma$$

$$E = 3G_0$$

Elasto-capillary length :

$$\boxed{l_{ec} = \frac{\gamma}{3G_0}}$$

$d_0 < l_{ec}$ Surface energy prevails

$d_0 > l_{ec}$ Bulk elasticity prevails

$$G_0 = 1000Pa \quad \gamma = 50mN/m \quad \rightarrow l_{ec} = 17\mu m$$

$$G_0 = 50Pa \quad \gamma = 50mN/m \quad \rightarrow l_{ec} = 333\mu m$$

Case of viscoelastic fluids

Maxwell fluid with elastic modulus G_o and a relaxation time τ

$$G' = G_0 \frac{(\omega\tau)^2}{1+(\omega\tau)^2} \quad \text{with} \quad \omega = \frac{1}{\tau_{exp}}$$

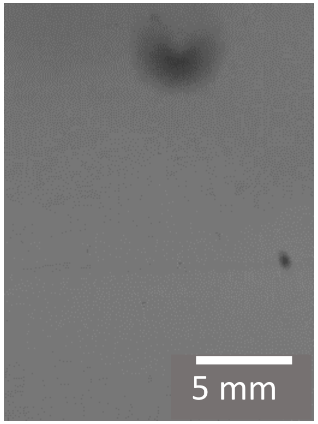
$$G'' = G_0 \frac{\omega\tau}{1+\omega\tau}$$

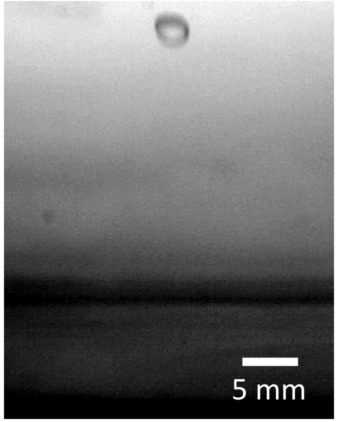
$$\boxed{De = \frac{\tau}{\tau_{exp}}} \longrightarrow$$

$$G'(De) = G_0 \frac{De^2}{1+De^2}$$

$$G''(De) = G_0 \frac{De}{1+De}$$

Deceleration 300x





Drop impact

Upon impact :

Inertial forces → radial expansion of the sheet

Stored elastic energy → retraction after maximal expansion

Goal:

- Rationalize the respective role of

Inertia Capillarity Elasticity Dissipation

$$\frac{1}{2}mv_{impact}^2 \approx \frac{1}{2}\pi\gamma d_{max}^2 + V_{bead}G\lambda^2 + E_{diss}$$

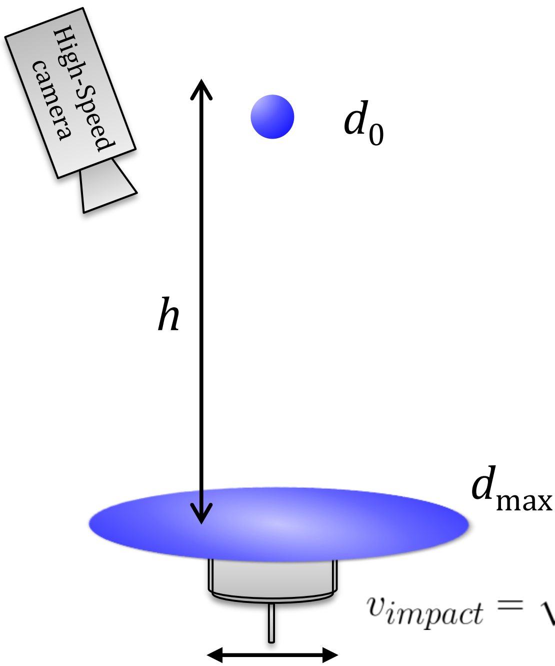
$$\lambda = \frac{d_{max}}{d_0}$$

- Find adequate system

Impact of Newtonian fluid

- On a small target

$$\frac{1}{2}mv_{impact}^2 \approx \frac{1}{2}\pi\gamma d_{max}^2 + \cancel{V_{bead}}G\lambda^2 + E_{diss}$$



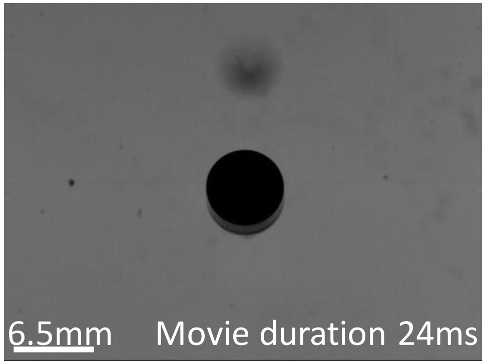
$v_{impact} = \sqrt{2gh} = 4.22\ m/s$

$d_t = 6.5$ mm

S. Arora et al, 2017

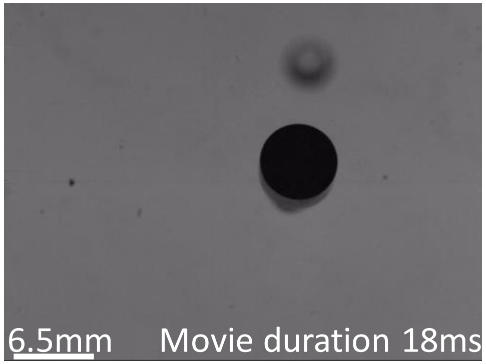
Silicone oil 5 mPas

$\lambda =$ 6.2



Silicone oil 350 mPas

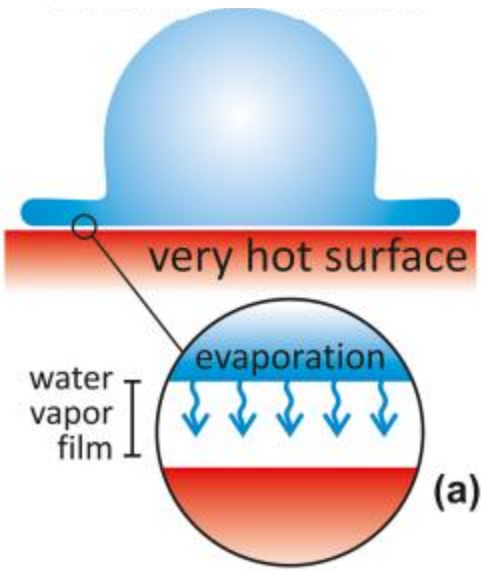
$\lambda = 1.8$



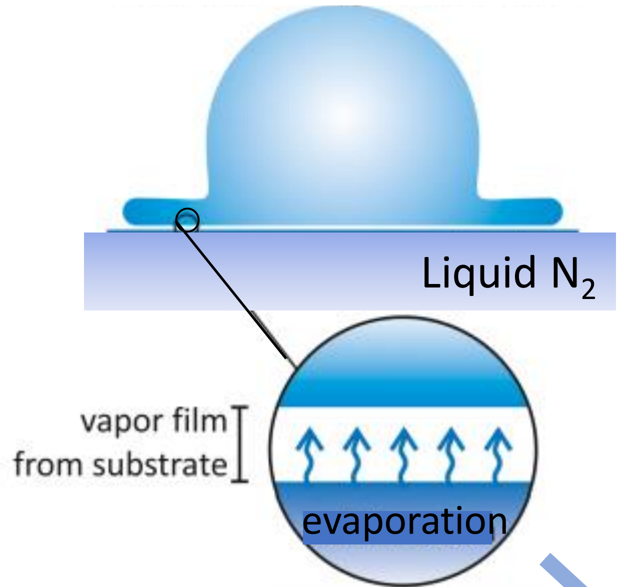
➡ **Dissipation effect due to target**

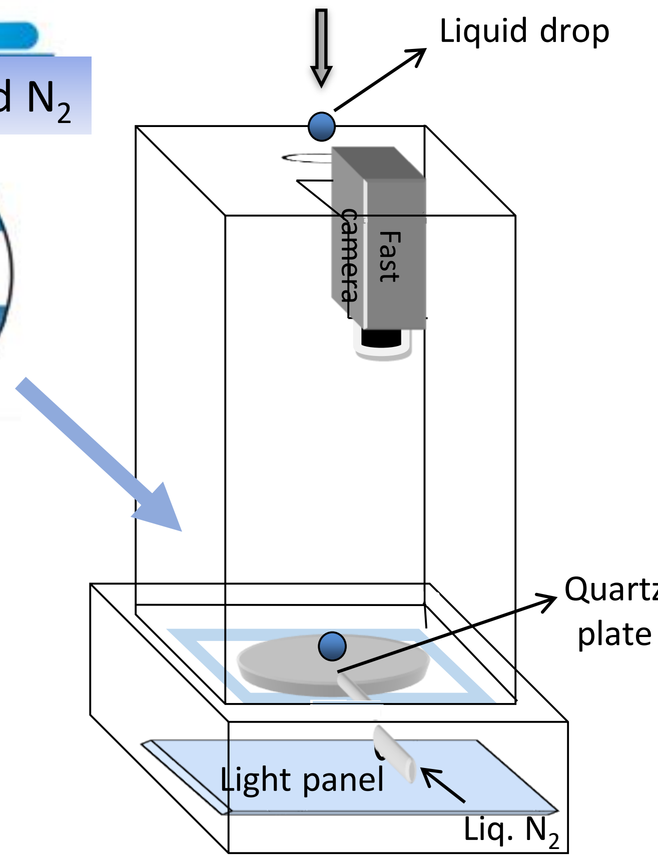
Drop impact Inverse Leidenfrost effect

Leidenfrost effect



Inverse Leidenfrost effect





Water Drops Dancing on Ice: How Sublimation Leads to Drop Rebound,
C. Antonini, I. Bernagozzi, S. Jung, D. Poulikakos, and M. Marengo
Phys. Rev. Lett., 2013

Impact of Newtonian fluids

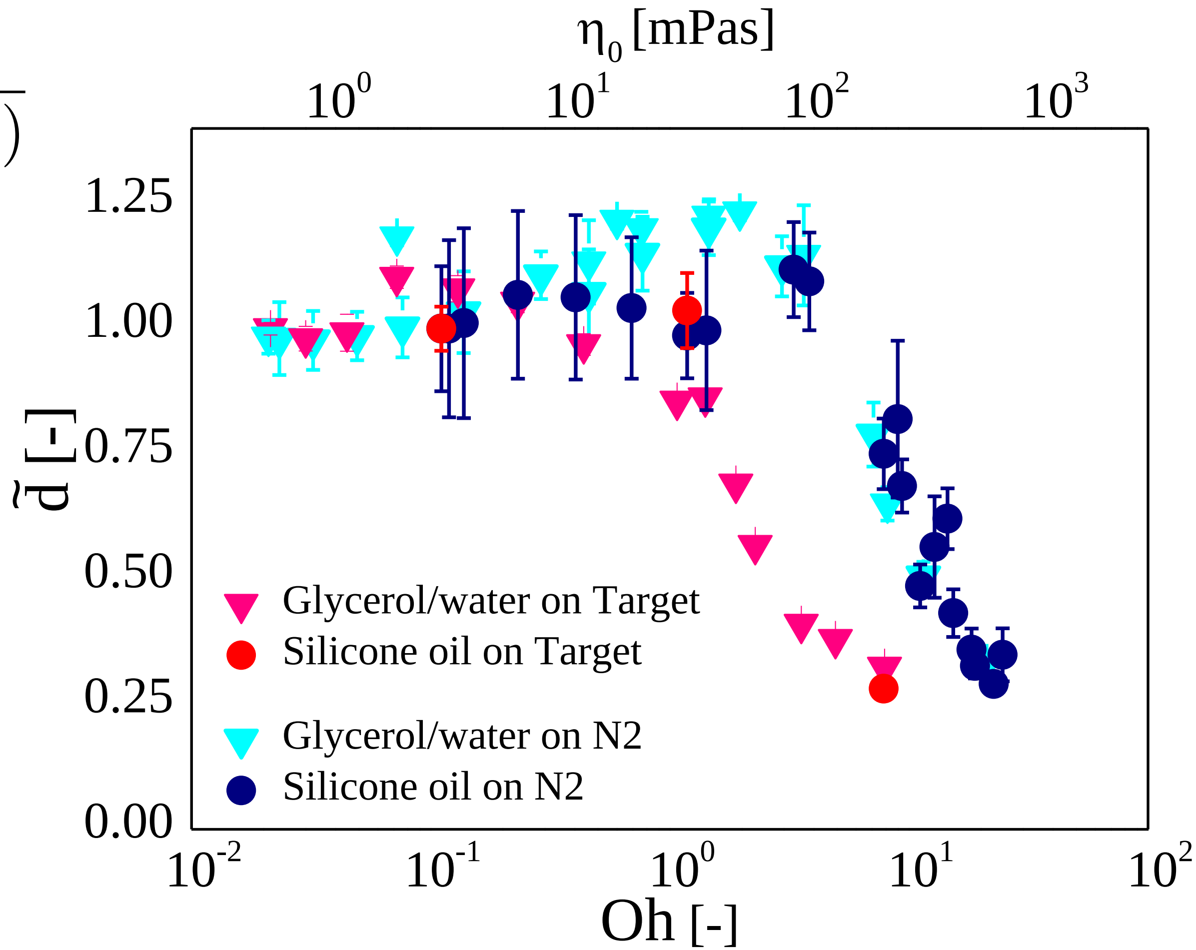
$$Oh = \frac{\eta_0}{\sqrt{\rho\gamma d_0}}$$

$$\tilde{d} = \frac{d_{max}}{d_{max}(\eta_0 \rightarrow 0)}$$

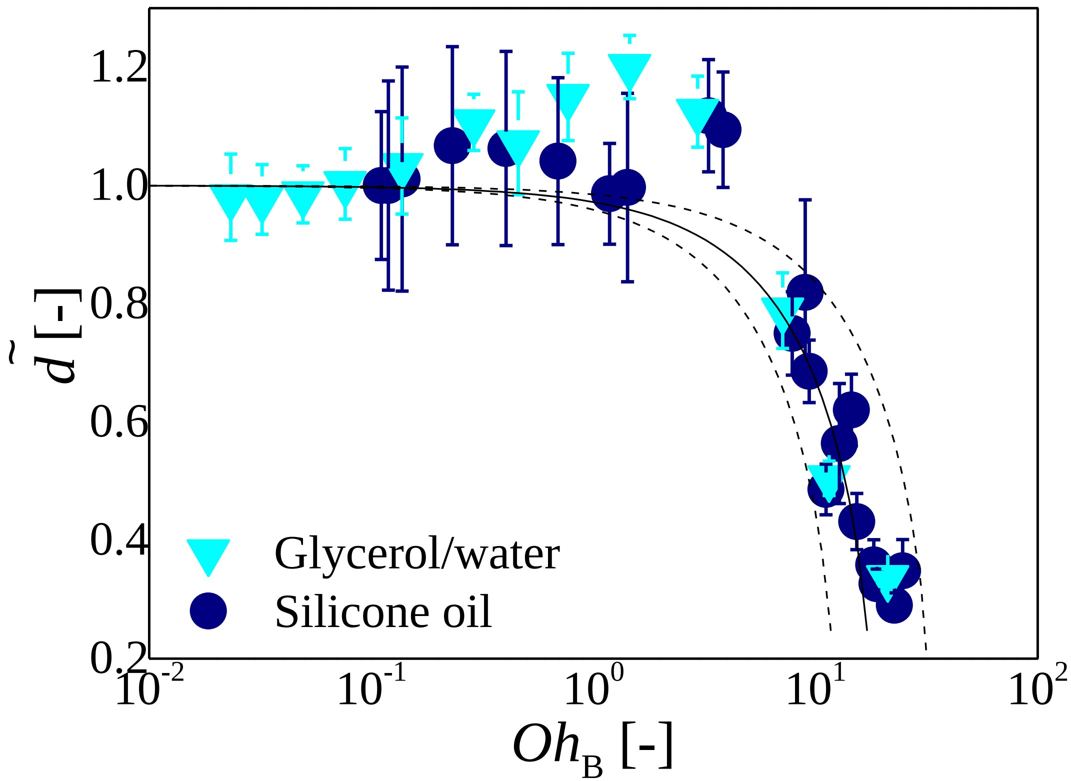
Sheet expansion governed by :

$Oh << 1$ Balance between inertia and surface tension

$Oh >> 1$ Viscous dissipation



Impact of Newtonian fluids



Scaling approach

$$\tilde{d} = \sqrt{1 - \frac{2E_B}{mv_{impact}^2}}$$

With $E_B \approx \eta_B \frac{\pi d_0^2}{6} \frac{(d_{Max} - d_0)^2}{d_{Max}\, t_{Max}}$

On the role of extensional viscosity in the expansion dynamics of thinning viscoelastic sheets
A. Louhichi , S. Arora , C-A. Charles , L. Bouteiller , D. Vlassopoulos , L. Ramos and C. Ligoure
Submited Soft matter, 2019

Impact of soft elastic bead

With no viscous shear dissipation

and for large deformations (λ >>1)

$$\lambda = \frac{d_{max}}{d_0}$$

Kinetic energy

Surface energy at max expansion

Elastic energy

$$\frac{1}{2} m v_0^2 \approx \frac{1}{2} \pi \gamma d_{max}^2 + V_{bead} G_0 \lambda^2$$

$$\frac{1}{\sqrt{2}} v_0 = \lambda \sqrt{U_L^2 + U_S^2}$$

Velocity of the free oscillations of a drop

$$U_L = \sqrt{\frac{3\gamma}{\rho d_0}}$$

Sound velocity in the elastic medium

$$U_S = \sqrt{\frac{G_0}{\rho}}$$

l_{ec}

$$\frac{U_L}{U_S} = \sqrt{\boxed{\frac{3\gamma}{G_0}} \frac{1}{d_0}}$$

Impact of Beads and Drops on a Repellent Solid Surface: A Unified Description,
S. Arora, J.-M. Fromental, S. Mora, Ty Phou, L. Ramos, and C. Ligoure
Phys. Rev. Lett., 2018

Impact of soft elastic bead

With no viscous shear dissipation

and for large deformations (λ >>1) $\lambda = \frac{d_{max}}{d_0}$

Kinetic energy

Surface energy at max expansion

Elastic energy

$$\frac{1}{2}mv_0^2 \approx \frac{1}{2}\pi\gamma d_{max}^2 + V_{bead}G_0\lambda^2$$

Two elastic contributions :

- Surface tension
- Bulk elasticity

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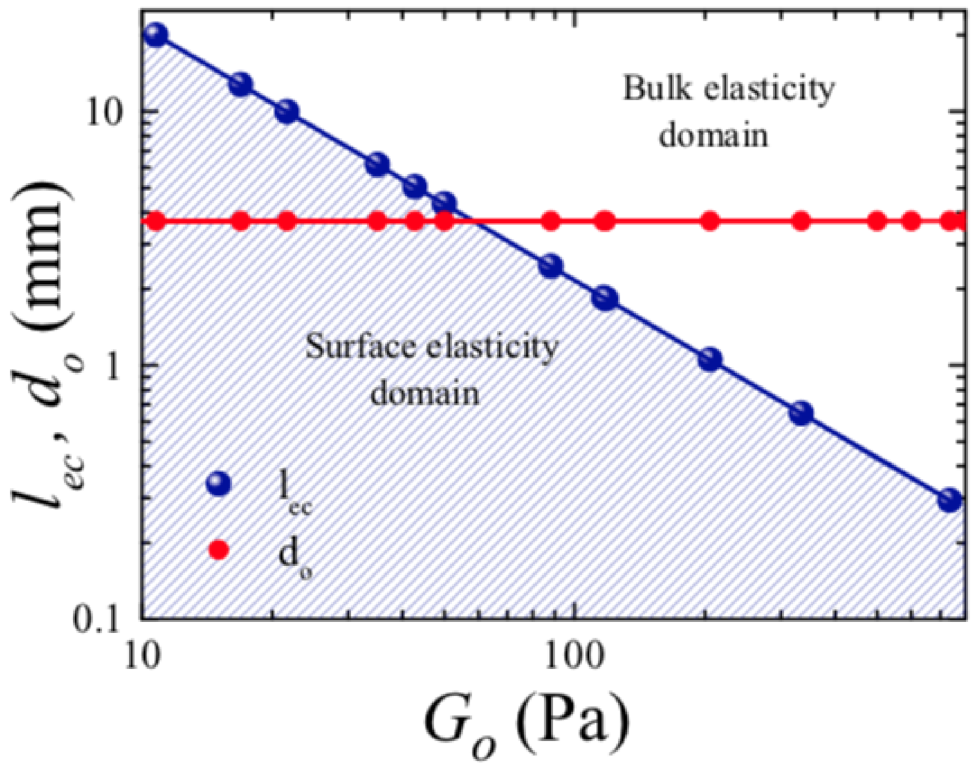
Impact of soft elastic bead

With no viscous shear dissipation

and for large deformations ($\lambda >>1$)



$d_0 = 3.7mm$
$\gamma = 72mN/m$

Vary d_o or G_o

Impact of Beads and Drops on a Repellent Solid Surface: A Unified Description,
S. Arora, J.-M. Fromental, S. Mora, Ty Phou, L. Ramos, and C. Ligoure
Phys. Rev. Lett., 2018

Impact of viscoelastic fluids

Reminder

Maxwell fluid with elastic modulus G_o and a relaxation time τ

$$G'(De) = G_0 \frac{De^2}{1+De^2}$$

with $\omega = \frac{1}{\tau_{exp}}$

$$G''(De) = G_0 \frac{De}{1+De}$$

$\tau_{exp} \sim 10ms$

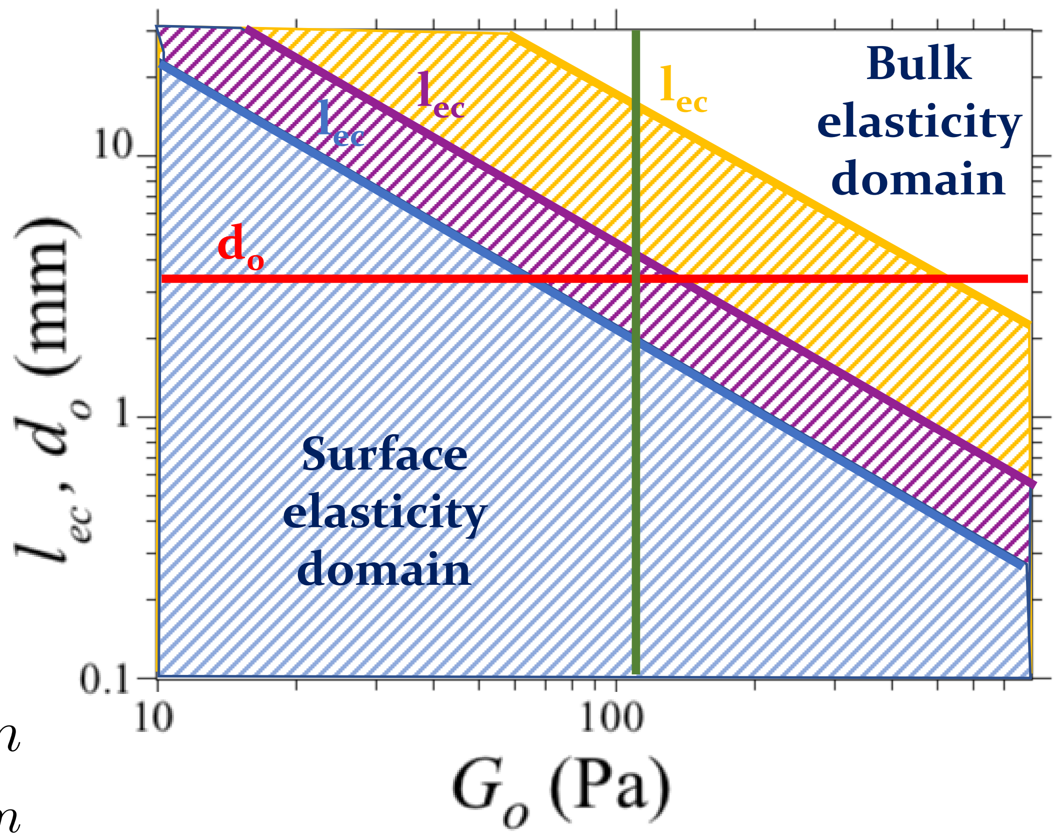
Dynamic elasto-capillary length :

$$\boxed{l_{ec}(De) = l_{ec} \frac{1+De^2}{De^2}}$$

Impact of viscoelastic fluids

$$\lambda(De) \approx \frac{1}{\sqrt{2}} \frac{v_0}{U_L} \sqrt{\frac{1}{1 + \frac{d_0}{l_{ec}(De)}}}$$

Fixed G_o



$De >> 1$

$De \simeq 1$

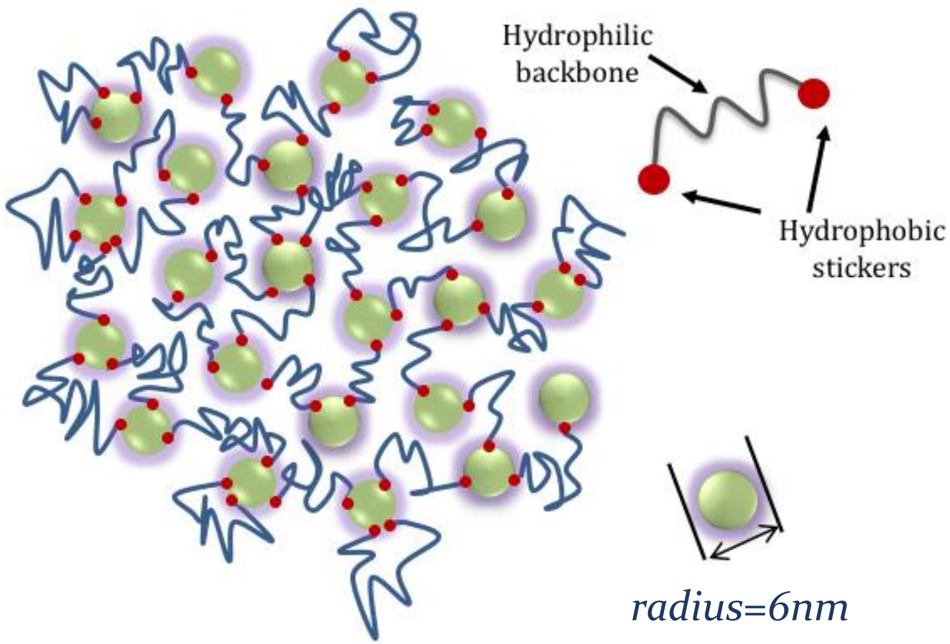
$De << 1$

$d_0 = 3.7mm$

$\gamma = 72mN/m$

Microemulsions

Microemulsions reversibly linked by telechelic polymers,
C_n -(PEO)$_{35k}$- C_n (n = 12, 14, 18)



radius=6nm

r = number of stickers per droplet
Φ = mass fraction of droplet

$$\boxed{G_0 = \mu k_B T}$$

$\mu = Number\ density\ of\ active\ chains$

$$\boxed{\tau = \tau_0\ e^{\frac{E_a}{k_B T}}}$$

$E_a \propto n_{CH_2}$

Impact of Beads and Drops on a Repellent Solid Surface: A Unified Description,
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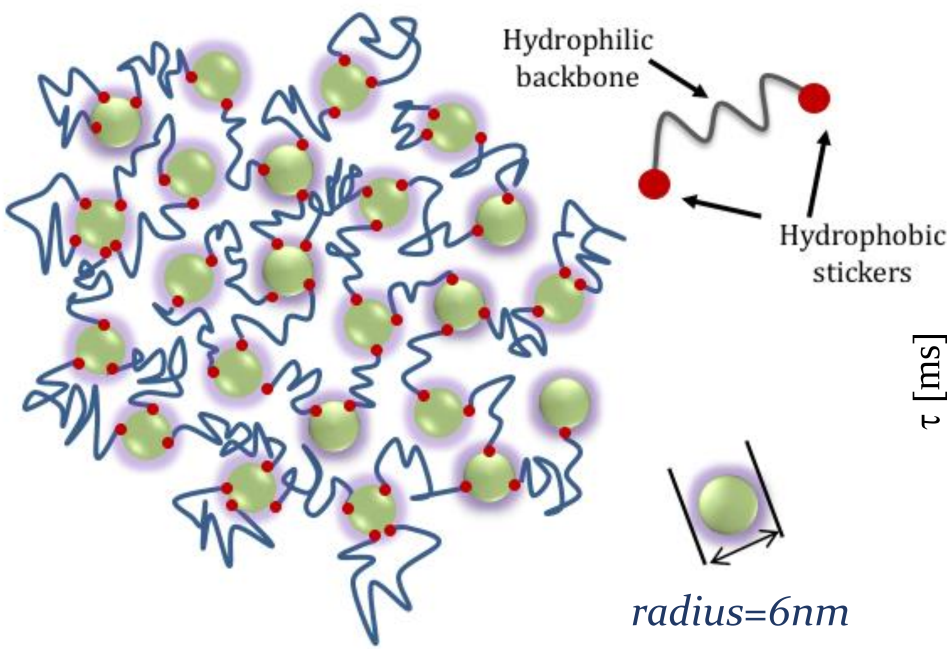
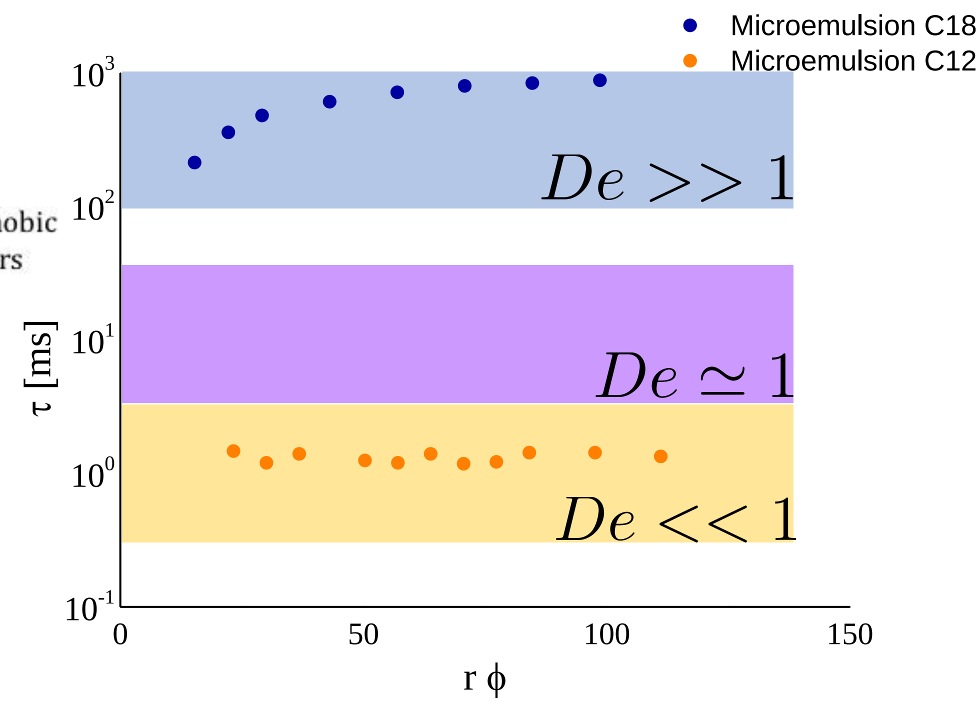


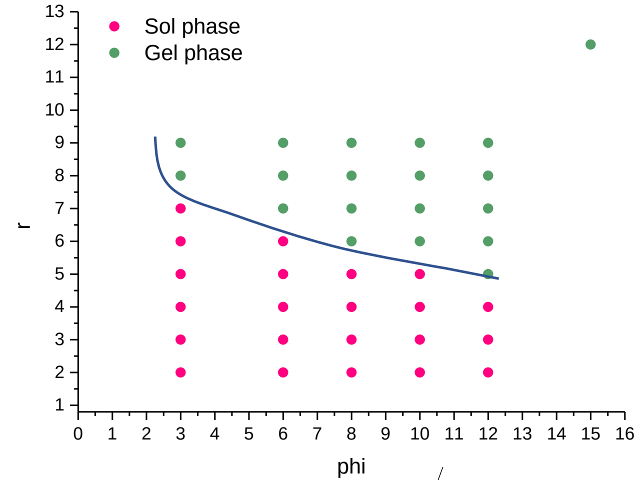


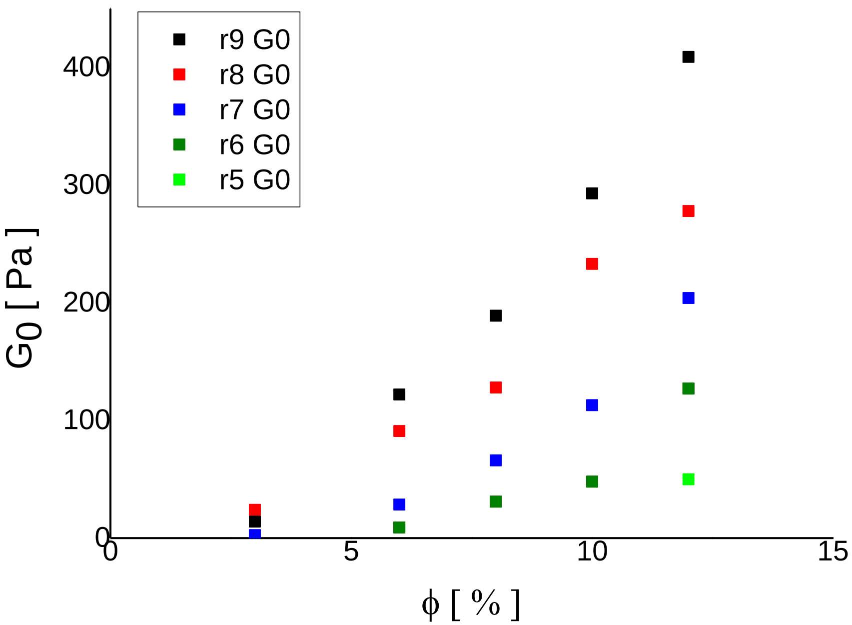
r = number of stickers per droplet
Φ = mass fraction of droplet

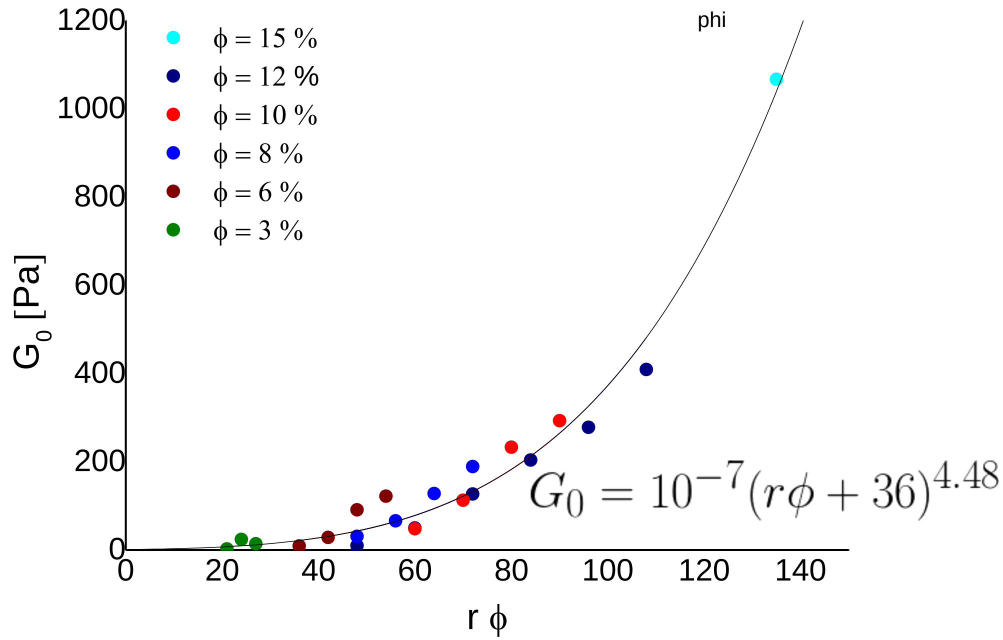
Impact of Beads and Drops on a Repellent Solid Surface: A Unified Description,
S. Arora, J.-M. Fromental, S. Mora, Ty Phou, L. Ramos, and C. Ligoure
Phys. Rev. Lett., 2018

Microemulsions C_{14}

r = number of stickers per droplet
Φ = mass fraction of droplet
r Φ = total polymer fraction



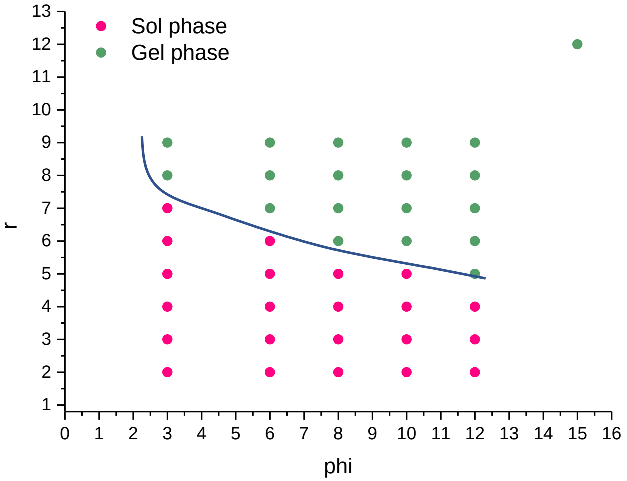


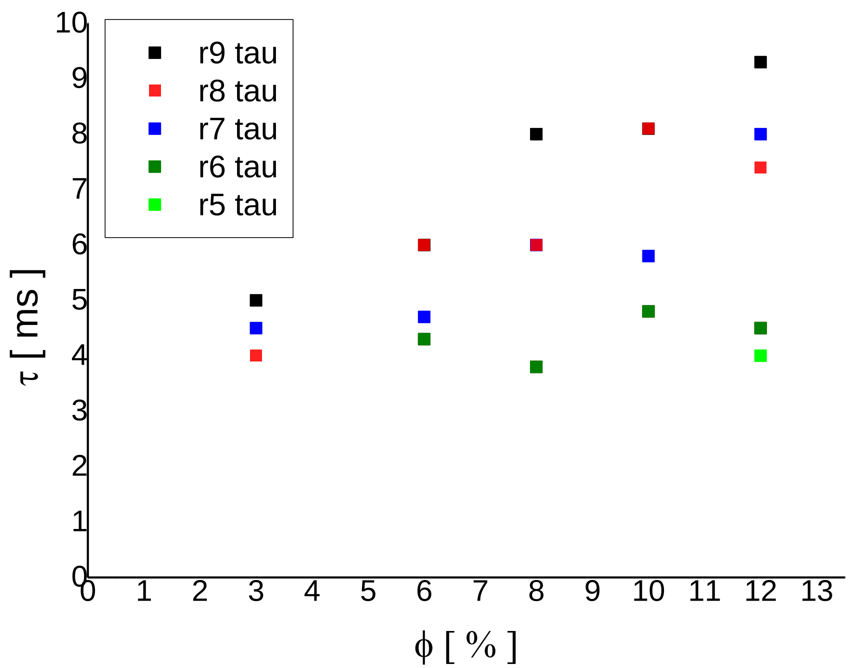


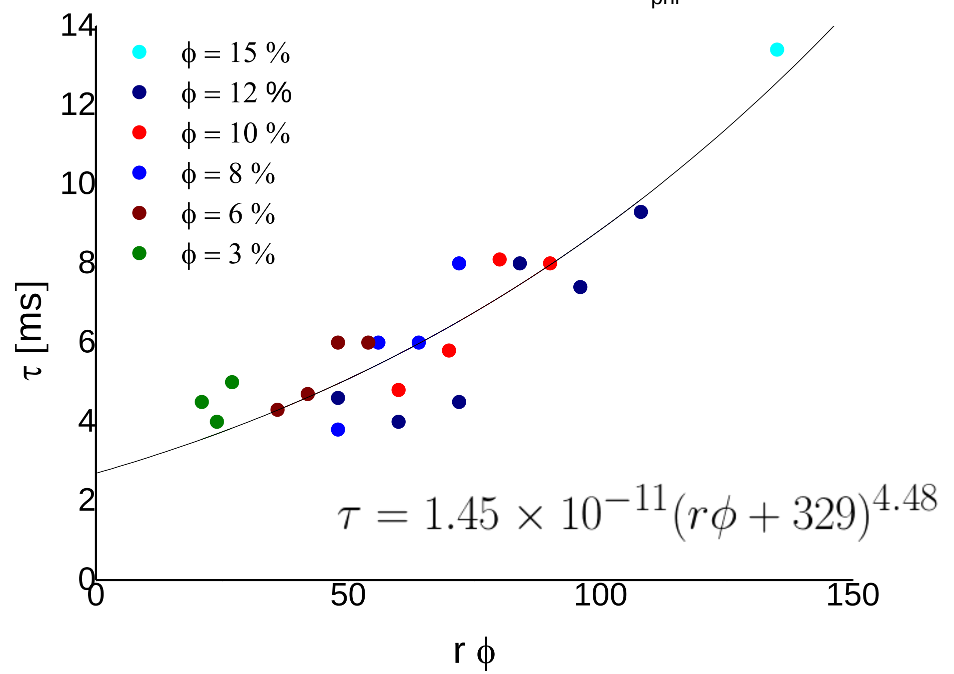
$$3Pa < G_0 < 1070Pa$$

Microemulsions C14

r = number of stickers per droplet
Φ = mass fraction of droplet
r Φ = total polymer fraction



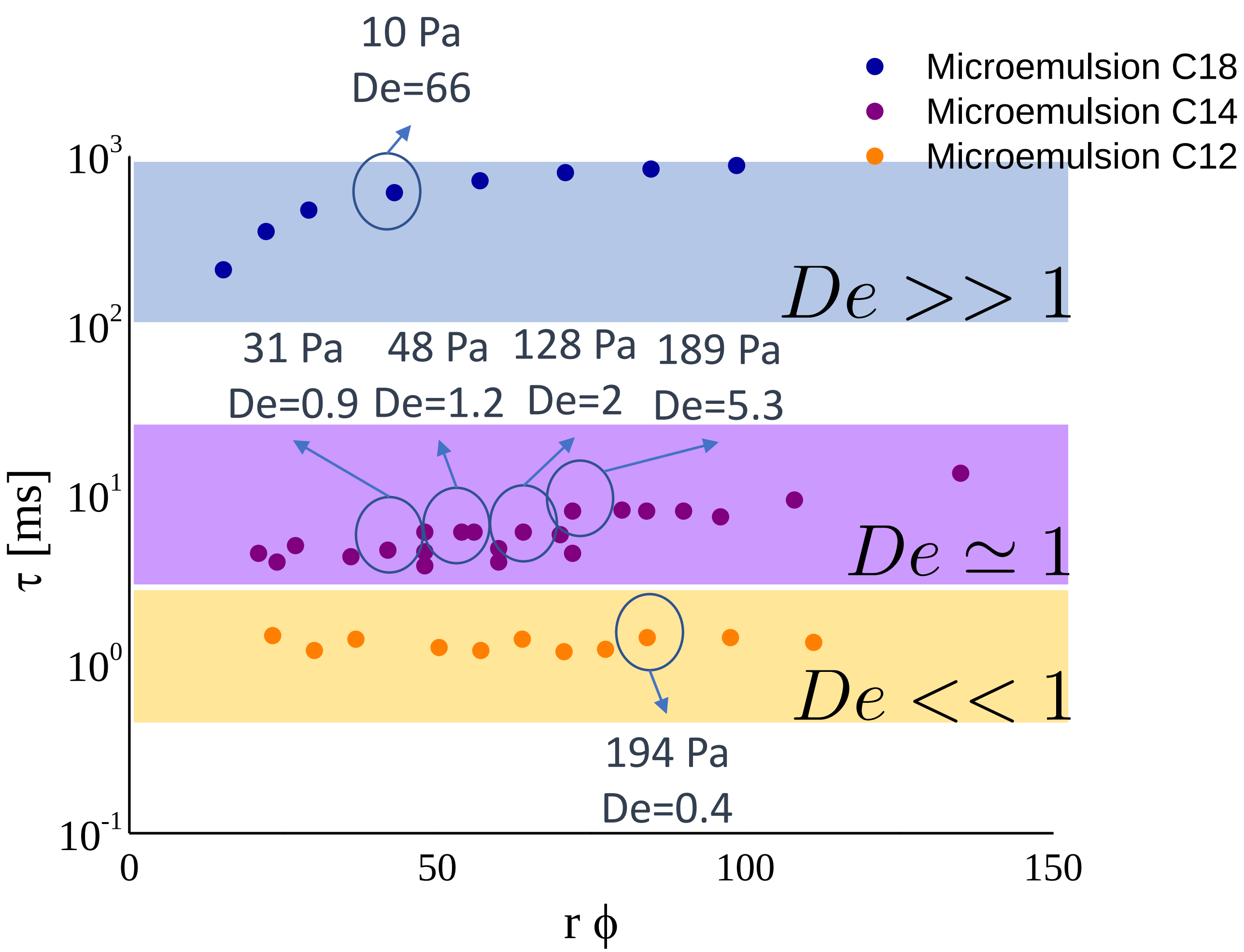




$$4ms < \tau < 13.4ms \quad \Rightarrow \quad De \simeq 1$$

Microemulsions impact

$$De = \frac{\tau}{t_{max}}$$

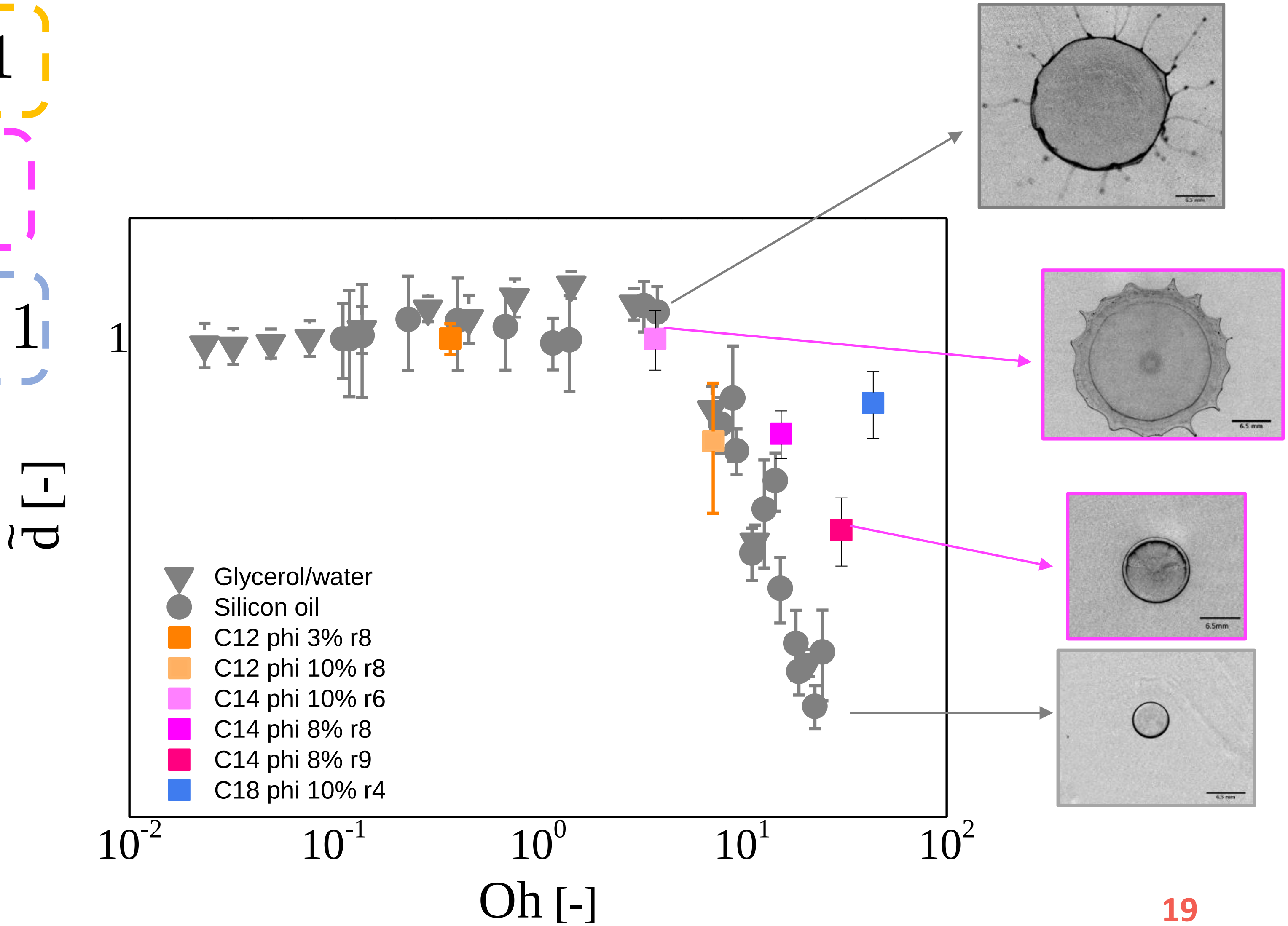


Microemulsions impact at v_0=4.2m/s

$De << 1$

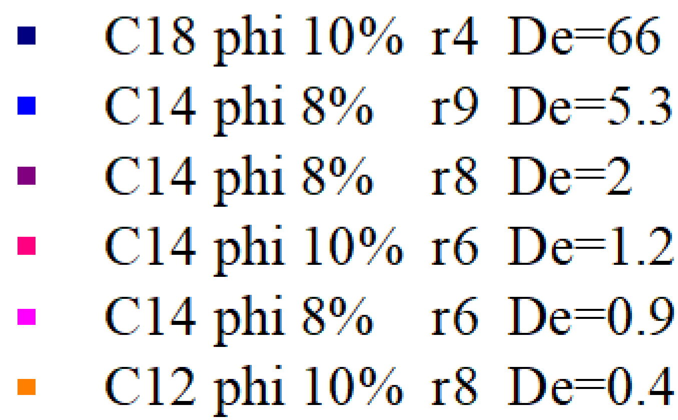
$De \simeq 1$

$De >> 1$

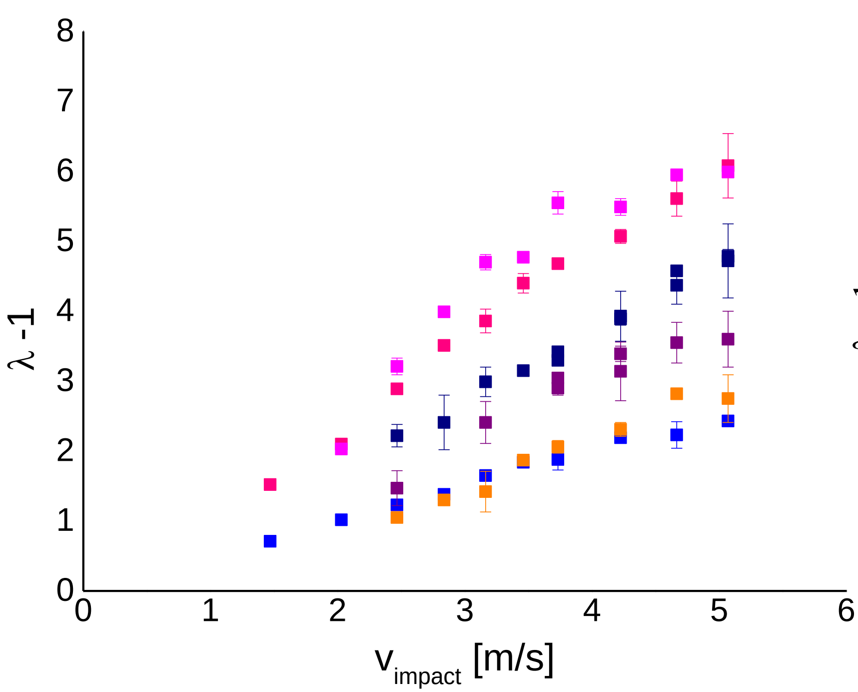


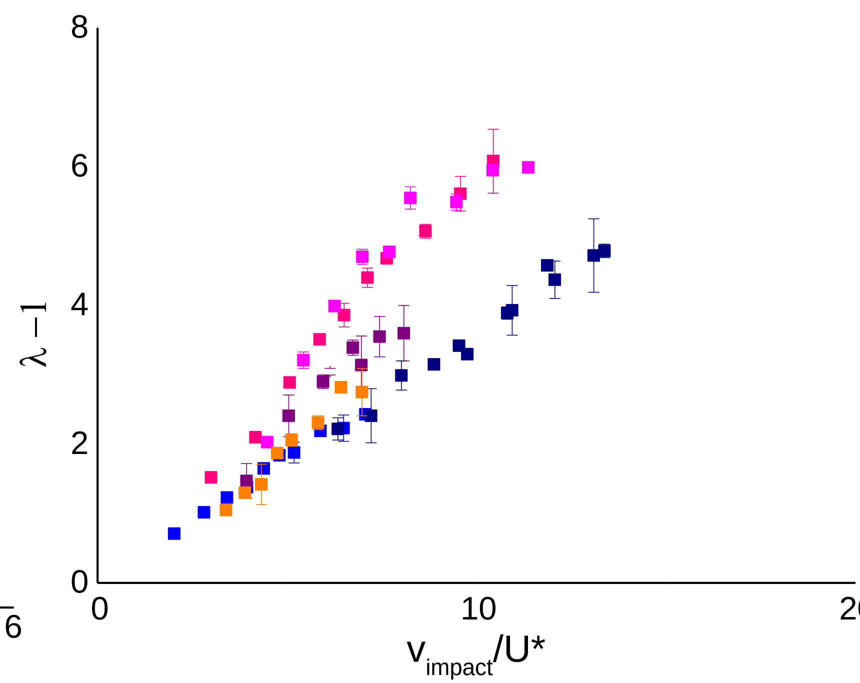
Microemulsions

$$v_{impact} = \sqrt{2gh}$$ Ranging from 1.5 to 5 m/s



$$U^* = \sqrt{U_L^2 + U_S^2} \qquad U_L = \sqrt{\frac{3\gamma}{\rho d_0}} \qquad U_S = \sqrt{\frac{G_0}{\rho}}$$





Microemulsions

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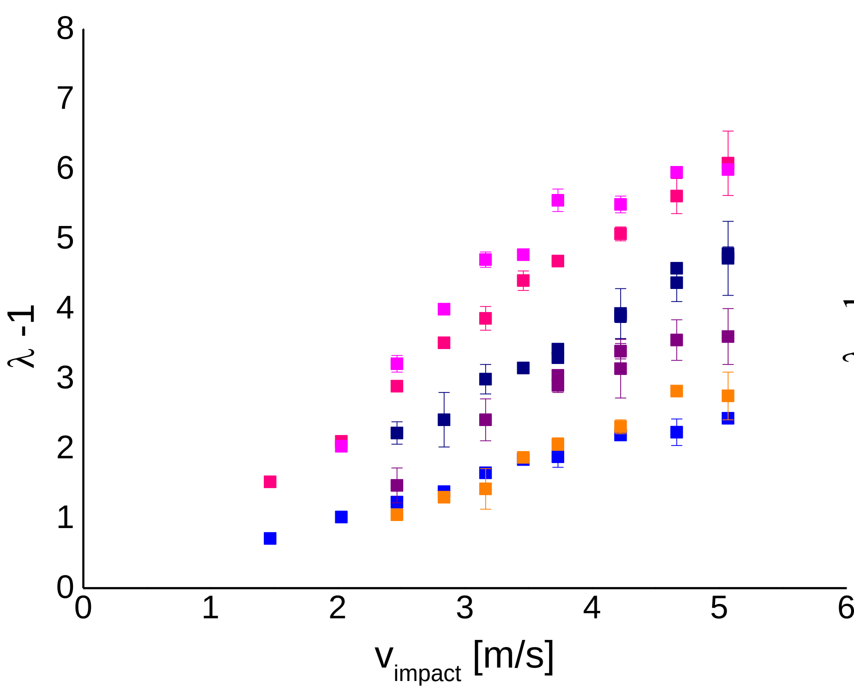
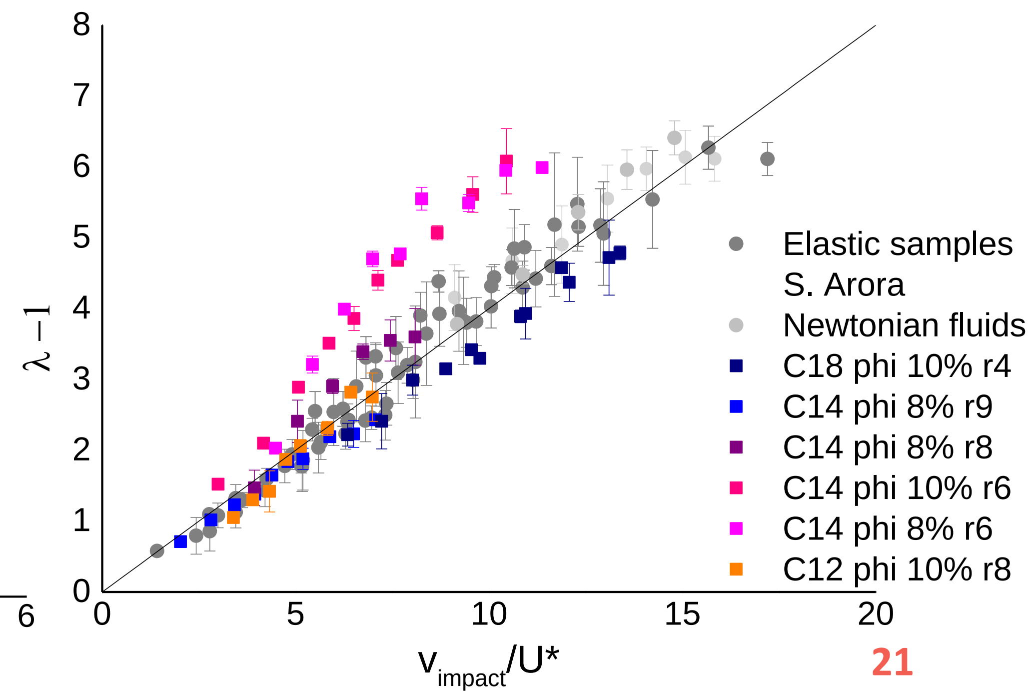
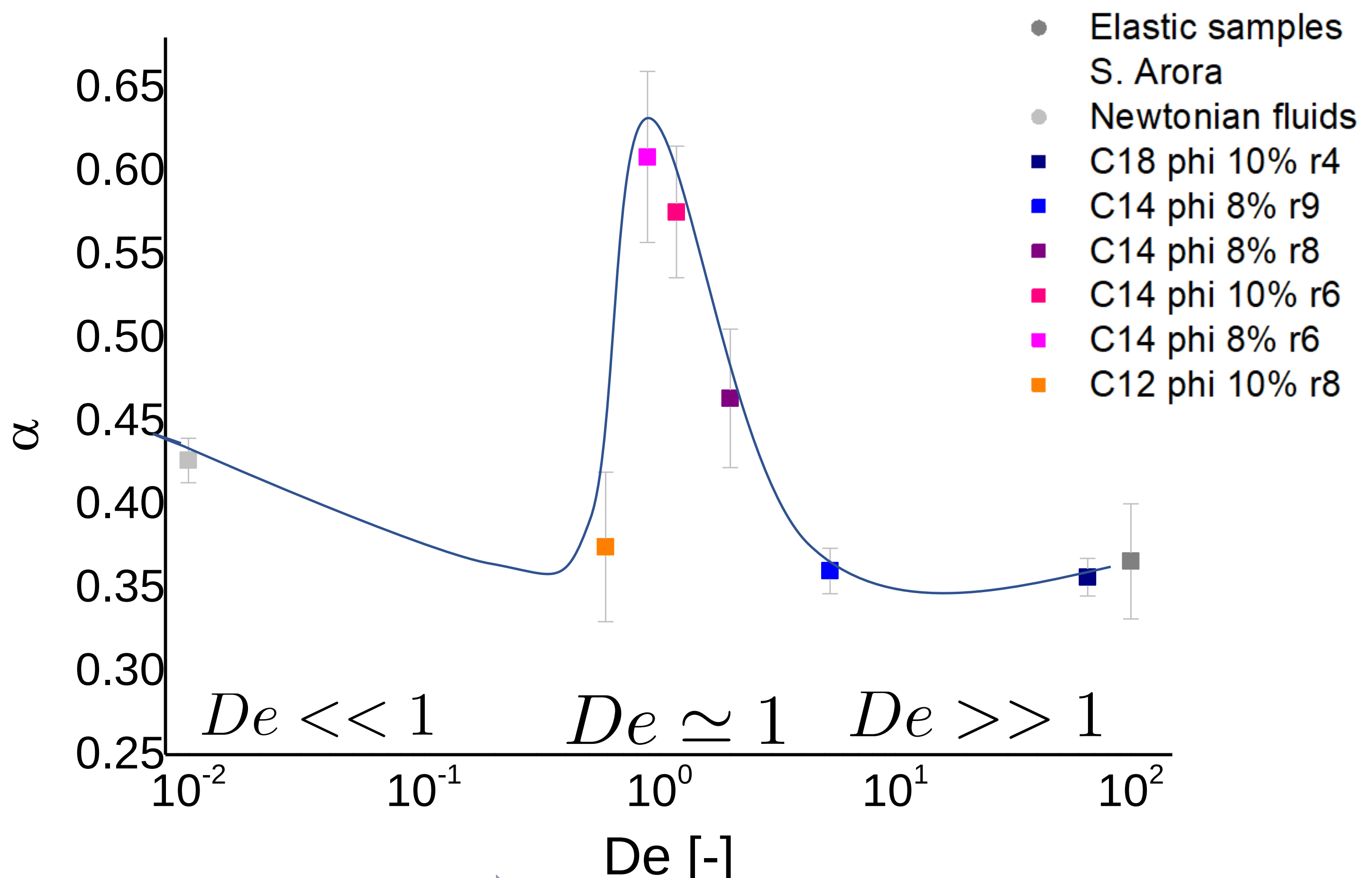




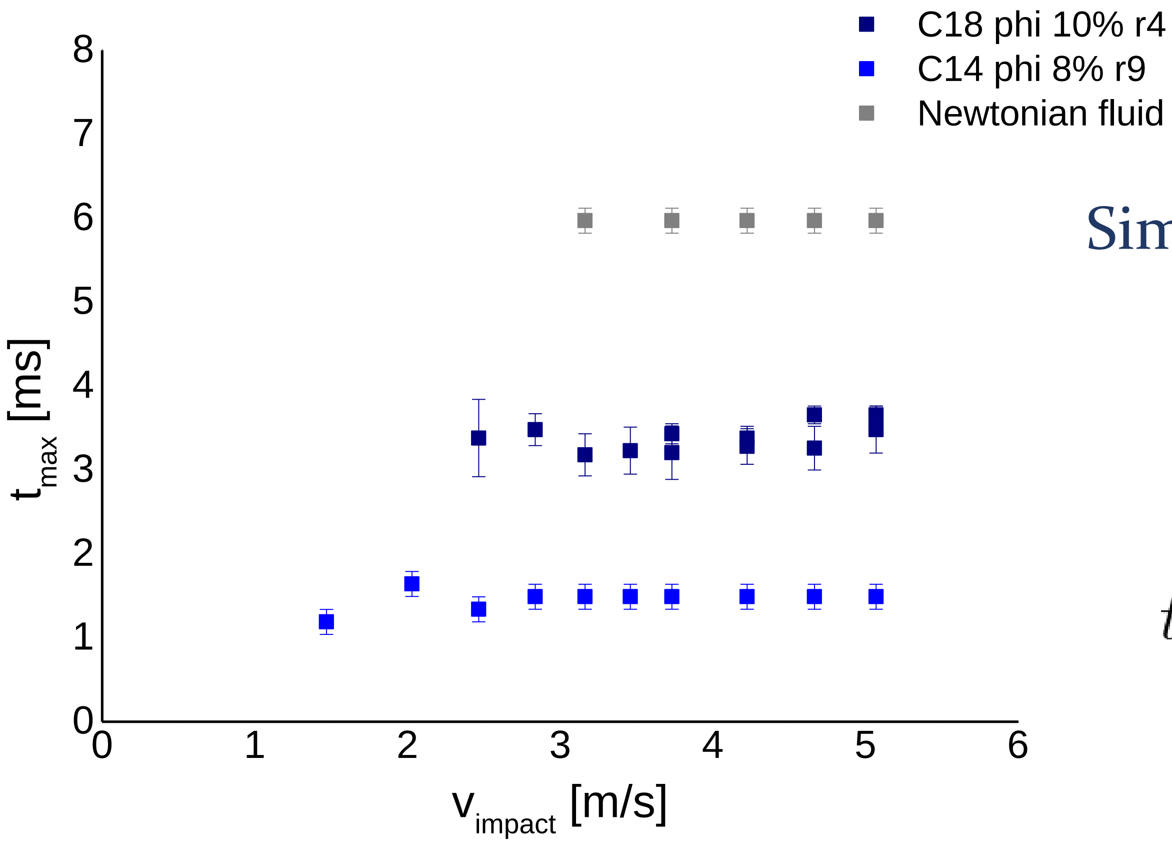
Deborah number effect



Viscoelastic effect at De close to 1

Microemulsions

$v_{impact} = \sqrt{2gh}$ Ranging from 1.5 to 5 m/s



Simple harmonic motion

$$\frac{1}{2}m\dot{d}^2 + \frac{1}{2}kd^2 = constant$$

k the spring constant

$$t_{max} = \frac{T}{4} = \frac{\pi}{2}\sqrt{\frac{m}{k}}$$

$$\rightarrow t_{max} \approx \frac{\pi}{4}\frac{d_0}{U^*}$$

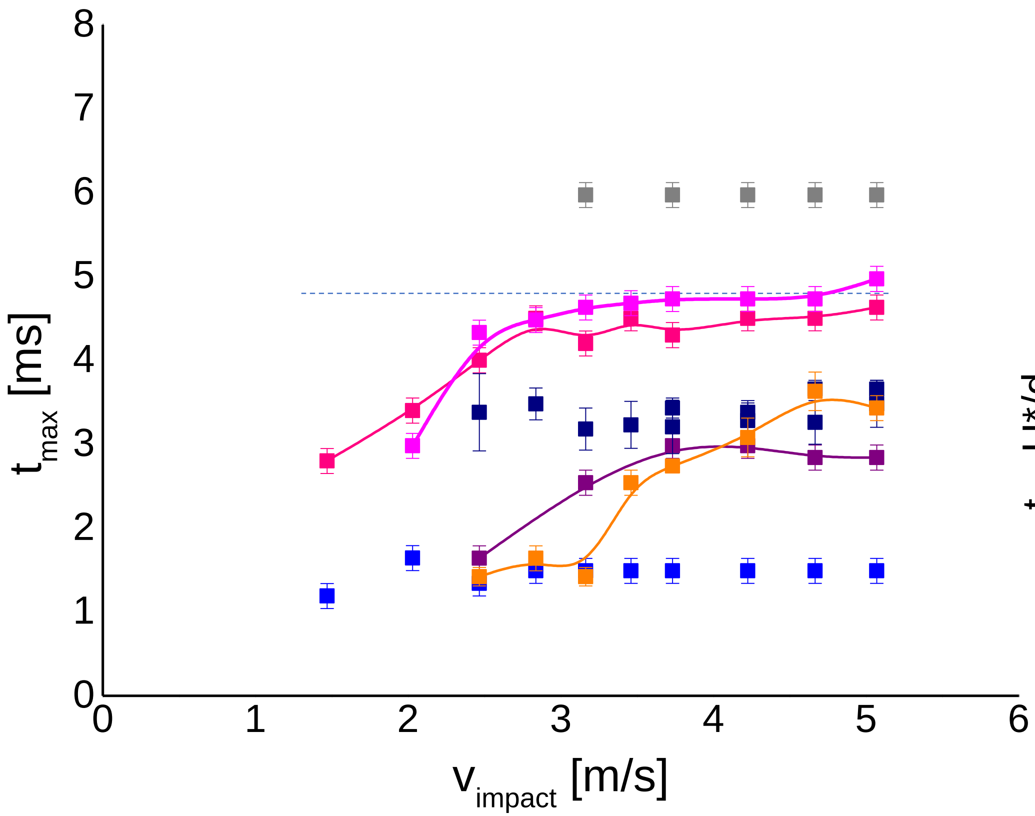
Does not depend on v_{impact}

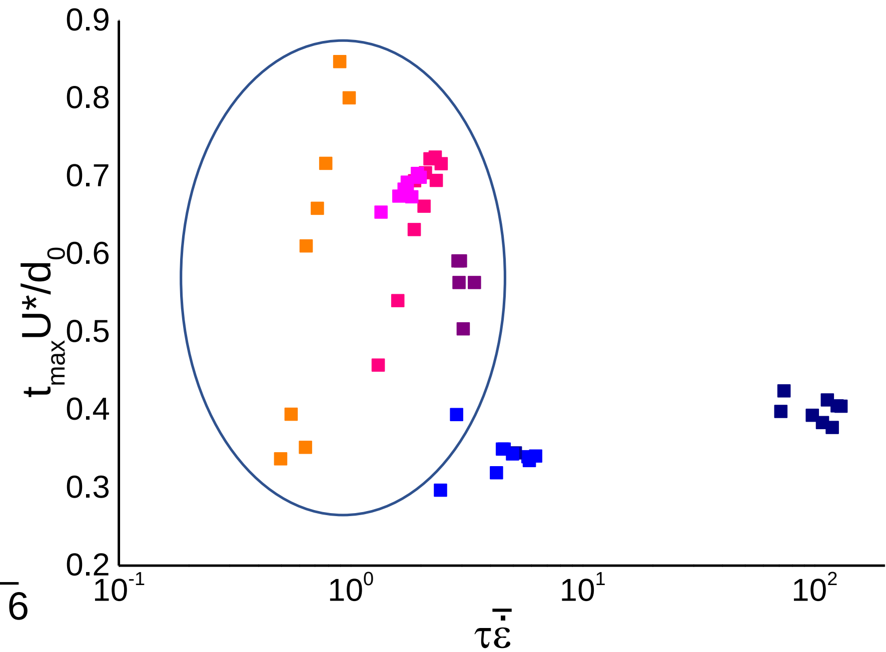
A. L. Biance, F. Chevy, C. Clanet, G. Lagubeau and D. Quéré. On the elasticity of an inertial liquid shock. Journal of Fluid Mechanics, vol. 554, page 47, may 2006.

Microemulsions

$v_{impact} = \sqrt{2gh}$ Ranging from 1.5 to 5 m/s

■ C18 phi 10% r4 De=66
■ C14 phi 8% r9 De=5.3
■ C14 phi 8% r8 De=2
■ C14 phi 10% r6 De=1.2
■ C14 phi 8% r6 De=0.9
■ C12 phi 10% r8 De=0.4





➡ t_{max} not constant for samples with De close to 1

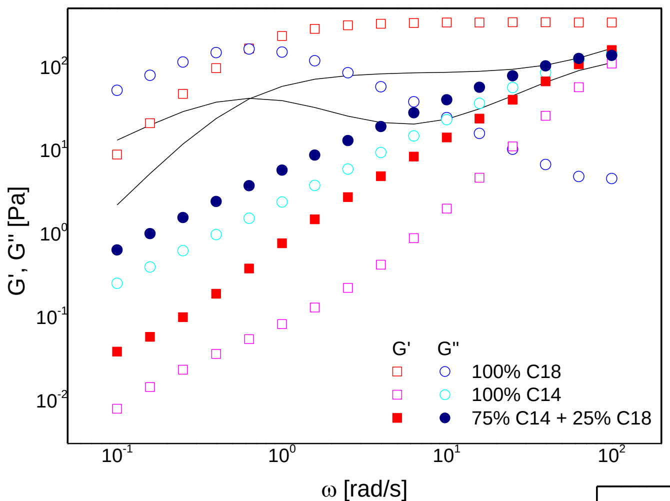
What's next?

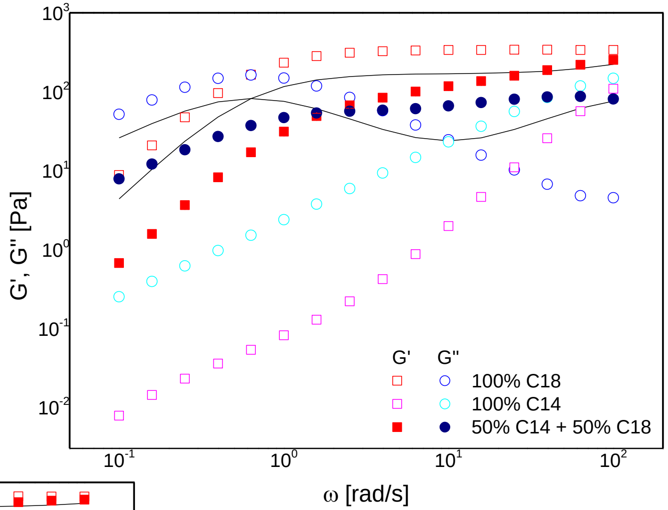
- Understand the decrease of t_{max} with the impact velocity

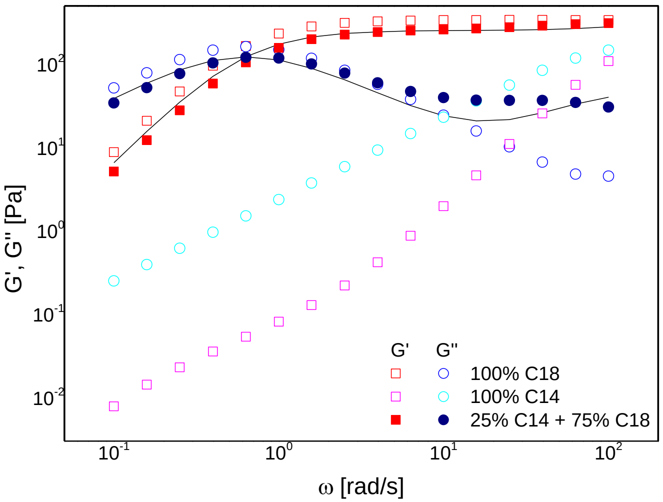
- On liquid nitrogen continue the study of the thickness field and impact of :
  - C14 Microemulsions
  - C14 and C18 Microemulsion mixes
  - Samples from Michel Cloitre
  - Double dynamic networks from DoDyNet

- Model the sheet expansion in collaboration with Prof. Daniel Read

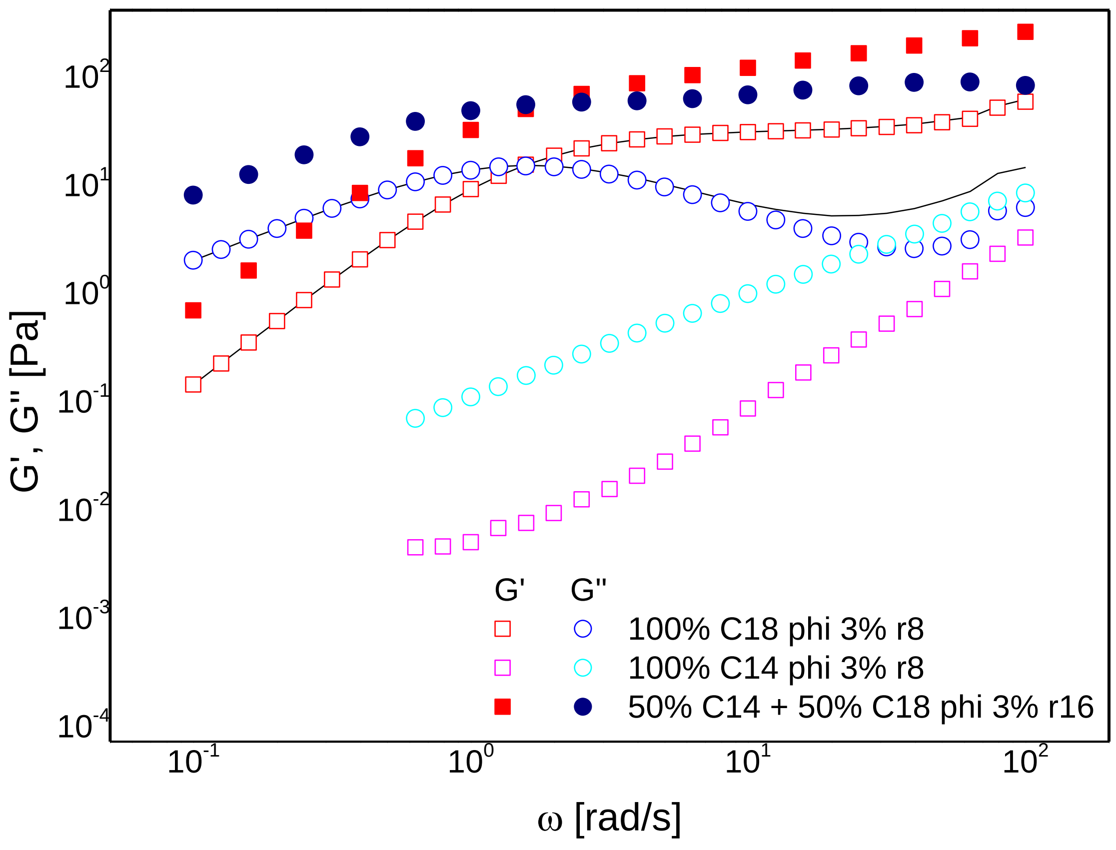
Micro-emulsion mixture C18-C14
phi=3% r=16







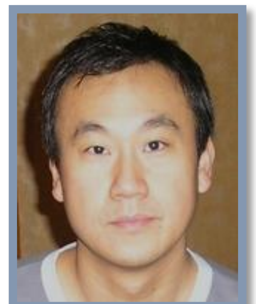
Micro-emulsion mixture C18-C14
phi=3% r=16 compared with phi=3% r8



Acknowledgment


Christian Ligoure


Laurence Ramos


Ty Phou


Jean-Marc Fromental


Ameur Louhichi

INITIAL TRAINING NETWORK

Thank you for your attention