# Elastocapillary effects in double dynamic networks

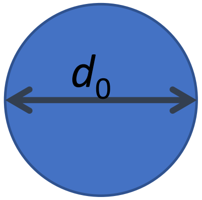
Carole-Ann Charles

Supervisors:
Christian Ligoure
Laurence Ramos

# 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 :**

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

$d_0 < l_{ec}$ 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 $\tau$

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

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

**Dynamic elasto-capillary length :**

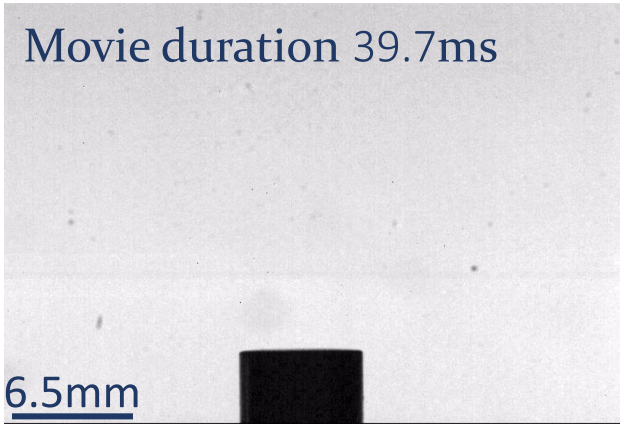
$$l_{ec}(De) = l_{ec} \frac{1 + De^2}{De^2}$$

$De >> 1 \qquad l_{ec}(De) = l_{ec}$

$De << 1 \qquad l_{ec}(De) = \frac{l_{ec}}{De^2}$

→ Surface elasticity effects can play a role at much larger $d_o$

# Drop impact



Impact of a water droplet on a small target

## Upon impact :

Inertial forces ➡ radial expansion of the sheet

Stored elastic energy ➡ retraction after maximal expansion

## Goal:

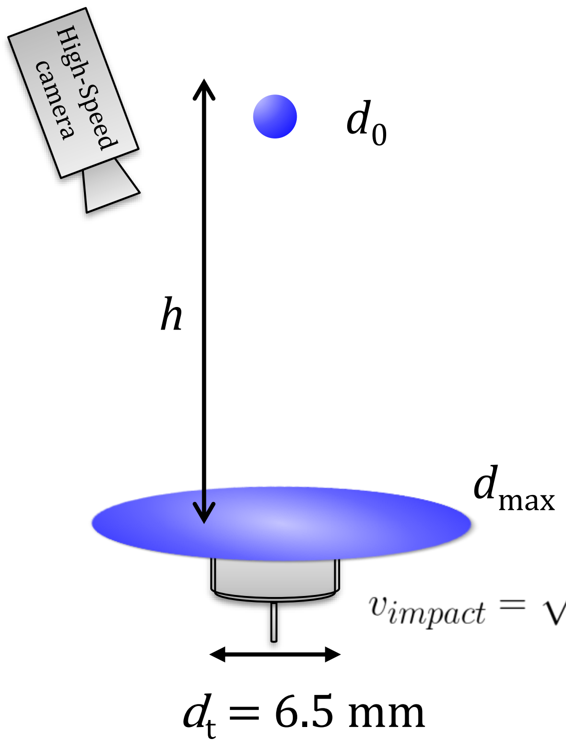
- Rationalize the respective role of
  - Inertia
  - Elasticity
  - Capillarity
  - Dissipation

- Find adequate system

# Impact of Newtonian fluid

- On a small target

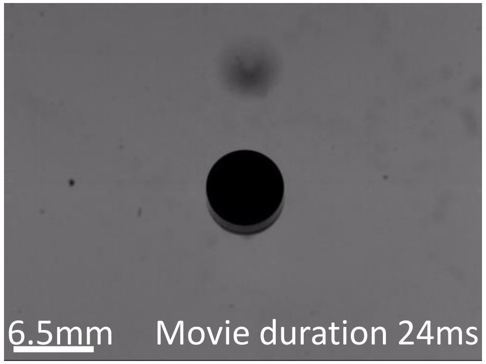
$$\lambda = \frac{d_{max}}{d_0}$$




S. Arora et al, 2017

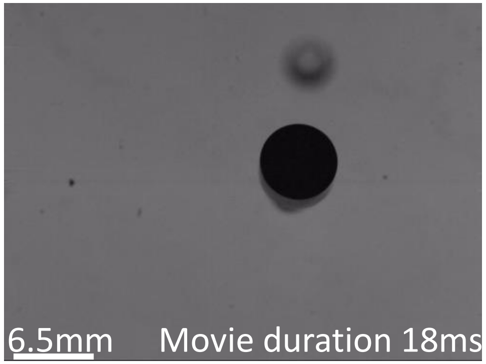
Silicone oil 5 mPas

$\lambda = 6.2$




Silicone oil 350 mPas

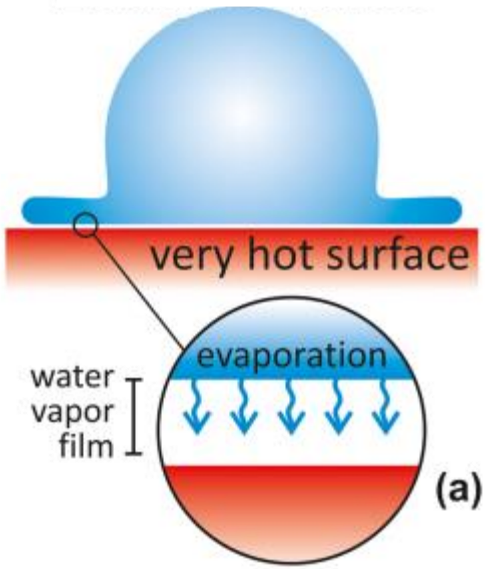
$\lambda = 1.8$



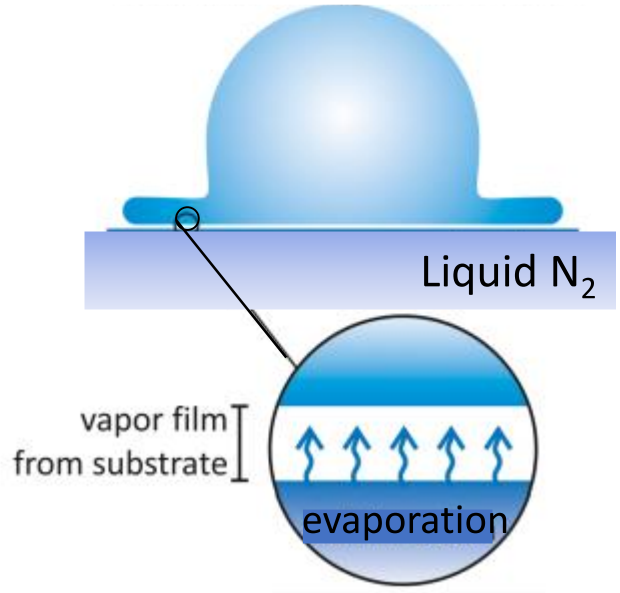

→ **Dissipation effect due to target**

# Drop impact Inverse Leidenfrost effect

Leidenfrost effect




Inverse Leidenfrost effect




C. Antonini et al., Phys. Rev. Lett., 2013

# Impact of Newtonian fluids

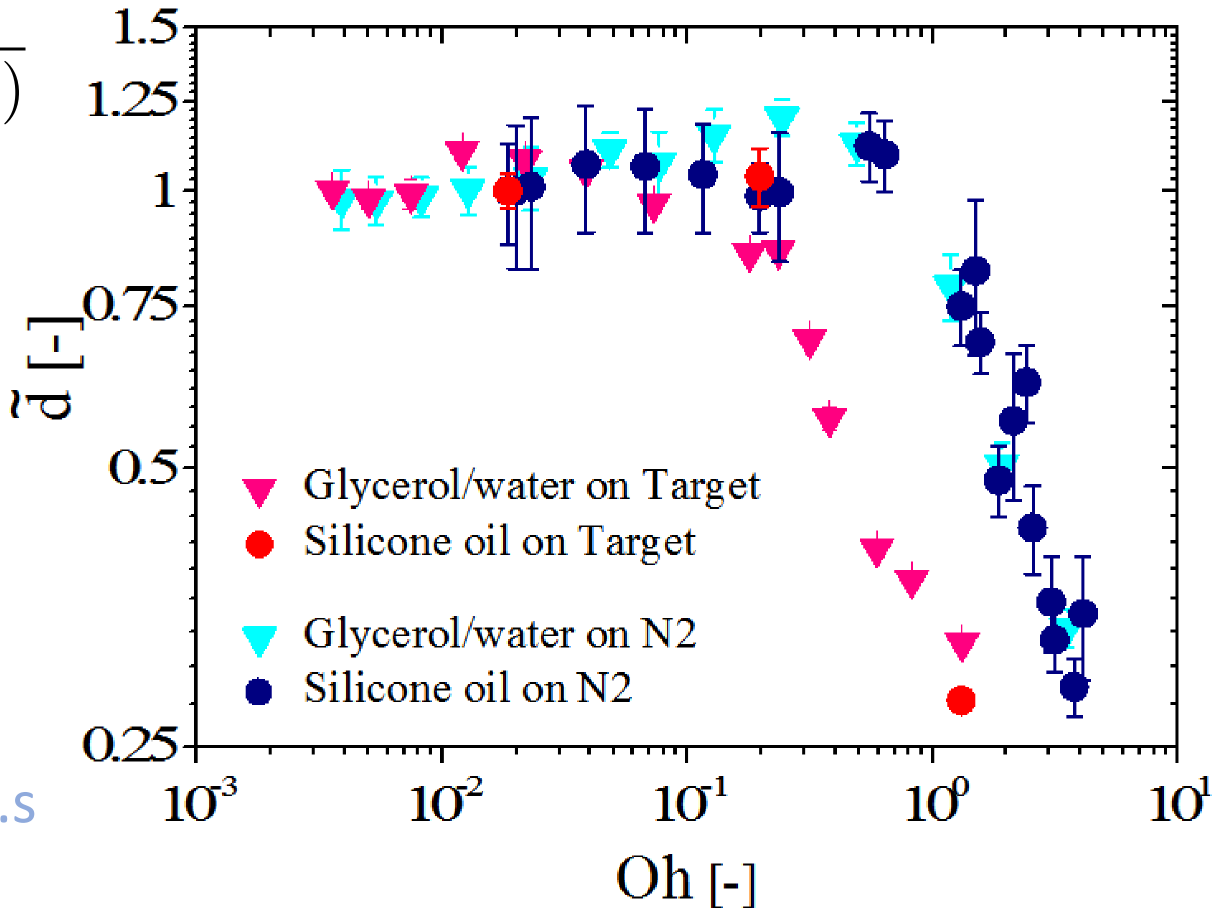
$$Oh = \frac{\eta_0}{\sqrt{\rho\gamma d_0}}$$

**Sheet expansion governed by :**

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

$Oh >> 1$ Viscous dissipation

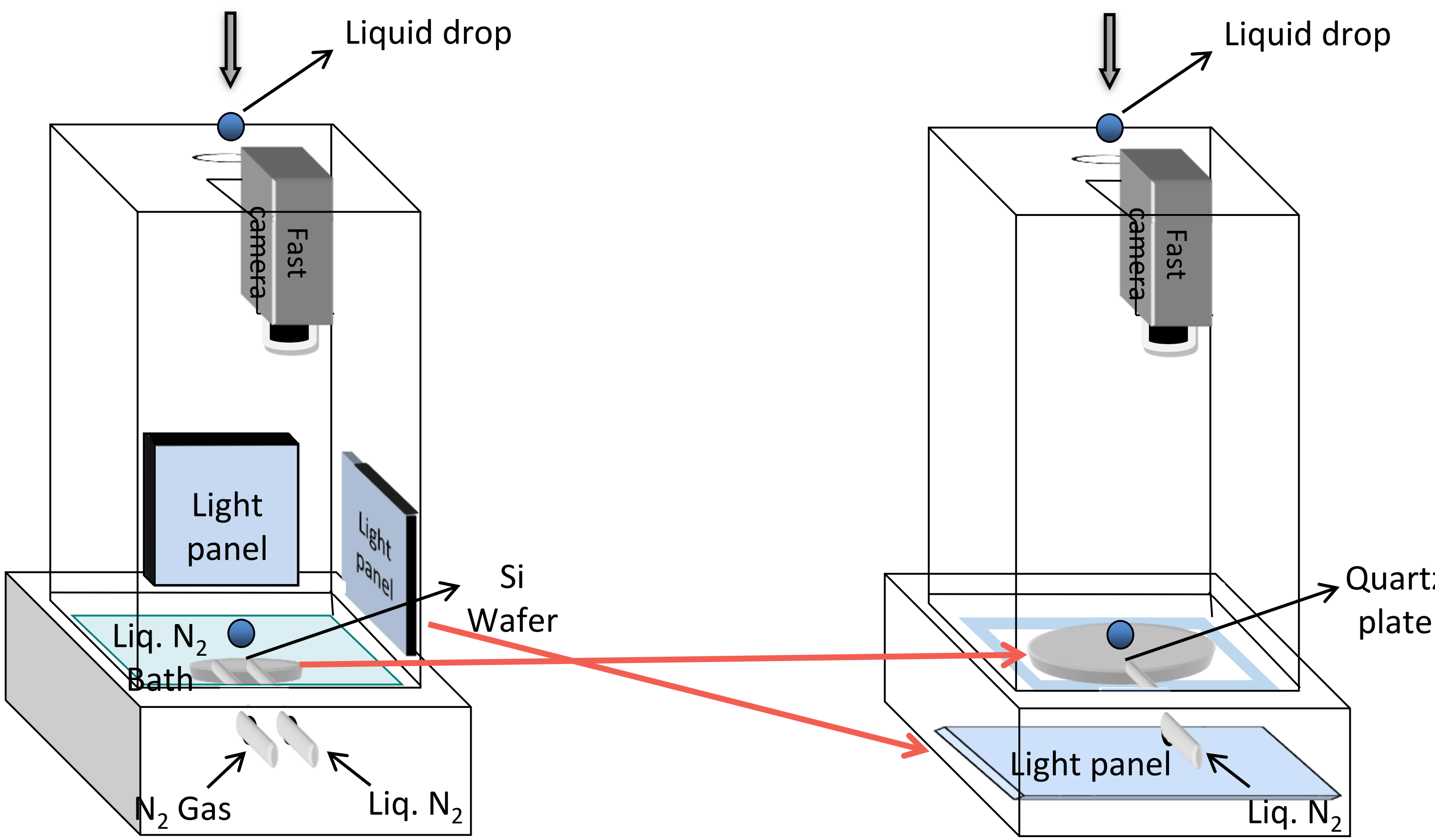
$$\tilde{d} = \frac{d_{max}}{d_{max}(\eta_0 \rightarrow 0)}$$




2 ⟶ 1000 mPa.s

# Inverse Leidenfrost effect :

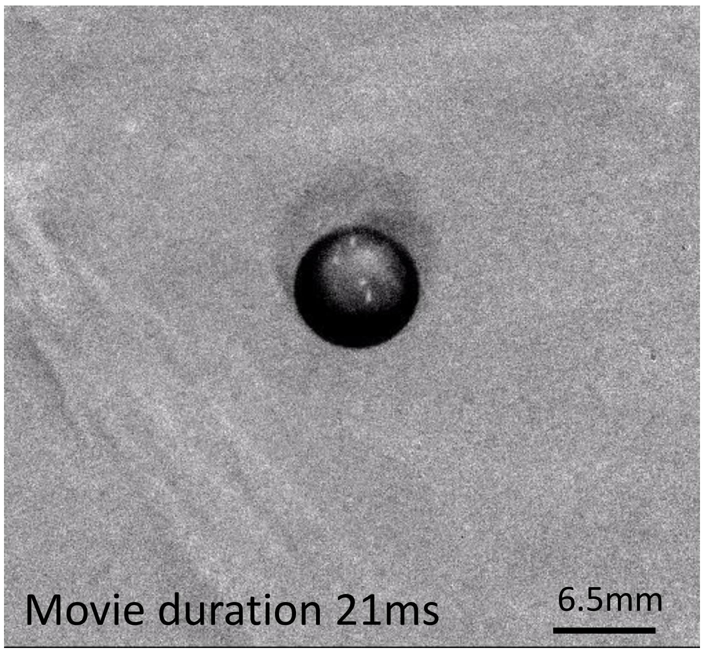
## Set up improvement



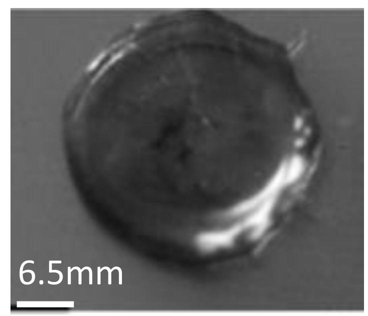

S. Arora et al, 2017

# Inverse Leidenfrost effect :

## Set up improvement

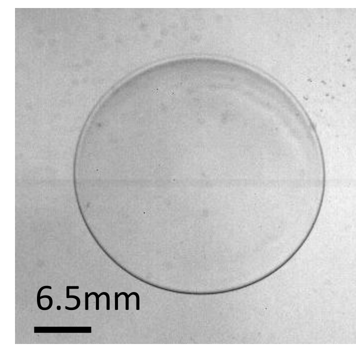



Before




S. Arora et al., 2017

After

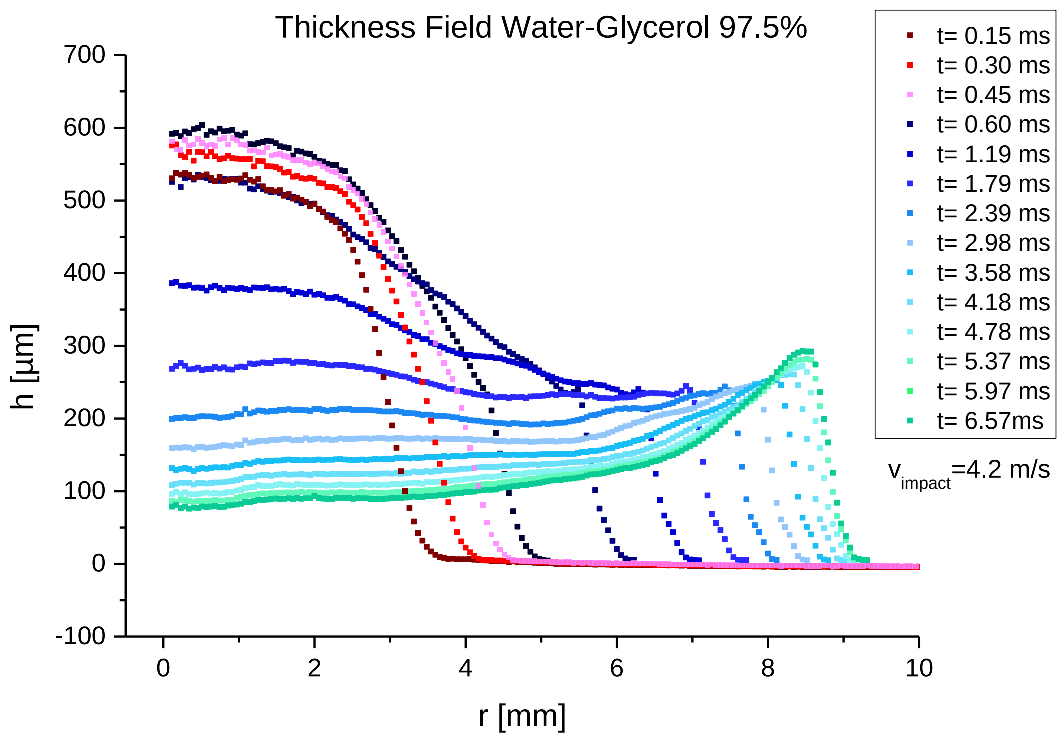


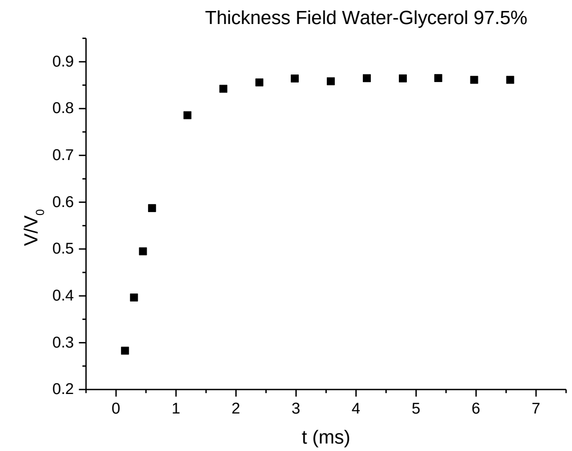

➡ Enables semi-automatic analysis

➡ Enables the analysis of the sheet thickness field

# Sheet thickness field

## Water – Glycerol 93% 365 mPas



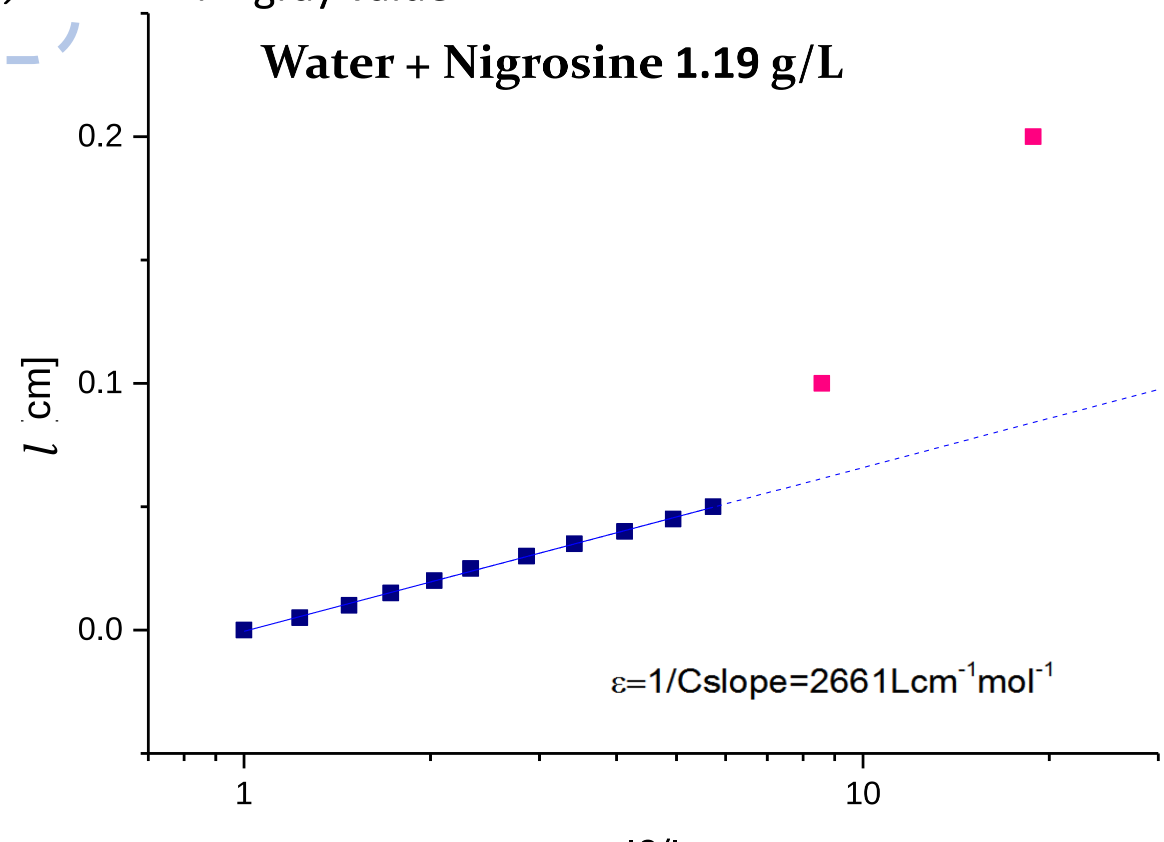



# Sheet thickness field

**Beer-Lambert law :**

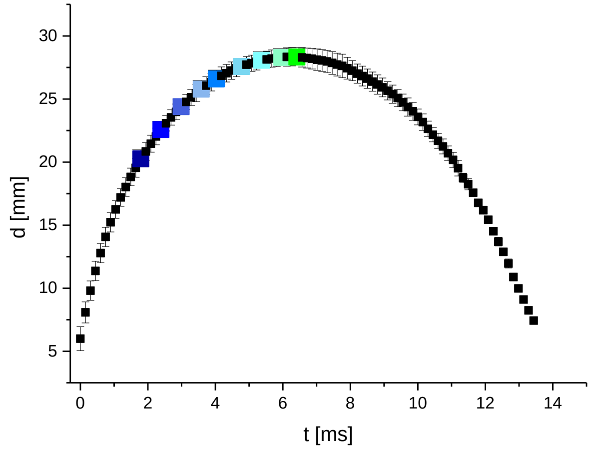
$$\epsilon\, lc = log\left(\frac{I_0}{I}\right)$$

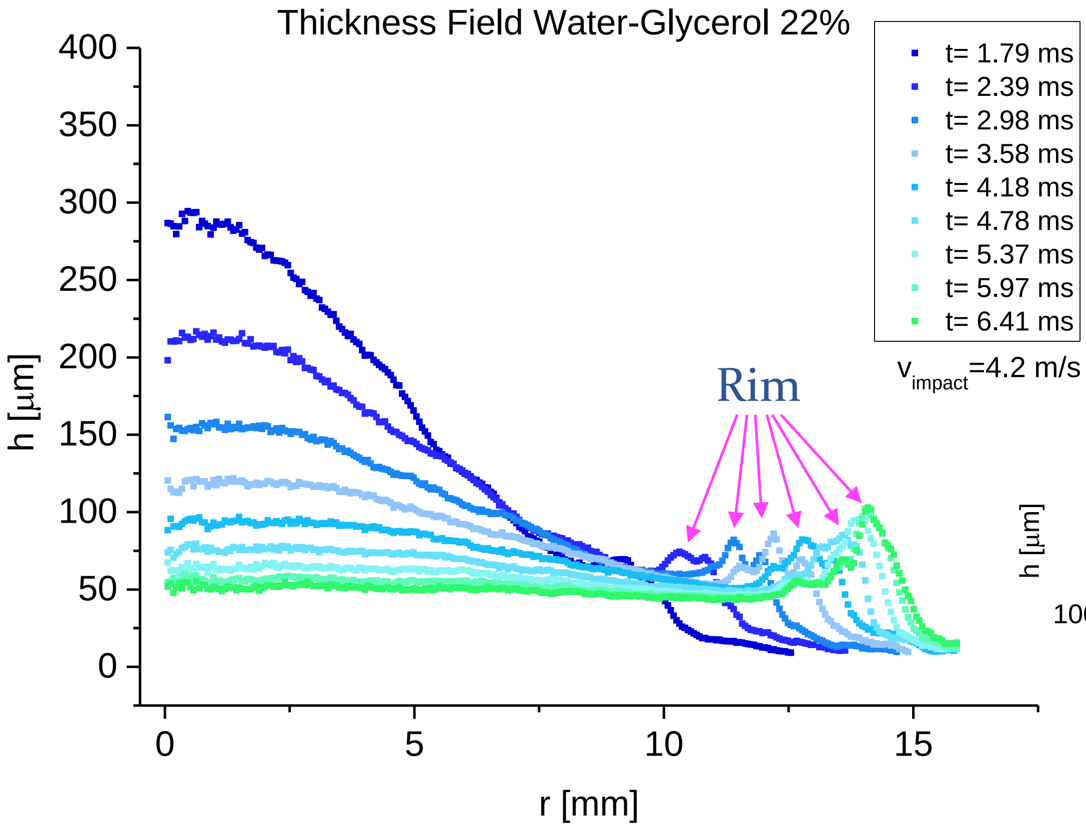
$\epsilon$ = molar extension coefficient (L.mol$^{-1}$.cm$^{-1}$)
$l$ = thickness (cm)
$c$ = molar concentration (mol.L$^{-1}$)
$I_0$ = Initial gray value
I = gray value

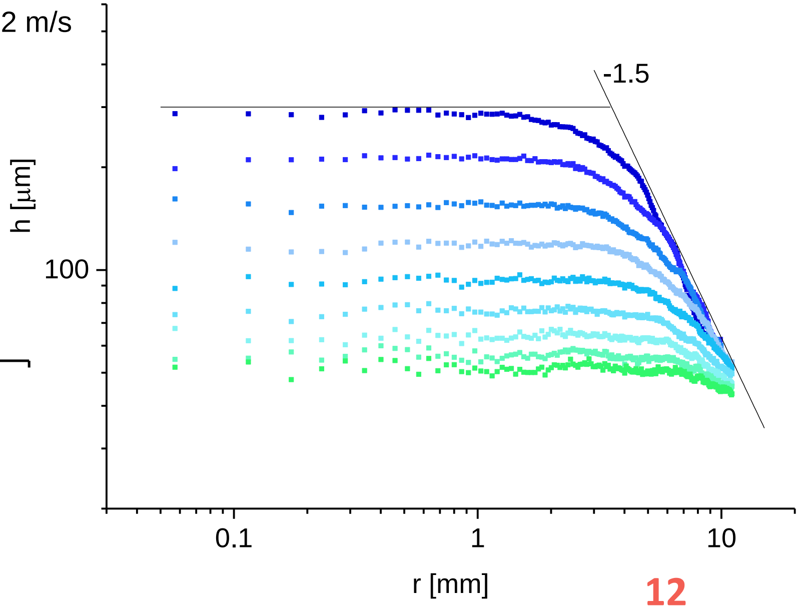


# Sheet thickness field

## Water – Glycerol 22% 2 mPas

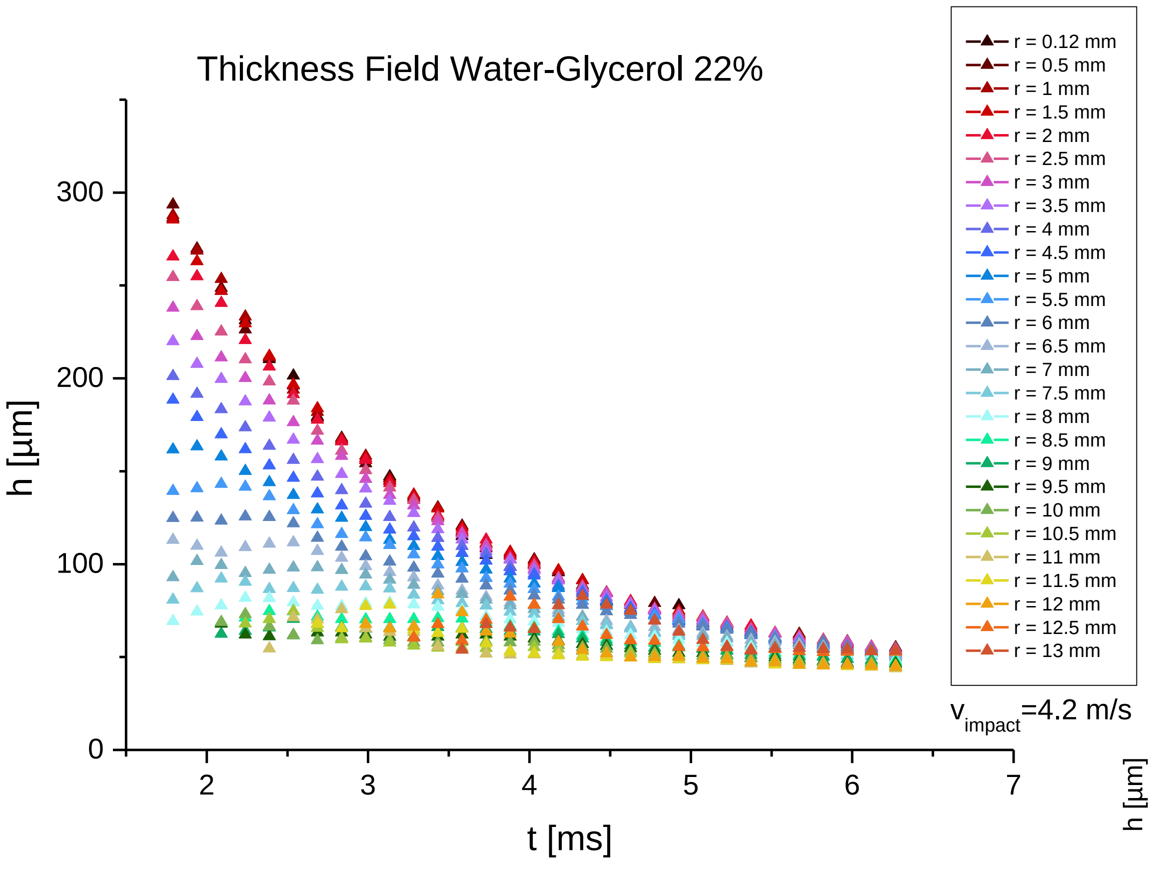


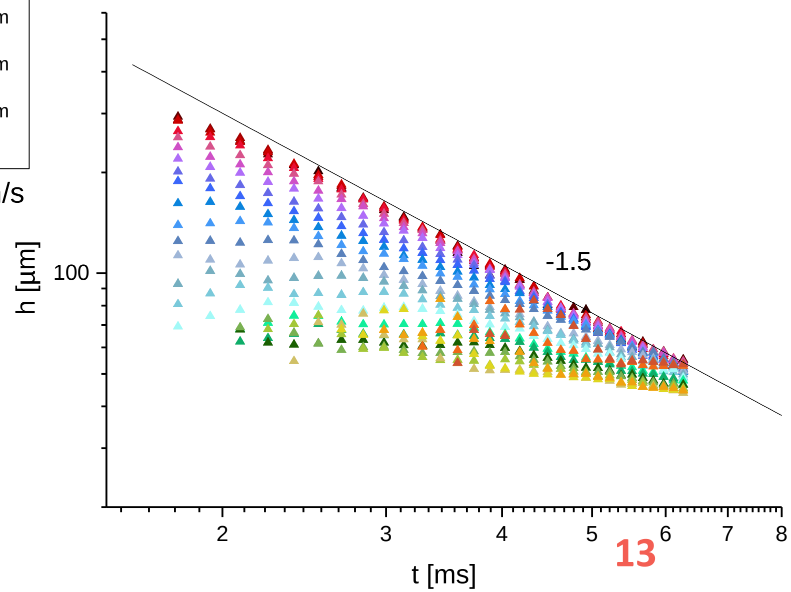



# Sheet thickness field

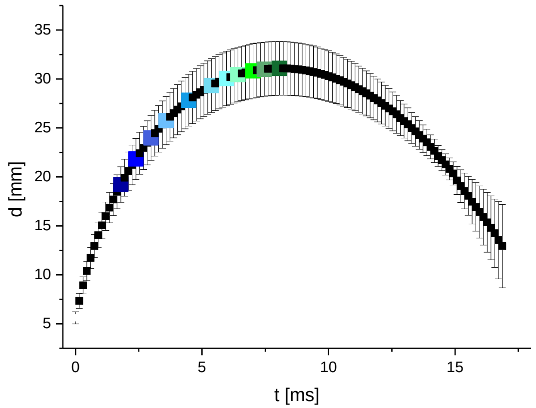
## Water – Glycerol 22% 2 mPas

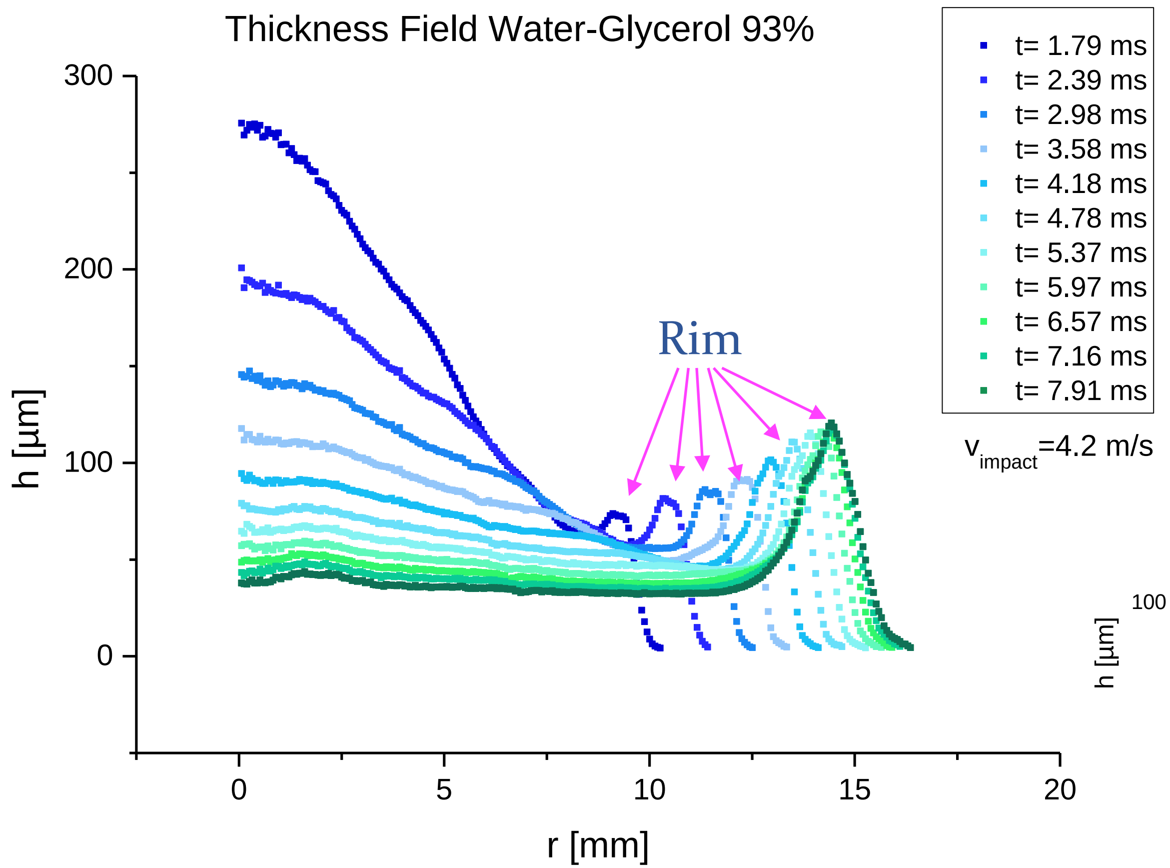


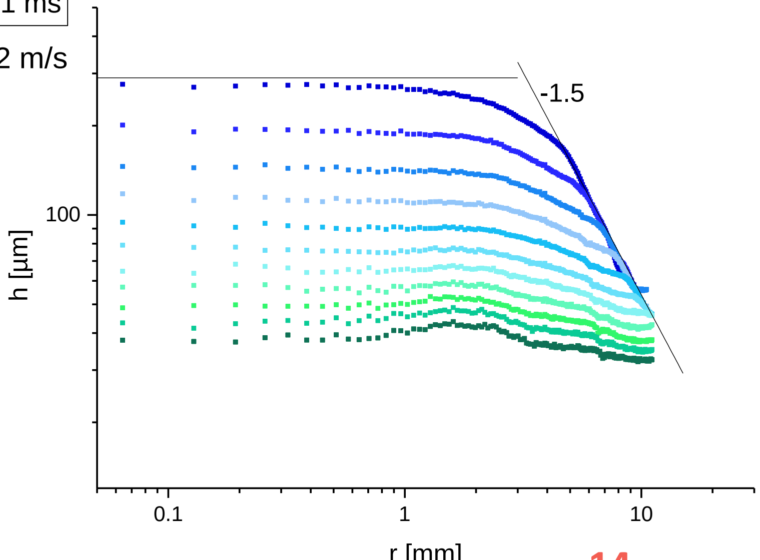



# Sheet thickness field

## Water – Glycerol 93% 365 mPas

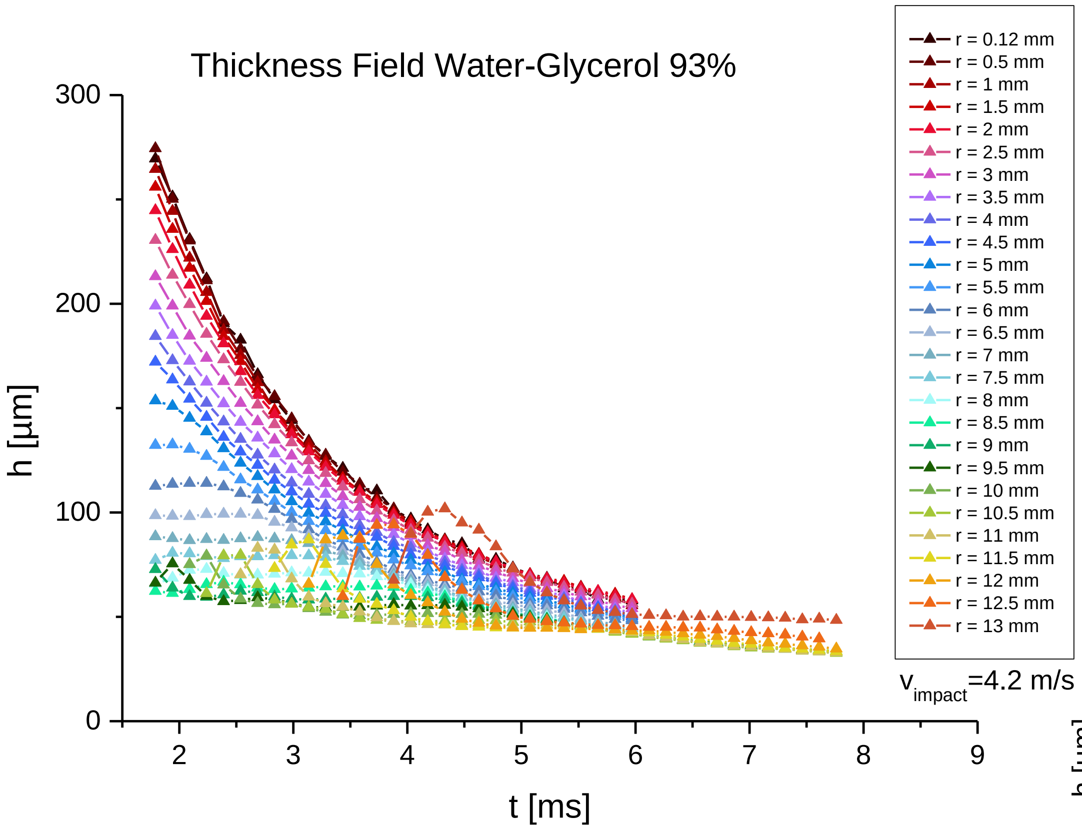


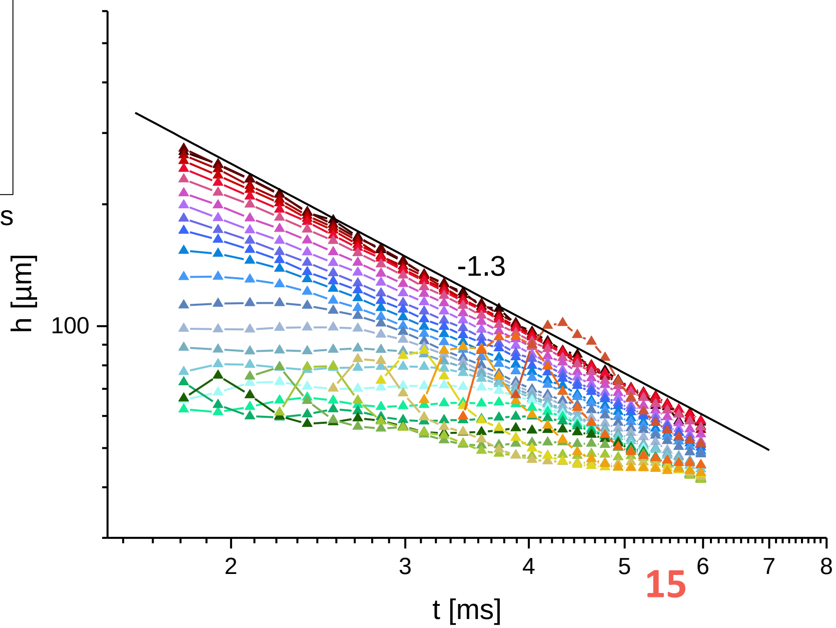



# Sheet thickness field

## Water – Glycerol 93% 365 mPas



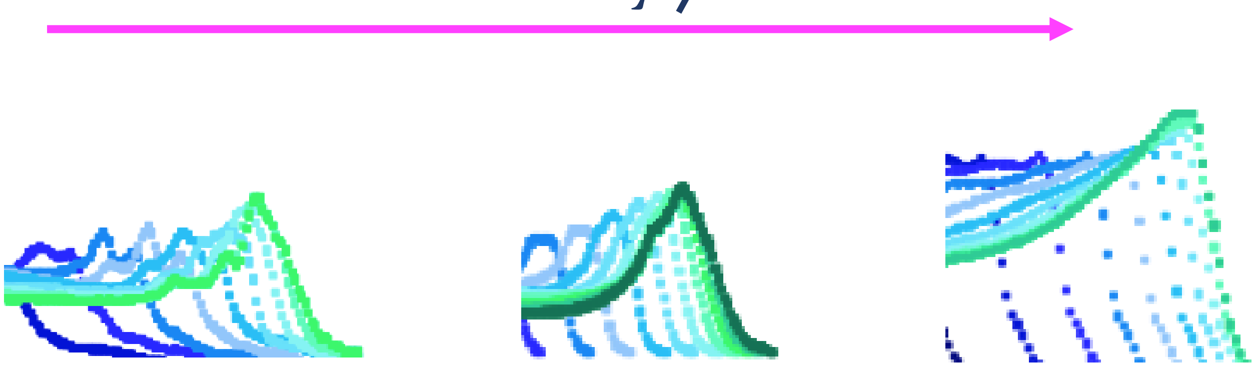



# What's next?

- Study the thickness field at short times and at the center of the sheet.

- Study the shape of the rim

Viscosity ↗



# Impact of soft elastic bead

With no viscous shear dissipation

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

Kinetic energy — Surface energy at max expansion — Elastic energy

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

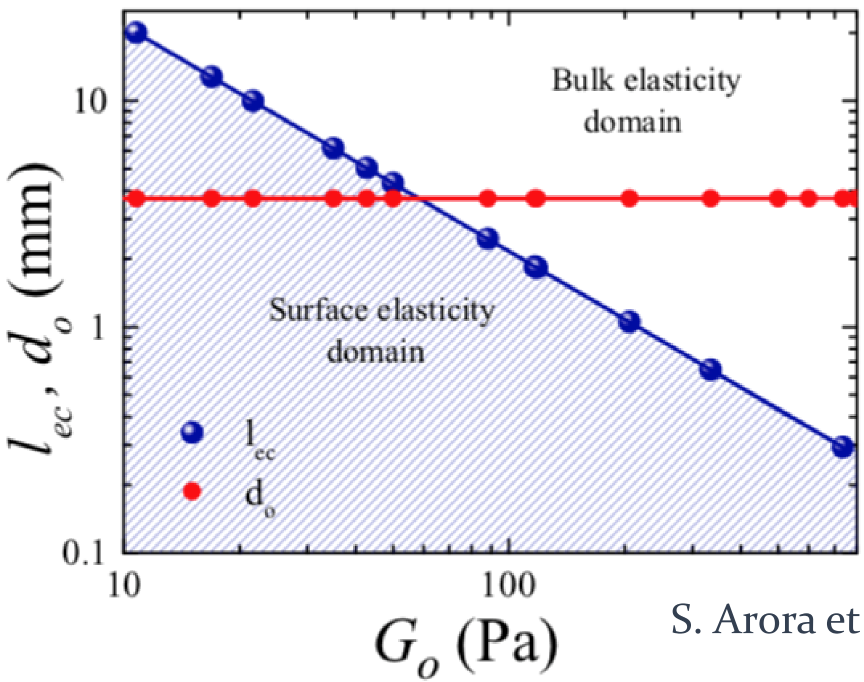
$$\lambda = \frac{d_{max}}{d_0}$$

Two elastic contributions :

- Surface tension
- Bulk elasticity

**Vary $d_o$ or $G_o$**

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




S. Arora et al, 2017

# Impact of viscoelastic fluids

## Reminder

Maxwell fluid with elastic modulus $G_o$ and a relaxation time $\tau$

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

with

$$De = \frac{\tau_{rel}}{\tau_{exp}}$$

$$\tau_{exp} \sim 10ms$$

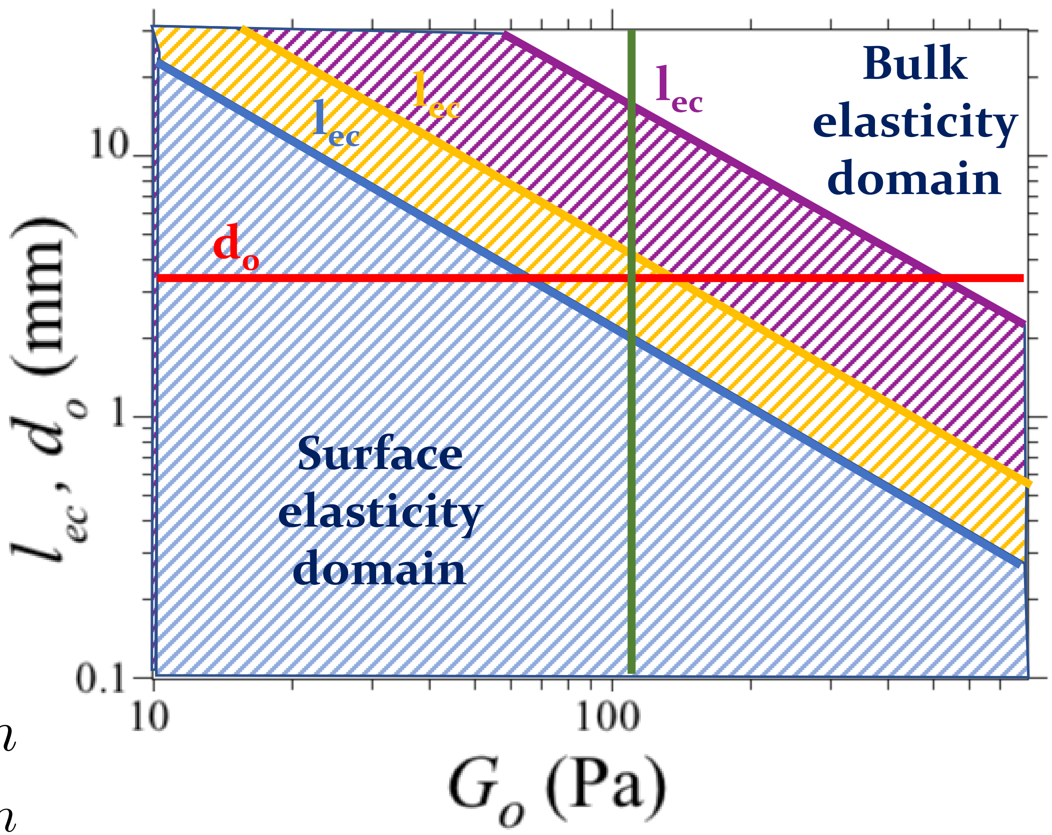
**Dynamic elasto-capillary length :**

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

# 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 $G_o$




$De >> 1$

$De \simeq 1$

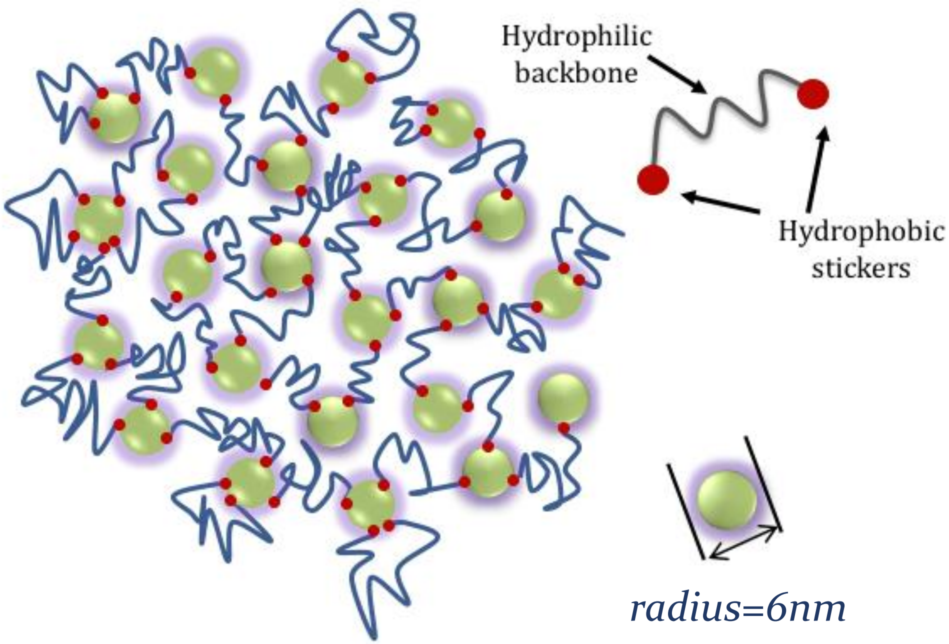
$De << 1$

$d_0 = 3.7mm$

$\gamma = 72mN/m$

# Microemulsions

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




$$G_0 = \mu k_B T$$

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

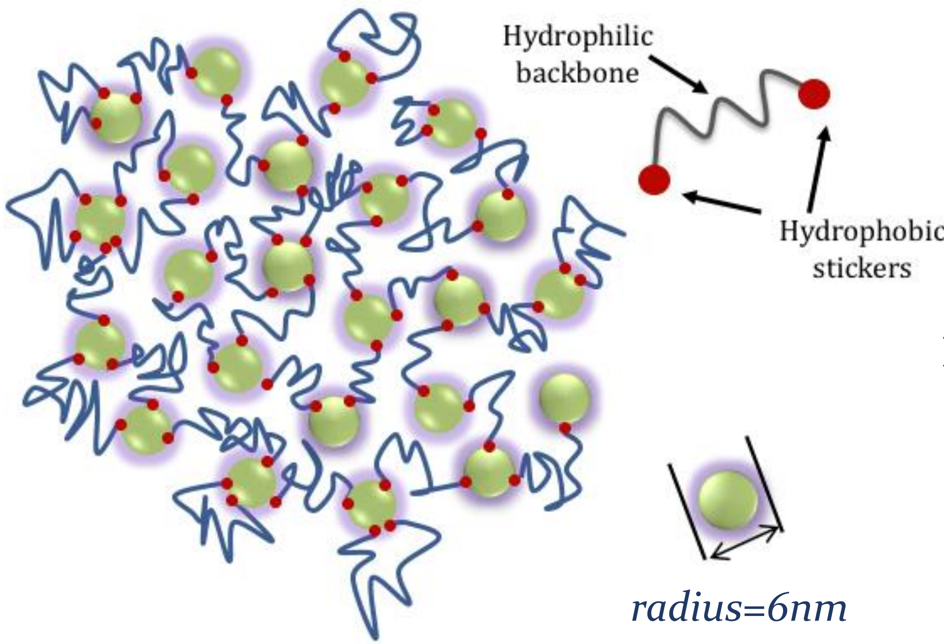
$$\tau = \tau_0\ e^{\frac{E_a}{k_B T}}$$

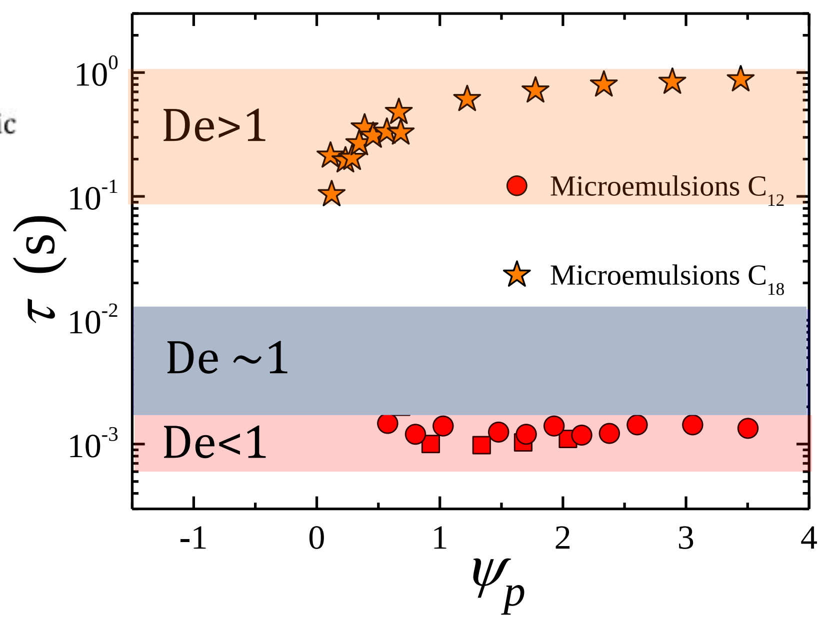
$E_a \propto n_{CH_2}$

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

# Microemulsions

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



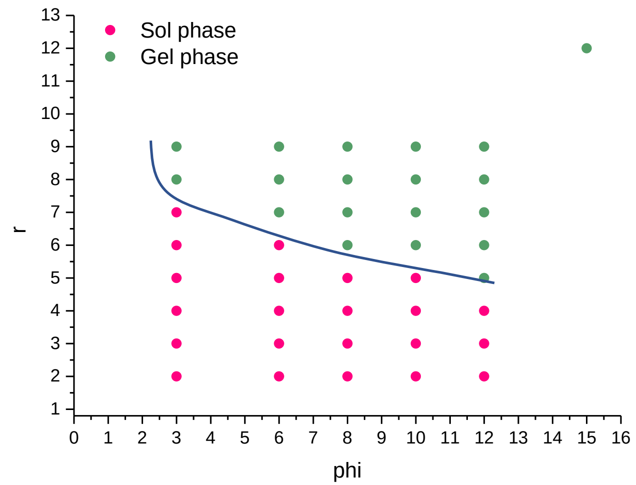



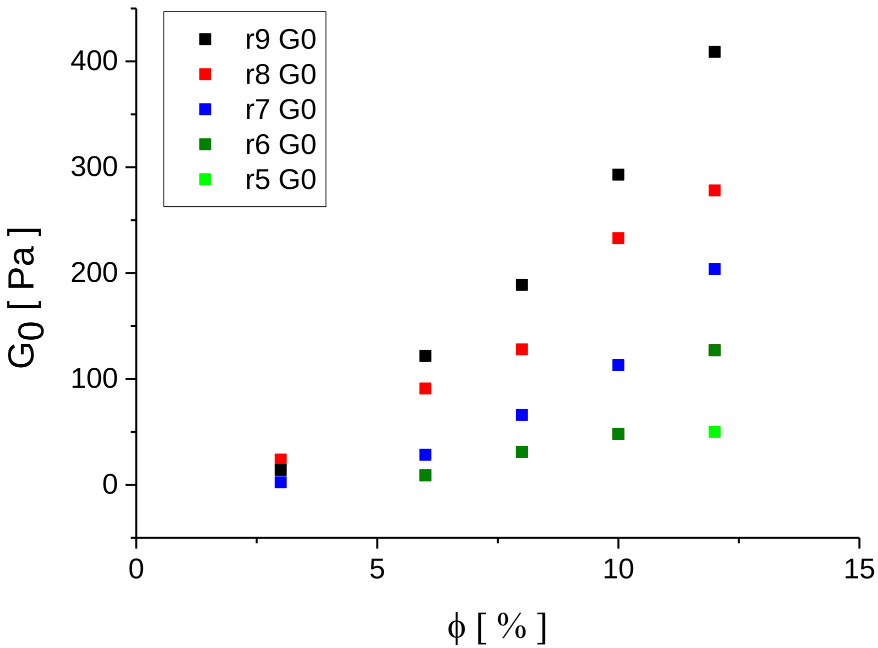

r = number of stickers per droplet
Φ = mass fraction of droplet

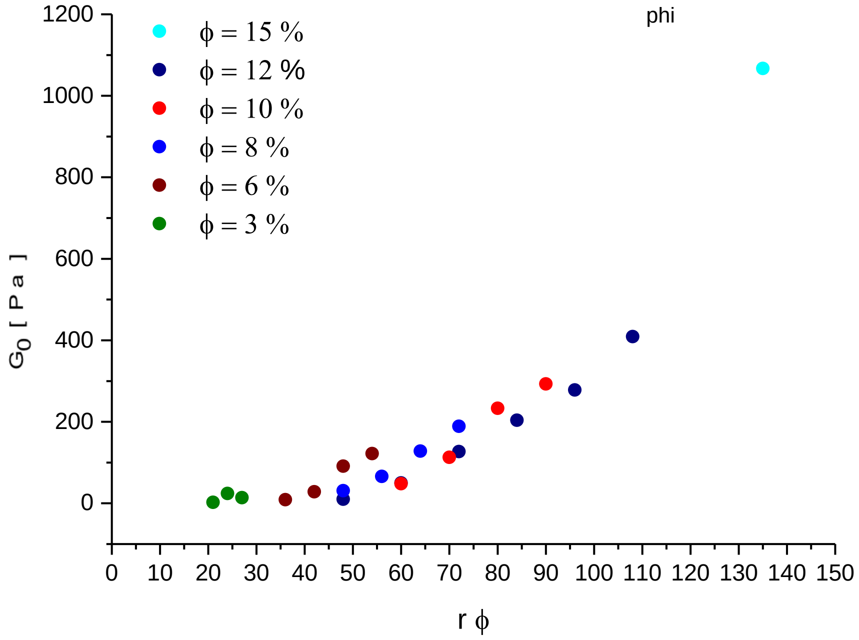
S. Arora et al, 2017

# Microemulsions $C_{14}$

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



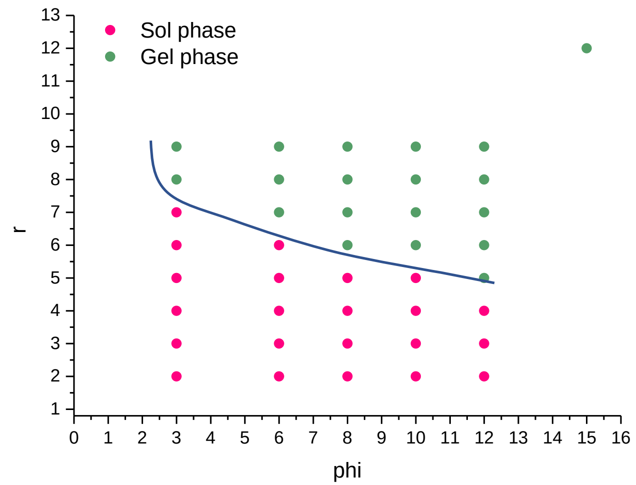



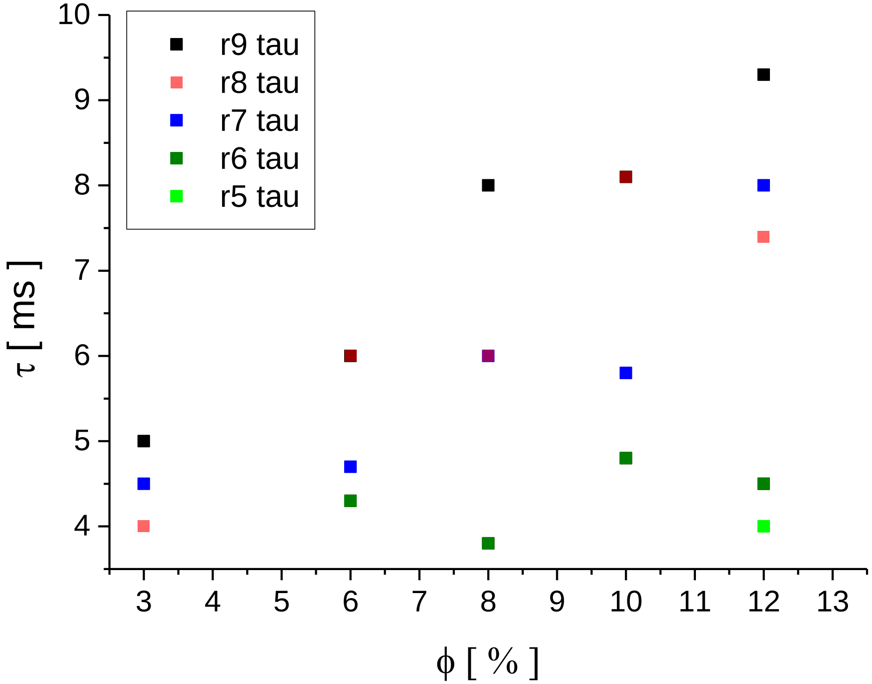



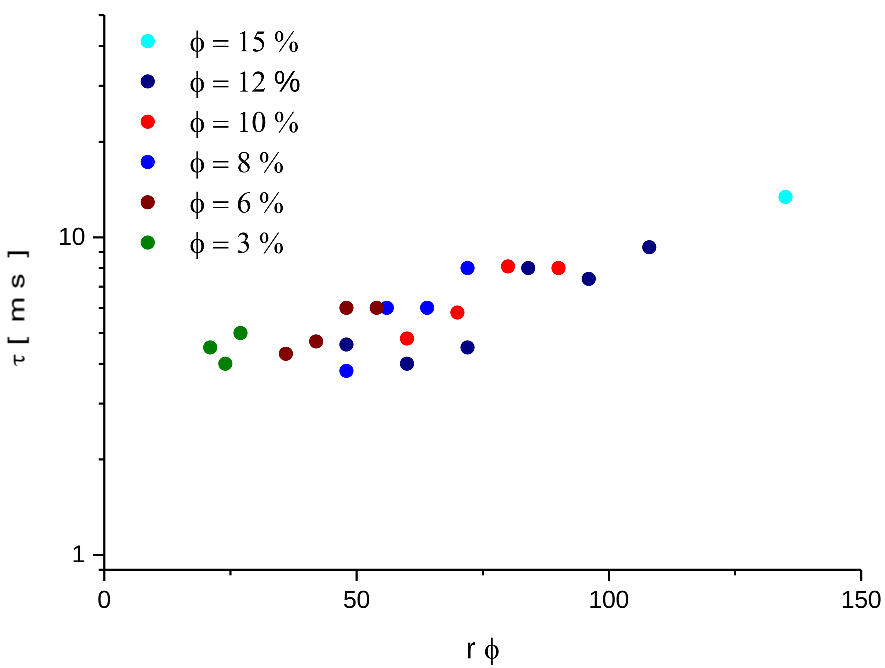

$$3Pa < G_0 < 1070Pa$$

# Microemulsions C14

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



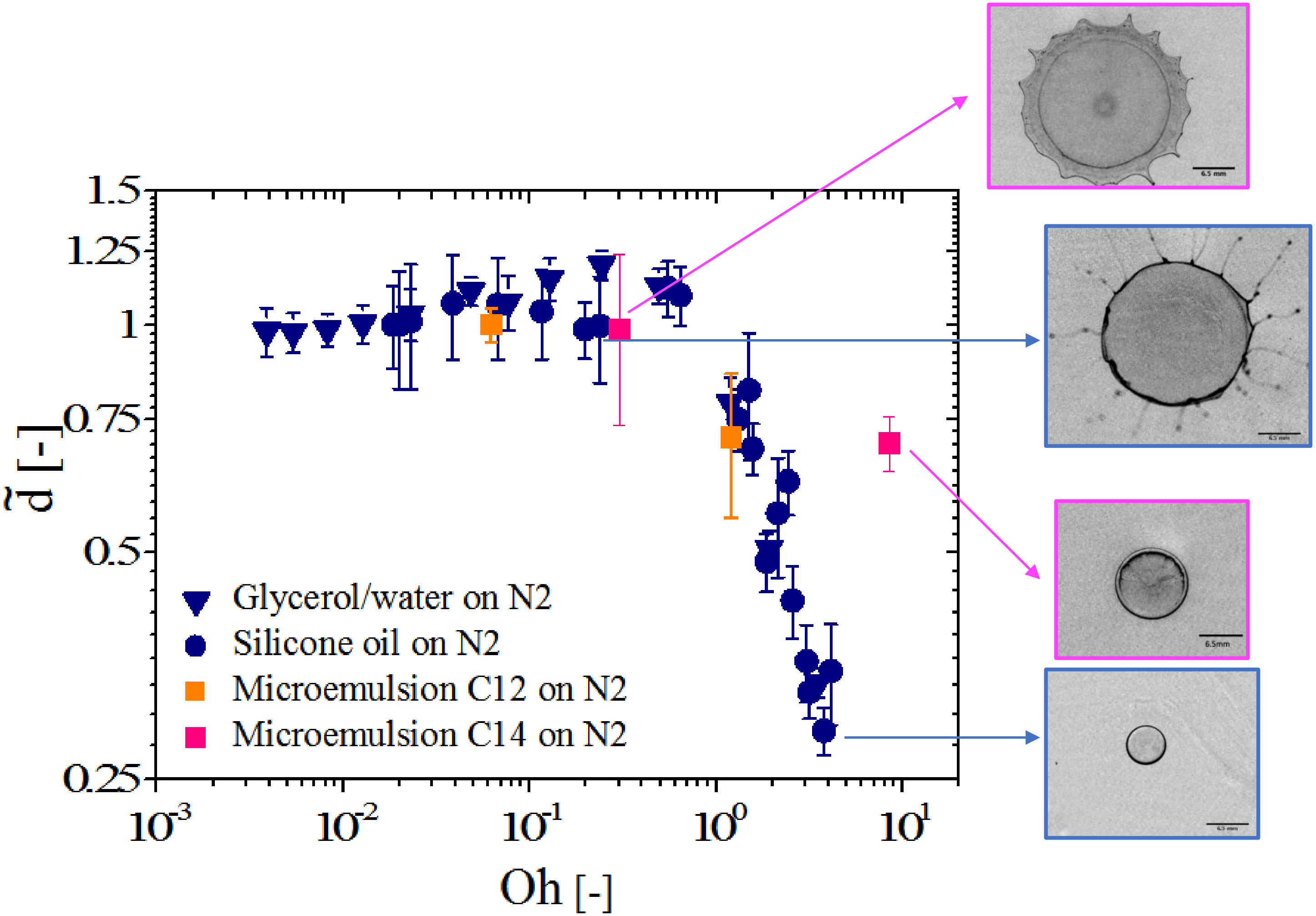




$$4ms < \tau < 13.4ms \quad \Rightarrow \quad De \simeq 1$$

# Microemulsions C12 and C14 phi =10% r=8

$De \simeq 1$

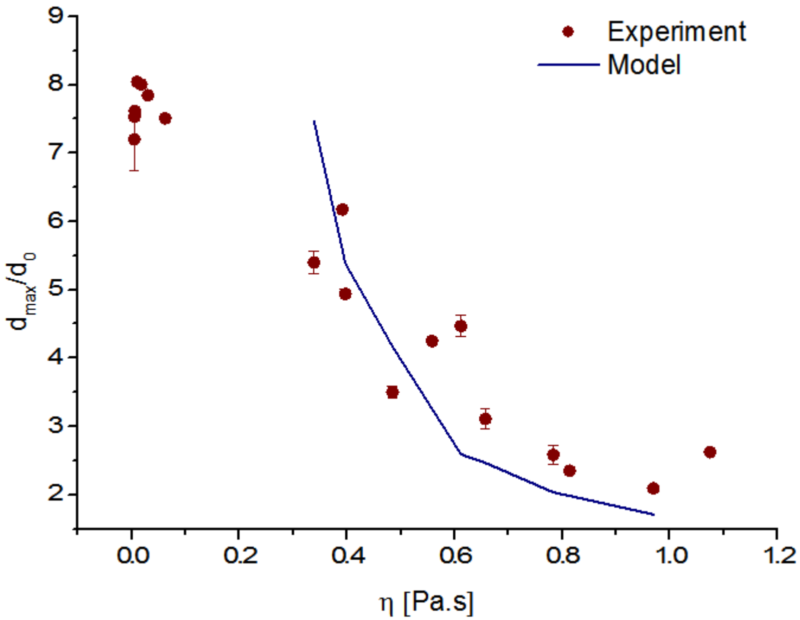
$De << 1$

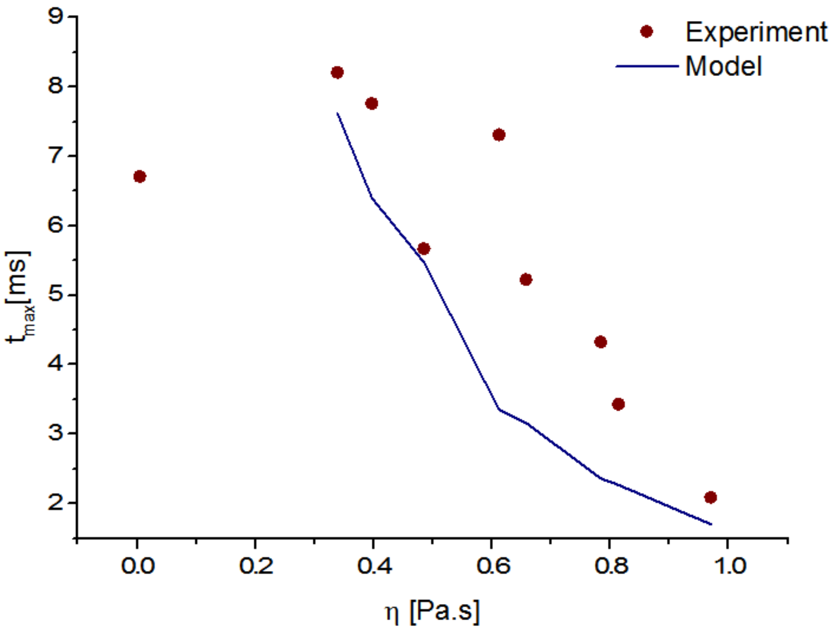


# What's next?

- On liquid nitrogen study the thickness field and impact of :
  - C14 Microemulsions
  - C14 and C18 Microemulsion mixes
  - Double dynamic networks from DoDyNet
- Model the sheet expansion with Daniel Read

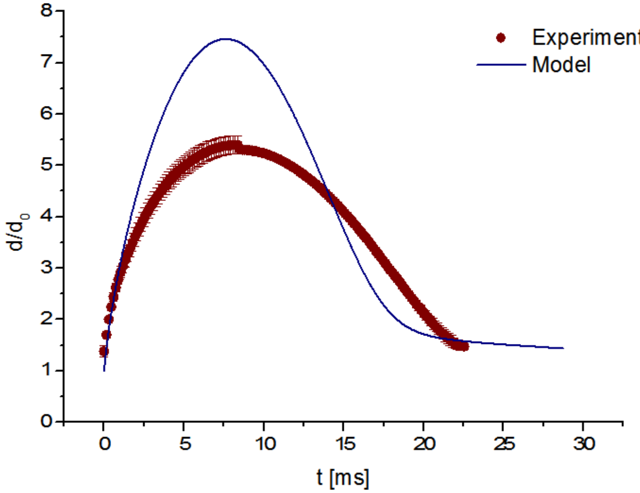
# Simple model from Daniel Read



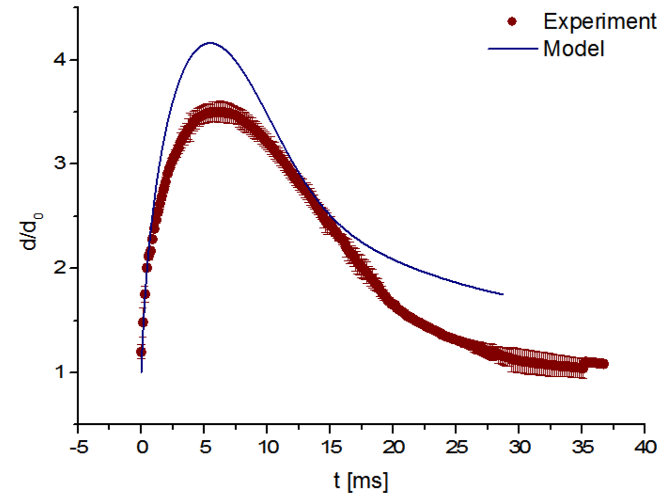



# Simple model from Daniel Read

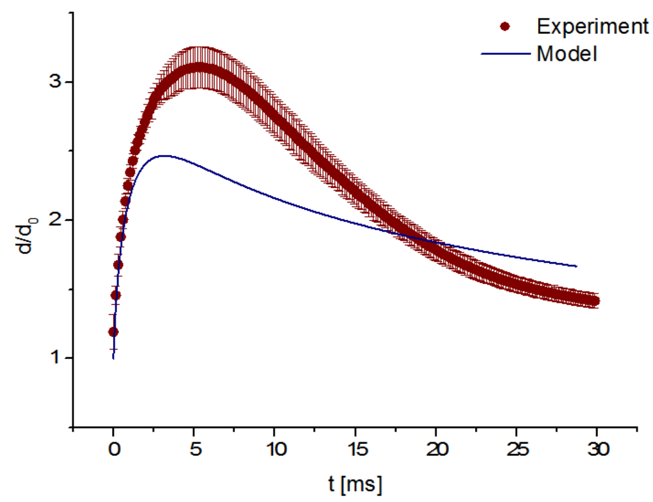
339 mPas




485 mPas



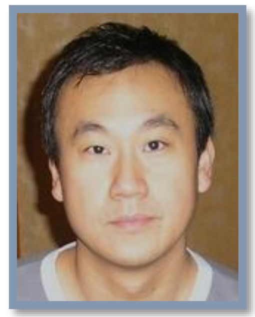

658 mPas



# Acknowledgment

Christian Ligoure

Laurence Ramos



Ty Phou

Jean-Marc Fromental

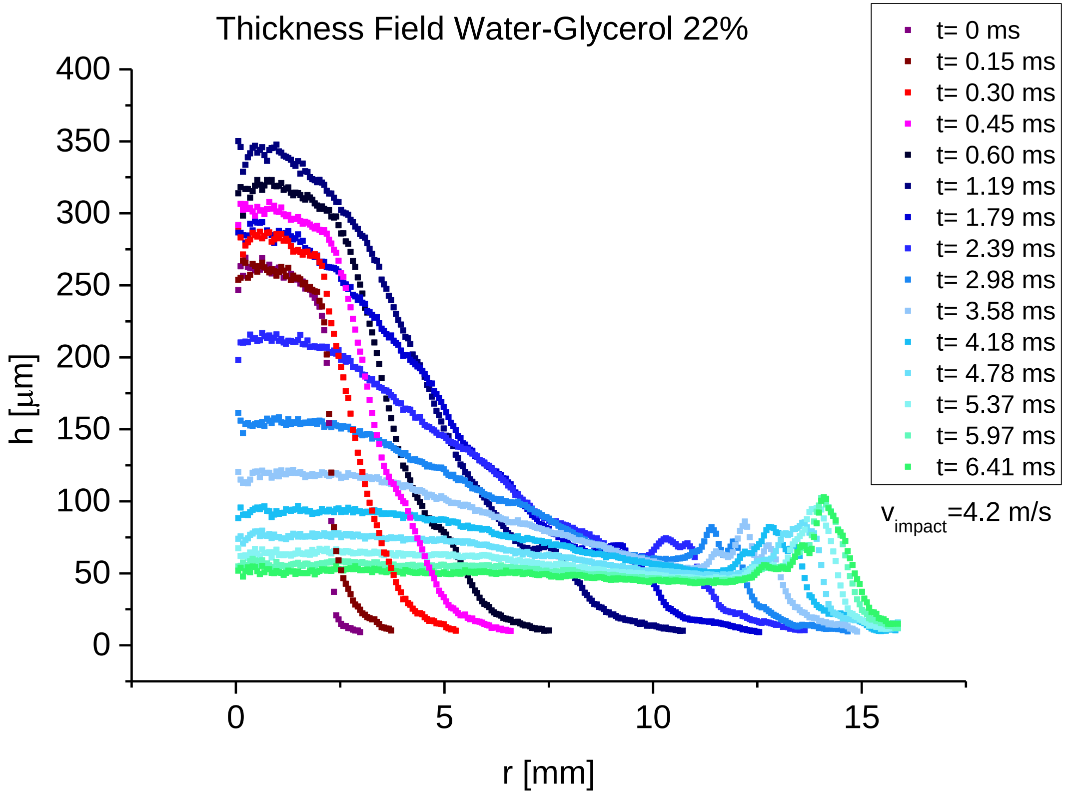
Ameur Louhichi

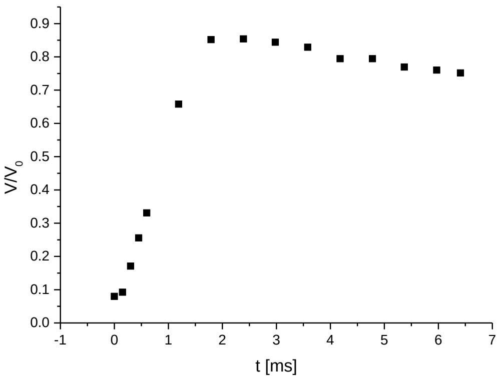
INITIAL TRAINING NETWORK

# Thank you for your attention

# Sheet thickness field

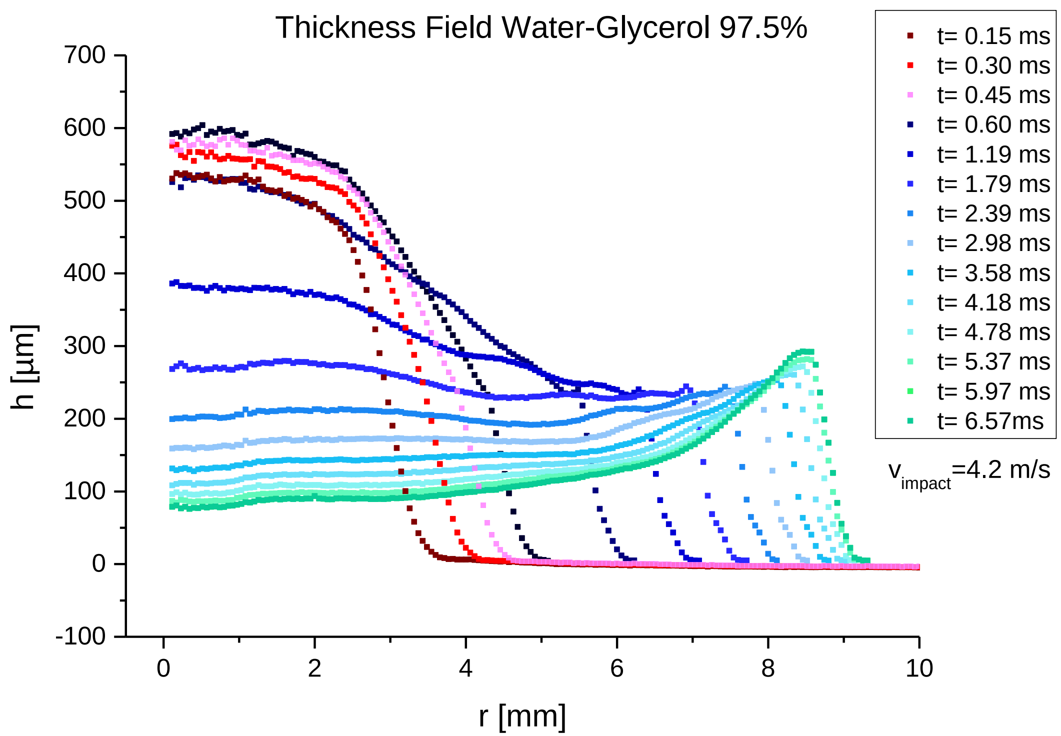
## Water – Glycerol 22% 2 mPas

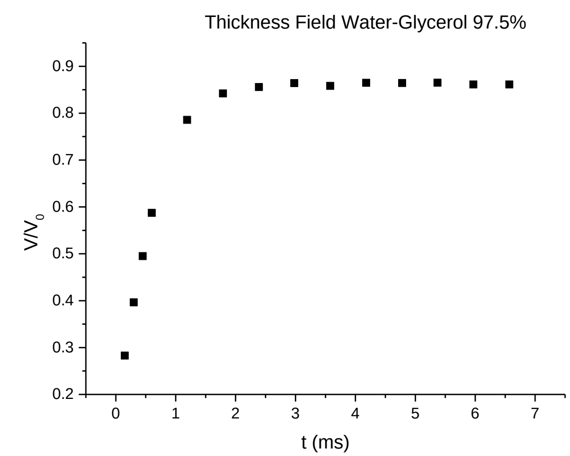


# Sheet thickness field

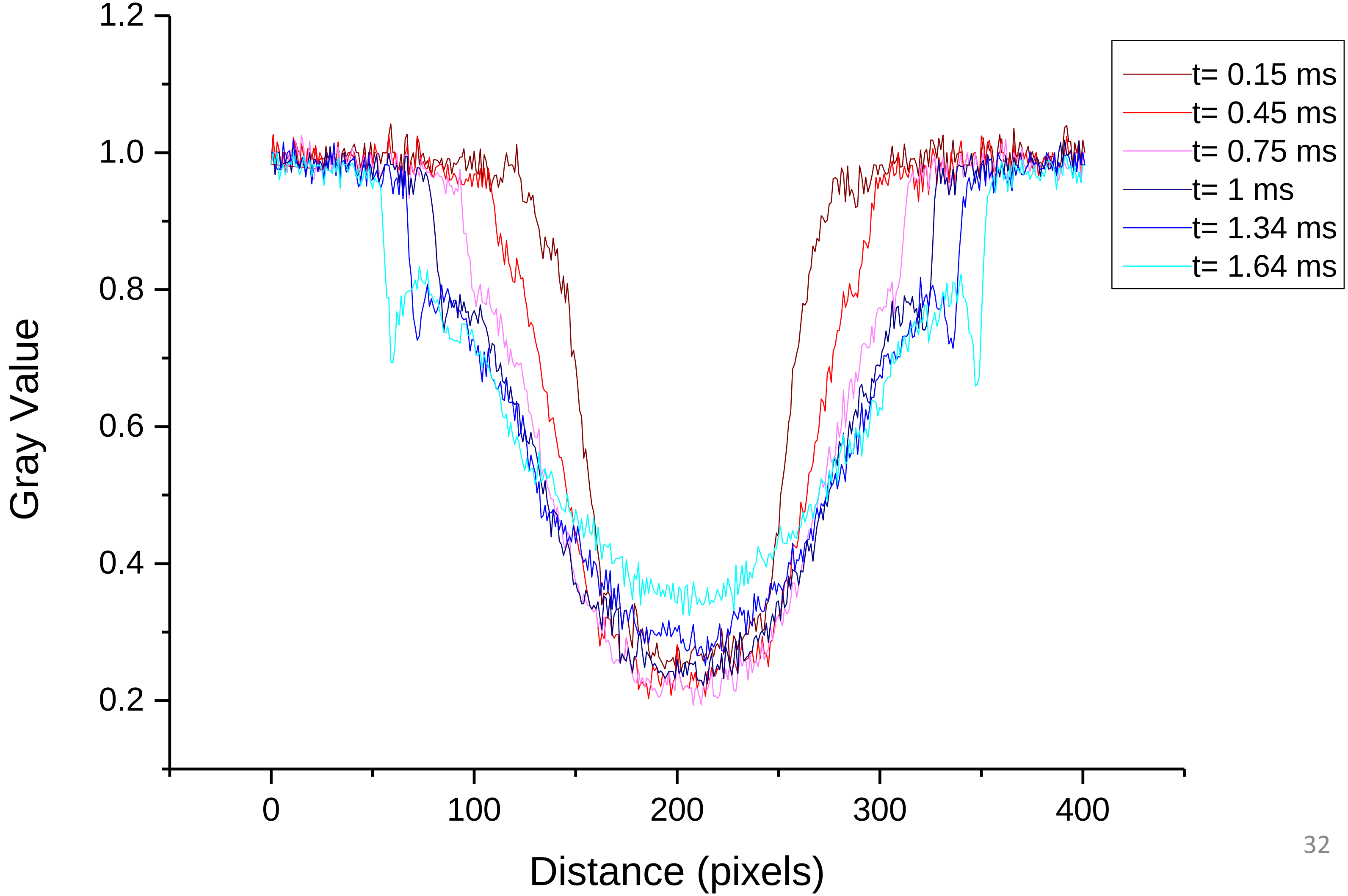
## Water – Glycerol 93% 365 mPas



# Sheet thickness field

## Water – Glycerol 93% 365 mPas



# Sheet thickness field

## Water – Glycerol 93% 365 mPas