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# Experimental and Numerical Investigation of Two Phase Flow in a Model of Nanoporous Medium

## LowPerm 2015

Les rencontres scientifiques d'IFP Energies Nouvelles

Antoine Naillon<sup>1,2</sup> – Philippe Lefort<sup>1</sup> – Sandrine Geoffroy<sup>3</sup> – Marc Prat<sup>1</sup> – Pierre Joseph<sup>2</sup>

(<sup>1</sup> : IMFT, <sup>2</sup> : LAAS, <sup>3</sup> : LMDC)

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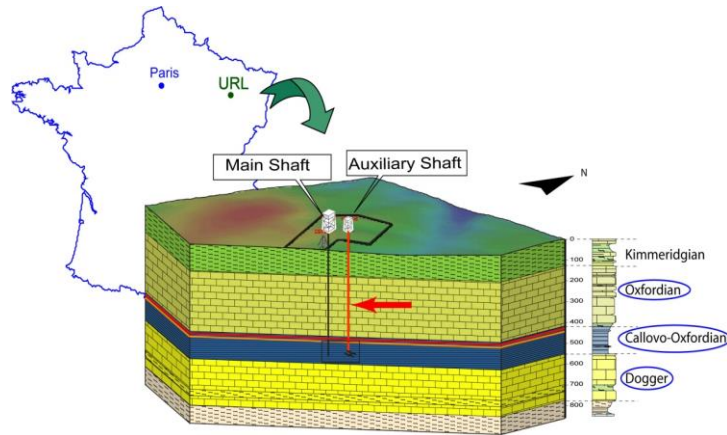
# 1. Motivation / Context

## 2. Fabrication and procedure

## 3. Two phase flow in dead end nanochannels

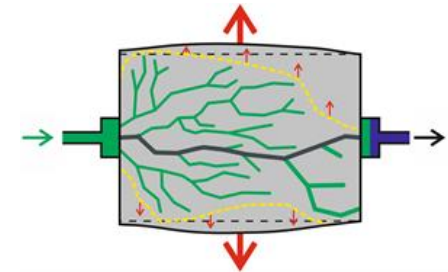
## Conclusion

# Repository Issue of Long Life Radioactive Wastes



ANDRA's project of repository of long life radioactive wastes

- Specificities of this deep repository:
  - **Gas generation** (mainly H<sub>2</sub> from corrosion of metallic component )

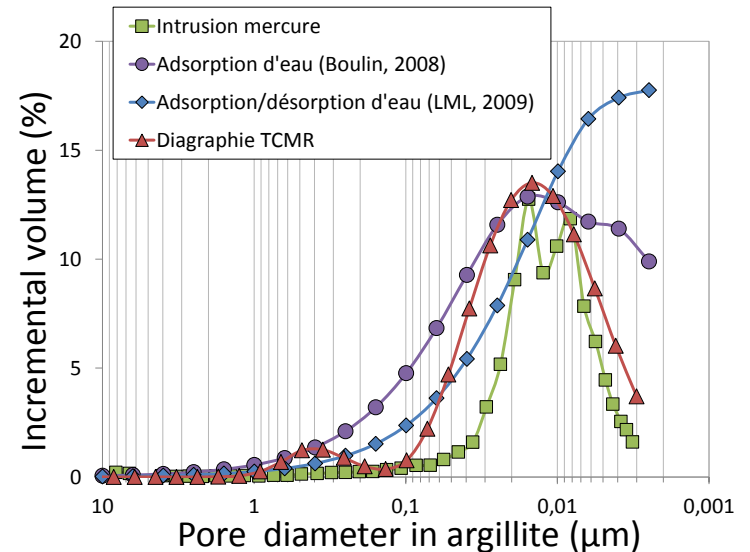


Drainage experiment of BGS

- Typical pore size : **few tens of nanometre**

- Issues:

- Influence of gas generation on fluid flow around repository galleries?



JC Robinet - ANDRA

# Goals : specificities due to nanometer scale

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- **Validation of hydraulic law**
  - Kinetics of imbibition
  
- **Effect of high capillary pressure**
  - Flow and mechanical deformation



$$P_c = \frac{2\gamma}{a} = 72 \text{ bar}$$

$$a = 20 \text{ nm}, \gamma = 72 \text{ mN/m (water)}$$

- **Modification of physical properties:**
  - Dissolution properties
  - Cavitation
  - Rarefied gas

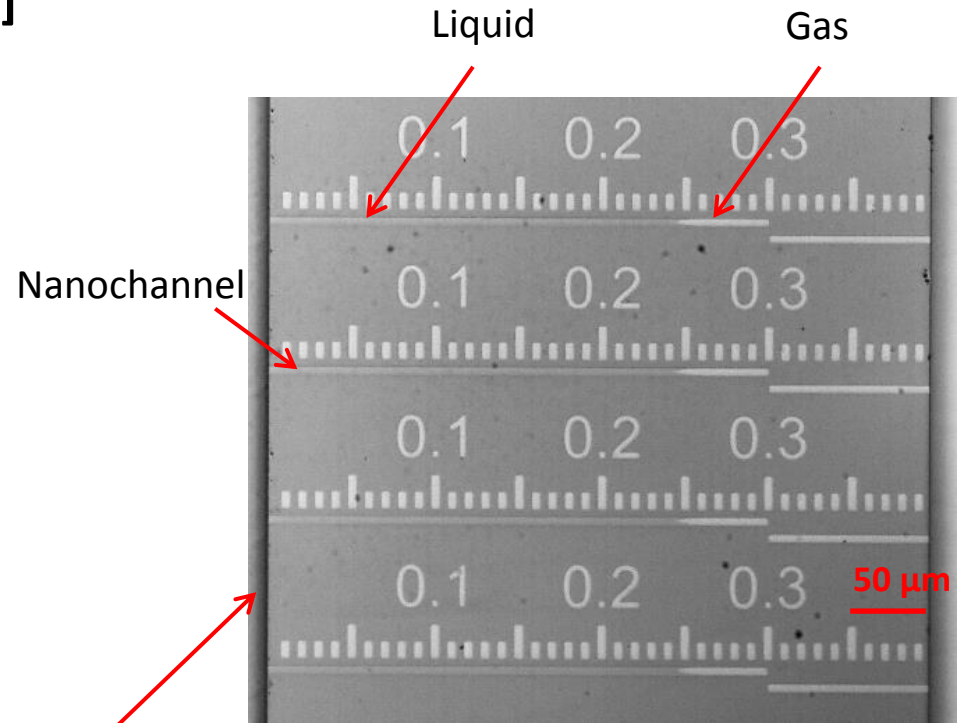
# Our approach : Nano-fabrication

- **Classical use of model system: [1]**

- Controlled geometry
- Phase visualisation
- Parallelization of experiments
- High reproducibility

- **Emergence of nanofluidics**

**< 200 nm [2]**



*Picture of two phase flow in dead end nano channel  
(depth = 54 nm)*

[1] P. Lenormand et al., *J. Fluid Mech.* (1988)

[2] C. Duan et al., *Biomicrofluidics* (2013)

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**1. Motivation / Context**

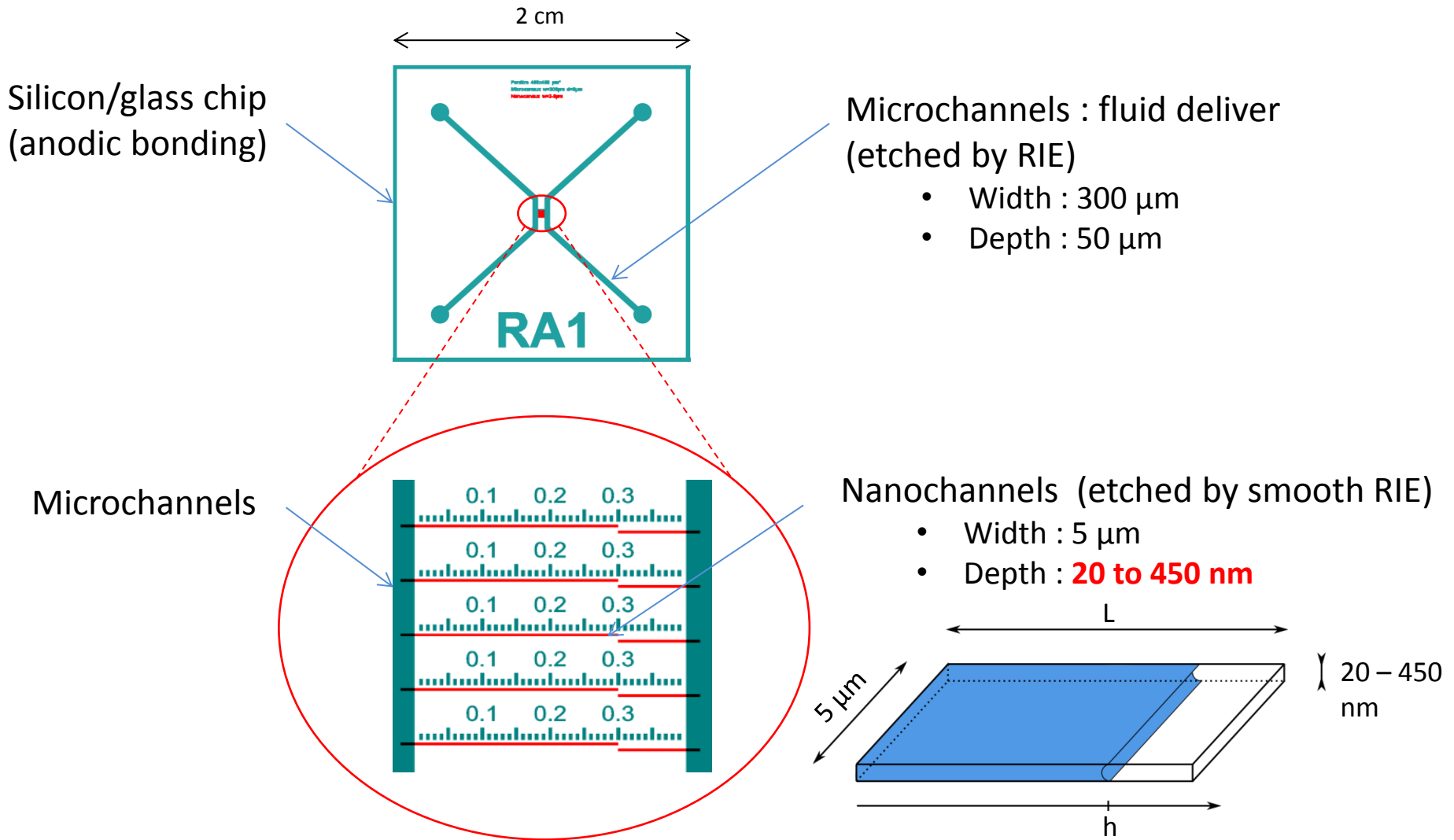
**2. Fabrication and procedure**

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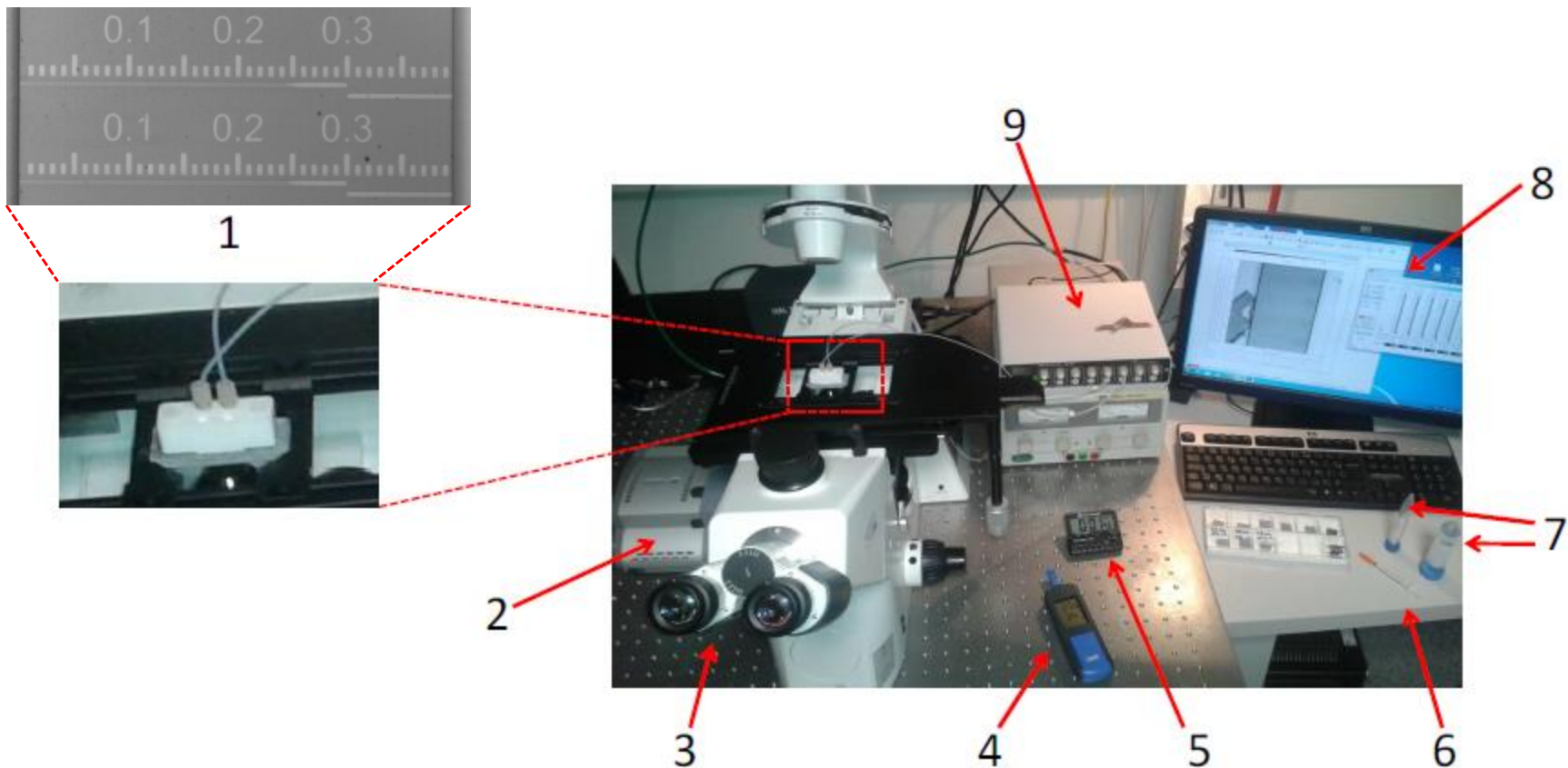
**Conclusion**



# Nano-fabricated chip



# Experimental Procedure



- 1. Experimental support
- 2. Video camera
- 3. Inversed microscopy

- 4. Thermo and moisture meter
- 5. Chronometer
- 6. Needle

- 7. Sample
- 8. Control screen
- 9. Pressure deliver

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**1. Motivation / Context**

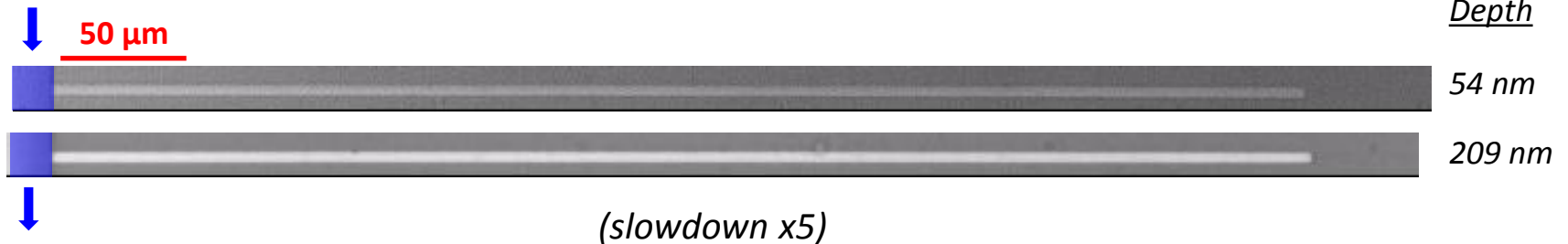
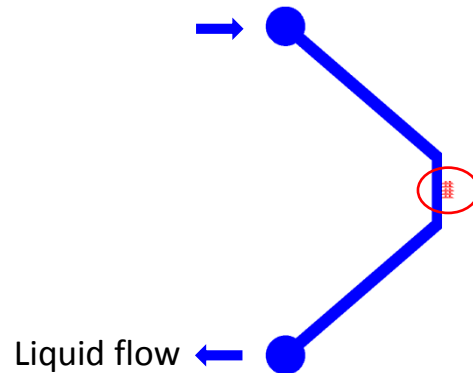
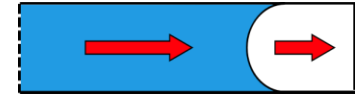
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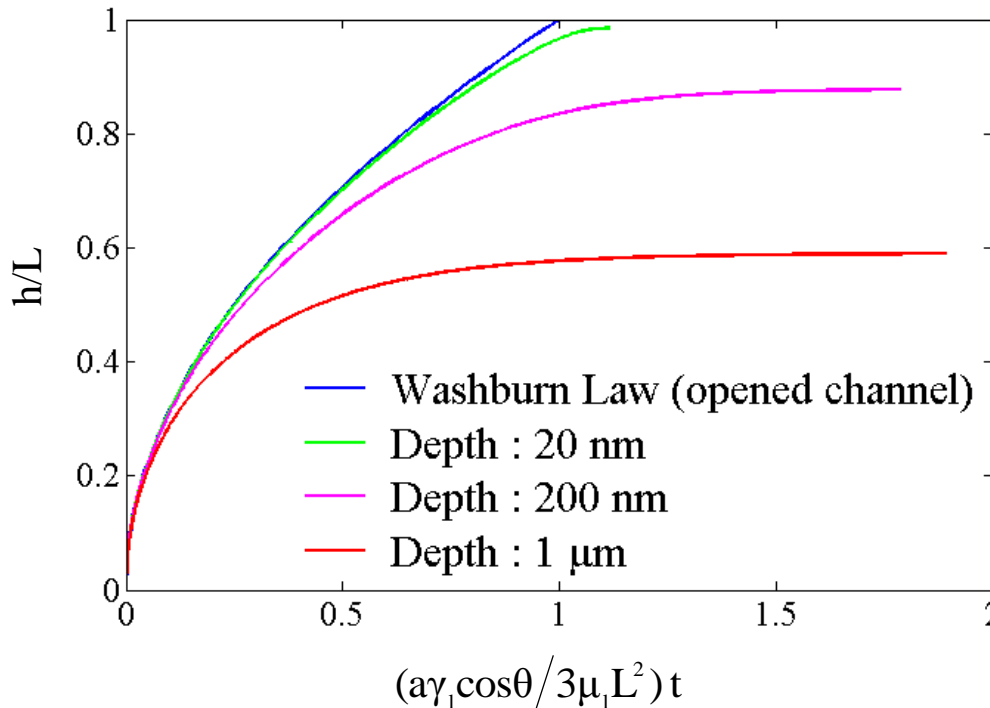
# Imbibition in dead end nanochannels

- **Beginning of imbibition** => gas pressurization



=> Meniscus dynamics is less affected at nanometer scale by gas pressurization effect

# Imbibition in dead end nanochannels



$h$ : meniscus position

$a$ : channel depth

$L$ : channel length

$\gamma_l$ : surface tension

$\mu_l$ : liquid viscosity

$\Theta$ : contact angle

$$\alpha = \frac{p_0}{p_{\text{cap}}}$$

Washburn law:

$$h = \sqrt{\frac{a\gamma_l \cos\theta}{3\mu_l}} t$$

Imbibition in dead end channel : (with gas compression) [1]

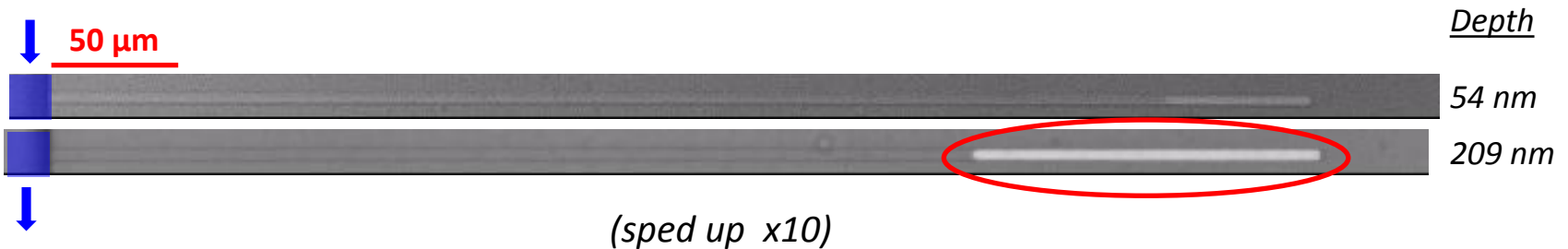
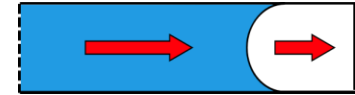
$$t(h) = \frac{h^2}{2(1+\alpha)} - \frac{\alpha h}{(1+\alpha)^2} - \frac{\alpha}{(1+\alpha)^3} \ln[1 - (1+\alpha)h]$$

**=> Gas compression has low influence on filling kinetics for the smallest depth**

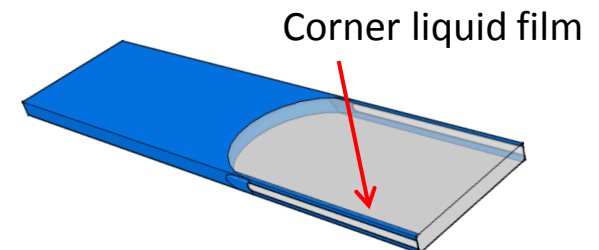
[1] V.N. Phan et al., *Langmuir*, 2010

# Imbibition in dead end nanochannels

- End of imbibition => gas dissolution

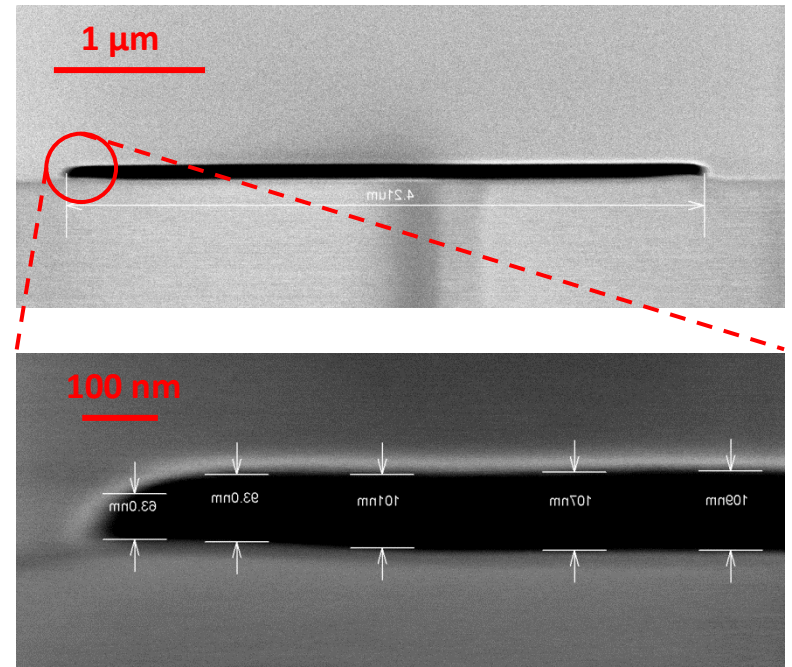
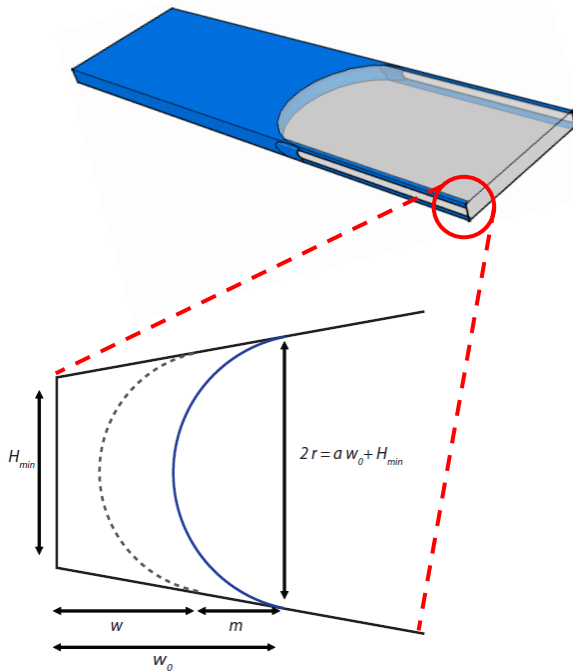


- Gas dissolution is faster for the lowest depths :  
=> Higher gas concentration :  $c_{eq}(\text{gas})=H \cdot P_{\text{gaz}}$
- Channel can be filled from the end !  
=> end of channel is supplied by corner liquid films



# Imbibition in dead end nanochannels

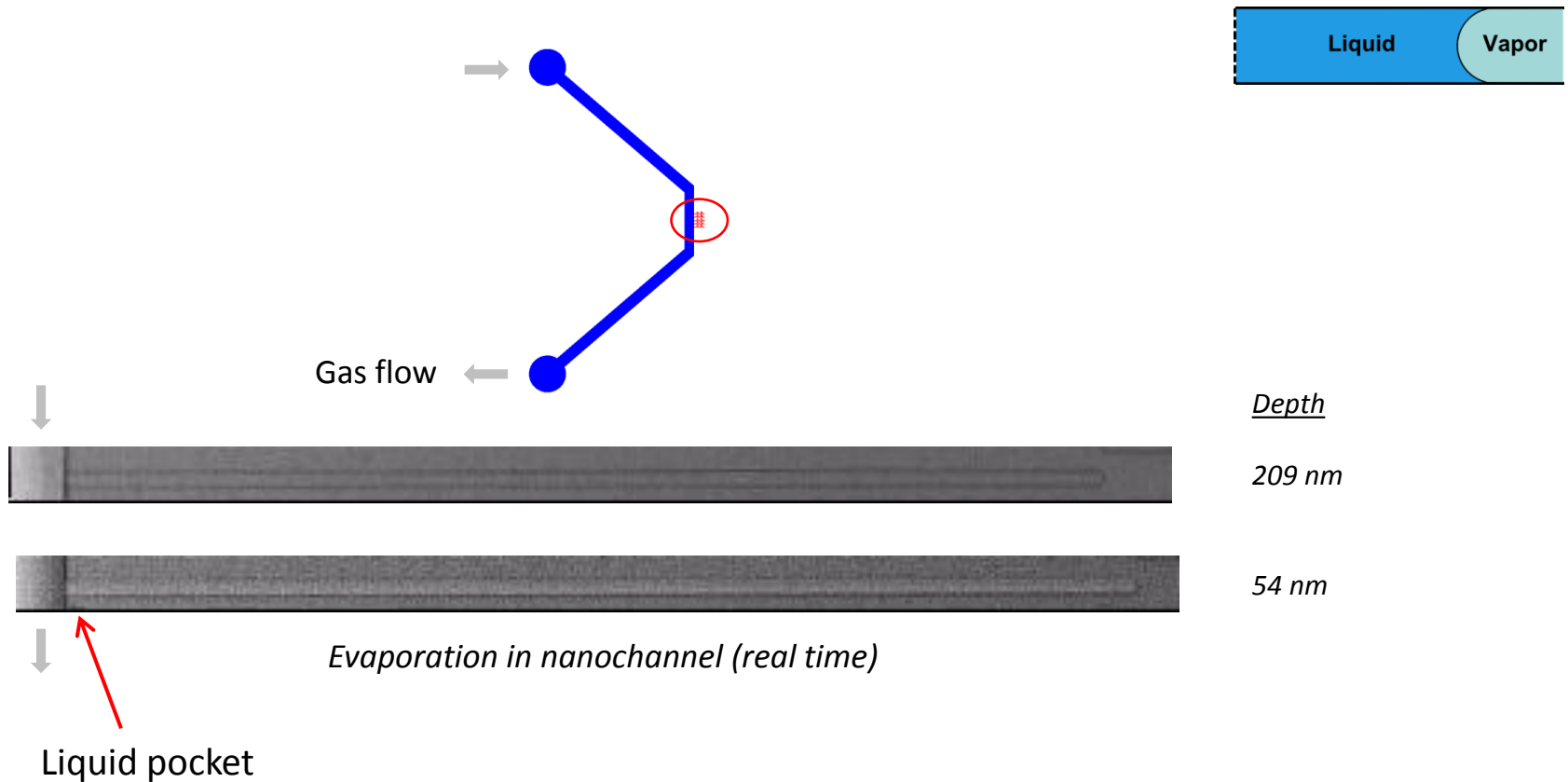
- Presence of thick liquid film if walls are not strictly parallel [1]



SEM imaging of nanochannels

[1] E. Keita, Thesis, 2014

# Evaporation in dead end nanochannels



- ⇒ Presence of gas bubble modifies the kinetics of evaporation (similar in [1])
- ⇒ Evaporation from inside the liquid appears only for depth lower than 104 nm (with ethanol) (same observation as [2])

[2] C. Duan et al., *Proc. Natl. Acad. Sci. U. S. A.* (2012)

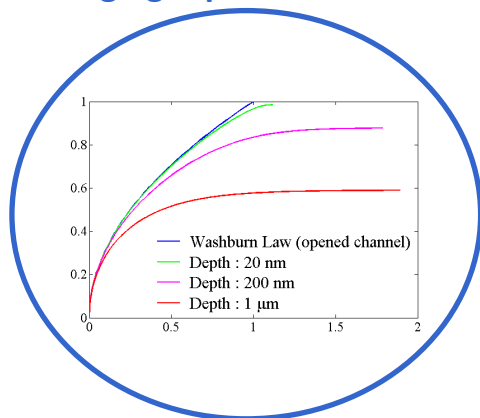
[1] O. Vincent et al., *PRL* (2014)



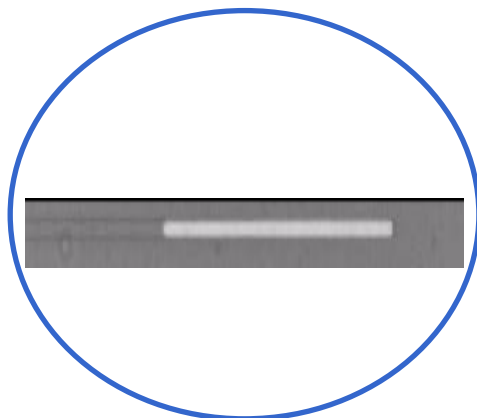
# Conclusion

## Two phase flow at nanometer scale presents particularities

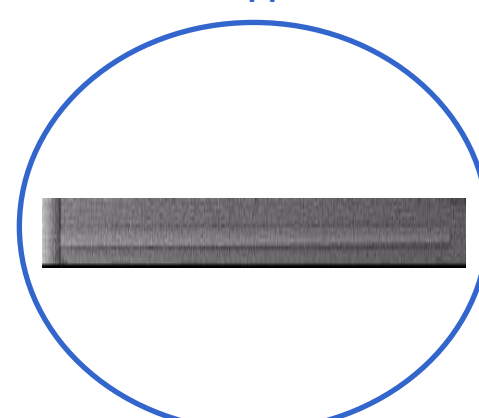
High gas pressurization



Filling from the end



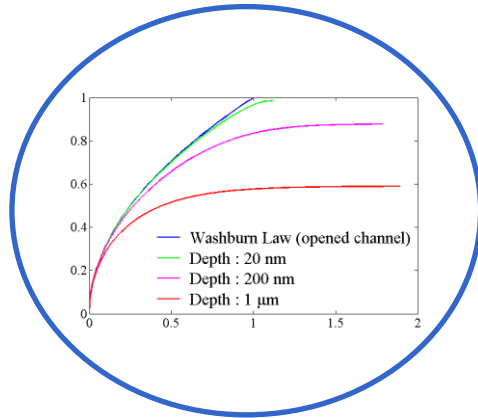
Bubbles appearance



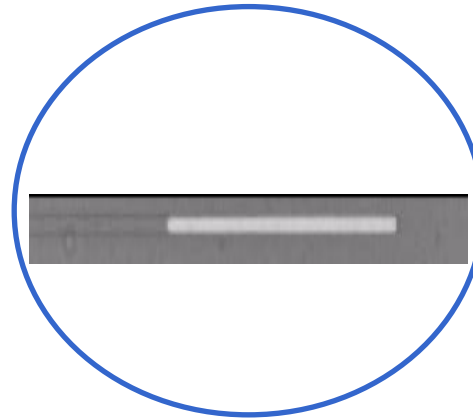
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## Two phase flow at nanometer scale presents particularities

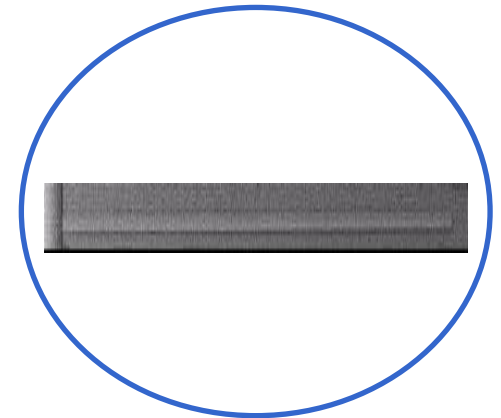
High gas pressurization



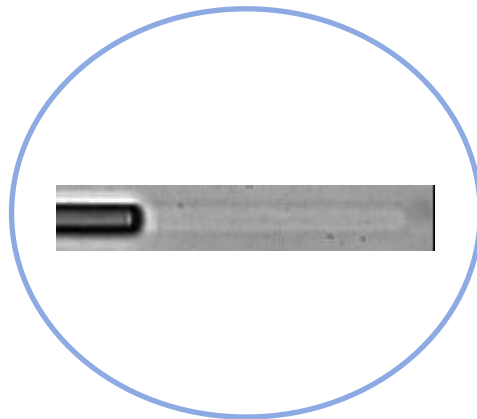
Filling from the end



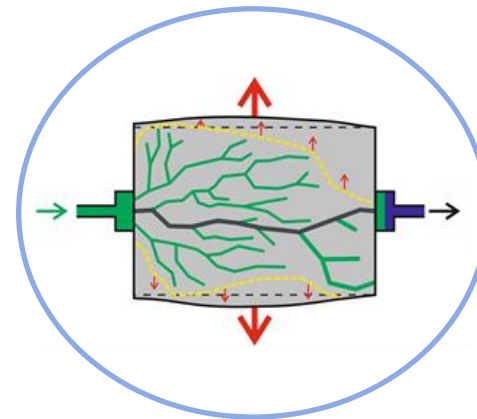
Bubbles appearance



Pore size effect on crystallization

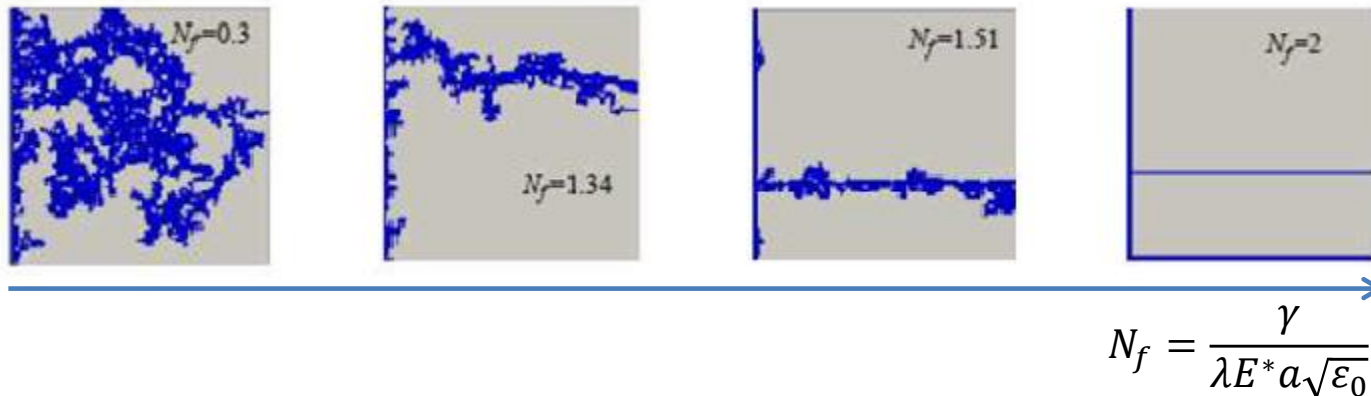
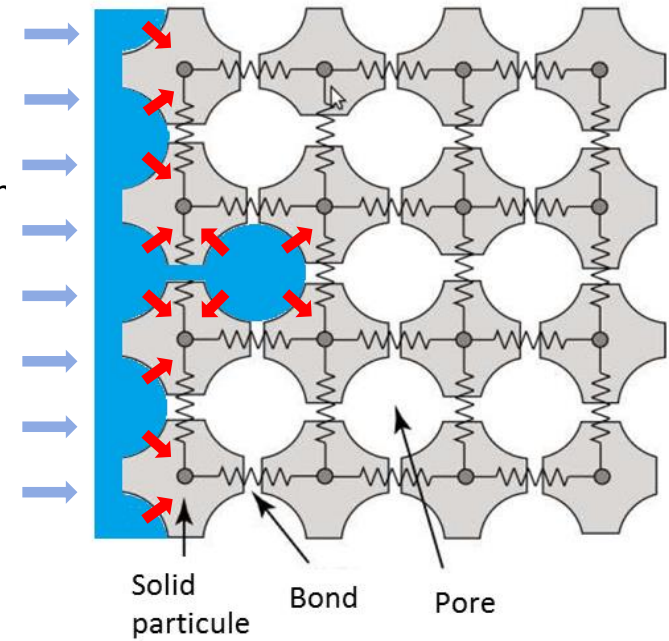


Fluid structure interaction



# Perspective: deformable medium

- Approach of [1] and [2]
  - Simulation on pore network coupling:
    - Flow pore network (resolve by invasion percolation algorithm)
    - Spring network (elastic deformation)
- Goal = study the impact of deformation on invasion pattern

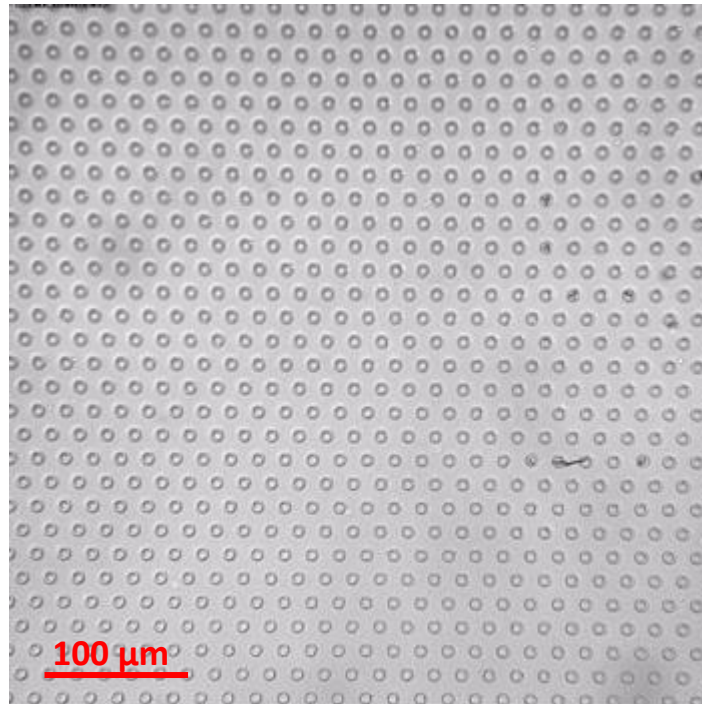
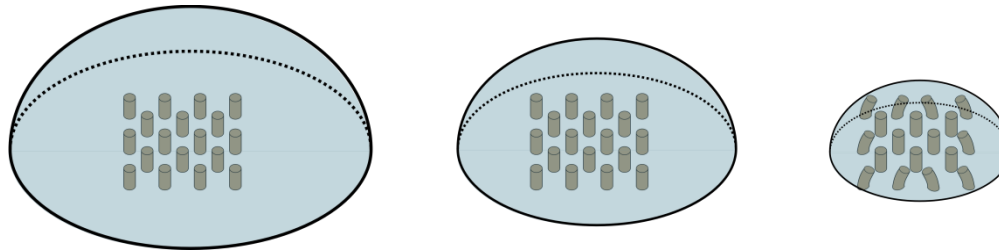


[1] Holtzman & Juanes, *Physical Review E*. (2010)

[2] P. Lefort, *PhD Thesis* (2014)

# Perspective: deformable medium

- Evaporation of a droplet in a network of pillars



=> Bending and collapse of pillars by capillarity

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Thank you for your attention