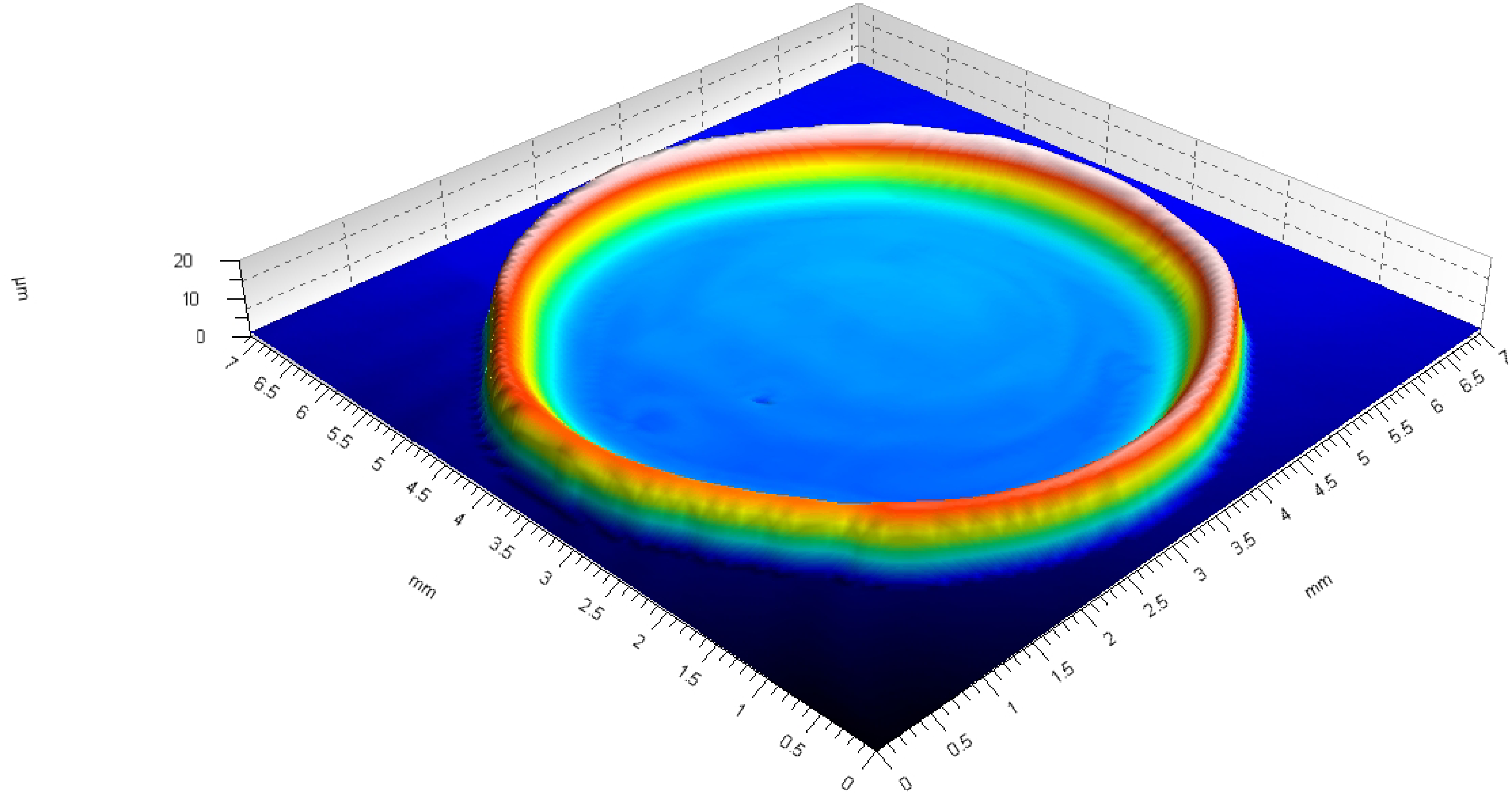
Thin Film Behavior after Ink Transfer in Printing Processes

N. Bornemann, H. M. Sauer, E. Dörsam



Overview
Thin Film Behavior after Ink Transfer in Printing Processes

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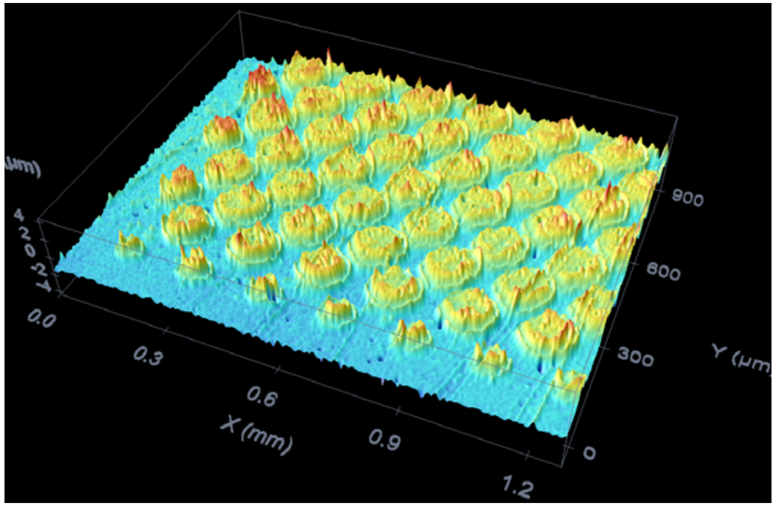
- ***Motivation***
  - Graphic vs. functional printing
  - Printing processes for organic electronics, challenges
  - Film formation process in R2R: Process chain

- ***Theory***
  - Navier-Stokes in the lubrication limit: The Landau-Levich equation
  - Effects of surface tension and concentration gradients
  - Stability analysis: Phase diagrams

- ***Stability analysis***
  - Constant surface tension
  - Why is a puddle stationary flat?
  - Additional forces

Motivation

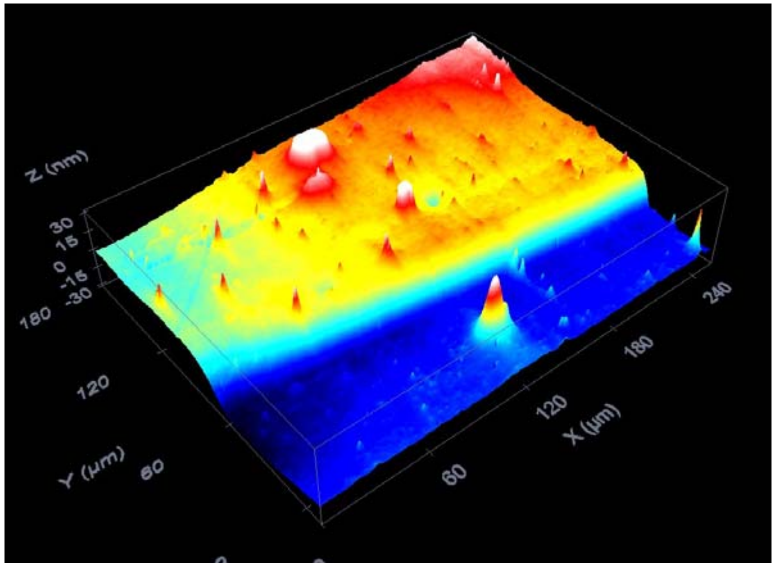
Graphic vs. functional printing



GRAPHIC printing:

- blue ink gravure printed on PET,
- 1.2mm x 0.9mm, height **~ 4µm**

⇒ **HOMOGENOUS, DEFINED DOT SCREENS**



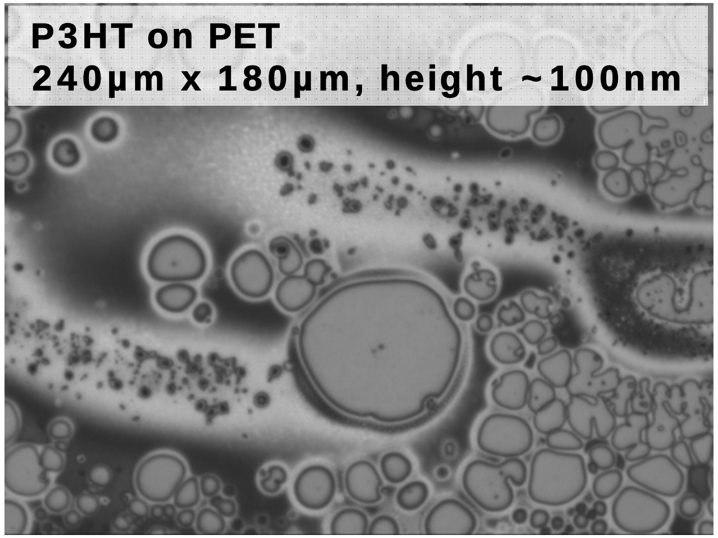
FUNCTIONAL printing:

- SY organic polymer for OLEDs, gravure printed on PET,
- 240µm x 180µm, height ~ **30nm**

⇒ **HOMOGENOUS, DEFINED CLOSED LAYERS**

Motivation

Printing process for organic electronics: Challenges



Thin and homogenous layers i.e. OLEDs:

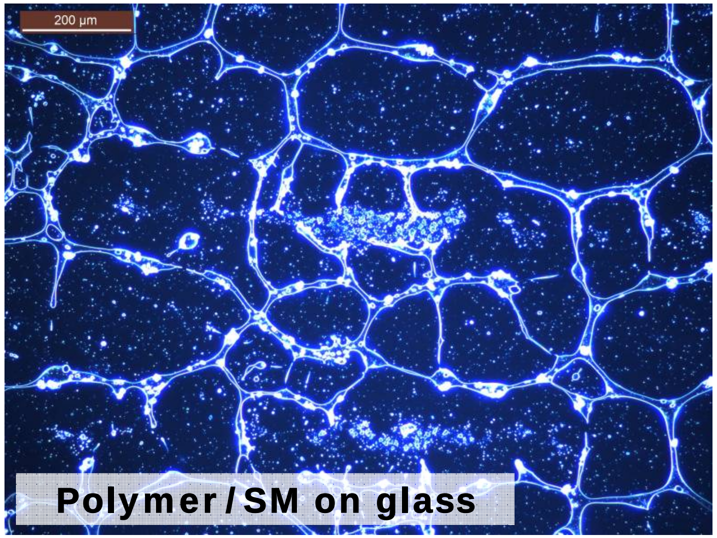
- dewetting: rupture, holes
- crystallization

Multilayer devices:

- compatibility of material sets
- stability of under-laying film
- diffusion of liquid or solutes into under-laying film
- register accuracy

Multi-component fluids:

- different solutes: polymers and/or small molecules
- different liquids: water-based and/or solvent-based solution



Film formation in R2R: Process chain

Film formation

⇒ Ink absorption from ink tank

⇒ Blade process → printing zone

⇒ Printing zone → ink transfer

⇒ **Fluid dynamics of the thin liquid film**

⇒ Transition to drying

⇒ Drying

Theory
Navier-Stokes in the lubrication limit: The Landau Levich equation

Lubrication limit:

Landau Levich equation [2], [3] :

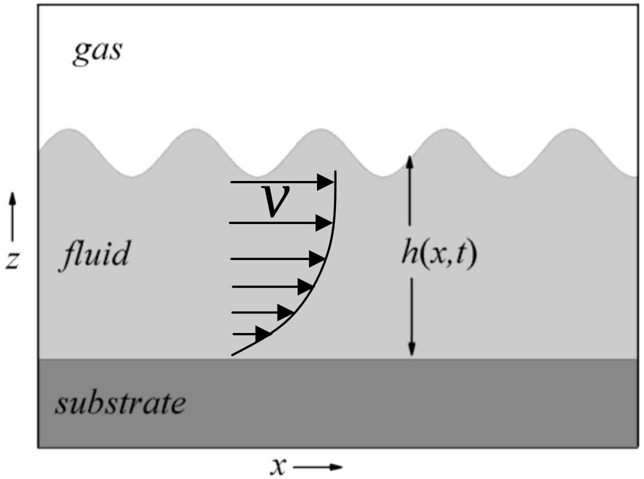
$$\frac{\partial h(x,t)}{\partial t} = \frac{\partial}{\partial x}\left[-\frac{h^3}{3\eta}\frac{\partial}{\partial x}\left(\sigma\frac{\partial^2 h}{\partial x^2} - P_n(h)\right) + \frac{h^2}{2\eta}\frac{\partial \sigma}{\partial x}\right] \quad (1)$$

surface tension gradient

η **: dynamic viscosity**

surface tension curvature pressure

- **gravity**
- **Van der Waals: (~80nm [4])** $\propto \frac{A}{h^{\mu}}$, $\mu = 4$



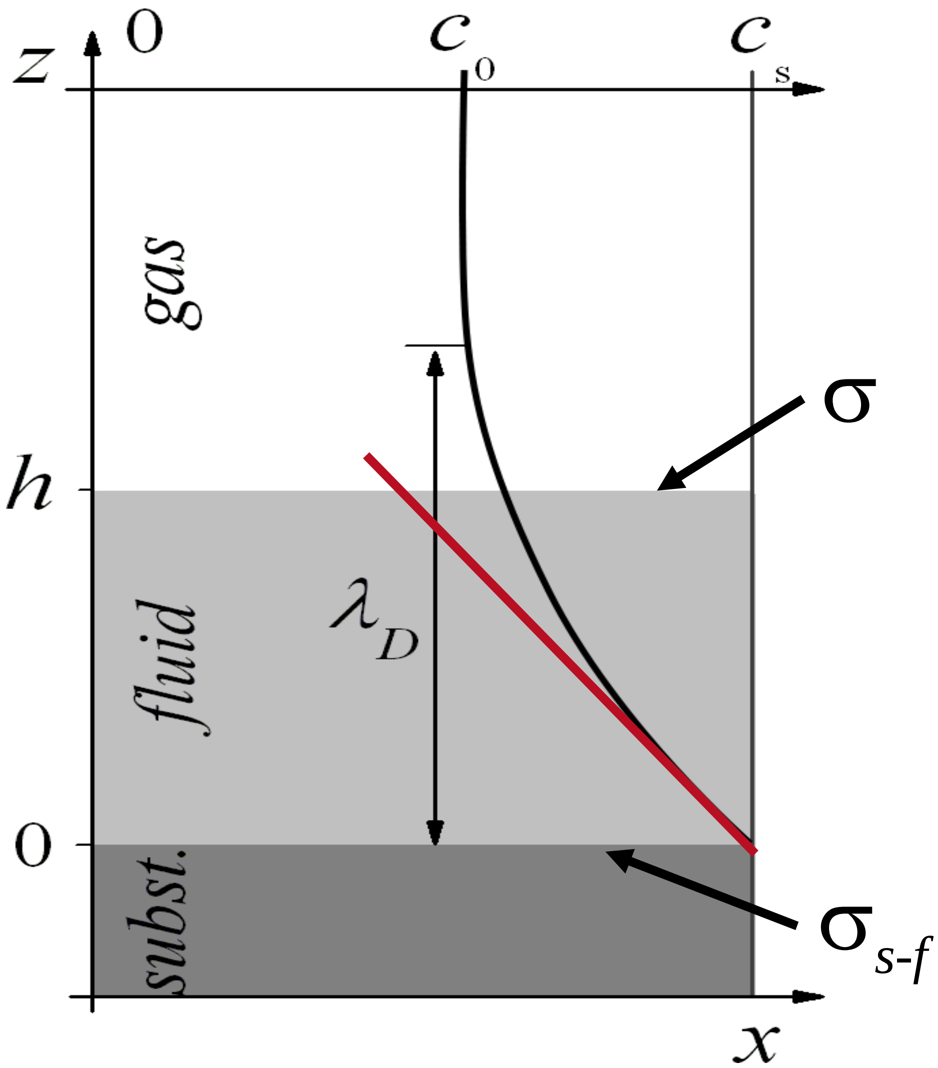
Small perturbed liquid film, leveling time:

$$\tau \propto \frac{\sigma h_0^3}{\eta \lambda^4}$$

[2] L. Landau, B. Levich, Acta Physicochim. URSS. **1942**, 42-54
[3] A. Oron, S.G. Bankoff, Rev. Mod. Phys. **1997**, 69, 931-980
[4] P. de Gennes, Rev. Mod. Phys. **1985**, 57, 827-863.

Theory

Effects of surface tension and concentration gradients



Thin liquid film of a binary system:

C : concentration of solute in solution

σ : surface tension

λ_D: diffusion length

Useful relation [1]:

$$\left.\frac{\partial C}{\partial z}\right|_{z=0} = \frac{\lambda_D}{2k_B T}\frac{\partial \sigma_{sf}}{\partial C}$$

In the following:

Evaporation and temperature gradients effects are neglected.

[1] J.W. Cahn, J. Chem. Phys. **1977**, 66, 3667

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Stability analysis: Phase diagrams

When do we have solutions of L.L. eq. (1) for stable, homogenous flat, large-scale films concerning ***C* , σ gradients** and Van der Waals forces?

STABLE : $\frac{\partial h(x,t)}{\partial t} = 0 \quad \Rightarrow \quad \text{eq. (1)} \rightarrow h'(h)$

GRADIENTS of ***C* , σ** : $\longrightarrow \beta$

VAN DER WAALS : $\longrightarrow A$

INTEGRATION CONSTANT: c_0

$$\Rightarrow \quad h'(h)\Big|_{\beta, A, c_0}$$

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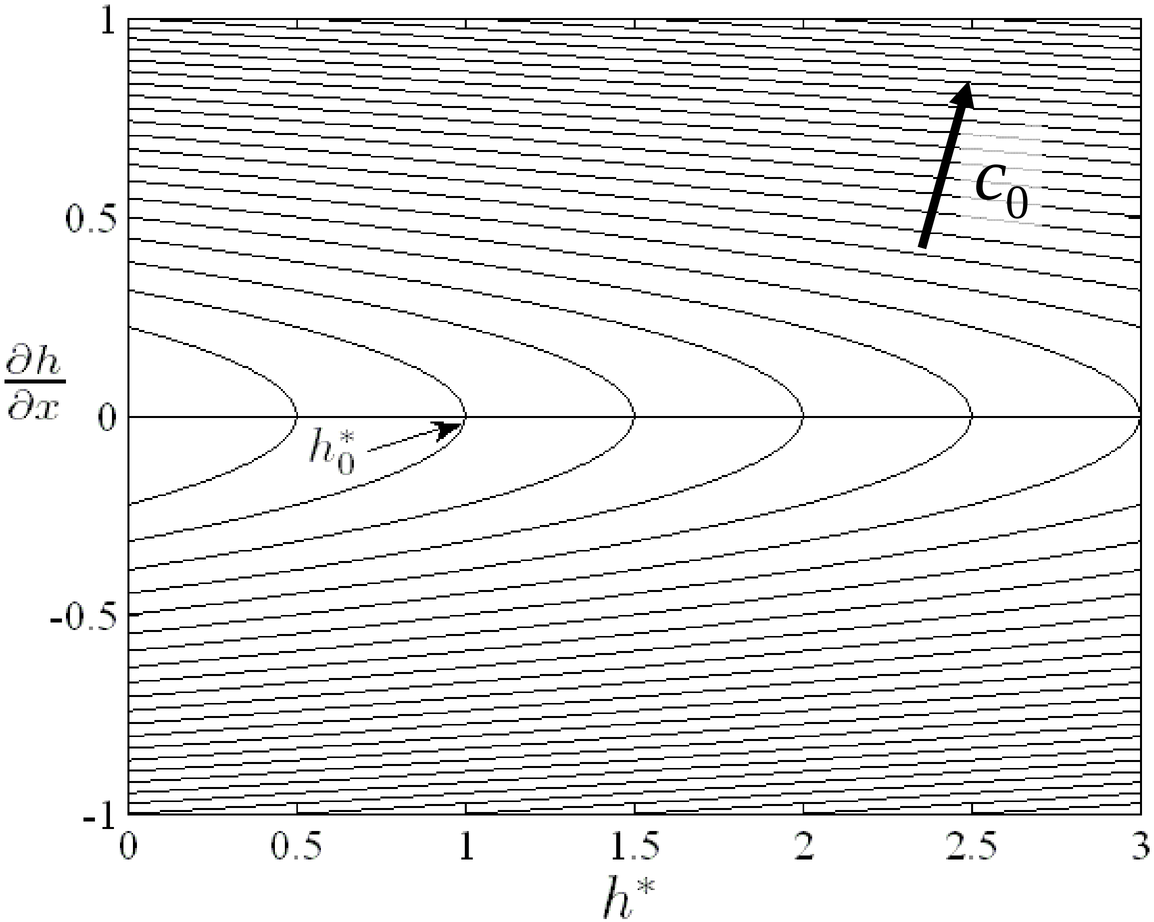
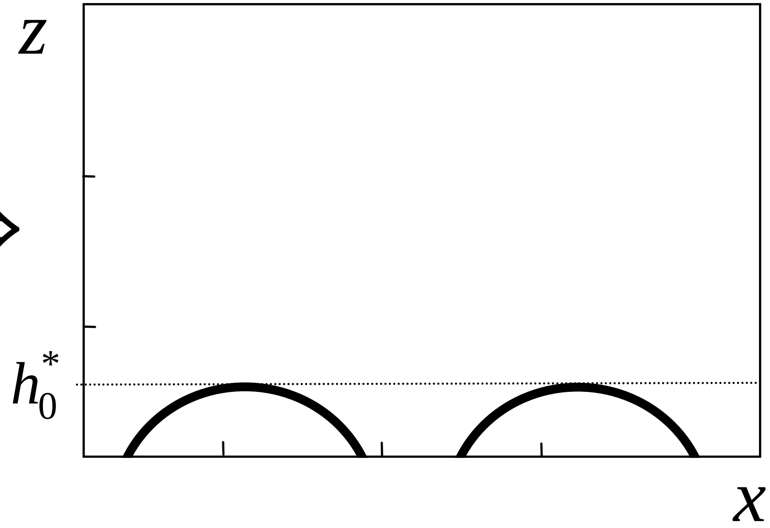
Stability analysis

Constant surface tension

No additional forces: $\partial\sigma/\partial x = 0$ and $A = 0$



$\Rightarrow$



Why is a puddle stable?

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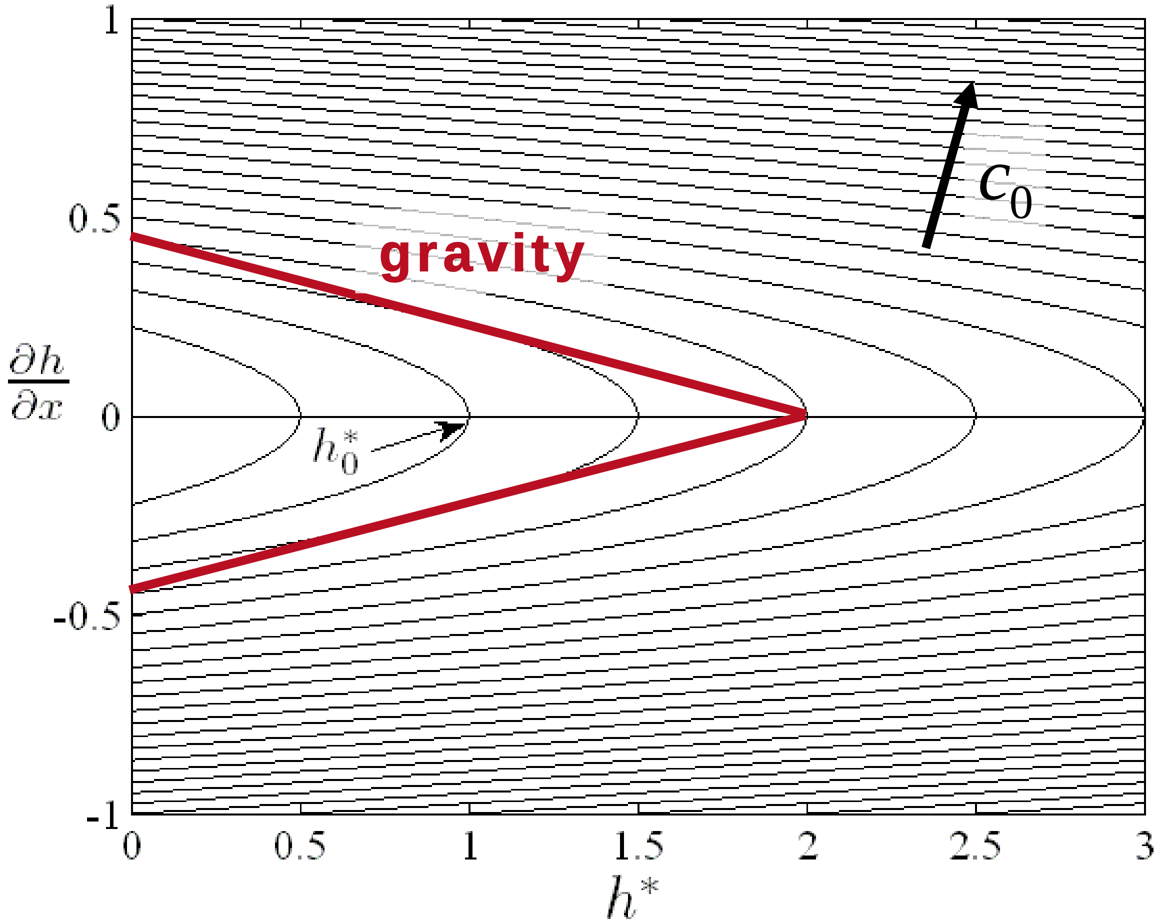
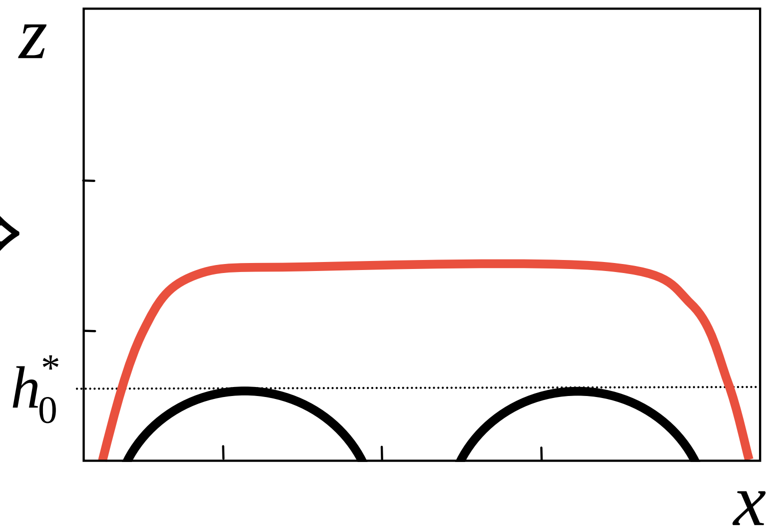
Why is a puddle stationary flat?

No additional forces: $\partial\sigma/\partial x = 0$ and $A = 0$



$\Rightarrow$



Why is a puddle flat?
Because of gravity!

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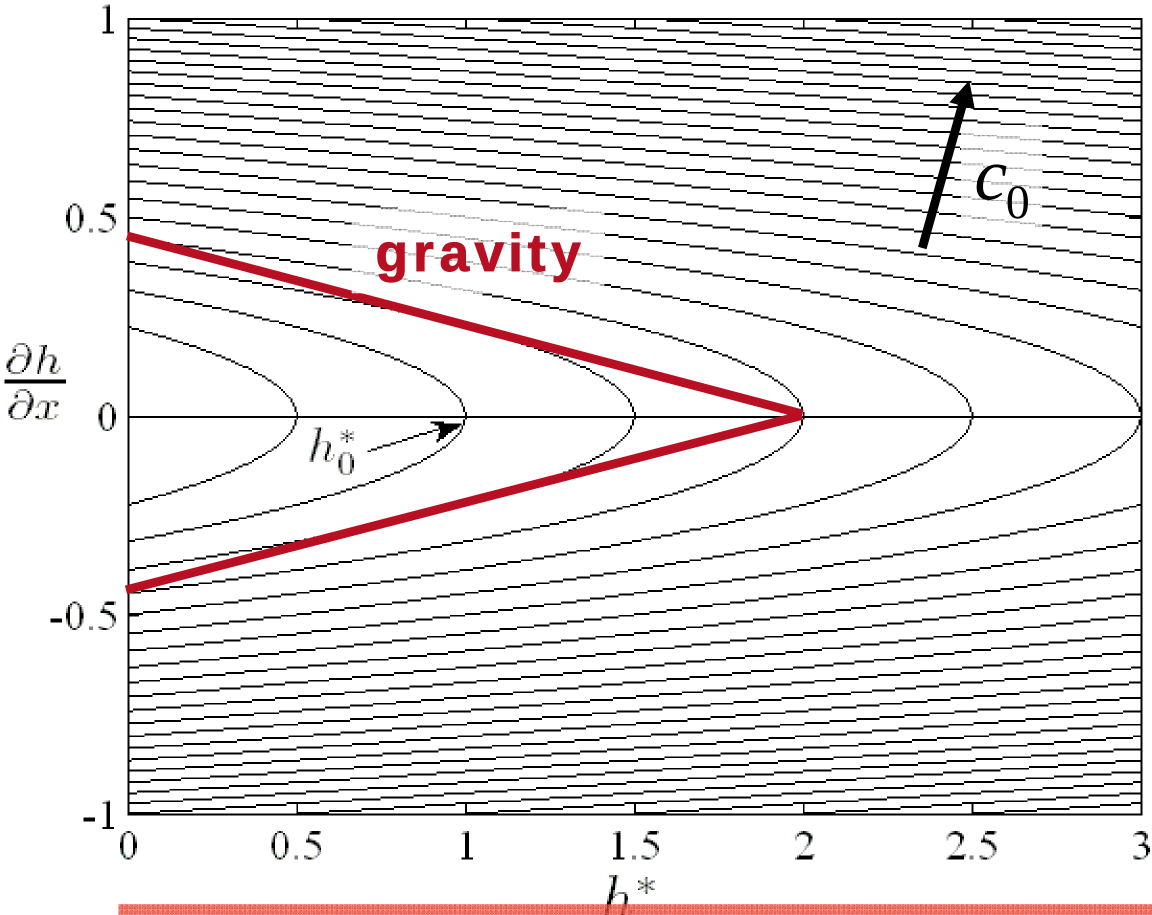
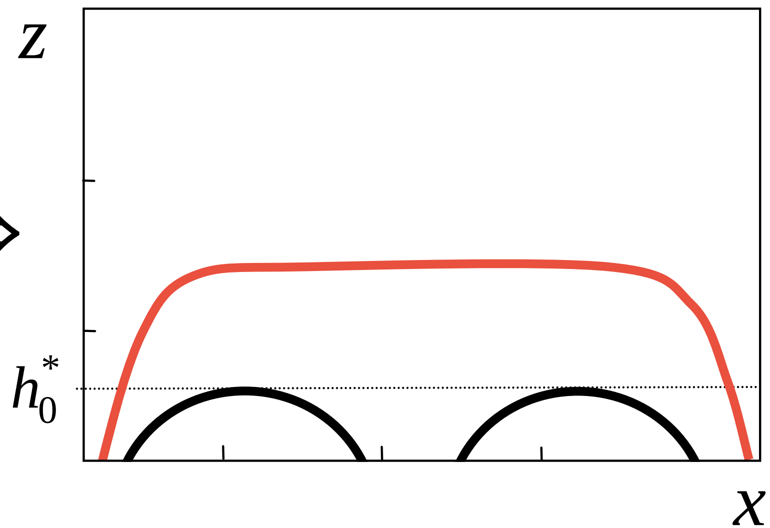
Stability analysis

Why is a puddle stationary flat?

No additional forces: $\partial\sigma/\partial x = 0$ and $A = 0$



$\Rightarrow$



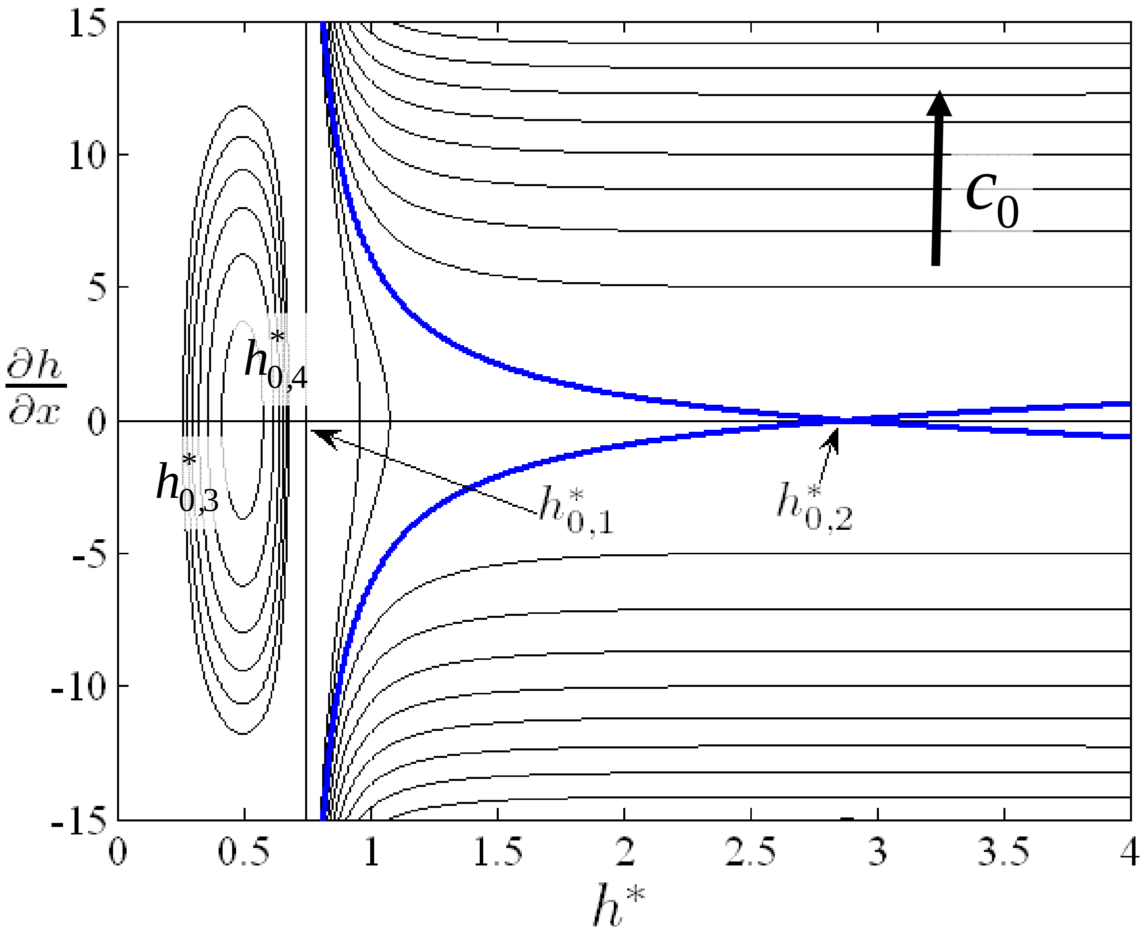
Why is a puddle stable?
Because of gravity!

Additional forces required for stable homogenous flat films!

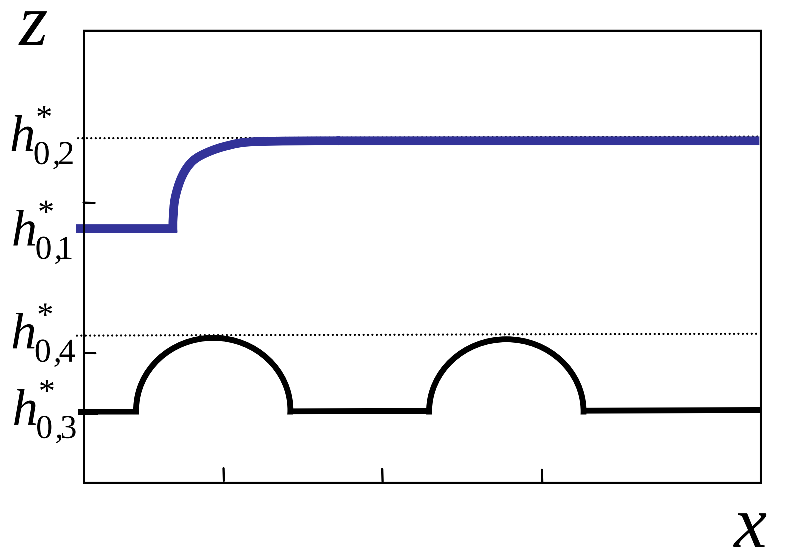
Stability analysis

Additional forces

Gradients in C, σ: $\beta = 2$ and Van der Waals forces: $A = 2$



⇒



Stability for $A \cdot \beta > 0$

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Thank You for Your Attention !

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