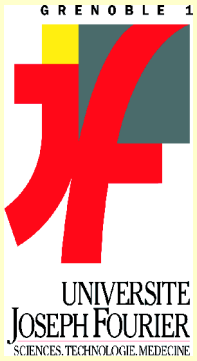


A LOCAL DESCRIPTOR OF T1s AND ITS COUPLING WITH GLOBAL FLOW

Benjamin DOLLET

Laboratoire de Spectrométrie Physique, Université Grenoble 1, France

François GRANER (U. Grenoble),
Miguel AUBOUY (CEA Grenoble),
Catherine QUILLIET (U. Grenoble),
Florence ELIAS (U. Paris 6),
Christophe RAUFASTE (U. Grenoble).

OUTLINE

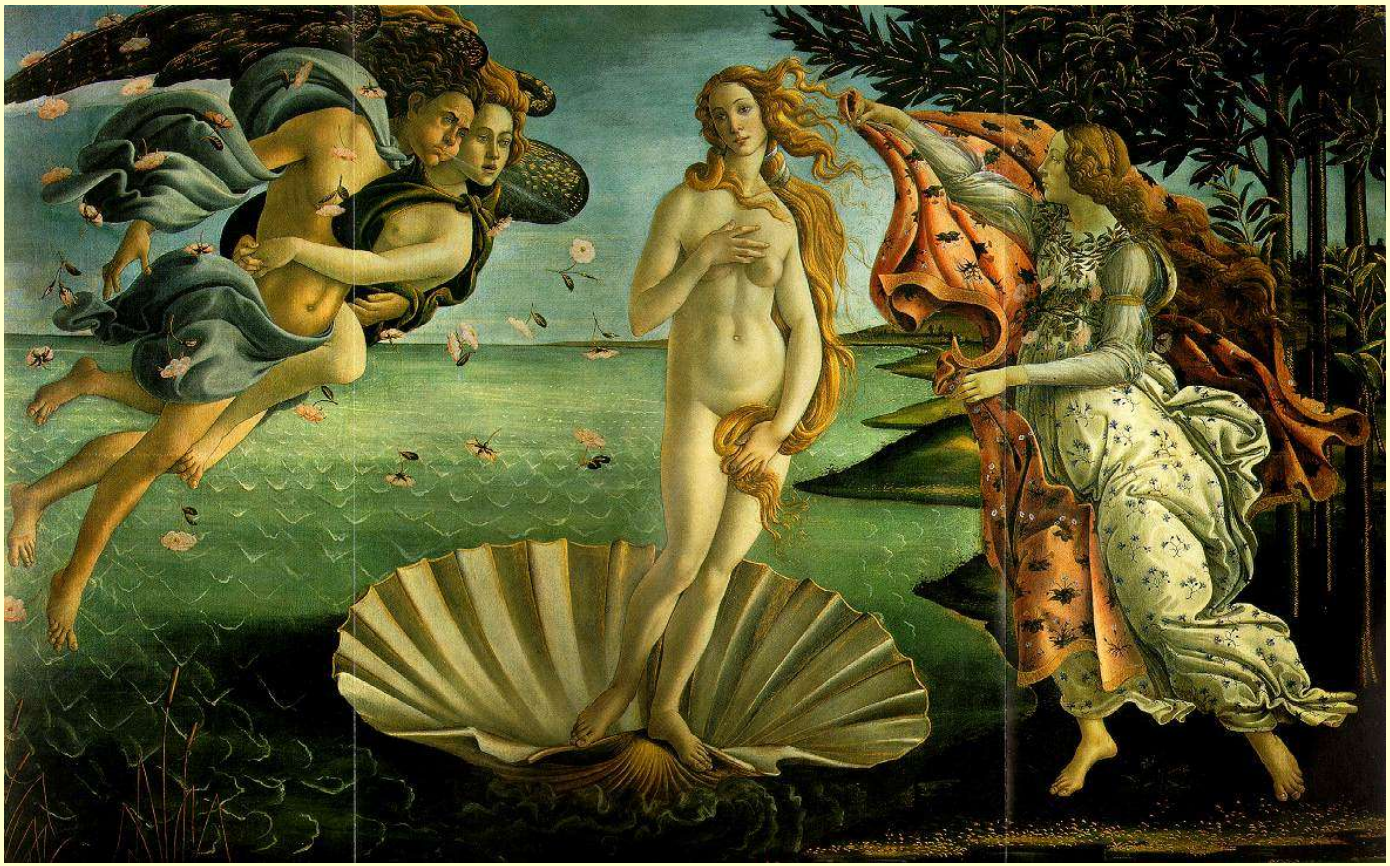
- introduction: aphrodynamics and experimental setup
- global measurements: drag on a circle
- local analysis: velocity and deformation
- lift
- T1s: tensorial descriptor, results and interpretation

INTRODUCTION: aphrodynamics

What does it mean?

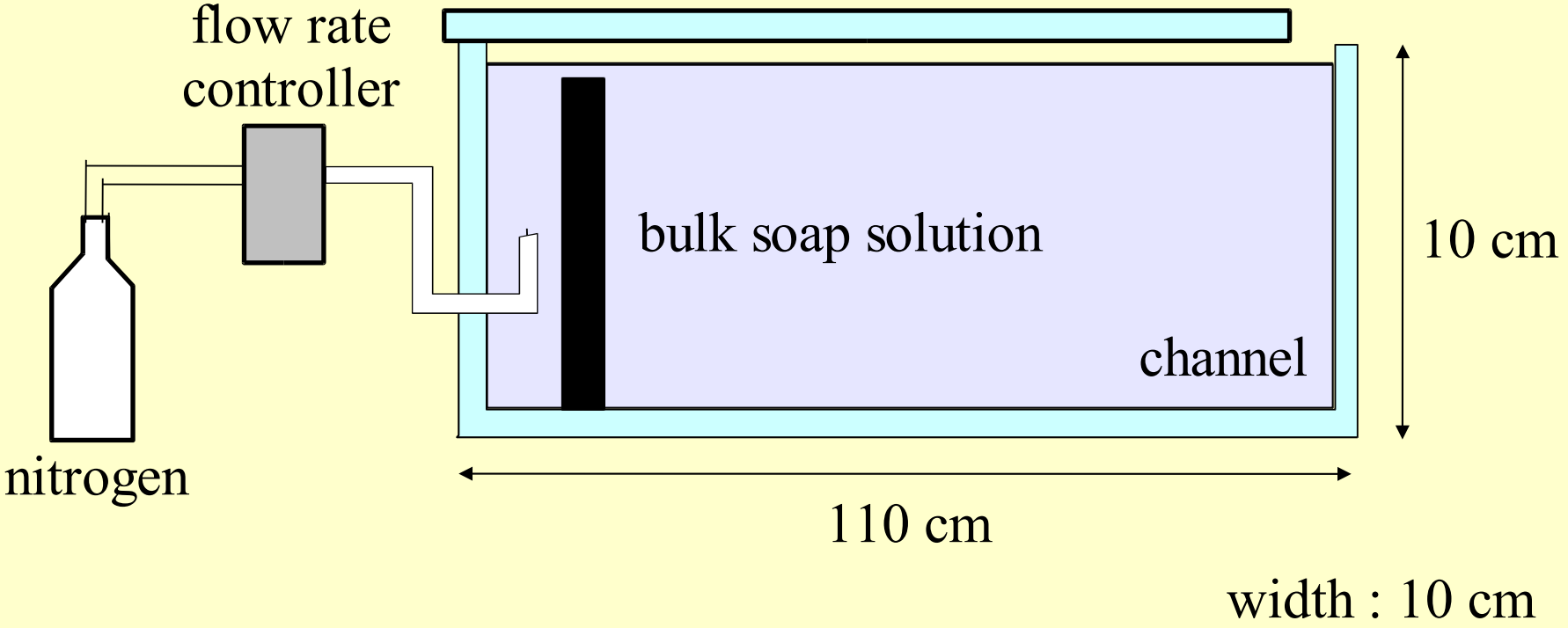
foam dynamics

ο αφρός : the foam

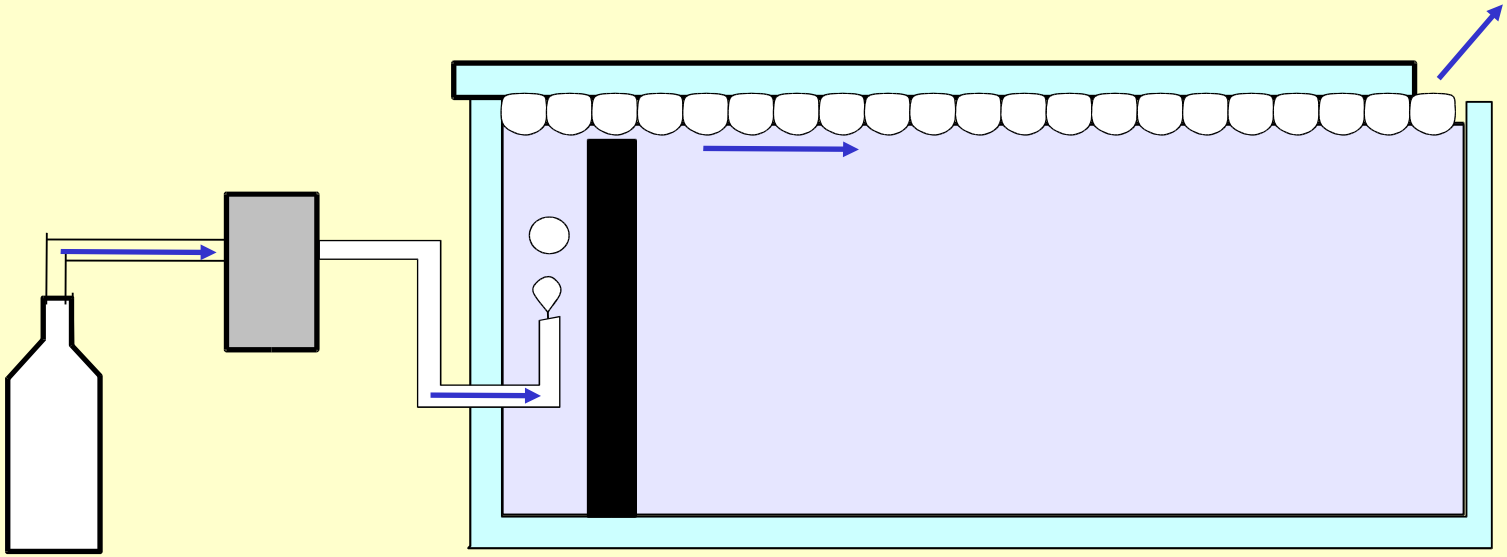


The Birth of Venus, Sandro Botticelli, 1486

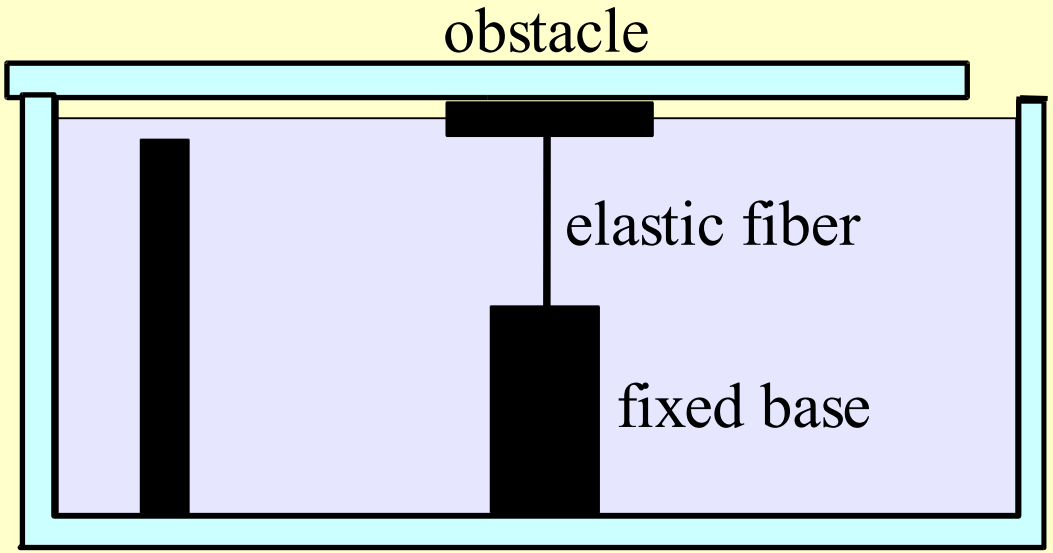
EXPERIMENTAL SETUP : overview



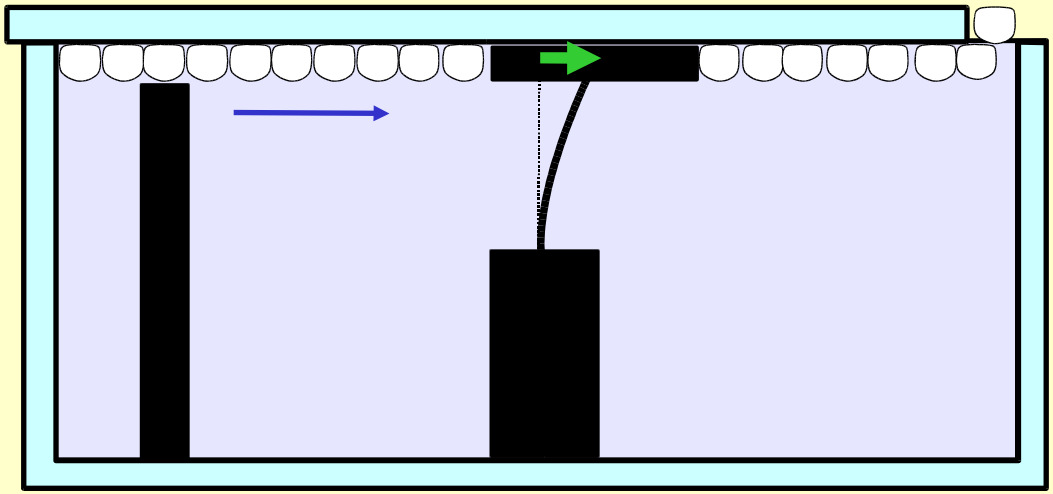
EXPERIMENTAL SETUP : overview



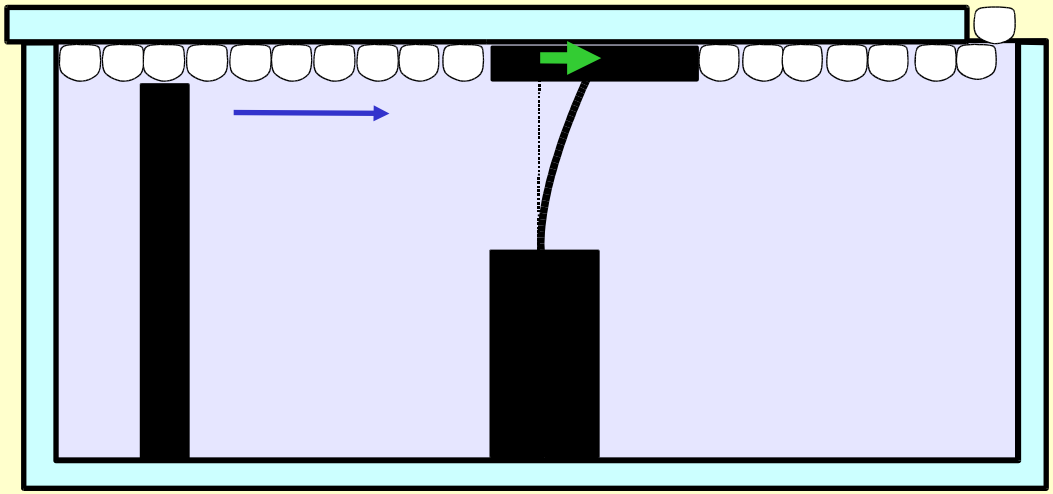
EXPERIMENTAL SETUP : force measurement



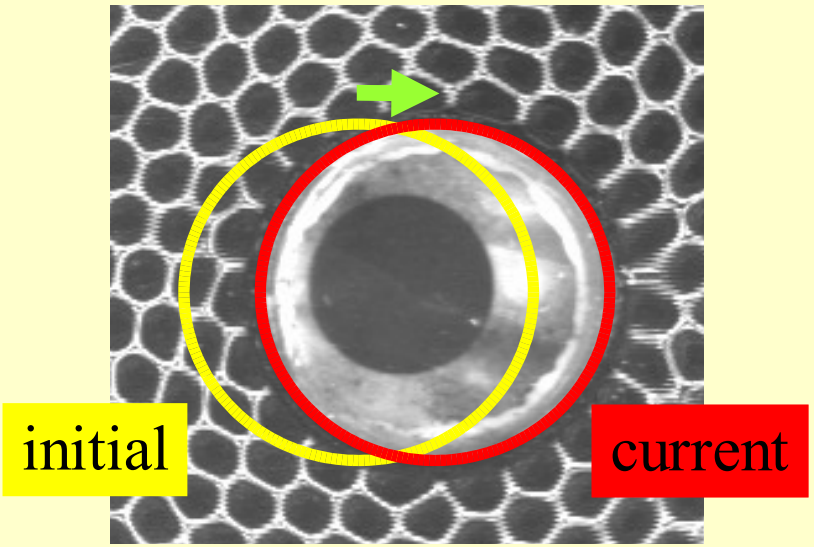
EXPERIMENTAL SETUP : force measurement



EXPERIMENTAL SETUP : force measurement



imaging the obstacle:



Movie

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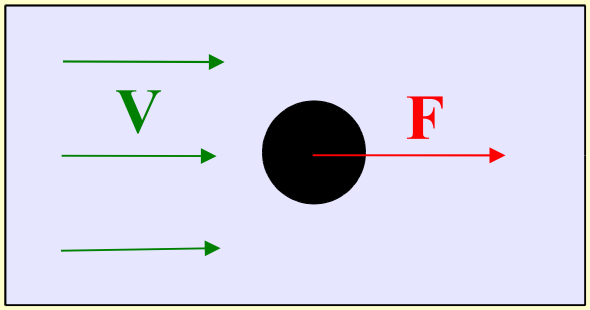
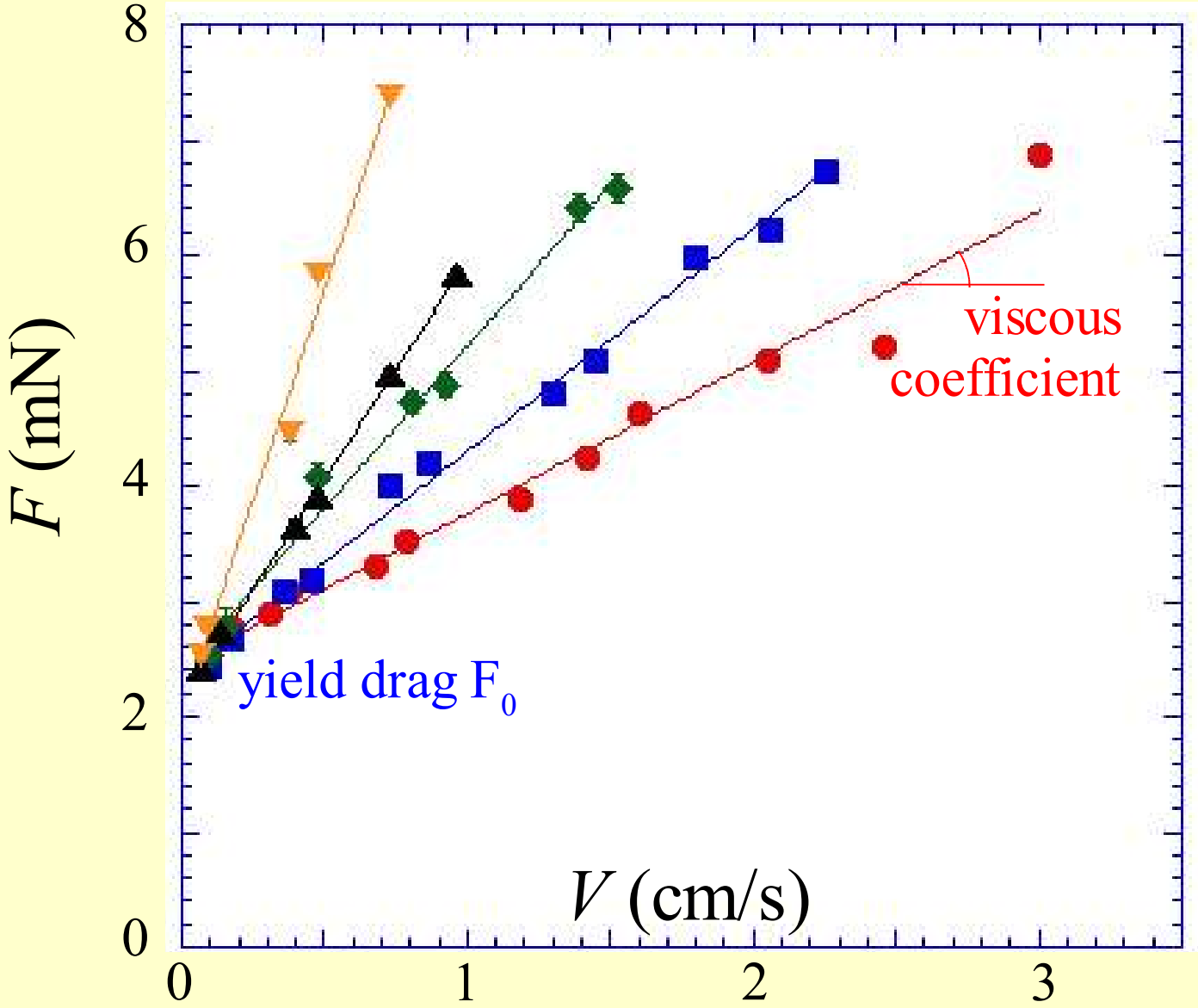
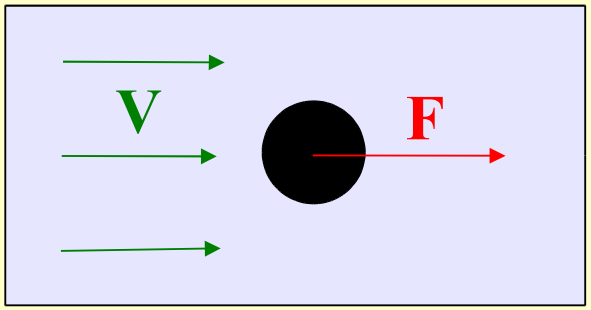
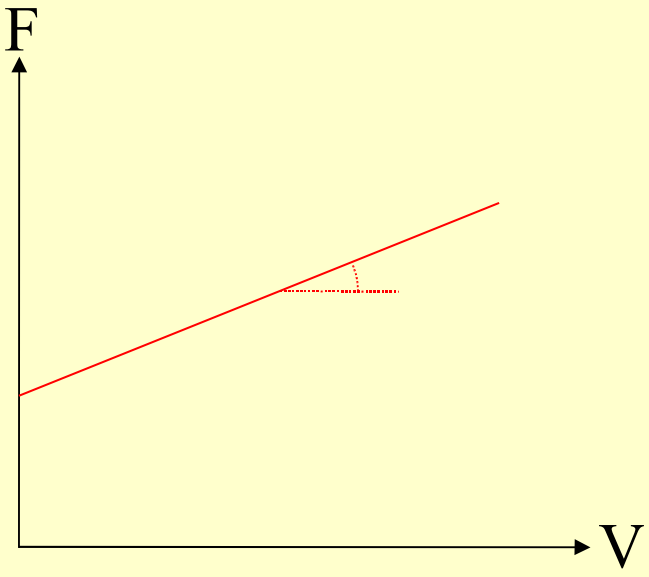
GLOBAL MEASUREMENTS : drag





GLOBAL MEASUREMENTS : drag





Yield drag:

independent of bulk viscosity

decreases with bubble area

Viscous coefficient:

increases nonlinearly with bulk viscosity

$$F - F_0 \propto \eta^{0.77 \pm 0.05}$$

decreases with bubble area

Dollet et al., PRE **71**, 031403 (2005)

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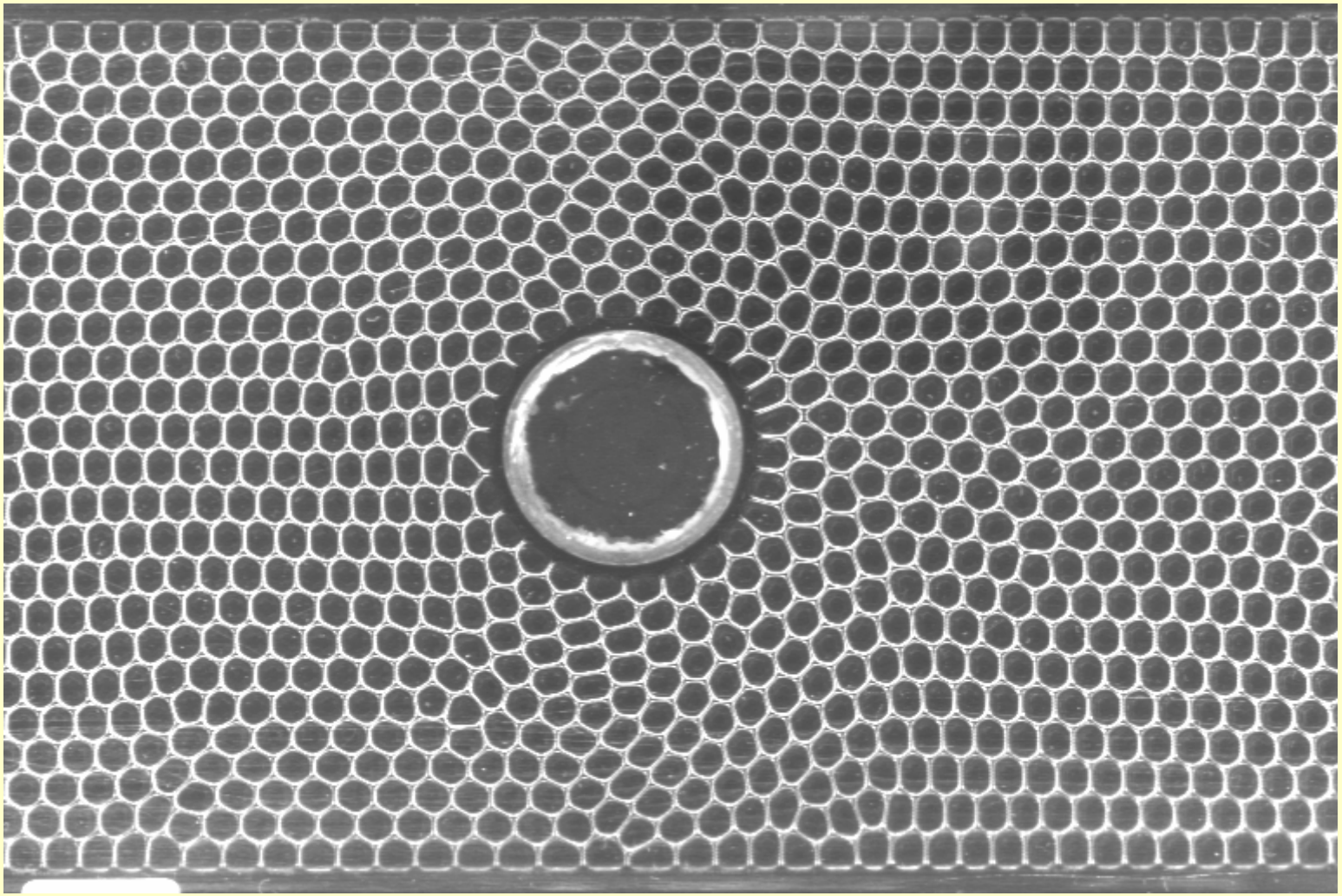
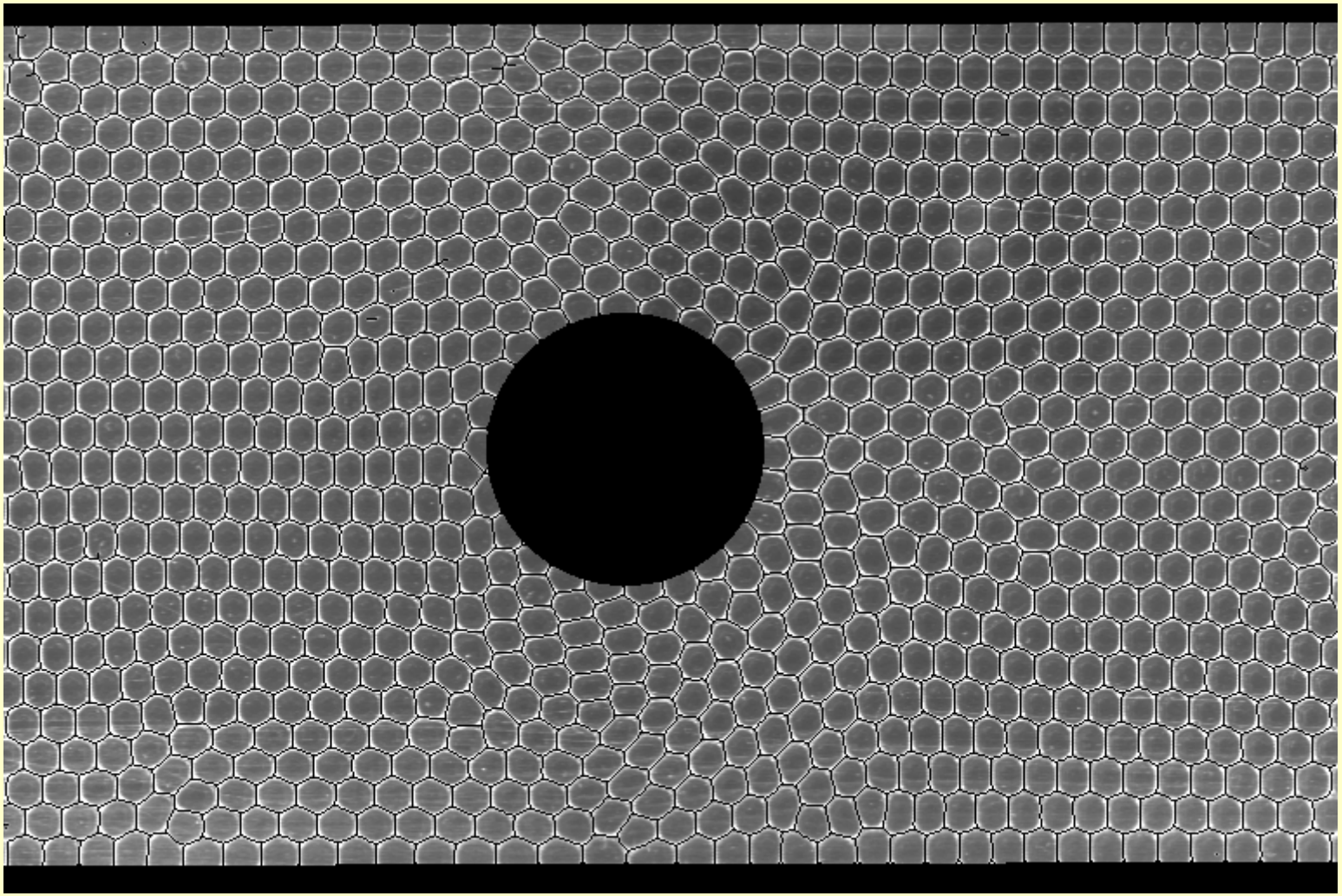
LOCAL ANALYSIS: principle

threshold and skeletonisation

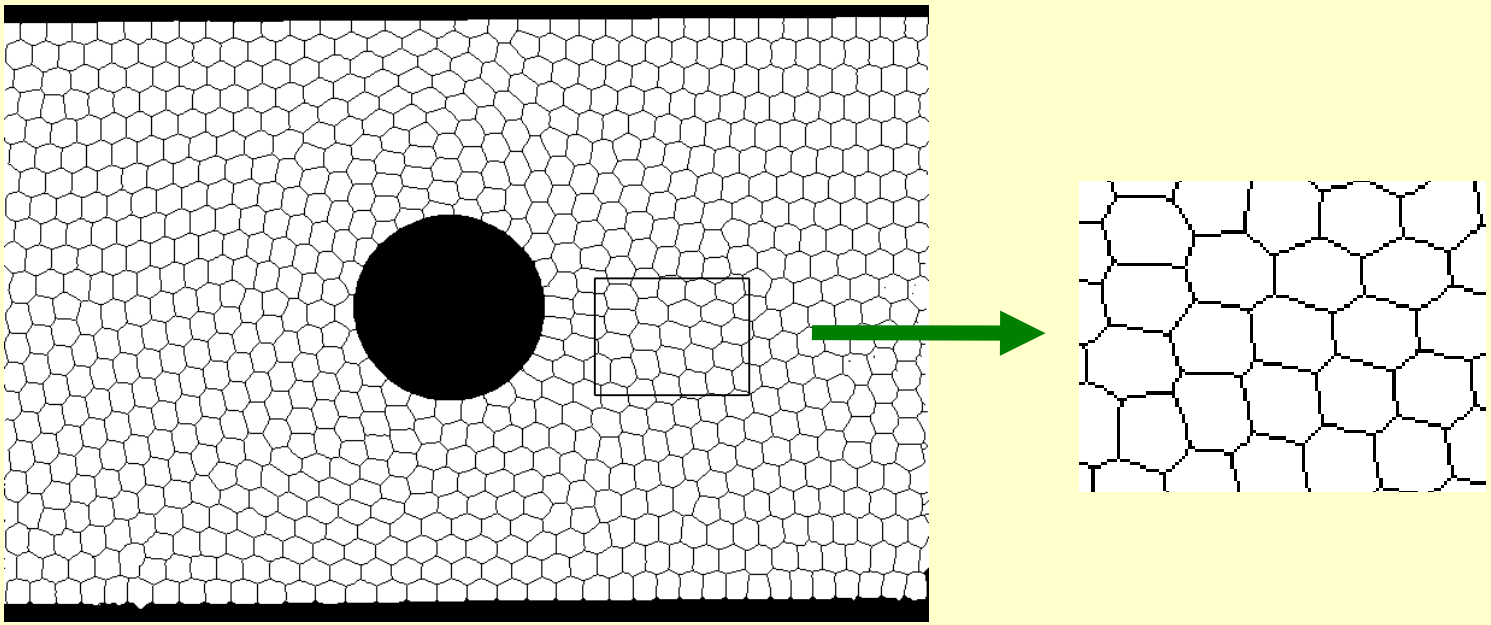


LOCAL ANALYSIS: principle

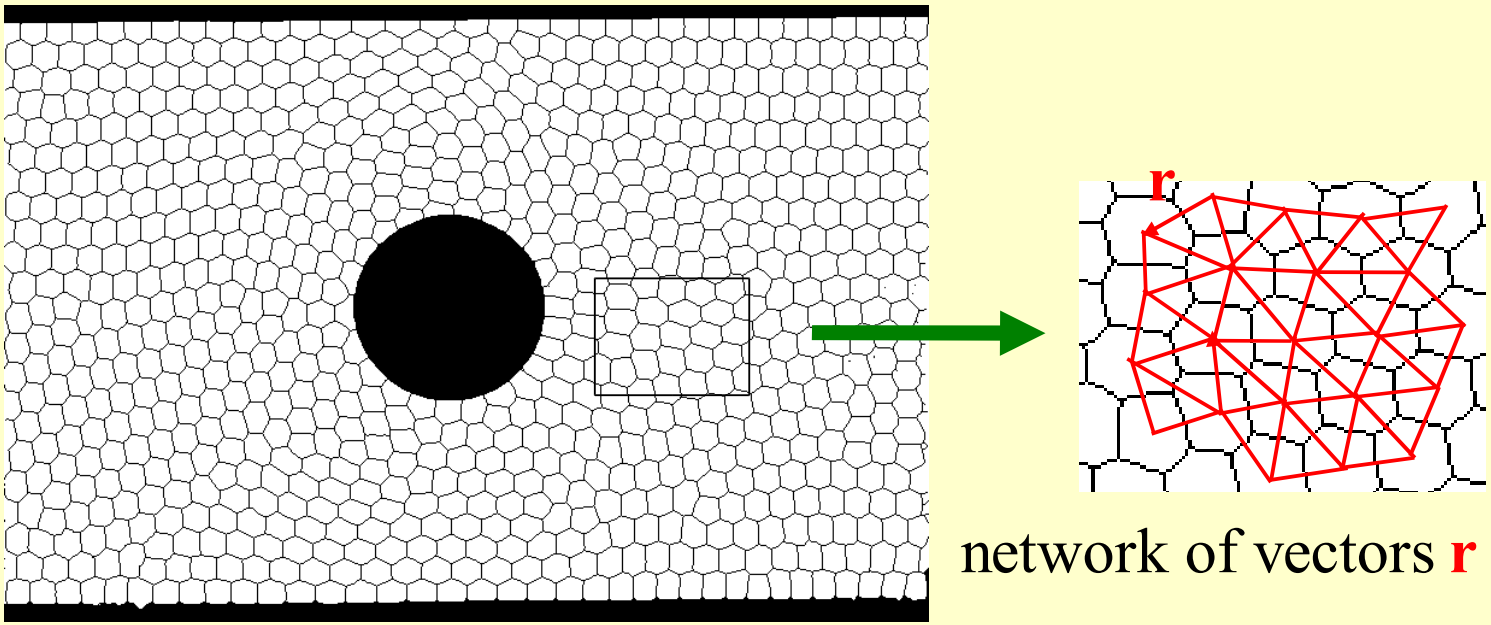
threshold and skeletonisation



LOCAL ANALYSIS: principle



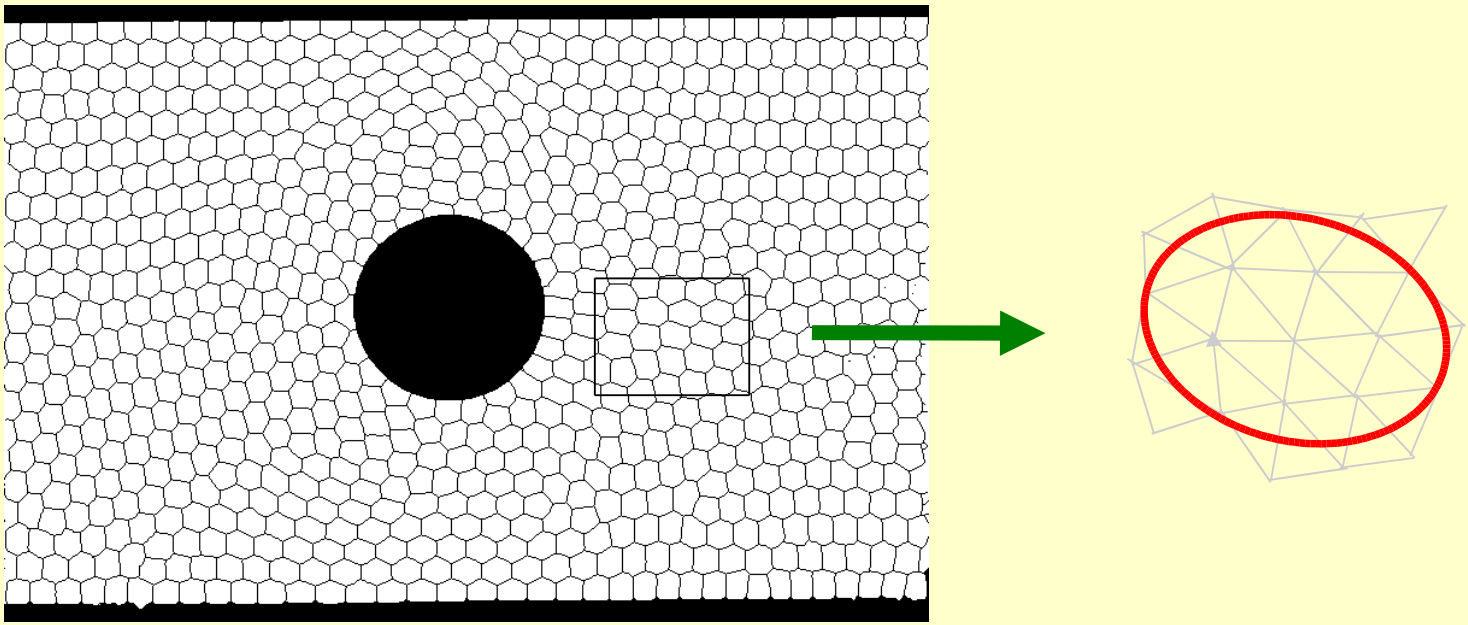
LOCAL ANALYSIS: principle



network of vectors **r**

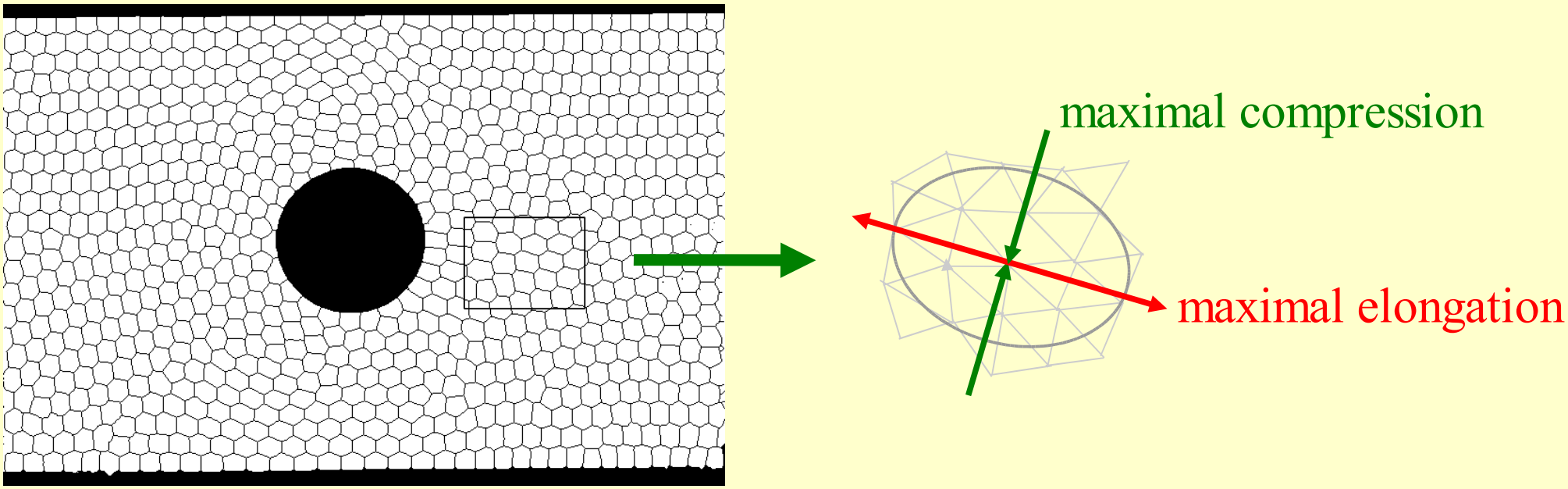
linking the centers of bubbles in contact

LOCAL ANALYSIS: principle



Texture tensor: quantifies the deformation of the bubbles $M_{ij} = \langle r_i r_j \rangle$

LOCAL ANALYSIS: principle



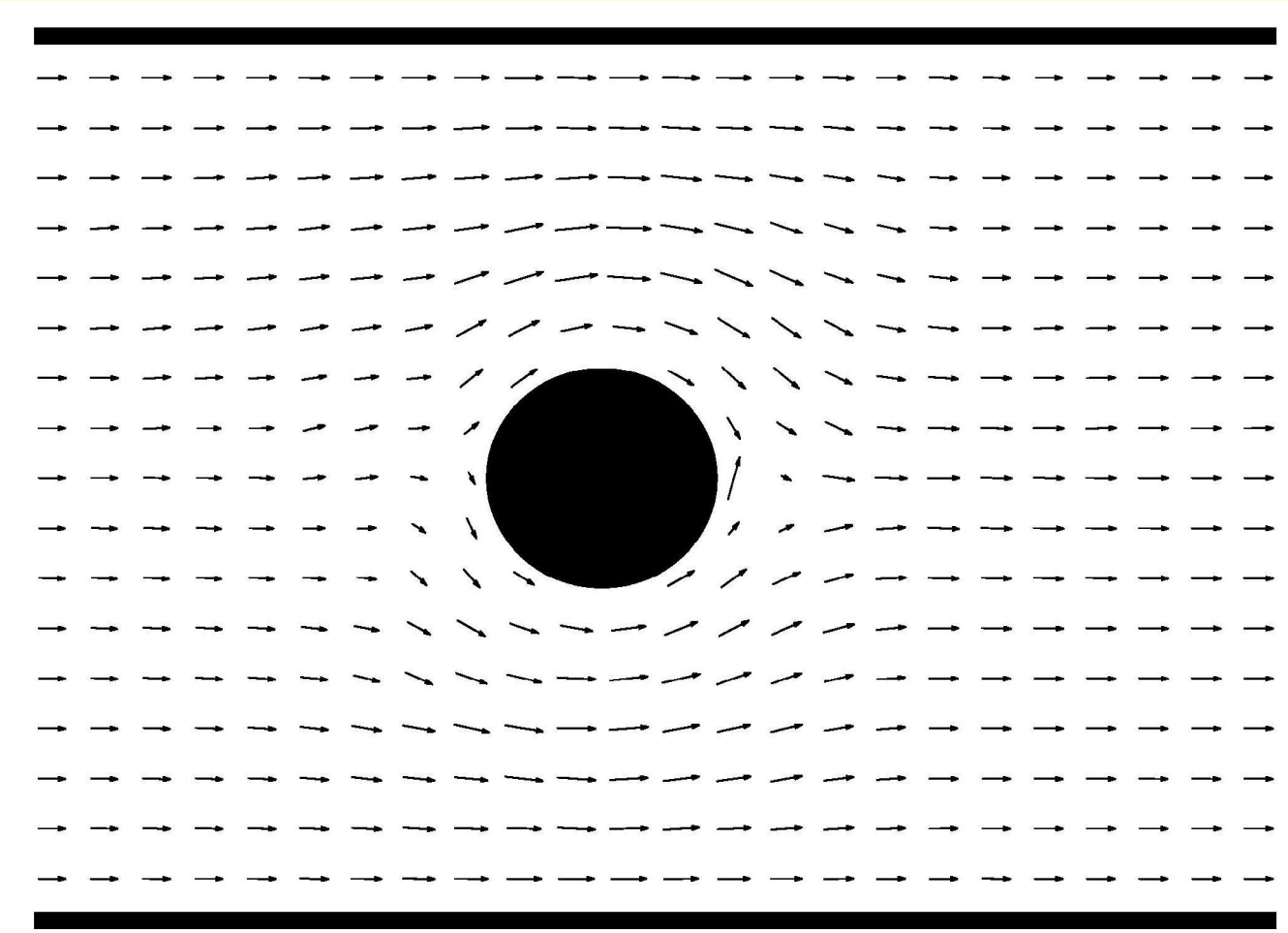
Texture tensor: quantifies the deformation of the bubbles $M_{ij} = \langle r_i r_j \rangle$

statistical deformation: $U_{ij} \simeq (M_{ij} - \langle \vec{r}^{\,2} \rangle \delta_{ij})/2$

Other fields: pressure and elastic stresses

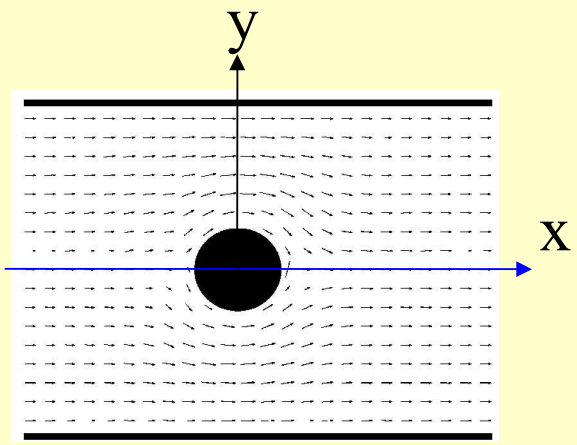
LOCAL ANALYSIS: velocity

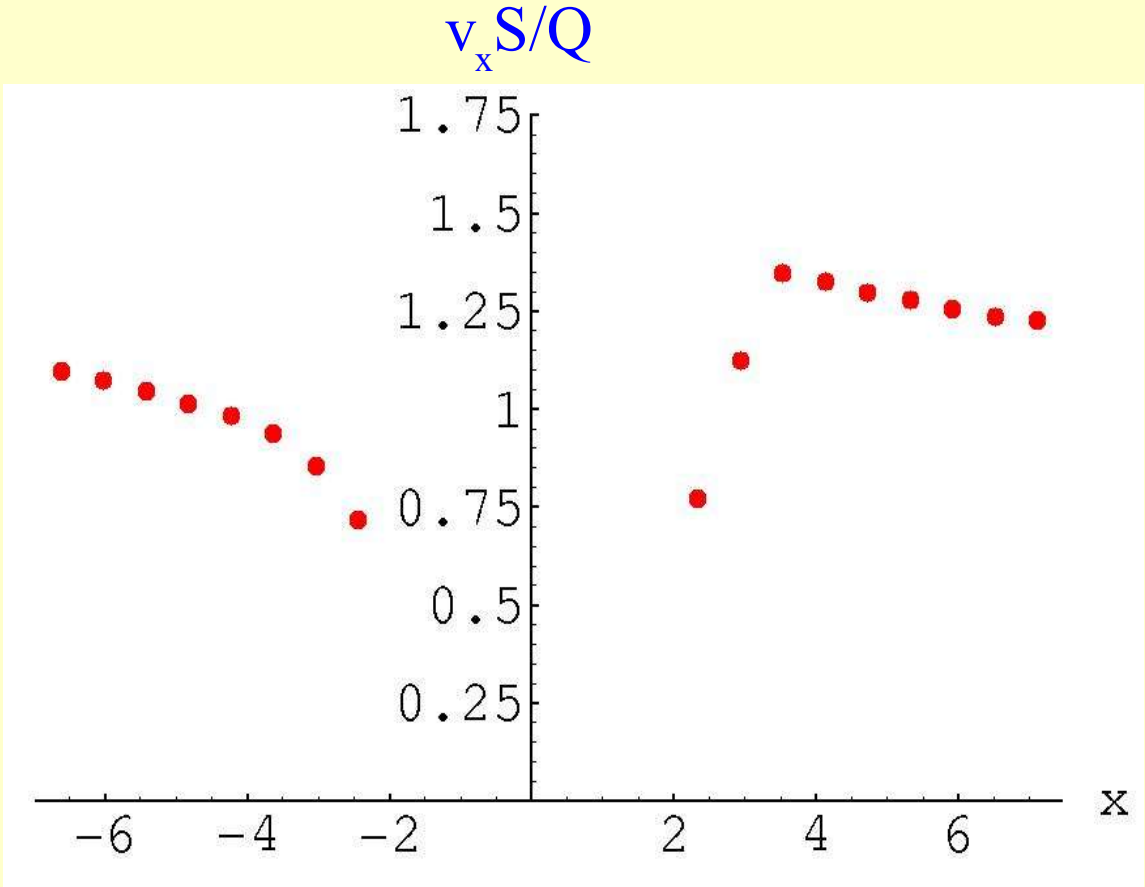
10^3 images
2×10^6 bubbles



seems Newtonian, but...

LOCAL ANALYSIS: flow around a circle





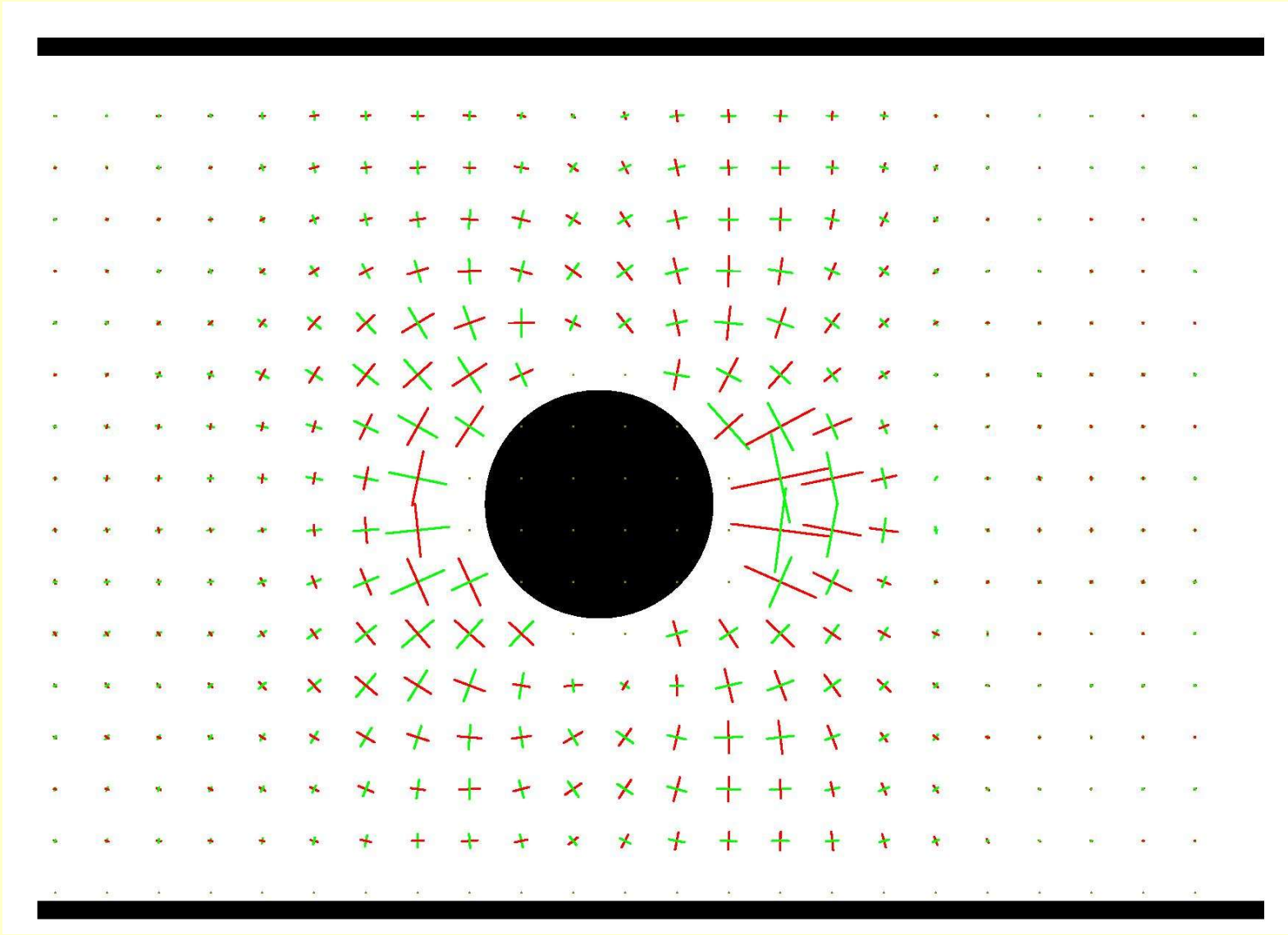
asymmetry up/downstream,

contrary to Newtonian and Bingham fluids

$\Rightarrow$ elastic property

LOCAL ANALYSIS: velocity gradients

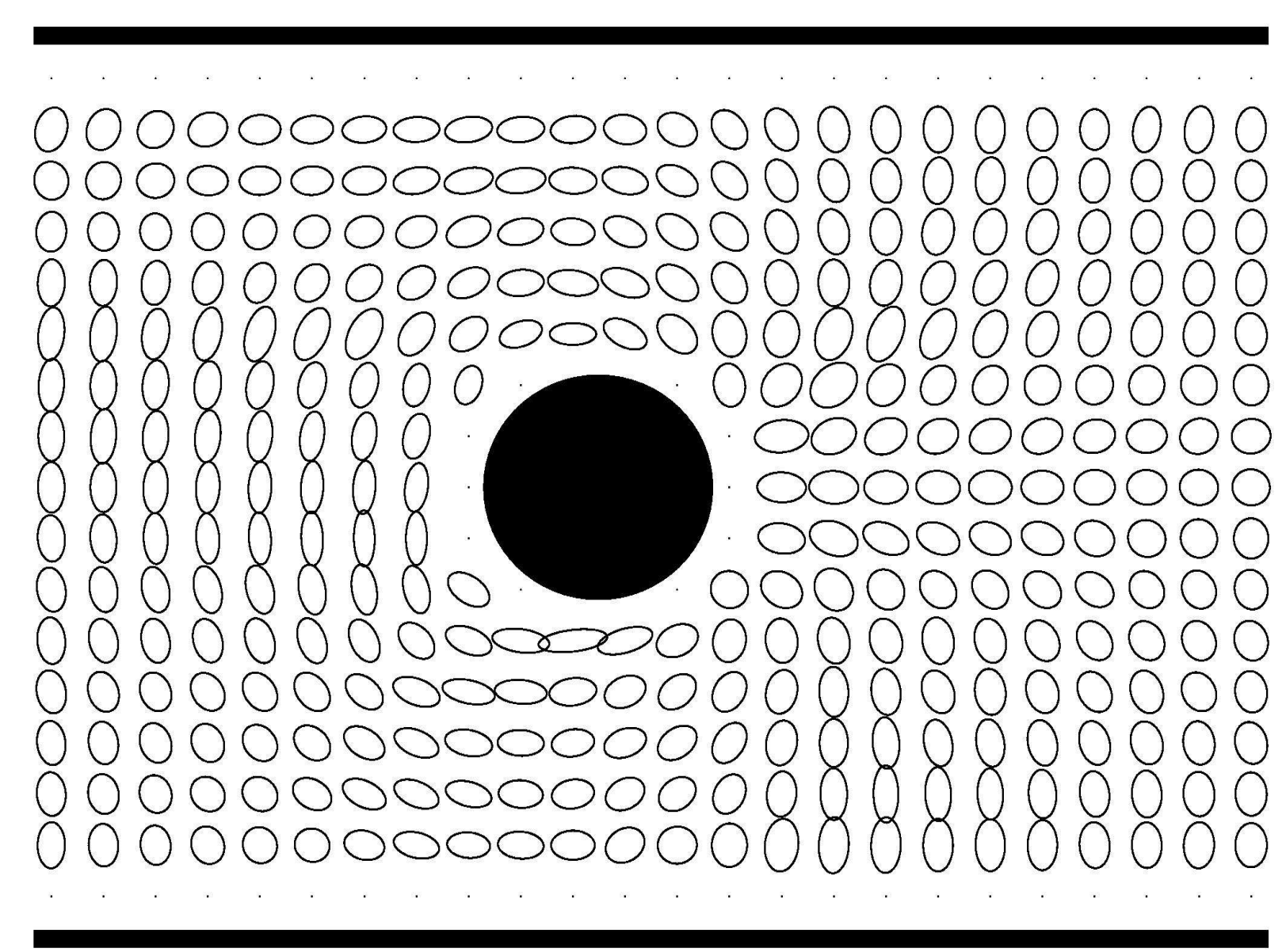
Velocity gradient: deformation rate tensor $e_{ij} = \frac{1}{2}\left(\frac{\partial v_i}{\partial x_j} + \frac{\partial v_j}{\partial x_i}\right)$



maximal elongation rate

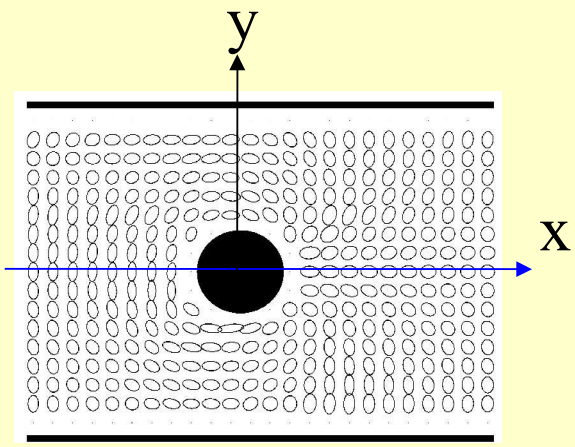
maximal compression rate

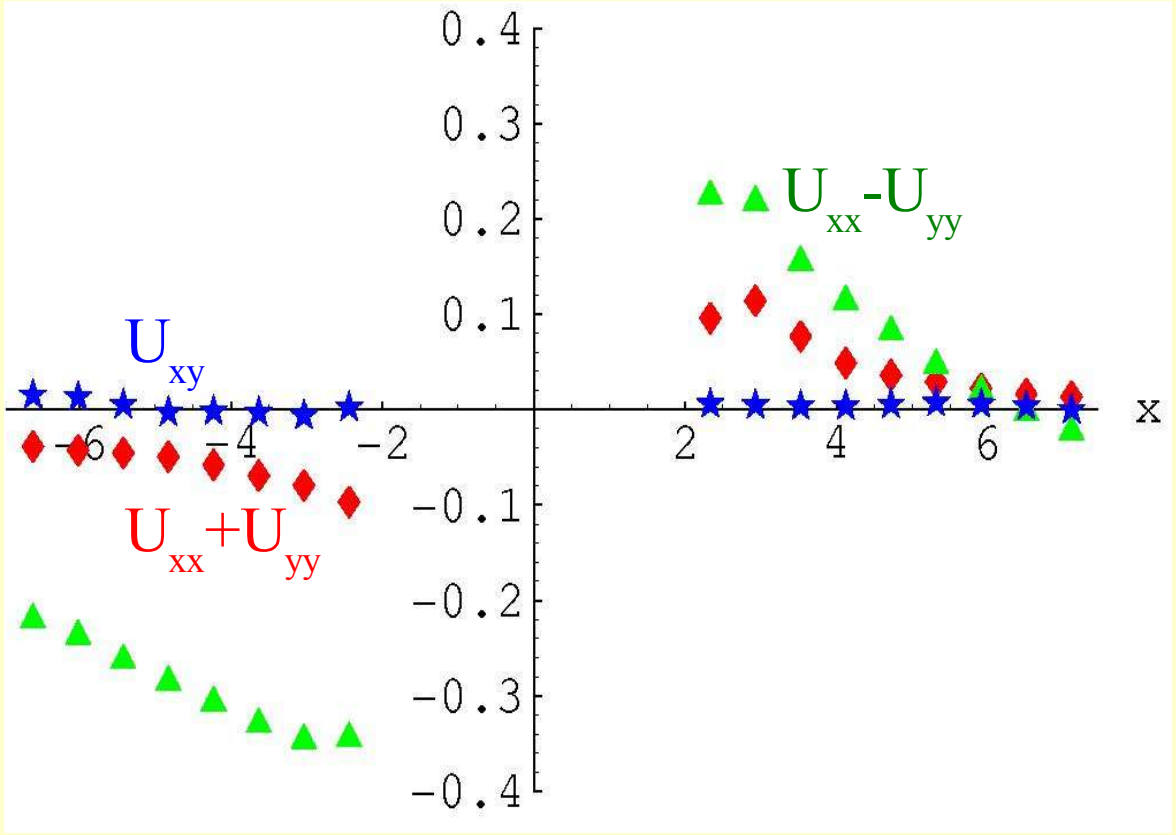
LOCAL ANAYSIS: bubble deformation



LOCAL ANALYSIS: flow around a circle

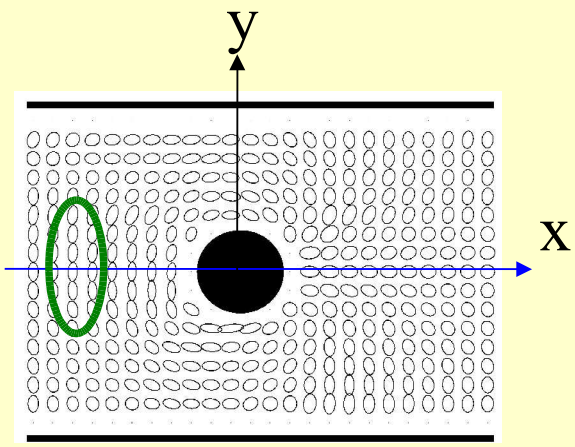
amplitude of statistical deformation

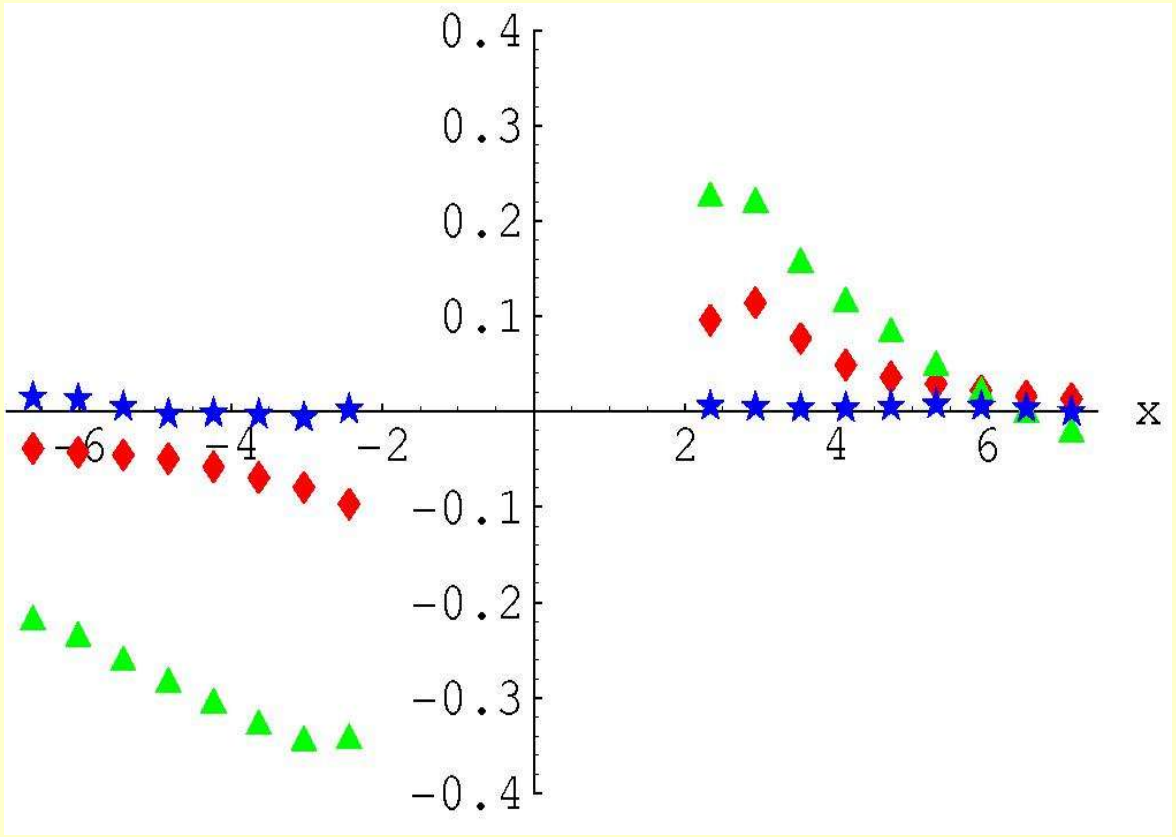




LOCAL ANALYSIS: flow around a circle

amplitude of statistical deformation



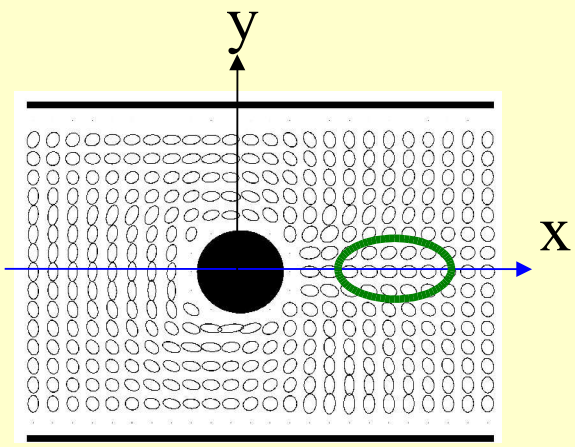


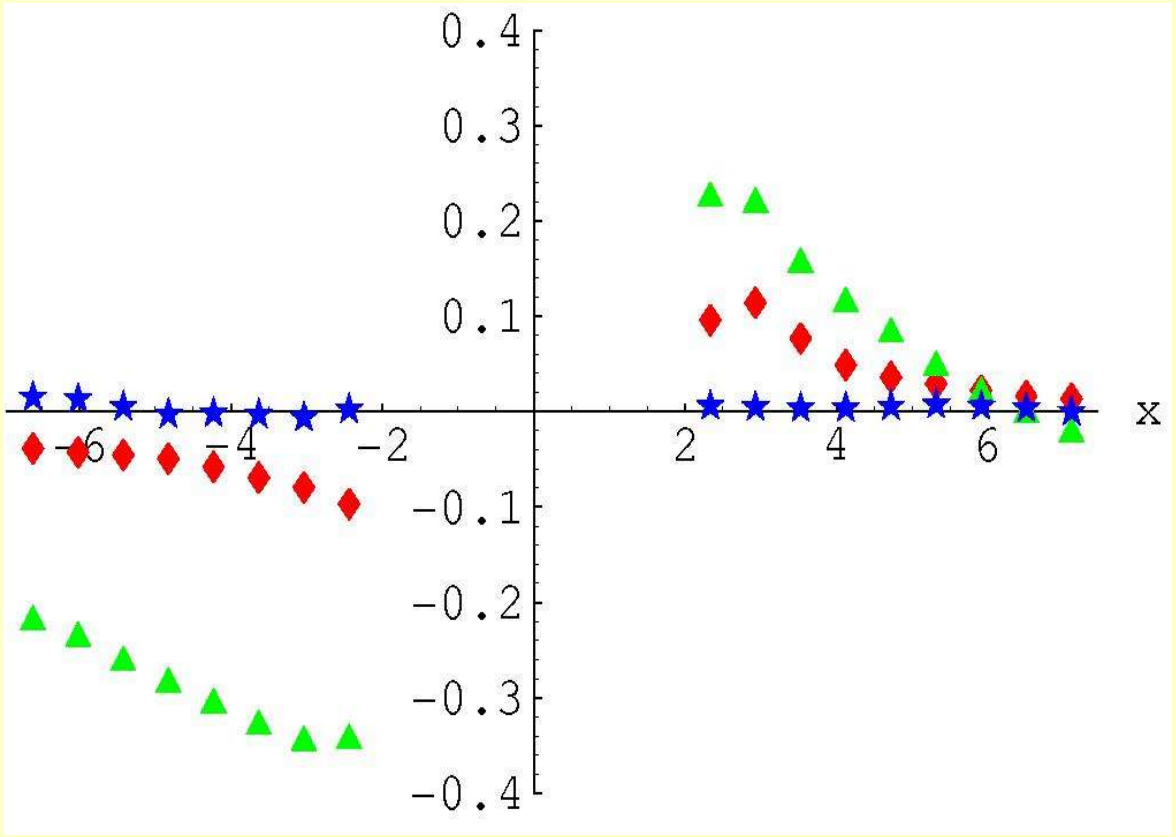
U_{xx}-U_{yy} < 0:
bubbles stretched spanwise

U_{xx}+U_{yy} < 0: contraction

LOCAL ANALYSIS: flow around a circle

amplitude of statistical deformation



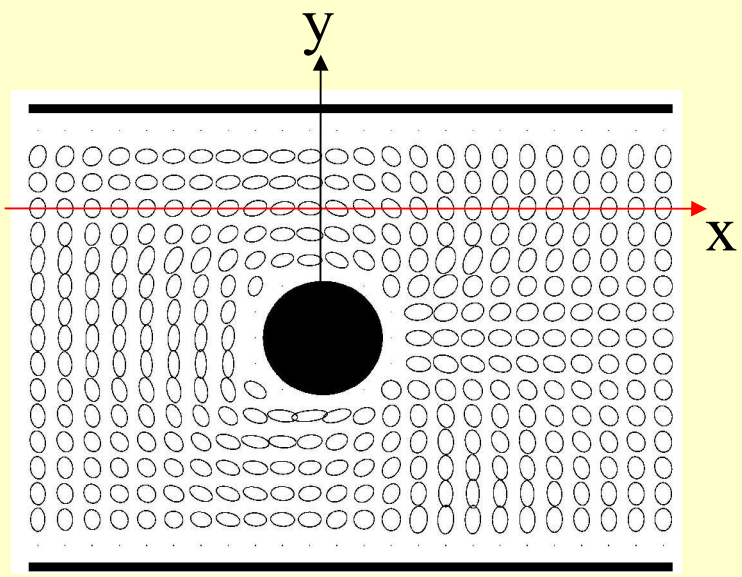


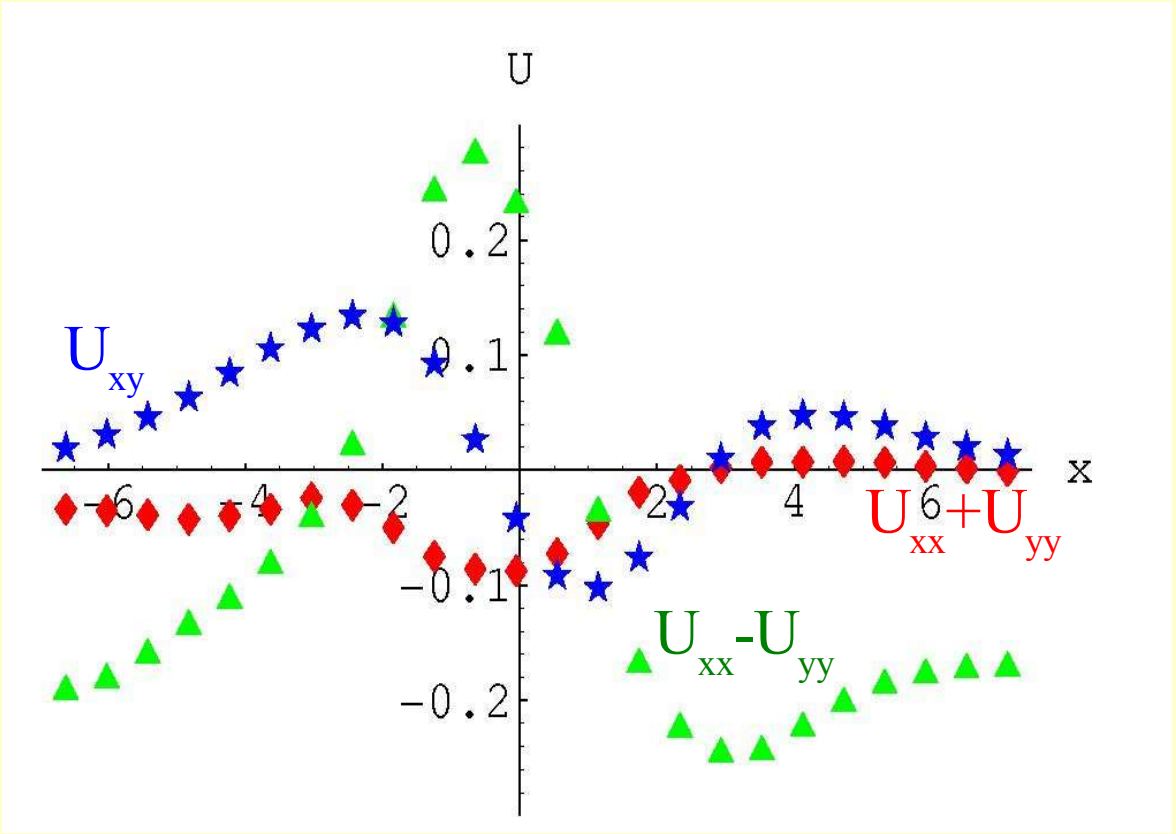
U_{xx}-U_{yy} > 0:
bubbles stretched streamwise

U_{xx}+U_{yy} > 0: expansion

LOCAL ANALYSIS: flow around a circle

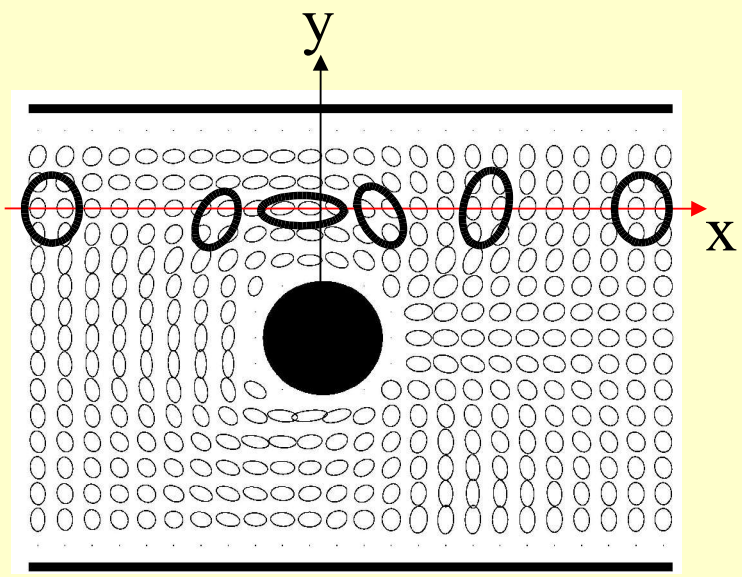
deformation on the side of the obstacle: complex and asymmetric

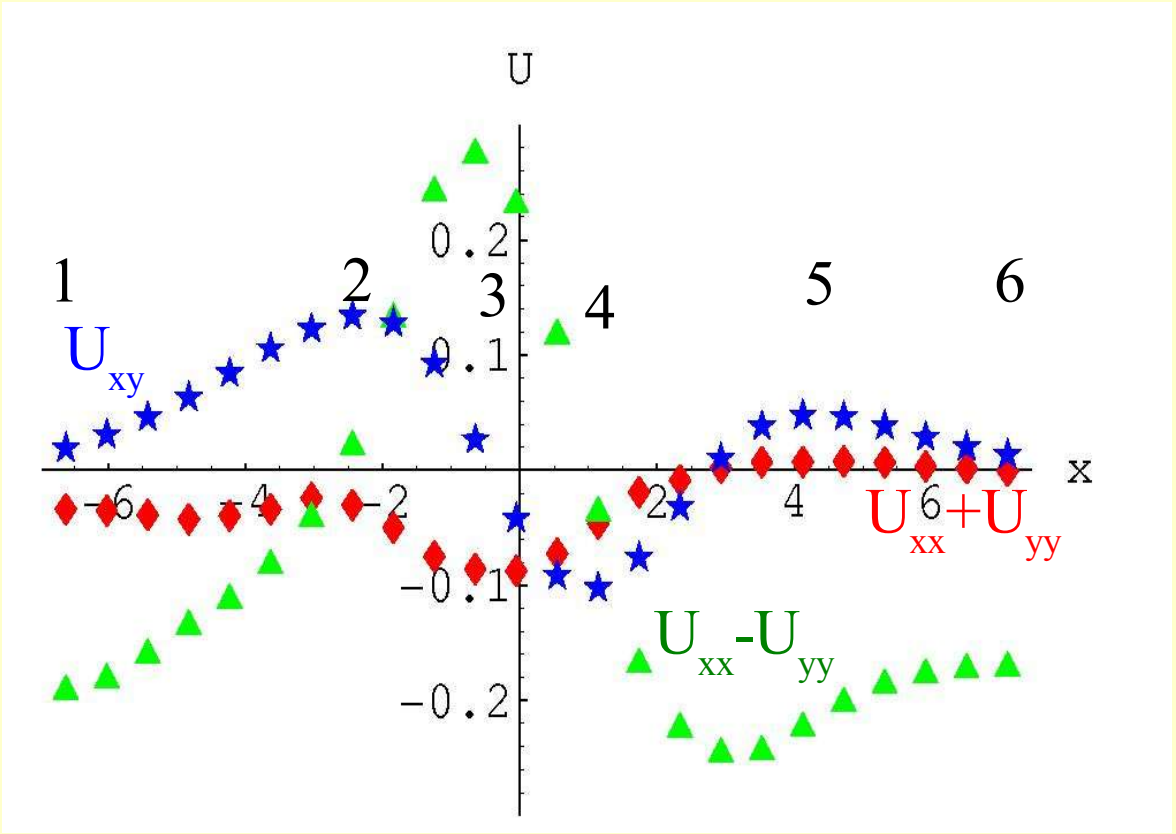




LOCAL ANALYSIS: flow around a circle

deformation on the side of the obstacle: complex and asymmetric





Velocity and deformation are quantitatively independent of the flow rate!

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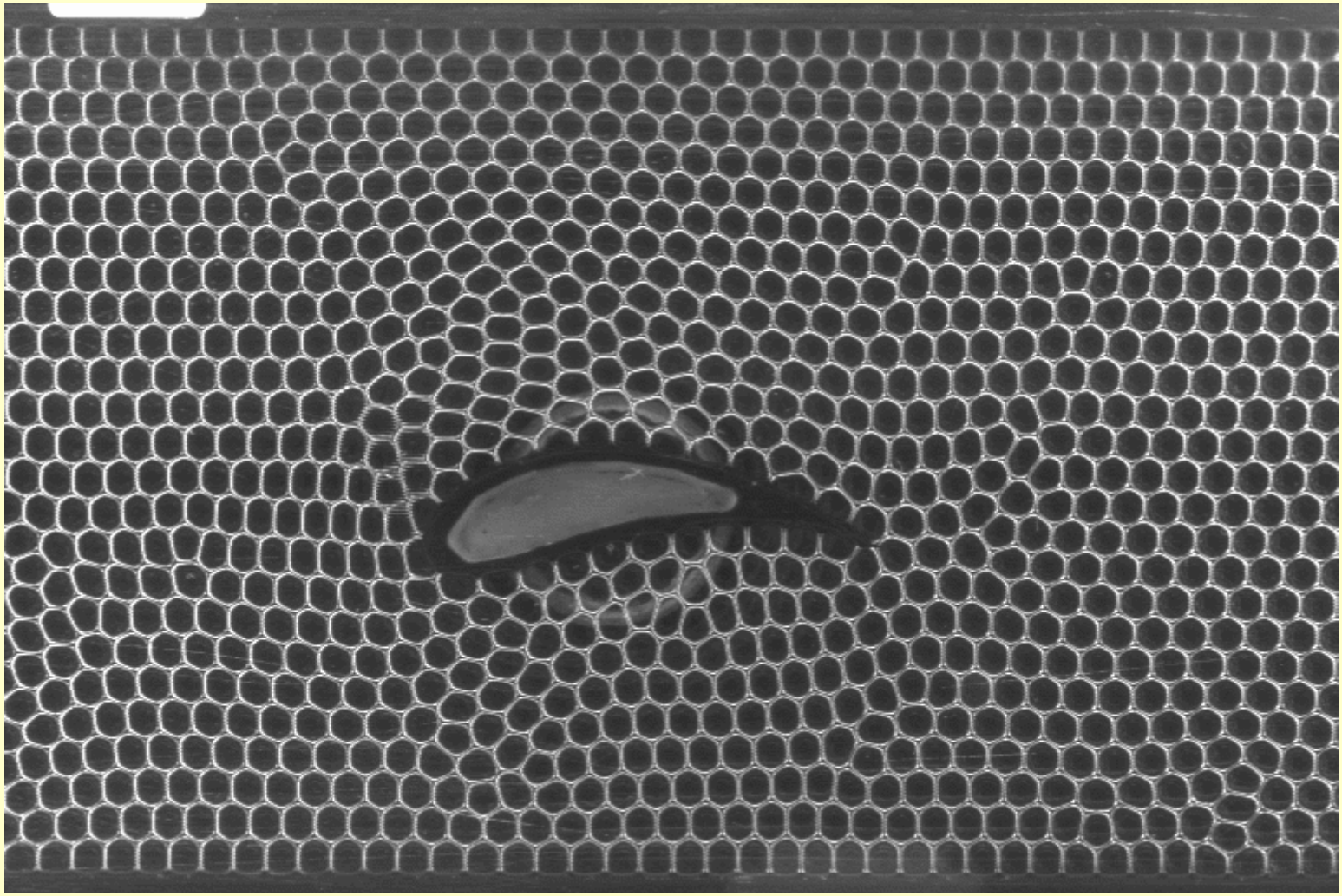
LIFT: the phenomenon

flow around a cambered airfoil

Movie airfoil

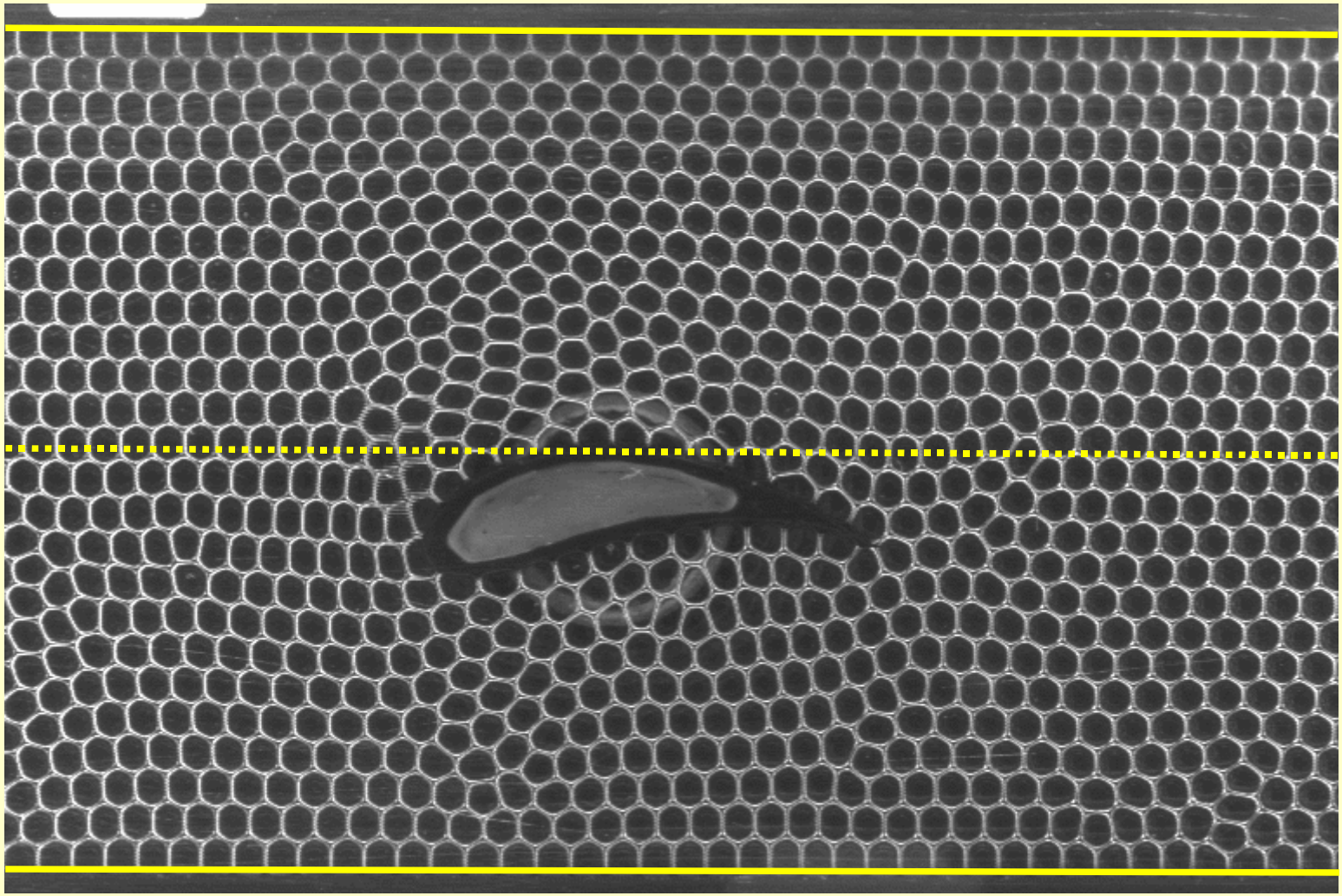


LIFT: the phenomenon

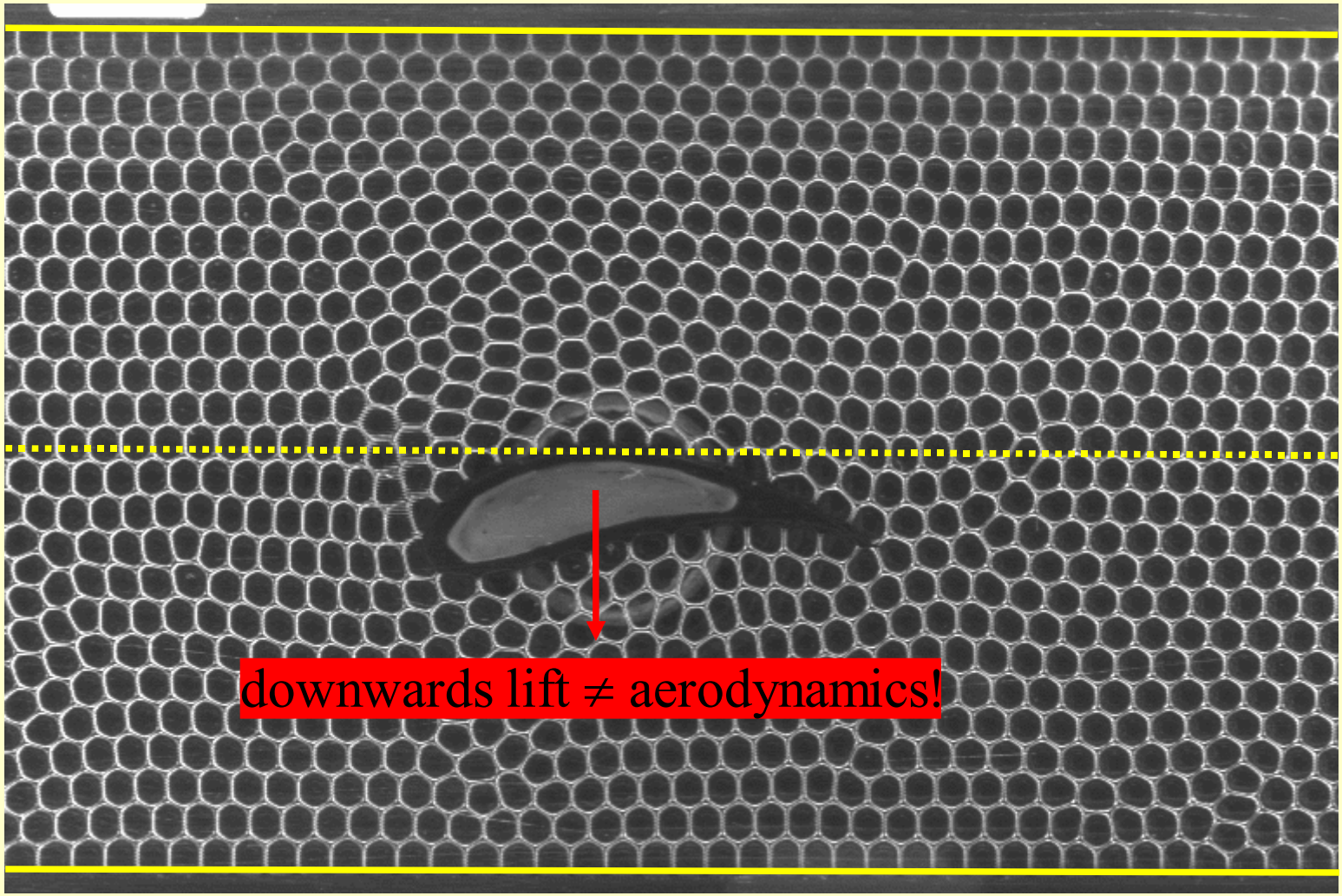
top boundary

symmetry axis:
starting position

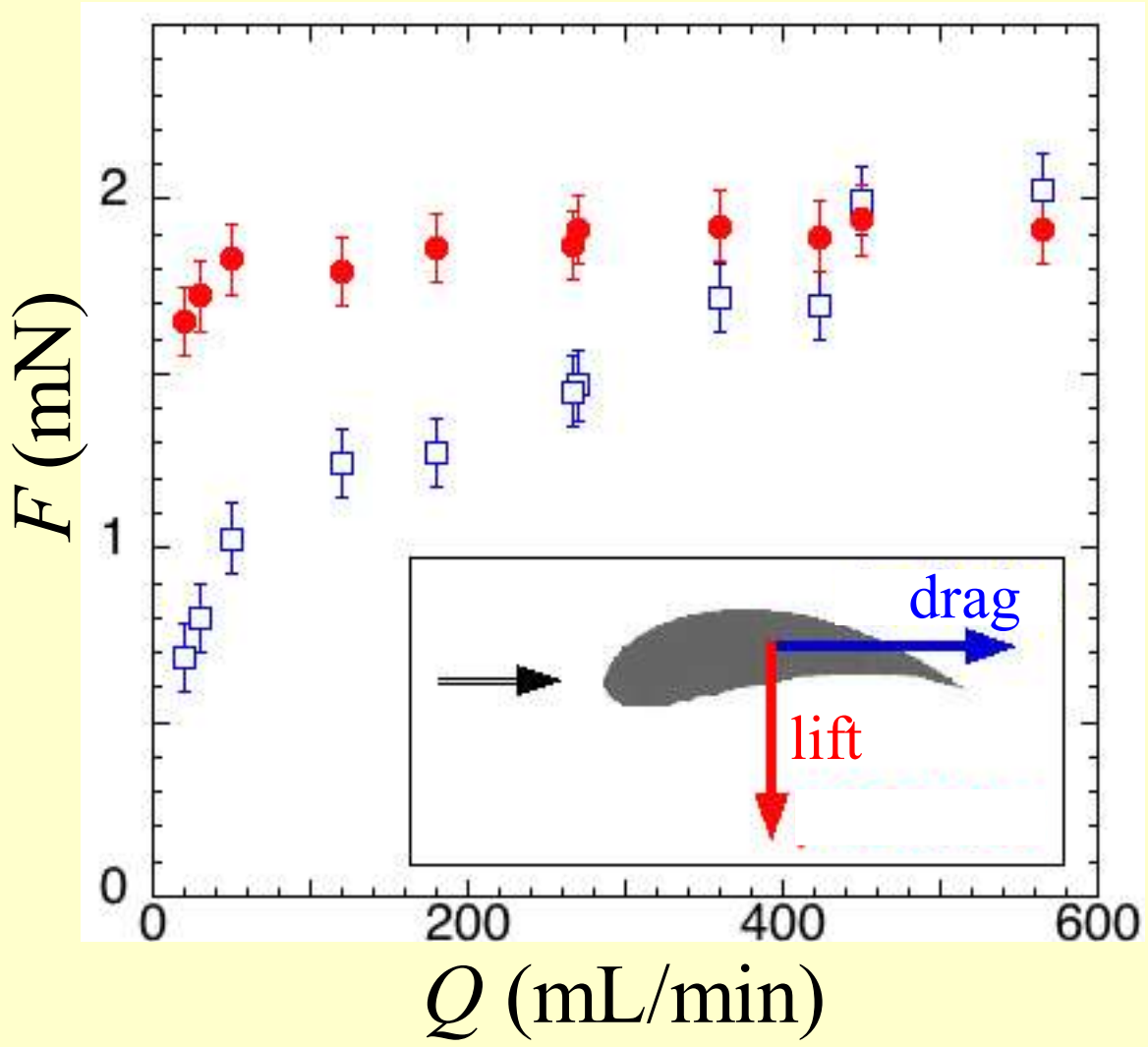
bottom boundary



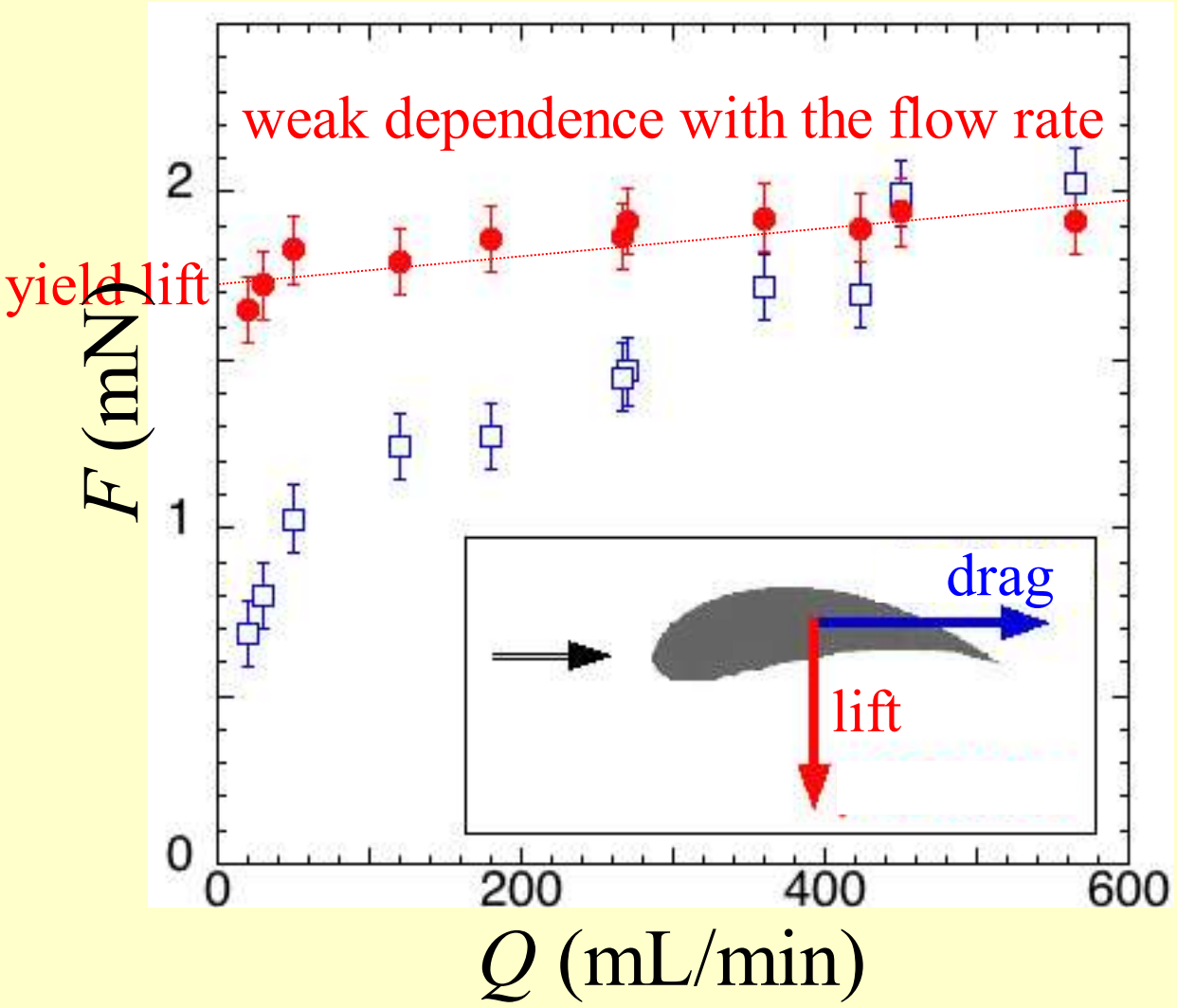
LIFT: the phenomenon



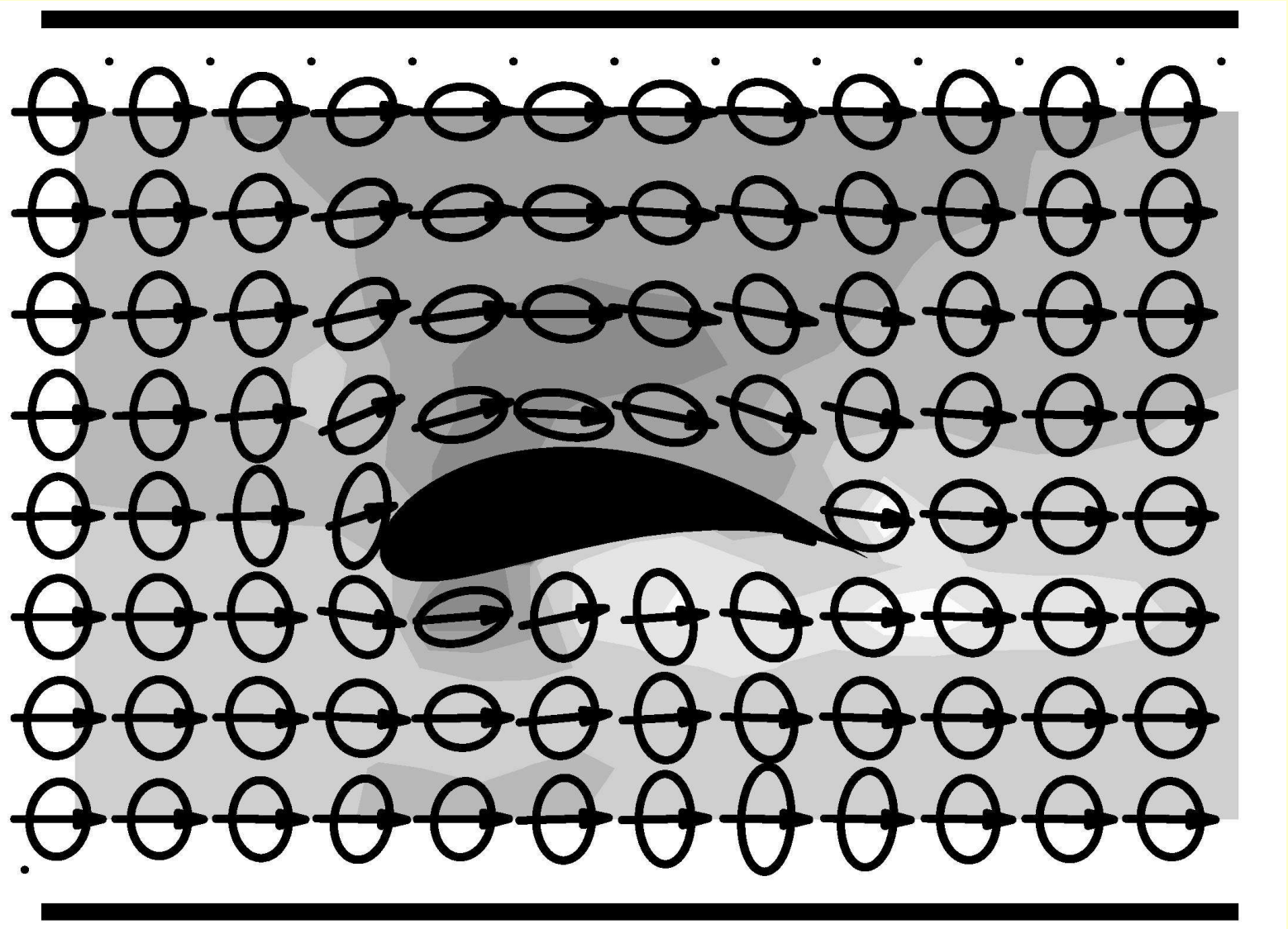
LIFT: variation with the flow rate



LIFT: variation with the flow rate

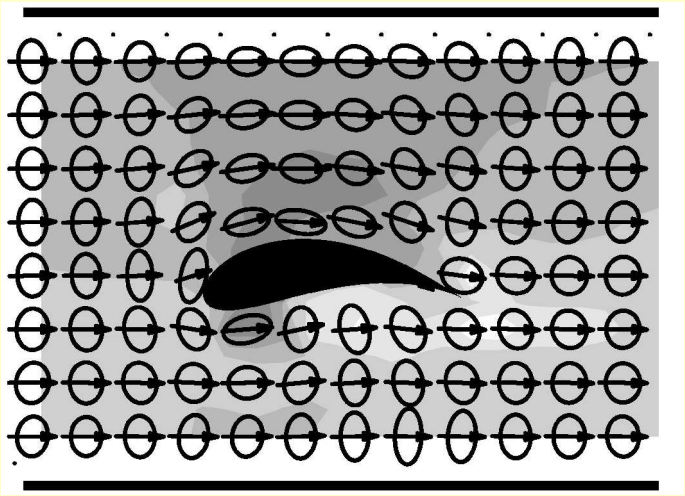


LIFT: local measurements



Bubble area: 16.0 mm²
Bulk viscosity: 1.1 mm²/s
Flow rate: 50 mL/min

LIFT: scenario



velocity

deformation

stress

force

obstacle to pass around

⇓

shear and elongation

⇓

stretching and compression

⇓

elastic stress and pressure

⇓

downwards lift

scenario qualitatively independent on the distance from the walls

Dollet, Aubouy & Graner, submitted, cond-mat/0411632

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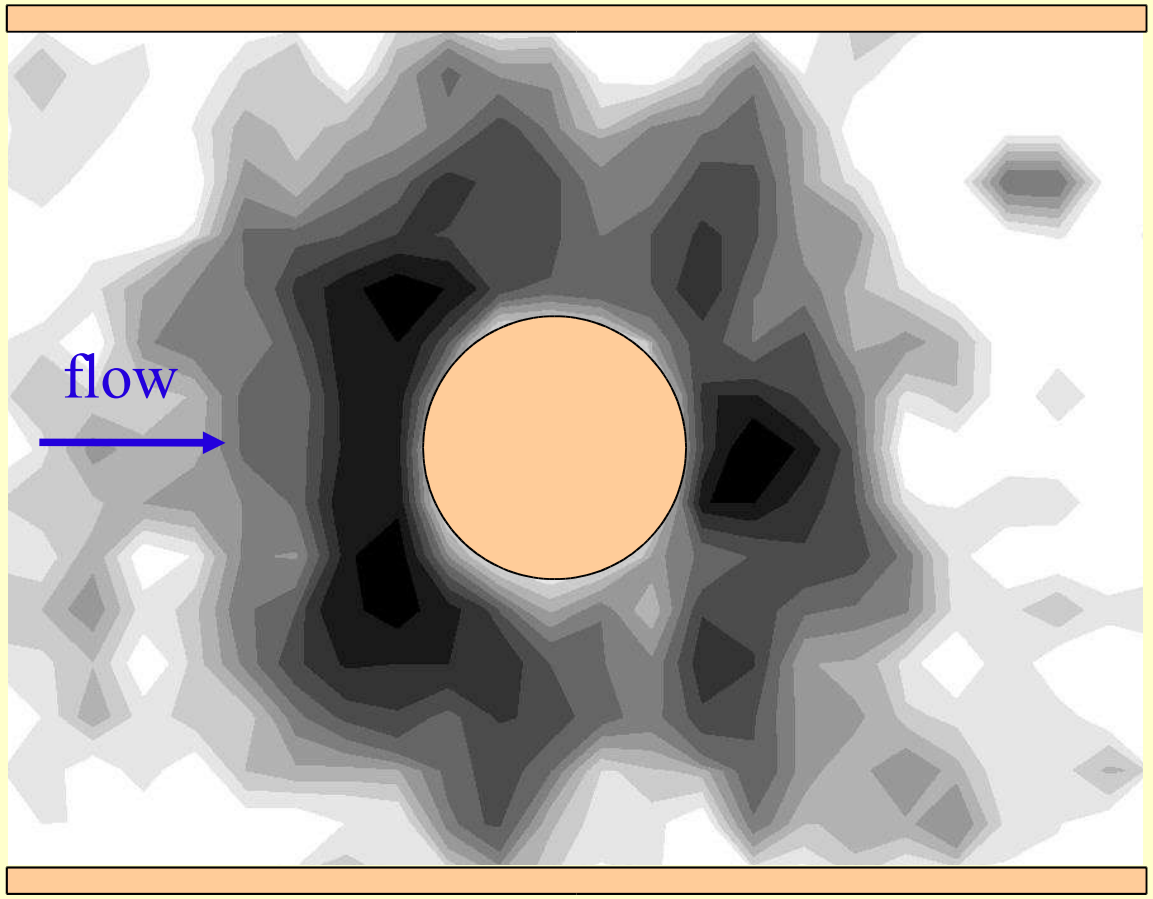
T1s: spatial distribution



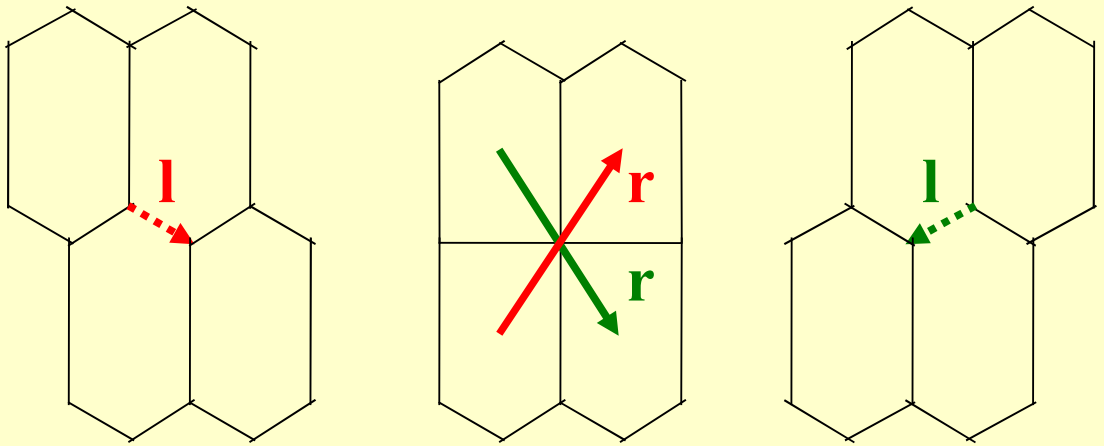
asymmetry up/downstream

like in 3D Stokes experiments [Cantat, Pitois, in preparation]

can we go further?

T1s: local tensorial description

T1: not only the localization, but also the direction, is relevant



description of the direction:

singular on the bubble edges **l**

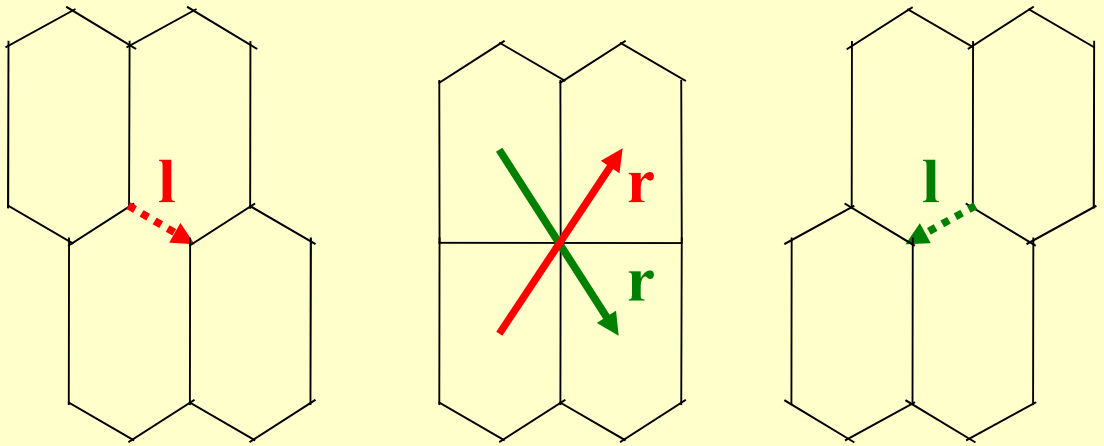
regular on the vectors **r** linking detaching/attaching bubbles

orientation of **r** irrelevant:

tensor $r_i r_j$ or $\hat{r}_i \hat{r}_j$ $\quad (\hat{r} = \vec{r}/r)$

T1s: global tensorial description

T1: not only the localization, but also the direction, is relevant



Definition: attaching tensor $T^a_{ij} = N_a \langle \hat{r}_i \hat{r}_j \rangle_a$

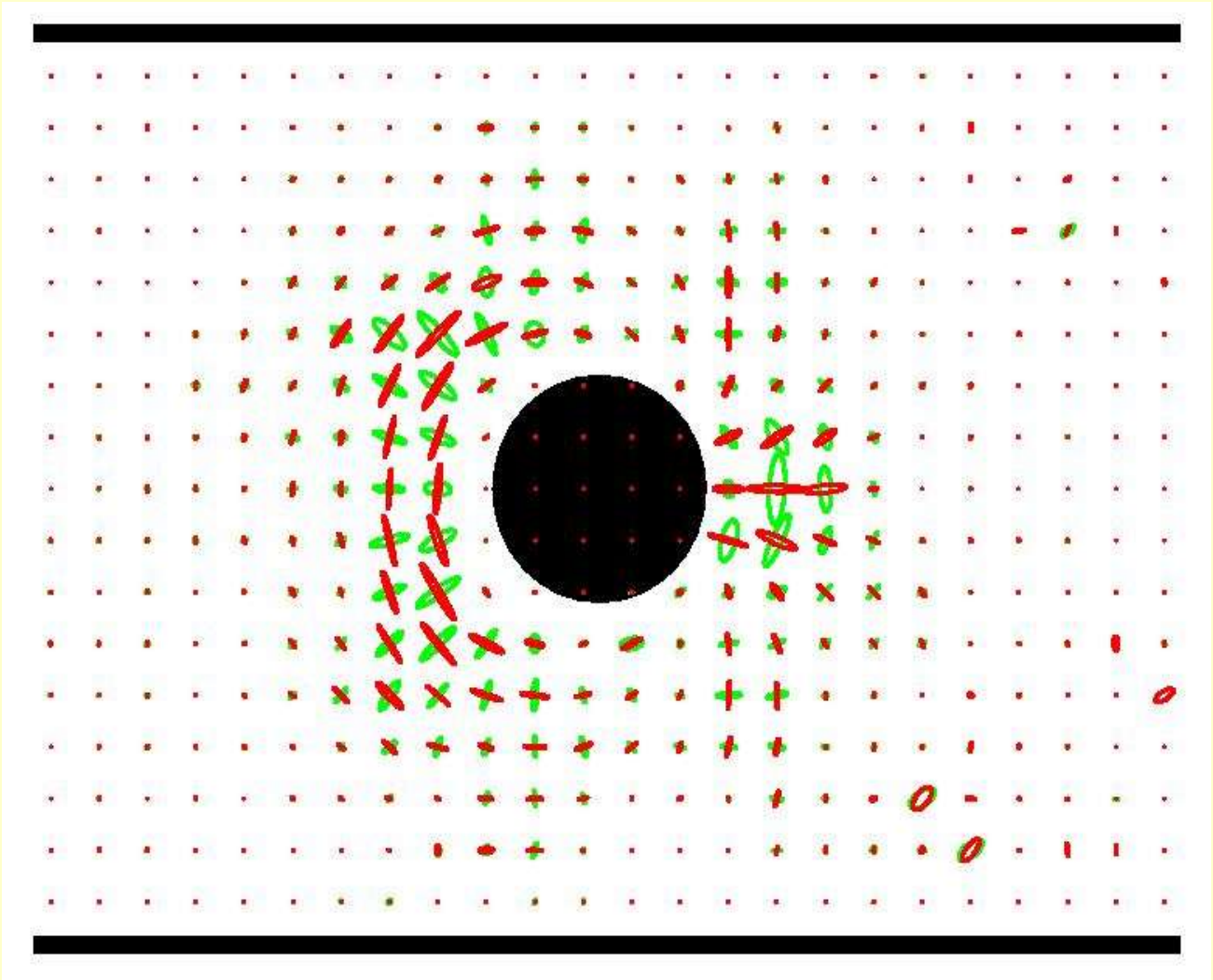
number of attaching events

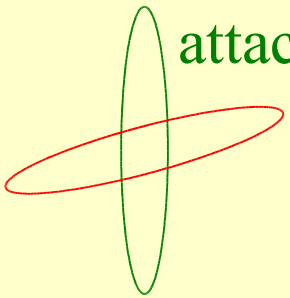
average over attaching events in a box

same definition for the detaching tensor T^d_{ij} , and T1 tensor $T_{ij} = T^a_{ij} - T^d_{ij}$

for a T1, $N_a = N_d$

T1s: representation

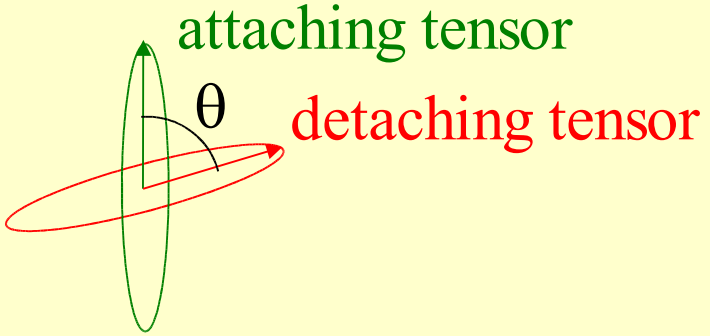


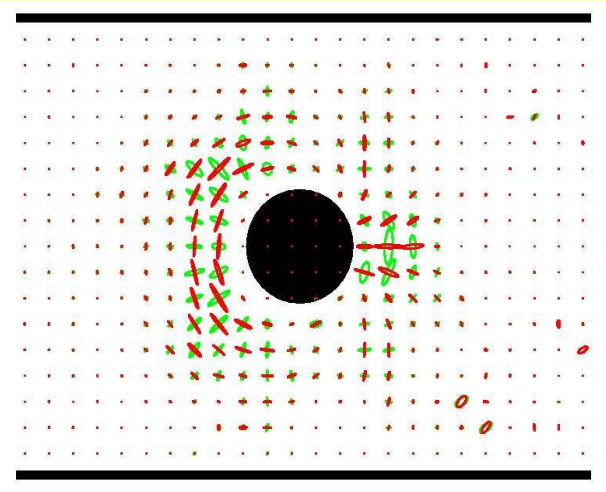


attaching tensor

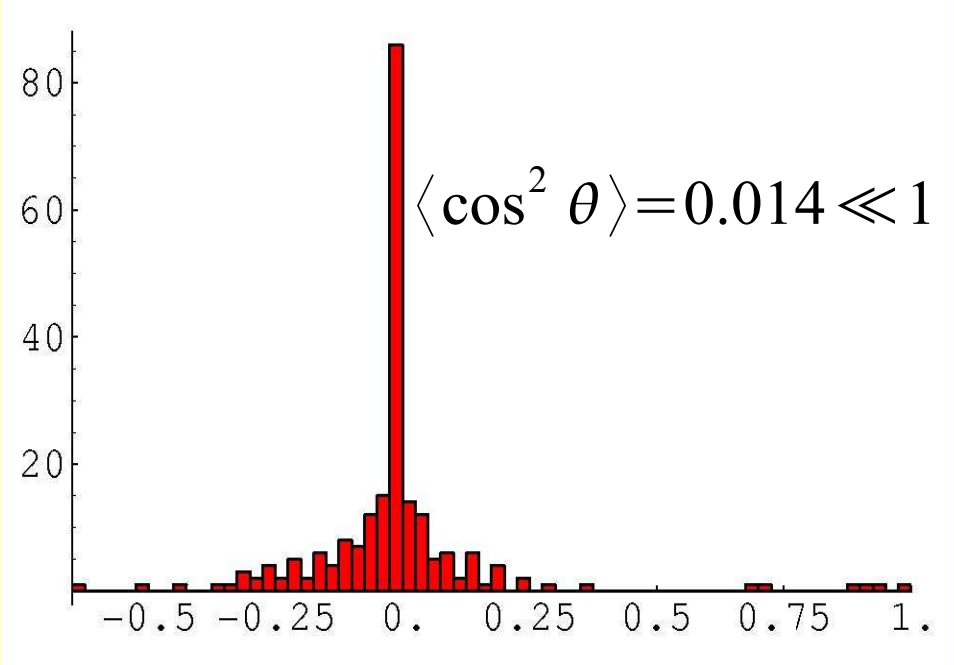
detaching tensor

T1s: orthogonality



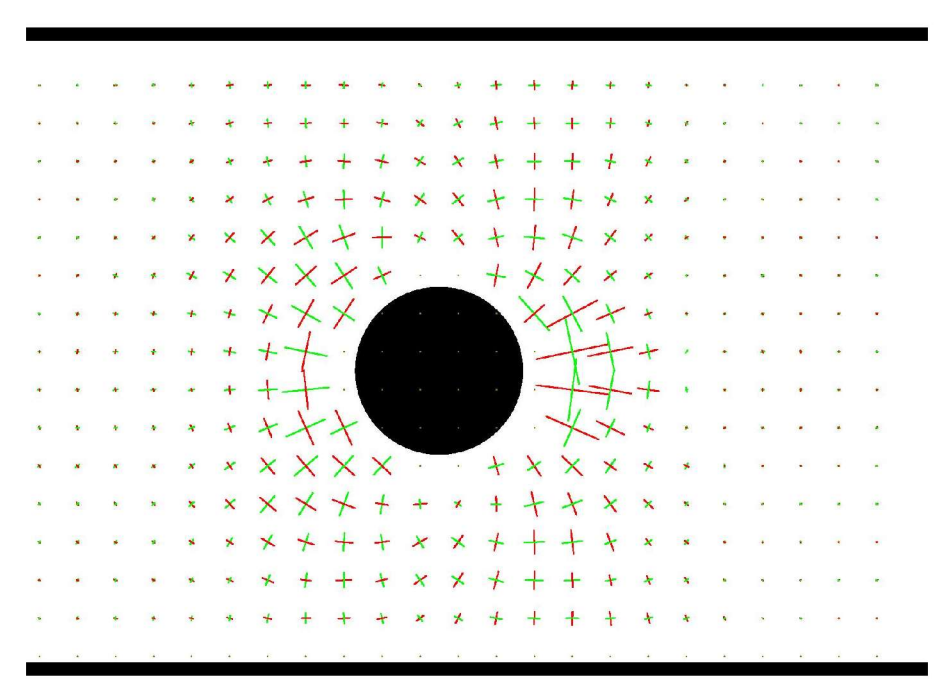


Histogram of $\langle \cos\theta \rangle$ box per box:

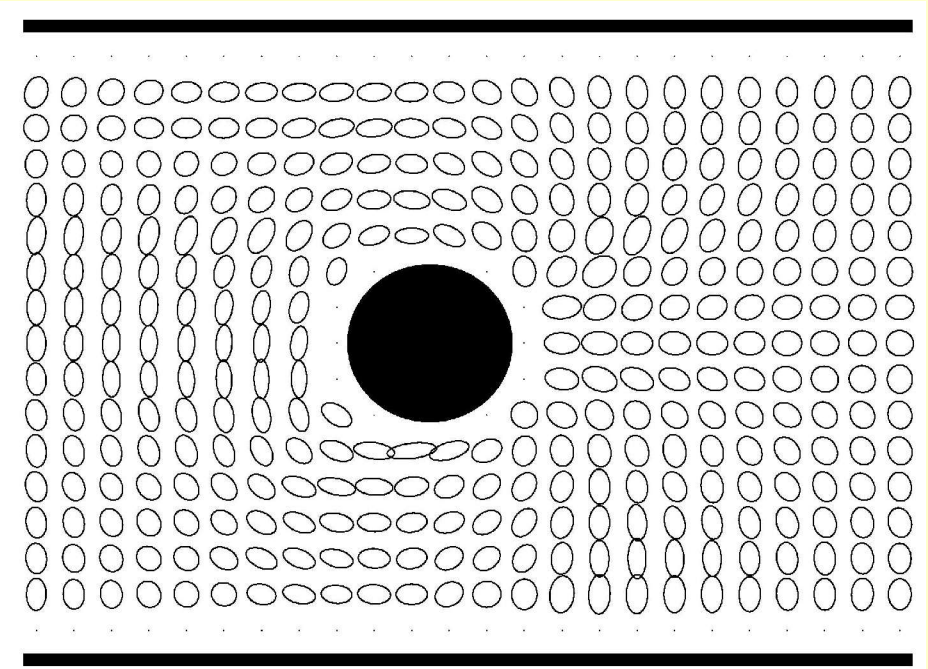


The directions of attachment and detachment are in average orthogonal

T1s: coupling with bubble deformation and flow

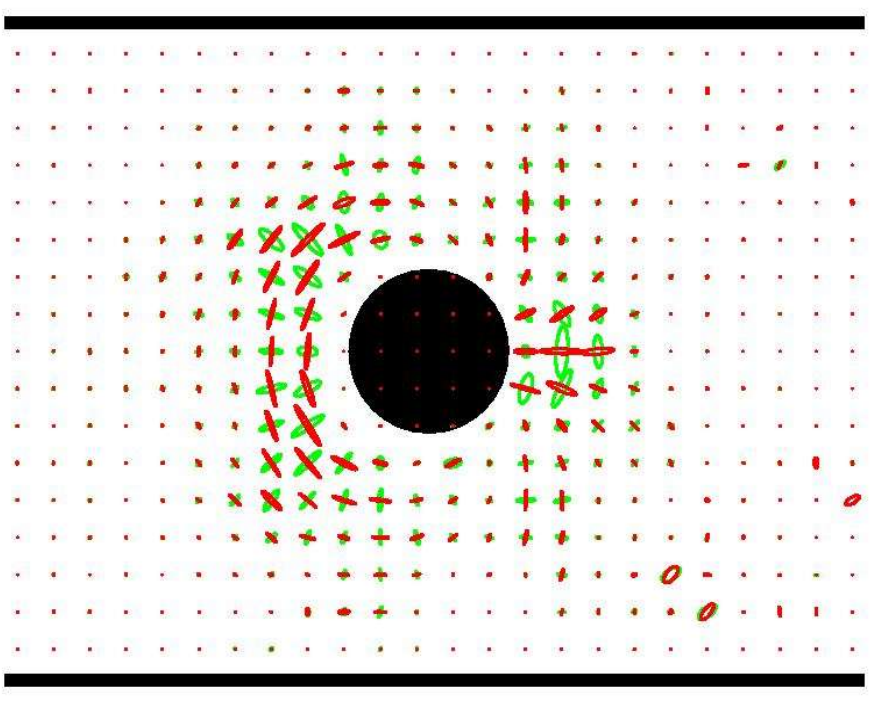


deformation rate

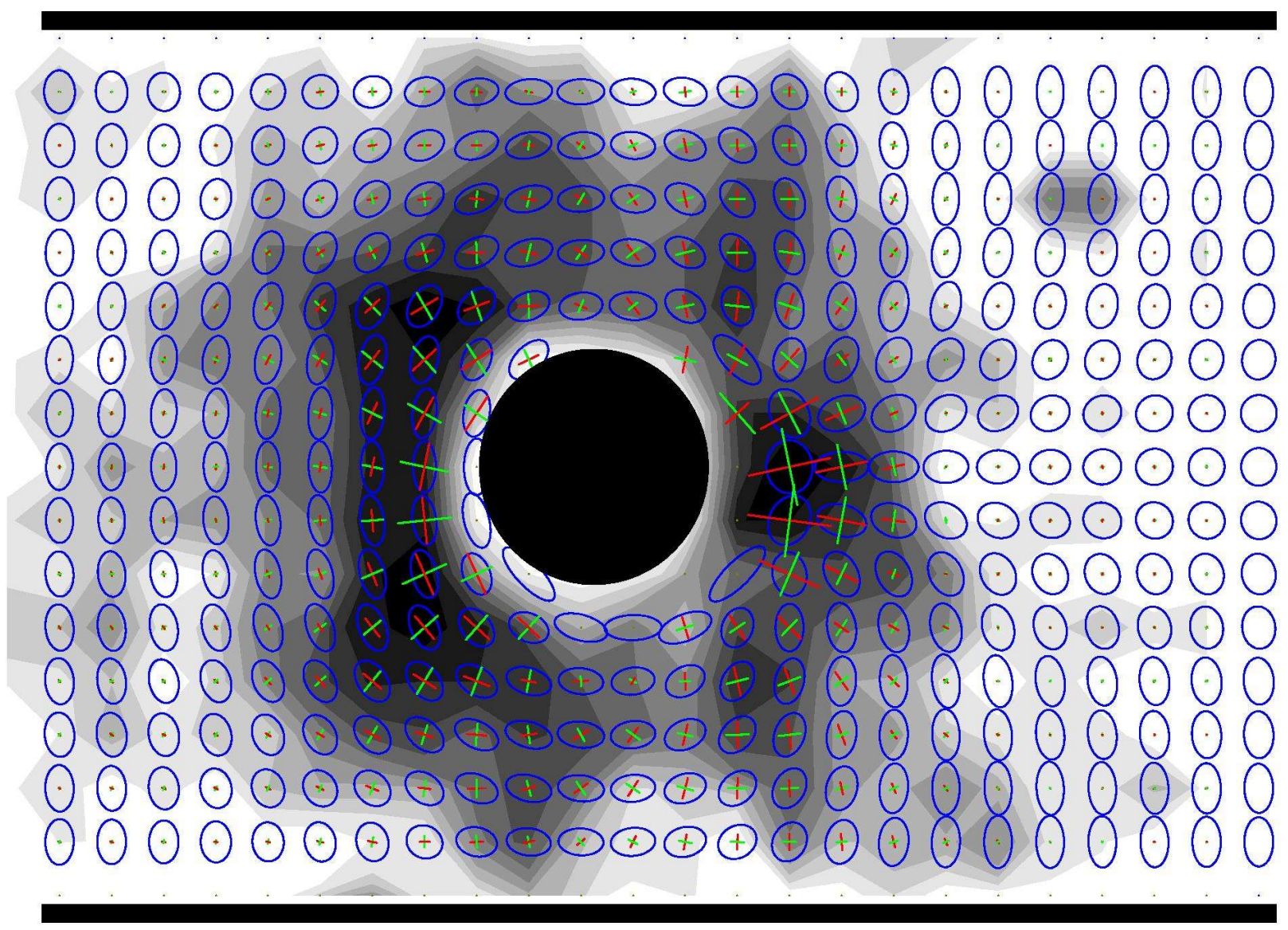


bubble deformation

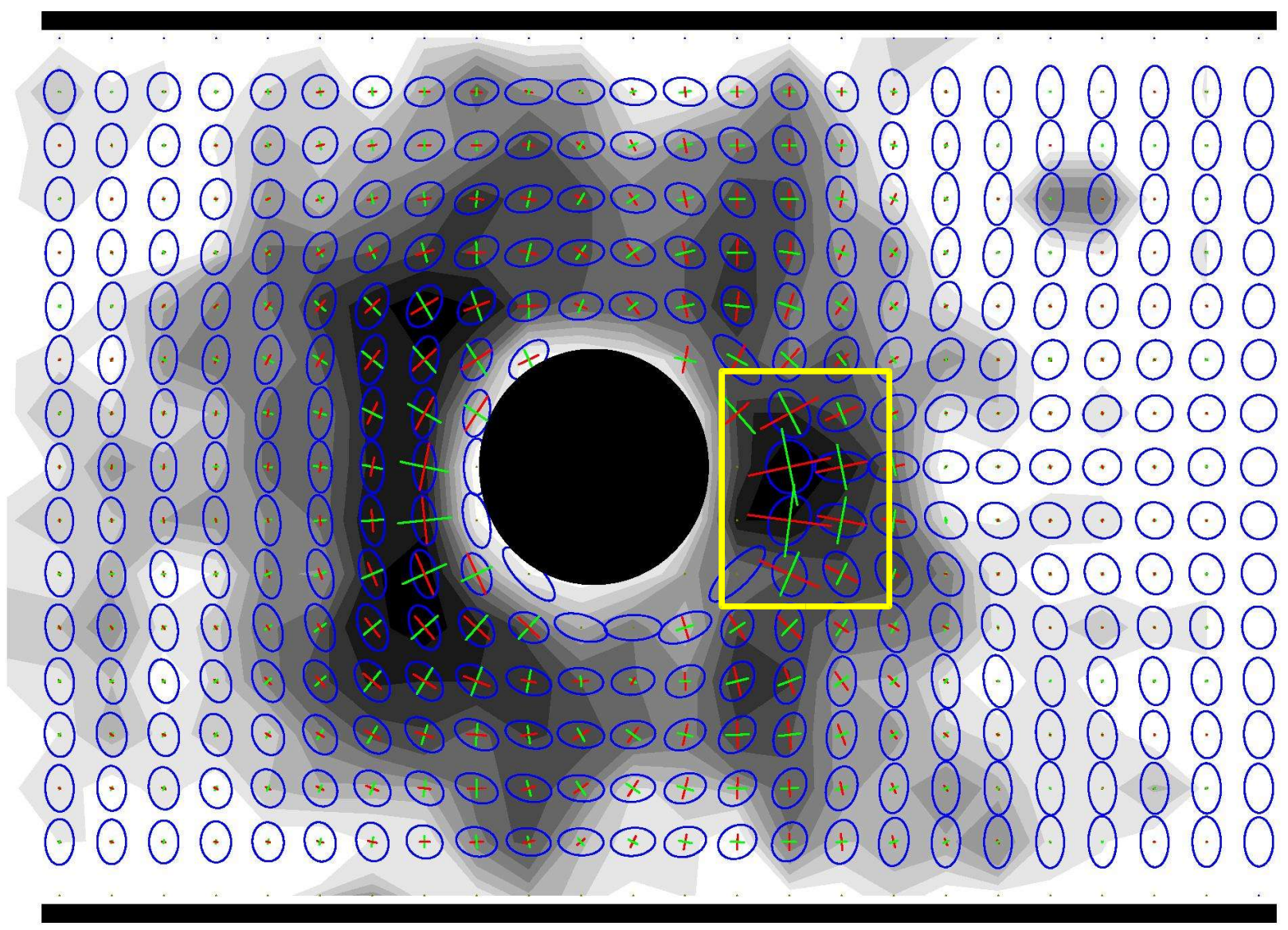
T1s



T1s: coupling with bubble deformation and flow

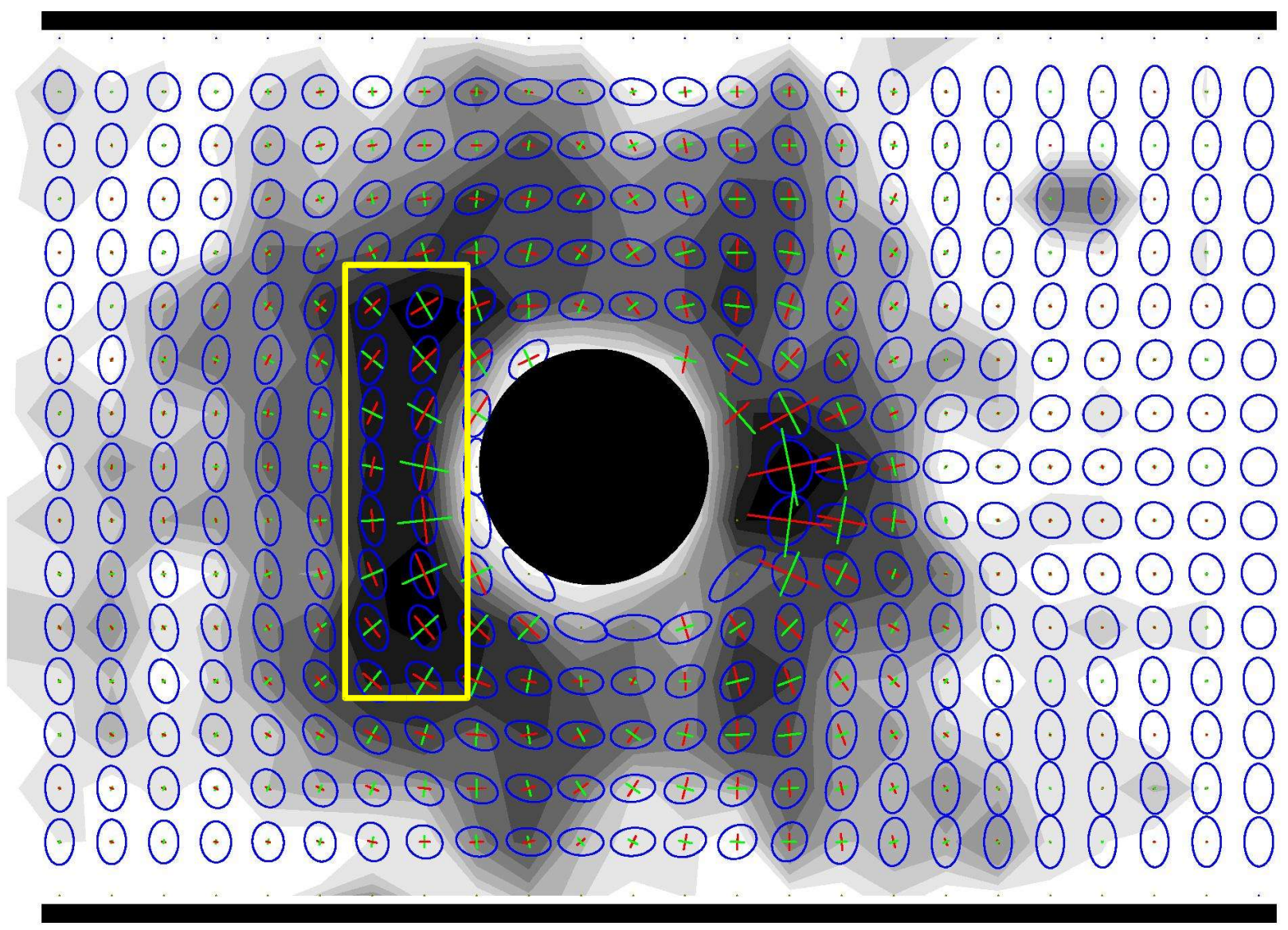


T1s: coupling with bubble deformation and flow



T1s occur when the velocity gradients are high

T1s: coupling with bubble deformation and flow



T1s occur when the velocity gradients are high

or when deformation and velocity gradient are in the same sense

CONCLUSION

Foam flow around an obstacle: a rich experiment

global measurements: forces

elasticity: yield drag

fluidity: drag increase with velocity, pressure gradient

local analysis: detailed description of the flow

elasticity: statistical deformation

plasticity: T1 tensorial descriptor

fluidity: velocity, velocity gradients

perspectives:

to quantify the correlations between T1s, deformation and velocity gradients

intrinsic vs. external dissipation

Ph. D thesis, to be defended Sept. 16, 2005