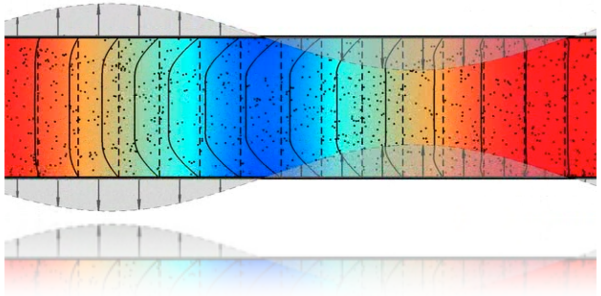
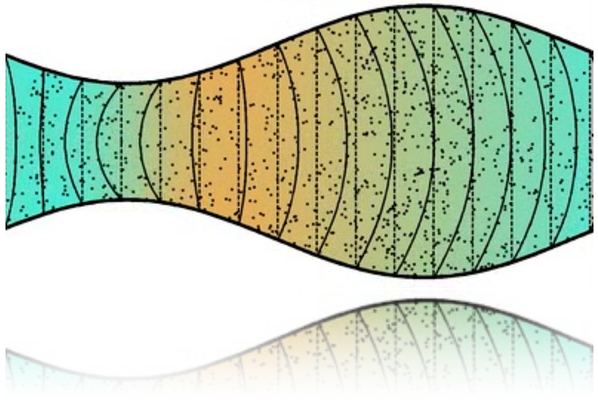
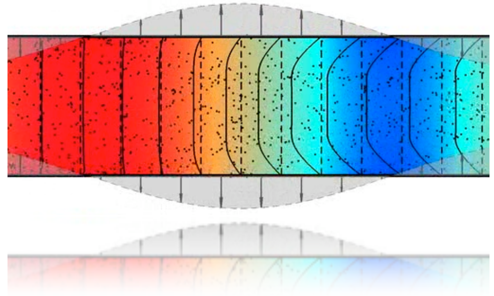




Pumping from the walls

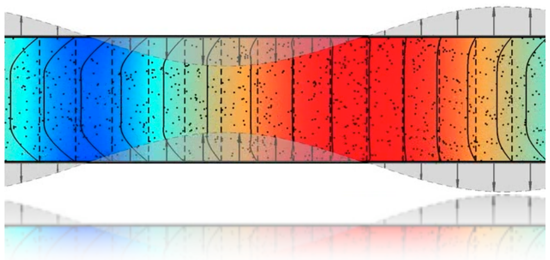
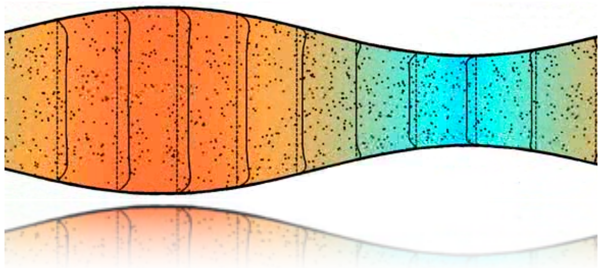
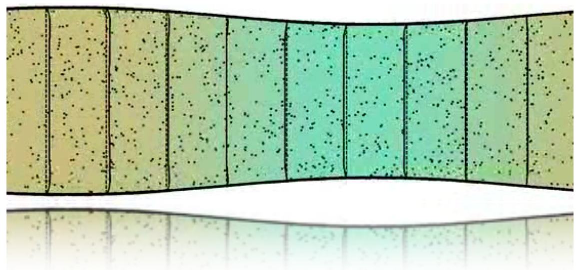
“La distinction des mécanismes”

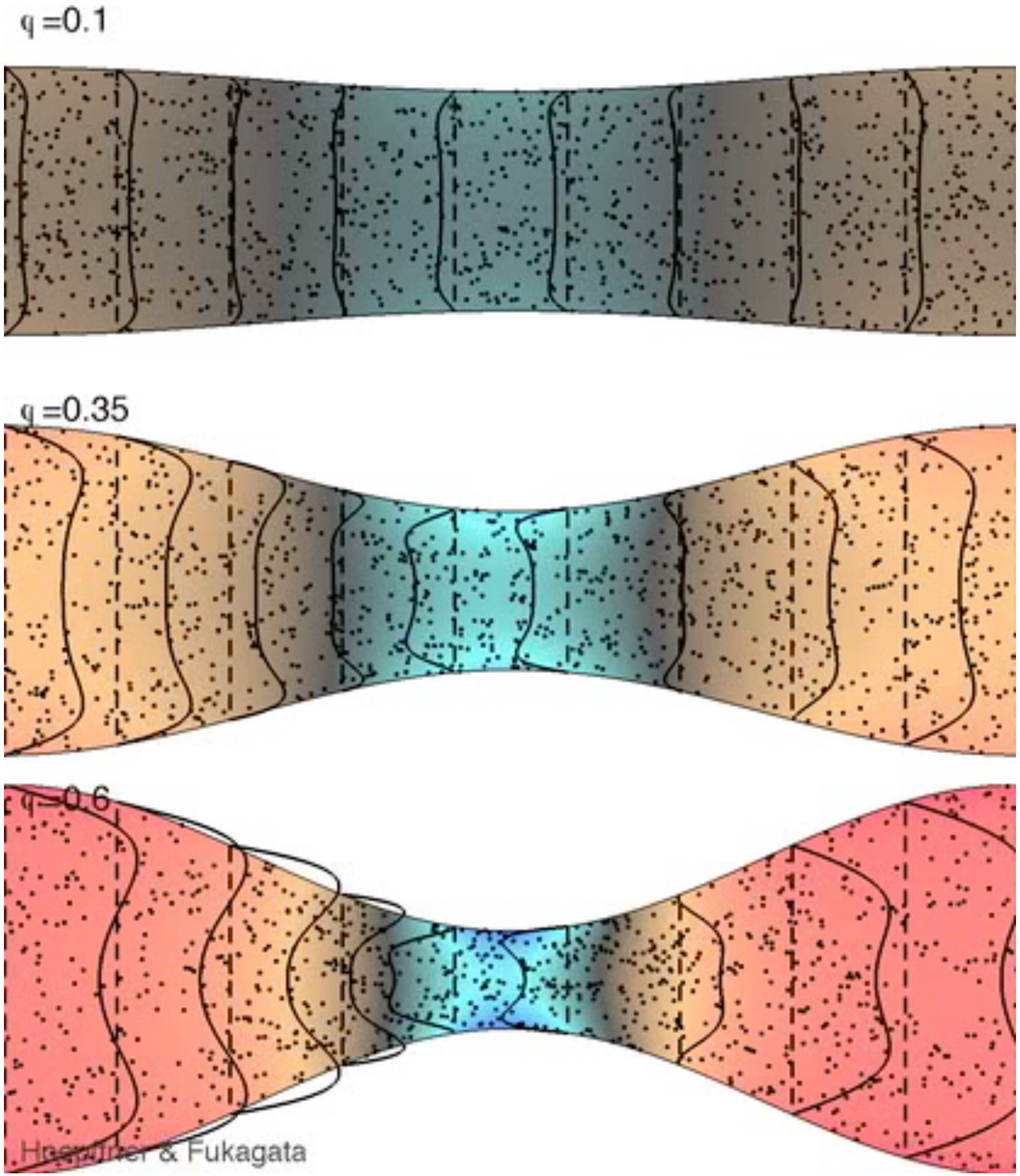
Jérôme Hœpffner

Koji Fukagata

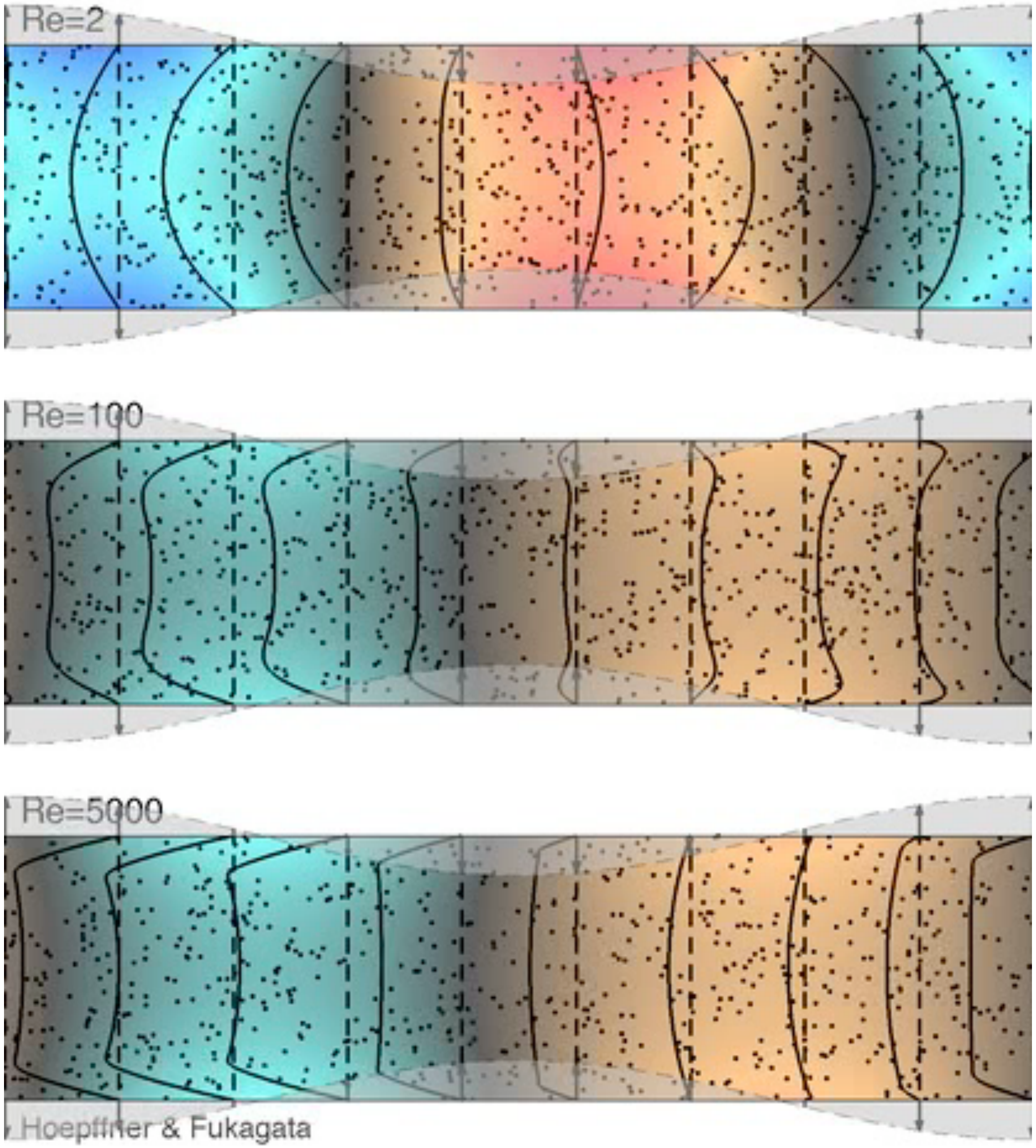
Keio University, Yokohama, Japan.

Institut Jean le Rond D’Alembert, Paris, France.

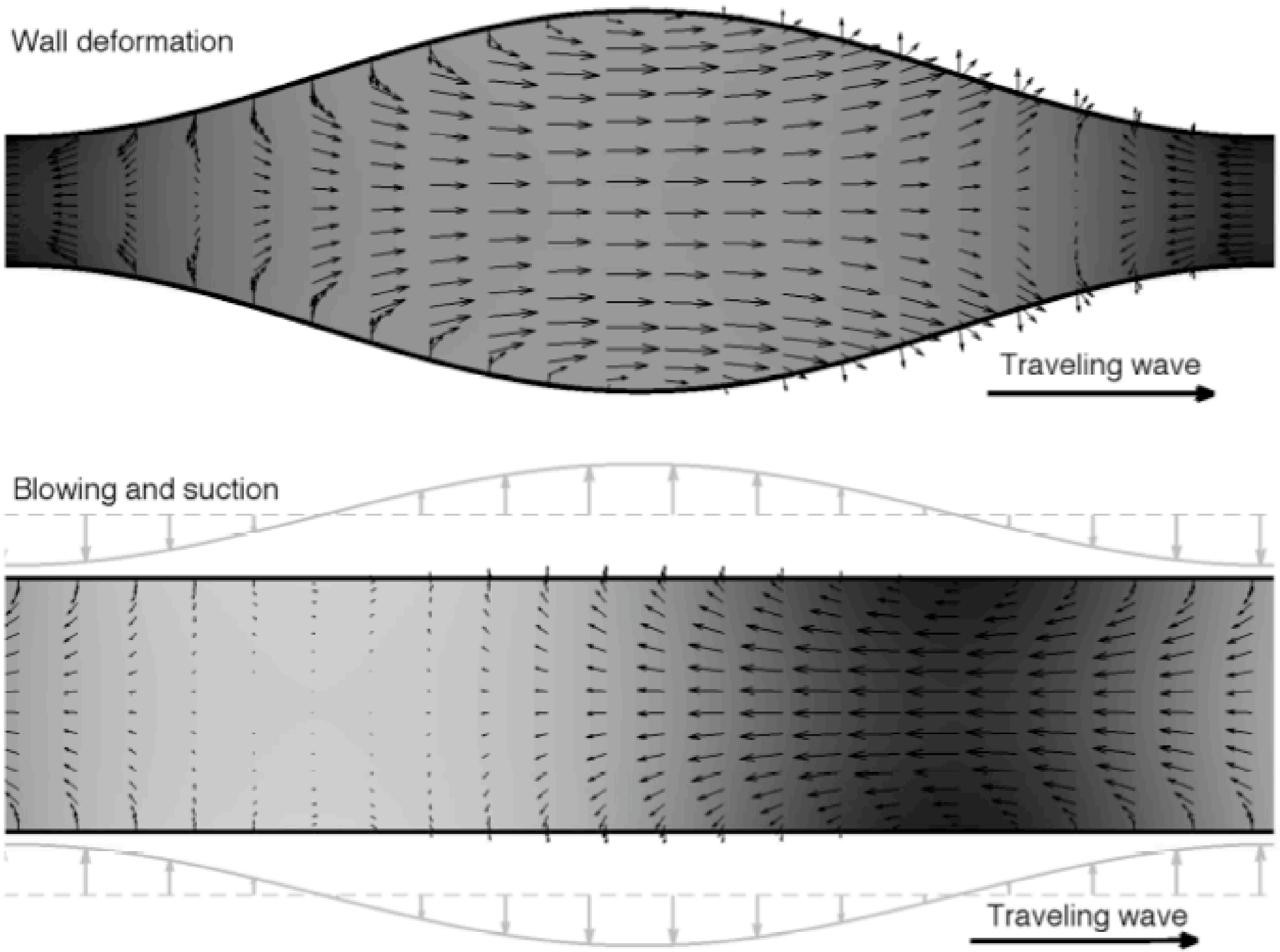




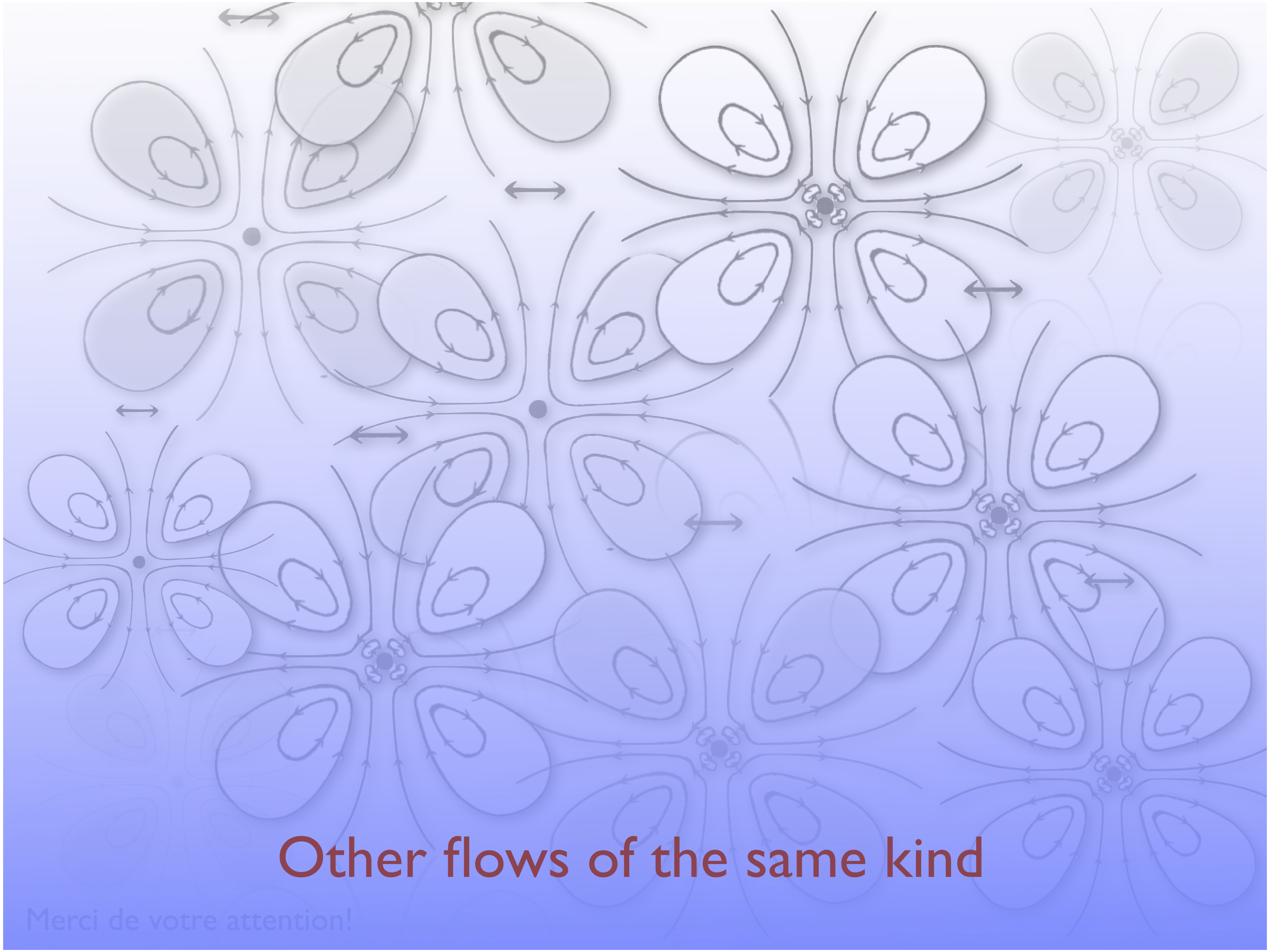


q =0.1
q =0.35
q =0.6
Hoepffner & Fukagata


Re=2
Re=100
Re=5000
Hoepffner & Fukagata

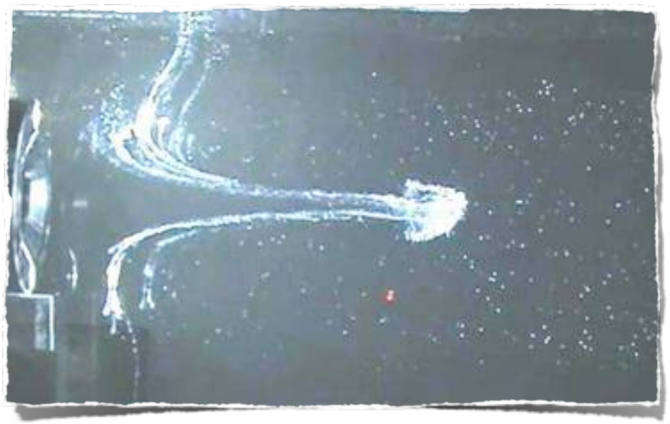
Pumping in two directions





Other flows of the same kind

“Quartz wind”

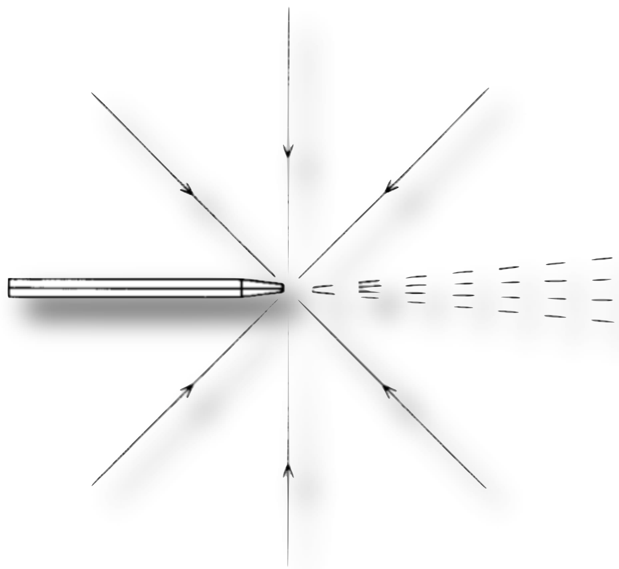


Jet generated by an ultrasonic beam

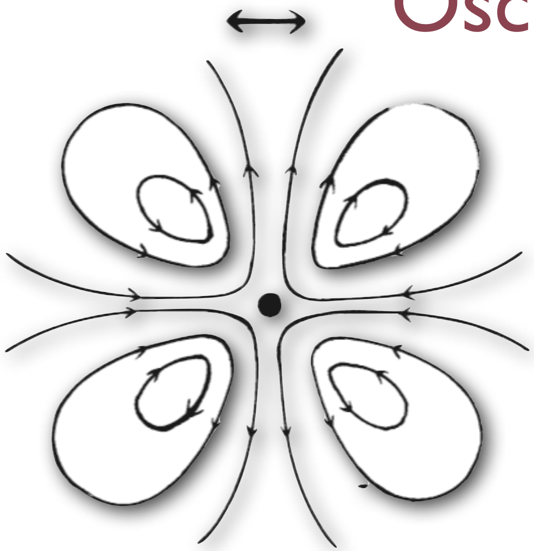
http://www.lmfa.ec-lyon.fr/perso/Valery.Botton/acoustic_streaming_bis.html

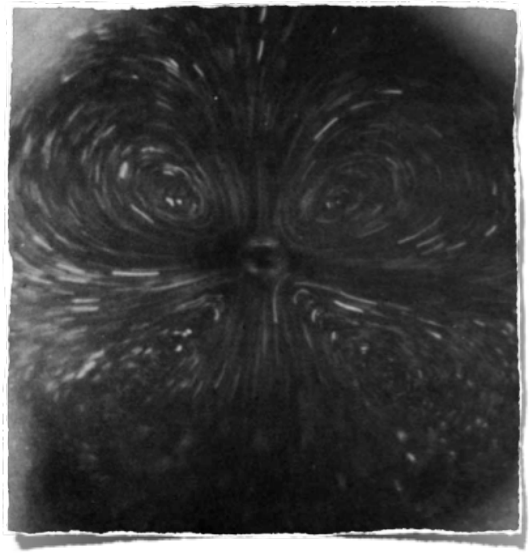
Journal of Sound and Vibration (1978) **61**(3), 391–418
ACOUSTIC STREAMING†

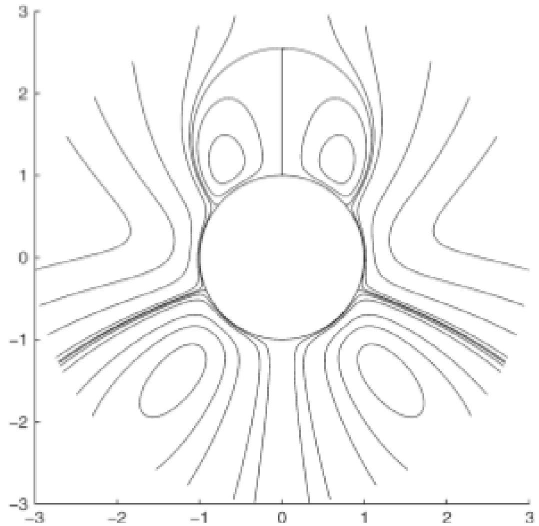
SIR JAMES LIGHTHILL



Oscillating cylinder







STEADY STREAMING AROUND A SPHERICAL DROP DISPLACED FROM THE VELOCITY ANTINODE IN AN ACOUSTIC LEVITATION FIELD

by A. Y. REDNIKOV, HONG ZHAO, S. S. SADHAL[†]

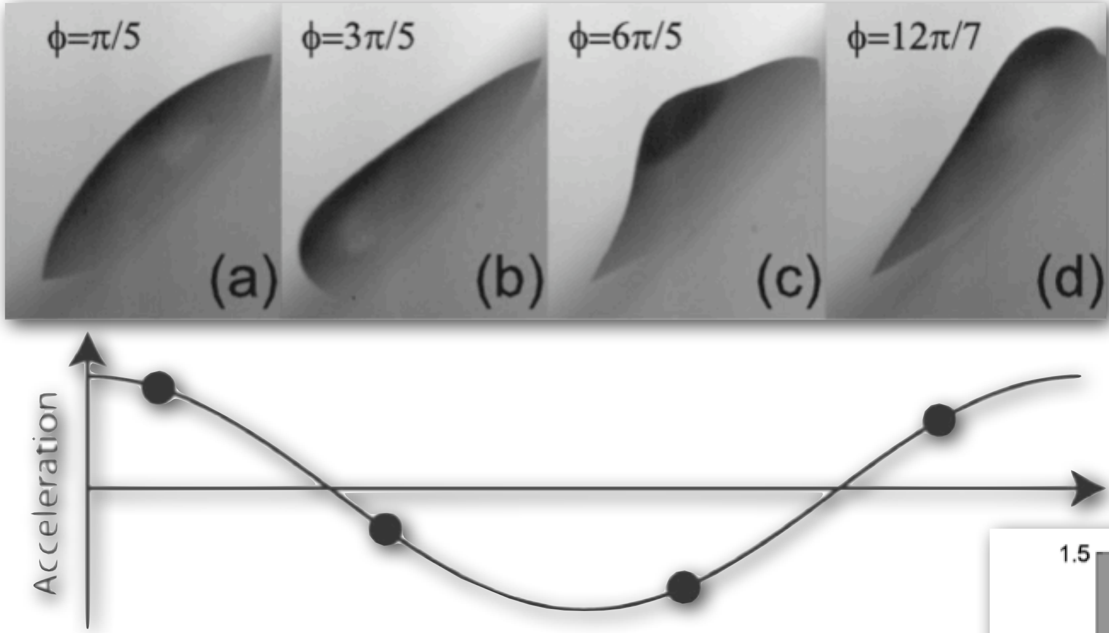
Flow near an oscillating cylinder in dilute viscoelastic fluid

THERE are many natural phenomena in which nonlinear interactions of time-dependent inputs give rise to steady—that is, time-independent outputs. One of these is a steady streaming belonging to a class of secondary flows sometimes called acoustic streaming. It occurs when a circular cylinder oscillates normal to its axis in an unbounded Newtonian fluid[1-3]. We report here on the steady secondary flow induced when a long thin cylinder oscillates as described in a viscoelastic liquid. We found that the direction of steady streaming is opposite to that found for the bulk of fluid when the experiment is performed with a Newtonian fluid.

CHINGFENG CHANG
W. R. SCHOWALTER

Nature Vol. 252 December 20/27 1974

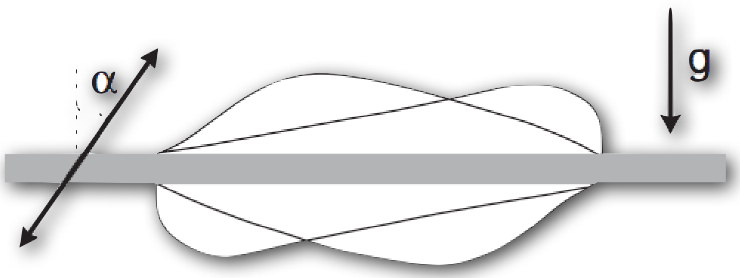
Climbing drop

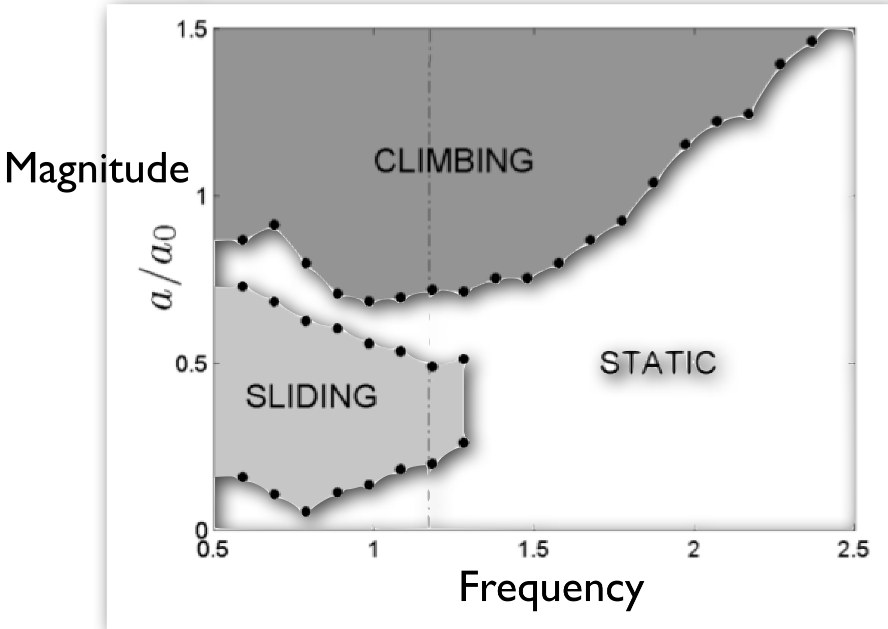


Vibration-Induced Climbing of Drops

P. Brunet,* J. Eggers, and R. D. Deegan

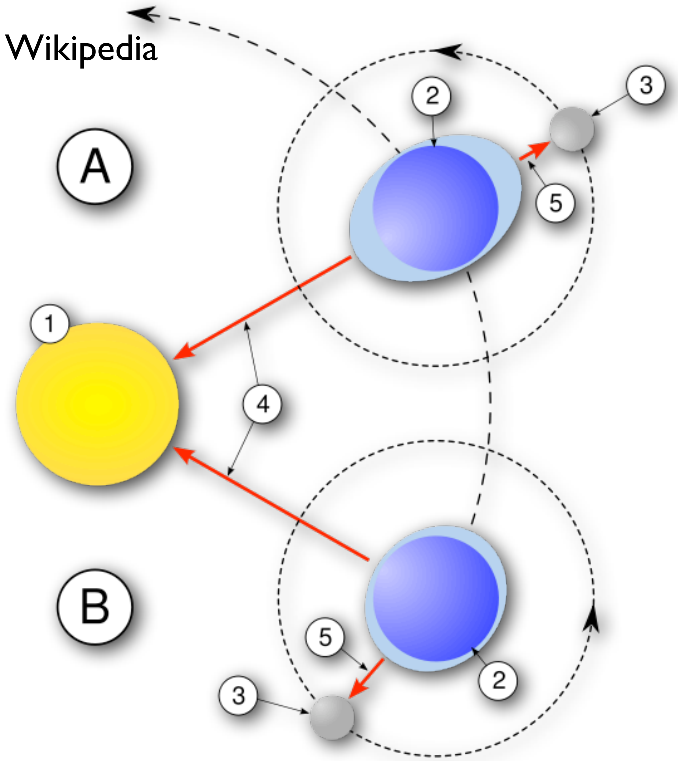
PRL **99,** 144501 (2007)



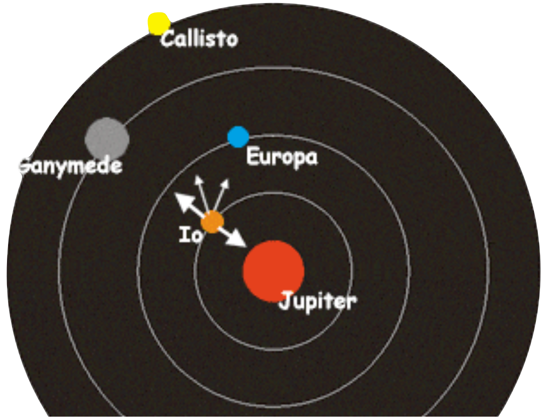


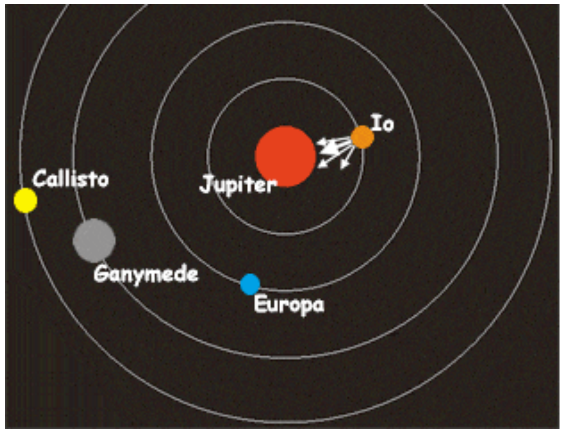
Tidal forcing

Wikipedia



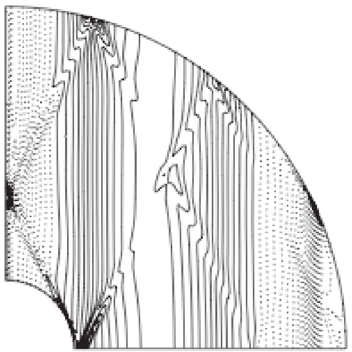
Io: satellite of Jupiter





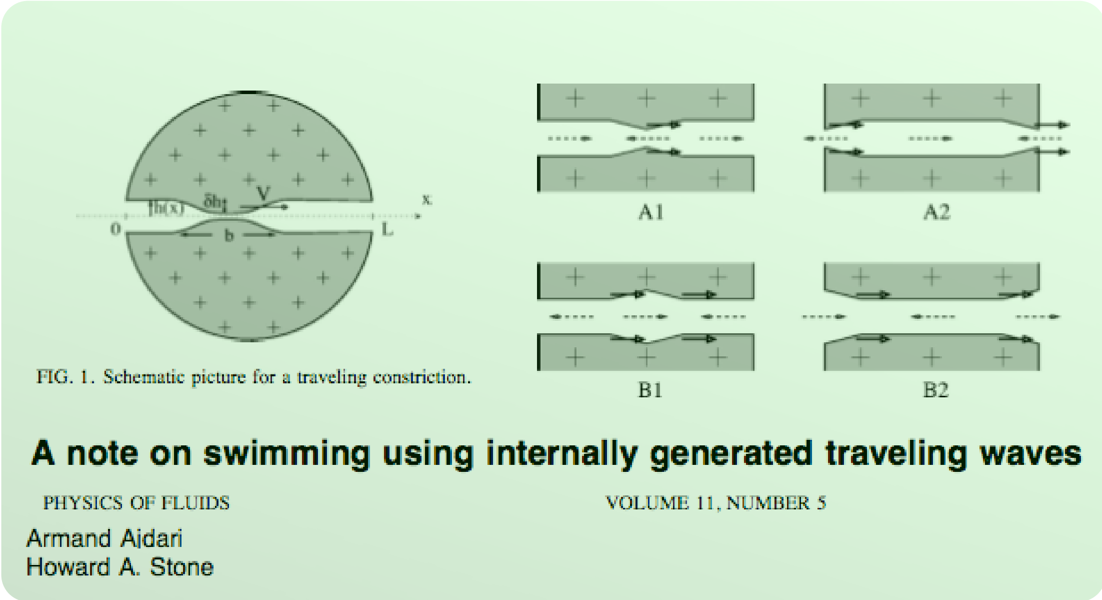
Zonal Wind Driven by Inertial Modes

A. Tilgner
PRL **99**, 194501 (2007)



http://spaceplace.nasa.gov/en/kids/gll_io_fact.shtml

Life



Microorganisms

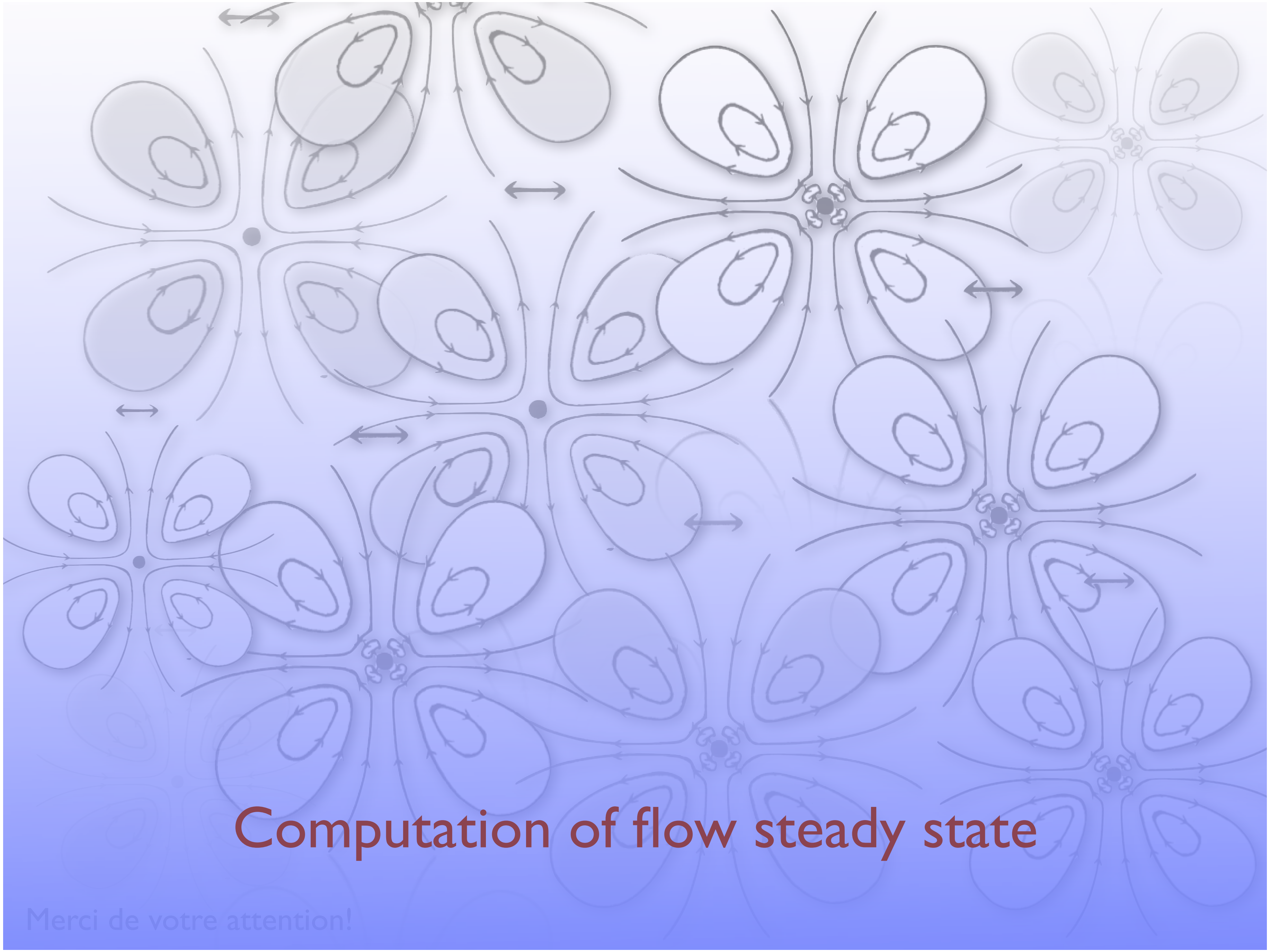
Image: youtube

Gatsro-intestinal tract

Pumping in the gastro-intestinal tract, and in the ureter

Industry

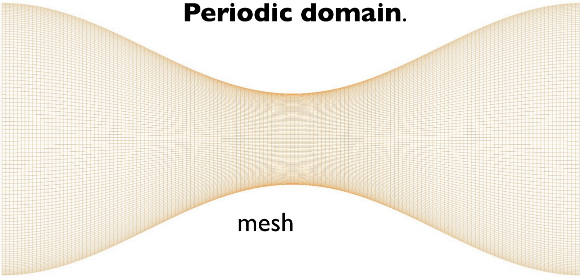
Computation of flow steady state

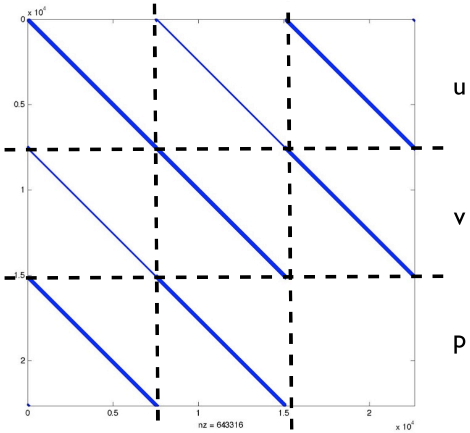


Tools: steady state

1) Nonlinear: steady state

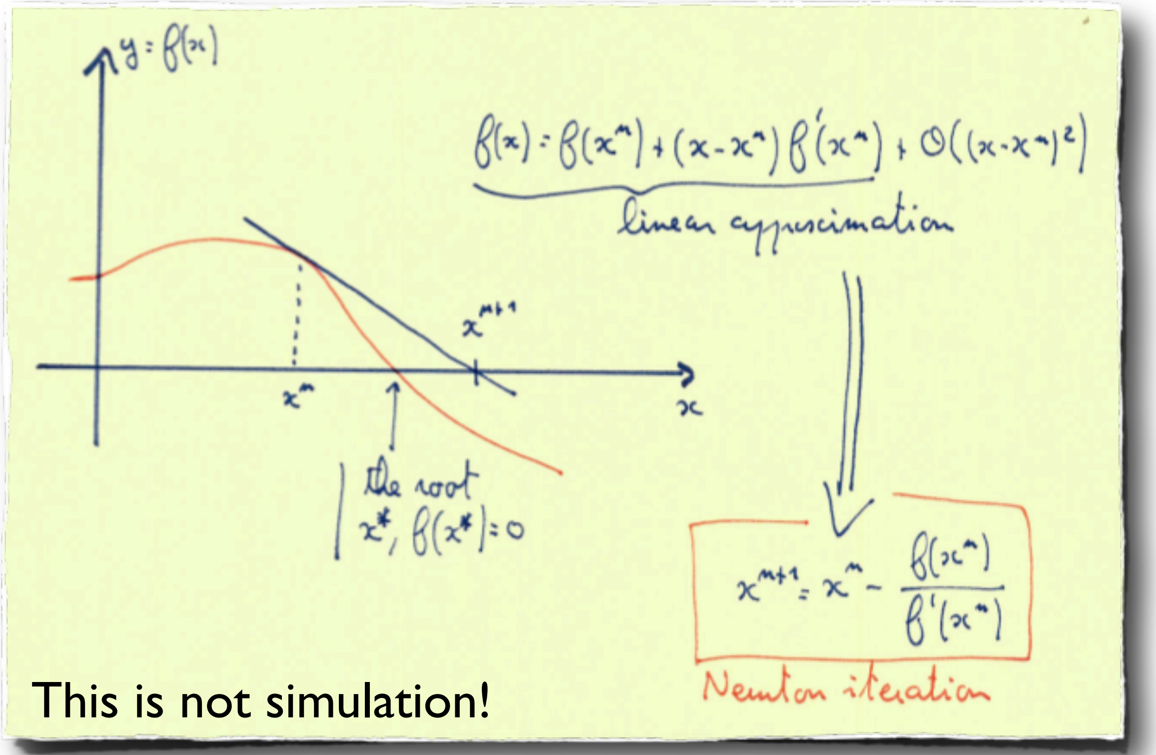
Flow is steady in frame travelling with the wave.
Periodic domain.

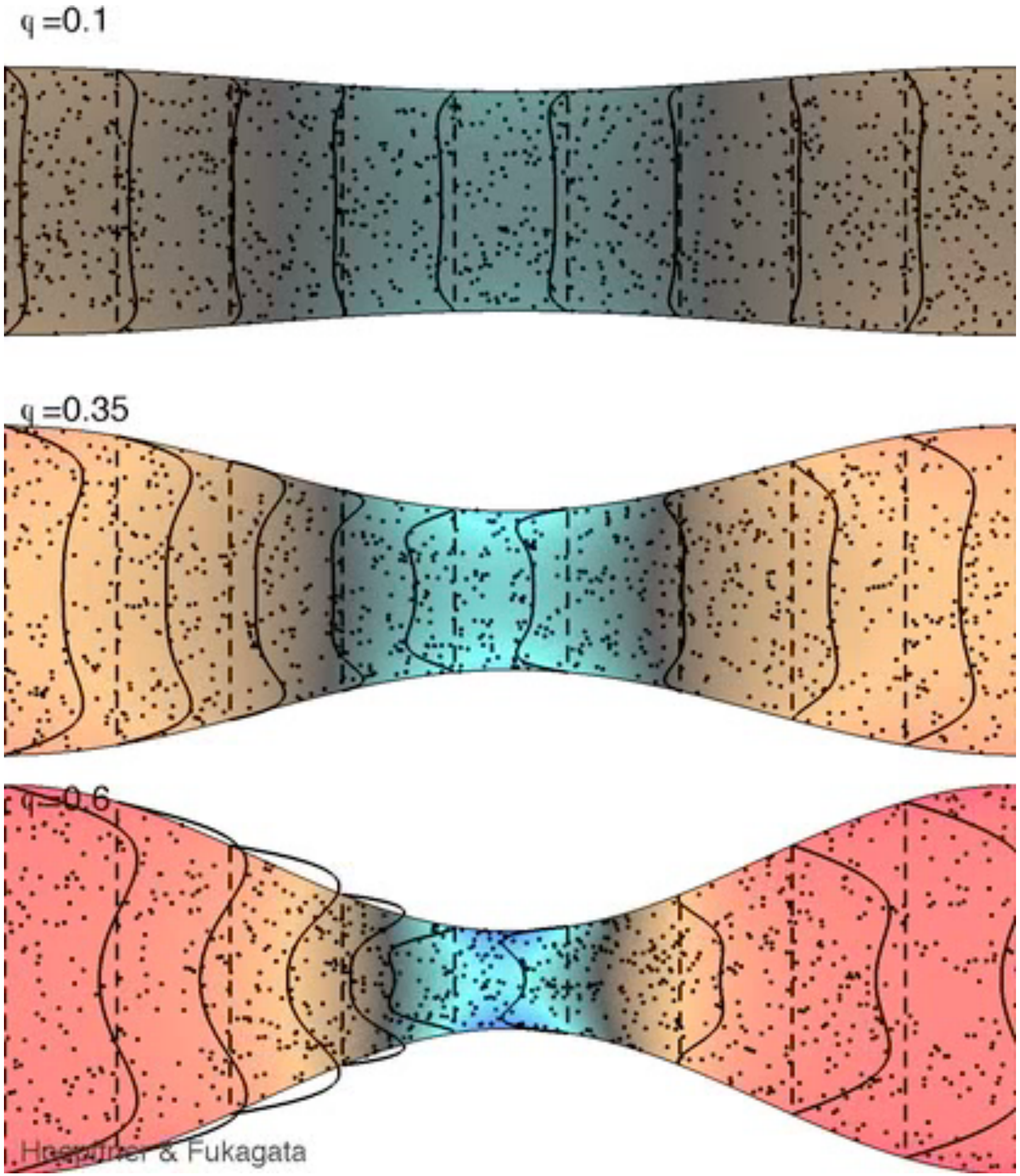


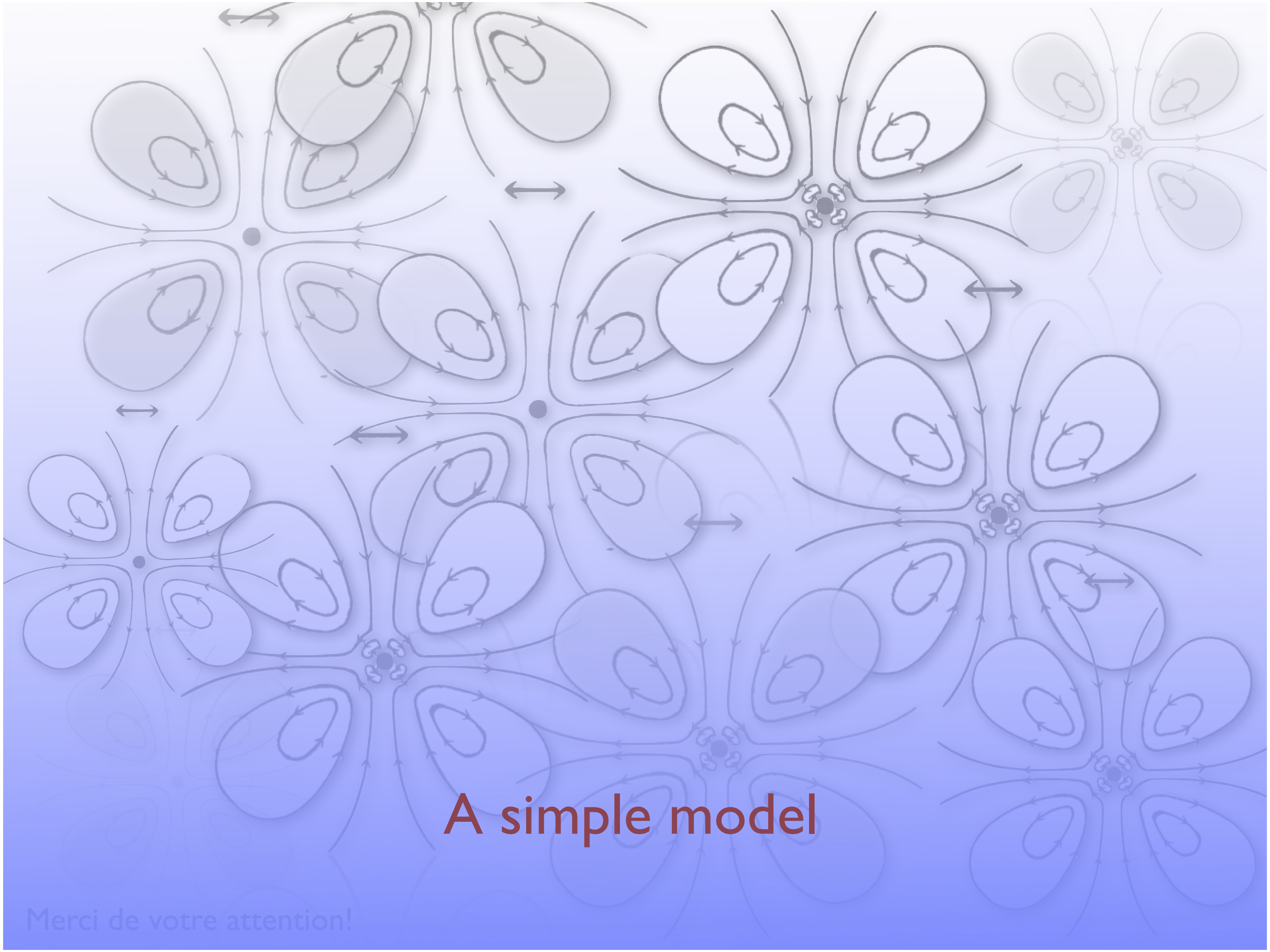


Compute steady state using Newton iterations.
Here the structure of the **Jacobian**

Finite difference/finite difference.
Sparse matrices



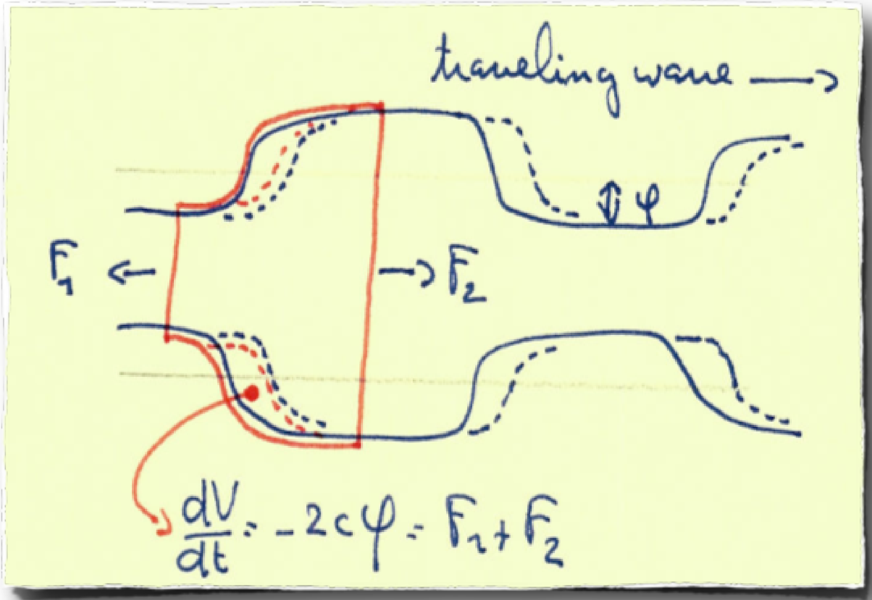

q =0.1
q =0.35
q =0.6
Hoepffner & Fukagata



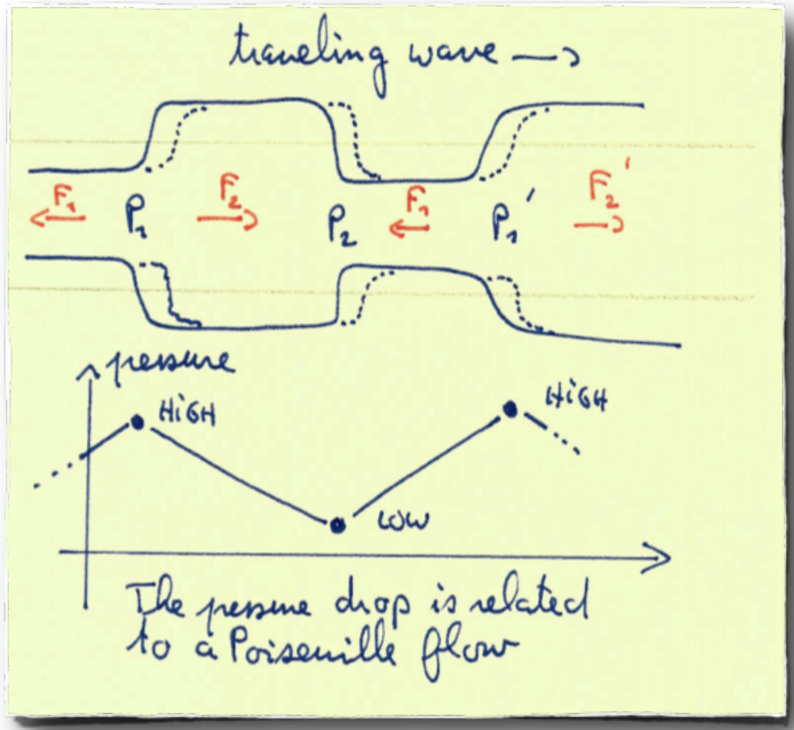
A simple model

Merci de votre attention!

Conservation model



Mass conservation

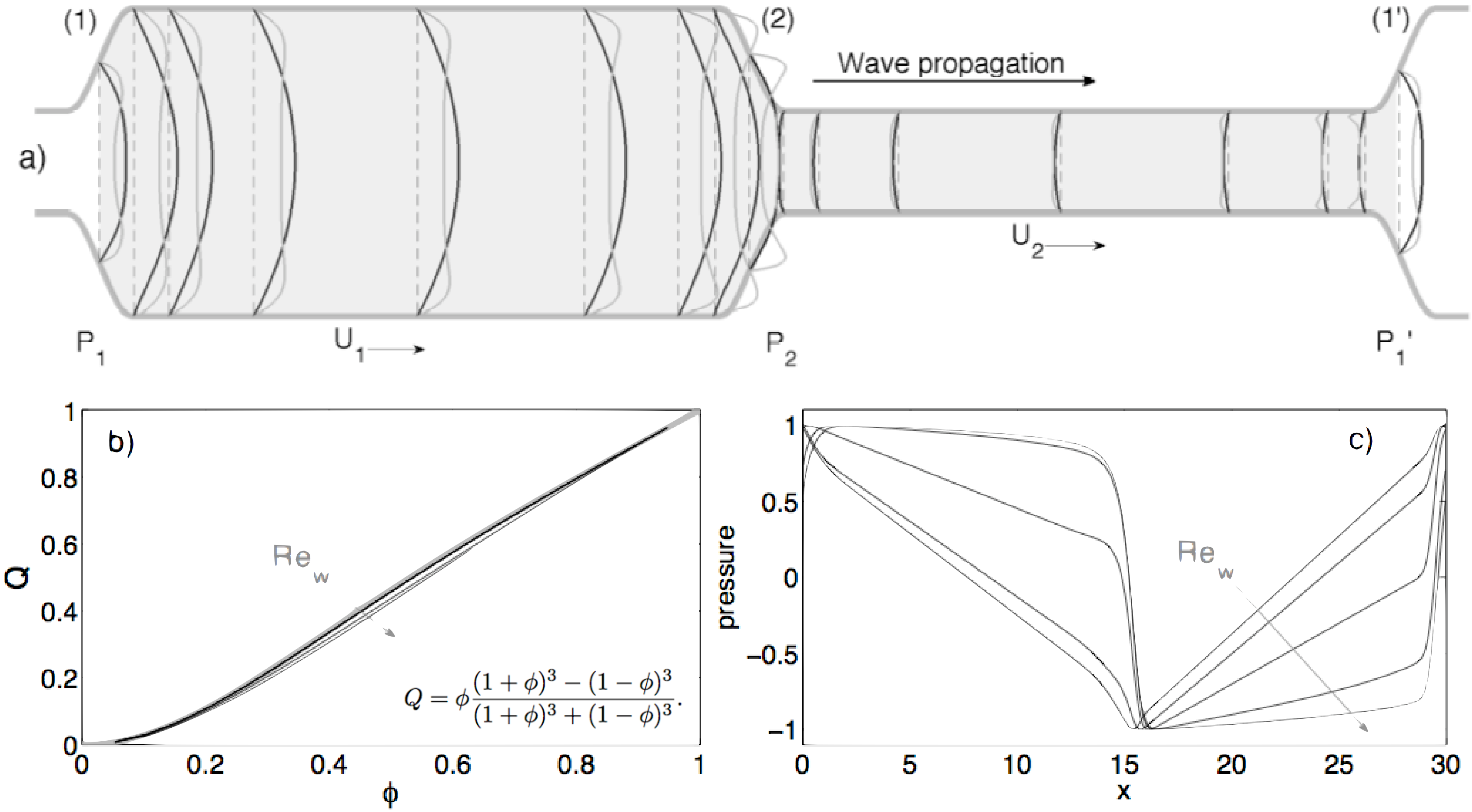


Pressure drop

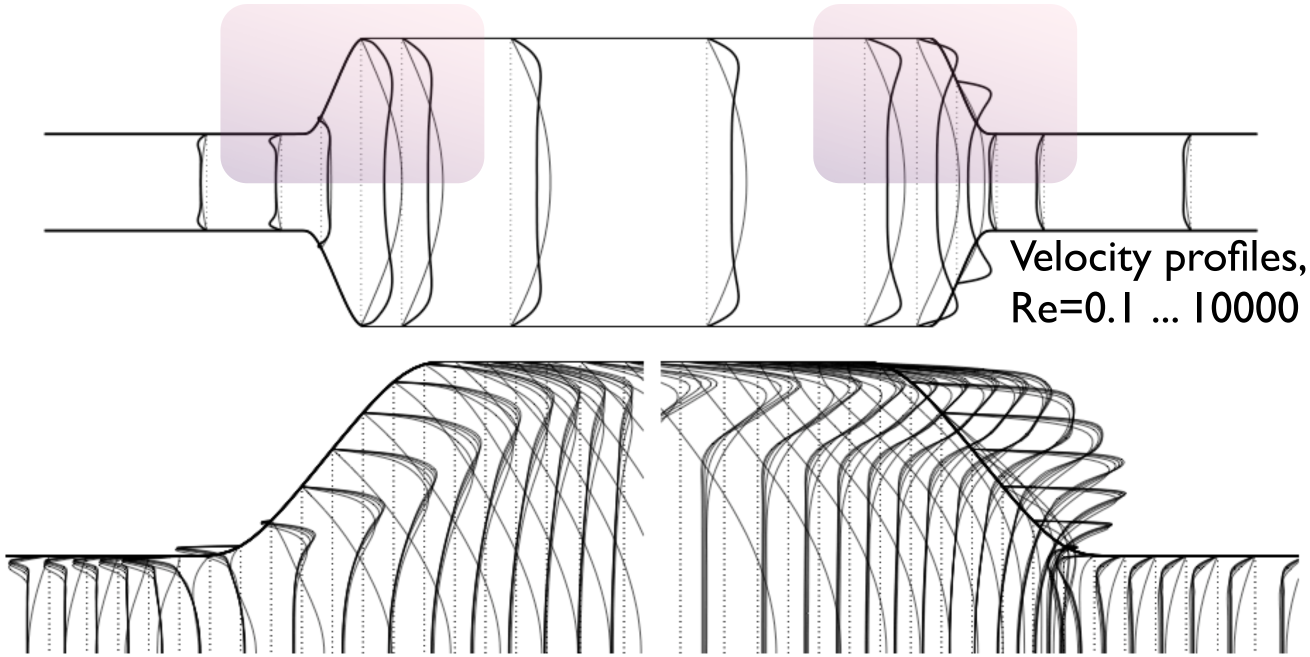
$$Q = \phi \frac{(1+\phi)^3 - (1-\phi)^3}{(1+\phi)^3 + (1-\phi)^3}.$$

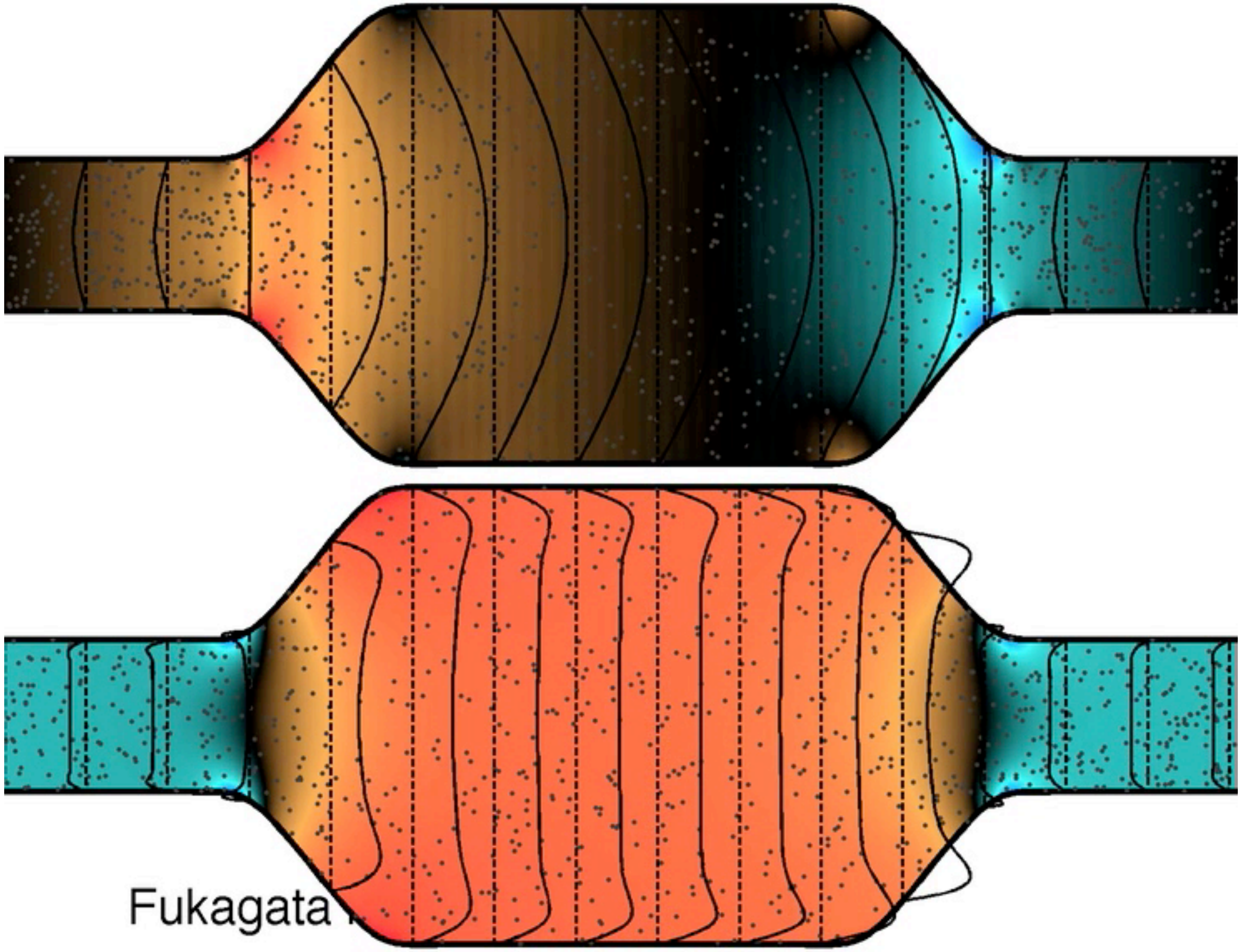
No Reynolds number effect!

Pumping mechanism



Velocity profiles

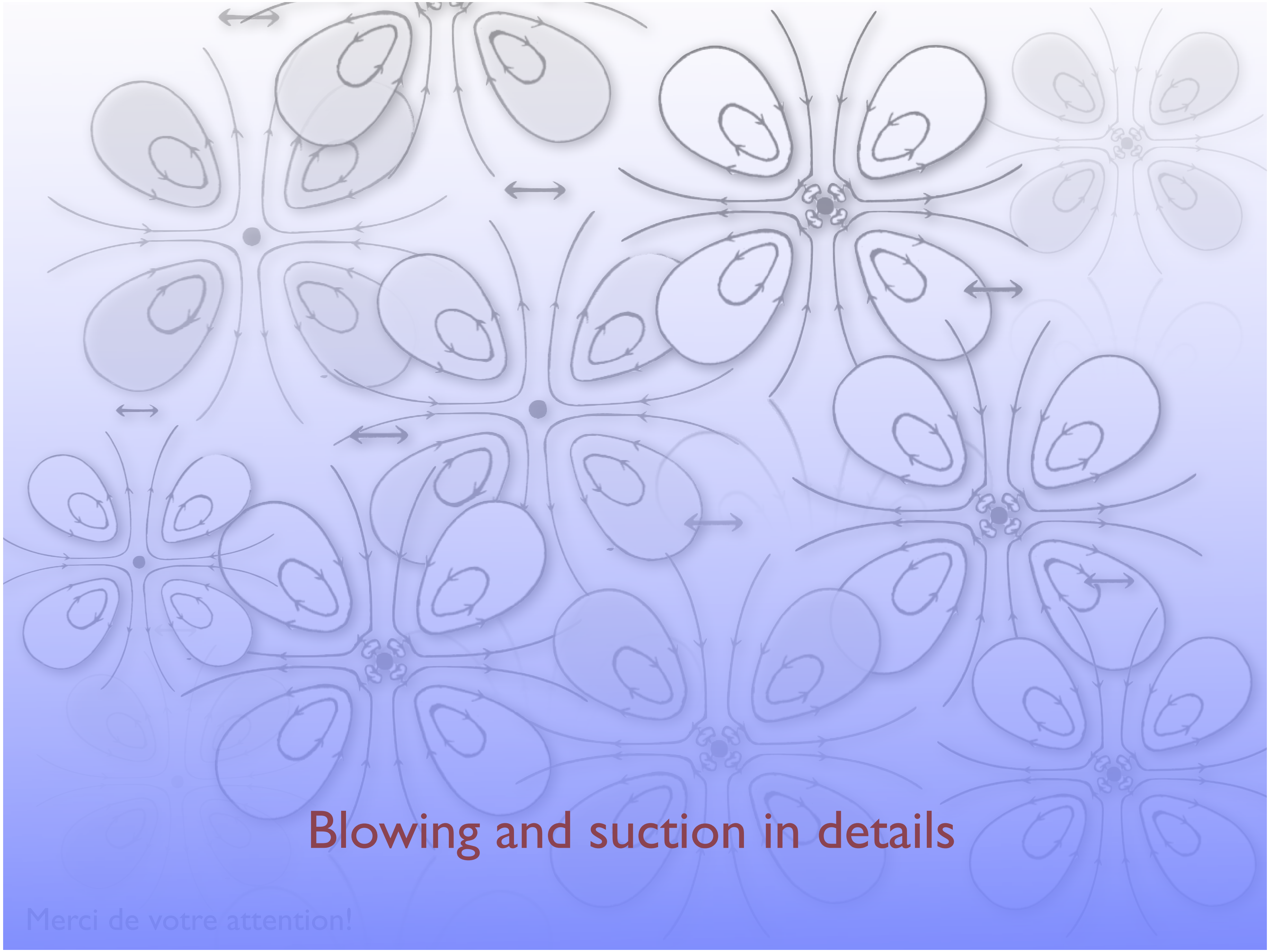




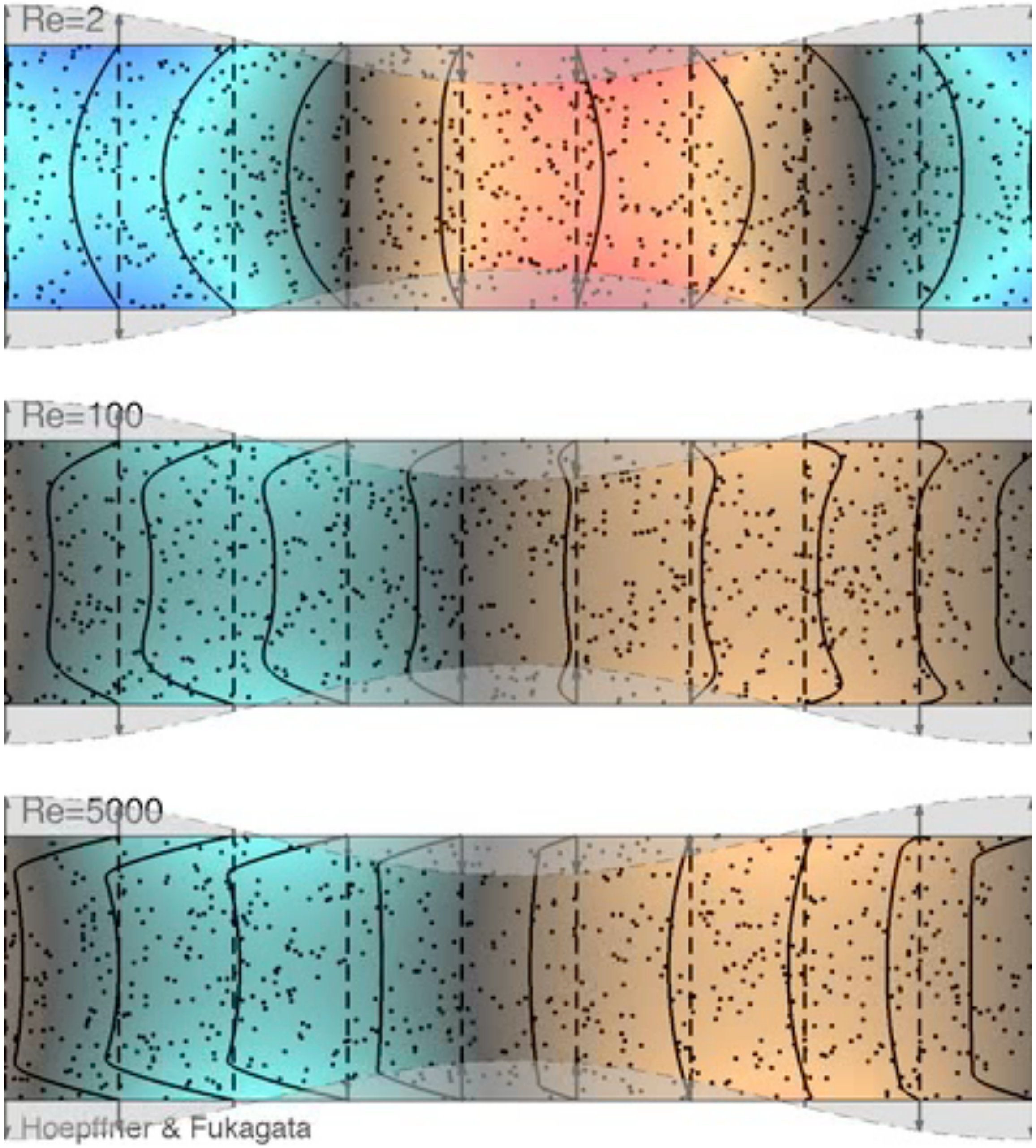
Re=1

Re=1000

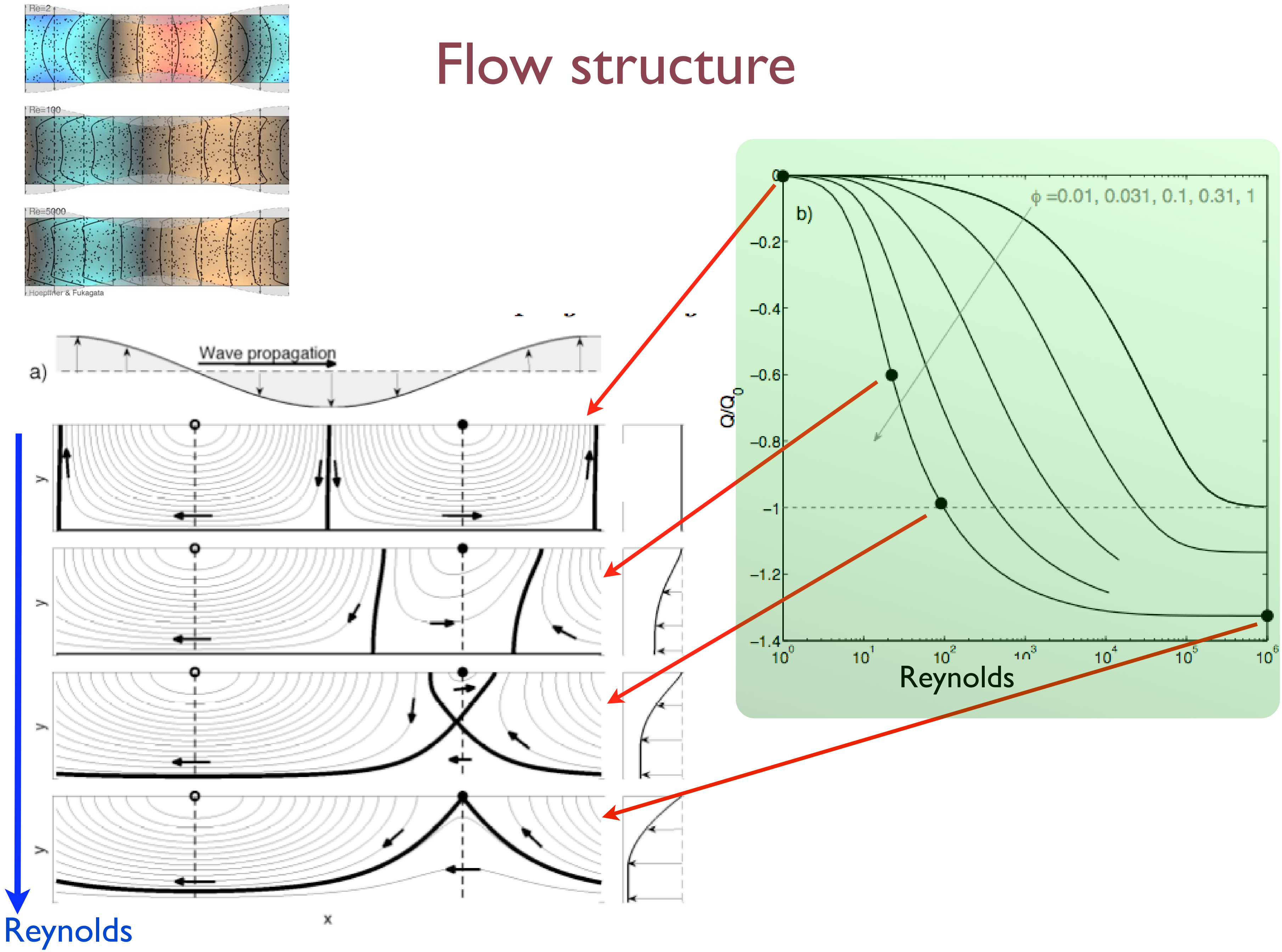
Blowing and suction in details



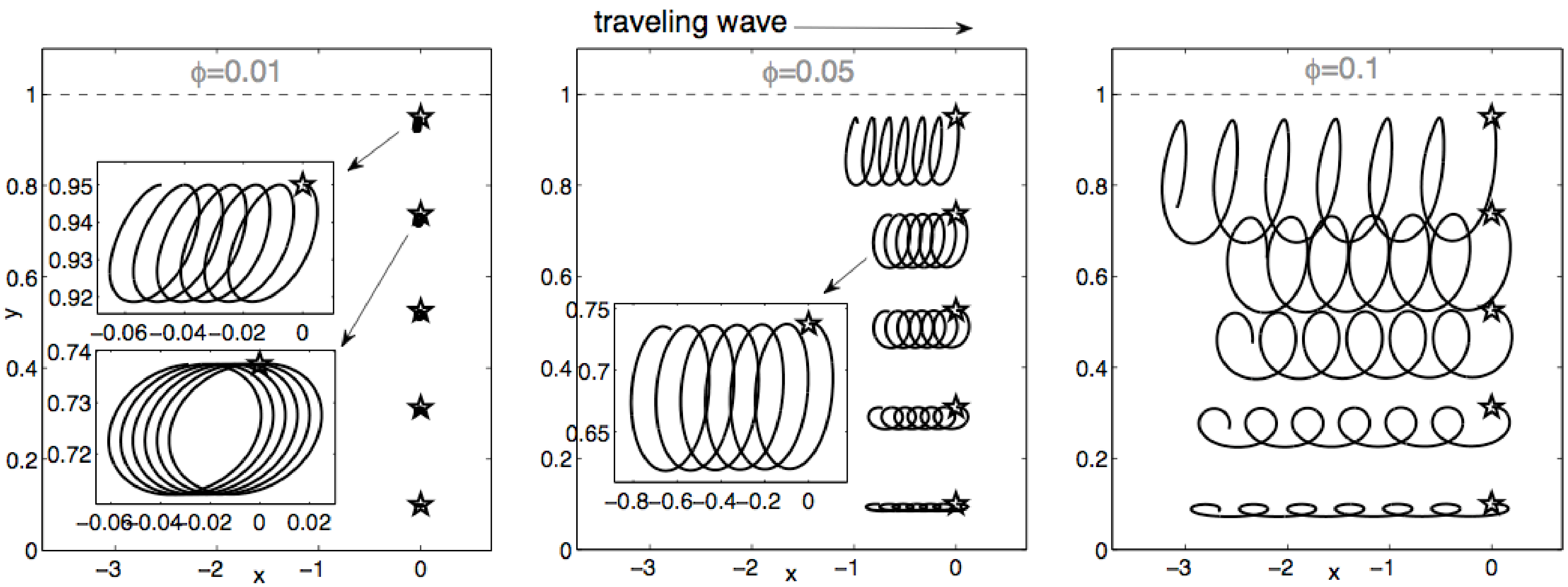
Merci de votre attention!


Re=2
Re=100
Re=5000
Hoepffner & Fukagata

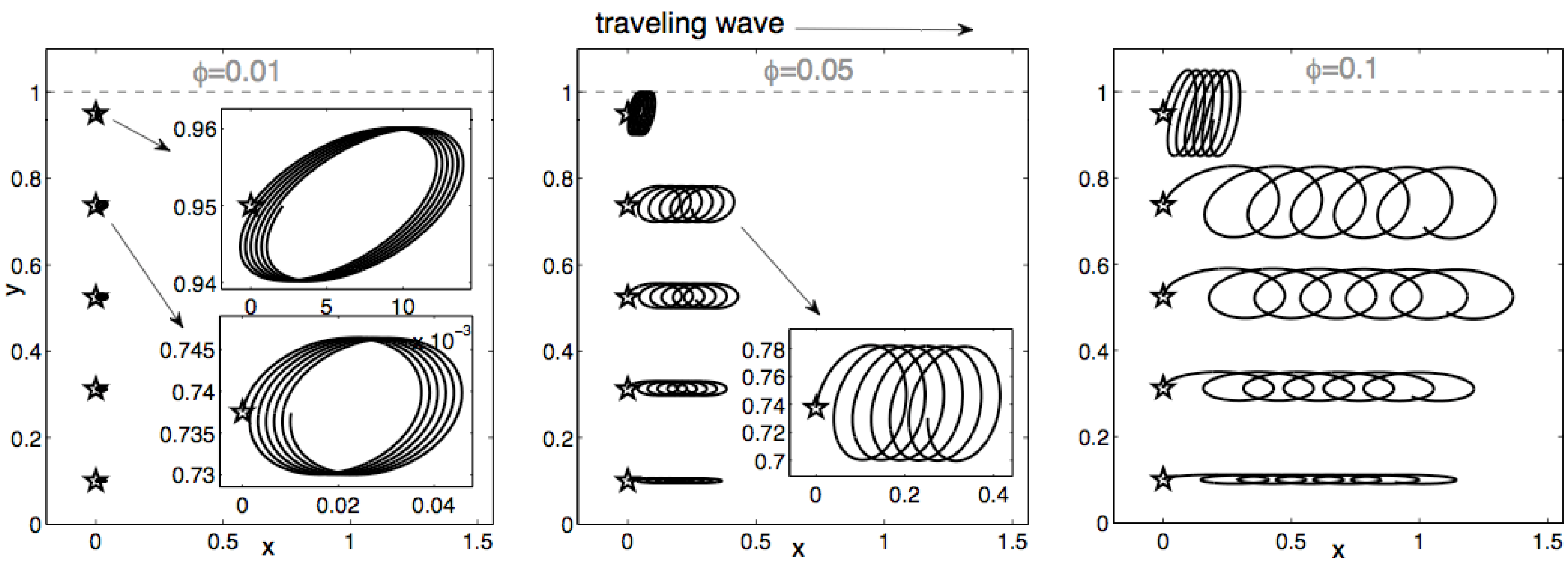
Flow structure

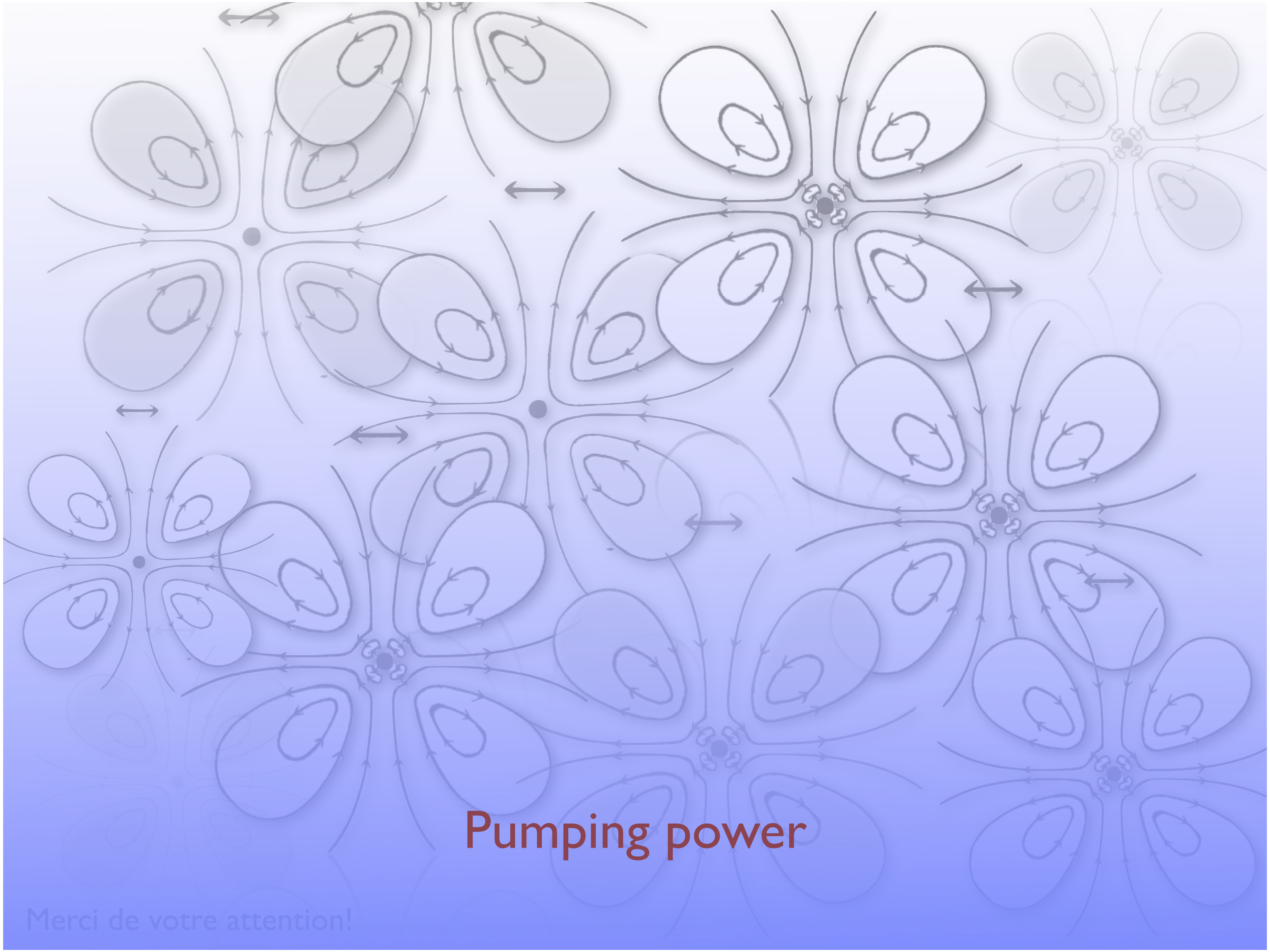


Blowing&suction: trajectories



Peristalsis: trajectories

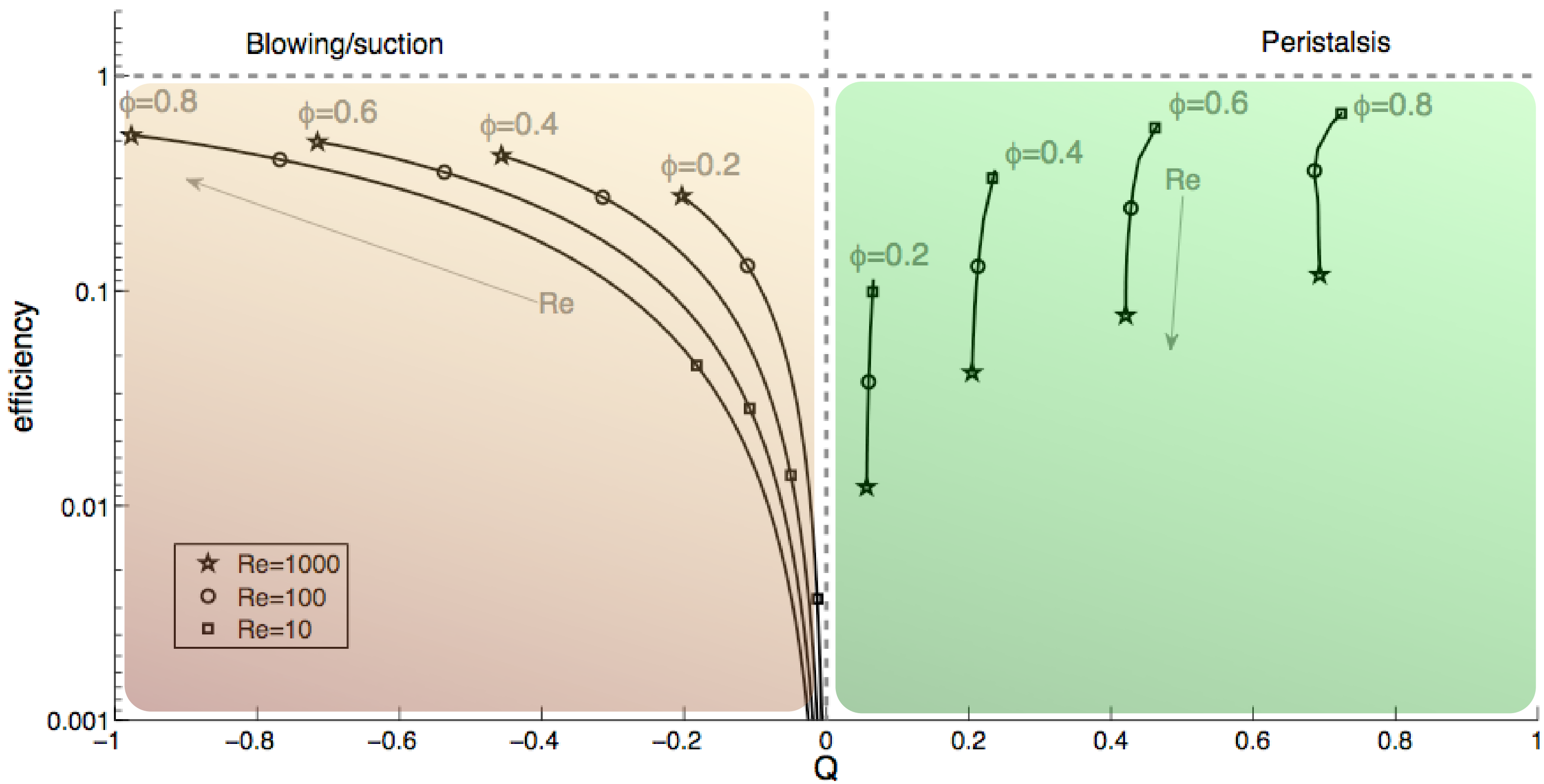




Pumping power

Merci de votre attention!

Energy



Pumping flux Q

Efficiency: $\dfrac{\text{energy for this flux by Poiseuille}}{\text{energy spent here}}$

Linear & weakly nonlinear analysis:

small amplitude

Merci de votre attention!

Weakly nonlinear

Weakly nonlinear: Fourier modes

Taylor expantion in (small) boundary condition amplitude: $u = u^{(0)} + \epsilon u^{(1)} + \epsilon^2 u^{(2)}/2 + \dots$

Order 0: Poiseuille
Order 1: Orr-Sommerfeld
Order 2:

$$\frac{1}{Re} u^{(2,0)}_{yy} = \overline{v^{(1)} u^{(1)}_y}$$

Order 2 solution, Fourier mode 0:
pumping profile

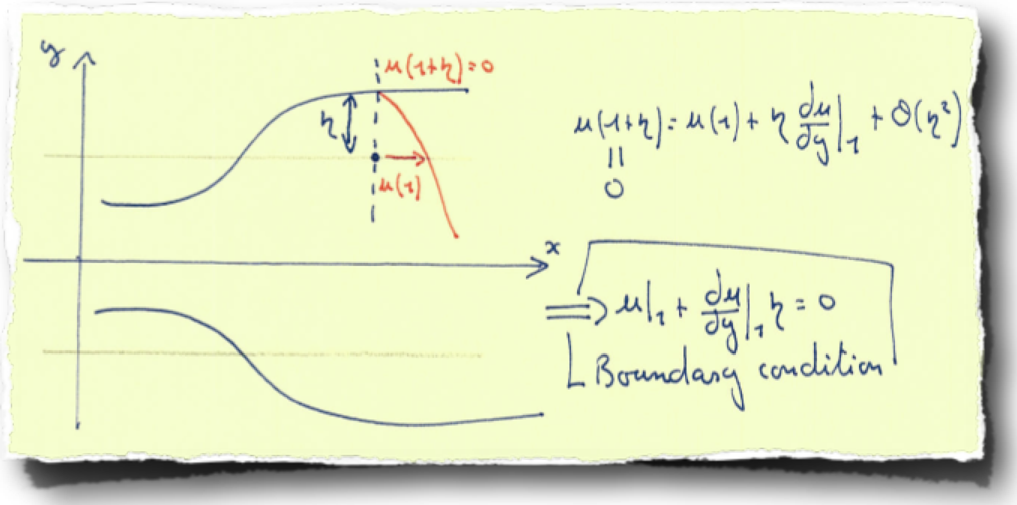
Average in time and in space

Order 0: Poiseuille - steady - due to the external pressure gradient
Order 1: Orr-sommerfeld, oscillatory, no mean motion
Order 2: Forced by the order one: pumping

Boundary conditions

Peristalsis: No slip condition at the displaced wall

$$u_{|1+\varepsilon\eta} = 0 = u_{|_1} + \varepsilon\eta\, u_{y|_1} + \frac{(\varepsilon\eta)^2}{2} u_{yy|_1}$$



$$\begin{aligned} u|_{1+\eta} = 0 \quad = \quad & [U + \varepsilon u' + \frac{\varepsilon^2}{2} u'']|_1 \\ + \quad & \varepsilon\eta\, [U_y + \varepsilon u'_y + \frac{\varepsilon^2}{2} u''_y]|_1 \\ + \quad & \frac{(\varepsilon\eta)^2}{2} [U_{yy} + \varepsilon u'_{yy} + \frac{\varepsilon^2}{2} u''_{yy}]|_1 . \end{aligned}$$

Double expantion:
different order are mixed

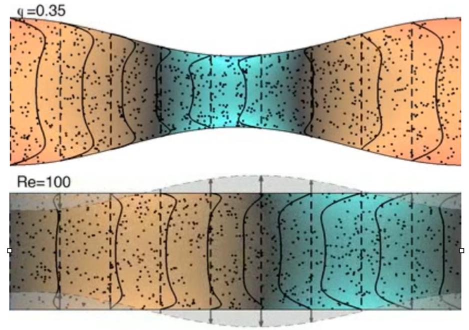
$$\begin{array}{lll} \text{Peristalsis:} & u'|_{\pm 1} = 0, & v'|_{\pm 1} = \eta_t, \\ \text{Blowing/suction:} & u'|_{\pm 1} = 0, & v'|_{\pm 1} = \eta, \end{array}$$

$$\begin{aligned} \overline{u''}|_{\pm 1} &= \overline{\eta u'_y}|_{y=\pm 1}, \\ \overline{u''}|_{\pm 1} &= 0. \end{aligned}$$

Slip condition for peristalsis!

Main conclusions

1) oscillatory forcing can lead to mean drift - many examples
2) Similar flows, opposite flux



Levels of modelisation:

- **Steady state solution**:
  extract data from the equations

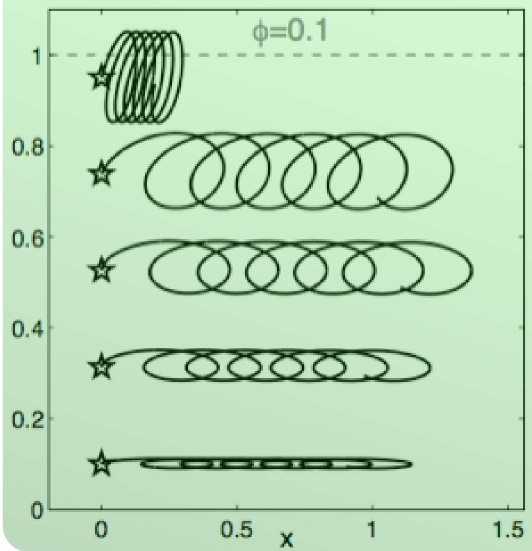
- **Conservation laws**:
  allowed to change the geometry to enlight the physics

- **Low amplitude perturbations**
  (asymptotics): extract structure from the equations

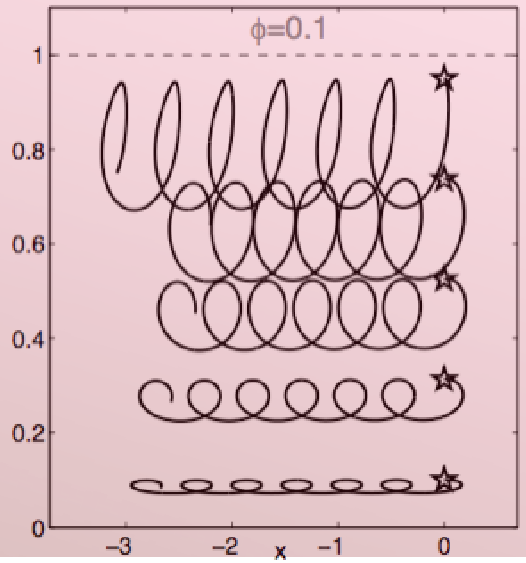
A general feature

1) particles are entrained into a **circular motion** by the wall actuation
2) the pumping direction originates from a different viscous damping during the **backward and forward** motion of fluid particles along this circular trajectories.

For **peristalsis**, the particles' backward motion takes place in the constricted section of the channel, where viscosity slows down the flow.



For **blowing and suction**, the particles' forward motion takes place close to the walls, where viscosity slows down the flow.



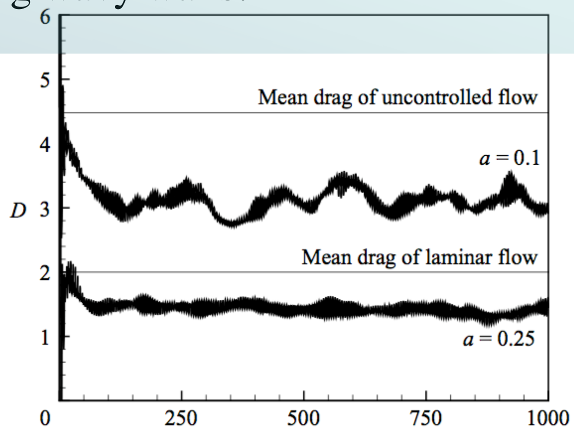
J. Fluid Mech. (2006), *vol.* 558, *pp.* 309–318.
doi:10.1017/S0022112006000206 Printed in the United Kingdom

Sustained sub-laminar drag in a fully developed channel flow

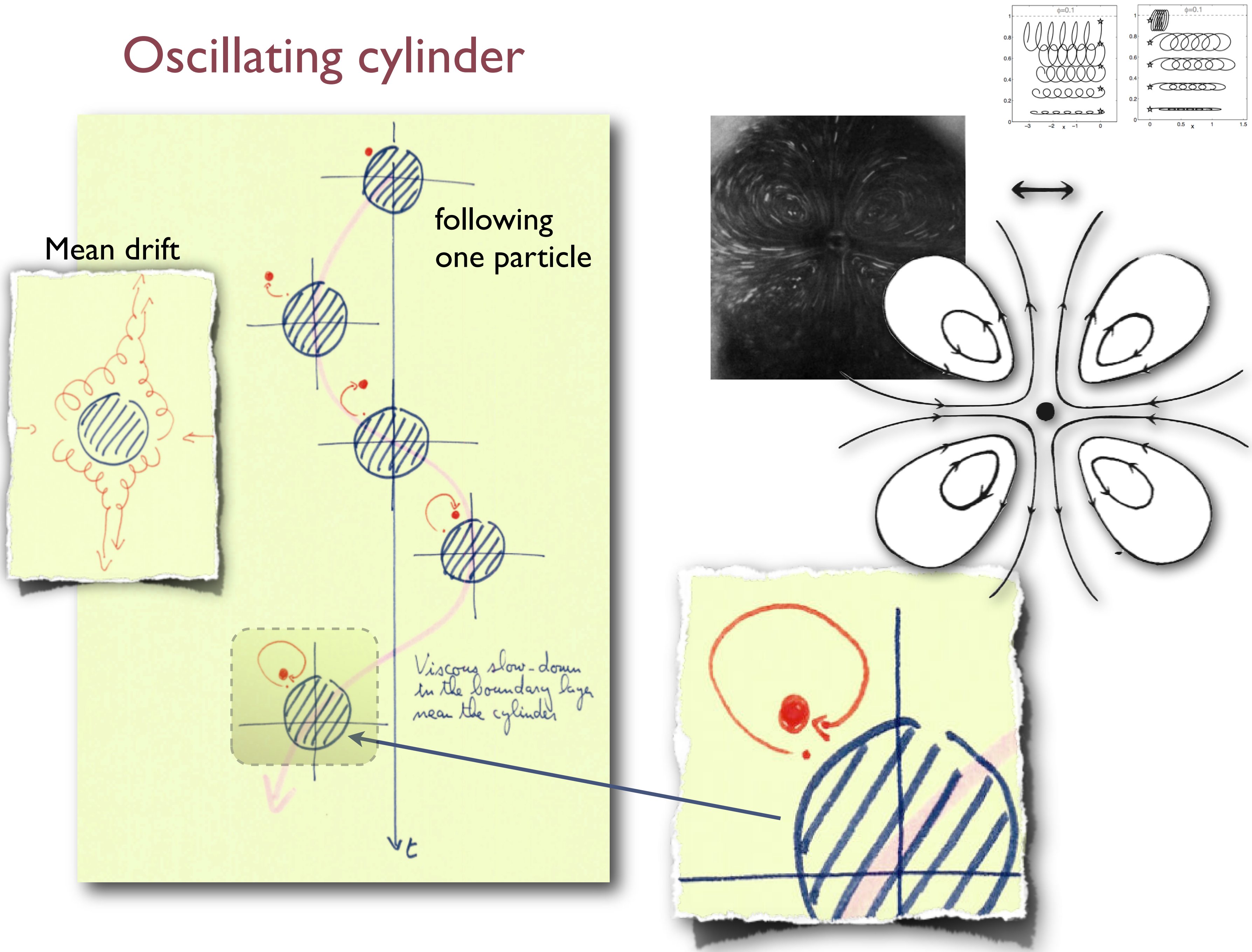
By TAEGEE MIN, SUNG MOON KANG, JASON L. SPEYER AND JOHN KIM

Finally, the current control scheme, consisting of surface blowing and suction in the form of travelling waves, is mathematically simple [...], yet it may not be straightforward to implement in real flows. [...]

However, a moving surface with wavy motion would produce a similar effect, since wavy walls with small amplitudes can be approximated by surface blowing and suction. We plan to perform simulations over moving wavy walls.

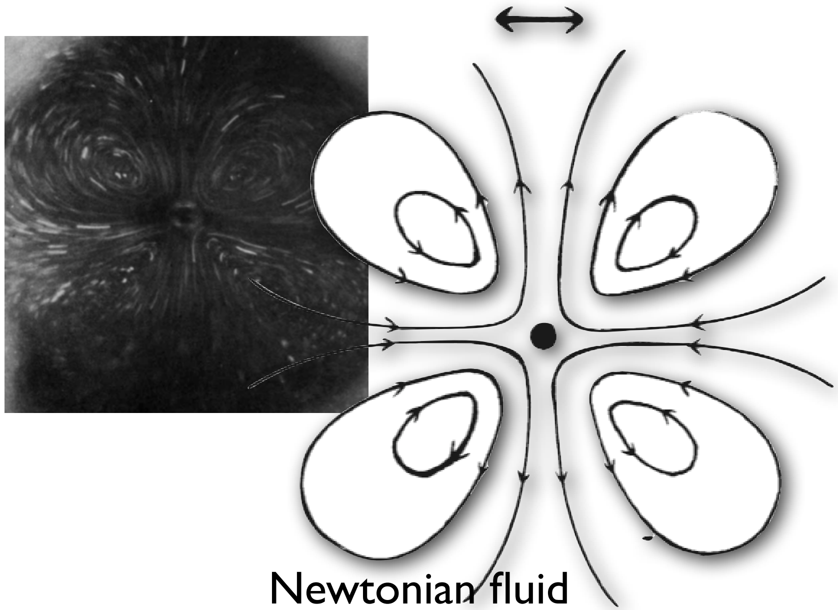


Oscillating cylinder

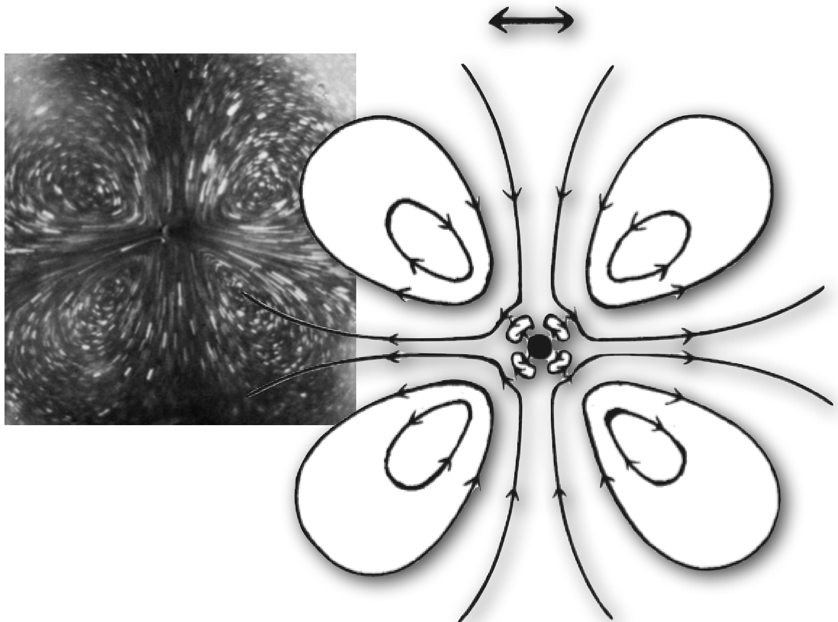


Oscillating cylinder

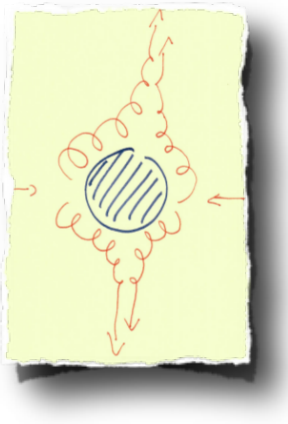
Flow near an oscillating cylinder
in dilute viscoelastic fluid



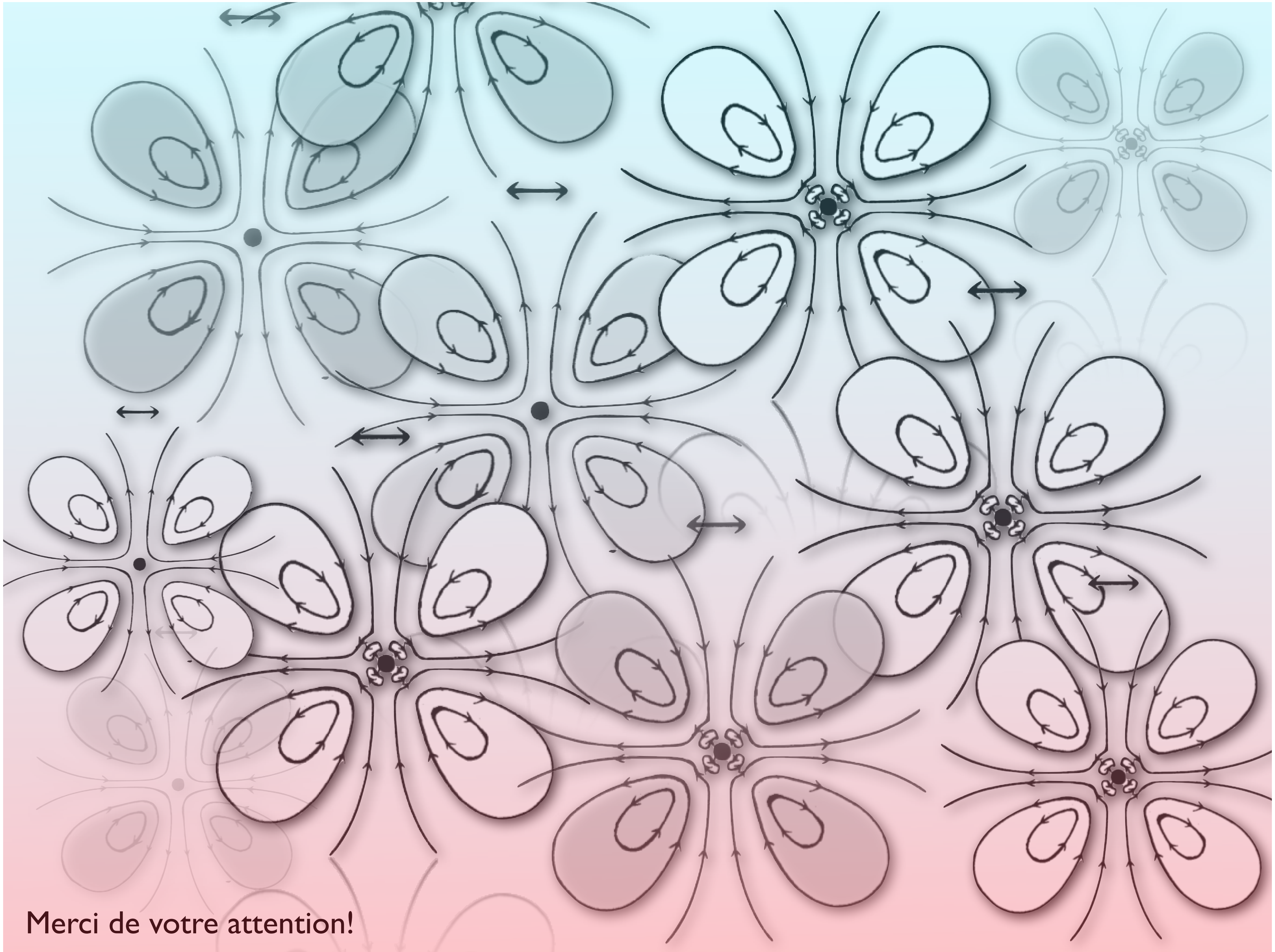
Newtonian fluid



Viscoelastic fluid



Viscoelastic:
flux in direction opposed as to Newtonian



Merci de votre attention!