Relaminarisation of fully turbulent pipe flow

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Numerical simulations**: Baofang Song (Tjanjin), Burak Budanur (IST), Ashley Willis (Sheffield) and Marc Avila (Bremen)**

Nonlinear Dynamics & Turbulence Group

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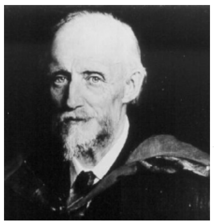
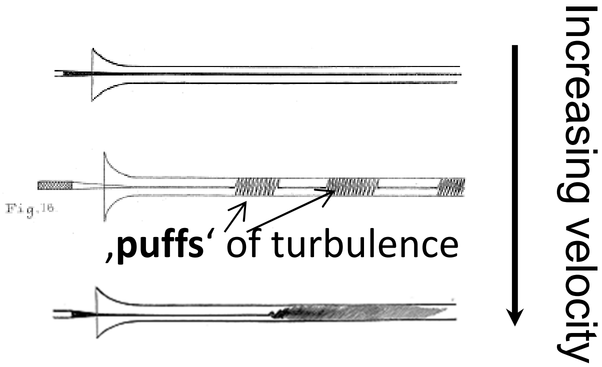
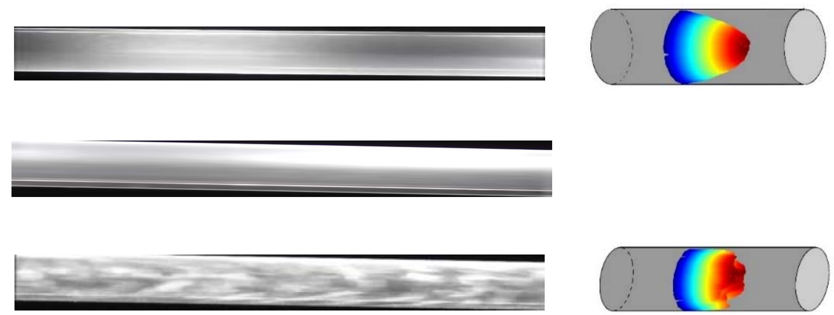
Reynolds pipe experiments







O. Reynolds Phil. Trans. R. Soc. 1883

- Re= UD / **ν** =velocity×diameter/kin.visocisty ~ inertial/viscous forces

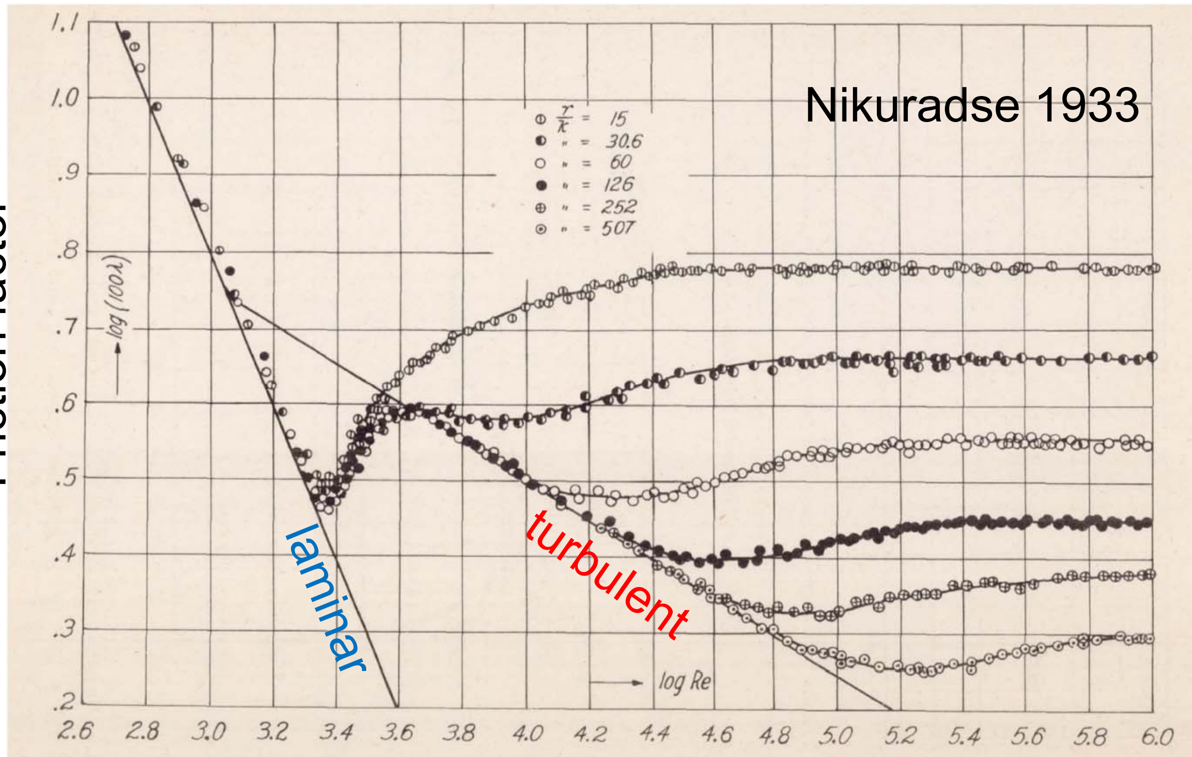
Reynolds number is the **only** parameter of the problem
small Re ➔ laminar flow
large Re ➔ turbulence

However: transition usually occured at Re=2000, but for an improved set up at Re=13 000

Laminar flow is linearly stable

Friction in pipes

Friction factor

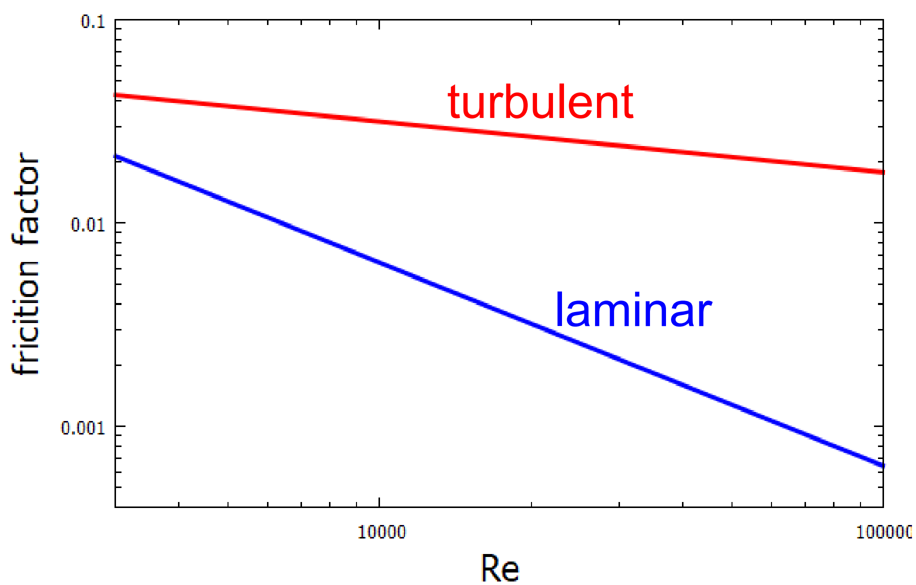


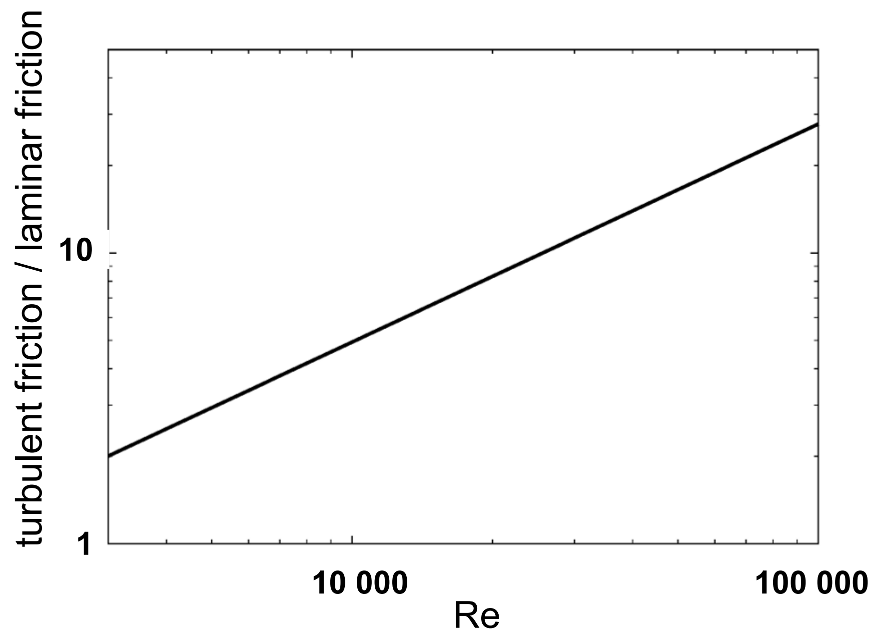
Reynolds number

$\Delta p = f\, \rho\, U^2\, L/(2\, D)$

Laminar flow: f~ 1/Re f ~ U

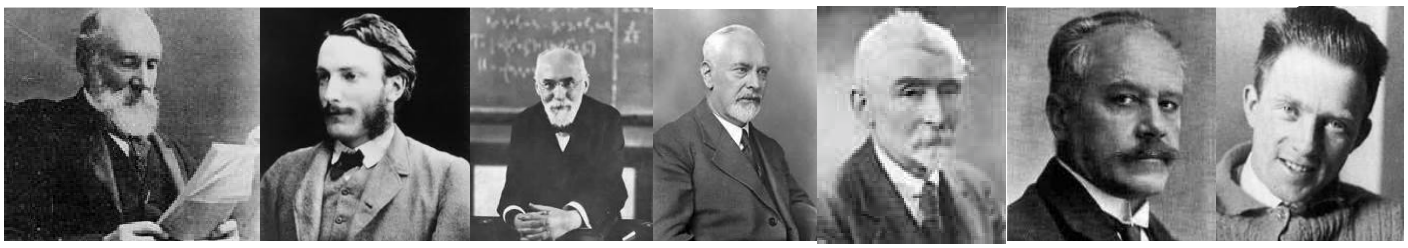
Turbulent flow: f~ $1/Re^{-0.25}$ f ~ $U^{1.75}$


0.1
0.01
0.001
fricition factor
turbulent
laminar
10000
100000
Re


turbulent friction / laminar friction
10
1
10 000
100 000
Re

The onset of turbulence

Can we define a critical point for transition?



Kelvin Rayleigh Lorentz Prandtl Orr Sommerfeld Heisenberg

Prandtl (1921): "…and so, once more, we do not obtain a critical Reynolds number. There seems to be a very nasty devil in the turbulence so that all mathematical efforts are doomed to failure."

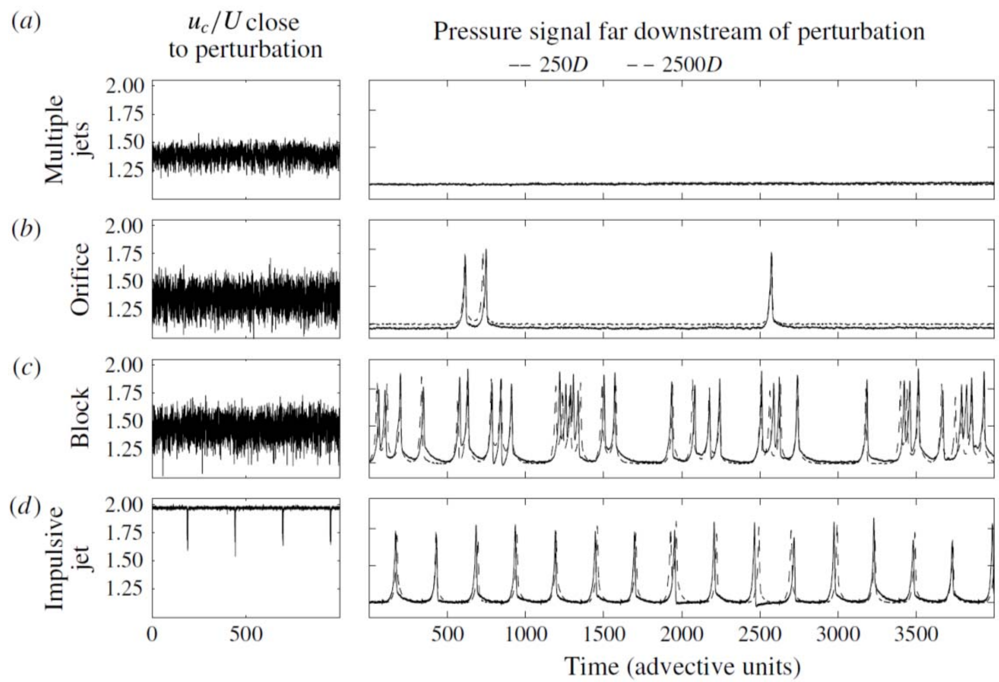
O. Reynolds Phil. Trans. R. Soc. Lond. A 174 1883

, it became clear to me that if in a tube of sufficient length the water were at first admitted in a high state of disturbance, then as the water proceeded along the tube the disturbance would settle down into a steady condition, which condition would be one of eddies or steady motion, according to whether the velocity was above or below what may be called the real critical value.

Experimental difficulties

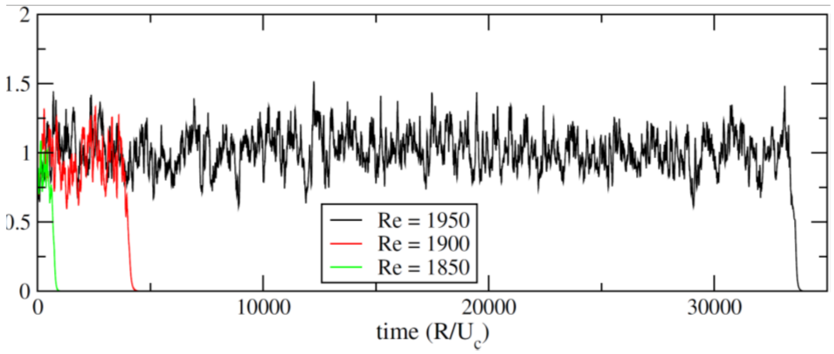
Dependence on perturbation:

Re=2100



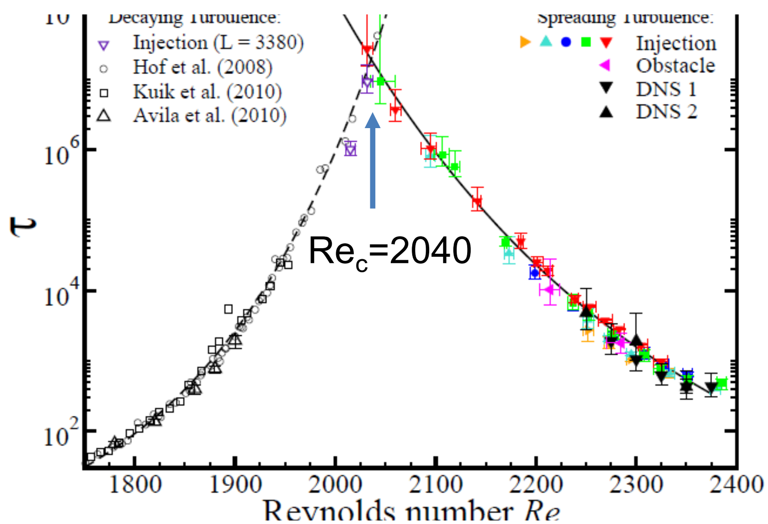
Dynamics of individual puffs

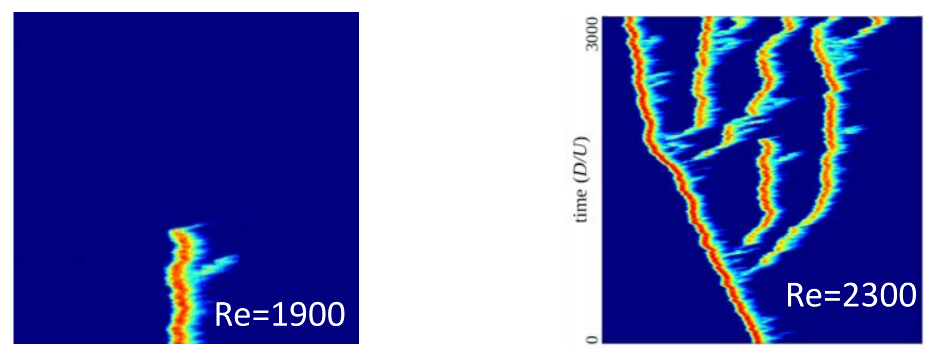
Decay of turbulent puffs



- •Turbulent puffs decay suddenly after long times
- •Memoryless process

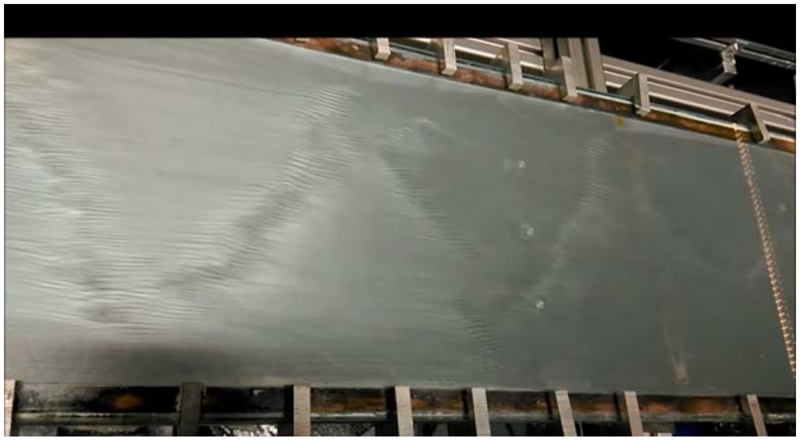
$$P(t, Re)=\exp(-t / \tau (Re))$$





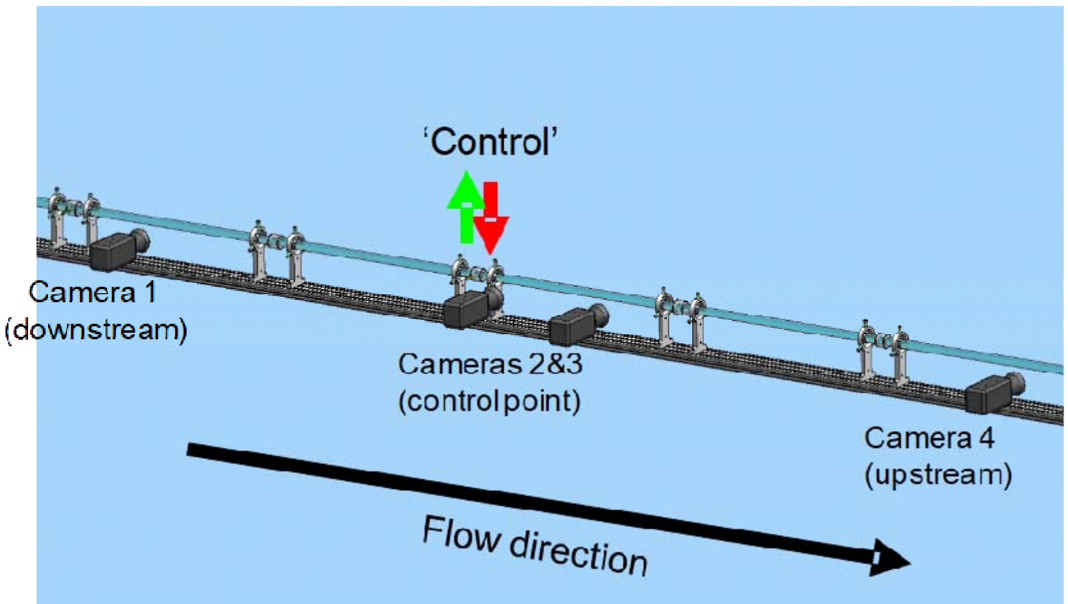
(Avila, Moxey, de Lozar, Avila, Barkley, Hof, *Science* 2011)

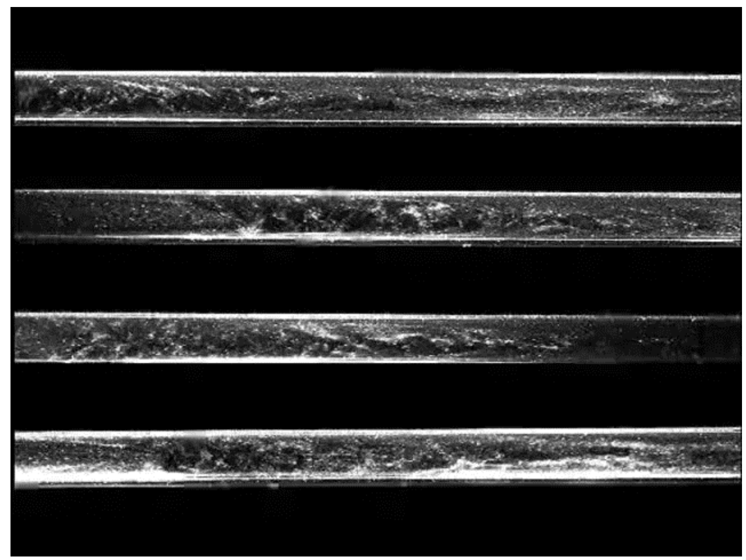
Transition (in Couette flow) belongs to the „directed percolation“ universality class (Lemoult et al. Nature Physics 2017)



Why is turbulence localised?

Puff interactions





Hof, deLozar, Avila, Tu, Schneider Science 2010

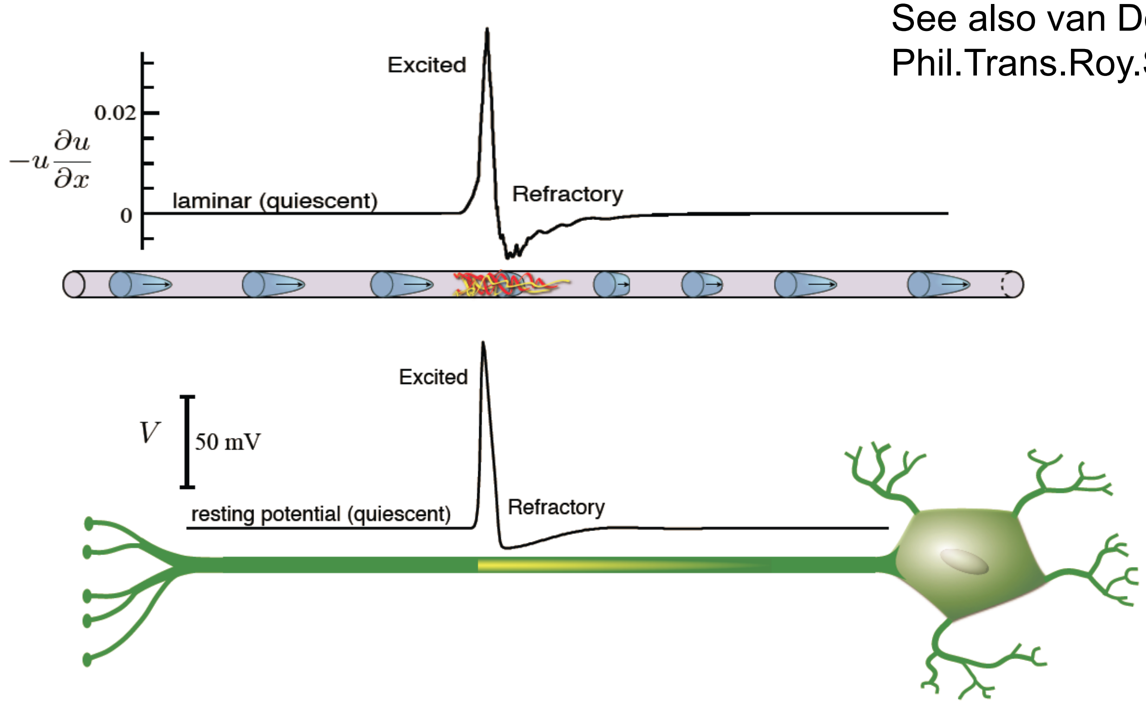
A different frame of reference

DNS by Baofang Song and BH

Refractory region

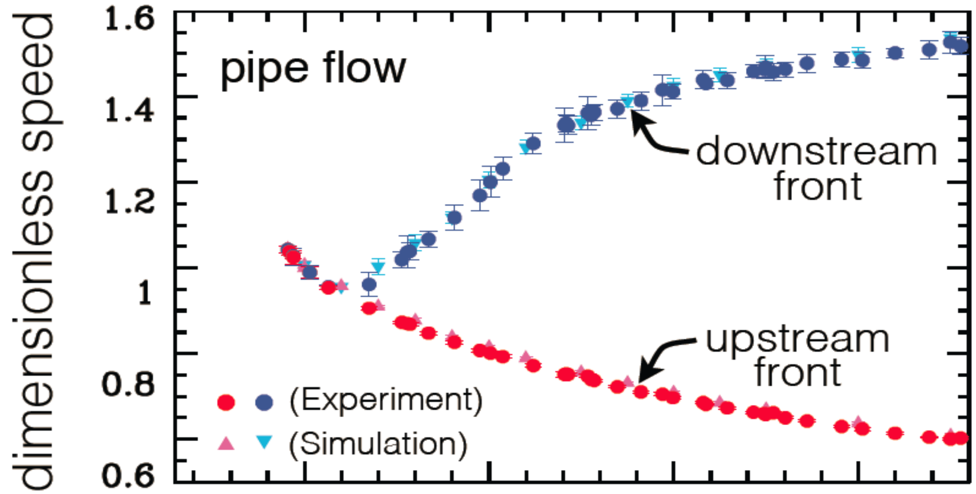
Puffs are ‘parasites’ that feed on the upstream laminar flow.

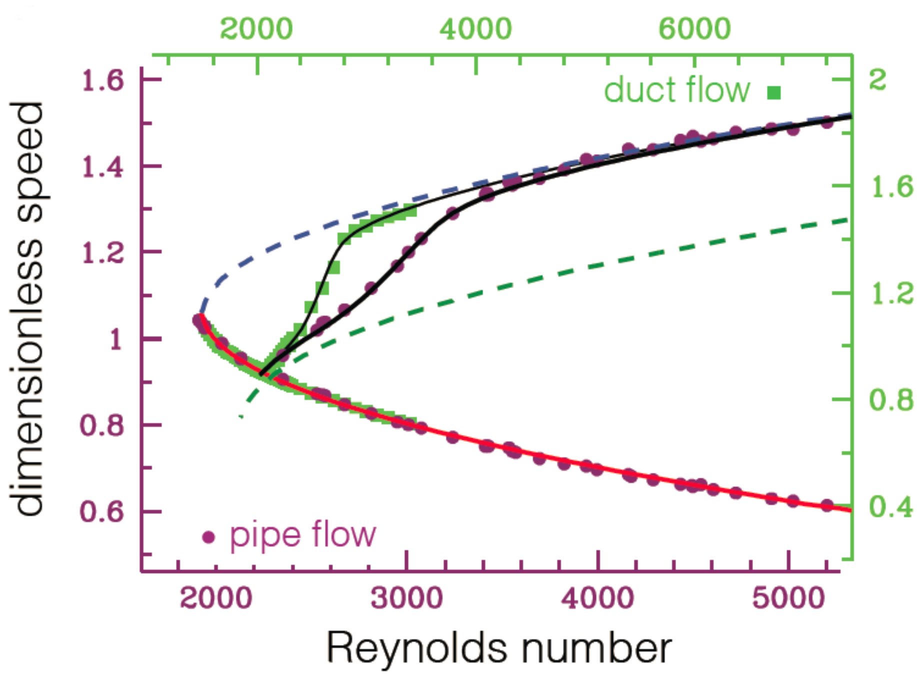
See also van Doorne and Westerweel
Phil.Trans.Roy.Soc. 2009



Barkley PRE 2011
Barkley JFM 2017

Laminar Turbulent fronts



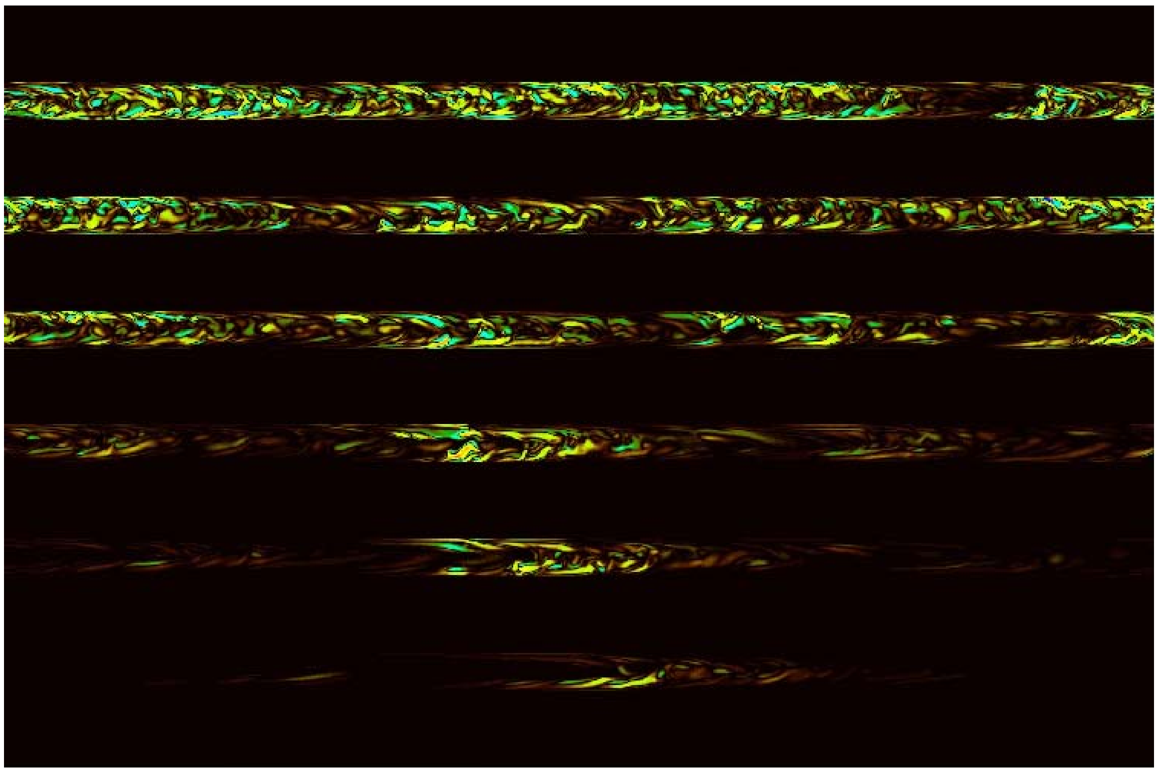


Barkley, Song, Mukund, Lemoult, Avila & Hof
Nature 2015

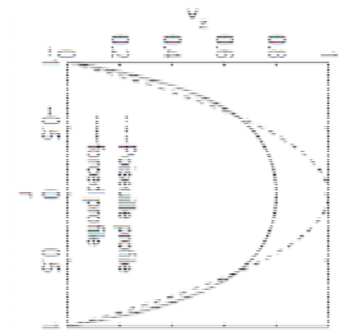
Prediction: **Profile change can make fully turbulent flow refractory**

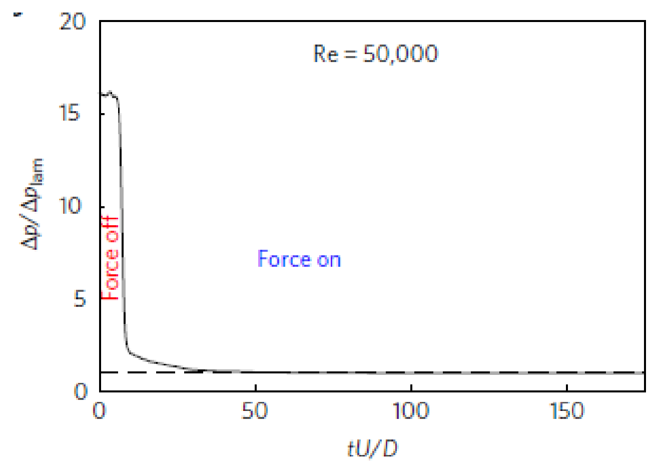
Relaminarization in direct numerical simulations

DNS pipe flow by Marc Avila: Flow relamianrizes if profile is flattened

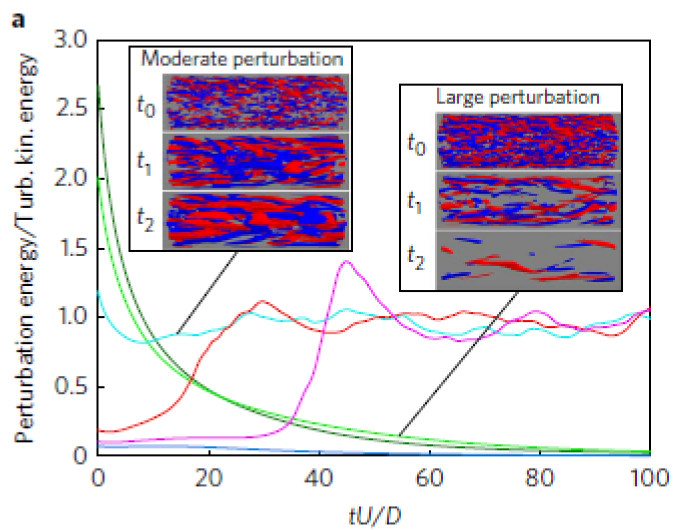


(see also Hof et al. Science 2010)

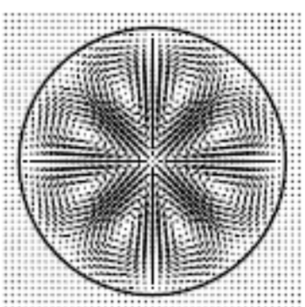


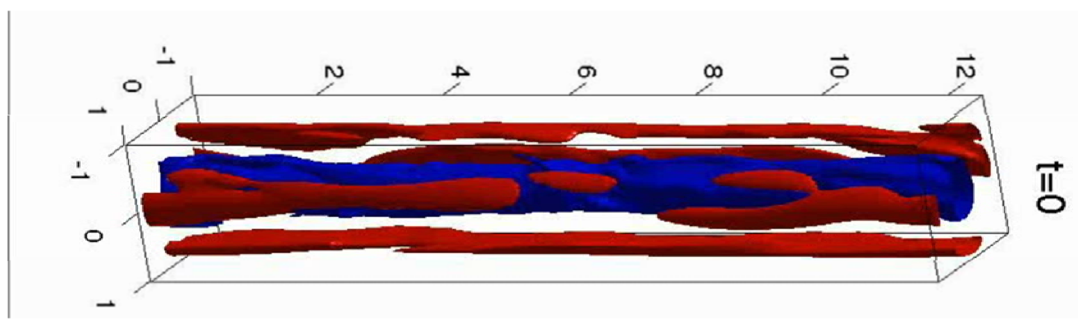


Making the flow more turbulent

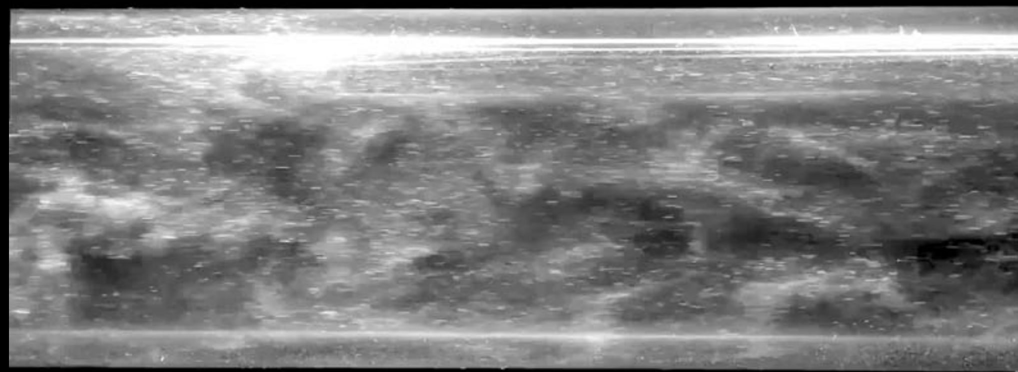


DNS by Baofang Song and Burak Budanur

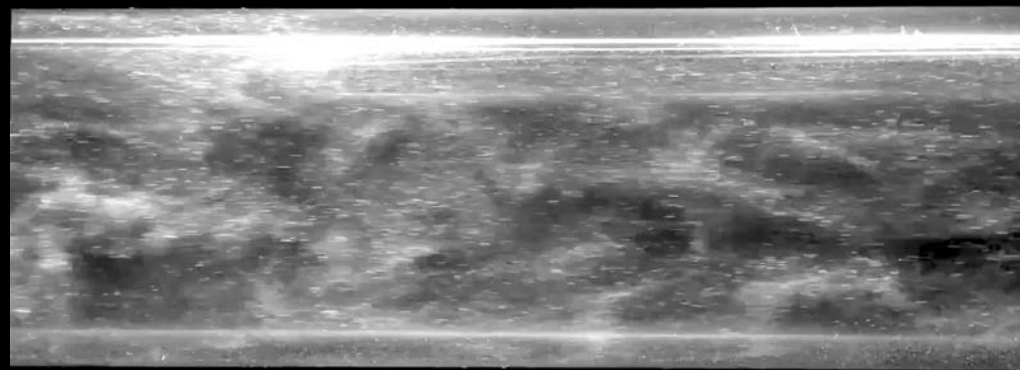


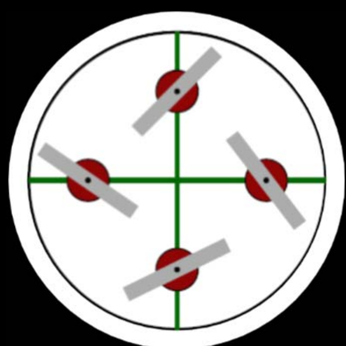


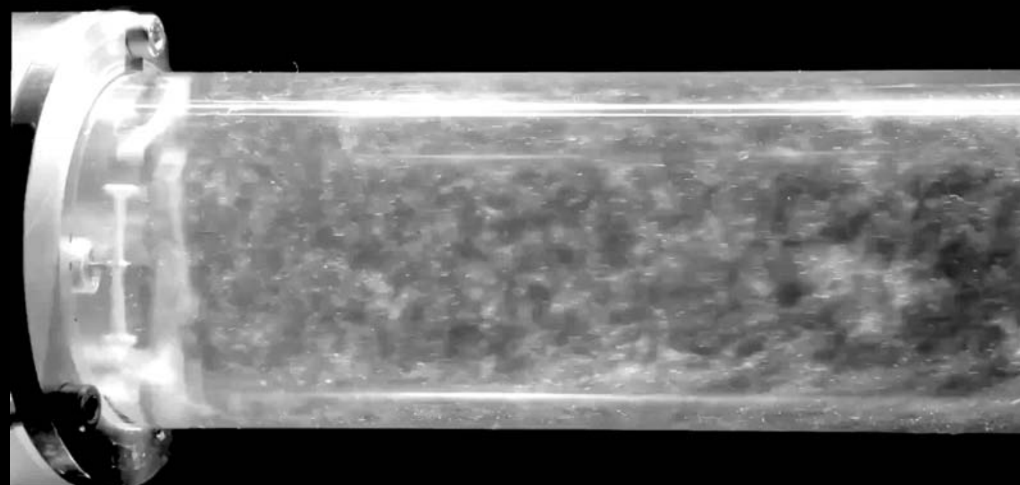
Re=3500



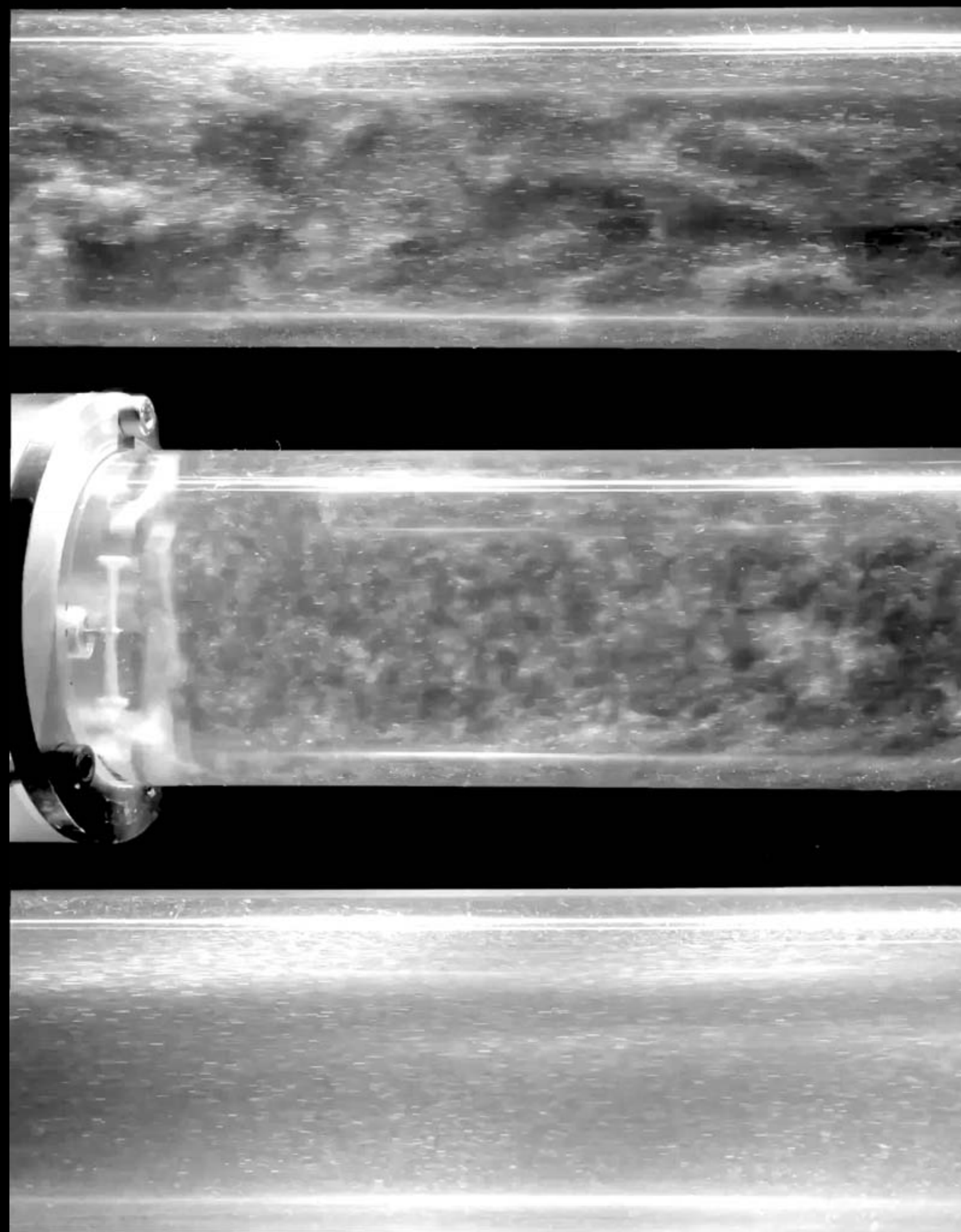
Re=3500

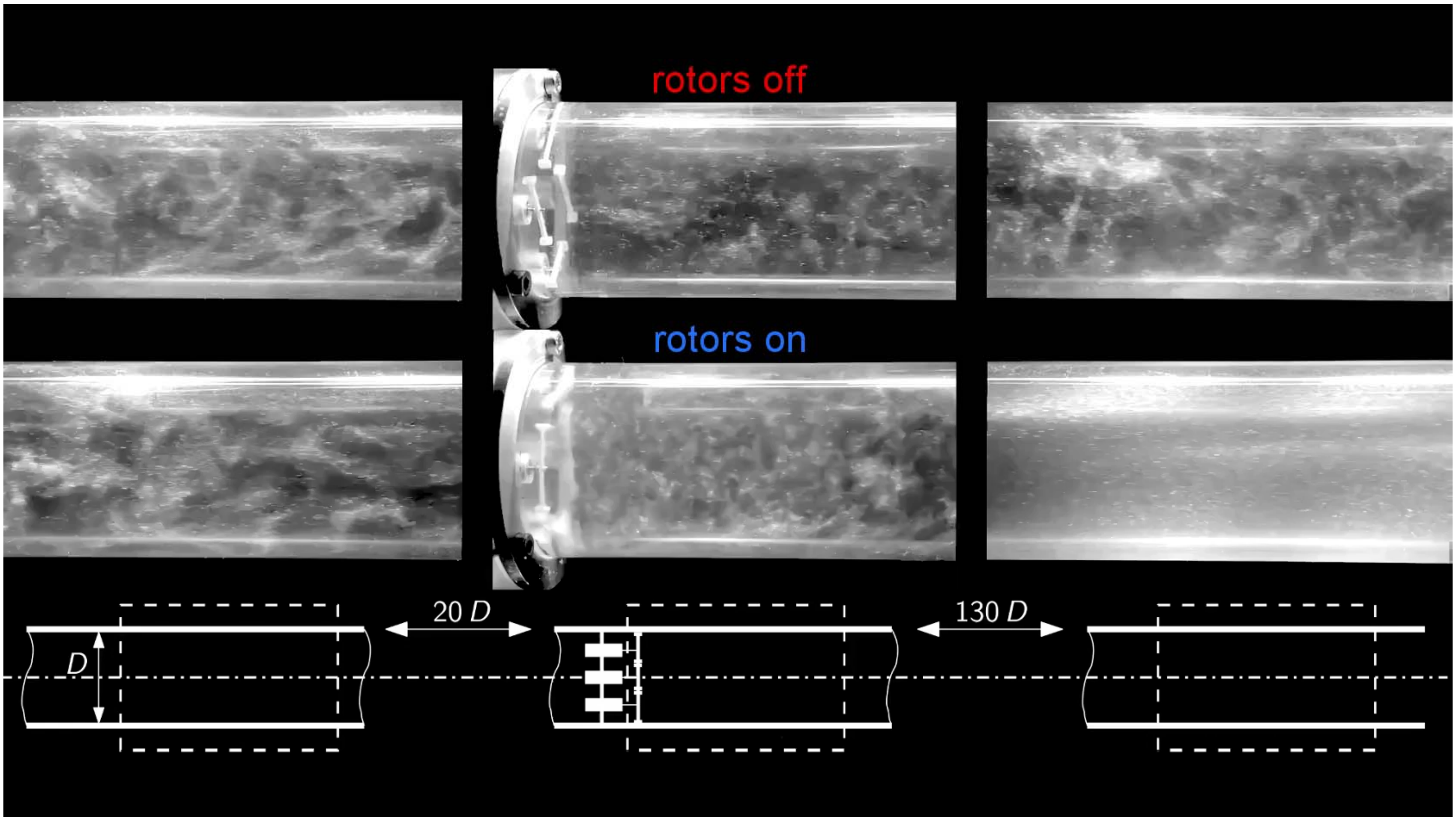




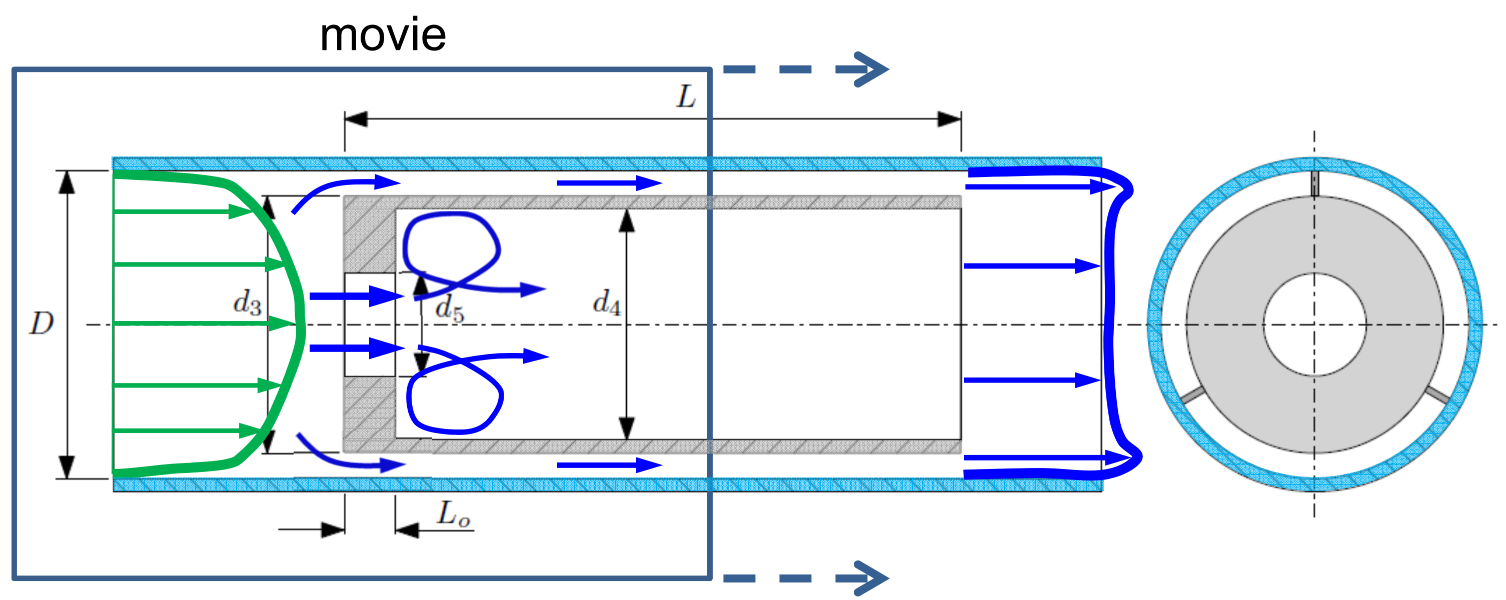


Re=3500

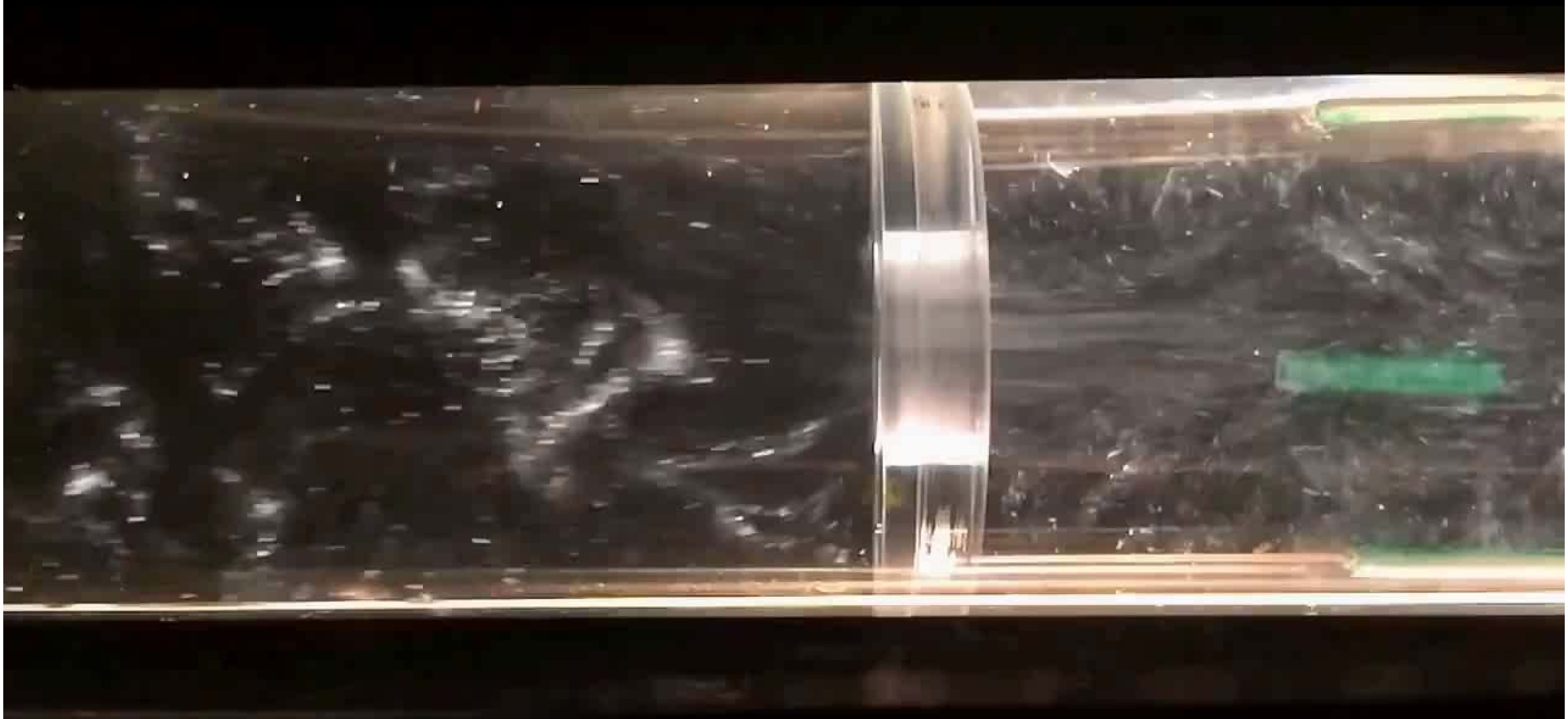



rotors off
rotors on
20 D
130 D
D

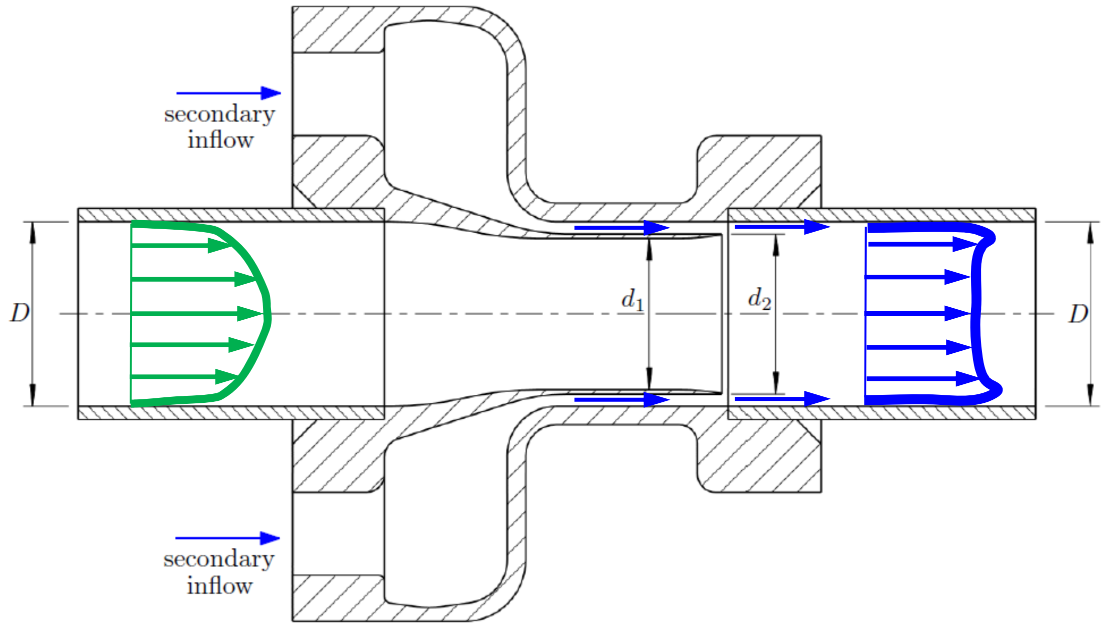
Passive device: mechanism



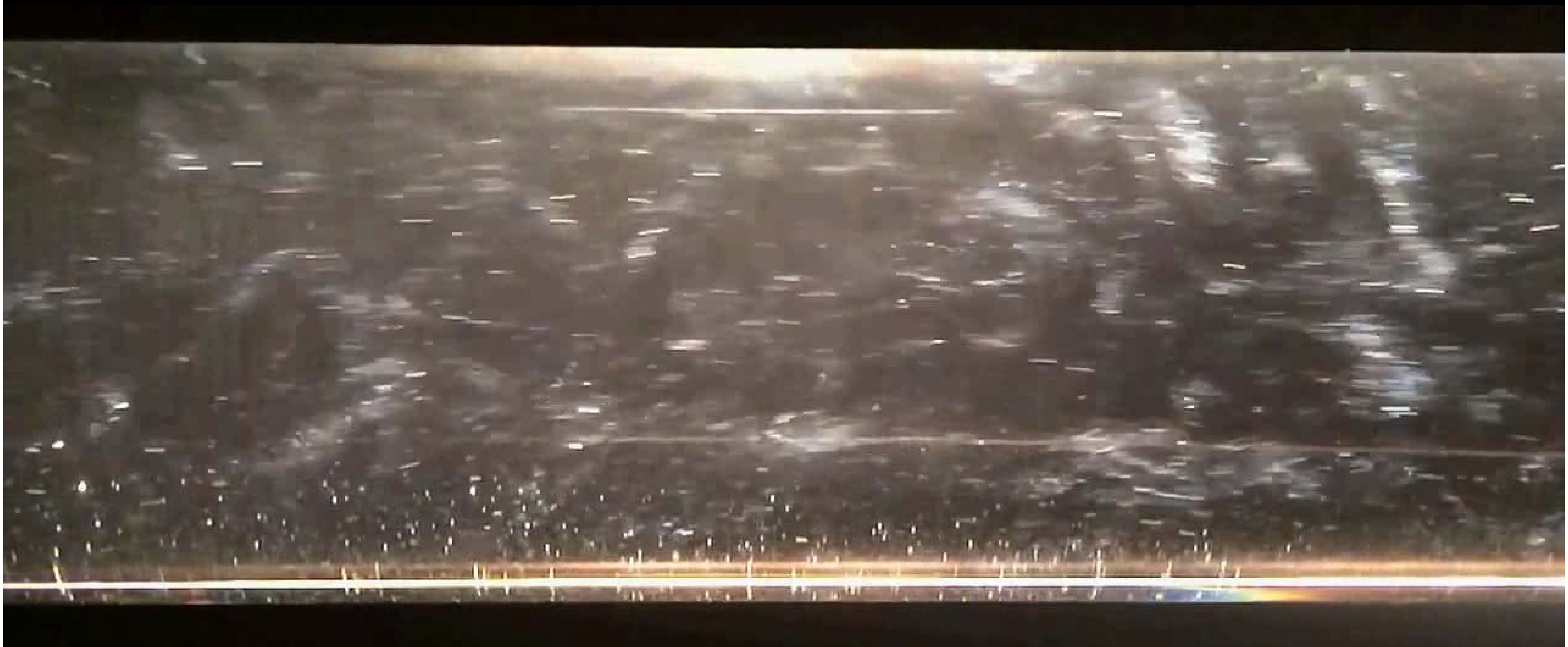
Re = 4000, camera comoving with bulk velocity of the flow



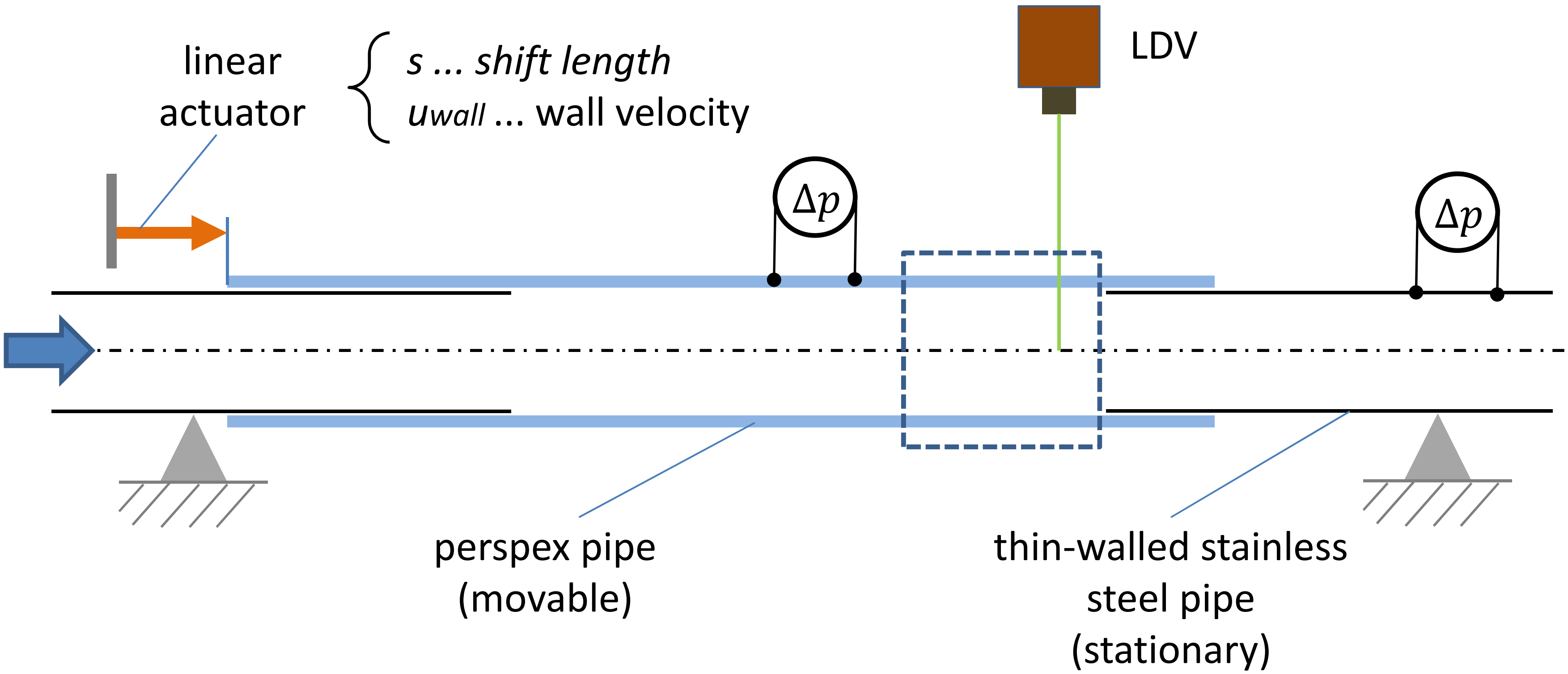
Injection through a radial gap: mechanism

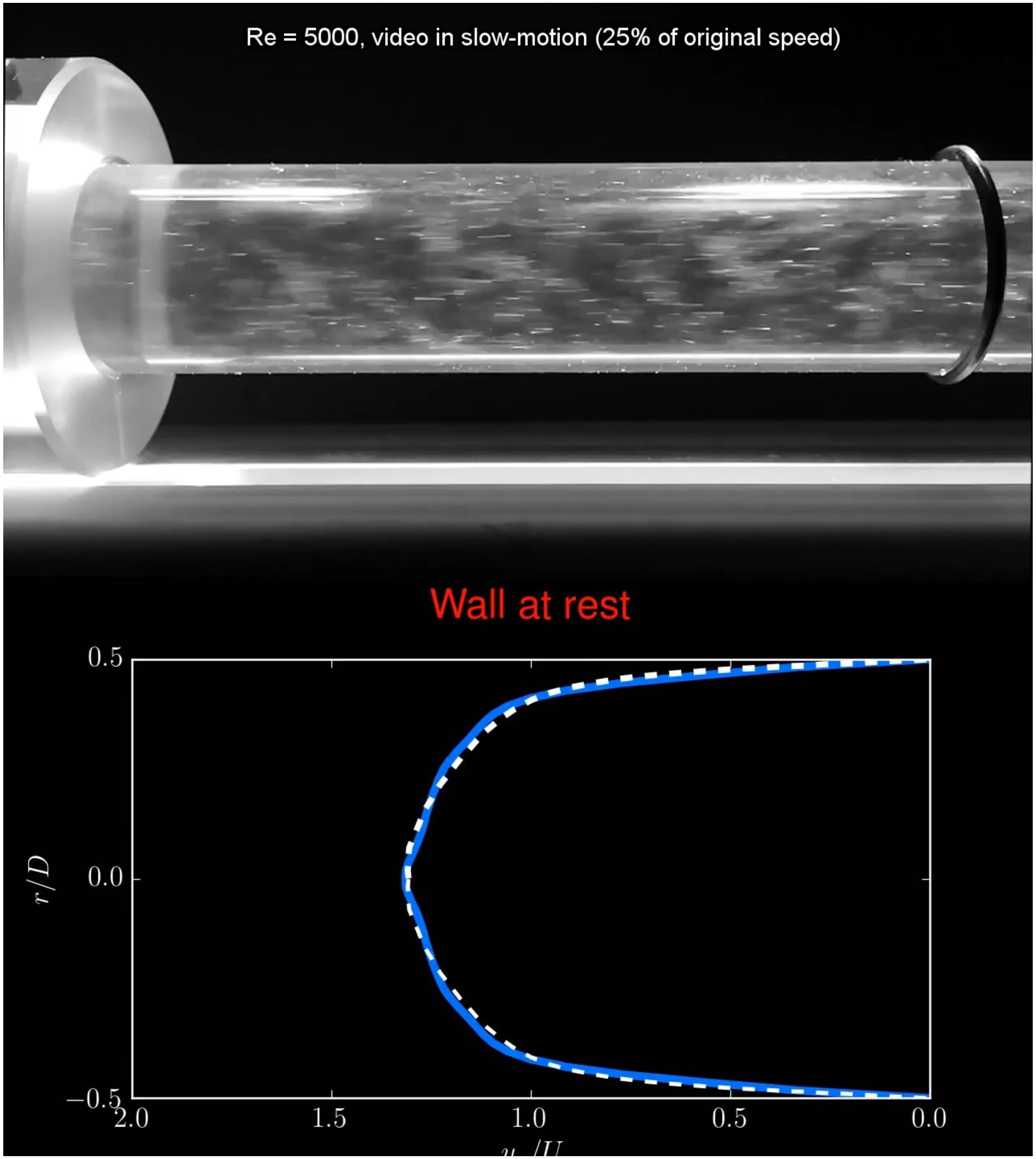


Re = 5000, injection off-on

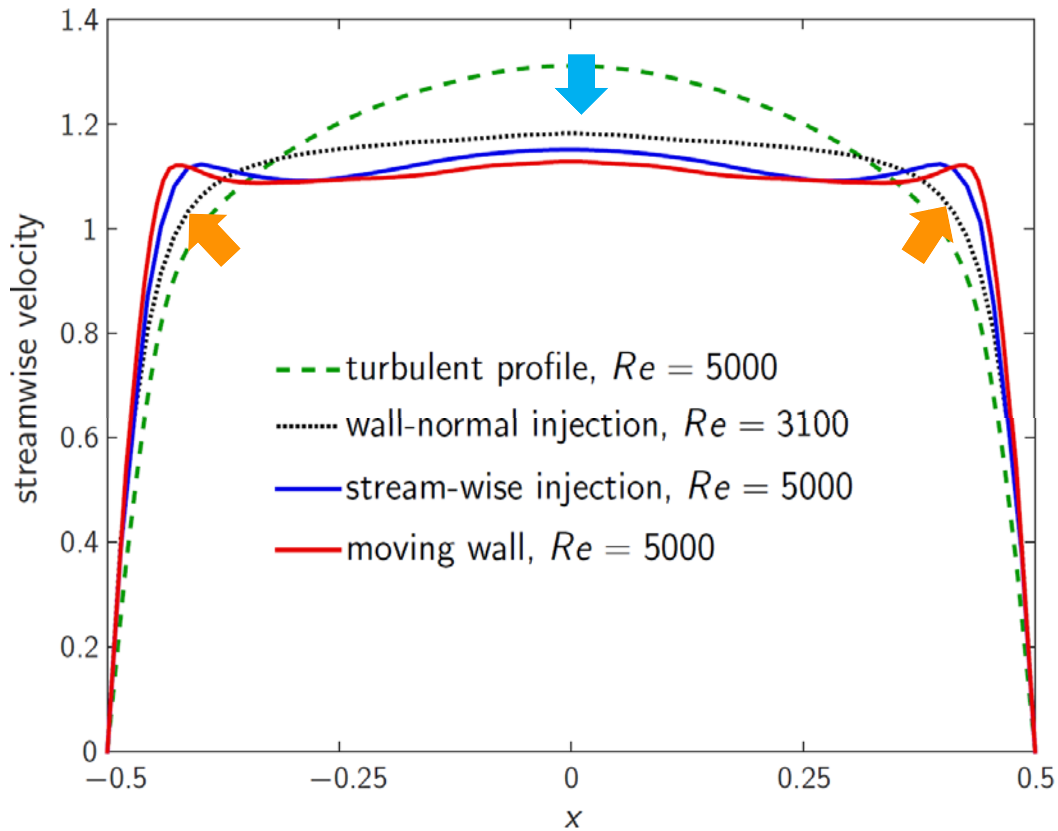


Shifting wall: control mechanism




Re = 5000, video in slow-motion (25% of original speed)
Wall at rest
r/D
0.5
0.0
−0.5
2.0
1.5
1.0
0.5
0.0

Common feature of all control mechanisms



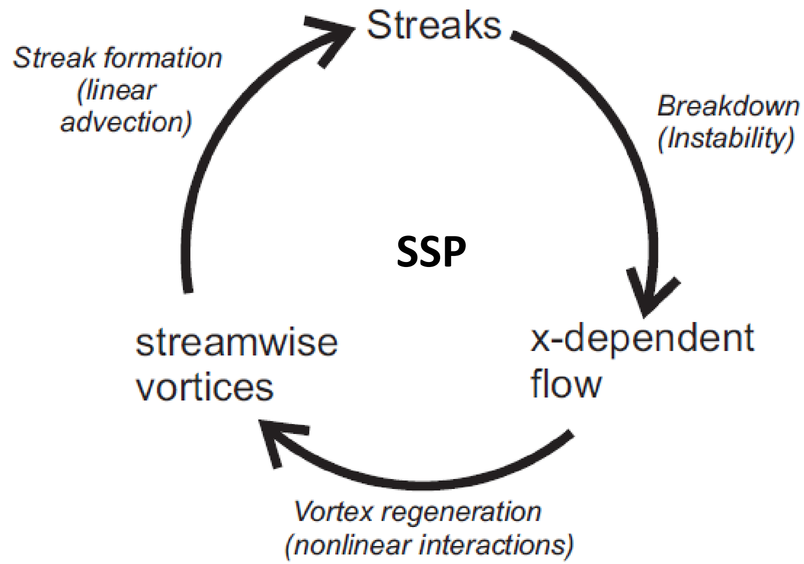
streamwise velocity profile more flat/blunt due to
$\Rightarrow$ increased turbulence intensity and/or
$\Rightarrow$ incr. velocity at the wall/decr. vel. in the center

$\Rightarrow$ steeper gradient at the wall, increased friction

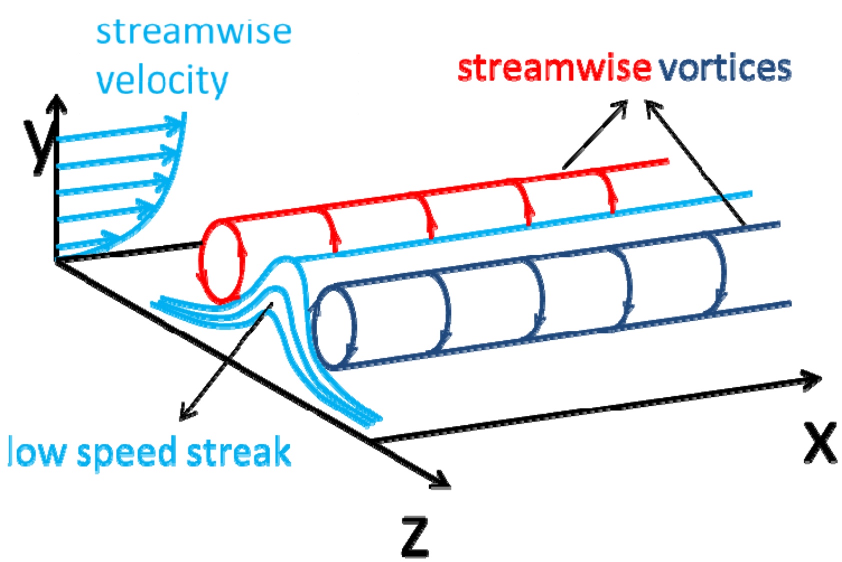
The self sustaining process

Lift up mechanism
transient growth

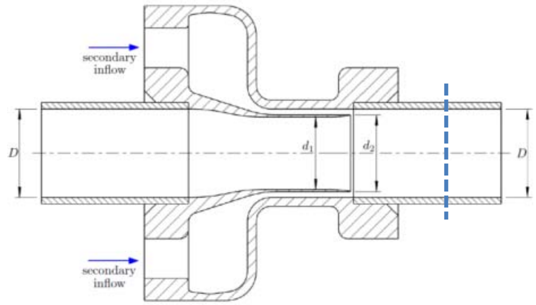
See e.g. Brandt E.J.Mech. B/Fluids 2014,
Reddy&Henningson JFM 1993,
Trefethen et al. Science 1994….

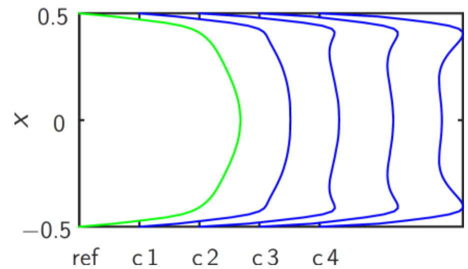


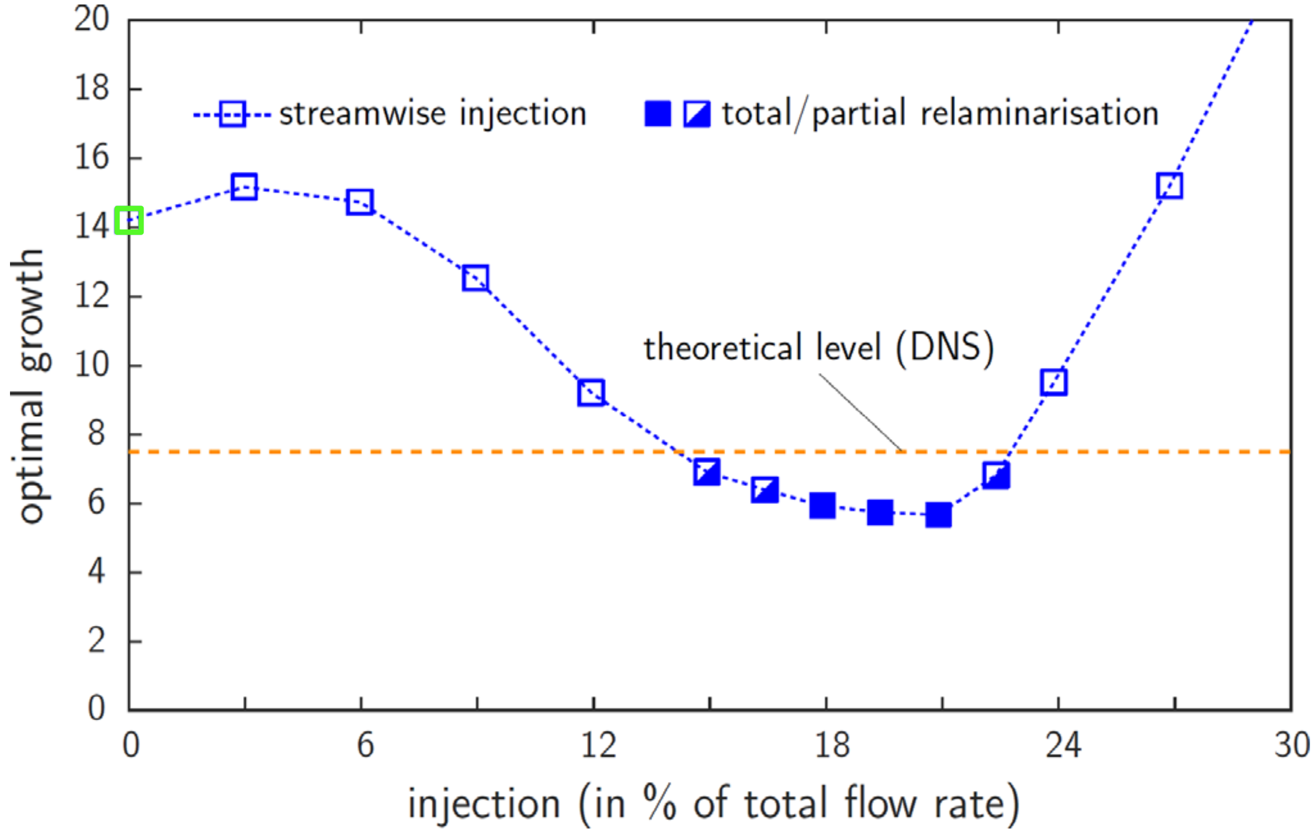
Hamilton, Kim, Walleffe JFM 1995



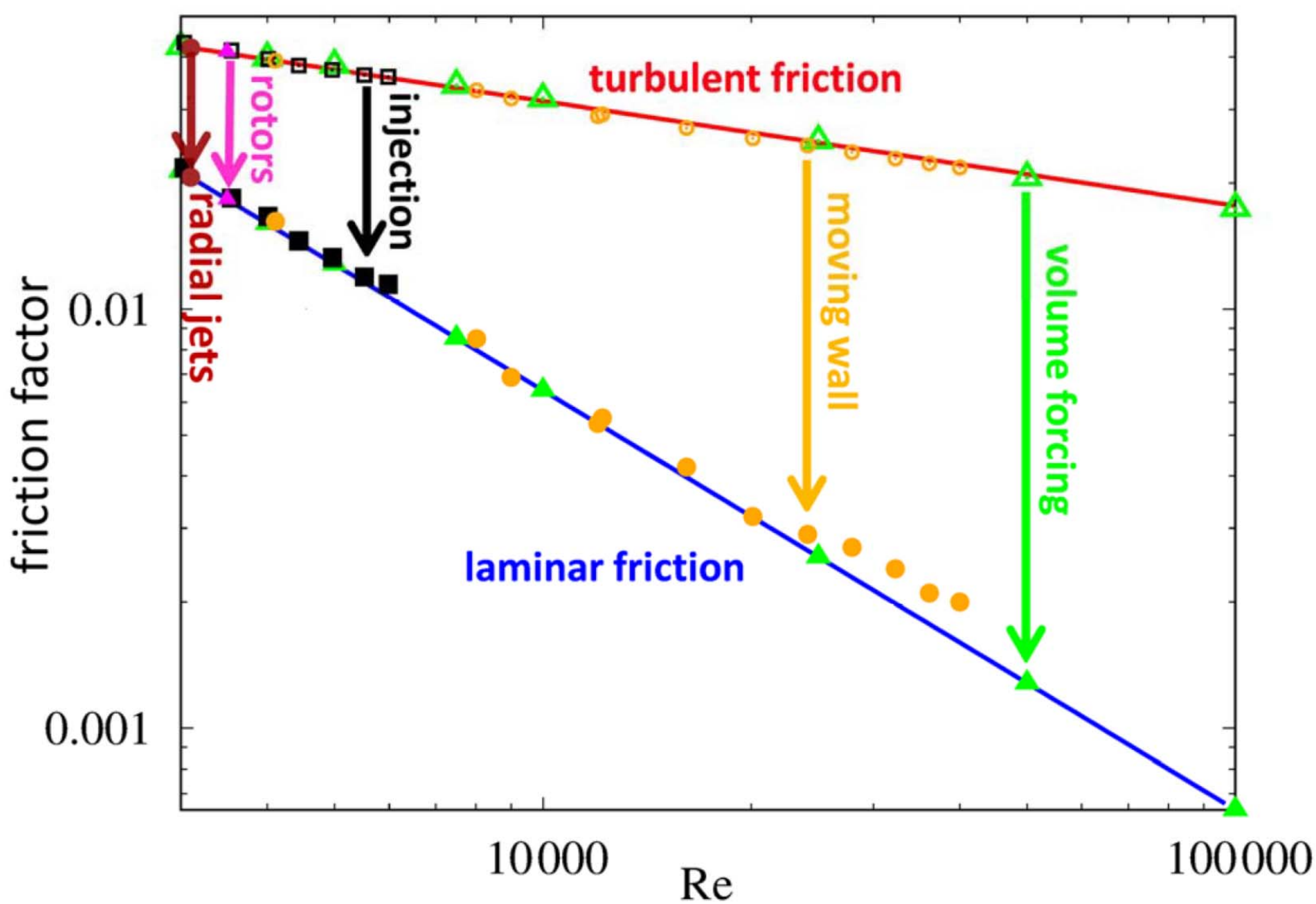
Transient/optimal growth







Drag reduction



Kühnen, Song, Scarselli, Budanur, Riedl, Willis, Avila & Hof Nature Physics 2018