Bifurcations and multistability in turbulence

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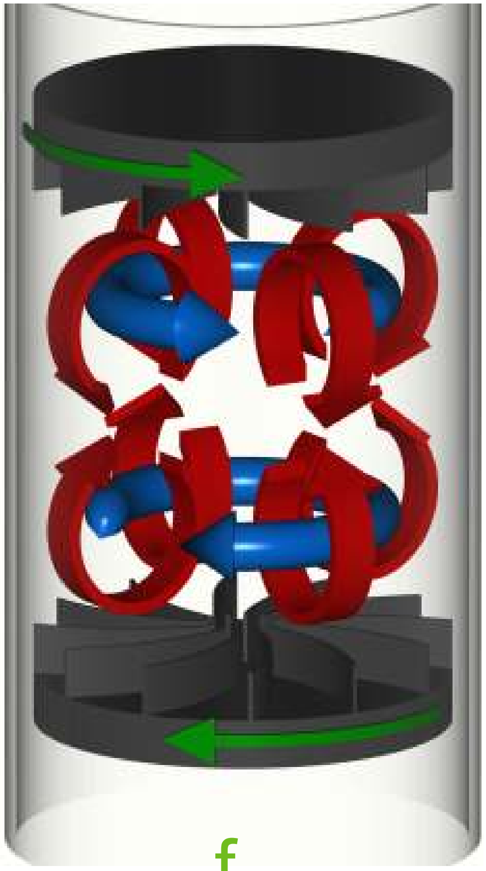
Bifurcations and multistability in turbulence

Bifurcations in turbulent flows:

1. von Karman : bifurcation between mean flows
2. Couette flows: turbulent spiral and stripes
3. VKS: - dynamo action
   - multistability

Turbulent von Karman flow



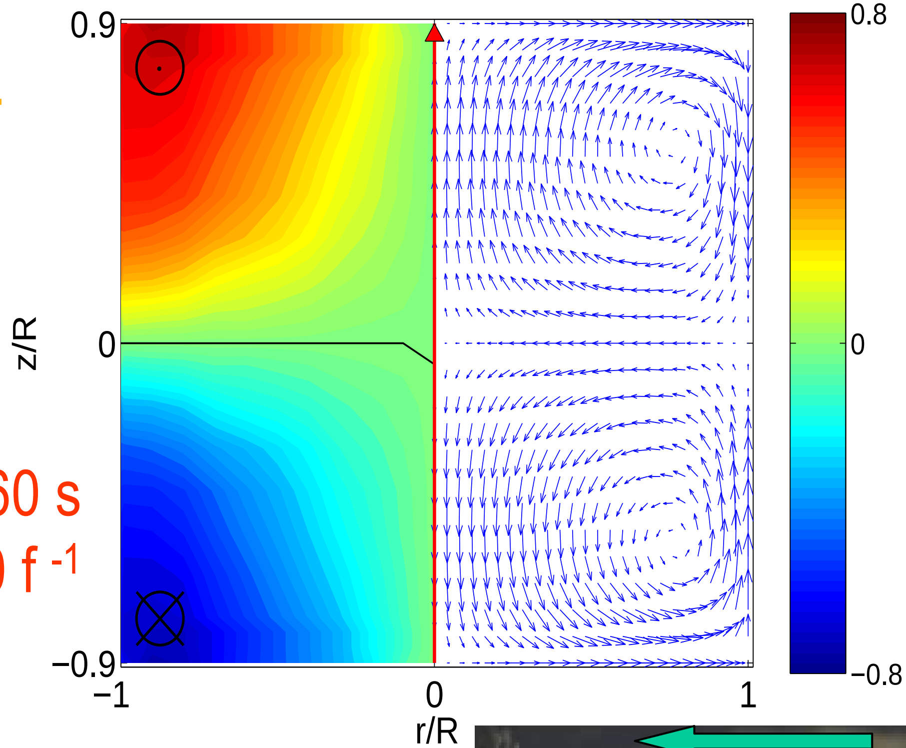
- Axisymmetry
- Rπ symmetry / radial axis

- R_c=100 mm
- H=180 mm
- f=2-20 Hz
- Re= $2\pi R_c f^2 / \nu = 10^2 - 10^6$
- fluid: water and glycerol-water

Inertial stirring

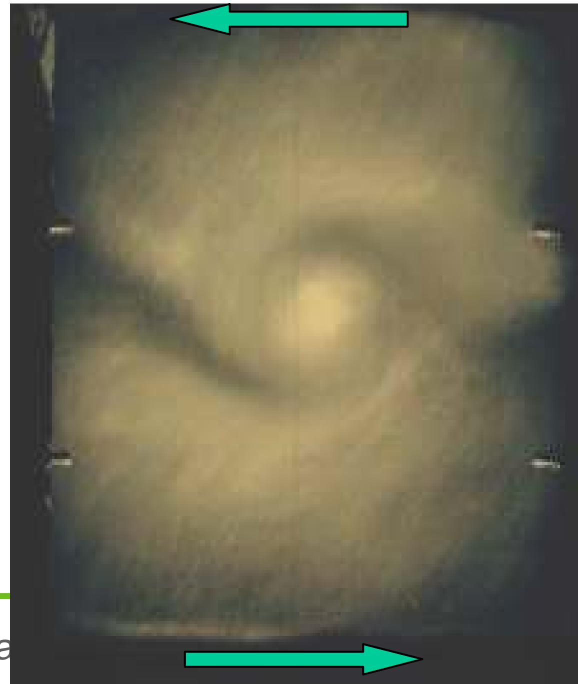
3 « scales »

$$Re \simeq 10^6$$



Mean on 60 s
500 f^{-1}

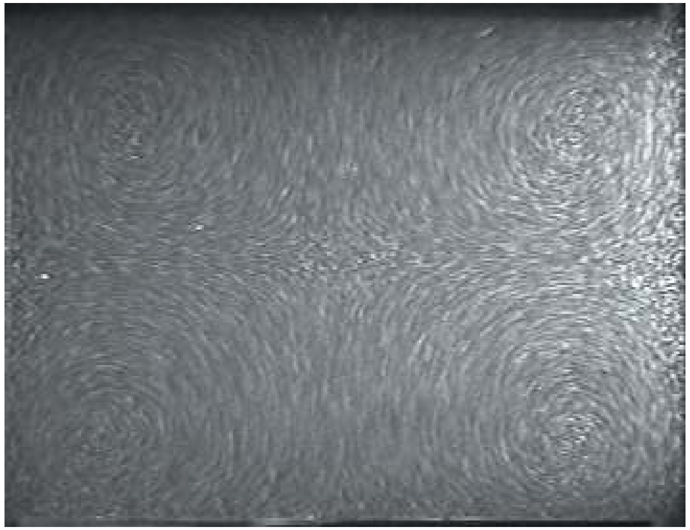
Mean on 1/20 s
1/2 f^{-1}

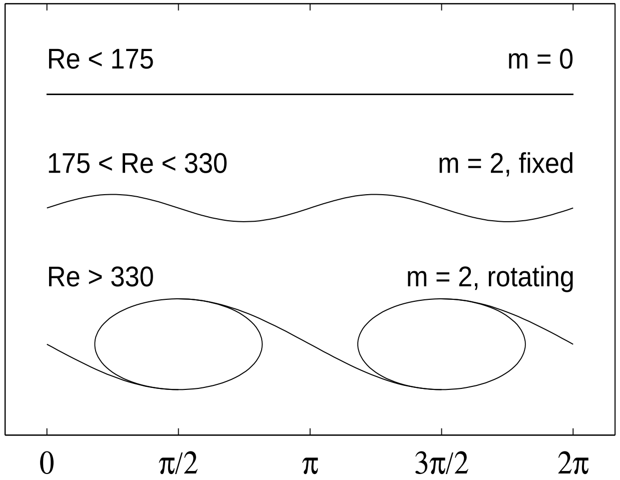


Mean on : 1/500 s
1/50 f^{-1}

First bifurcations and symmetry breaking

meridian plane: poloïdal recirculation





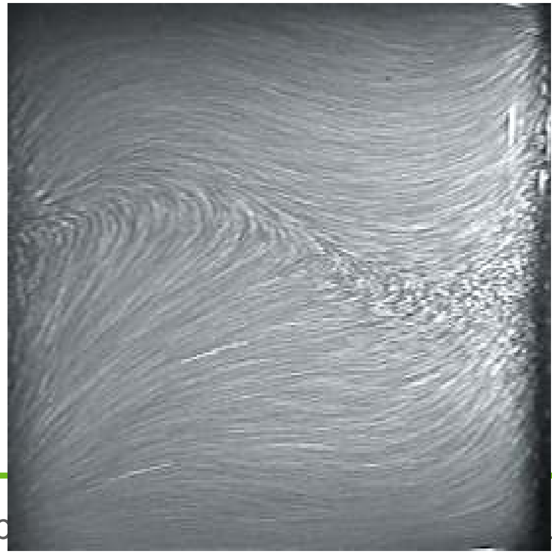
Tangent plane : shear layer

Re = 90

Stationary axisymmetric

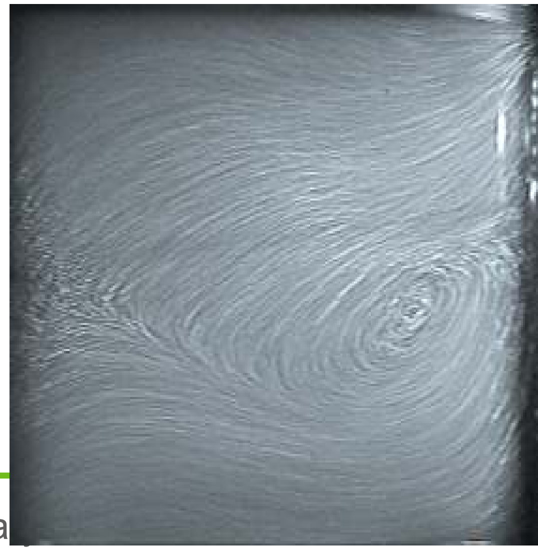
Re = 185

m = 2 ; stationary



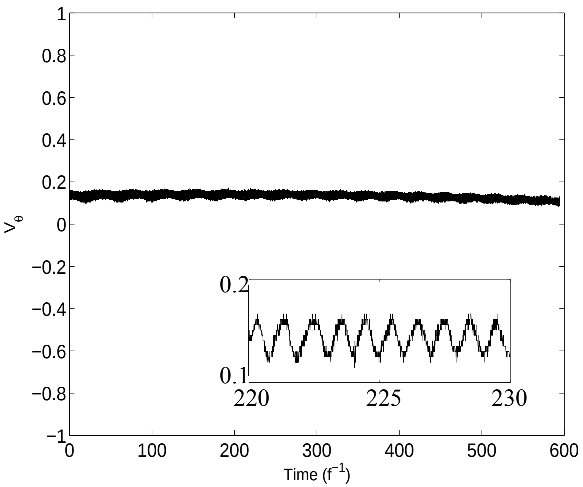
Re = 400

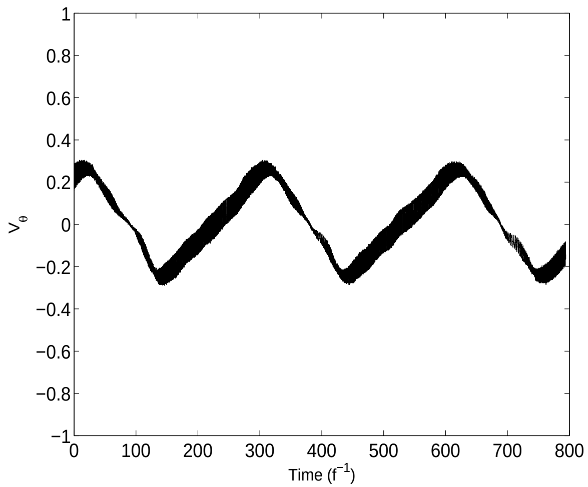
m = 2 ; periodic

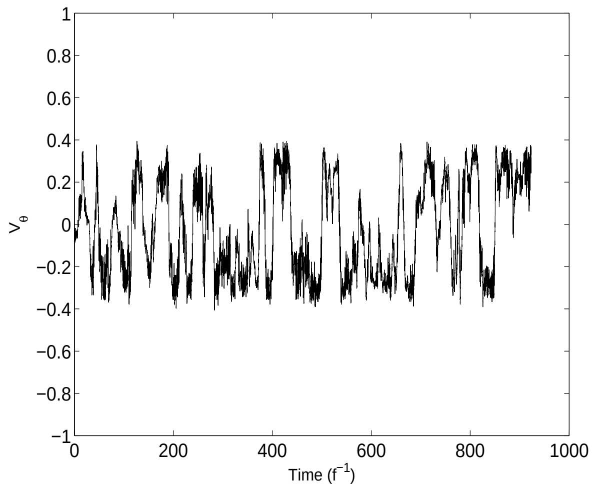


Time spectra as a function of Re

v_θ en $\{r = 0.9; z = 0\}$



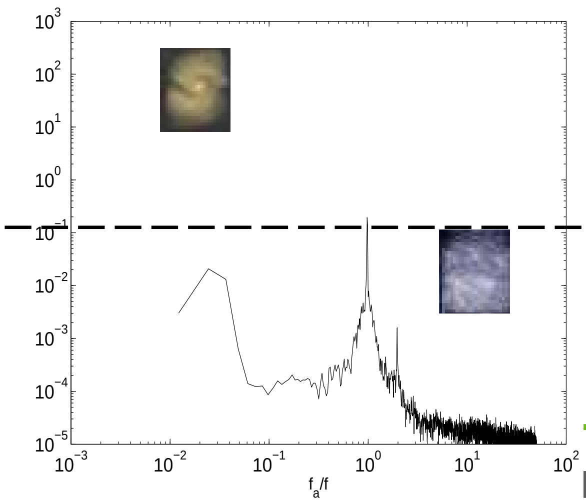


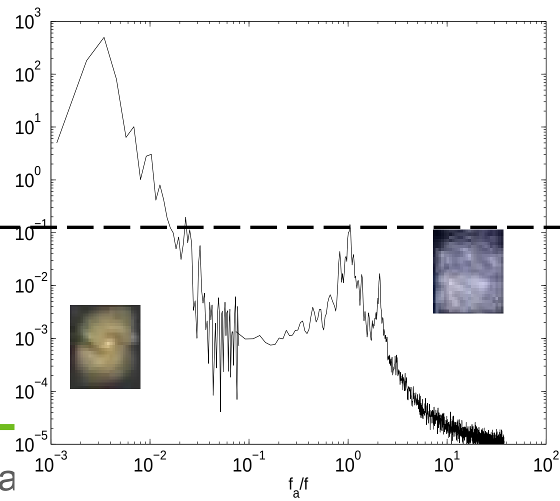


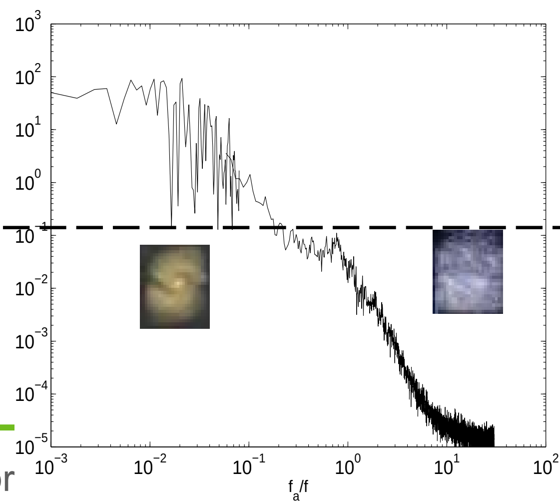
Re = 330
Periodic

Re = 380
Quasi-Periodic

Re = 440
Chaotic







Time spectra as a function of Re

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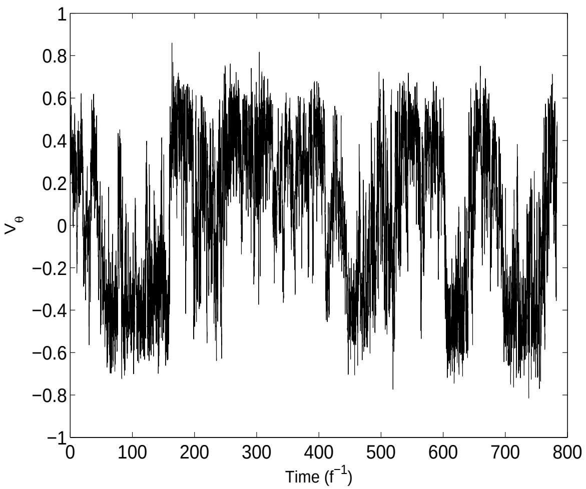
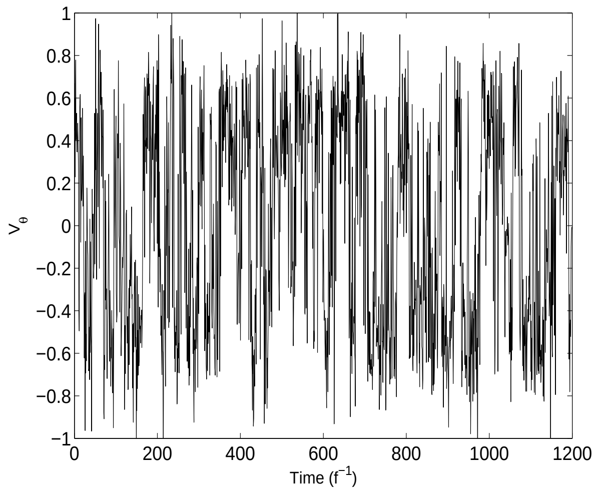
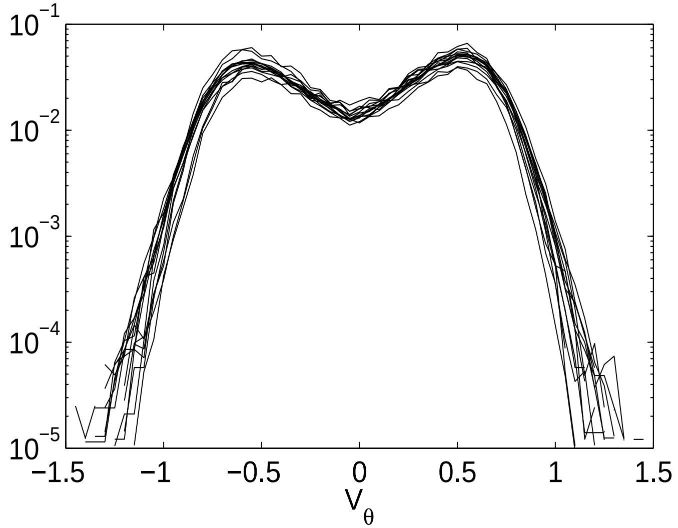






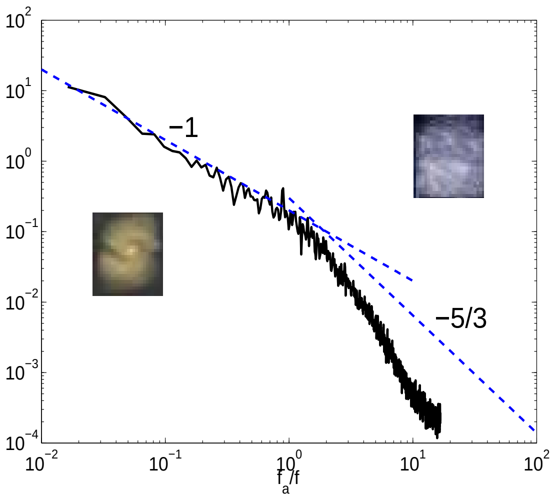
Re = 1000

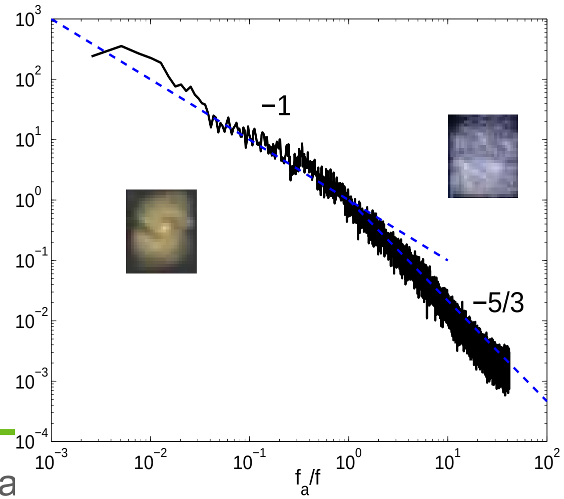
Chaotic

Re = 4000

Turbulent

2000 < Re < 6500

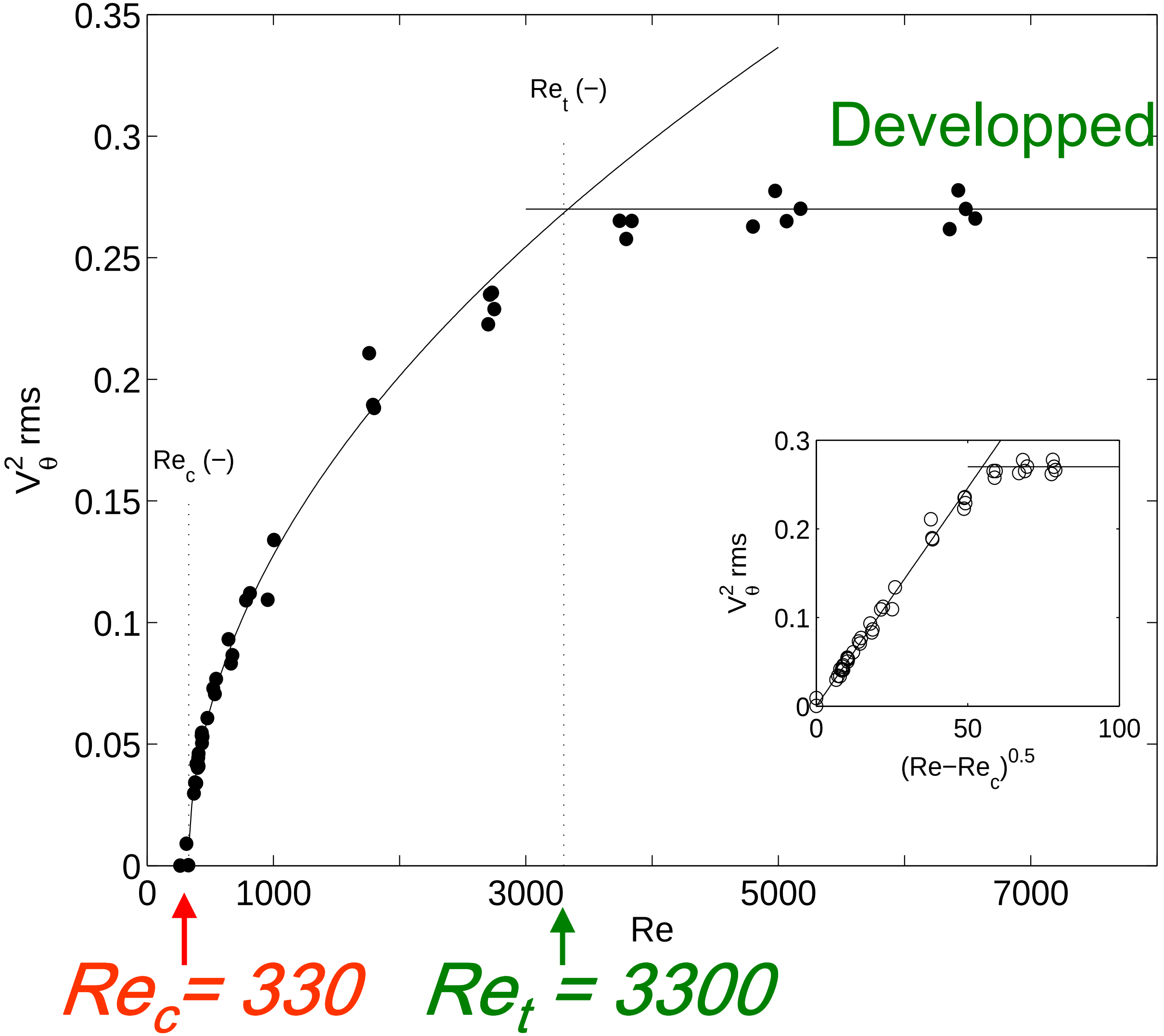




Bimodal distribution :

signature of the turbulent shear

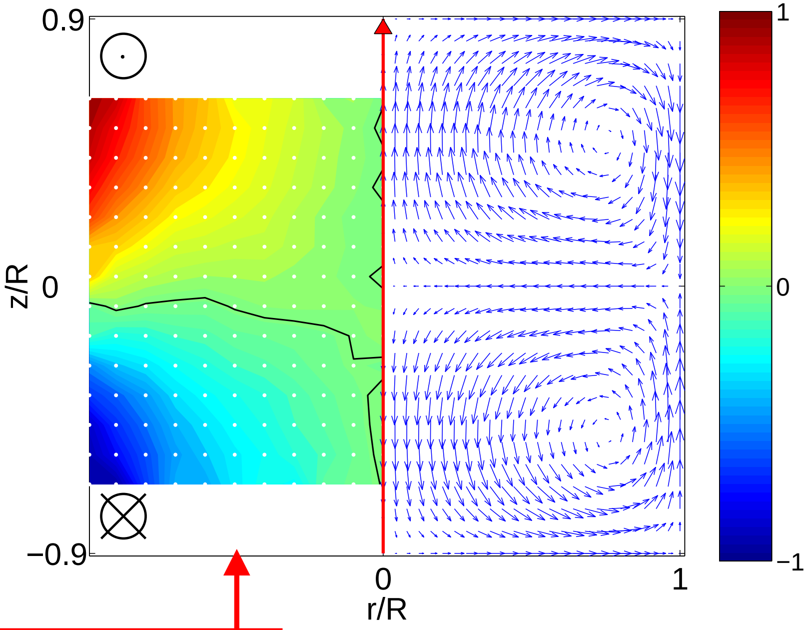
Transition to turbulence: fluctuations kinetic energy



Globally supercritical transition via a Kelvin-Helmoltz type instability of the shear layer and secondary bifurcations

Ravelet et al. JFM 2008

Turbulent Bifurcation of the mean flow

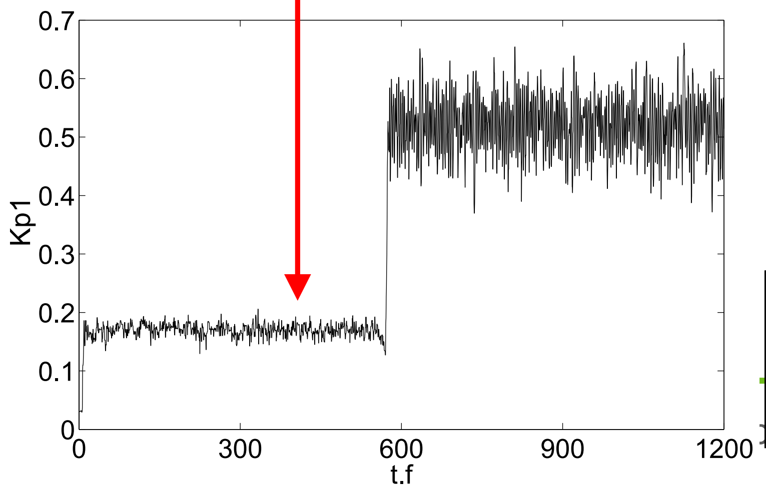


Symmetry broken:
2 different mean flows
exchange stability.

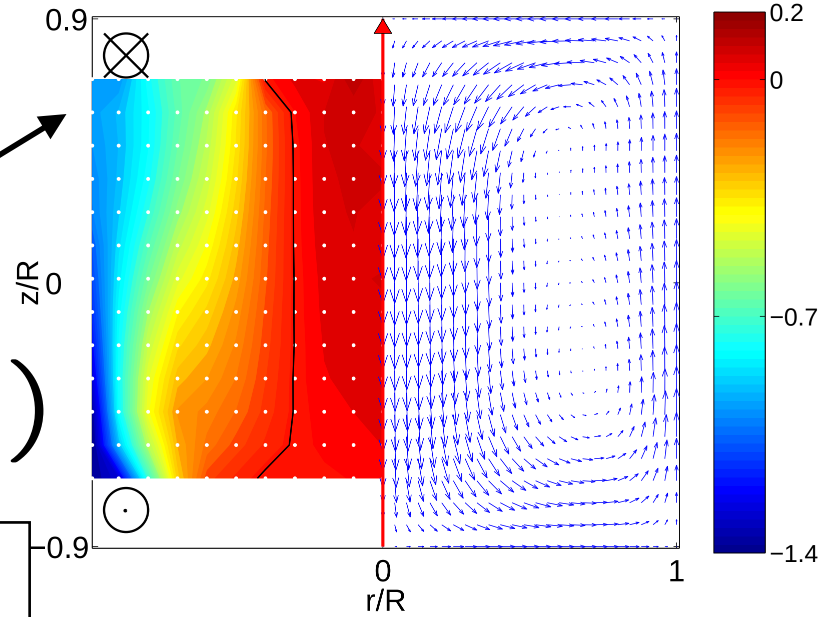
Bifurcated flow (b) : no more shear layer broken symmetry

two cells
one state

(s)



(b_2)

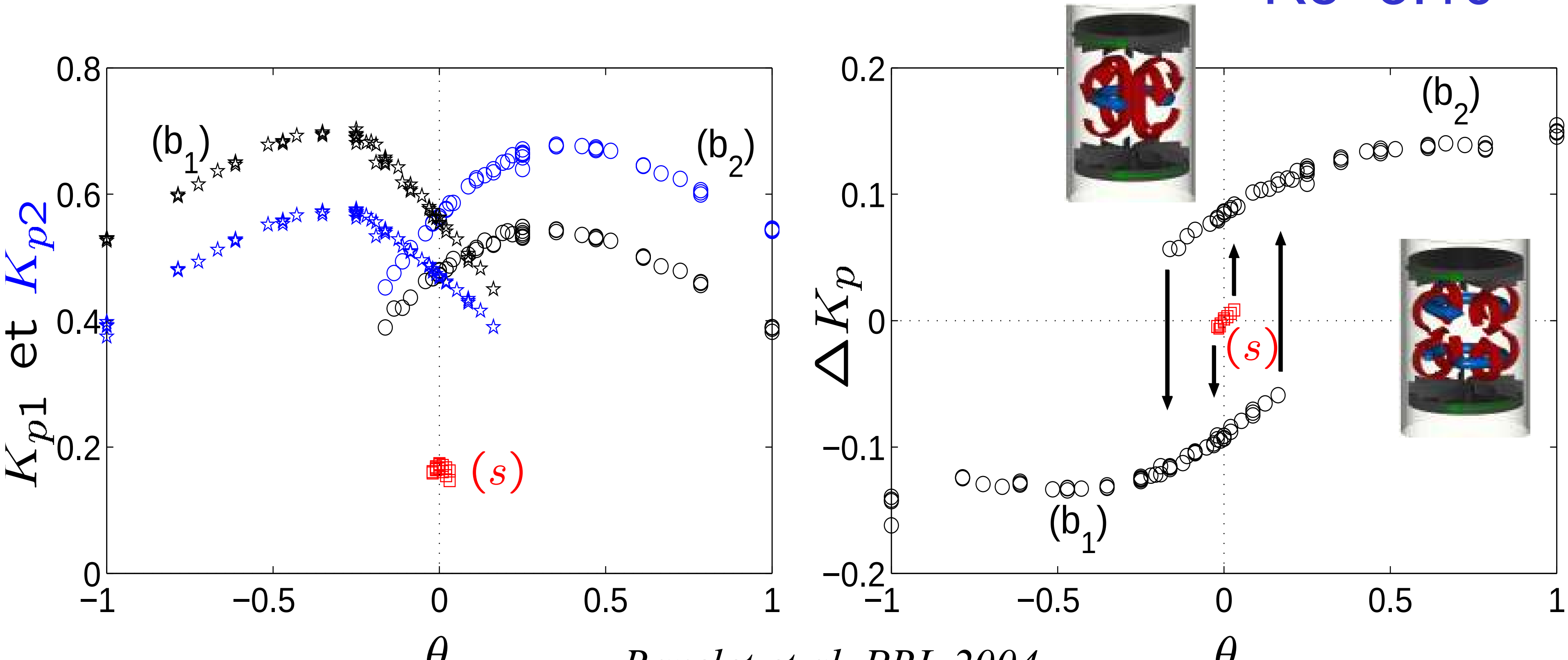


one cell
two states

Turbulent Bifurcation: memory effect?

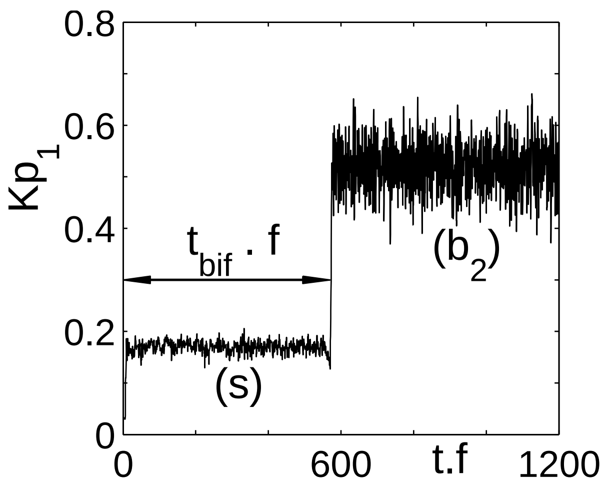
- $Kp = \text{Torque}/\rho R_c^5 (2\pi f)^2$
- $\theta = (f_2 - f_1) / (f_2 + f_1)$
- $Re = (f_1 + f_2)^{1/2}$

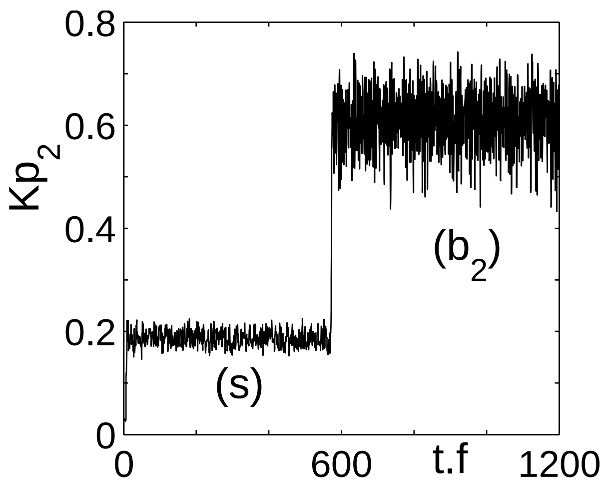
Re=3.10⁵



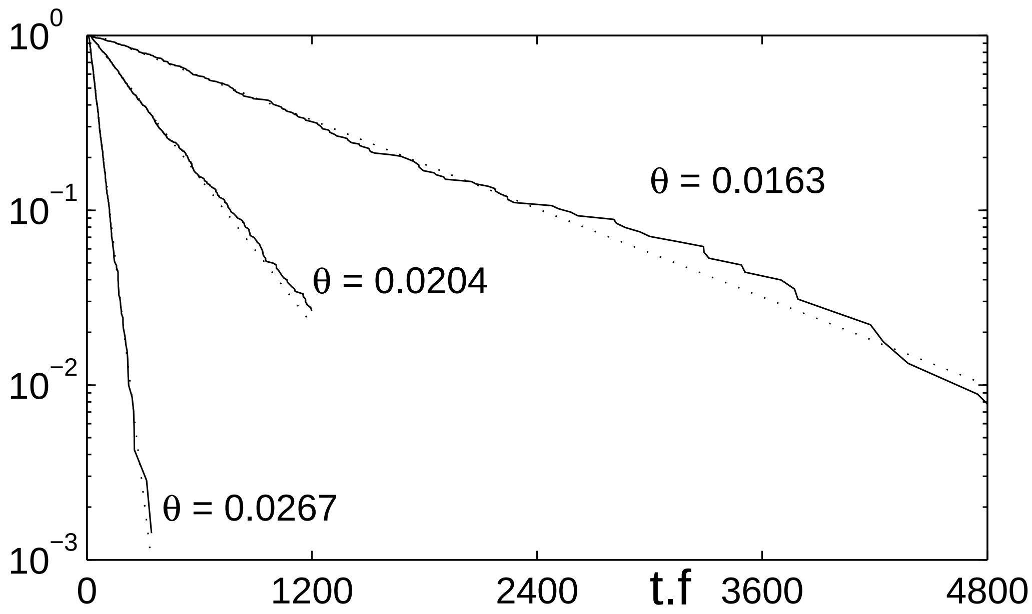
Ravelet et al. PRL 2004

Stability of the symmetric state





Statistics on 500 runs for different θ



Cumulative distribution functions of bifurcation time t_{bif}:

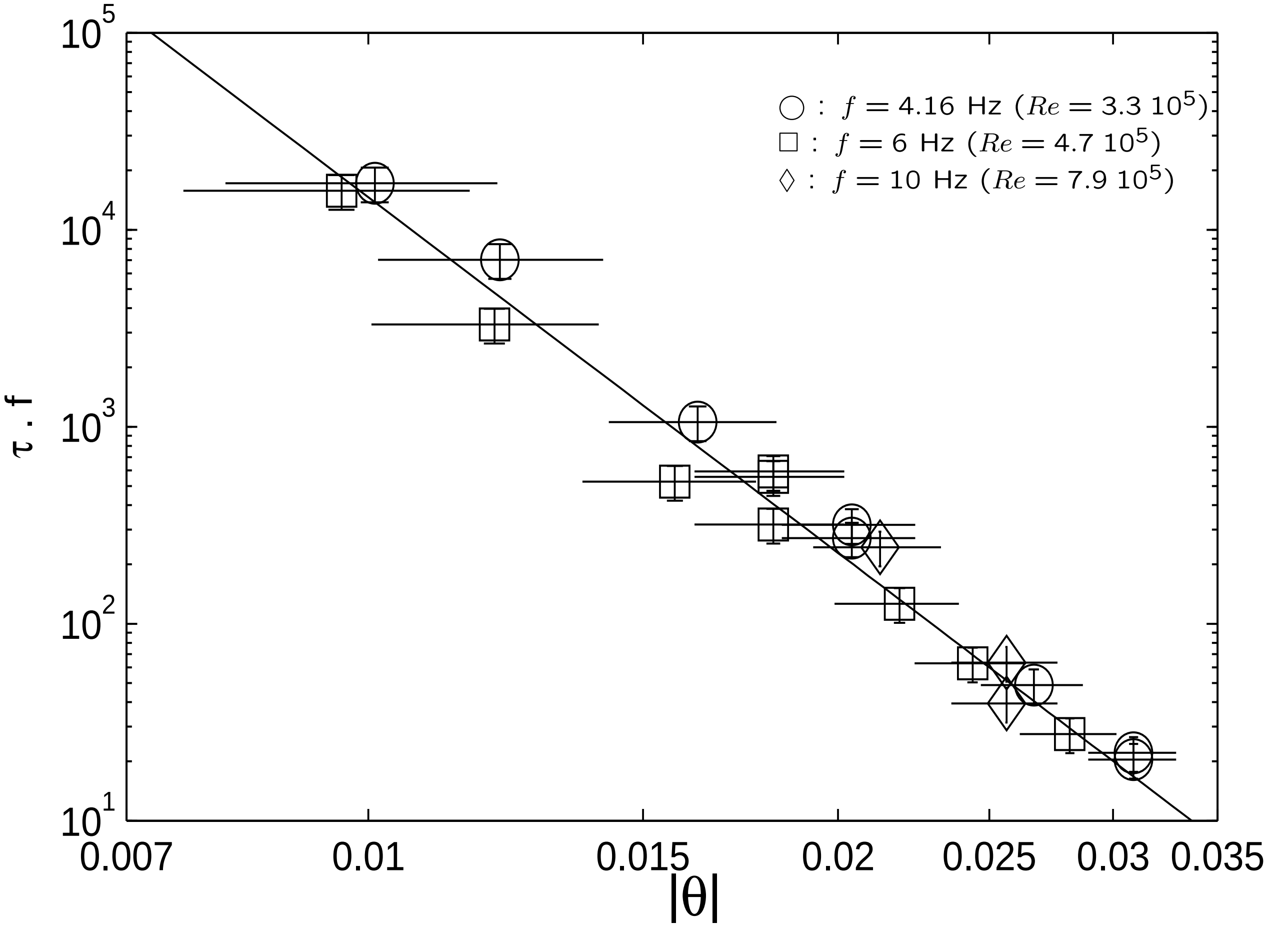
$P(t_{bif}>t)=A\ exp(-(t-t_0)/\tau)$

- $t_0 f \sim 5$
- τ: characteristic bif. time

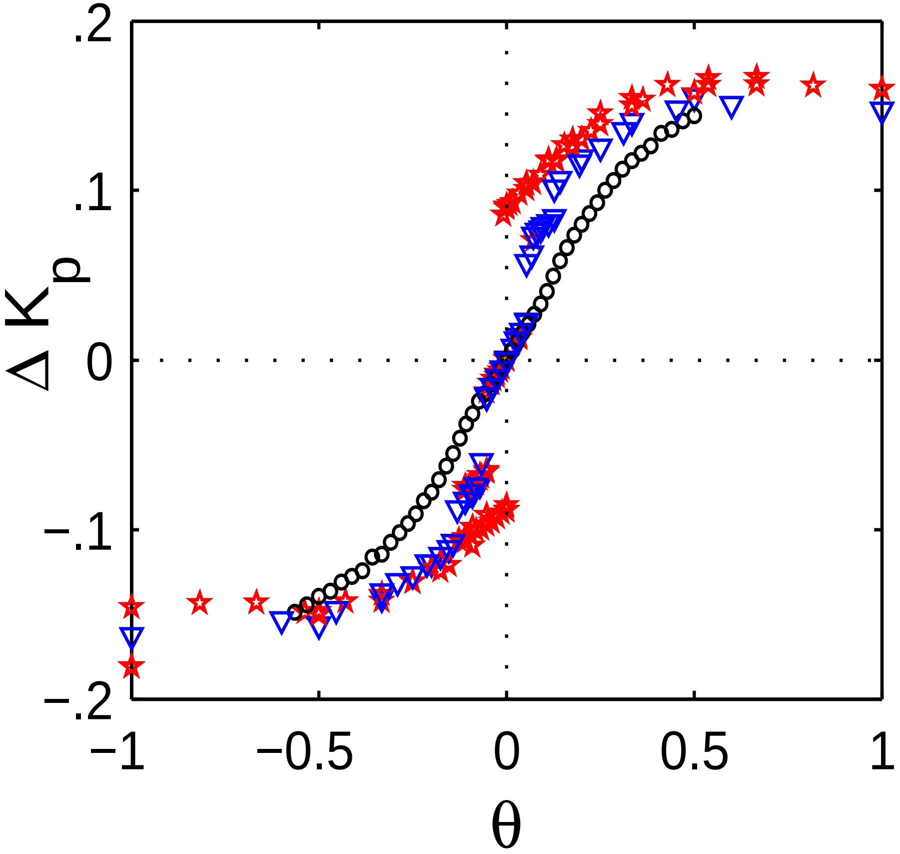
Stability of the symmetric state

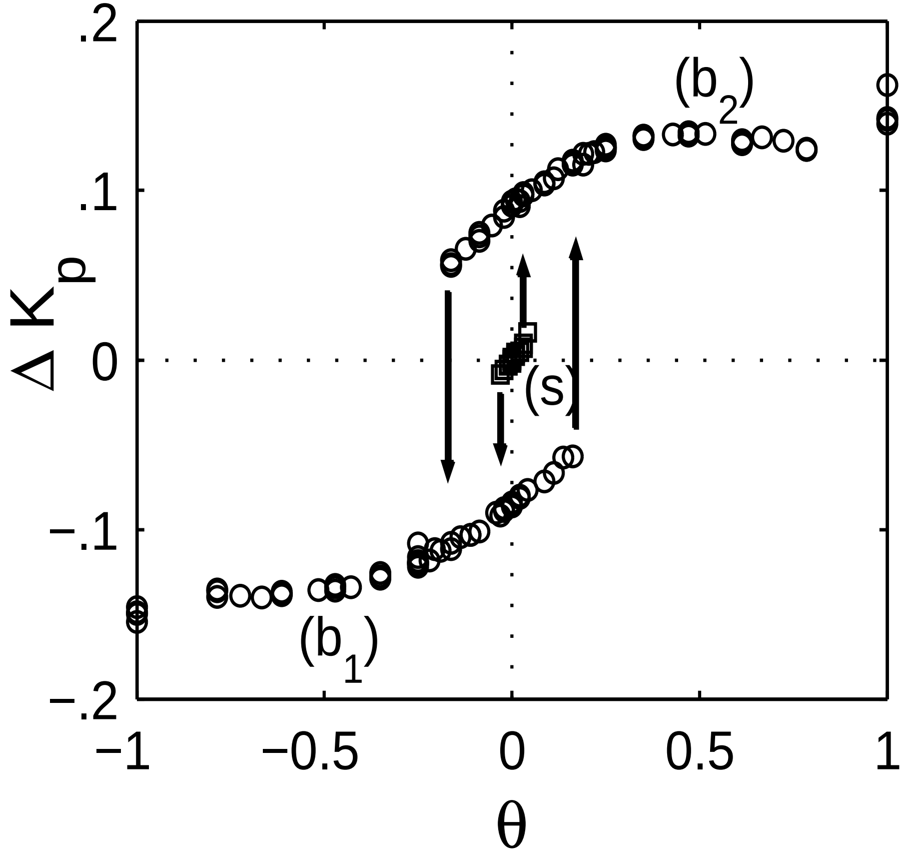
- fit: power law
exponent = -6

- symmetric state
marginally stable
$\tau \rightarrow \infty$ when $\theta \rightarrow 0$



Mutistability = f(Re)

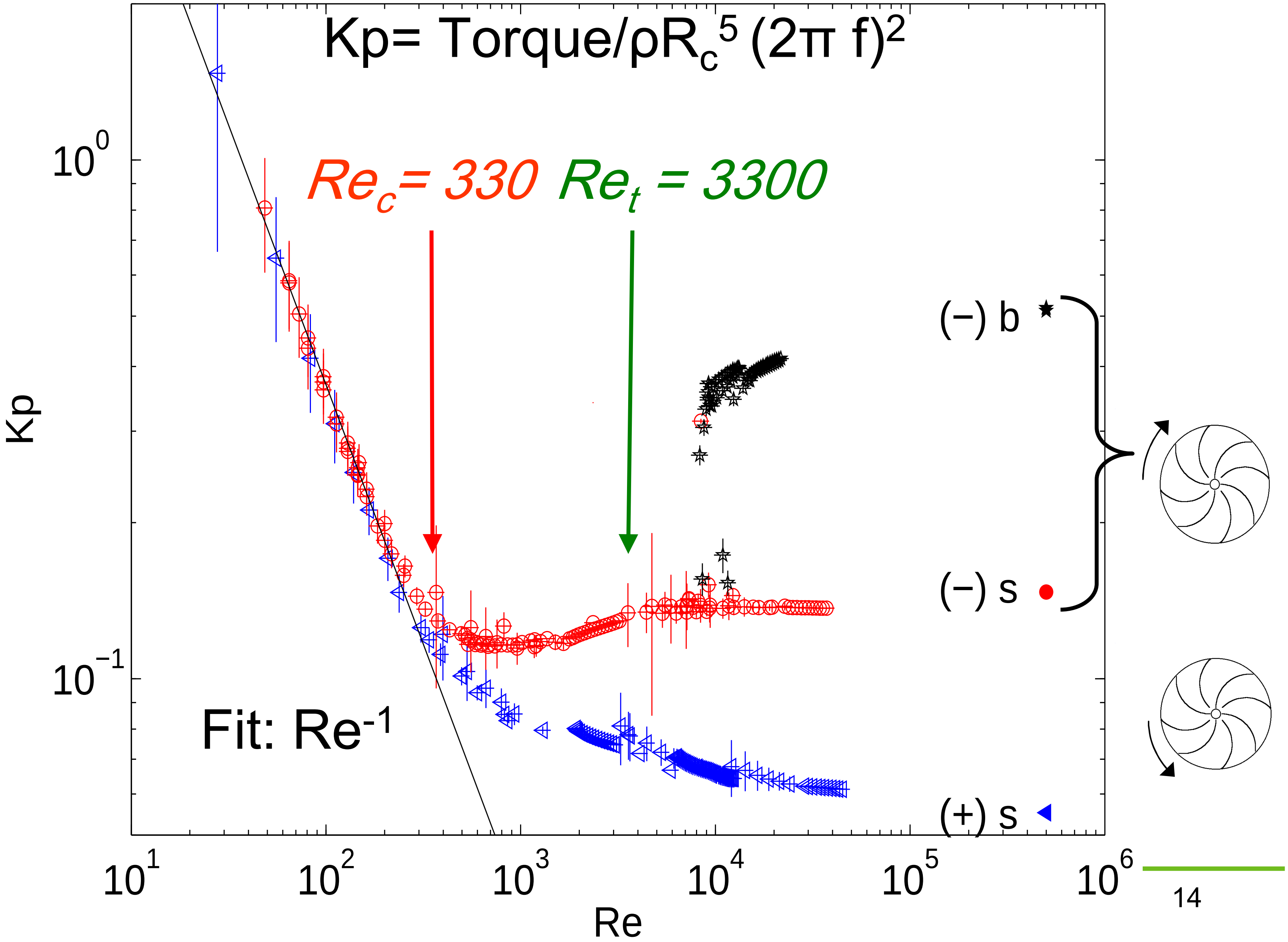




○ : $Re = 800$
▽ : $Re = 5\,000$
★ : $Re = 10\,000$

$Re = 3 \times 10^5$

Multiplicity of solutions



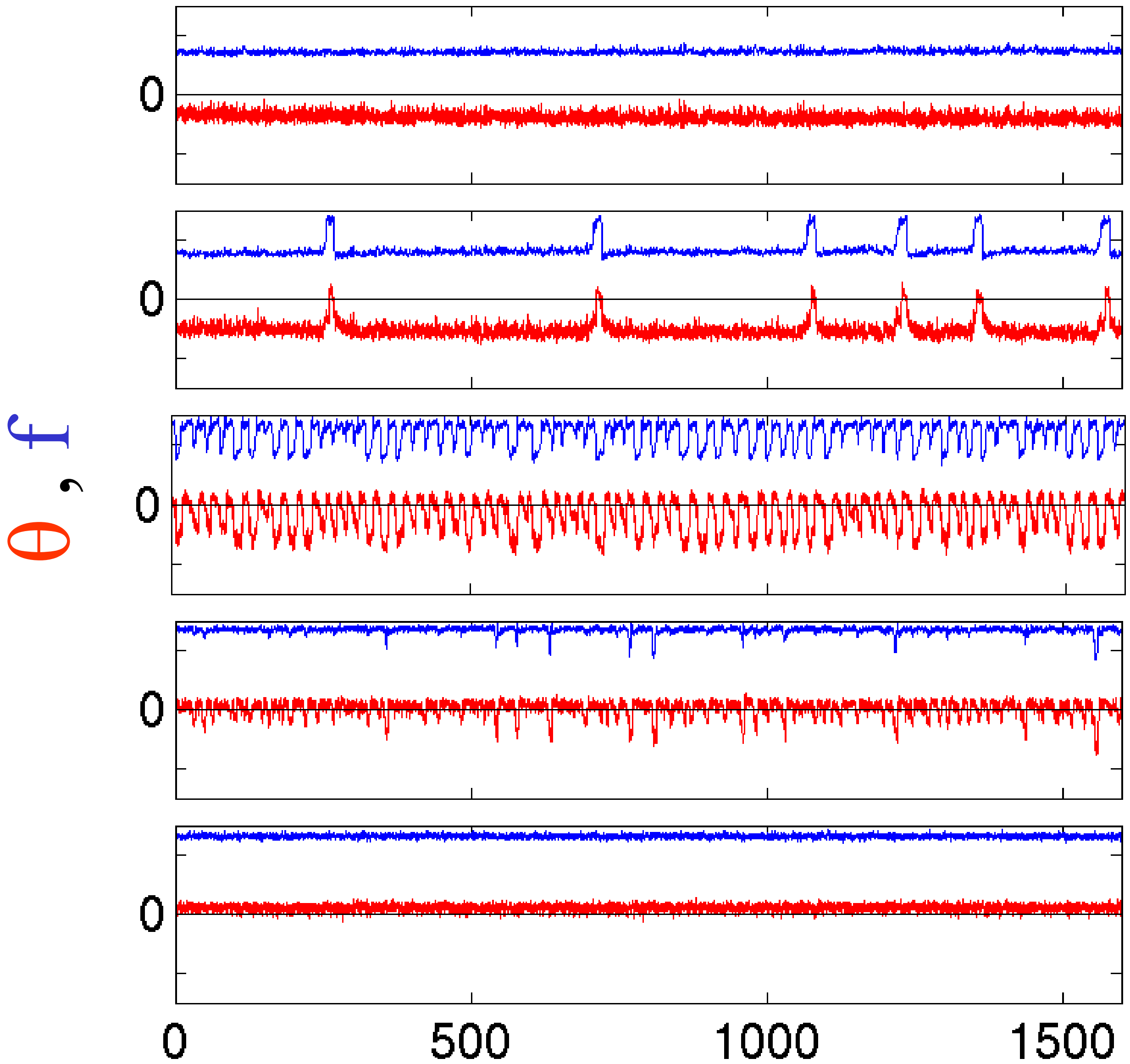
Torque regulation: stochastic transitions
1cell state → 2 cells states

$Kp_1 \neq Kp_2 \Rightarrow$ 1 cell

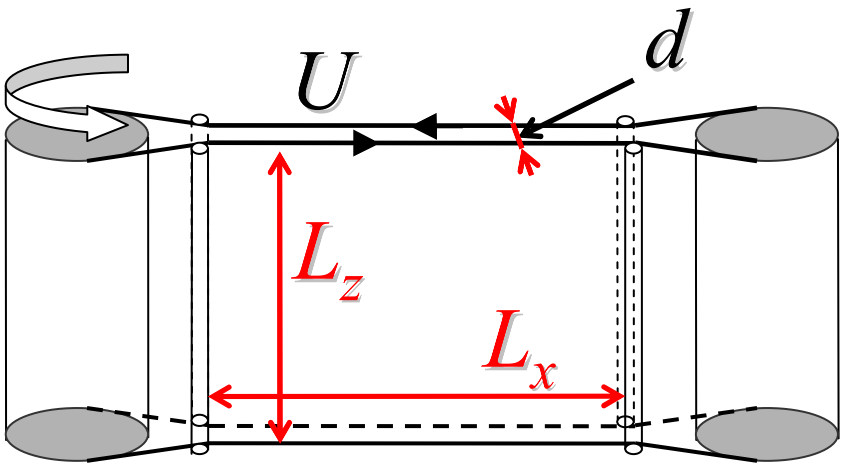
$Kp_1 \sim Kp_2$,
"oscillation"
between 2 states

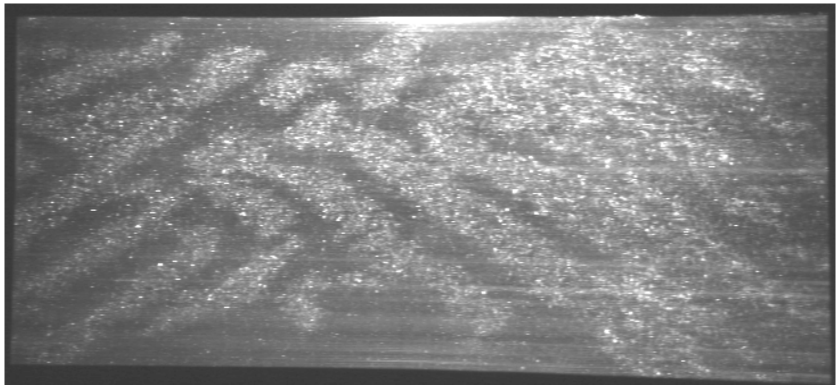
$Kp_1 \approx Kp_2 \Rightarrow$ 2 cells

Concep



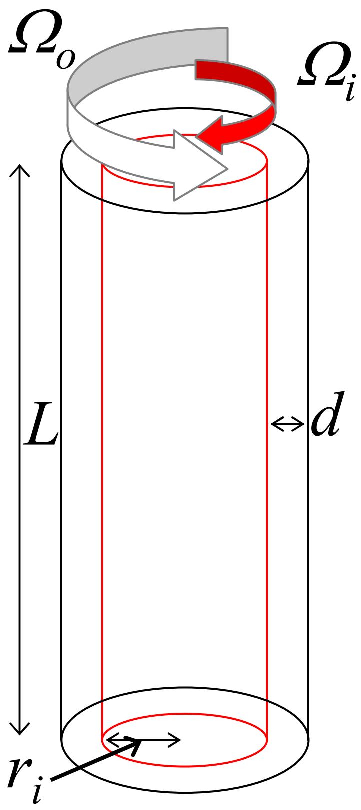
Couette flows

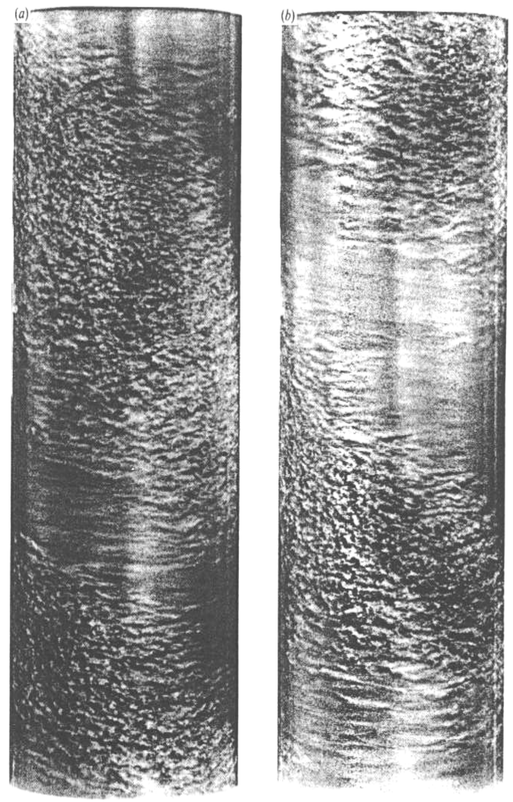




$$\Gamma_x = L_x / d$$

$$\Gamma_z = L_z / d$$



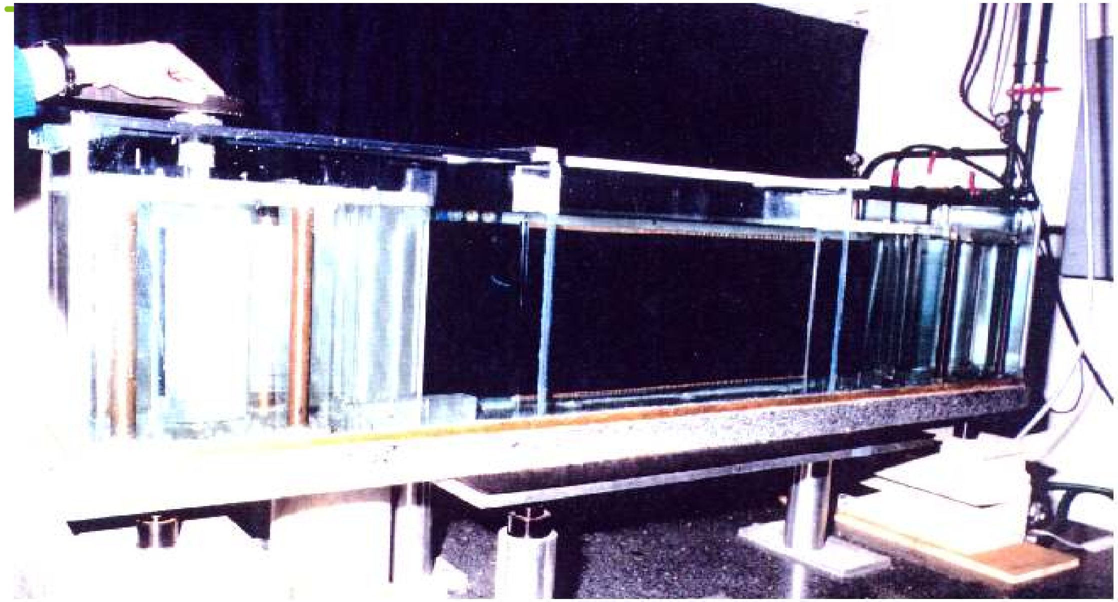


$$\eta = r_i / r_o$$

$$\Gamma_\theta = \pi (r_i + r_o) / d$$

$$\Gamma_z = L / d$$

Plane Couette flow setup



$d = 2h = 7\ ,\ 3.5\ ,\ 1.5\ \text{mm}$
$L_x = 578\ \text{mm}$
$L_z = 255\ \text{mm}$

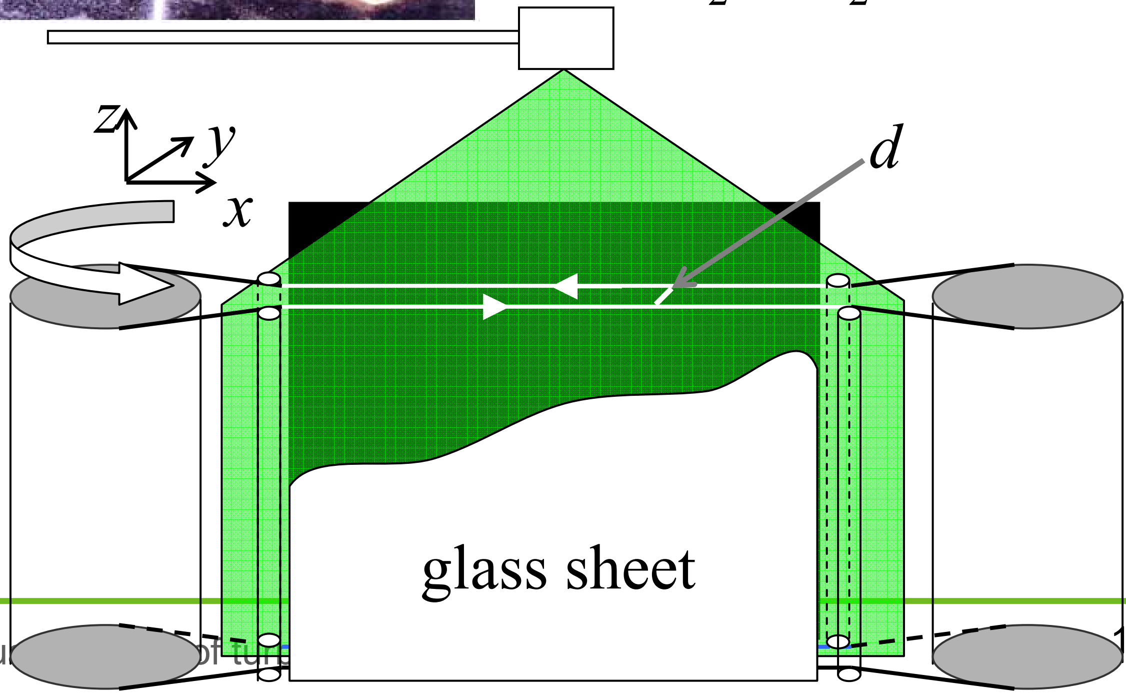
$$\Gamma_x = L_x / d = 385$$

$$\Gamma_z = L_z / d = 170$$

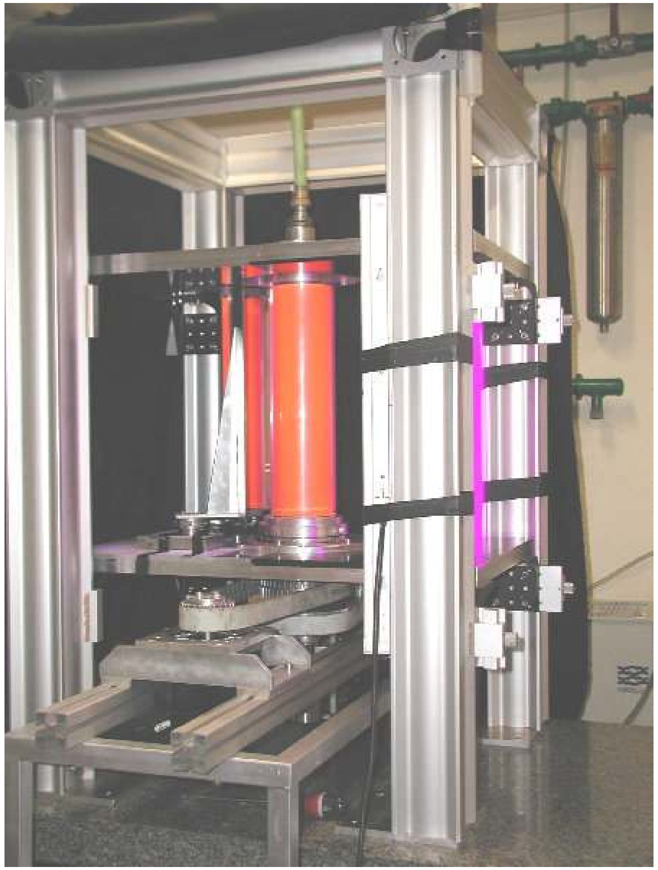
1 control parameter :

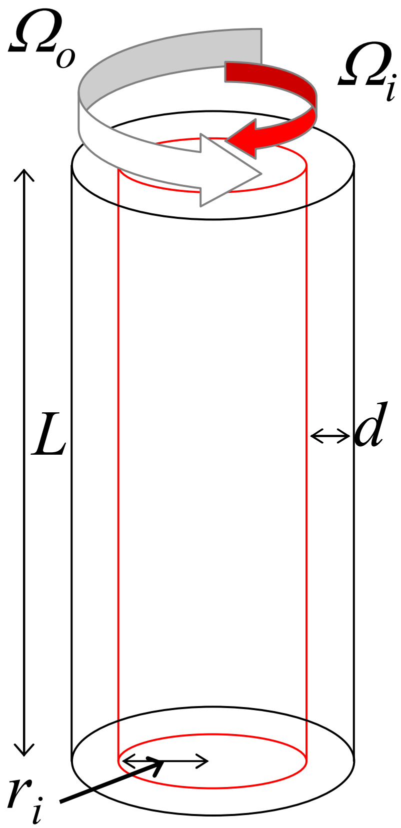
$$R_{Cp} = \frac{Uh}{\upsilon}$$

Daviaud PRL 92



Cylindrical Couette setup





$$\eta = r_i / r_o$$

$$\Gamma_\theta = \pi (r_i + r_o) / d$$

$$\Gamma_z = L / d$$

2 control parameters :

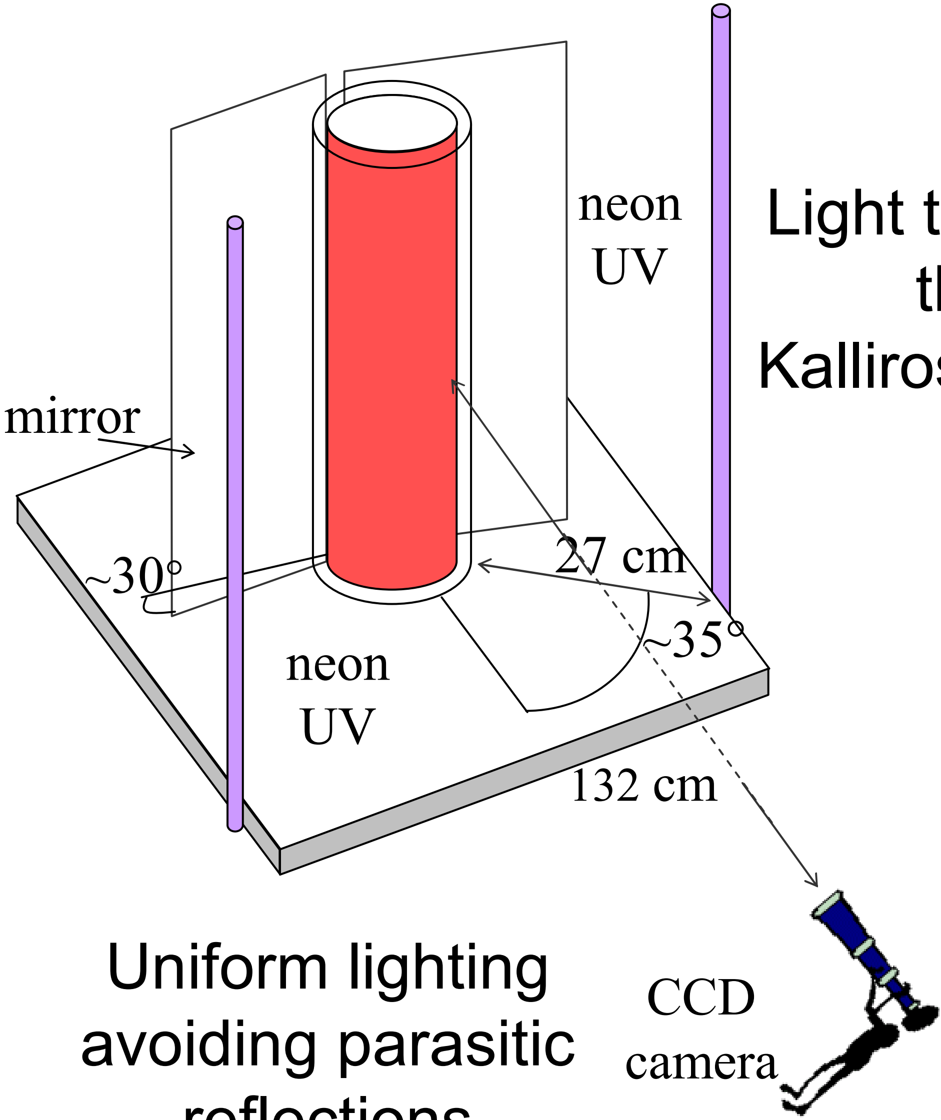
$$R_i = \frac{\Omega_i r_i d}{\upsilon} \quad \text{and} \quad R_o = \frac{\Omega_o r_o d}{\upsilon}$$

Setup	r_i (mm)	d (mm)	η	Γ_z	Γ_θ
$TC_{\eta 1}$	49.09	0.87	0.983	431	358
$TC_{\eta 2}$	48.11	1.85	0.963	203	167

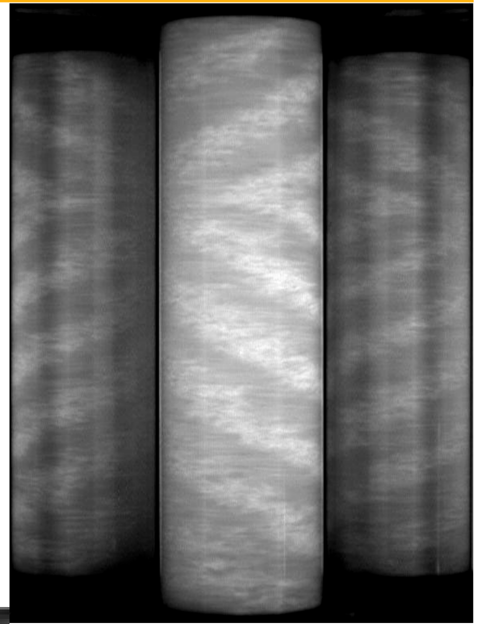
Physical control parameter :

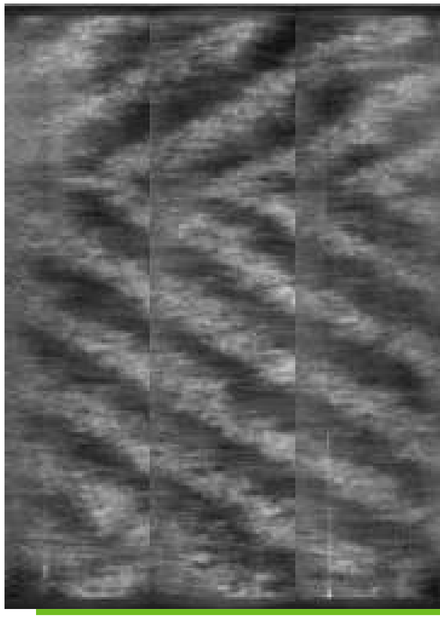
$$R_{TC} = \frac{|\eta R_o - R_i|}{2(1+\eta)}$$

Taylor-Couette flow visualization



Light transmission through Kalliroscope flakes



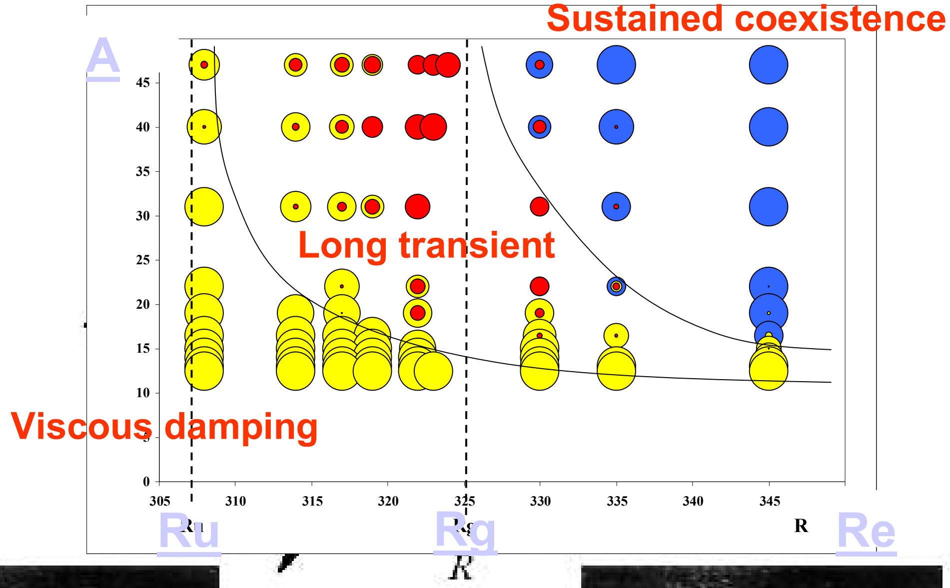


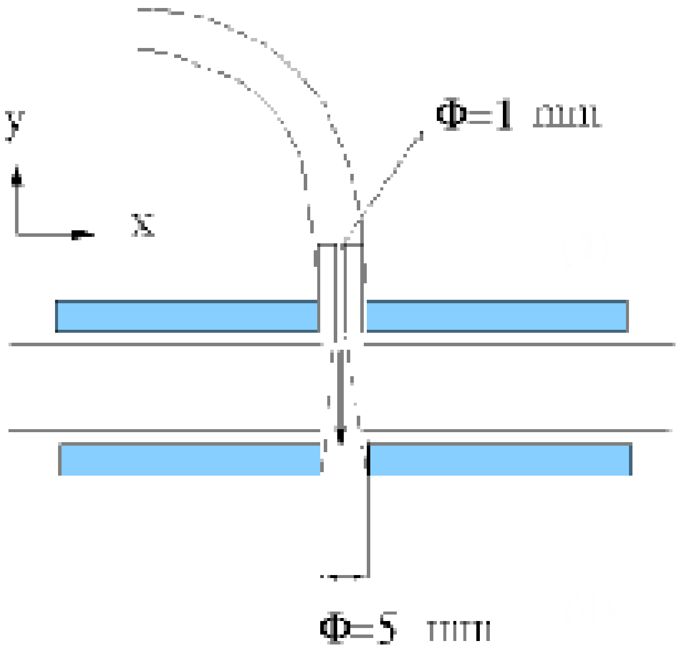
Uniform lighting avoiding parasitic reflections

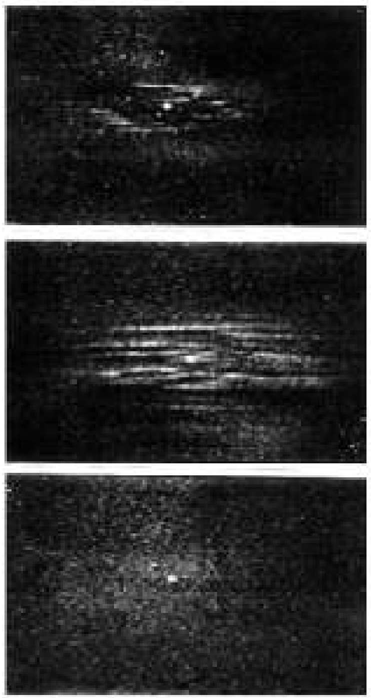
Prigent et al. PRL 2002

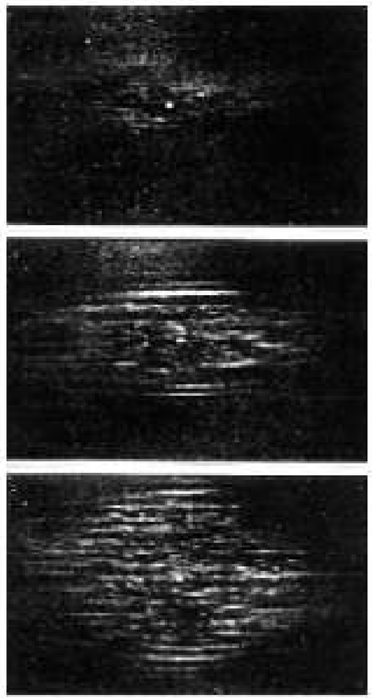
Transition from laminar *to* turbulent flow

Response to localized & instantaneous finite amplitude perturbation



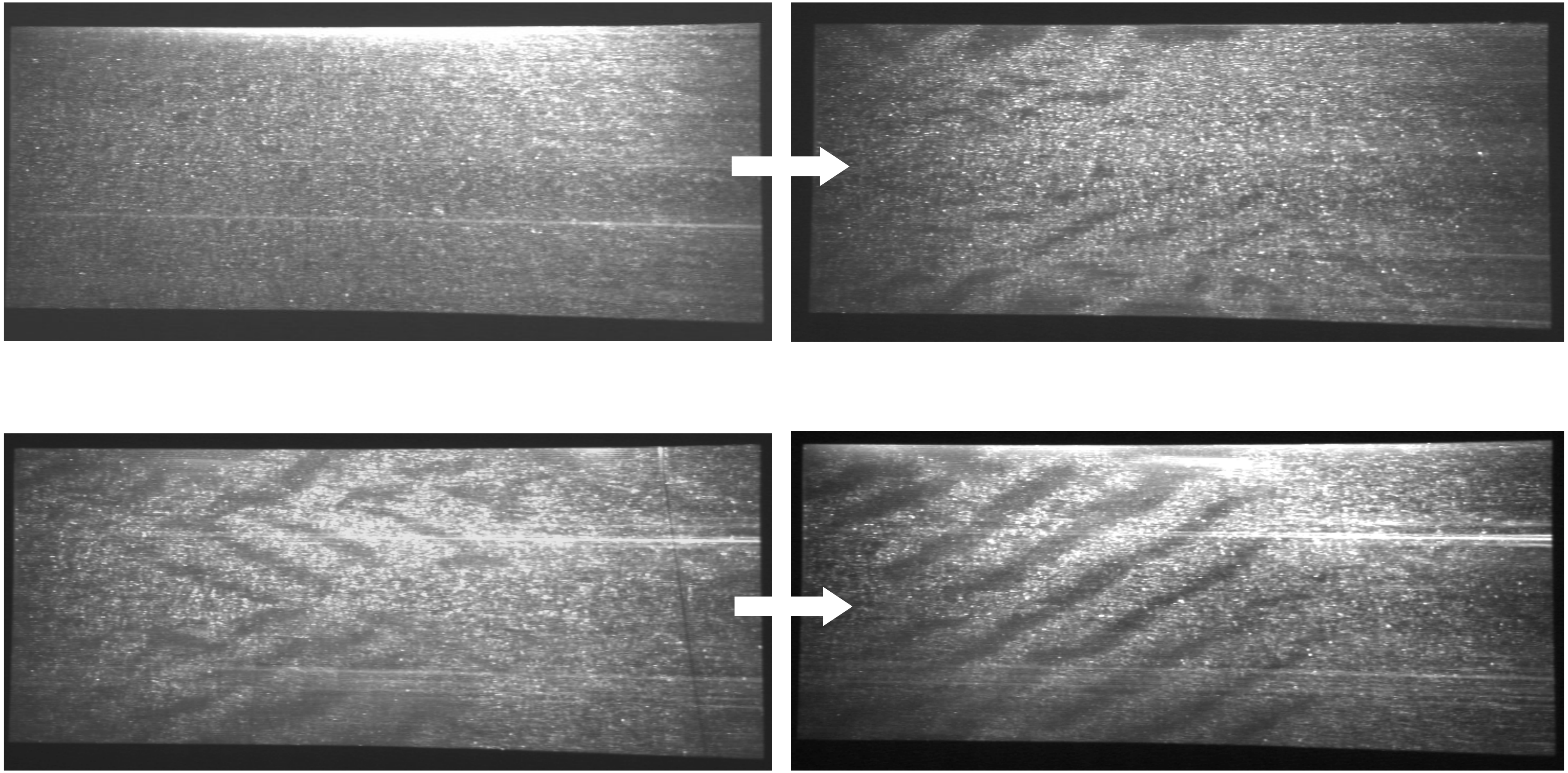






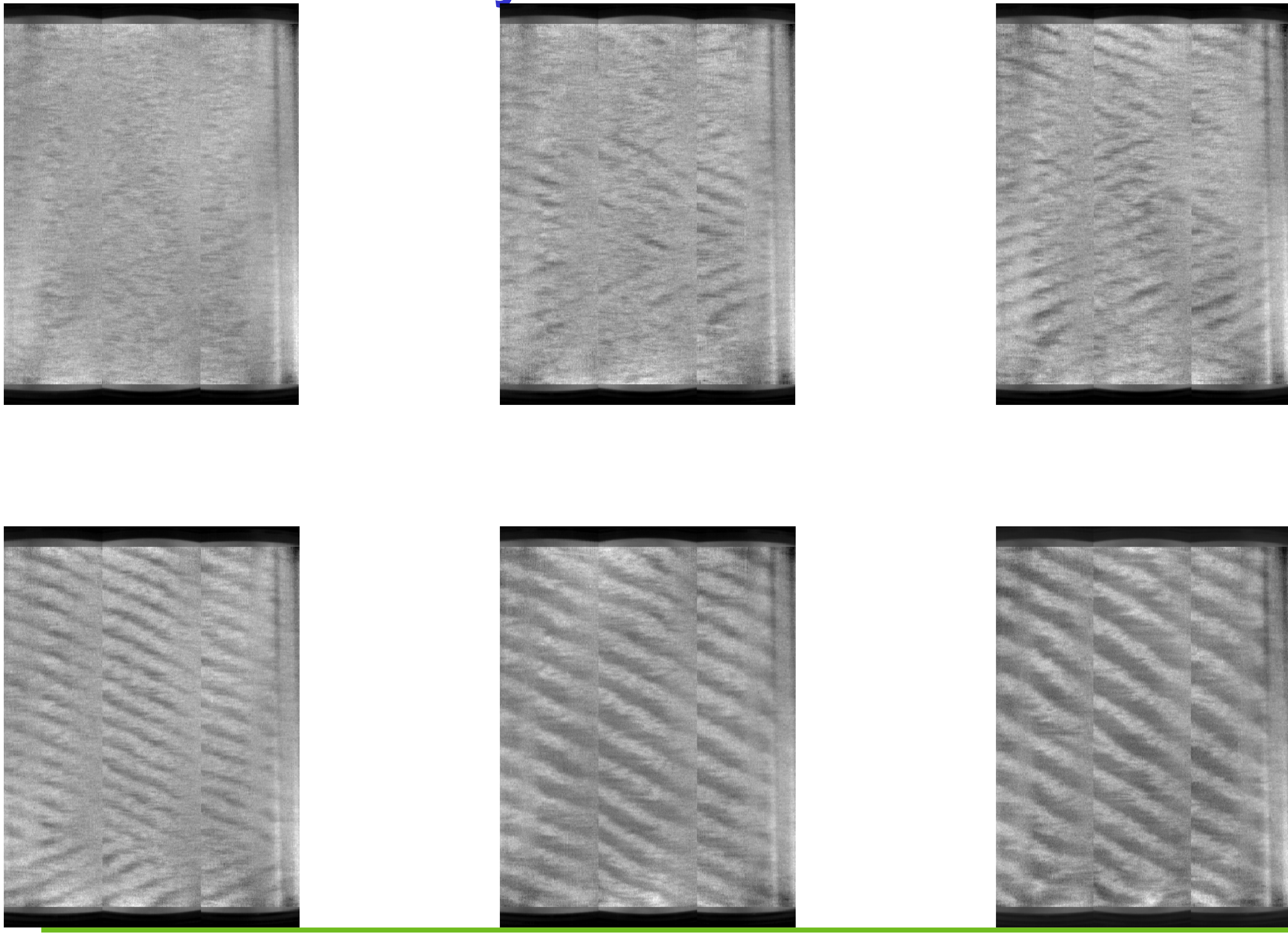
Dauchot Daviaud POF 95

Transition *from* turbulent to laminar flow
in plane Couette flow

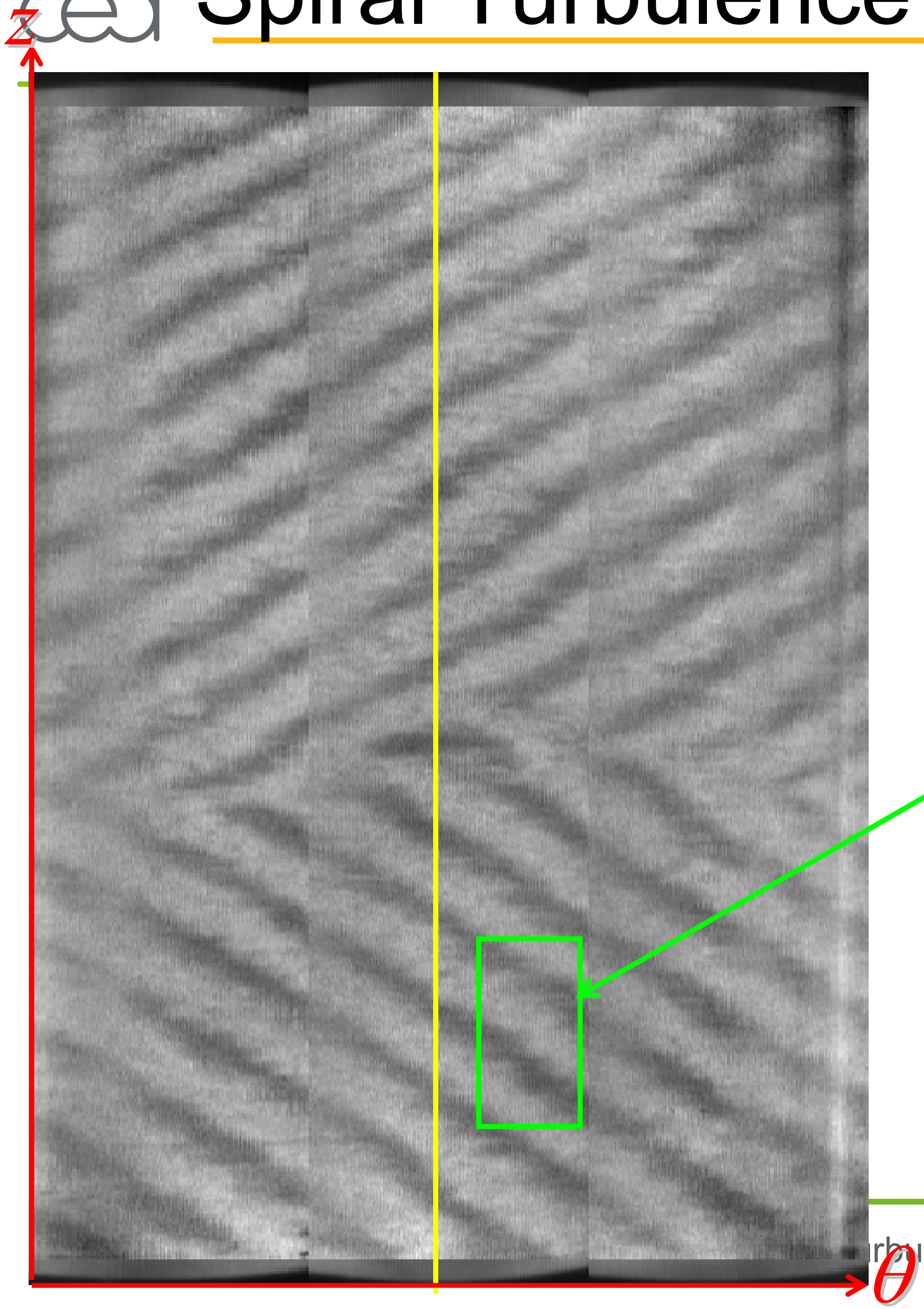


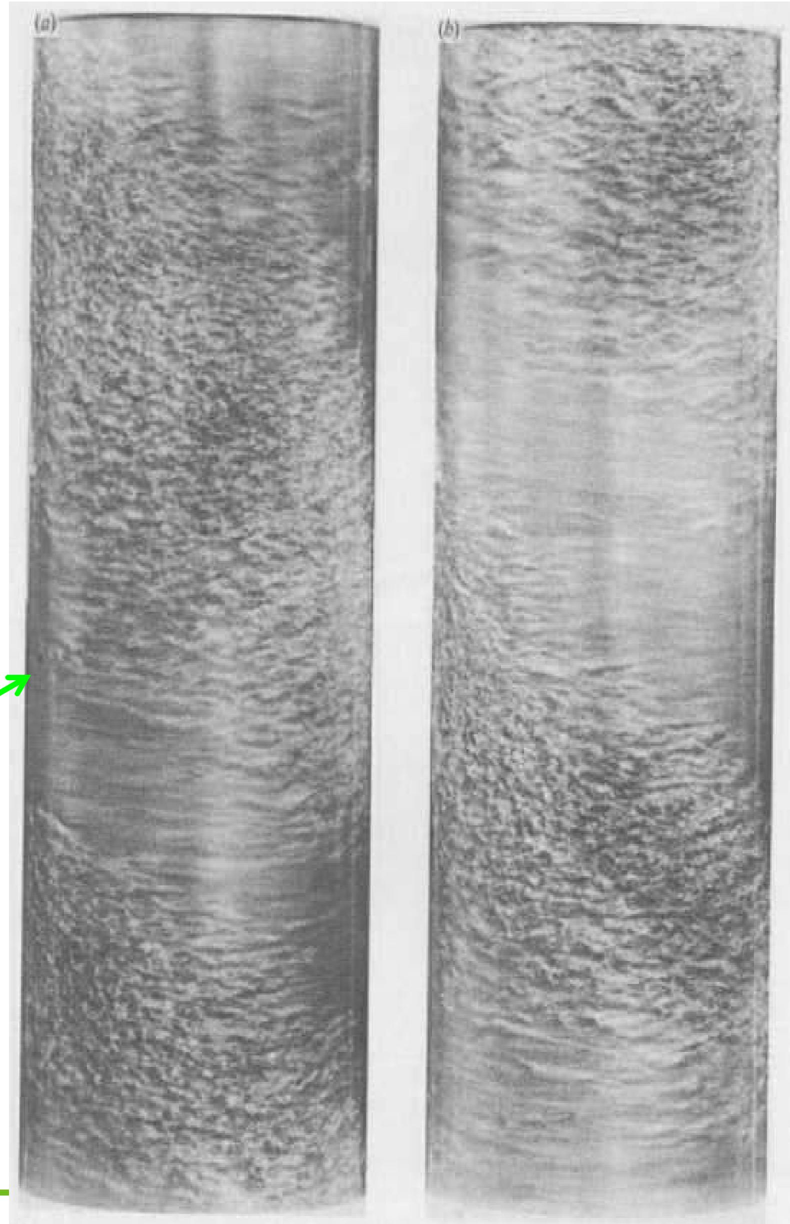
Transition *from* turbulent to laminar flow

in Taylor Couette flow



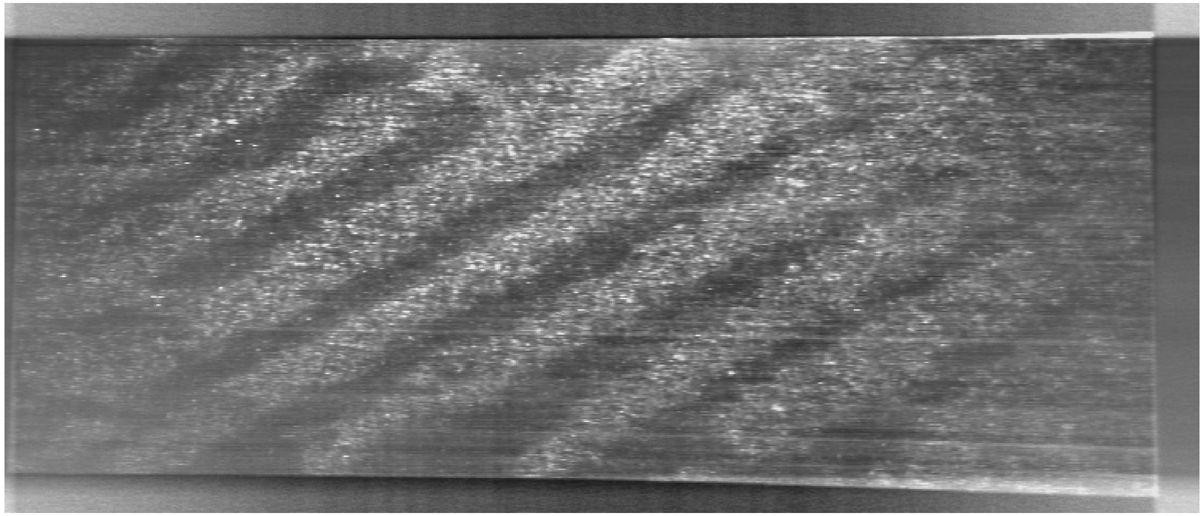
Spiral Turbulence in extended geometry



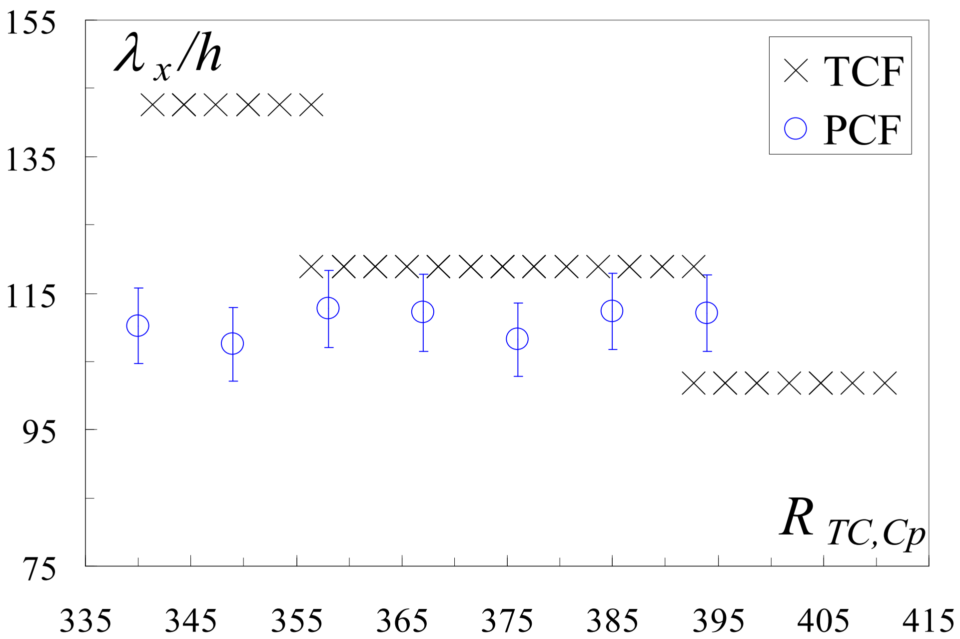


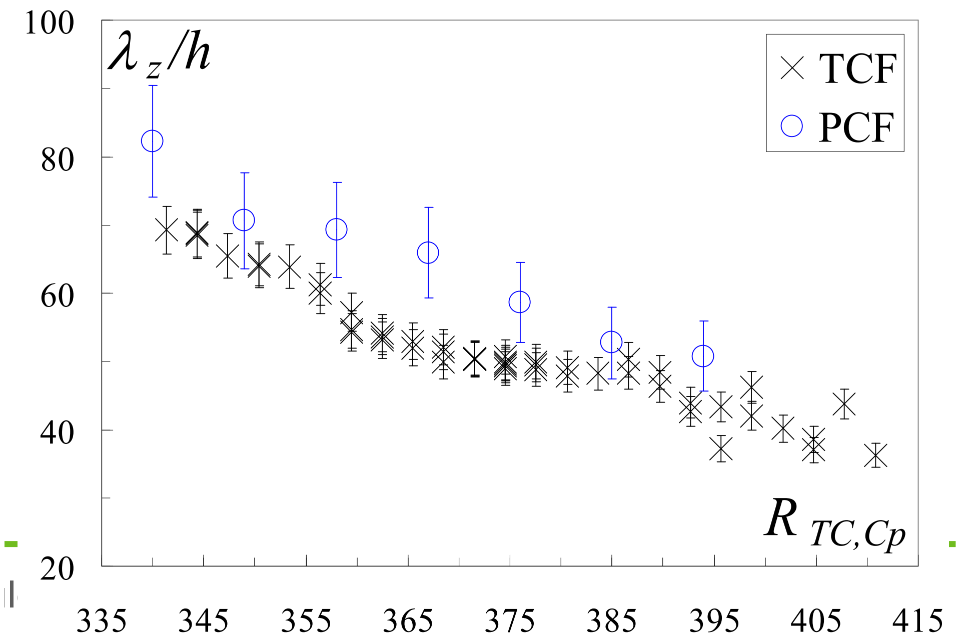
Andereck, Liu, Swinney, *J. Fluid Mech* (1986)

Turbulent stripes in plane Couette flow

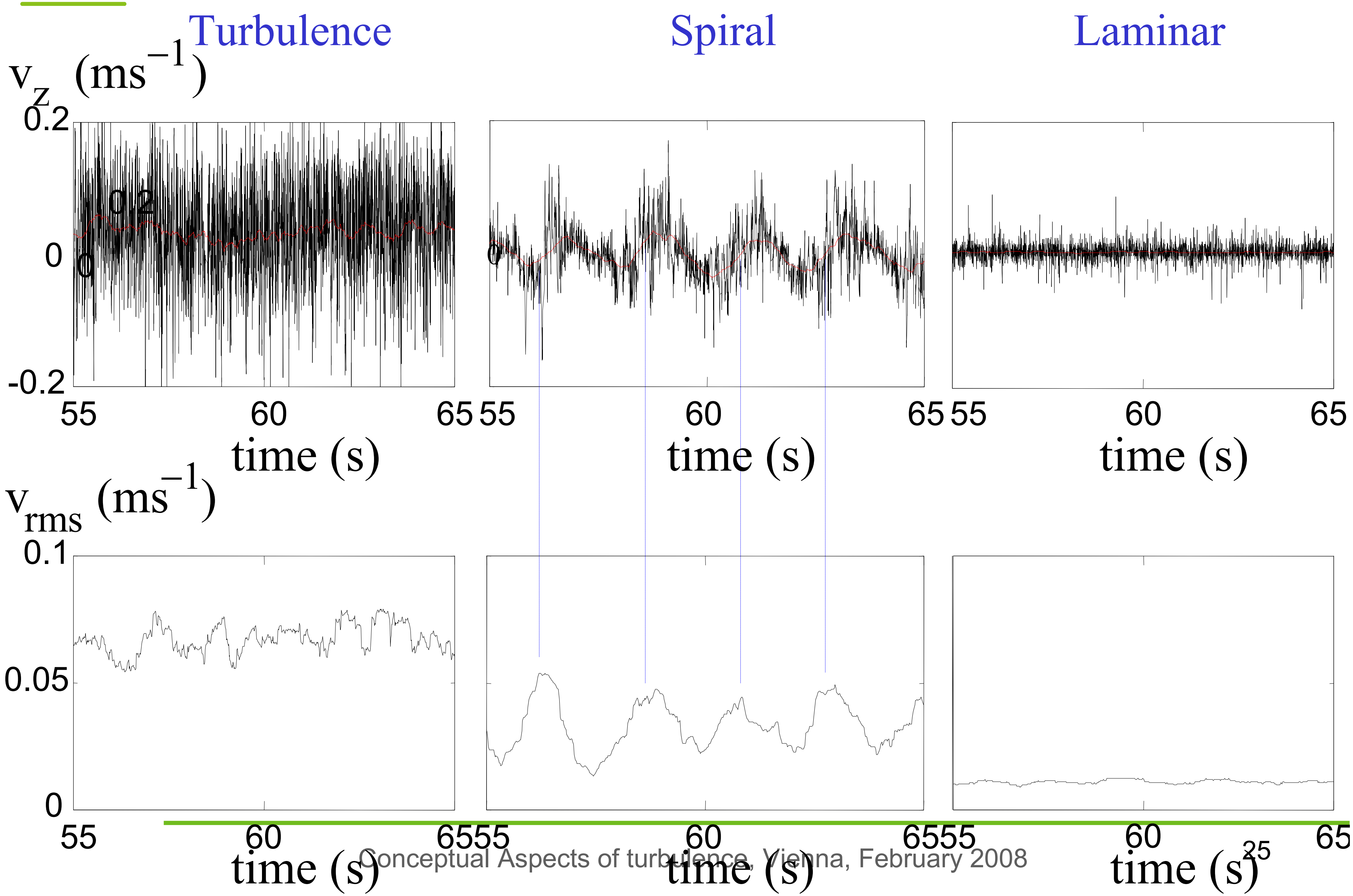


Comparison with Taylor-Couette flow when $W_i = -W_o$

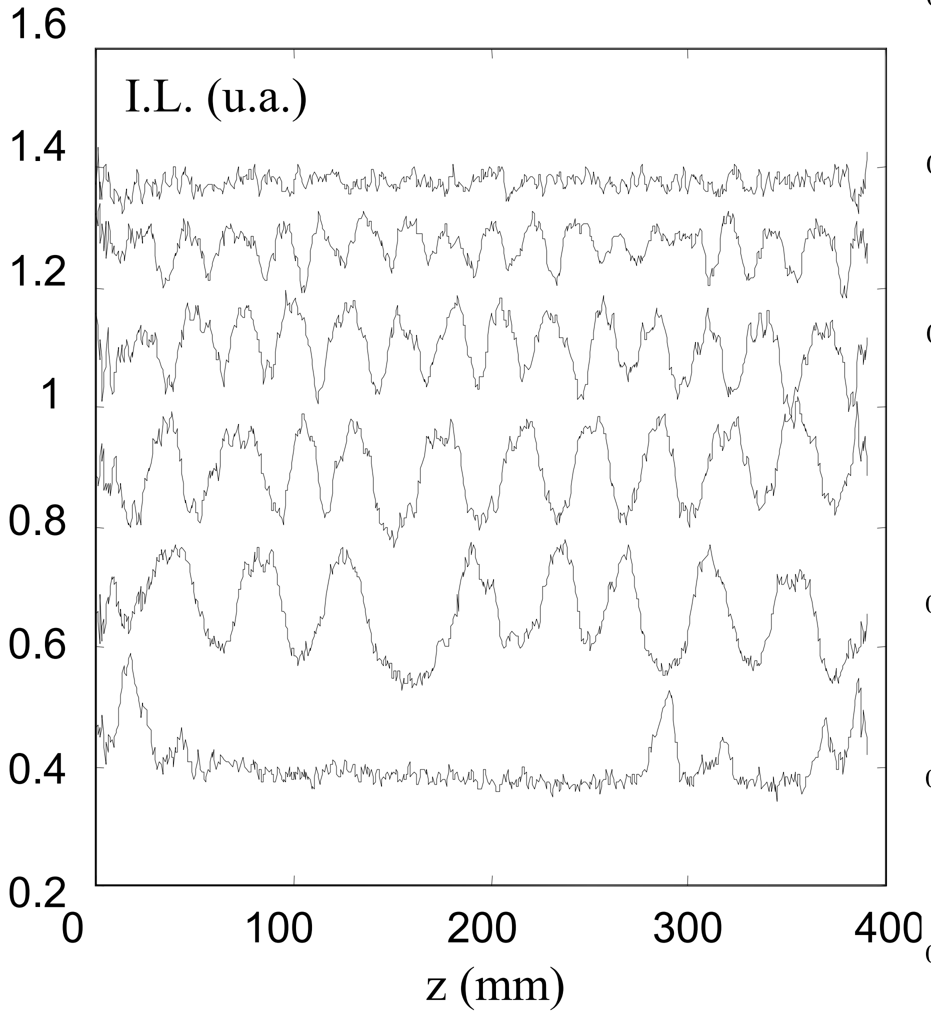


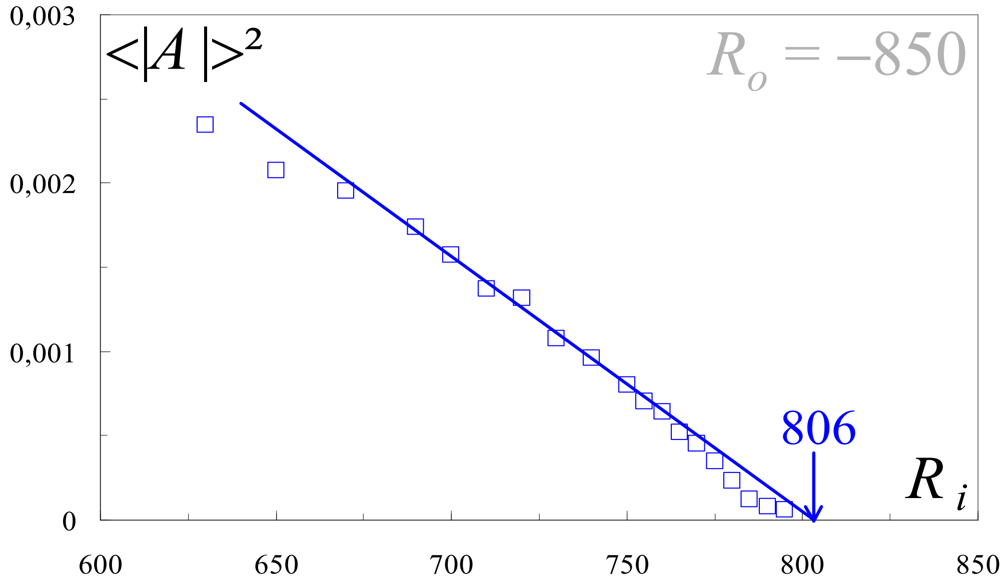


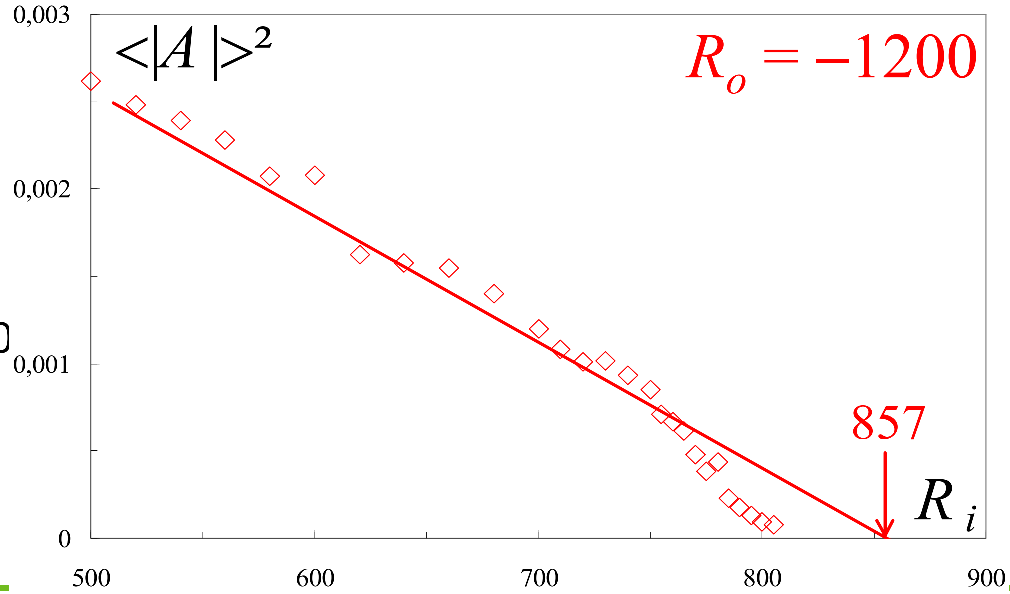
TC flow: LDV measurements



From Turbulence to Spiral Turbulence

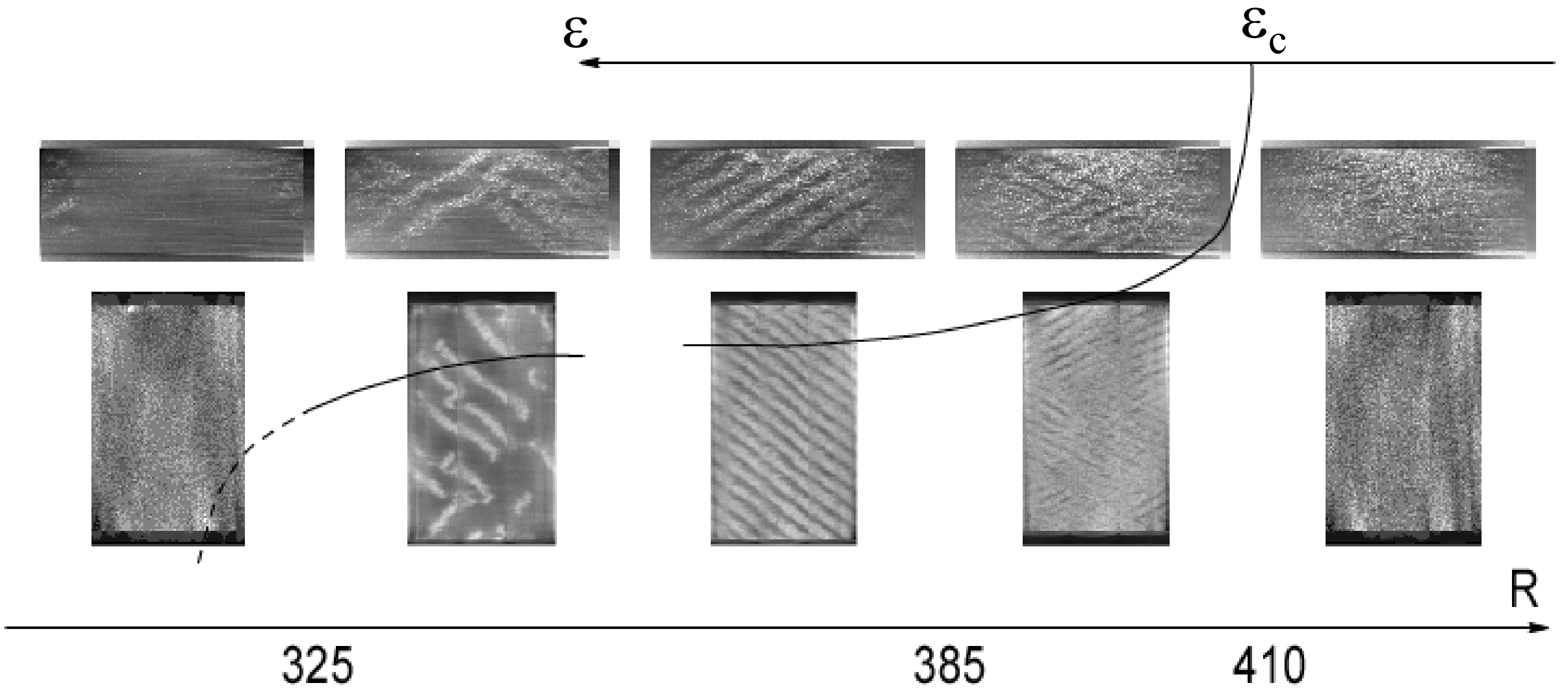






~ supercritical bifurcation

Couette flows: summary



- A discontinuous transition from laminar to turbulent flow (unstable finite amplitude solutions)

- A continuous transition from turbulent to laminar flow (Ginzburg-Landau equations + noise)