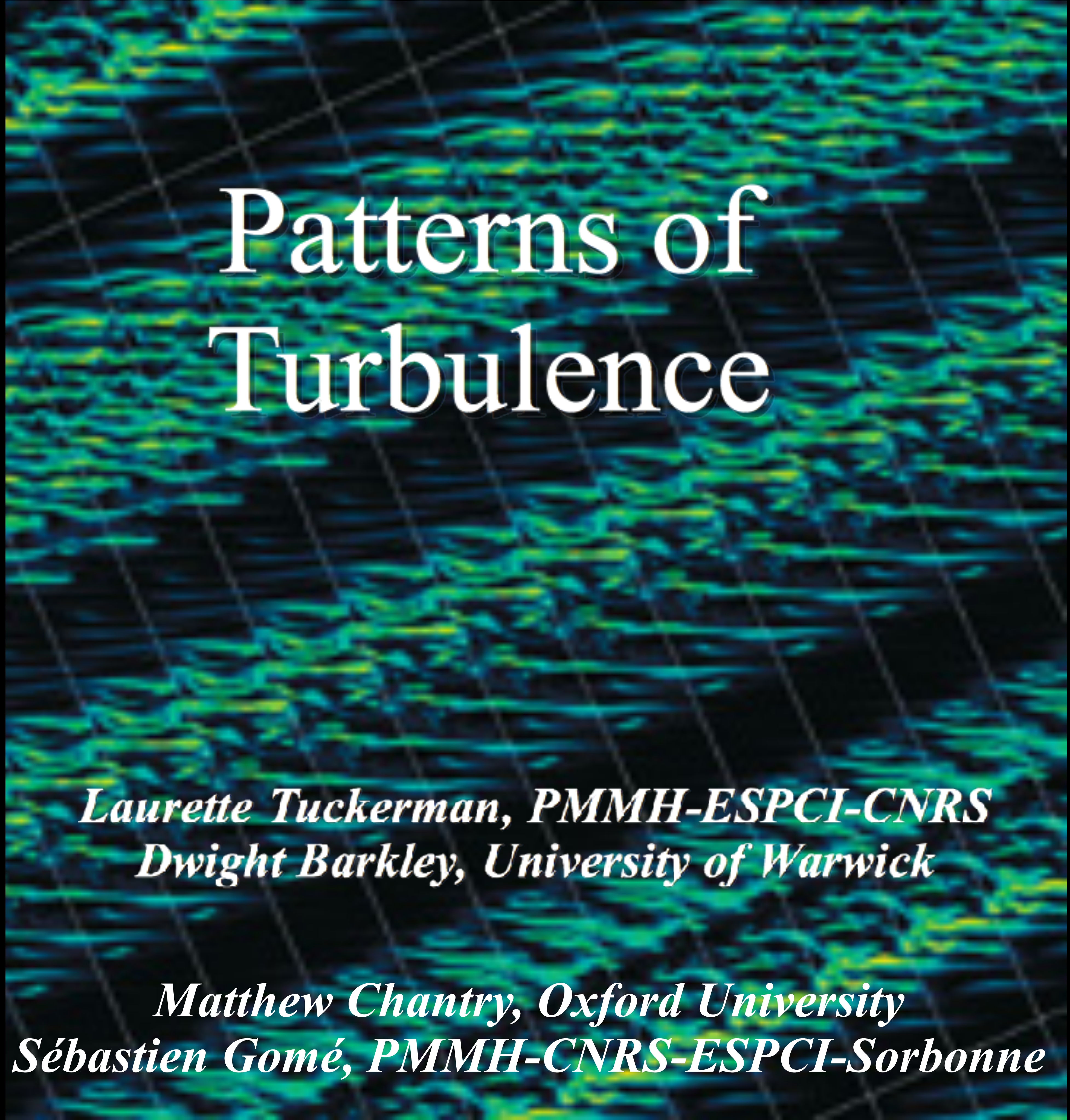
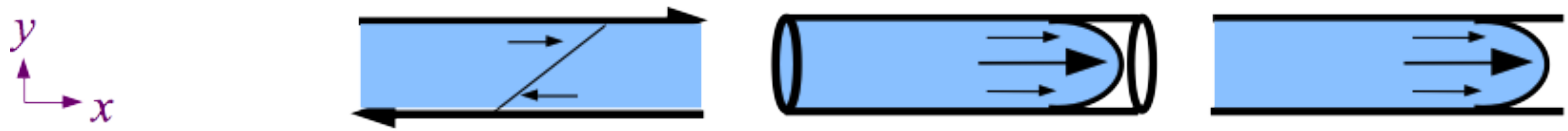


Patterns of Turbulence

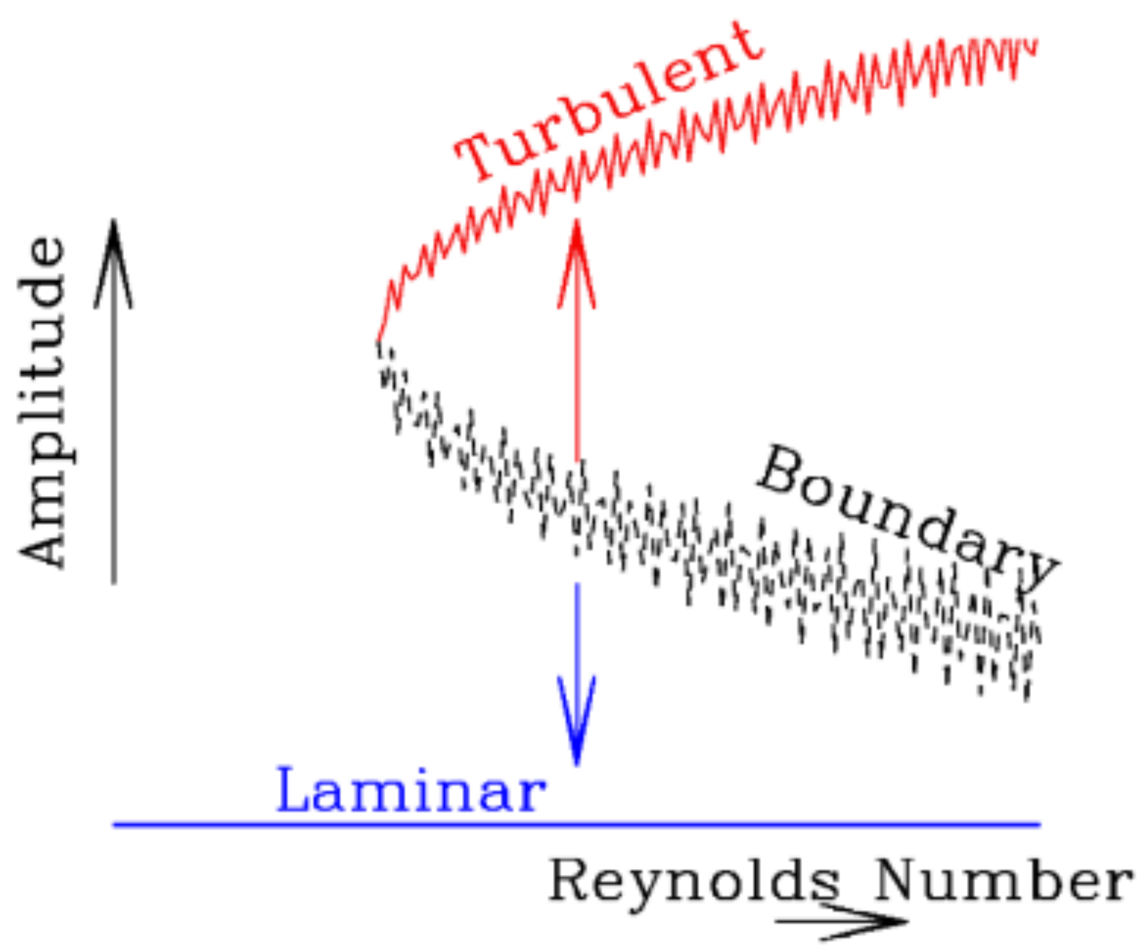
Laurette Tuckerman, PMMH-ESPCI-CNRS
Dwight Barkley, University of Warwick

Matthew Chantry, Oxford University
Sébastien Gomé, PMMH-CNRS-ESPCI-Sorbonne

Wall-bounded shear flows



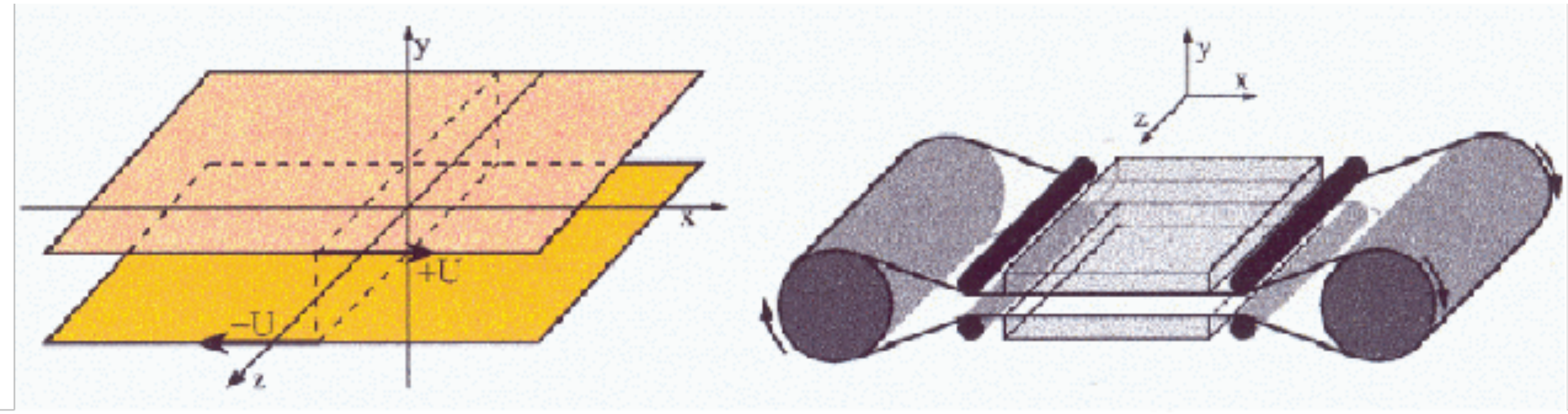
	Couette	**Pipe**	**Poiseuille**
linear instability:	Re $= \infty$ *(Romanov)*	Re $= \infty$	Re $= 5772$ *(Orszag)*
transition to turbulence:	Re ≈ 300	Re ≈ 2000	Re ≈ 1000



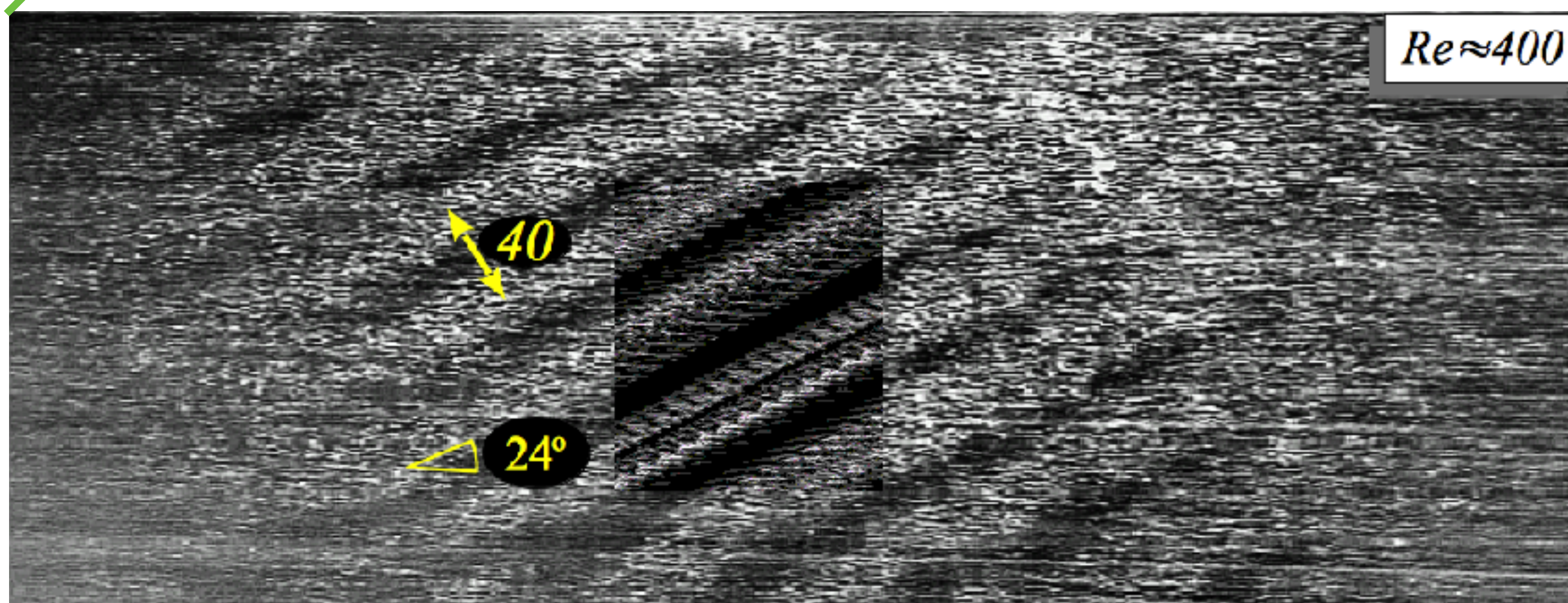
Experiments at CEA/Saclay by Prigent, Dauchot (2000-3)

Plane Couette Flow

$$Re_{\mathrm{Cou}} \equiv \frac{\Delta U \, \Delta Y}{4\nu}$$



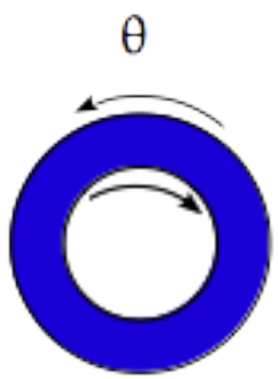
Gap 2



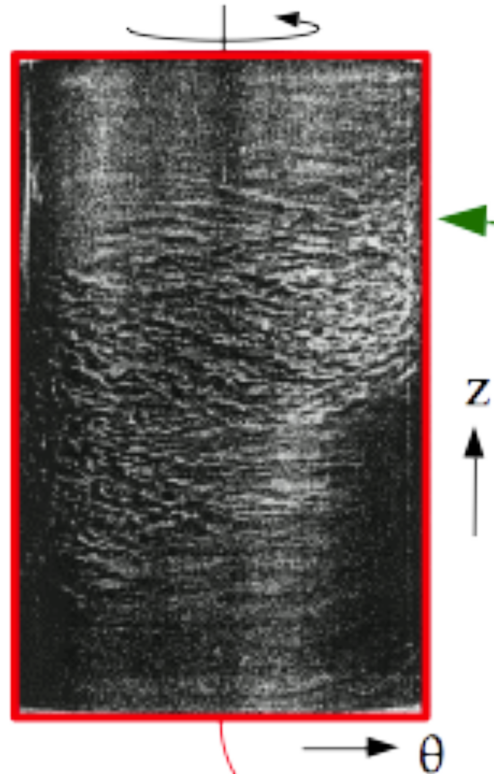
Spanwise

Length 770 half-gaps — Streamwise

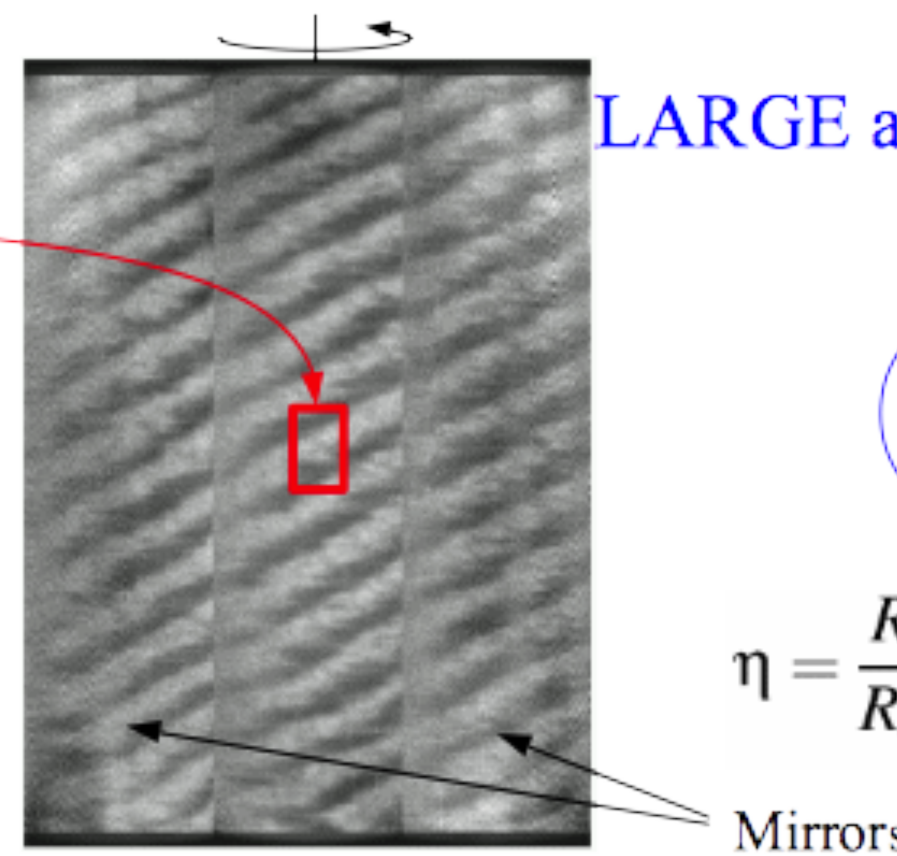
Spiral Turbulence
in counter-rotating Taylor-Couette Flow



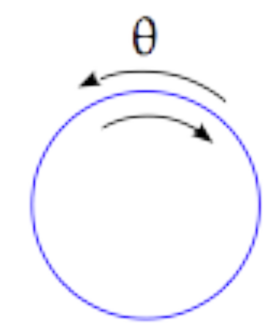
$$\eta = \frac{R_{\text{in}}}{R_{\text{out}}} = 0.88$$



- ***Coles JFM (1965)***
- ***van Atta JFM (1966)***
- ***Andereck et al. JFM (1986)***



LARGE aspect ratio



$$\eta = \frac{R_{\text{in}}}{R_{\text{out}}} = 0.983$$

Prigent & Dauchot PRL (2002)

Between rotating and stationary disks

3758 Phys. Fluids, Vol. 14, No. 11, November 2002 A. Cros and P. Le Gal

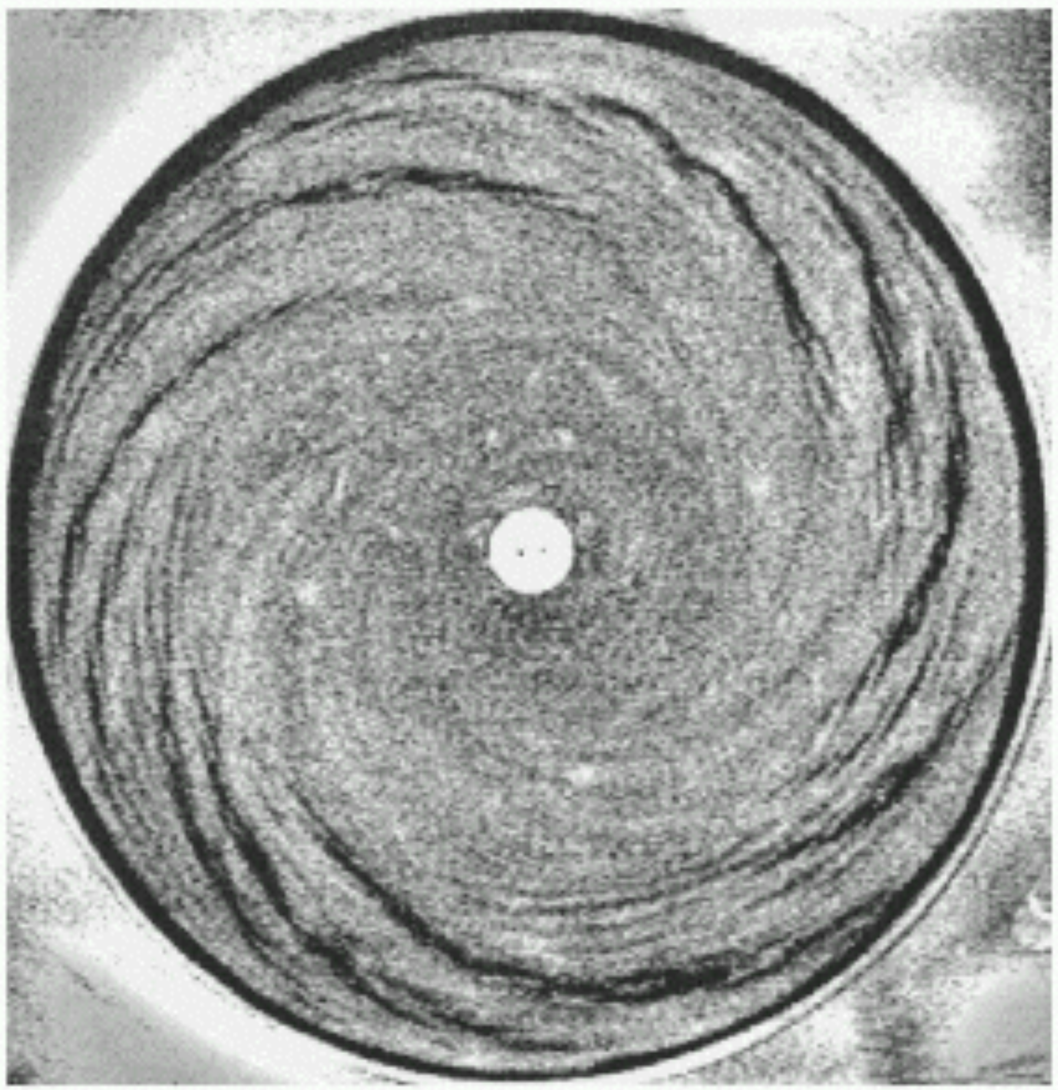


FIG. 5. Turbulent spirals for $h=2.2$ mm and $\Omega=52$ rpm clockwise ($Re=106\,700$).

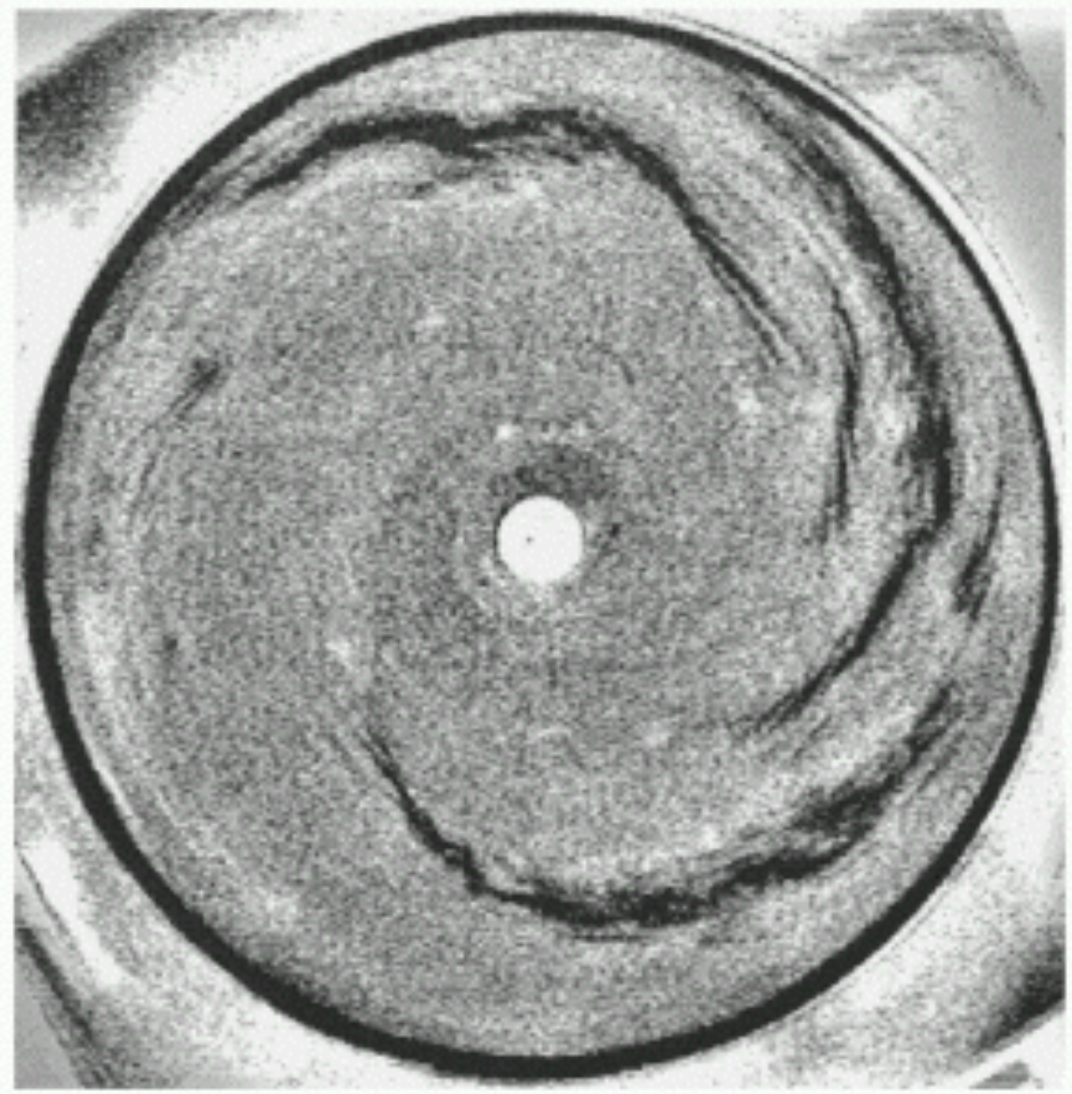
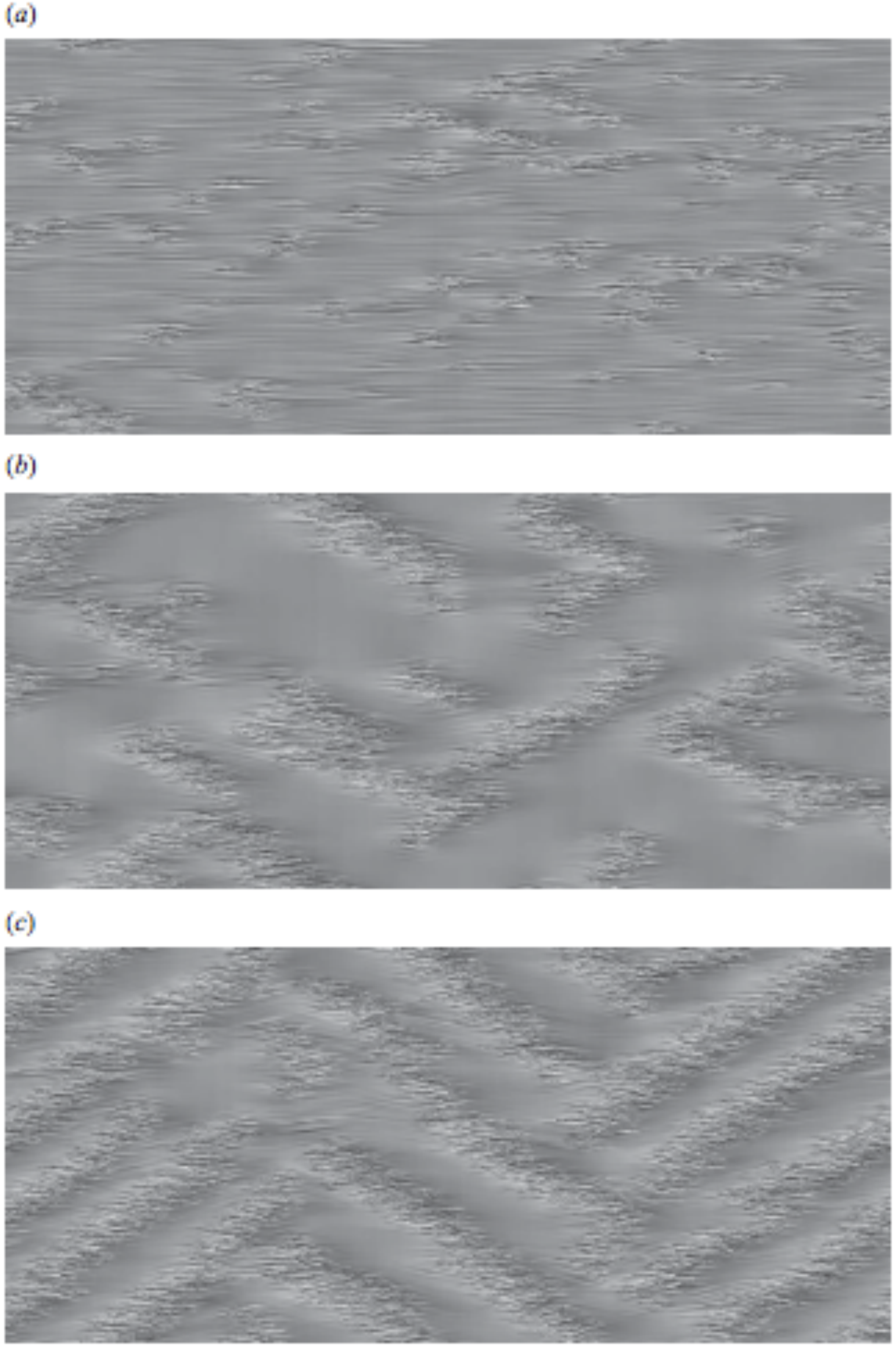


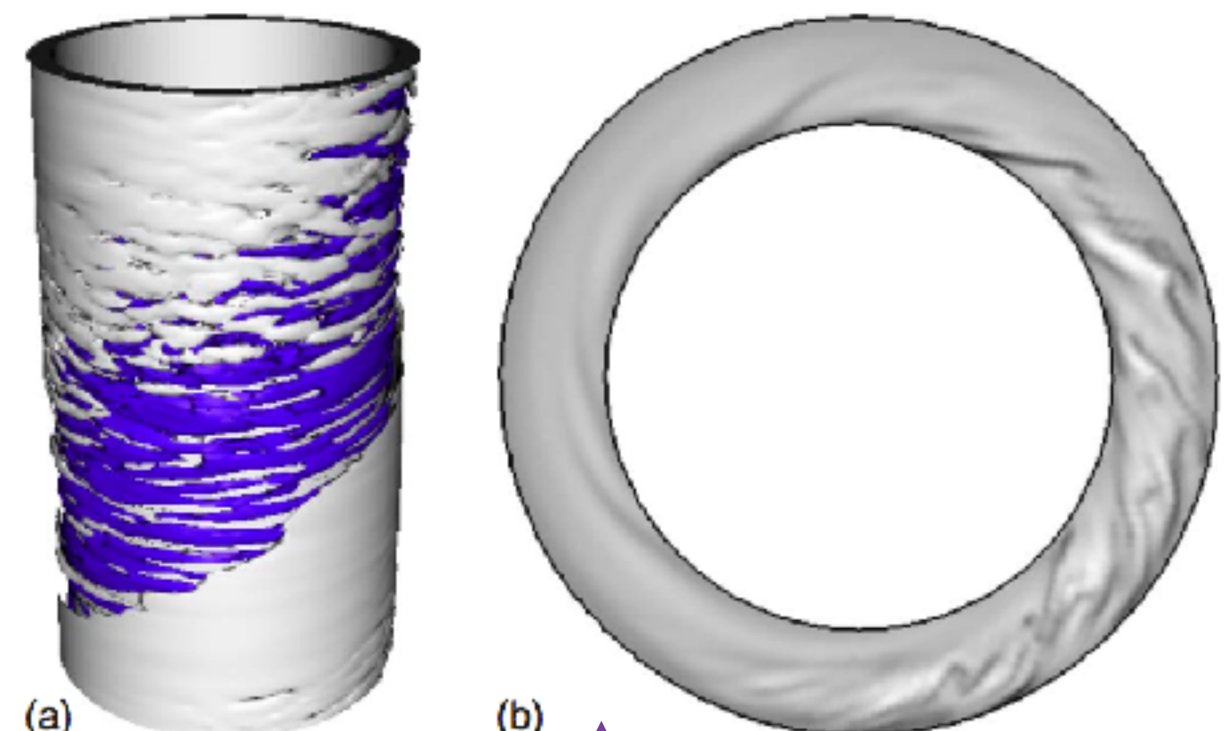
FIG. 7. Turbulent spirals for $h=2.2$ mm and $\Omega=74$ rpm clockwise ($Re=151\,900$). One spot is visible on the left side of the disk.



J. Fluid Mech. (2010), *vol.* 650, *pp.* 119–129. © Cambridge University Press 2010 119
doi:10.1017/S0022112010000297

Formation of turbulent patterns near the onset of transition in plane Couette flow

Y. DUGUET[1,2]†, P. SCHLATTER[1] AND D. S. HENNINGSON[1]
[1]Linné Flow Centre, KTH Mechanics, SE-10044 Stockholm, Sweden
[2]LIMSI-CNRS, UPR 3251, 91403 Orsay, France



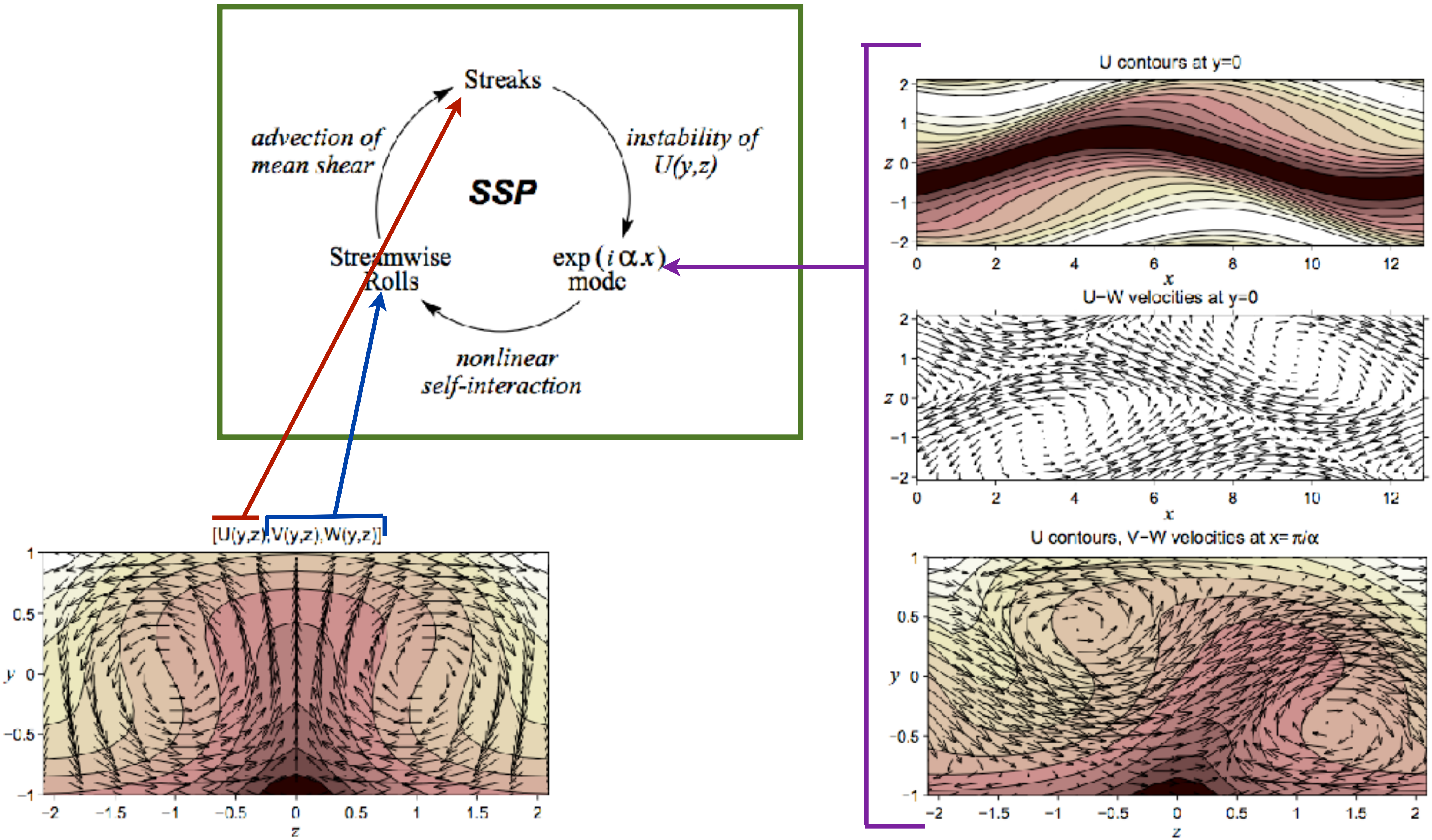
PHYSICAL REVIEW E **80**, 046315 (2009)

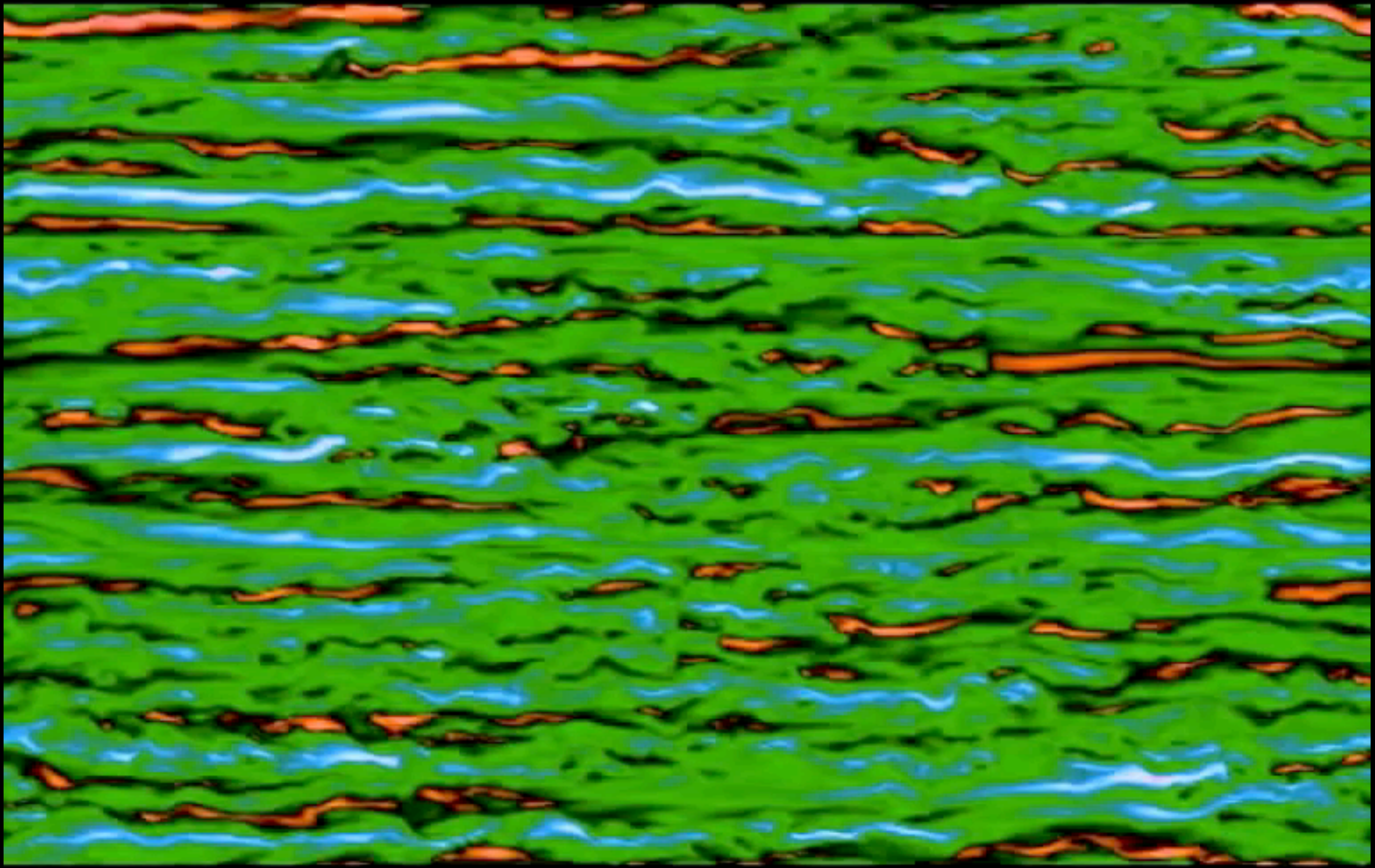
Instability mechanisms and transition scenarios of spiral turbulence in Taylor-Couette flow

Alvaro Meseguer,[1,*] Fernando Mellibovsky,[1] Marc Avila,[2] and Francisco Marques[1]
[1]*Departament de Física Aplicada, Universitat Politècnica de Catalunya, 08034 Barcelona, Spain*
[2]*Max Planck Institute for Dynamics and Self-Organization, 37073 Göttingen, Germany*

Waleffe: self-sustaining process (SSP)

F. Waleffe & J. Kim, How streamwise rolls and streaks sustain in a shear flow: Part 2, AIAA paper 98-2997 (Albuquerque, June 1998)
F. Waleffe, On a self-sustaining process in shear flows, Phys. Fluids 9, 883-900 (1997)

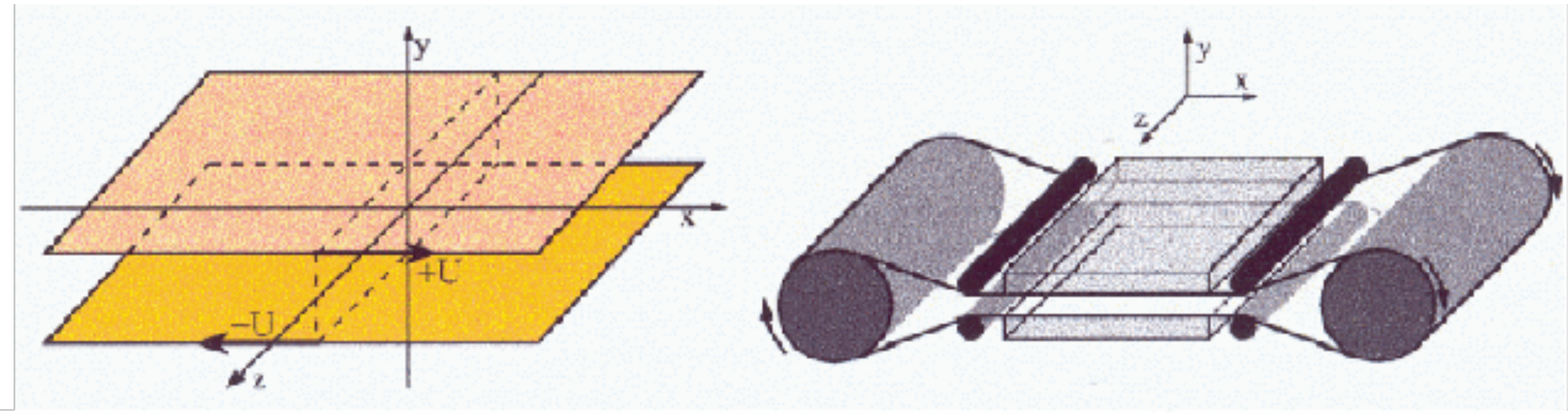




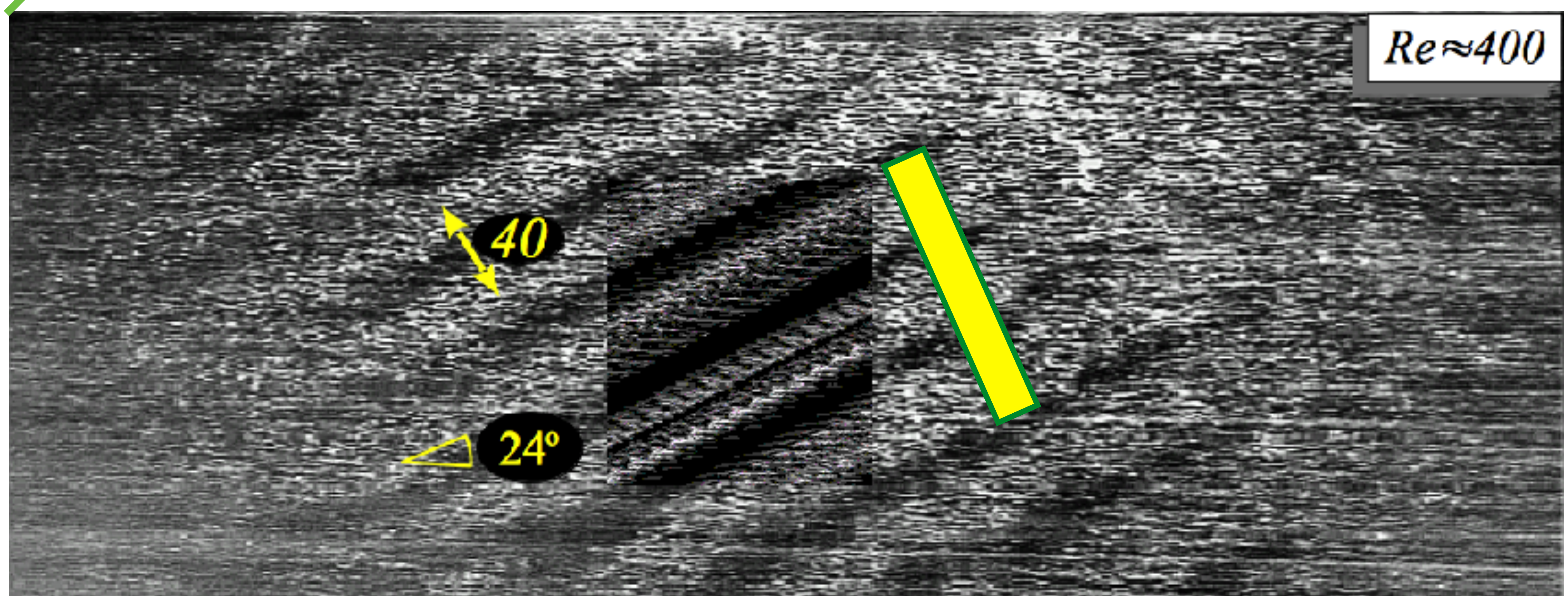
Experiments at CEA/Saclay by Prigent, Dauchot (2000-3)

Plane Couette Flow

$$Re_{\mathrm{Cou}} \equiv \frac{\Delta U \, \Delta Y}{4\nu}$$



Gap 2

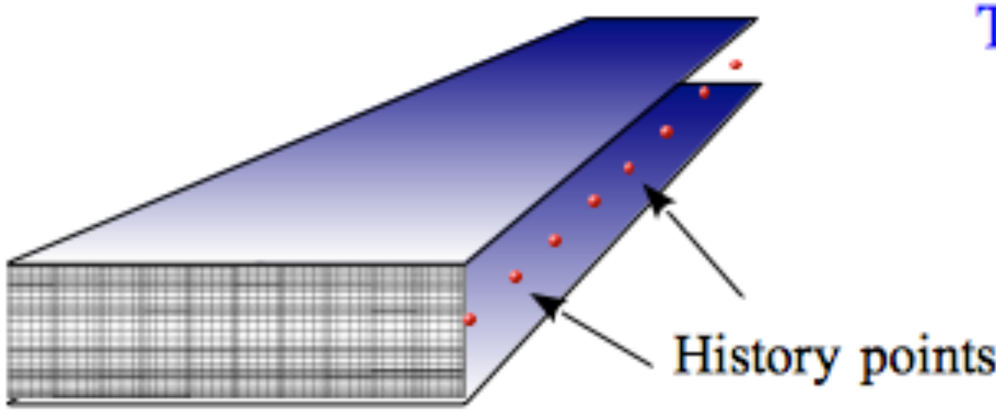


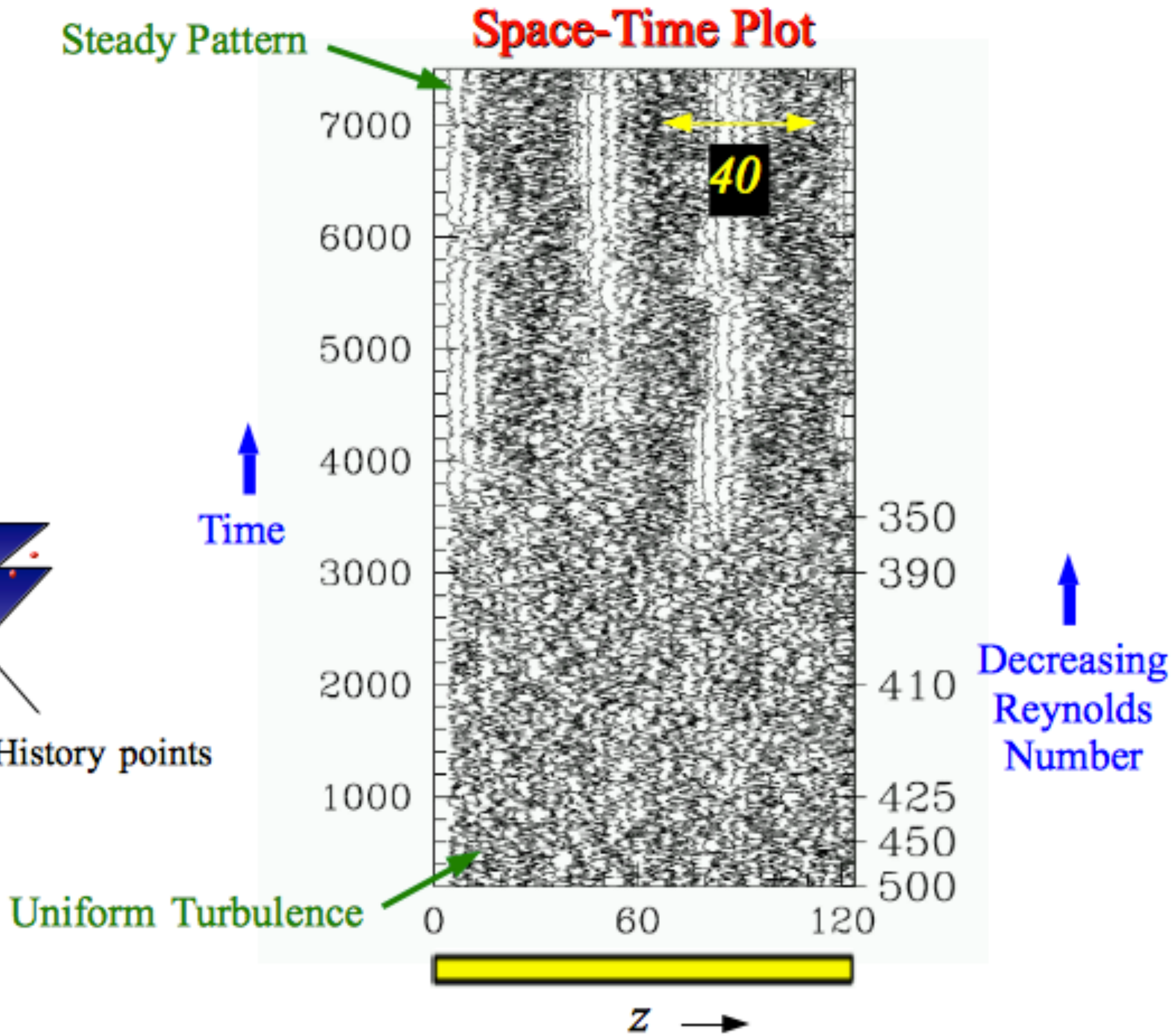
Length 770 half-gaps — Streamwise

Couette Flow: spatio-temporal scan

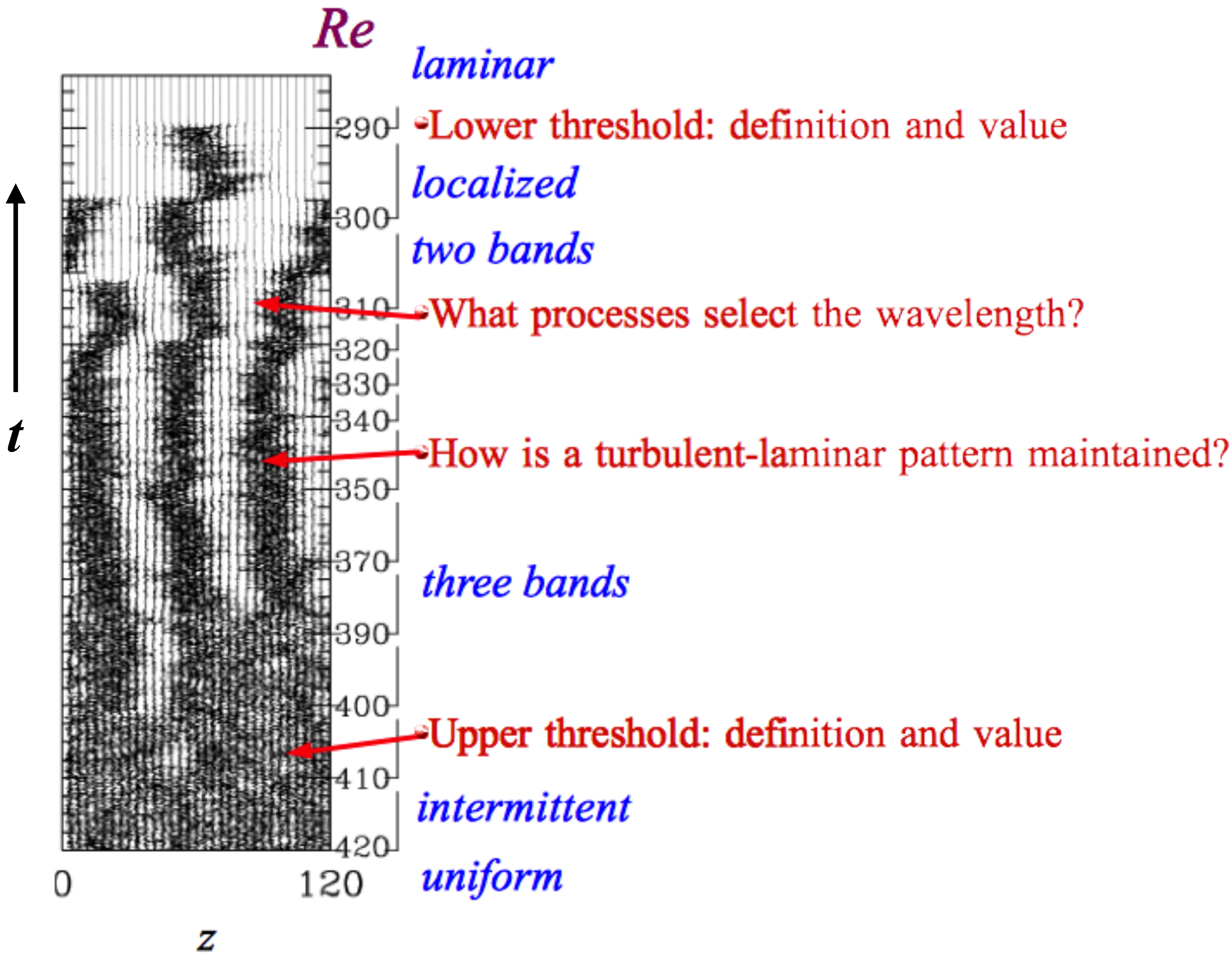
For each domain:

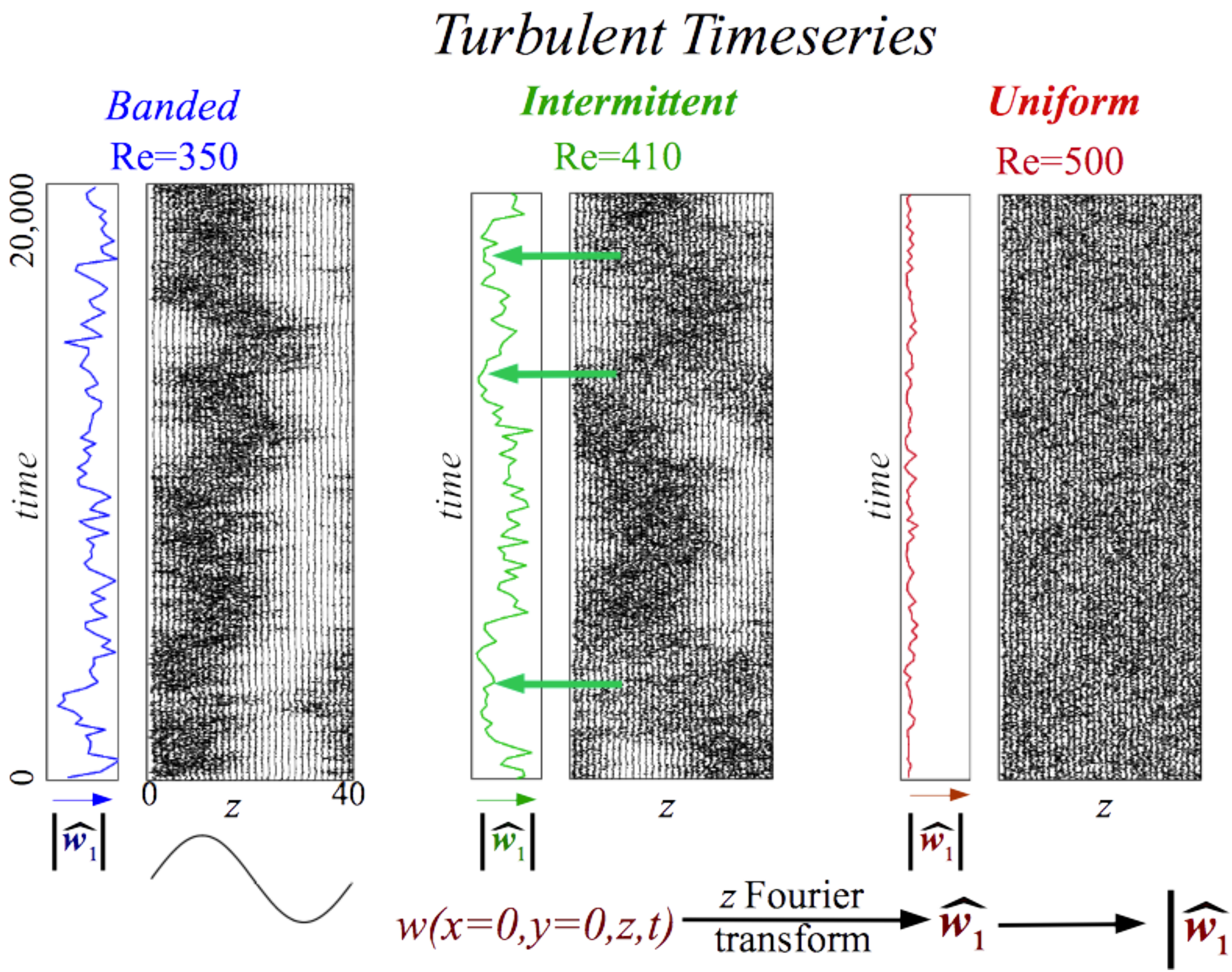
- Start at *Re = 500*
- Obtain turbulent flow
- Decrease *Re*
- Monitor turbulence





Couette Flow: spatio-temporal scan

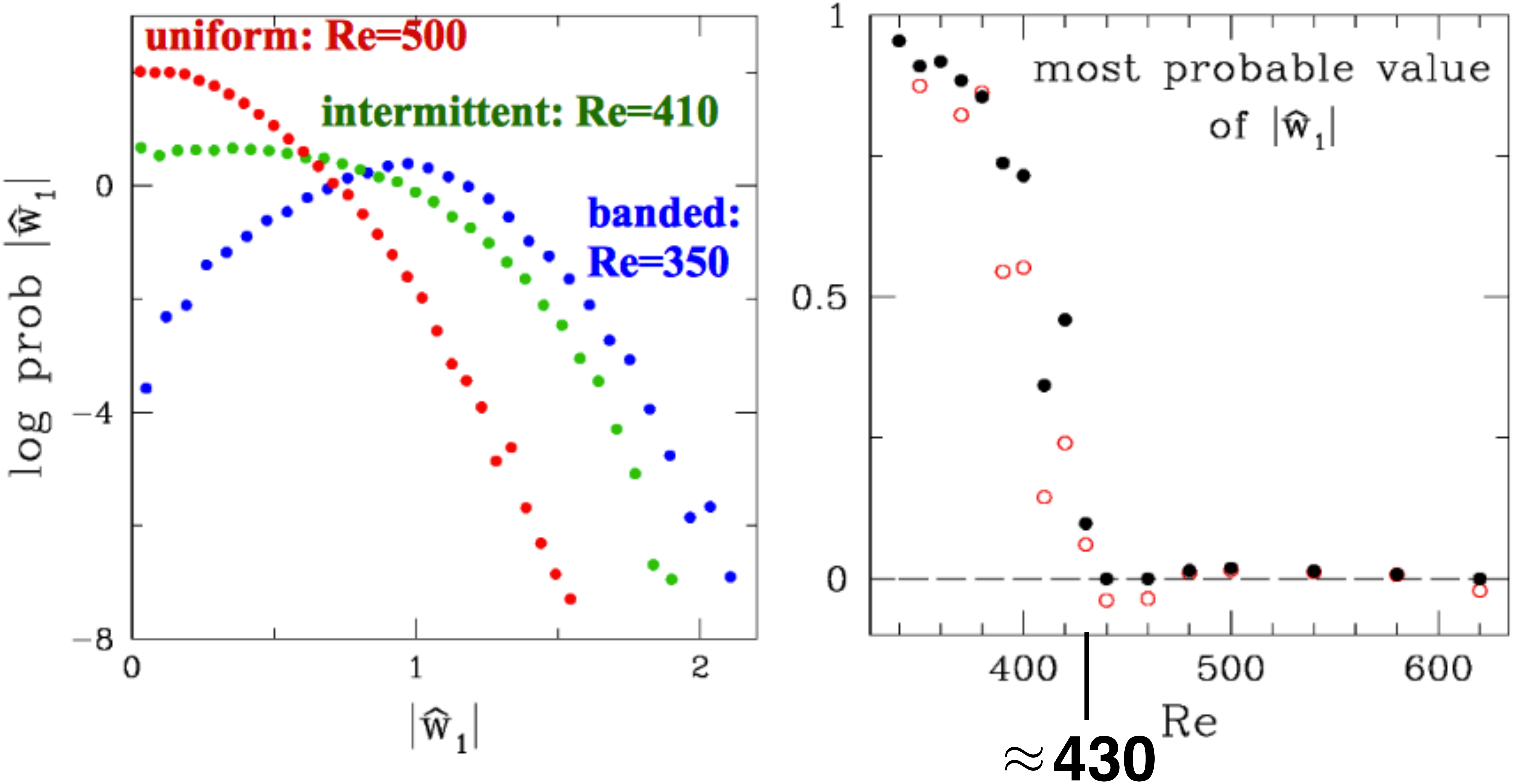




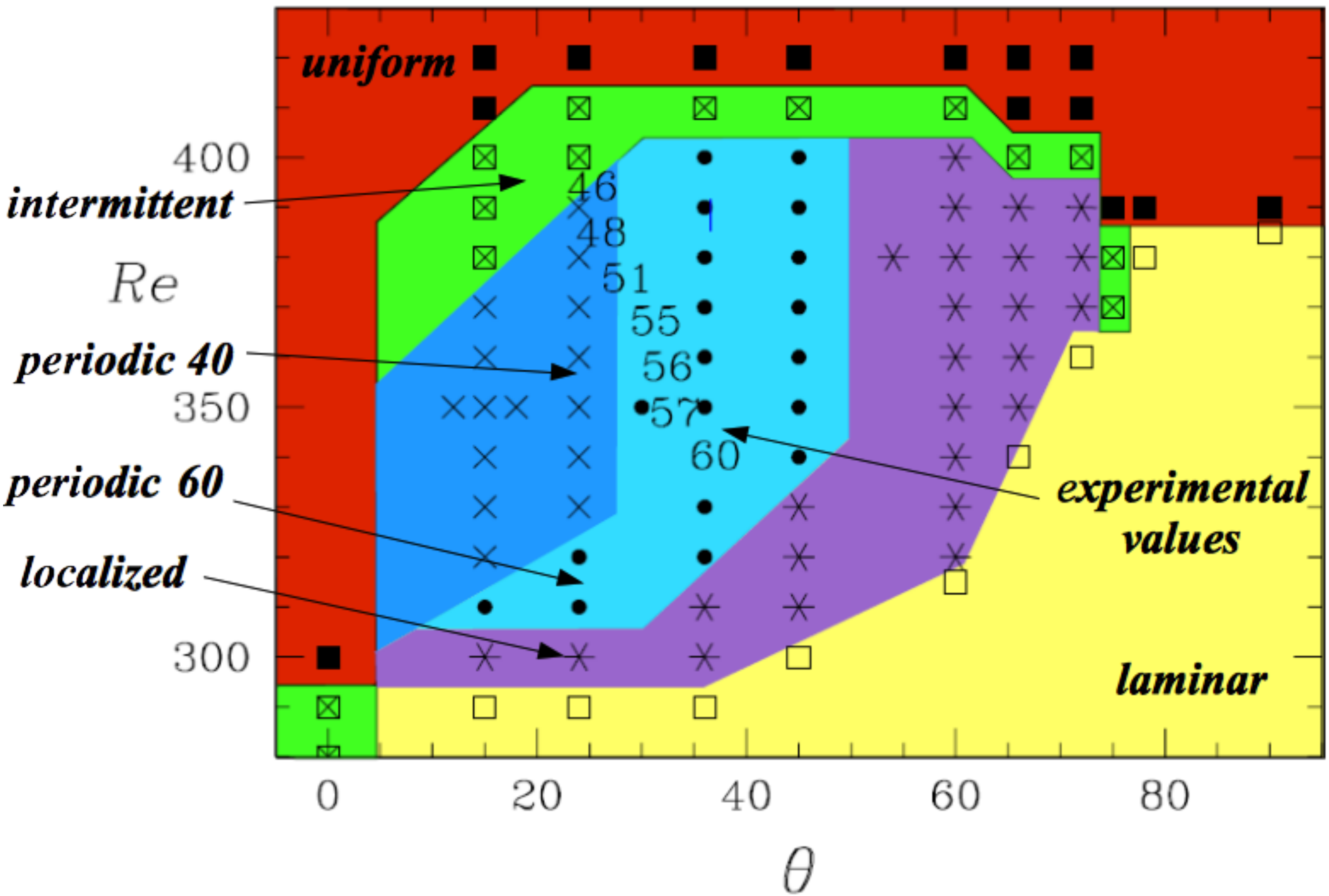
Turbulent Timeseries
Banded
Re=350
Intermittent
Re=410
Uniform
Re=500
20,000
0
time
time
time
0
40
z
z
z
$|\hat{w}_1|$
$|\hat{w}_1|$
$|\hat{w}_1|$
$w(x=0,y=0,z,t)$
z Fourier transform
$\hat{w}_1$
$|\hat{w}_1|$

Upper Threshold

Probability Distribution Function of $\left|\widehat{w}_1\right|$
(modulus of $m=1, \lambda=40$ *component of spanwise velocity)*



Varying angle: Regimes as a function of θ, Re

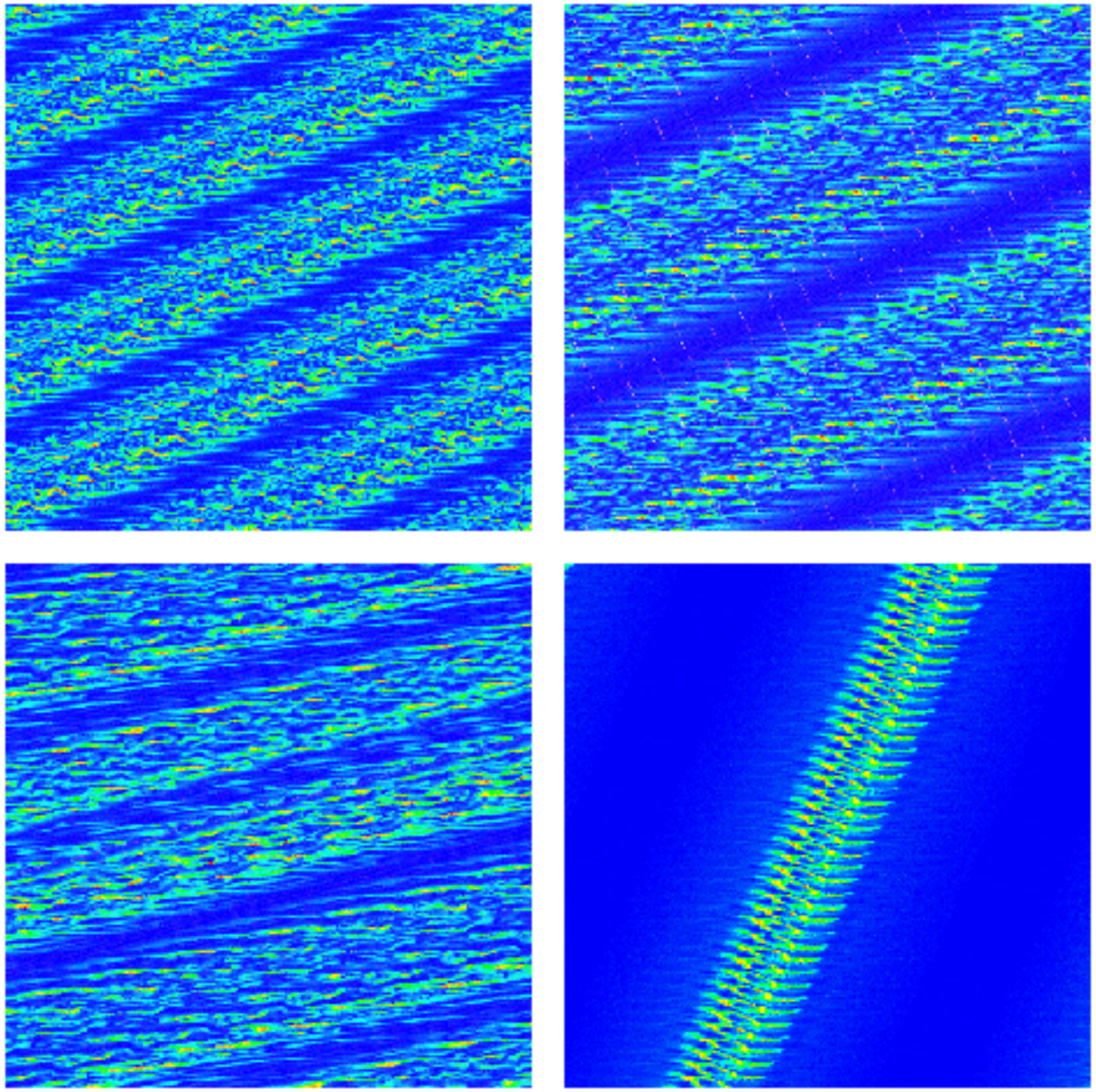


Extreme
Wavelengths and Tilt Angles

Fixed *Re = 350*

Minimum
Wavelength 35
at $\theta = 24^o$

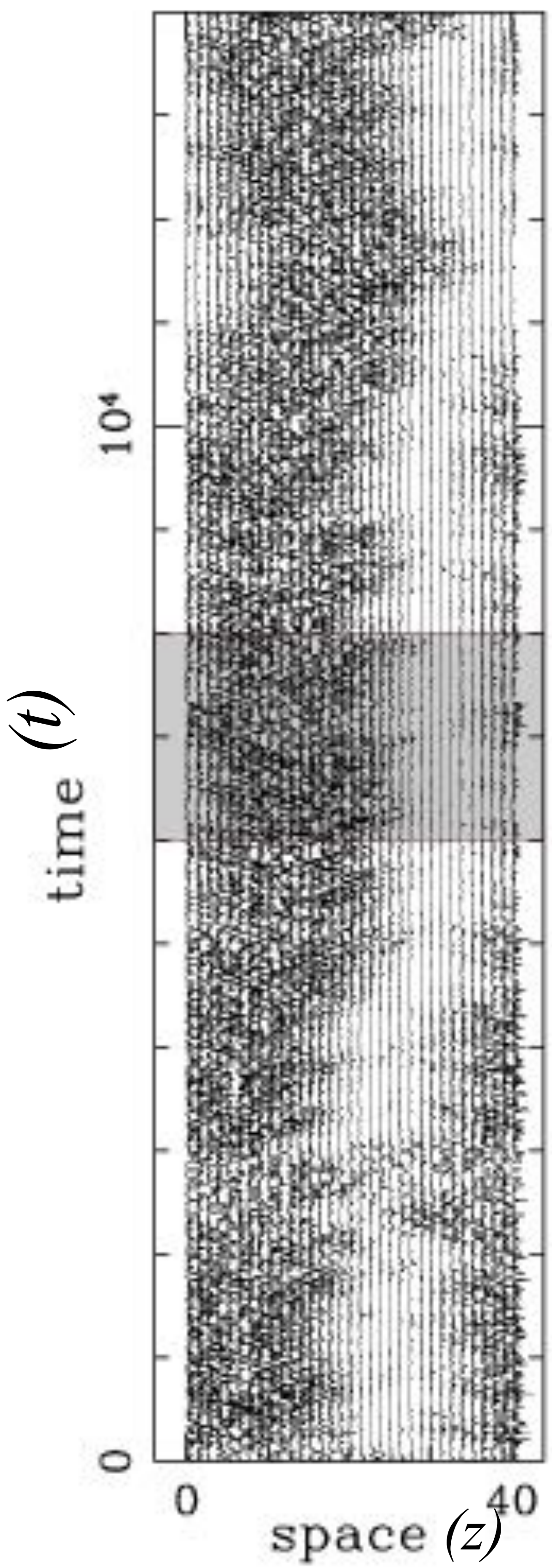
Maximum
Wavelength 65
at $\theta = 24^o$



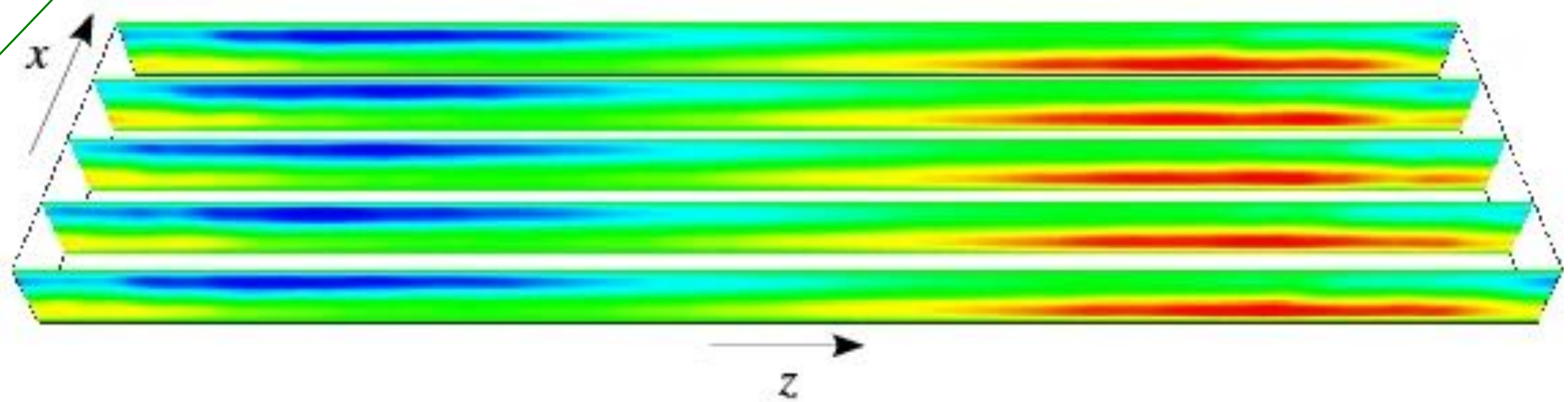
Minimum tilt 15^o
at $L_{z'} = 120$

Maximum tilt 66^o
at $L_{z'} = 120$

Average: in time, then in x



u(x=0,y=0,z,t)



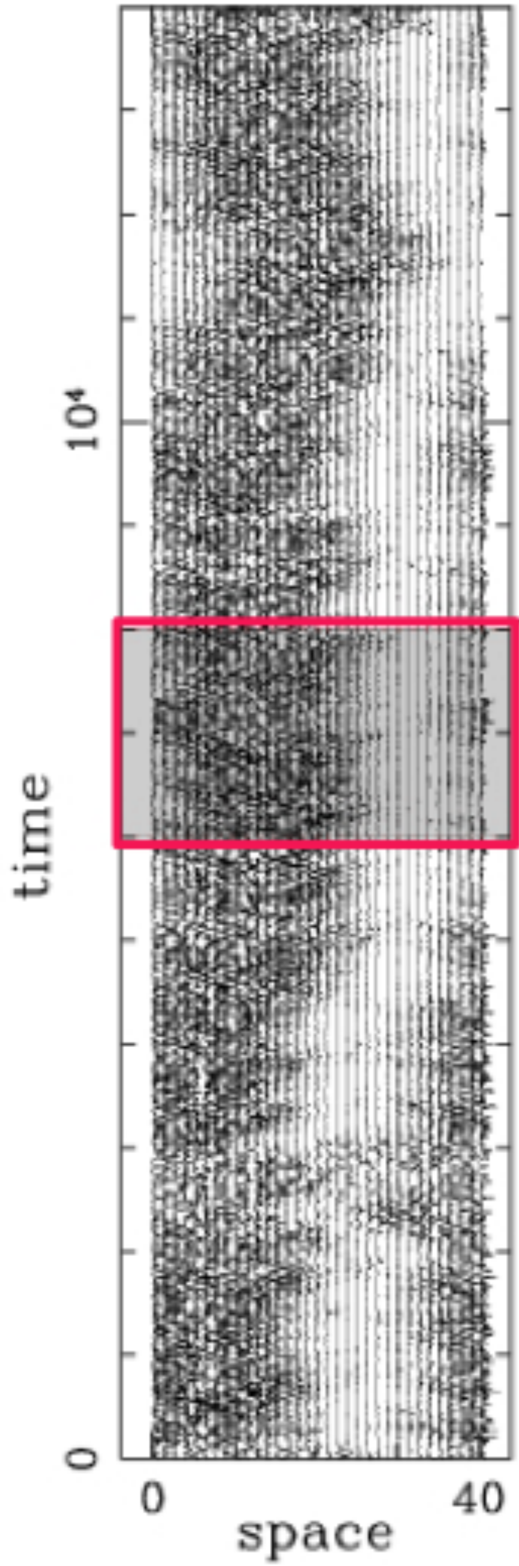
time average

Mean flow

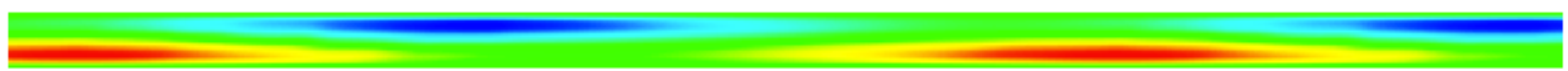
Average: in time and in along-band direction

$$\mathbf{U}(y,z) \equiv \langle \mathbf{u} \rangle \equiv \int dx \int dt\, \mathbf{u}(x,y,z,t)$$

$$\tilde{\mathbf{u}} \equiv \mathbf{u} - \mathbf{U}$$



$u(x=0,y=0,z,t)$



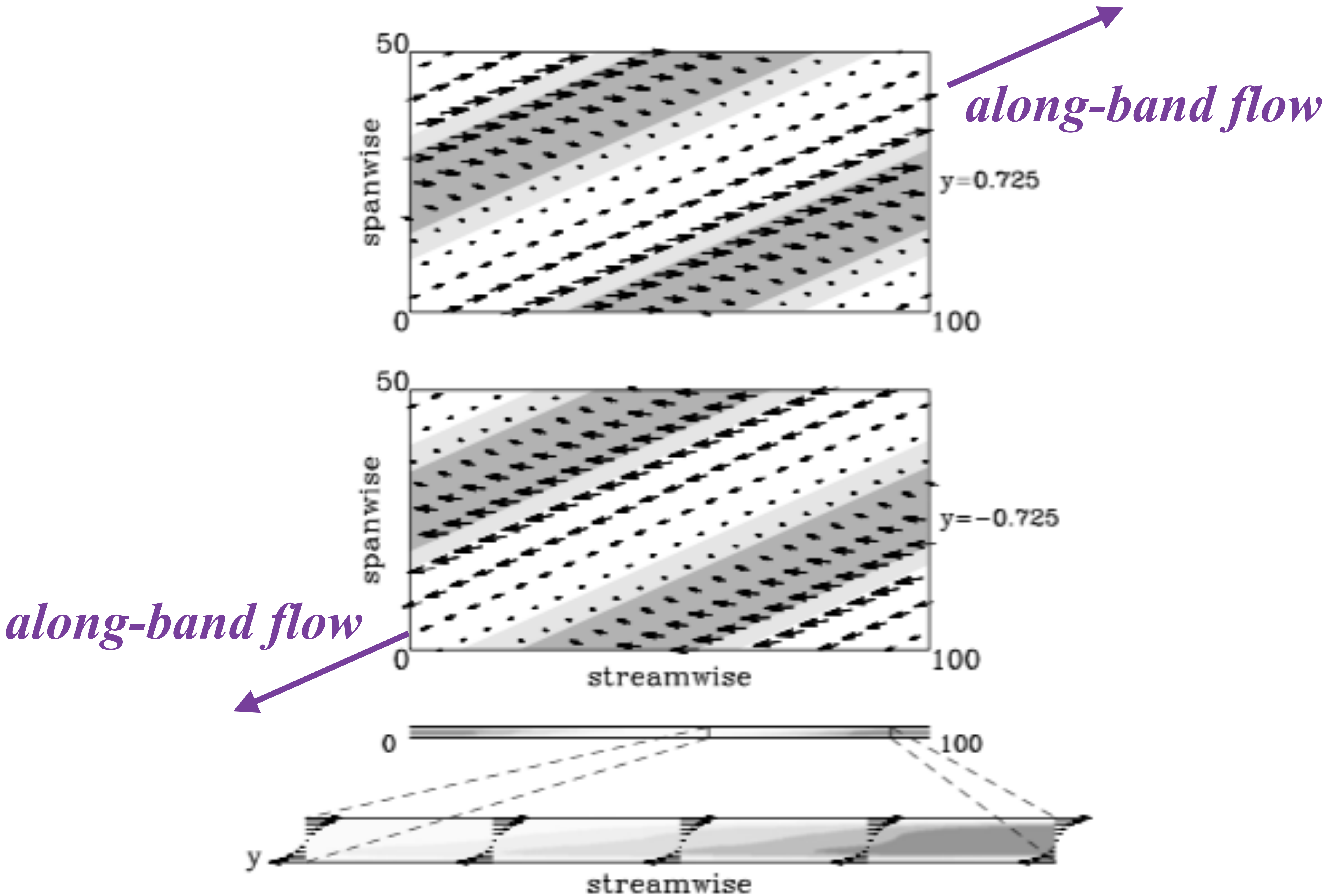
$U(y,z) - U_{Couette}$ $\quad y \quad z \longrightarrow$

$\Psi(y,z) - \Psi_{Couette}$ (y-z streamfunction)

$\langle \tilde{\mathbf{u}} \cdot \tilde{\mathbf{u}} \rangle / 2$ turbulent kinetic energy

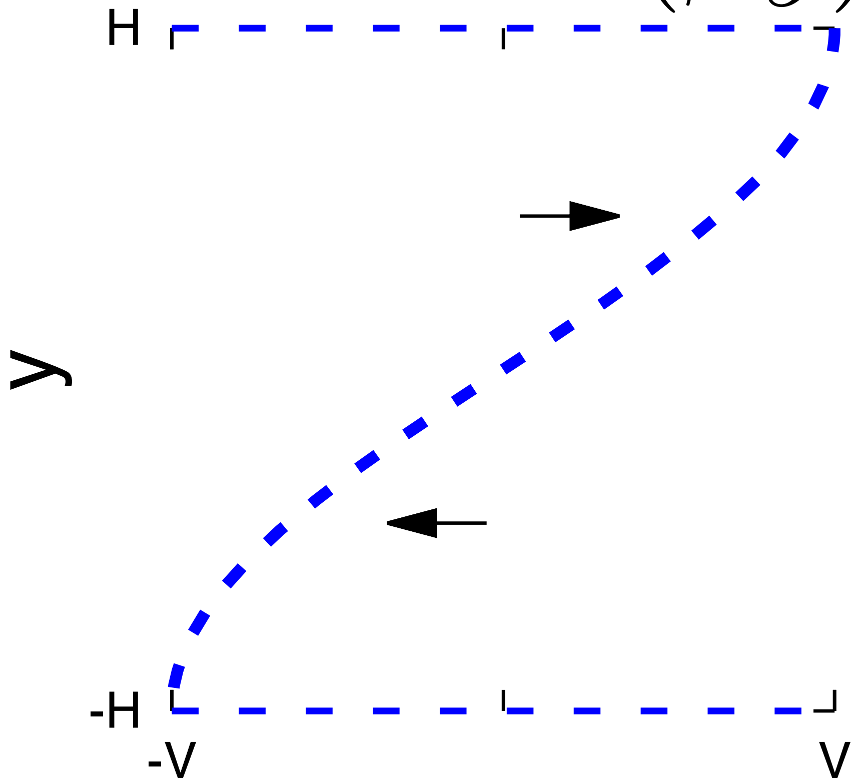
$P(y,z)$ pressure

Mean flow (seen in horizontal plane)



Waleffe flow

$$u = V\sin(\beta y)$$



Laminar flow

Toy model of plane Couette flow

Stress free boundaries in y

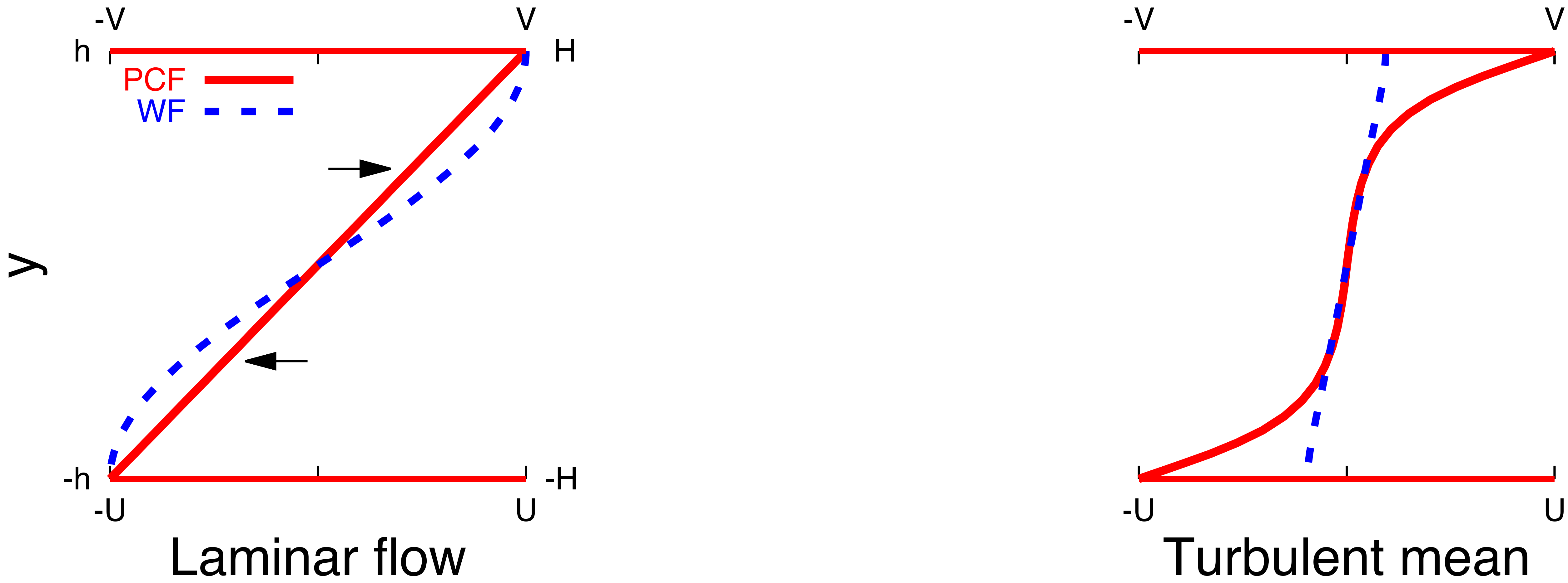
Body forced, $F = C\sin\left(\frac{\pi}{2}\frac{y}{H}\right)$

Demonstration of self-sustaining process.

Confined Kolmogorov flow

Do the same structures emerge?

PCF vs Waleffe flow

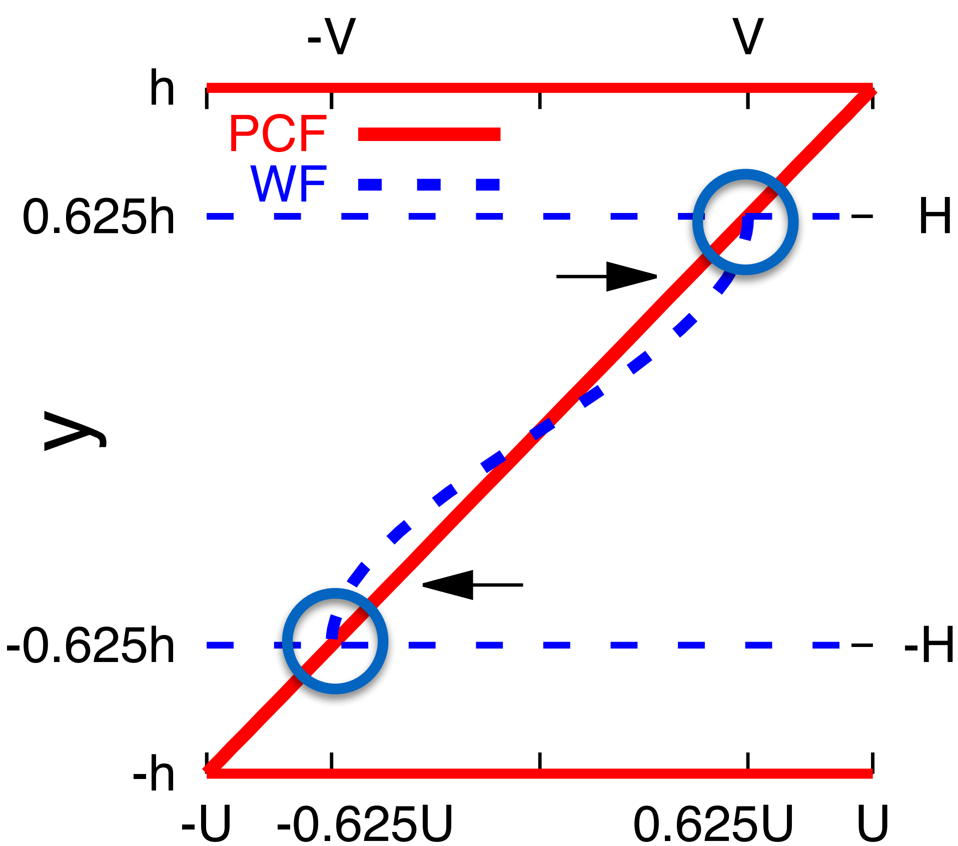


PCF
Linear laminar profile

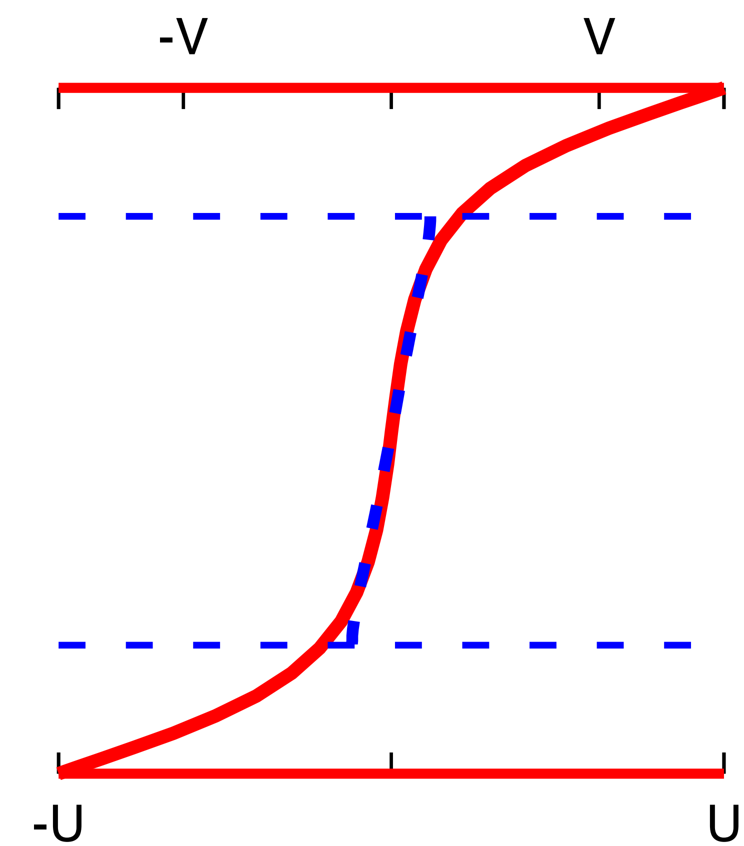
Waleffe flow
Linear turbulent profile

PCF vs Waleffe flow

Waleffe flow captures the interior of PCF



Laminar flow



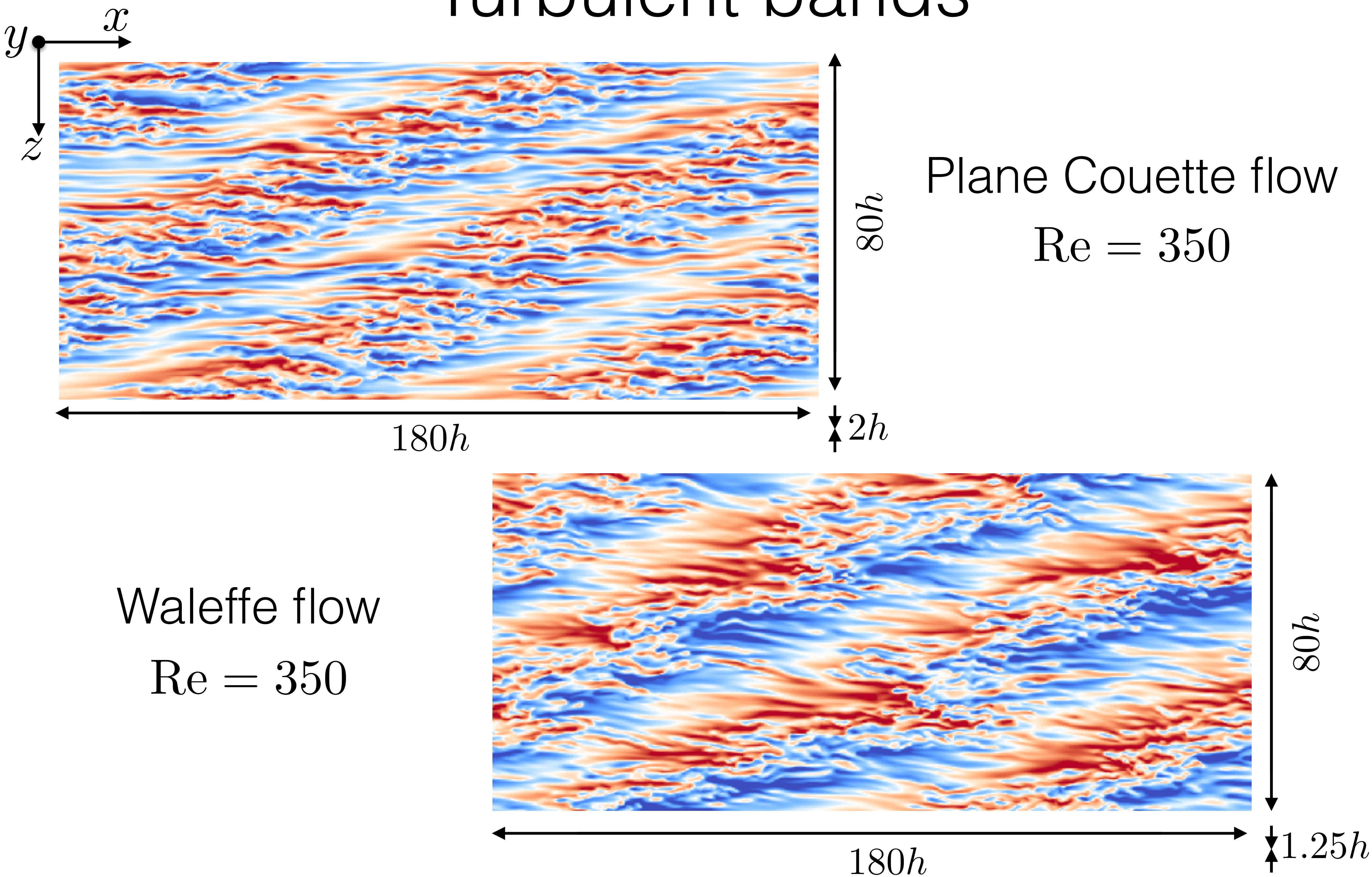
Turbulent mean

Rescale relative to PCF

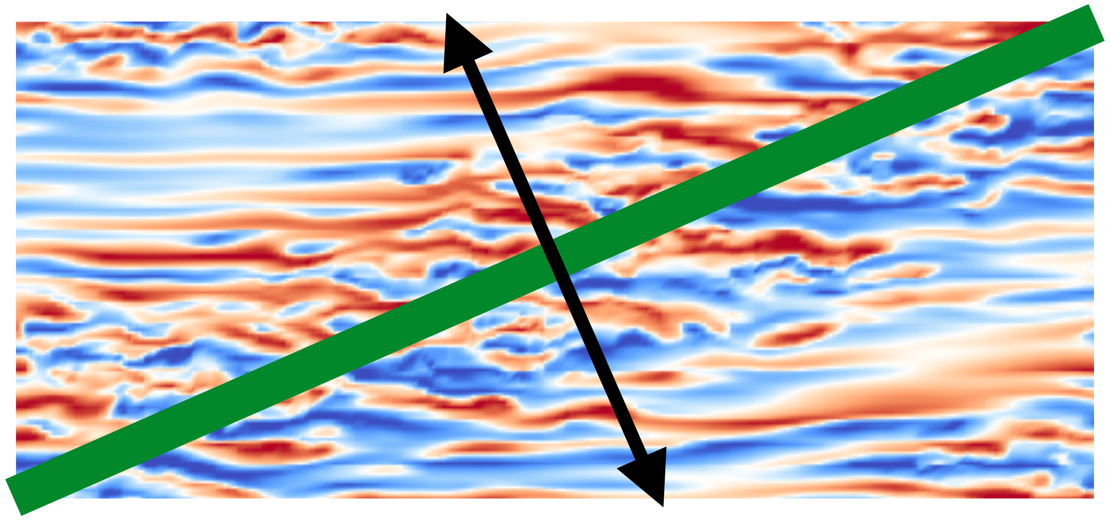
$$H = 0.625h, \; V = 0.625U$$

$$\mathrm{Re} = \frac{Uh}{\nu} = \frac{VH}{0.625^2 \nu}$$

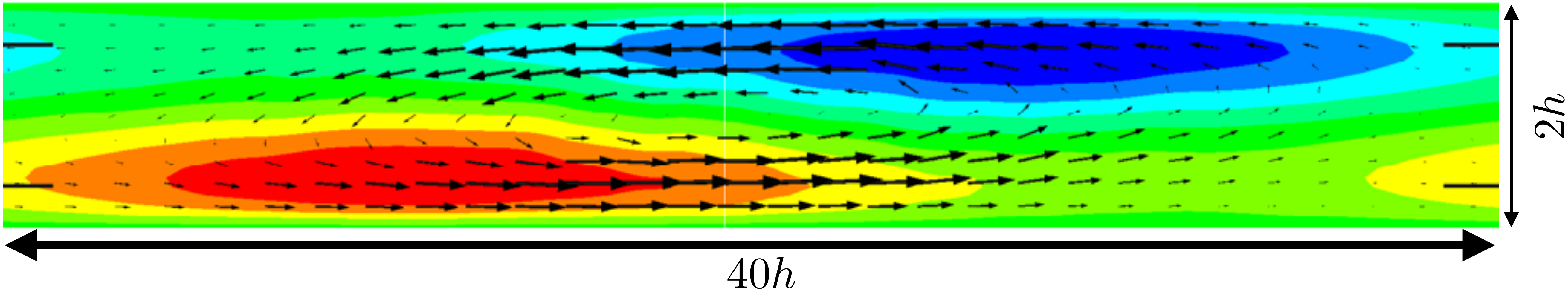
Turbulent bands

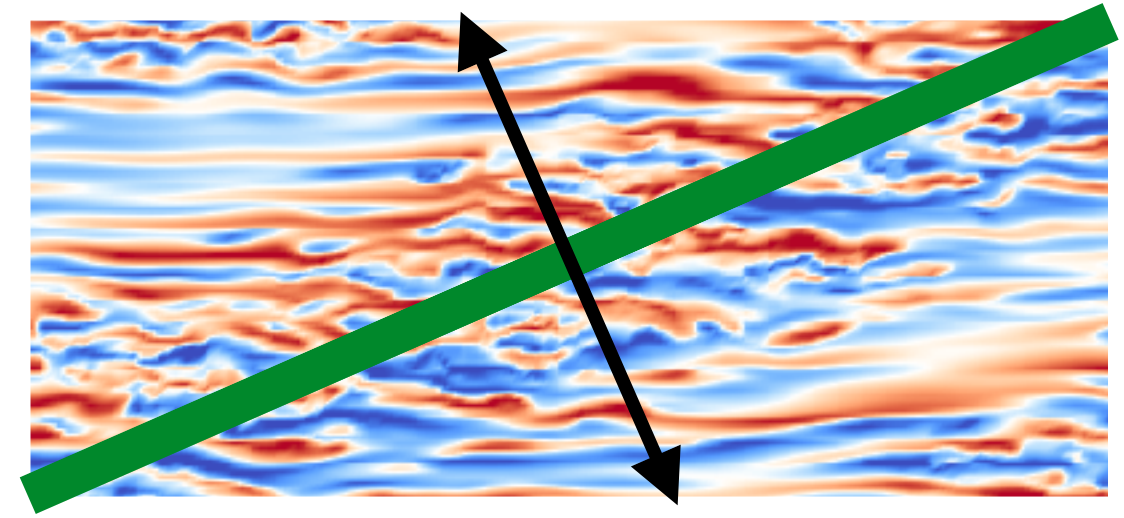


Mean structure



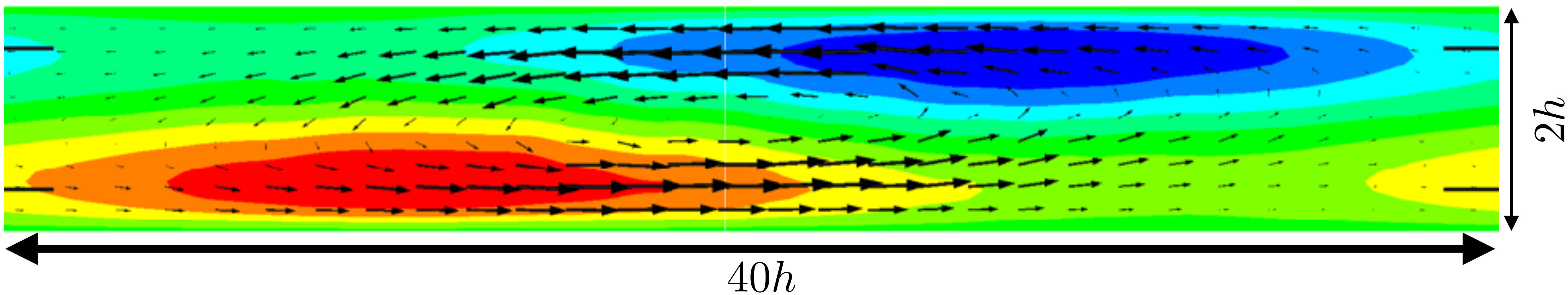
Plane Couette flow, $\mathrm{Re} = 350$



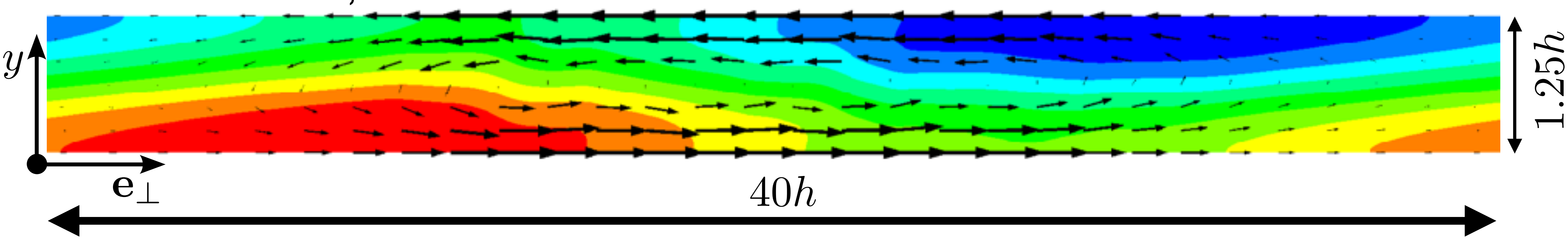


Mean structure

Plane Couette flow, $\mathrm{Re} = 350$



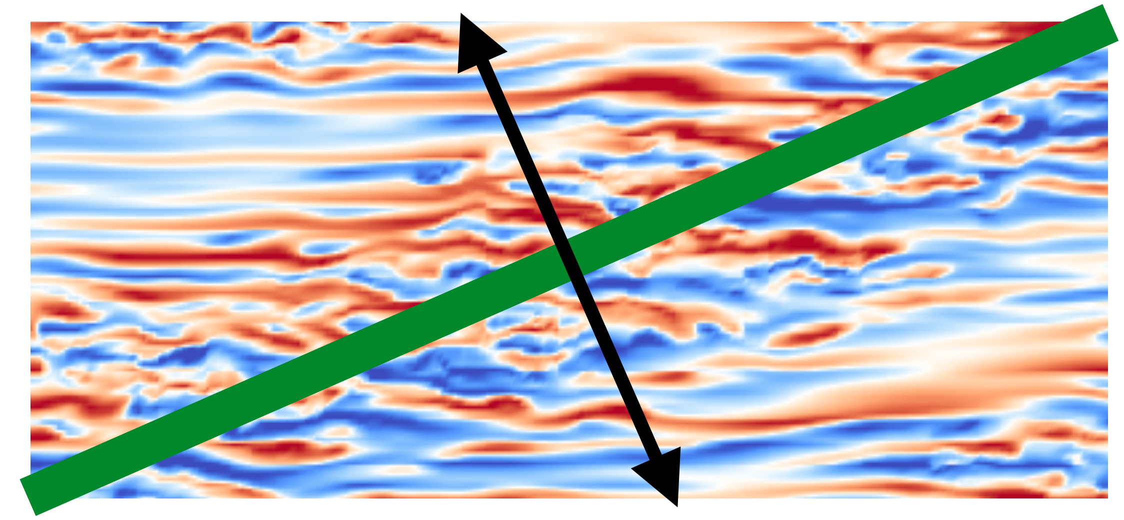
Waleffe flow, $\mathrm{Re} = 350$



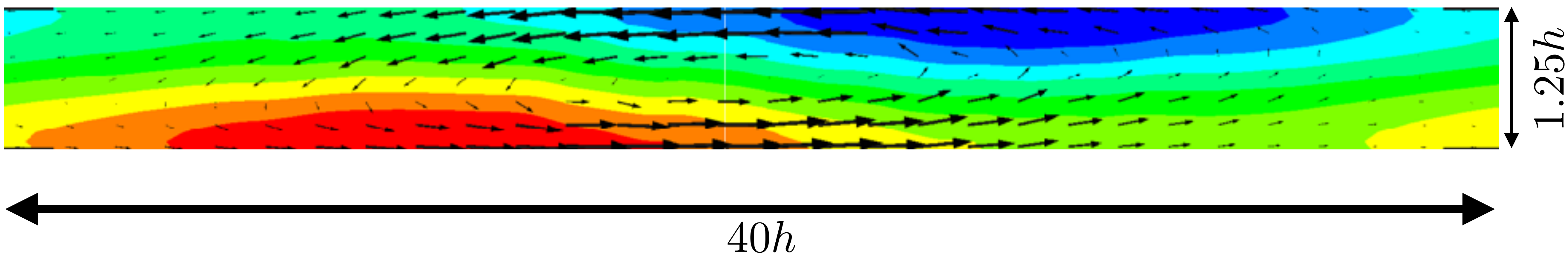
Existence range: PCF $\mathrm{Re} \in [325, 420]$

WF $\mathrm{Re} \in [260, 640]$

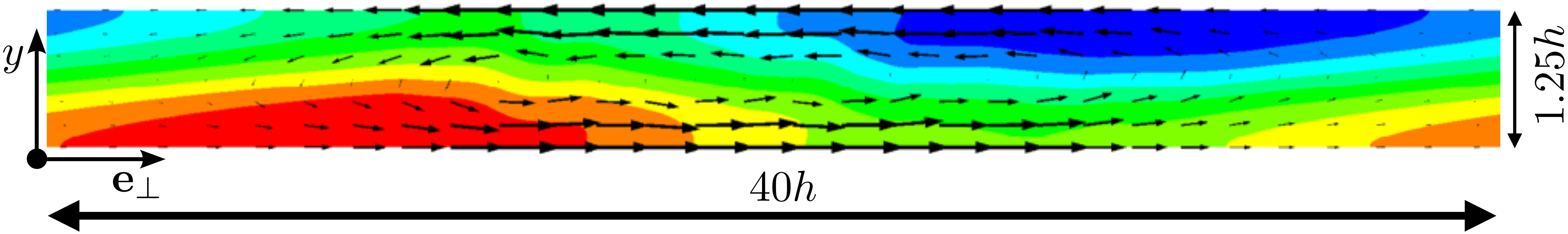
Mean structure



Plane Couette flow, $\mathrm{Re} = 350$



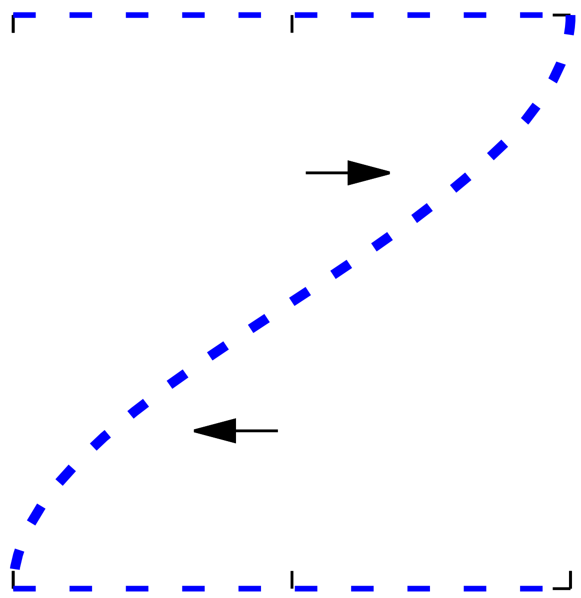
Waleffe flow, $\mathrm{Re} = 350$



Existence range: PCF $\mathrm{Re} \in [325, 420]$

WF $\mathrm{Re} \in [260, 640]$

Modelling Waleffe flow

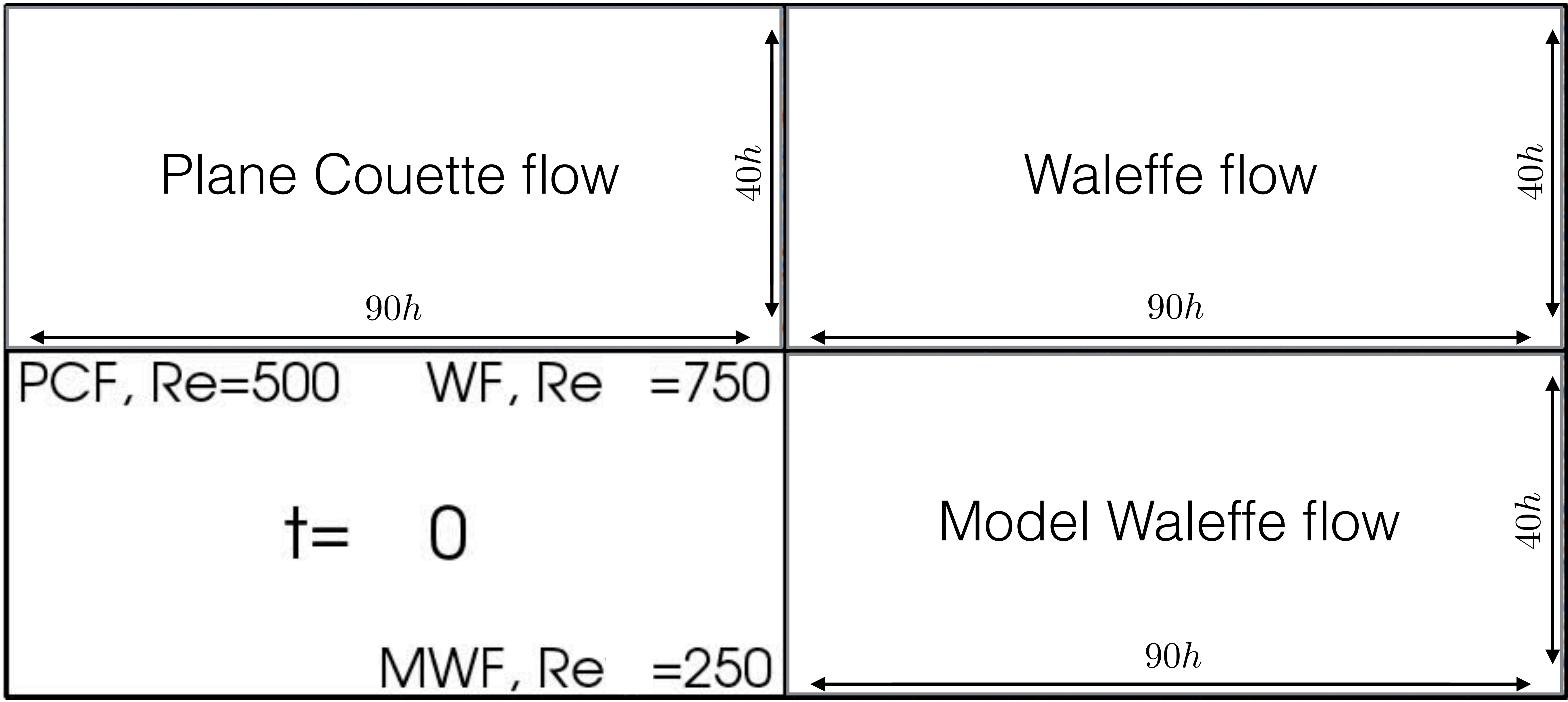


Using leading 4 Fourier modes that satisfy BC

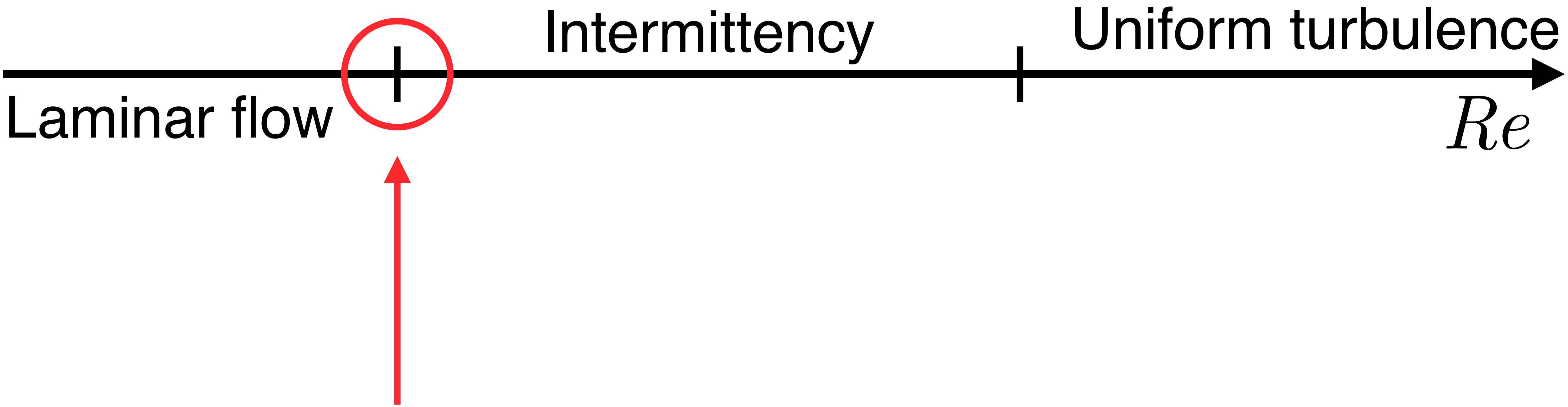
$$u(x,y,z) = u_0(x,z) + u_1(x,z)\sin(\beta y) + u_2(x,z)\cos(2\beta y) + u_3(x,z)\sin(3\beta y),$$

Result: 7 PDEs in (t,x,z)

Also requires only half the resolution in *x,z*


Plane Couette flow
40h
90h
Waleffe flow
40h
90h
PCF, Re=500
WF, Re =750
t= 0
MWF, Re =250
Model Waleffe flow
40h
90h

Defining and characterizing the lower bound



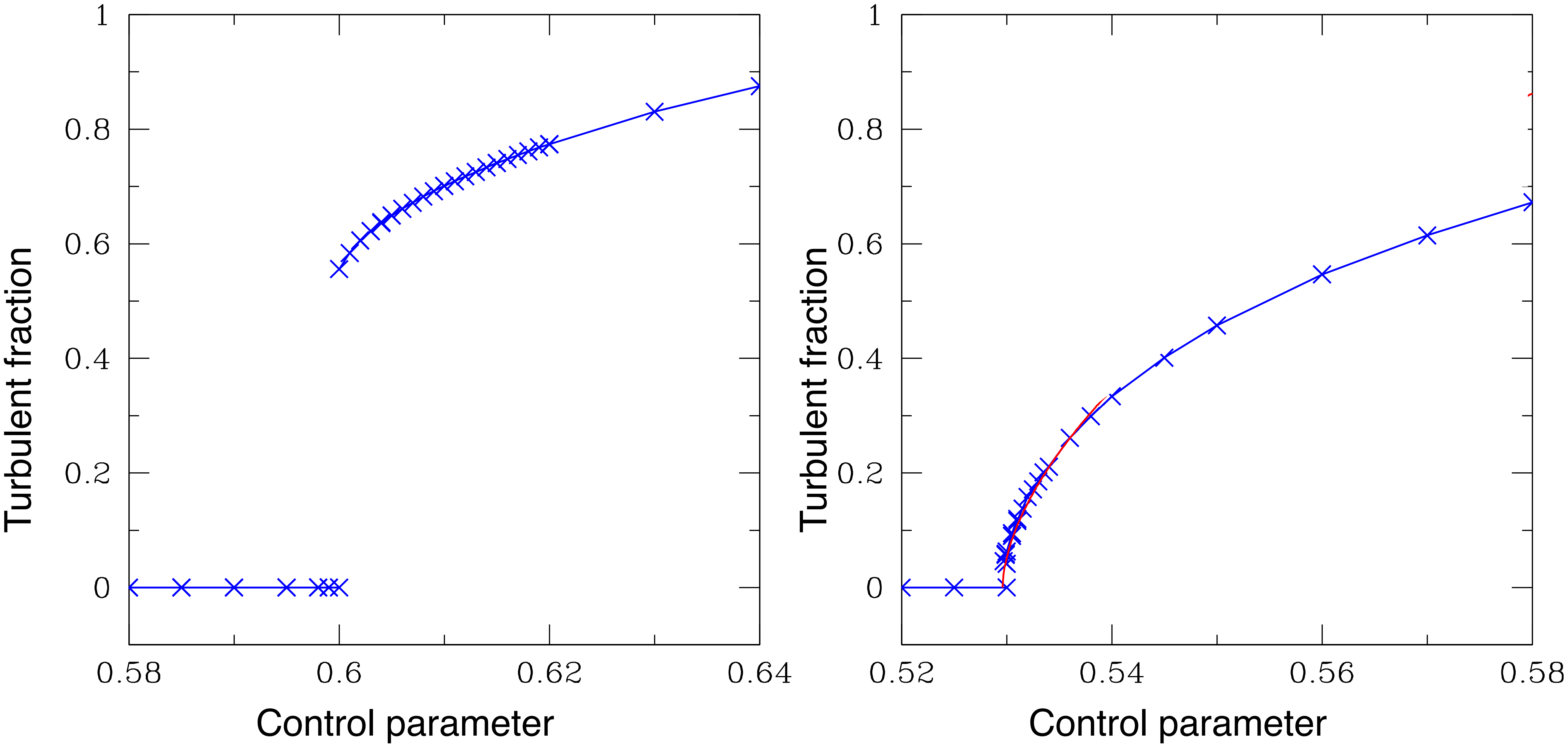
How low does turbulence go?

Continuous or discontinuous?

Universal or not?

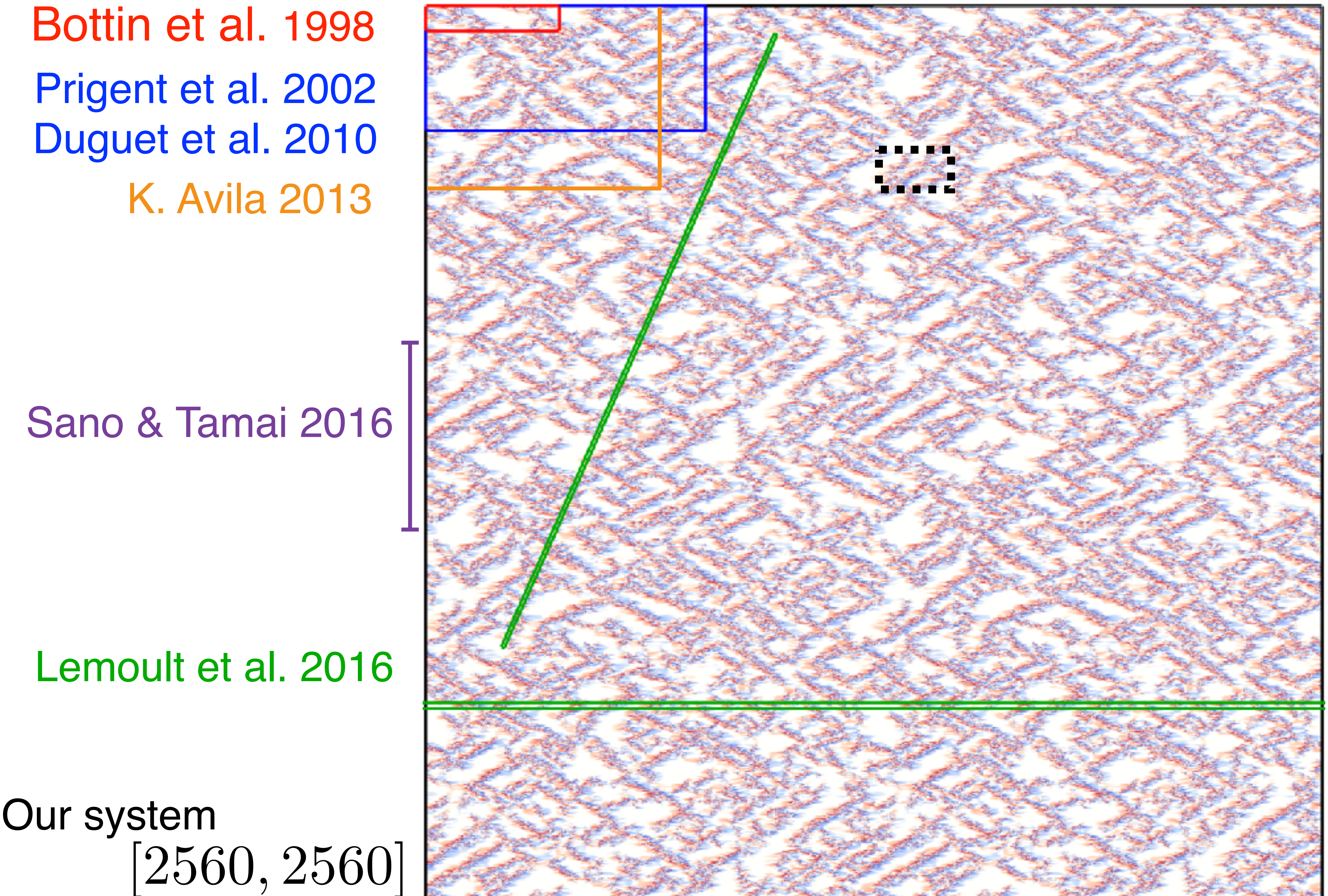
First asked by Pomeau 1986

Discontinuous or Continuous?



Supersize me

$\mathrm{Re} > \mathrm{Re}_c$



Supersize me

$\mathrm{Re} \approx \mathrm{Re}_c$

Bottin et al. 1998

Prigent et al. 2002

Duguet et al. 2010

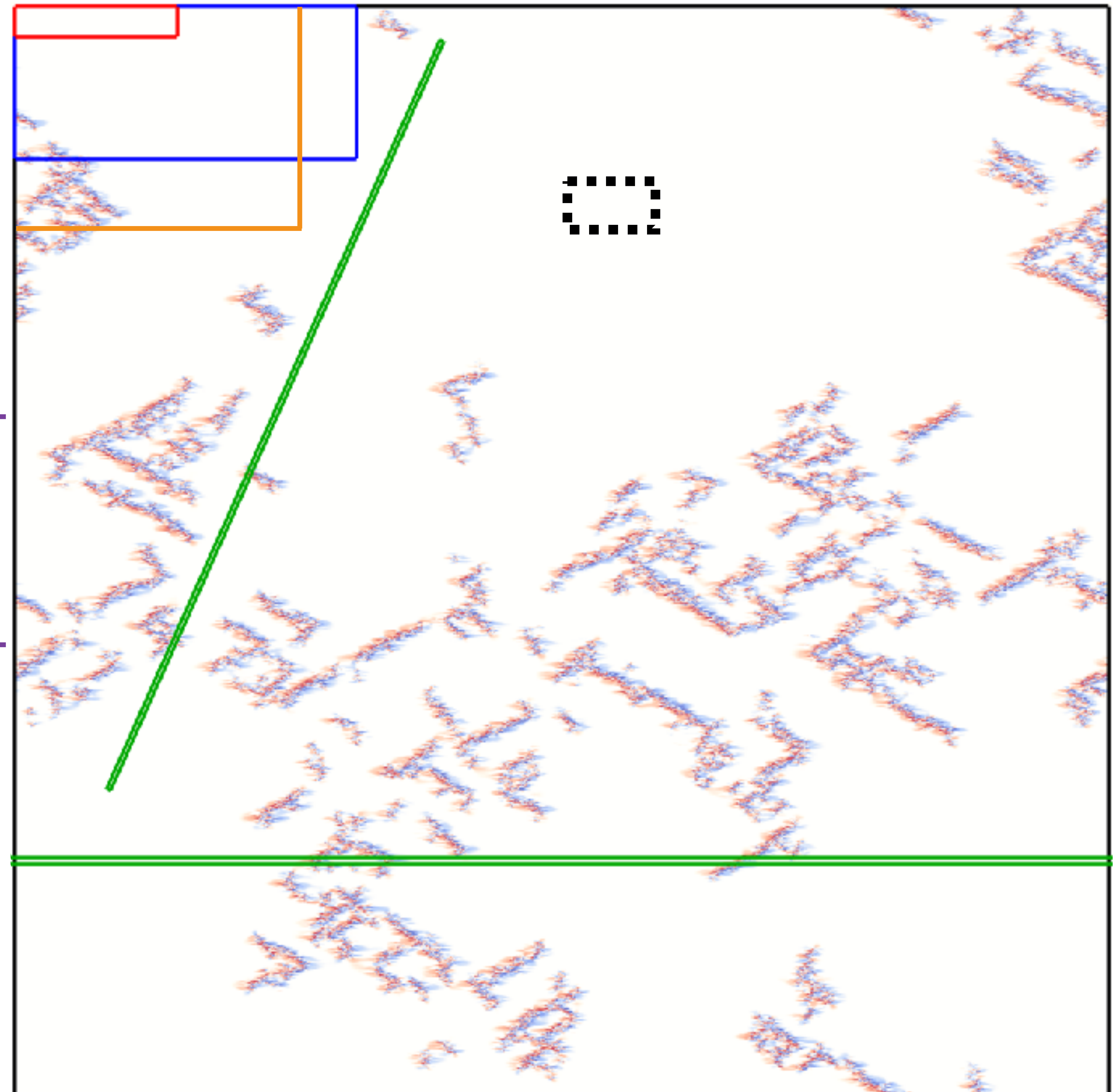
K. Avila 2013

Sano & Tamai 2016

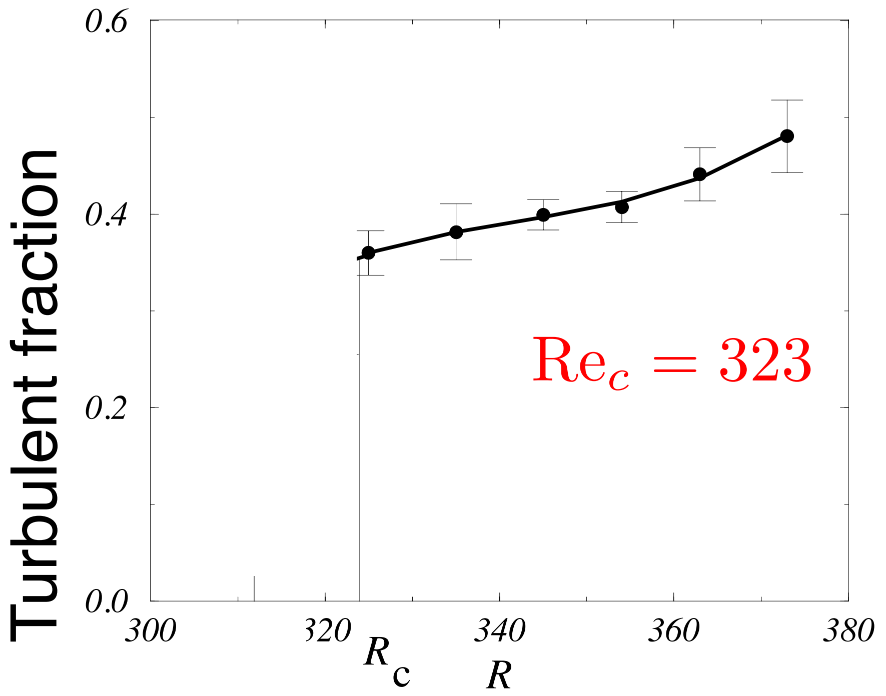
Lemoult et al. 2016

Our system

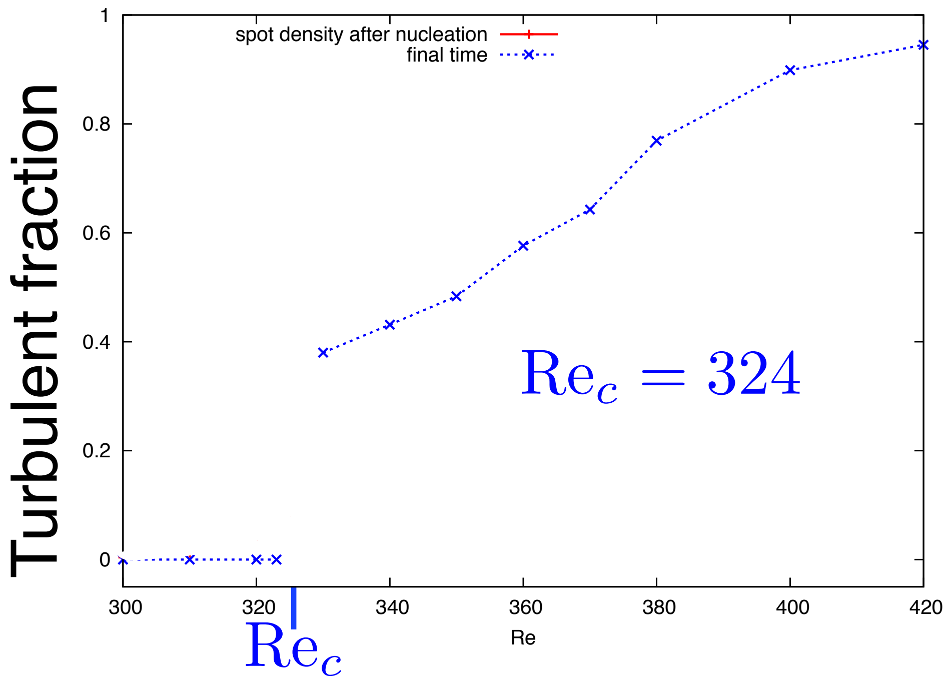
$[2560, 2560]$



Previous studies: **discontinuous**

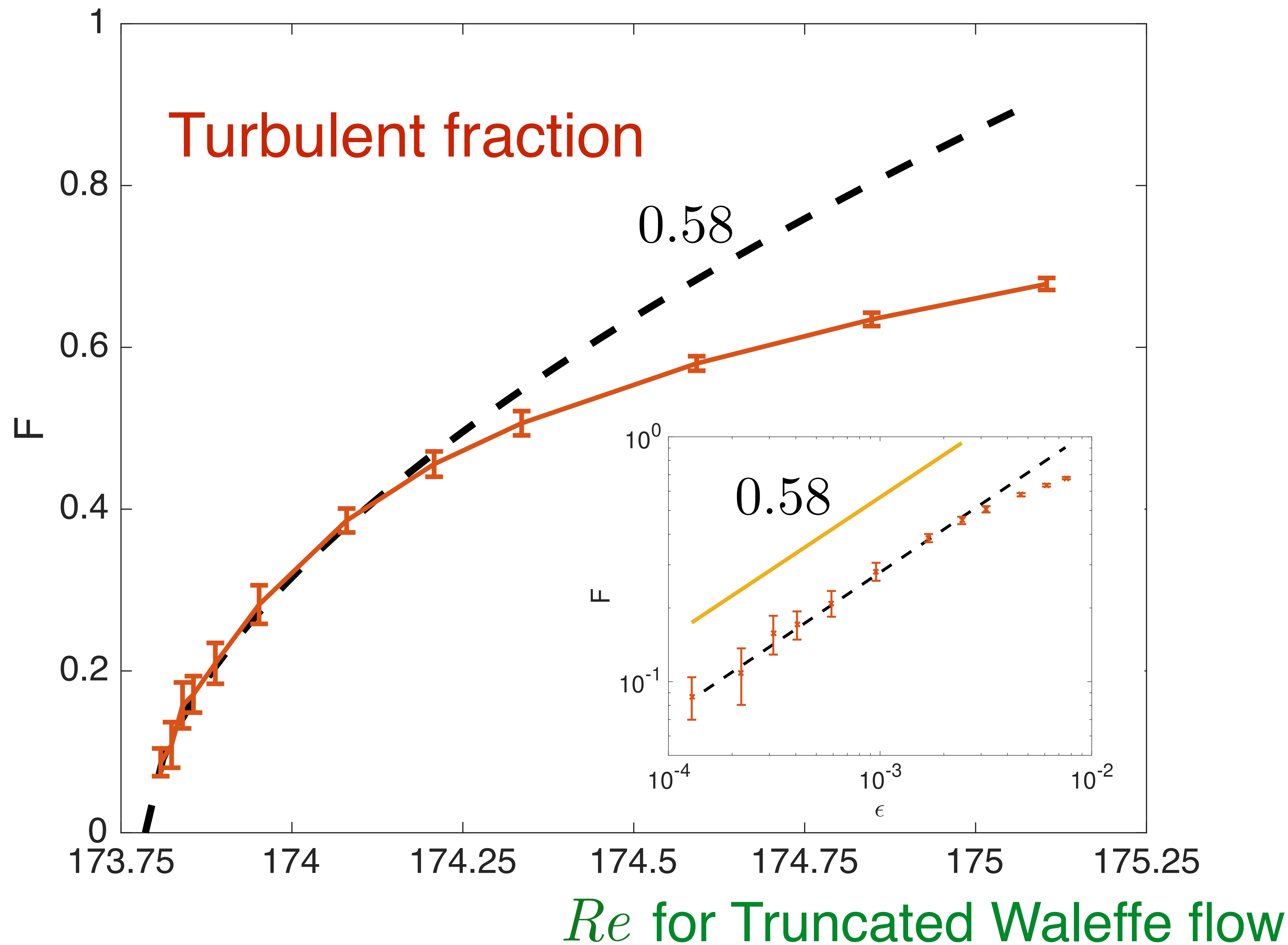


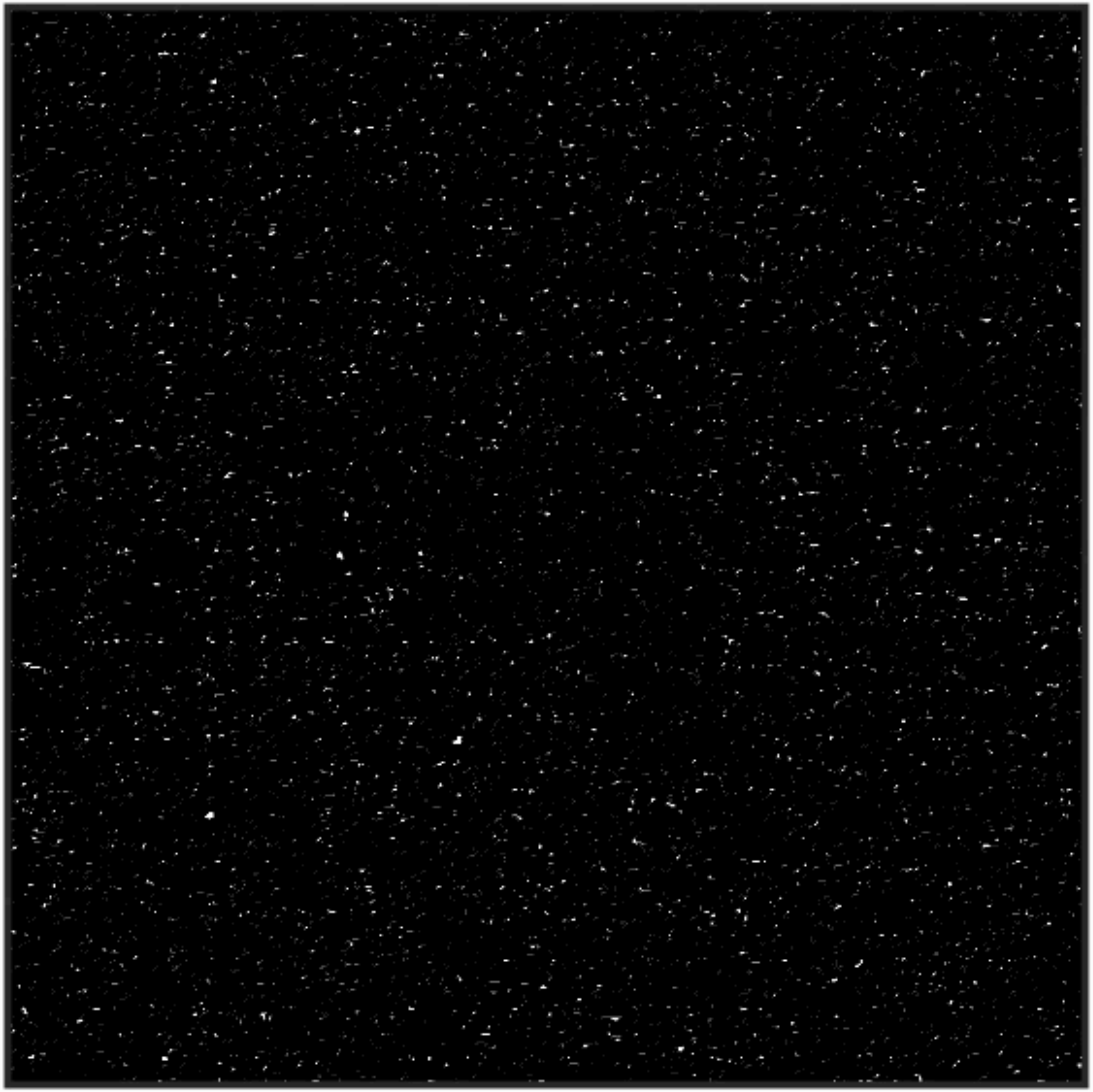
Bottin & Chaté 1998



Duguet et al. 2010

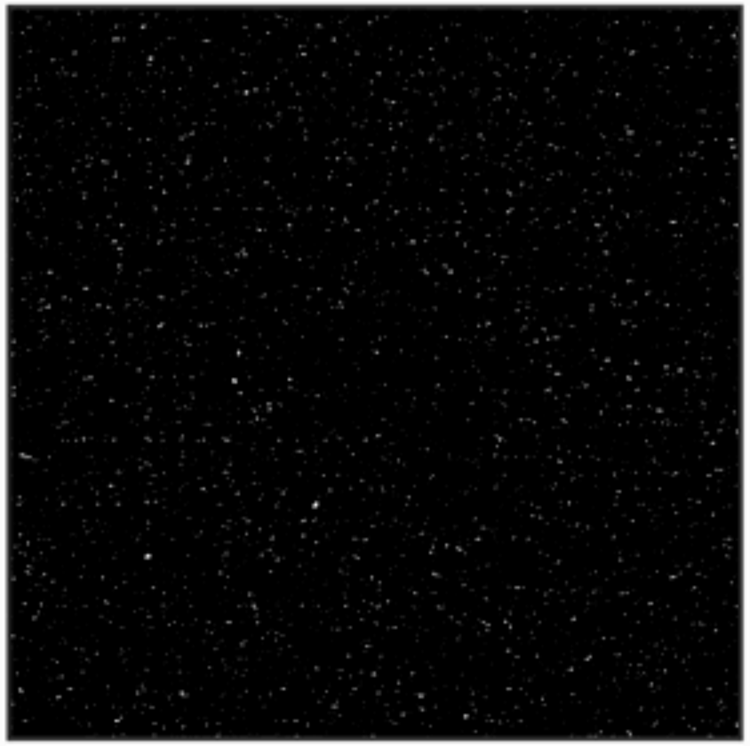
Our result: **Continuous**

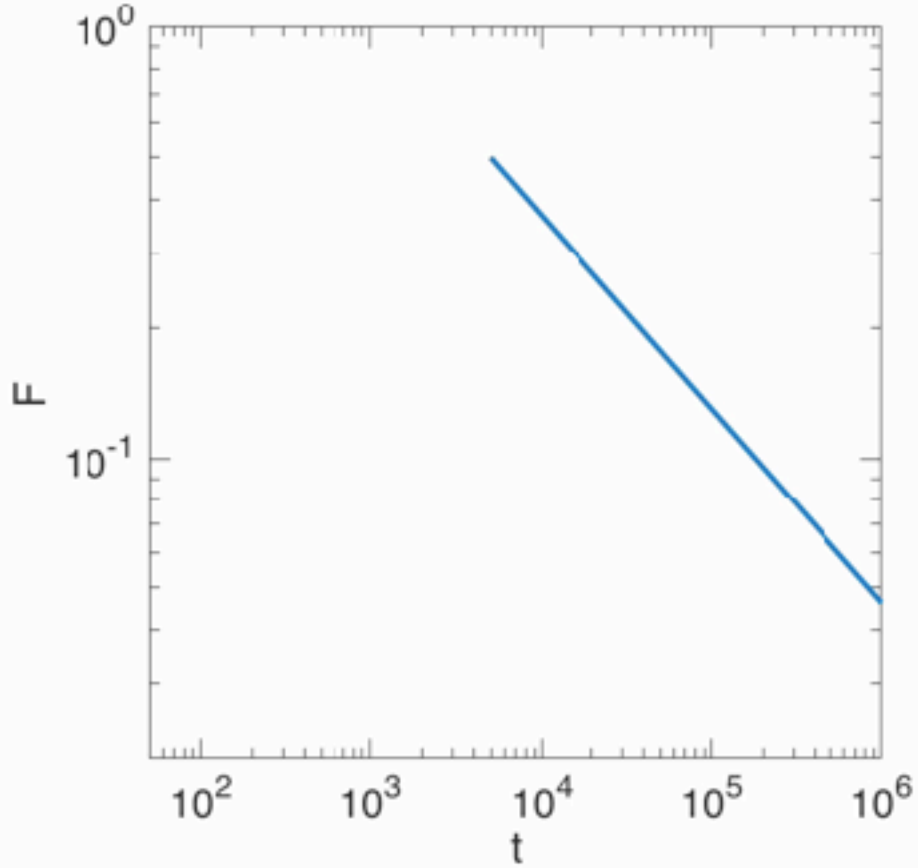




$1 \text{ sec} = 10^4\ h/U$

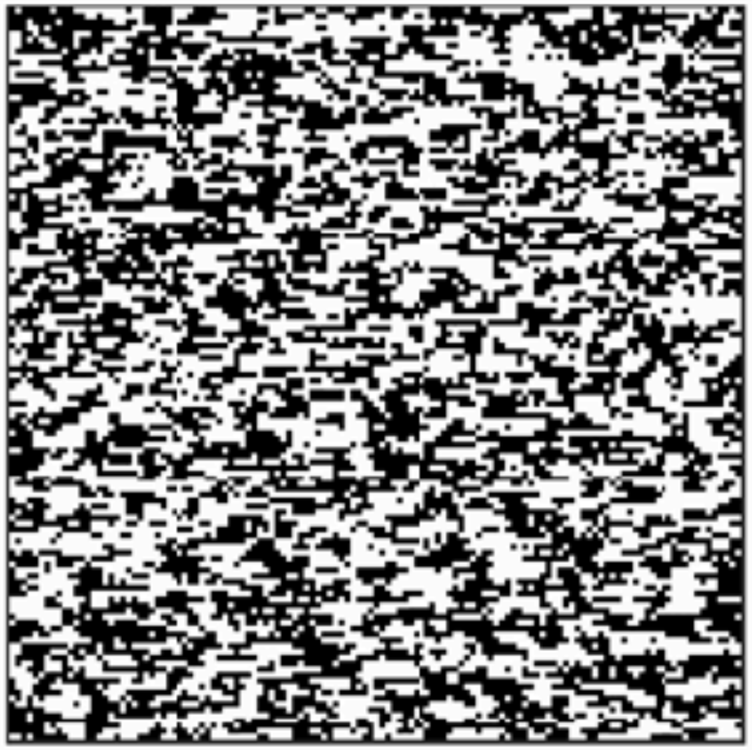
Shear flow

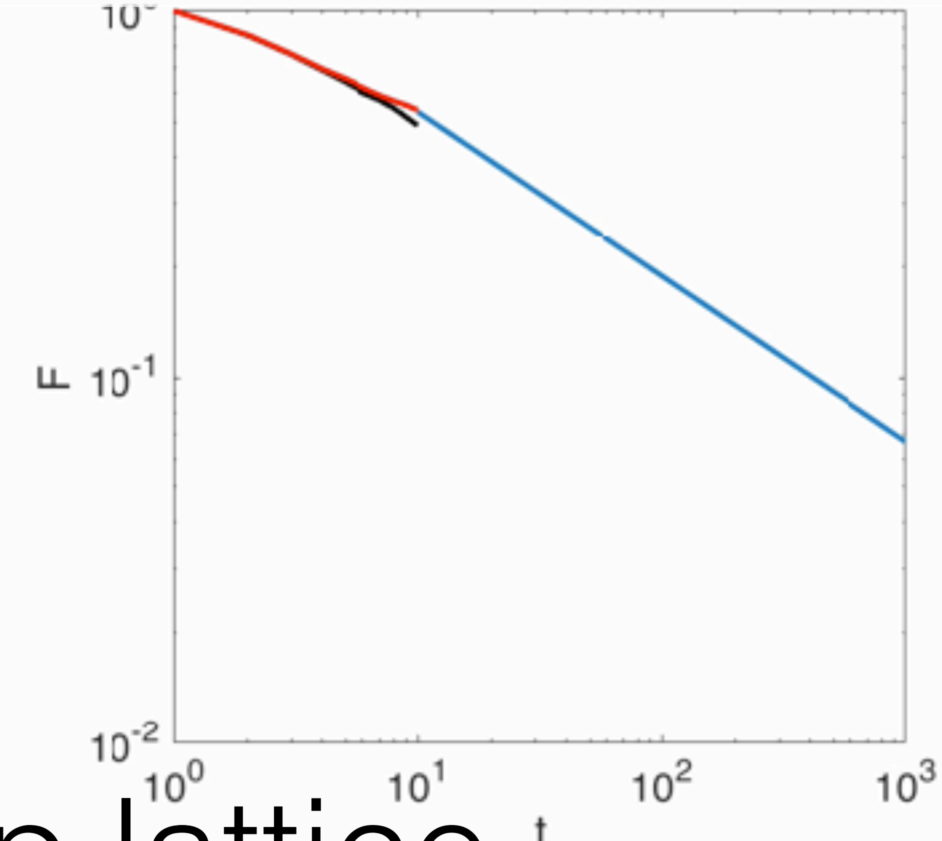


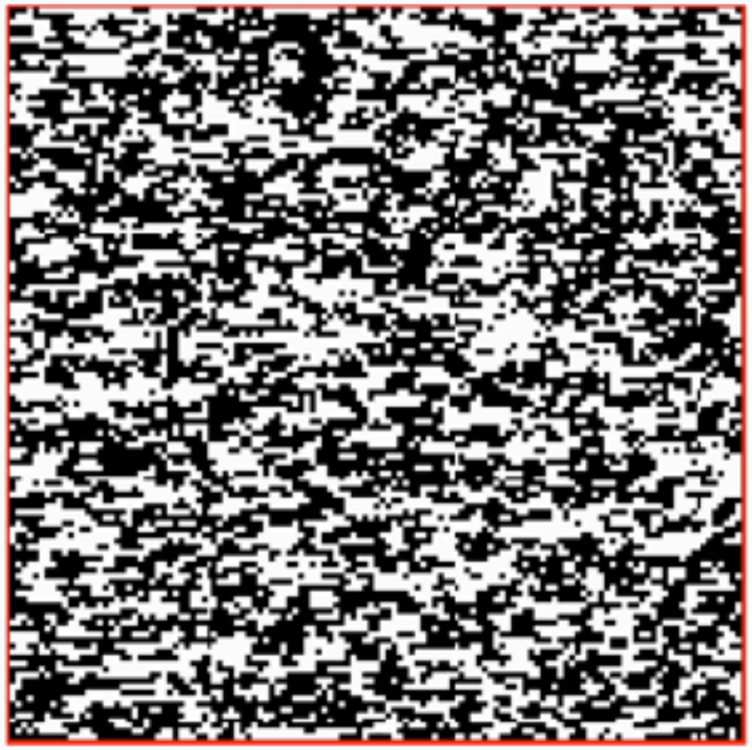


$\mathrm{Re} \approx \mathrm{Re}_c$

$\mathrm{Re} > \mathrm{Re}_c$







Coupled map lattice

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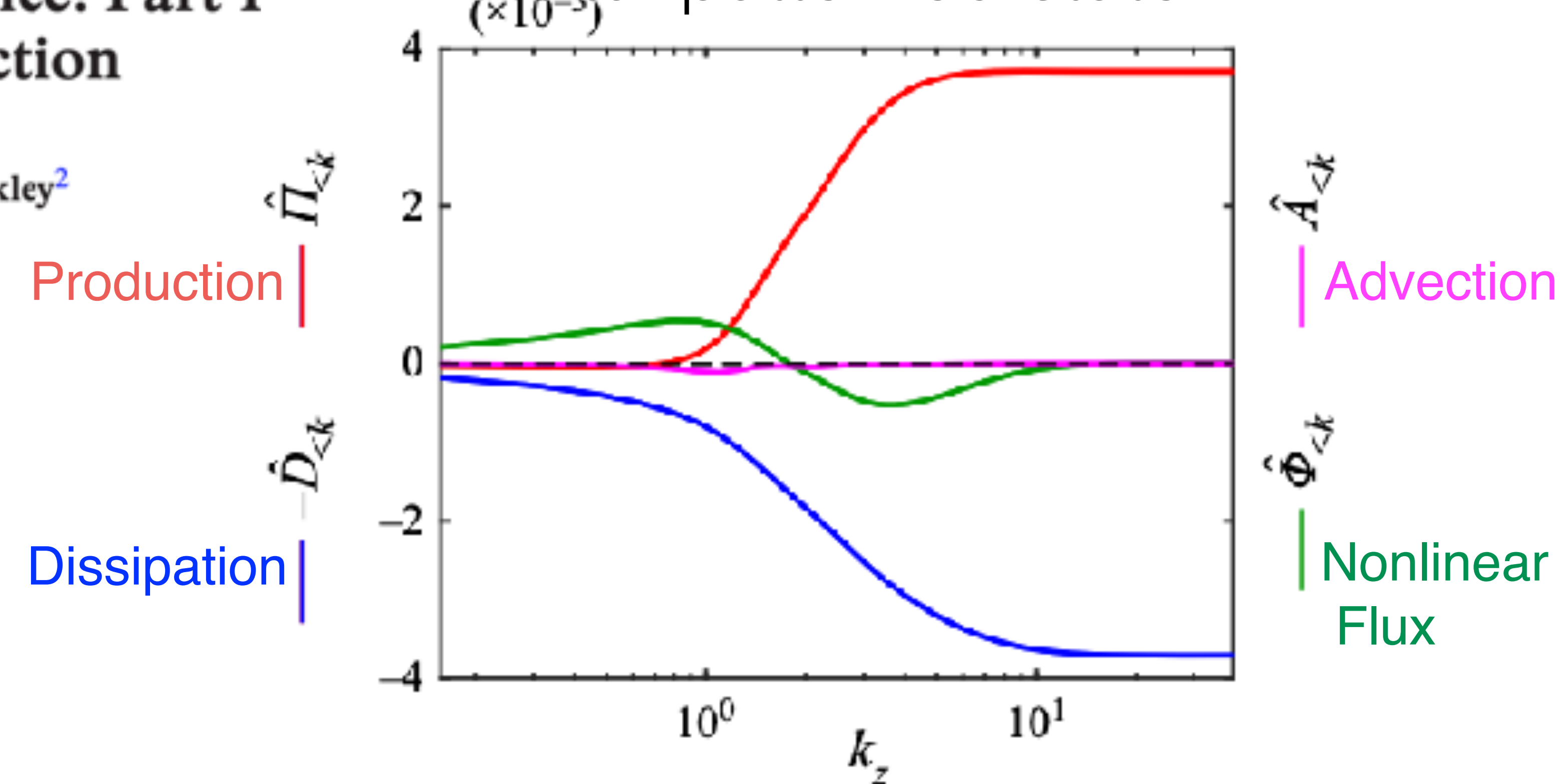
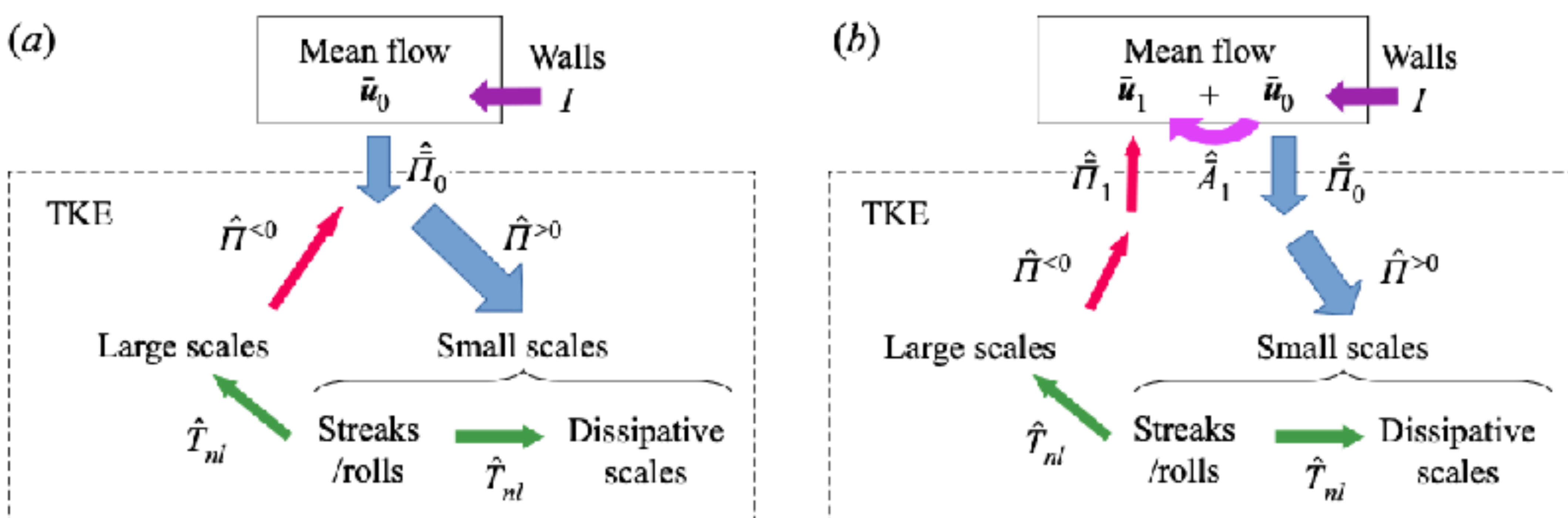
Spectral energy balance of patterned state





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Patterns in transitional shear turbulence. Part 2. Emergence and optimal wavelength

Sébastien Gomé[1,†], Laurette S. Tuckerman[1] and Dwight Barkley[2]