

Wavy Taylor-vortex instability and Self-Sustaining Process / Vortex-Wave Interaction

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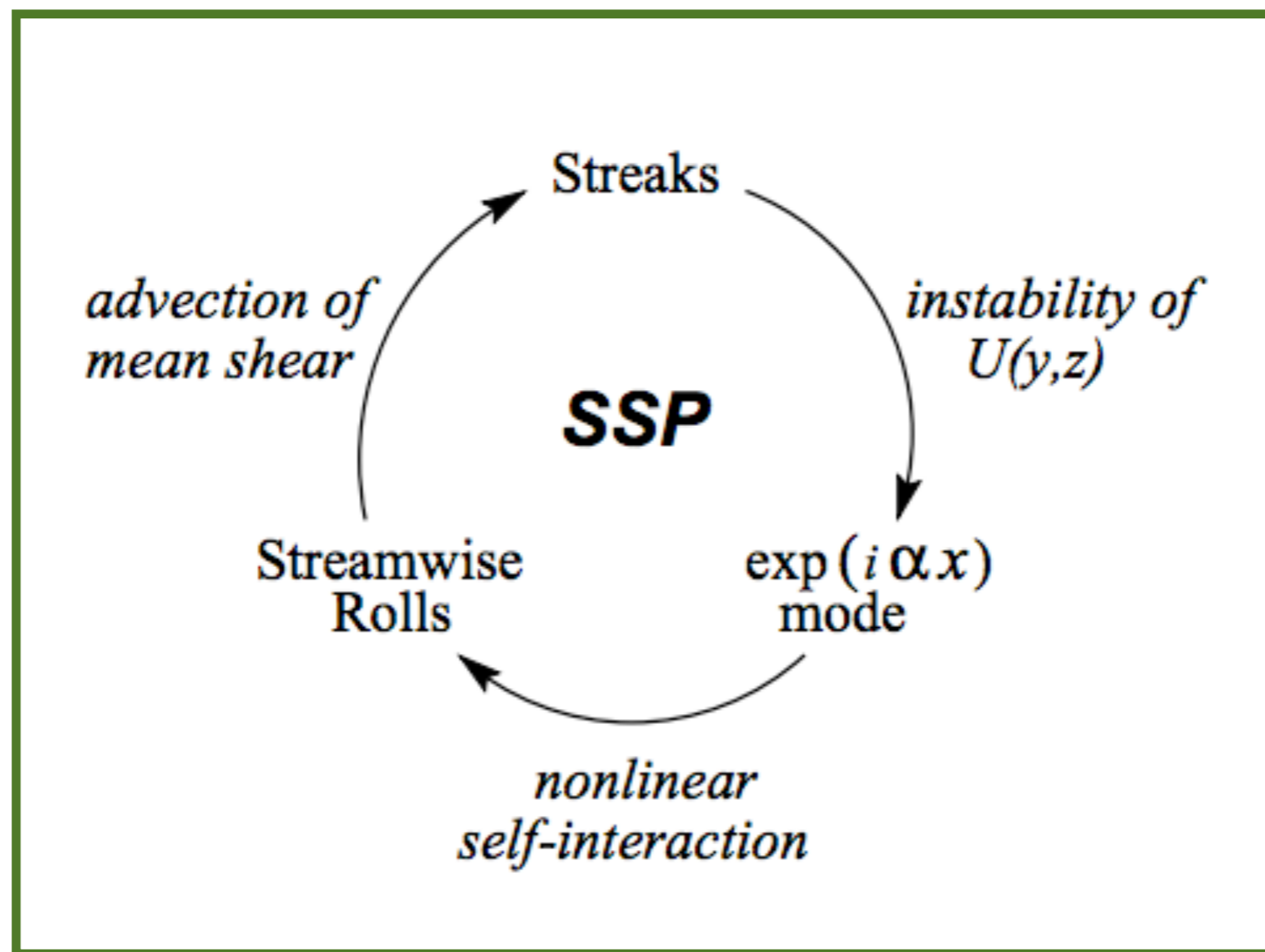
Ashley Willis, Sheffield

PHYSICAL REVIEW FLUIDS 3, 123902 (2018)

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)





Lower branch equilibria in Couette flow: the emergence of canonical states for arbitrary shear flows

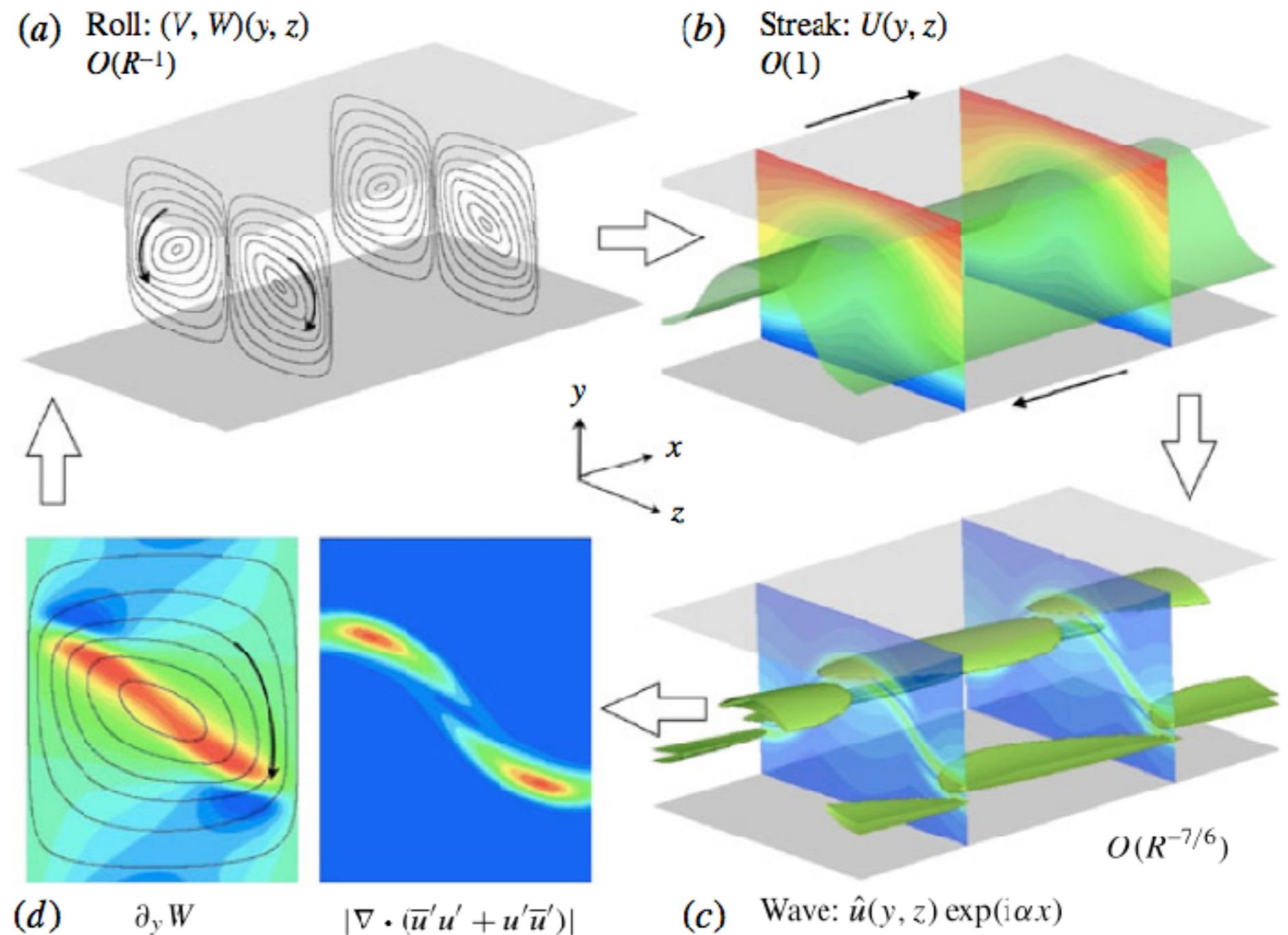
H. M. Blackburn¹, P. Hall² and S. J. Sherwin³

Vortex-Wave Interaction

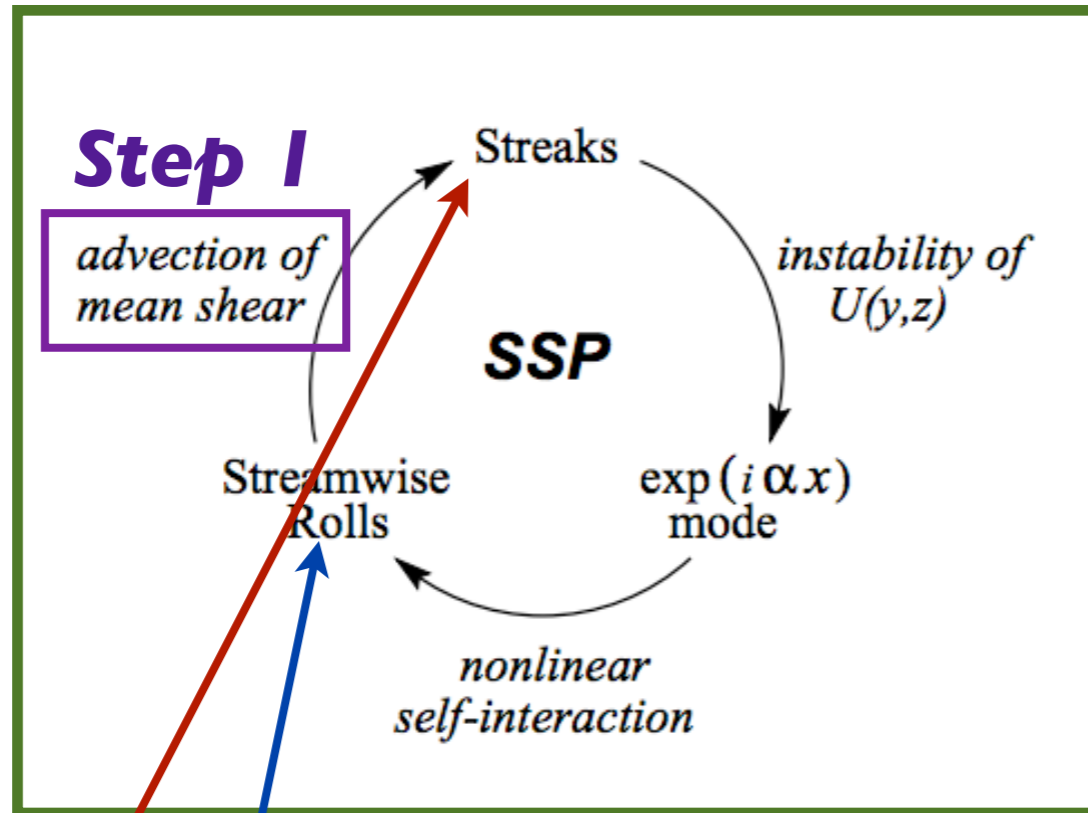
Hall & Smith 1991

Hall & Sherwin 2010

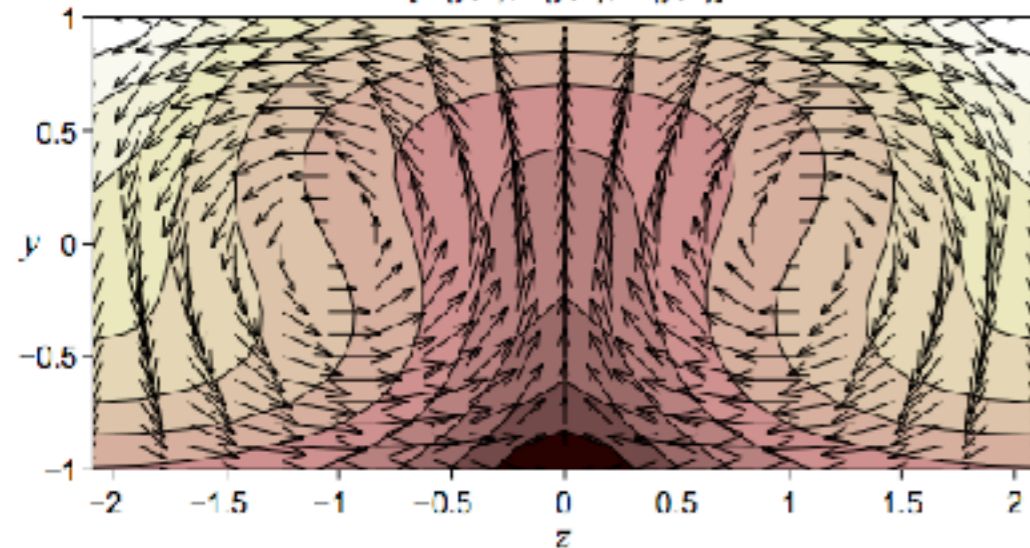
Blackburn, Hall & Sherwin 2013



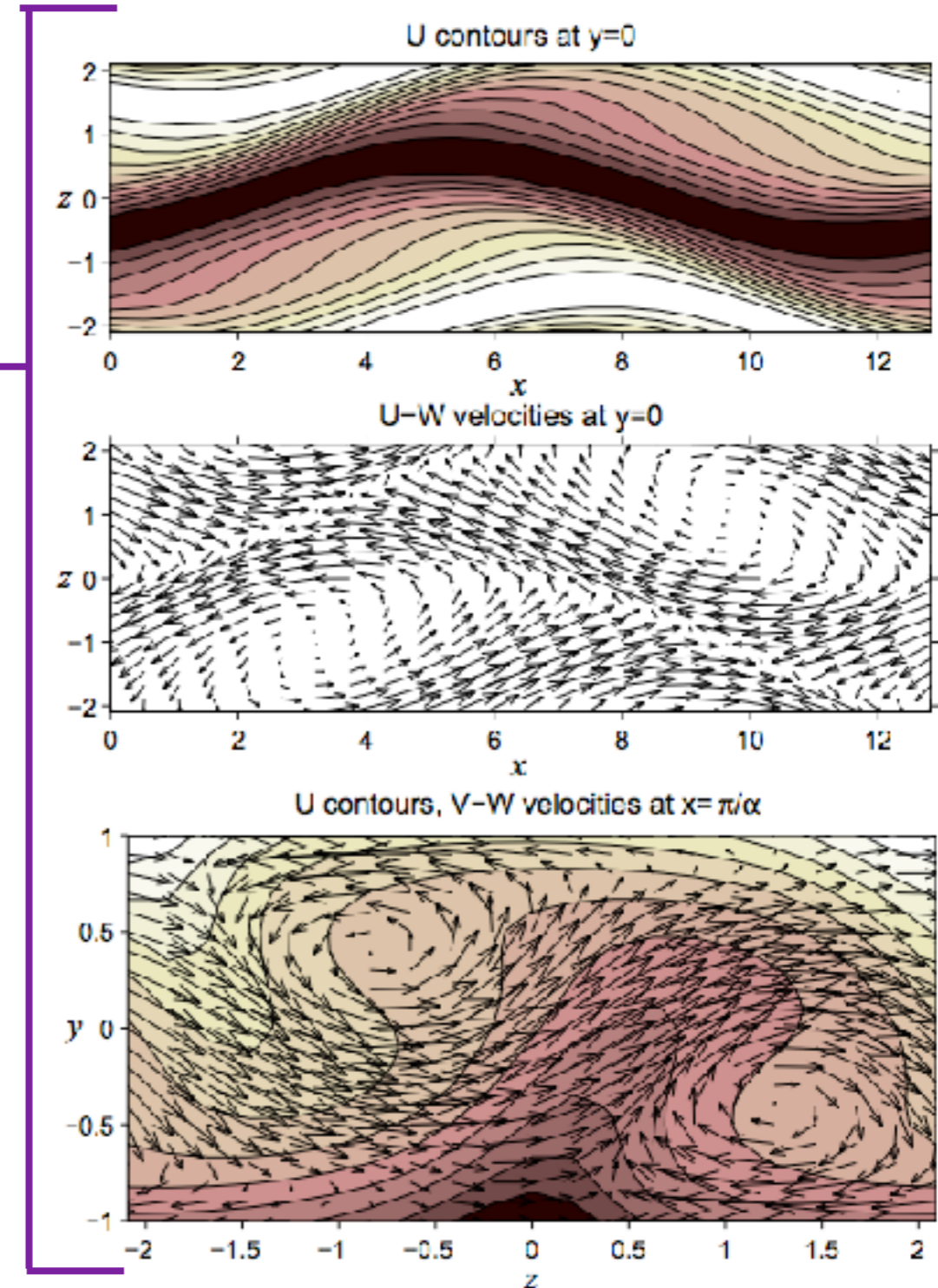
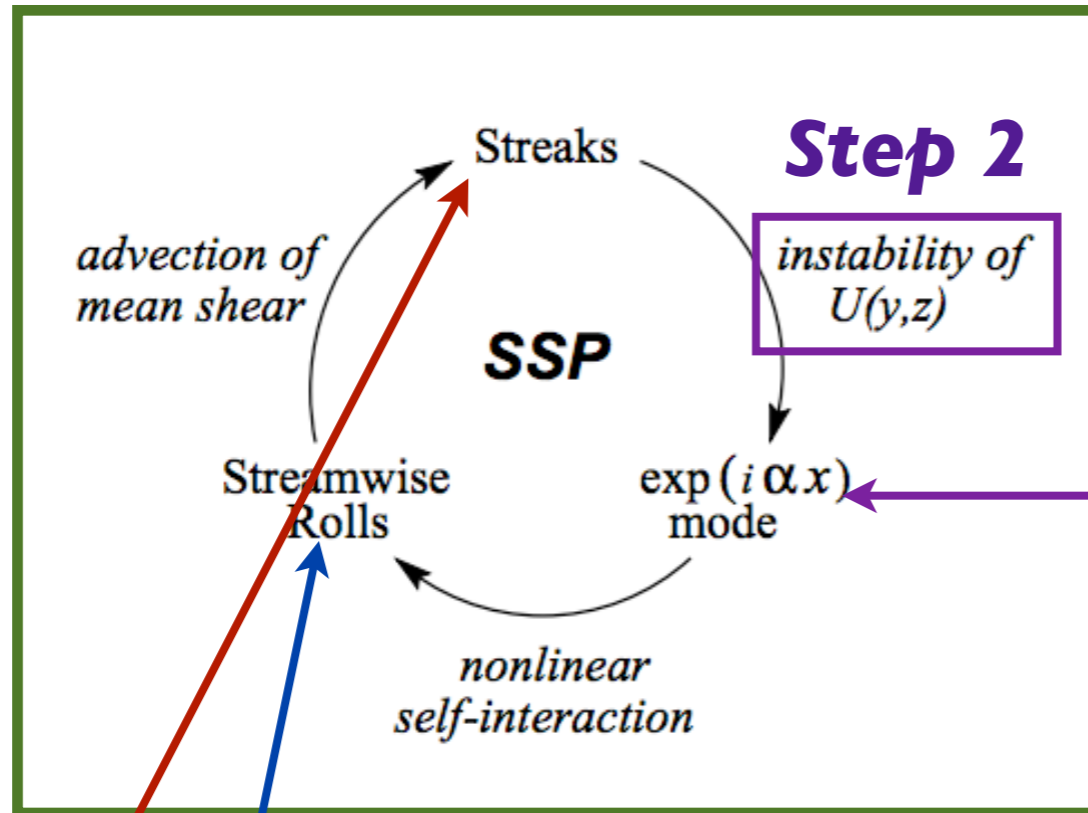
Waleffe: self-sustaining process (SSP)



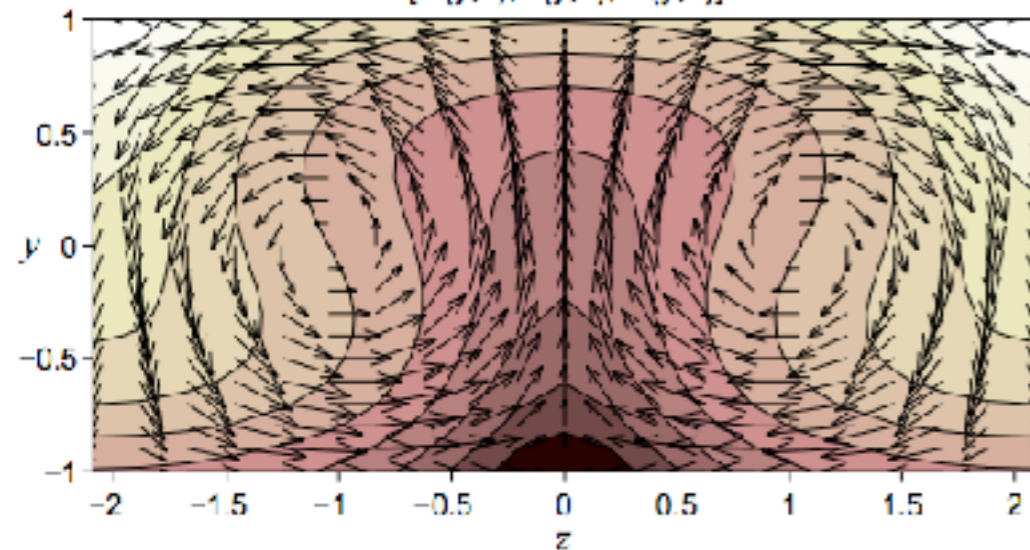
$[U(y,z), V(y,z), W(y,z)]$



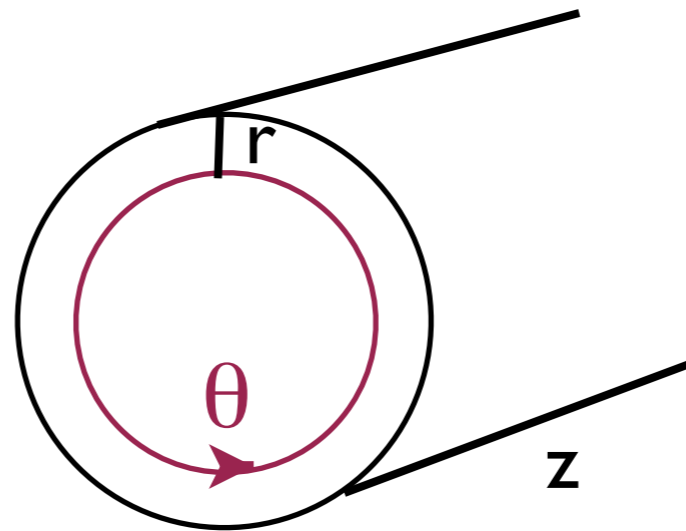
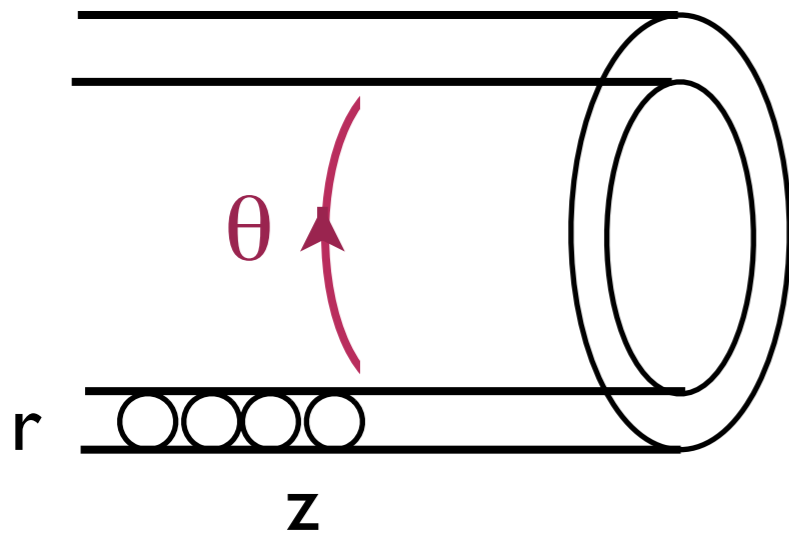
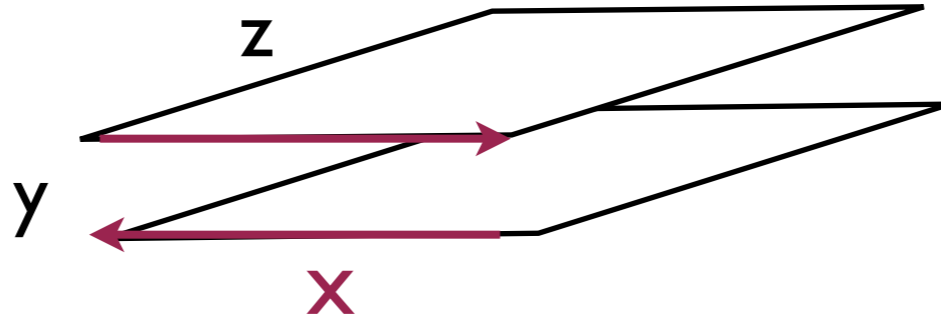
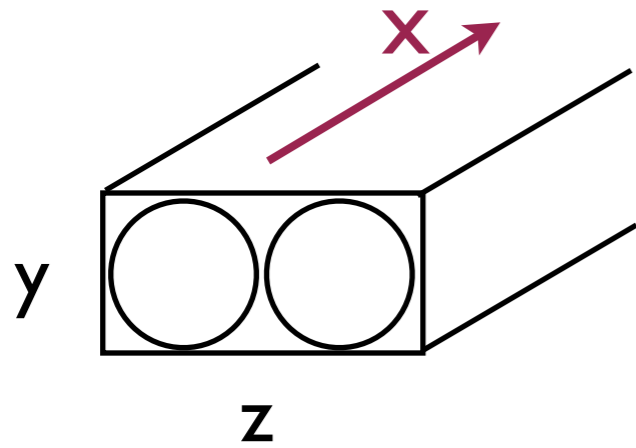
Waleffe: self-sustaining process (SSP)



$[U(y,z), V(y,z), W(y,z)]$



Taylor \leftrightarrow plane Couette flow



Many other Taylor \leftrightarrow plane Couette flow studies

Steady states, bifurcations

Nagata

Faisst, Eckhardt

Lifetimes

Faisst, Eckhardt

Borrero-Echeverry, Schatz, Tagg

Turbulent-laminar patterns

Prigent, Dauchot

Shi, Avila, Hof

Transient growth

Meseguer

Hristova, Roch, Schmid, Tuckerman

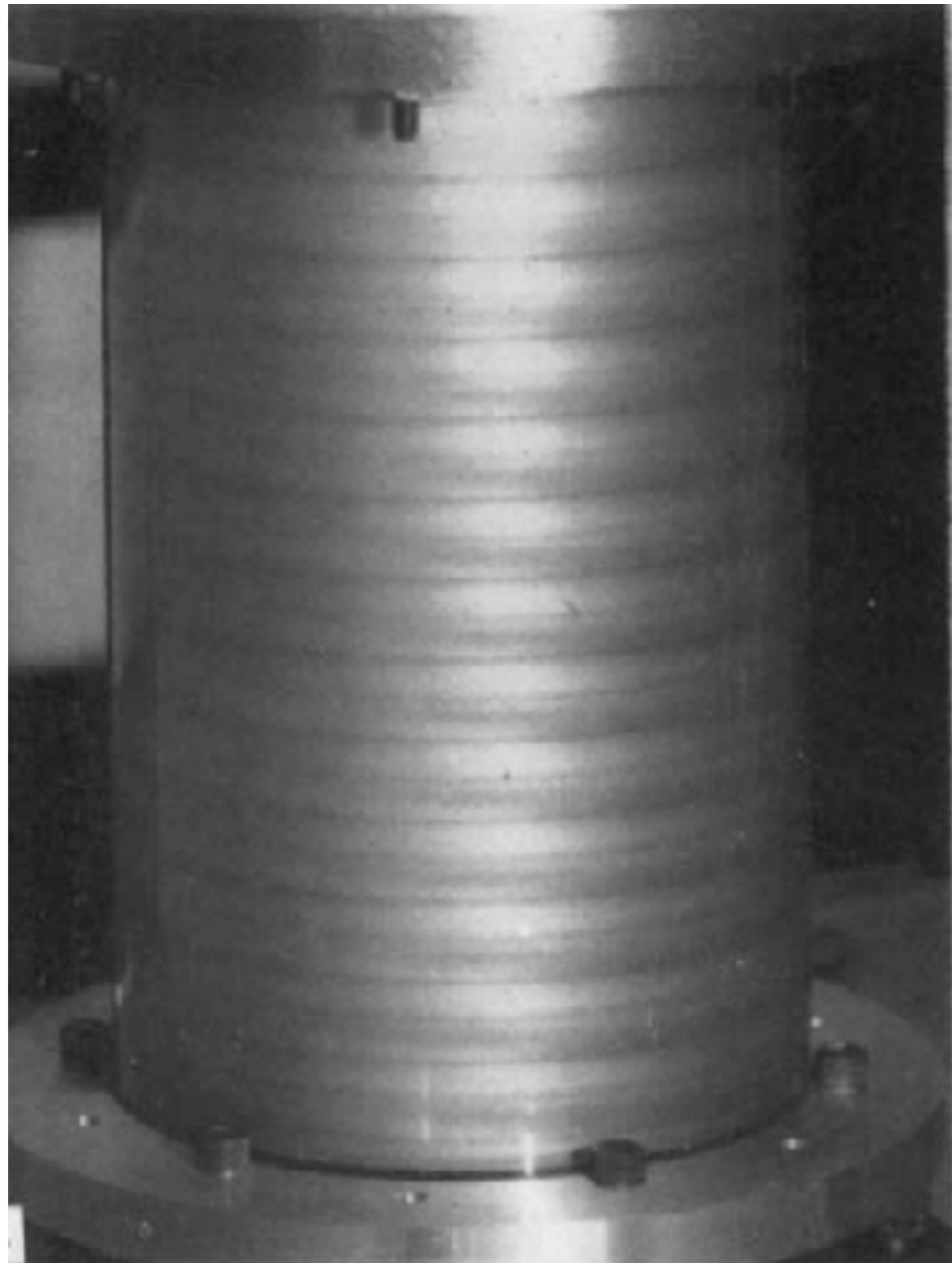
Maretzke, Hof, Avila

Simulations using pseudospectral
Taylor-Couette flow code (Willis) with
 $N_r = 33, N_\theta = 48, N_z = 48$ gridpoints
Nonlinear (axisymmetric and 3D)
and linearized (WVF eigenvector with single m)

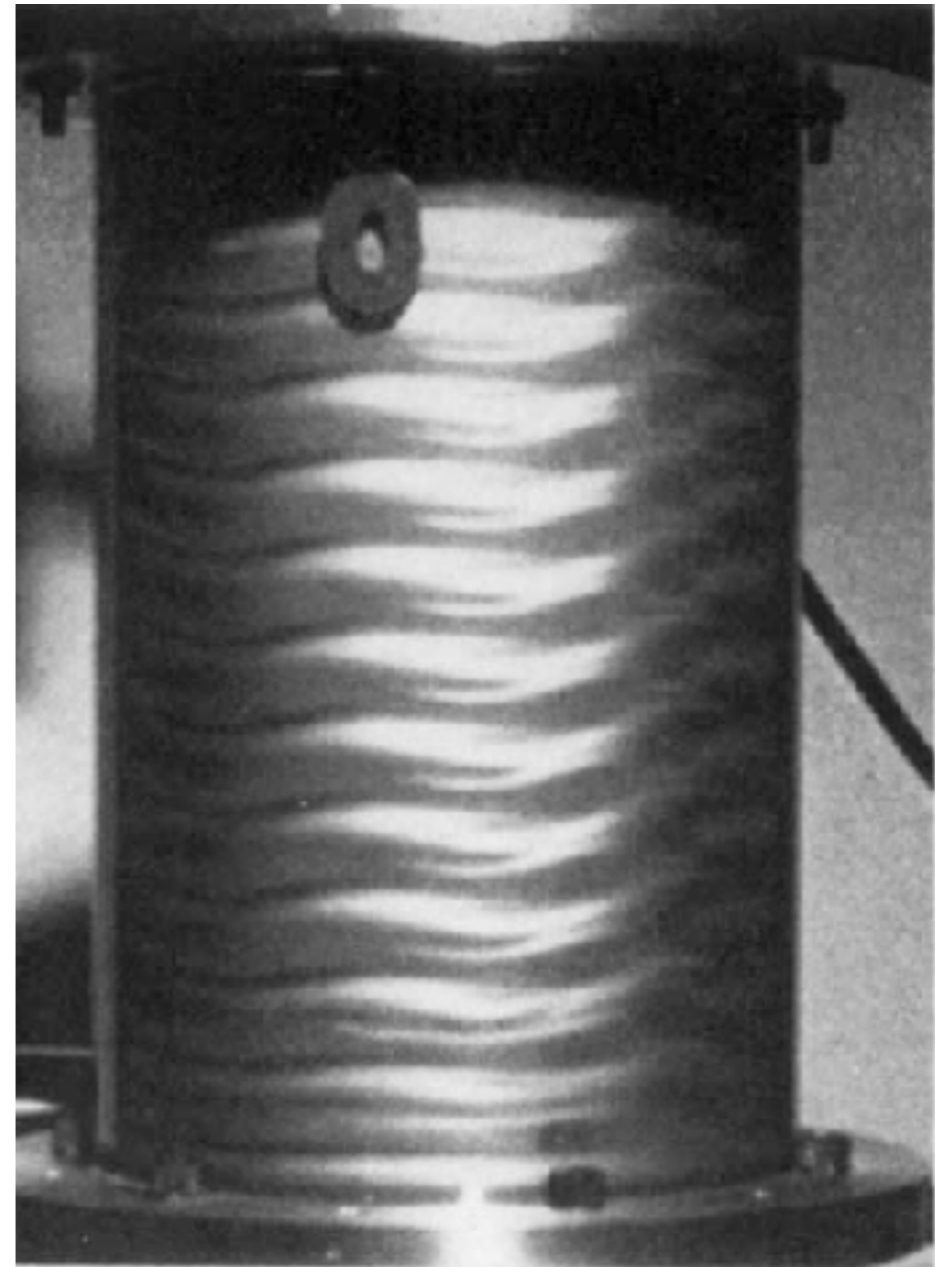
$$\eta = r_{\text{in}}/r_{\text{out}} = 0.92, m = 15$$

$$\lambda_\theta = \frac{2\pi\bar{r}}{m} = 10$$

Taylor Vortex Flow

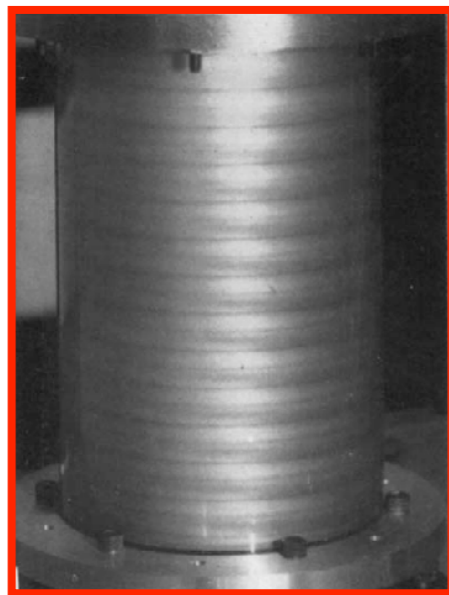
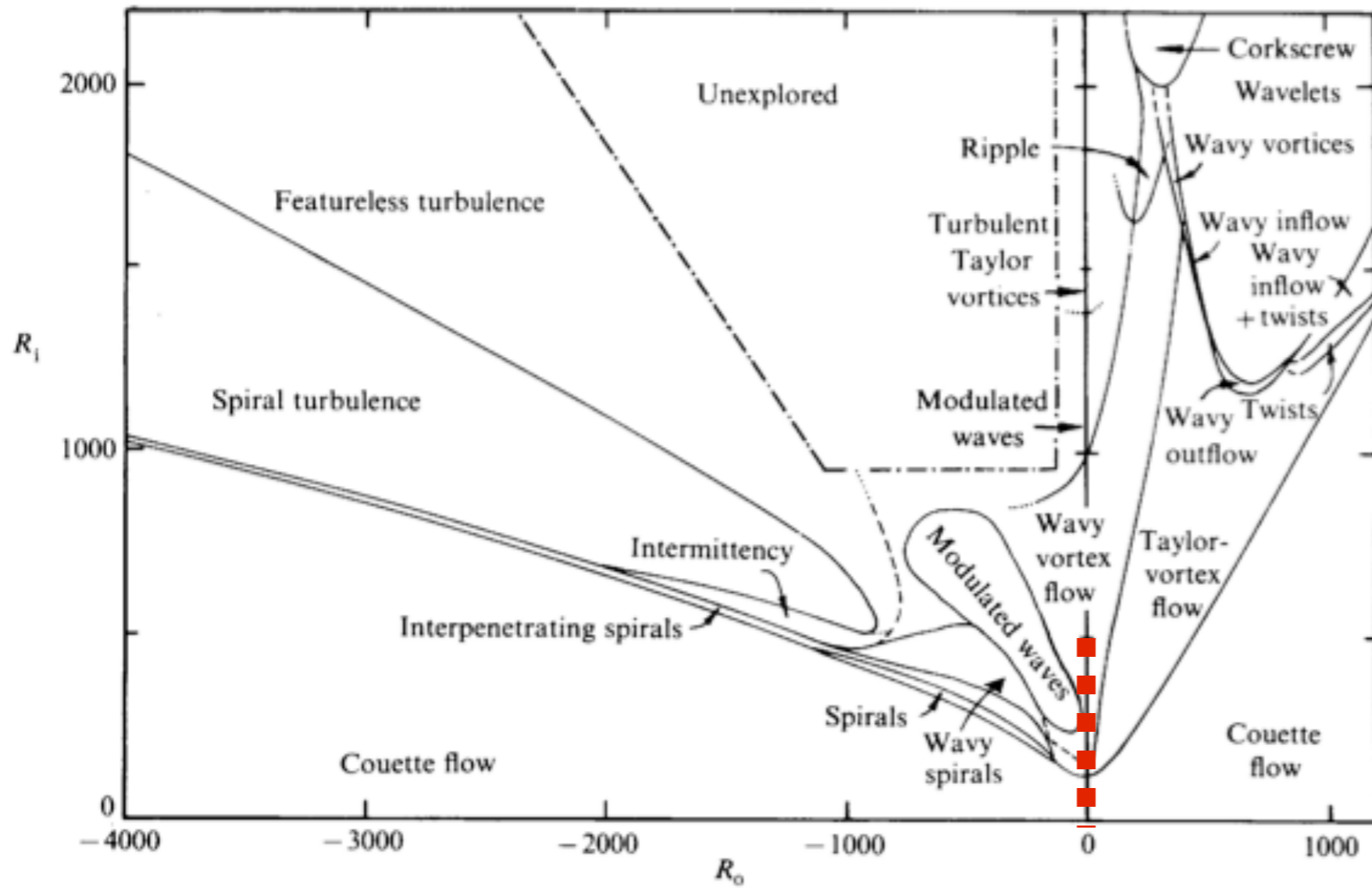


Wavy Vortex Flow

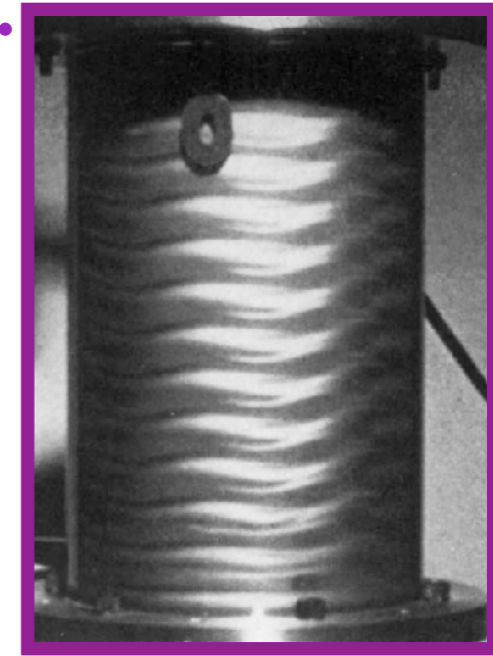
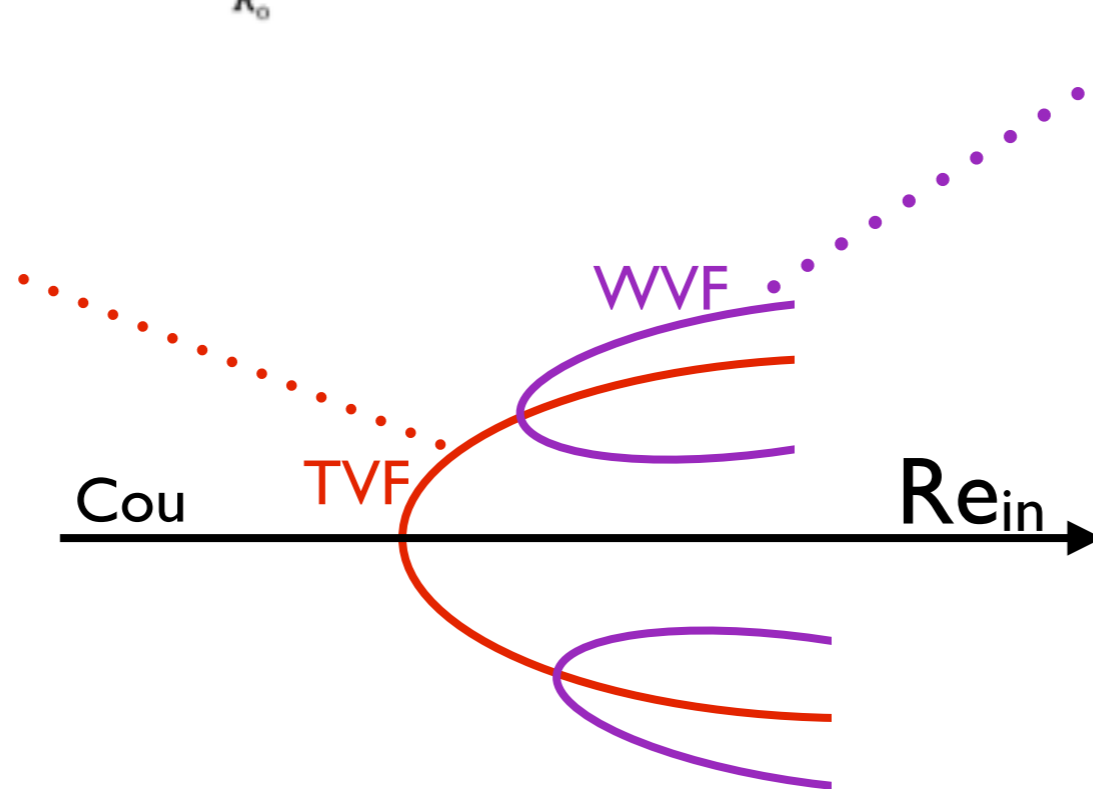


D. Coles, JFM 1965

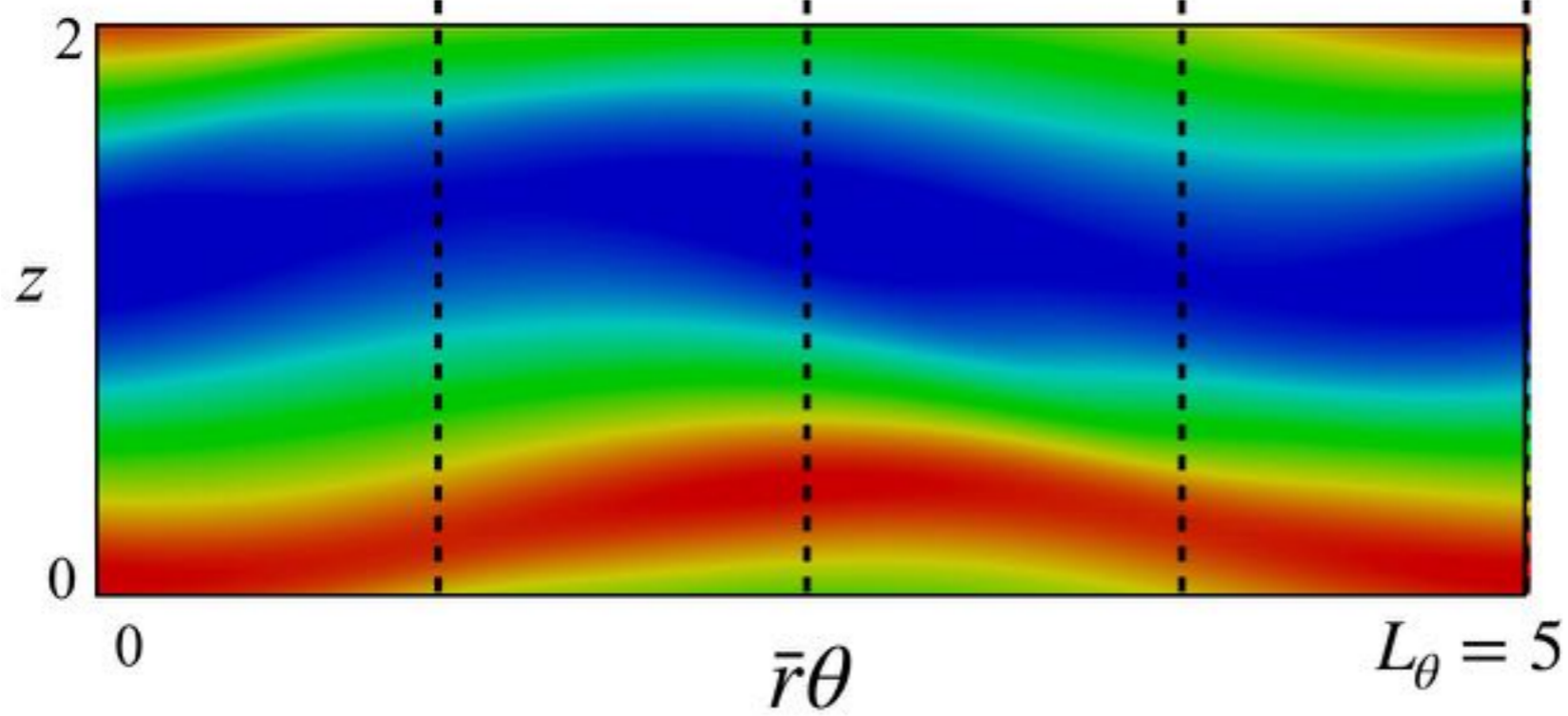
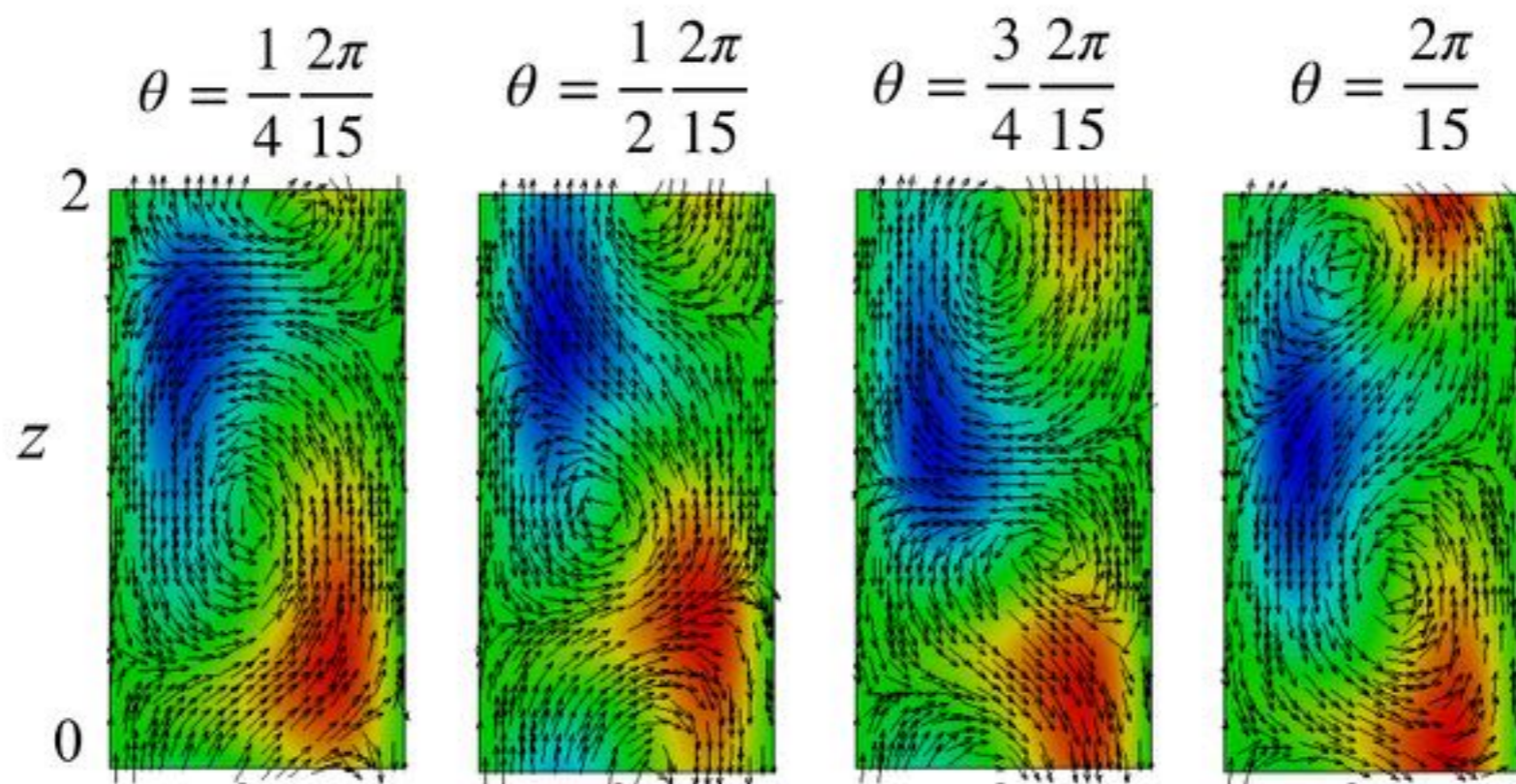
Andereck, Liu & Swinney 1986



TVF



WTVF

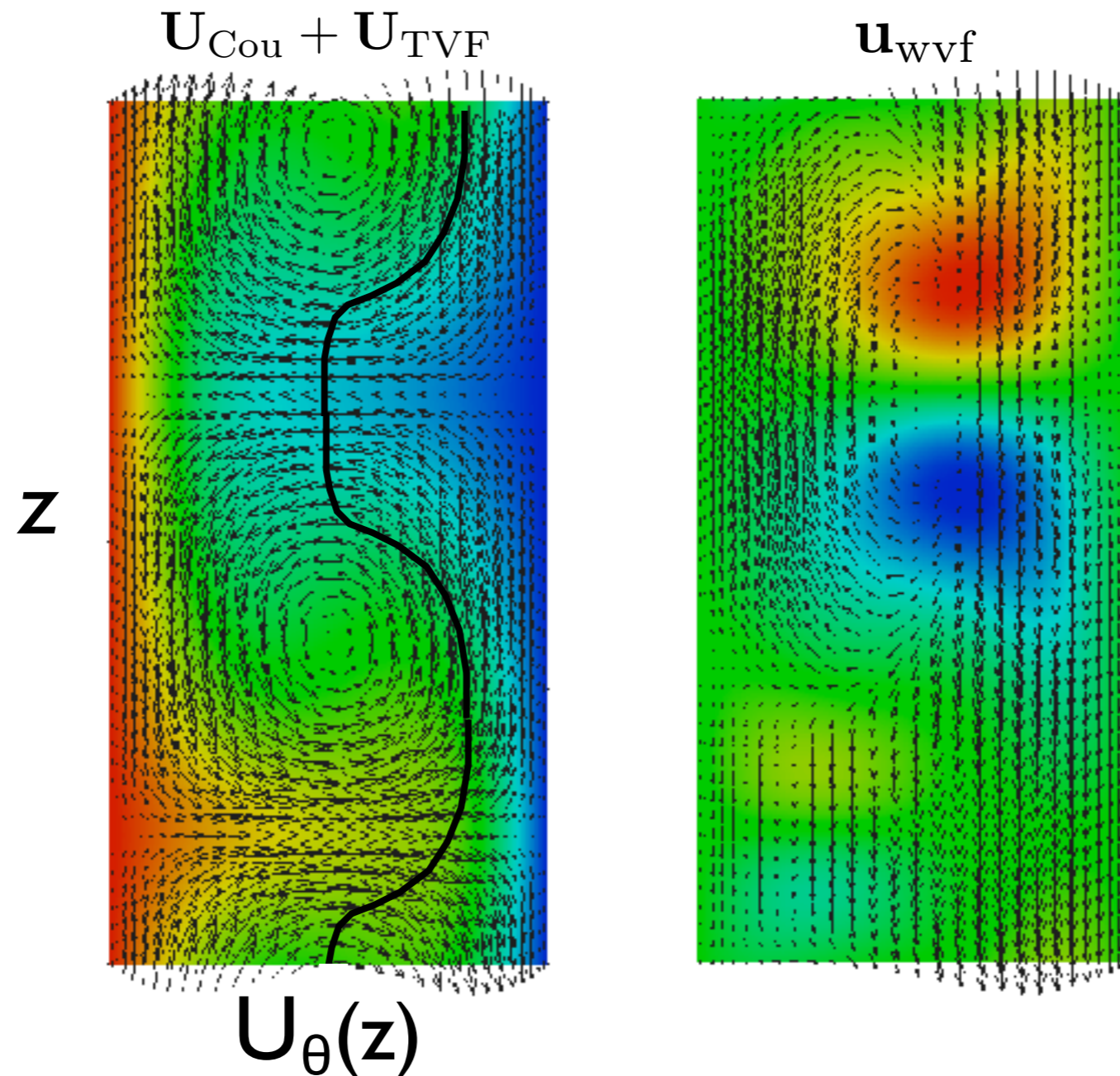


What is the physical mechanism?

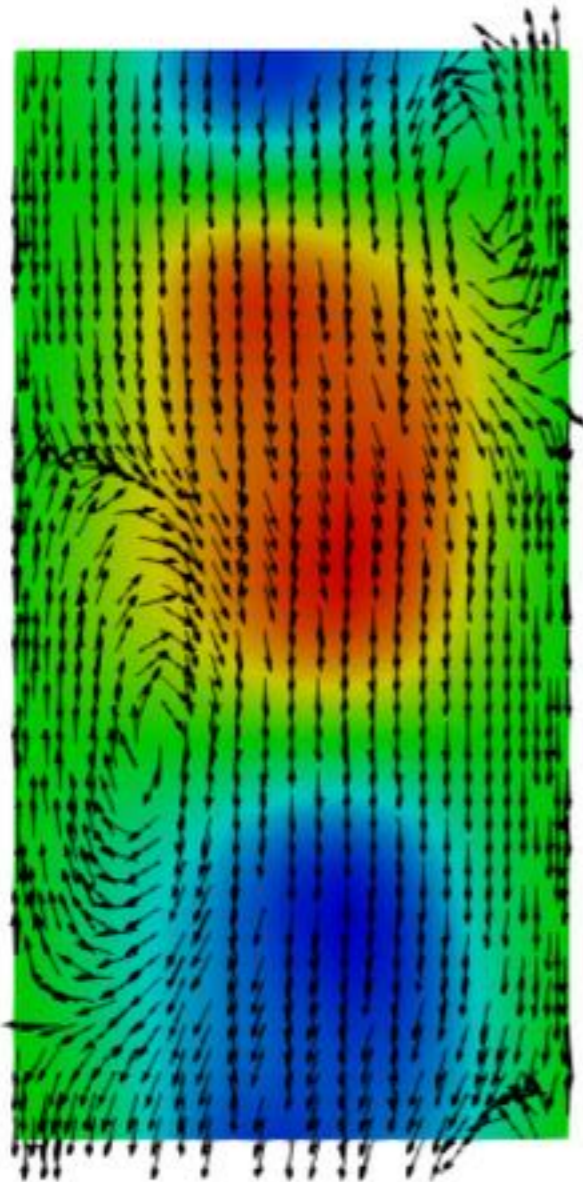
Jones JFM 1981: inflectional instability of U_θ

i.e. Kelvin-Helmholtz

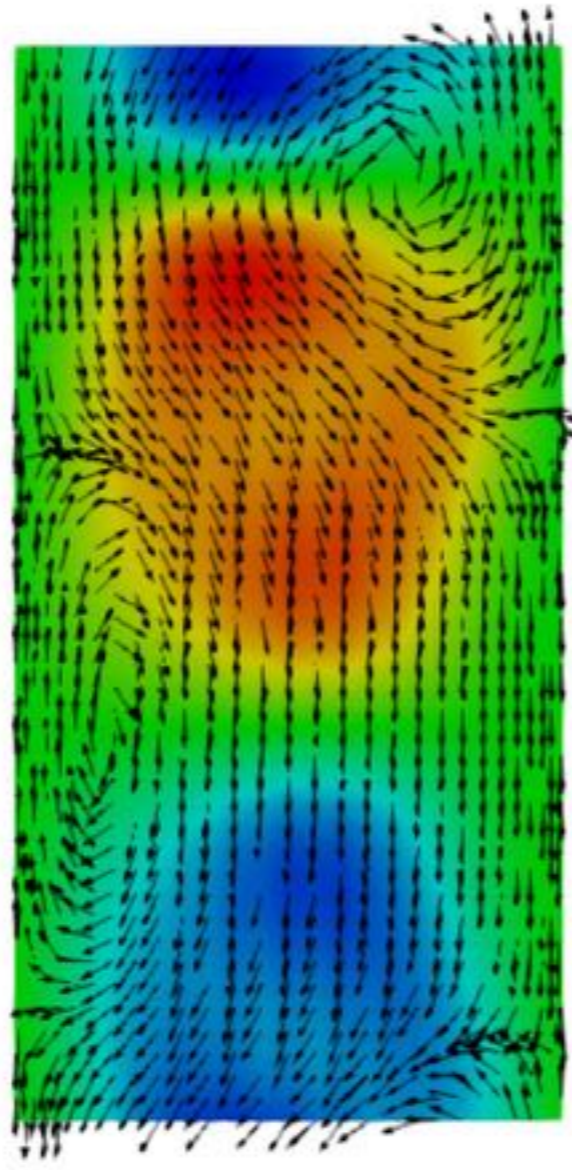
Martinand, Serre, Lueptow (Phys. Fluids 2014)



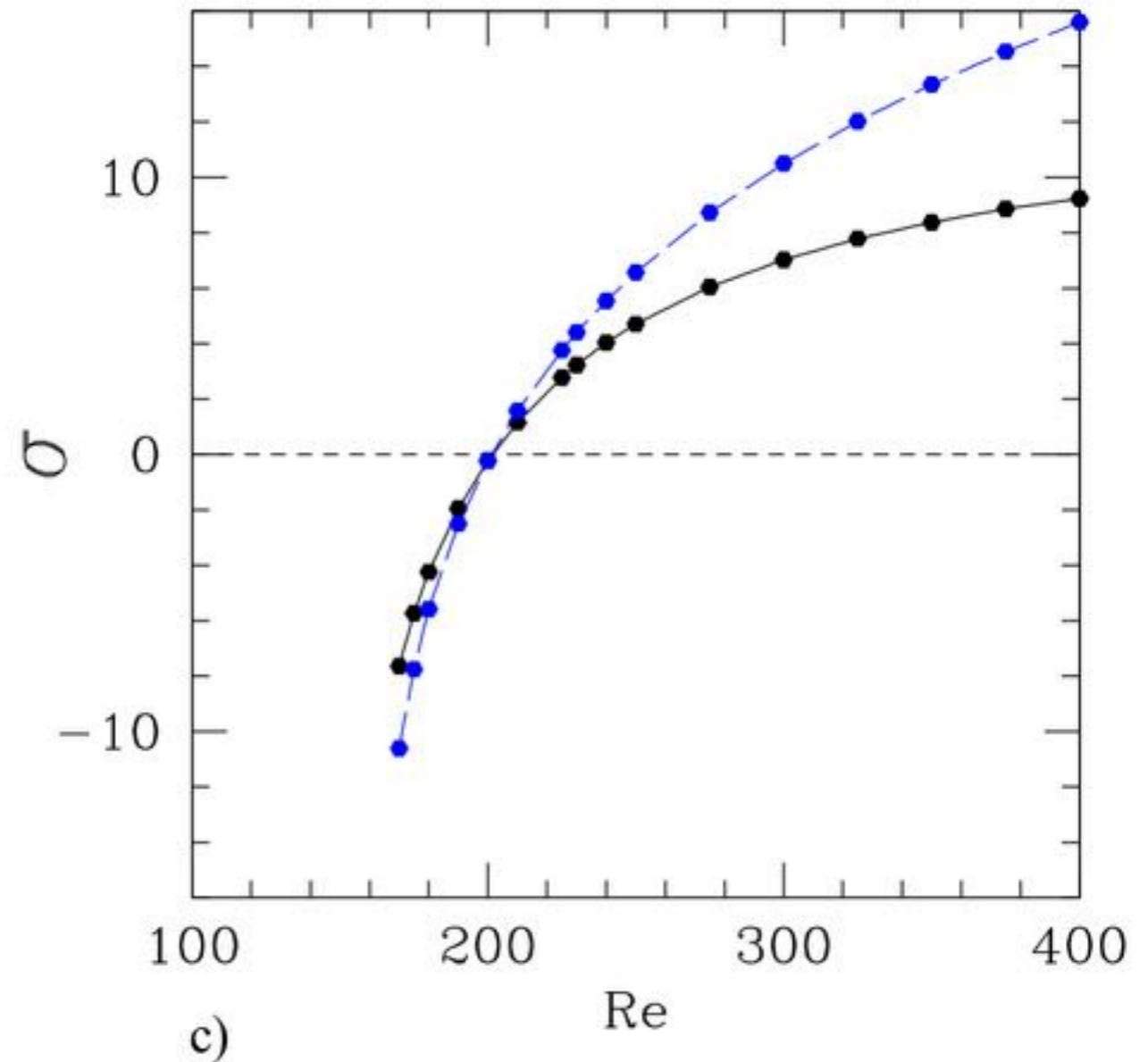
Instability due solely to streaks, not to rolls:
linearization about flow with and without rolls leads
to same eigenvectors and eigenvalues



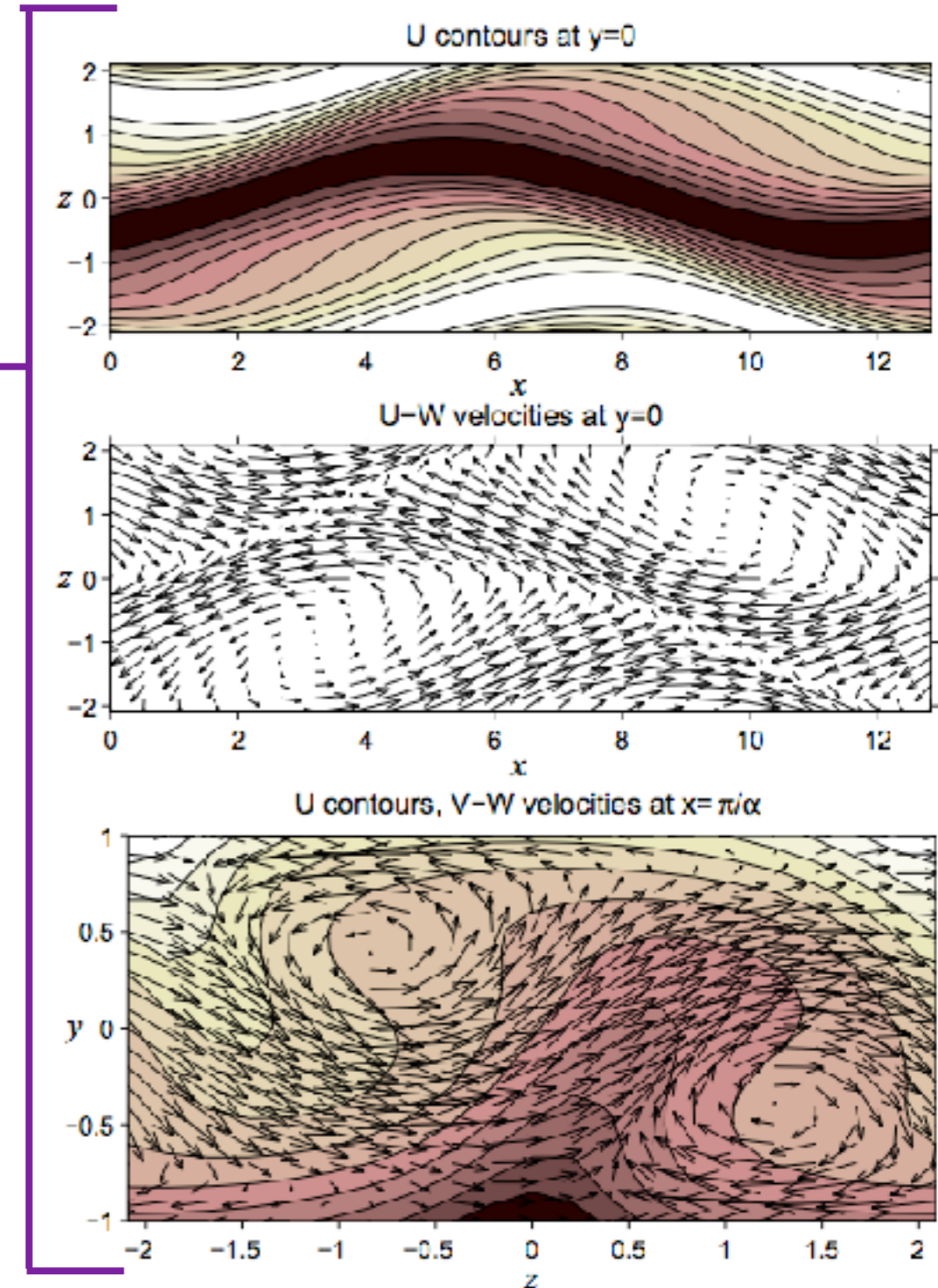
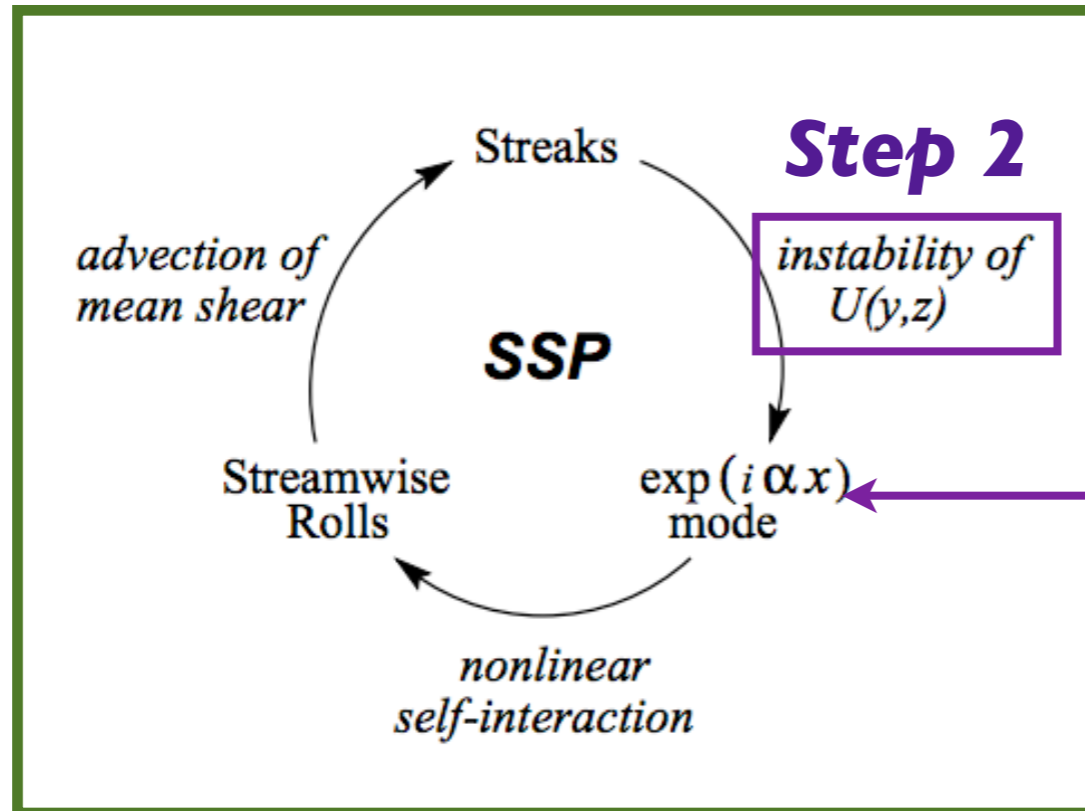
a) \mathbf{u}_{wvf} from $\mathbf{U}_{\text{TVF}} - \mathbf{U}_{\text{roll}}$



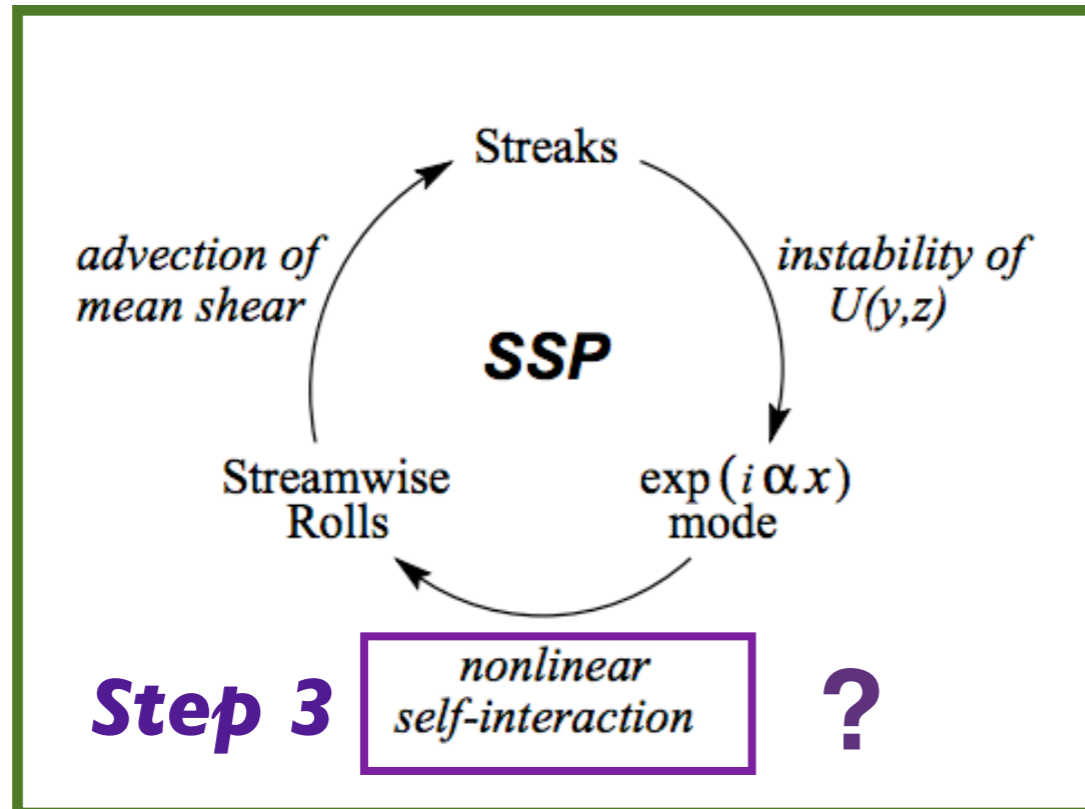
b) \mathbf{u}_{wvf} from \mathbf{U}_{TVF}



Waleffe: self-sustaining process (SSP)

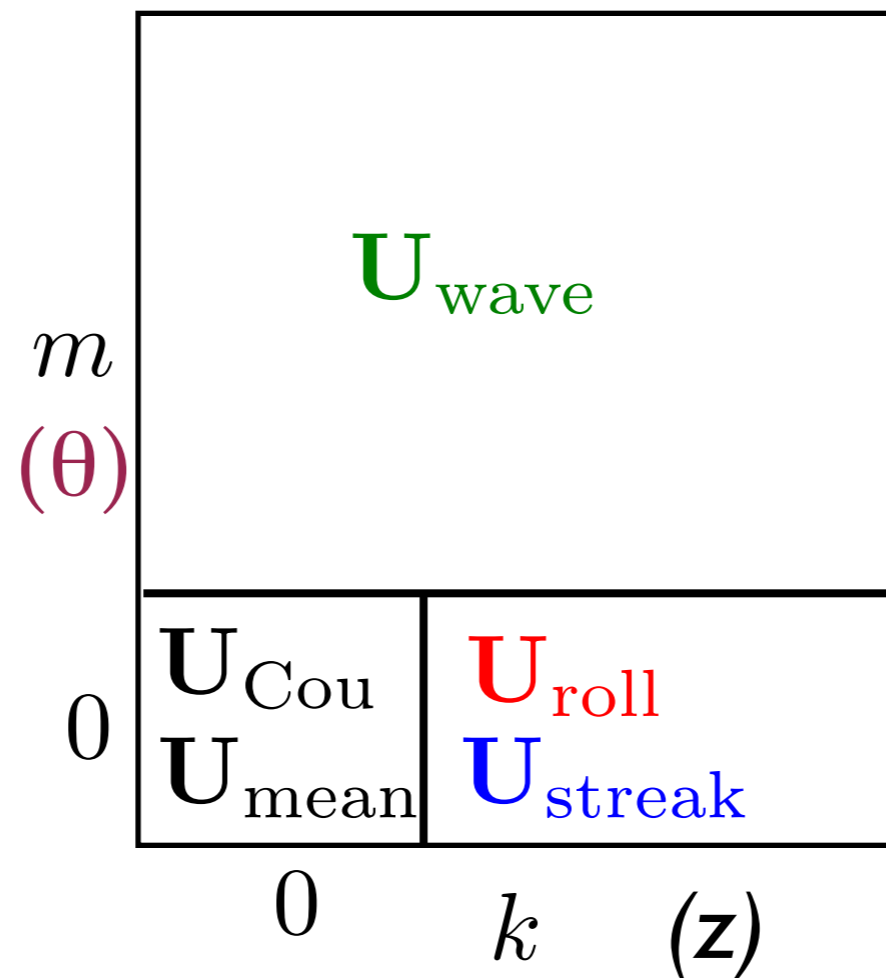


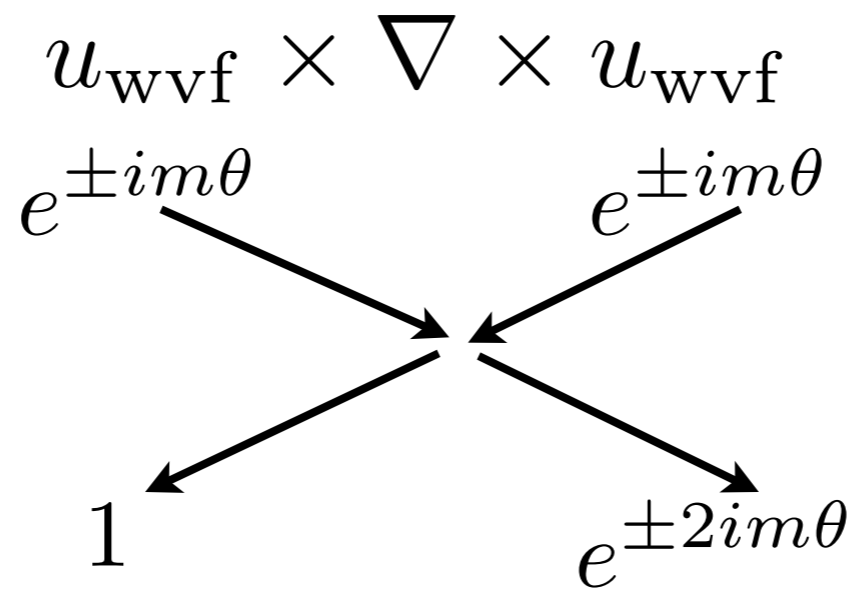
Waleffe: self-sustaining process (SSP)



Flow decomposition

$$\mathbf{U} = \sum_{\substack{k=0 \\ m=0}} (\mathbf{U}_{\text{Cou}} + \mathbf{U}_{\text{mean}}) + \sum_{\substack{\text{TVF} \\ k \neq 0 \\ m=0}} (\mathbf{U}_{\text{roll}} + \mathbf{U}_{\text{streak}}) + \sum_{\substack{\text{WVF} \\ k \\ m \neq 0}} \mathbf{U}_{\text{wave}}$$

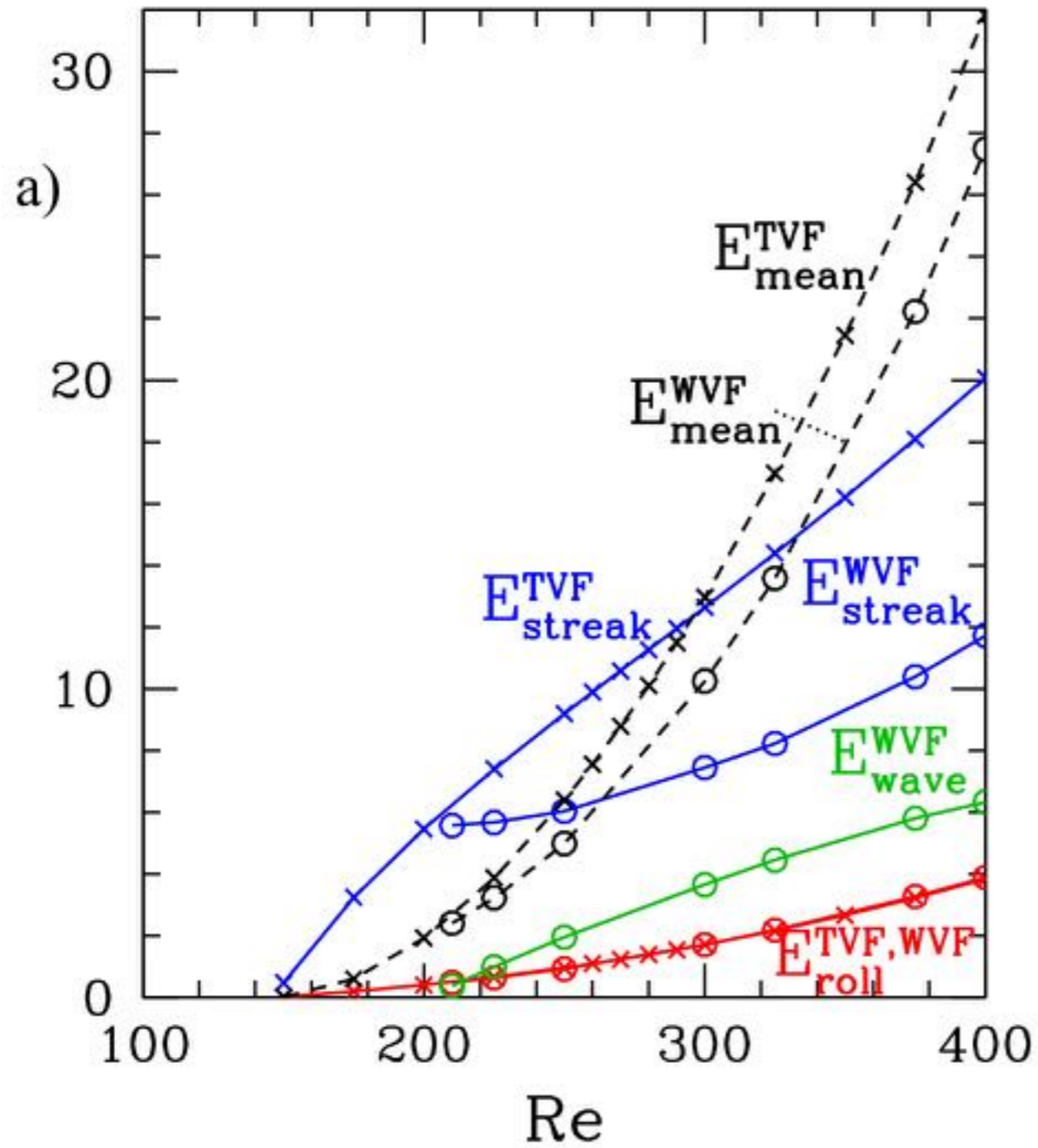




$$\partial_t U_0 = \dots \langle u_{\text{wvf}} \times \nabla \times u_{\text{wvf}}, U_0 \rangle U_0$$

$$\partial_t \begin{pmatrix} \boxed{U_{\text{mean}}} \\ \boxed{U_{\text{roll}}} \\ \boxed{U_{\text{streak}}} \end{pmatrix} = \dots \langle u_{\text{wvf}} \times \nabla \times u_{\text{wvf}}, \begin{pmatrix} \boxed{U_{\text{mean}}} \\ \boxed{U_{\text{roll}}} \\ \boxed{U_{\text{streak}}} \end{pmatrix} \rangle \begin{pmatrix} \boxed{U_{\text{mean}}} \\ \boxed{U_{\text{roll}}} \\ \boxed{U_{\text{streak}}} \end{pmatrix}$$

Bifurcation diagram

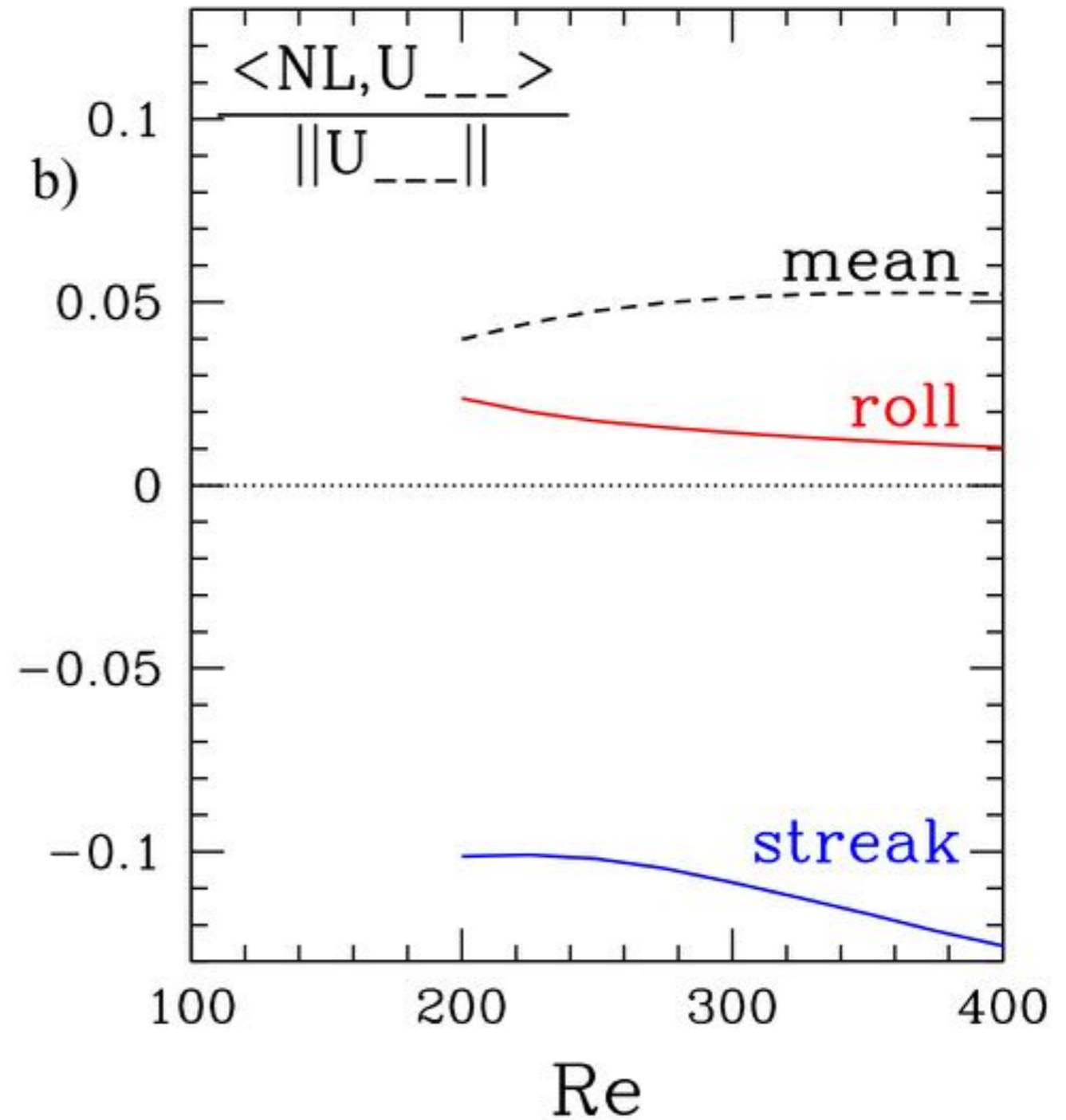


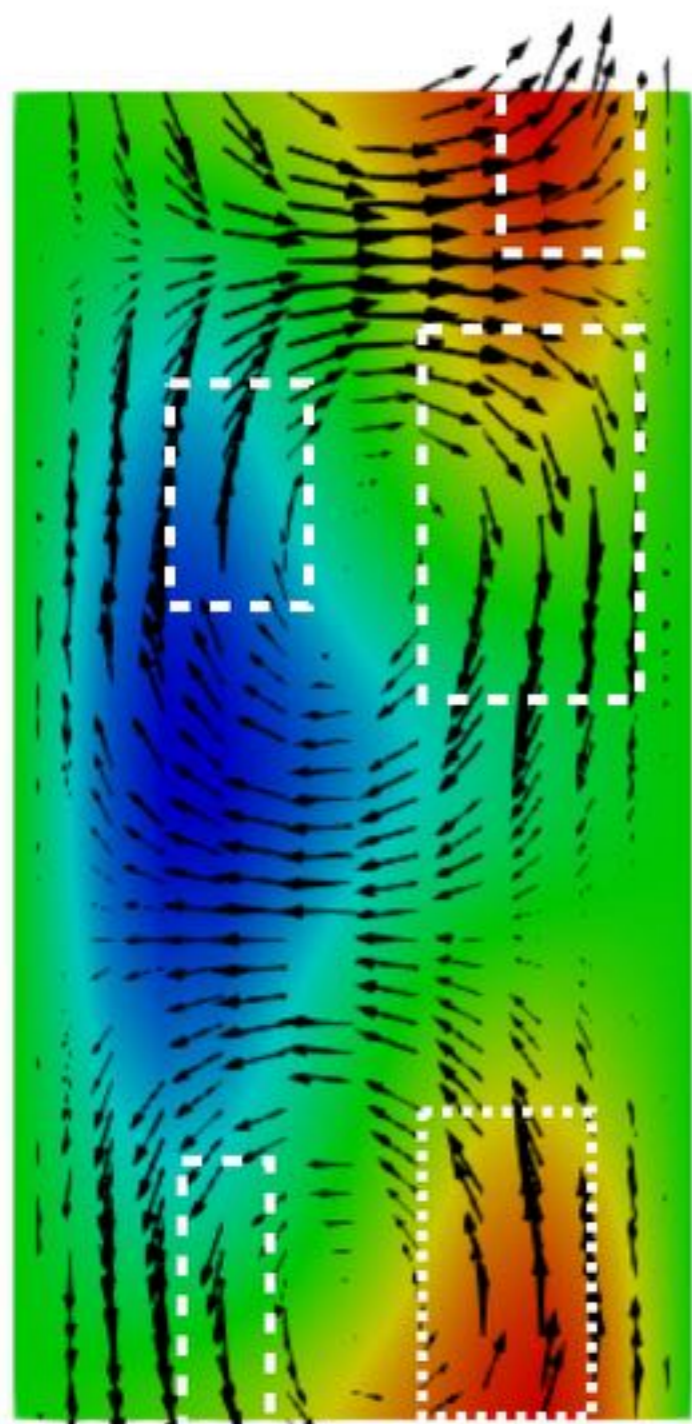
Overlap between

$$u_{\text{wvf}} \times \nabla \times u_{\text{wvf}}$$

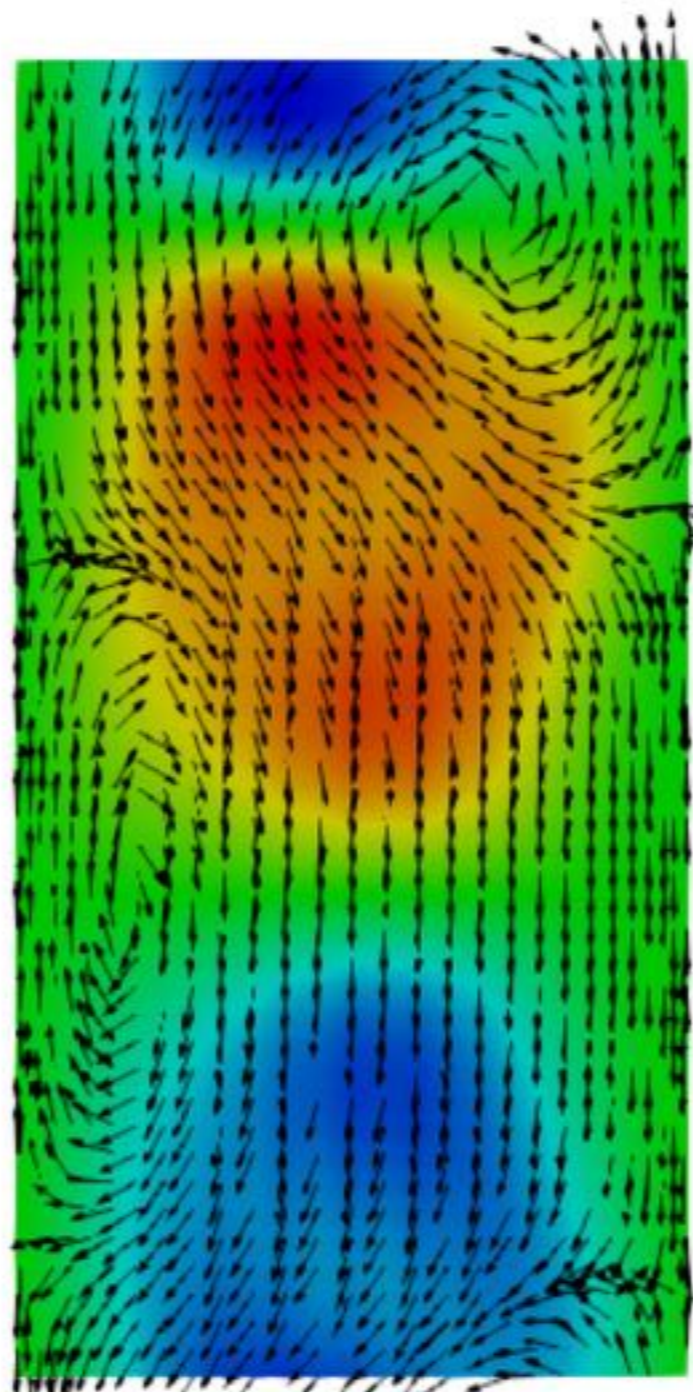
and

\mathbf{U}_{roll} $\mathbf{U}_{\text{streak}}$ \mathbf{U}_{mean}

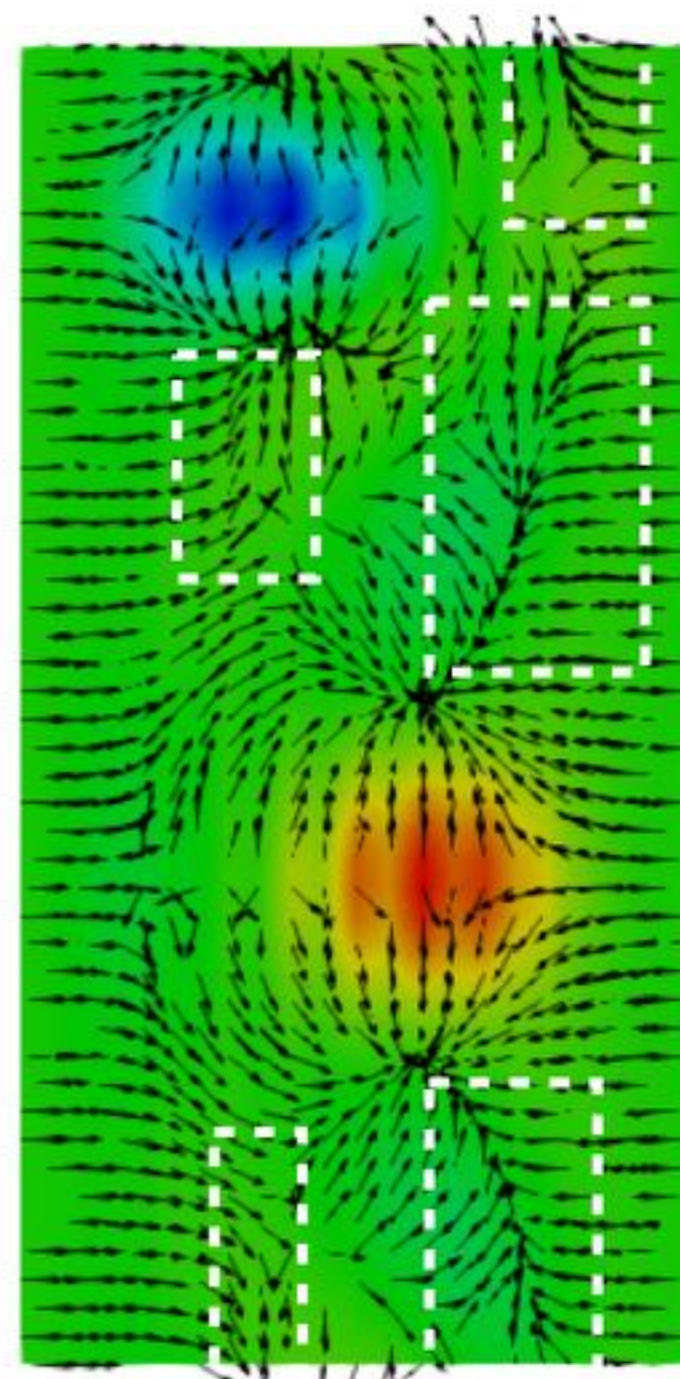




a) $\mathbf{U}_{\text{TVF}} - \mathbf{U}_{\text{Cou}}$



b) \mathbf{u}_{wvf}



c) $\langle \mathbf{u}_{\text{wvf}} \times \nabla \times \mathbf{u}_{\text{wvf}} \rangle$

Thank you!