About the transition to/from turbulence in wall-bounded flows

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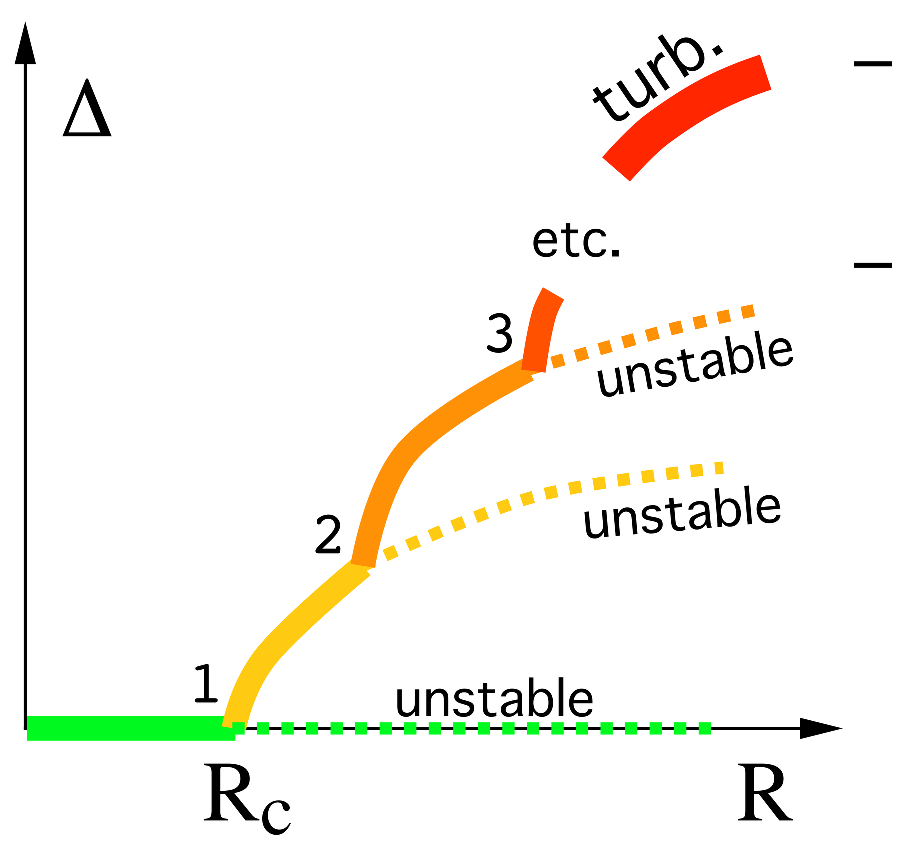
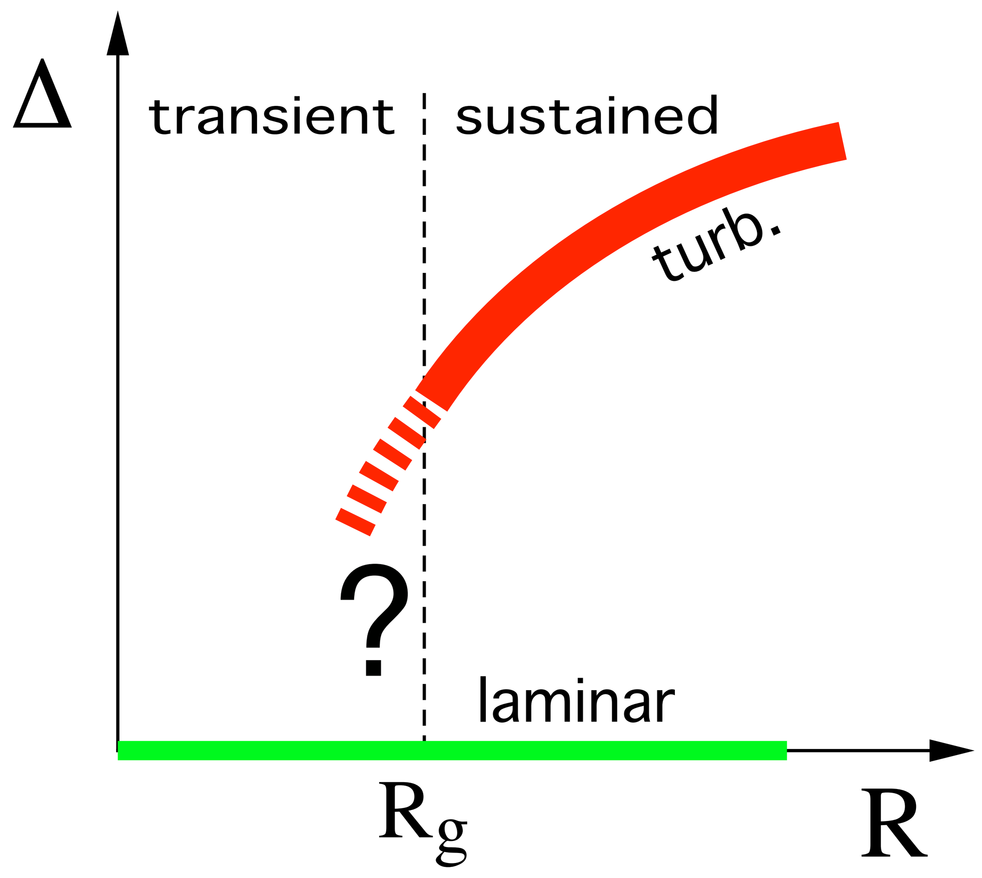
• **Context.** Transition to turbulence in Navier–Stokes flows: Two basic cases:



– left: free shear flow (jet, wake): KH install. and low-R globally super-critical cascade à la Landau
– right: wall-bounded flow (pipe, channel): sub-critical transition at moderate R, coexistence of laminar and nontrivial flow at given R
issue: understand what is hidden under "?"
(a) dynamical systems theory (self-sustainment)
(b) statistical mechanics (transitions & decay)

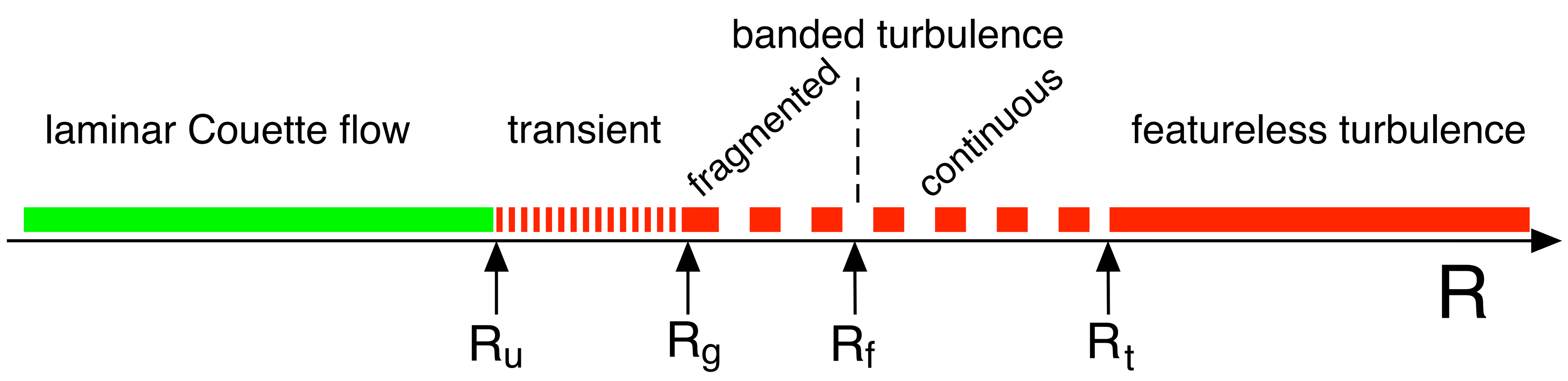


distinguish transition to turbulence at increasing R and transition from turbulence at decreasing R

◇ transition to turbulence via temporal chaos à la Ruelle-Takens [1]: moderate R supports dynamical systems interpretation: phase space coexistence (mostly) 0D in physical space, periodic orbits, strange attractors, etc.

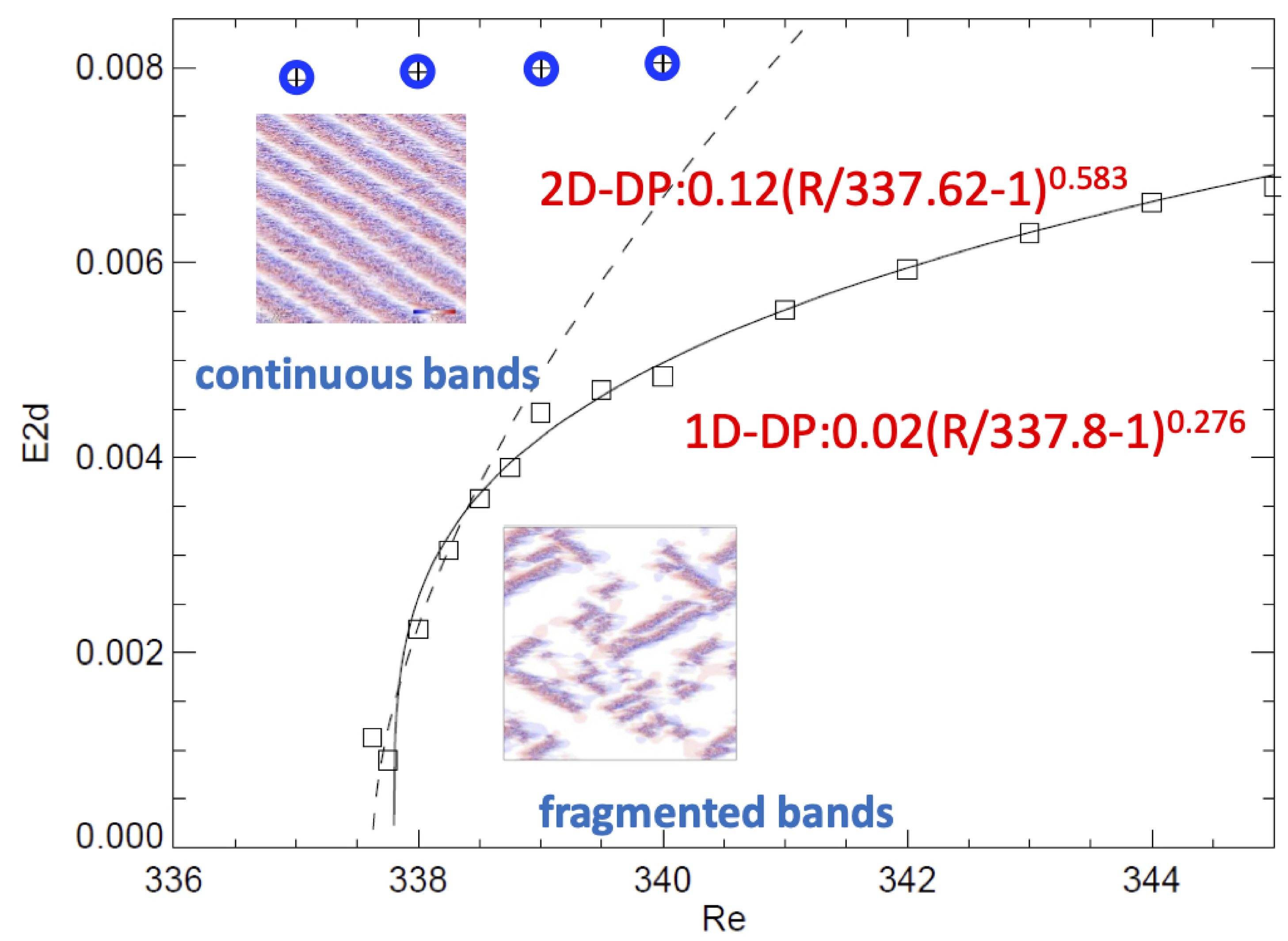
◇ transition from turbulence as a spatiotemporal process: laminar flow linearly stable hence absorbing, nontrivial active states belong to a disconnected branch: spatiotemporal intermittency à la Pomeau hint at critical-phenomena universality and directed percolation [2]
apparent experimental support in both quasi-1D and quasi-2D case but things are more complicated:
at decresing R: featureless turbulence, next laminar-turbulent pattern [3], next ultimate decay
but emergence, evolution and ultimate decay of laminar-turbulent pattern depends on case considered and the experimental protocol (quench vs. annealing)

• **Example: plane Couette flow.** Bifurcation diagram [4]

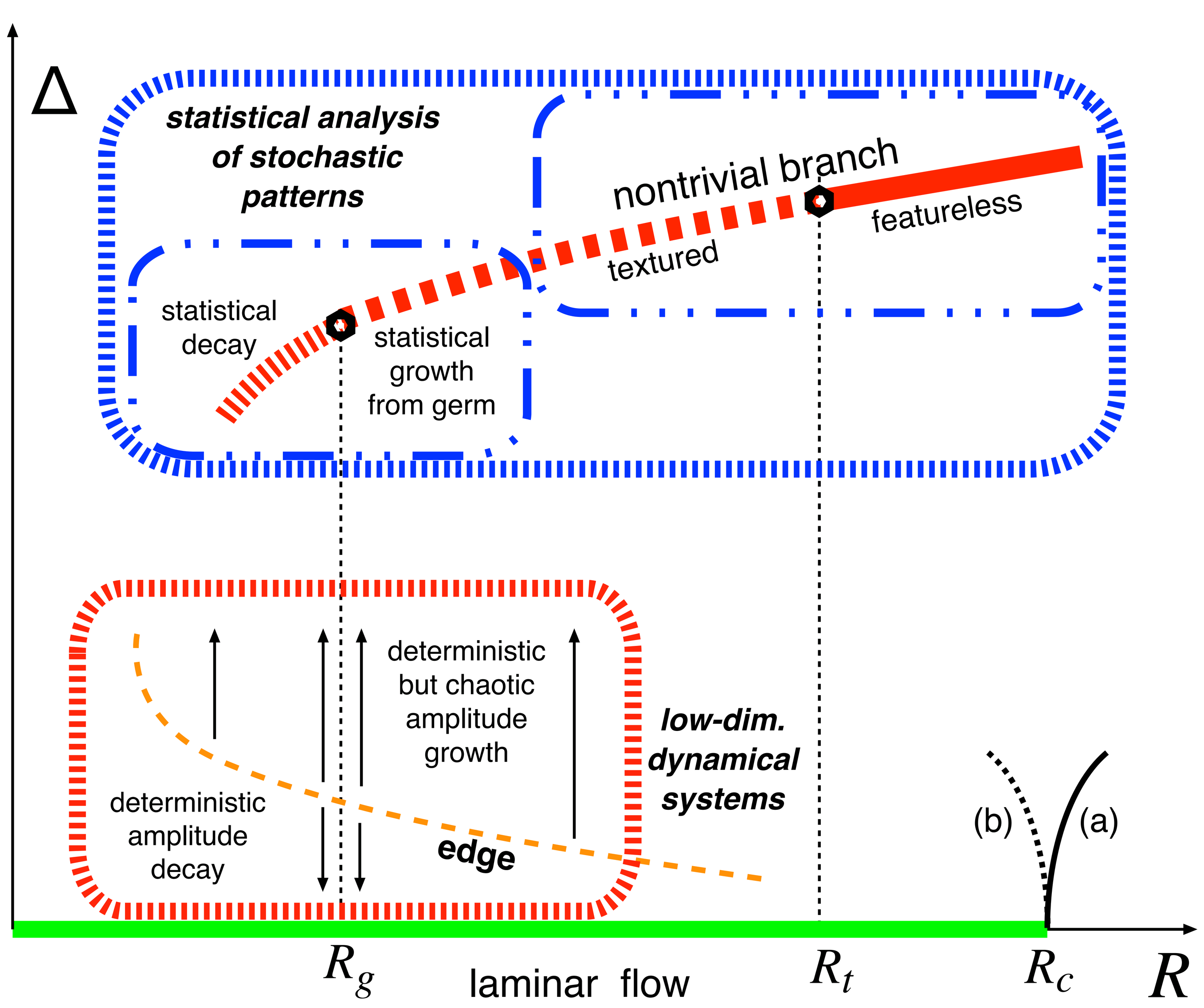


deep quench: 1D-DP except extremely close to threshold
but why 1D when 2D expected?
annealing: discontinuous transition (large deviations)

phenomenological stochastic cellular automata model helps us understand results (i) variation of splitting probabilities with R, (ii) stability of continuous bands against band splitting via large deviations thanks to large scale flows (to be part of models)



• **Outlook.** Generic global subcriticality, Lam.Turb. coexistence in phase space & physical space; pattern for $R \in [R_g, R_t]$;
other quasi-2D cases similar: e.g. plane Poiseuille flow [5];
– dynamical systems: transition at $R \nearrow$;
– statistical physics of phase transitions: transition at $R \searrow$;
– DP universality OK but tricky (effective space dimension is system dependent + sensitivity to experimental protocol);
wanted: realistic model for oblique large scale patterning.



[1] Kawahara *et al.* Annu. Rev. Fluid Mech. 44, 203–225 (2012).
[2] Pomeau. Physica D 23, 3 (1986); Lemoult *et al.* Nature Physics 12, 254 (2016) [1D-DP]; Klotz *et al.* Phys. Rev. Lett. 128, 014502 (2022) [2D-DP]; see also [5].
[3] Manneville, Entropy 19, 316 (2017); Tuckerman *et al.* Annu. Rev. Fl. Mech. 52, 343 (2020).
[4] Bottin, PhD, 1998; Prigent PhD, 2001; $R_t \sim 415$, $R_f \sim 350$, $R_g \sim 325$; $R_u \sim 280$, $R_c = \infty$.
[5] Shimisu & Manneville. Phys. Rev. Fluids 4, 113903 (2019); Entropy 33, 1348 (2020).