Subcritical bubble break-up

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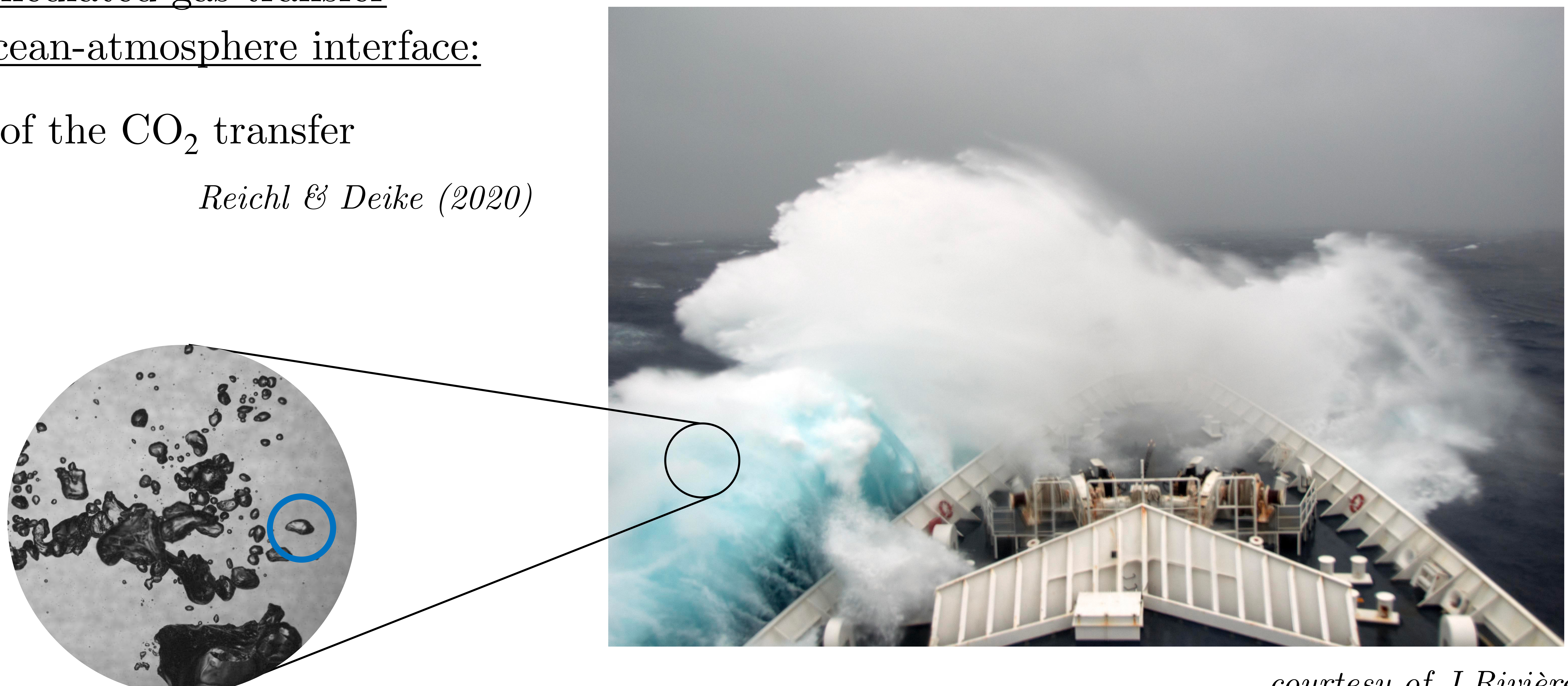
Bubbles enhance gas transfers

Bubble mediated gas transfer
at the ocean-atmosphere interface:

40% of the CO_2 transfer

Reichl & Deike (2020)



courtesy of J.Rivière

Experiment by D.J.Ruth

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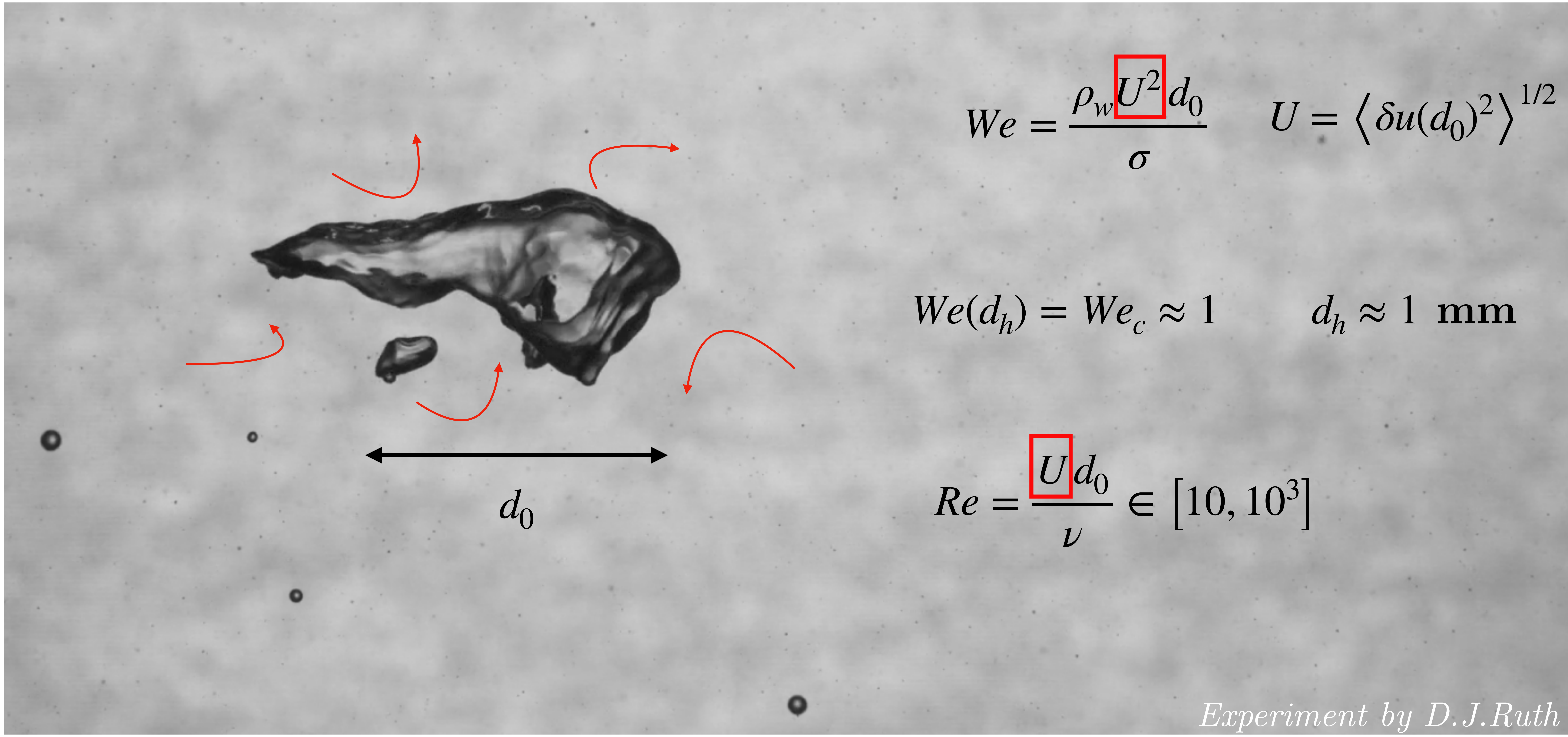
A fluctuating flow



Large distribution of We_c: between 1 and 10.

Risso & Fabre (1998), Martinez-Bazan et al (1999a), Rivière et al. (2021), Masuk et al. (2021)

Must take into account the **local flow geometry**

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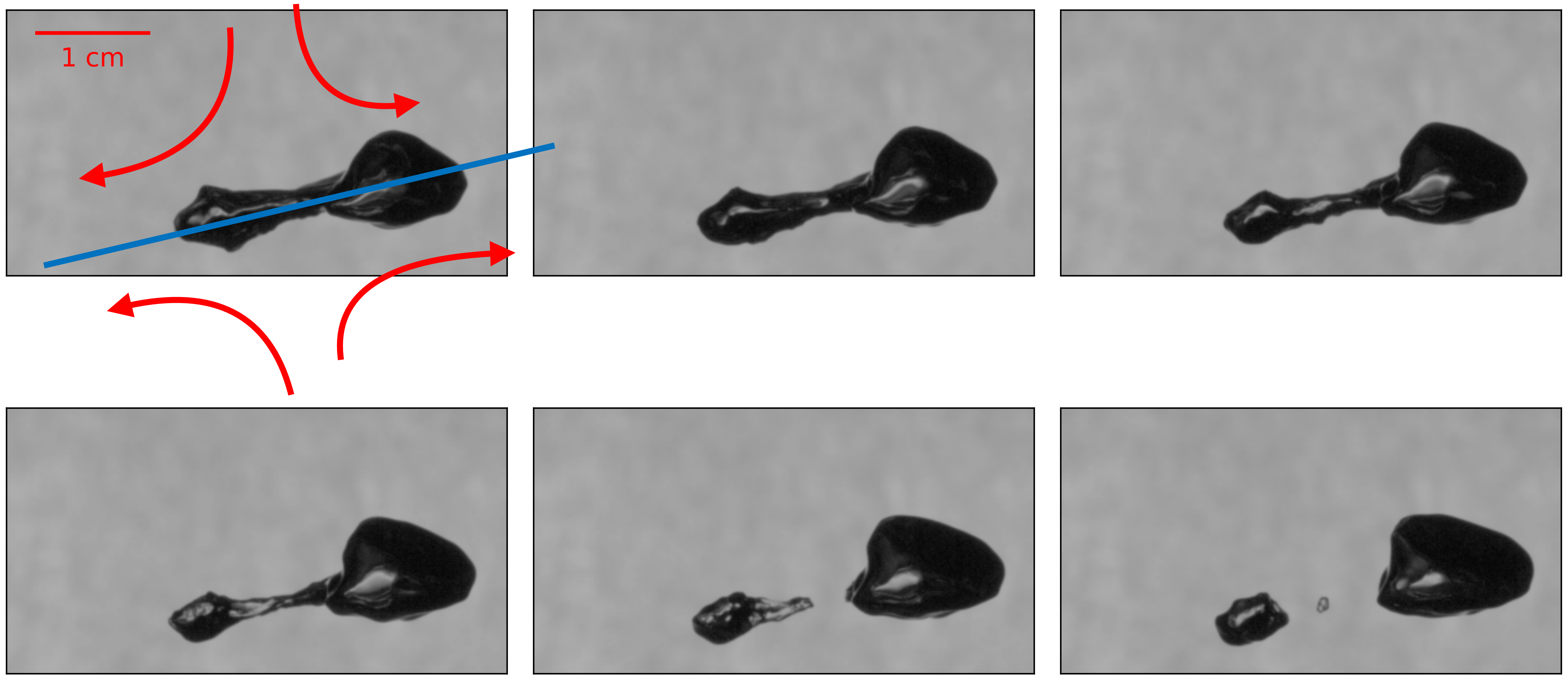
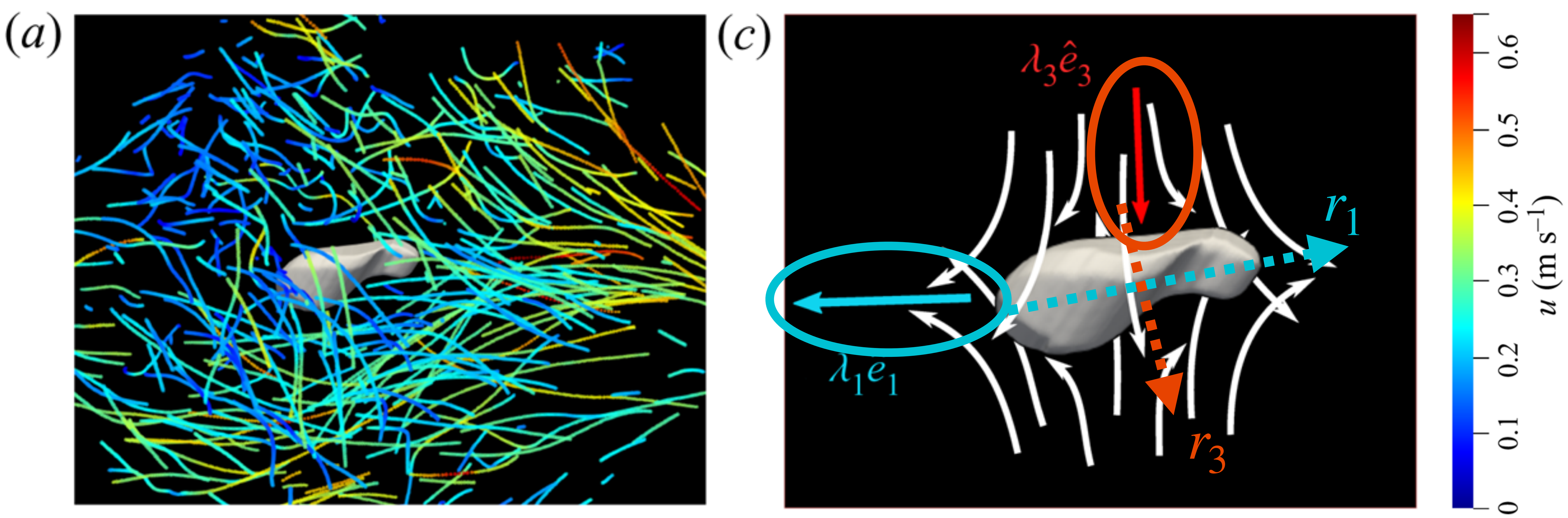
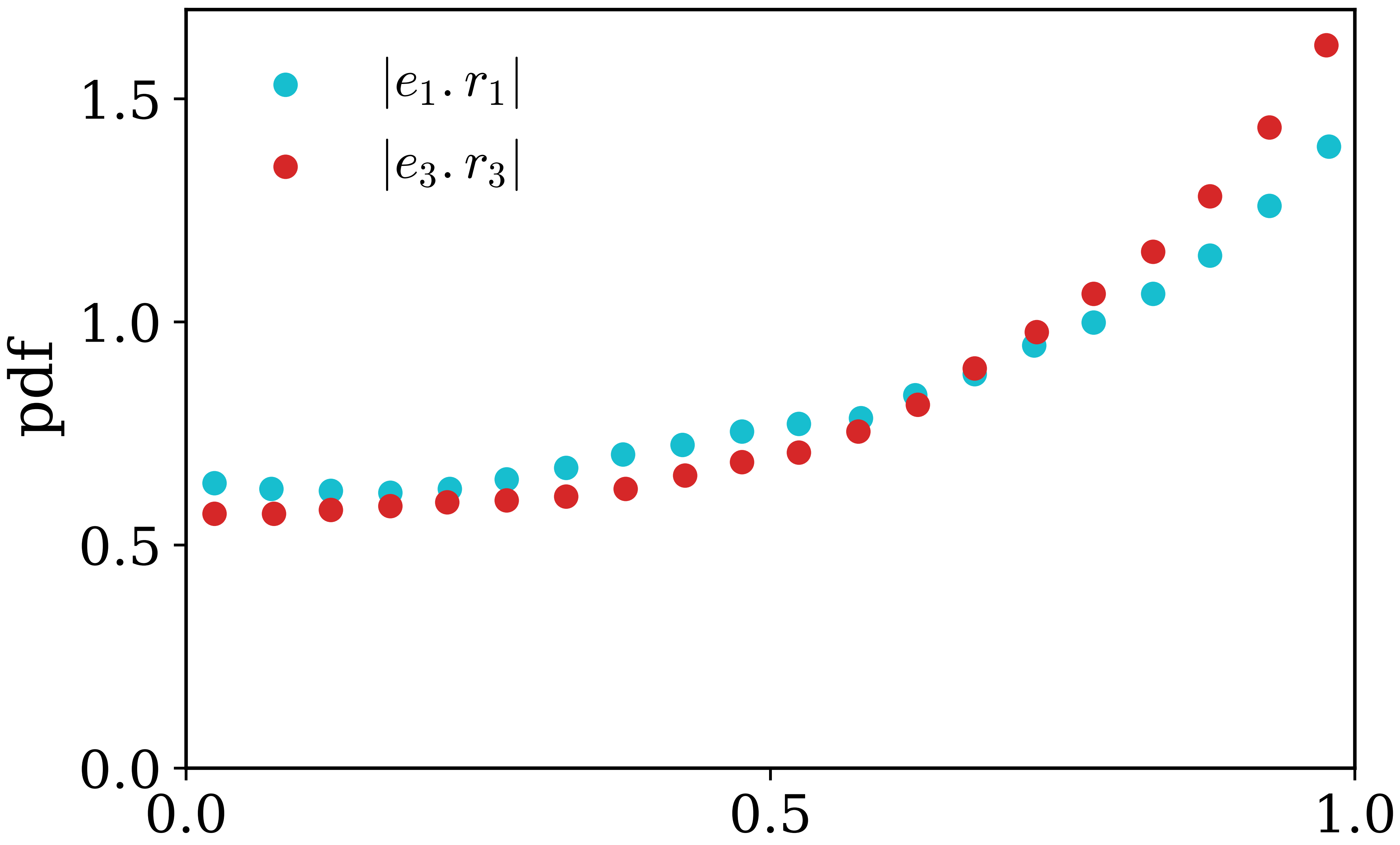
From turbulence to a model flow



Experiment by D.J.Ruth



Masuk et al. (2021)



Masuk et al. (2021)

Rodriguez-Rodriguez et al. (2006)

Revuelta (2006)

Masuk et al. (2021a,b,c)

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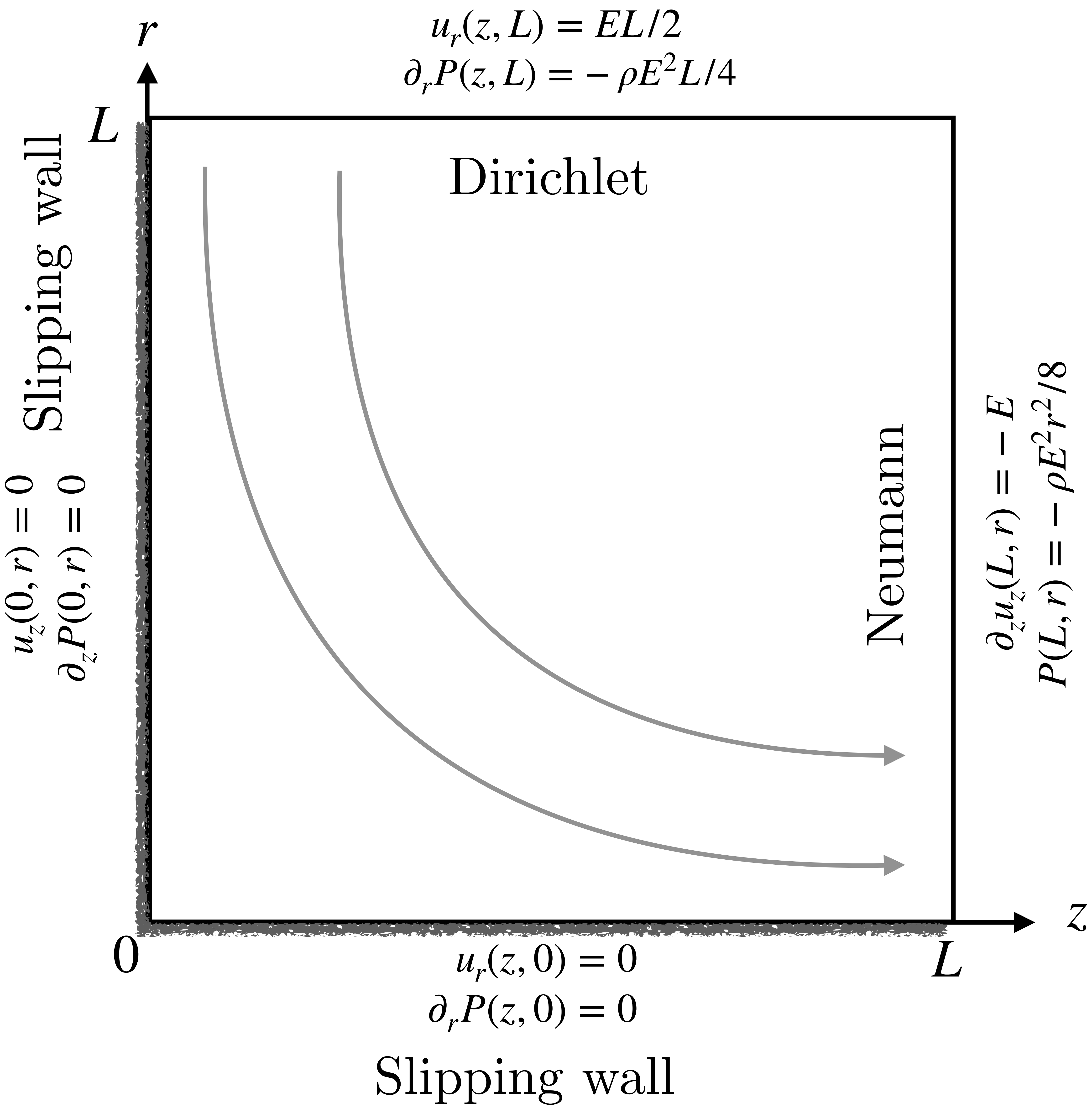
Numerical configuration - Flow creation



$$\mathbf{v}(z, r) = -\frac{E}{2} r \mathbf{e_r} + E z \mathbf{e_z}$$

Solve axisymmetric NS equations with *Basilisk:*

- momentum conserving scheme
- geometric VOF method
- AMR

http://basilisk.fr

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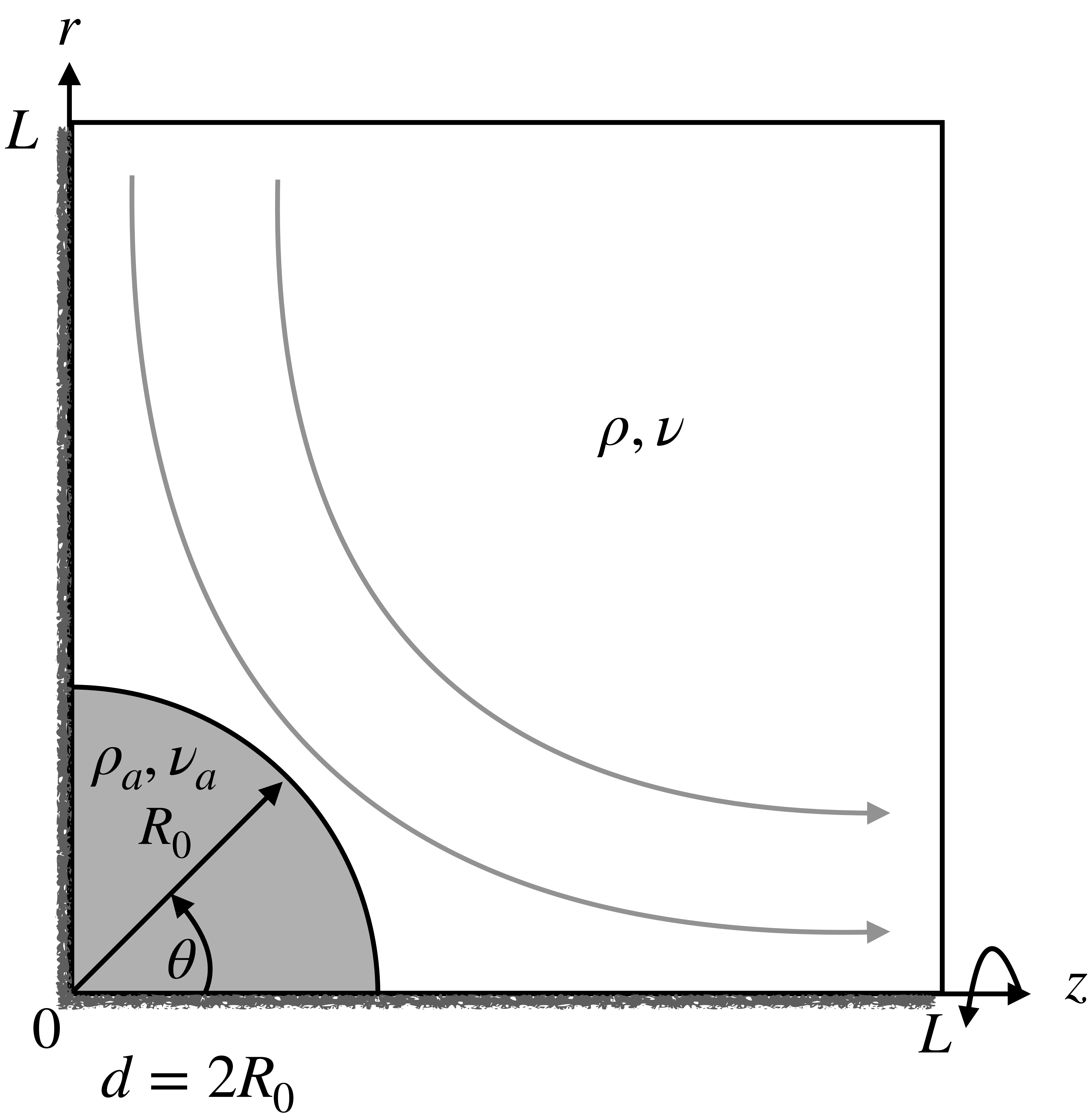
Numerical configuration - Bubble injection



$$\mathbf{v}(z, r) = -\frac{E}{2} r \mathbf{e_r} + E z \mathbf{e_z}$$

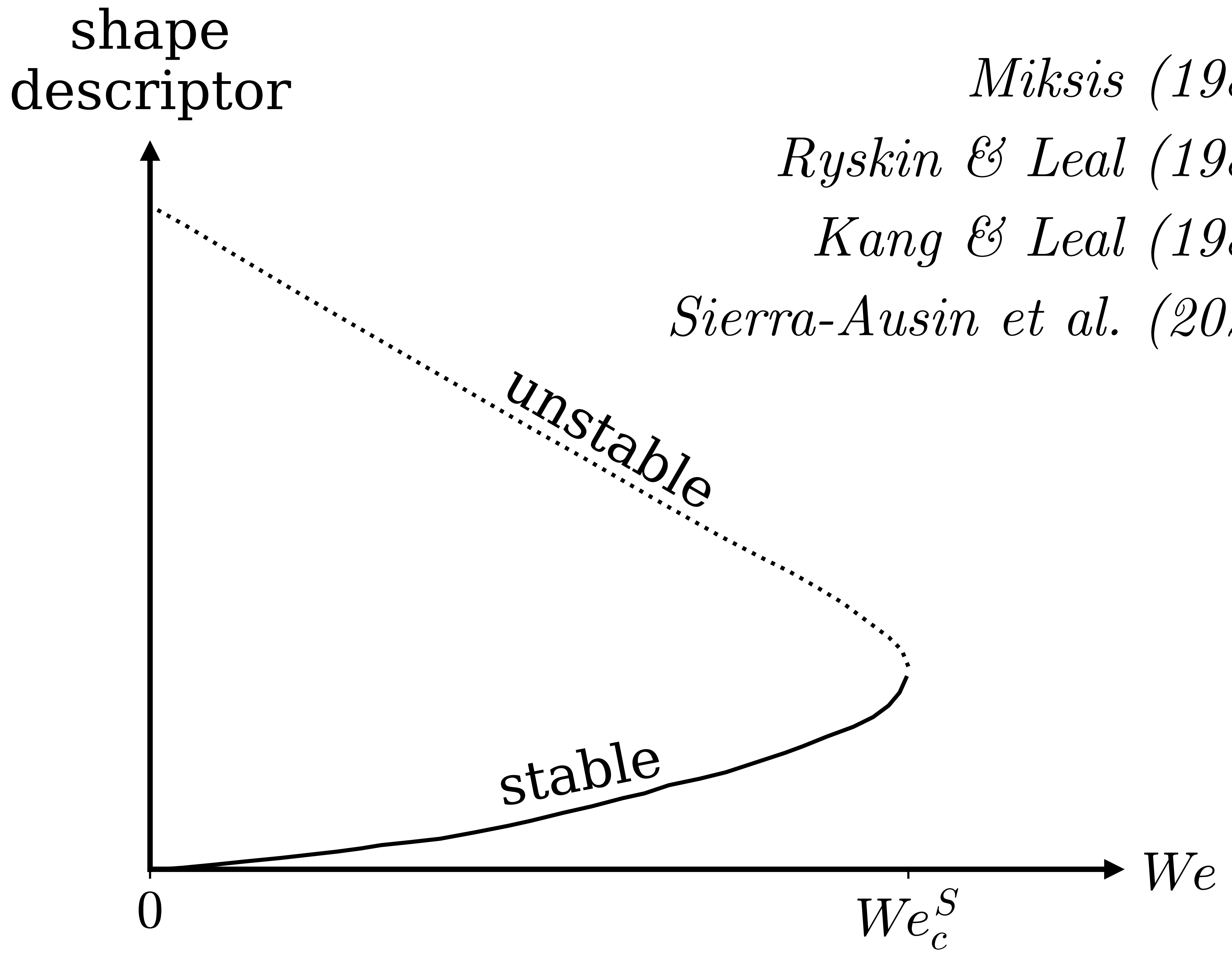
$$We = \frac{\rho U^2 d}{\gamma}$$

$$U = Ed$$

$$Re = \frac{Ud}{\nu} \gg 1$$

Phase diagram: Equilibrium positions

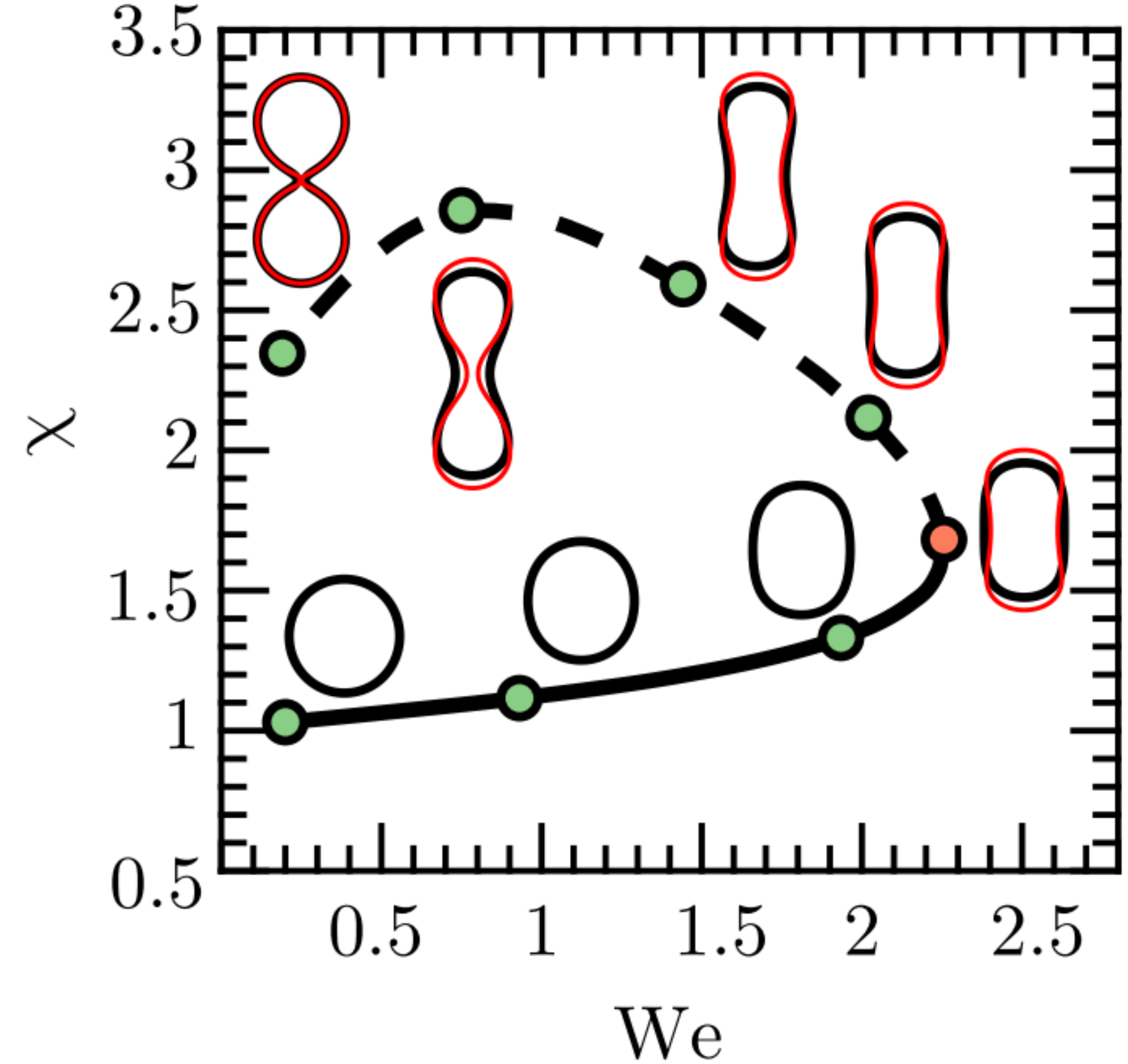
Saddle-node bifurcation



Miksis (1981)
Ryskin & Leal (1984)
Kang & Leal (1987)
Sierra-Ausin et al. (2022)

$$Oh = \frac{\sqrt{We}}{Re}$$

Sierra-Ausin et al. (2022)



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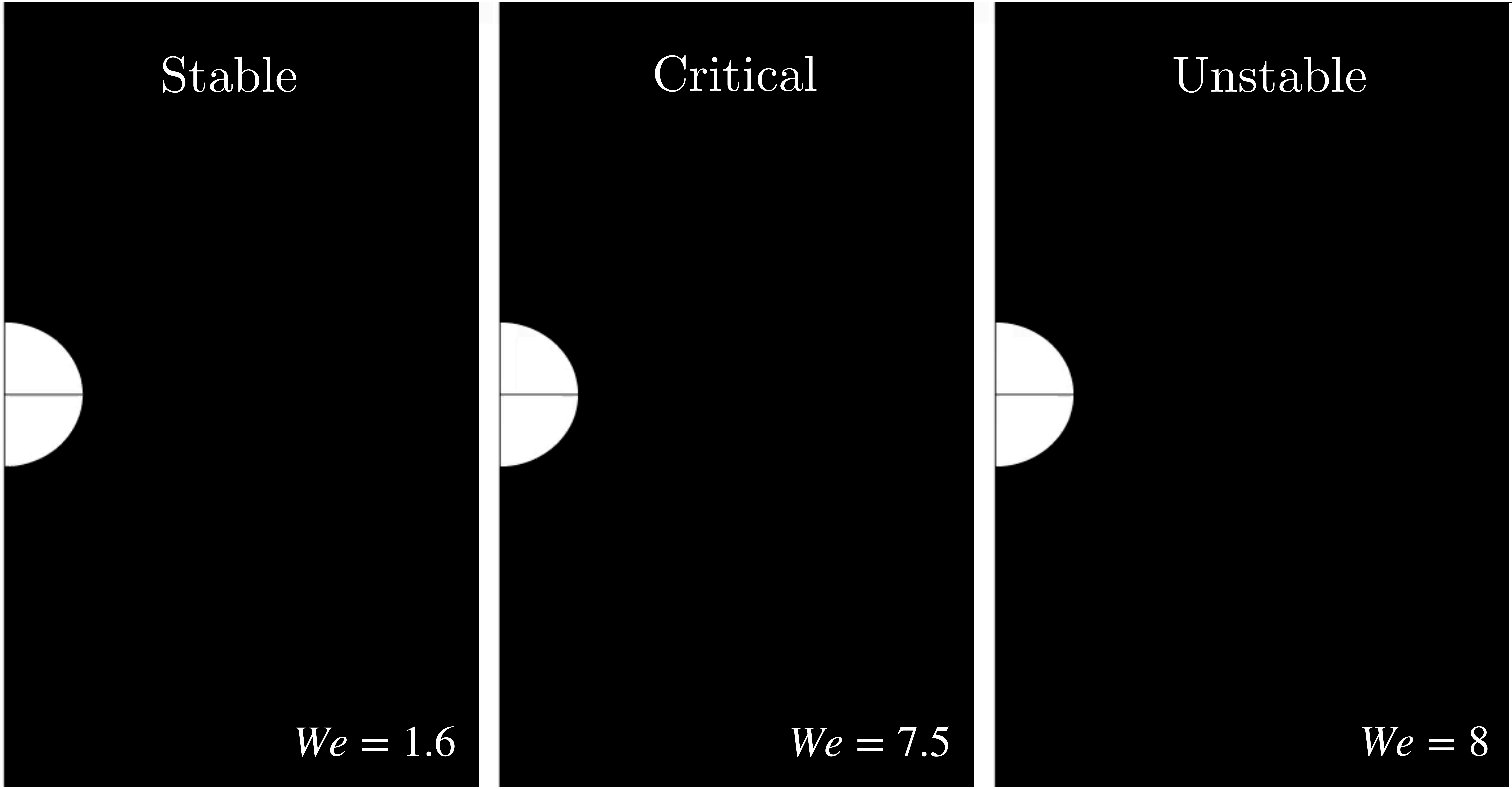
Phase diagram

$Re = 400$



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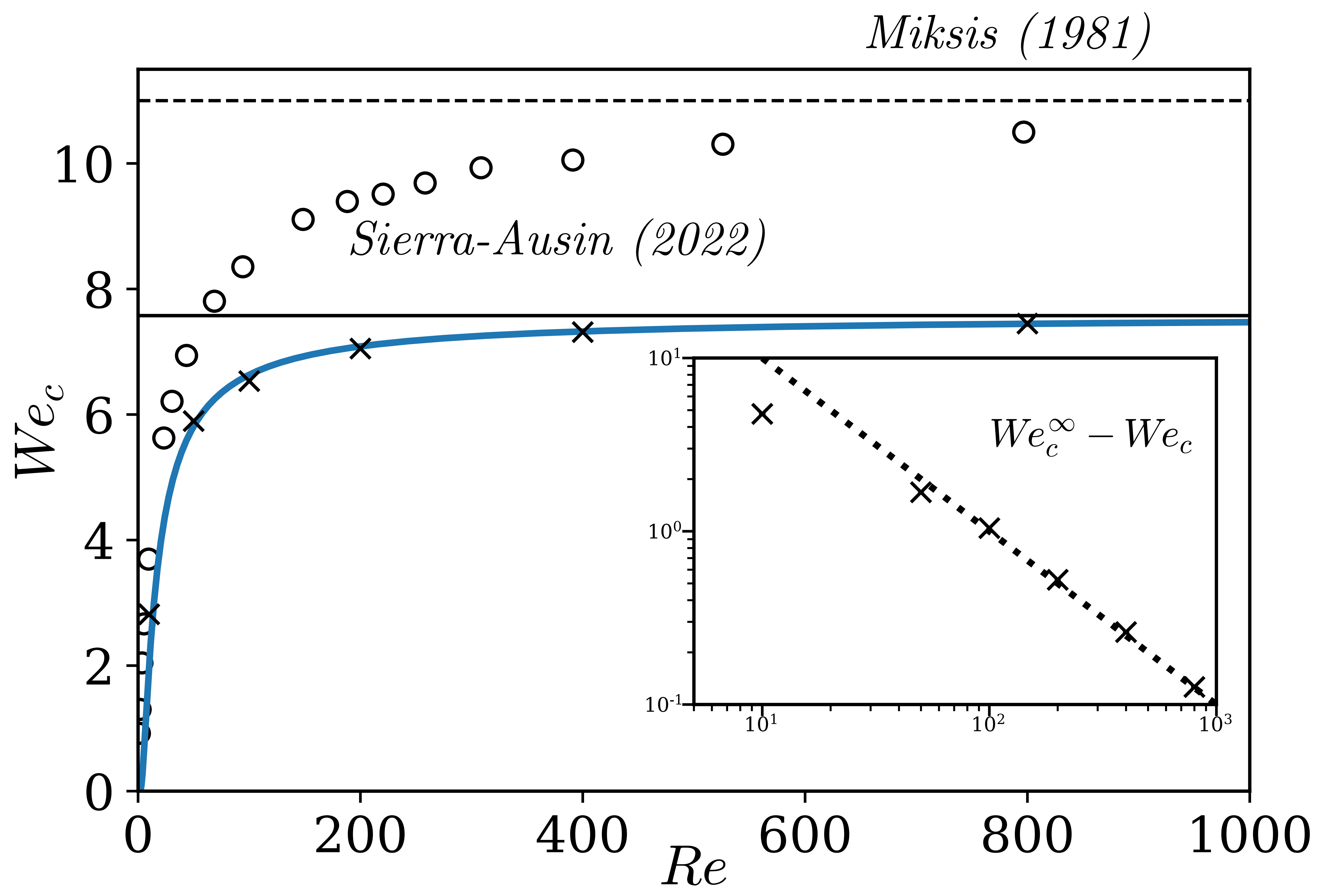
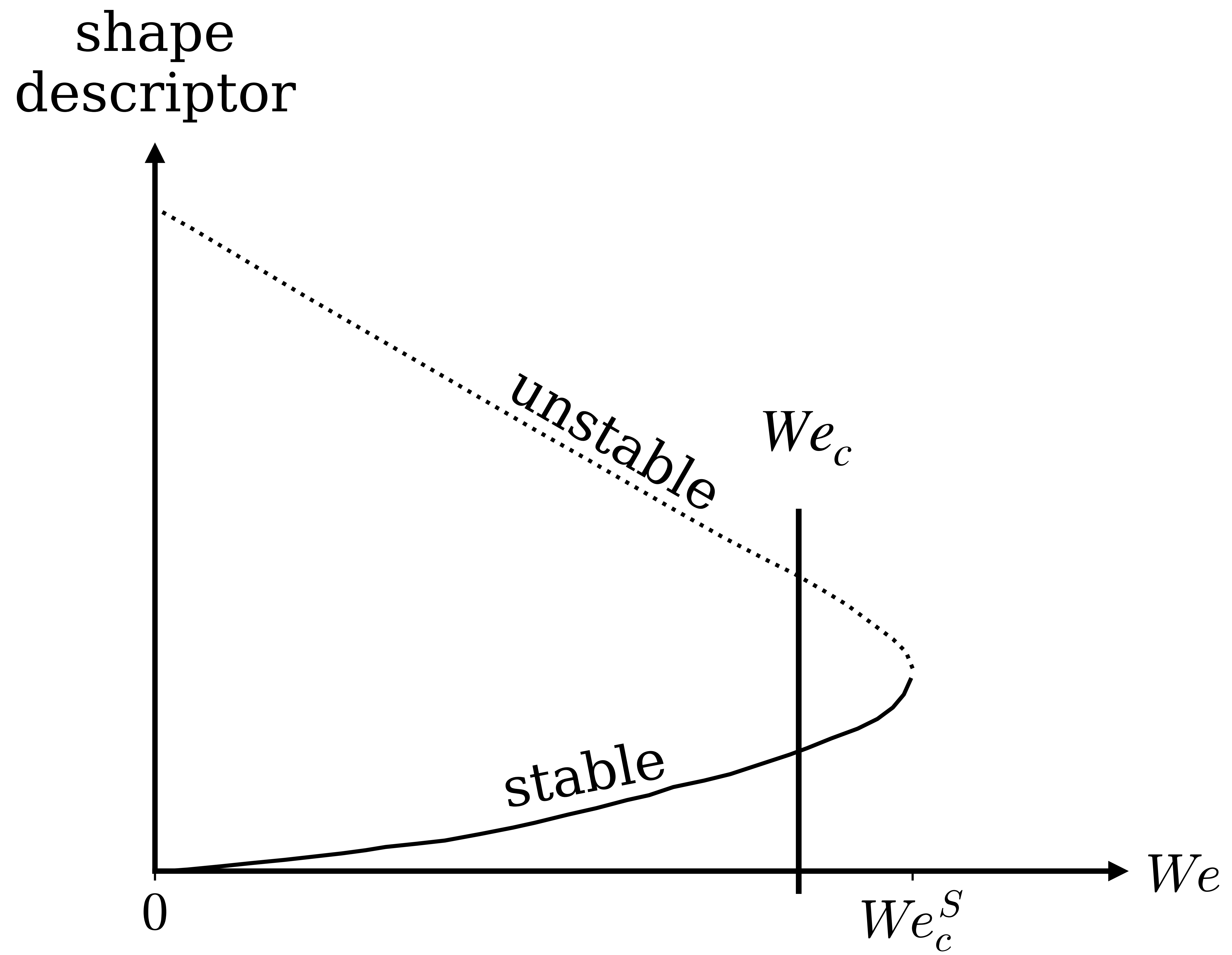
Phase diagram: Importance of the IC



Viscosity is destabilizing



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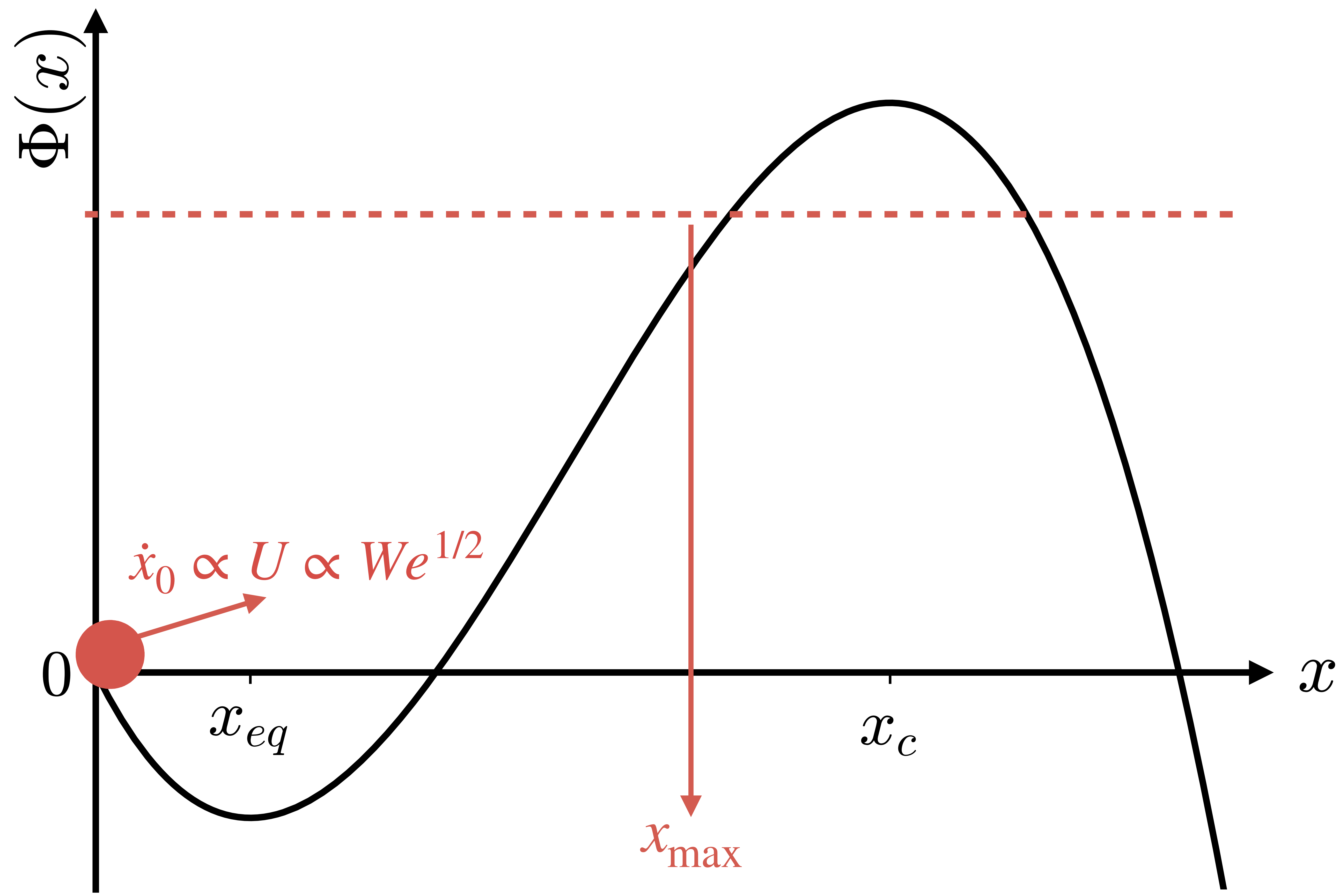
Phase diagram: A bubble as a particle

$$We = \frac{\rho U^2 d}{\gamma} = \frac{\rho E^2 d^3}{\gamma}$$



Sub-critical break-up

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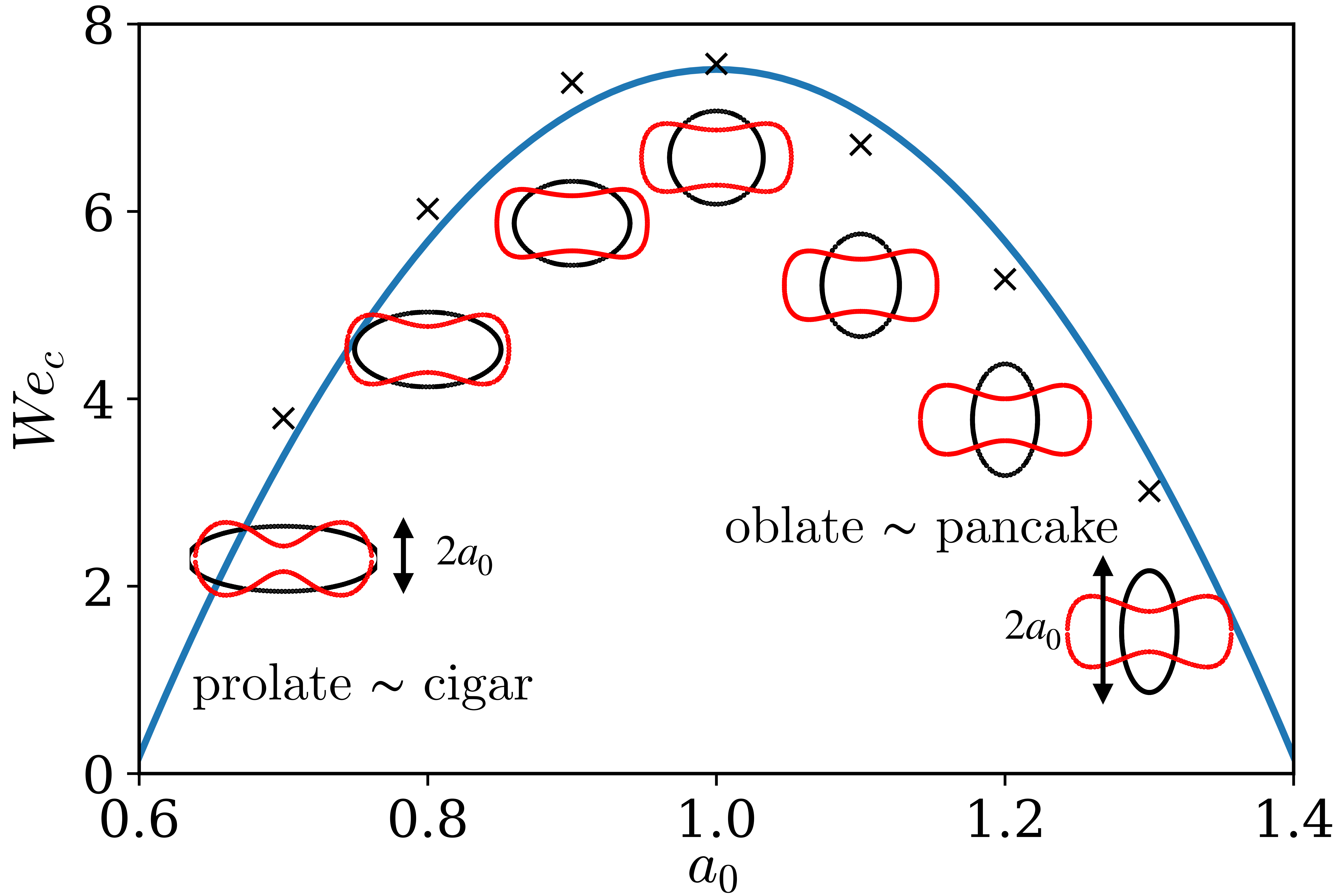
Dependance on the IC



History matters

We must describe the **whole dynamics**.

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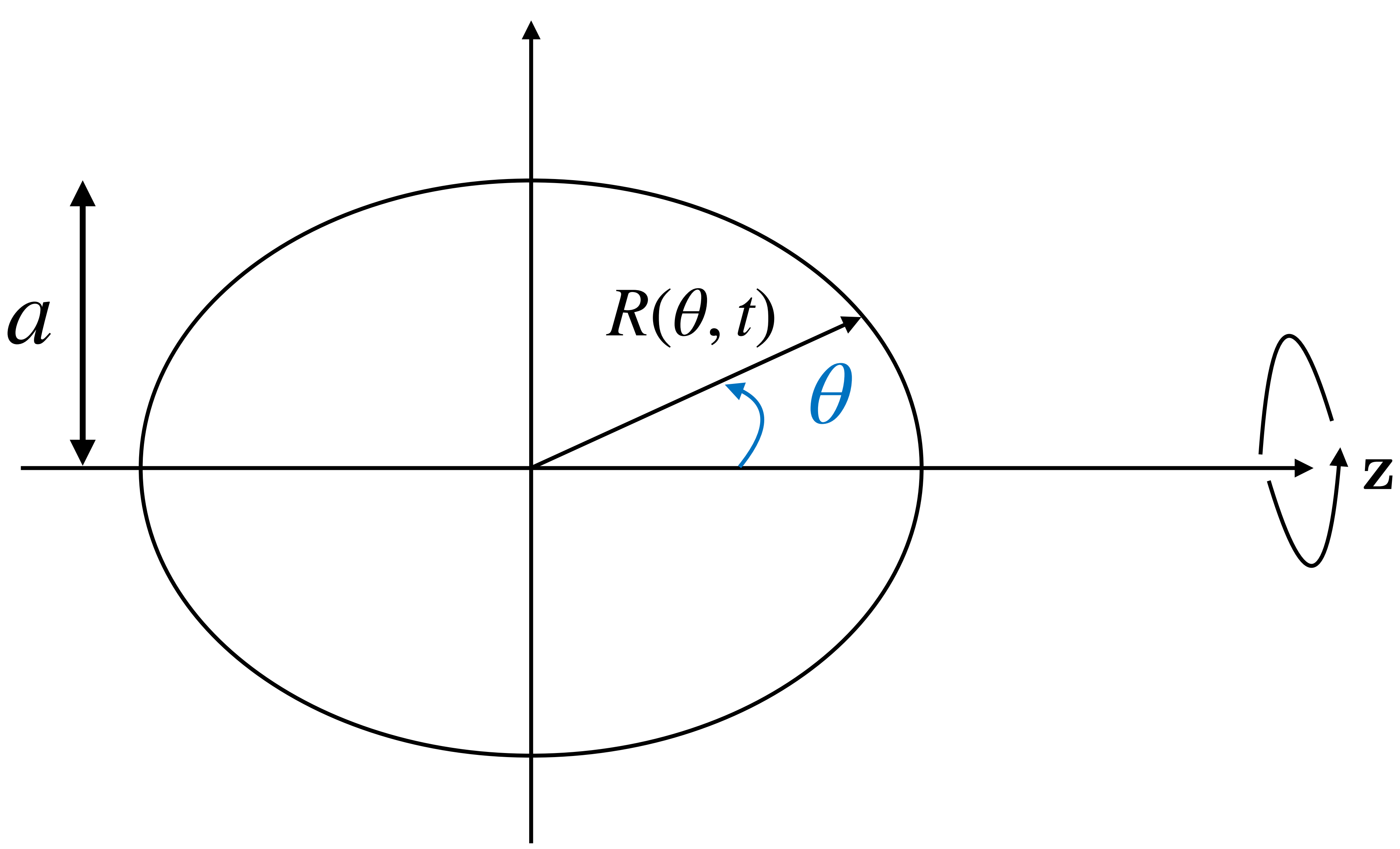
Deformation quantification

$$R(\theta,t) = R_0 + \sum_{\ell=0}^{\infty} c_{\ell,0}(t) Y_\ell^0(\theta)$$

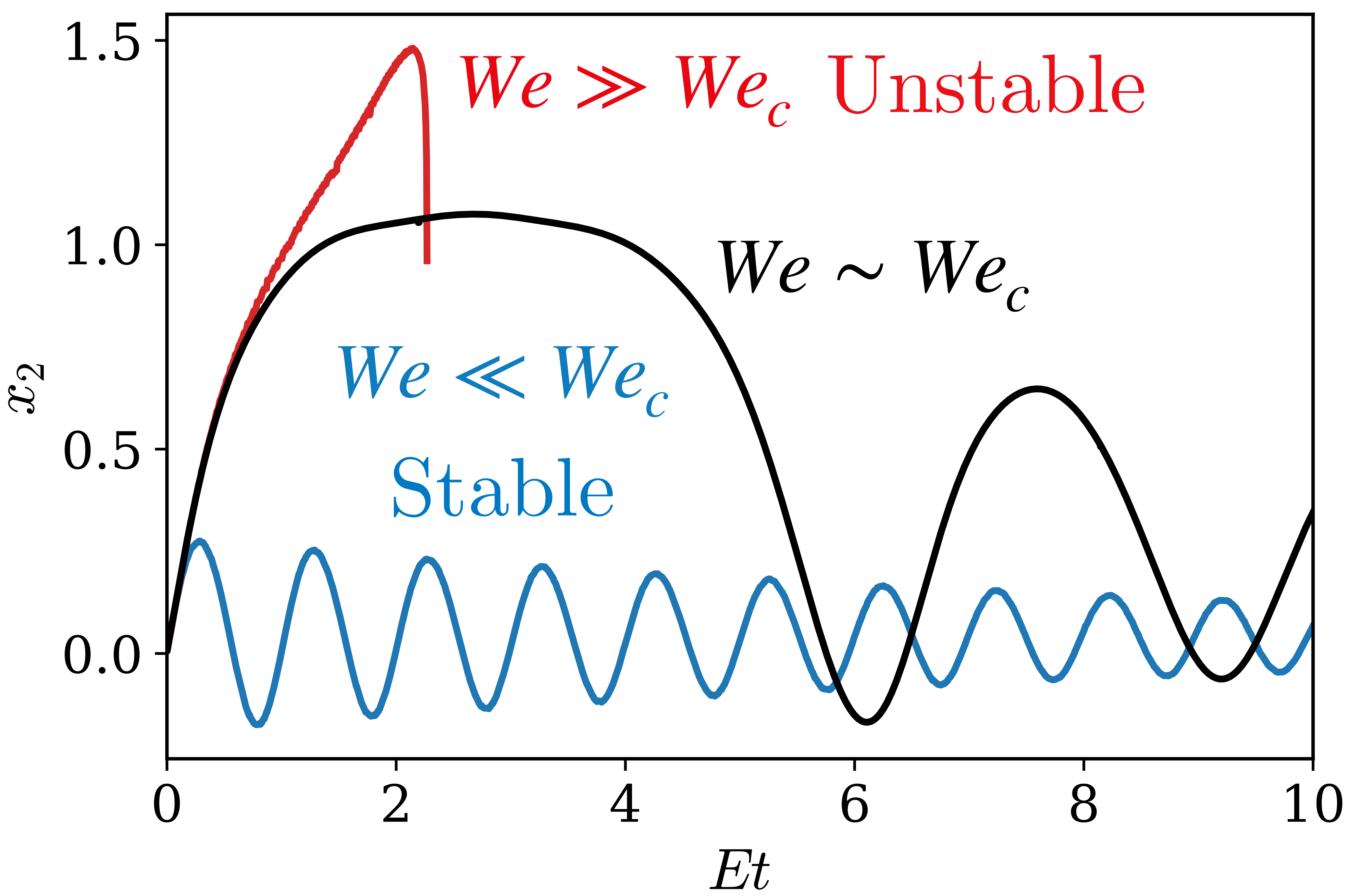


Mode 2 dominates

Risso & Fabre 1998, Lalanne et al. 2019, Perrard, Rivière et al. 2021

$$x = \frac{c_{2,0}}{R_0}$$

$Re = 400$



$$\ddot{x} + \Lambda \dot{x} = -\nabla V(x, We, Re, a_0)$$

$$t' = \omega_2 t$$

$$\omega_2 = \sqrt{12}\sqrt{\frac{\gamma}{\rho R_0^3}}$$

Rayleigh (1879)

$$\Lambda = 20\sqrt{\frac{2}{3}}\frac{\sqrt{We}}{Re}$$

Lamb (1932)
Kang & Leal (1987)

$$deg(V) = 3$$

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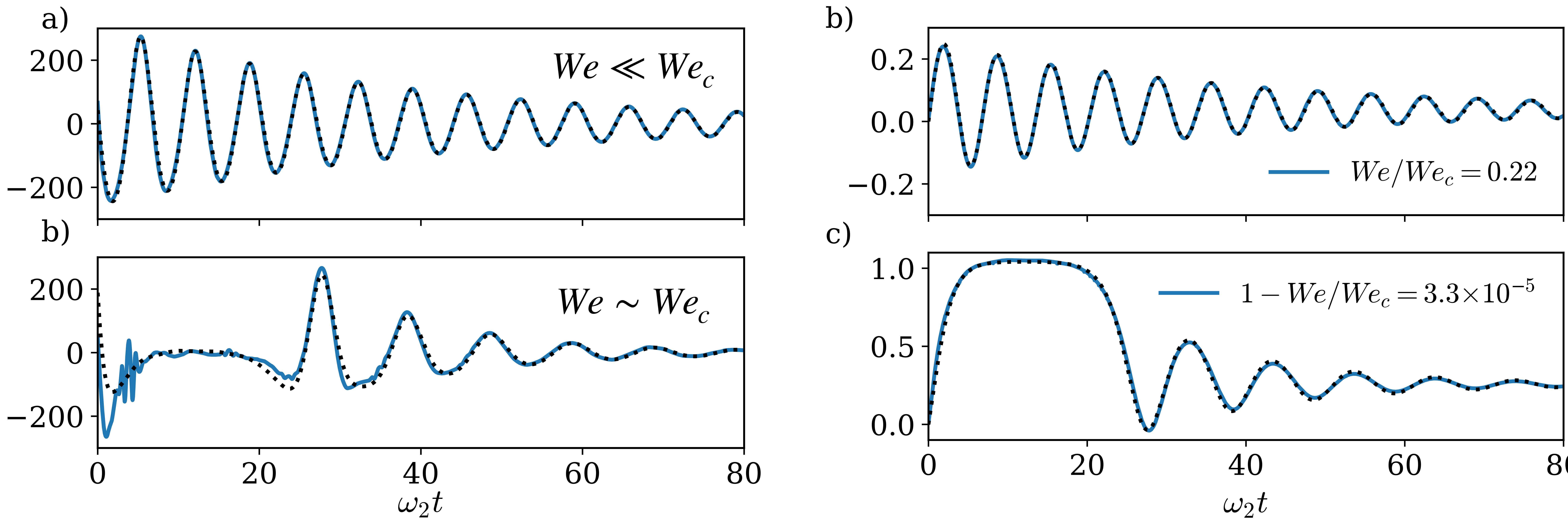
Model fitting

$Re = 400$

$$\ddot{x} + \Lambda \dot{x} = -\nabla V(x, We, Re, a_0)$$

Acceleration $\ddot{x}$ | Position x



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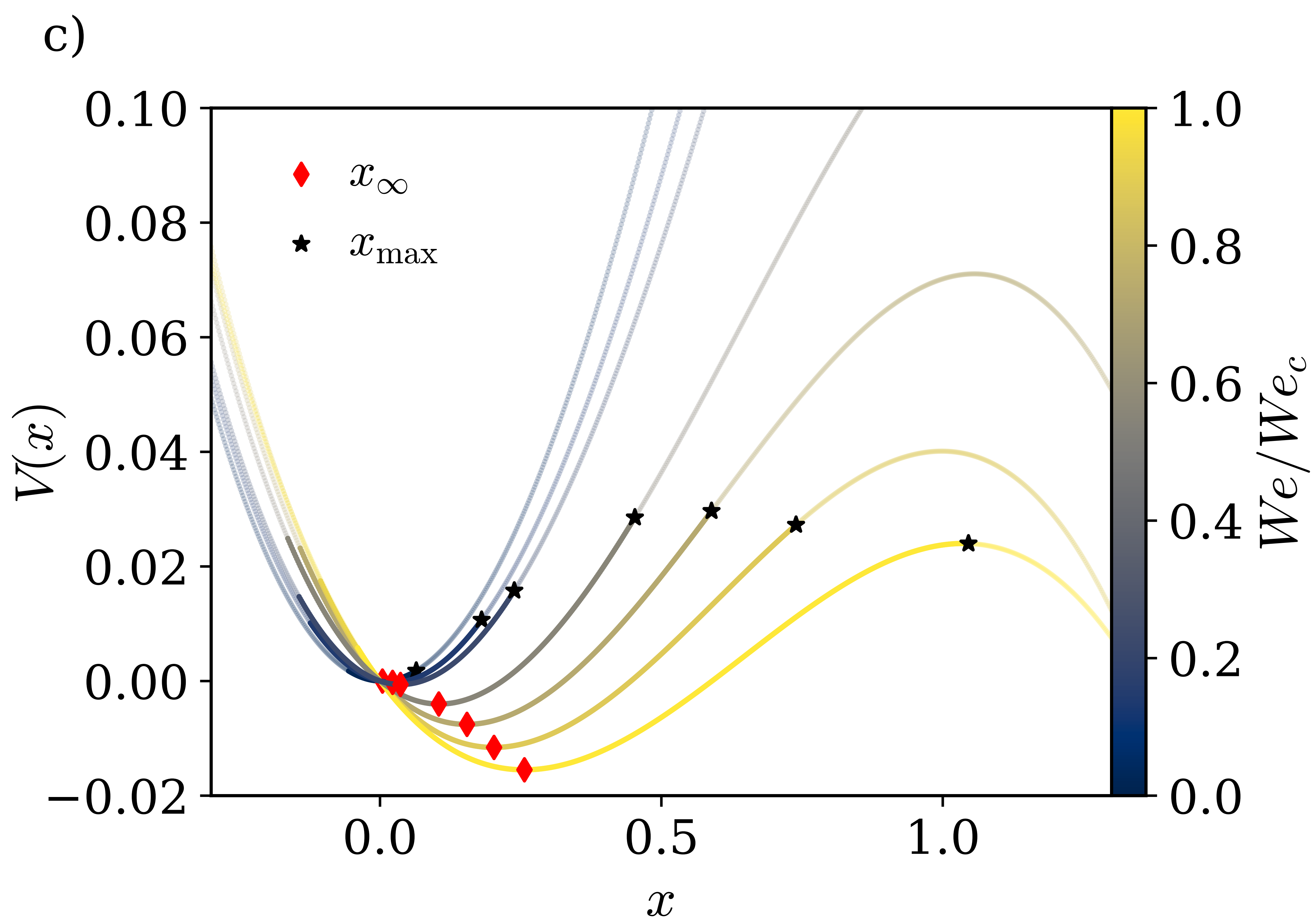
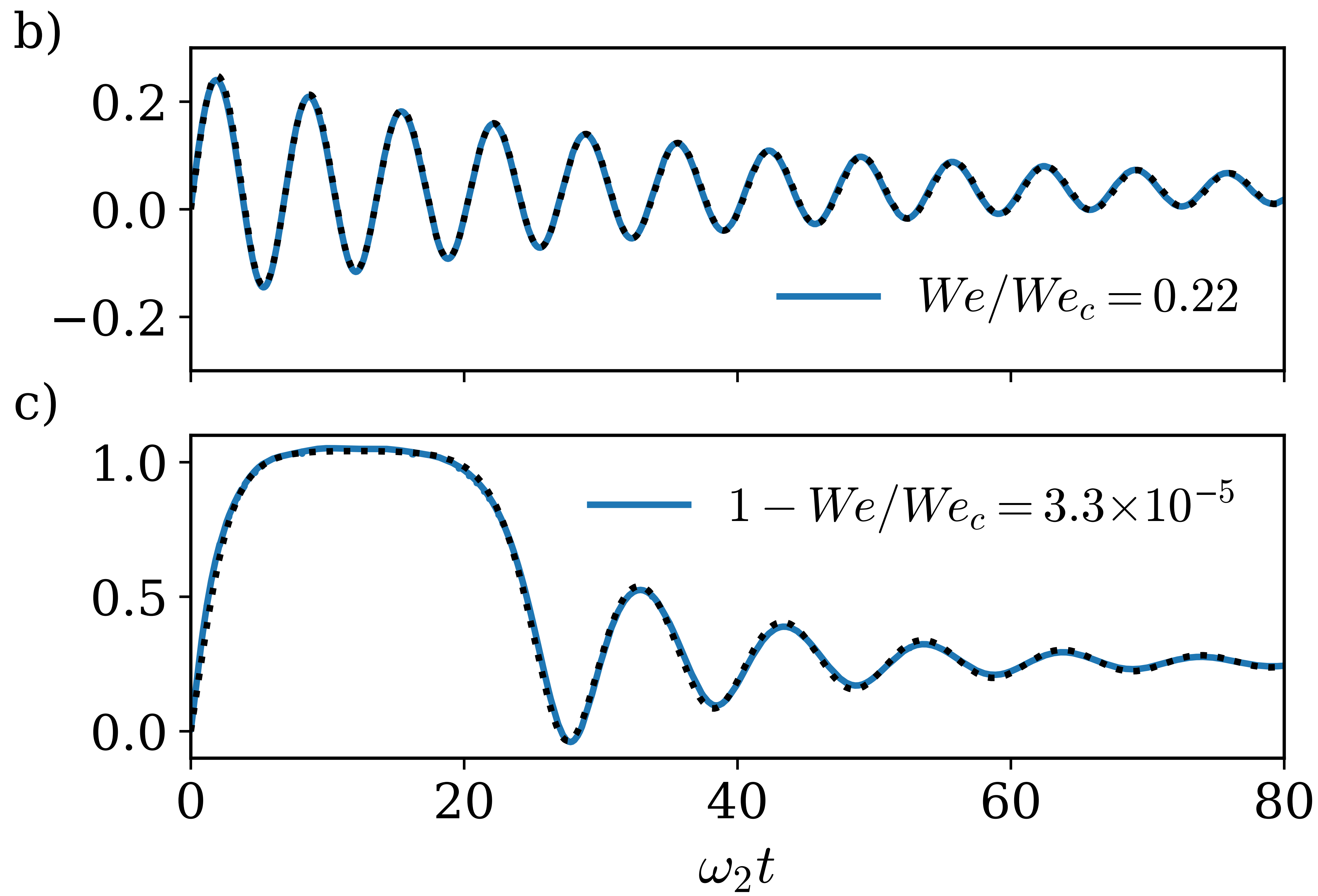
Effective potential shape - Impact of We

$Re = 400$

$$\ddot{x} + \Lambda \dot{x} = -\nabla V(x, We, Re, a_0)$$



Position x



We_c combination of

1. initial velocity
2. potential shape

$\dot{x}_0 \propto \sqrt{We}$

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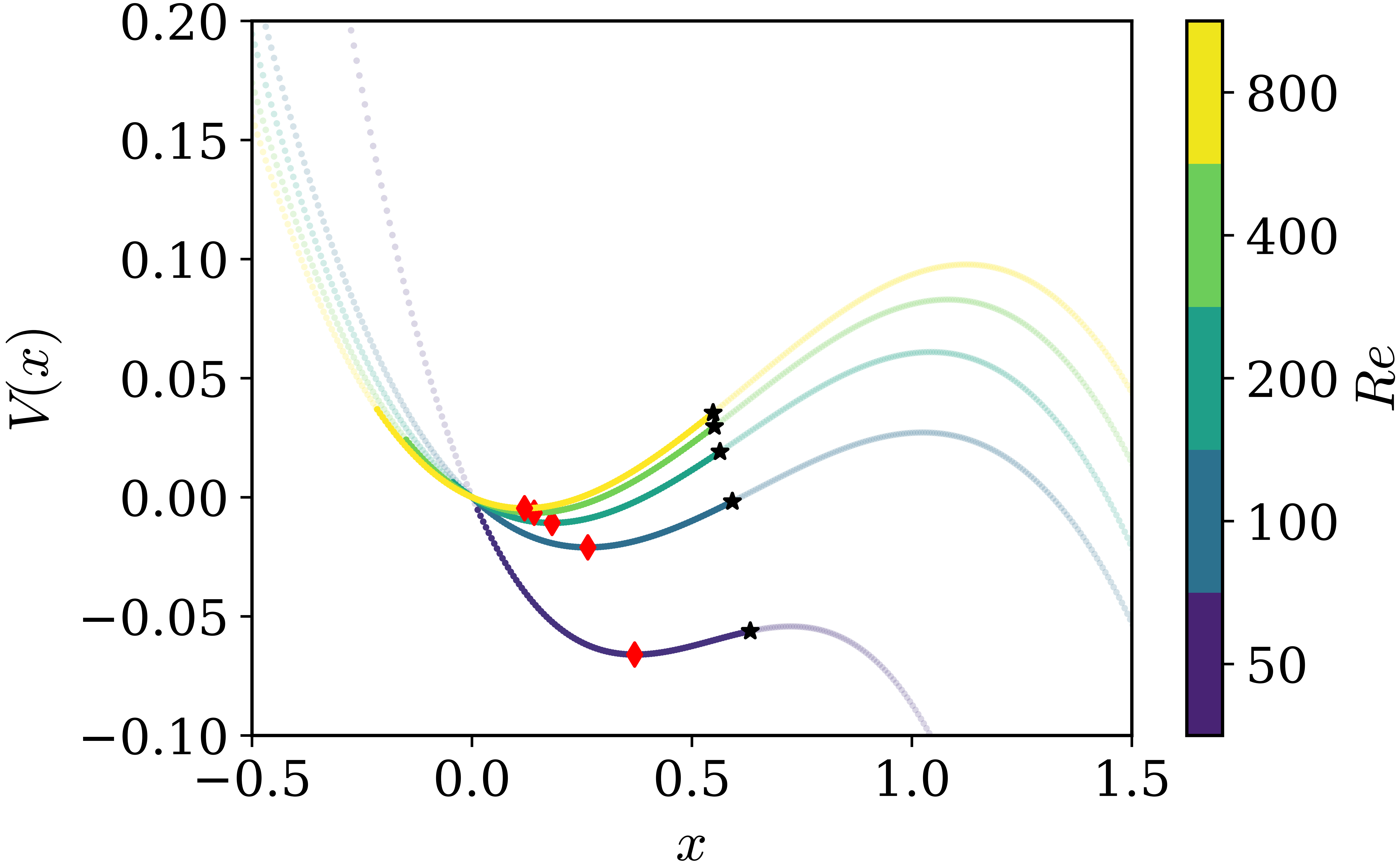
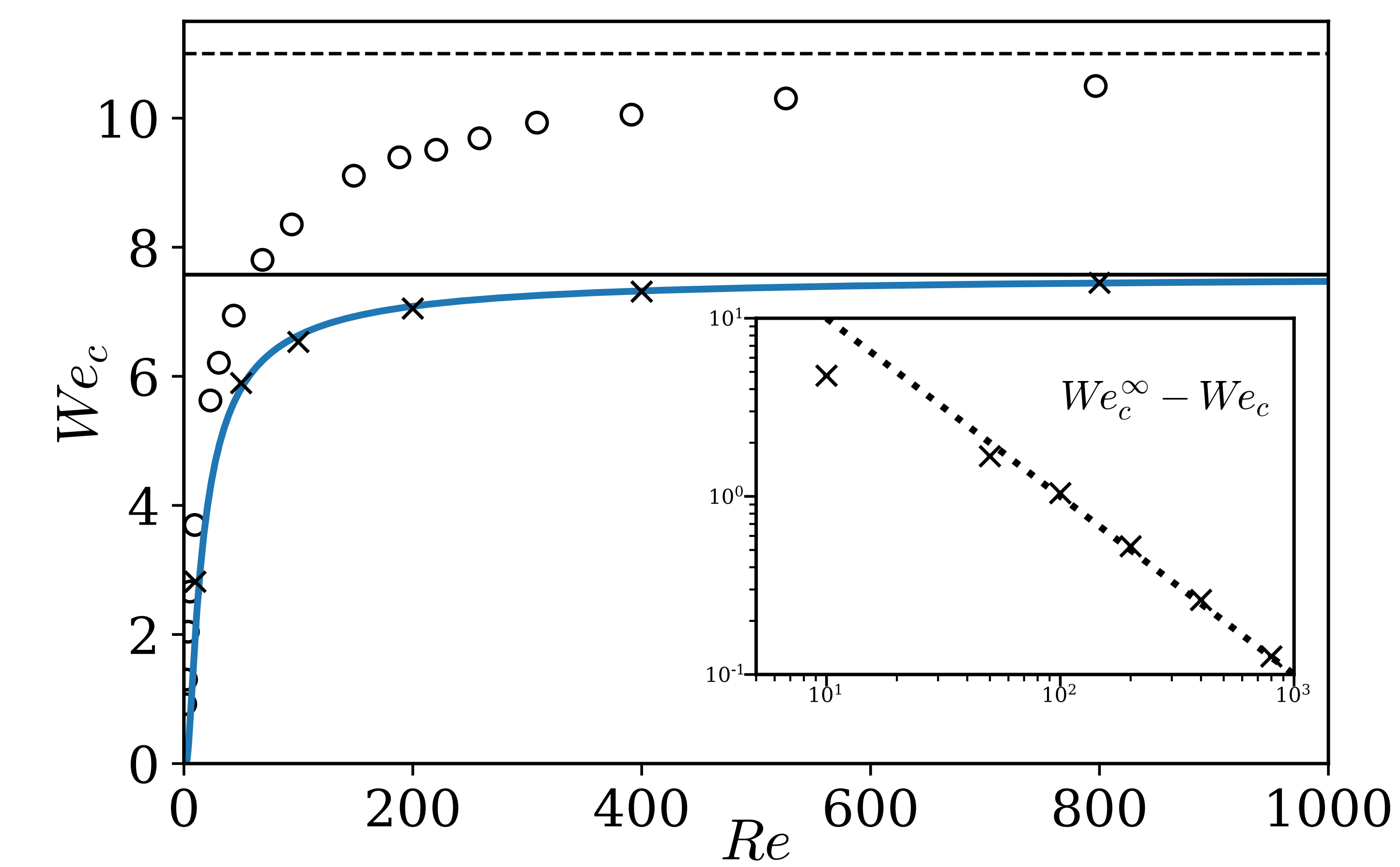
Destabilizing effect of viscosity

$We = 5$





Viscosity is destabilizing

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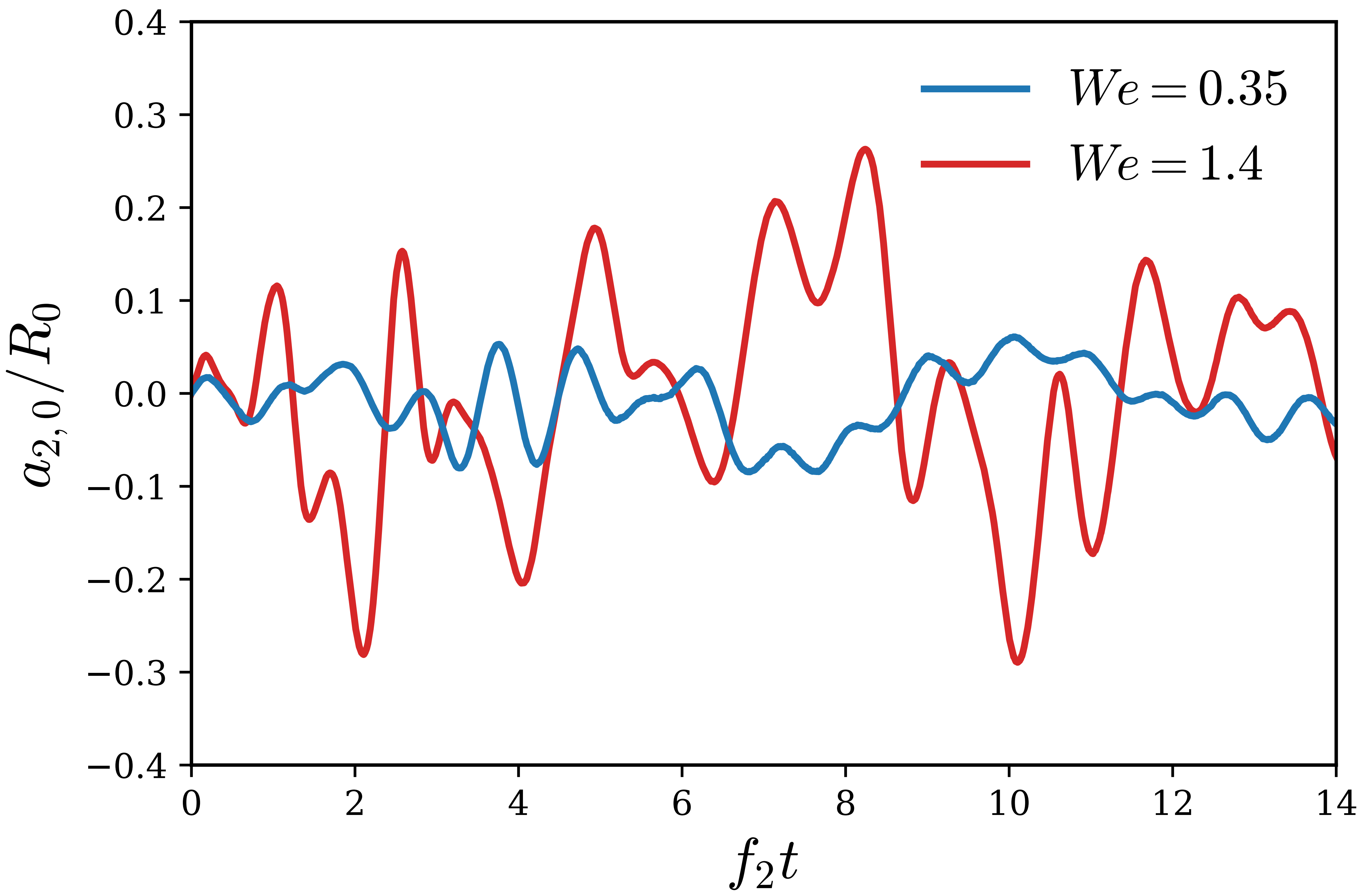
Conclusions & Perspectives

- Observed transitions are always **subcritical:** call for a **dynamical description**
  →No loss of stability
  →Initial bubble shape matters

- Quantitative coupling between flow and interface: **1D** non linear oscillator

Rivière & al, Bubble break-up reduced to a 1D non-linear oscillator, *Under review at PRF*

- Model for bubble in turbulent flows at low *We*



$$\ddot{x} + \Lambda(t)\dot{x} = -\nabla V(x, We(t), Re(t))$$

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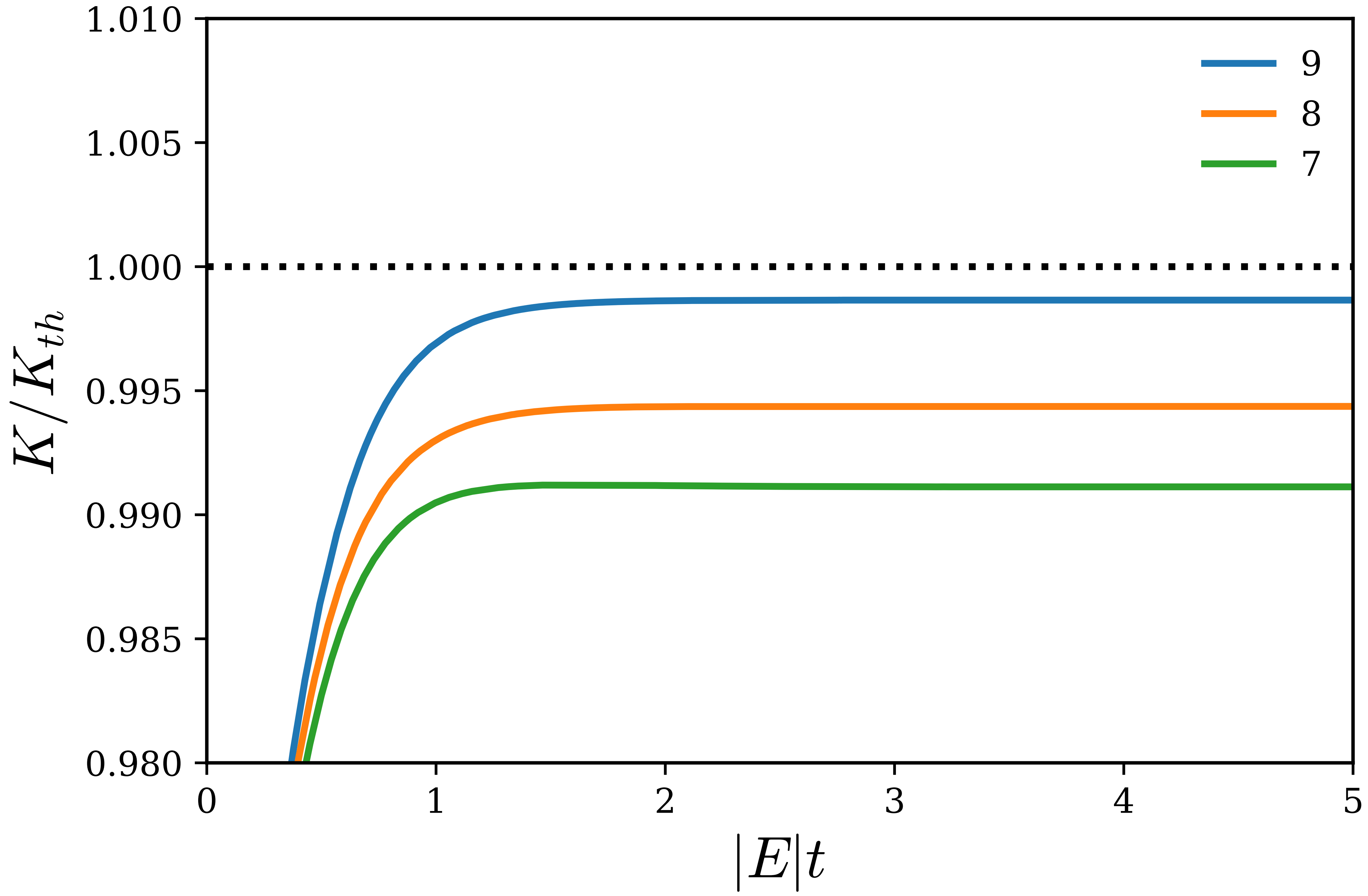
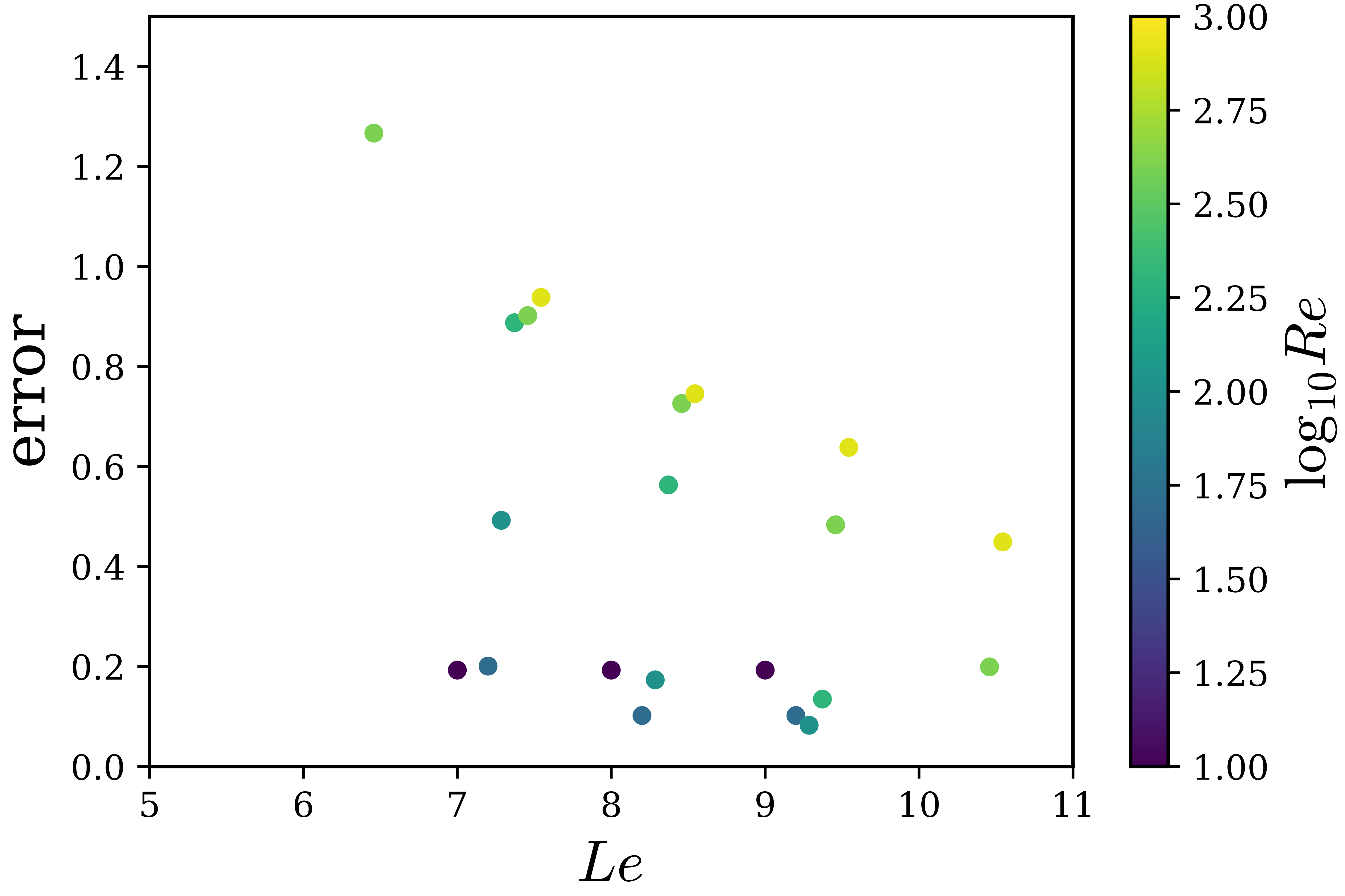
Convergence study - Flow

$Re = 200$



$$\textbf{error} = \frac{|K - K_{th}|}{K_{th}}.100$$



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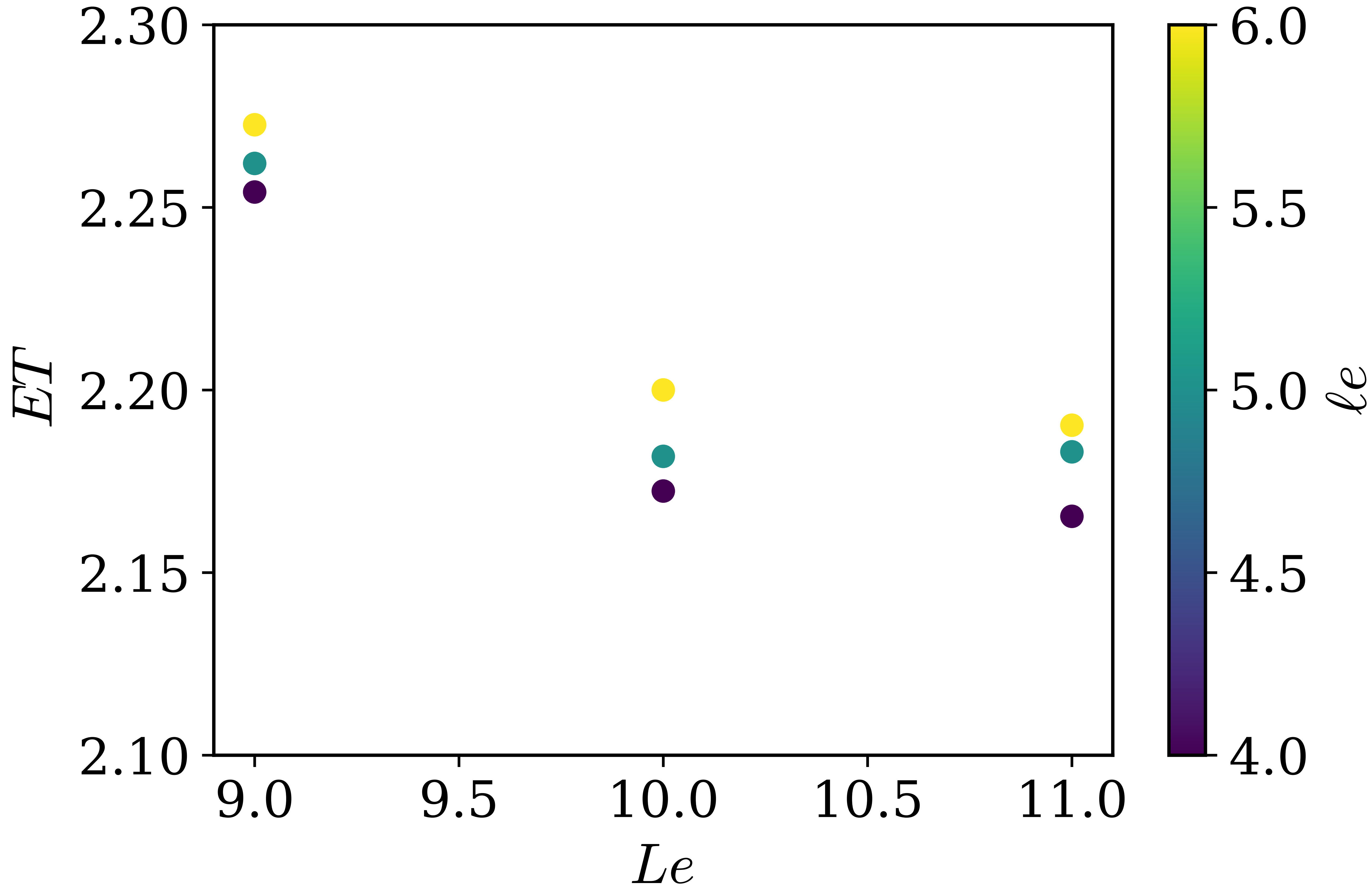
Convergence study - Bubble



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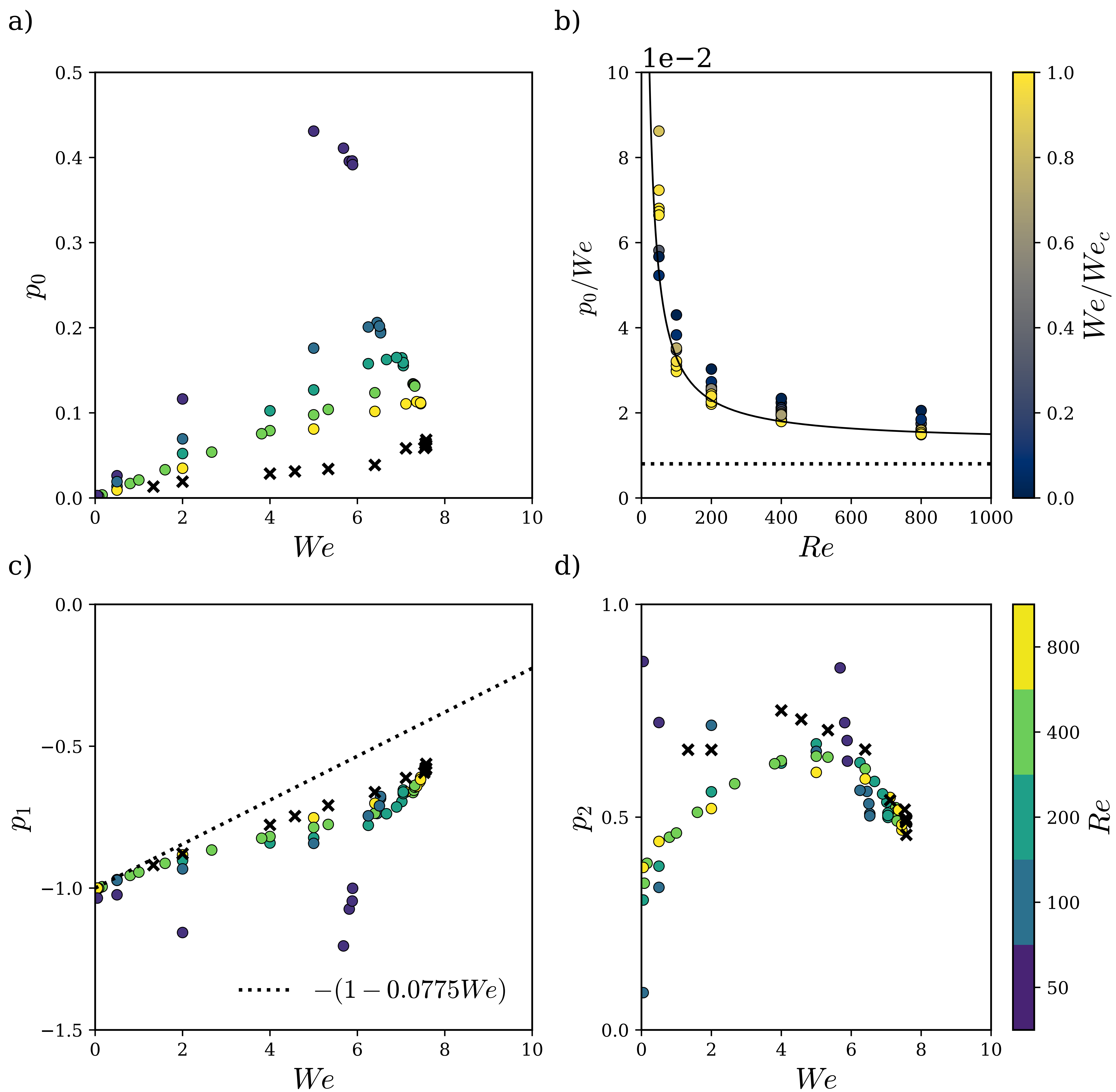
Potential coefficients

$$\ddot{x} + \Lambda\dot{x} = -\nabla V(x, We, Re, a_0)$$

$$\ddot{x} + \Lambda\dot{x} = p_0 + p_1 x + p_2 x^2$$



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