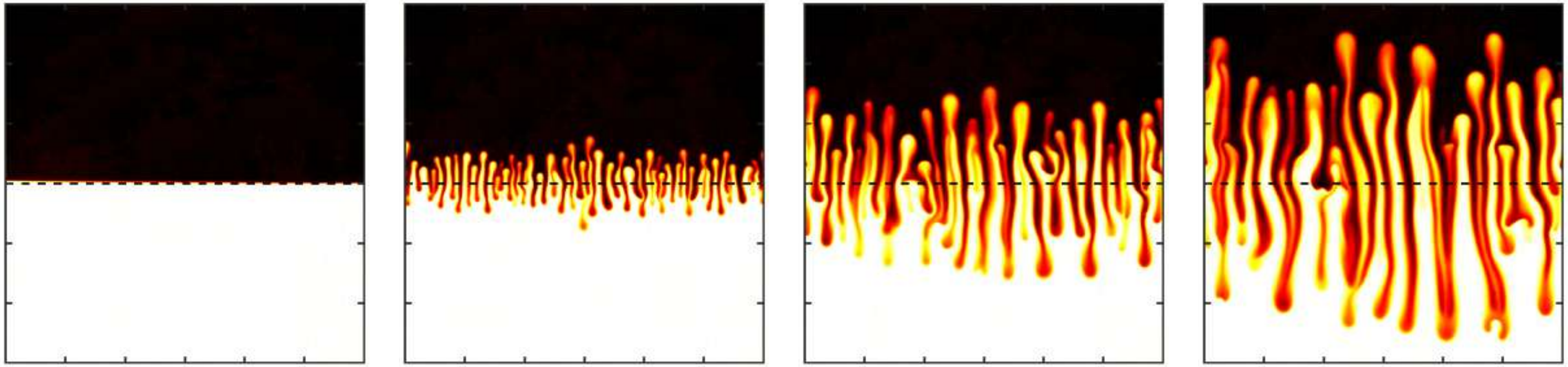
EUROMECH COLLOQUIUM 619
OBERBECK - BOUSSINESQ HYPOTHESIS AND BEYOND IN STRATIFIED TURBULENCE

Experimental investigation on Rayleigh-Taylor instability in confined porous media



Physics of Fluids

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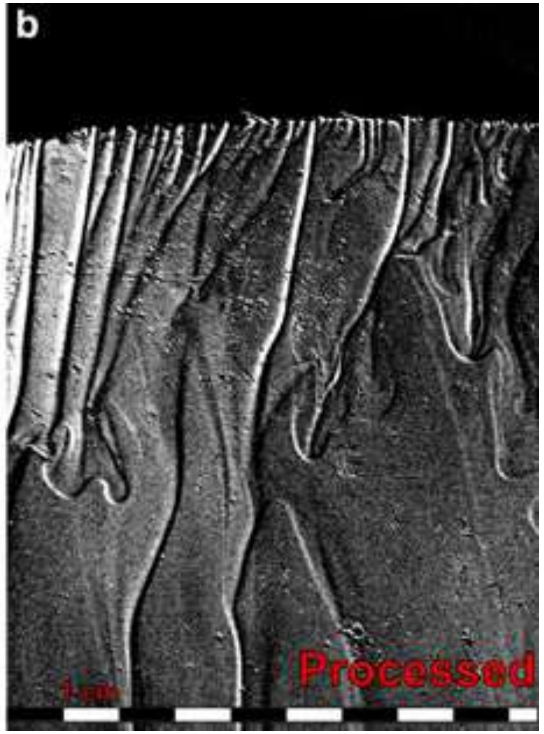
EUROPEAN MECHANICS SOCIETY

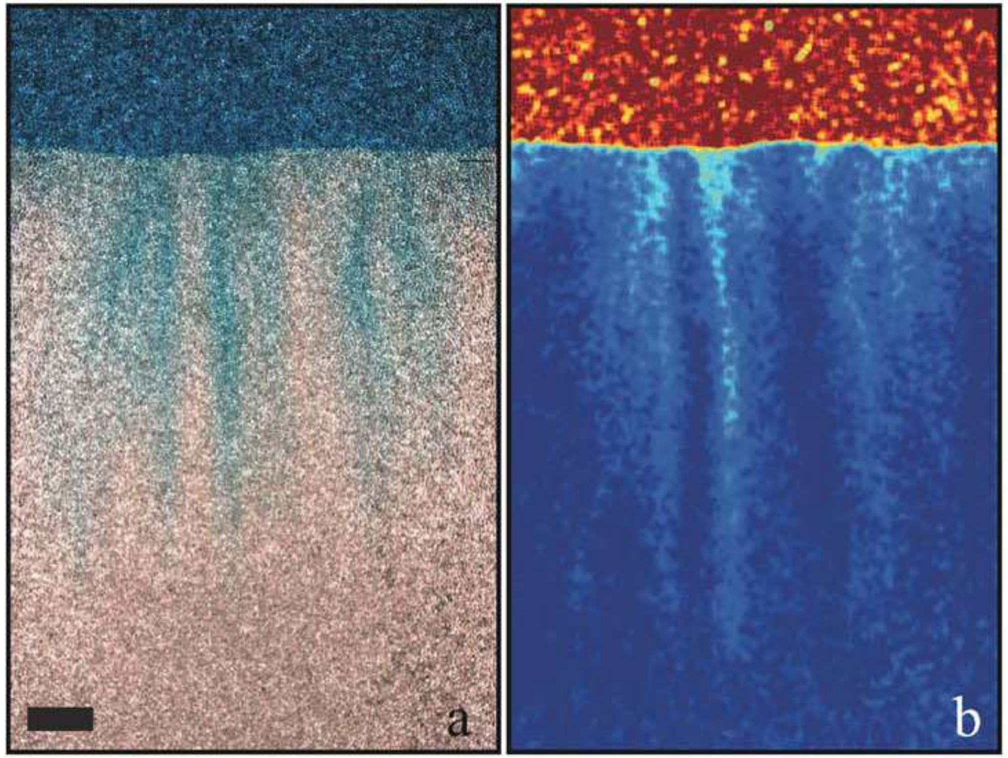
July 6-8, 2022, Vienna (Austria)

Sea ice formation



Middleton et al., " Visualizing brine channel development and convective processes during artificial sea-ice growth using Schlieren optical methods". *J. Glaciology* (2016).

Groundwater flows



Neufeld, J. A. et al. 'Convective dissolution of carbon dioxide in saline aquifers.' *Geophys. Res. Lett.* (2010).

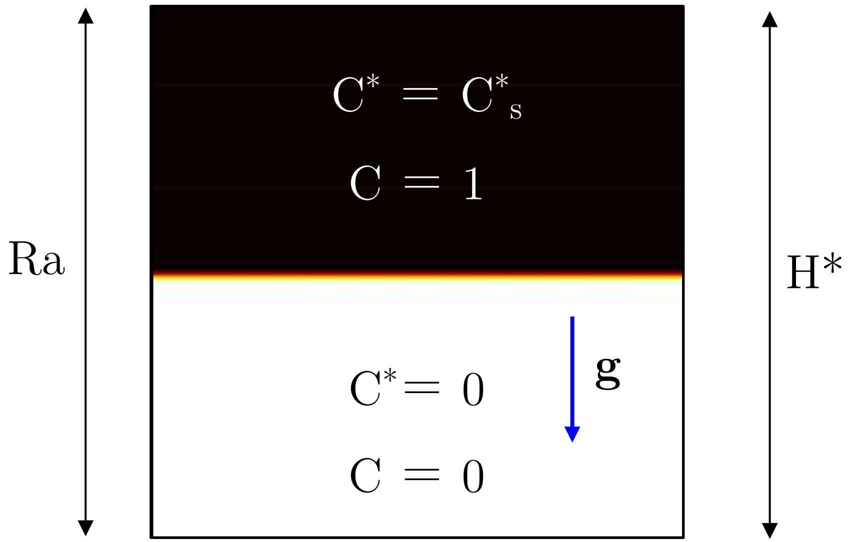
Simmons et al., "Variable-density groundwater flow and solute transport in heterogeneous porous media: approaches, resolutions and future challenges," *J. Contam. Hydrol.* (2001).

Molen et al., "Transport of solutes in soils and aquifers," *J. Hydrol.* (1988).

LeBlanc, *Sewage plume in a sand and gravel aquifer, Cape Cod, Massachusetts* (US Geological Survey, 1984).

Transition from two- to three-dimensional flows

- Rayleigh-Taylor (RT) instability
- Two fluids of different density
- Unstable configuration
- Time-dependent flow dynamics



- Homogeneous and isotropic porous medium
- Incompressible flow
- Low-Reynolds number (Darcy flow)

$$\frac{\mu}{k} w = -\frac{\partial p}{\partial z} - \rho g$$

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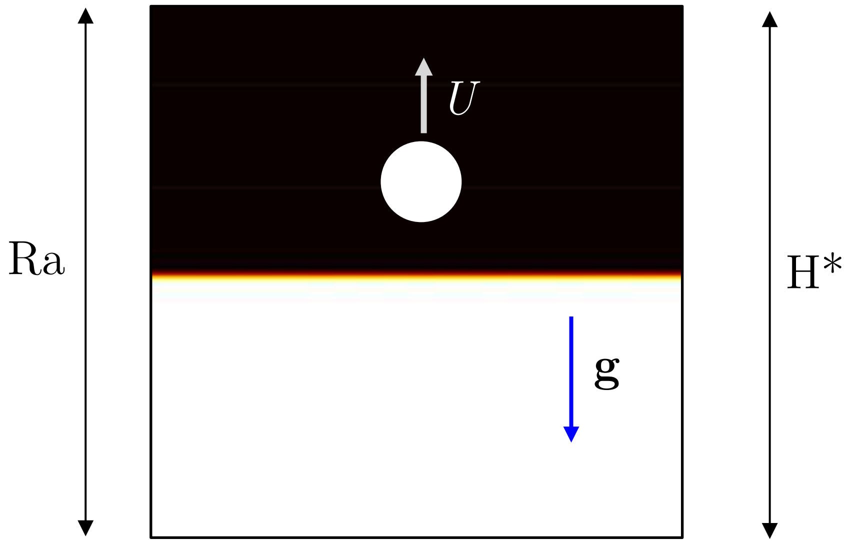

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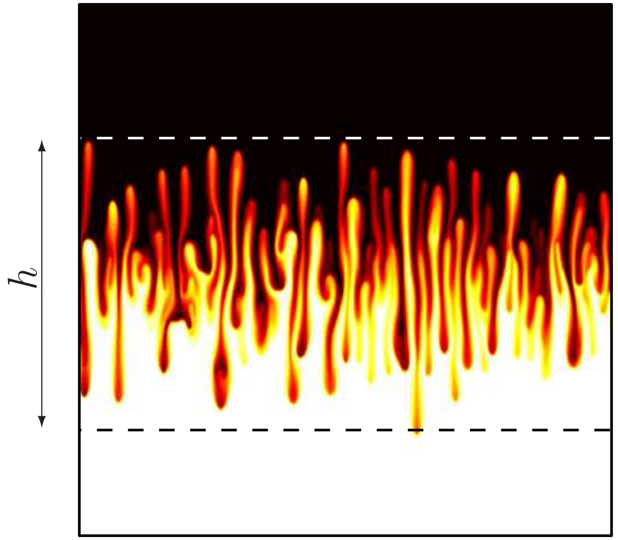
Ultimately, the velocity of a light fluid parcel should not exceed the buoyancy velocity

$$U = \frac{g\Delta\rho k}{\mu}$$

as a result of balance between gravity and friction

Scaling for the mixing length

- Rayleigh-Taylor (RT) instability
- Two fluids of different density
- Unstable configuration
- Time-dependent flow dynamics



$$h(t) \sim t$$

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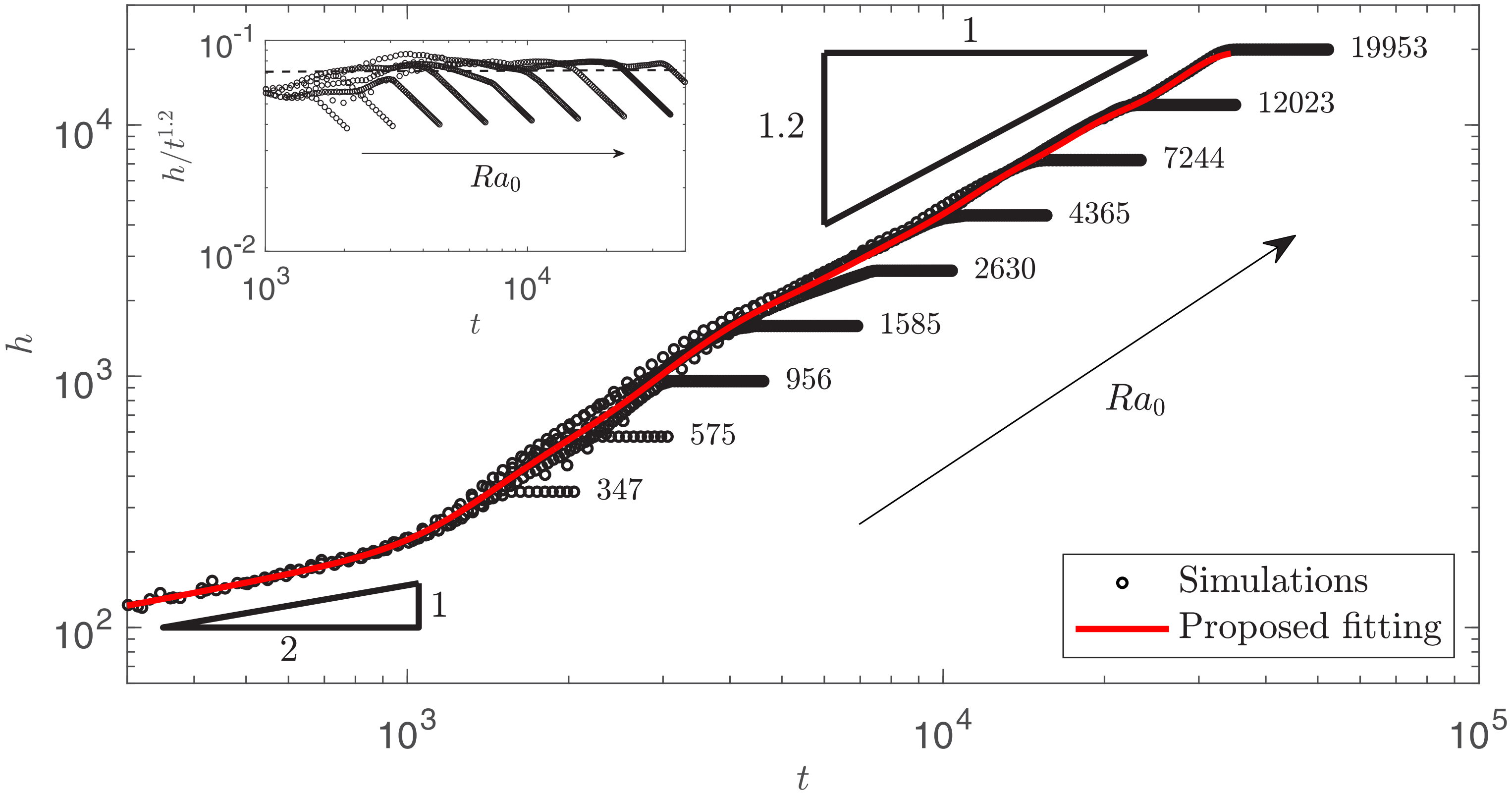
Scaling for the mixing length

simulations



Anomalous scaling is observed in 2D RT convection in porous media, but $h(t)$ scaling is not anomalous in 3D

Finite-size (i.e., finite Ra or finite t) effect? Due to initial acceleration?

Anomalous scaling

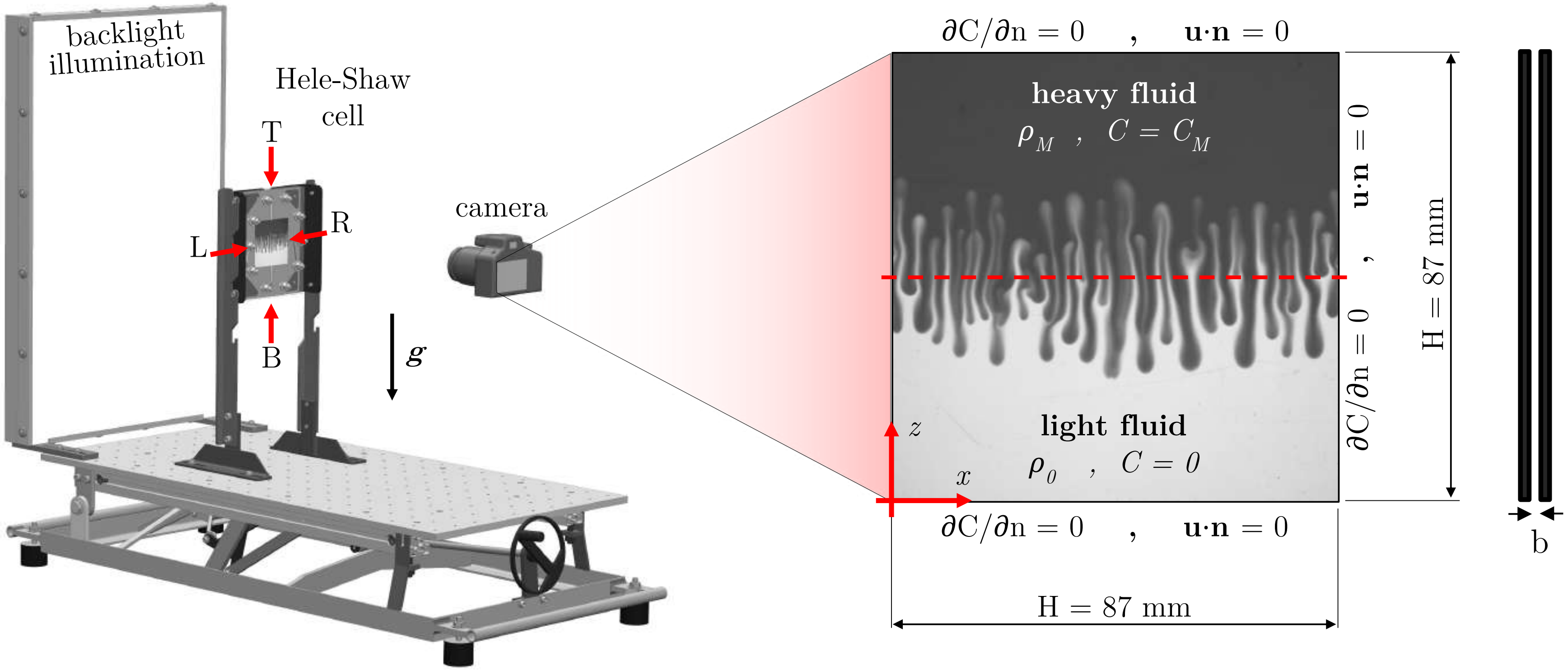
$$h(\mathrm{t}) \sim \mathrm{t}^{1.2} \neq t$$

Simulations

De Paoli, Zonta & Soldati, *Phys. Rev. Fluids* (2019)
Boffetta *et al.*, *Phys. Rev. Fluids* (2020, 2021)

Experimental setup

(a) (b)



$$Ra = \frac{g \Delta\rho_s^* (b^*)^2 H^*}{12\mu D}$$

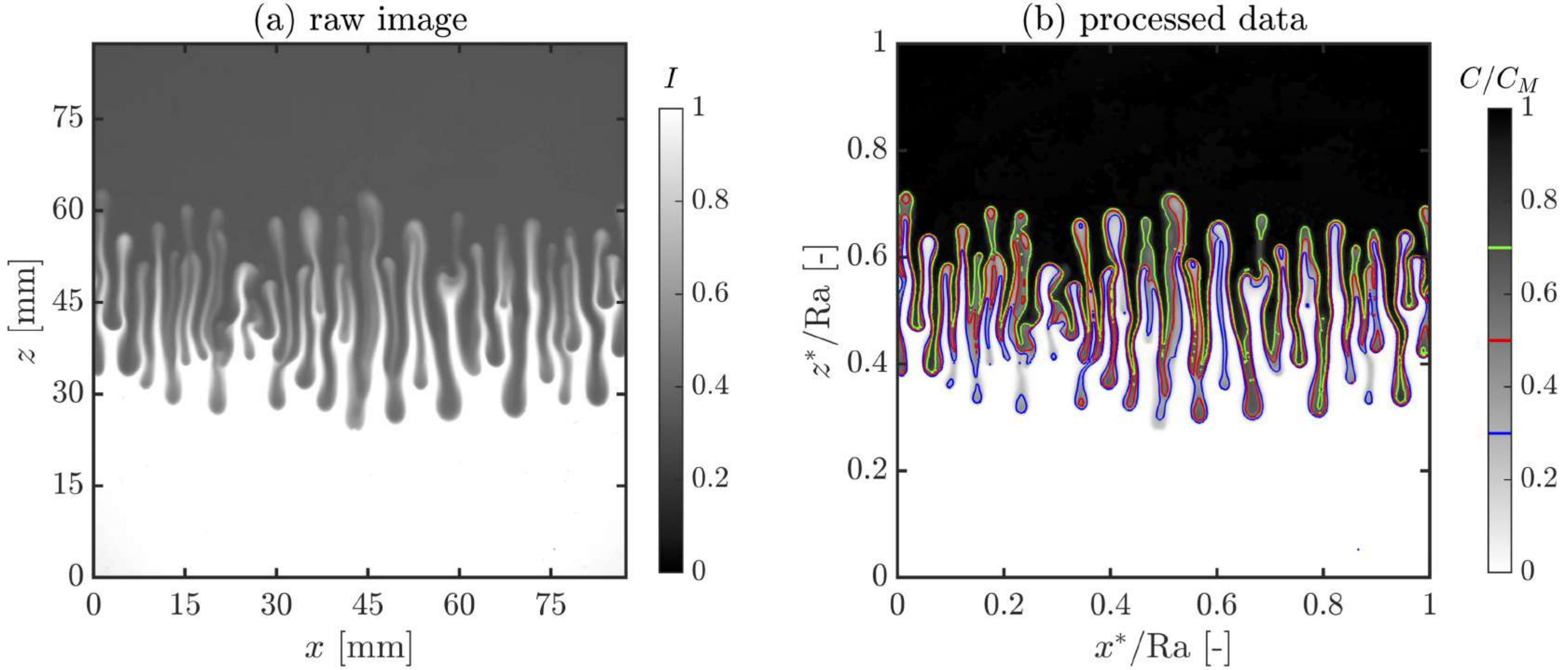
$Ra \in [4\times10^3 \; ; \; 5.4\times10^4]$

Ra varied with $\Delta\rho^*$

- Acquisition rate: 0.2 fps, 2 Mpx
- KMnO4 in water
- Linear dependency $\rho^*(C^*)$

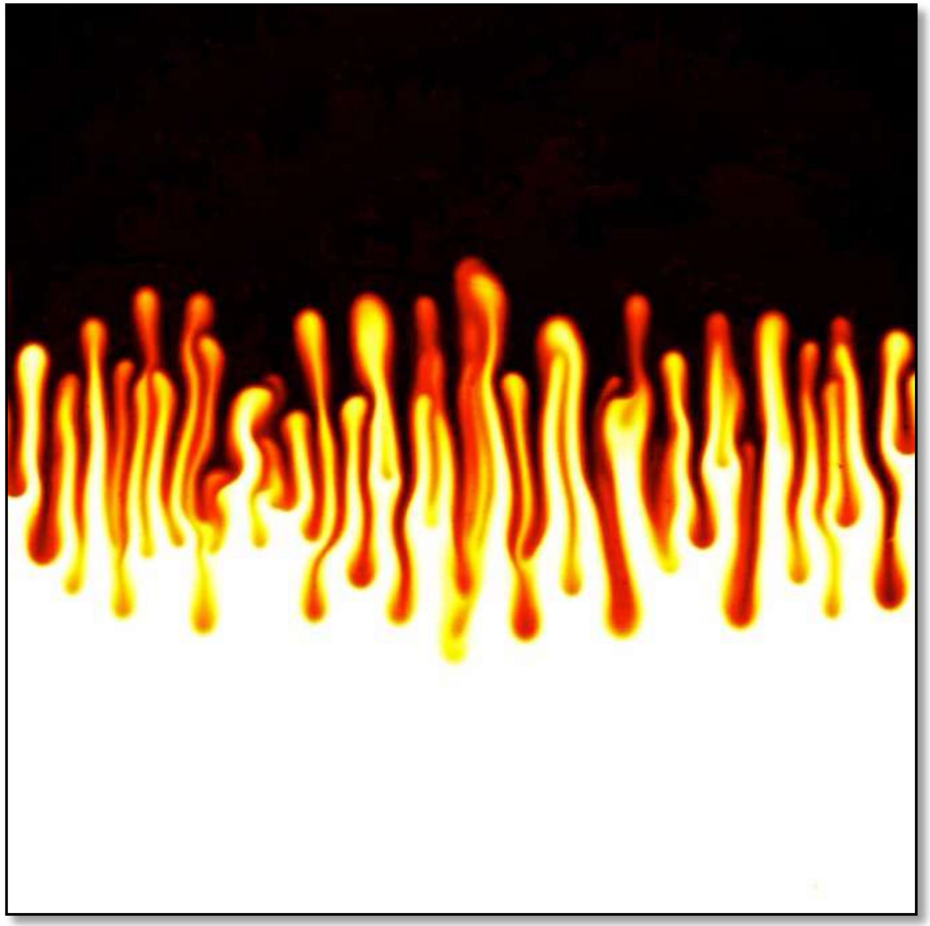
fluid	*geometry*
$\Delta\rho^* \leq 45$ kg/m^3	$b = 0.3$ mm
D=1.7×10^{-9}m^2/s	$H = 87$ mm
μ=9.2×10^{-4} Pa s	

Quantitative concentration measurements



Qualitative flow dynamics

experiments



De Paoli, Perissutti, Marchioli & Soldati, *arXiv* (2022)

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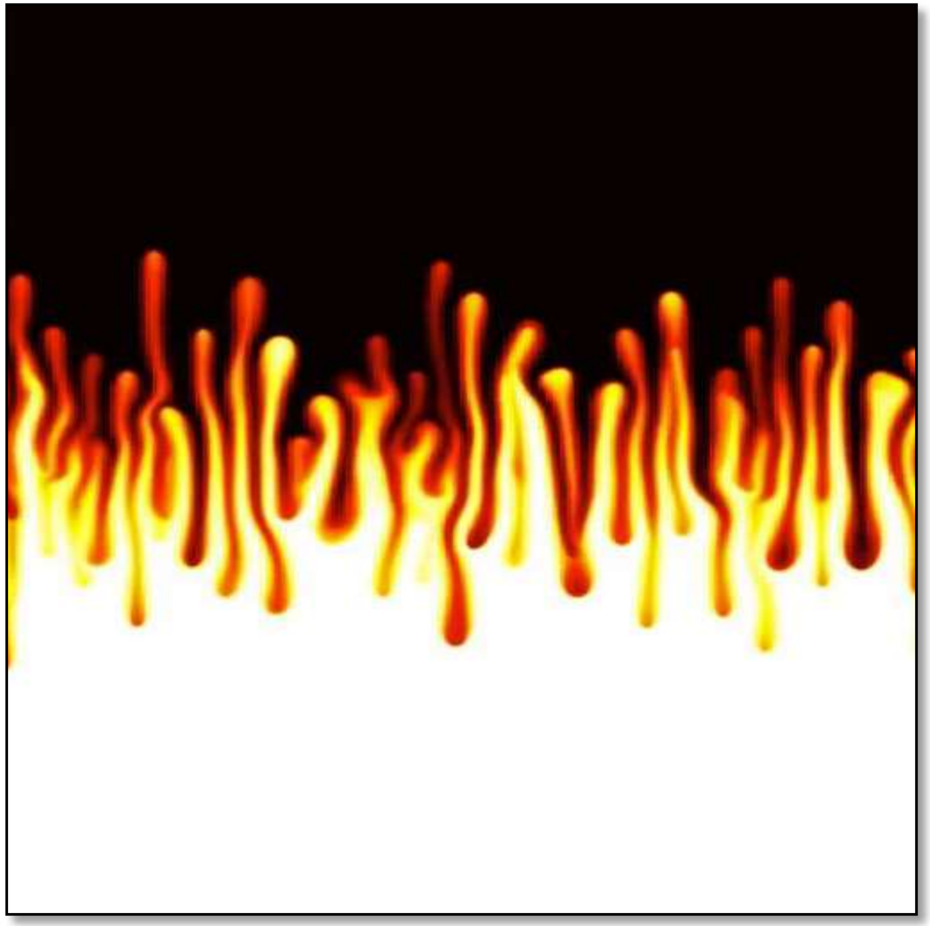
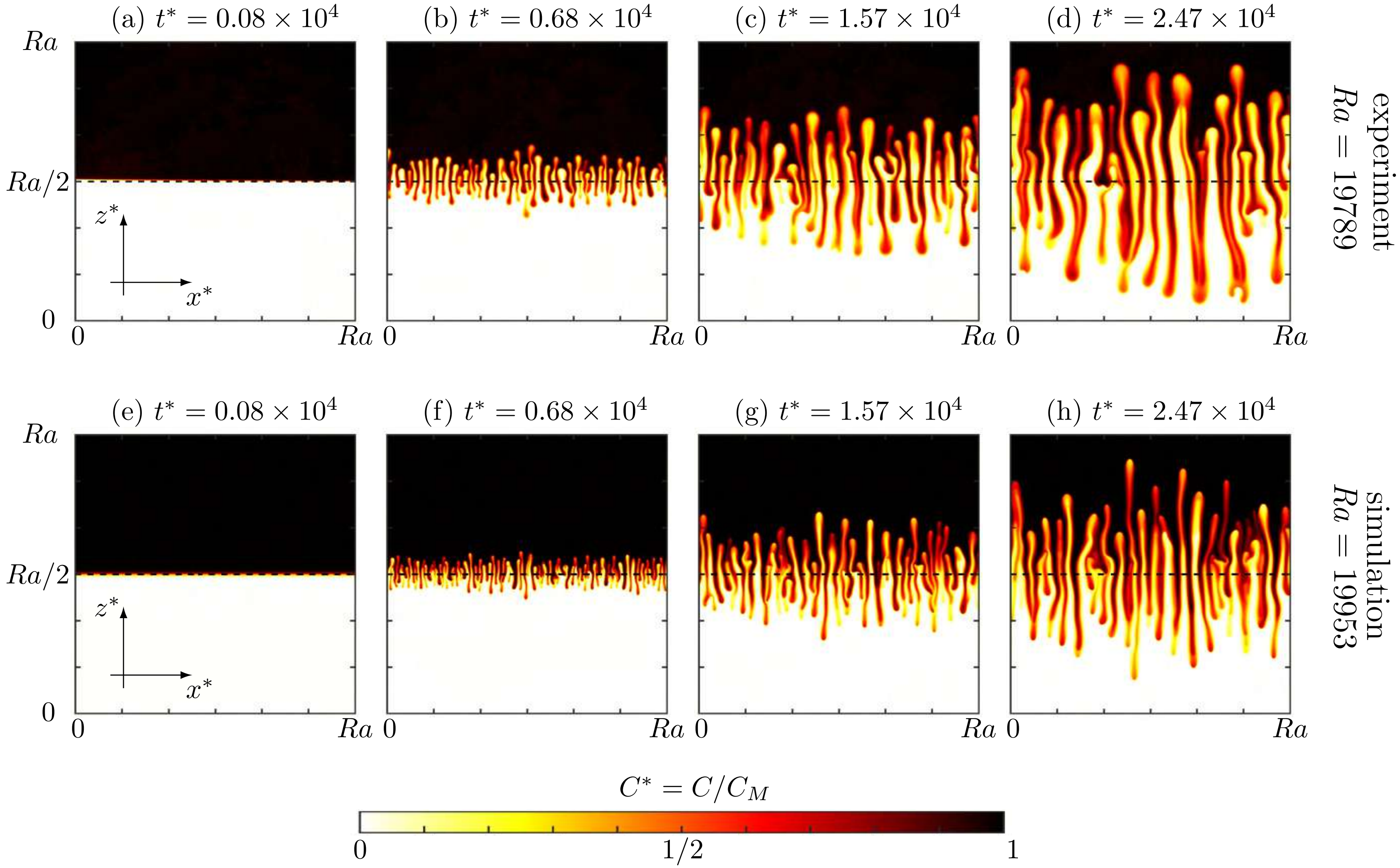
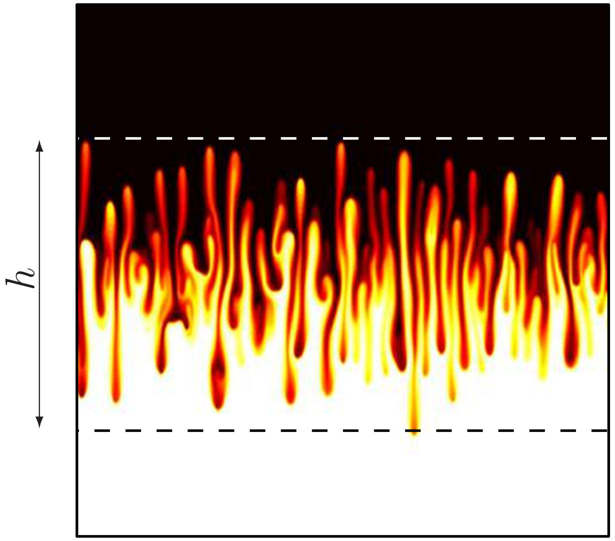


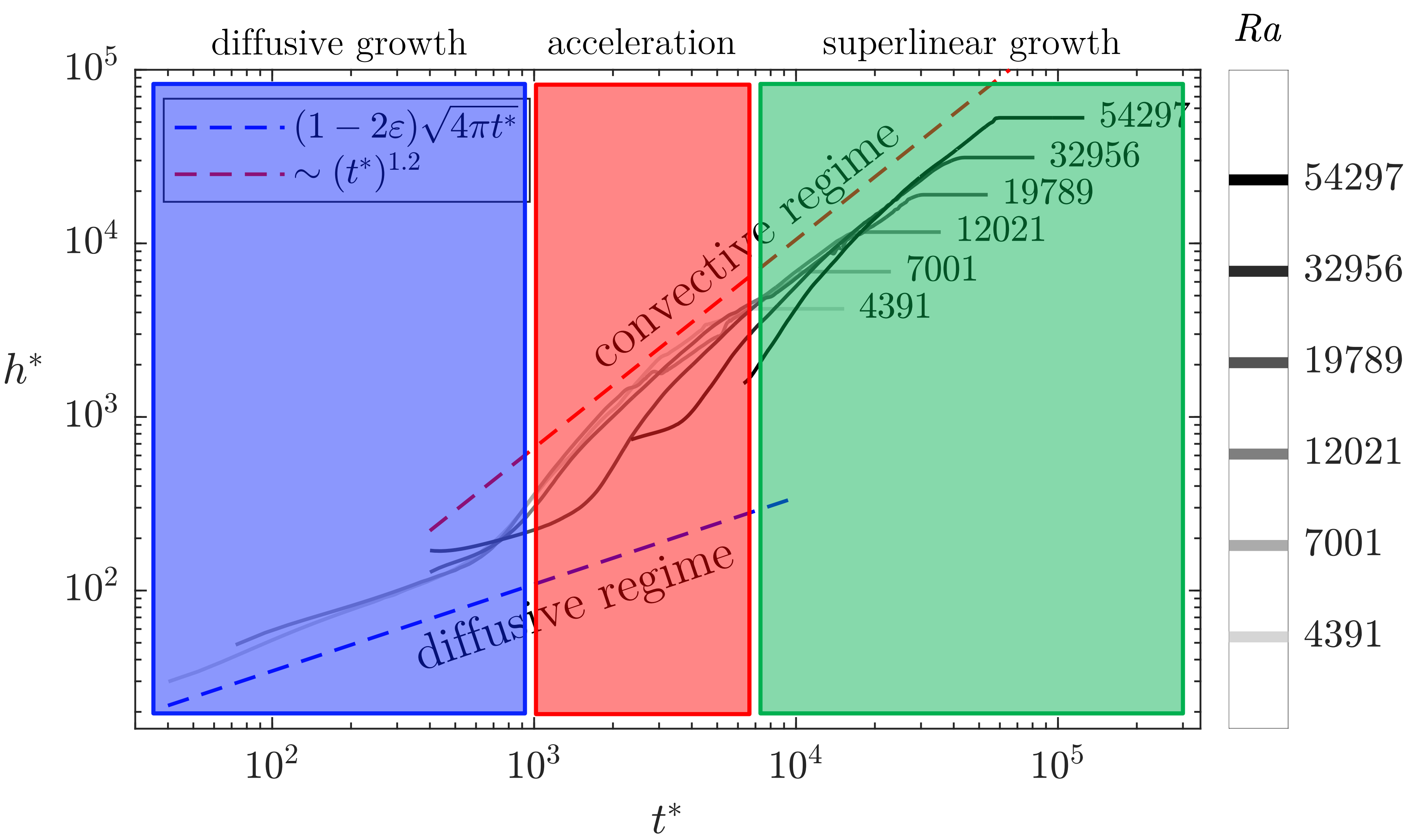
De Paoli, Zonta & Soldati, *Phys. Rev. Fluids* (2019a,b)

Qualitative flow dynamics



Mixing length evolution





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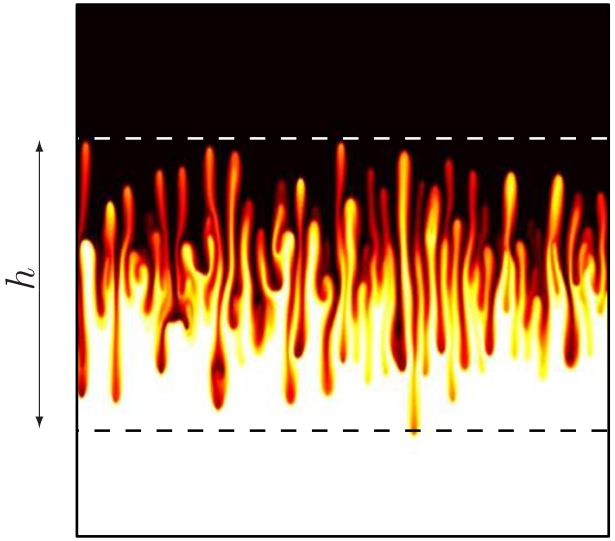
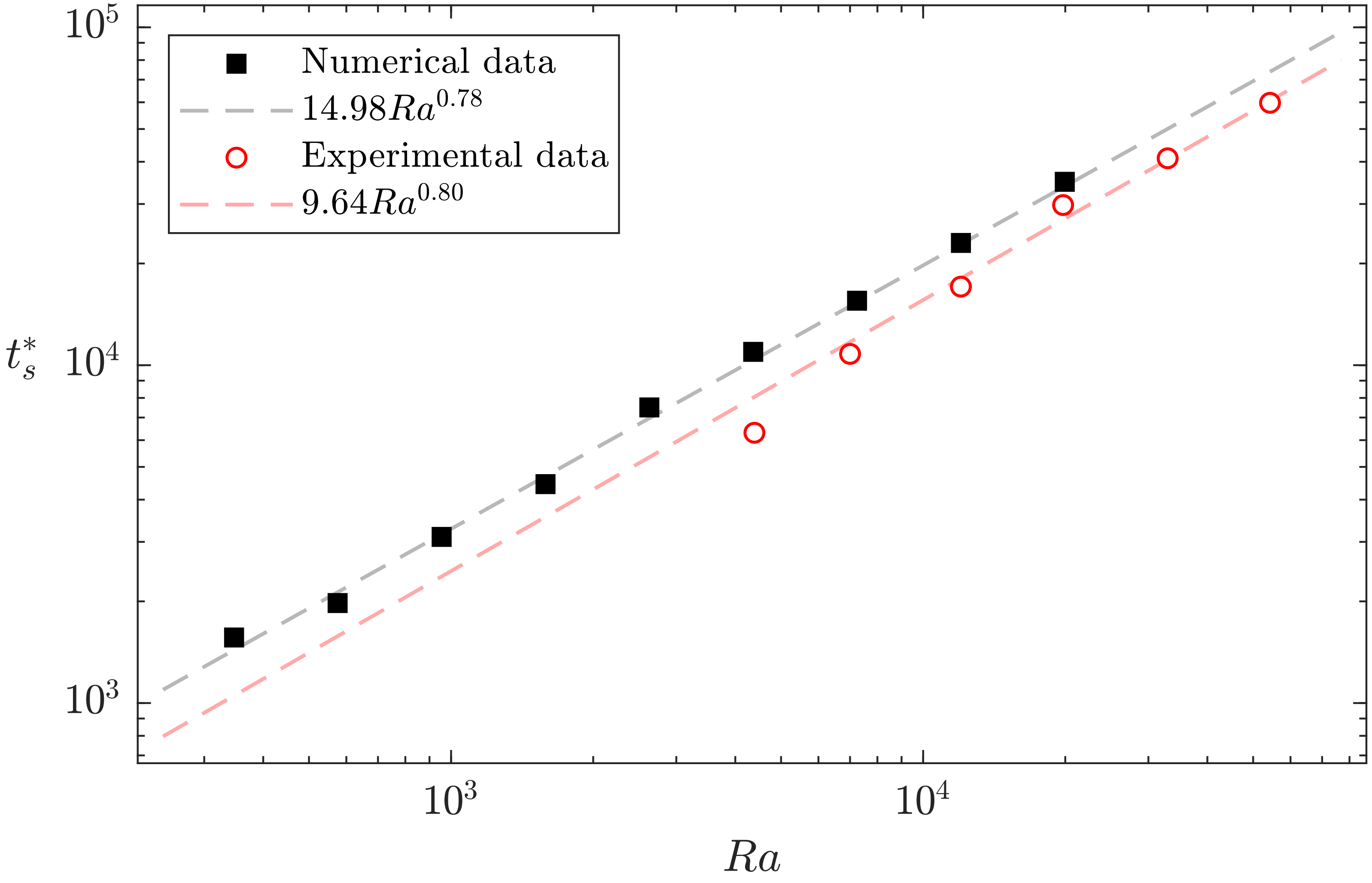
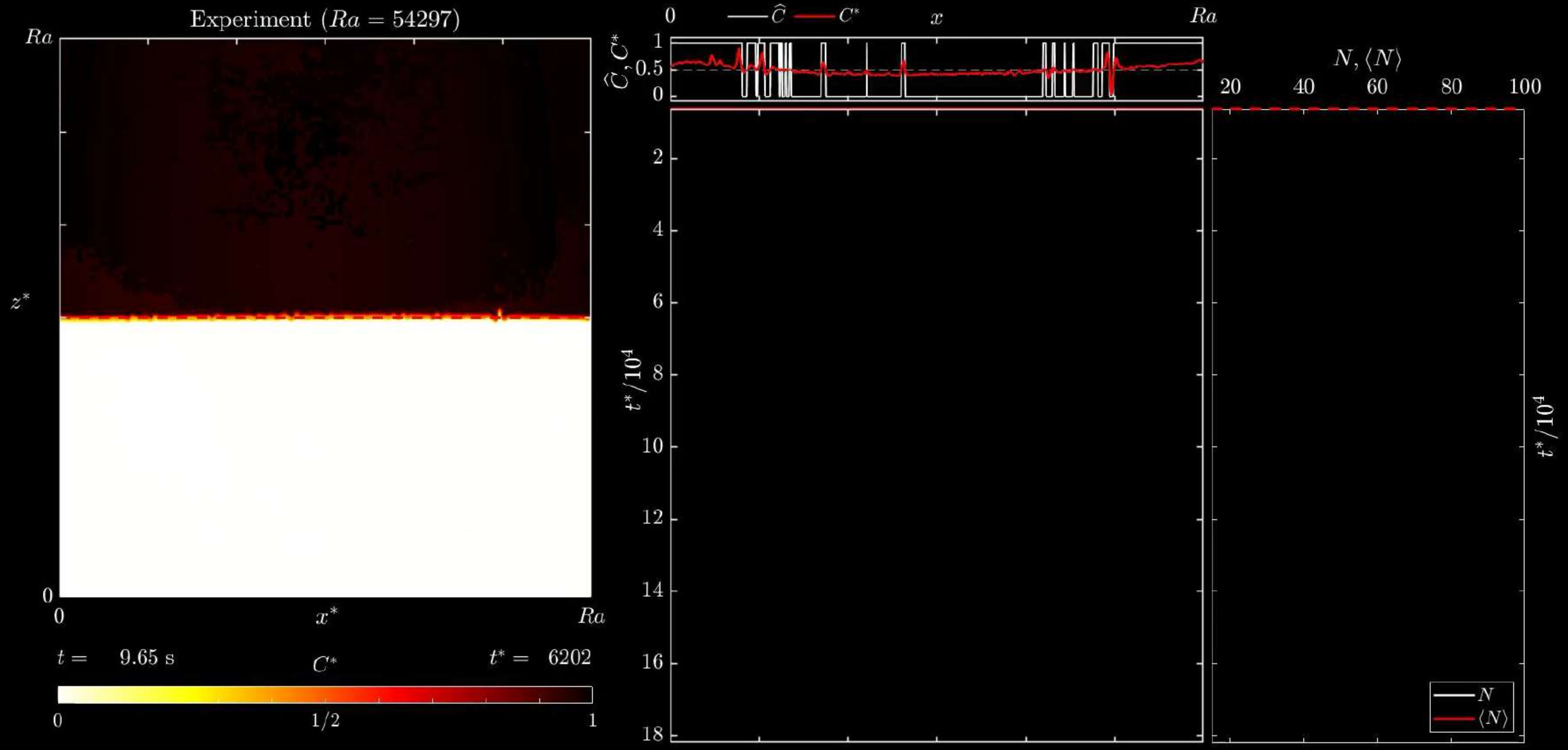
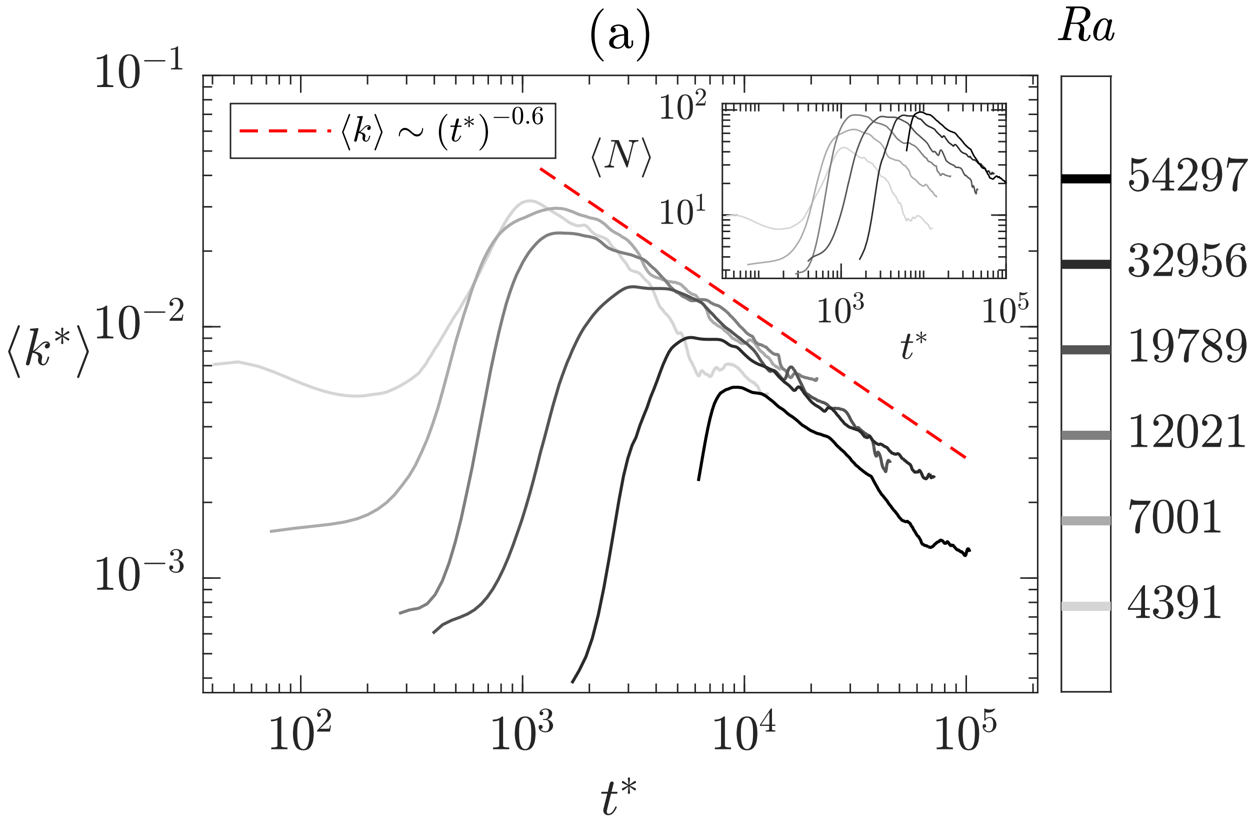
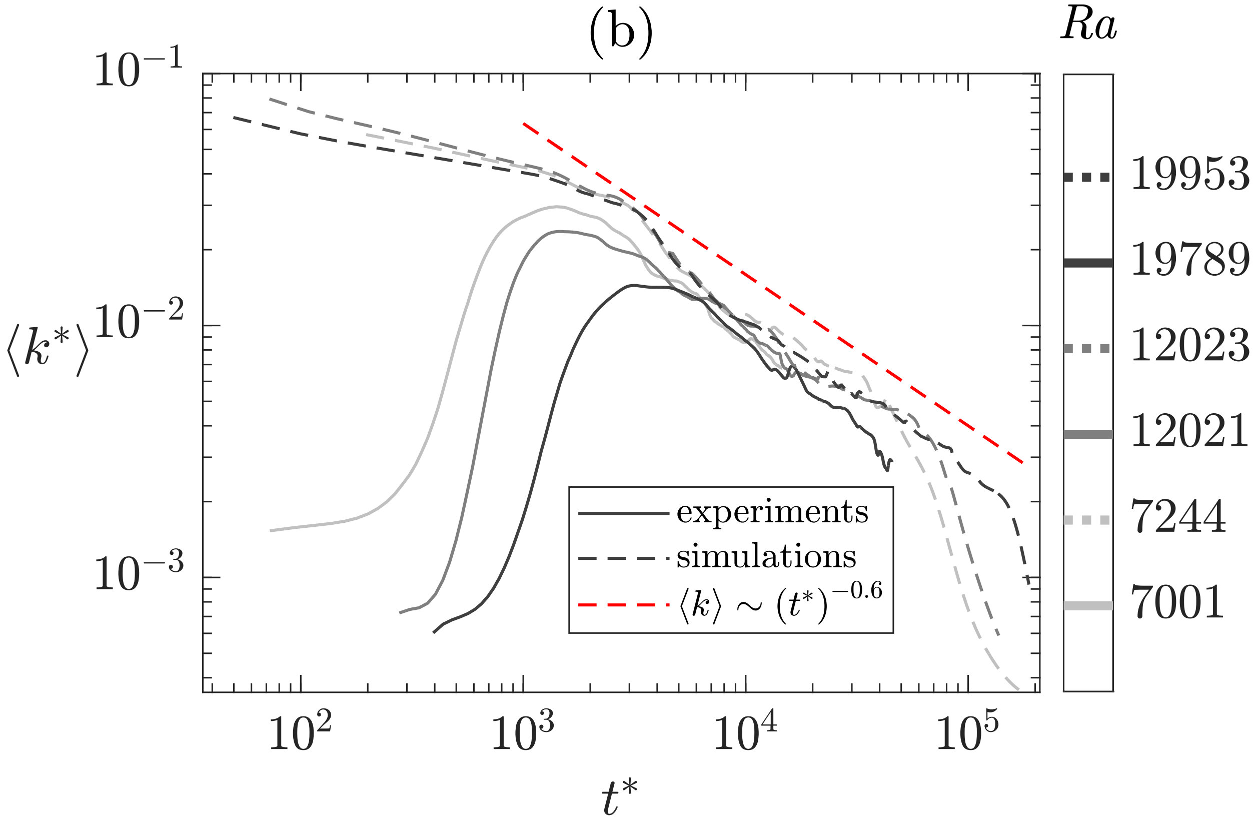




Wavenumber


Experiment ($Ra = 54297$)
Ra
z^*
0
0
x^*
Ra
$t =$ 9.65 s
C^*
$t^* =$ 6202
0
1/2
1
0
$\widehat{C}$
C^*
x
Ra
$\widehat{C}, C^*$
1
0.5
0
$t^*/10^4$
2
4
6
8
10
12
14
16
18
$N, \langle N \rangle$
20
40
60
80
100
$t^*/10^4$
N
$\langle N \rangle$





Simulations

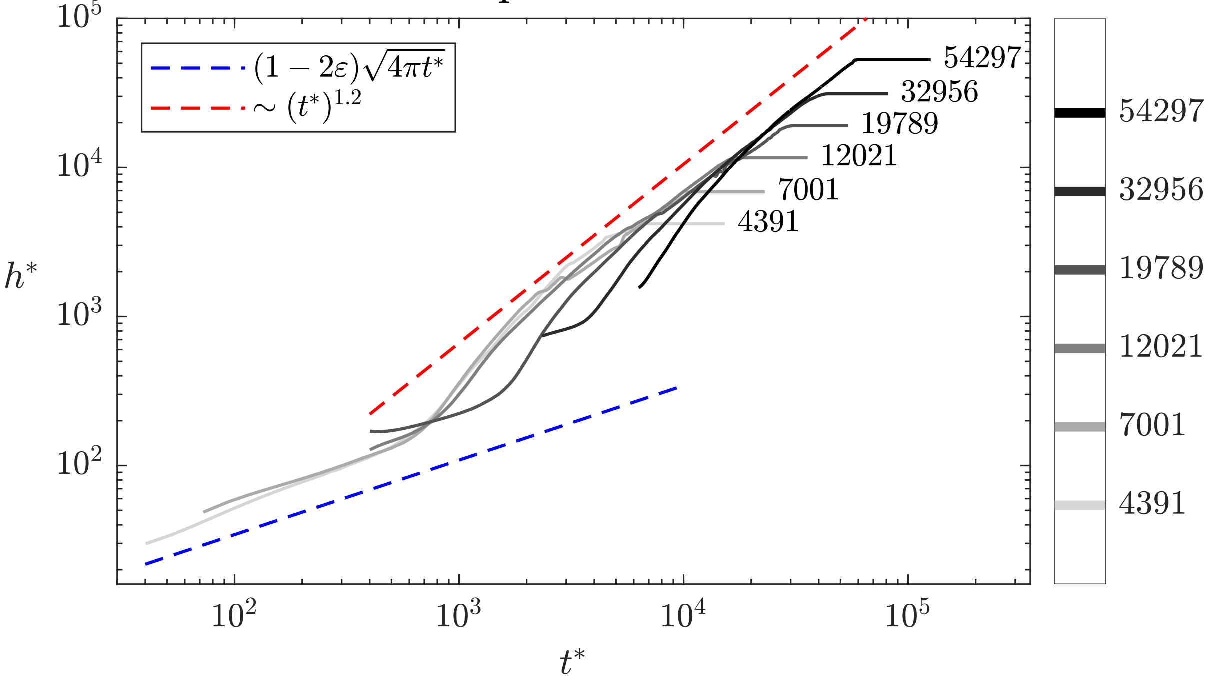
De Paoli, Giurgiu, Zonta & Soldati, *Phys. Rev. Fluids* (2019)

Experiment

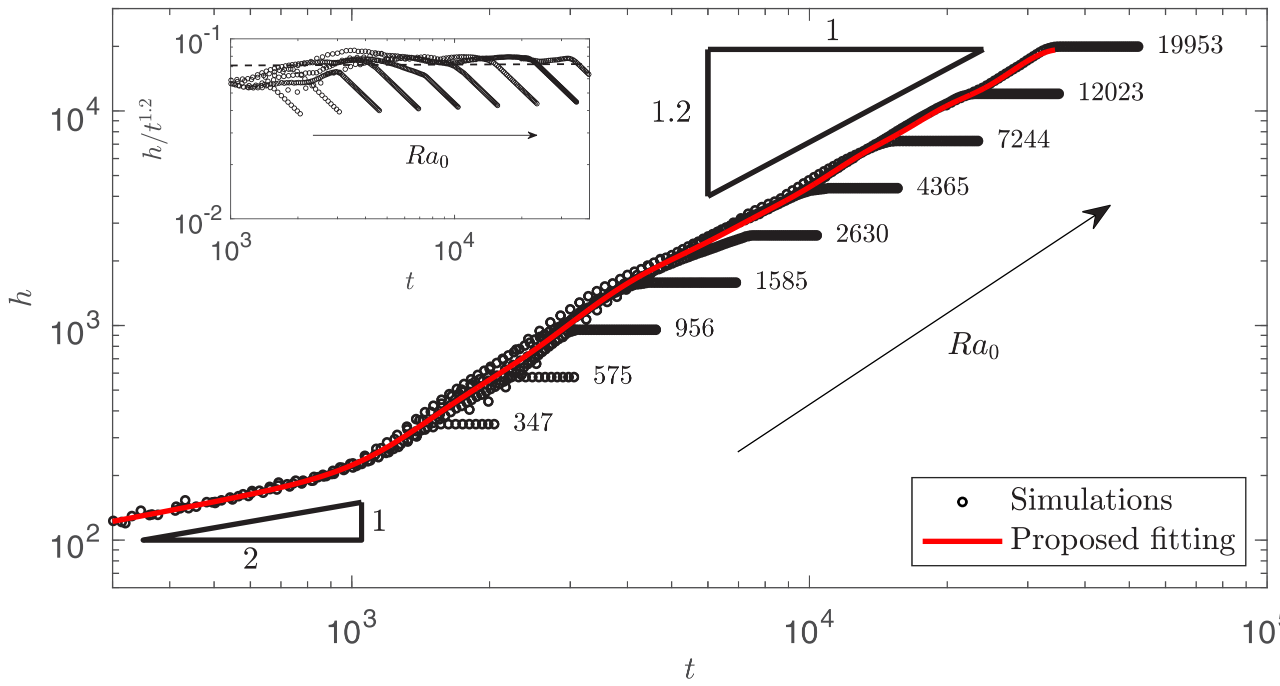
De Paoli, Perissutti, Marchioli & Soldati, *arXiv* (2022)

Conclusions

experiments



simulations



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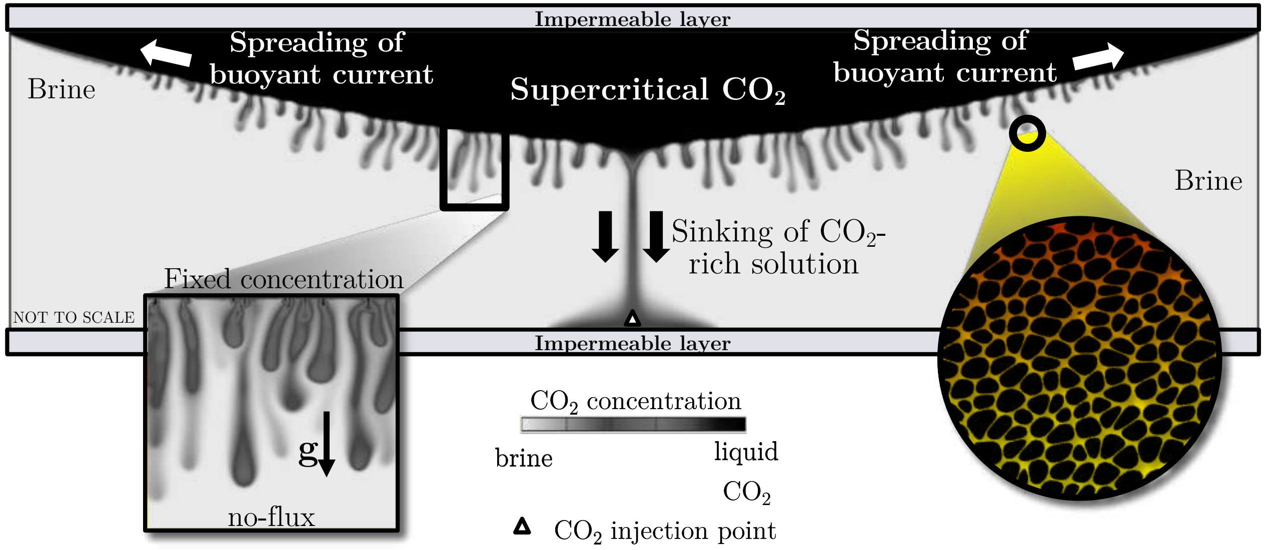
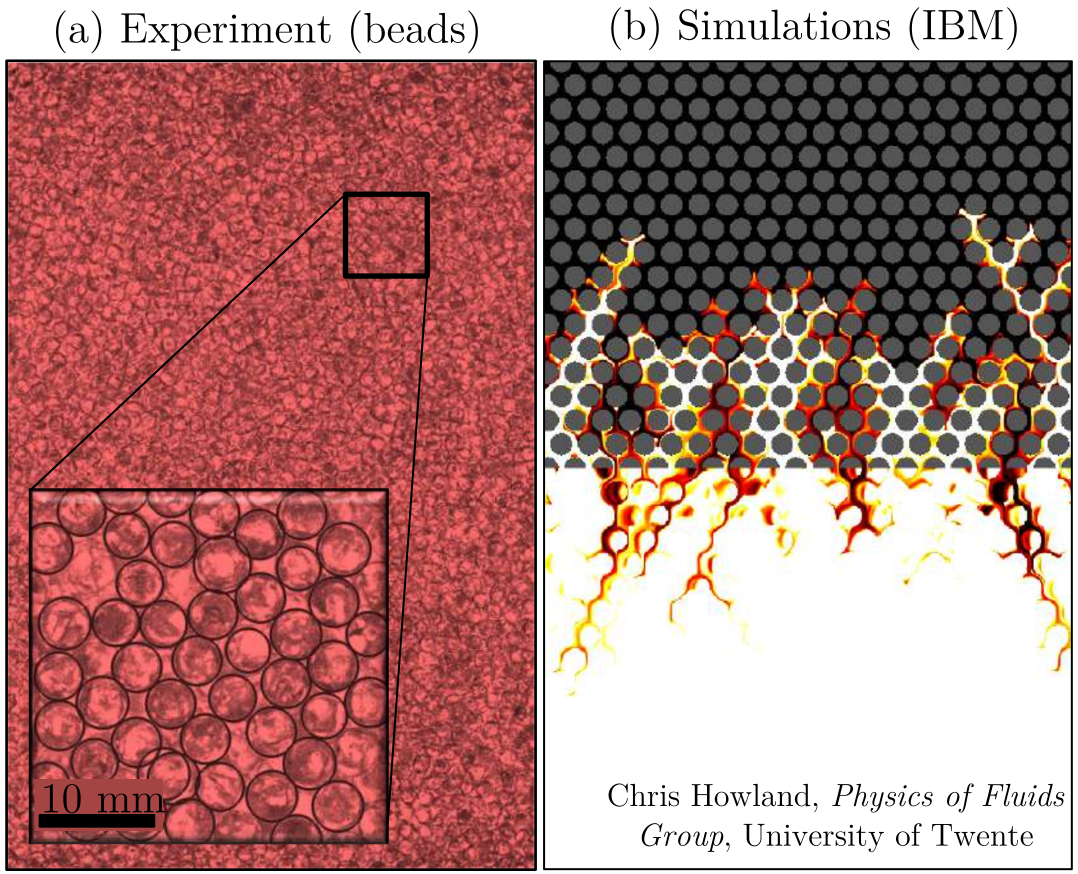
Future developments – pore-scale dynamics



Numerical and experimental investigation of pore-scale dispersion effects on convective dissolution



Thank you for your attention!
Questions?

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Der Wissenschaftsfonds.

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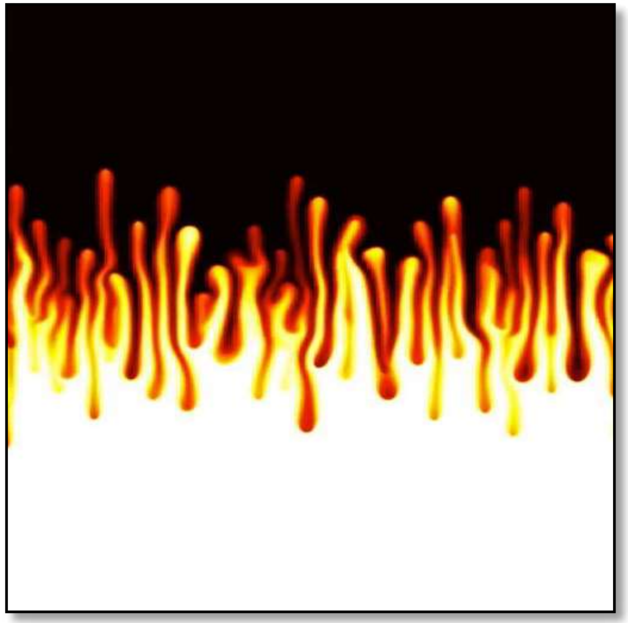

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High-resolution images, movies and slides are available upon request to m.depaoli@utwente.nl