

Inertial Effects on Fluid Flow through Natural Media

Sahrish B. Naqvi^a, Damian Śniezek, Dawid Strzelczyk^{a,b}, Mariusz Mądrala, **Maciej Matyka**^{a,b}

^a Institute of Theoretical Physics, Faculty of Physics and Astronomy, University of Wrocław, Poland

^b Laboratory of Parallel and Distributed Systems, Institute Jožef Stefan, Ljubljana, Slovenia

Key Points

- We investigate **inertial effects in the pore-space fluid flow** through natural porous media at varying Reynolds number.
- Tortuosity** and energy distribution change with the structure of the flow in the microscale (vortex formation and identification).
- We find scaling law for **apparent permeability-tortuosity** relation in the inertial regime (numerical study).

Methodology

Navier-Stokes equations for the fluid flow through the sample (pore-scale level):

$$\nabla \cdot \mathbf{u} = 0, \quad \rho(\mathbf{u} \cdot \nabla \mathbf{u}) = -\nabla p + \mu \nabla^2 \mathbf{u} + \mathbf{f}$$

- Solution with OpenFOAM (<https://www.openfoam.com/>)
- Semi-Implicit Method for Pressure-Linked Equations (SIMPLE) algorithm

Sample



Fig. The slice of the intact clastic rock sample filled with synthetic resin (the photo of cross-sectional plane).

Analysis with Re

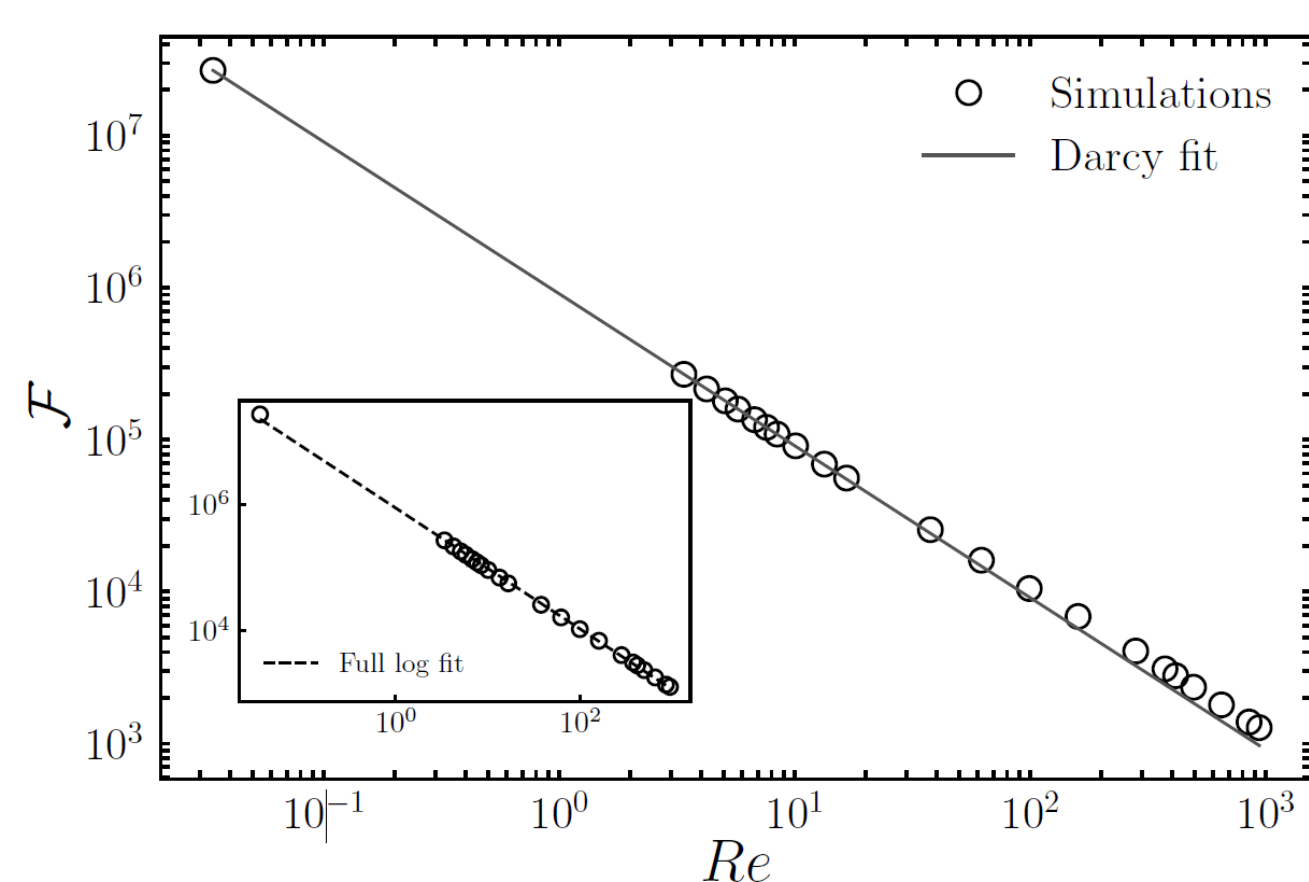


Fig. Friction factor – no deviation from Darcy Law?

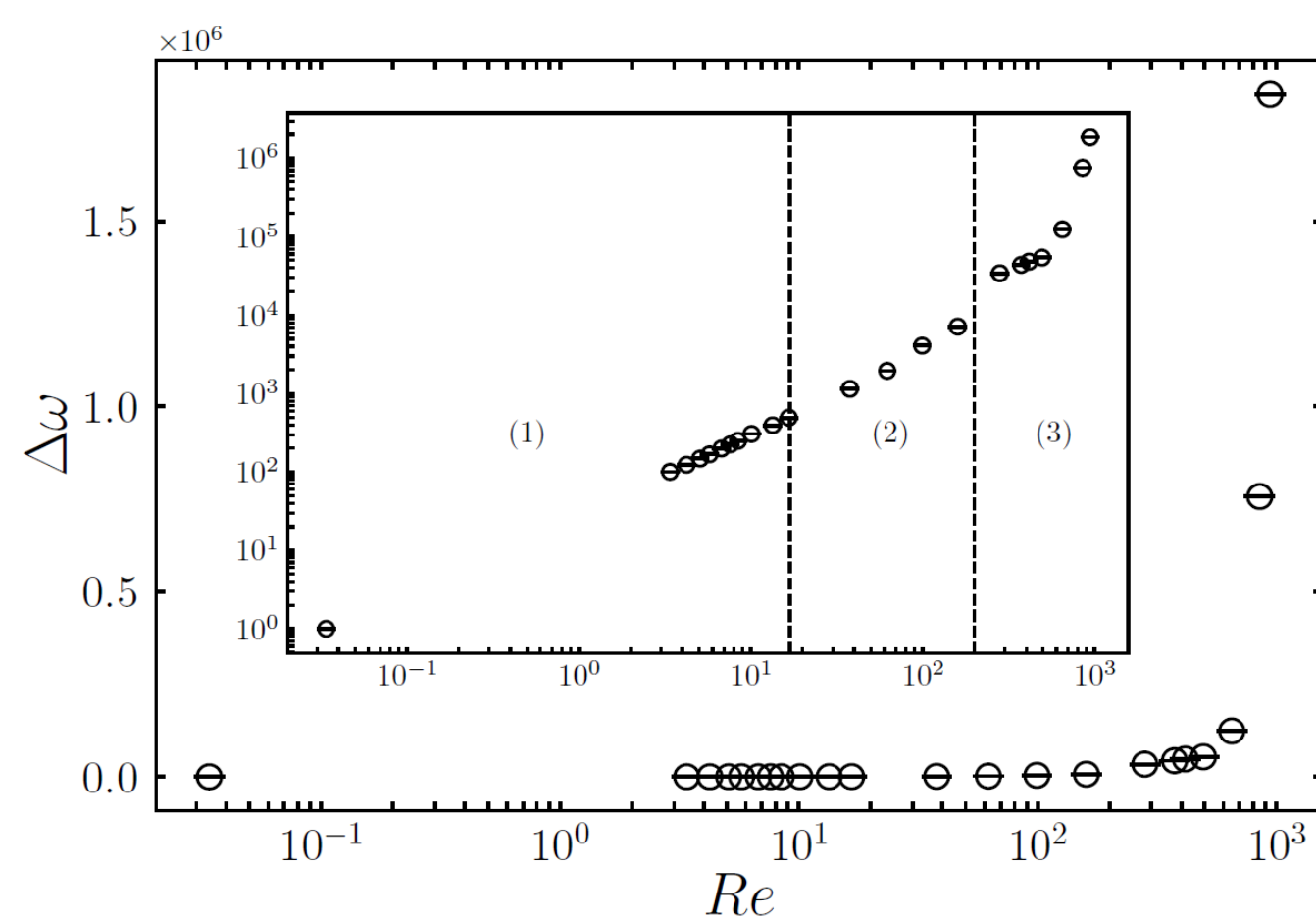


Fig. Three regimes of flow asymmetry.

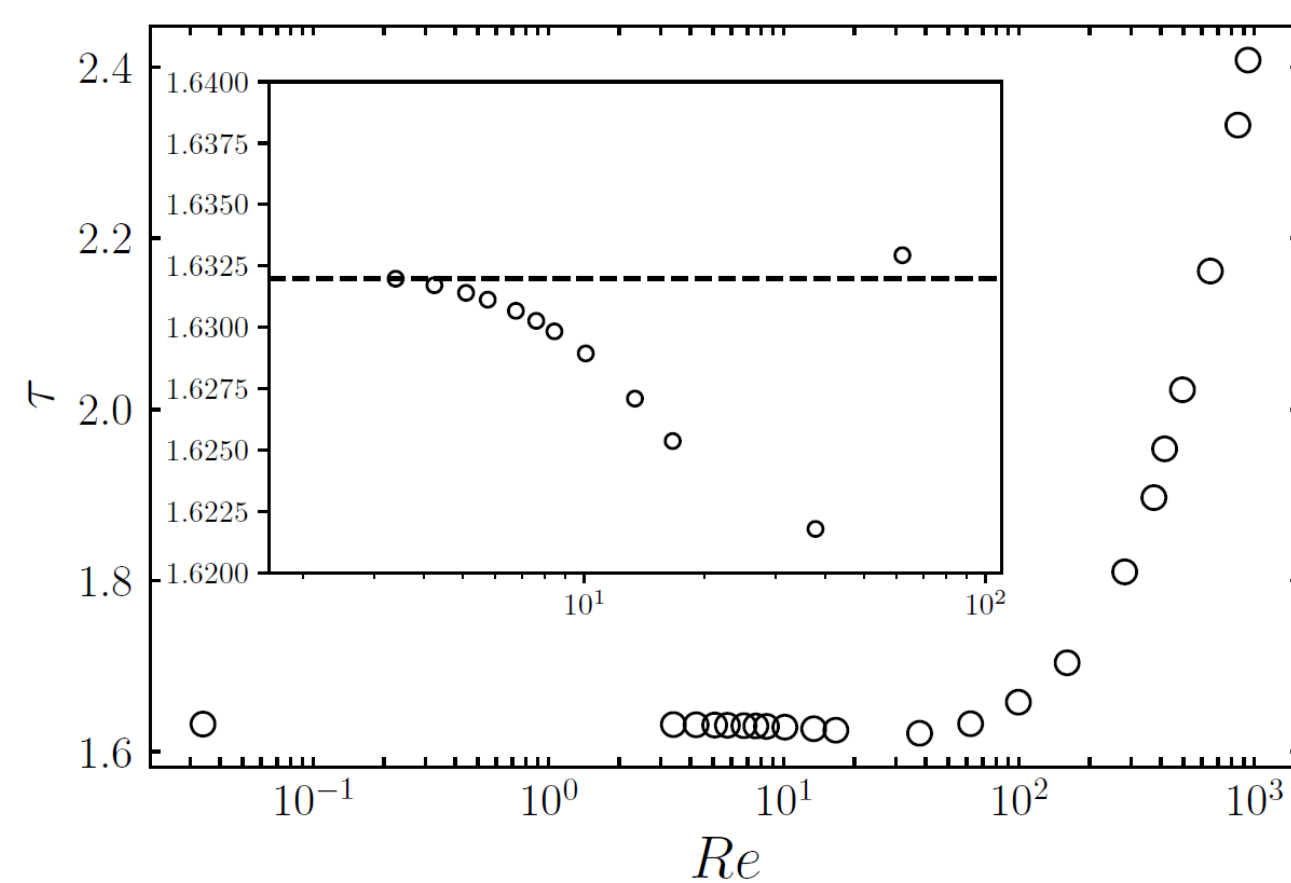


Fig. Tortuosity (rapidly) rises with Re.

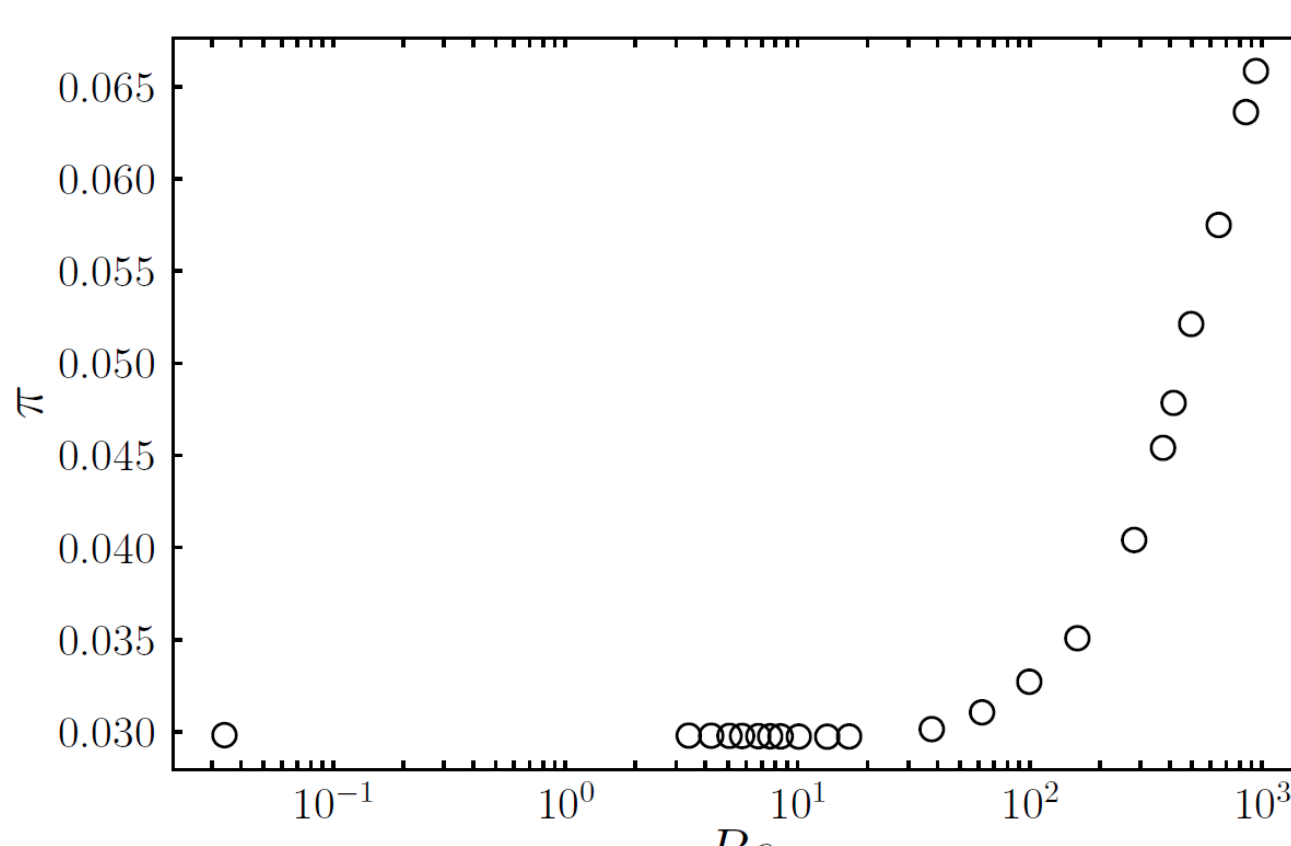


Fig. Participation number growth (rapid).

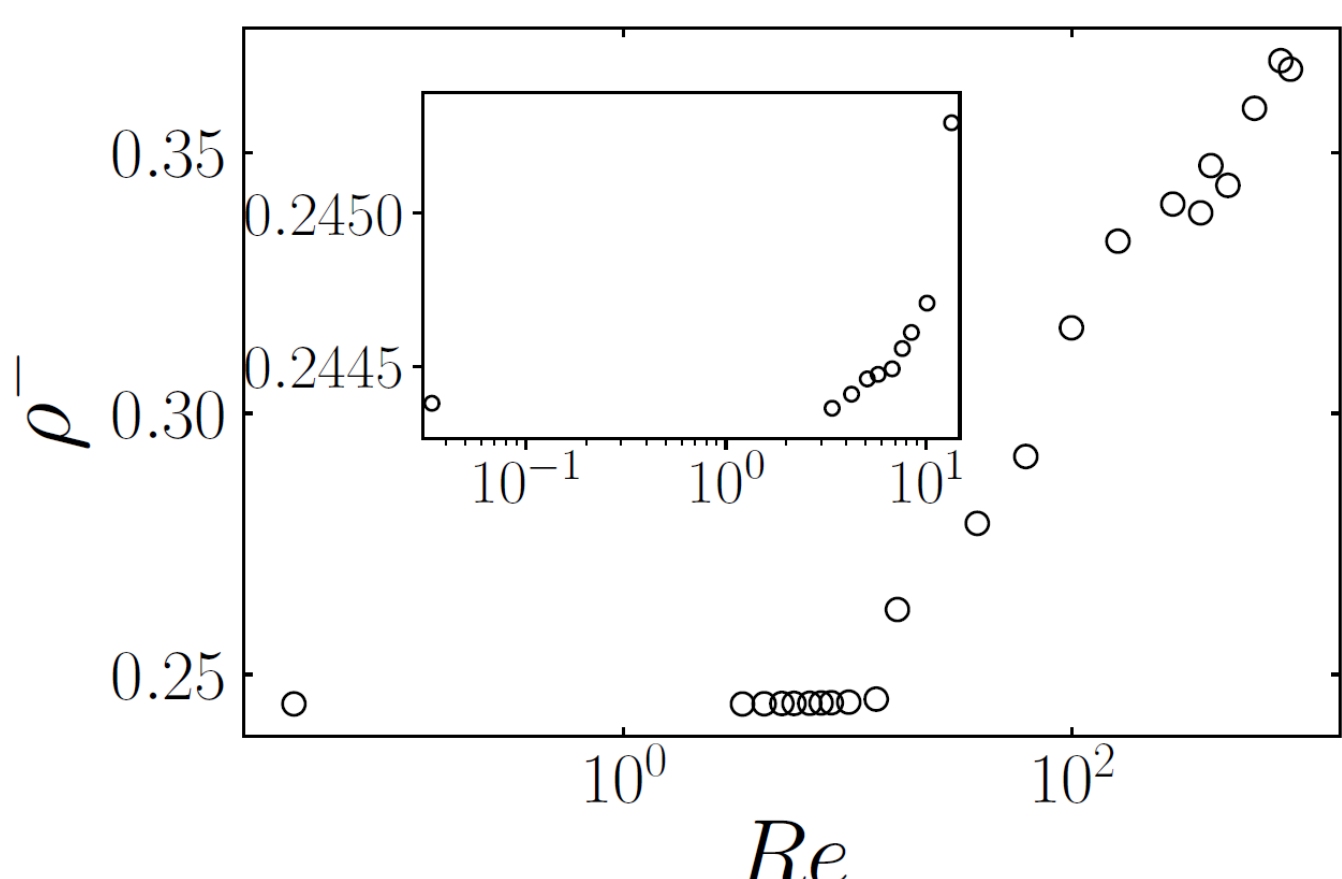


Fig. Negative streamwise v (lowRe!).

Pore scale flow

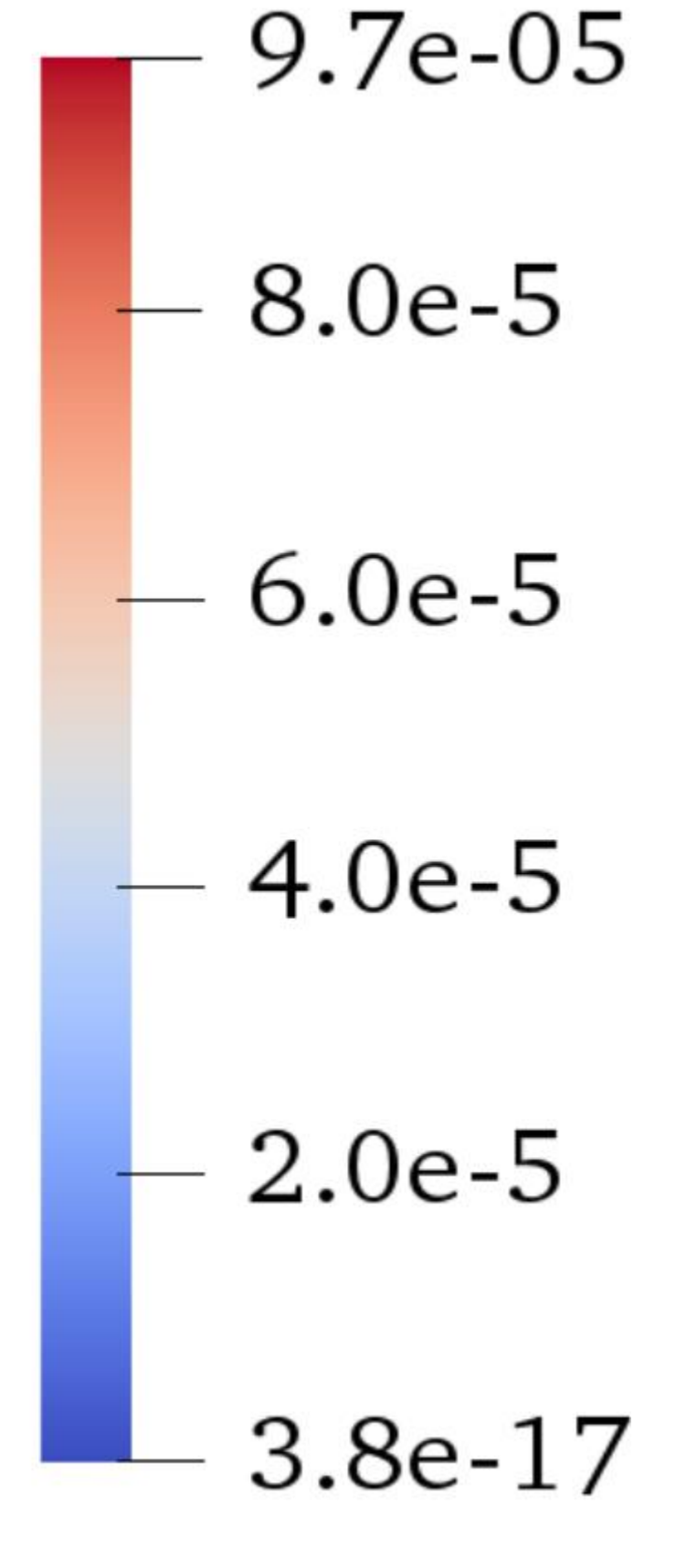
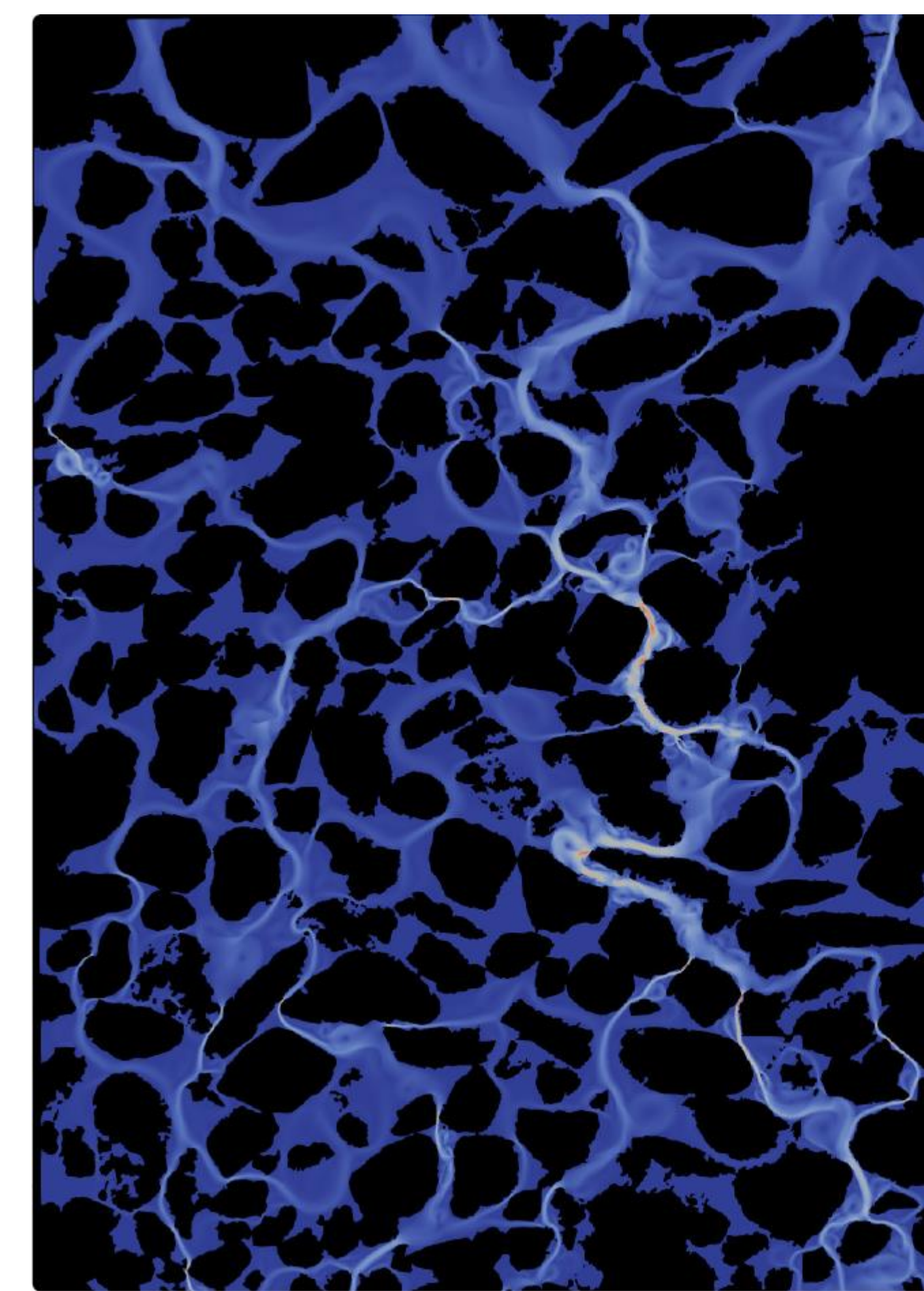
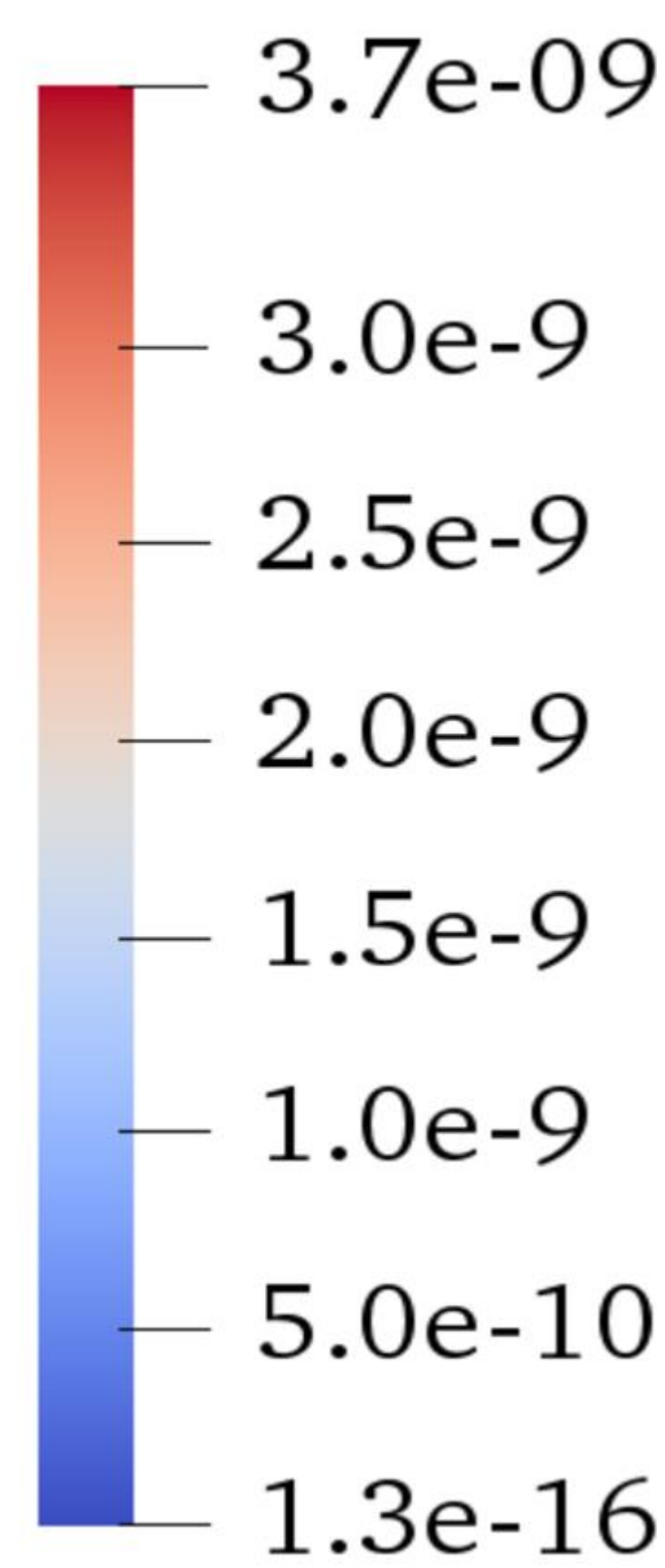
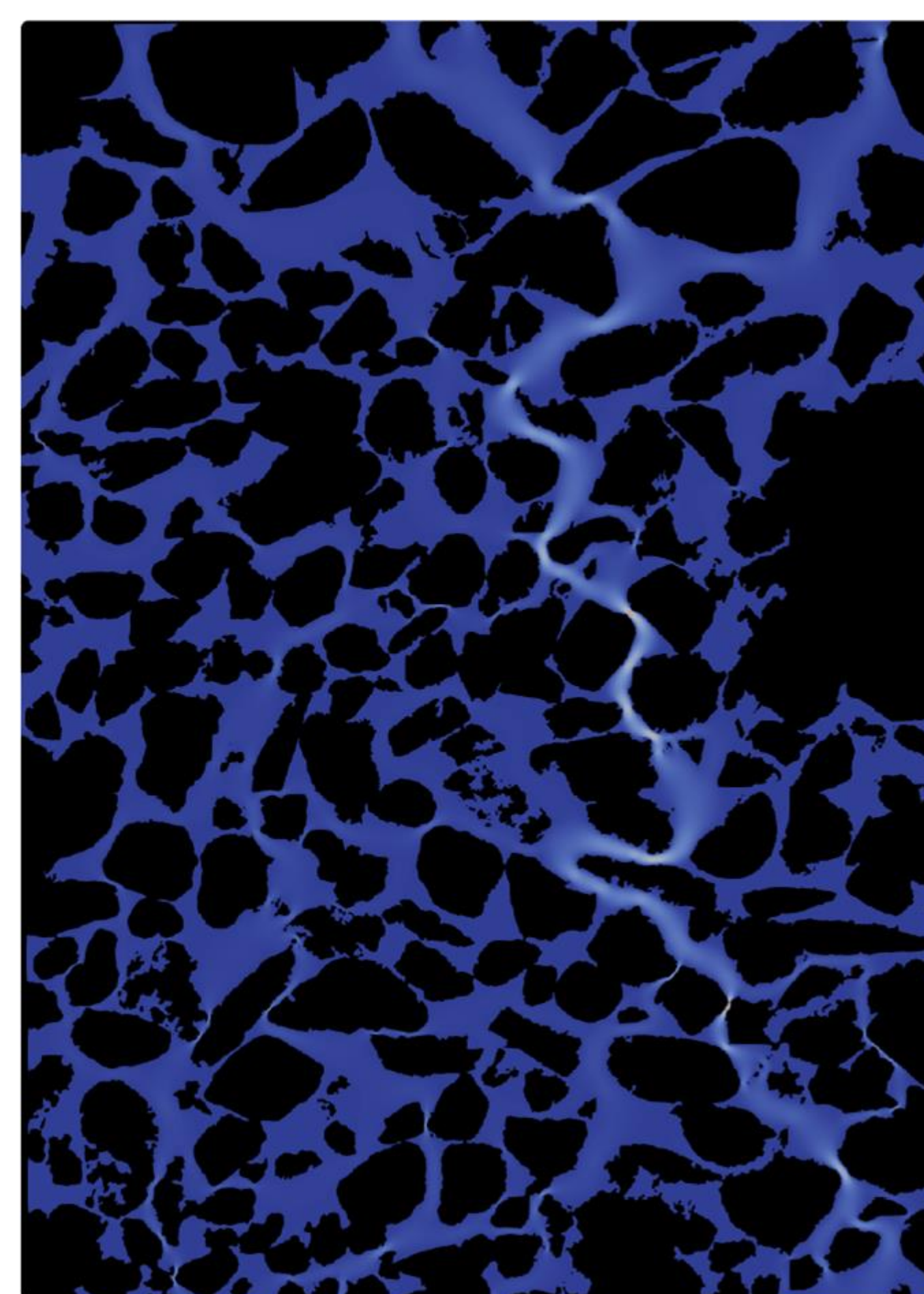


Fig. The magnitude of the velocity field at Re = 0.03 (left) and Re = 9.62 (right).

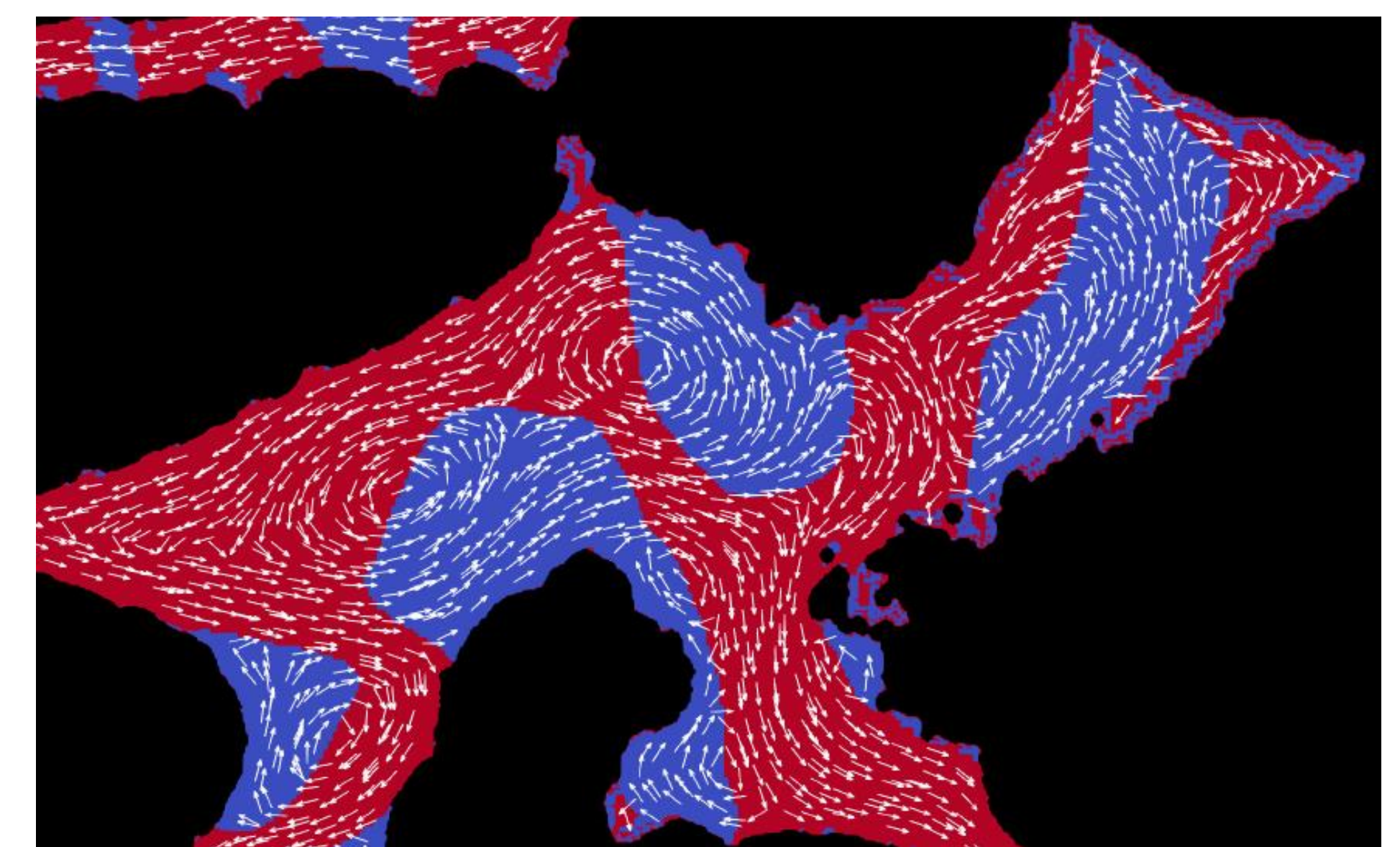
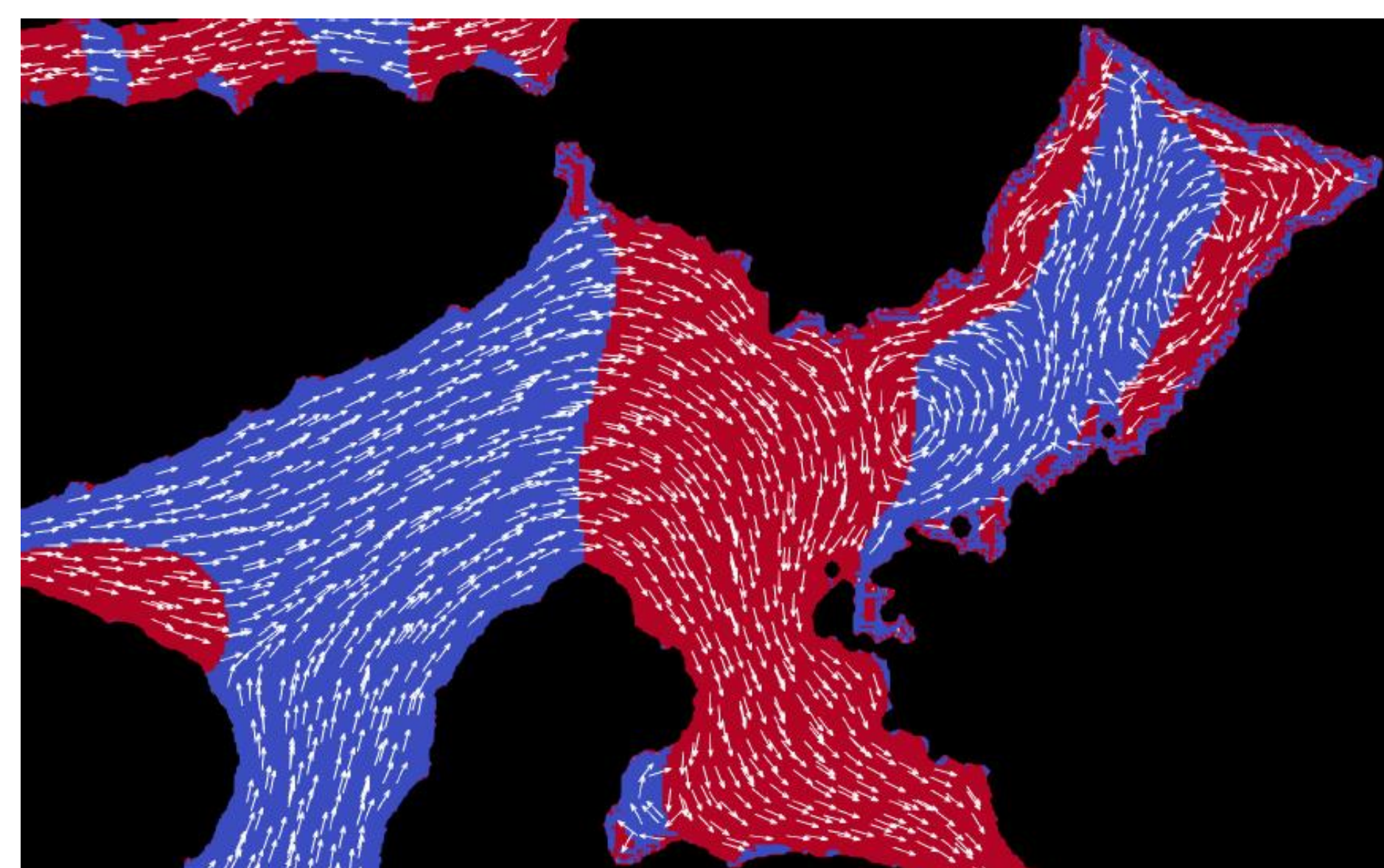


Fig. Surprising, backward flows at low Re (left) compared to typical vortex dominated flow at high Re (right).

Main Finding

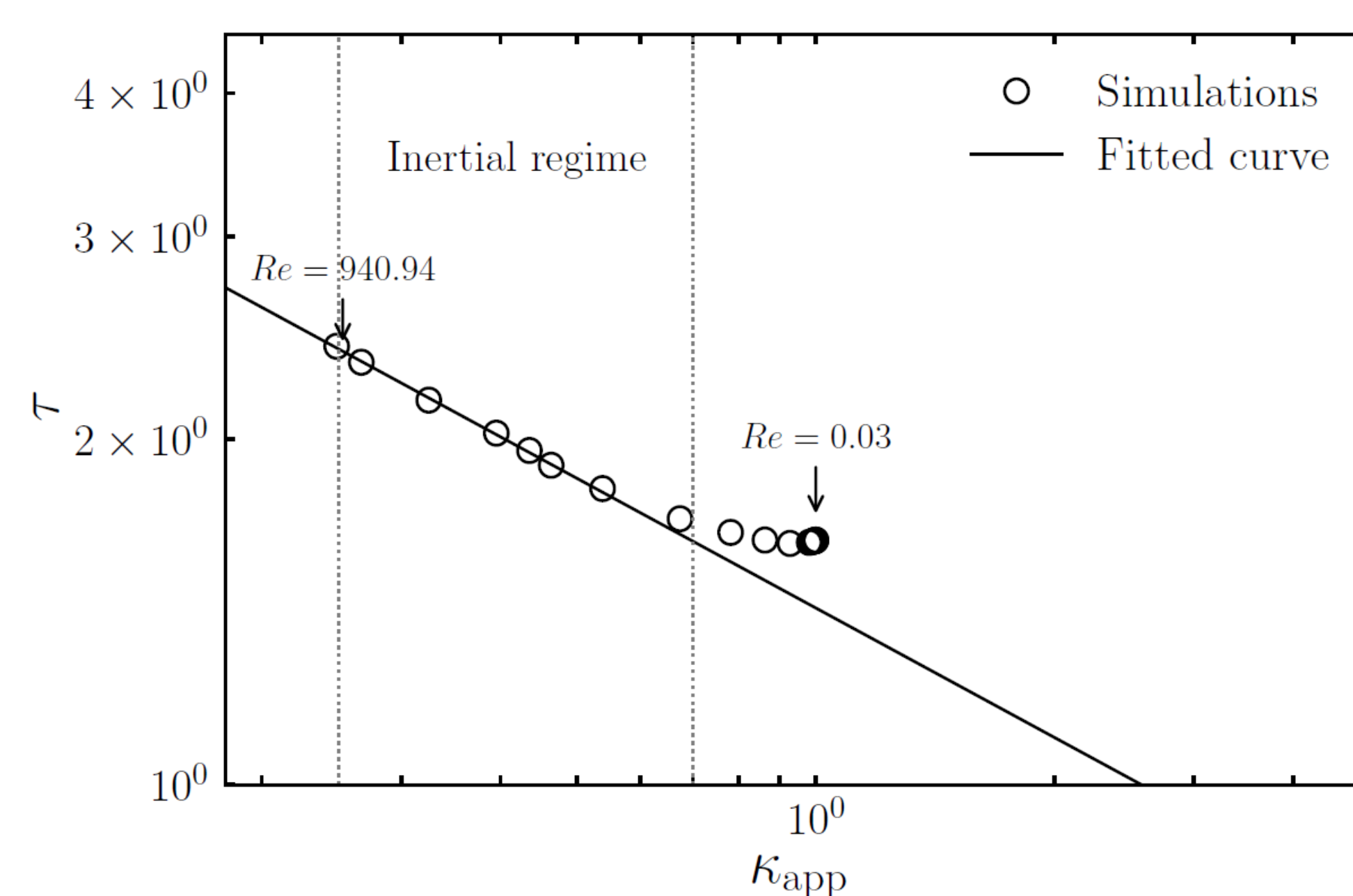
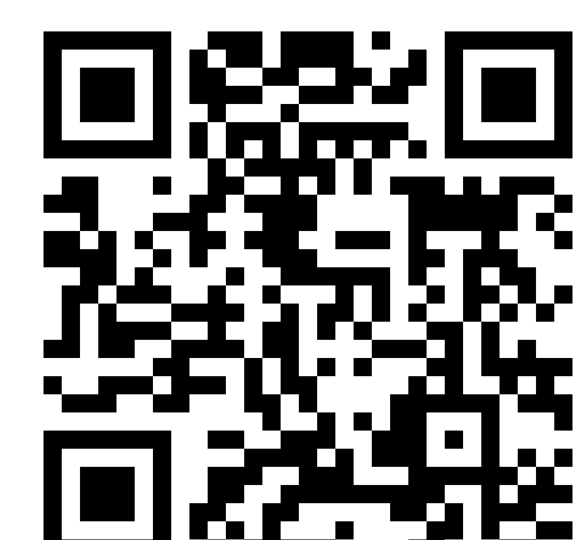


Fig. Apparent permeability scales with tortuosity according to power law $k_{app} \propto \tau^{-1/3}$ in the inertial regime.

Papers

<https://arxiv.org/abs/2505.10418>
(submitted in 2025)



Funding

Funded by National Science Centre, Poland under the OPUS call in the Weave programme 2021/43/I/ST3/00228.