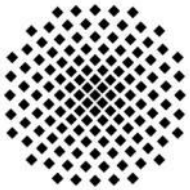
# Free flow / porous-medium flow coupling

T. Fetzer, University of Stuttgart
C. Grüninger, University of Stuttgart

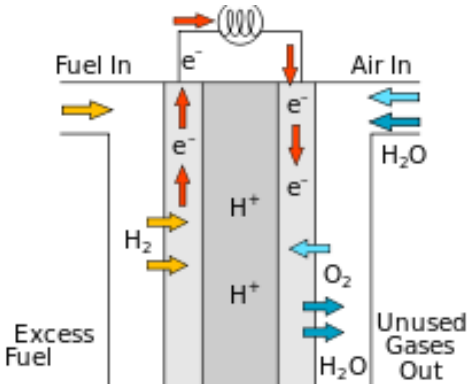
DuMu$^x$ User Meeting 2015, Stuttgart



University of Stuttgart
Germany

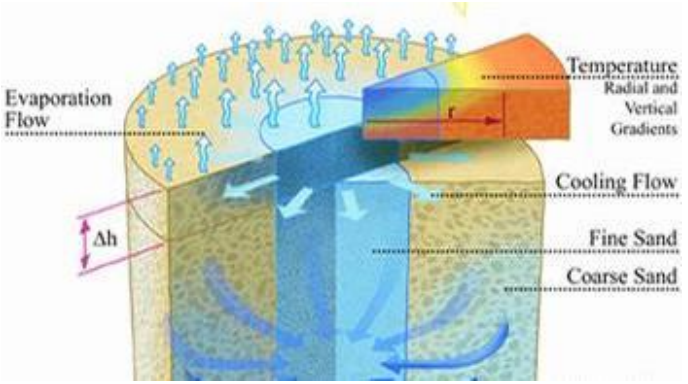
# Introduction – Motivation

- fuel cells




www.en.wikipedia.org

- evaporation

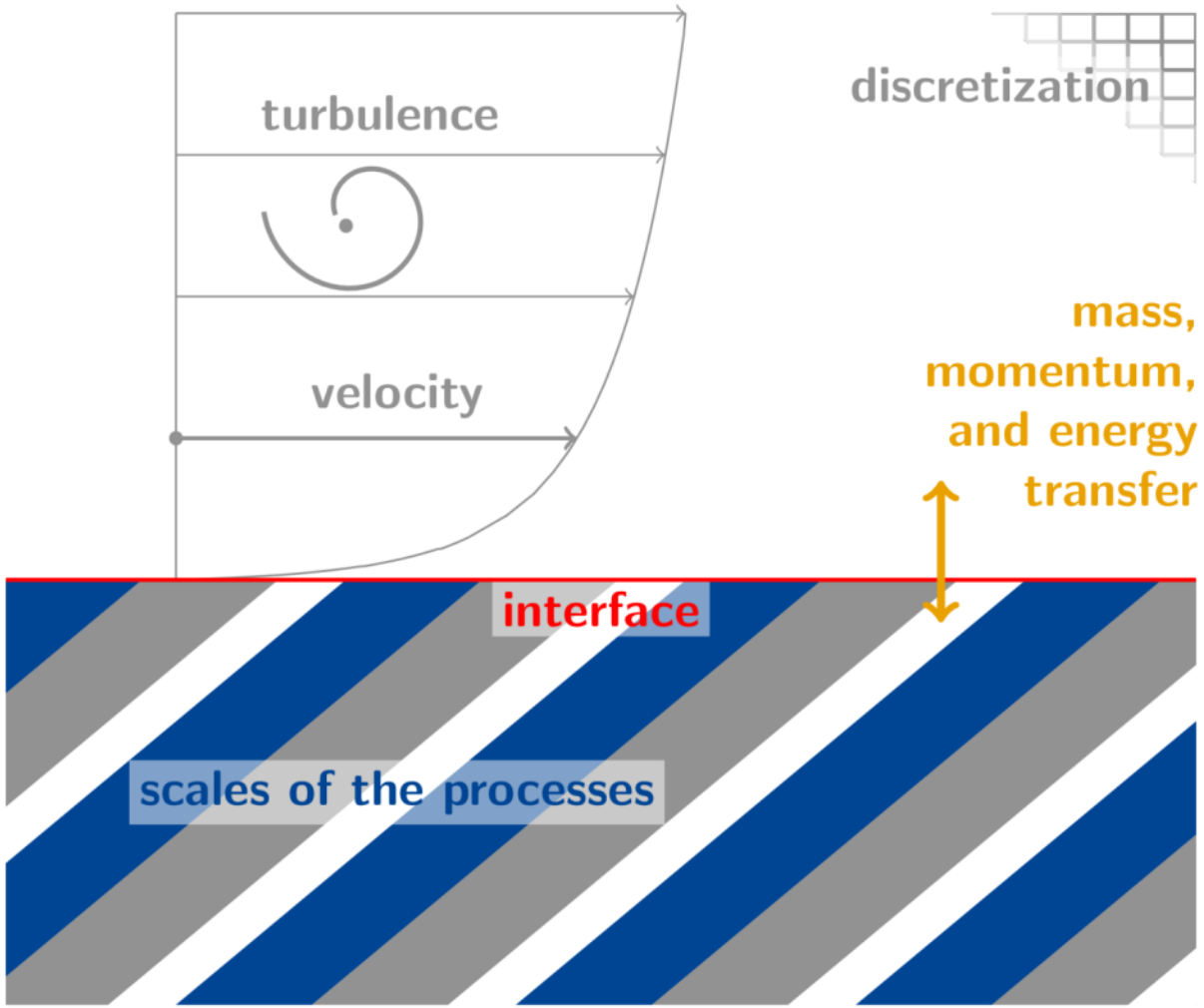



www.step.ethz.ch

- salinization

www.fao.org

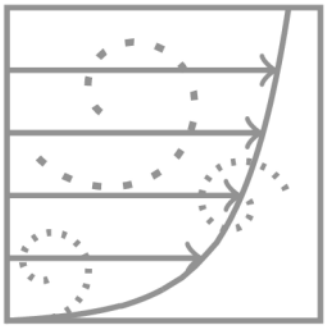
# Introduction – Challenges



# Models – Coupling Concepts

- one domain [Brinkman 1949]
  - `not (anymore) implemented`
  - Stokes/Darcy
  - interface region
- two domains
  - `test/multidomain/*`
  - (Navier-)Stokes/Darcy
  - sharp interface

free flow

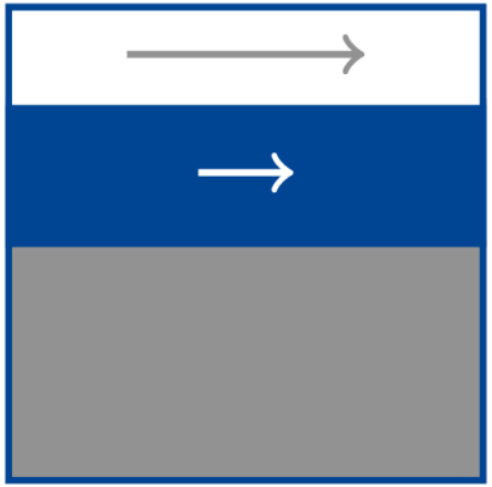


sharp interface

porous medium flow

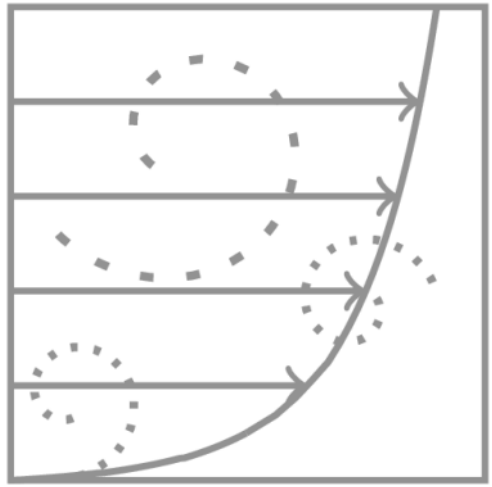
# Models – Porous Medium Model

- REV concept, Darcy‘s law
- two fluid phases (gas, liquid)
- two components (air, water)
- non-isothermal
- equilibrium phase transitions
- $p_g, S_l$ or $X_g^w, T$



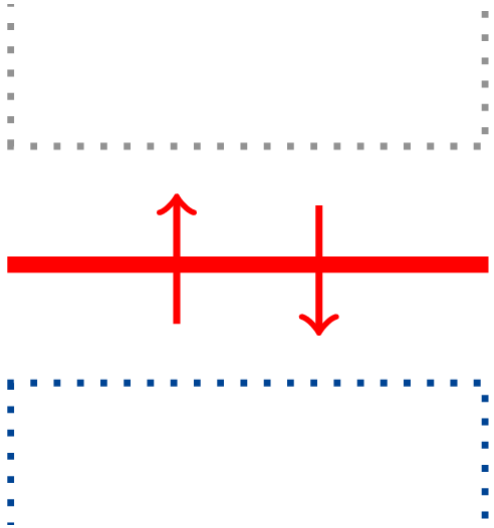
# Models – Free Flow

- laminar/turbulent (RANS)
- single phase (gas)
- two components (air/water)
- non-isothermal
- incompressible
- $p_g, \mathbf{v}_g, X_g^w, T$



# Models – Coupling Model

- [Mosthaf et al. 2011]
- local thermodynamic equilibrium
- continuity of fluxes
- continuity of primary variables



# Implementation, DuMuX, etc.

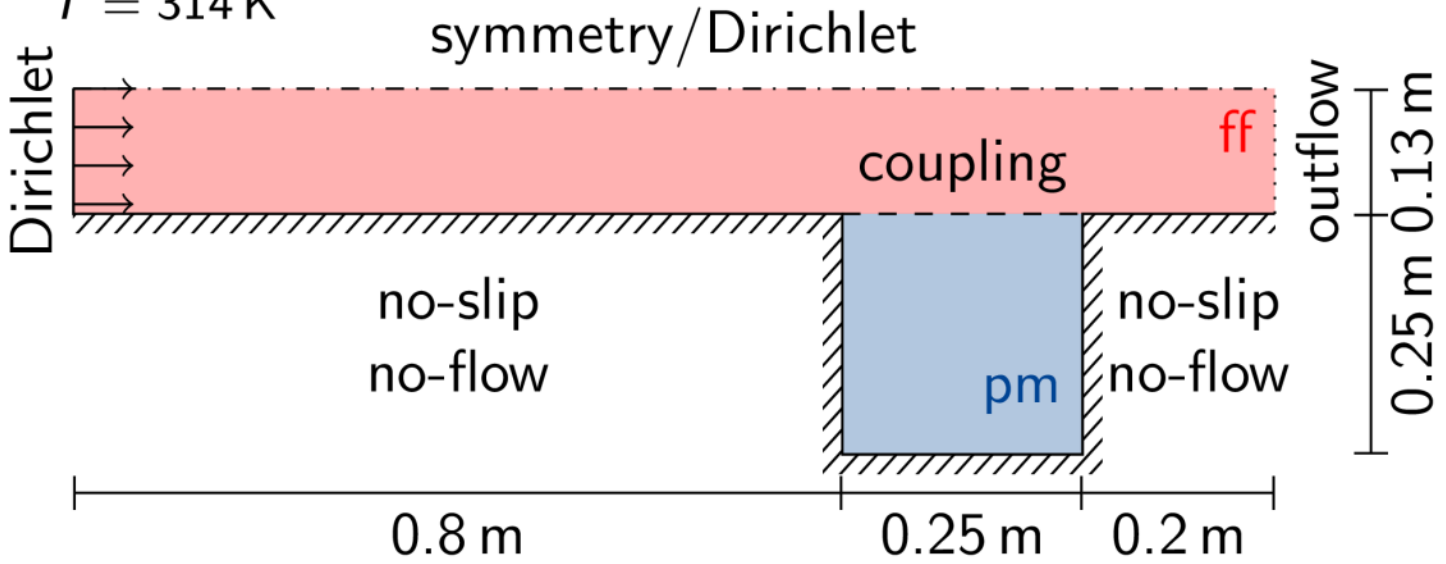
- discretization
  - space: box (2D)
  - time: implicit
  - coupling: fully implicit
- only direct solvers
  - SuperLU
  - Pardiso
  - UMFPack
- special features of the model
  - coupling operators → couple eqs. via residua of other domains
  - coupling local residual → calculate fluxes, set PV at interface
  - custom grid creator (different start routine)

# Results – Setup

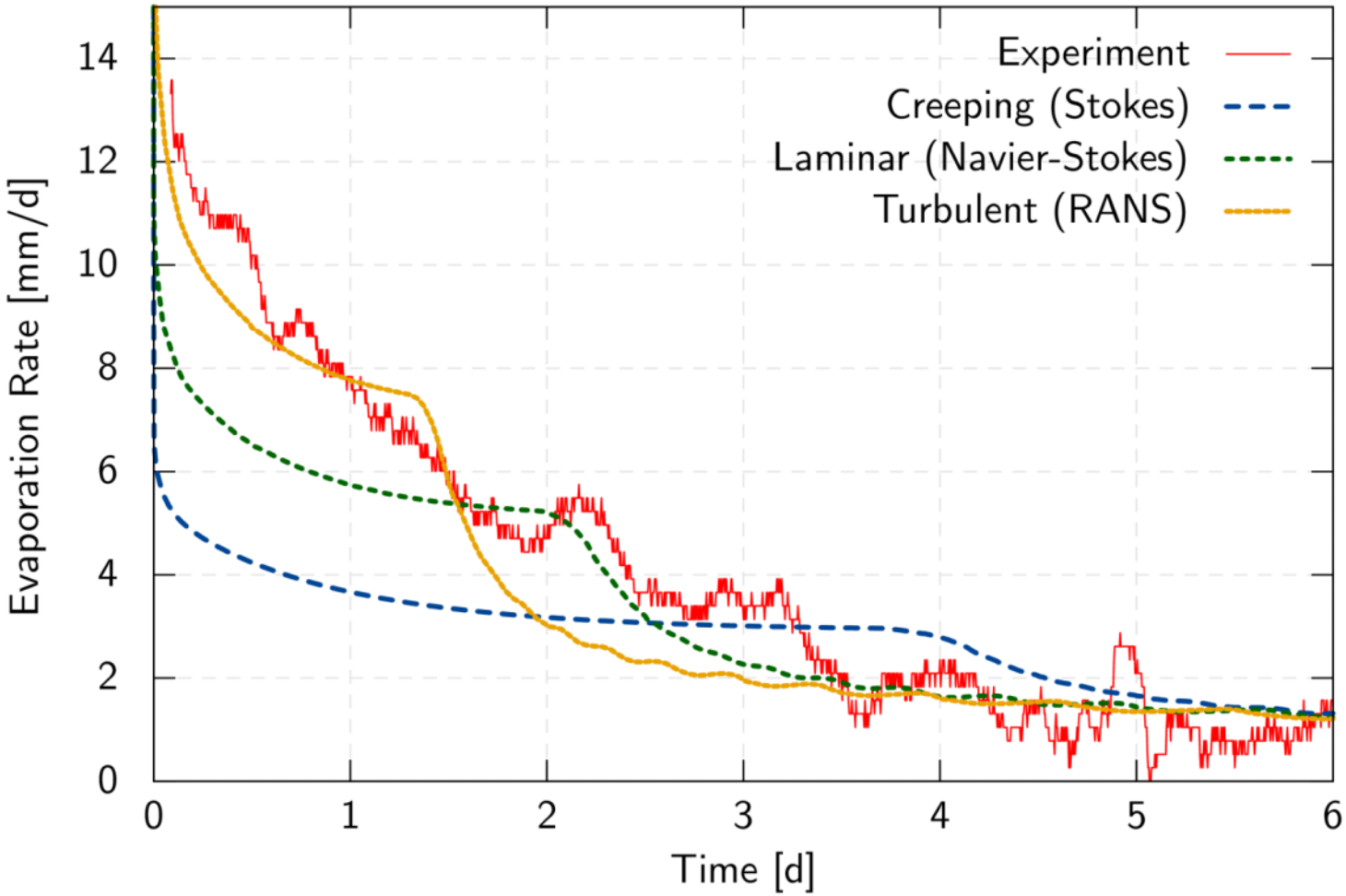
- numerical simulator


- experiments by [Davarzani et al. 2014]

$p_g = 1 \cdot 10^5$ Pa
$u_g = 1.22$ m/s
$X_g^w = 0.0032$
$T = 314$ K



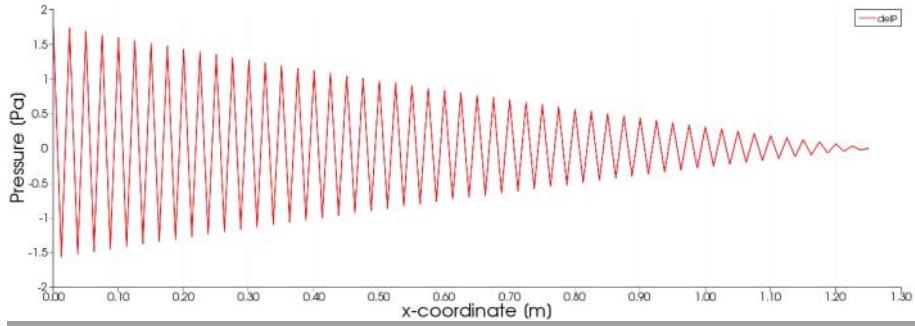
# Results – Evaporation

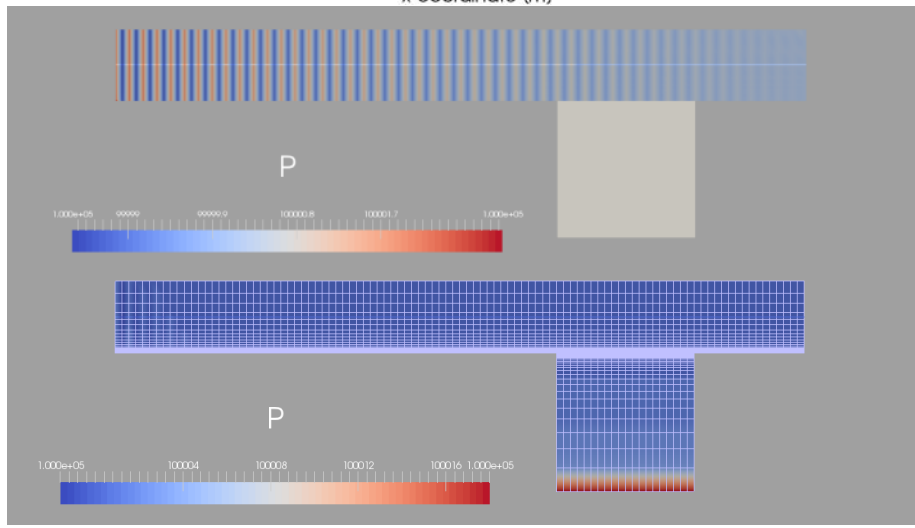


# Intermediate Summary

- existing models
  - free flow
  - coupling
  - turbulence

- open challenges
  - oscillations
    → discretization (space)
  - computational time
    → discretization (time)
    → efficient solution strategies

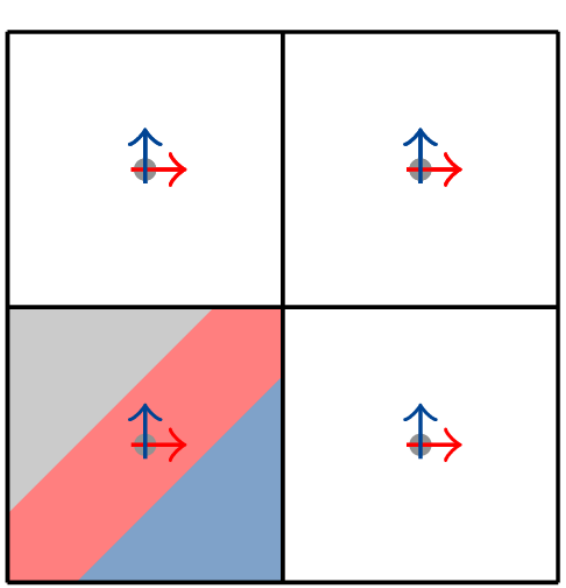


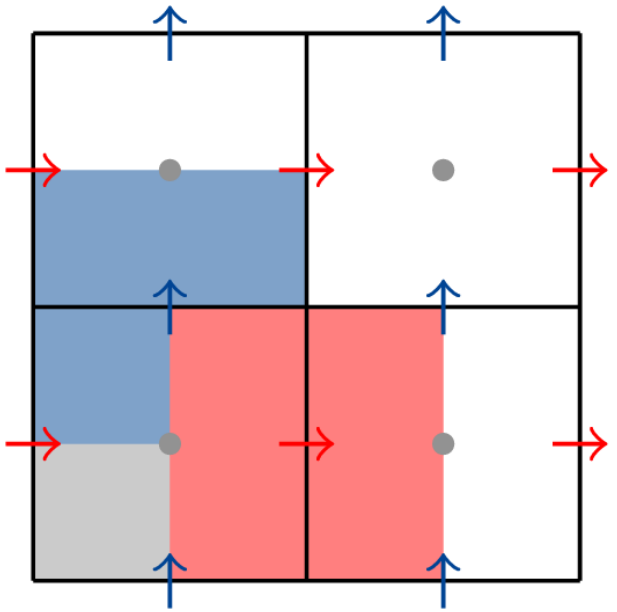



# Staggered Grid – Discretization

cell centered

staggered grid



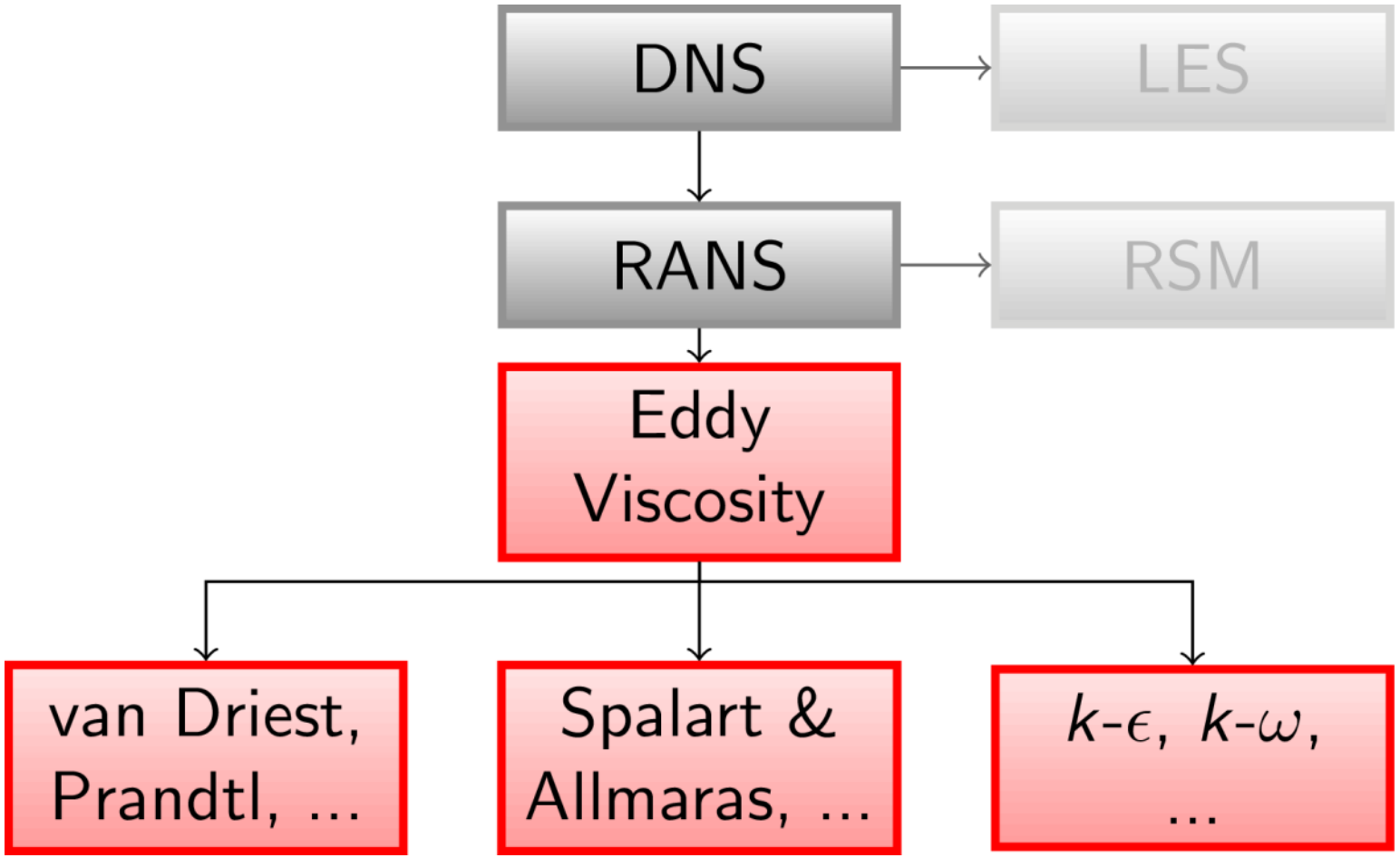


$p, X_g^\kappa, T$

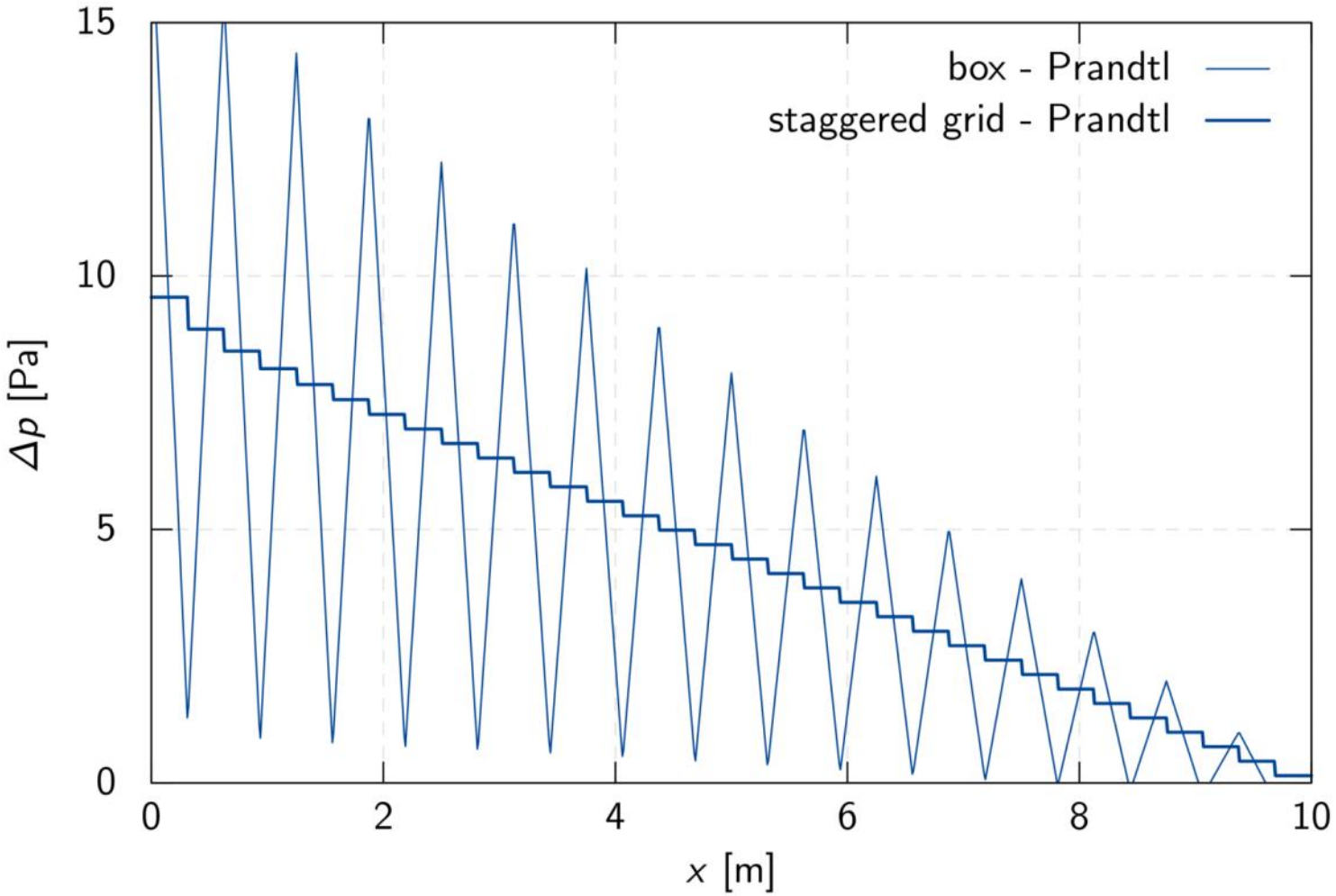
$u$

$v$

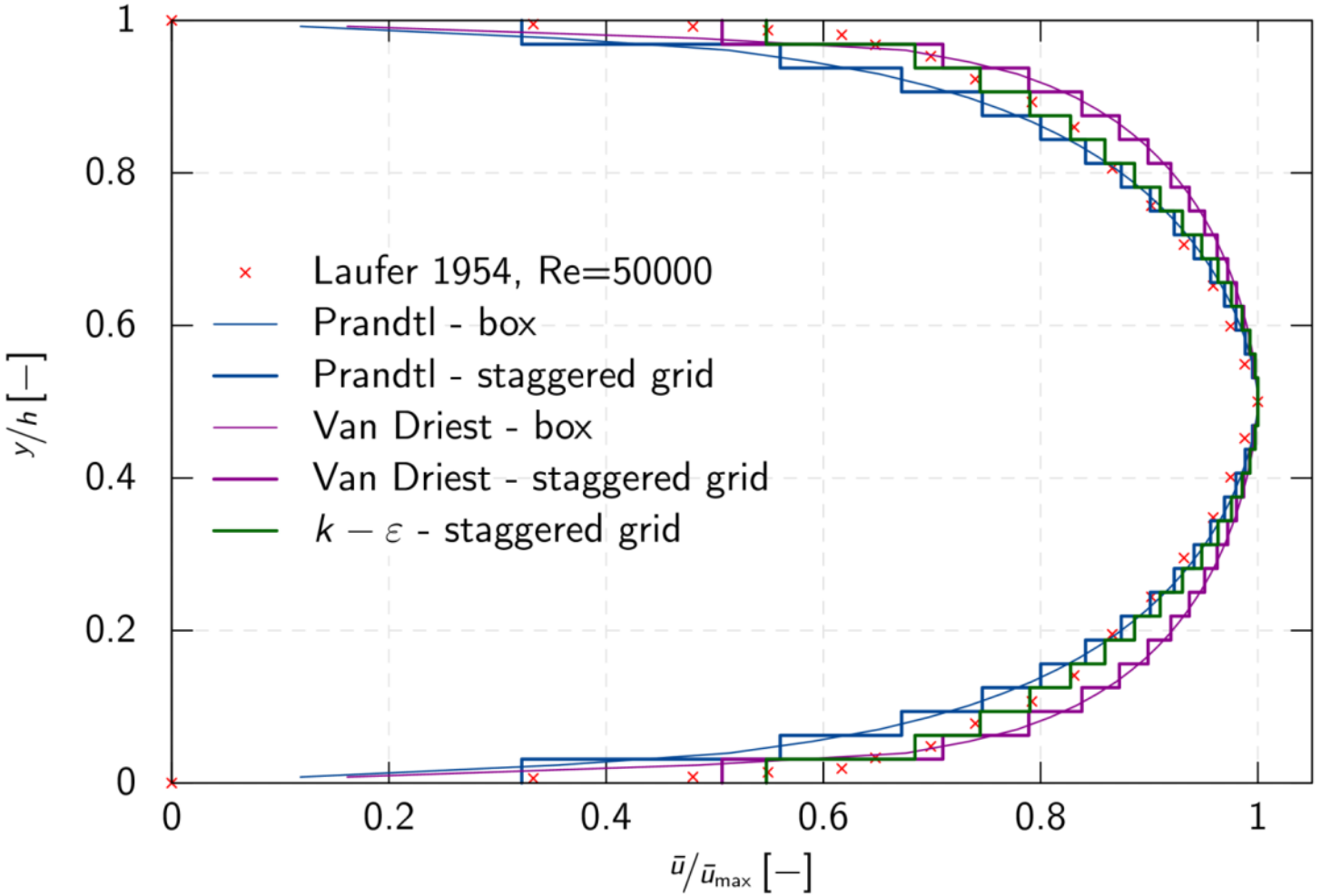
# Staggered Grid – Turbulence Models



# Staggered Grid – Oscillations



# Staggered Grid – Turbulence Models



# Outlook

- model
  - improve discretization of numerical free flow model
  - improve coupling of the domains
  - roughness
  - gravity
  - upscale/simplify model
- model + experiments
  - heterogeneities
  - more detailed sand-grain roughness studies
  - discrete roughness elements

# Other DuMuX Developments

- gnuplot interface
  - plot porous medium material laws
  - live output of data

# Thank you for your attention!


- [Brinkman 1949] - A calculation of the viscous force exerted by a flowing fluid on a dense swarm of particles
  *Applied Scientific Research*, **1949**, *1*, 27-34
- [Mosthaf et al. 2011] - A coupling concept for two-phase compositional porous-medium and single-phase compositional free flow
  *Water Resources Research,* **2011**, *47*, W10522
- [Davarzani et al. 2014] - Study of the effect of wind speed on evaporation from soil through integrated modeling of the atmospheric boundary layer and shallow subsurface
  *Water Resources Research,* **2014**, *50*, 1-20


International Research Training Group nupus

# New Navier-Stokes

## Advantages of PDELab

- Purpose is to write discretizations
- Generalized DoF handling
- Different DoF patterns
- More natural with Multidomain

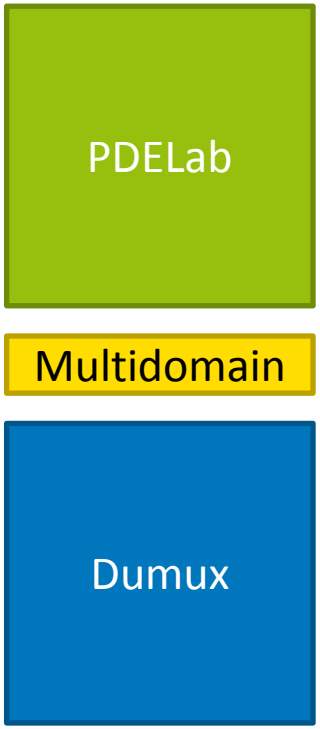
## Disadvantages

- Different / alien style
- Integration in DuMu$^x$ more work

# New coupling

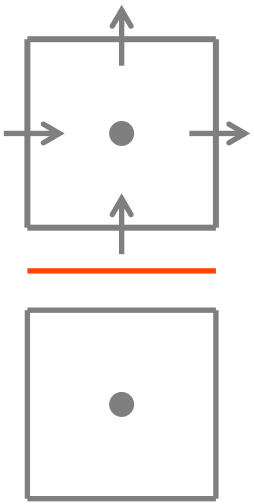
Couple

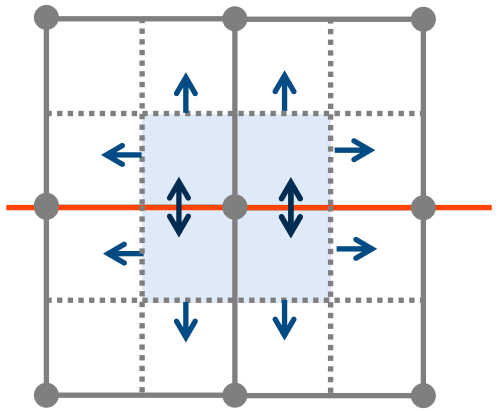
- PDELab / Navier-Stokes
- DuMu$^x$ / Darcy
- using Multidomain



# Discretization

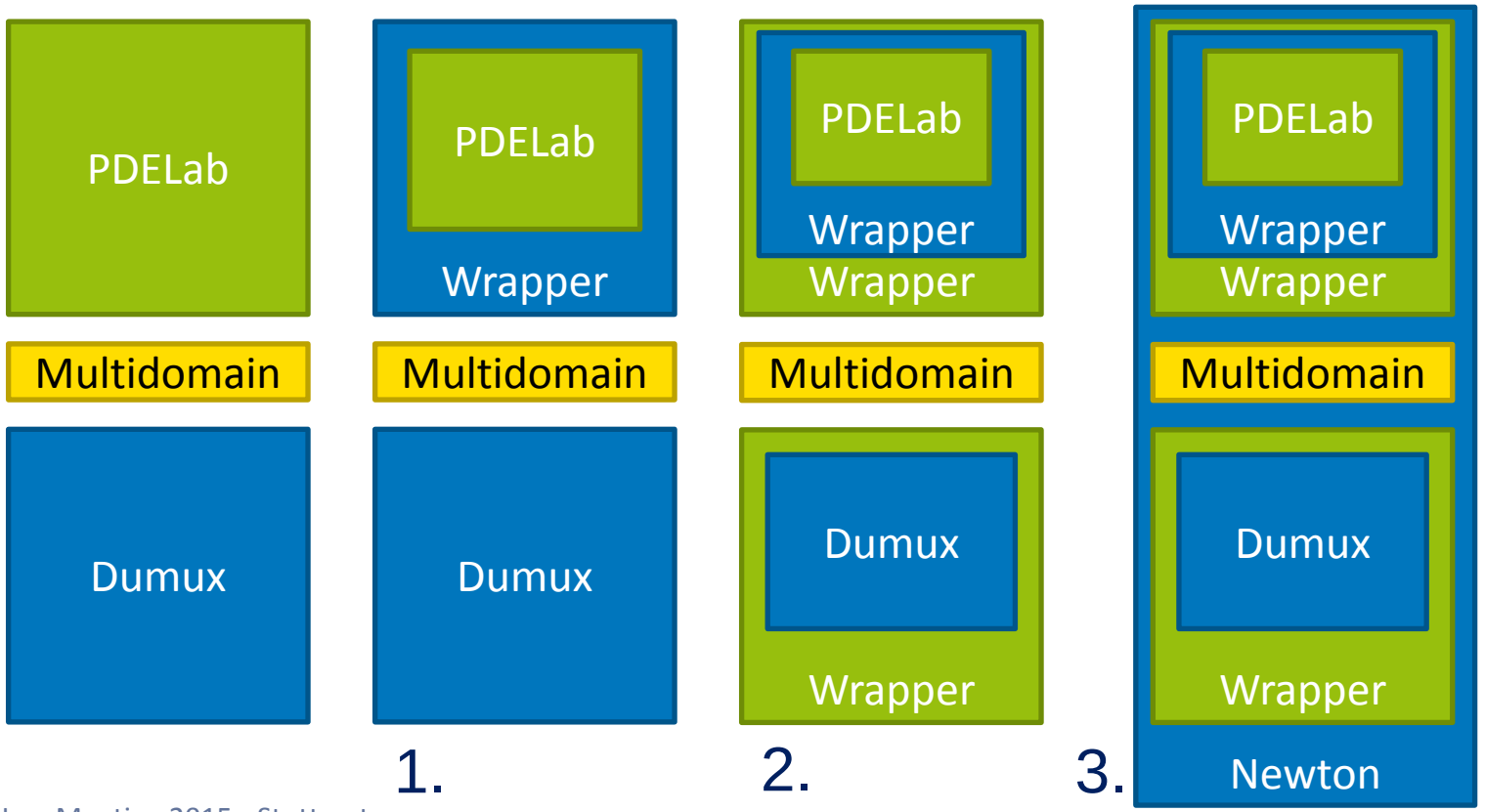
- Coupling conditions from [Mosthaf et al. 2011, Baber et al. 2012]
- Coupling via Neumann fluxes instead of Dirichlet values





# What we actually do

1. PDELab wrapped in DuMu$^x$: TypeTags, physical laws
2. Multidomain calls PDELab local operators
3. Custom Newton method

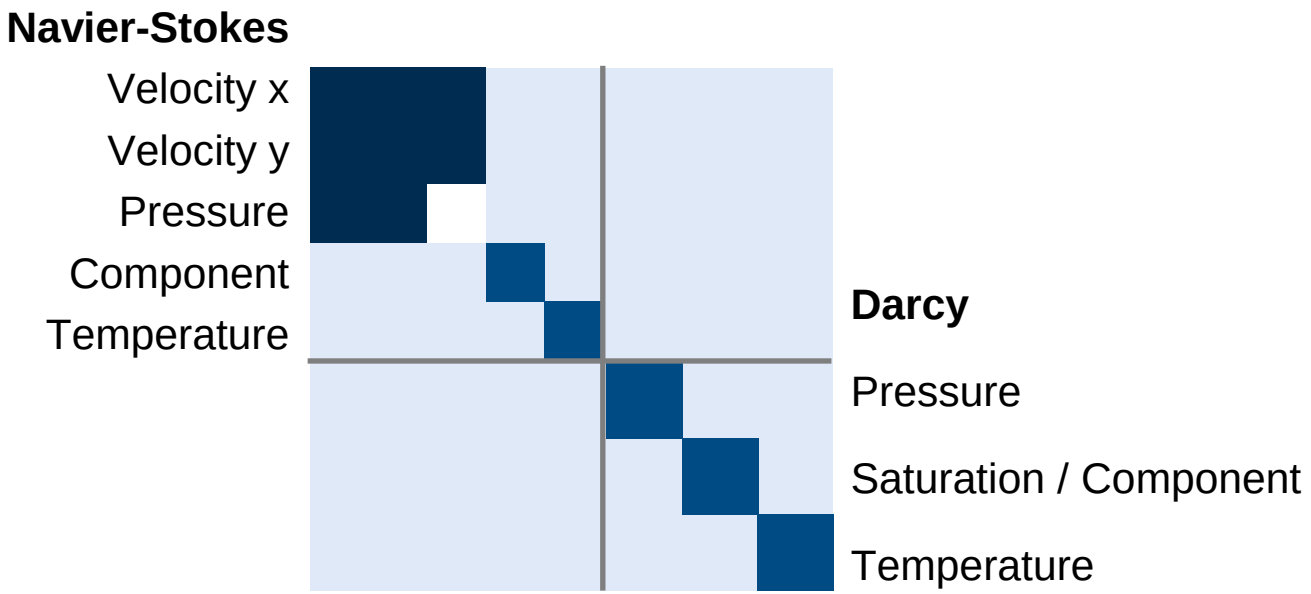


# Effects

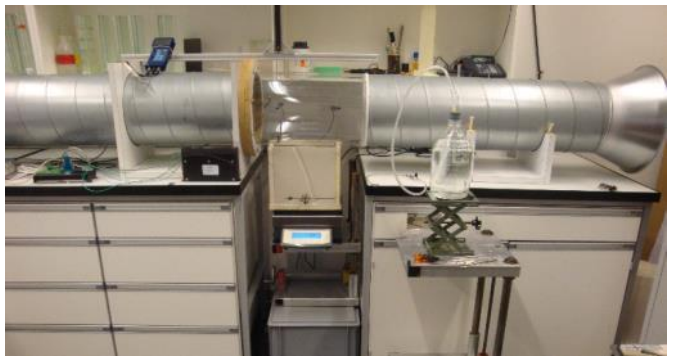
- Wrappers are inexpensive
- Better solvable linear system
- Comparable complexity to old approach

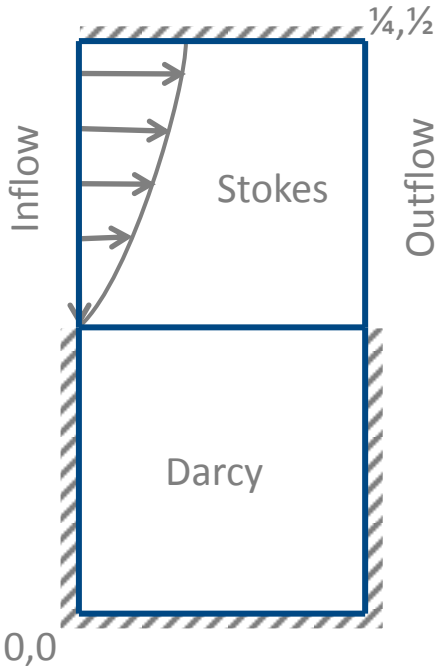
# Linear system

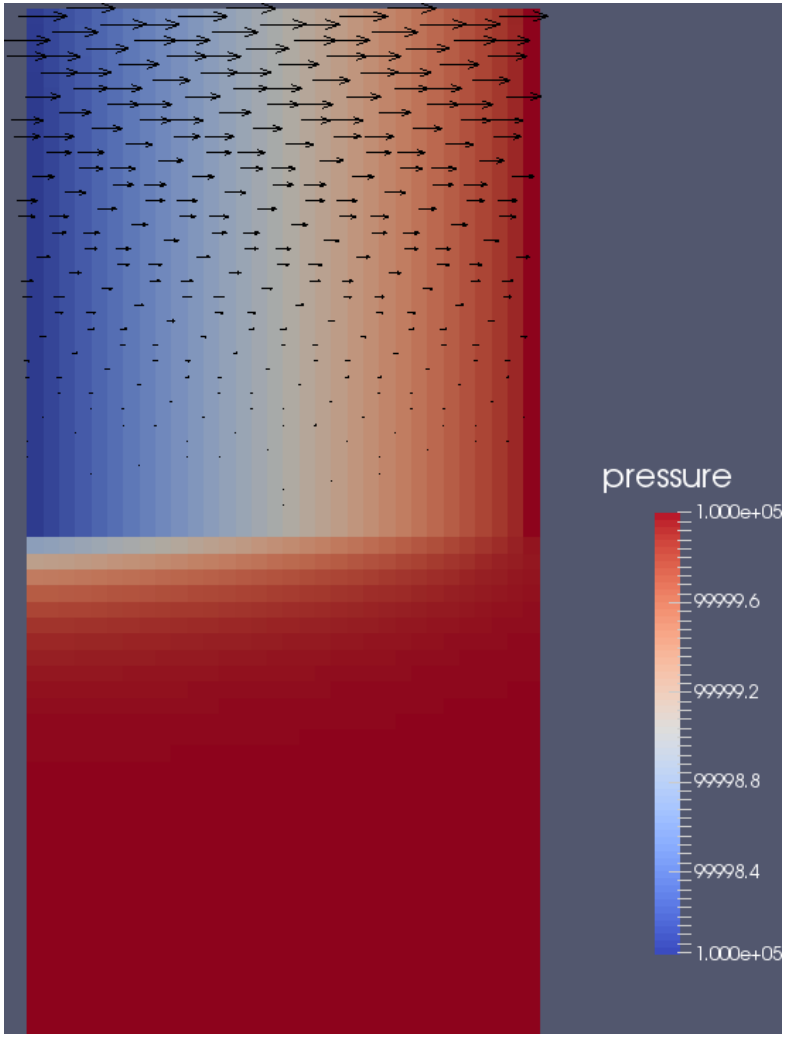
- Linearize whole system with Newton‘s method
- One huge linear system
- Contains a saddle point problem



# Simulation, 1p





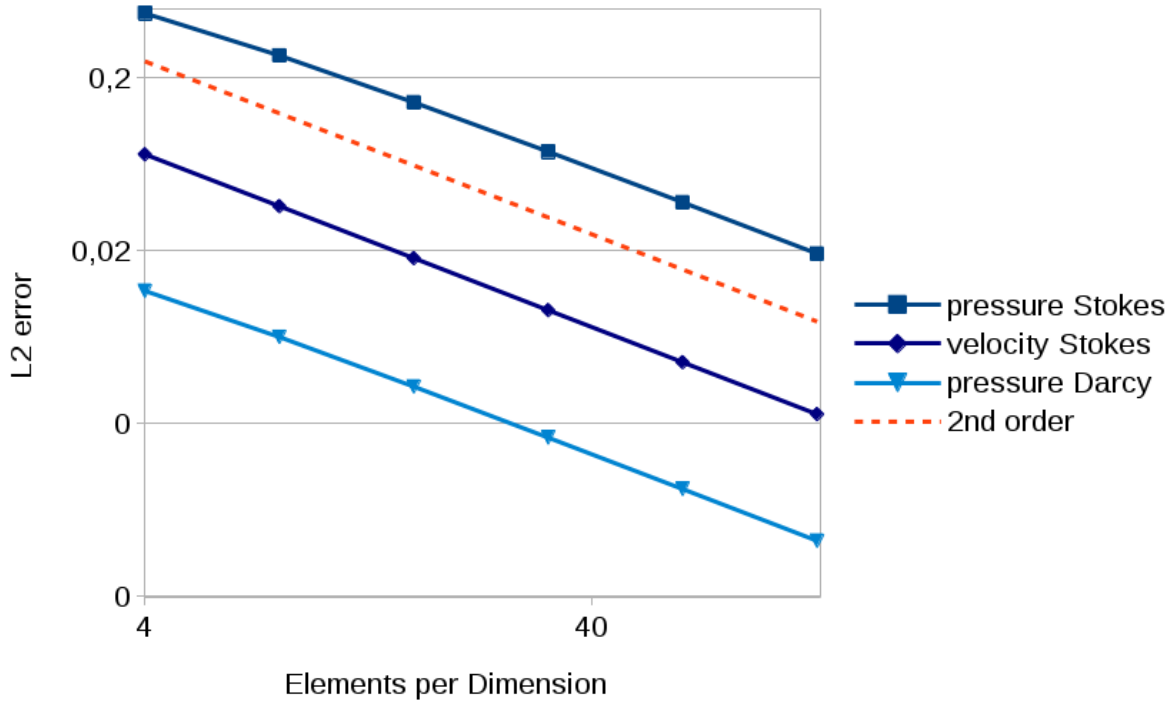
# $L^2$ convergence

- Analytic example
- Domain Stokes: [0,1] x [1,2], Darcy: [0,1] x [0,1]
- Dirichlet boundary conditions

$$v = \begin{pmatrix} 10\exp(-y) \\ 2y \end{pmatrix}$$

$$p_{\text{Stokes}} = -2y + 6$$

$$p_{\text{Darcy}} = -2y + 4$$



# Outlook

- Coupling planned to be ready in fall
- Integration to stable DuMu$^x$ in 2.9?