

## Chapter 4

# Modeling flow in capillaries

## Examples of data integration, challenges / opportunities



*Chapter 4 Example 1*

# Flow in relativistic microvascular networks

Geometry and boundary conditions?



# Geometry from measurements

- **Main difficulty: complex pipeline**
  - Advances biological lab protocols (e.g. make rat brain transparent)
  - State-of-the-art microscopic techniques
  - Image processing to segment vessels (state-of-the-art filter and deep learning-based tools)
  - Image processing to turn segmented vessels into graph
  - Poor quality of graph model often not directly suited for simulation (artifcats)
  - First full brain vasculature data from rats (ca. 5 Million vessels) in 2020



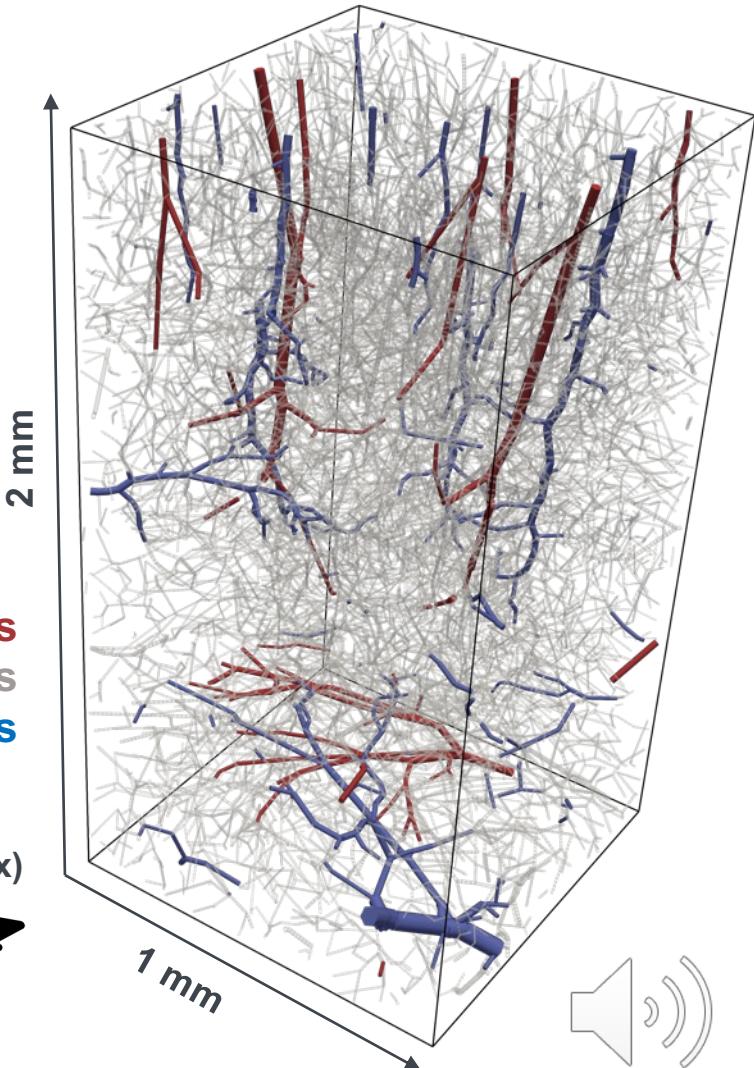
# Geometry from measurements



K. Möller et al: 10.1186/2040-7378-4-20 CC-BY-2.0

Arterioles  
Capillaries  
Venoles

Rat brain (cortex)

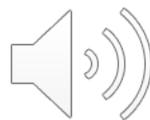
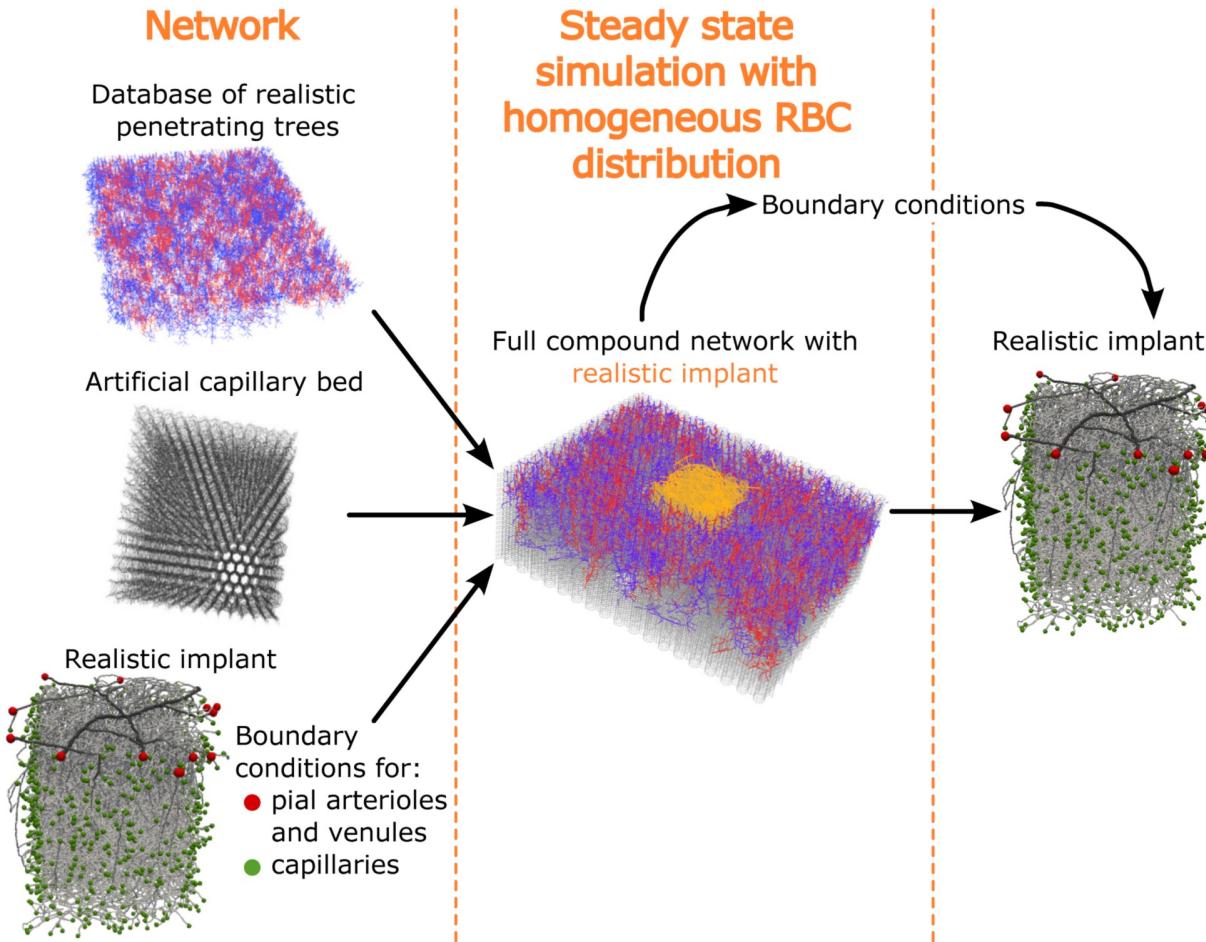


# Boundary conditions

- **Boundary conditions at all terminal vessels**
  - Pressure or flow rate
  - Hematocrit

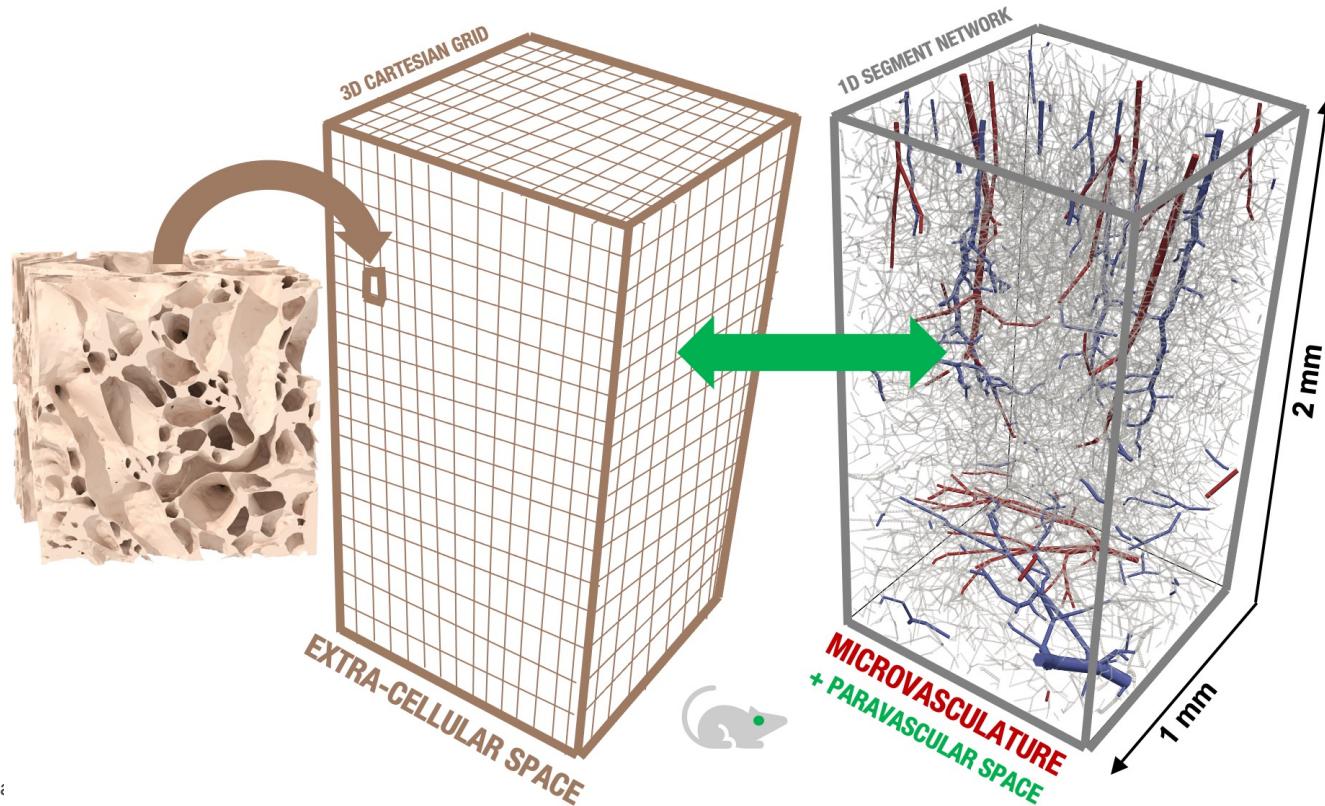


# Boundary conditions



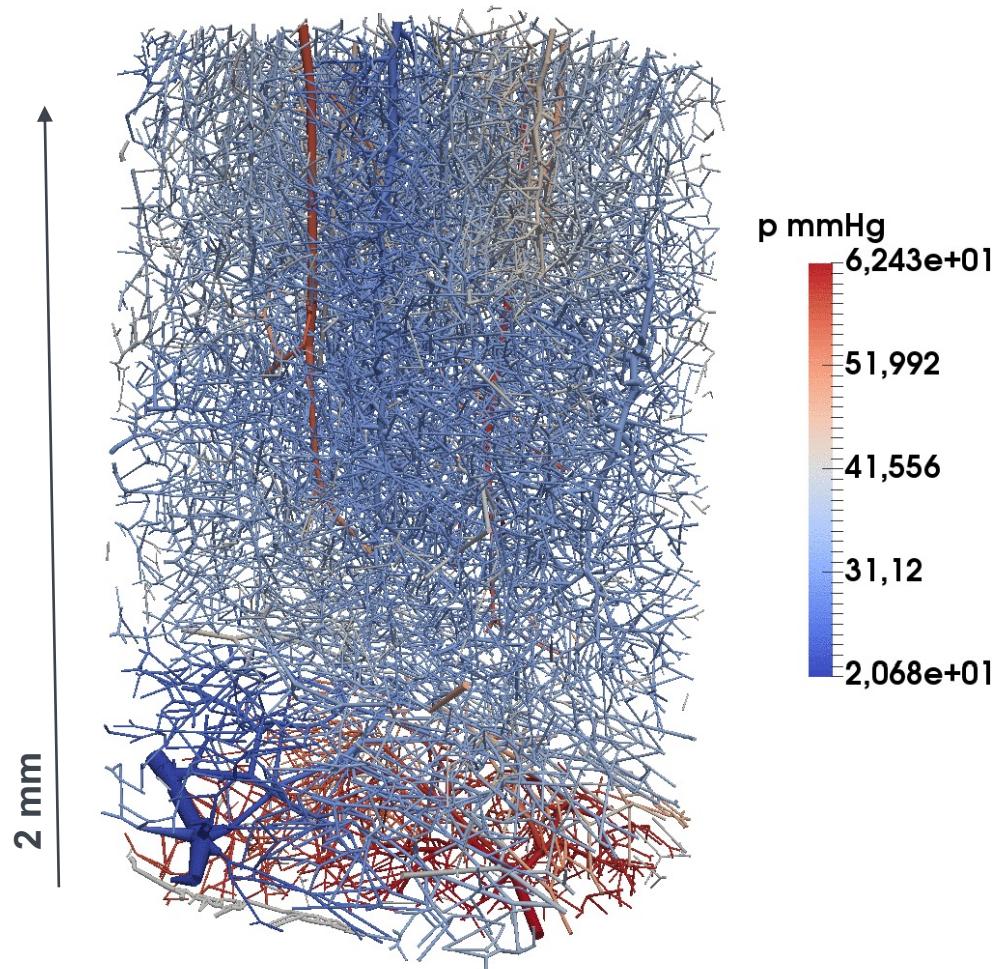
# Boundary conditions

- „Boundary conditions“ / “Coupling conditions“
  - $P_{ext}$  in Starling's law? → Coupling with extravascular tissue flow model



# Flow in microvascular networks

- Video sequences:
  1. Pressure in all vessels
  2. Larger vessels ( $R > 7\mu\text{m}$ )
  3. Grid of embedding domain
  4. Pressure in tissue ( $P_{\text{ext}}$ )



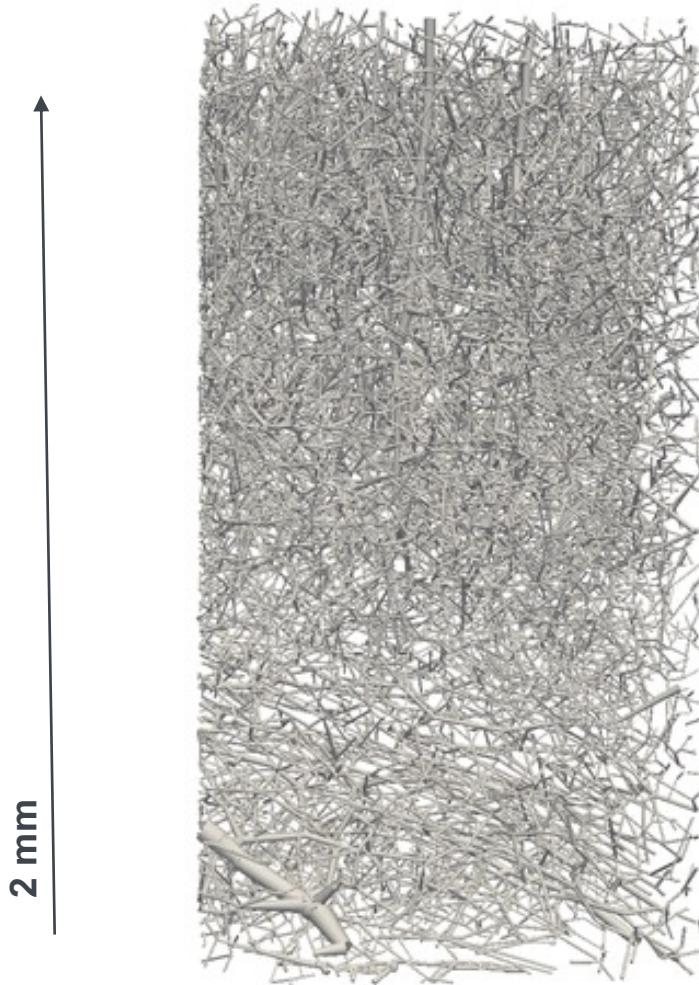
*Chapter 4 Example 2*

# Transport in microvascular networks

Clinical data and resolution gap



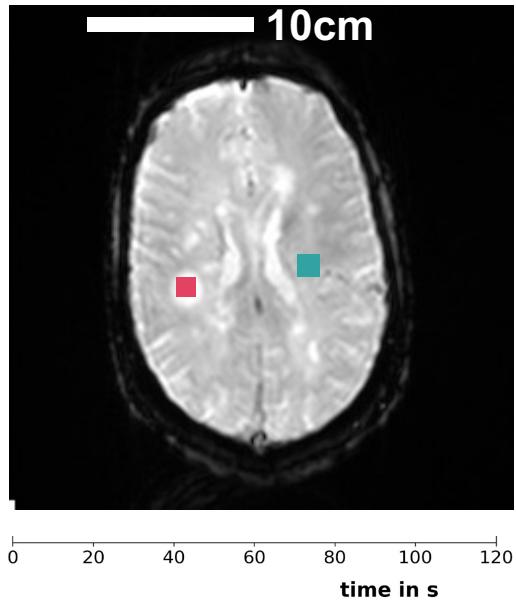
# Transport in microvascular networks



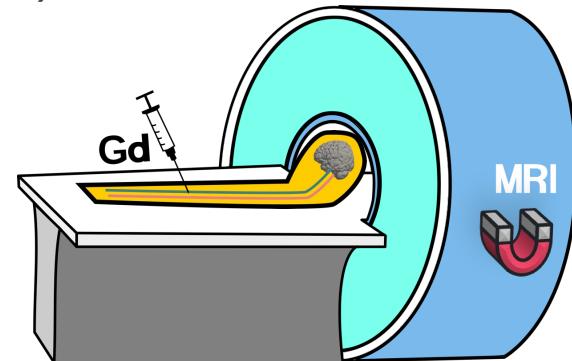
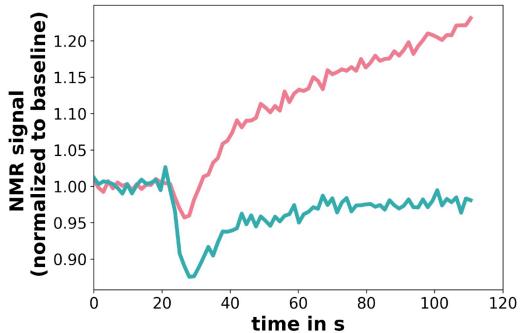
# Transport in microvascular networks

- Main difficulty: Data for model validation on different scale
  - MRI has a typical resolution of 1-5 mm per voxel (size of our simulation domain)

data courtesy of Roland Wiest, *Inselspital Bern*



**Example: Multiple Sclerosis**  
→ Vessels are more leaky (red)

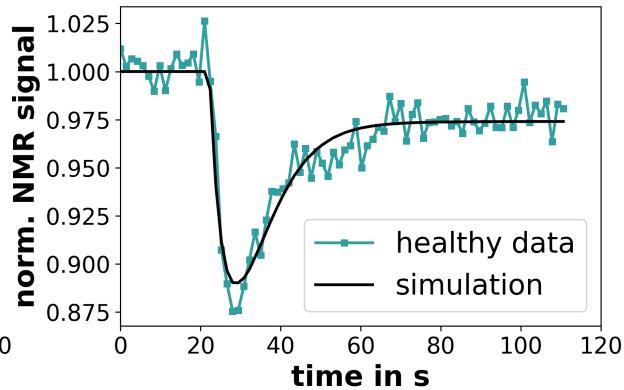
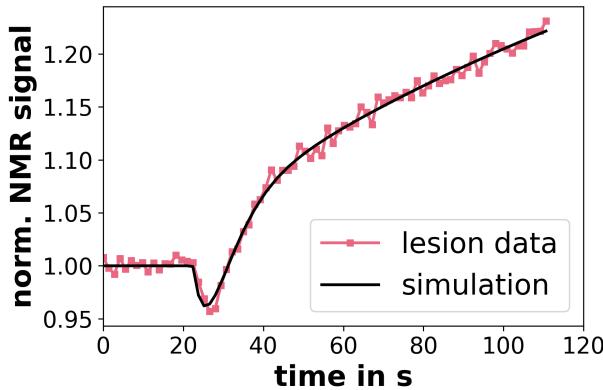
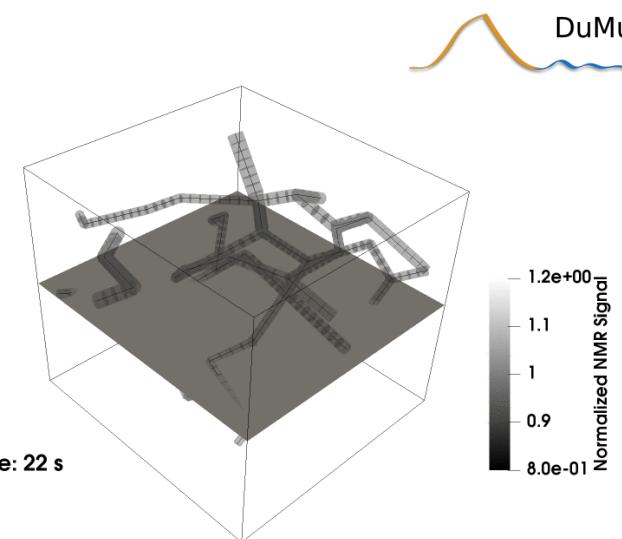


DSC-MRI T2\*-weighted sequences

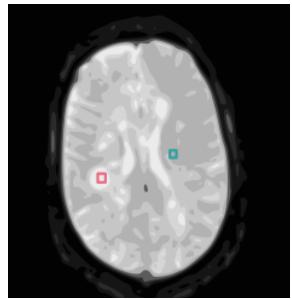


# Transport in microvascular networks

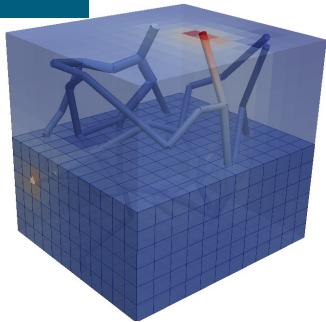
- Idea: Coupling flow+transport to MRI simulation
  - Volume averaging of MRI signal for comparison
  - Parameter estimation of microvascular model
  - Uncertainty quantification



# Data-integrated simulation framework



1



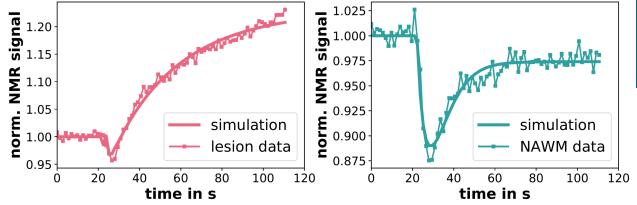
Flow field simulation



3

Volume-averaging

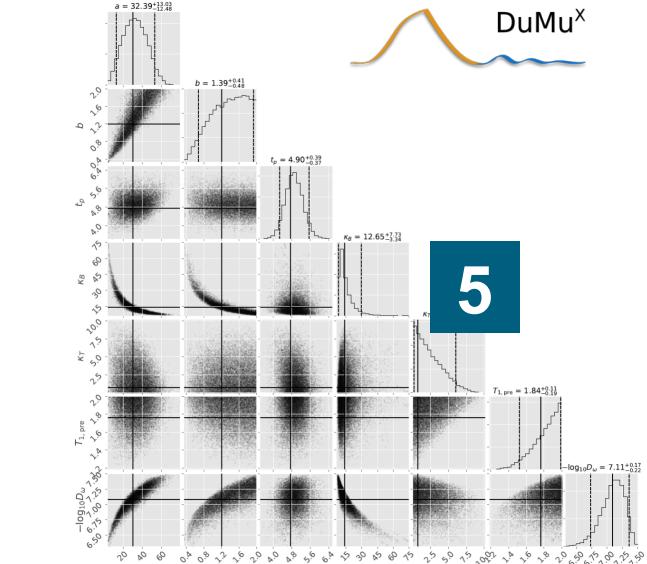
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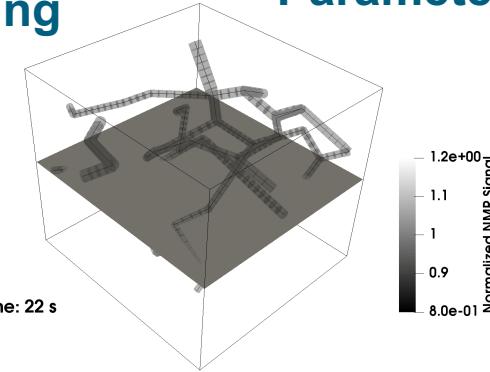
Comparison with clinical data

4

5



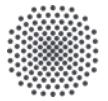
Parameter estimation (+UQ)



2

Contrast agent transport + MRI signal simulation

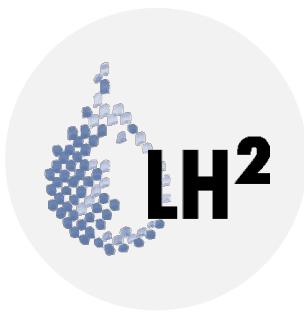




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**Thank you!**



<https://www.iws.uni-stuttgart.de/lh2/>

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