Combined in-situ diagnostic tools for detection of liquid water evolution in PEMFC

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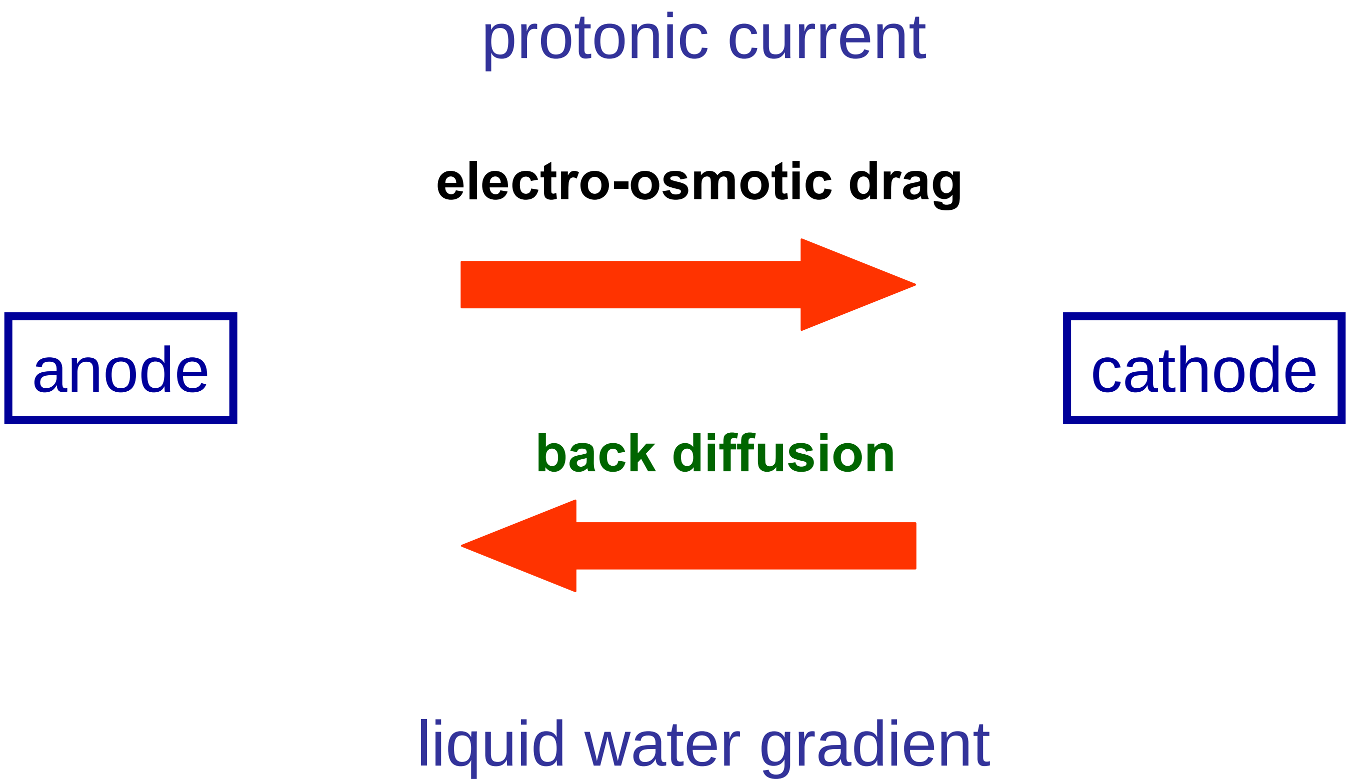
where is liquid water in an operating fuel cell ?

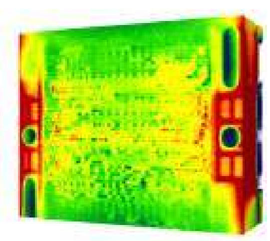
water distribution in fuel cells

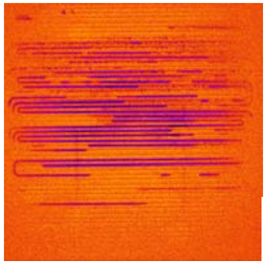
two main factors influence the distribution and the balance between anode and cathode:

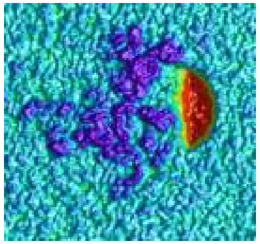
- electro-osmotic drag (protonic current)
- back diffusion (liquid water gradient)



presented methods for fuel cell research







neutron tomography

neutron radiography

synchrotron radiography

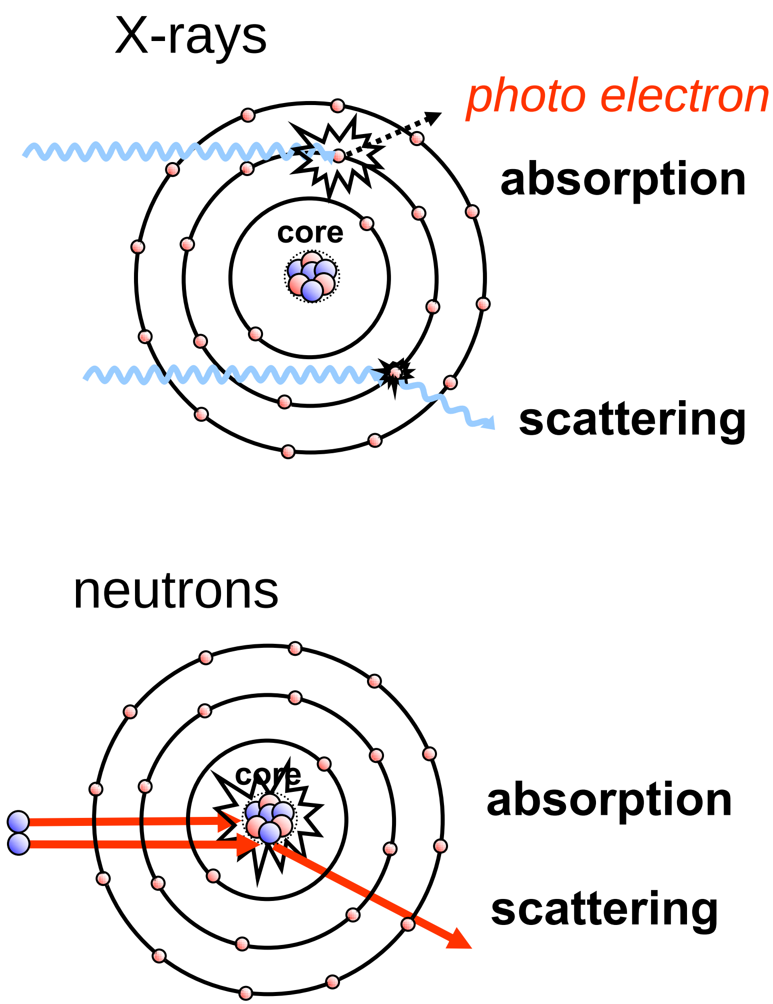
spatial resolution

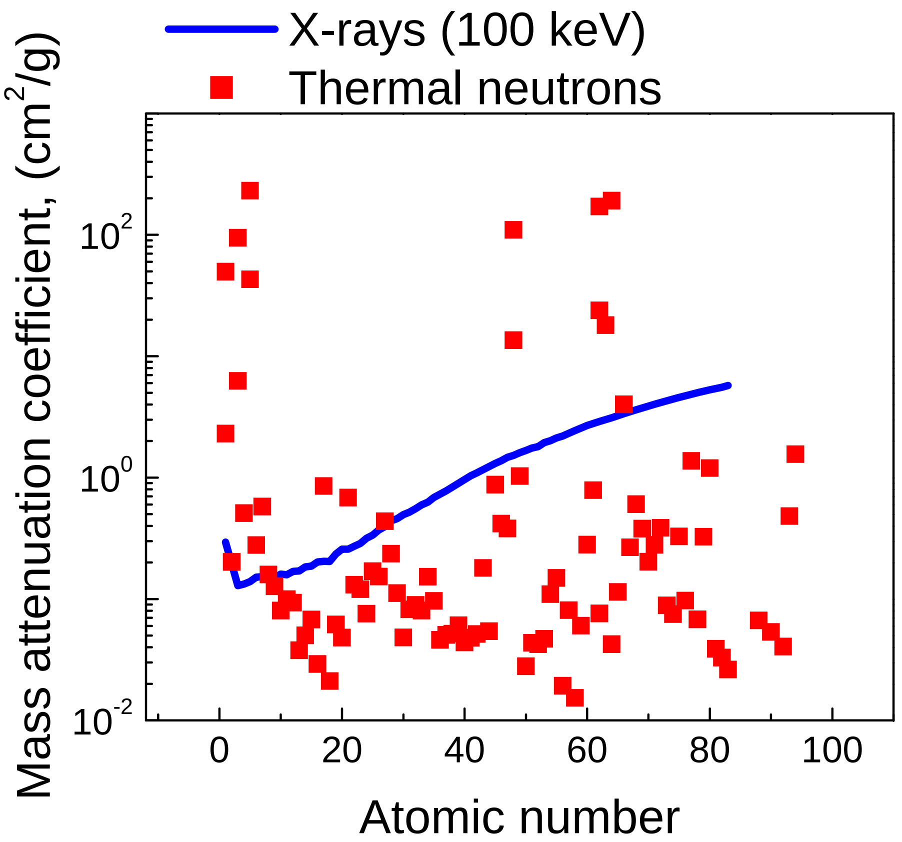
200 µm

80 µm

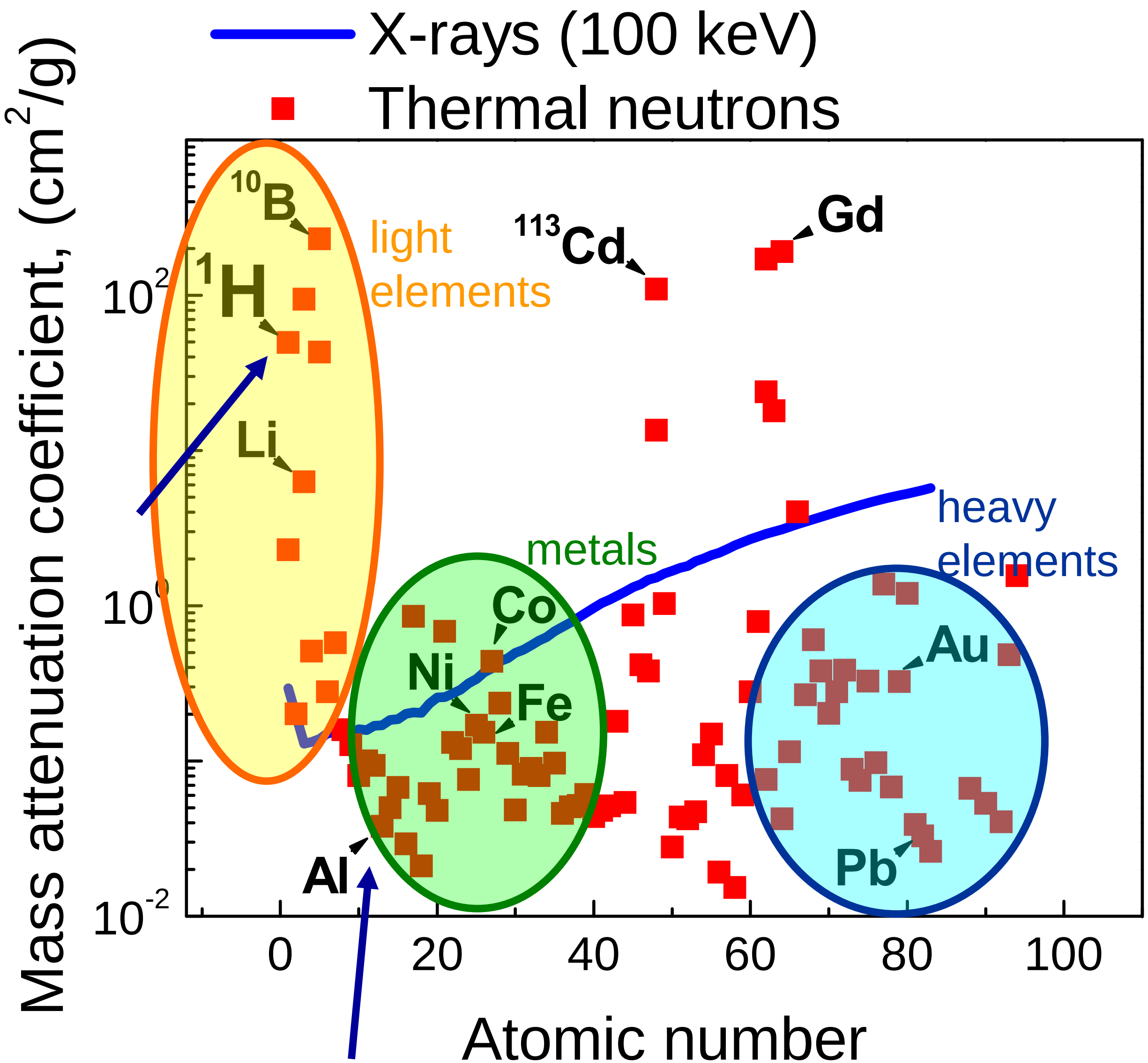
3 µm

comparison between X-rays and neutrons



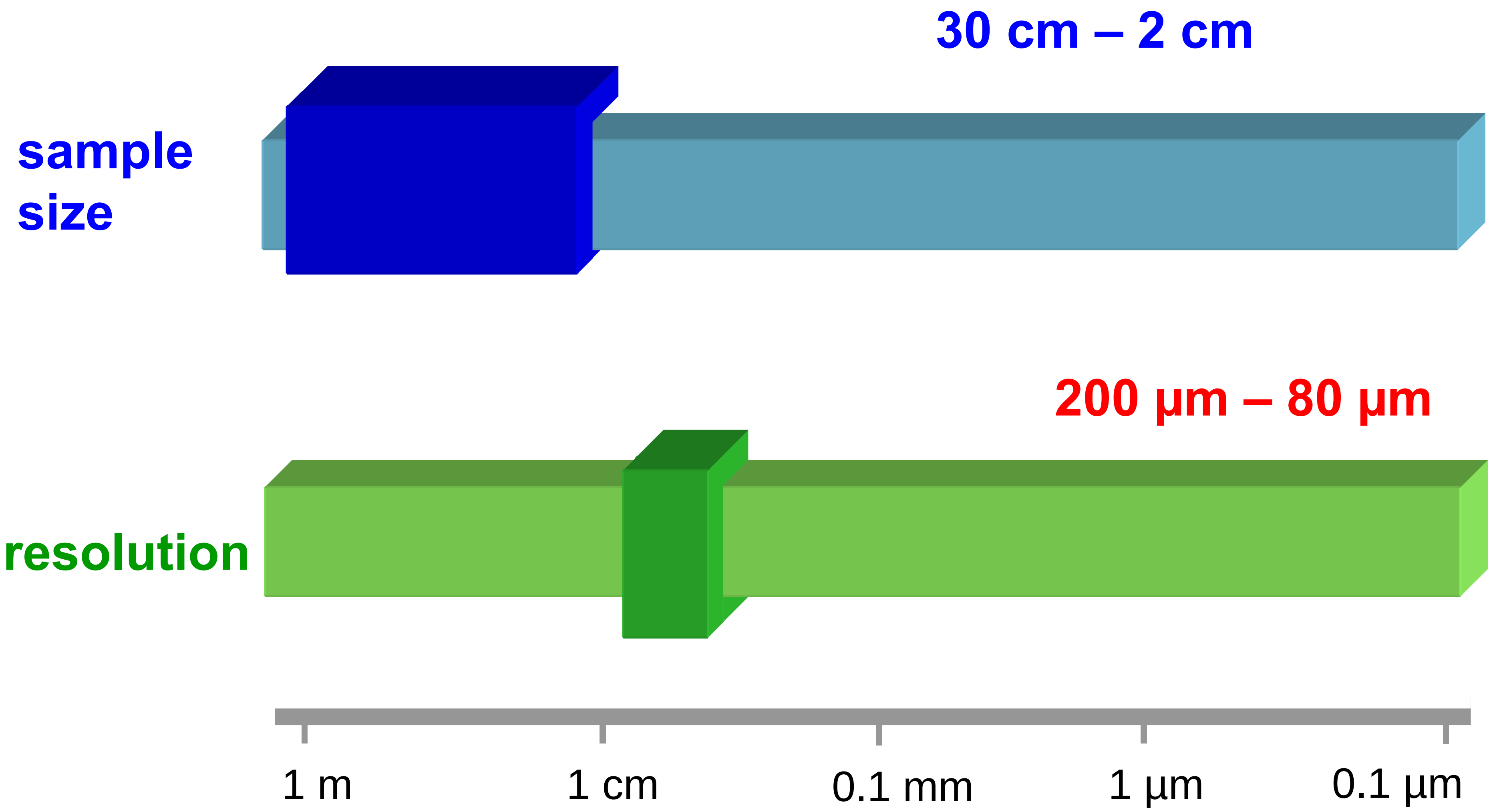


why neutrons?



neutron radiography

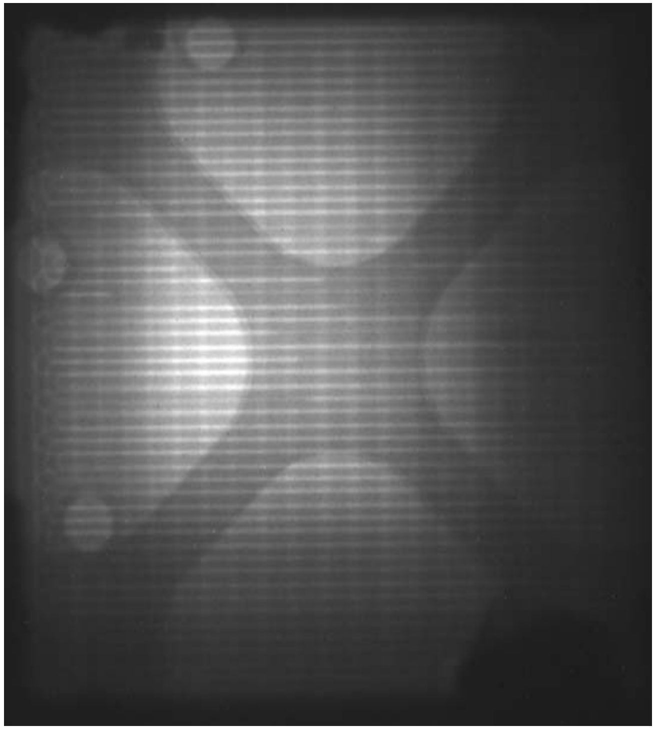
neutron tomography and radiography



neutrons can ‘see’ water in fuel cells

normalization of images: water distribution map

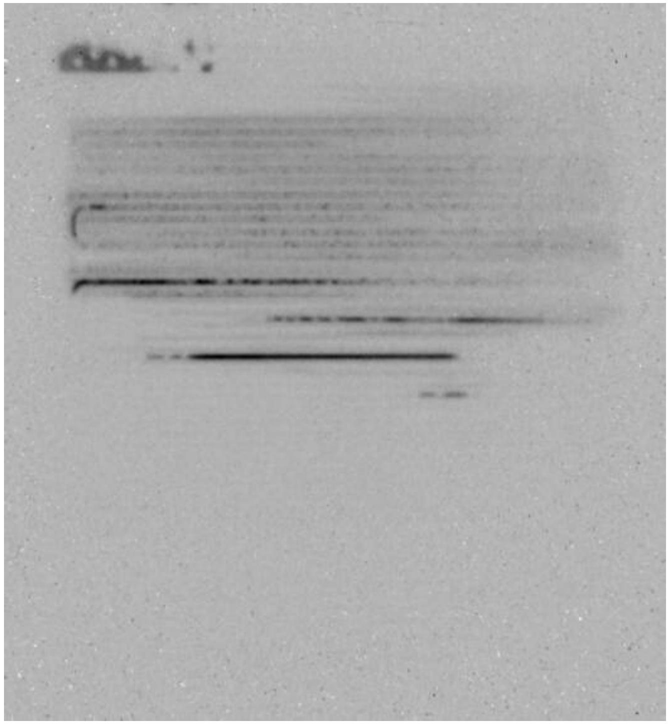
original radiography



← 100 mm →

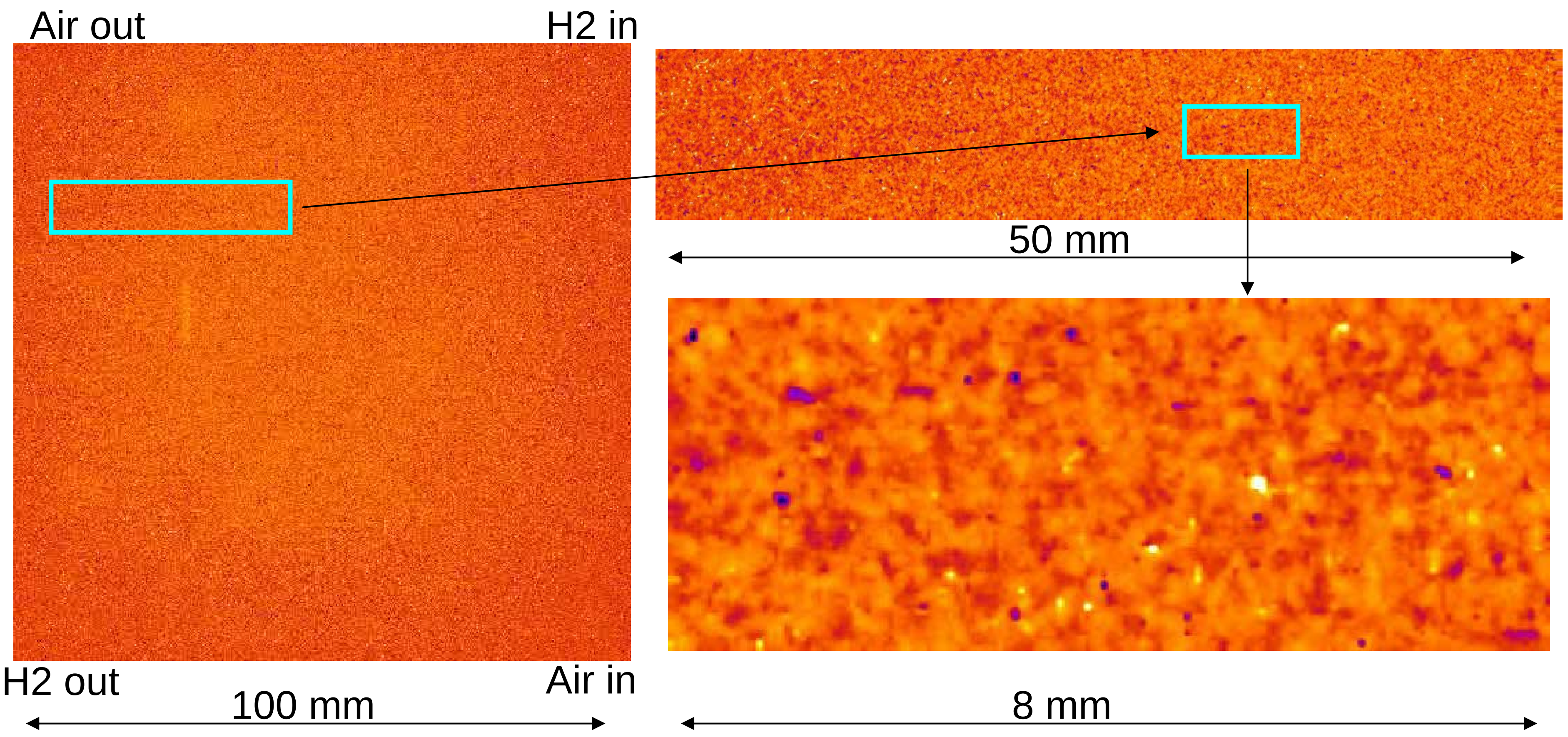
ratio:
water filled cell
/empty cell

water distribution



neutrons can 'see' water in fuel cells

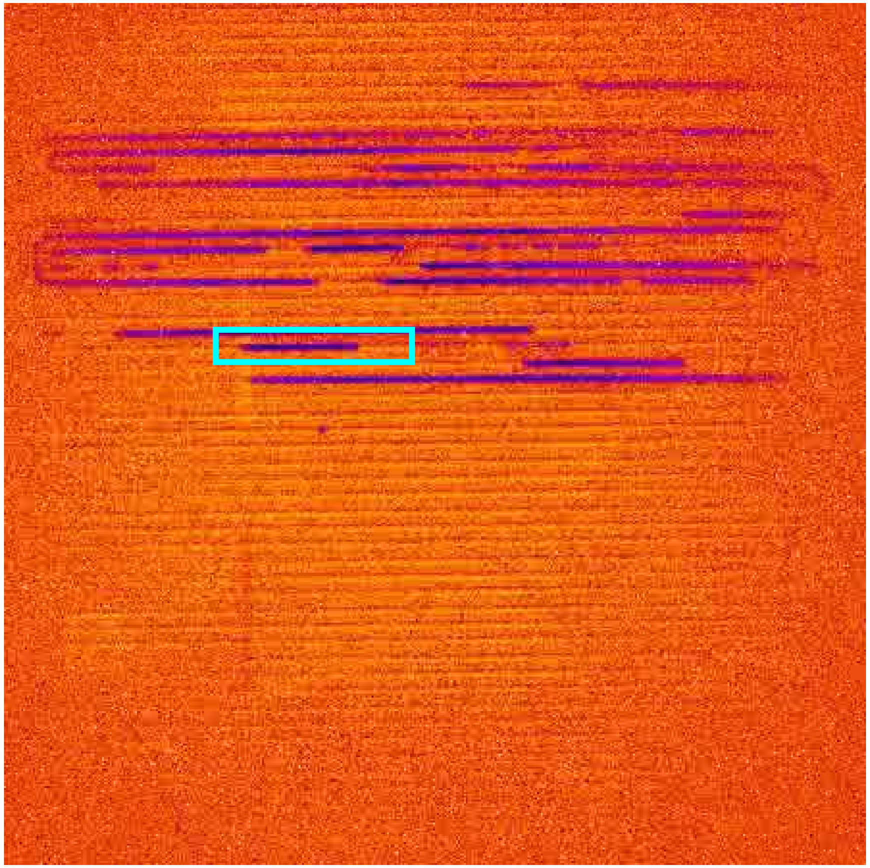
evolution of liquid water on anode side



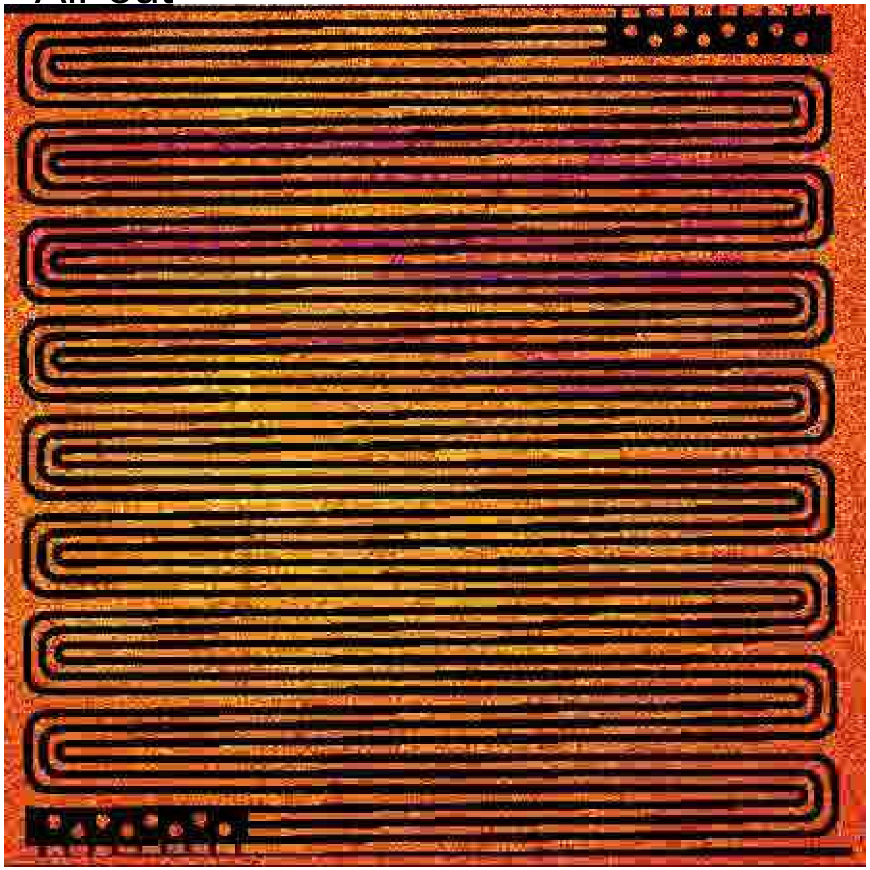
neutrons can 'see' water in fuel cells

single cell water distribution

200 mA/cm2, 60% u.C, 20% u.A
cathode outlet 100% r. H. ,
anode inlet 0% r. H.



mask for anode channel

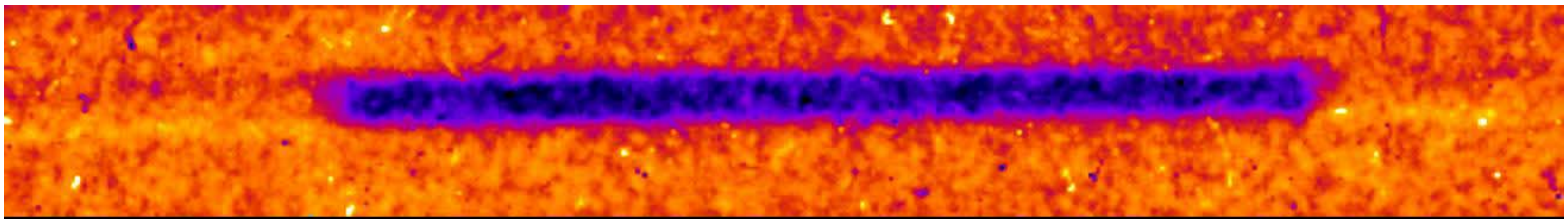


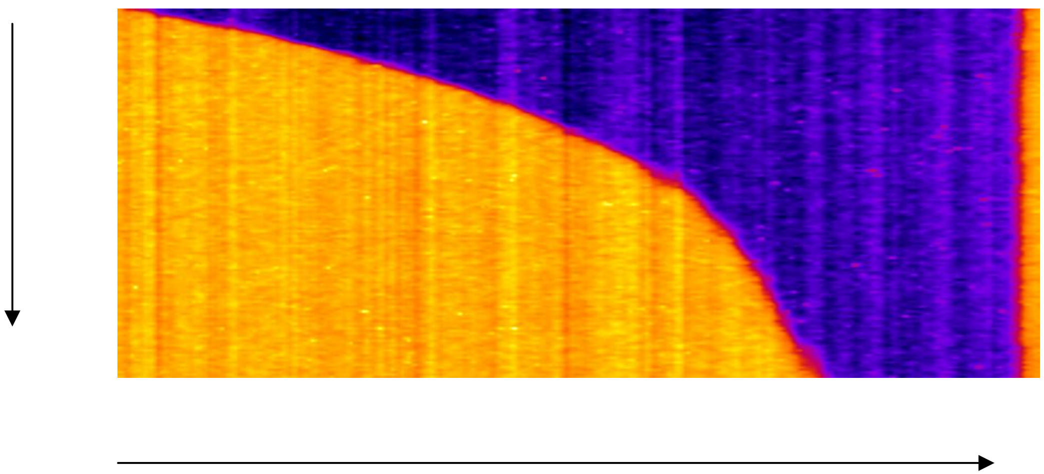
neutrons can 'see' water in fuel cells

evaporation of liquid water in a channel

200 mA/cm2, 60% u.C, 20% u.A
cathode outlet 100% r. H. ,
anode inlet 0% r. H.

38 min real time

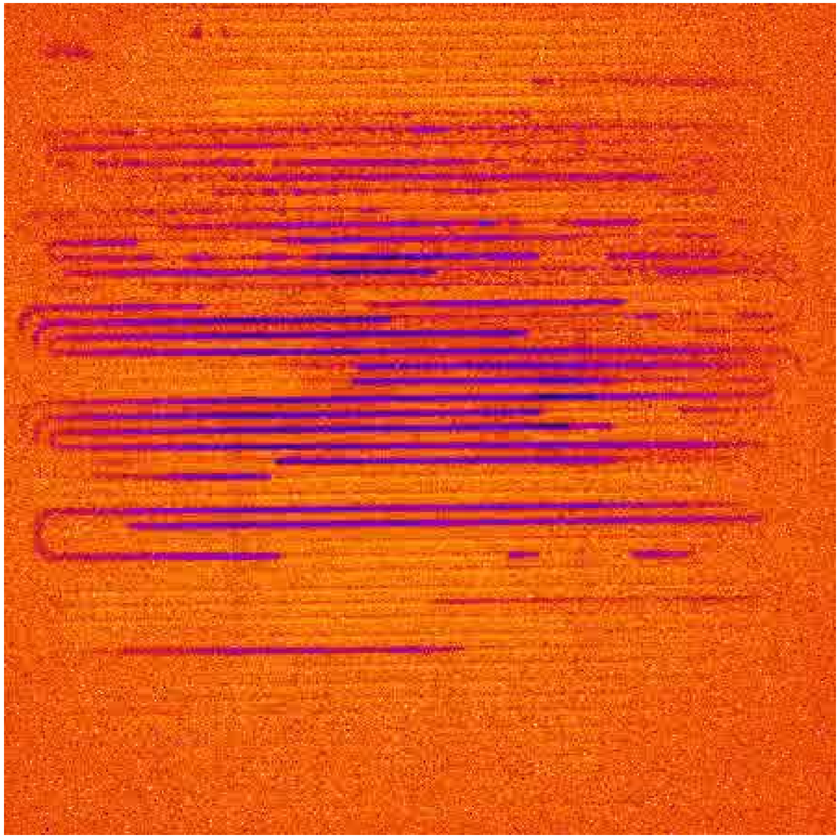




neutrons can ‘see’ water in fuel cells

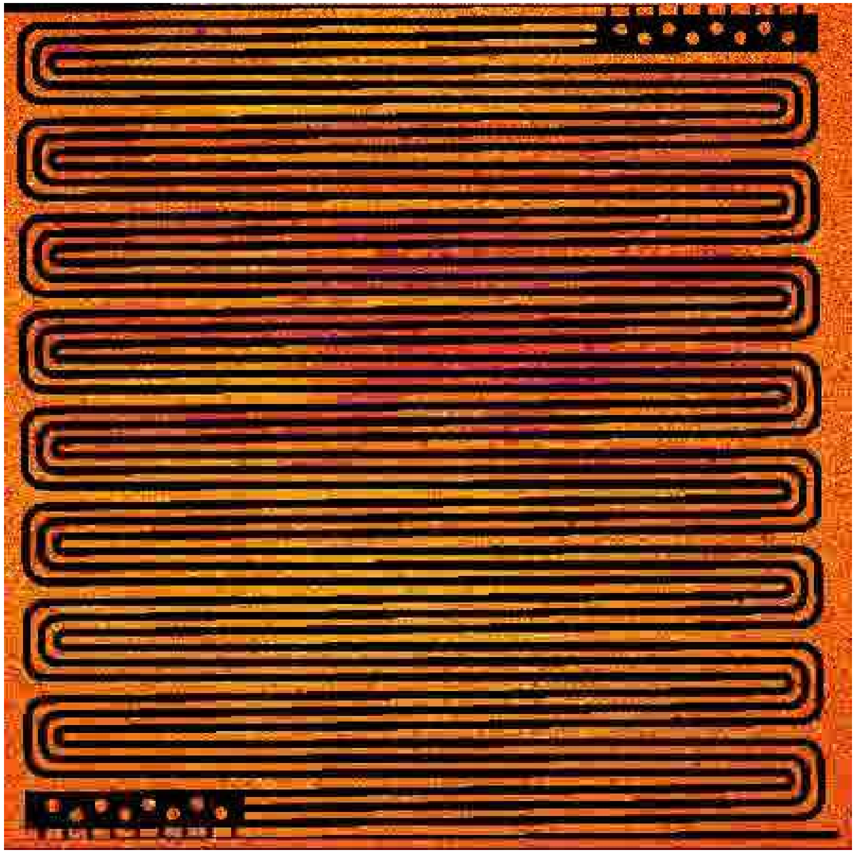
single cell water distribution

500 mA/cm2, 60% u.C, 20% u.A
cathode outlet 100% r. H. ,
anode inlet 0% r. H.



mask for anode chanel

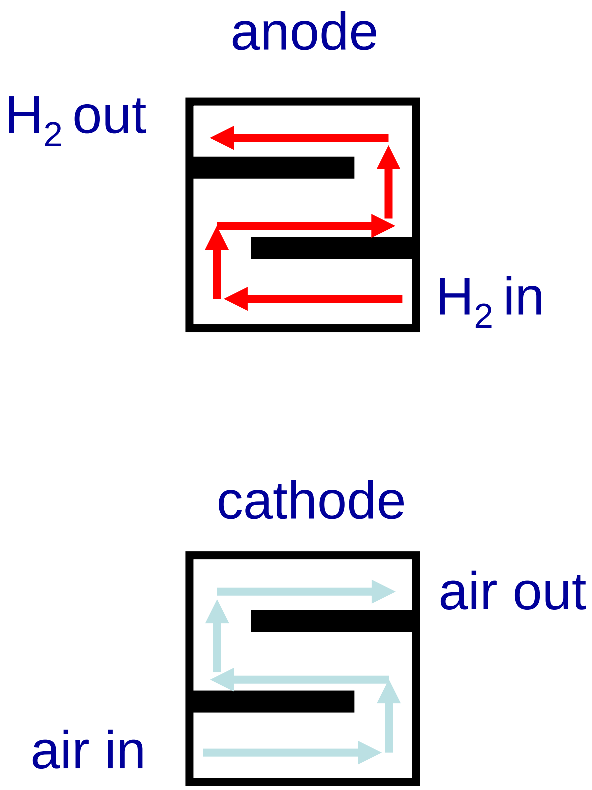
Air out H2 in

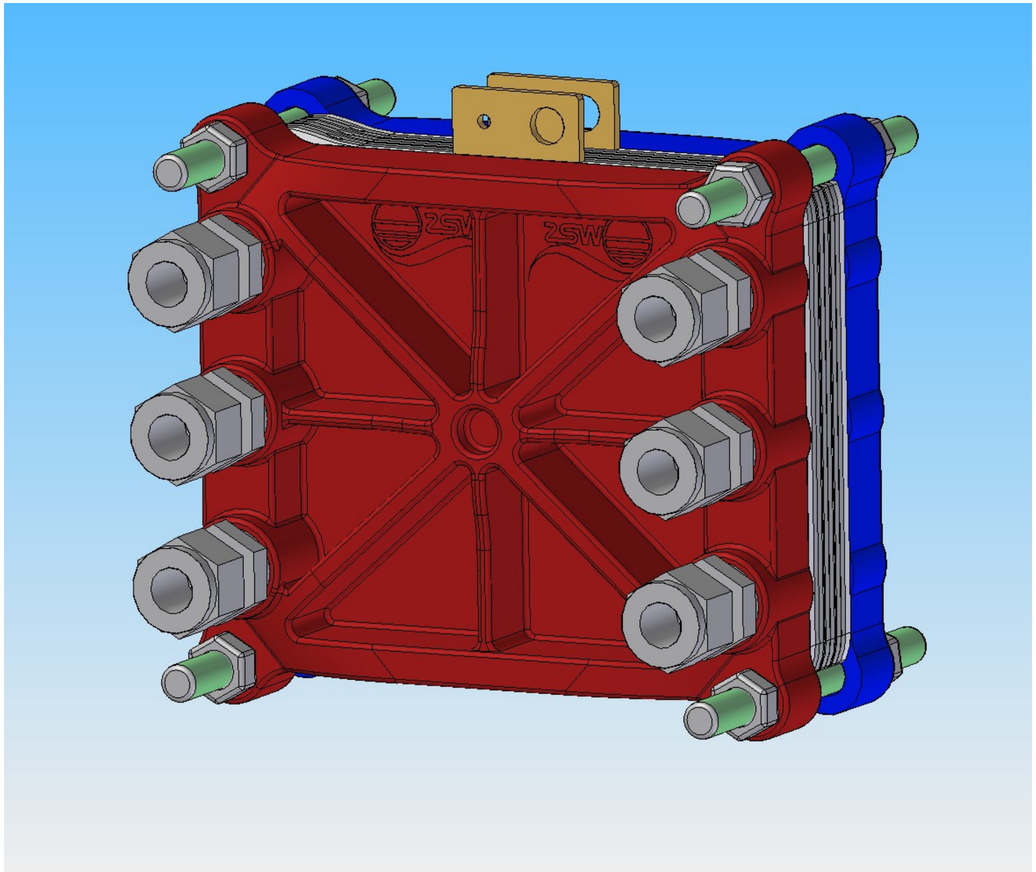


H2 out Air in

neutron tomography

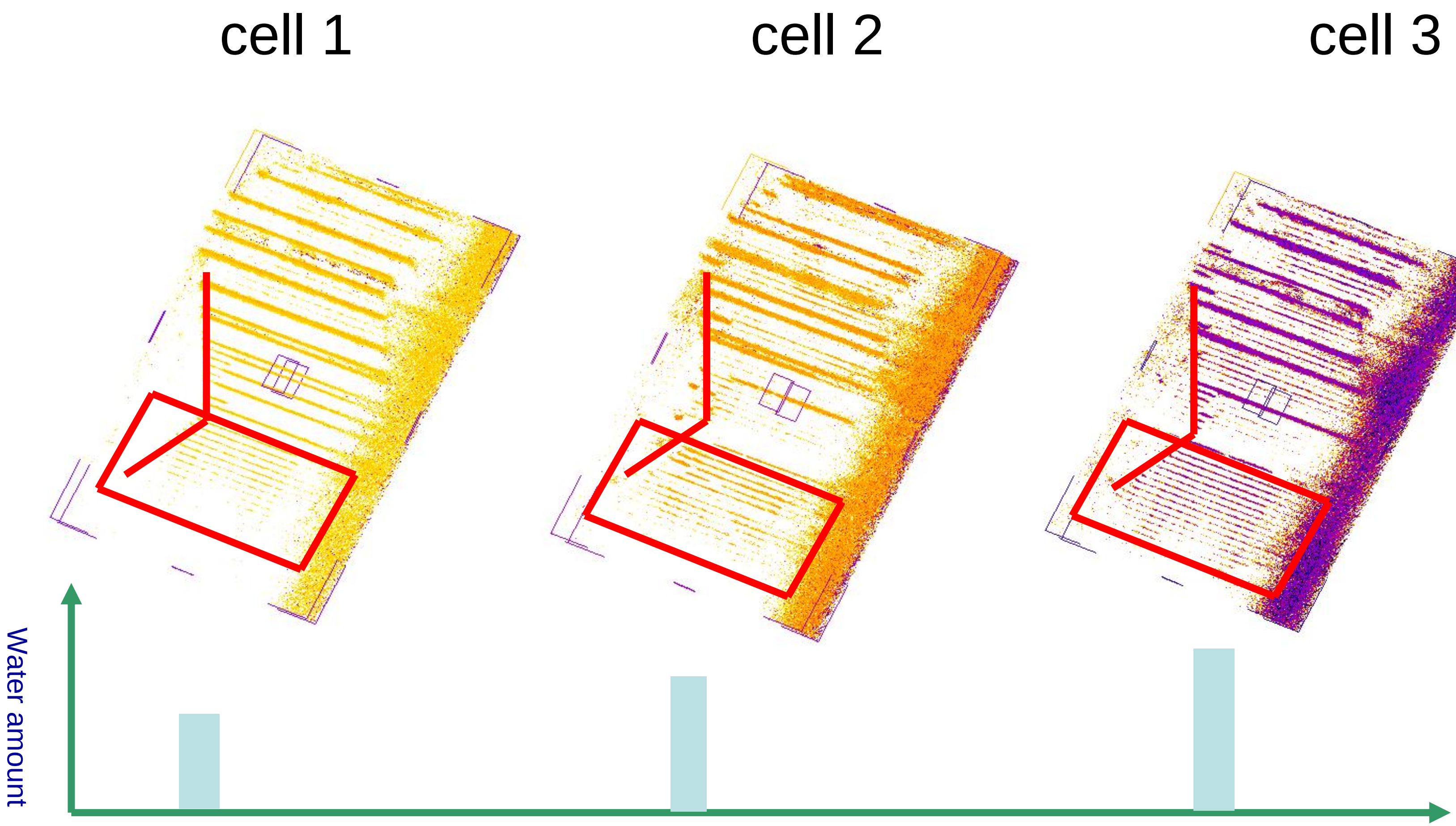
neutron tomography





neutron tomography

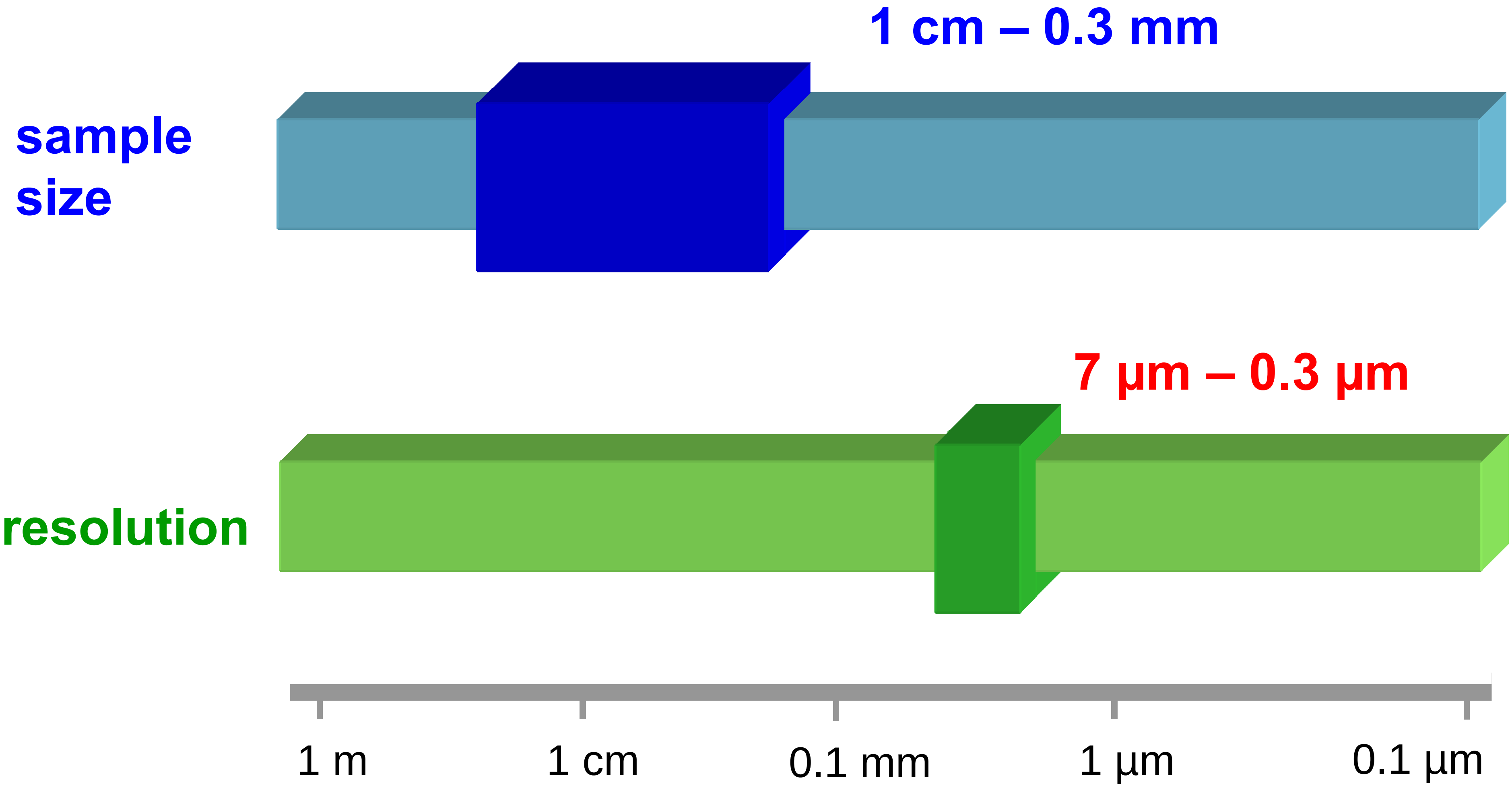
neutron tomography: triple stack



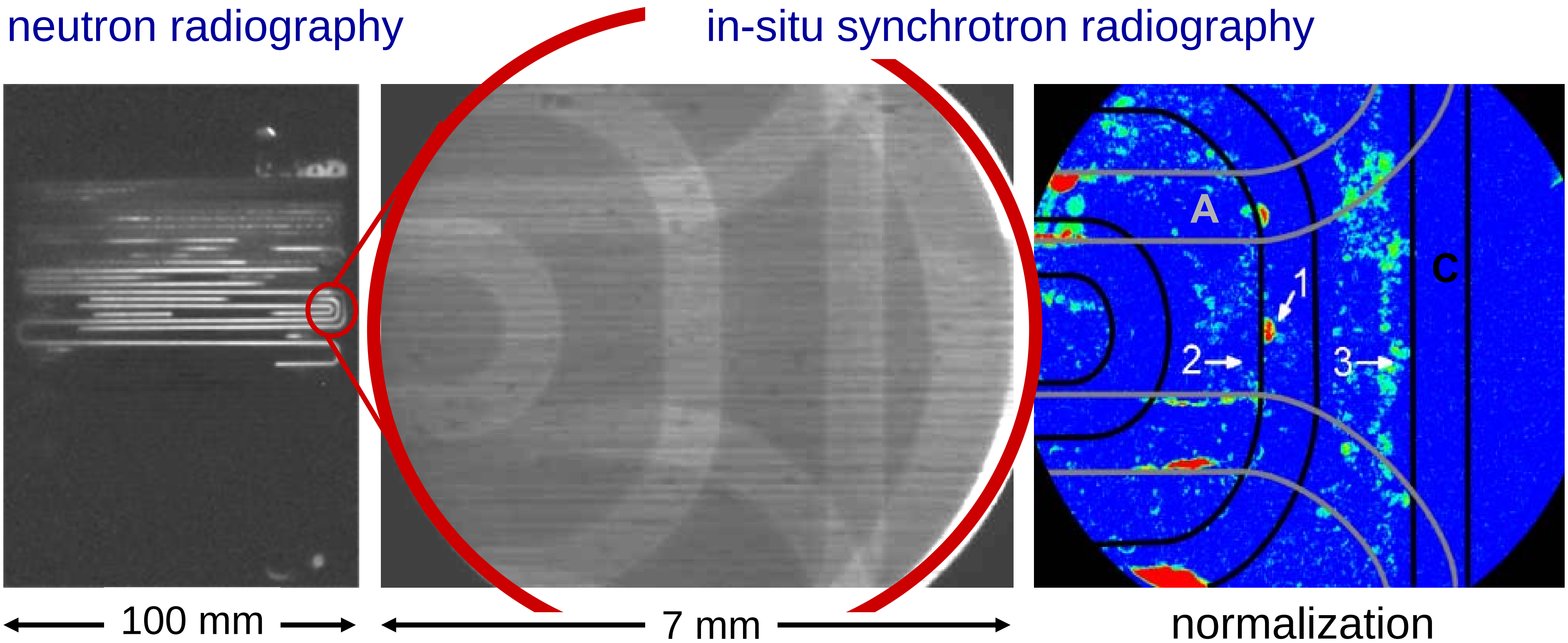
- separate analysis of cells in a multi-stack
- differentiation between anode and cathode

synchrotron radiography

synchrotron radiography



high resolution in-situ synchrotron radiography

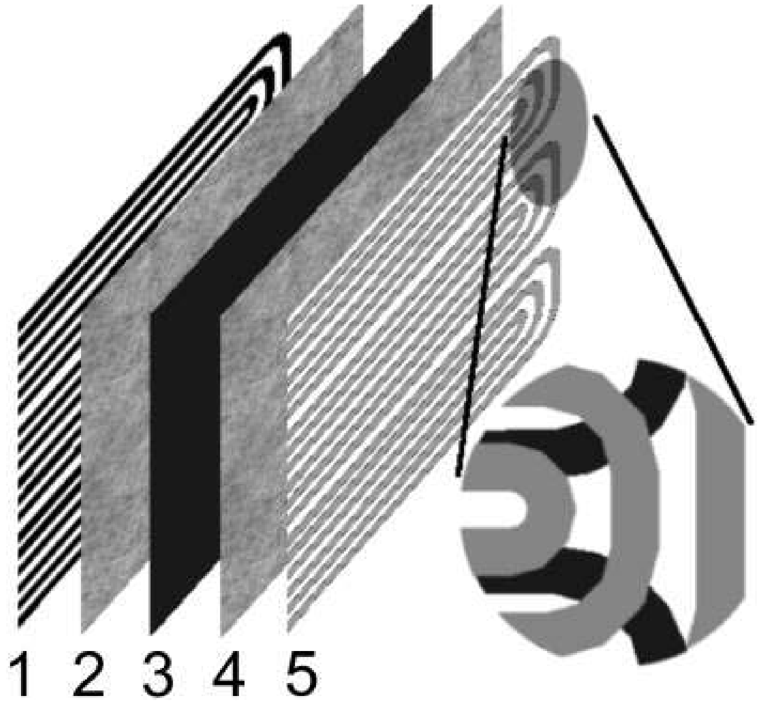


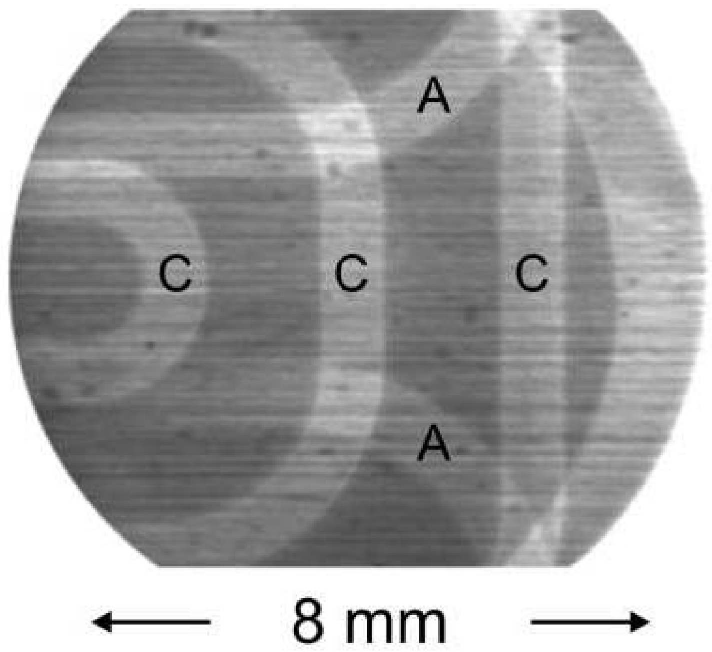
100 times higher spatial resolution +

1000 times higher water sensitivity compared to neutron-based methods

[I. Manke, Ch. Hartnig *et al.* Applied Physics Letters 90, 174105 (2007)]

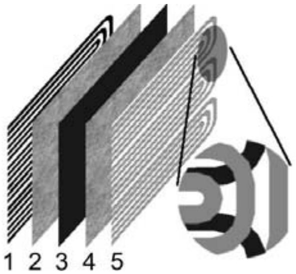
through plane view

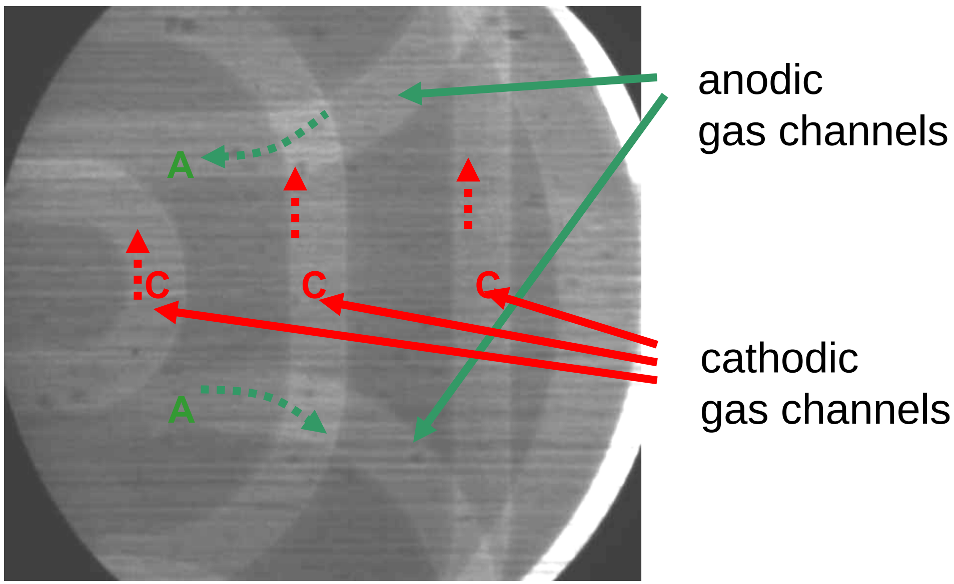




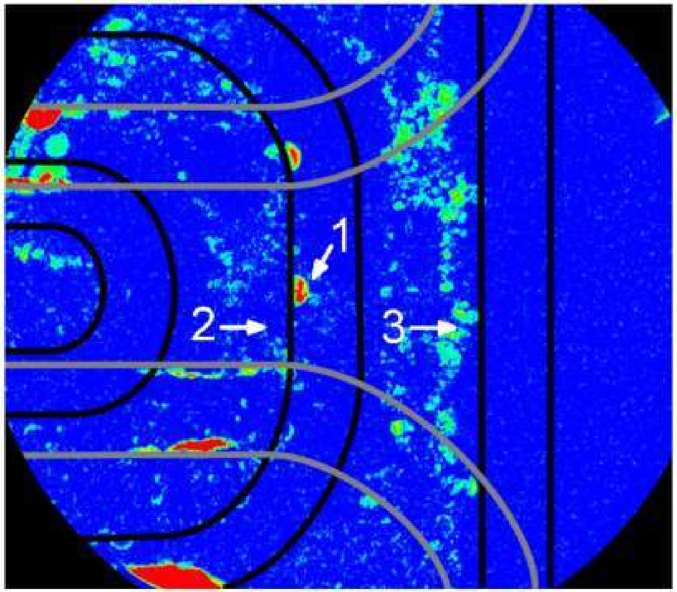
integral imaging: summarized presentation of the cathodic and anodic channels and gas diffusion media

time dependence of liquid water evolution





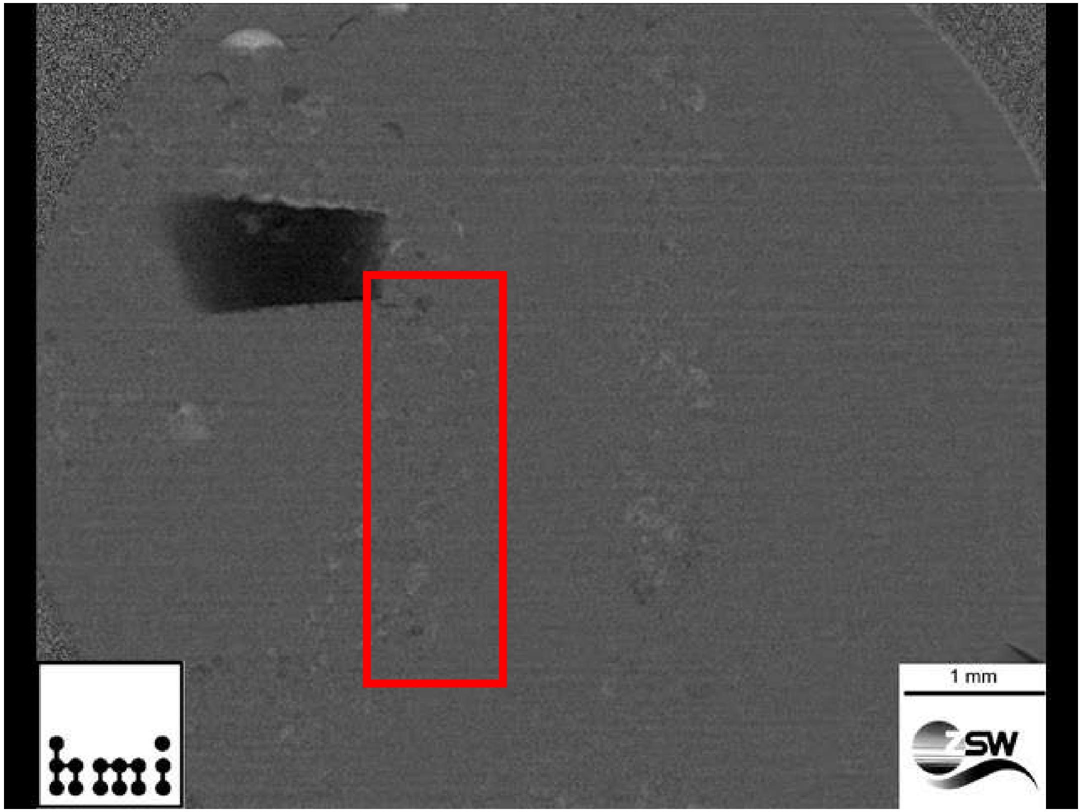
close look at three different spots:
1: in the channel
2: under the rib (next to point #1)
3: under the rib, no periodic pumping observed

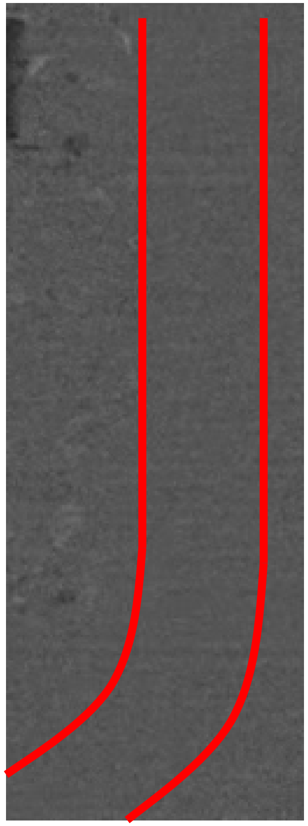


→ time dependence of the ‘filling degree’

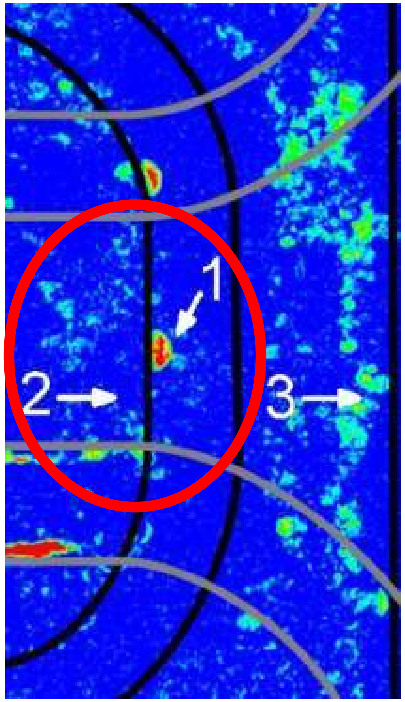
dynamics of liquid water evolution

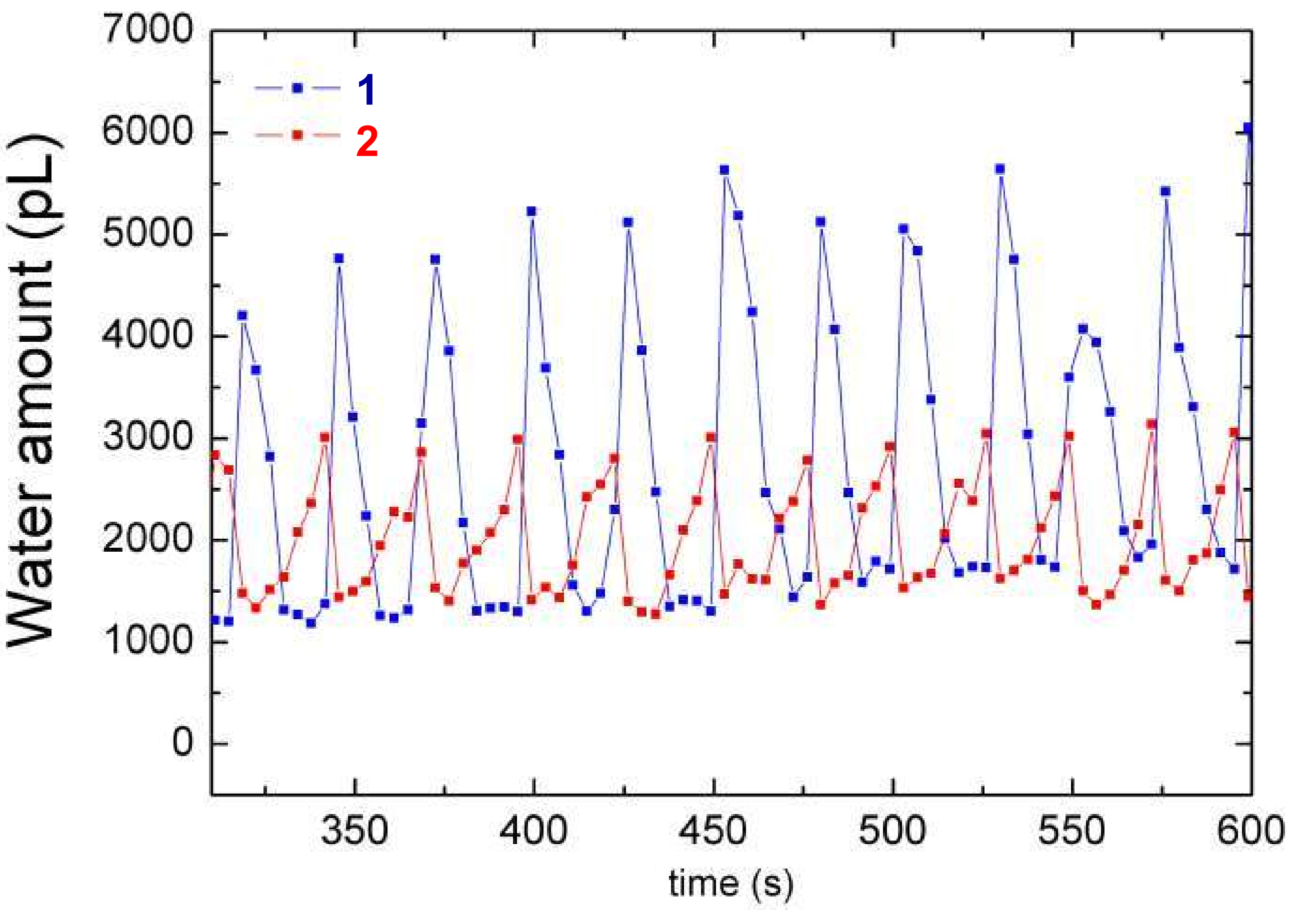
(time lapse movie)





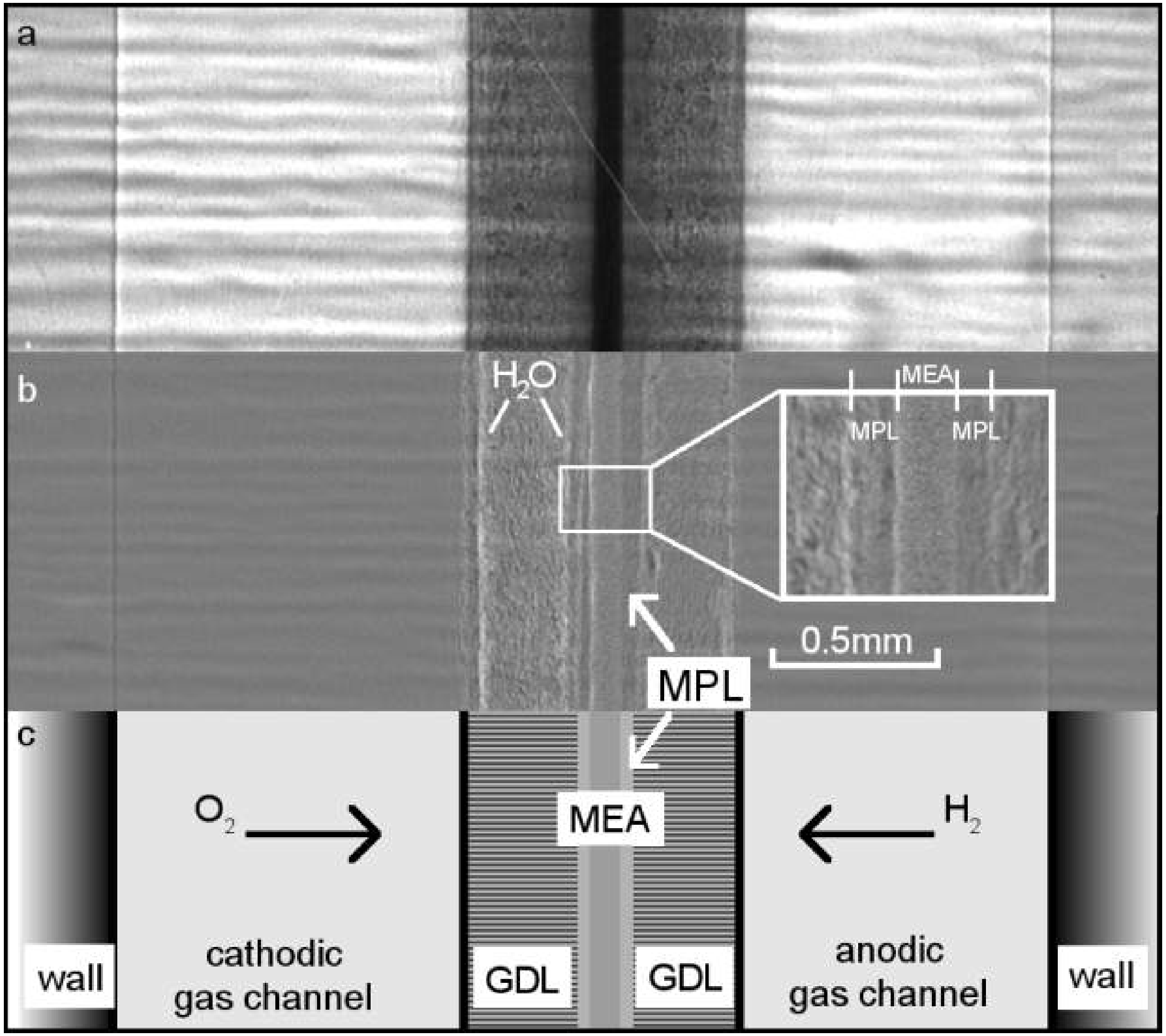
time dependence of liquid water evolution





- strong correlation of water content of the two adjacent positions in the channel and under the rib → transport pathway
- continous filling of the GDL + eruptive emptying of the pores

cross sectional view



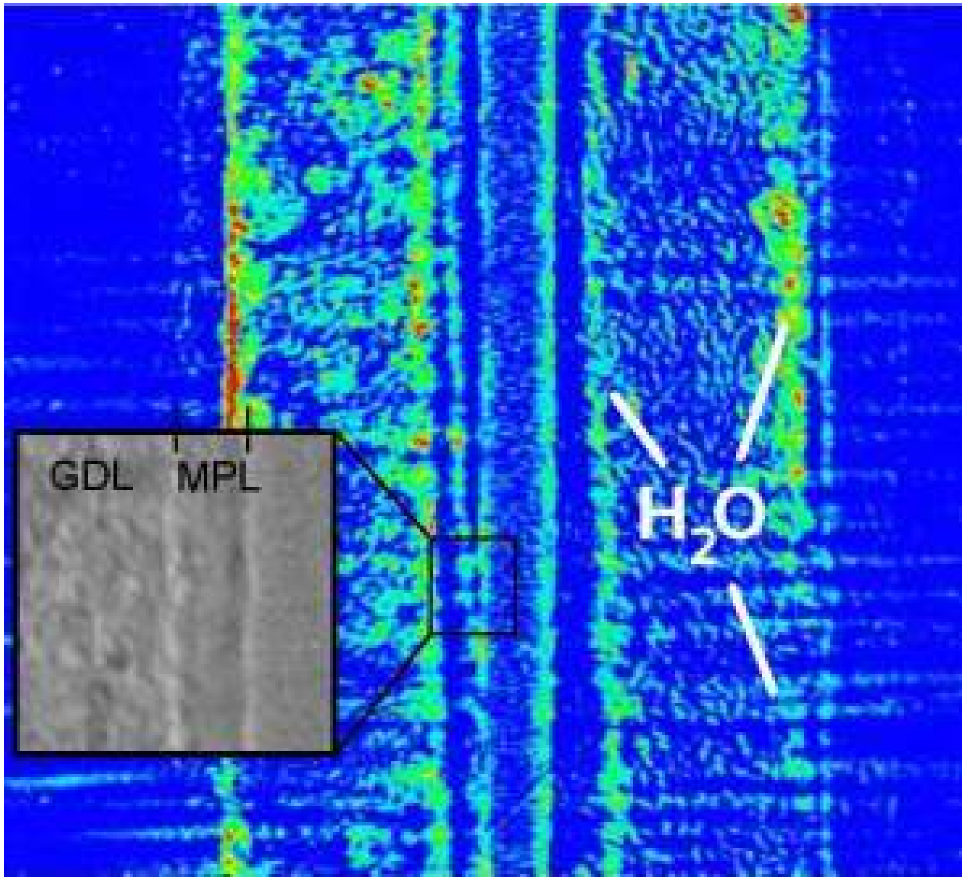
uncorrected image

after normalization with respect to an 'empty cell'

components

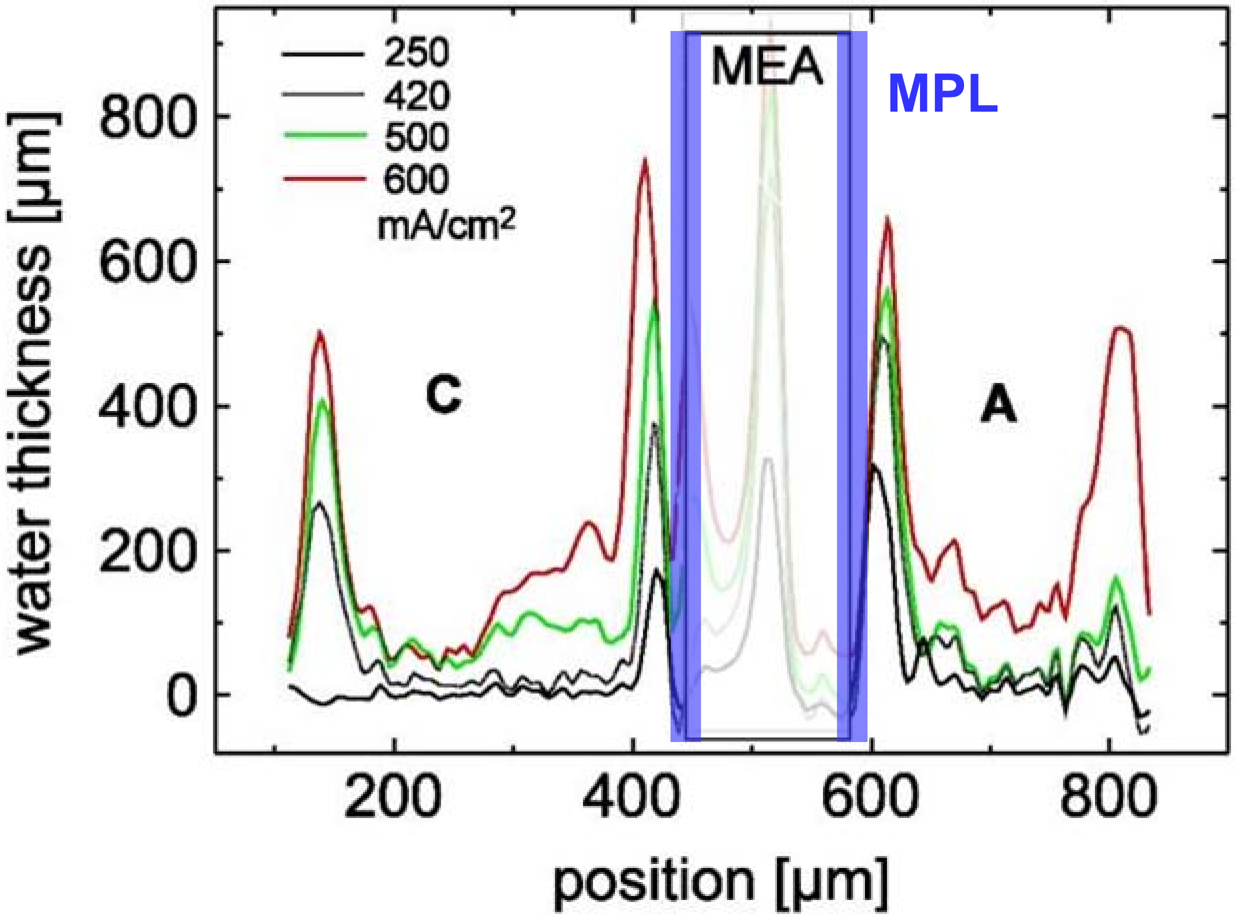
[Ch. Hartnig, I. Manke et. al, APL **92** (2008) 134106]

cross sectional insights



- differentiation between MPL and GDL (substrate)
- small water clusters in the nano-litre range detectable

depth profile of water distribution

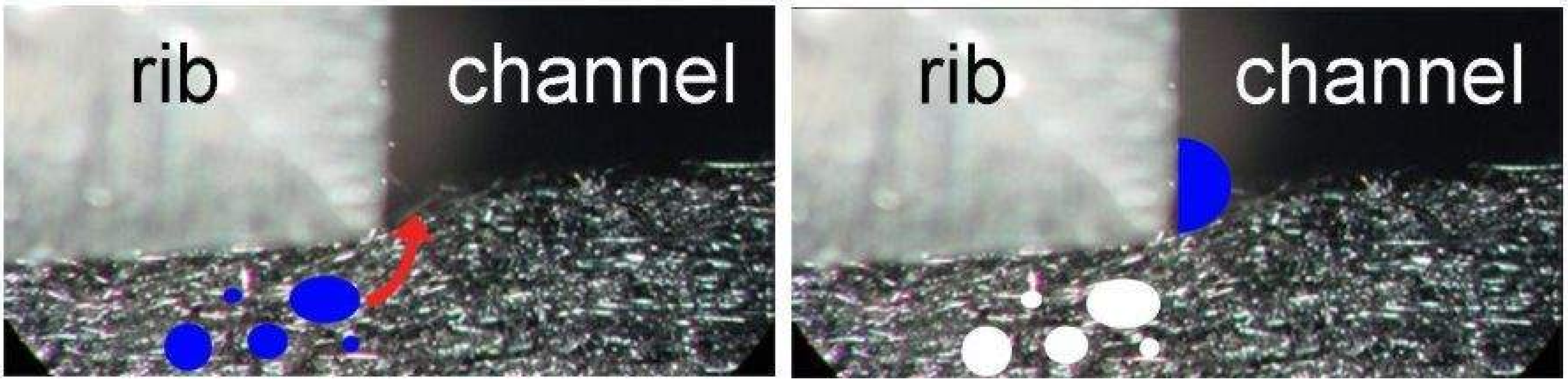


- quantification and differentiation of separate areas possible
- formation of water clusters next to the MPL (temperature difference)
- formation of a second diffusion barrier from i_0 > 400 mA/cm² onwards

augmented reality

proposed model for liquid water transport:

liquid water collects under the lands of the flow fields and is transferred to the channel in an eruptive mechanism



two different contributions:

- liquid water can evaporate and diffuse as vapour through the GDL
- liquid water collects in the GDL and erupts to the channel

conclusion / lessons learned

neutron radiography:

- determination of wet/dry cell regions
- evolution of water cluster on the anode side
- over all cell effects of flooding and opening of channels

neutron tomography:

- 3D distribution of liquid water in fuel cell stacks
- layer-by-layer determination of water distribution:

synchrotron radiography:

- initial formation of liquid water under the lands of the flowfield on the cathode side
- visualization of micro structure transport pathways

acknowledgements

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thank you for your attention!