ADVANCED INSTRUMENTATION AND DIAGNOSTICS FOR TWO-PHASE FLOW RESEARCH

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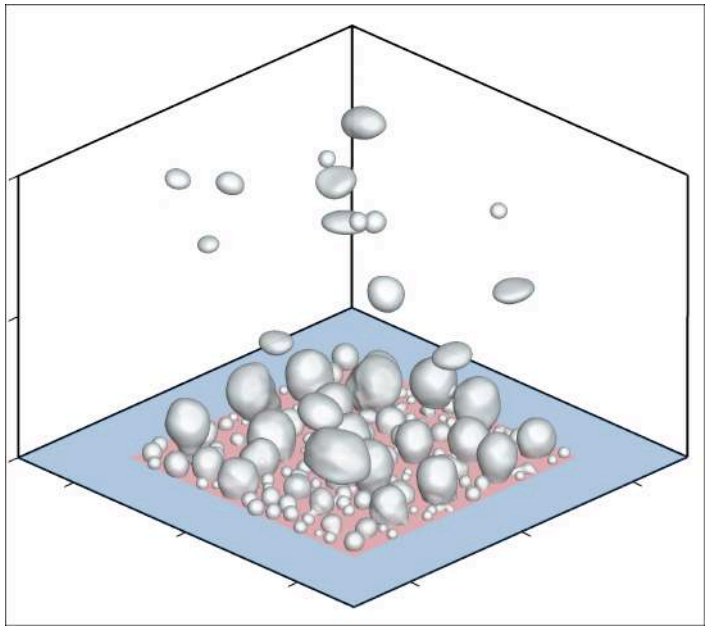
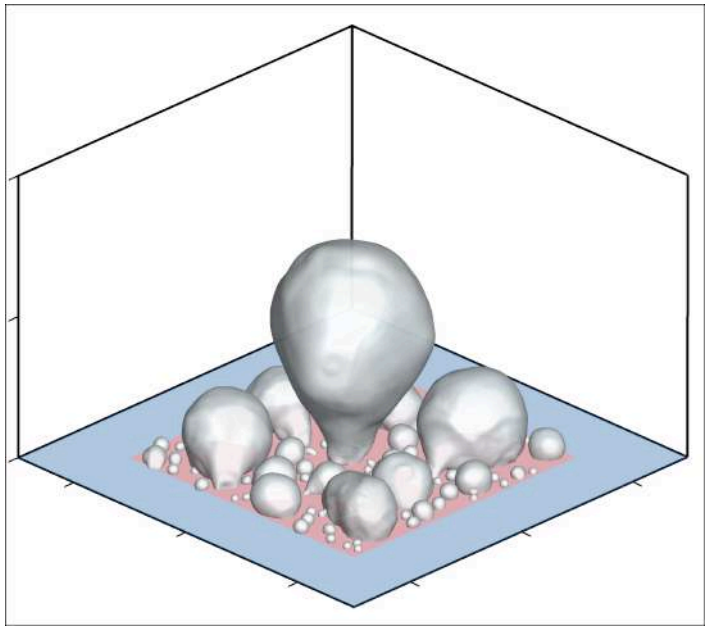
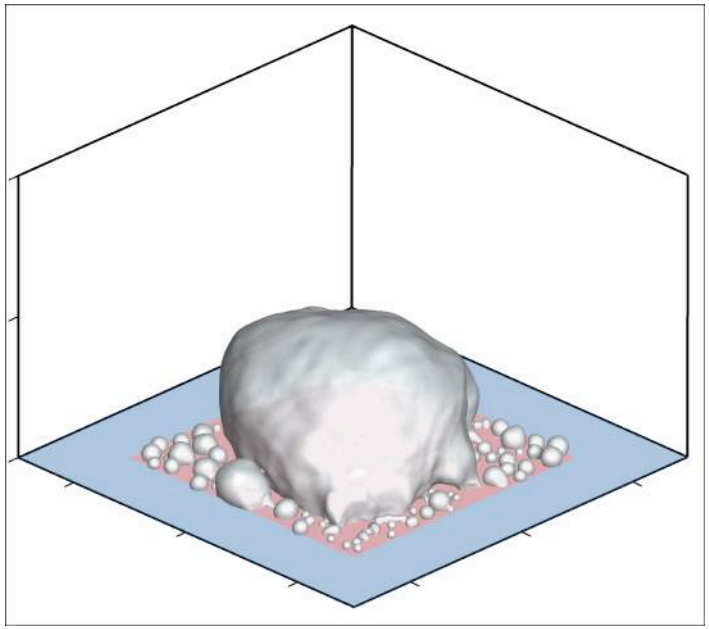
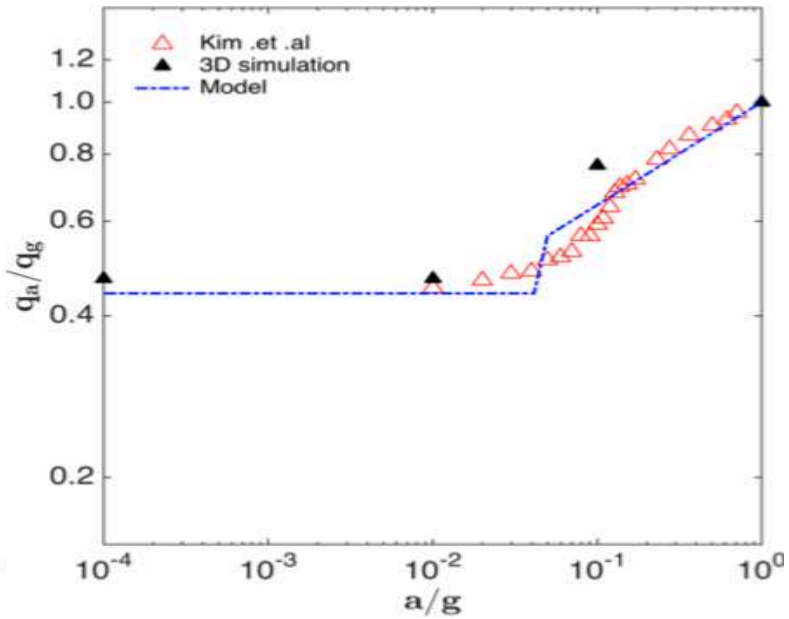
December 4, 2019

Numerical Simulations (GWU/UMD)



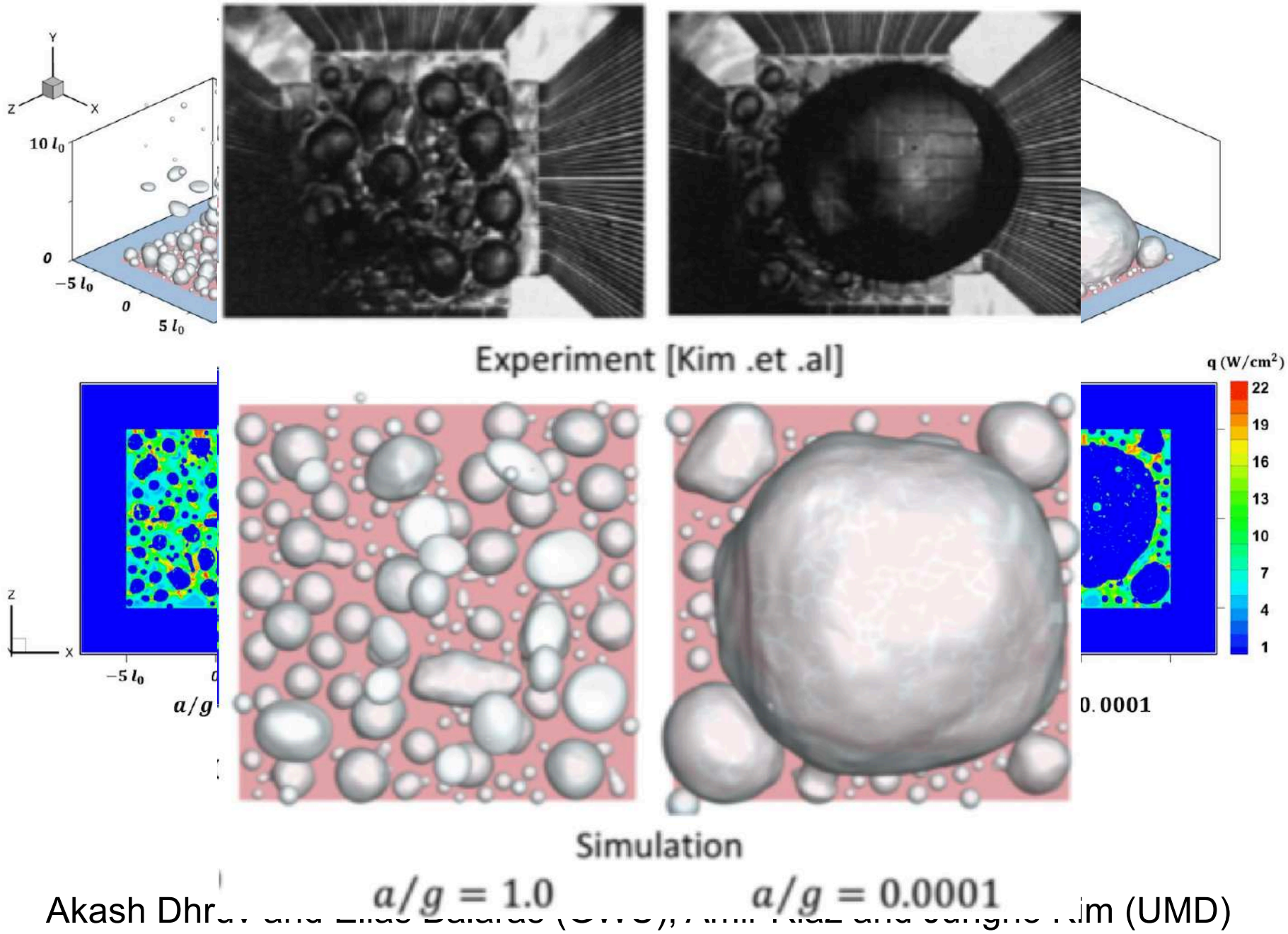






Akash Dhruv and Elias Balaras (GWU), Amir Riaz and J. Kim (UMD)

Pool Boiling Simulations (GWU/UMD)



Akash Dhruv and Elias Balaras (GWU), Amir Riaz and Junghee Kim (UMD)

How to Validate Numerical Simulations?

- Need a new generation of experimental capability to generate needed reference data

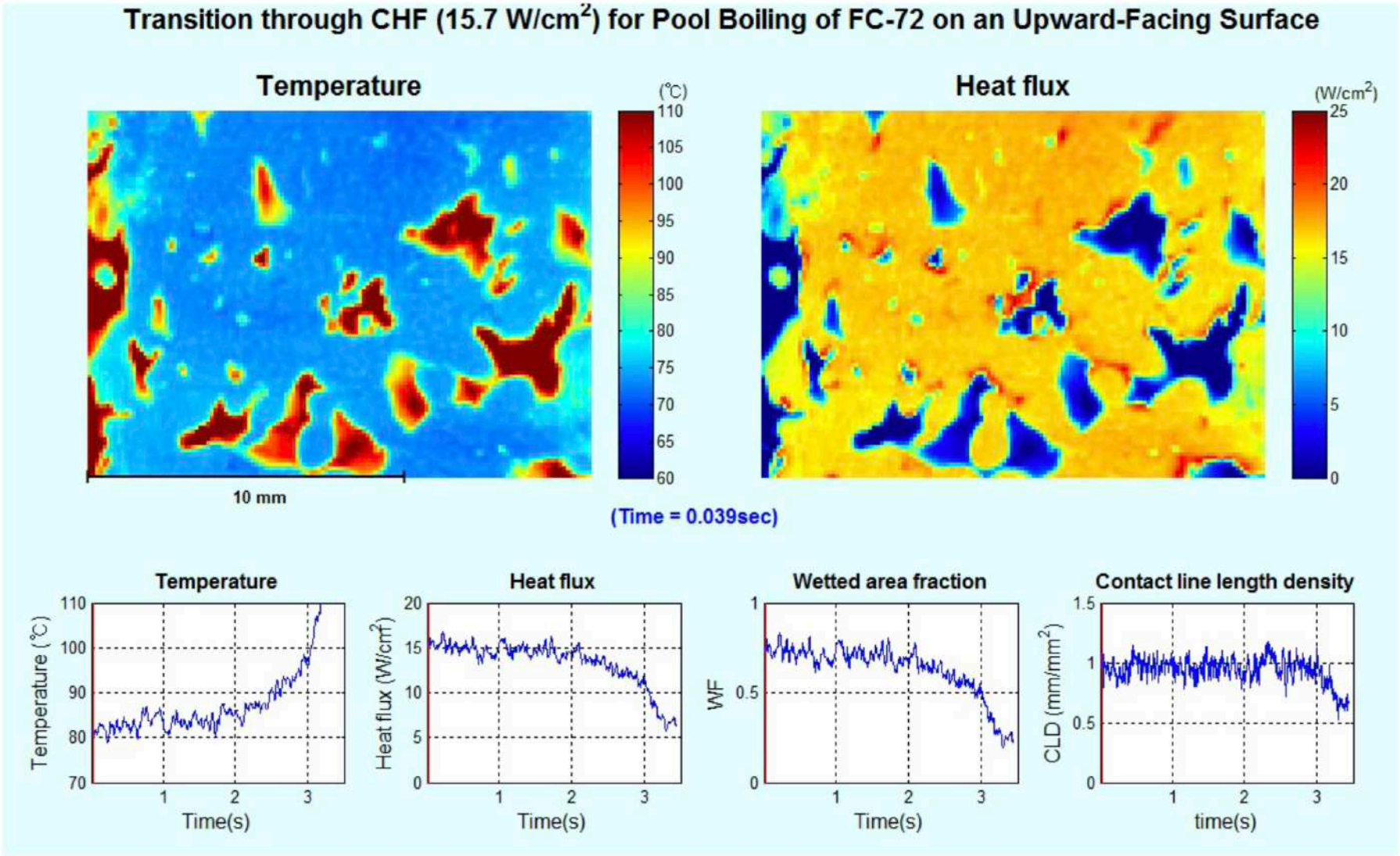
- Full field measurements of wall heat fluxes

- Measurements of full field data at small scales, e.g., within thin film and contact line, wetting of enhanced surfaces

- Measurements within the fluid

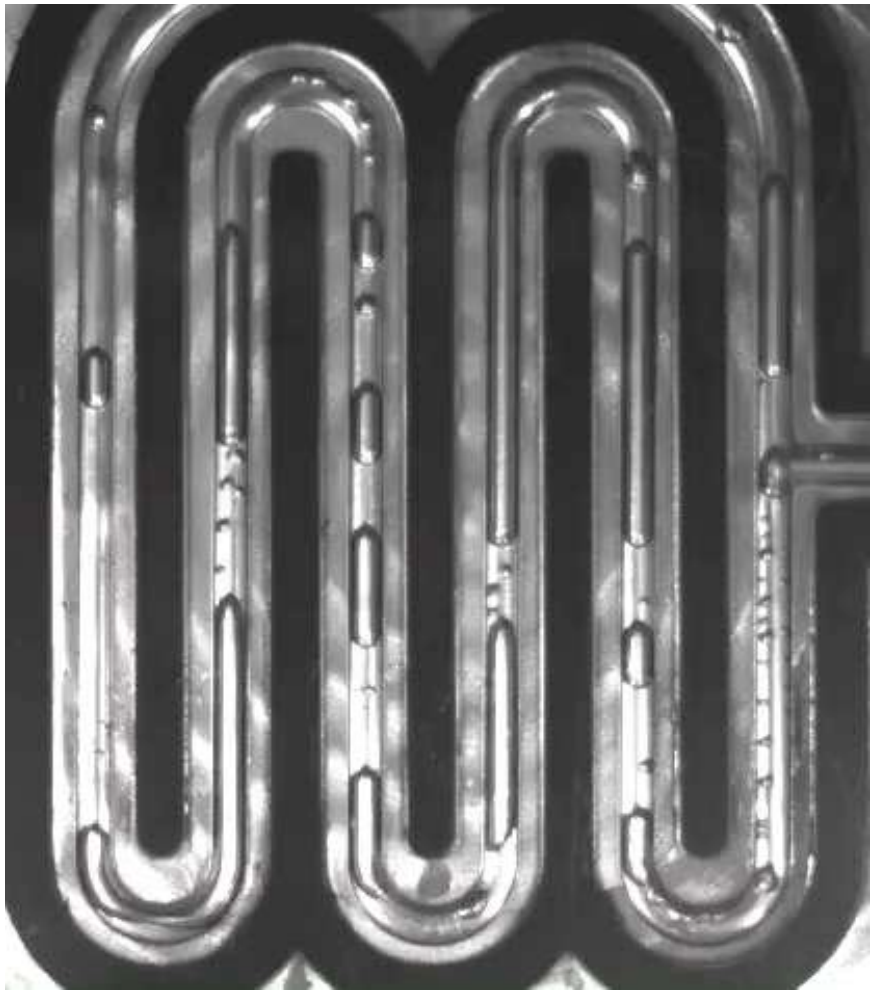
Full Field Wall Heat Transfer

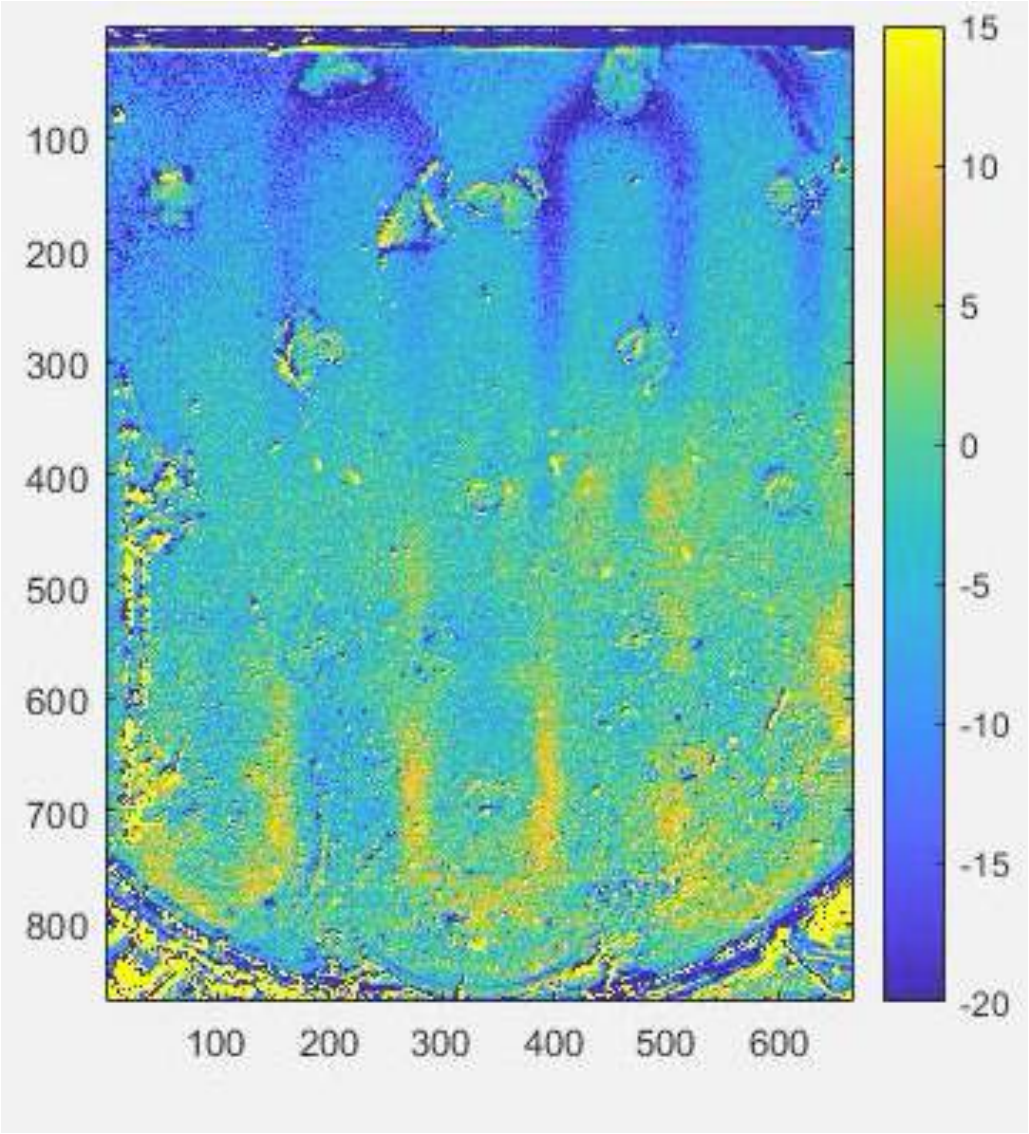
Wall Temperature and Heat Flux: Pool Boiling



Infrared measurements through a heated silicon heater

Wall Heat Transfer in Oscillating Heat Pipe





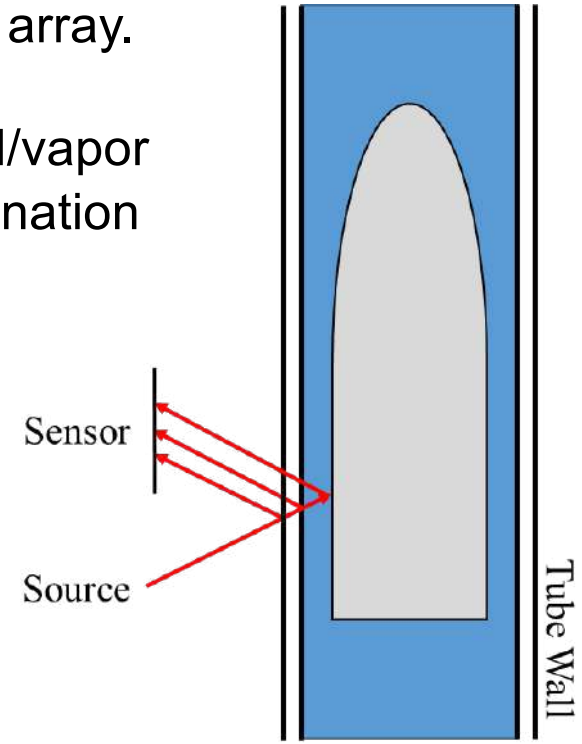
Temperature Sensitve Paints

Thin Film Measurements

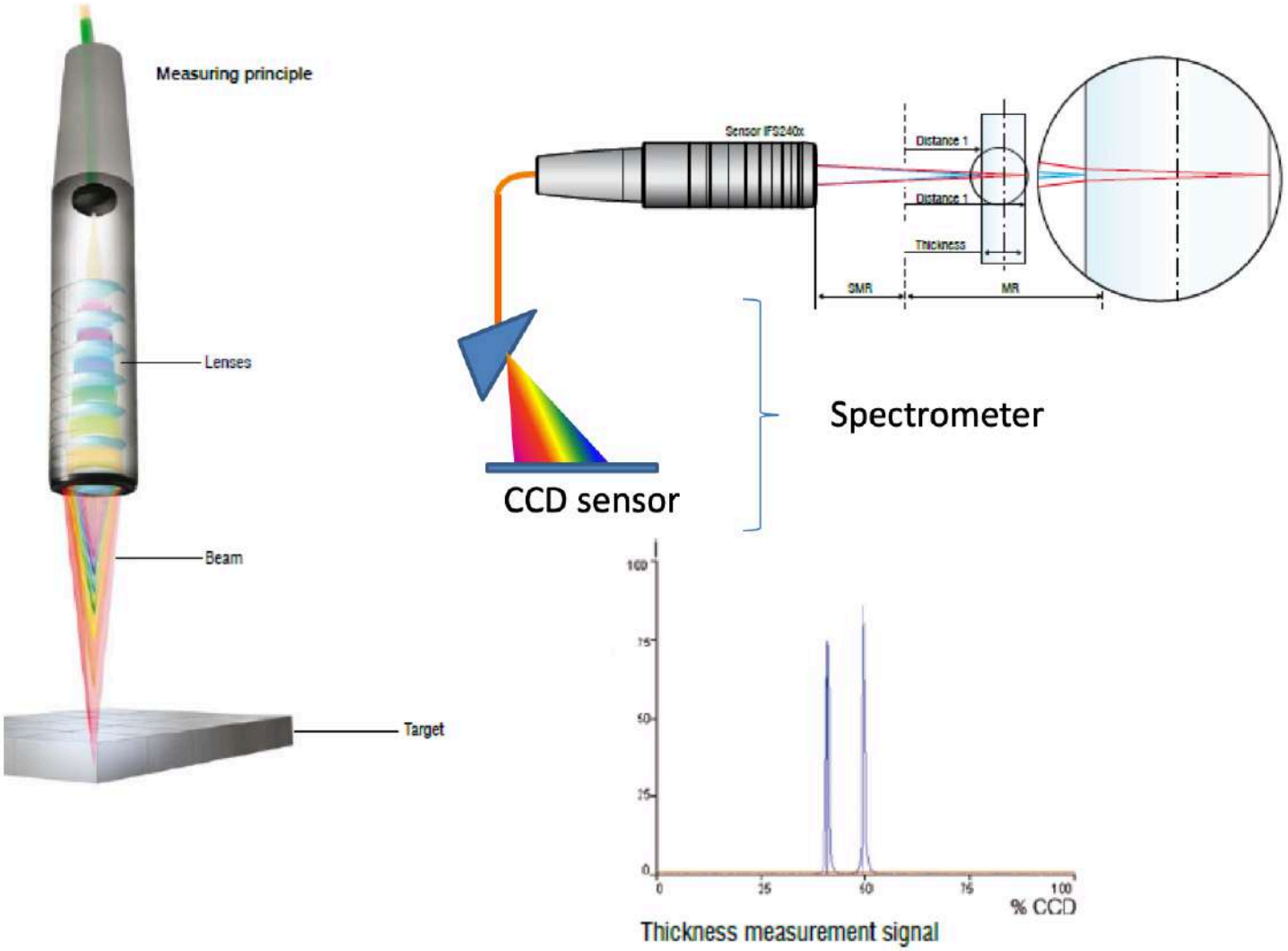
Thin Film Measurements: Triangulation

Keyence LK-G5000: Triangulation method

- Laser light exiting the sensor head at a specified angle is reflected from the inner and outer walls of the tube and from the bubble liquid/vapor interfaces
- Reflected beams intercept the sensor measurement array.
- The location at which the light reflects from the liquid/vapor interface depends on the film thickness, n, and inclination of the interface.
- Fast response (10's of kHz)
- Relatively low cost (~$8000)
- Only good for relatively flat interfaces



Thin Film Measurements: Confocal



High Resolution Thin Film Measurements

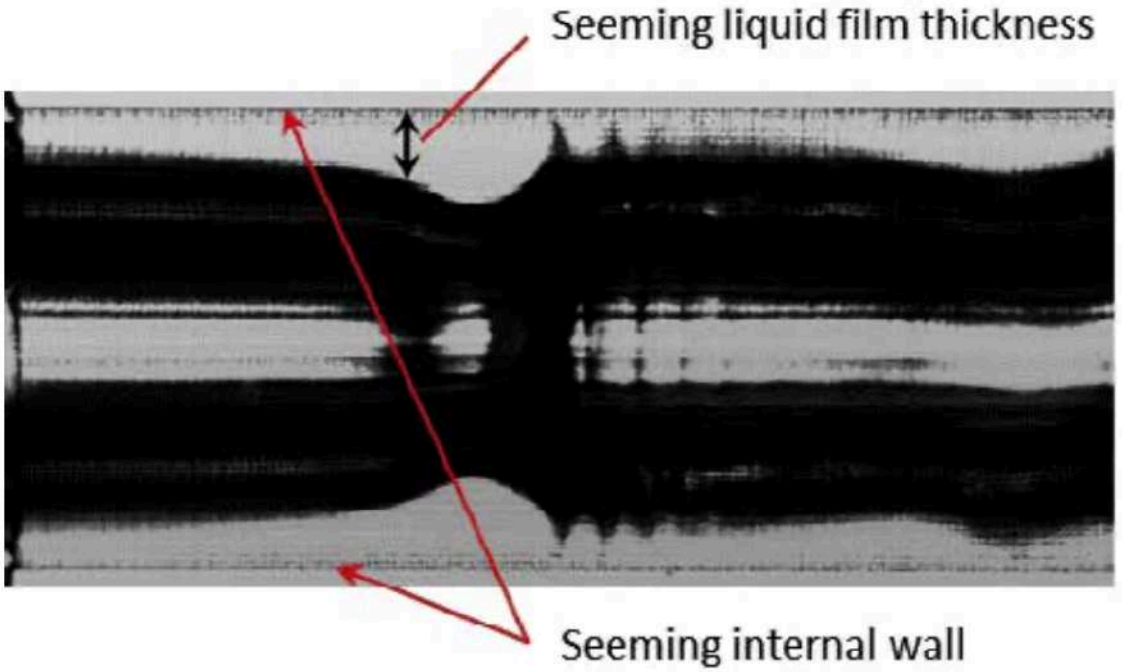
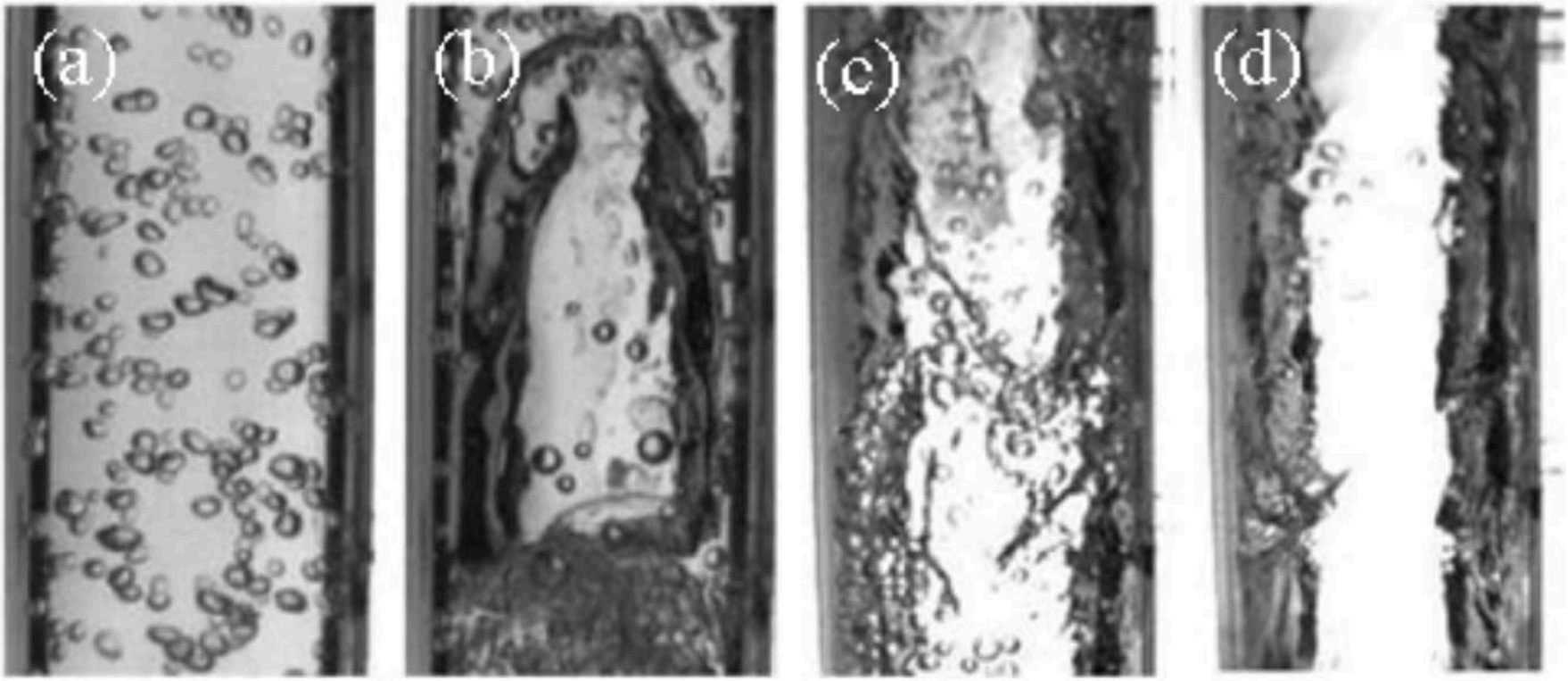


Figure 4: Example of image showing the magnification of liquid film thickness during microgravity inside a tube of 3.4 mm internal diameter.

Lavieille, Pascal et al (U. of Toulouse), New Measurement Technique of Liquid Film Thickness Distribution with High Spatial and Temporal Resolution: Application to Convective Condensation in Microgravity, 14th ITTW, Granada, Spain, 2019.

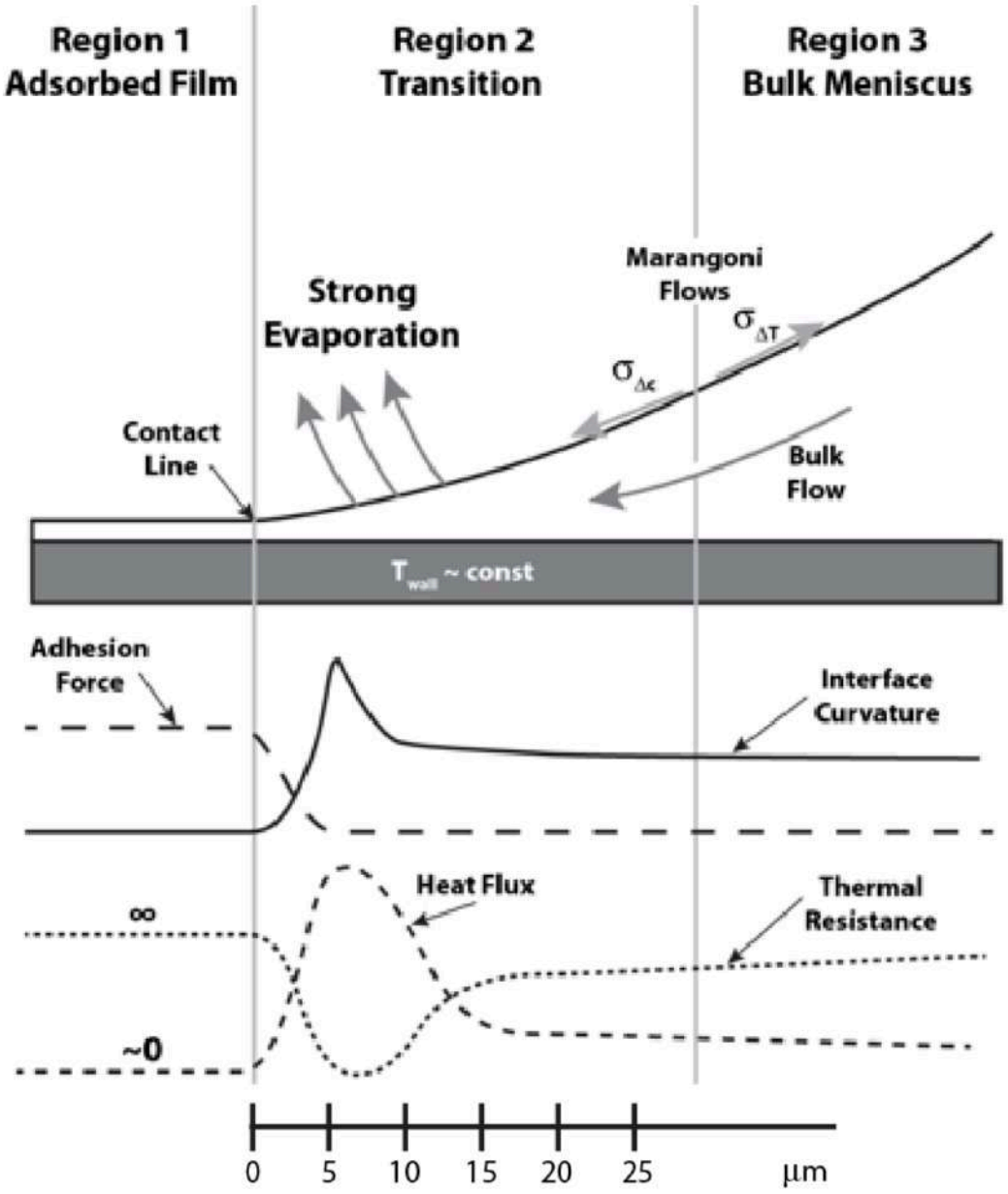
Bubbly Flow and Wavy Thin Films?



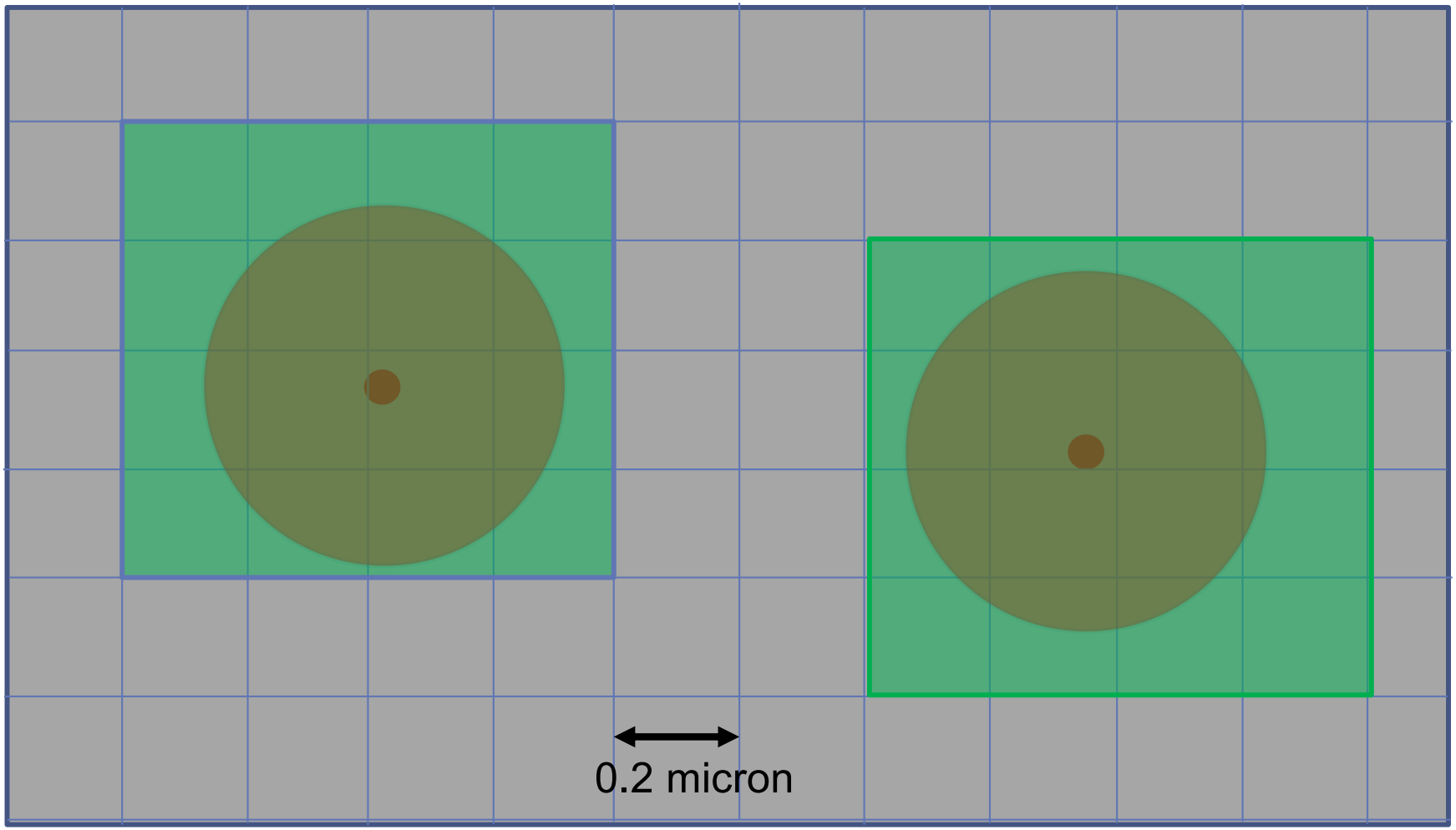
Example of the flow patterns in the vertical two-phase flow. Left to right: (a) bubbly flow; (b) slug flow; (c) Churn-Turbulent flow; (d) annular flow.

Contact Line Heat Transfer

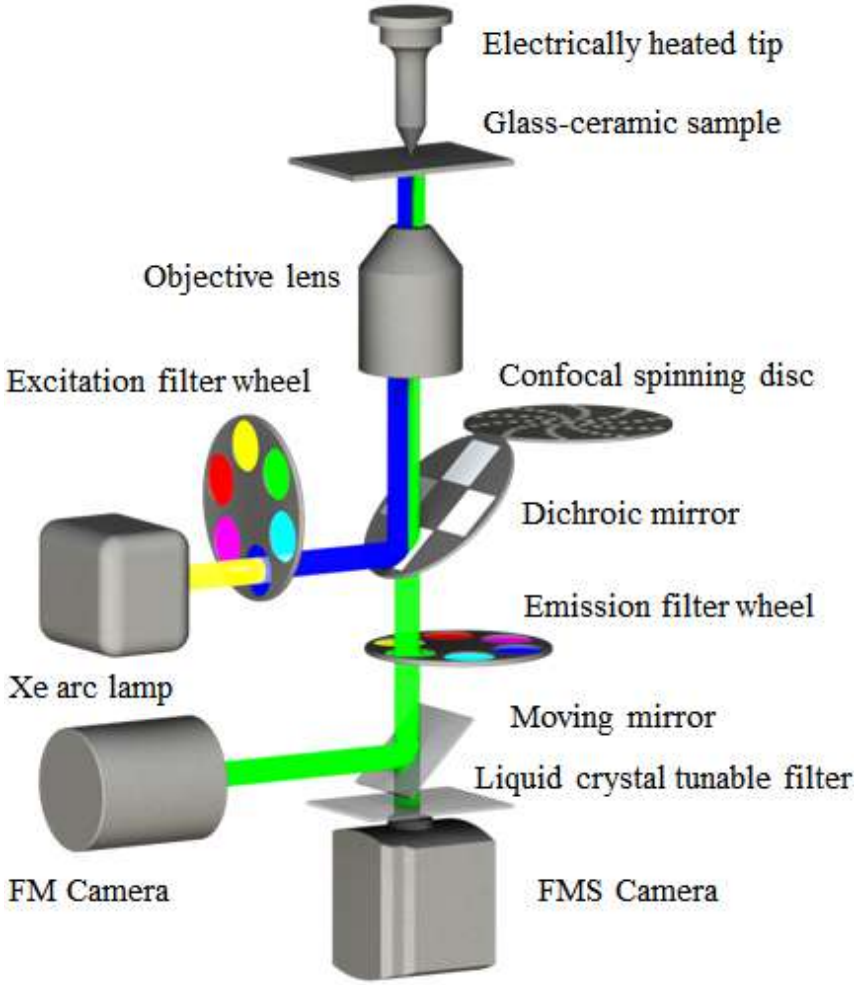
Contact Line Physics



Heat Transfer Measurements on the Submicroscale



Confocal Fluorescence

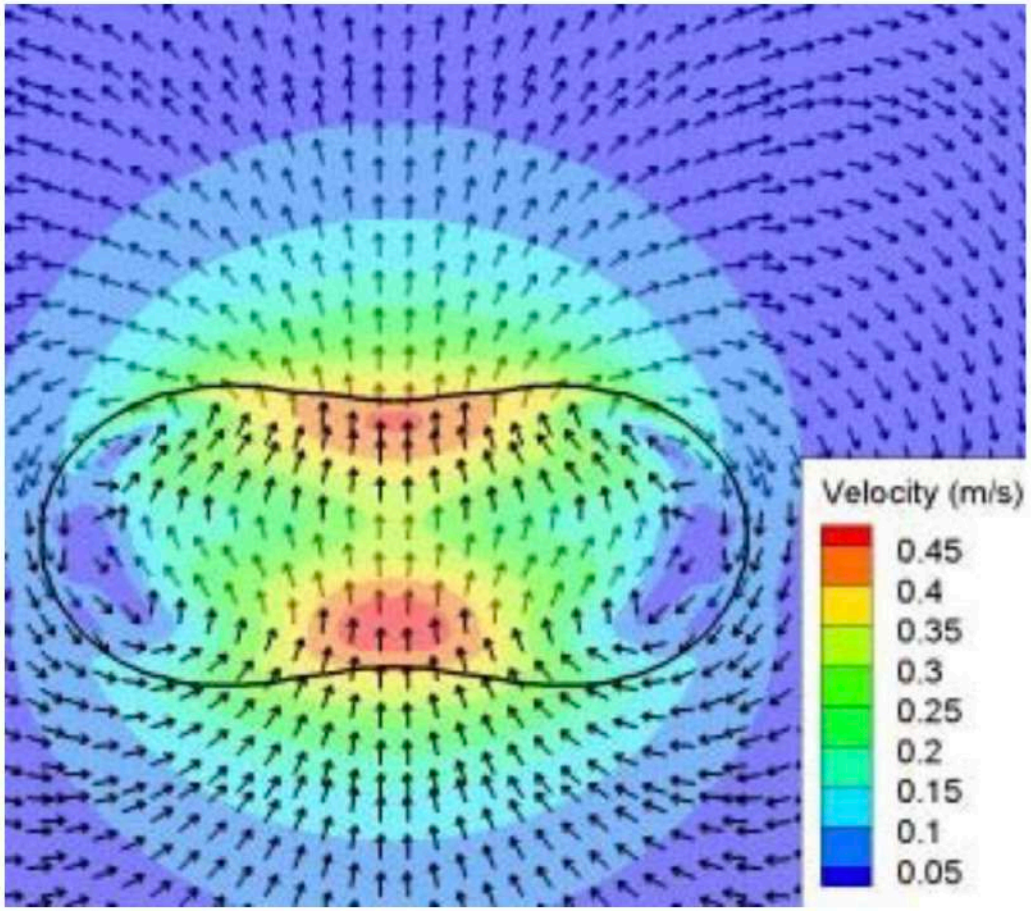


- Scanning to obtain 2-D temperature distribution within solid to get heat flux
- 400-500 fps with 0.5-0.74 micron resolution
- 1-2 K temperature resolution

Golobic and Strancar, Ljubljana, Slovenia

Measurements Within the Fluid

Full-Field Measurements Within the Fluid



Bubble shape, velocity vectors, and velocity magnitude contours for Bo=0.5 and A/D=0.1, (a) t=T/4, (b) t=T/2, (c) t=3T/4, (d) t=T

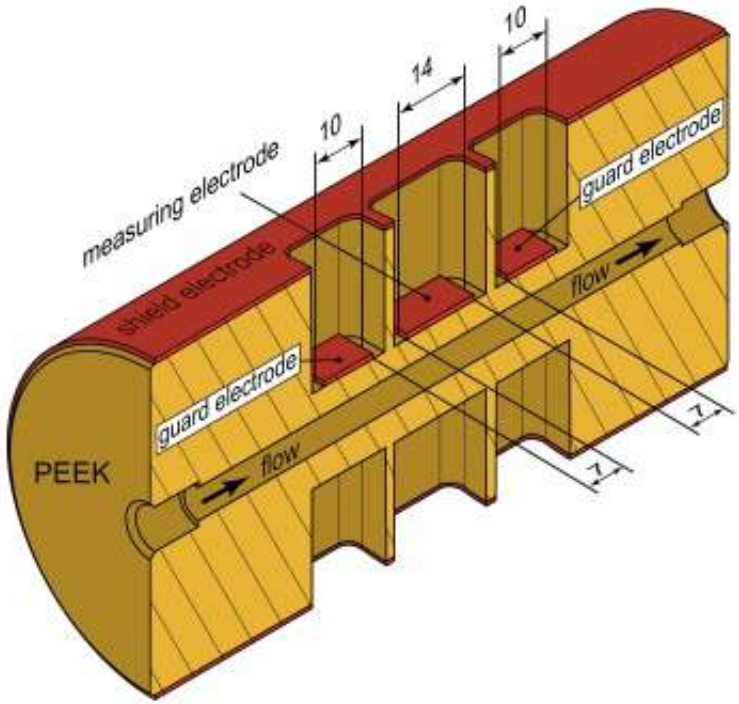
- Flow and temperature distributions
- Images of voids
- Fluorescence techniques have been tried with PIV
- Limited access to fluid due to bubbles.

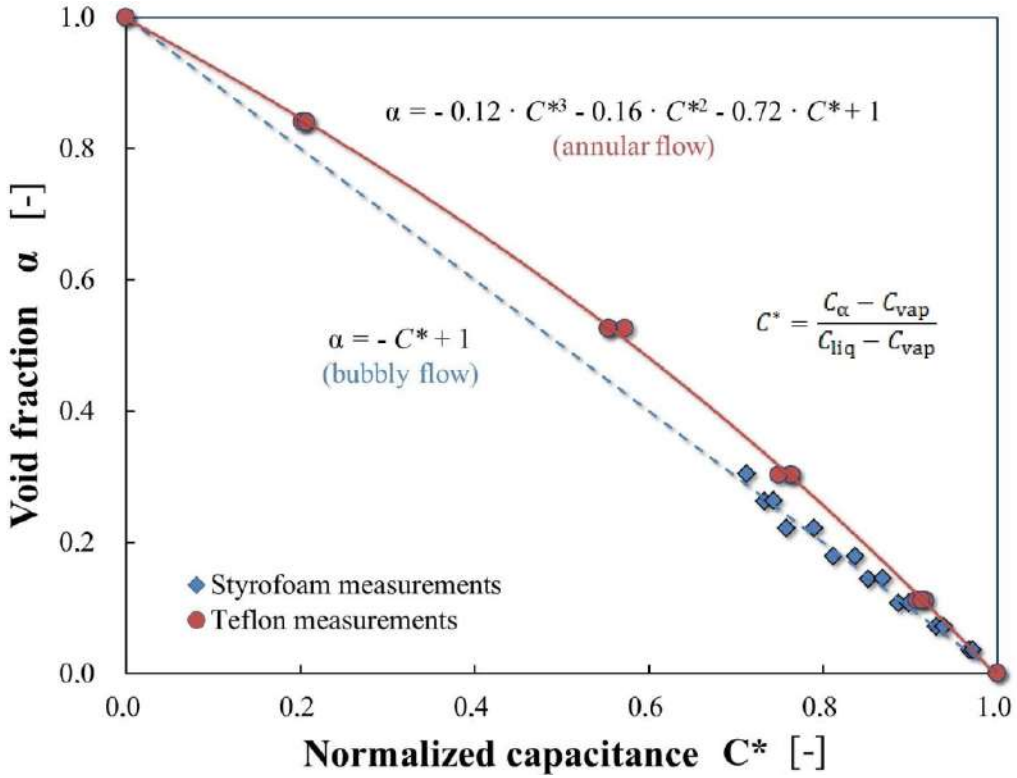
Markus Bussmann

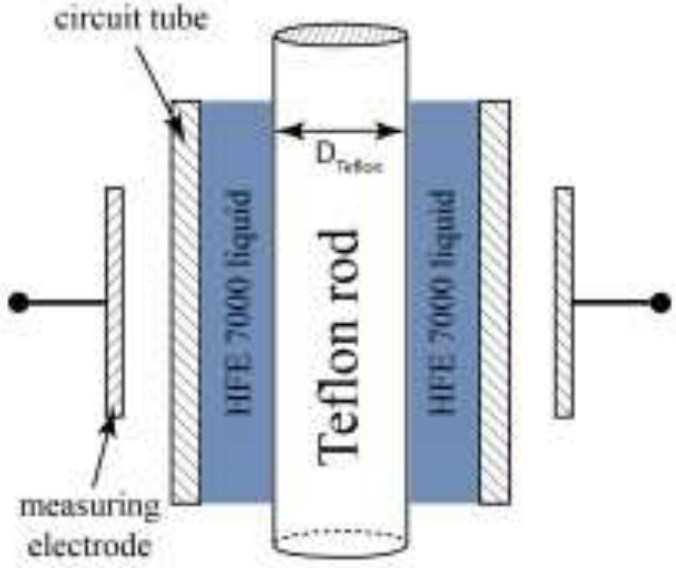
Capacitance probes:

· measurement of capacitance between two copper electrodes

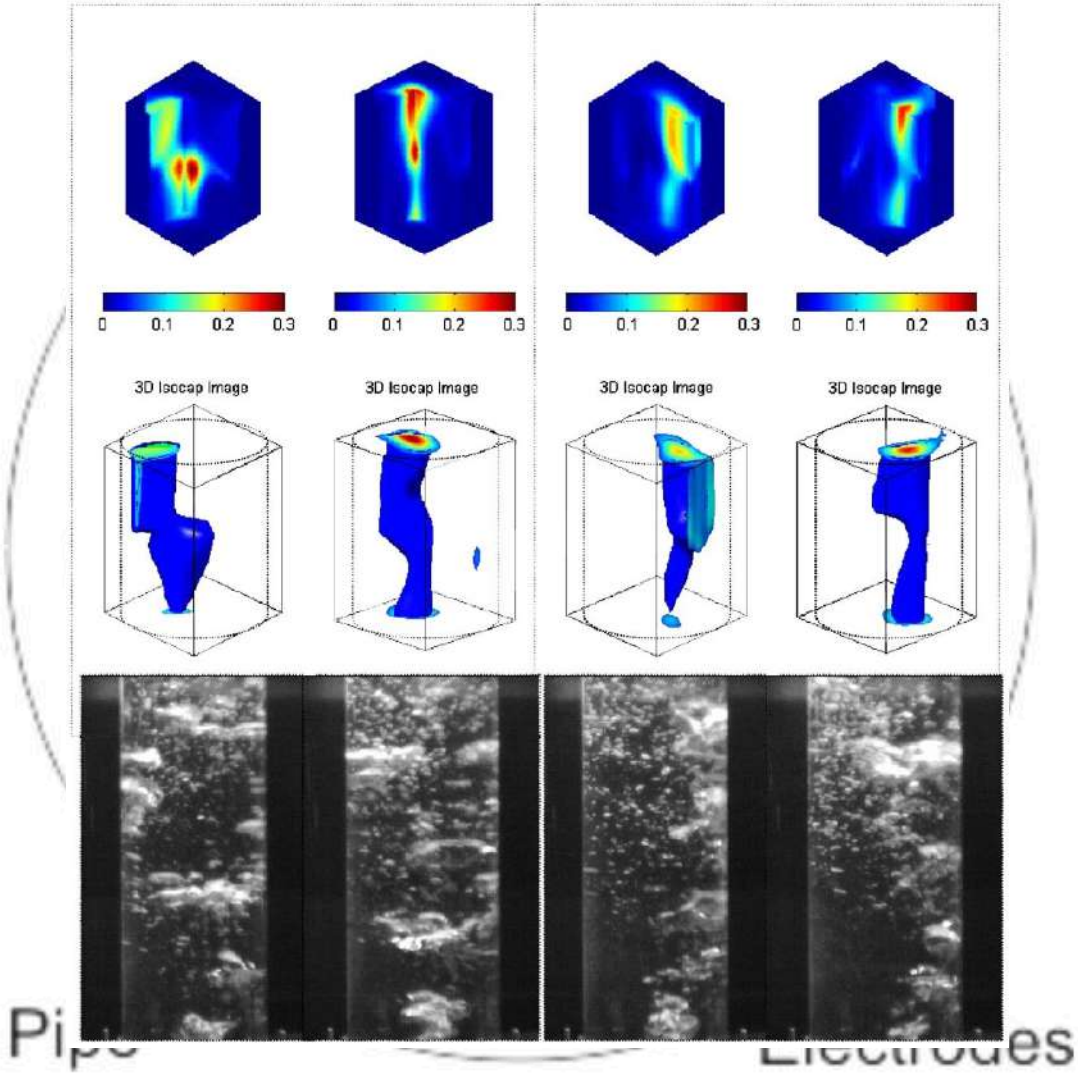
· experimental calibration using Teflon rods + numerical simulations with COMSOL







Tomography (Capacitance, Impedance, Resistivity)



Electrical Capacitance Volume Tomography

Warsito, W.; Fan, L.-S. (2005). "Dynamics of spiral bubble plume motion in the entrance region of bubble columns and three-phase fluidized beds using 3D ECT". *Chemical Engineering Science*. **60** (22): 6073–6084.

Computer Tomography: X-ray

https://youtu.be/ukY89OlOR3M

https://youtu.be/VLL7MDJQG9c

https://youtu.be/s7Wjl5lPGzU

https://youtu.be/-bOFRHgCOV0

3D Neutron Radiaography, Nuclear Rod

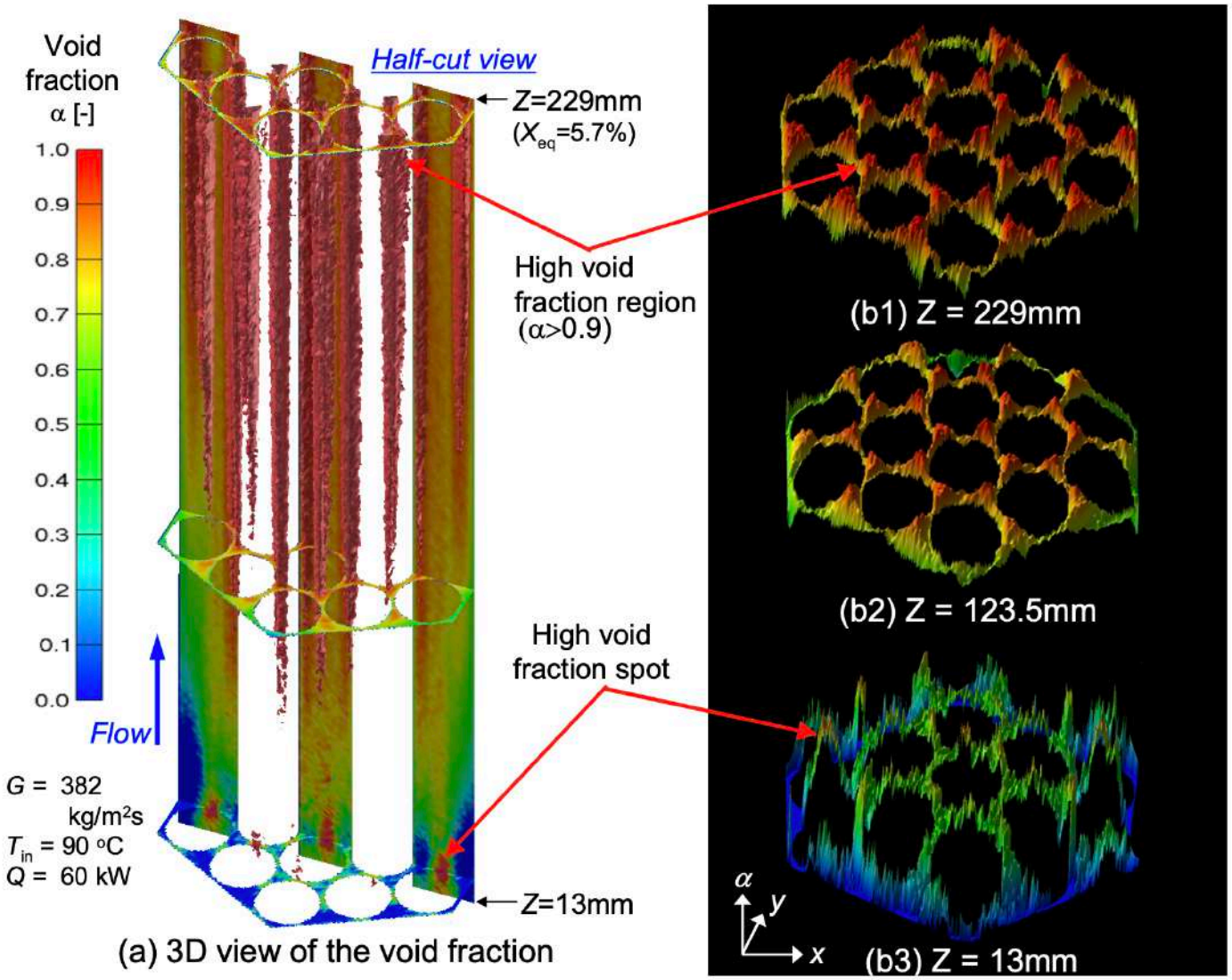
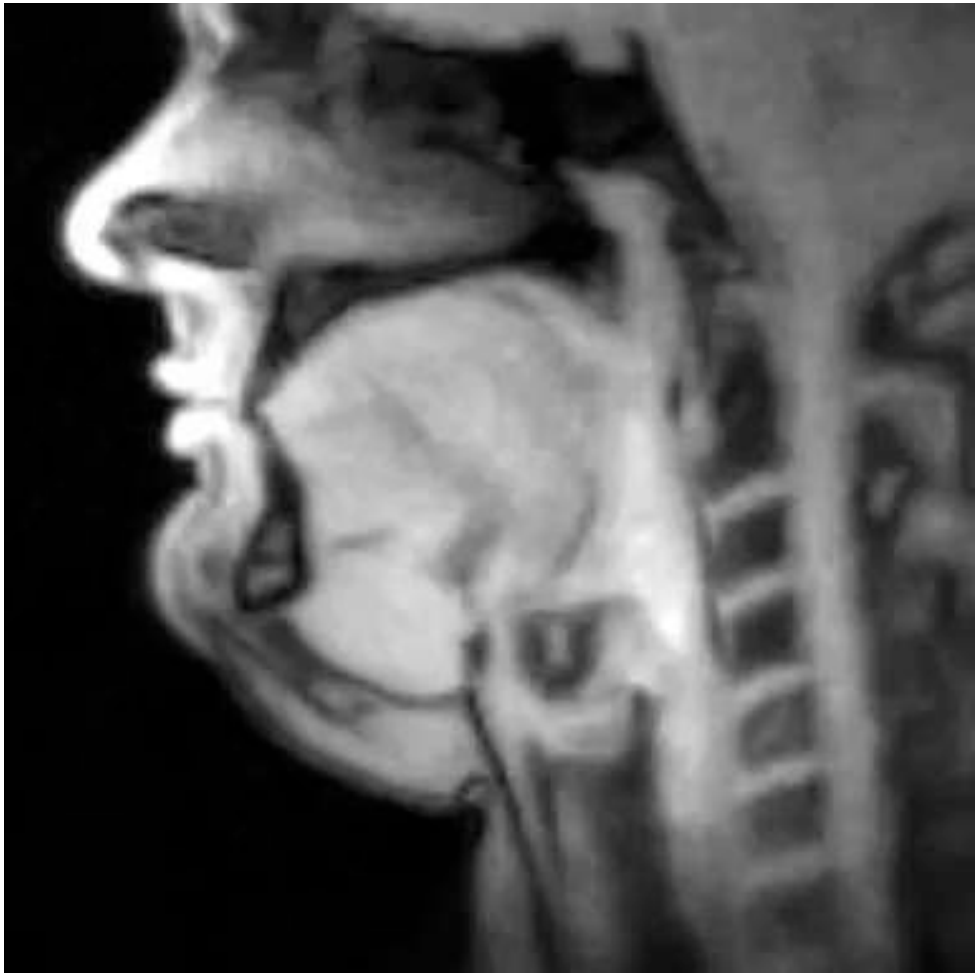


Fig. 13 Visualization of the void fraction distribution

Kureta, Masatoshi, JAEA, 2007

Nuclear Magnetic Resonance Imaging



M. Uecker, S. Zhang, D. Voit, A. Karaus, K.D. Merboldt, J. Frahm. Real-time MRI at a resolution of 20 ms. NMR Biomed. 23, 986-994 (2010)