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Simulation of the Acoustic Environment for the Manufacture of Graded Porosity of Materials by Sonication

COMSOL Conference,
Hannover
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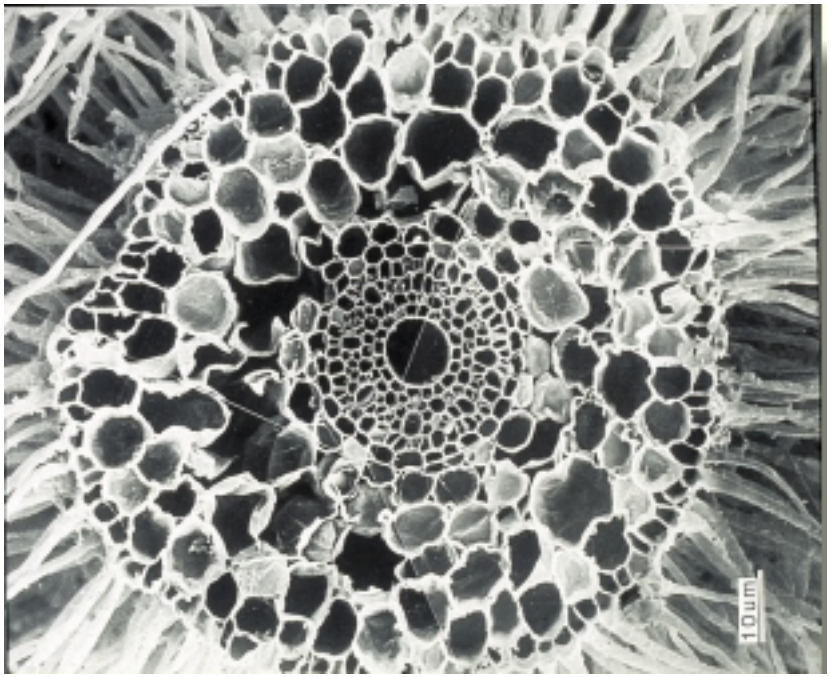
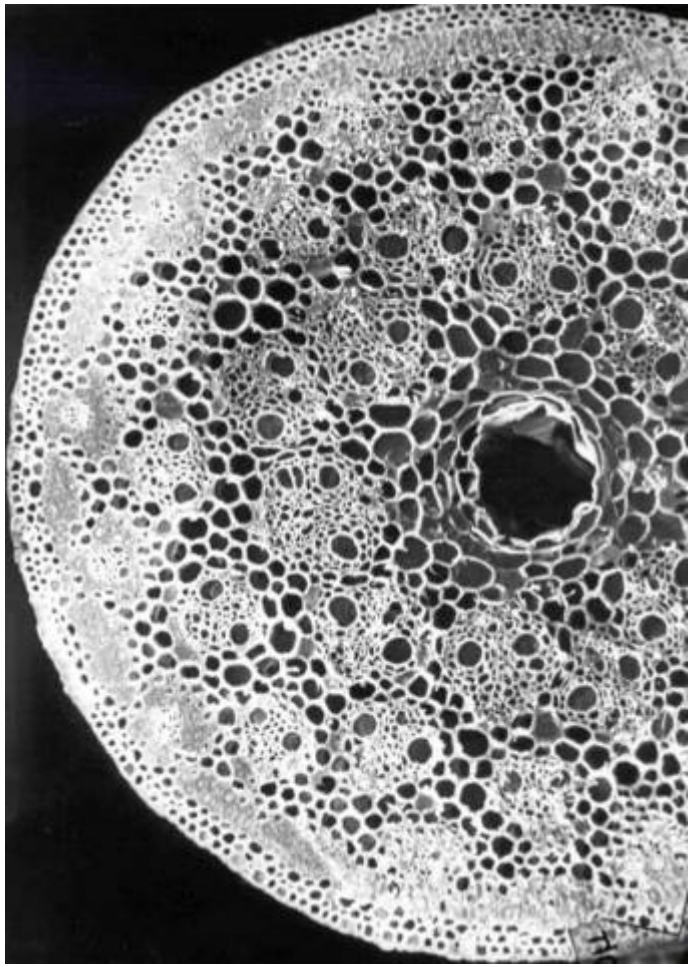
Motivation

CPD (Critical Point Dryer) Images



Root Hair, cryo-SEM preserved. As appeared in www.quorumtech.com on 8th June 2008



Transverse fracture of the young stem of young Bamboo (*Bambusa sp*) stem demonstrating xylem and phloem bundles and heavily thickened (lignified) epidermal and hypodermal cells. As appeared in www.quorumtech.com on 8th June 2008

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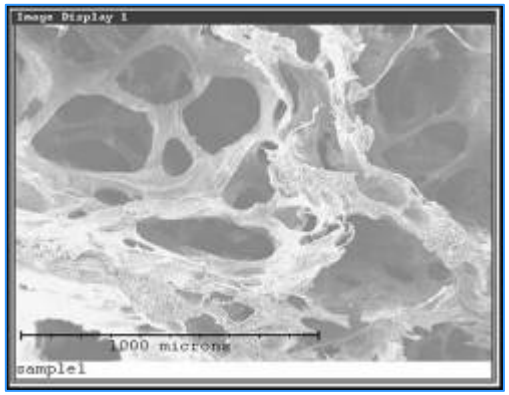
Outline

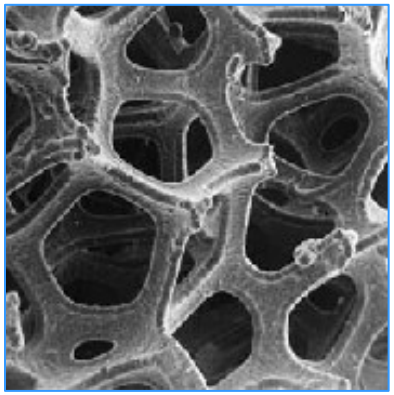
- Motivation
- Application of the manufacturing technique and its potential
- Results : engineered graded porous foams
- COMSOL modelling : boundaries and settings
- Acoustic Environment : control and comparison exp vs model
- COMSOL model : limitations and opportunities
- Research Opportunities in the manufacturing of materials

Motivation

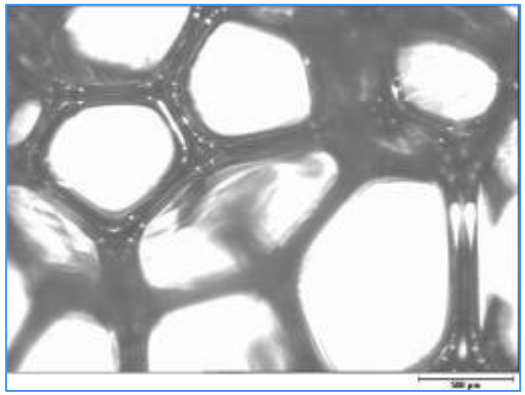
Synergy :: gradients of composition, structure, properties



(a) Natural Sponge[1]

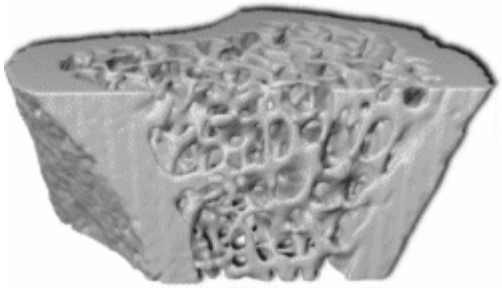


(b) Generic Metal Foam



(c) Reticulated polymeric foam

Engineered mechanism :: Digital customisation of porosity



(i) Tibia bone-model section[2]

'Translator':

digital representation into physical object

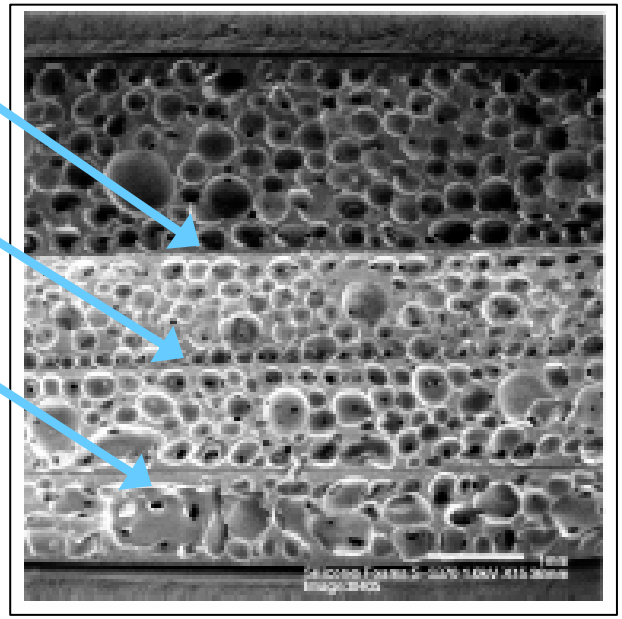
(ii) Bone cross-section[3]

Refs: 1. Yang T.H.J., 2006, Structure-property relationships of biological tissues. PhD Thesis. Heriot-Watt University
2. Stanford Synchrotron Radiation Laboratory. Studies of estrogen depletion in laboratory rats. www2.slac.stanford.edu
3. Fossil dinosaur bone microstructure. www.geo.ucalgary.ca

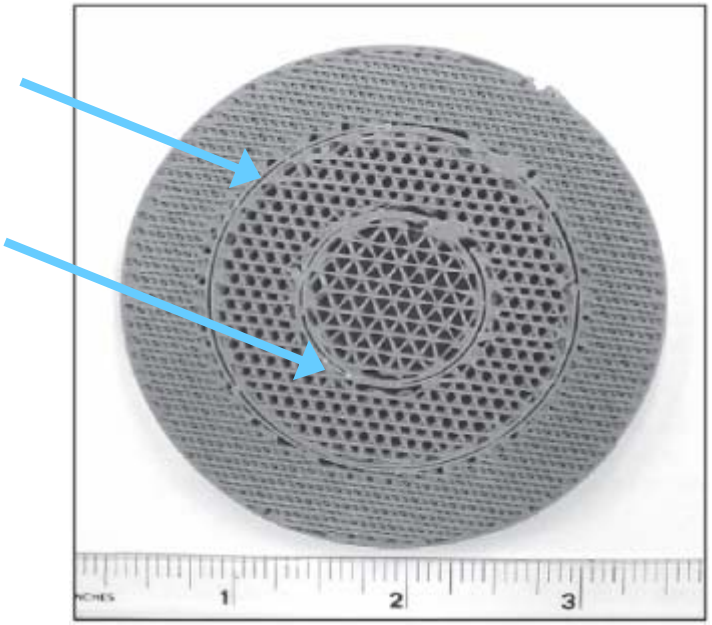
Motivation

Current foam manufacturing technologies are geared towards mass production of homogeneous materials

Heterogeneous materials have to be fabricated from segments of homogeneous parts



(a) Bergstrom JS et al., (1999), Rubber Chem. Technol., 72, 633-656



(b) Kalita SJ et al. (2003), Materials Science and Engineering: C, 23(5): p. 611-620

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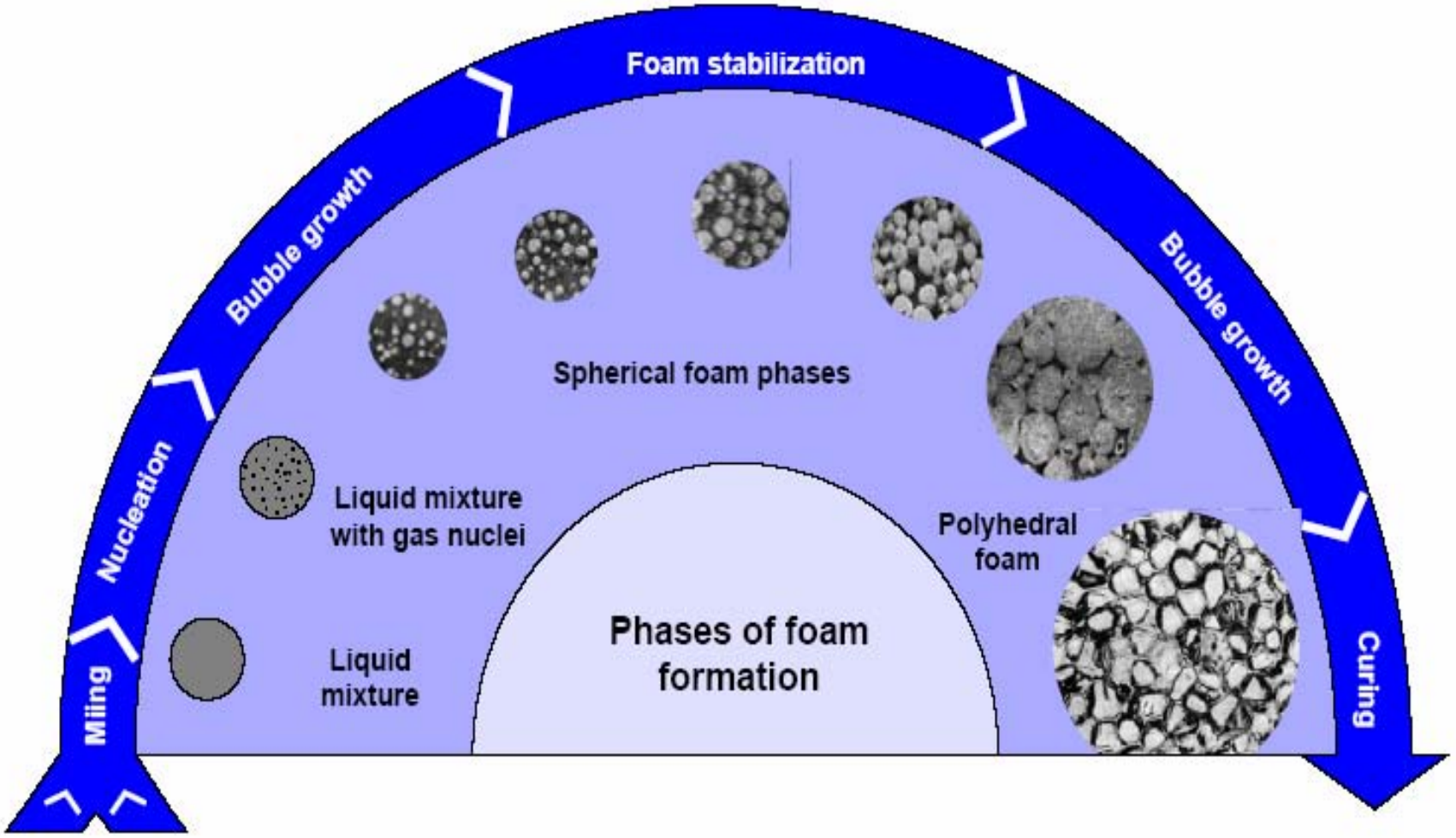
Polymeric Foams

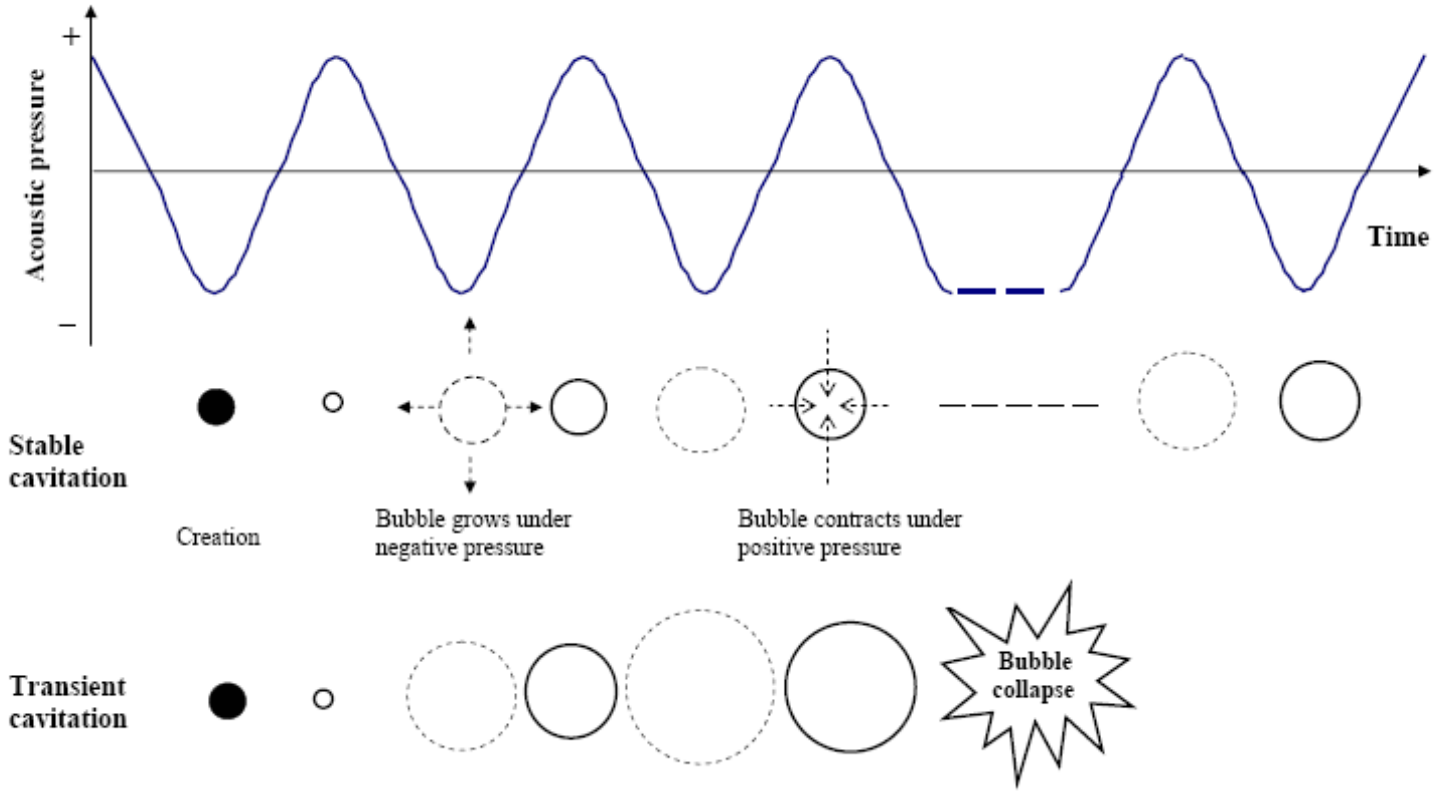
Phases of Foam Formation



Ref: Rompala et al., Alliance for the Polyurethanes Industry (API) Polyurethanes Conference 2002

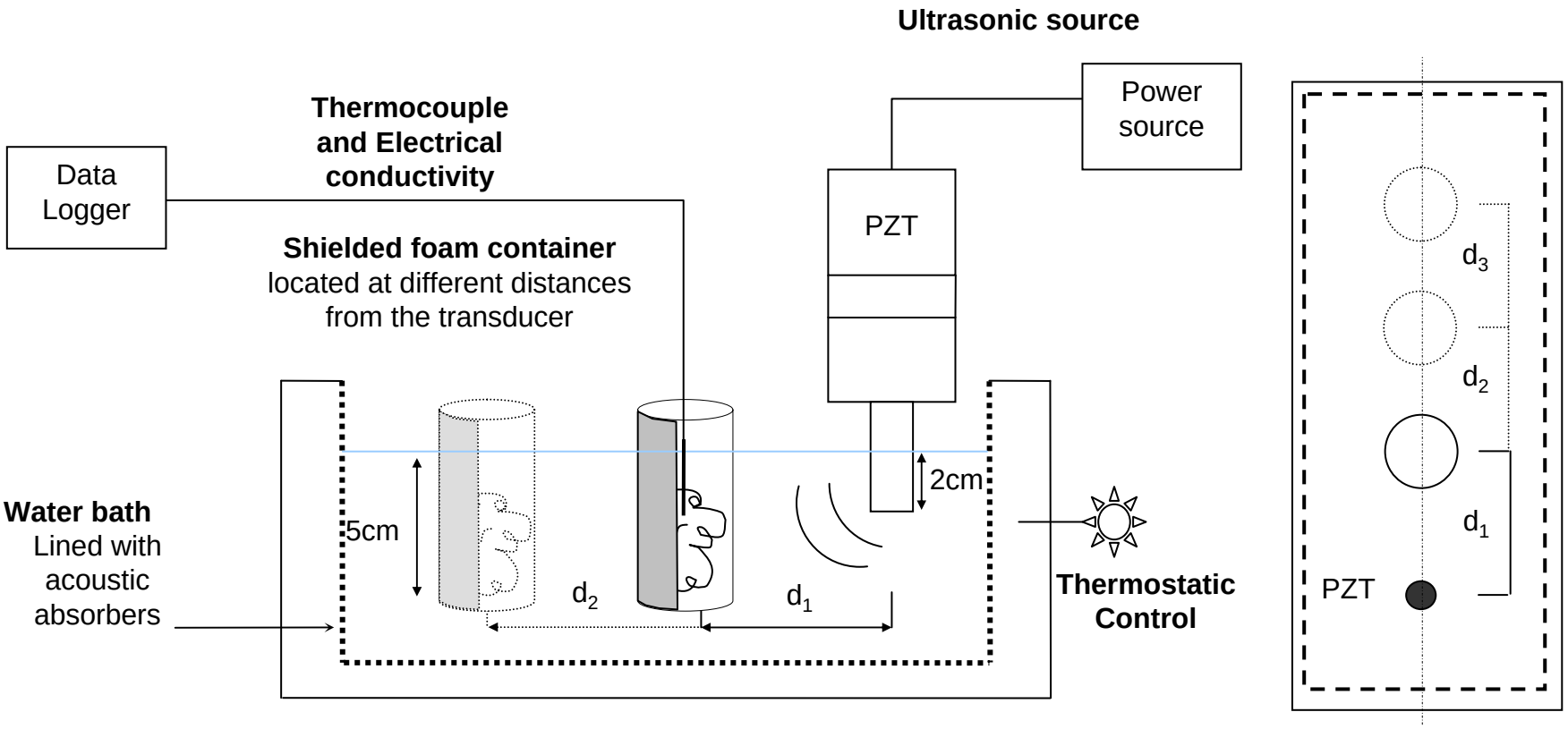
Ultrasound as porosity-tailoring agent

Stable cavitation vs Transient cavitation



Ref: Zheng, L. and Sun, D.W., *Innovative applications of power ultrasound during food freezing processes - a review.* Trends in Food Science & Technology, 2006. 17(1): p. 16-23

Experimental rig and Methodology



Ref: C. Torres-Sanchez and J.R. Corney, "Effects of ultrasound on polymeric foam porosity", Ultrasonics Sonochemistry, Vol. 15, No 3, 2008, pp 408-415

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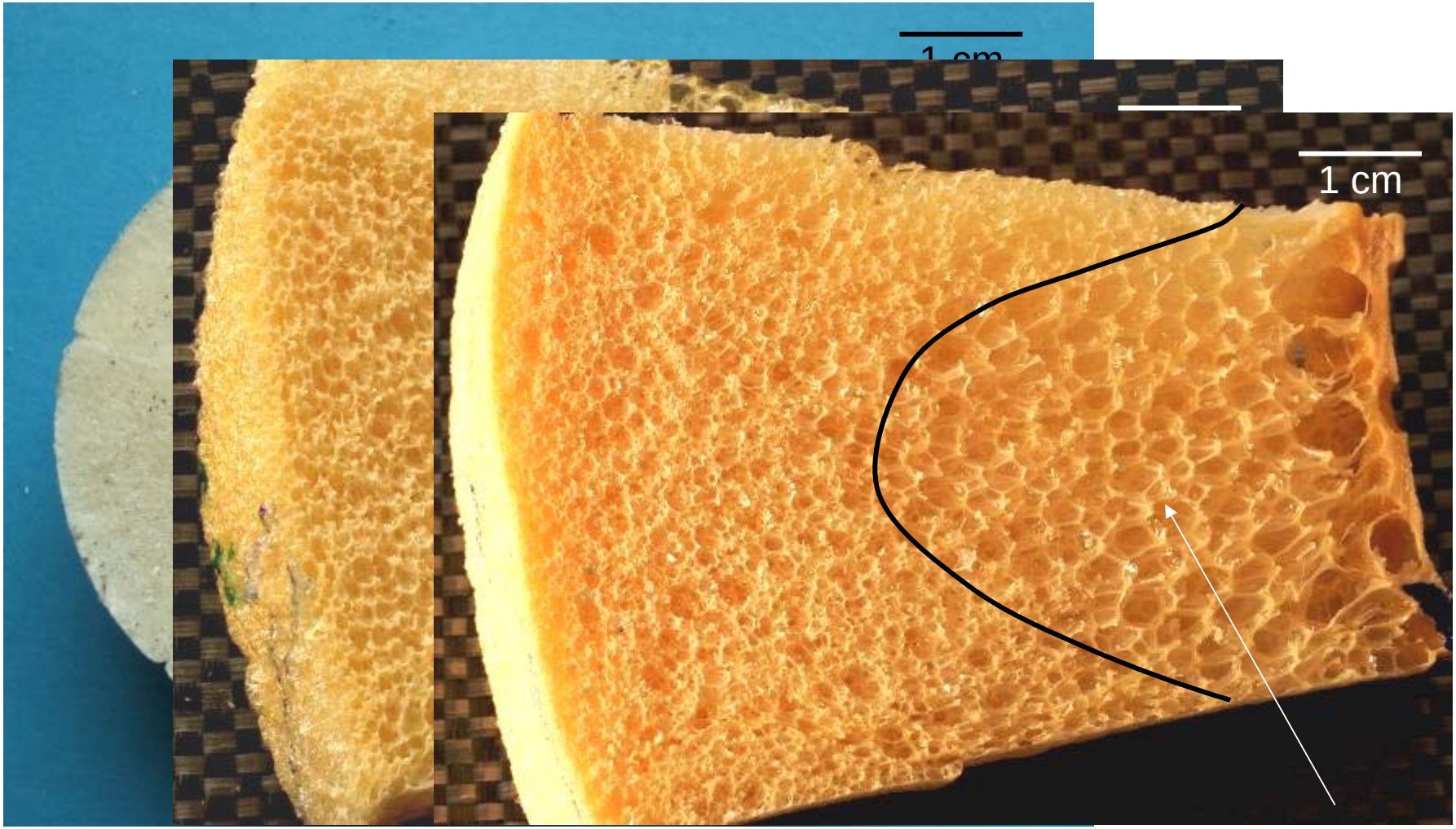
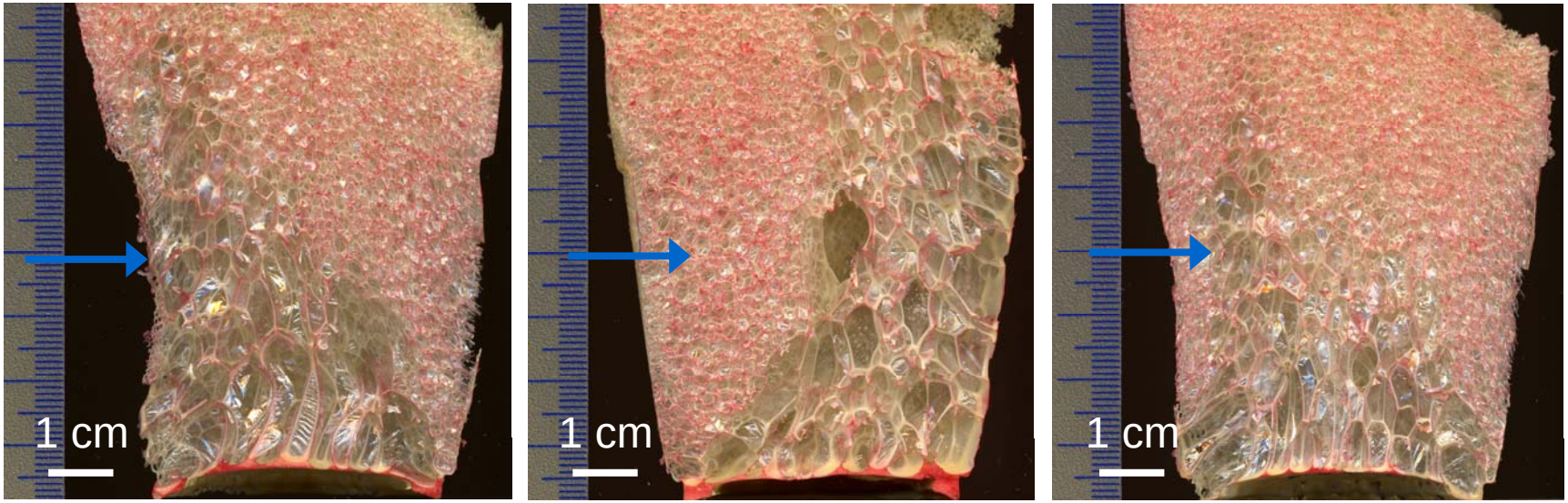
Results: patterns in sonicated foams



Results : controlled porosity distribution

Strategic placement in a controlled acoustic environment in order to obtain a desired porosity distribution



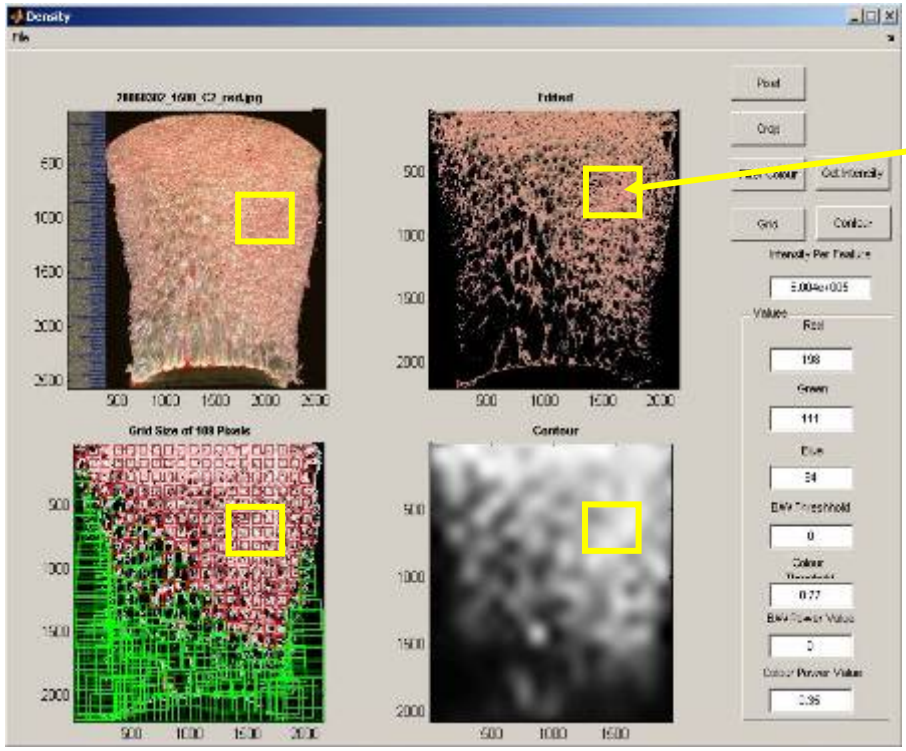
Cross-section of Sonicated foams at difference distances from probe (on the left)

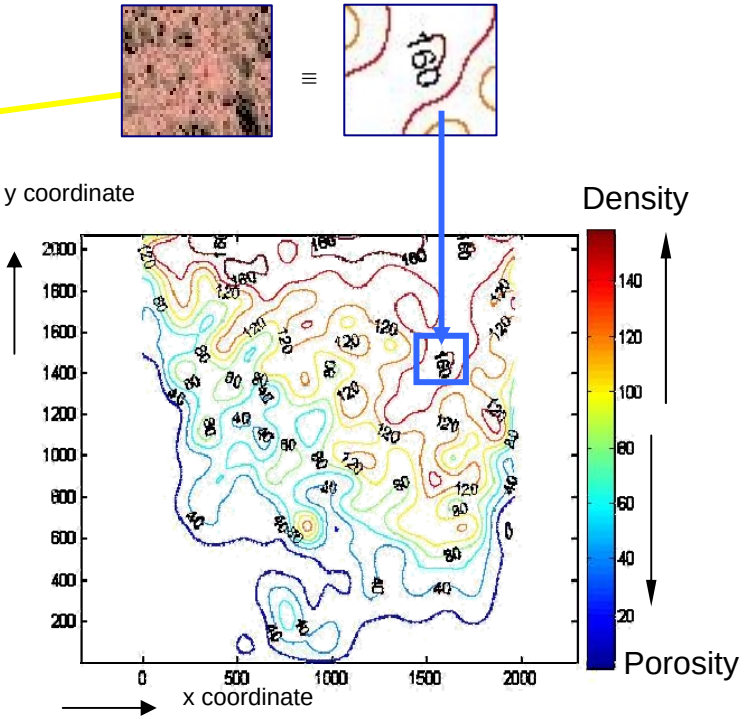
20-30kHz :: equal acoustic pressure (with a %tolerance)

Quantifying porosity distribution

Bespoke Image Analysis :: there is not a method to measure porosity gradation

Closed-pores, Local Variation => conventional methods of porosity measurement cannot be used





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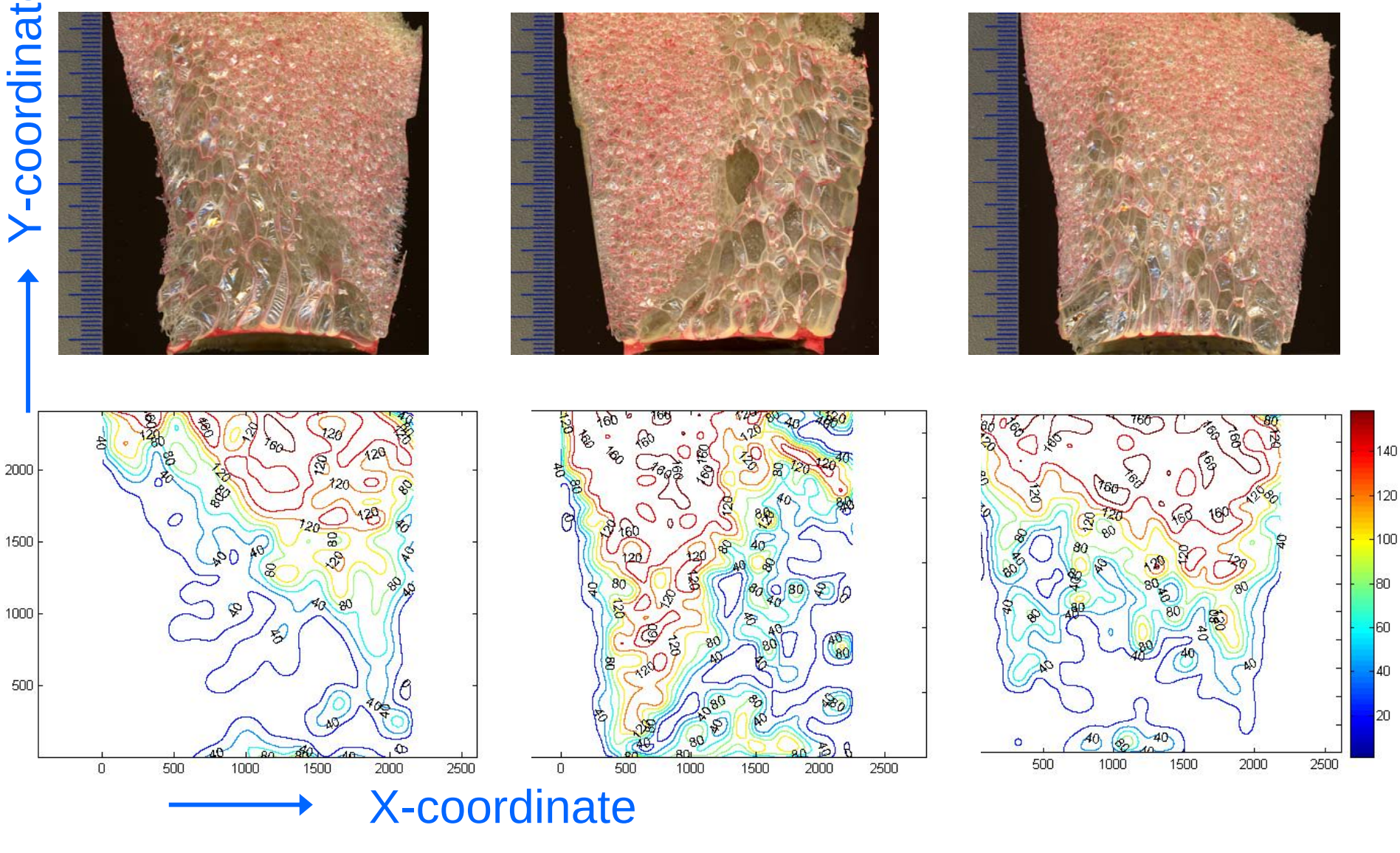
Quantifying porosity distribution



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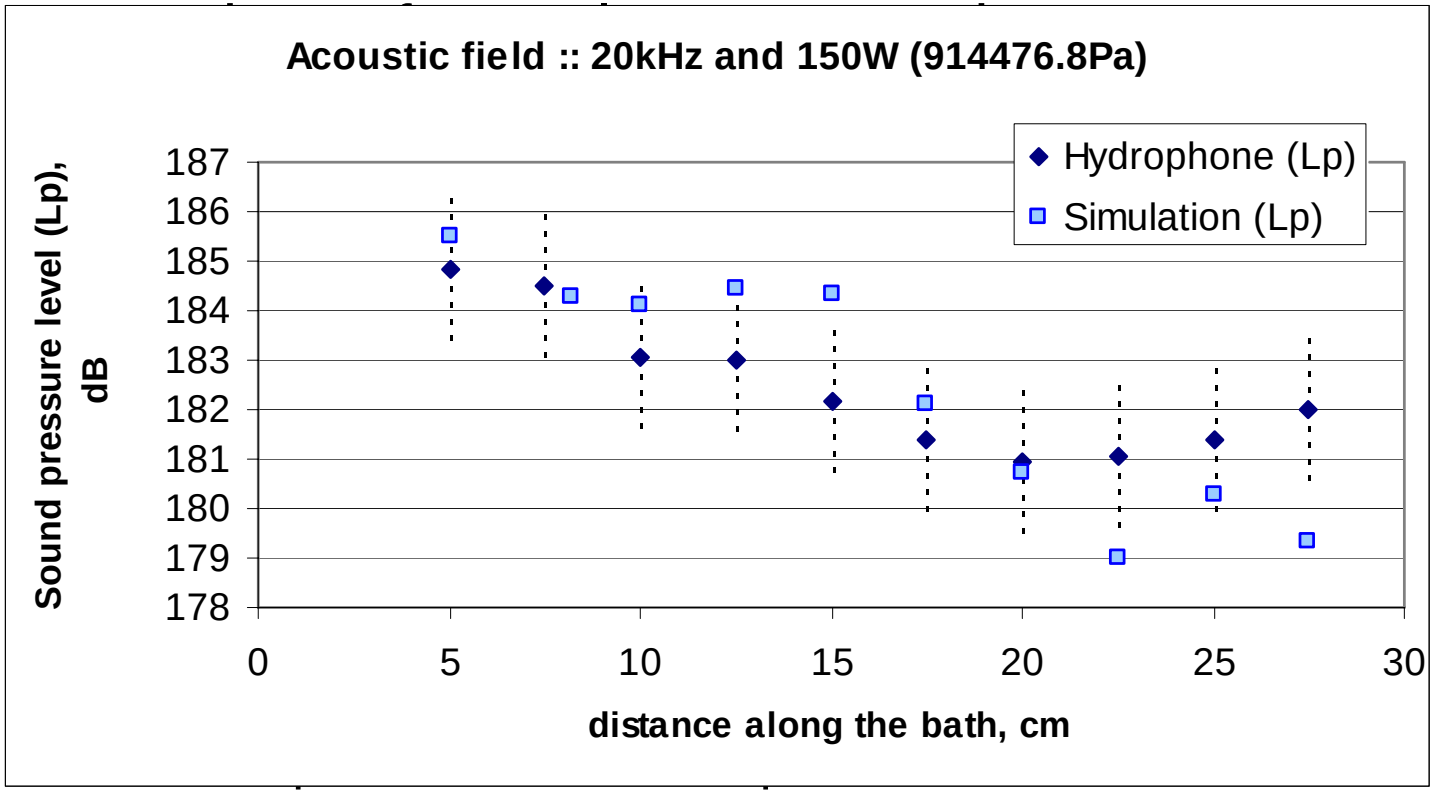
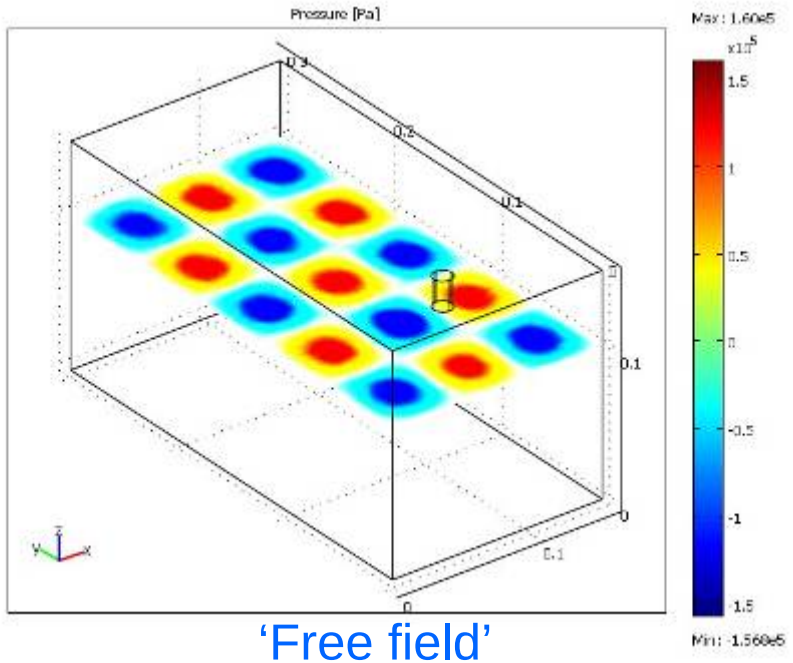
Acoustic Environment :
Exploring the boundary conditions and settings

- Locations of vessels-to-sonotrode
- Sonotrode intensity
- Wave profile type: Radiation :
  - For this application ‘spherical’ and ‘cylindrical’ drew very similar results
- Subdomain nature
  - Both subdomains could not be simultaneously manipulated
- Boundary conditions for the bath and vessels
  - Not a perfect match : compromised ‘soft/hard’
- Comparison hydrophone vs modelled results

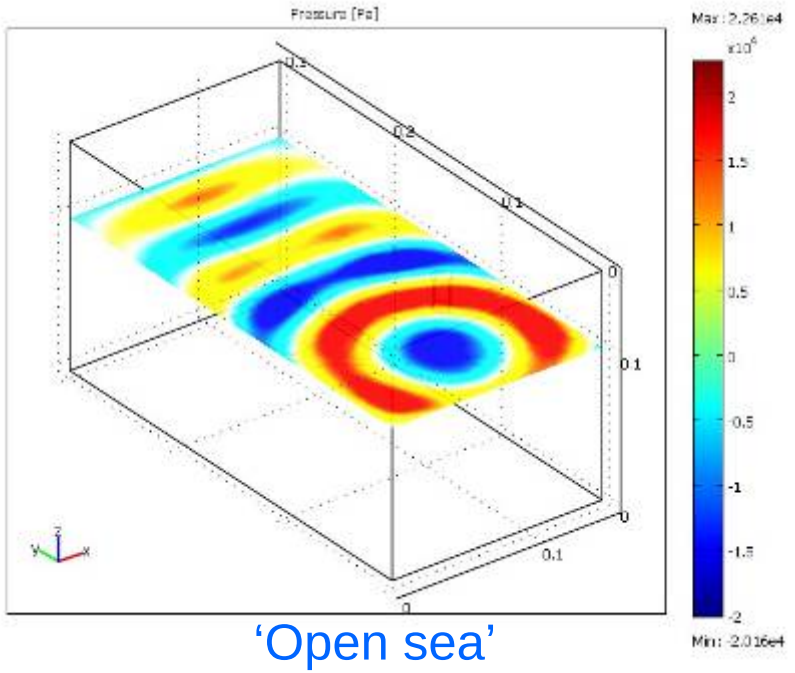
Acoustic Environment :
Exploring the boundary conditions and settings



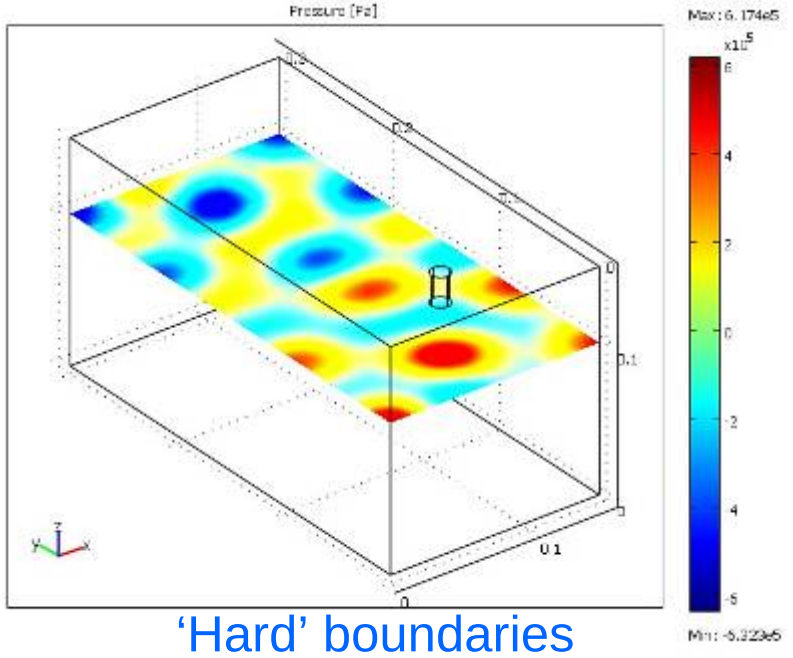
- Comparison hydrophone vs modelled results



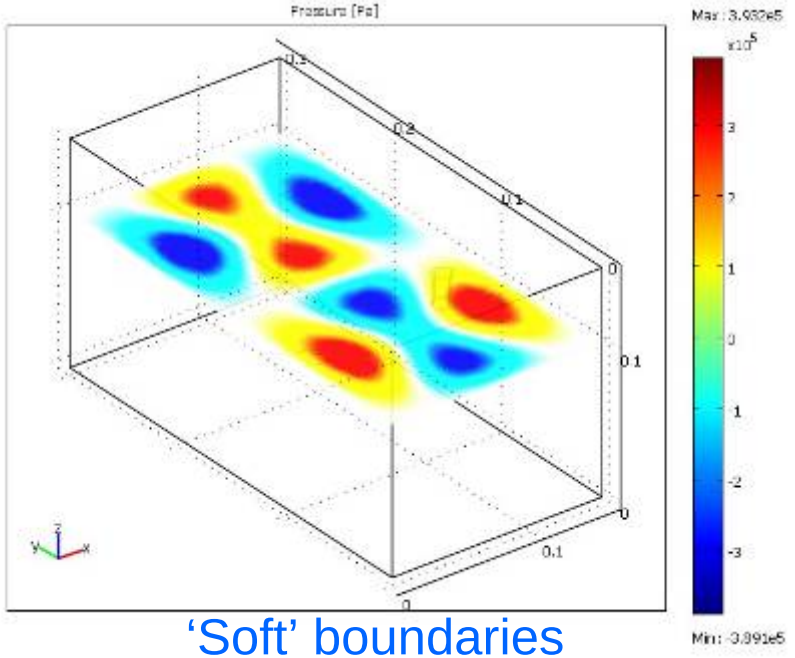
‘Free field’



‘Open sea’



‘Hard’ boundaries



‘Soft’ boundaries

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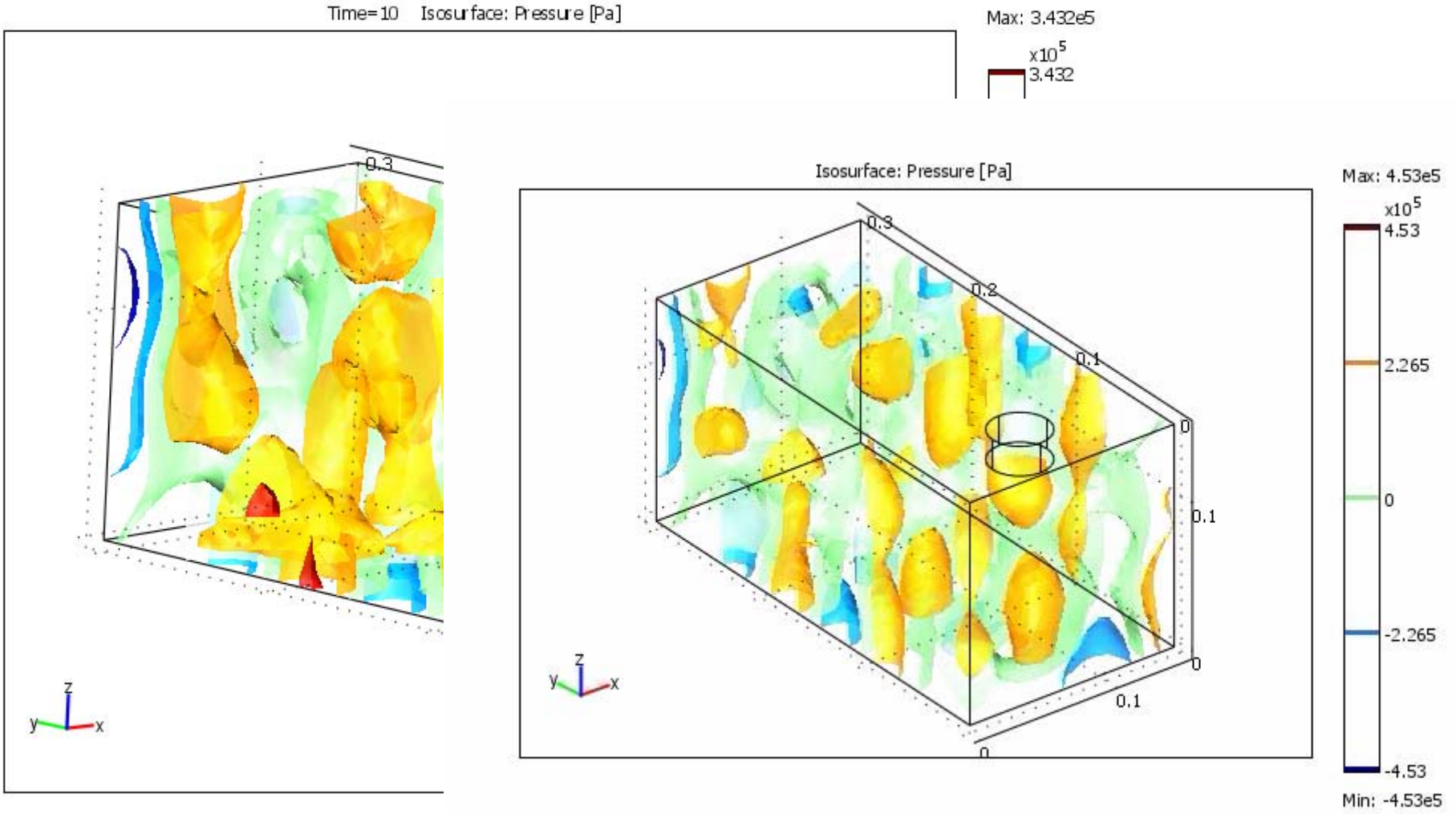
Experimental rig : Acoustic Environment



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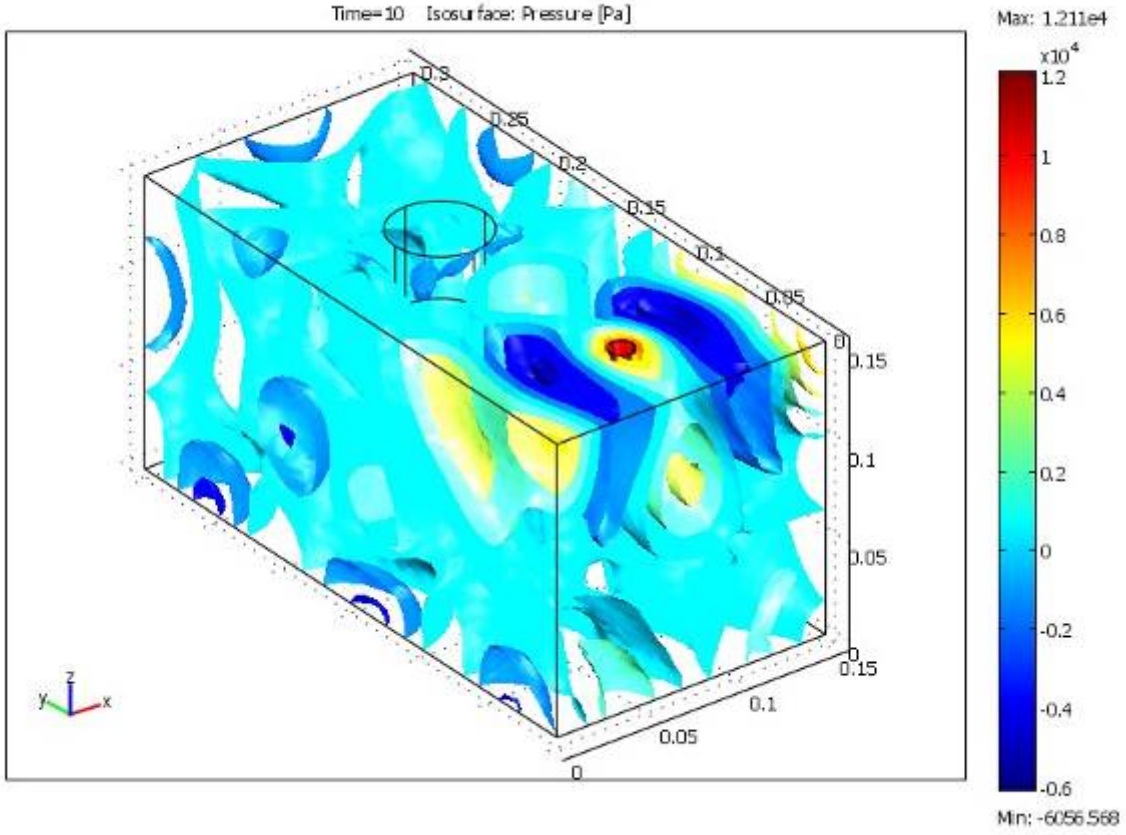
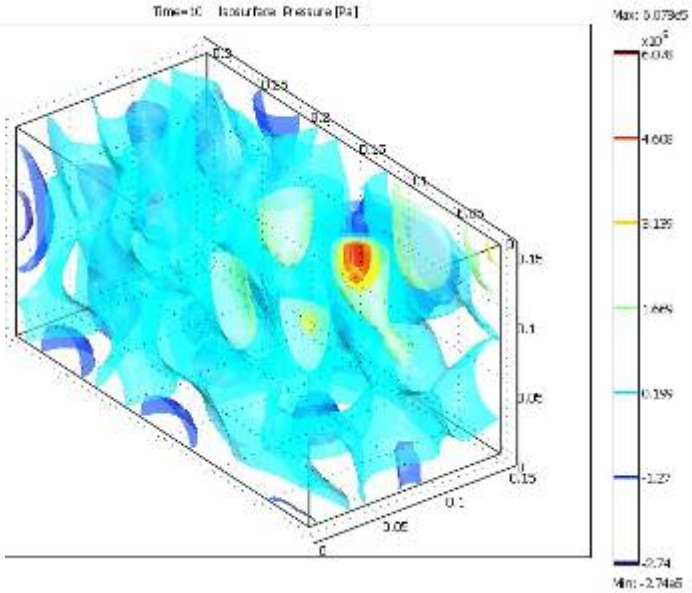
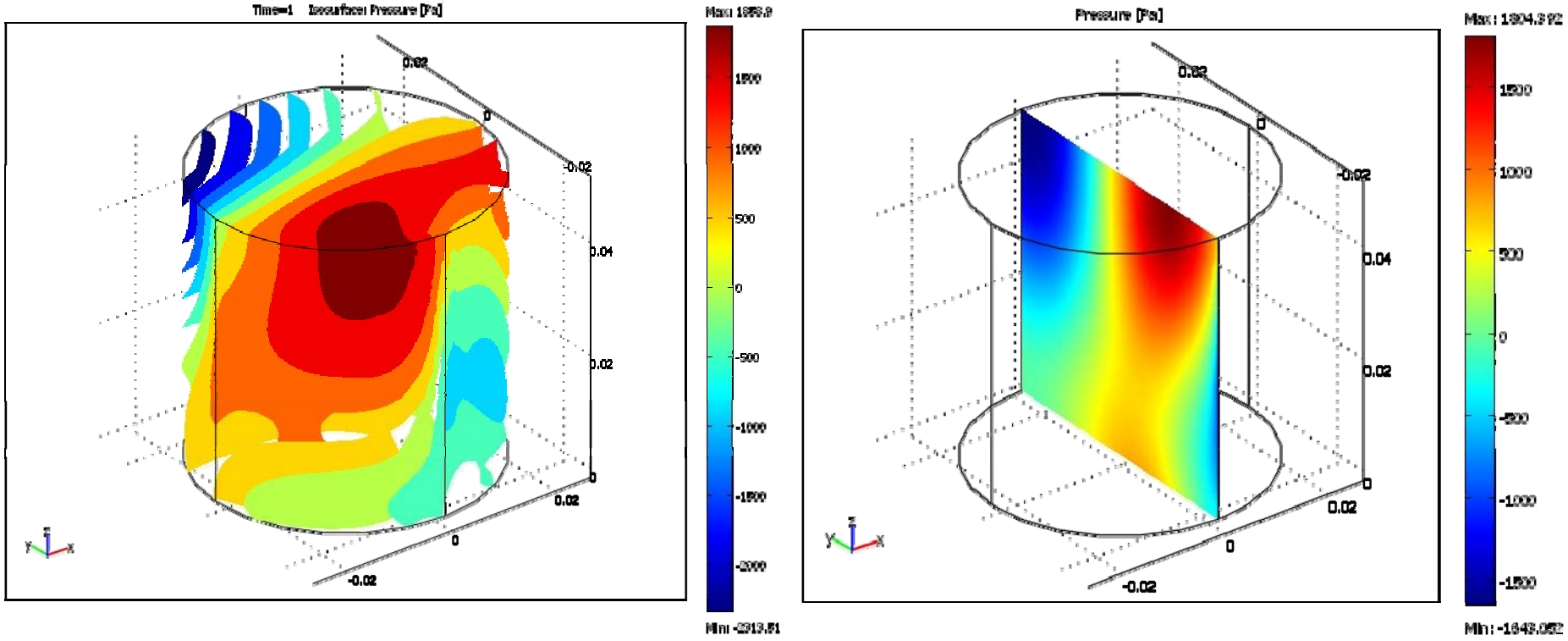
Experimental rig : Acoustic environment





Experimental rig : Acoustic Environment

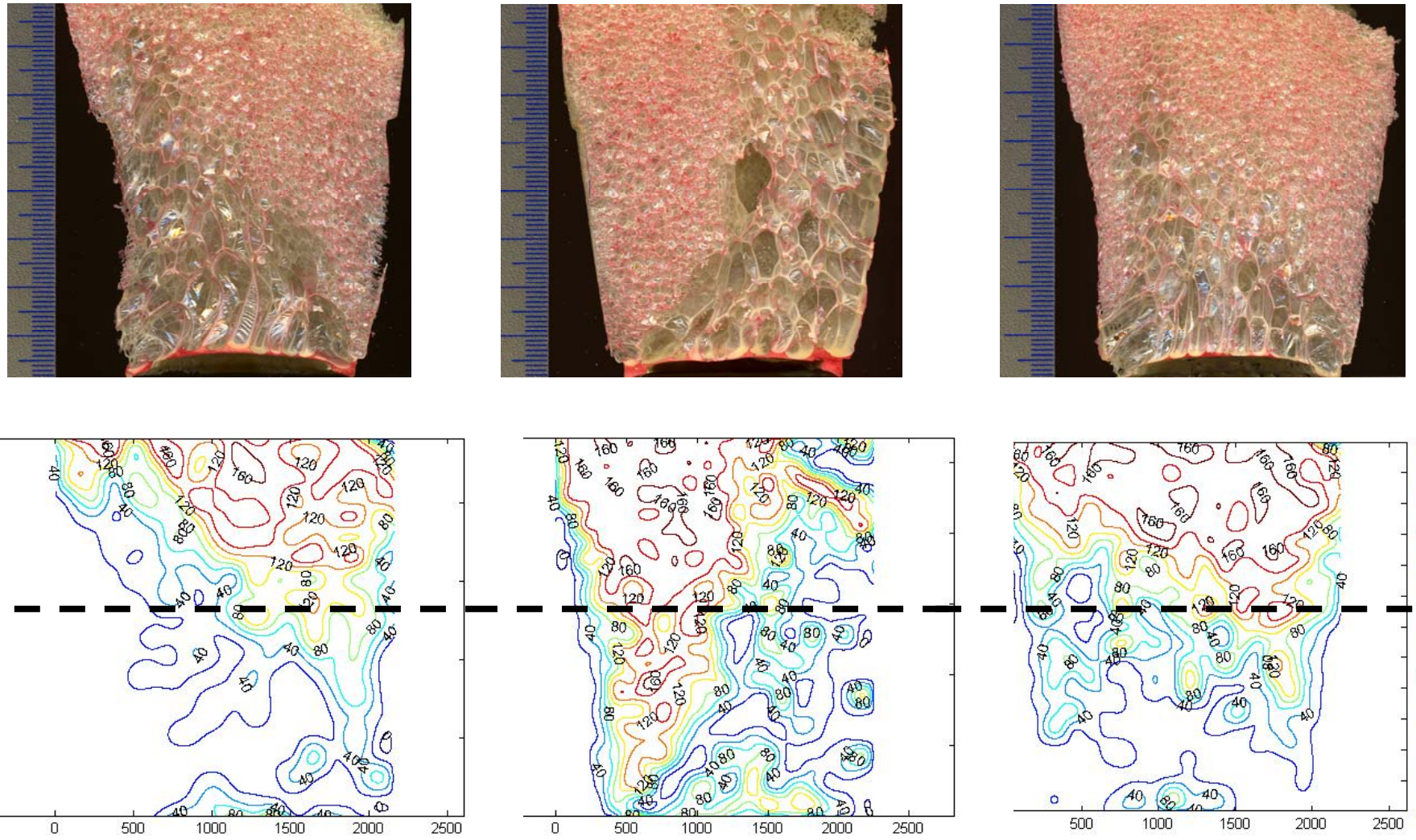
Acoustic pressure distribution inside of vessels



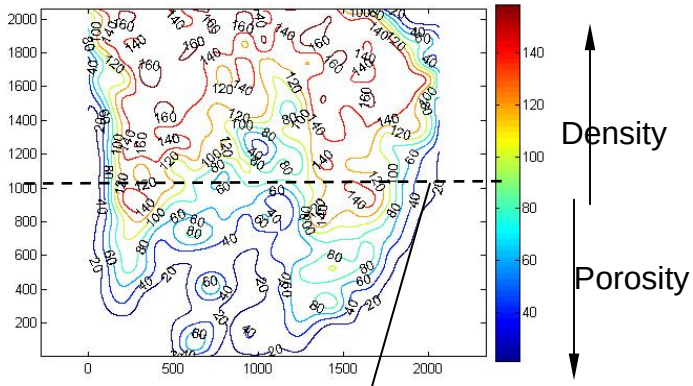
Experimental rig : Acoustic Environment

- Limitations in the simulated environment:
  - Acoustic impedance is a constant in the simulated model :: "*Working Boundaries*"
  - Approximated to **initial** liquid nature ($Z=Z_{water}$= 1.48 MRayl)
  - Approximated to **final** state i.e. soaked solid ($Z=Z_{cortical\ bone}$= 2.6 MRayl)

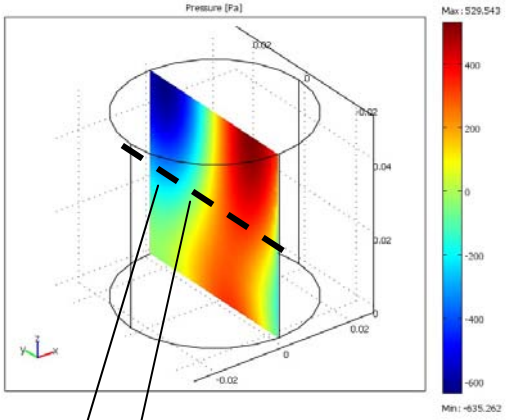
Results : sonicated foams '*contour maps*'



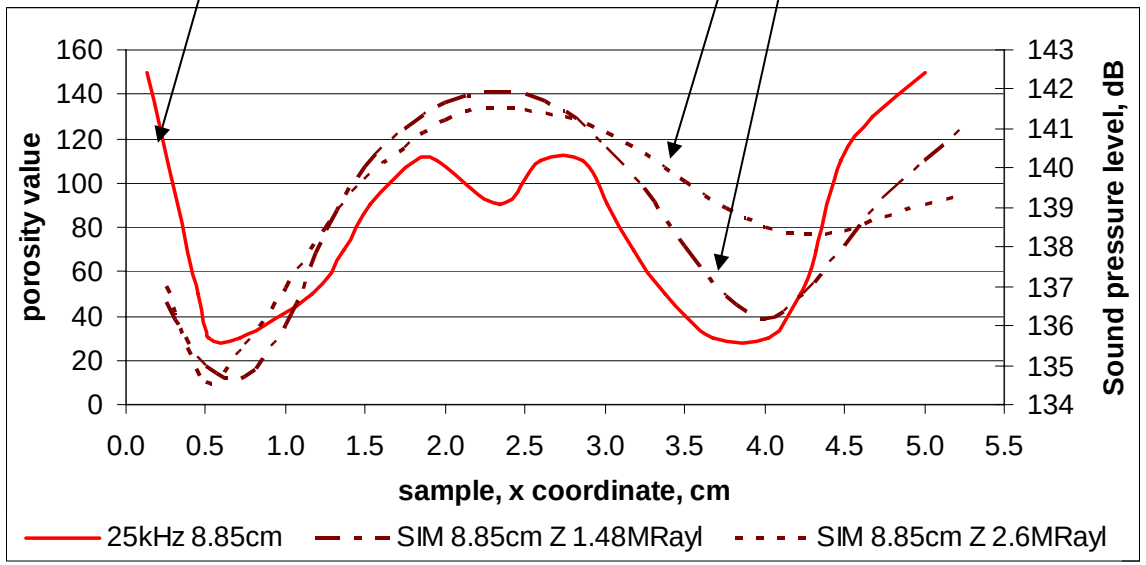
Comparison Experimentation vs Simulation



Cross-section of the sample in ‘contour lines’ mode



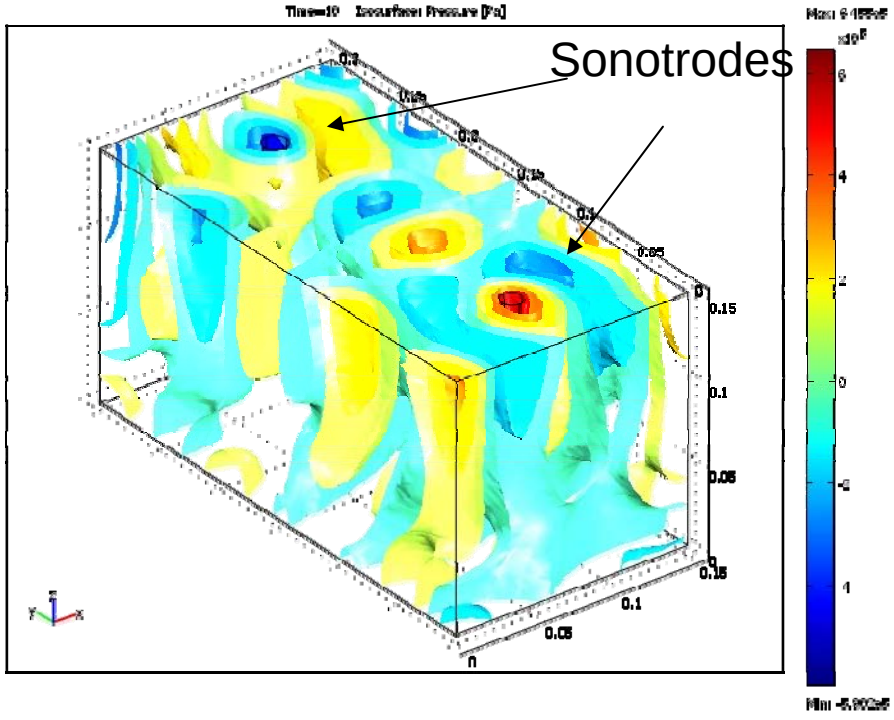
Vertical plane from modelled vessel

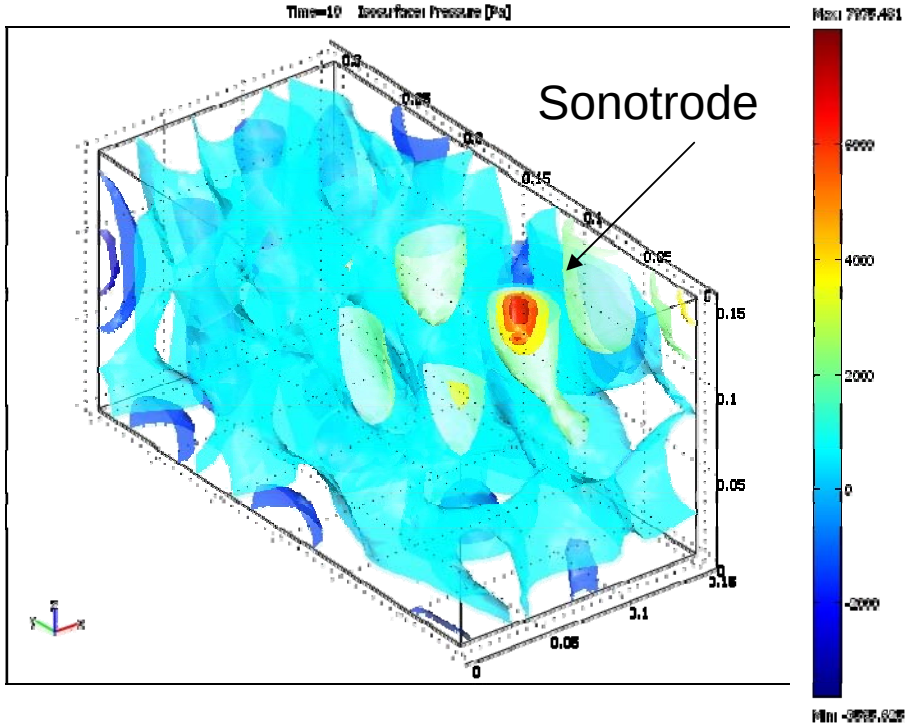


Comparison porosity (experimental) vs sound pressure distributions (simulation) for irradiated foam

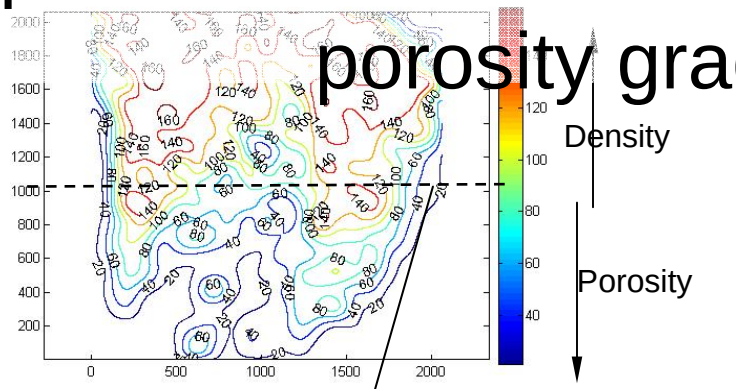
Research Opportunities

Multi-source experimental rig and coupling agent :: exploration

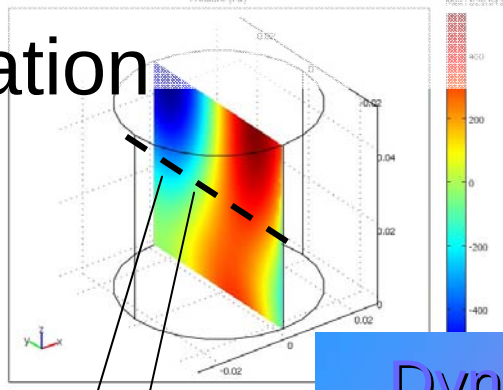




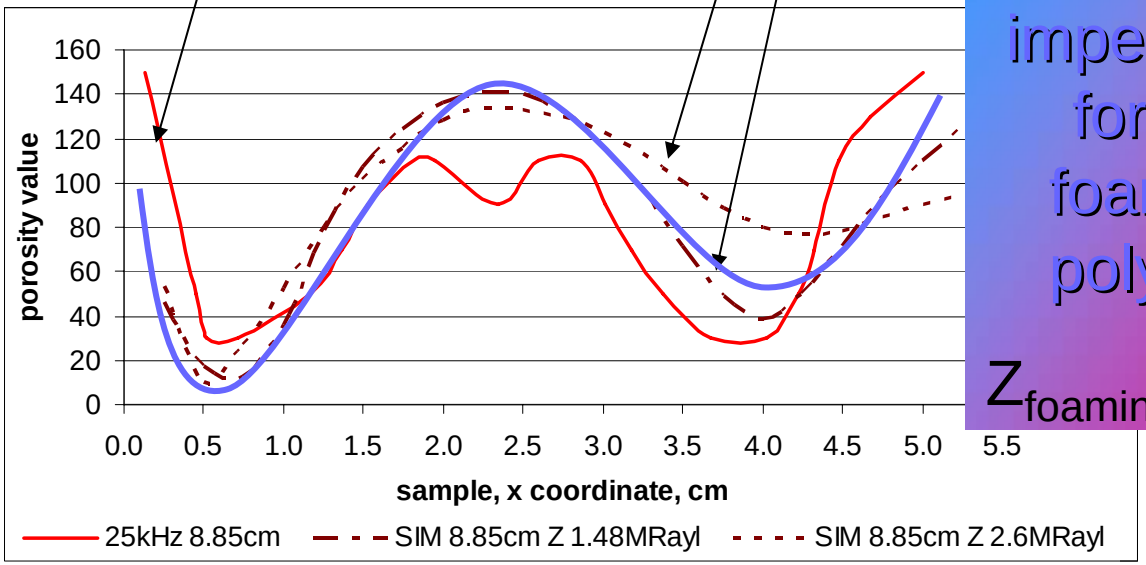
A more direct comparison between Experimental vs Simulated results for the porosity gradation



Cross-section of the sample in 'contour lines' mode



Vertical plane from mod



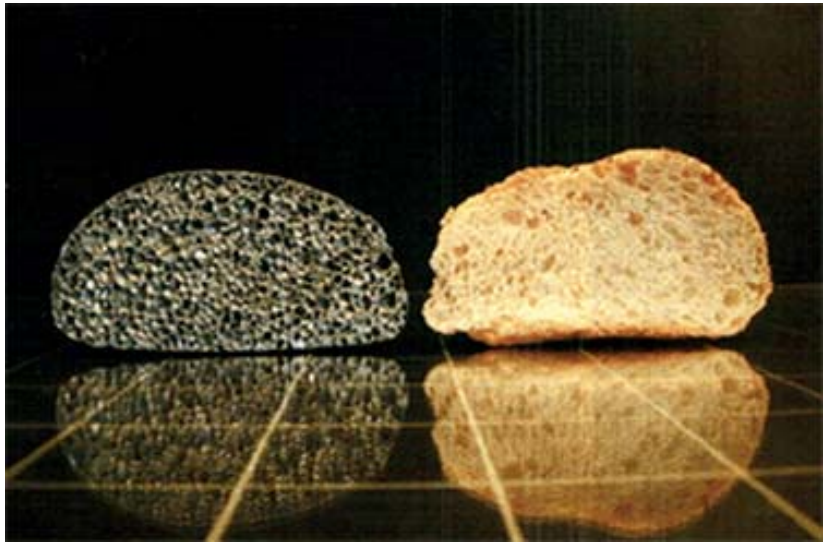
Dynamic acoustic impedance for the foaming polymer

$Z_{foaming\ polymer}$

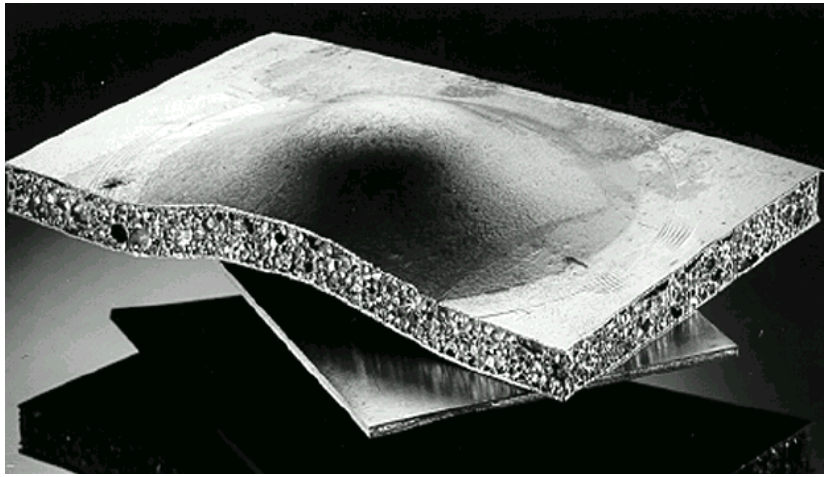
Comparison porosity (experimental) vs sound pressure distributions (simulation) for irradiated foam

Research Opportunities in Manufacture

(i) Al foam and bread, by J.Banhart

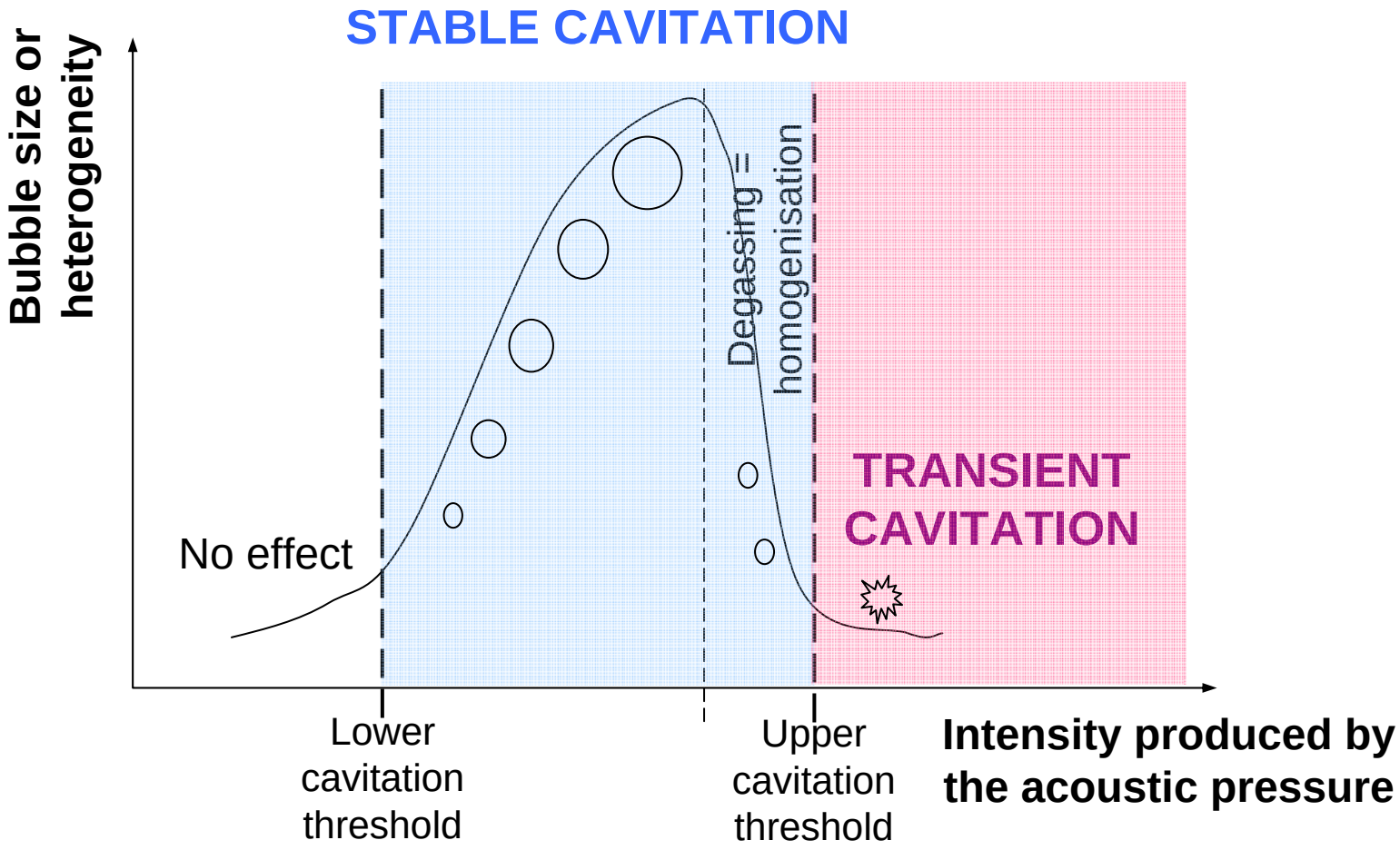


(ii) Metal foams and aerospace components, by J. Banhart



(iii) Bone cross-section, Fossil dinosaur bone microstructure. www.geo.ucalgary.ca

Underpinning principle



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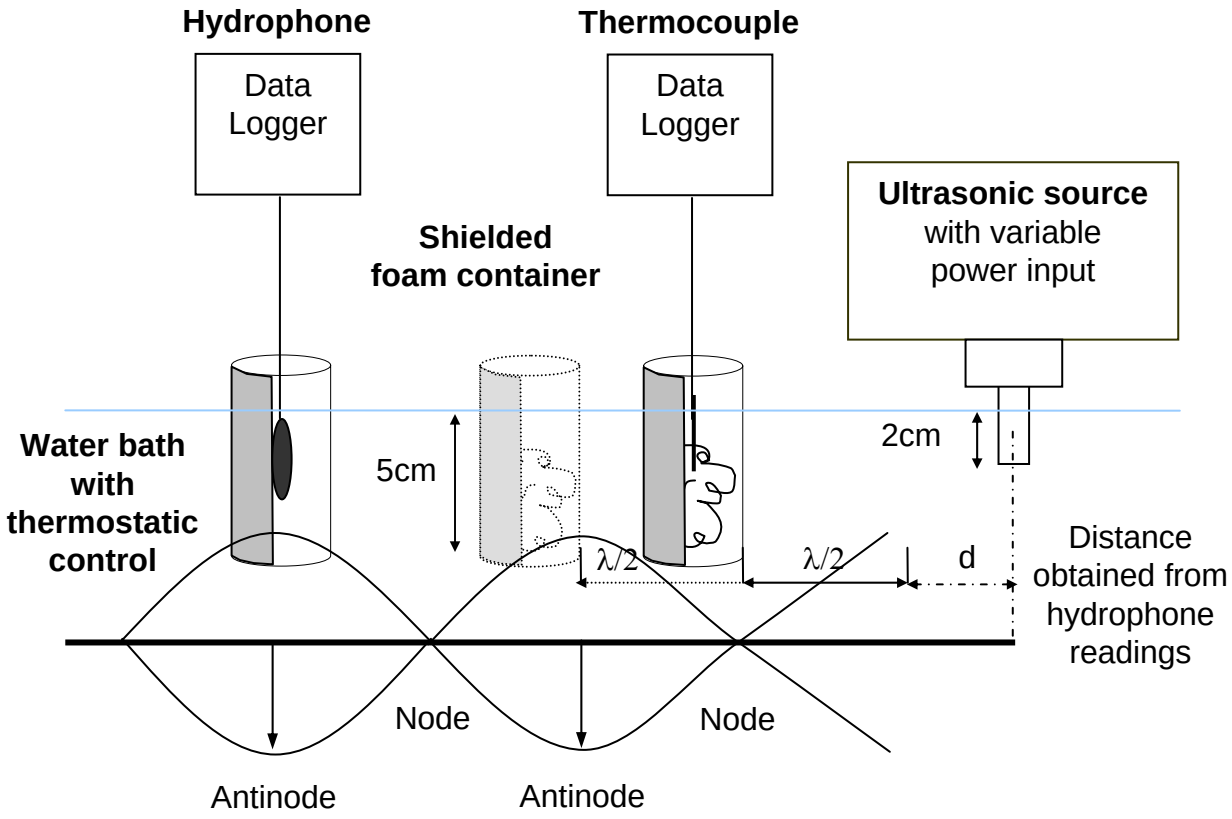

at Antinode: negative porosity gradation (from large to small pore size)

at Node: positive porosity gradation (from small to large pore size)