Karlsruhe Institute of Technology

3D Ultrasound Computer Tomography

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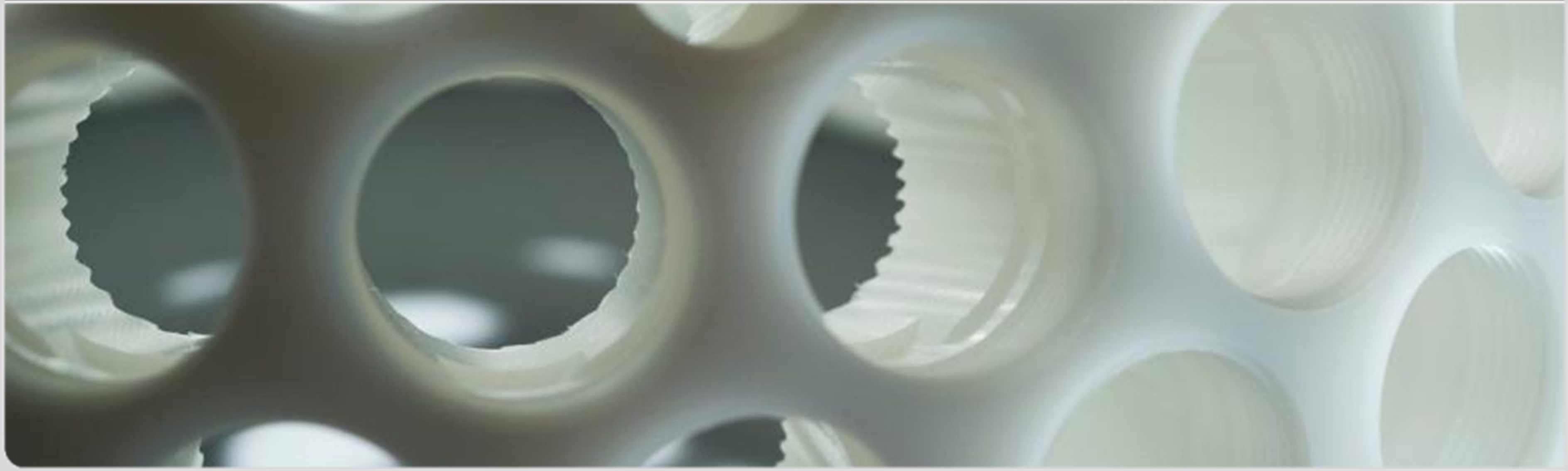
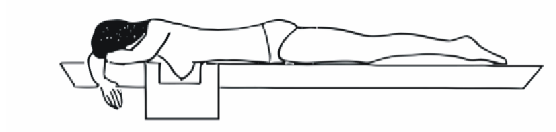
INSTITUTE FOR DATA PROCESSING AND ELECTRONICS



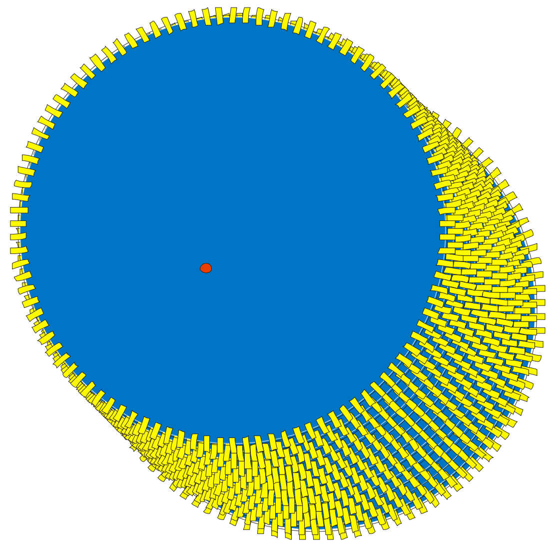
Ultrasound Computer Tomography

- Application: Breast imaging for cancer diagnosis



Breast imaging in fixed setup

- Basic idea:
  Surround object with (unfocused) ultrasound transducers in a fixed setup



Example setup

- Features:
  - Reproducible 3D images with ultrasound
  - Three modalities concurrently
  - Sub-millimeter volumes
  - Fast data acquisition
  - Optimally focused images in 3D (isotropic PSF)

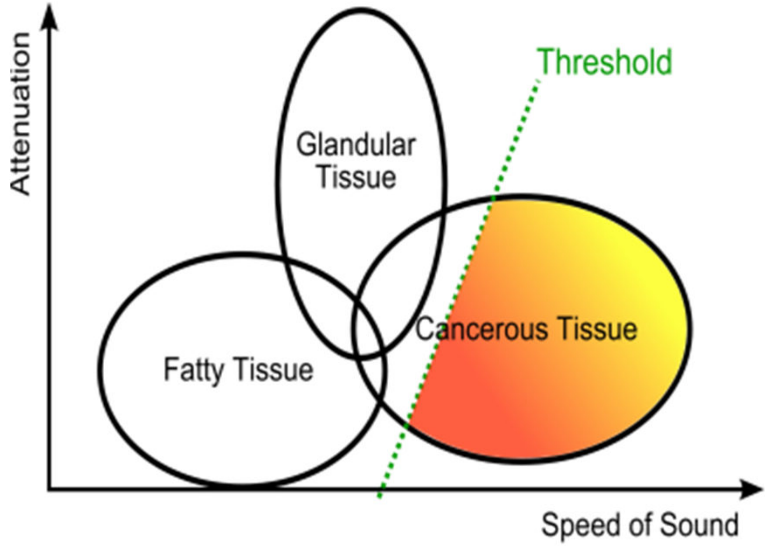
Worldwide unique!

Ideal for Breast Cancer Diagnosis?

- Images three modalities concurrently

- **Reflection**:
  High quality “B-Scans”

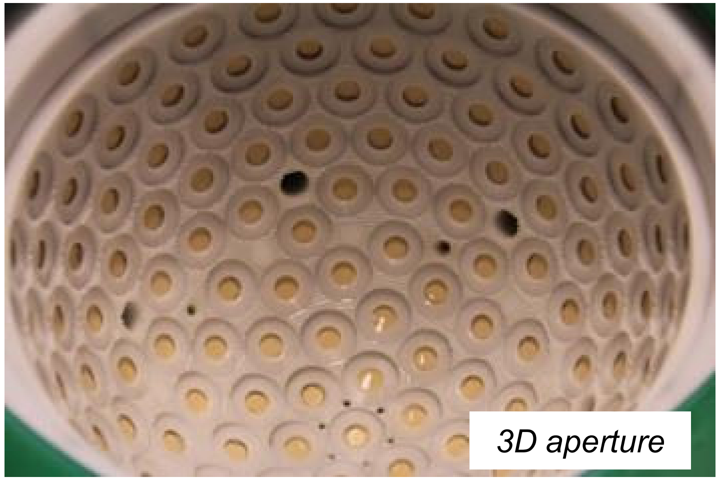
- **Speed of sound** and **attenuation**:
  Quantitative information

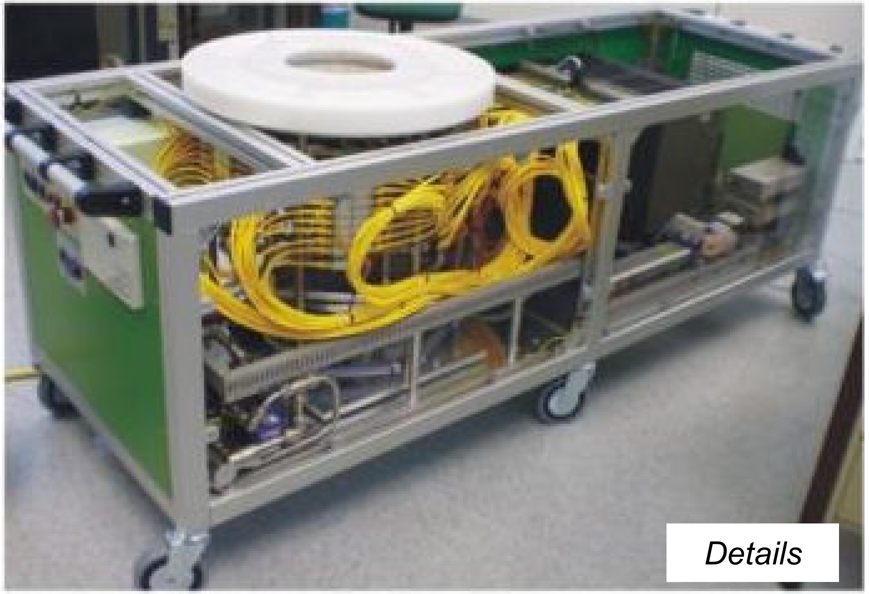


[*Simplified from Greenleaf et al.*]

- USCT for early breast cancer diagnosis:
  - as good as MRI?
  - as cheap as X-ray mammography?
  - as harmless as diagnostic ultrasound!

KIT 3D USCT





Transmission Tomography

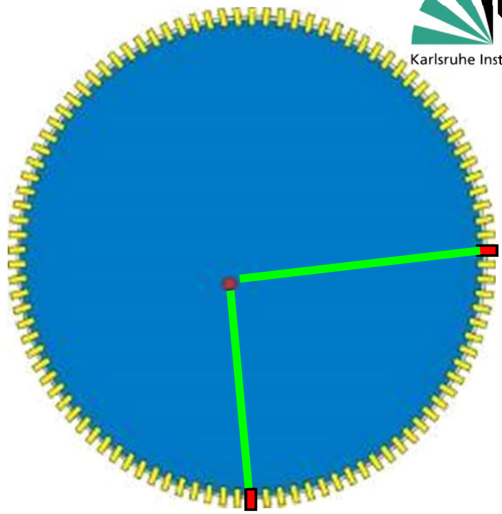
- **How it works** (example for speed of sound)
  - $t = l/c$
  - $$\begin{bmatrix} t_1 \\ \vdots \\ t_n \end{bmatrix} = \begin{bmatrix} l_{11} & \cdots & l_{1m} \\ \vdots & \ddots & \vdots \\ l_{n1} & \cdots & l_{nm} \end{bmatrix} \begin{bmatrix} 1/c_1 \\ \vdots \\ 1/c_m \end{bmatrix}$$
  - Solving a linear equation system using numerical optimization algorithm with Total Variation minimization (TVAL3)
- **Approximations and limitations**
  - Straight ray approximation
  - Optimal resolution: $(5\text{ mm})^3$
- **How was it improved?**
  - Refraction correction
- **Reconstruction load and performance**
  - Realistic scenario: Matrix dimensions of 3 000 000 x 1 500 000
  - Reconstruction in 5 minutes, refraction corrected in 8 hours

t: time of flight
l: travelled path
c: speed of sound
n: number of measurements
m: number of voxels

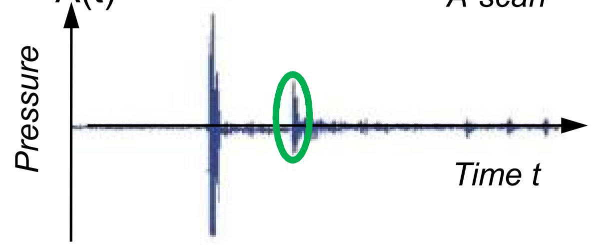
Reflection Tomography

- **How it works**:
  - 3D Synthetic Aperture Focusing Technique

$$f(\vec{x}) = \sum_{(i,k)} A_{(i,k)}\left(\frac{\|\vec{x}_i - \vec{x}\| + \|\vec{x} - \vec{x}_k\|}{\hat{c}(\vec{x}_i, \vec{x}_k, \vec{x})}\right)$$



- **Approximations and resolution**:
  - Born approximation, no refraction
  - Optimal resolution: $(0.24\ \text{mm})^3$



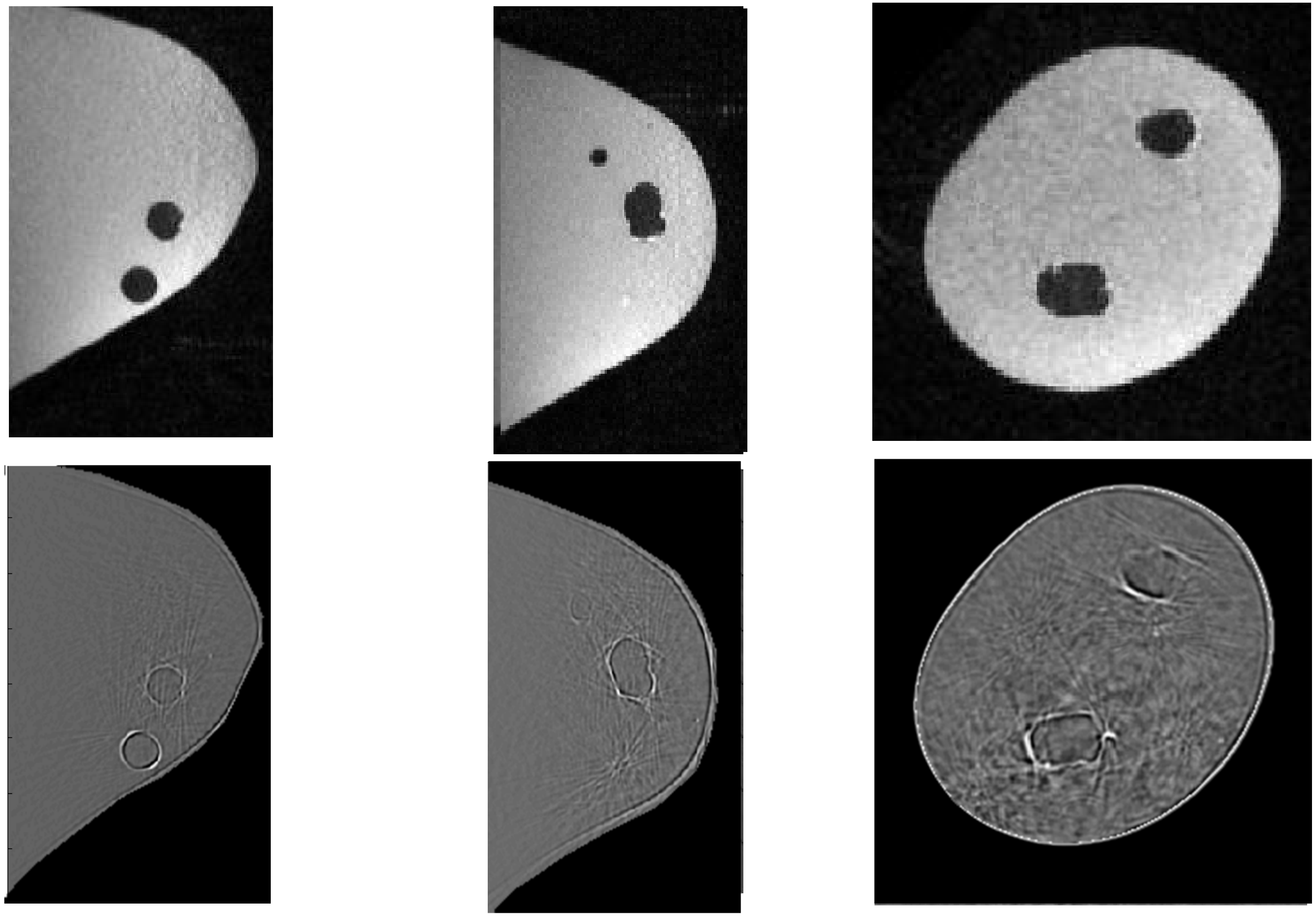
- **How was it improved?**
  - Speed of sound and attenuation correction
- **Reconstruction load and performance**
  - Realistic scenario: 256^3 voxels using 8 million A-scans (MRI resolution)
  - Using multi CPU and GPU cluster in 2 hours, corrected in 14 hours

Clinical Breast Phantom: Results

Transversal *Sagittal* *Frontal*

MRI

USCT

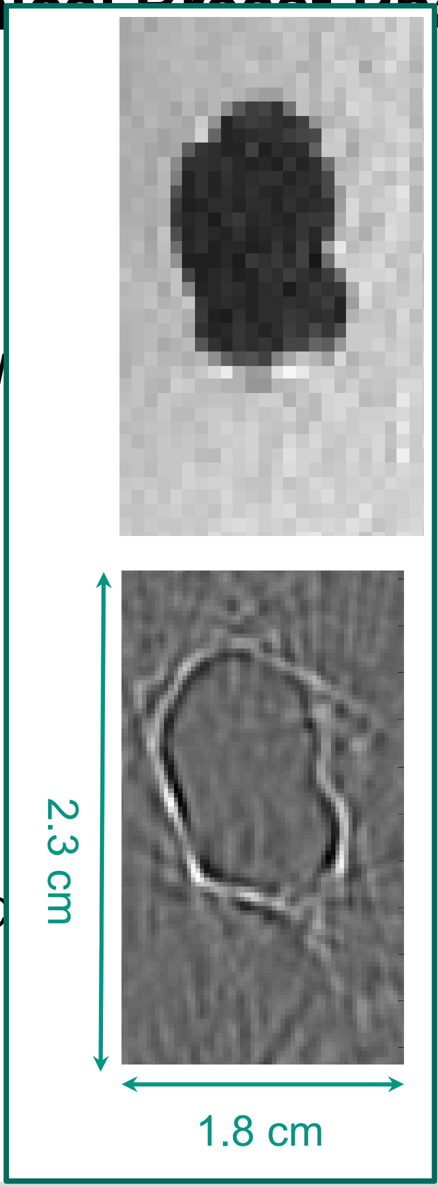


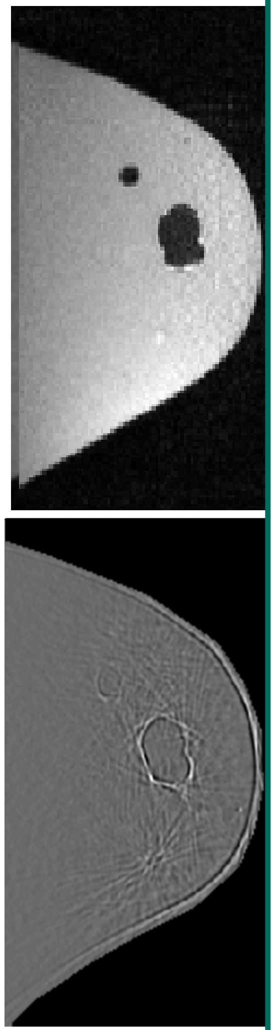
Clinical Breast Phantom: Results

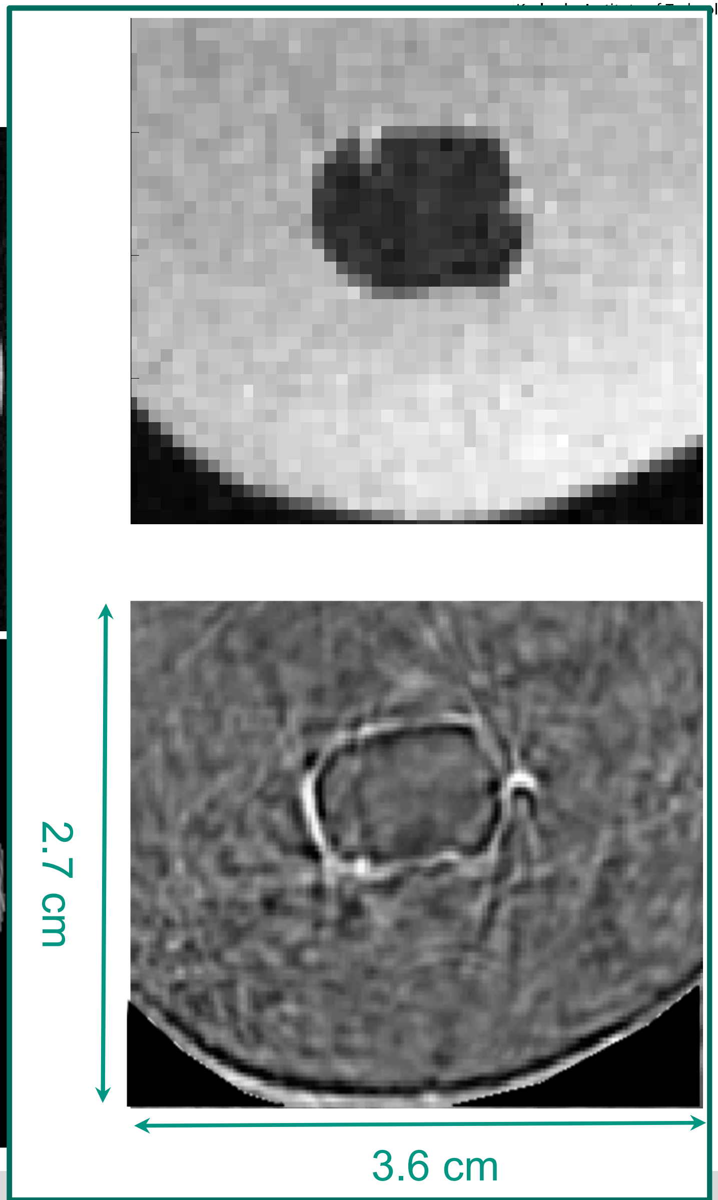
Sagittal

MRI

USCT

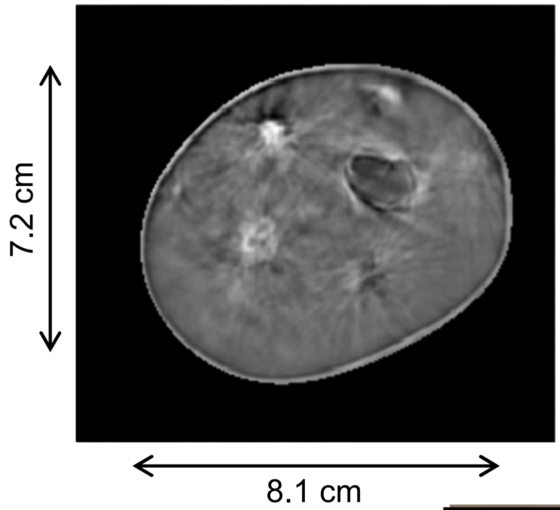




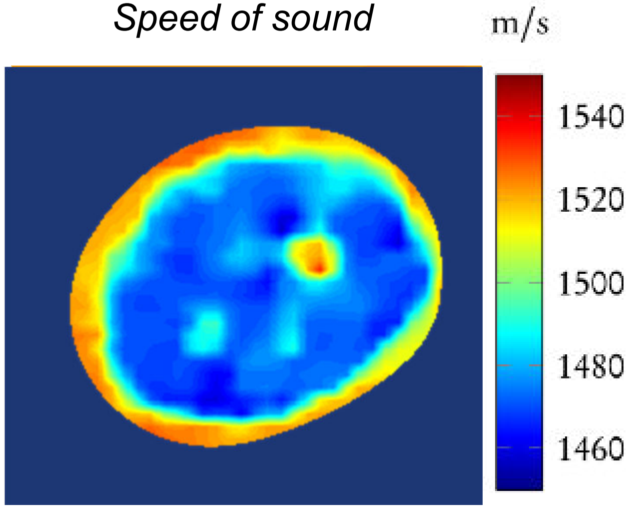


Clinical Breast Phantom: Speed of Sound and Attenuation

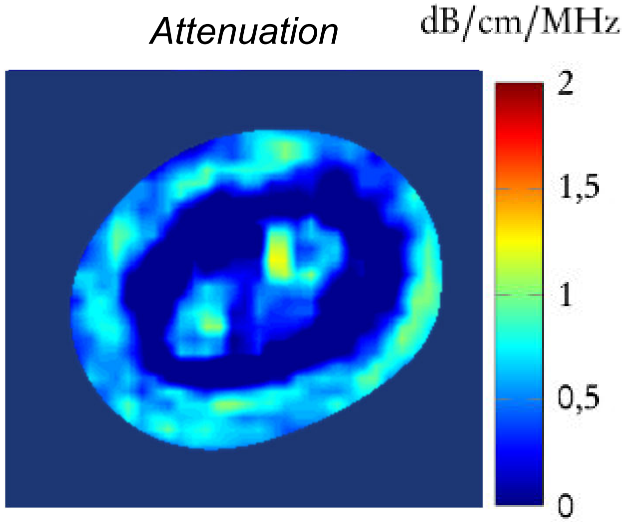
Reflectivity



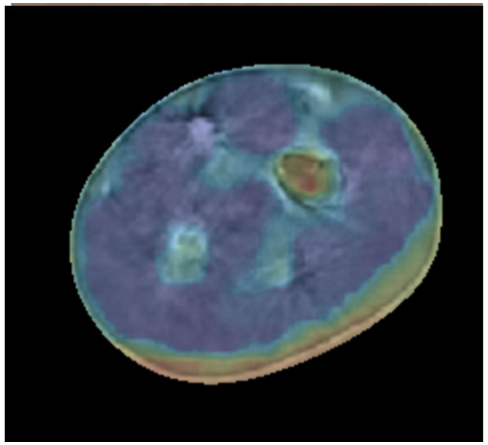
Speed of sound



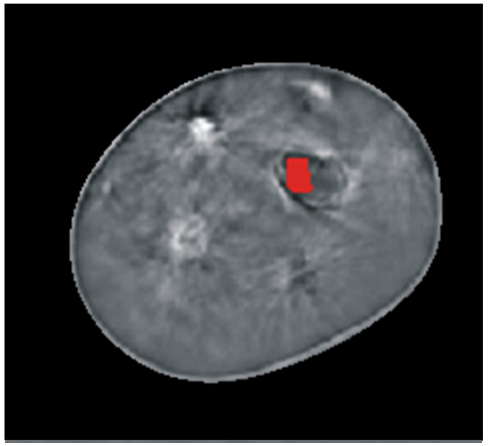
Attenuation



Exemplary image fusion



Fused reflectivity and speed of sound



All modalities with thresholding

Pilot Study

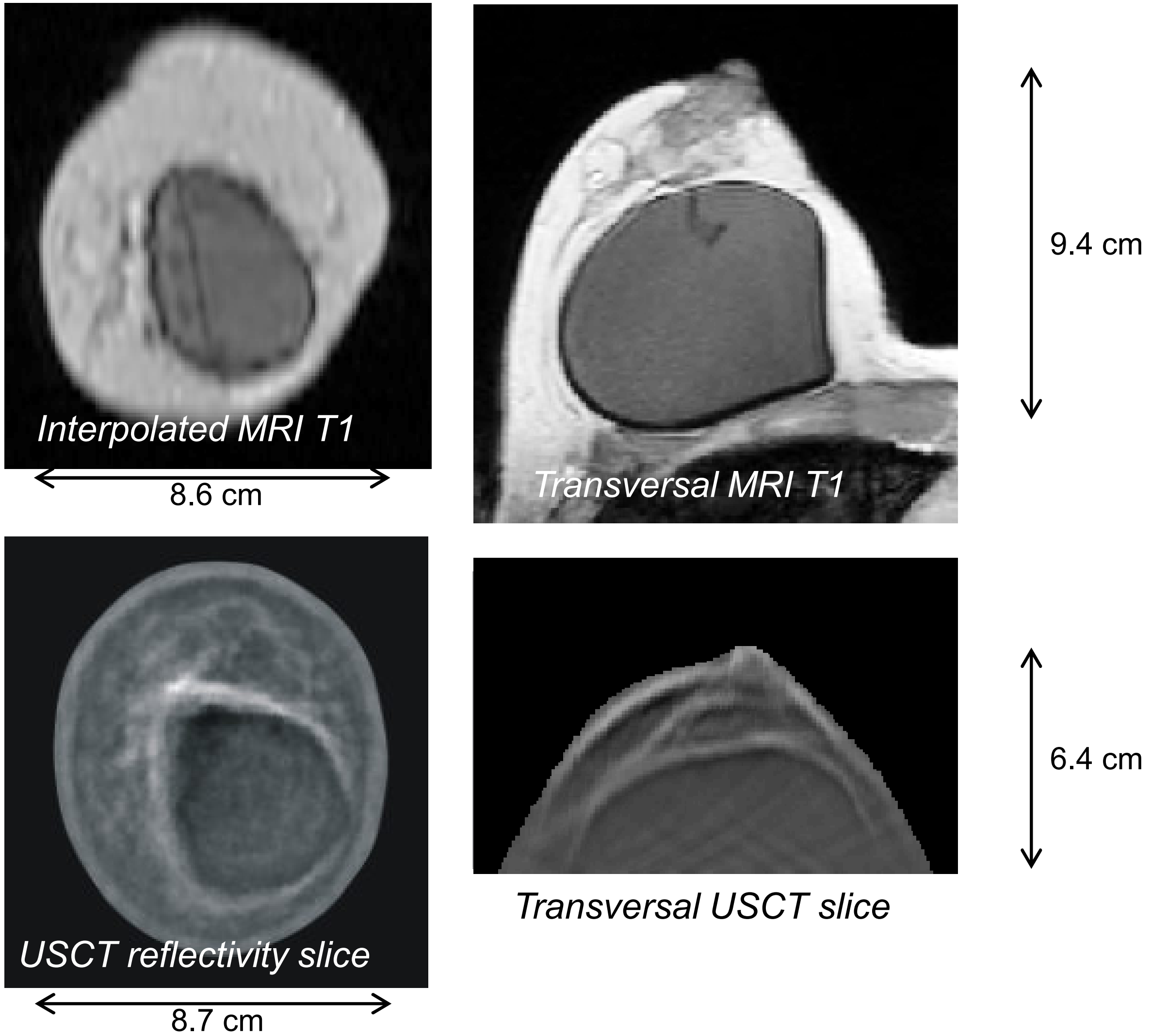
Test the USCT device on ten patients

1. Evaluate data acquisition and image reconstruction protocols
2. Test fused display of the multimodal USCT images
3. Test and optimize process of data acquisition

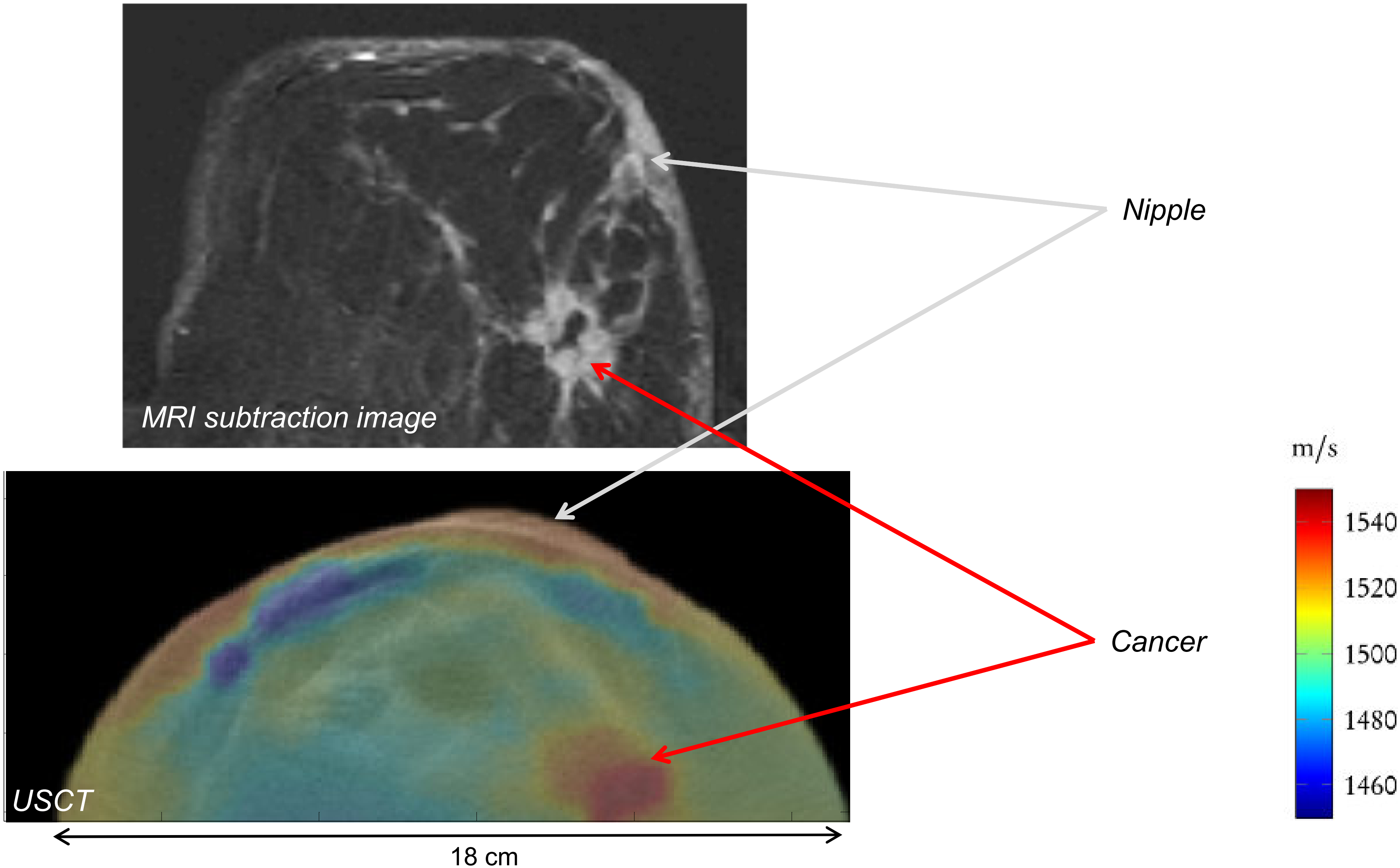
Pilot study was conducted

- at University Hospital Jena
- in 3 days in November 2012
- had MRI as ground truth

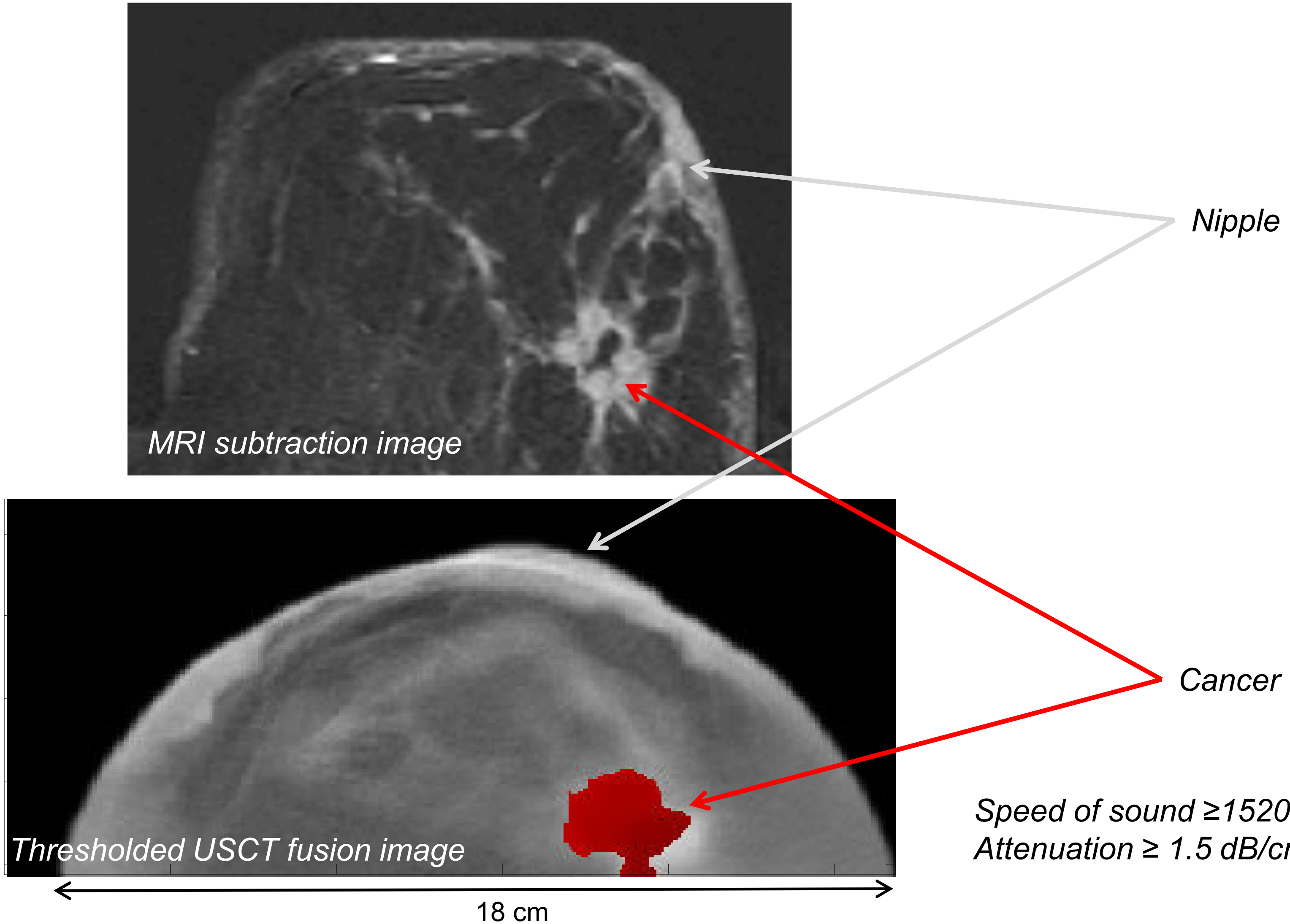
Patient with Implants



Reflectivity and Speed of Sound Fusion Image

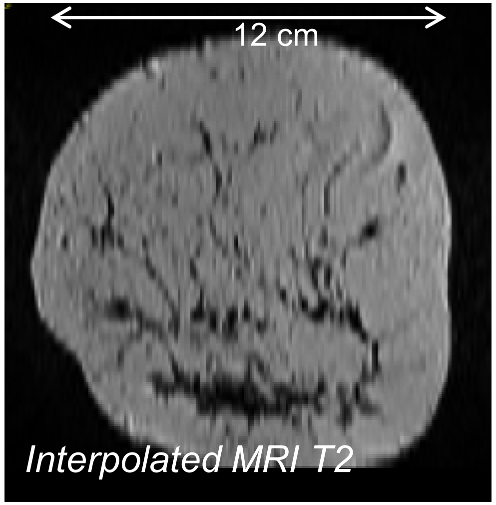


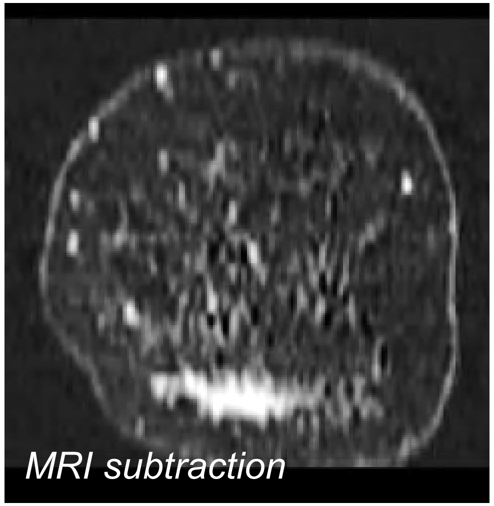
All Modalities with Thresholding

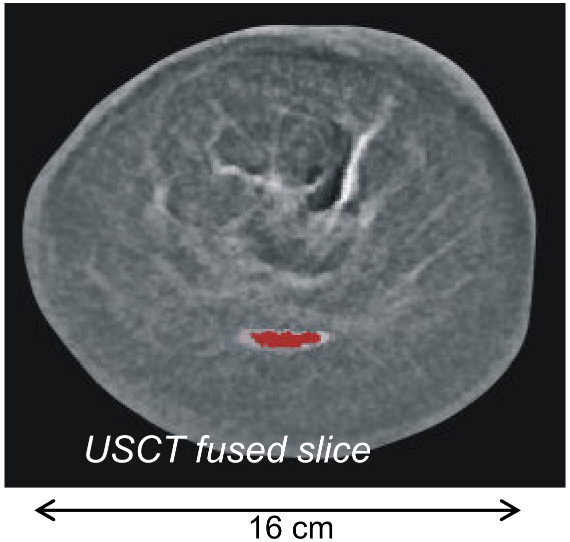


Speed of sound ≥1520 m/s
Attenuation ≥ 1.5 dB/cm

Another Patient with Cancer







Speed of sound ≥1520 m/s
Attenuation ≥ 1.5 dB/cm

Summary

- **First in vivo images**, it really works!
- Technical challenges could be met
- USCT has the potential to
  be the screening modality of the future

Ready for a larger clinical study at University Hospital Mannheim

Thank you!

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Karlsruhe Institute of Technology

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