Karlsruhe Institute of Technology

USCT

Three-Dimensional Ultrasound Computer Tomography at KIT

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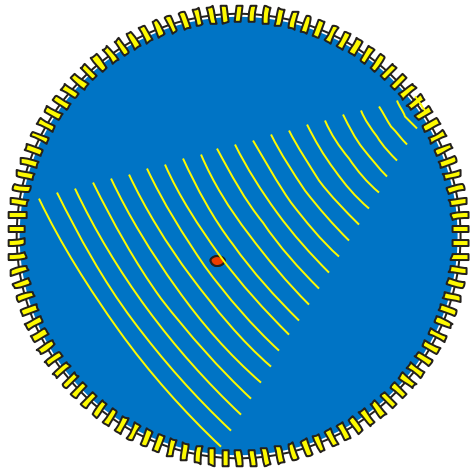
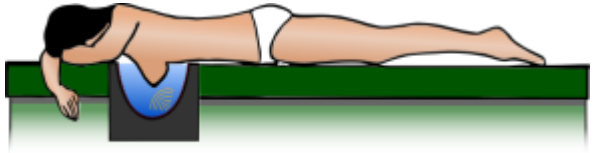
Ultrasound Computer Tomography

- Surround object with (unfocused) ultrasound transducers in a fixed setup
- Application: Breast imaging for cancer diagnosis
- Features:
  - Reproducible images with ultrasound
  - Sub-millimeter volumes
  - Three modalities concurrently

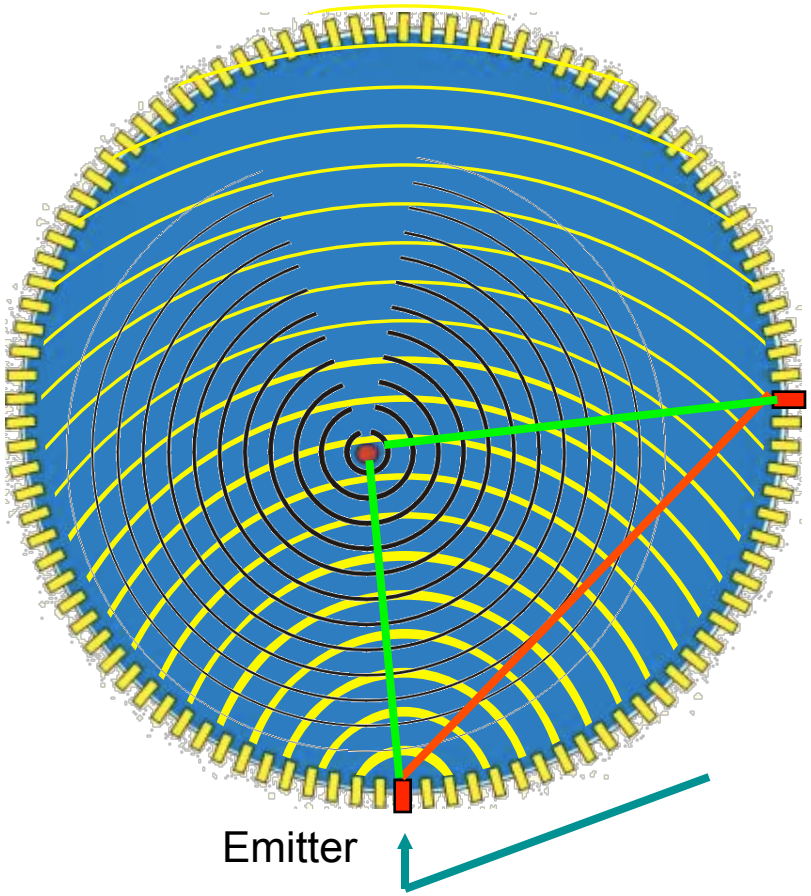


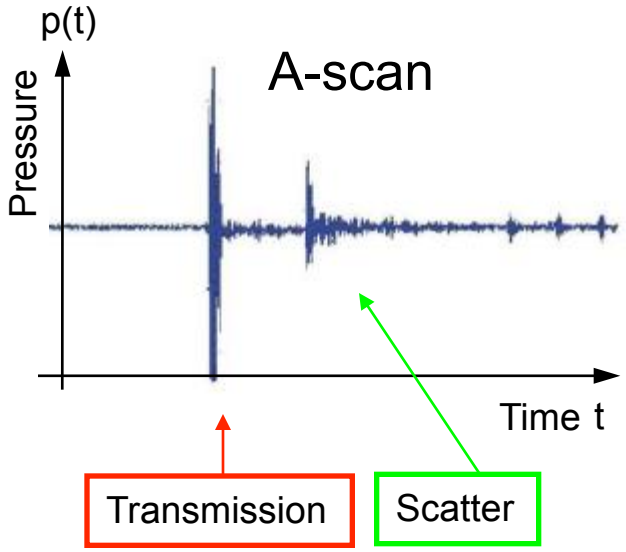
Example setup



Breast imaging in fixed setup

Imaging Principle

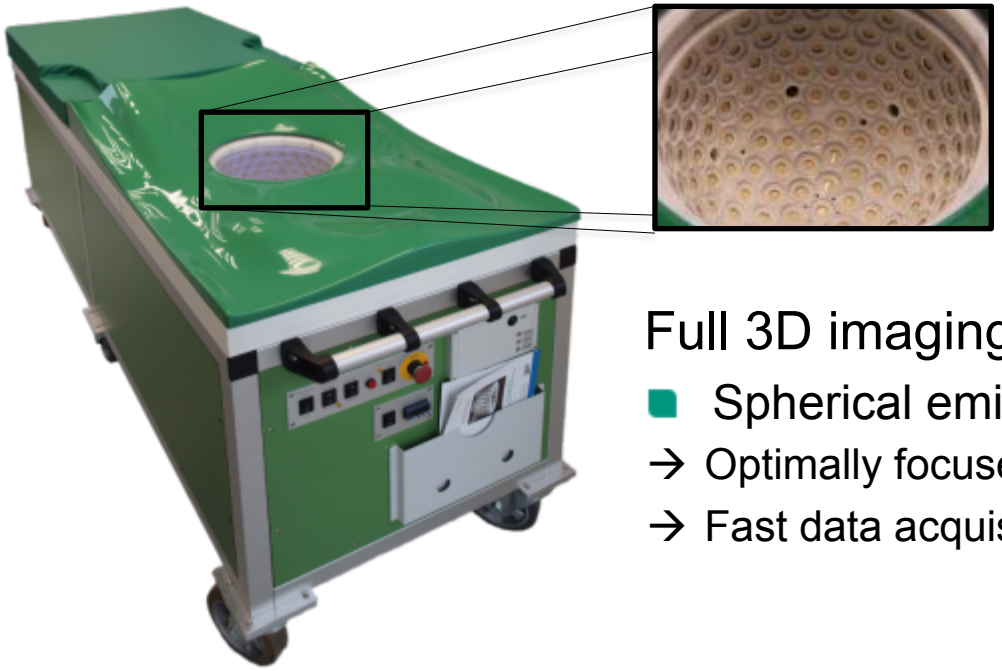


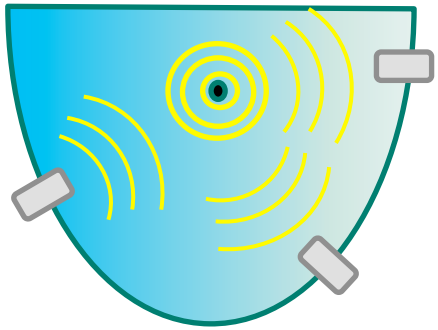


Reconstruction of
Speed of sound
Attenuation
Reflectivity

"Image one, get two free"

KIT 3D USCT system



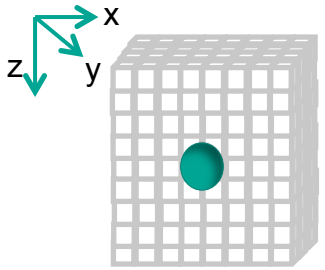


Full 3D imaging:

- Spherical emission and reception

→ Optimally focused images in 3D

→ Fast data acquisition



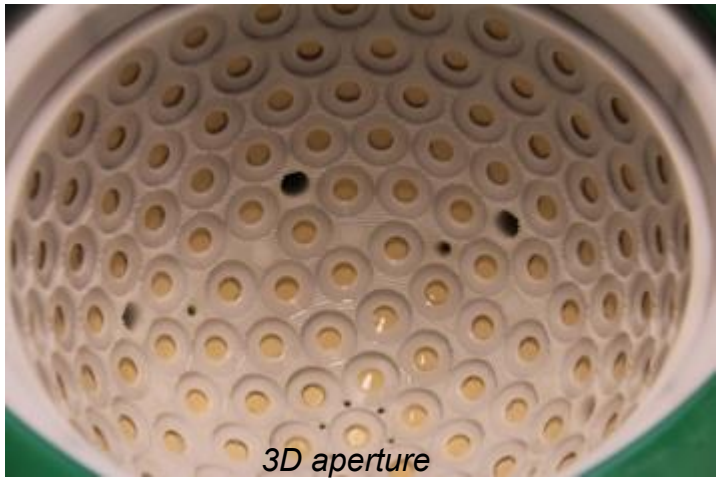
(3D) Ultrasound Tomography
for early breast cancer diagnosis …

- as harmless as diagnostic ultrasound
- as economical as X-ray mammography
- as sensitive as MRI (long term goal)

KIT 3D USCT


3D USCT during pilot study


Internal parts

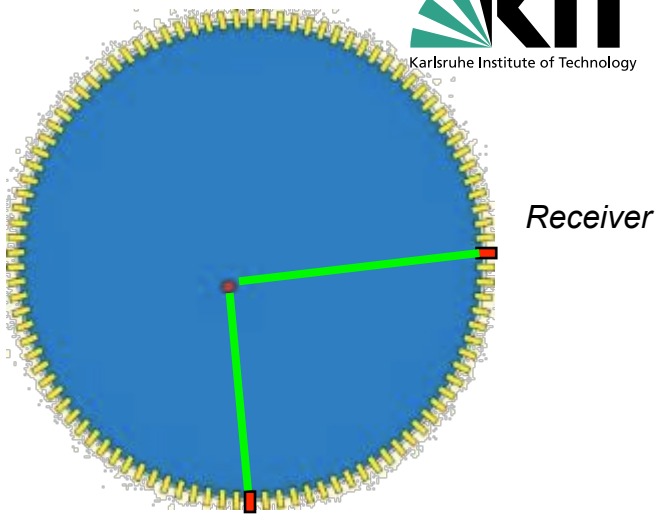

3D aperture

Specification	Value
Center frequency (bandwidth)	2.5 MHz (~50%)
Maximum resolution	$(0.24\ mm)^3$
# transducers	2041 (sparse!)
Raw data (# A-scans)	up to 80 GByte (~40 millions)
DAQ time for one volume	10 s - 4 min

Reflection Tomography

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

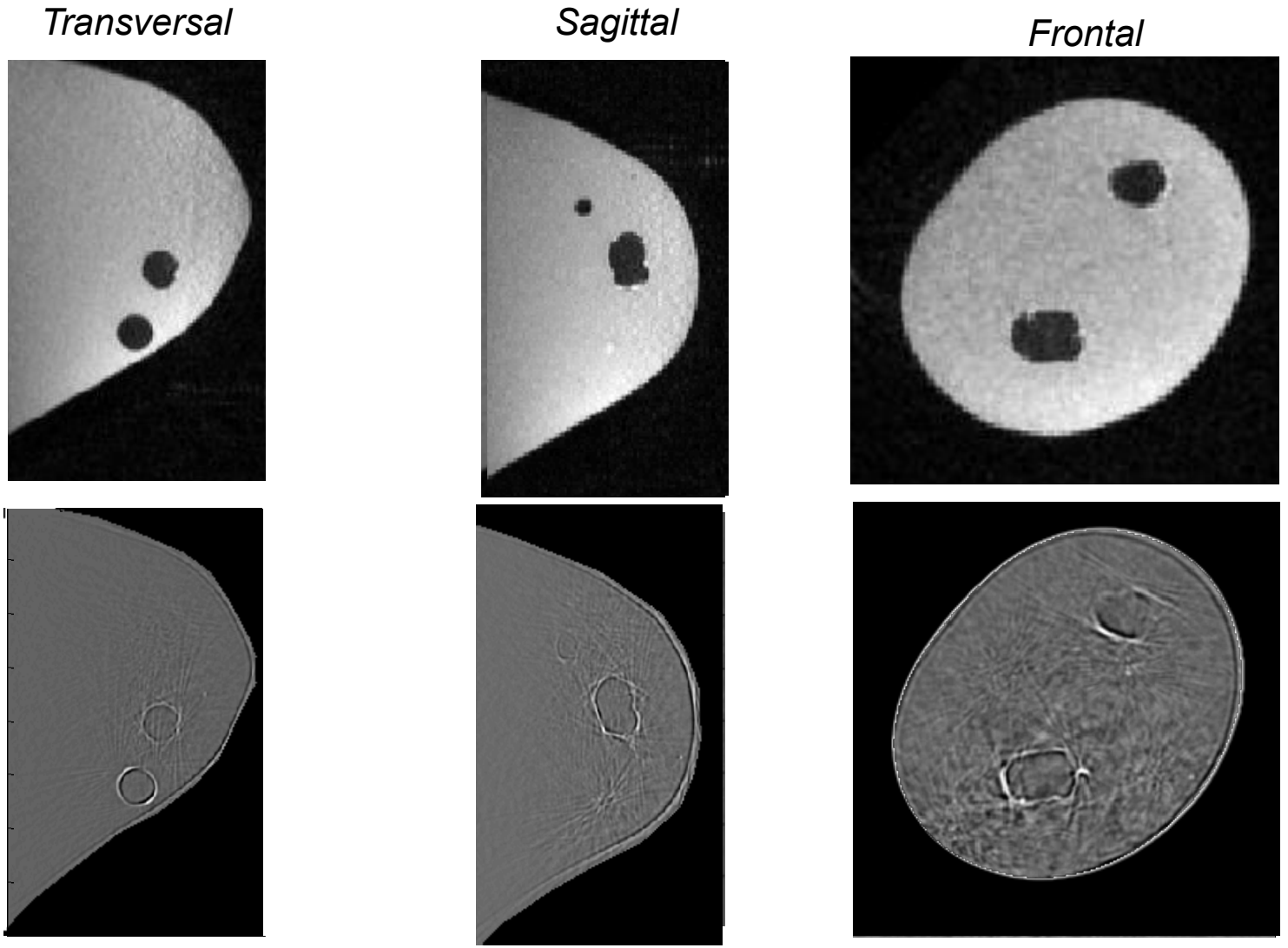
$$f(\vec{x}) = \sum_{(i,k)} A_{(i,k)} \left(\frac{\left\| \vec{x}_i - \vec{x} \right\| + \left\| \vec{x} - \vec{x}_k \right\|}{\hat{c}(\vec{x}_i, \vec{x}_k, \vec{x})} \right)$$



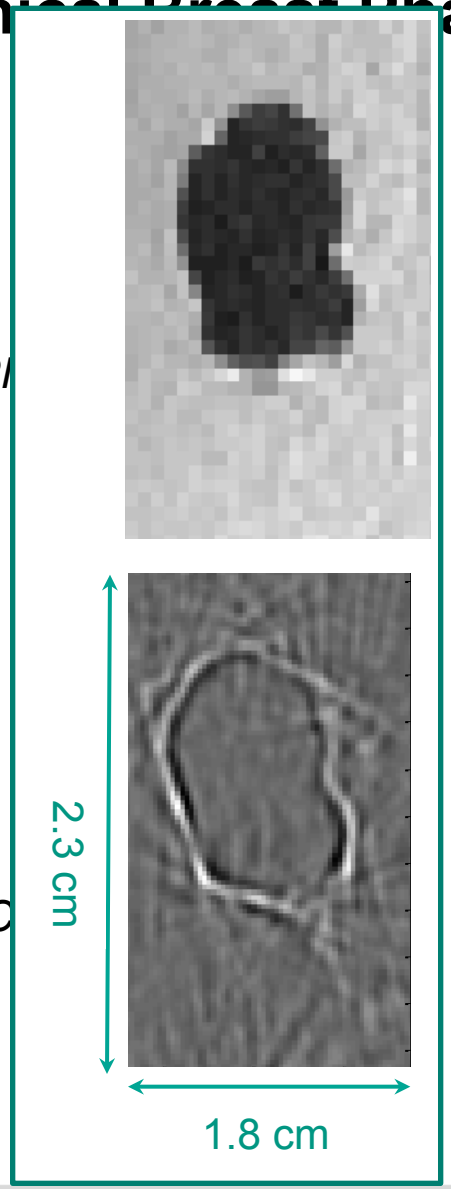
- **Approximations and resolution**:
  - Born approximation, no refraction
  - Optimal resolution: $(0.24\ \text{mm})^3$
  - Speed of sound and attenuation correction

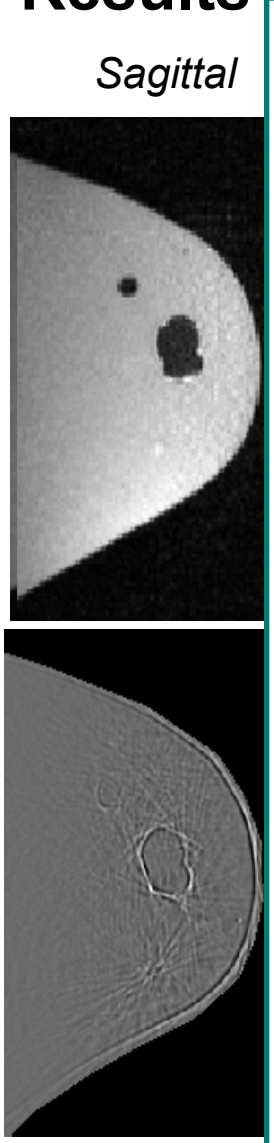
- **Reconstruction load and performance**
  - Realistic scenario: 256^3 voxels using 8 million A-scans (MRI resolution)
  - Using multi CPU and GPU cluster in 2 hours, corrected in 14 hours

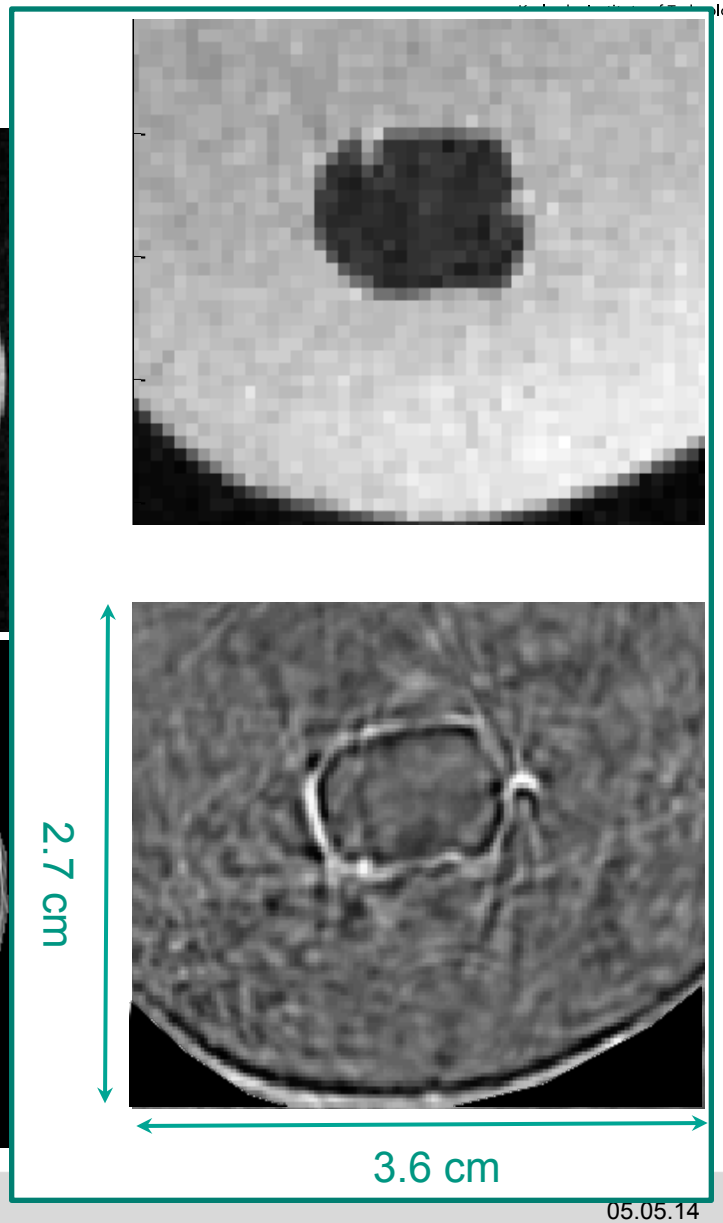
Clinical Breast Phantom: Results



Clinical Breast Phantom: Results







Transmission Tomography

- **How it works** (example for speed of sound)
  - $t = l / c$
  - $$\begin{bmatrix} t_1 \\ \vdots \\ t_n \end{bmatrix} = \begin{bmatrix} l_{11} & \cdots & l_{1m} \\ \vdots & \ddots & \vdots \\ l_{n1} & \cdots & l_{nm} \end{bmatrix} \begin{bmatrix} 1/c_1 \\ \vdots \\ 1/c_m \end{bmatrix}$$
  - Solve linear equation system using Total Variation minimization (TVAL3)

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

- **Approximations and limitations**
  - Straight ray approximation
  - Optimal resolution: $(5\ \text{mm})^3$
  - Refraction correction
- **Reconstruction load and performance**
  - Matrix dimensions of 3 000 000 x 1 500 000
  - Reconstruction in 5 minutes, refraction corrected in 8 hours

Clinical Breast Phantom: Speed of Sound and Attenuation

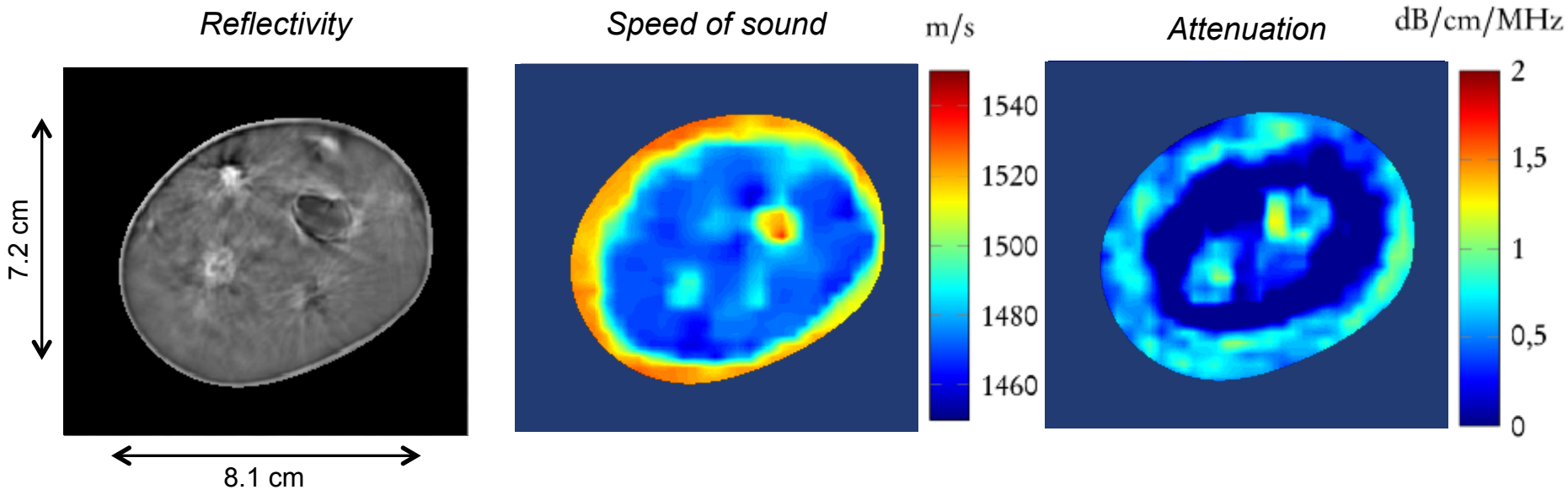


Image Fusion and Display

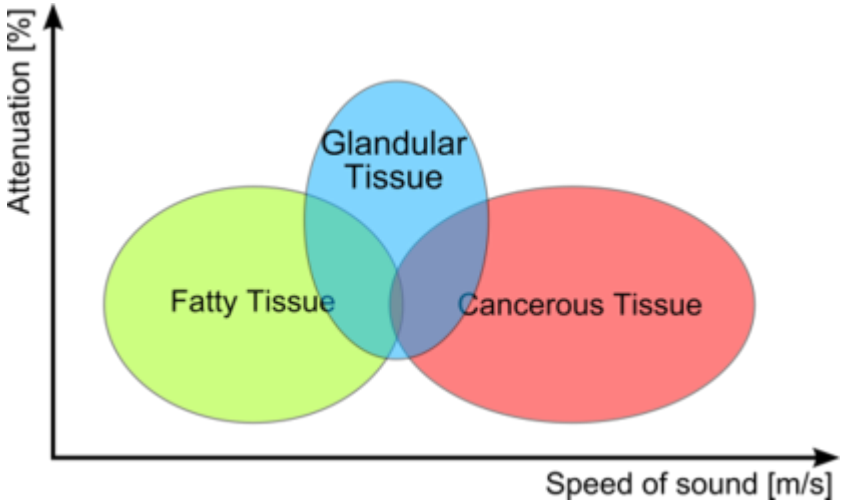
- Three types of images:
  - Reflectivity I_R
  - Speed of sound I_S
  - Attenuation I_A

- Overlaid images I_o:

$$I_O = I_R + I_T$$

- Thresholded fused images I_F*:

$$I_F = \left[I_R + I_{S=a}^{S=b} \right] + \left[I_{S>c} \bullet I_{A>d} \right]$$

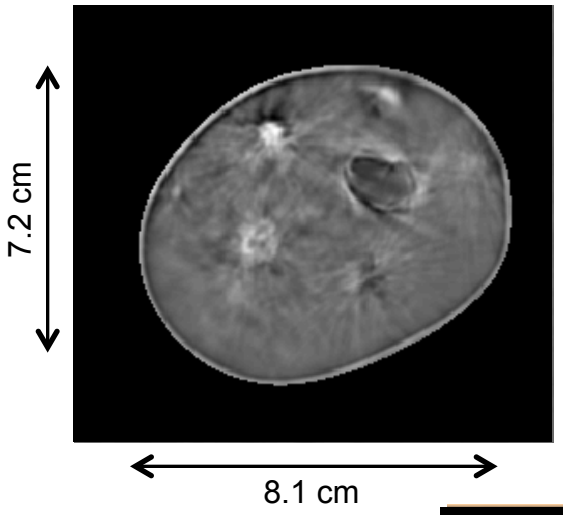


[Simplified, based on Greenleaf et al, Clinical Imaging 1981.]

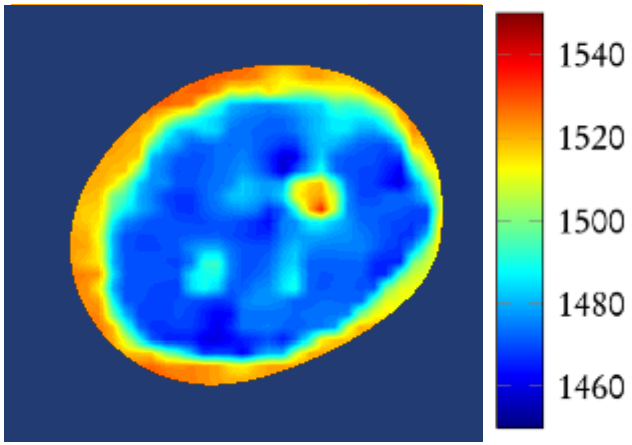
*N. Duric, P. Littrup, et al, “In-vivo imaging results with ultrasound tomography: Report on an ongoing study at the Karmanos Cancer Institute,” Proc. SPIE Medical Imaging, 2010.

Clinical Breast Phantom: Speed of Sound and Attenuation

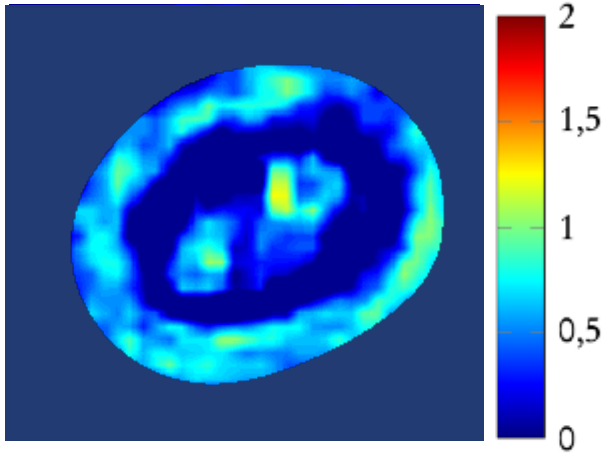
Reflectivity



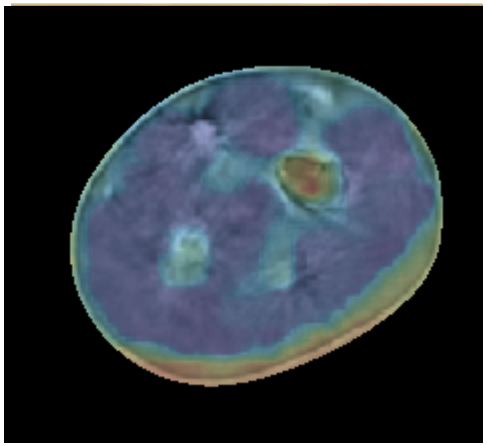
Speed of sound



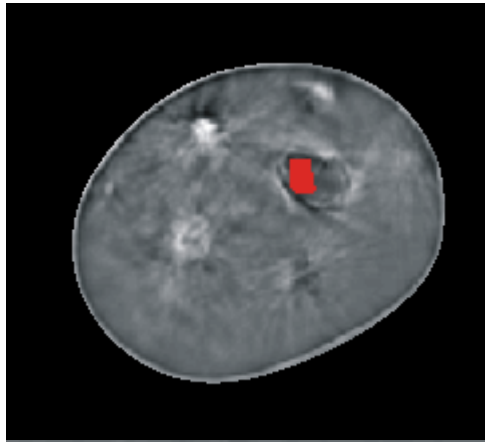
Attenuation



Exemplary image fusion



Fused reflectivity and speed of sound

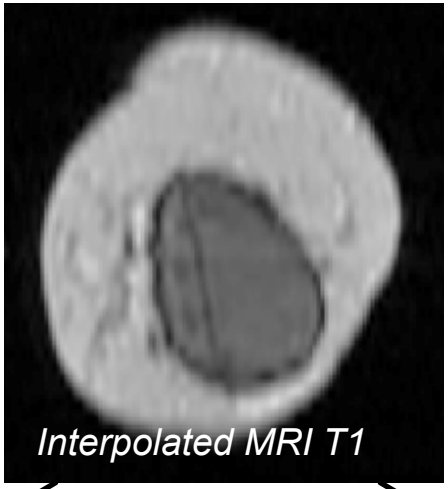


All modalities with thresholding

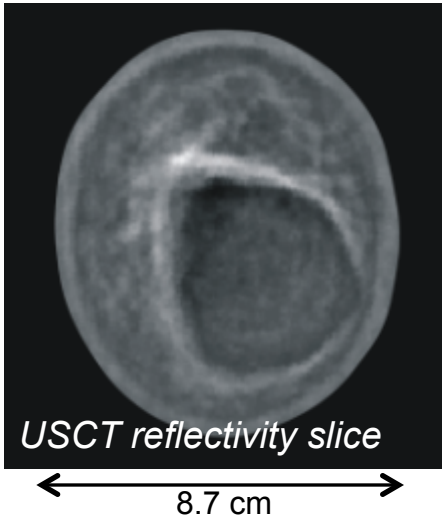
Overview of Pilot Study

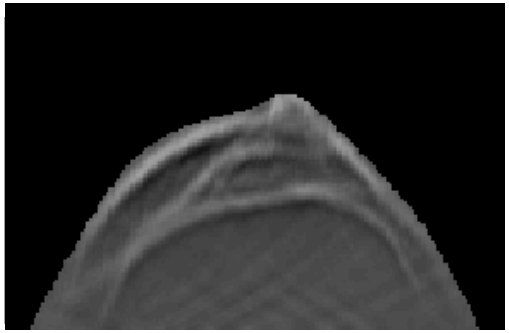
- First pilot study: Ten patients
  → Evaluate and optimize imaging protocols
- Ground truth available: Clinical MRI
- At University Hospital Jena

Patient with Implants



9.4 cm

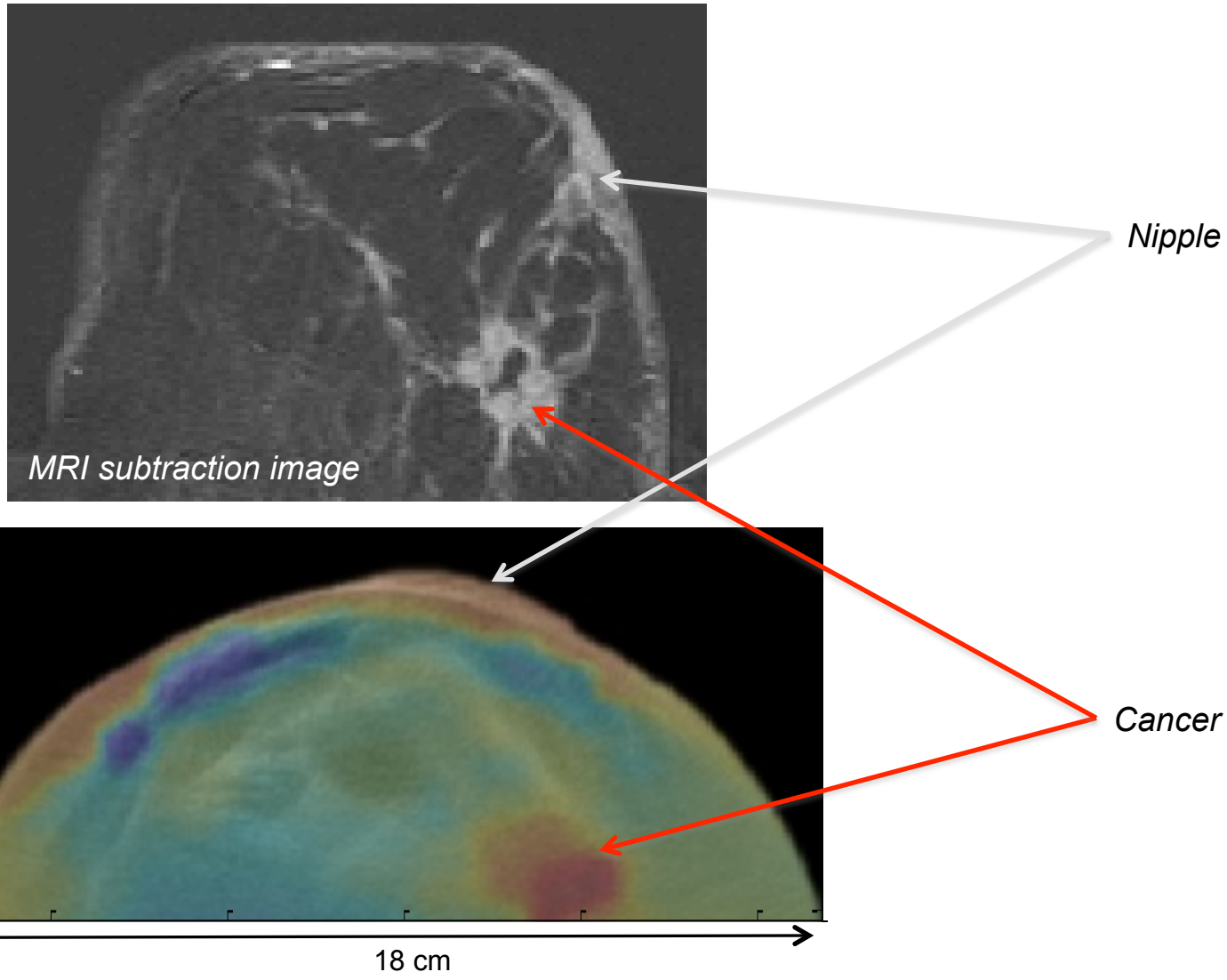




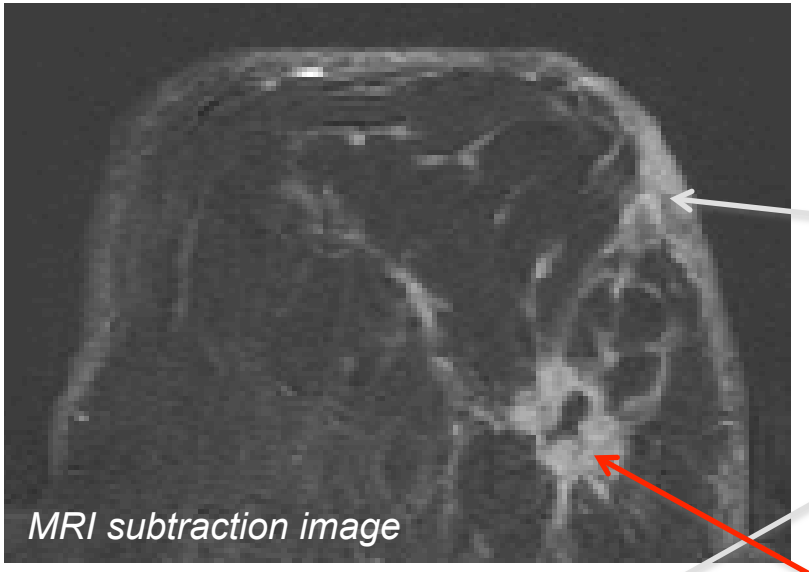
Transversal USCT slice

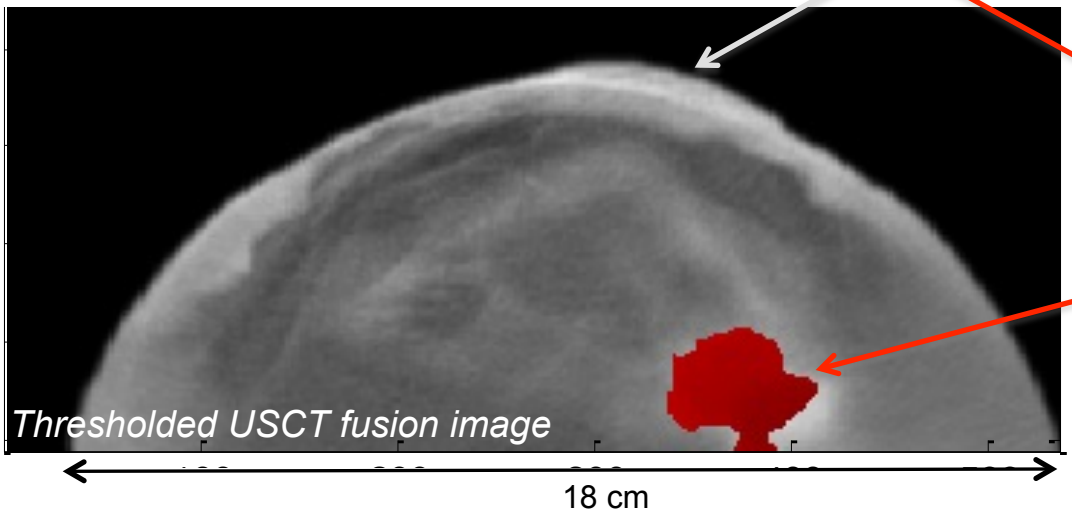
6.4 cm

Reflectivity and Speed of Sound Fusion Image



All Modalities with Thresholding



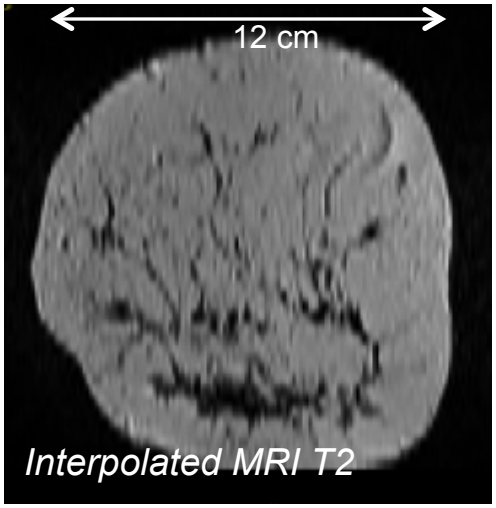


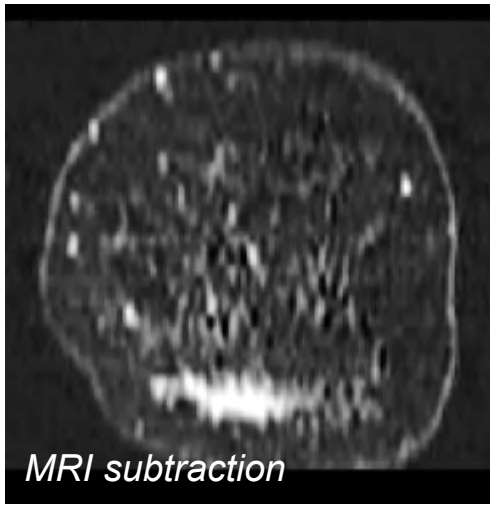
Nipple

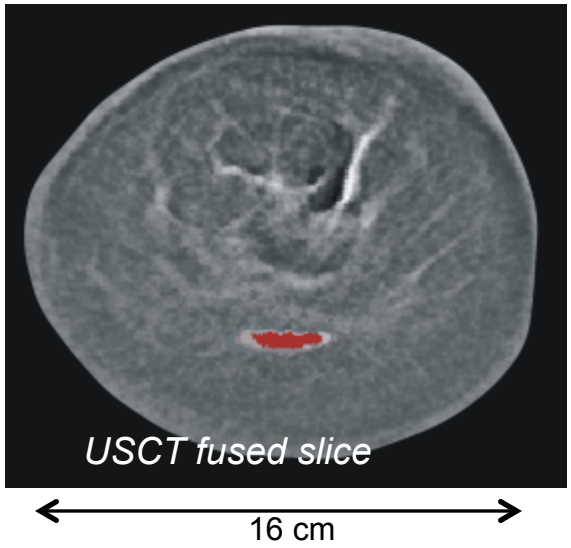
Cancer

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

- **KIT 3D USCT**
  - Fully operable 3D system
  - Isotropic point spread function
- **First pilot study successful:**
  - All ten patients could be imaged
  - First cancers could be “detected” in SOS images
- Next Steps:
  - Larger clinical study (200 patients) at University Hospital Mannheim
  - Next generation system

Thank you!

- Algorithms and Imaging
  N. V. Ruiter, M. Zapf, R. Dapp, T. Hopp, H. Gemmeke, et al.
- HW Acceleration
  E. Kretzek, M. Balzer, et al.
- Sensors
  M. Zapf, H. Gemmeke, et al.
- DAQ und Hardware
  D. Tscherniakhovski, S. Menshikov, et al.
- Design and Mechanics
  L. Berger, B. Osswald, T. Piller, W. Frank, et al.