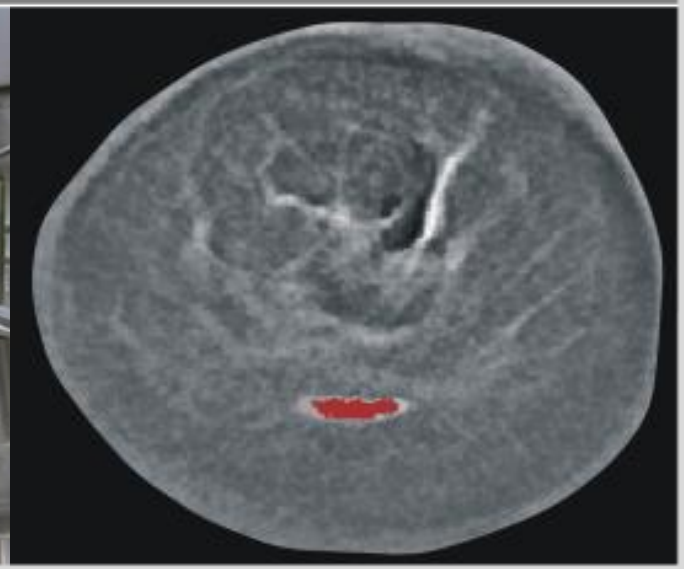
Karlsruhe Institute of Technology

USCT
3D Ultrasound Computer Tomography

3D Ultrasound Computer Tomography (USCT)

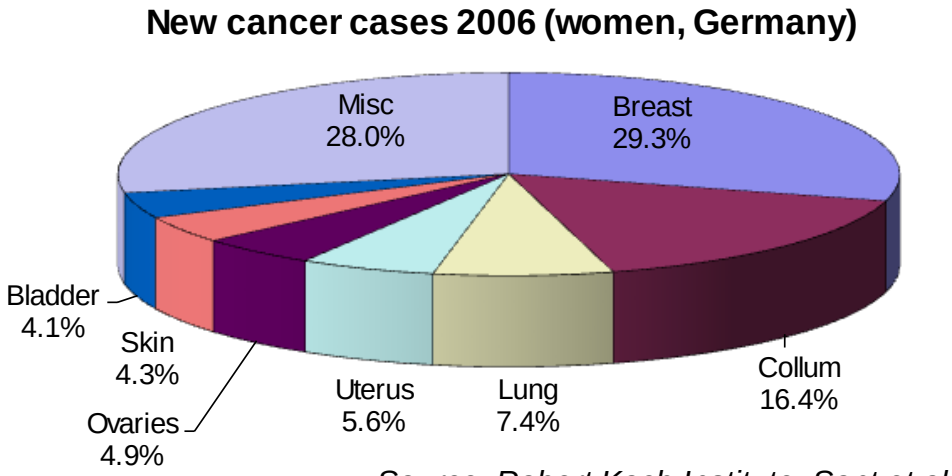
Nicole V. Ruiter, Michael Zapf, Torsten Hopp and Hartmut Gemmeke

INSTITUTE FOR DATA PROCESSING AND ELECTRONICS



Breast cancer

- Most common cancer of women in western world
  (every 10th woman)
- Challenge: Early diagnosis



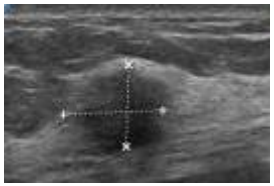
Source: Robert Koch Institute, Sant et al

- Current diagnosis methods

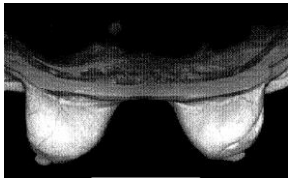
Palpation

X-ray mammography

Screening



Sonography



MRI

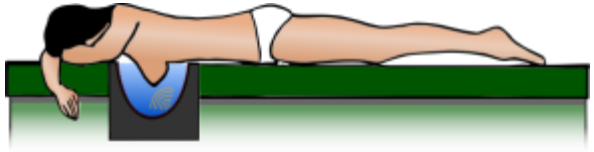
...

Symptomatic patients

Image sources: netdoctor.de, University Hospital Jena, University Hospital Mannheim

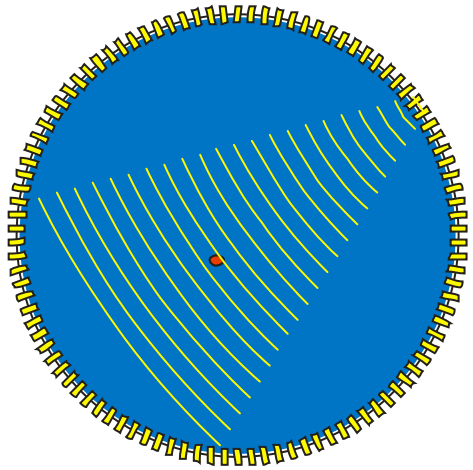
Ultrasound Computer Tomography (USCT)

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



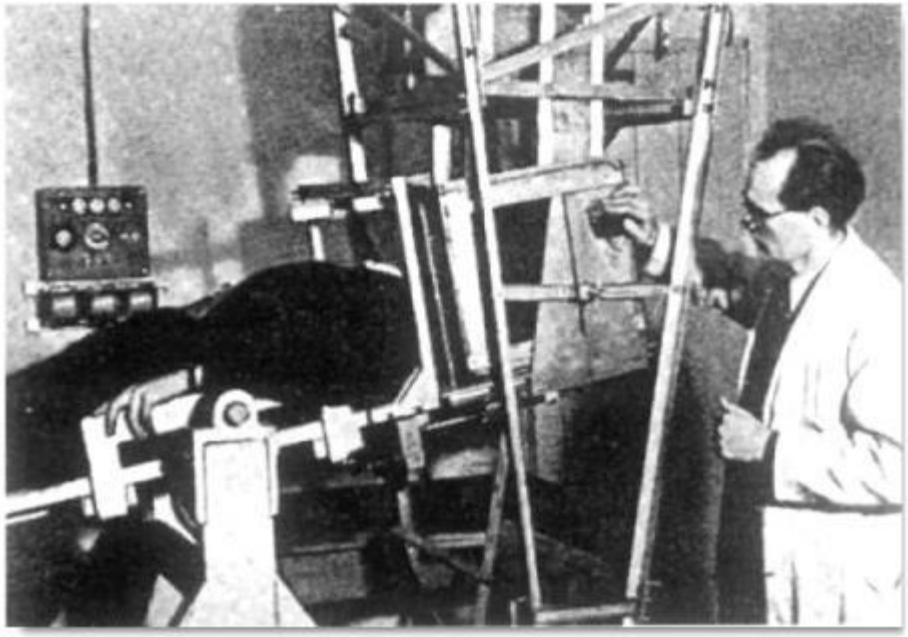
Breast imaging in fixed setup

- Features:
  - Reproducible 3D images with ultrasound
  - Sub-millimeter volumes
  - Multiple tissue information



Example setup

The beginning



First attenuation imaging (Dussik, 1946): Not so successful imaging of brain ventricles

First "USCT" device (Holmes et al., 1954): Slice image of the neck, compounding device

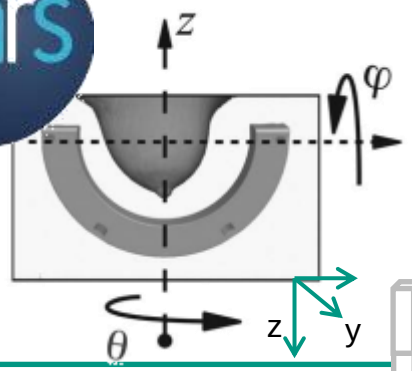
Sources: ob-ultrasound.net, Szabo: Diagnostic Ultrasound: Inside out.

State of the art

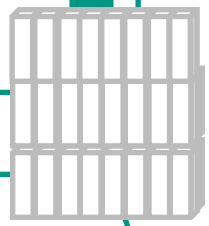
Delphinus Medical Technologies

MASTOSCOPIA
Advanced Medical Imaging Technologies

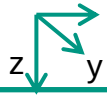
cnrs



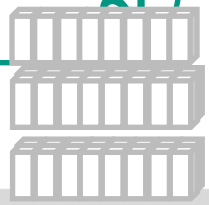
3D systems



TechniScan MEDICAL SYSTEMS

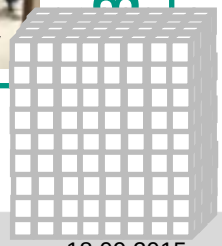


2,5D system



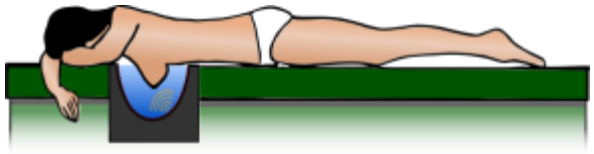
KIT Karlsruhe Institute of Technology

3D system



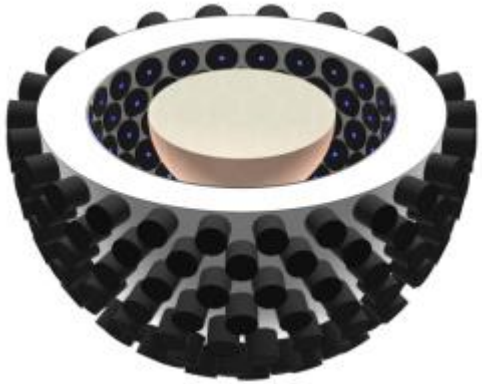
3D USCT at KIT

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



Breast imaging in fixed setup

- Features:
  - Reproducible 3D images with ultrasound
  - Sub-millimeter volumes
  - Multiple tissue information
  - Optimally focused images in 3D (isotropic PSF)
  - Fast data acquisition

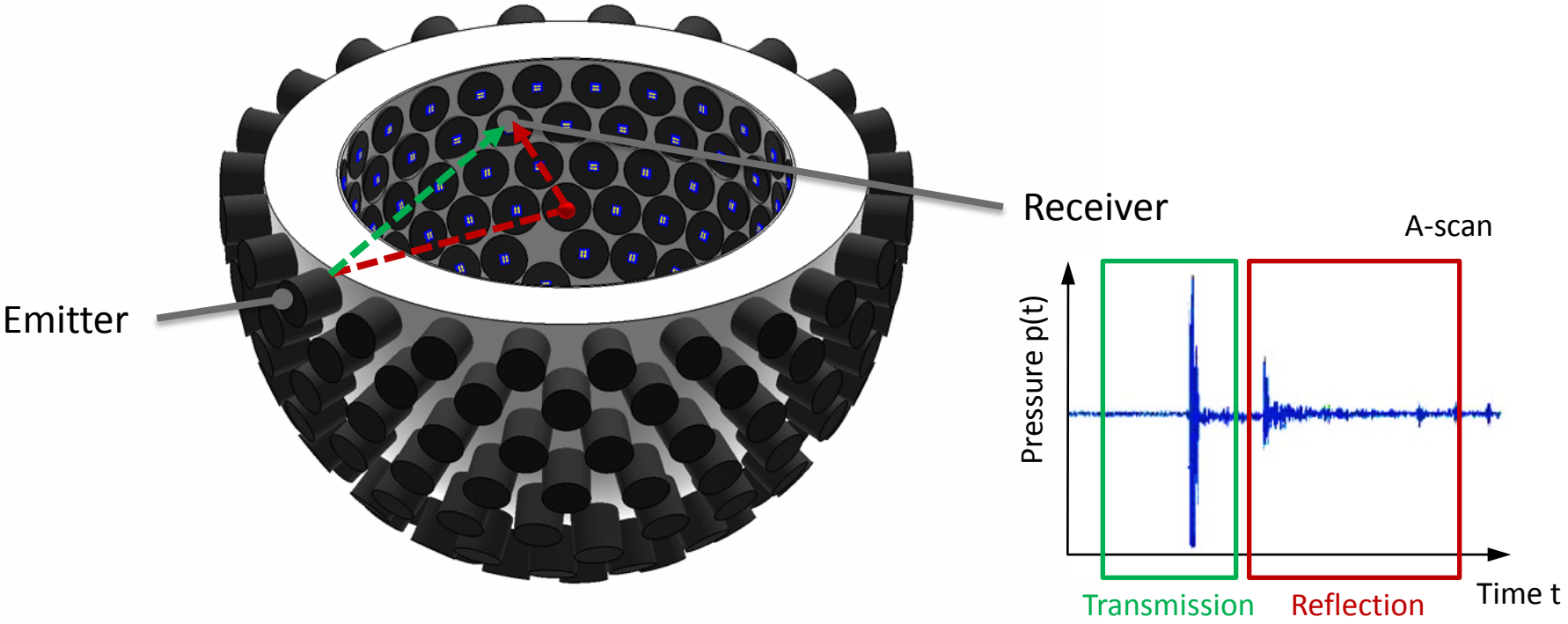


3D USCT imaging setup

3D Ultrasound Computer Tomography
for early breast cancer diagnosis …

- as harmless as diagnostic ultrasound
- as economical as X-ray mammography
- as sensitive as MRI

How does it work? Data acquisition



- >10 Mio. A-scans
- Up to 40 GB raw data per breast
- Measurement time 10 s to 4 min.

Image reconstruction

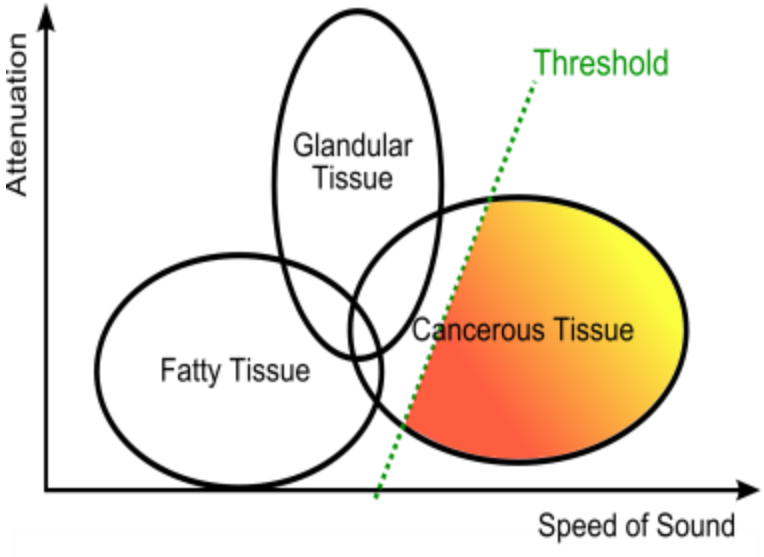
- Sound speed
- Attenuation
- Reflection

Image one, get two free

Images three modalities concurrently:

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

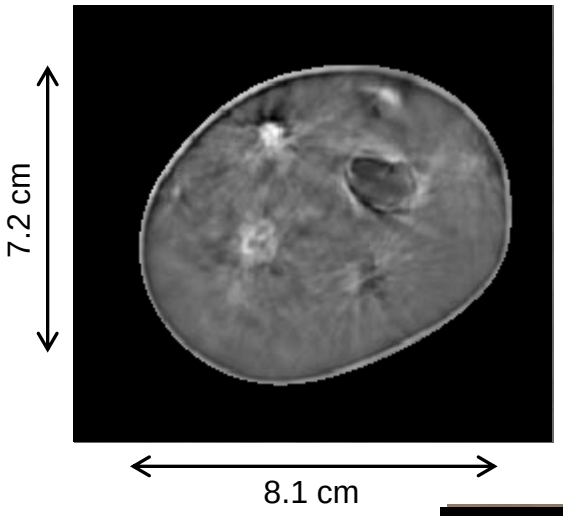
- **Speed of sound** and **attenuation**:
  Quantitative information
  Simple tissue classification possible?



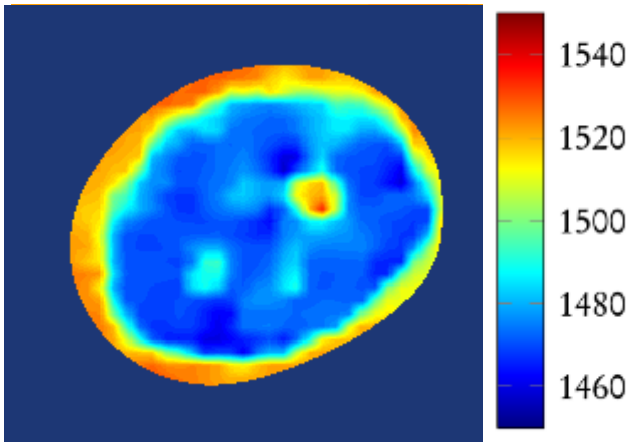
Source: Simplified from Greenleaf et al.

Image reconstruction

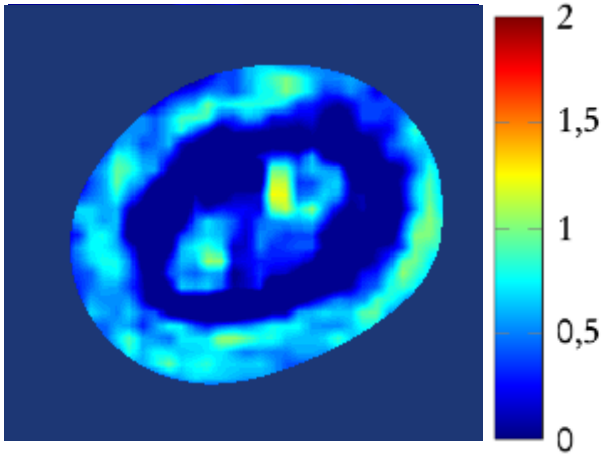
Reflectivity



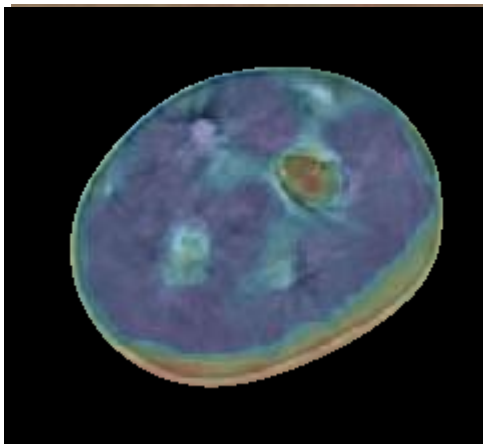
Speed of sound



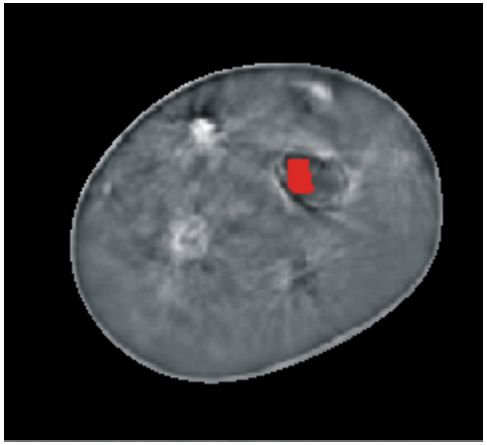
Attenuation



Exemplary image fusion



Fused reflectivity and speed of sound



All modalities with thresholding

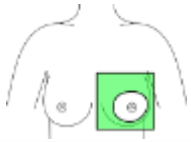
First clinical study: Patient population

- Title: “Pilotstudie 3D-Ultraschall-Computertomographie für die Brustkrebsdiagnose”

- University Hospital Jena (Prof. W.A. Kaiser)

- 10 patients, all with suspicious lesions (follow ups, transferals, BRCA patients)
- 2 implants, 4 cancers, papilloma, fibroadenoma, mastopathy, cysts
- Patients’ average age: 55.6 a (± 13.5 a)
- 4 B-cups, 4 C-cups, 2 D-cups

Patient 1: Comparability

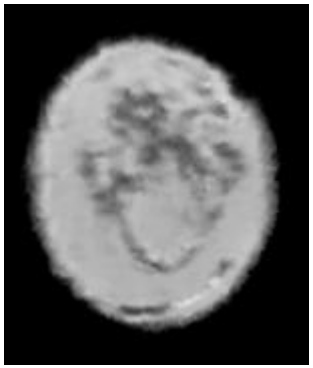


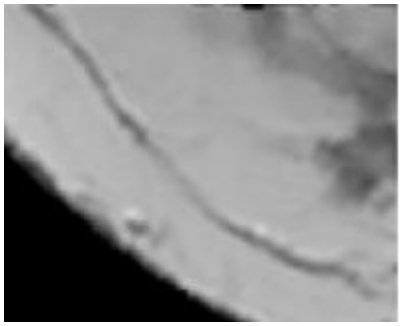
Coronal plane

Transversal plane

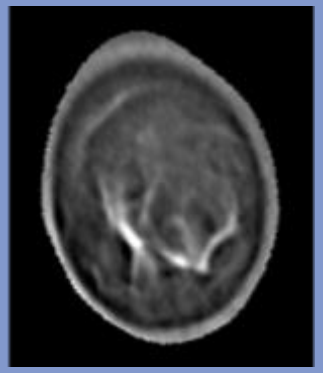
(detail view)

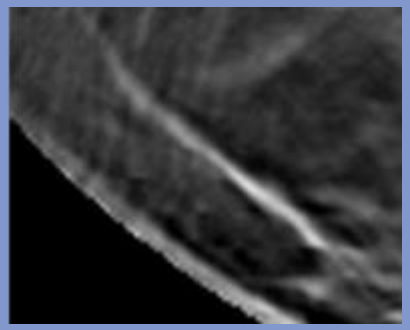
Registered MRI
T1-weighted





USCT
Reflectivity





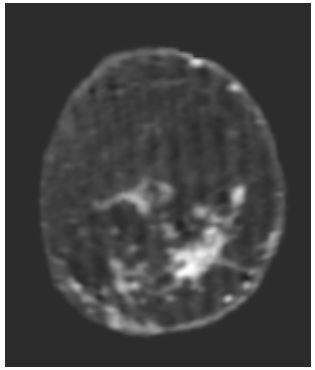
Patient 2: Inflammatory carcinoma

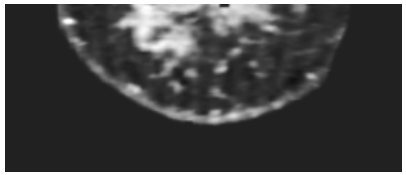
Coronal plane

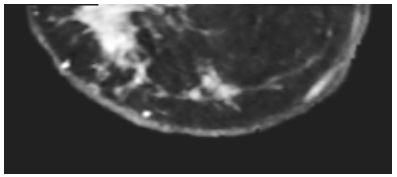
Sagittal plane

Transversal plane

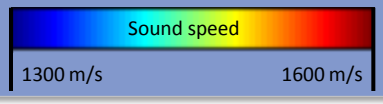
Registered MRI
T1 contrast enhancement

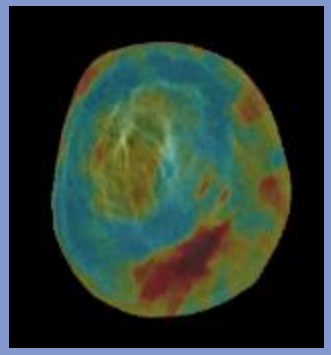


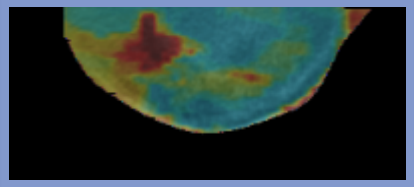


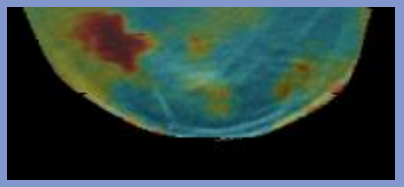


USCT image fusion:
Reflectivity + sound speed (color-coded)









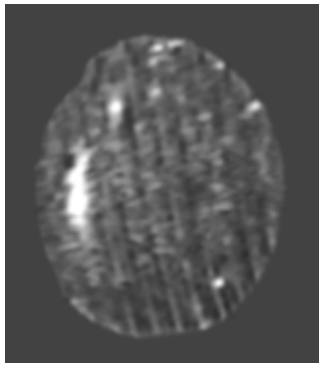
Patient 3: Multicenter carcinoma

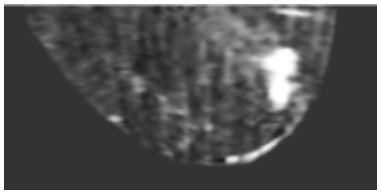
Coronal plane

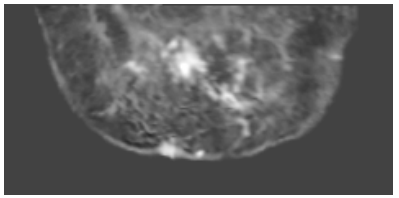
Sagittal plane

Transversal plane

Registered MRI
T1 contrast enhancement

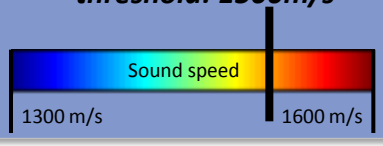


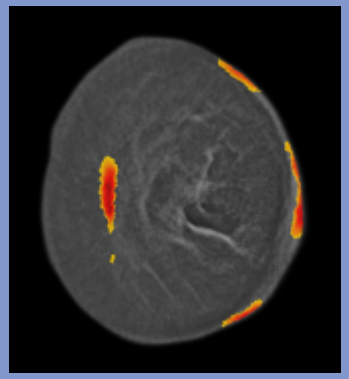


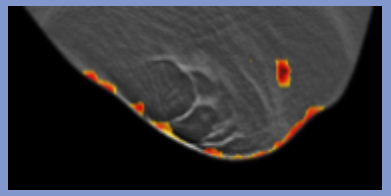


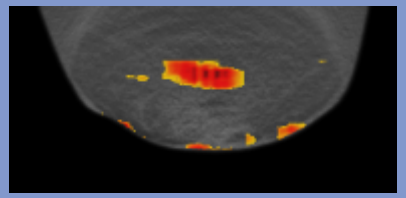
USCT image fusion:
Reflectivity + sound speed (color-coded)

threshold: 1500m/s









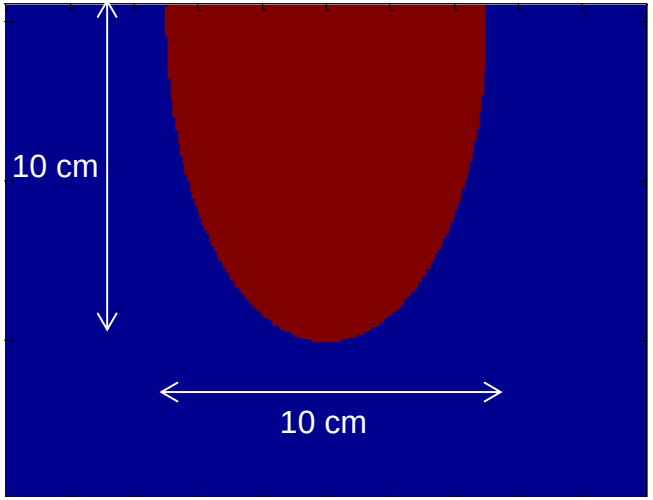
Second Study: University Hospital Mannheim

- Aims
  - Gives USCT as comparable diagnoses as MRI?
  - Analyze different lesion types
- 200 patients
- Start of study: September 2015

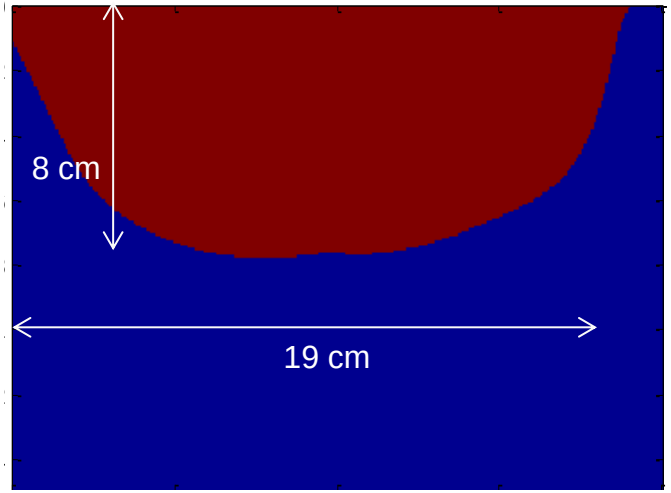
Build the next generation 3D USCT

Main objectives:

- Shorten data acquisition time
- Improve image quality
  - Adapt Region of Interest (ROI)
  - Reduce artefacts

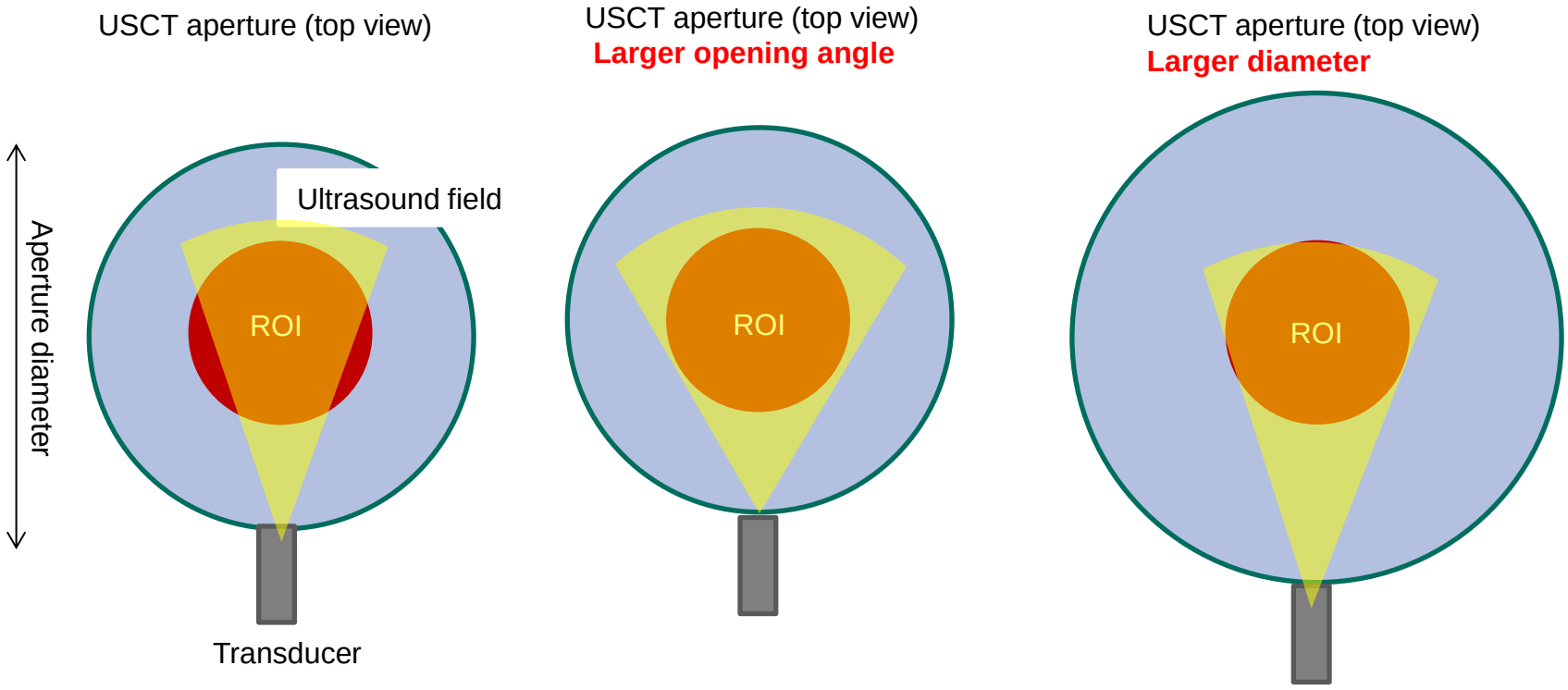


Current ROI ~ B-cup breast



Sum of position of all breasts in pilot study

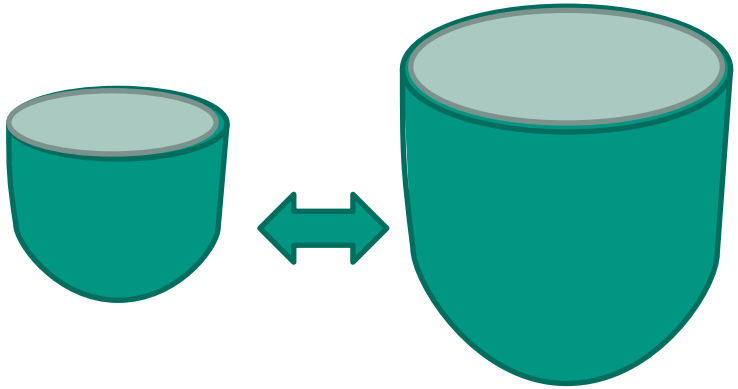
3D USCT III: ROI and aperture parameters



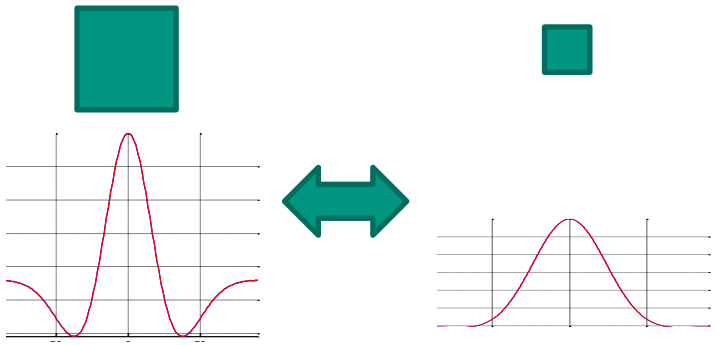
Trade off: Maximum feasible diameter of 35 cm and opening angle of 62°

Improve image quality and reduce artefacts

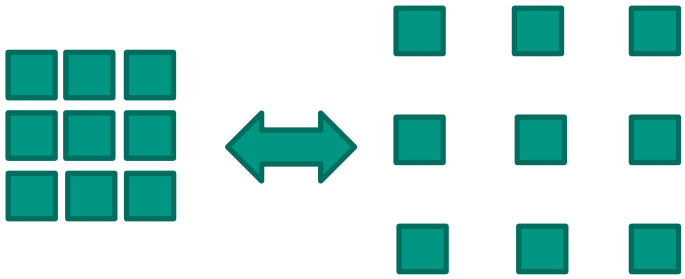
+ add transducers



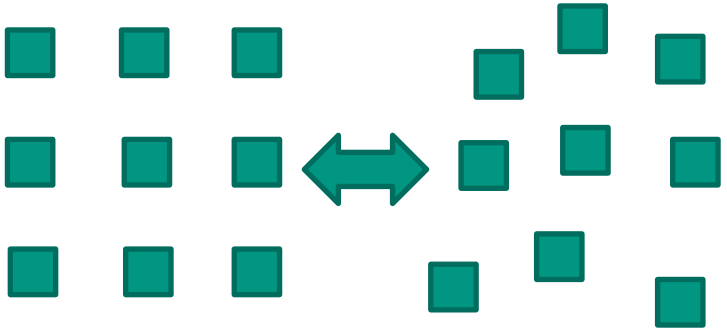
Diameter of aperture



Opening angle of transducers



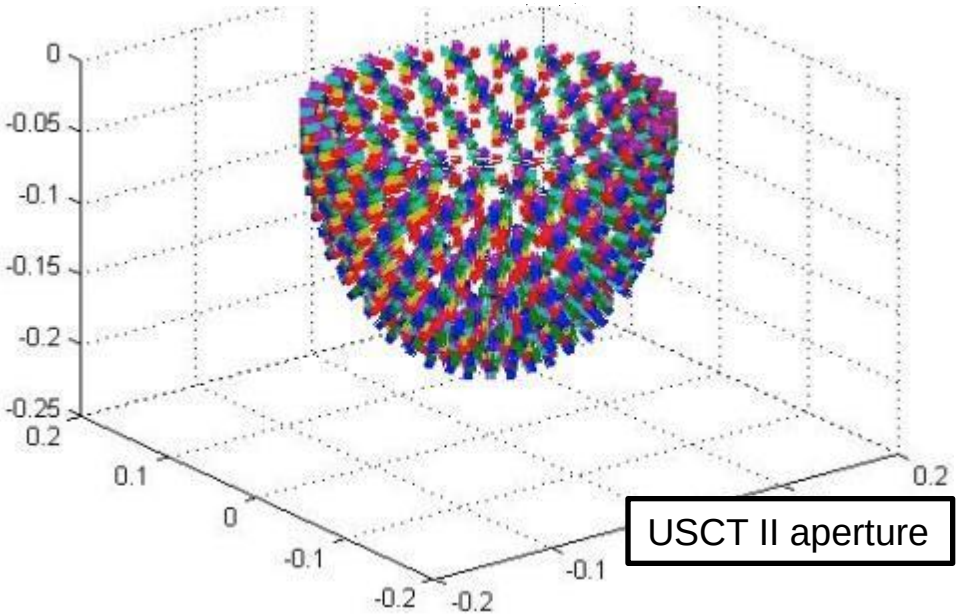
Clustering of transducers → global distribution



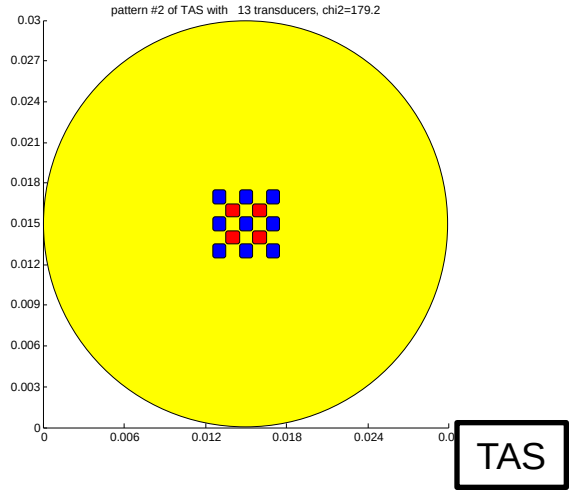
Random transducer distribution (e.g. [1])

[1] Diarra B, Robini M, Tortoli P, Cachard C, Liebgott H.: **Design of optimal 2-D nongrid sparse arrays for medical ultrasound.** IEEE Trans Biomed Eng. 2013 Nov;60(11):3093-102. doi: 10.1109/TBME.2013.2267742. Epub 2013 Jun 11.

USCT III – Vision: current 3D USCT II aperture



USCT II aperture



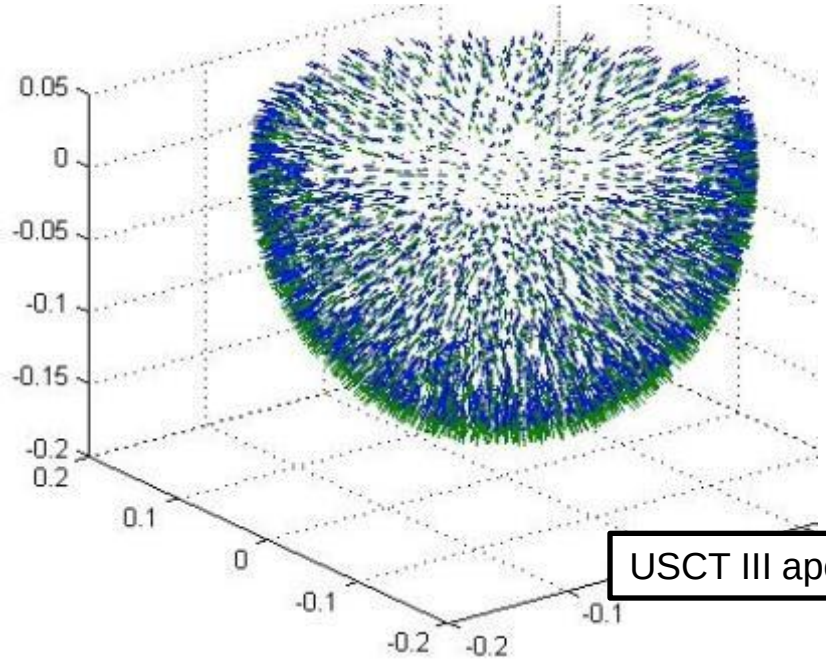
TAS

Diameter 26 cm
157 TAS
With 12 positions: 10.7 Mio. A-scans

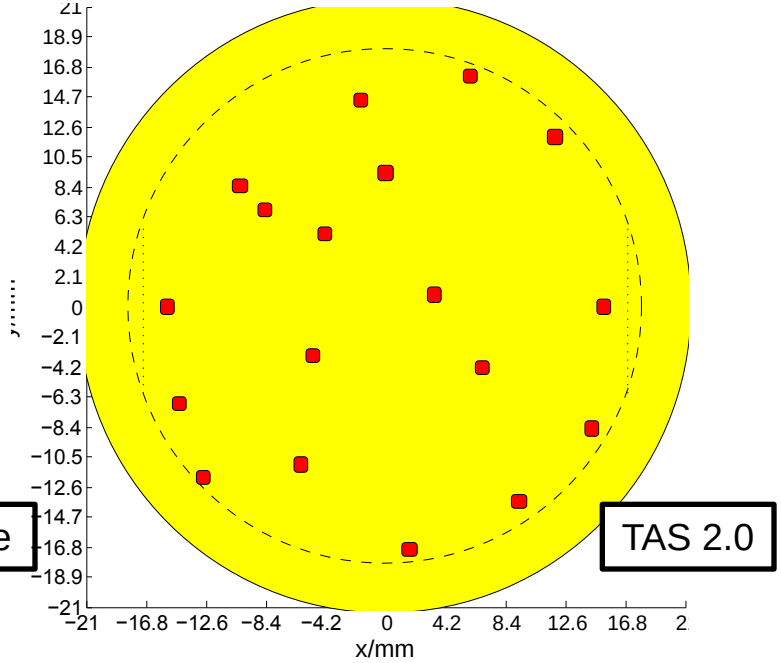
TAS diameter 2.8 cm
4 emitters (red)
9 receivers (blue)

- Next generation:
  - Faster DAQ → more transducers
  - Larger ROI →larger aperture and opening angle
  - Less artefacts → irregular and wider distributed transducer positioning

USCT III – Vision: bigger and denser aperture



USCT III aperture



TAS 2.0

Diameter **35 cm**
128 TAS
with **2** positions: ~10 Mio. A-scans

TAS diameter **4.15 cm**
~**18** transducers (pink)
both emitter and receiver

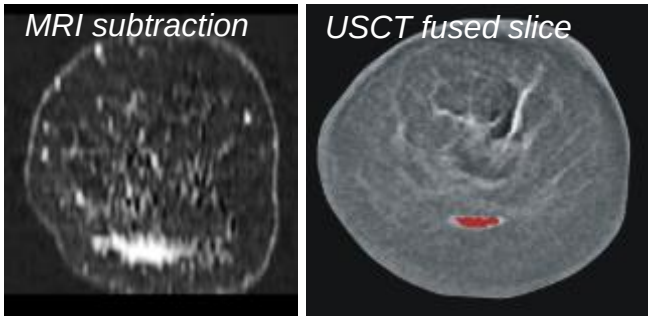
- Main challenges for transducer design:
  - Arbitrary irregular transducer pl
  - Reproducibilit

14:25 Kai Hohlfeld et al: Fabrication and evaluation of single fiber based piezo composite transducers for 3D USCT

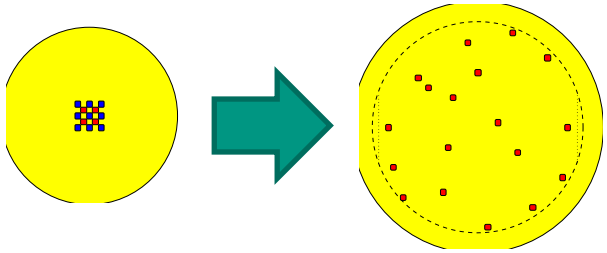
Summary

- Breast cancer is the most common cancer for women in the western world
- 3D USCT a new imaging method aimed at early breast cancer diagnosis

- First pilot study gave very promising results, second study currently beginning



- 3D USCT III:
  - Faster DAQ
  - Larger ROI
  - Randomly distributed transducer



Thank you!

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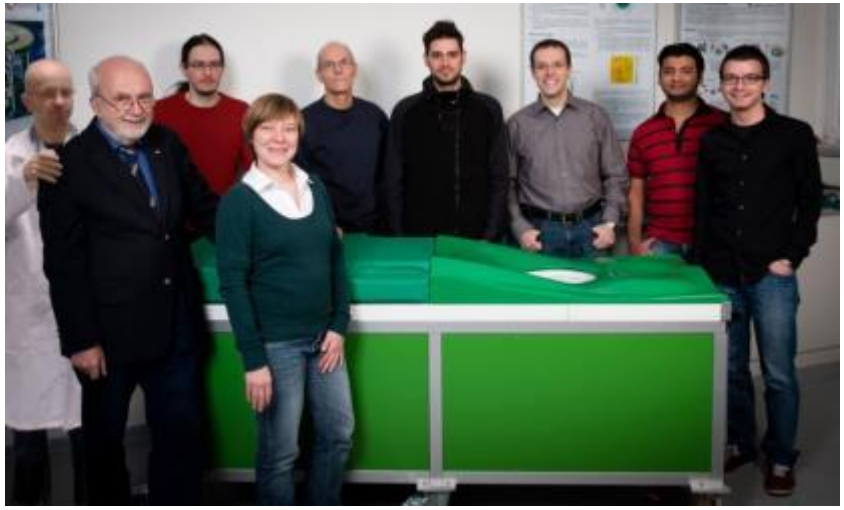

IPE USCT Group

- Algorithms / Imaging / Image Processing
  N. V. Ruiter, M. Zapf, T. Hopp, W.Y. Tan, H. Gemmeke, et al.
- Hardware acceleration
  E. Kretzek, M. Balzer, et al.
- Transducers
  M. Zapf, H. Gemmeke, et al.
- DAQ and Hardware
  D. Tscherniakhovski, A. Menshikov, et al.
- Design and Mechanics
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