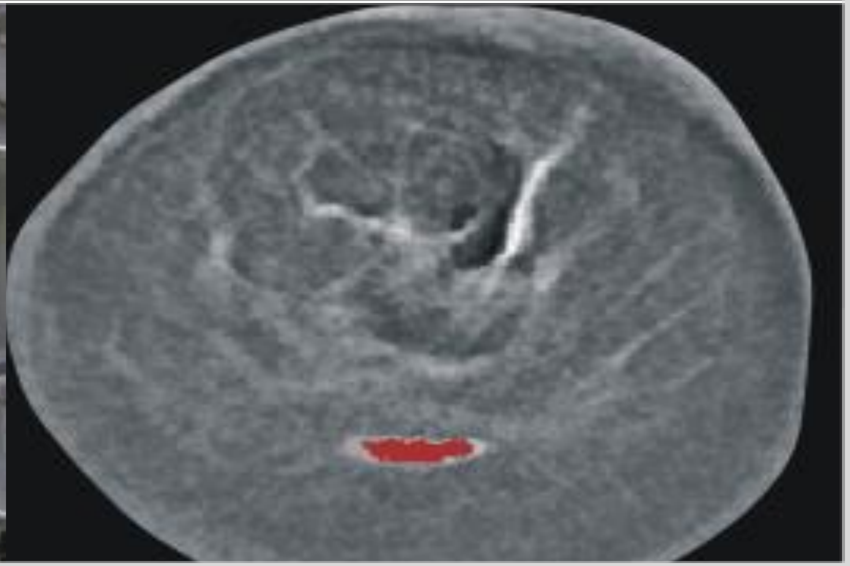
3D Image Reconstruction: Ultrasound Tomography for Breast Cancer Diagnosis

Nicole V. Ruiter

Karlsruhe Institute of Technology

3D Ultrasound Computer Tomography

INSTITUTE FOR DATA PROCESSING AND ELECTRONICS



www.kit.edu

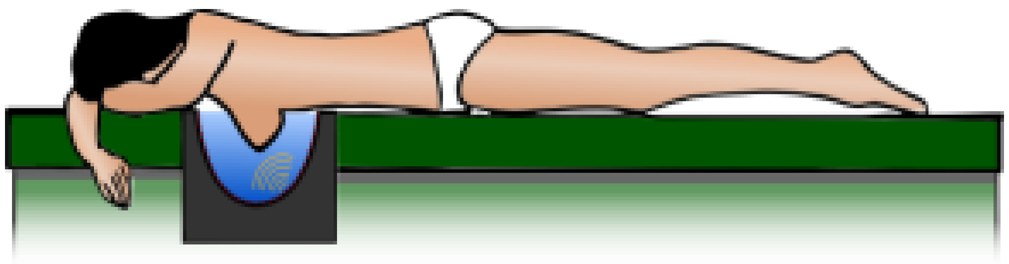
3D USCT and Breast Cancer

Basic idea

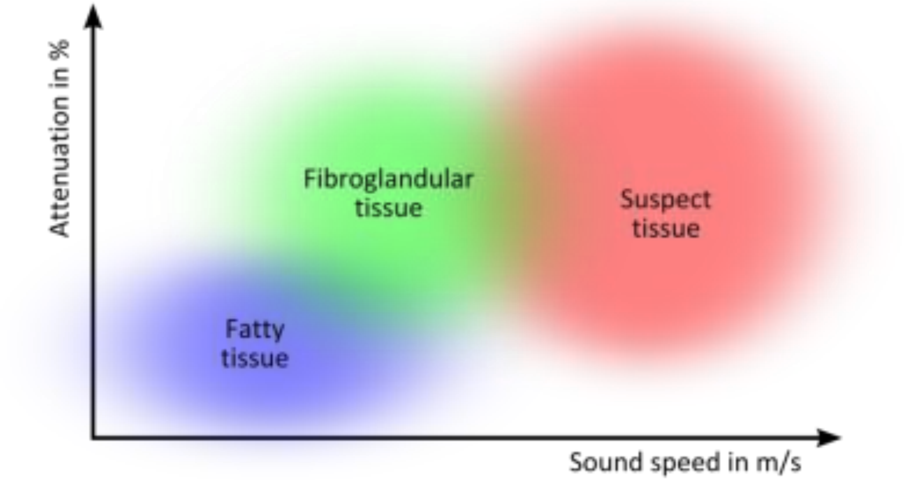
- Surround object with (unfocused) ultrasound transducers in a fixed setup

Diagnostic value

- Reproducible 3D images with ultrasound
- Images three modalities concurrently:
  - **Reflection**
    High quality “B-scans”
  - **Speed of sound** and **attenuation**
    Quantitative information

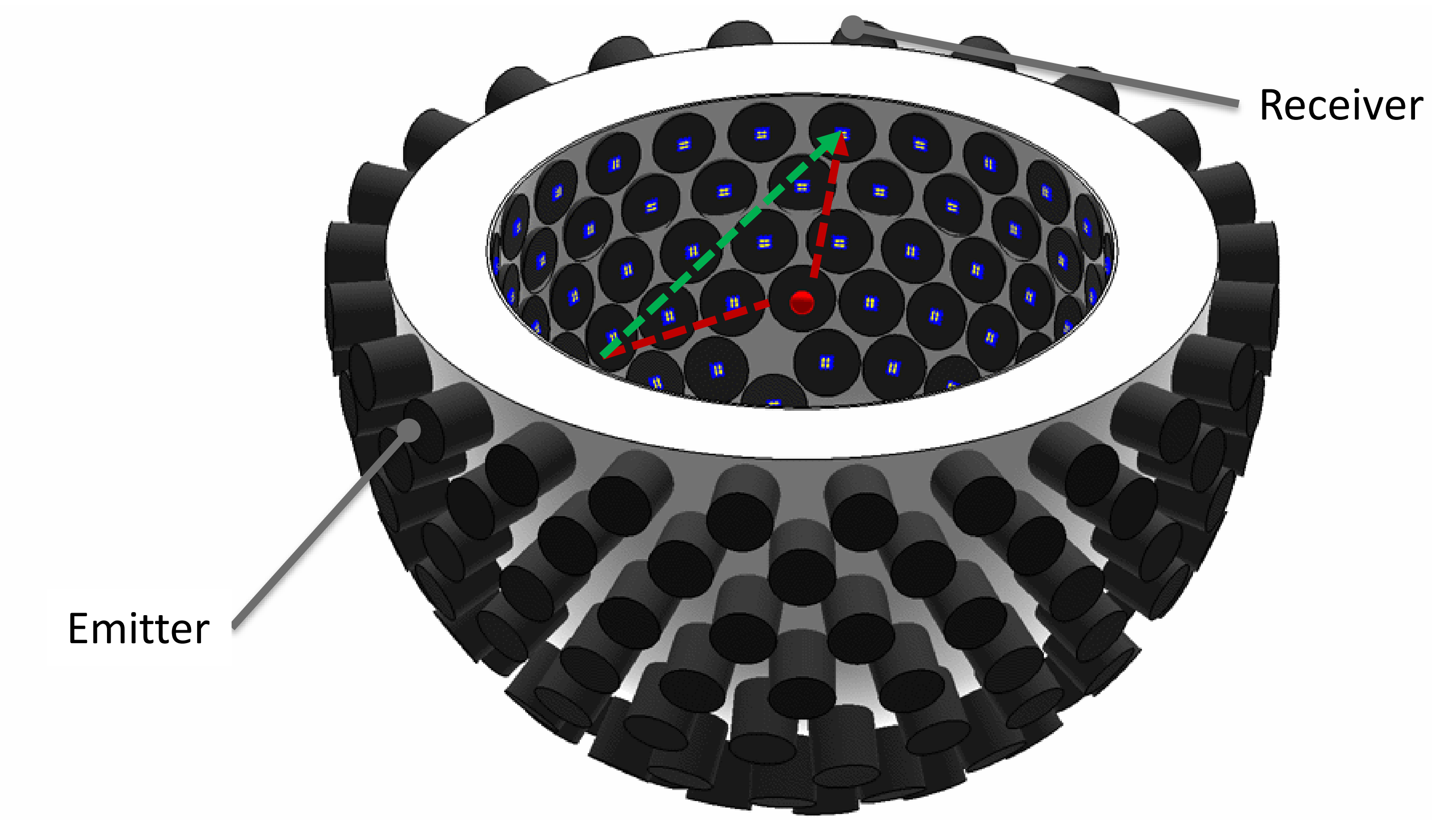


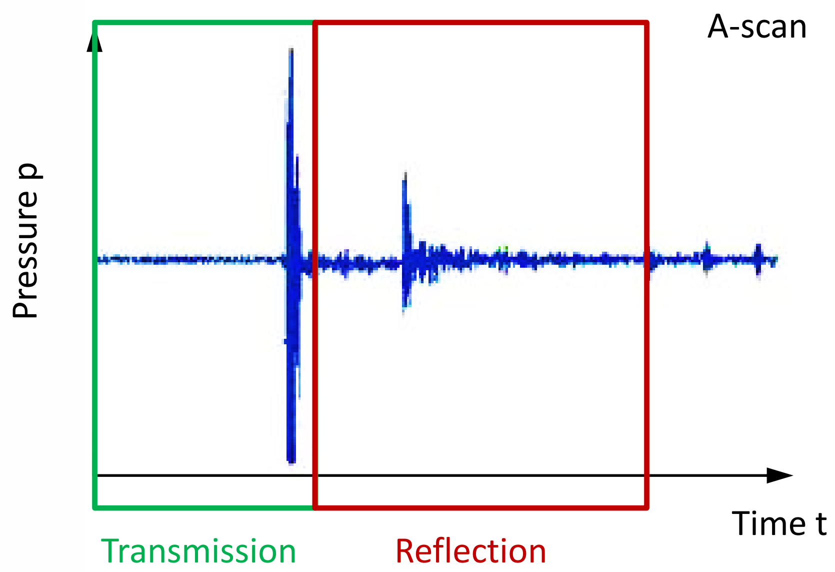
Breast imaging in fixed setup



Simplified from Greenleaf et al., 1981

How does it work? Data acquisition





- Thousands of transducers
- High data rates
- Small signals

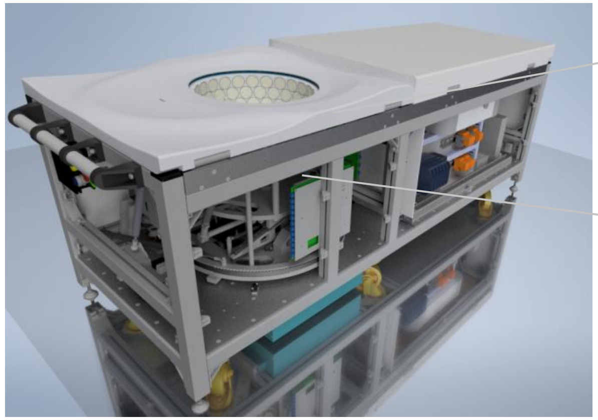
Acquired information
- **Sound speed**
- **Attenuation**
- **Reflection**

KIT 3D USCT II and USCT III

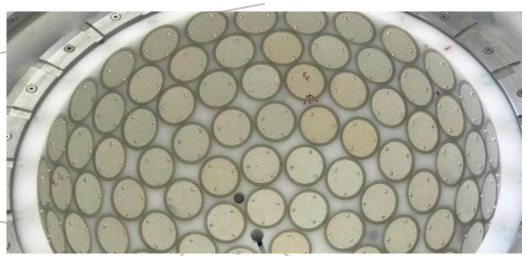
KIT 3D USCT II

Measurement aperture

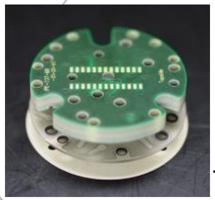
Transducer Array System

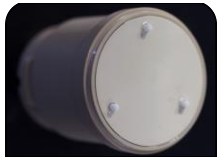


KIT 3D USCT III



Measurement aperture



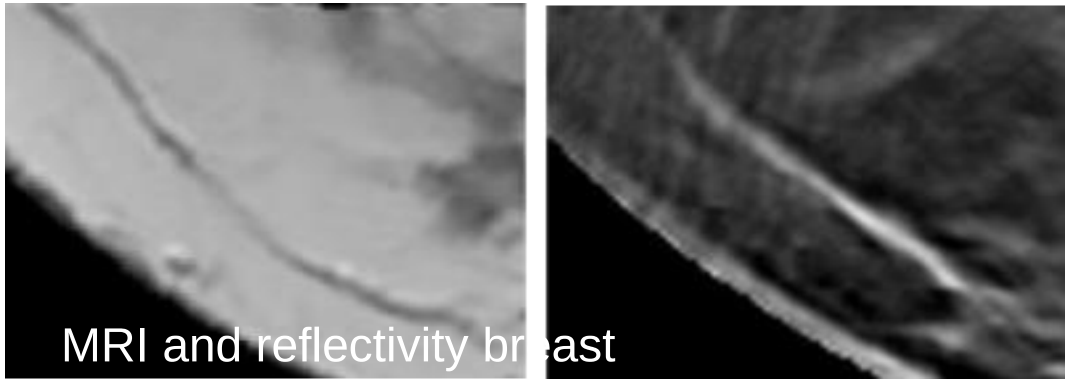


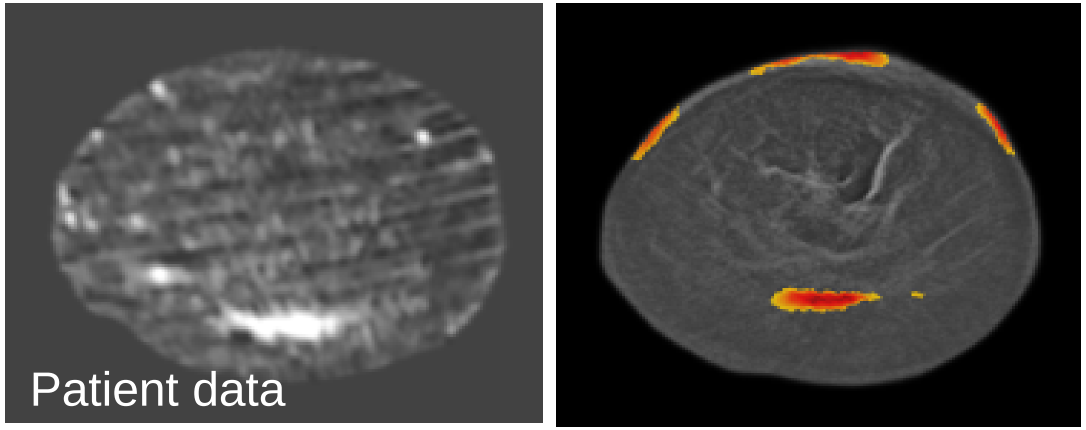
Transducer Array System

Specification	Value
Center frequency (bandwidth)	2.5 MHz (50%-70%)
Highest resolution	$(\lambda/2)^3 \approx (0.24\ \text{mm})^3$
# transducers	2041 - 2304 (sparse!)
Diameter (in meter and wavelength)	0.24 -0.32 m (~$500\ \lambda$)

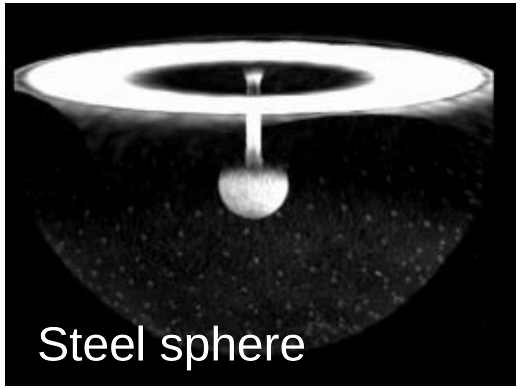
Patents: PCT/EP2012/000640, EP 2539870 A2 (2011), EP 2 056 124 (2009), EP 1 755 837 (2004), US.6.786.868 (2003).

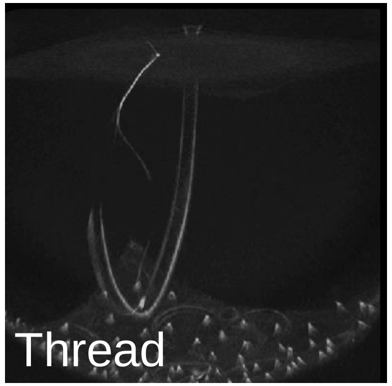
Some results

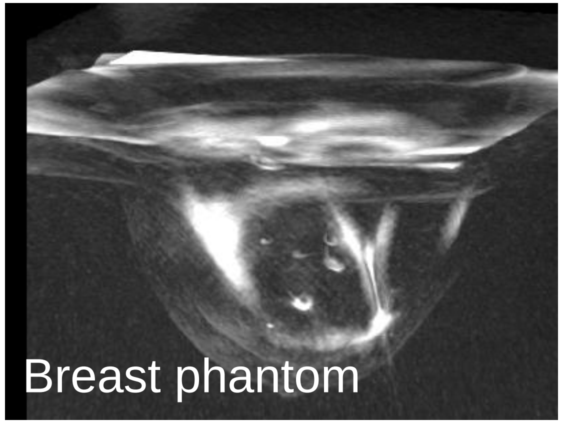




3D USCT II







3D USCT III

Image Reconstruction: Acoustic Wave Equation

- Linear acoustic wave equation for inhomogeneous water like materials:

$$\nabla^2 p(\vec{x}) + k_0^2 \left(\sqrt{\frac{K_0}{\rho_0}} \sqrt{\frac{\rho(\vec{x})}{K(\vec{x})}} + i\,\frac{\mu(\vec{x})}{k_0} \right)^2 p(\vec{x}) - \frac{1}{\rho(\vec{x})} \nabla \rho(\vec{x}) \nabla p(\vec{x}) = 0$$

- Three physical properties influence wave propagation:
  - Density ρ_0
  - Bulk modulus K
  - Absorption μ

- Typically reconstructed in USCT:
  - Qualitative gradient of acoustical impedance $\nabla(\mathrm{Z} = \rho_0 c)$,
  - Speed of sound $\mathrm{c} = \sqrt{\frac{K}{\rho_0}}$,
  - Attenuation $\alpha = \mu + \mu_s$

Image reconstruction: Typically used methods

- Reflectivity (Qualitative gradient of acoustical impedance):

B-scan

Com-pound-ing

SAFT

- Speed of sound and attenuation

Ray tomo-graphy

Iterative ray based tomo.

Eikonal inversion

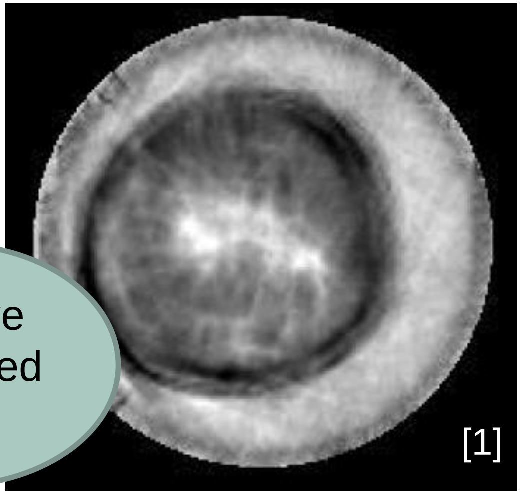
Born / Rytov inversion

Paraxial inversion

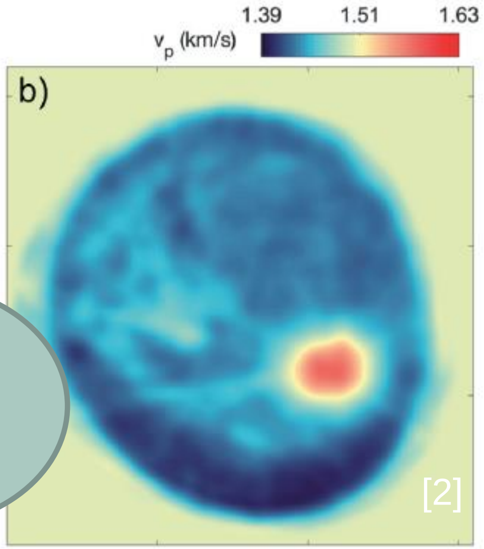
Full-waveform inversion

NeuroNet based recon.

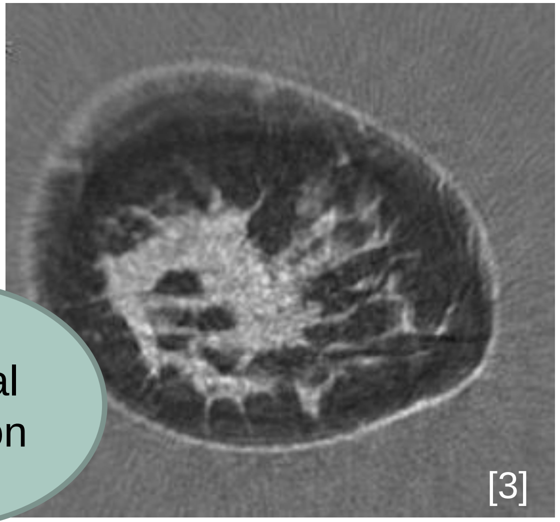
Breast Image Examples: 2D Speed of Sound



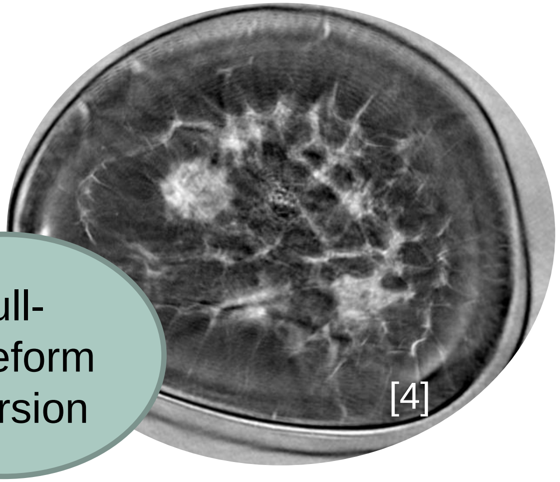
Iterative ray based tomo.



Eikonal inversion



Paraxial inversion

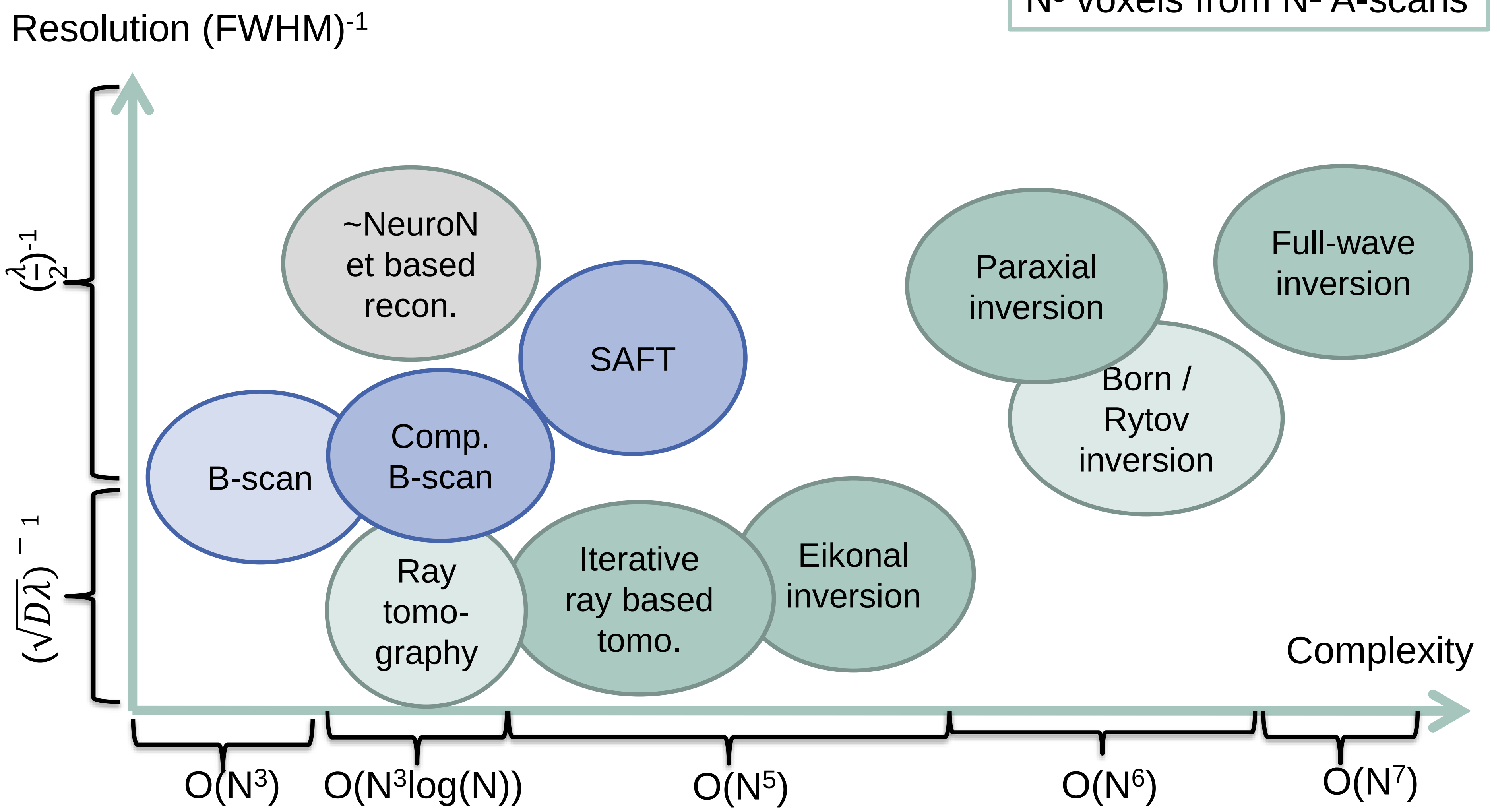


Full-waveform inversion

[1] Li et al. Proc. SPIE Medical Imaging, 2008
[2] Agudo, et al. *Proc. of MUST,* 2017
[3] Wiskin et al. Proc. SPIE Medical Imaging, 2020
[4] Littrup, Duric, et al. *Proc. of MUST,* 2017.

Challenge 3D: Computational Complexity

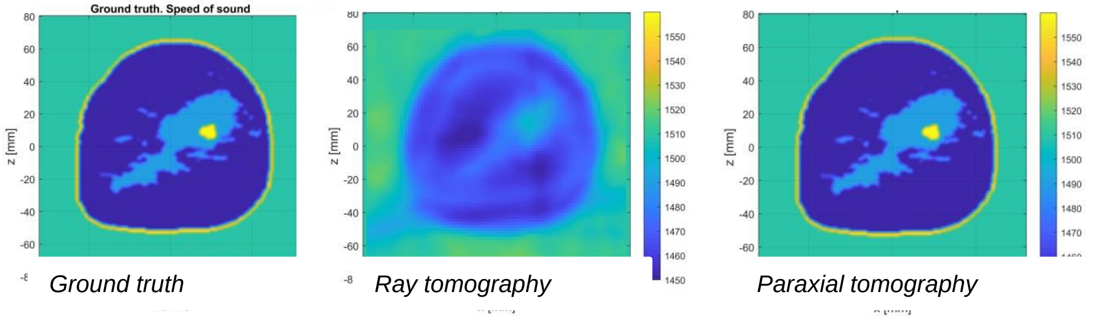
Example:
N^3 voxels from N^2 A-scans

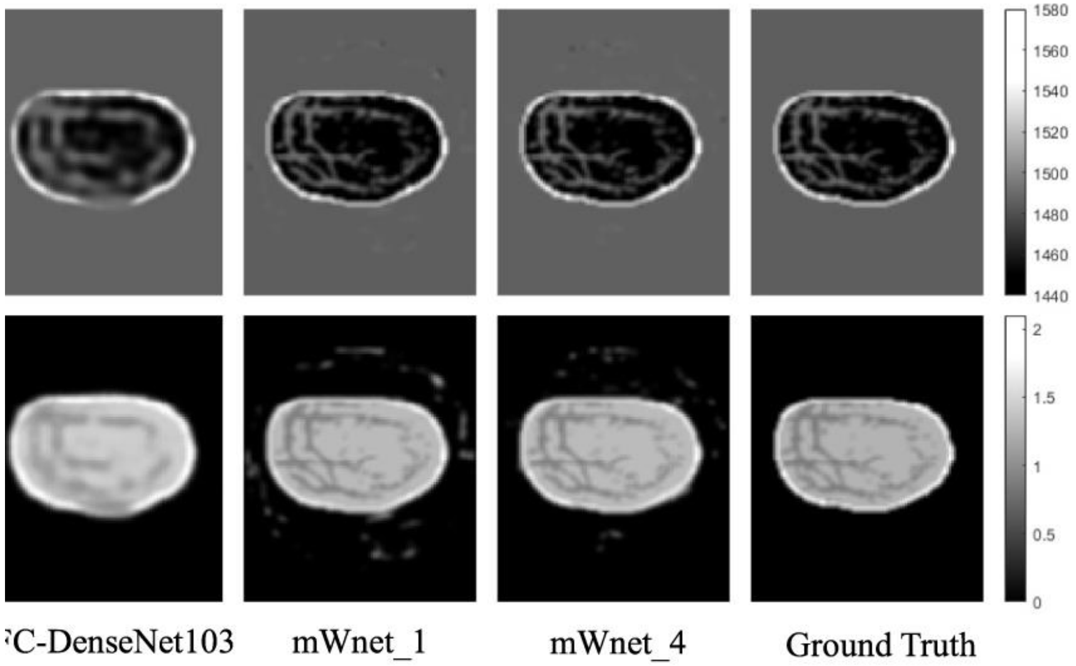


Althaus: On acoustic tomography using paraxial approximations, 2015.
Özmen: Ultrasound Imaging Methods for Breast Cancer Detection, 2015 (TU Delft).
Dapp: Abbildungsmethoden für die Brust mit einem 3D-Ultraschall-Computertomographen, 2013.
Hardt: Distributed Simulations for 3D USCT. Acoustic wave simulations for a new breast cancer imaging device, 2012.

Status at IPE

- Applied algorithms in clinical trials:
  - Speed of sound corrected SAFT with GPU cluster
  - Ray based speed of sound and attenuation
- Under development
  - Paraxial
  - Neuronal networks based reconstruction
- New grant (EIC pathfinder):
  - 3D FWI on supercomputers



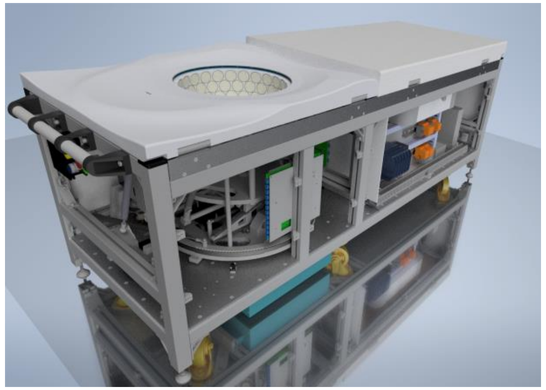


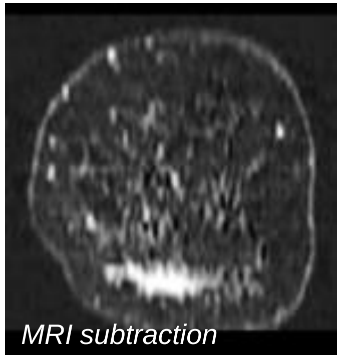
Reconstruction with Prelearned Convolutional Neural Network (simulated data)

Summary and possible collaborations

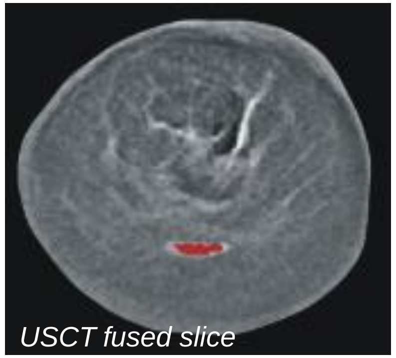
- 3D USCT is a new imaging method for early breast cancer diagnosis
- KIT 3D USCTs:
  first clinically applicable full 3D USCT

- New improved system in commissioning
- First pilot study successful,
  multicenter study planned





MRI subtraction



USCT fused slice

Possible collaboration

- Challenge: 3D, large scale problem, limited reconstruction time!

- Efficient solution of large scale inverse problem?
  - Optimization schemes, …
- Efficient forward method
  - Approximation(s) of wave equation for dedicated problem, …
- Neuronal networks
  - Learning parts of the image reconstruction problem?
  - Direct learning from data input to image output?

- Perspective topics: algorithms dedicated for future computing architectures
  - E.g. applicable problem for quantum computing?

Thank you!

KIT Karlsruhe Institute of Technology

Fraunhofer IKTS

BSC

Imperial College London

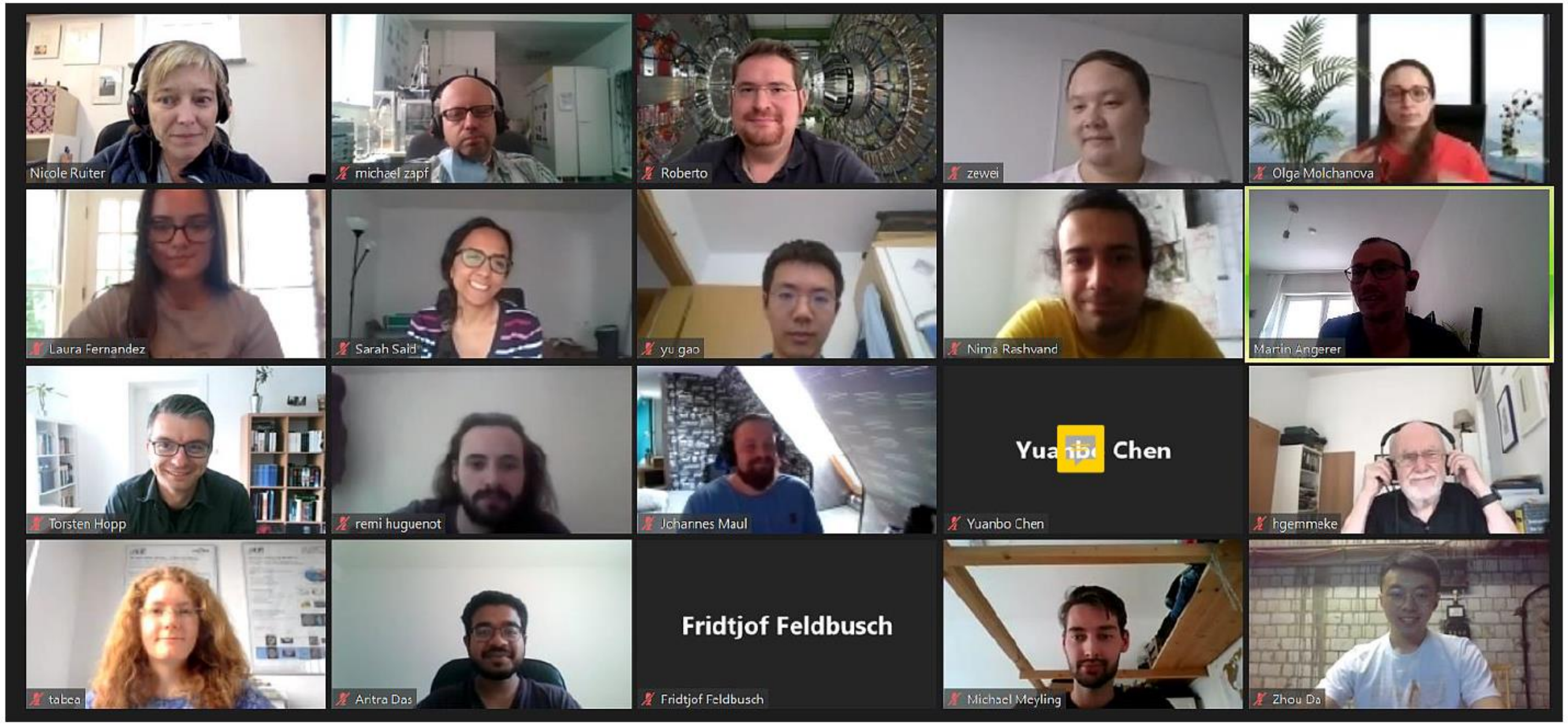
MEDIZINISCHE UNIVERSITÄT WIEN

UMM UNIVERSITÄTSMEDIZIN MANNHEIM

Vall d'Hebron Barcelona Campus Hospitalari

瑞康医药股份有限公司 Realcan Pharmaceutical Co., Ltd.

FrontWave Imaging



European Innovation Council

DFG

HEiKA

IPE