USCT

Ultrasound Computer Tomography for Breast Cancer Diagnosis

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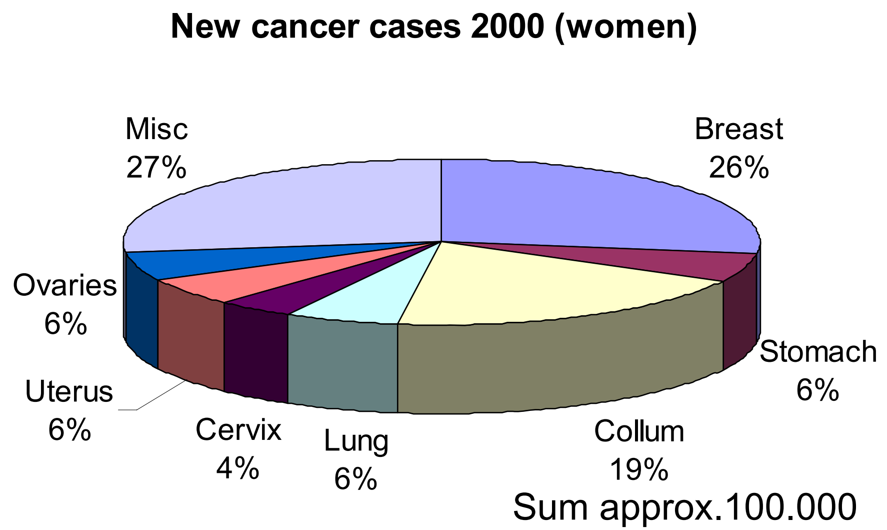
Breast Cancer: Most frequent cancer disease for females

- **Most common cancer of women in western world (every 10th woman)**
- **5 year survival rate of 76%.**
- **Steady increase of women affected pre menopause**
- **Most frequent cause of death due to cancer: 21% of all deaths**



→ Why? Primary breast cancer not lethal

→ Cause: Metastases (no symptoms in early stages)

→ Screening for early detection necessary

→ In general: the earlier the tumor is detected, i.e. the smaller it is, the lower probability for metastases and the better the survival probability of the patient

Source: Robert Koch Institut, Germany

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Current Status of Breast Cancer Diagnosis

Screening

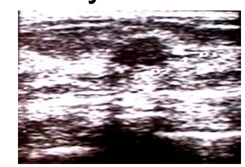
1. **Palpation:**
   - Self examination, >20a annually
   - ∅ tumor size ~2cm, approx. 60% metastases
2. **Mammography:**
   - If symptoms are present, >50a every 3a screening
   - ∅ tumor size ~1cm, approx. 30% metastases

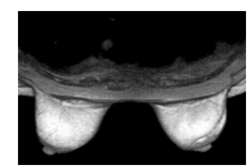
Symptomatic patients

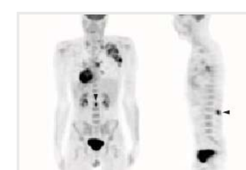
3. **Sonography (conventional Ultrasound):**
   - For clarification (or young patients with small breasts)
   - Tumor >5mm (if position of suspicious lesion is known)
4. **Magnetic Resonance Imaging with contrast agent:**
   - Additional clarification (e.g. implants)
   - Tumor >5mm (low specificity)
5. **Image guided biopsy and histological examination**
6. **Positron Electron Tomography (PET)**
   - Evaluation of lymph node metastases and metastases in other organs
   - Metastases size > 2cm


Palpation


X-ray mammo

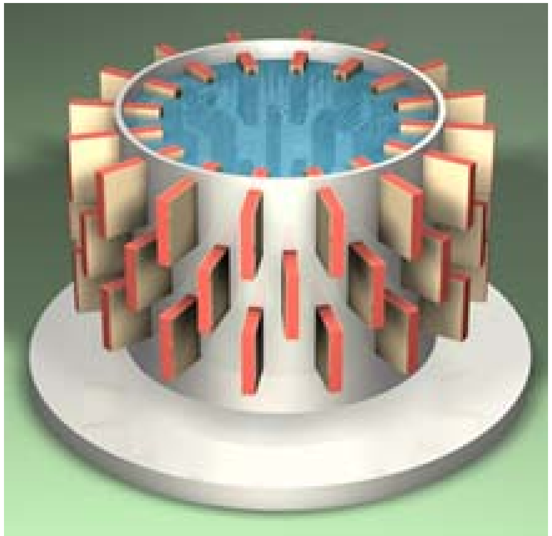

Sonography


MRI


PET

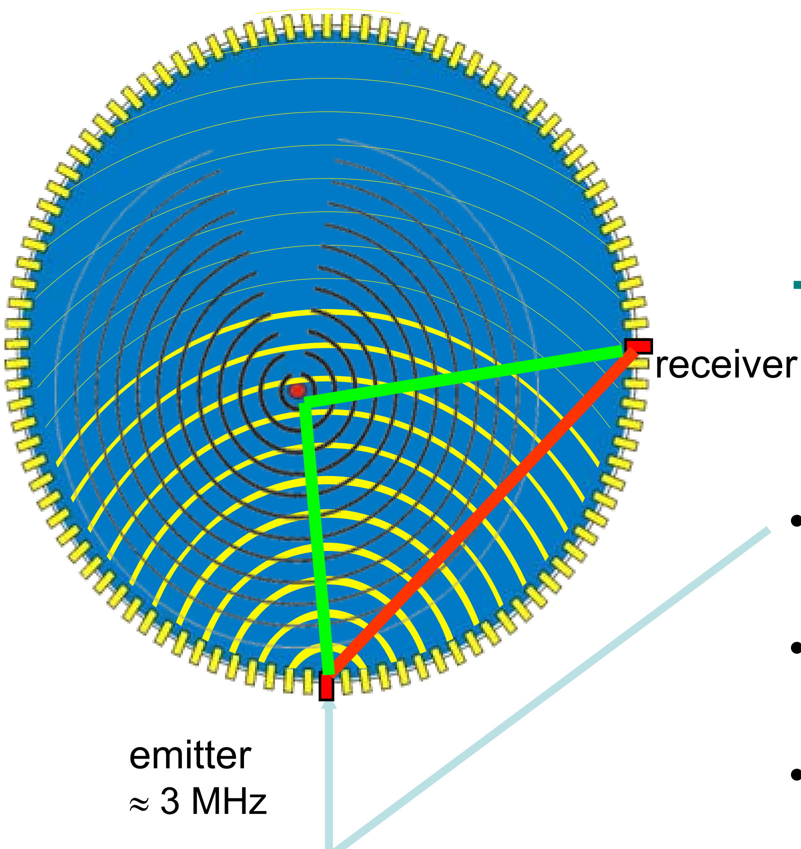
Ultrasound Computer Tomography

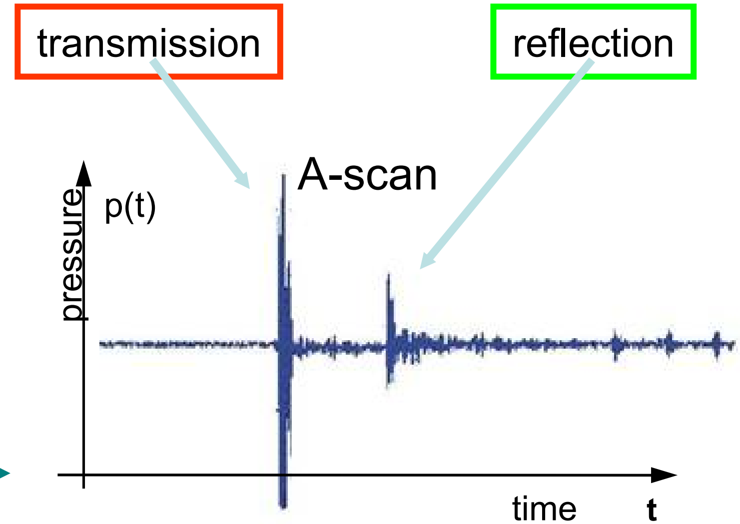
- **Basic idea:**
  - Surround object with transducers in fixed setup
- **Long term goal:**
  Early breast cancer diagnosis
  Vision: diagnostics at ∅ ≤ 5 mm?
  (Approx. 5% probability for metastases)
- **Since > 20 years**
- **Aim of current work:**
  - Build and operate first experimental 3D setup: Feasibility?
  - What are the next optimization steps?



Schematic drawing of 3D USCT, red-white boxes are transducer array systems (TAS)

Principle of our USCT

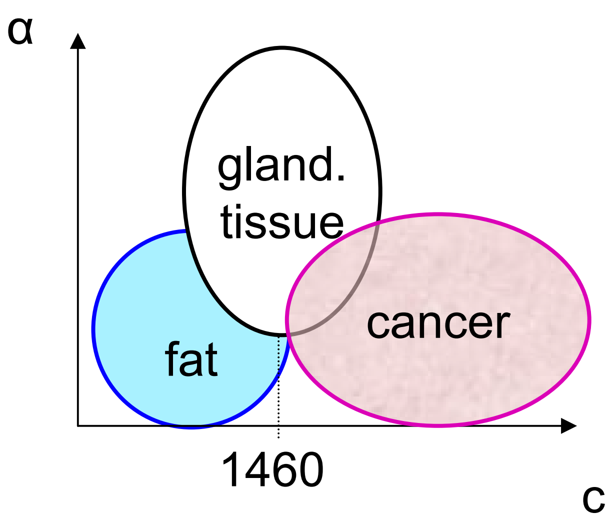




- **Sequentially, each emitter emits approx. spherical wave front**
- **All others receive scattered and reflected signals**
- **Until information from many directions is gathered**

Diagnostic Information USCT

- **Reflection r(x,y,z):**
  - **Morphology/structure**
- **Sound speed map c(x,y,z):**
  - **normal: 1350 – 1500 m/s**
  - **suspicious: 1460 – 1600 m/s**
- **Absorption α(x,y,z,f):**
  - **lower for cancer**
  - **additional information**



simplified, based on
Greenleaf et al, Clinical Imaging 1981.

→ Further information about absorption imaging see talk of Dr. R. Jirik

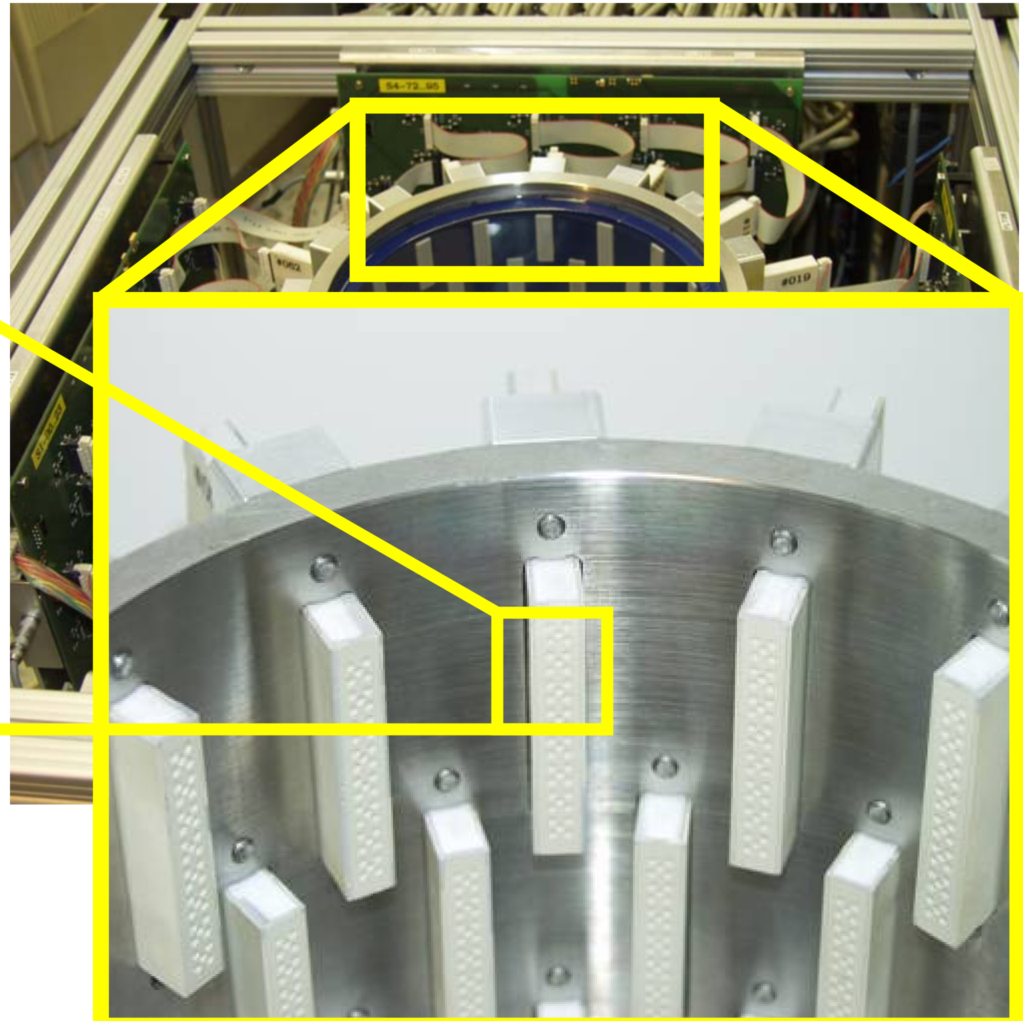
3D-USCT: Technical Challenges

- Large number of cheep and reproducible sensors necessary
- Large amount of data (20GB) and high data rates
- Computational expensive reconstruction

- Hardware to be build
  - Low cost sensor systems → low cost screening system
  - Data acquisition hardware → large number of parallel channels to cope with high data rate (20GB of data for one volume)

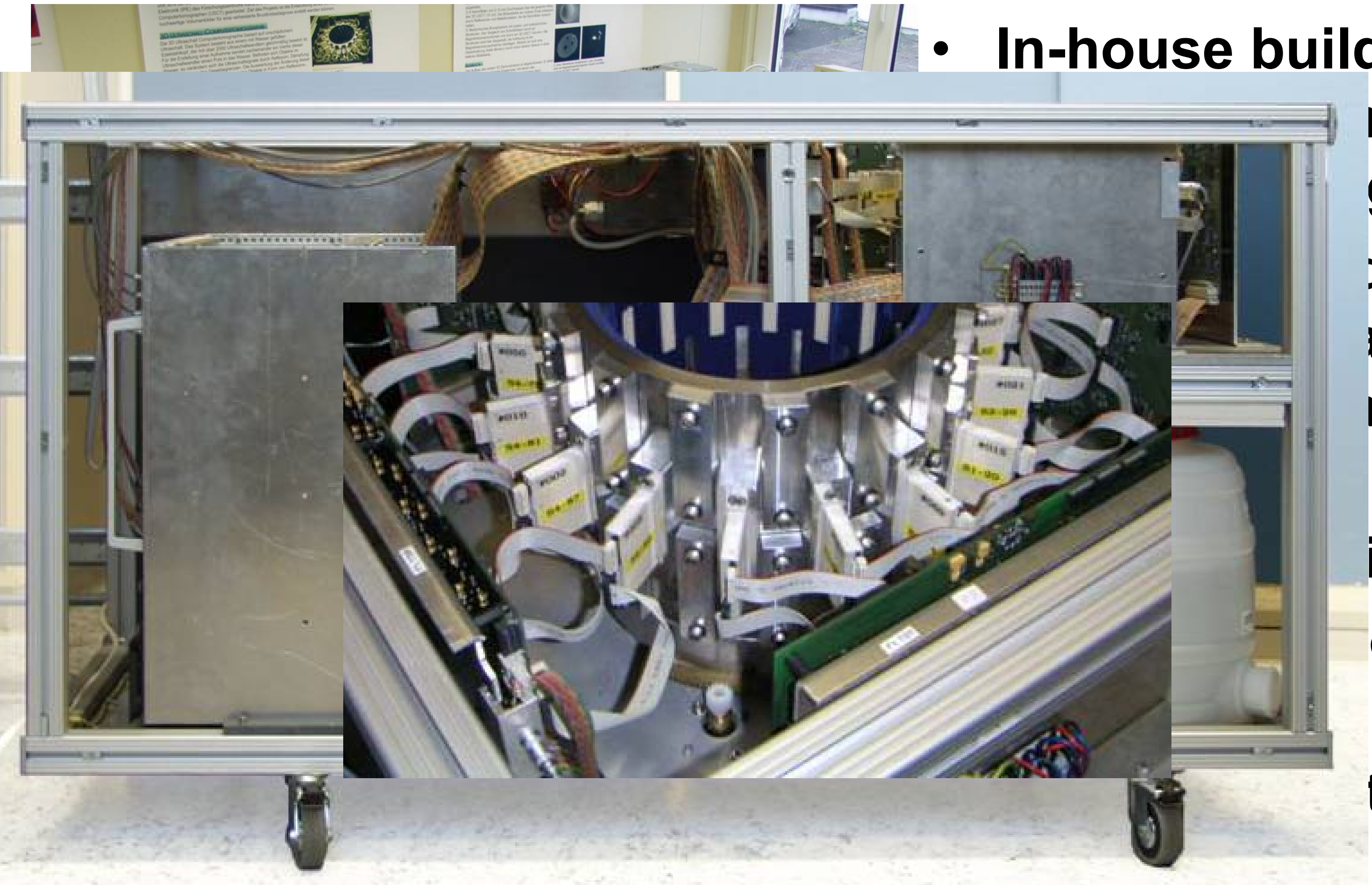
3D USCT Basic Configuration

- Cylinder
  - Diameter 18 cm
  - Height 15 cm
  - Couple medium: water



- Ultrasound-transducers
  - 384 emitter (red)
  - 1536 receiver (green)
  - Rotatable aperture

3D USCT Current Status



- In-house build low cost
  ns → low
  g system
  d data
  ardware →
  llel

  itioning
  on

  truction

Current limitations

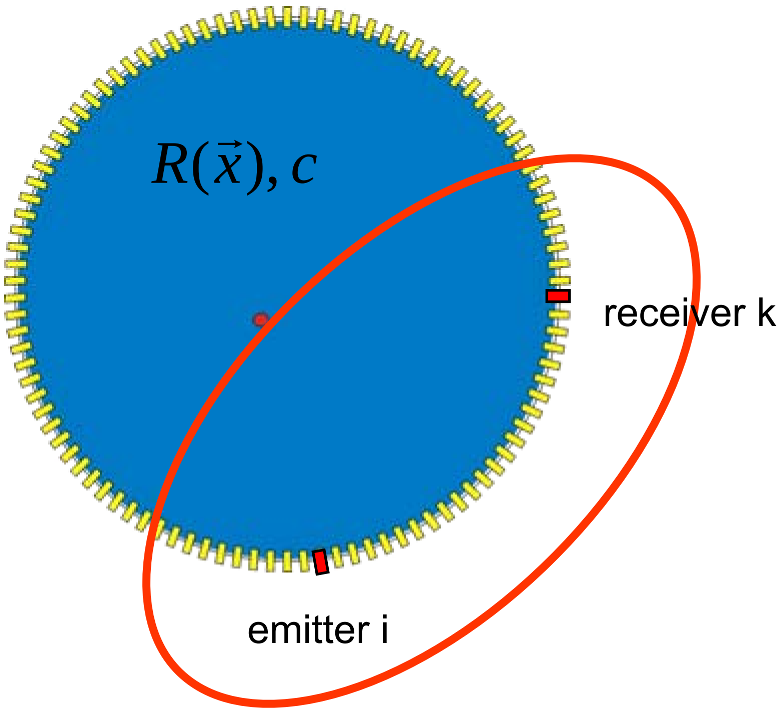
- **Data acquisition time: 8h**
- **Sparse aperture, limited opening angle:**
  limits image quality with simple SAFT reconstruction
- **Limited accuracy of calibration**
- **Reconstruction on single PC: up to months**

→ Calibration problem see talk of Prof J. Jan

Reflection Mode Imaging

- **Measured quantity: A-scans**
  - **I emitters**
  - **K receivers**
  - **Scattering medium with reflectivity map** $R(\vec{x})$ **and constant speed of sound** c
- **Then:** $$A_{i,k}(t) = \int_{\frac{\|\vec{x}-\vec{x}_i\|+\|\vec{x}-\vec{x}_k\|}{c}=t} R(\vec{x})d\vec{x}$$

- **Where all scatteres with same** t **(~ distance) lie on an ellipse (2D) or ellipsoid (3D), emitter** i **and receiver** k **are foci**



A: A-scan
x: spatial position
t: time delay
c: speed of sound
R: reflectivity map
i,k: number of emitter and receiver

Reflection Mode Imaging

- **Synthetic aperture focusing technique (SAFT):**

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

- **Dependence between** $R(\vec{x})$ **and** $f(\vec{y})$**:**

$$f(\vec{y}) = \sum_{i,k} \int_{\frac{\left\|\vec{x} - \vec{x}_i\right\| + \left\|\vec{x} - \vec{x}_k\right\|}{c} = t} R(\vec{x})\, d\vec{x}$$

$$= IK \cdot R(\vec{y}) + \sum_{i,k} \int_{\frac{\left\|\vec{x} - \vec{x}_i\right\| + \left\|\vec{x} - \vec{x}_k\right\|}{c} = t,\ \vec{x} \neq \vec{y}} R(\vec{x})\, d\vec{x}$$

$$= IK \cdot R(\vec{y}) + \varepsilon(\vec{y}, R(\vec{x}), i, k)$$

A: A-scan
x, y: spatial positions
T: time delay
c: speed of sound
R: reflectivity map
i,k: number of emitter and receiver
I,K: total number of I and k
f: reconstructed SAFT image
ε: error term

→ If IK*R large against ε , then

$$f(\vec{y}) \approx R(\vec{x})$$

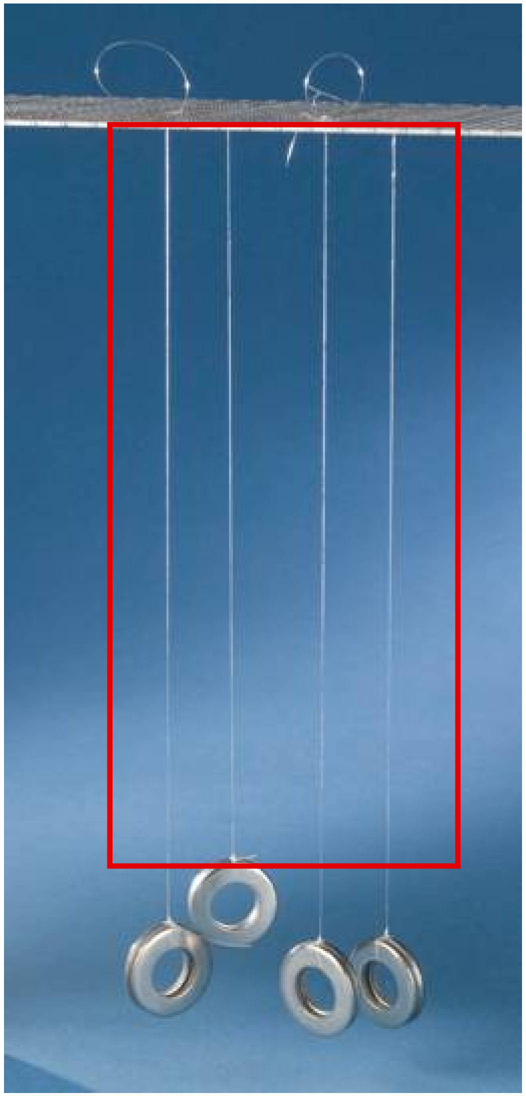
Reflection Mode Imaging

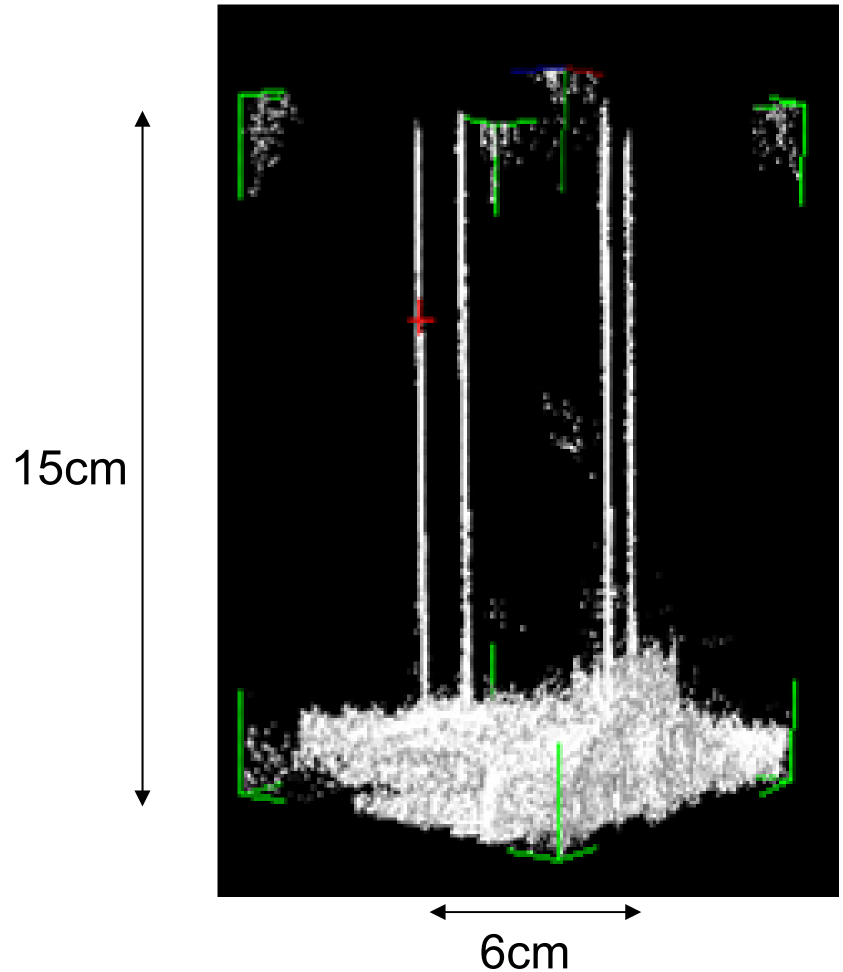
- **Many over-simplificating assumptions necessary:**
  - **Transducers are point sources**
  - **No damping, refraction, geometric loss**
  - **Constant speed of sound**
  - **Dirac pulses, …**
- **Current reconstruction approach:**

$$f(\vec{y}) = T_2 \sum_{(i,k)} T_1\left(A_{(i,k)}\left(\frac{\left\|\vec{y}-\vec{x}_i\right\| + \left\|\vec{y}-\vec{x}_k\right\|}{\hat{c}(\vec{x}_i, \vec{x}_k, \vec{y})}\right)\right)$$

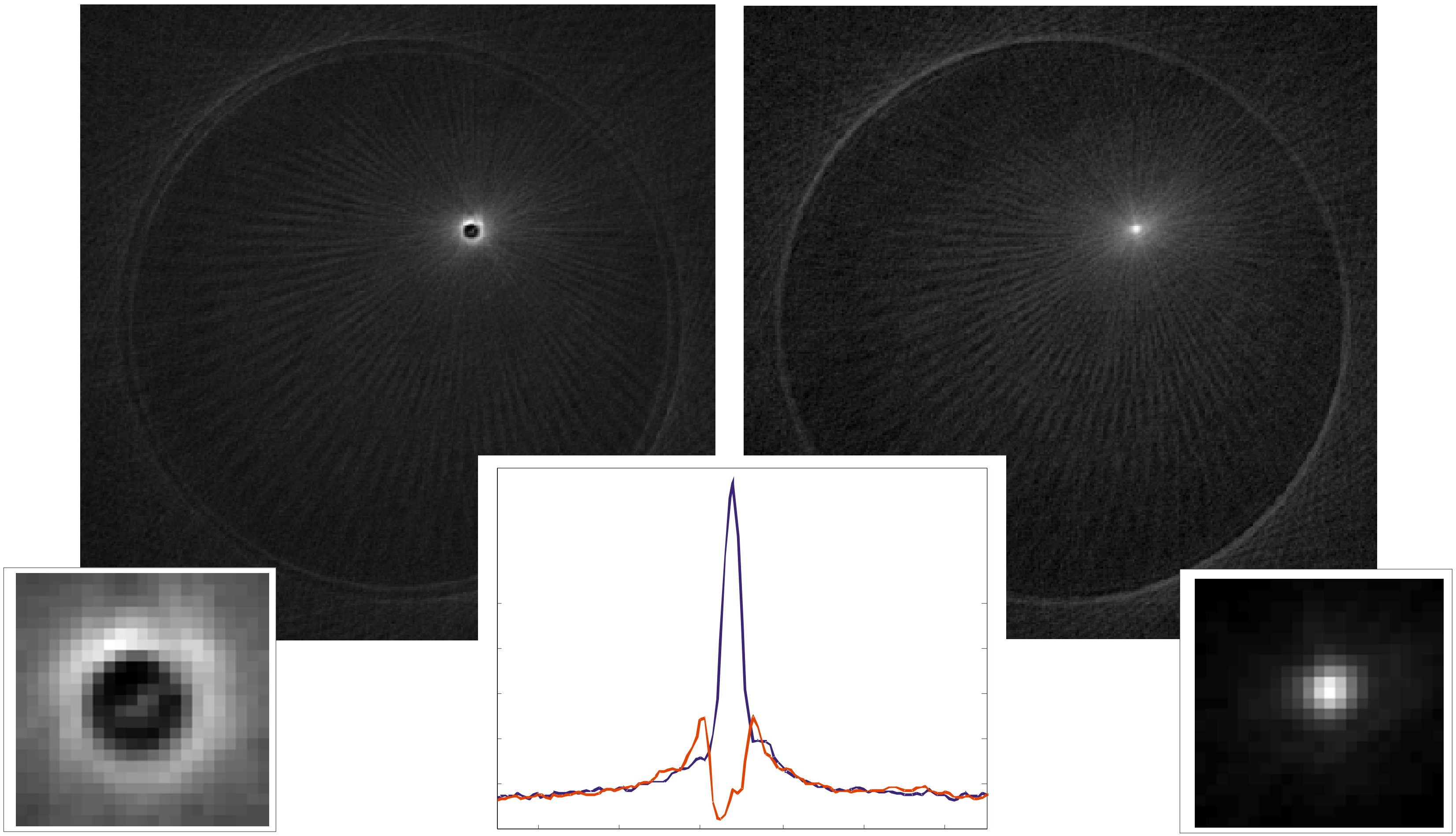
  - **T_1: signal processing, e.g. envelope, signal detection, …**
  - **T_2: image processing, e.g. local high pass, …**
  - **Introduction of speed of sound map**

Results: 4 Nylon Threads Ø 0.15 mm



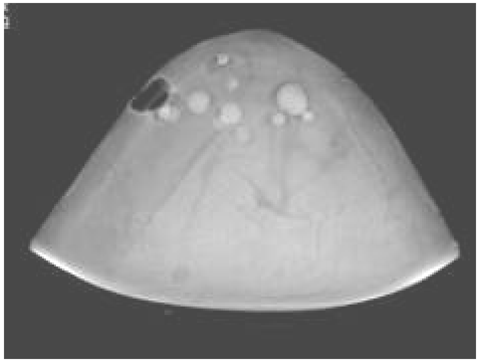


Results: Sound Speed Correction

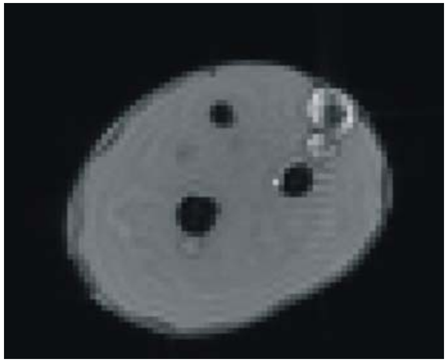


Results: CIRS Breast Phantom

- **CIRS Biopsy Phantom**
- **12 cm x $(10\ \text{cm})^2$**
- **Three Modalities:**
  - **XR, MRI, US**
- **„Cancer“: ∅ 2-8mm**
- **„Cysts“: ∅ 3-10mm**



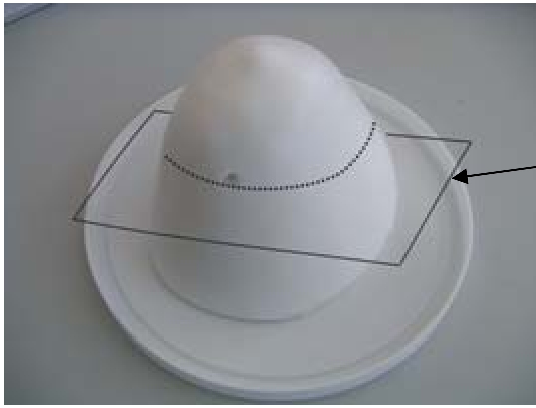
X-ray Mammography



MRI, “frontal”

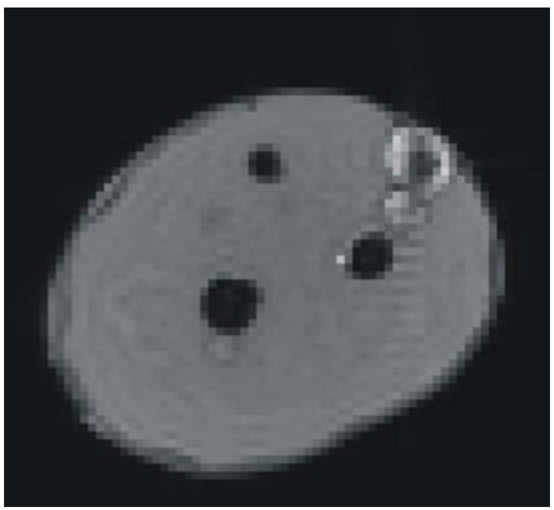
Ultrasound, 3.5MHz

Breast Phantom MRI - USCT

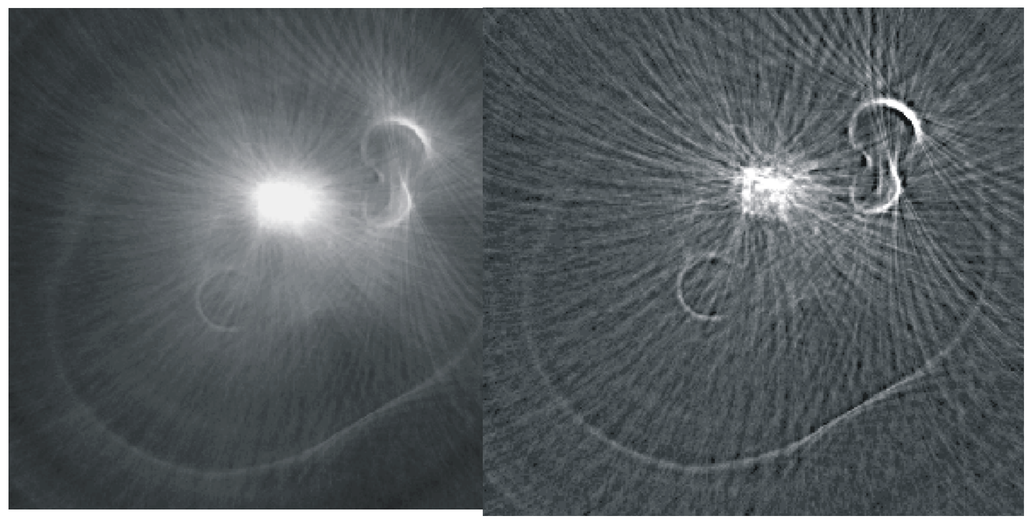


Imaged slice

Only one US-Ring (1/3 Sensors), structure above this plane outshines the image

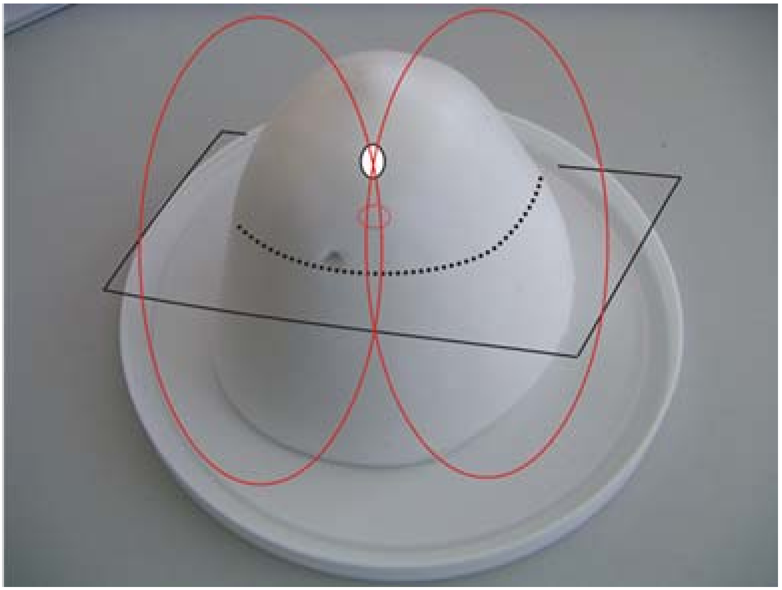


MRI



3D-USCT

Interpretation of Artifacts

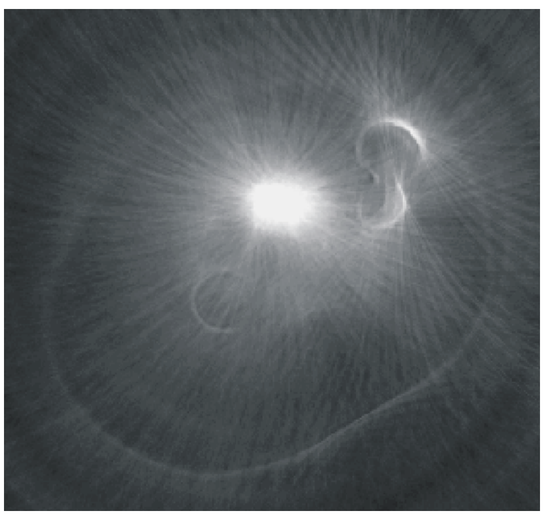


Object dynamics vs. number of sensors

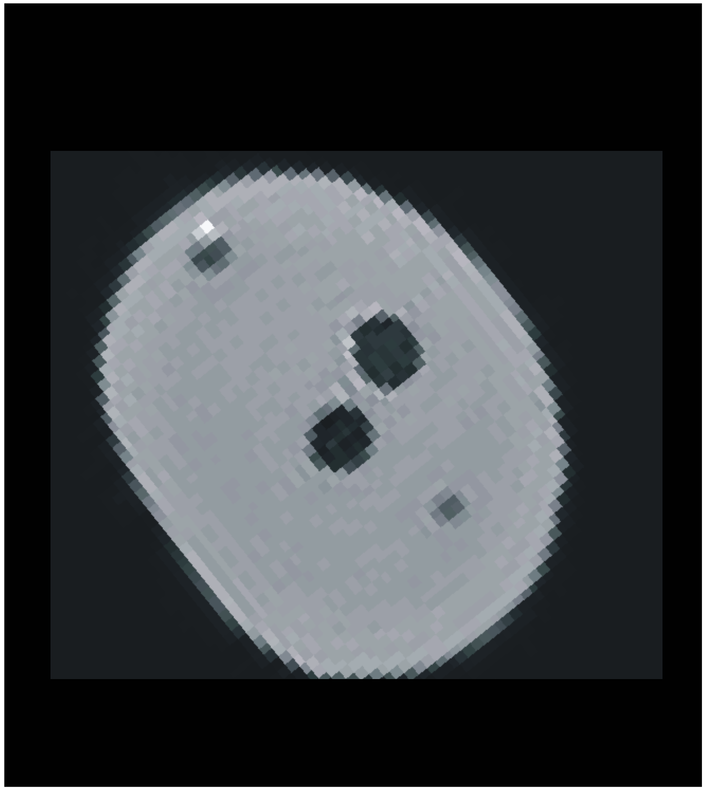
$$f(\vec{y}) = IK \cdot R(\vec{y}) + \varepsilon_{(I,K)}(\vec{y}, R(\vec{x}))$$

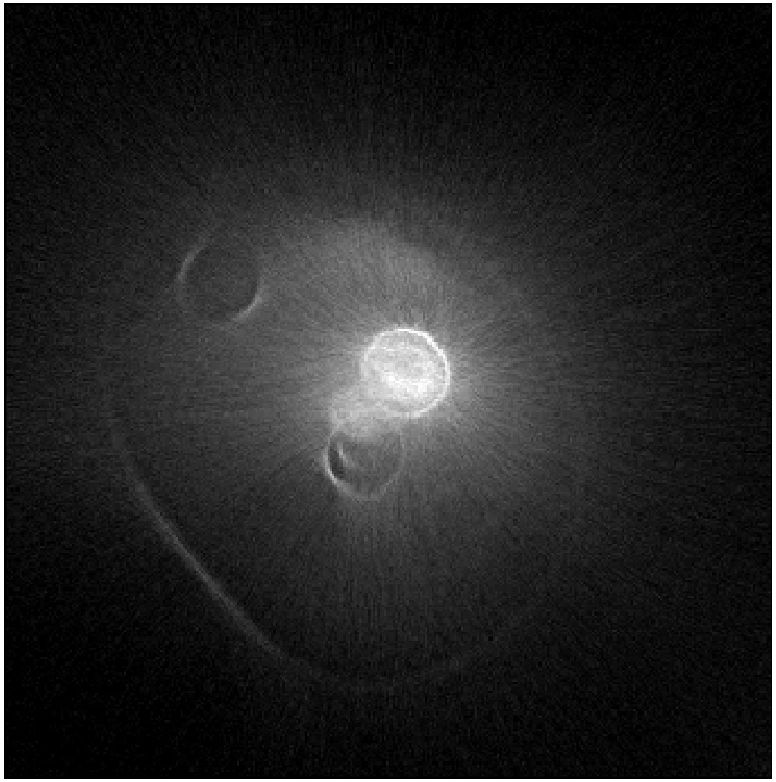
$$\Rightarrow \varepsilon_{(I,K)}(\vec{y}, R(\vec{x})) >> IK \cdot R(\vec{x})$$

Grating lobes due to sparse aperture

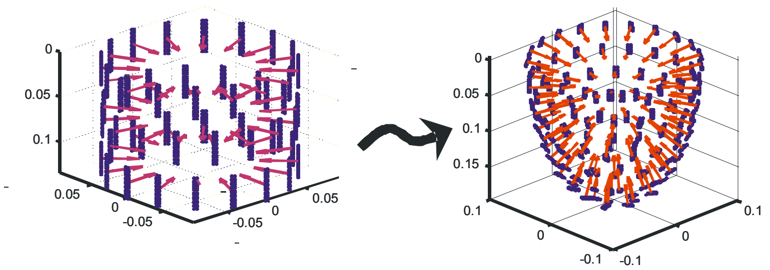


Current Image





Additional Topics



- Optimization of transducer aperture
- Optimization of US transducers
  - E.g. plastic molding processes for the Piezo transducers
- Signal compression and –denoising
- Statistical image reconstruction
- Higher order reconstruction using wave equation
- Reconstruction parallelization in
  - Grid
  - Hardware (reconfigurable FPGAs)
- …

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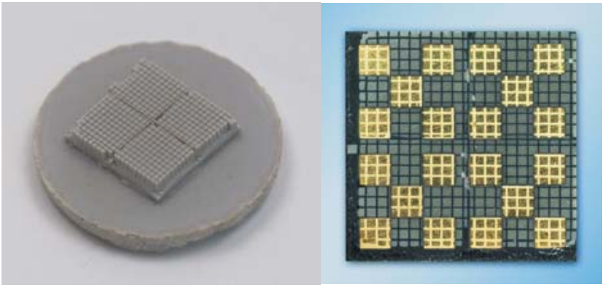

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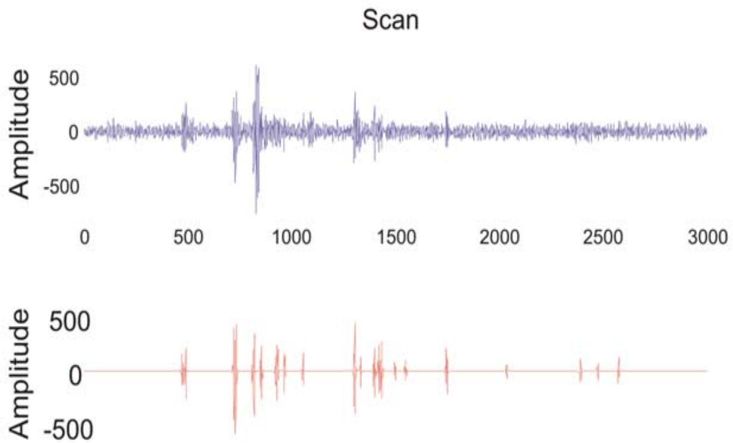

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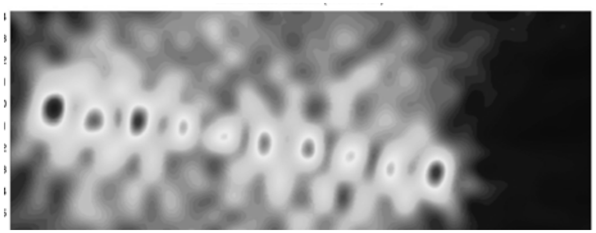

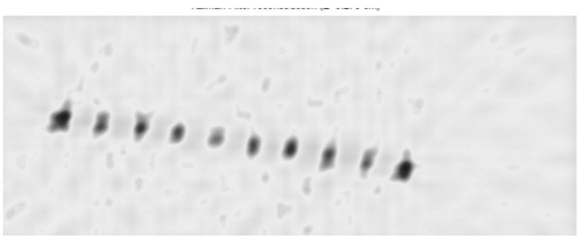

Summary

- First results show …
  - Sub-millimeter resolution possible, speckle reduction, but artifacts
  - Feasible, but long way to go to clinical applicability
- Next steps from basic research to application (>2007) :
  - Fast data acquisition for in vivo measurements
  - Optimized aperture for increase of image quality
  - Dynamic imaging with contrast agents
- Visions:
  - Biopsy whilst imaging
  - New applications: testicles cancer, hip-dysplasia of babies
  - Therapy with US-thermoablation

Thank you very much!

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