Karlsruhe Institute of Technology

USCT

Evaluation of directional reflectivity characteristics as new modality for 3D Ultrasound Computer Tomography

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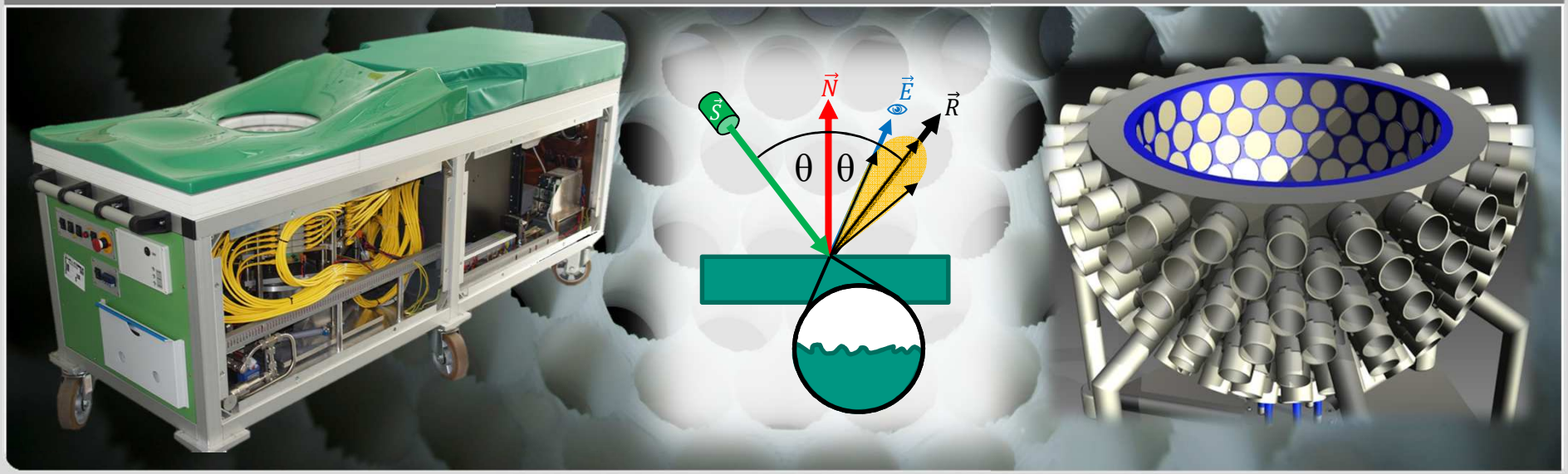
INSTITUTE FOR DATA PROCESSING AND ELECTRONICS

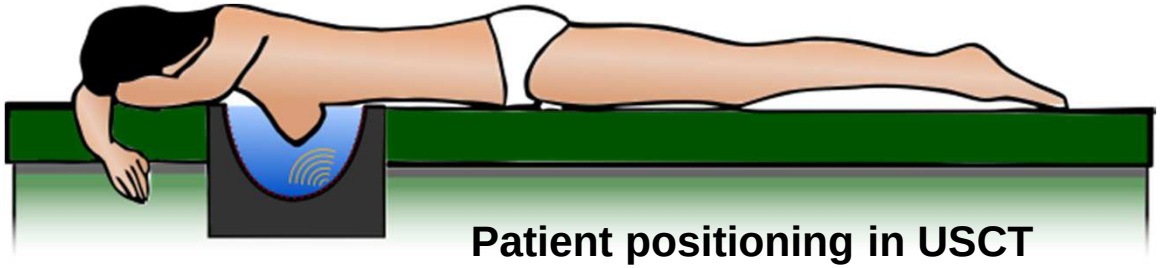


3D Ultrasound Computer Tomography (3D USCT)

3D USCT
high-quality 3D volumes for early breast cancer diagnosis …

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

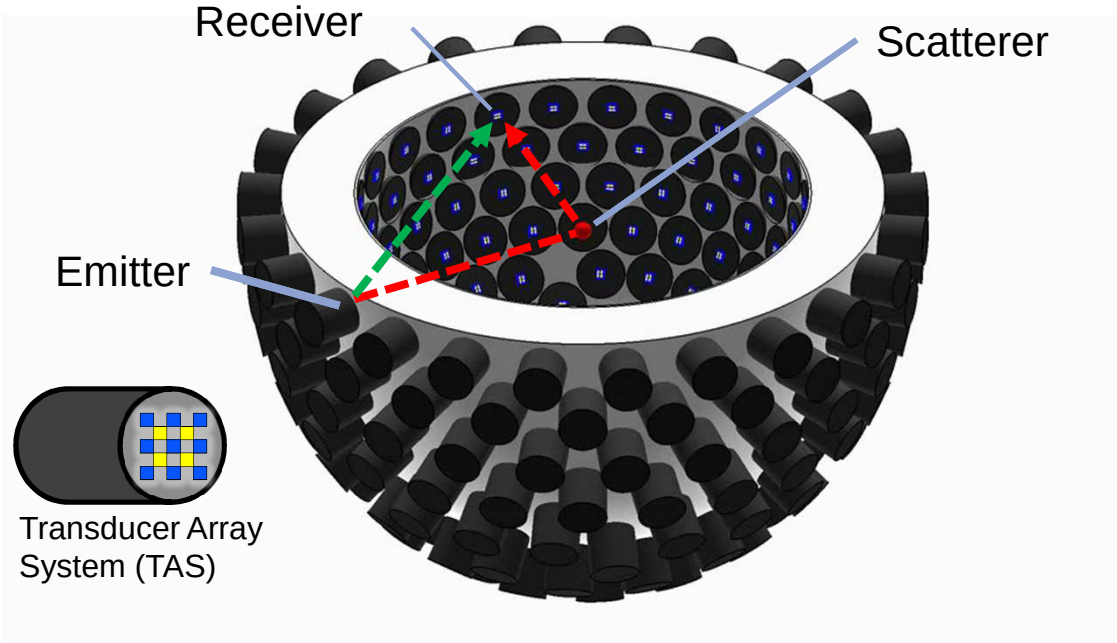
Vision: Detect tumors reliable at the size of 5 mm (5% probability of metastases)

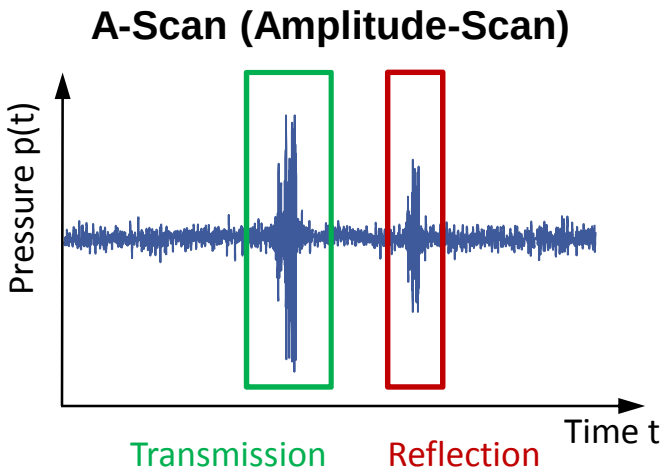


Patient positioning in USCT

IPE 3D USCT

Measurement Process





3D-USCT-Prototype

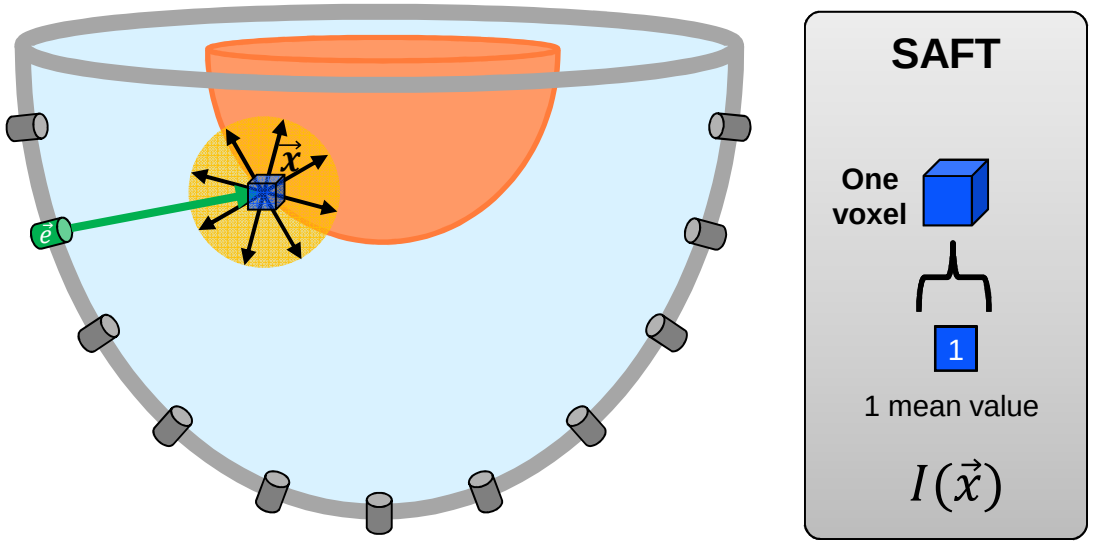
- 2041 ultrasound transducers on 157 TAS
- Data per breast: 10 Million A-Scans (20 GB)
- Measurement time: 4 min

Image reconstruction

- Speed of sound
- Attenuation
- Reflectivity

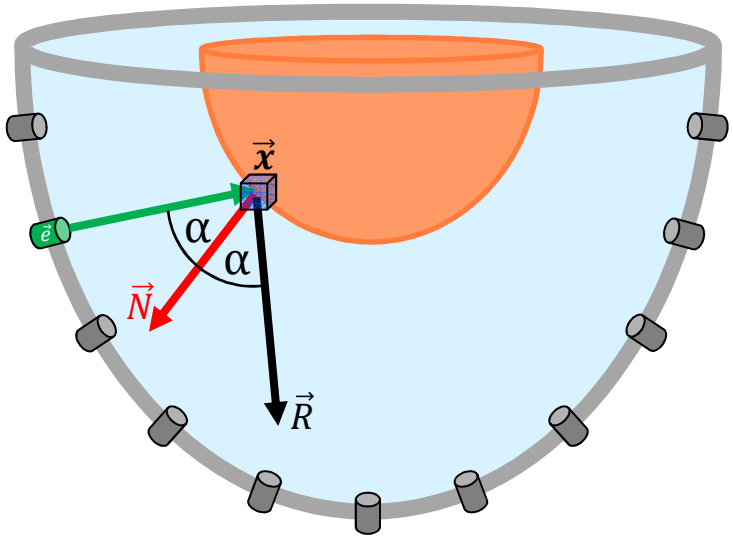
Reconstruction with Standard SAFT

- Assumption of SAFT:
  Reflections at ideal point scatterers with equal scattering in all directions.



Until now the directional information is not used for image reconstruction

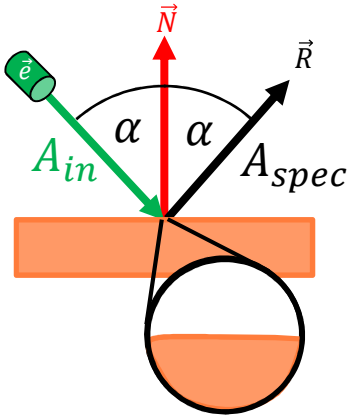
Reflections depends on surface condition

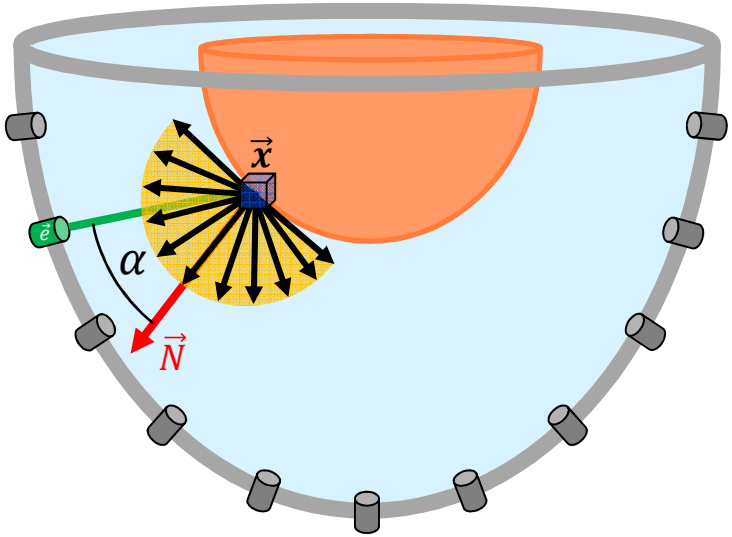


specular reflection

- Smooth surfaces
- Law of reflection:

$$\alpha_{out} = \alpha_{in}$$
$$A_{spec} = A_{in}$$

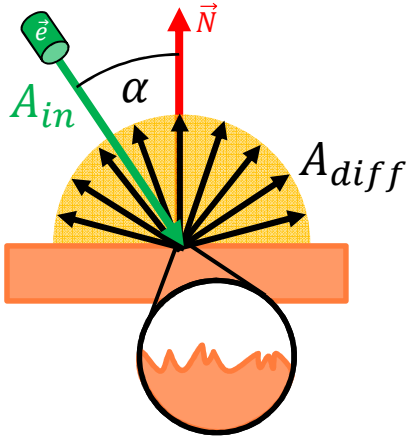




diffuse reflection

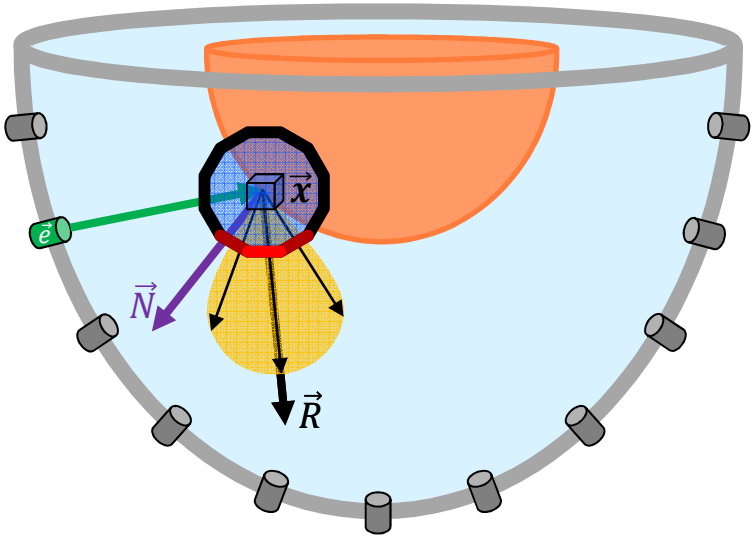
- rough surfaces
- Lambert's cosine law:

$$A_{diff} = A_{in} \cdot \cos\alpha$$

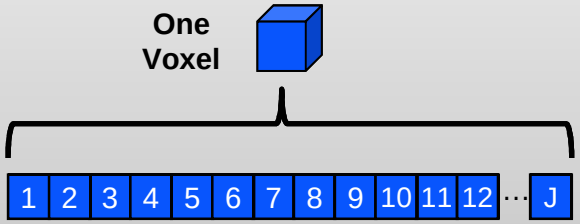


New Modality: Reflectivity characteristic

- Use uniqueness of 3D-USCT: three-dimensional measurement data
- Extend SAFT with directional information from



SAFT with reflectivity characteristic

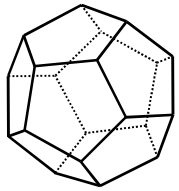


Mean value per direction $\vec{S}_j$

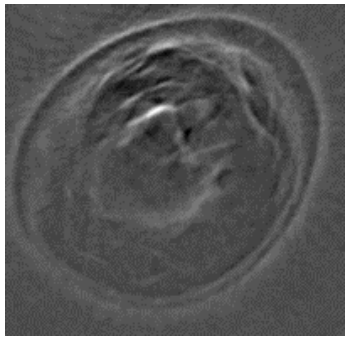
$$I(j, \vec{x}), \quad j = 1 \ldots J$$

Use directional information for a **new Modality**:
Reflectivity characteristic per voxel

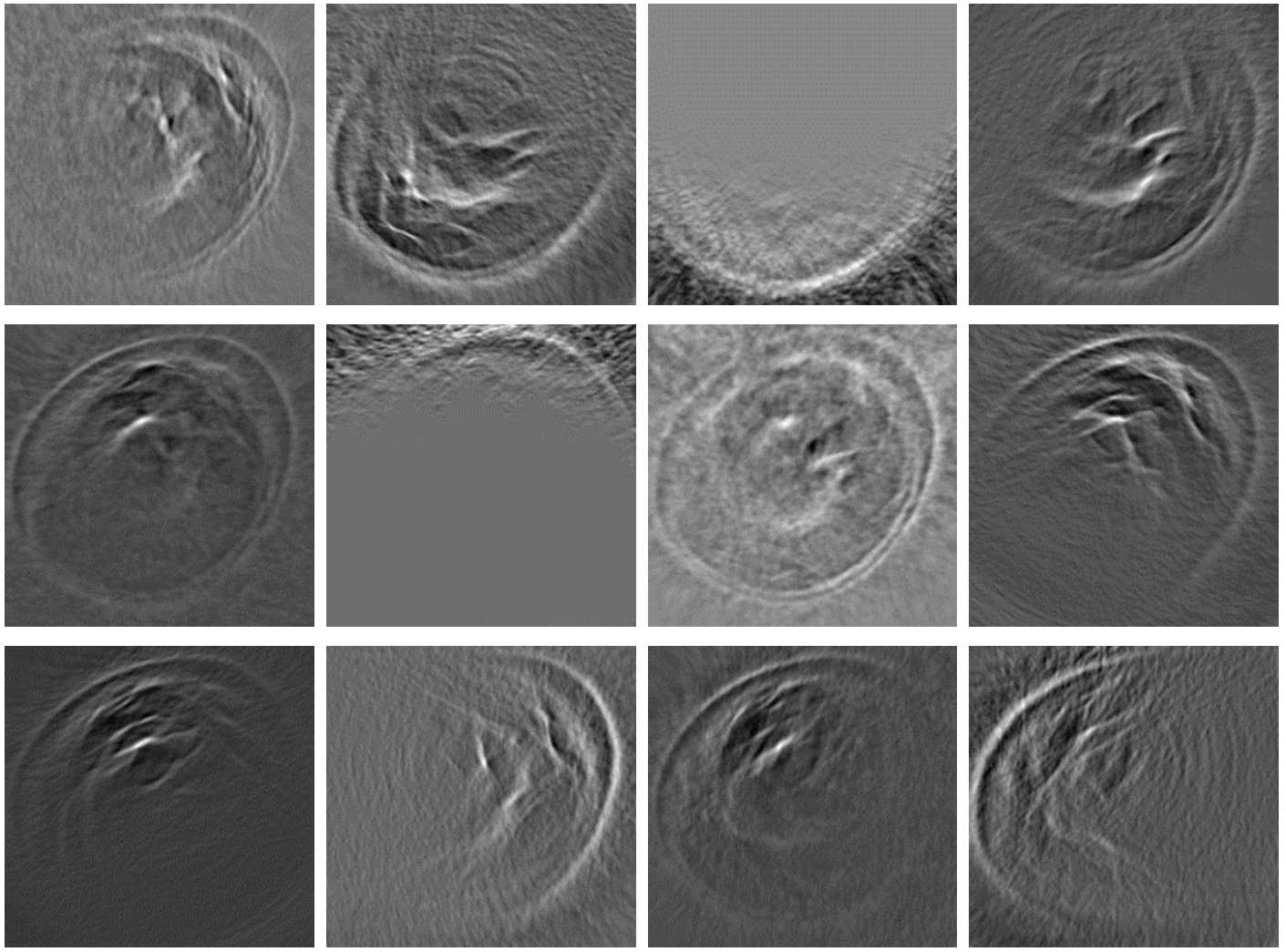
View from single Direction (Dodecahedron)



Dodecahedron
12 surfaces

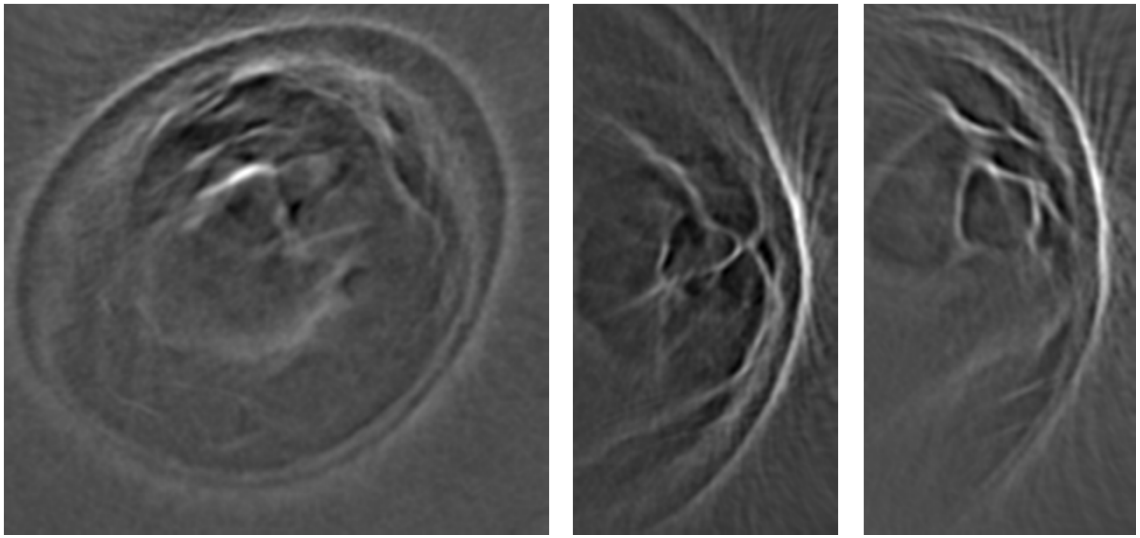


Standard SAFT



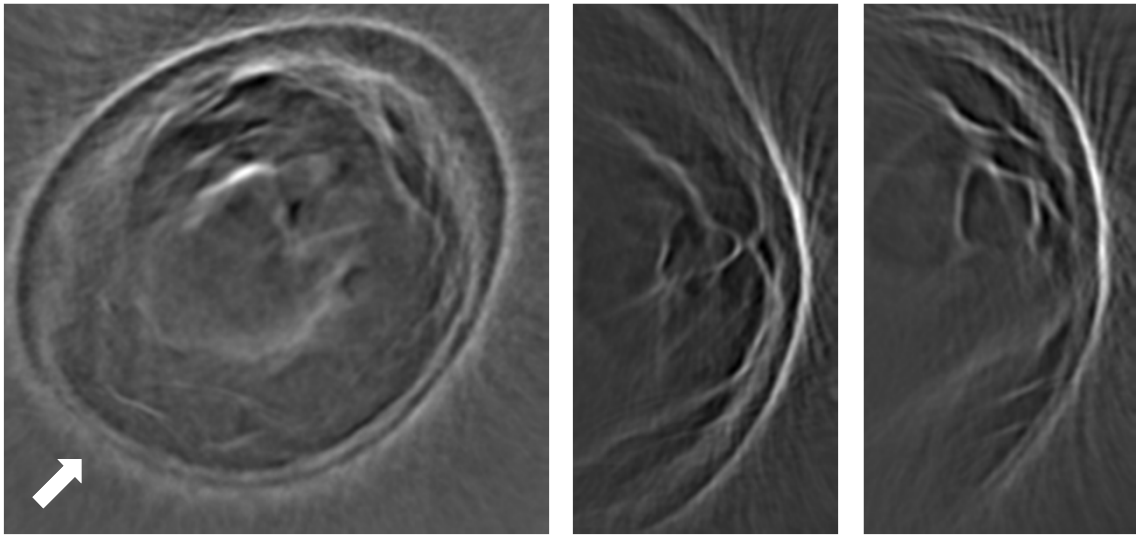
SAFT

Not weighted



Weighted

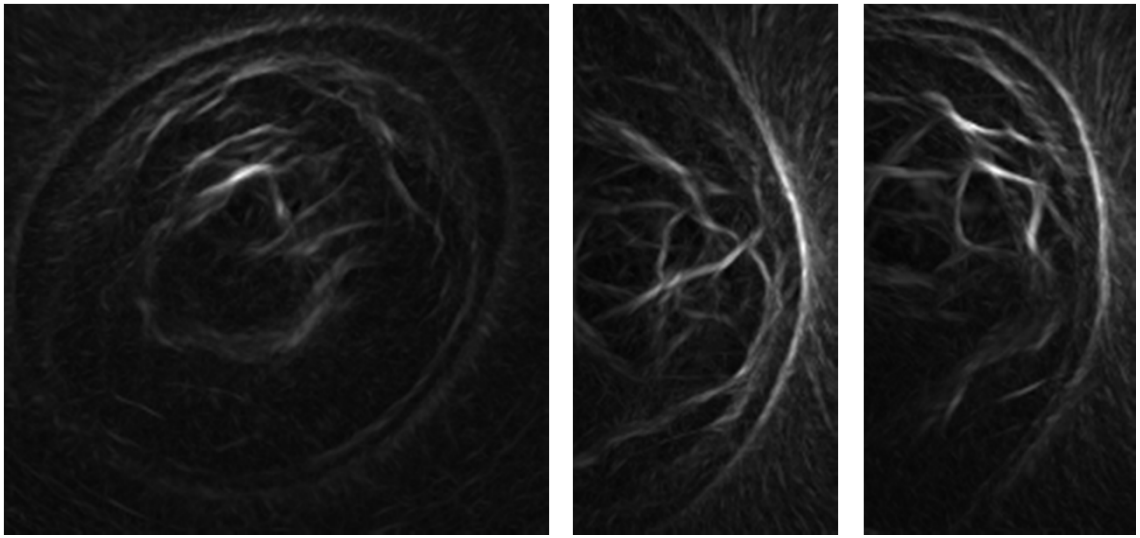
➔ equal illumination
for xy-slices



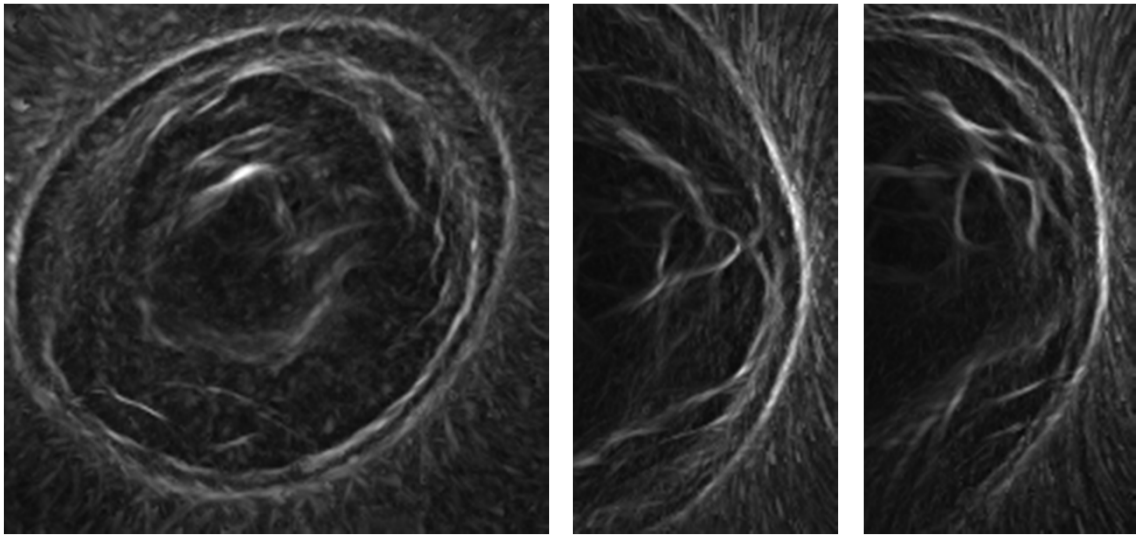
Surfce with maximum Energy

Not weighted

➔ PSNR: +32%

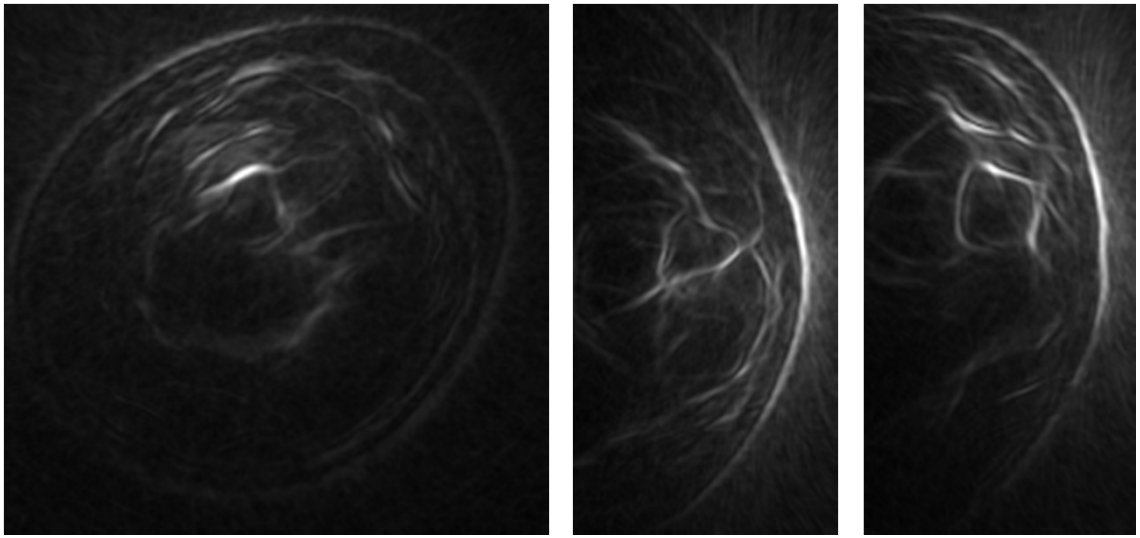


Weighted

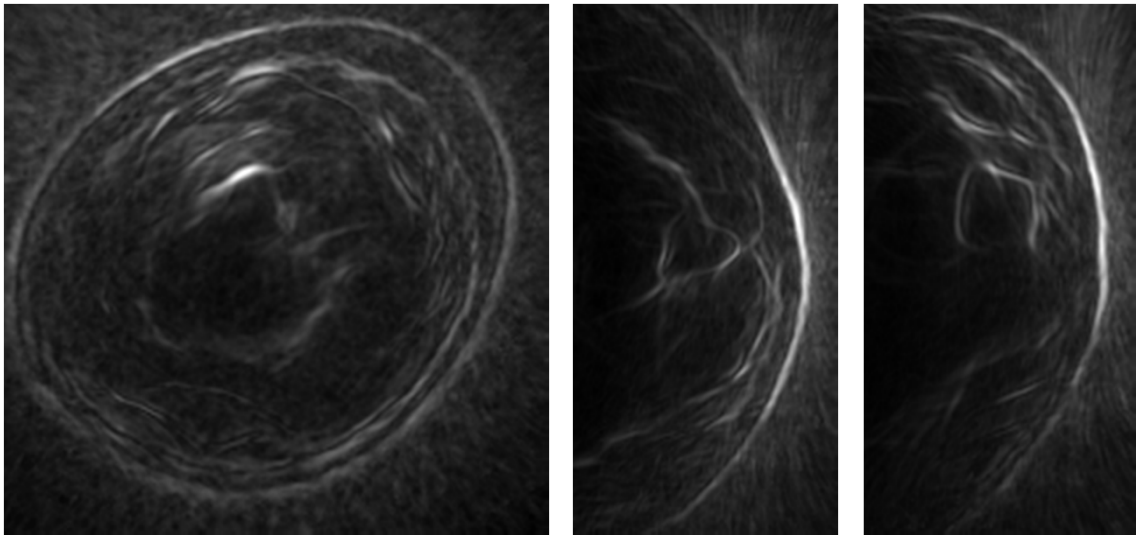


Standard Deviation of Surfaces

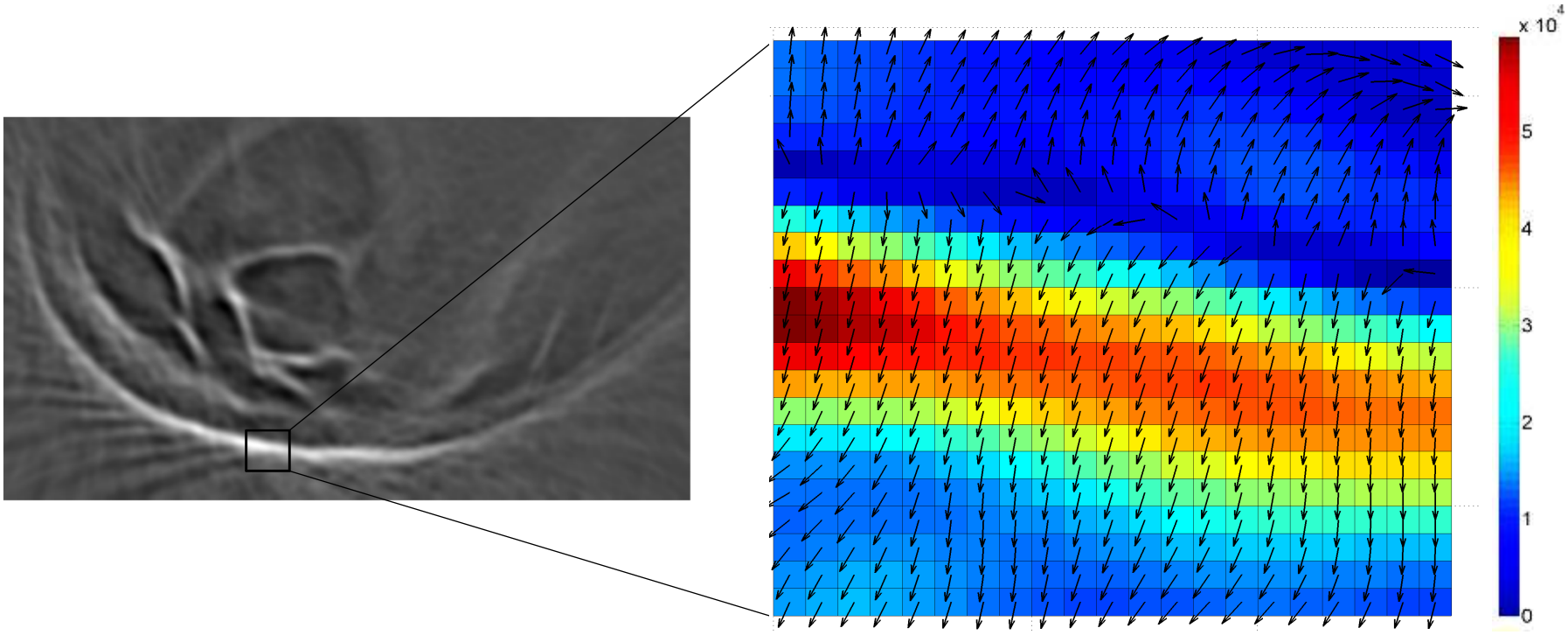
Not weighted



Weighted

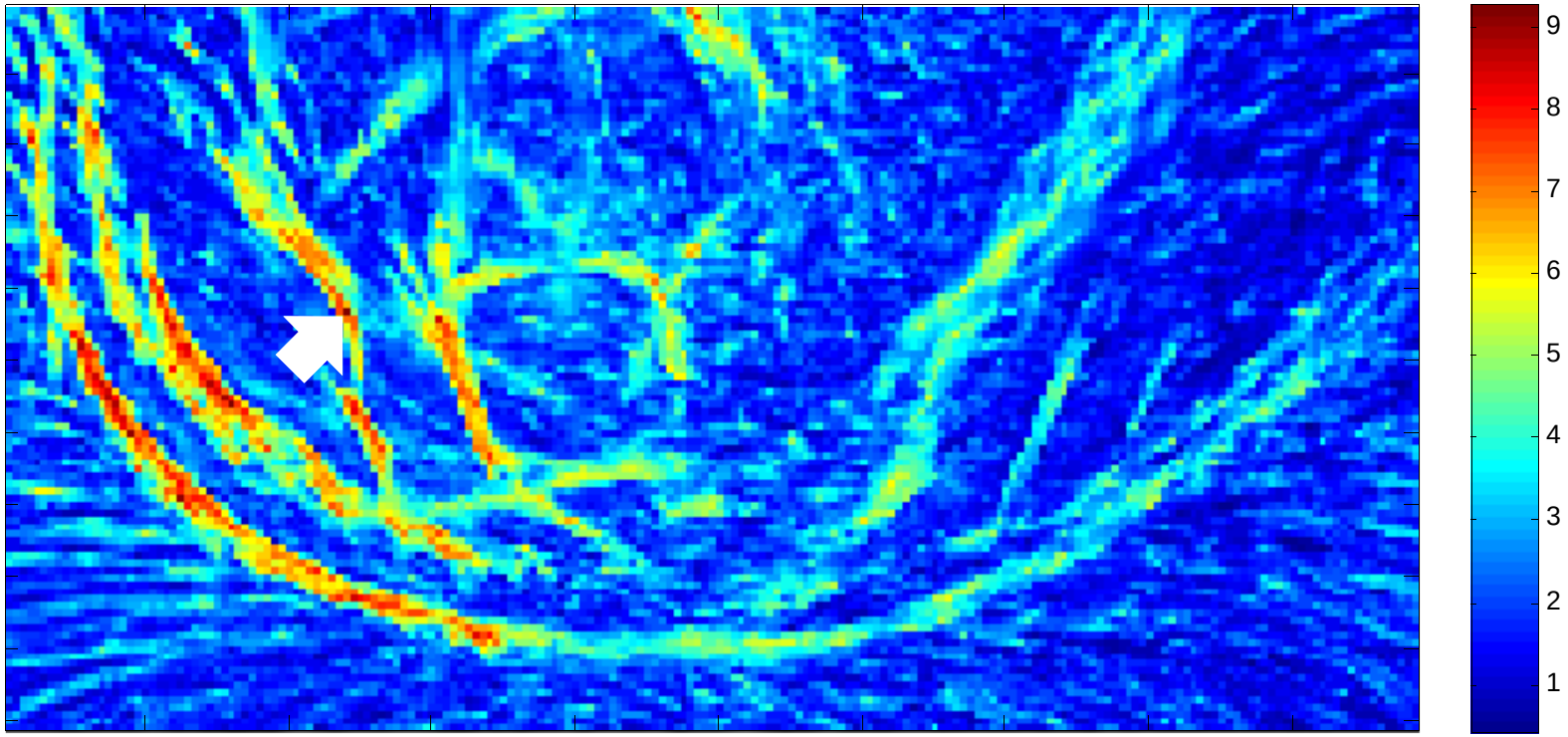


Surface Normals - Breast Surface



Correlation with Reference Voxel

- Reference voxel from glandular tissue
  Reflectivity characteristic determined with Spherical grid (30°,18°)



Performance on NVIDIA GTX TITAN GPU

- Calculation of reflectivity characteristic

Solid	# Surfaces	Memory	GVA/s	GVAS/s
Standard SAFT	1	268 MB	8.7	8.7
Dodecahedron	12	6.4 GB	4.0	47.5
Icosahedron	20	10.7 GB	2.2	43.1
Spherical Grid (30°,18°)	110	59.1 GB	0.4	47.3
Spherical Grid (5°,5°)	2522	1.4 TB	0.02	51.0

➔ Calculation with Dodecahedron: 46% of standard SAFT performance.

➔ Nearly constant performance normalised to the number of surfaces.

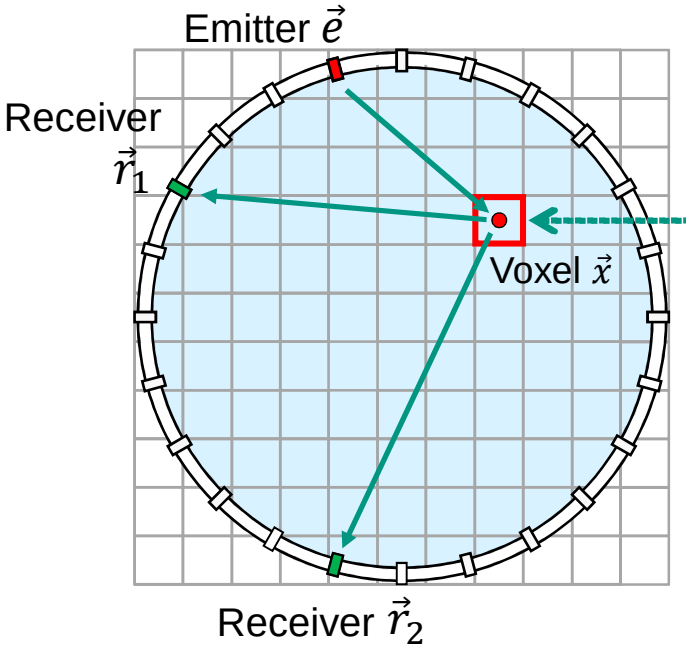
Summary, Conclusion and Outlook

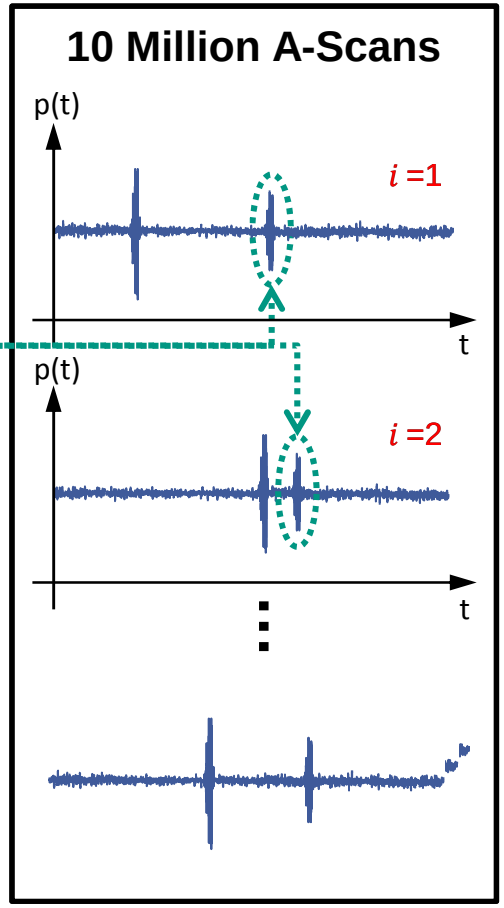
- Extended SAFT to calculate reflection characteristics per voxel
  - Using solids enable manageable data size
  - Performance on GPU up to 46% of standard SAFT
- Evaluation of reflection characteristic with in-vivo data:
  - Increased image quality (PSNR +32%)
  - Local normals can be approximated
  - Information about the directivity of the reflection
  - Potential for tissue classification
- Outlook
  - Quantitative analysis with simulation
  - Discriminate diffuse and specular reflections
  - Include speed of sound and attenuation correction

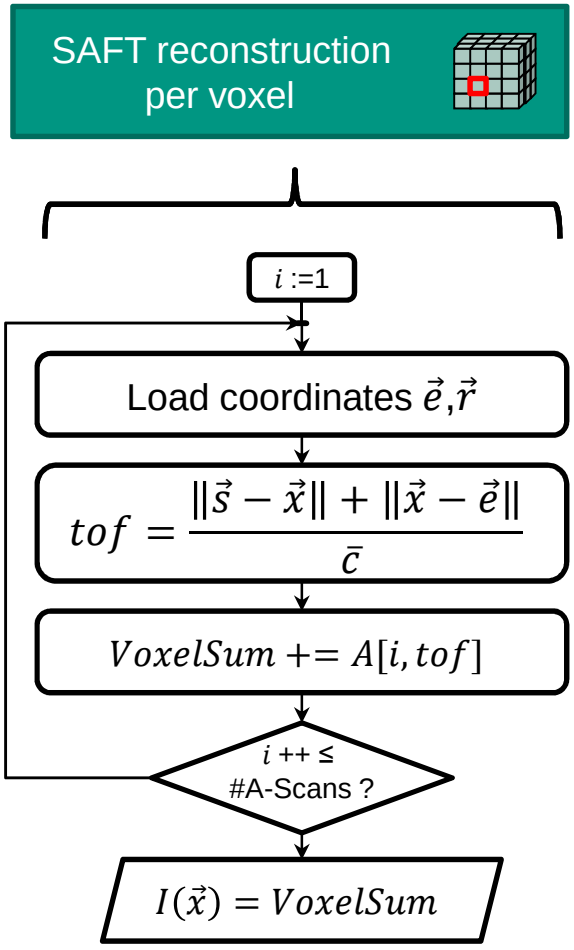
Thank you for your attention!

Reconstruction with Standard-SAFT

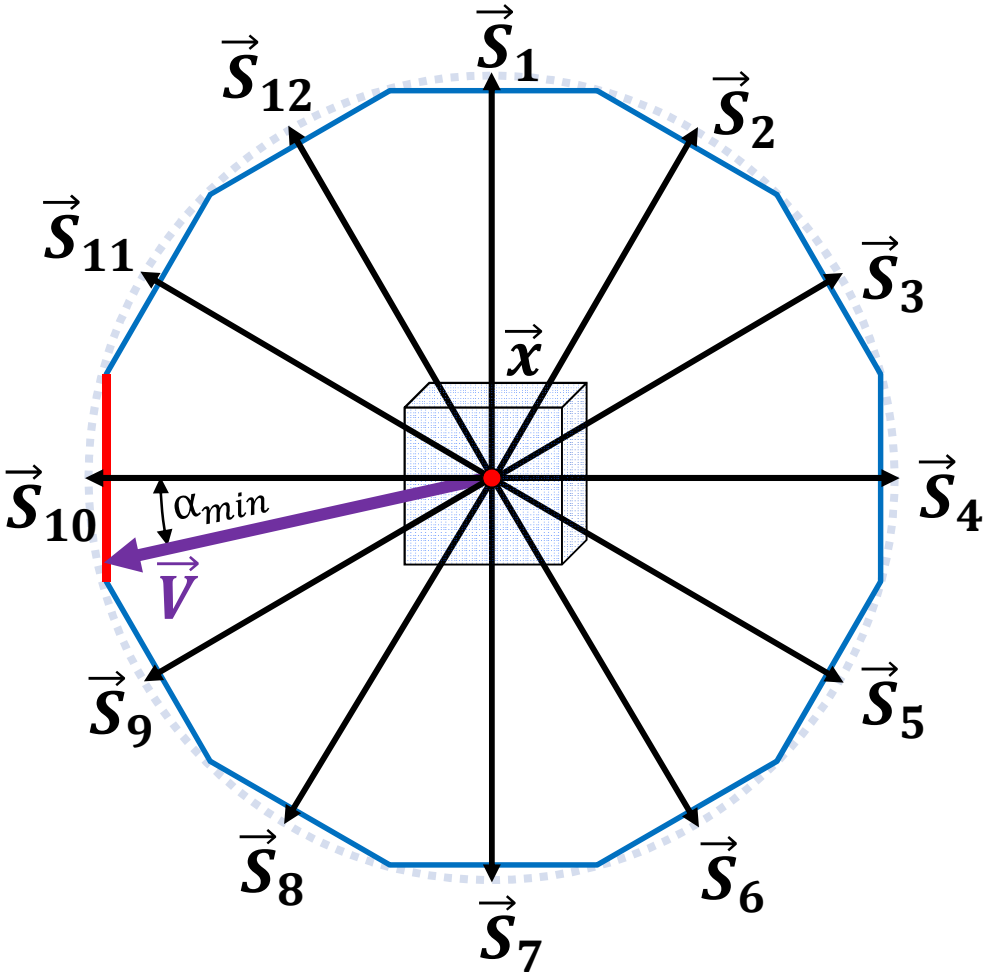
SAFT = synthetic aperture focusing technique

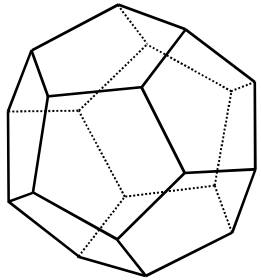




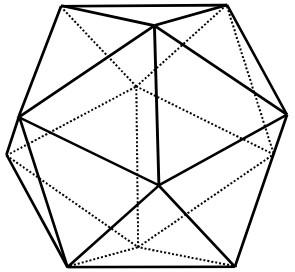


Mapping amplitudes to directions / Solids

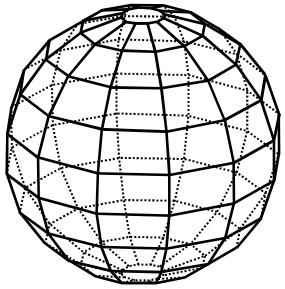




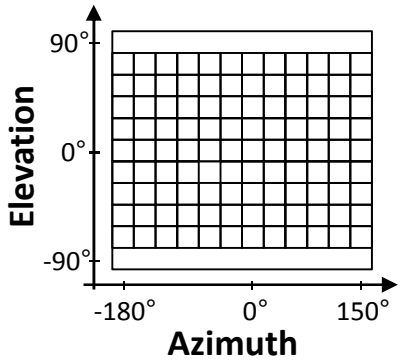
Dodecahedron



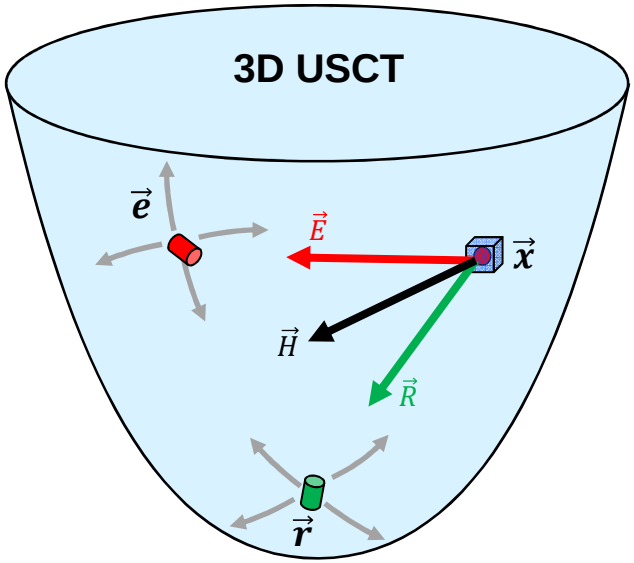
Icosahedron



Sphere grid

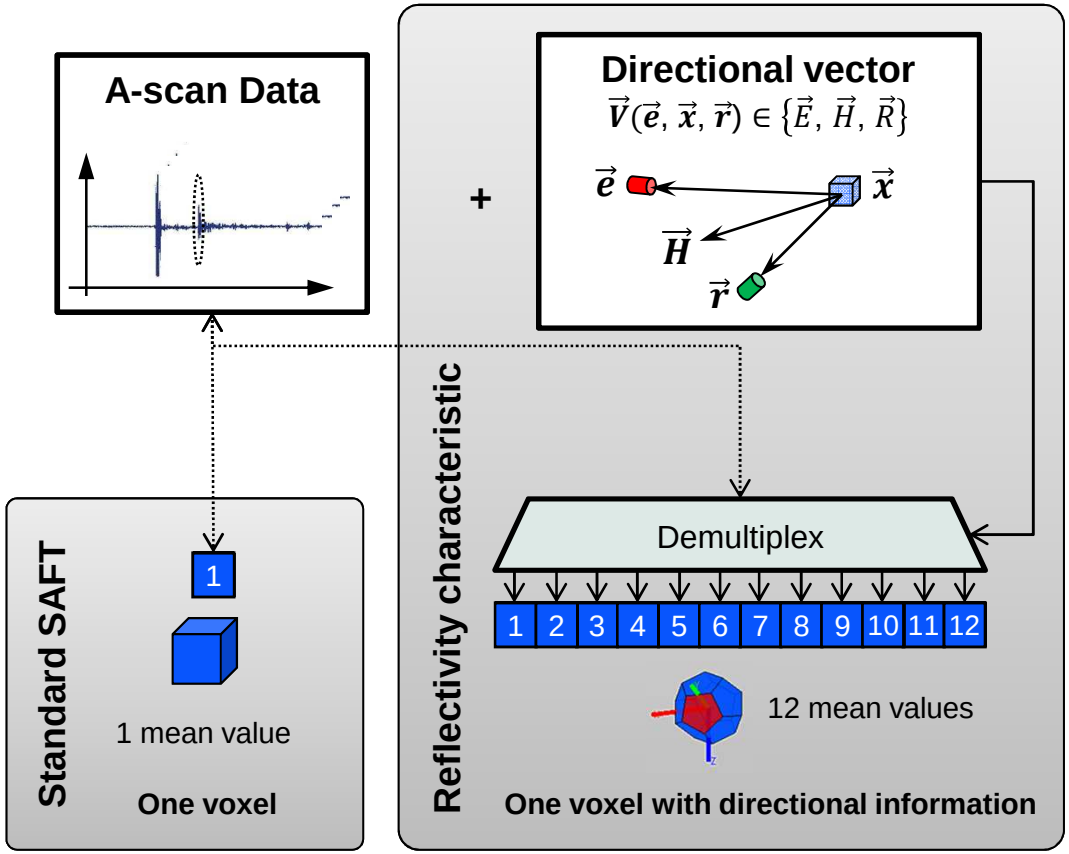


Calculation of reflectivity characteristic



Possible mapping of amplitudes with

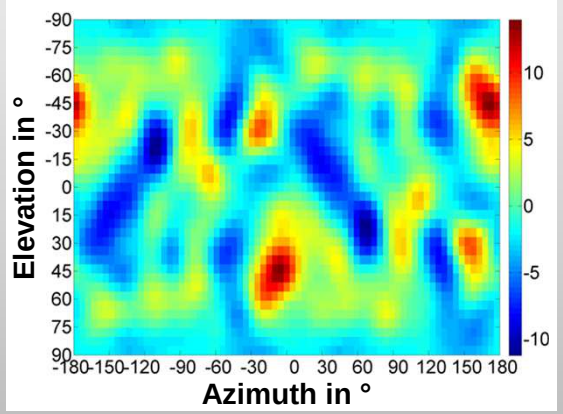
$$\vec{V} \in \{\vec{E}, \vec{H}, \vec{R}\}$$



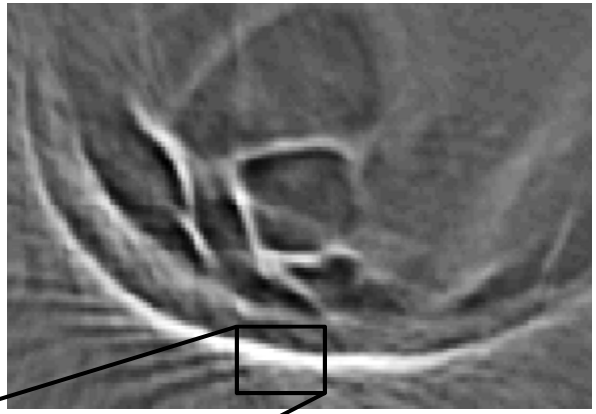
Potential of the reflectivity characteristic

Reflectivity characteristic per voxel

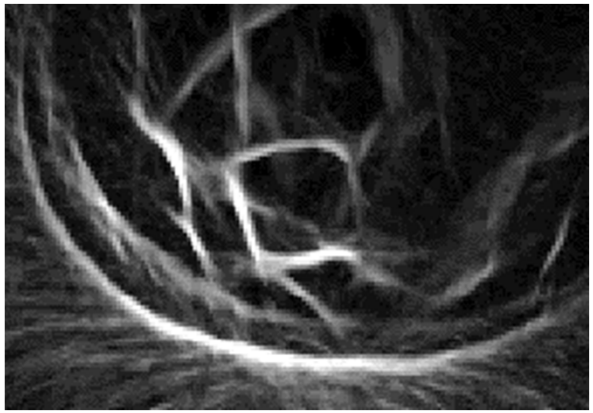
One voxel =



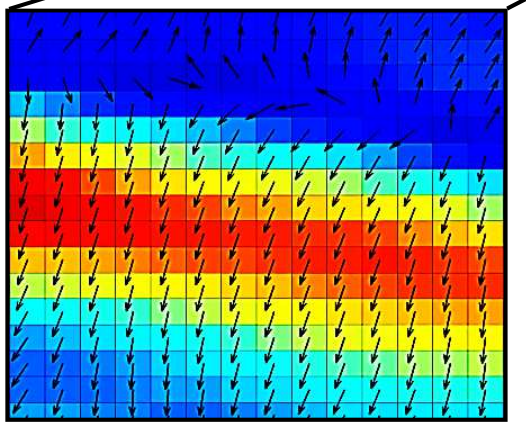
Standard SAFT xz-layer



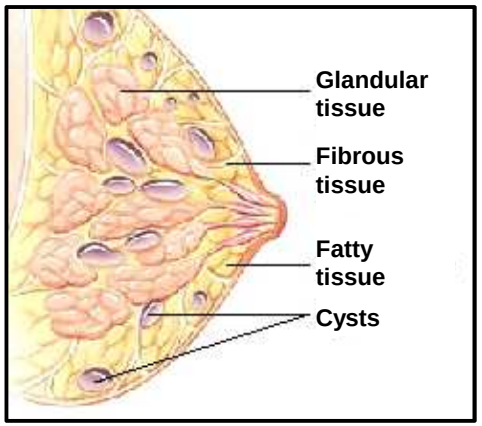
Sum



Maximum (PSNR +47%)

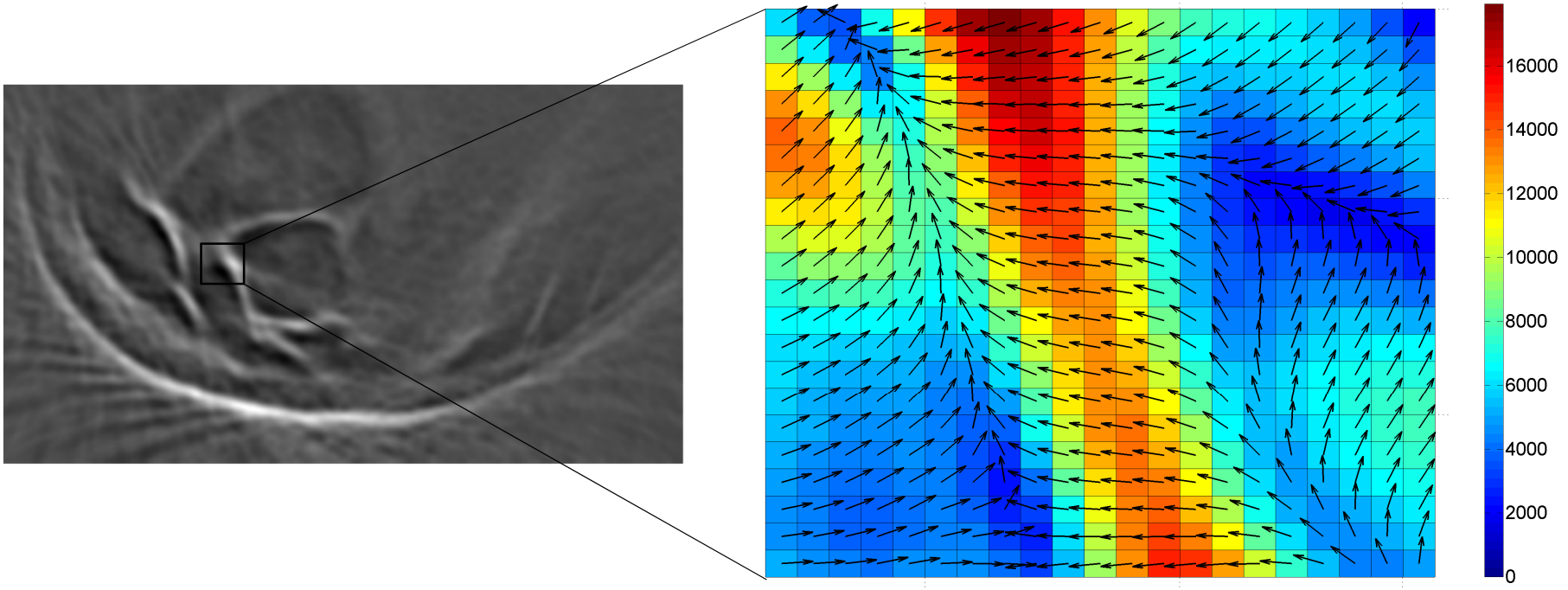


Surface normals



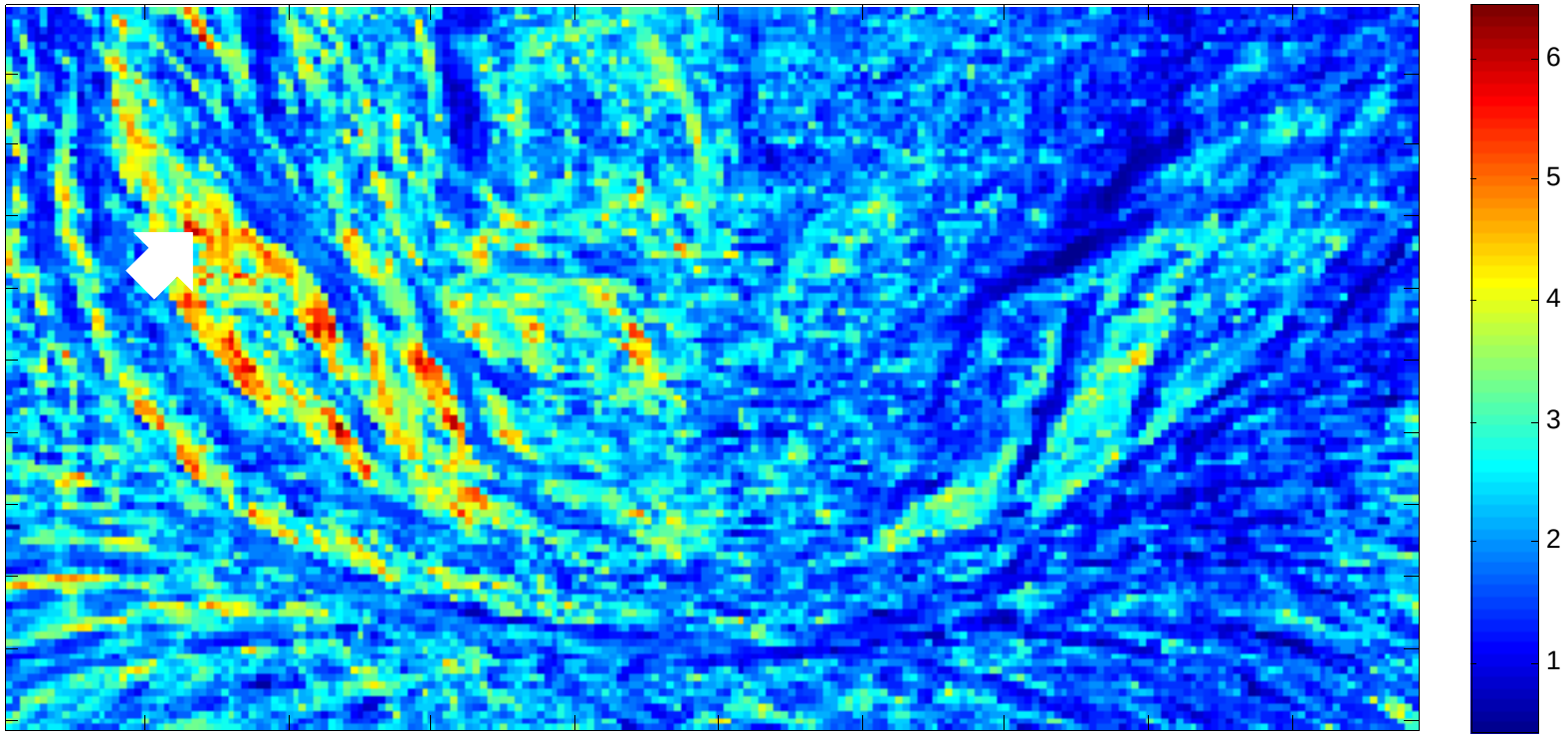
Possible tissue classification

Surface Normals - Glandular tissue



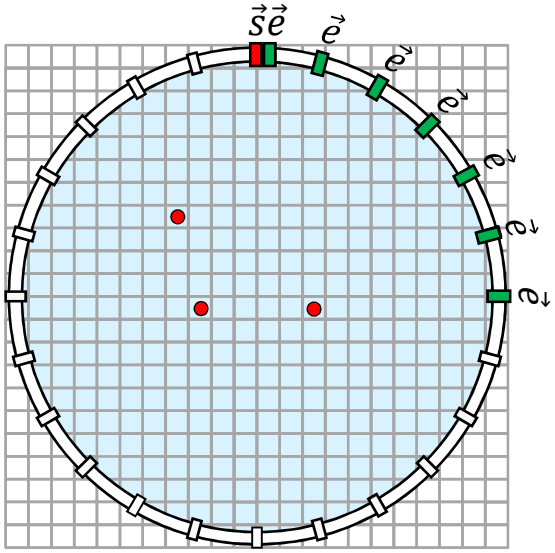
Correlation with Reference Voxel

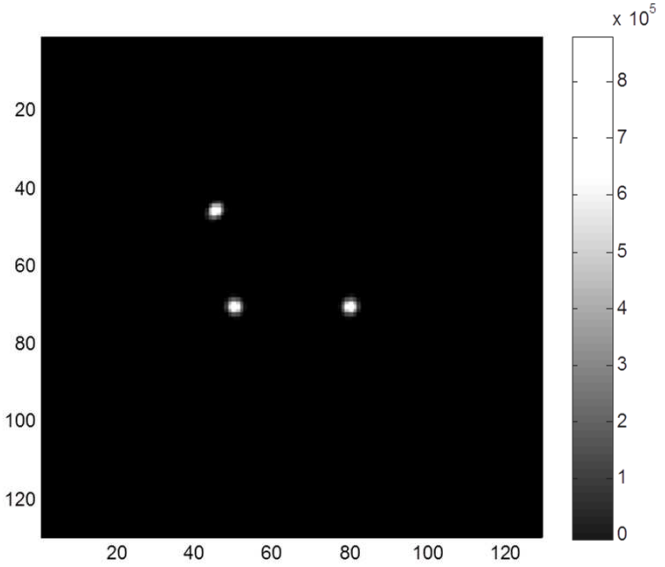
- Reference voxel from background
  Reflectivity characteristic determined with Spherical grid (30°,18°)



Example: Reconstruction of one Point Scatterer

With each emitter-receiver pair (= 1 A-Scan) the “Probability” of one reflection for each Voxel is summed up.





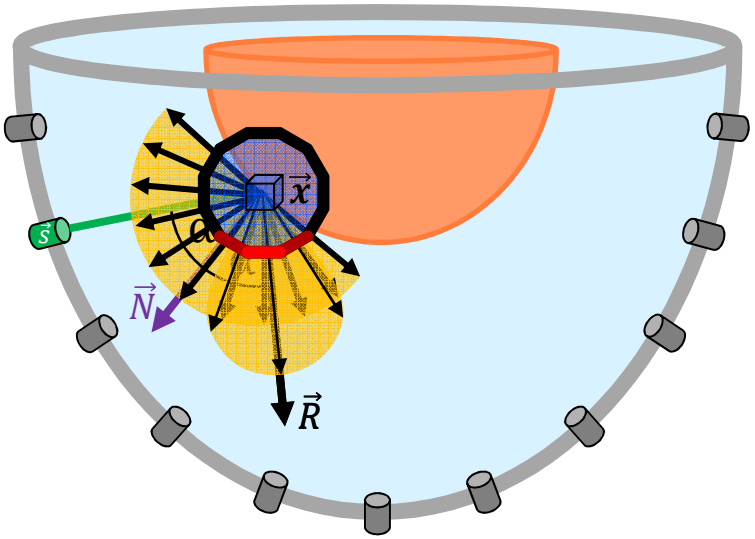
A-Scans

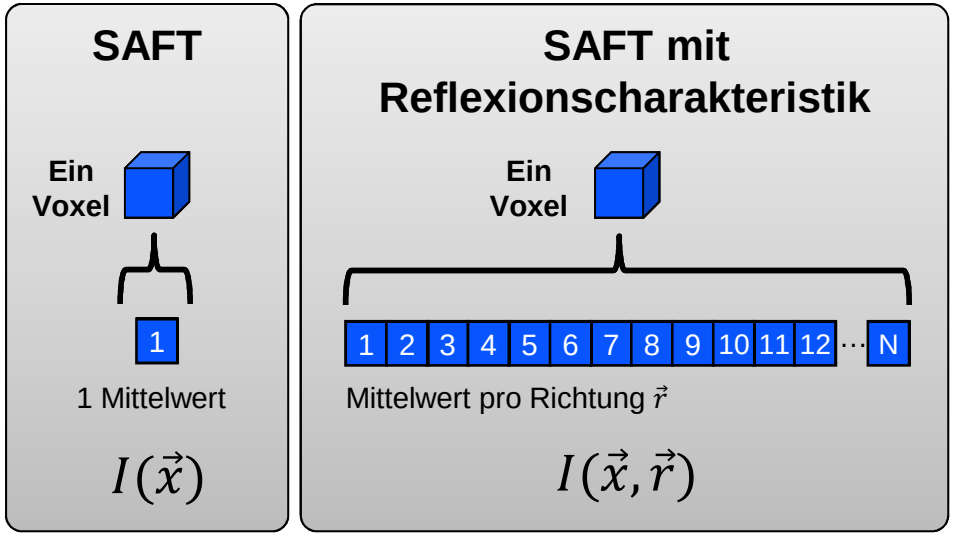
1
2
3
4
5
6
7
24
216
887364

SAFT- Equation: $$I(\vec{x}) = \sum_{\forall(s,e)} A_{(s,e)}\left(tof = \frac{\left\|\vec{s}-\vec{x}\right\| + \left\|\vec{x}-\vec{e}\right\|}{\bar{c}} \right)$$

New Modality: Reflection characteristic

- Use uniqueness of 3D-USCT: three-dimensional measurement data
- Extend SAFT with directional information from





Use directional information for a **new Modality**:
Reflection characteristic per voxel

Calculation of reflectivity characteristic