Numerical modeling of transcranial ultrasound

Blood flow and vascular pathologies modeling workgroup (INM RAS)
Grant RSF 14-31-00024

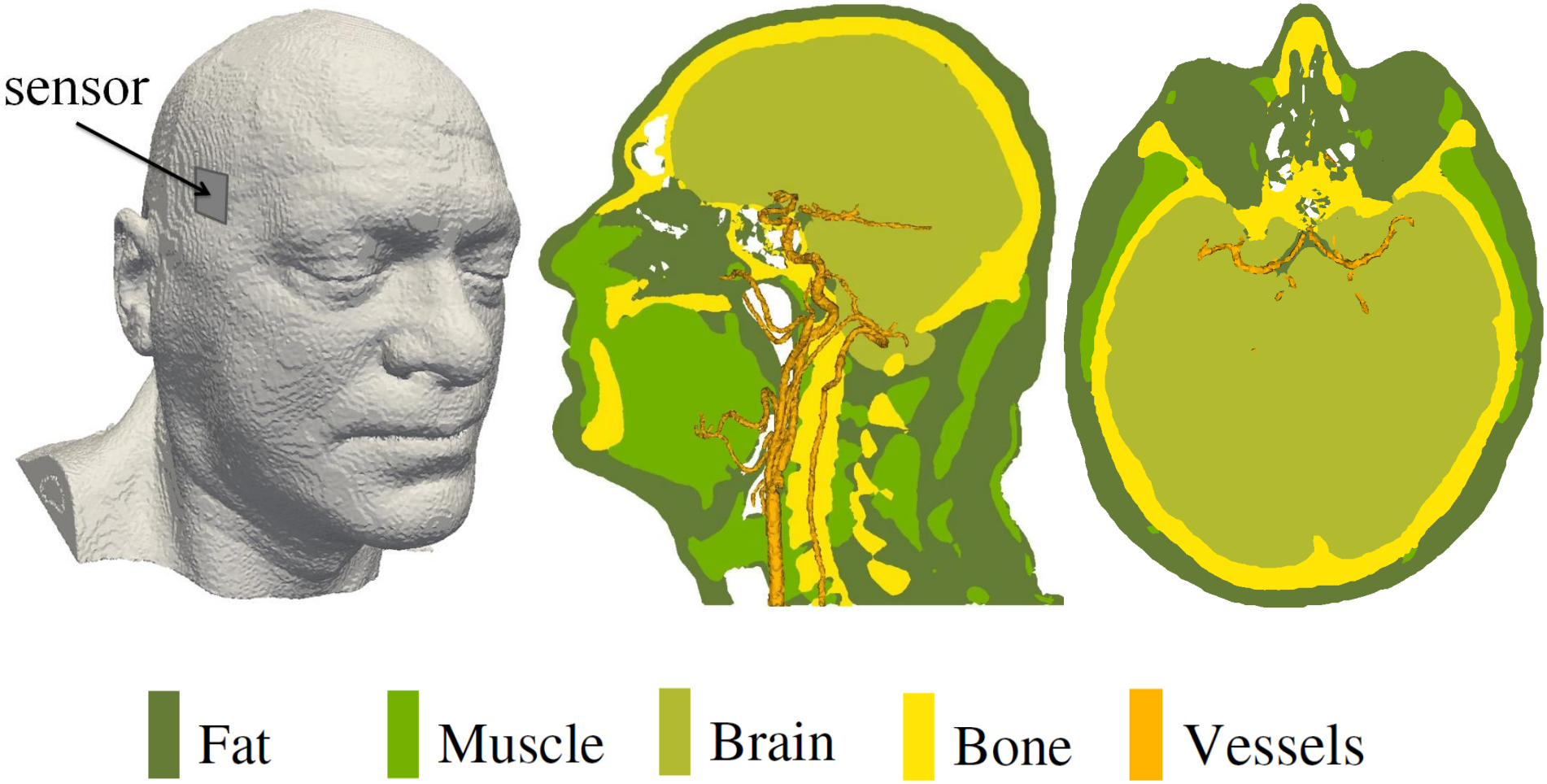
N.S. Kulberg — *Moscow Scientific and Practical Center of Medical Radiology*

G.K. Grigoriev — *MGTS Medical and health center*

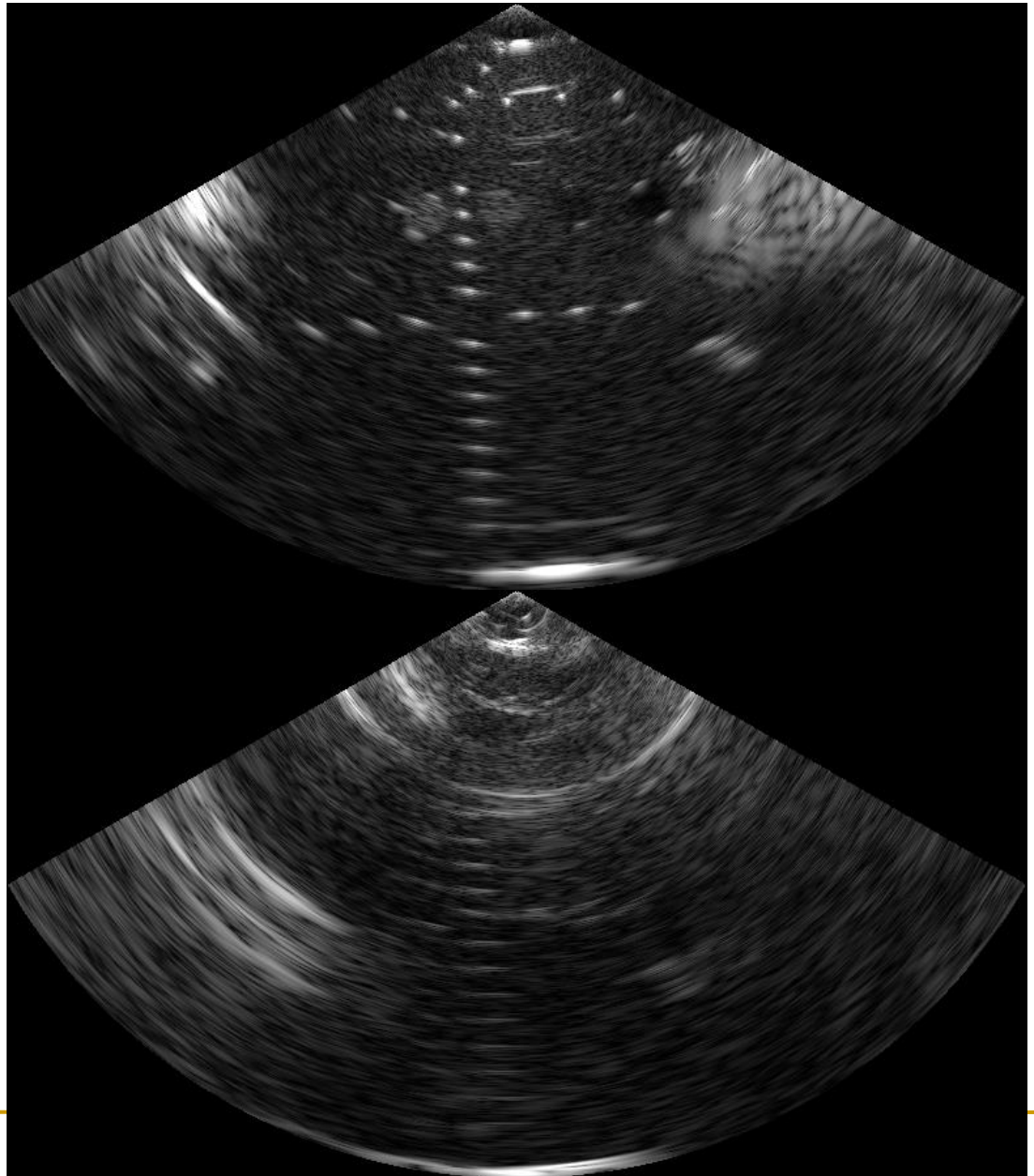
Y.V. Vassilevski — *INM RAS*
V.Y. Salamatova
A.A. Danilov

I.B. Petrov
A.V. Vasyukov
K.A. Beklemysheva
A.S. Ermakov
A.O. Kazakov — *MIPT*

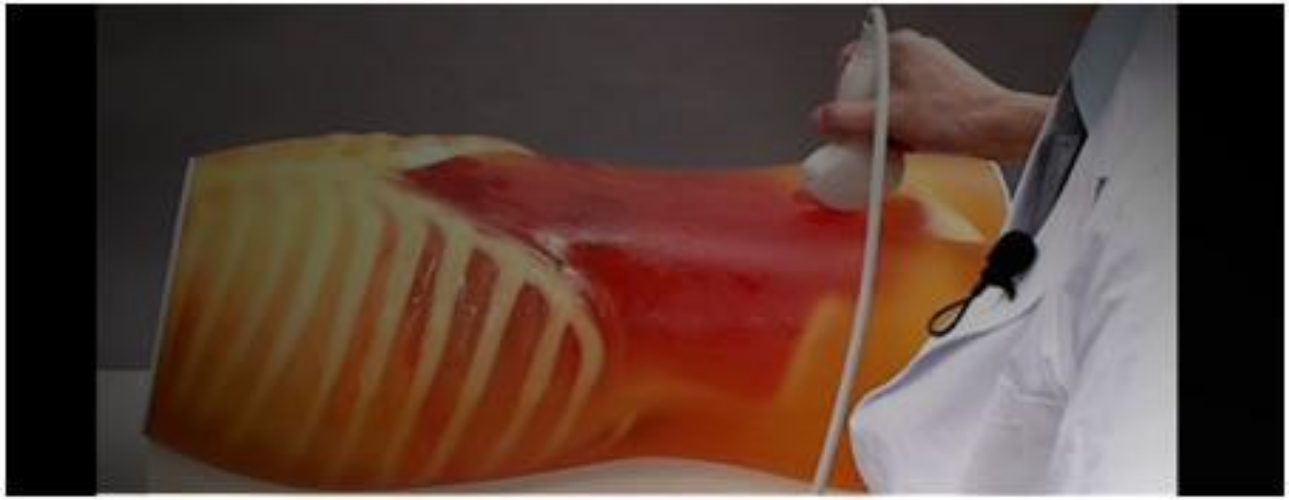
Problem statement:
transcranial ultrasound

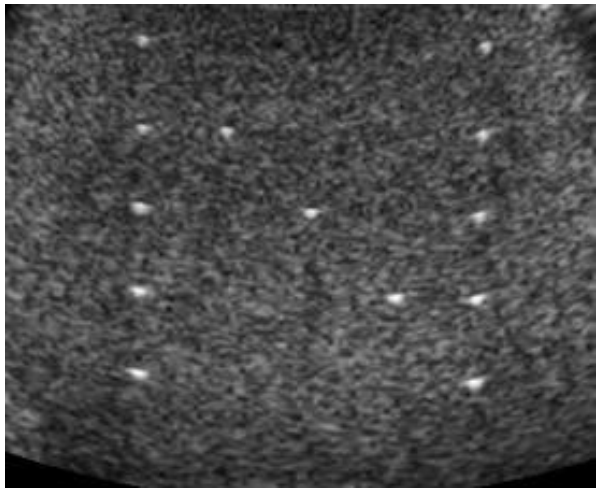


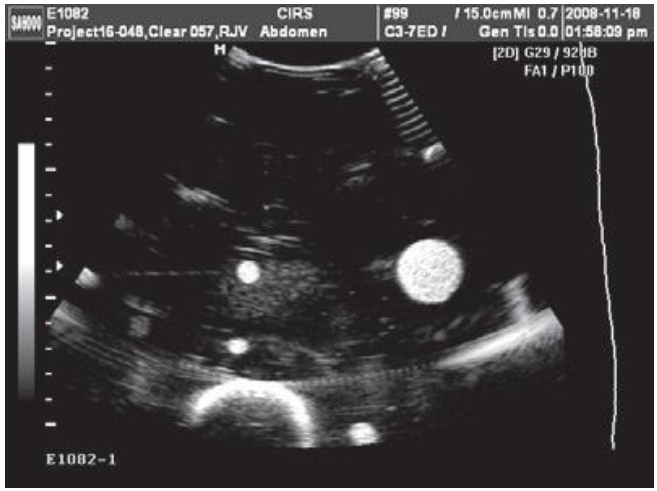
Problem statement: aberrations



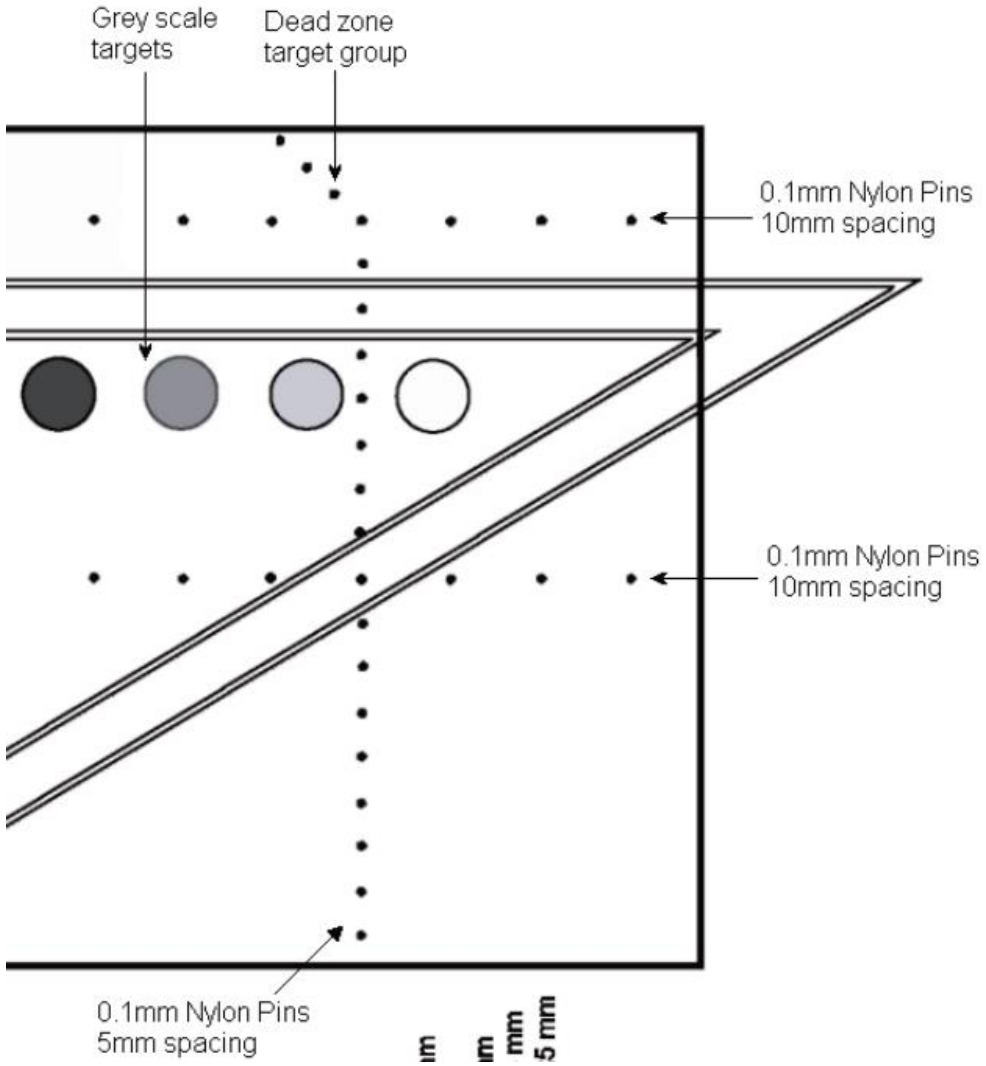
Problem statement: phantoms



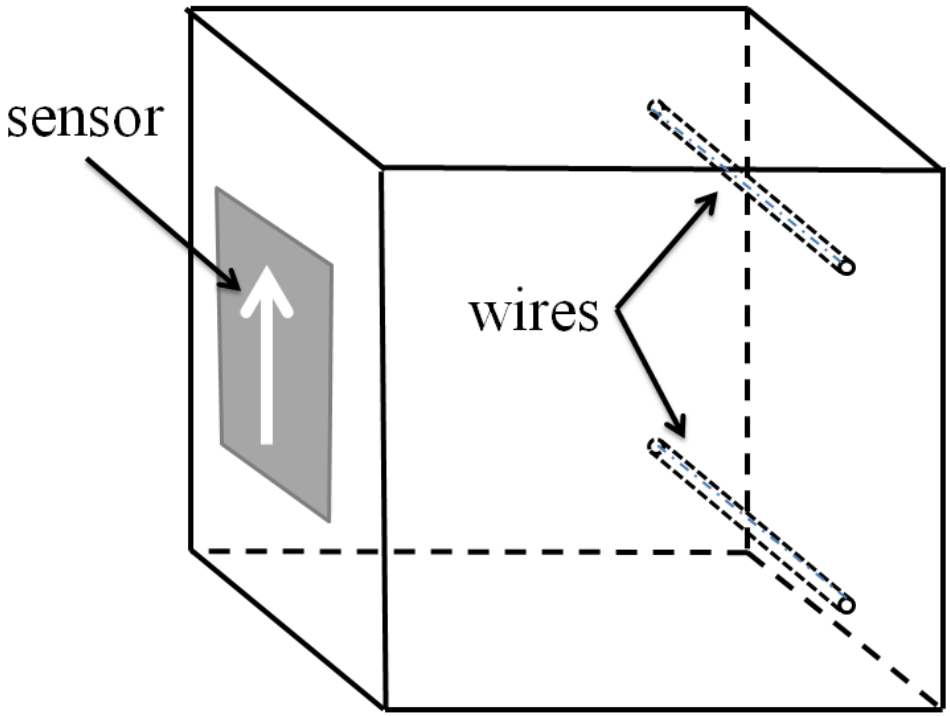


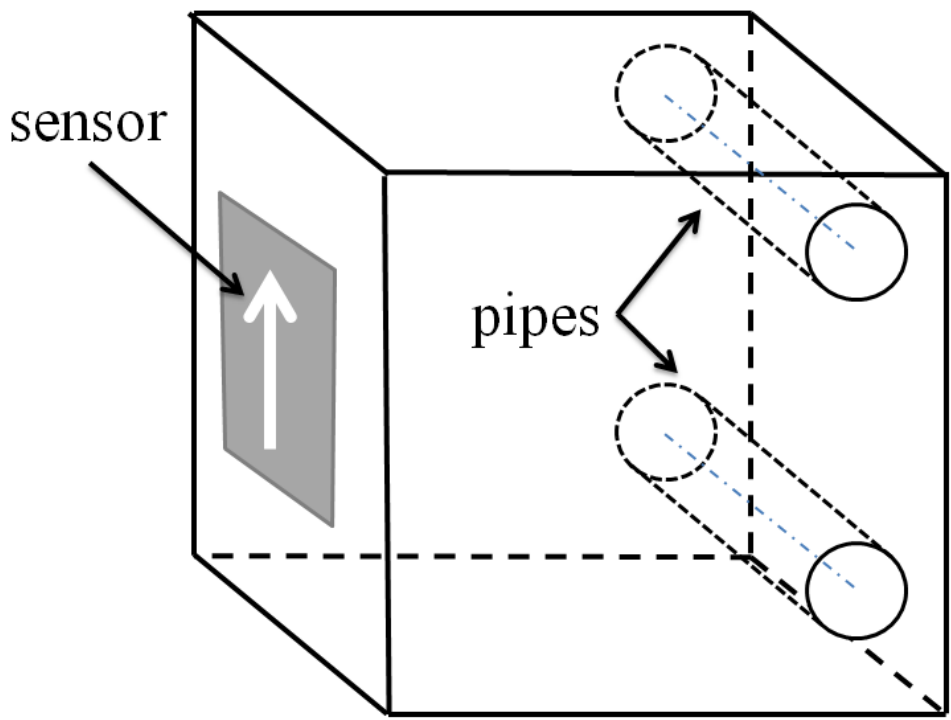


Phantom Gammex 1430 LE



GCM: problem statement

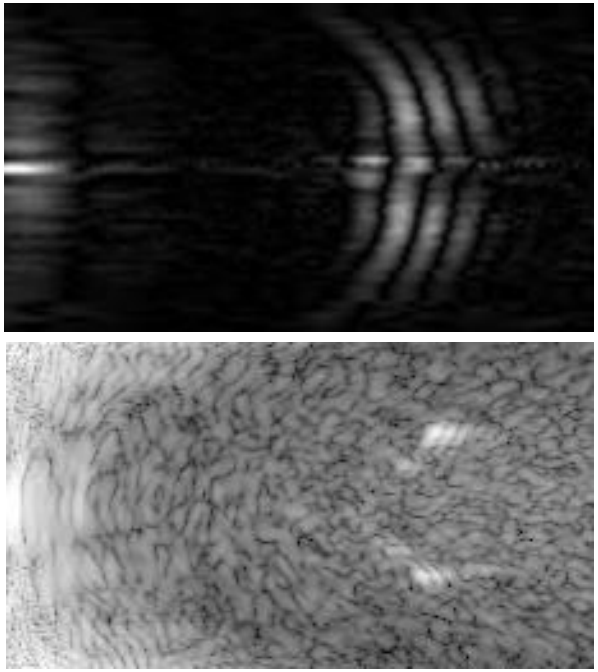


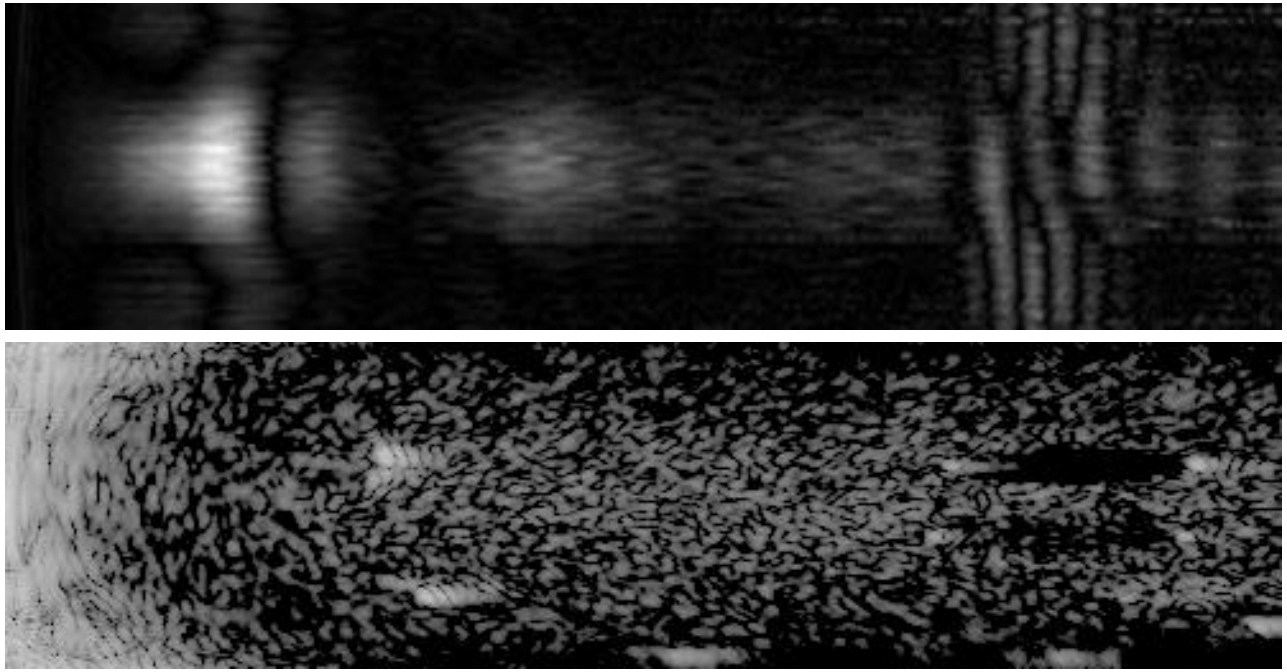


GCM: phantom Gammex 1430 LE

Nylon threads

Water pipes

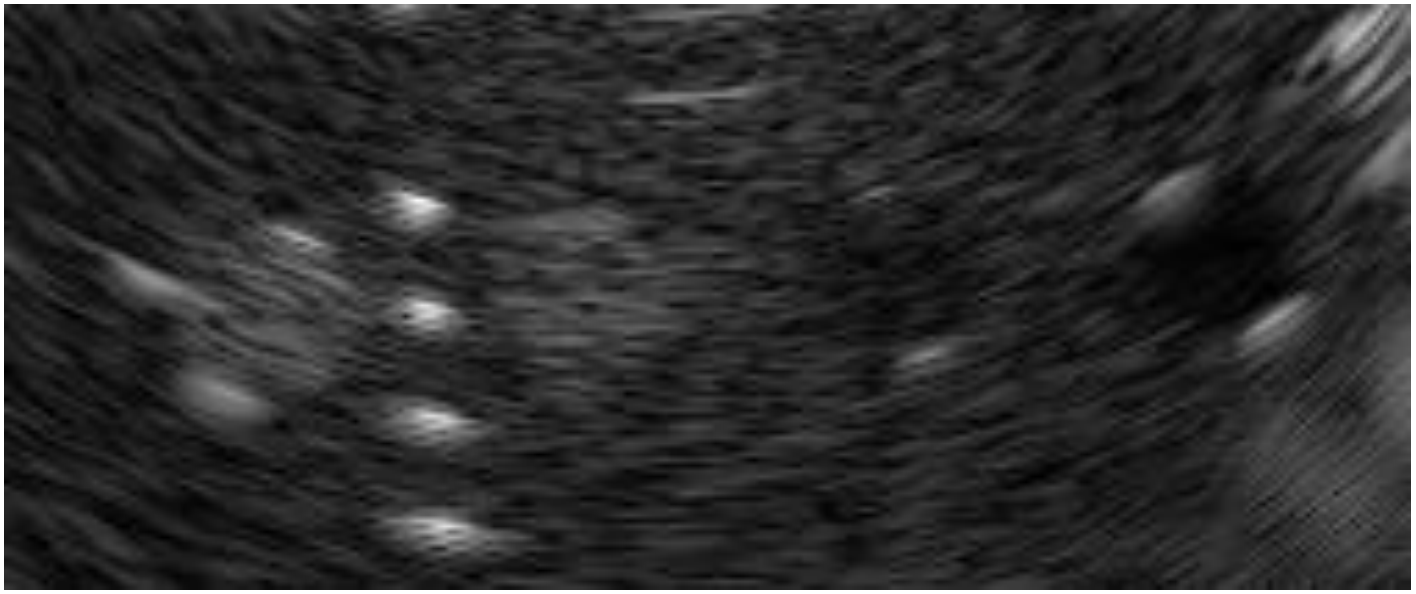




Type	Experiment	Calculation
Wires	15 +- 4	14 +- 8
Pipes	19 +- 4	20 +- 8

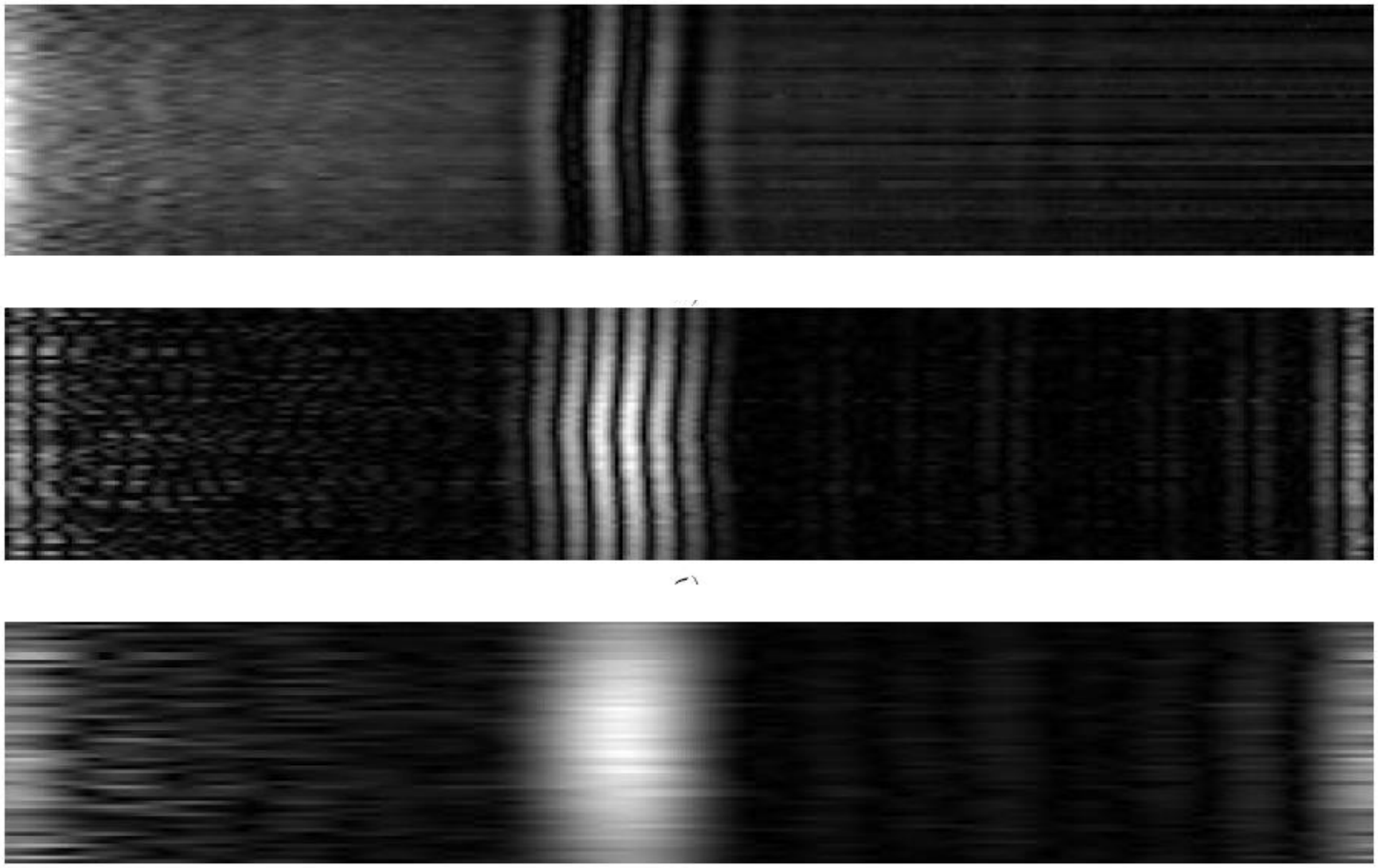
Problems

- The lack of information about the sensor structure
- Small size of nylon threads
- A great amount of scattered tiny point reflectors



GCM + numerical postprocessing pipeline

Single water pipe

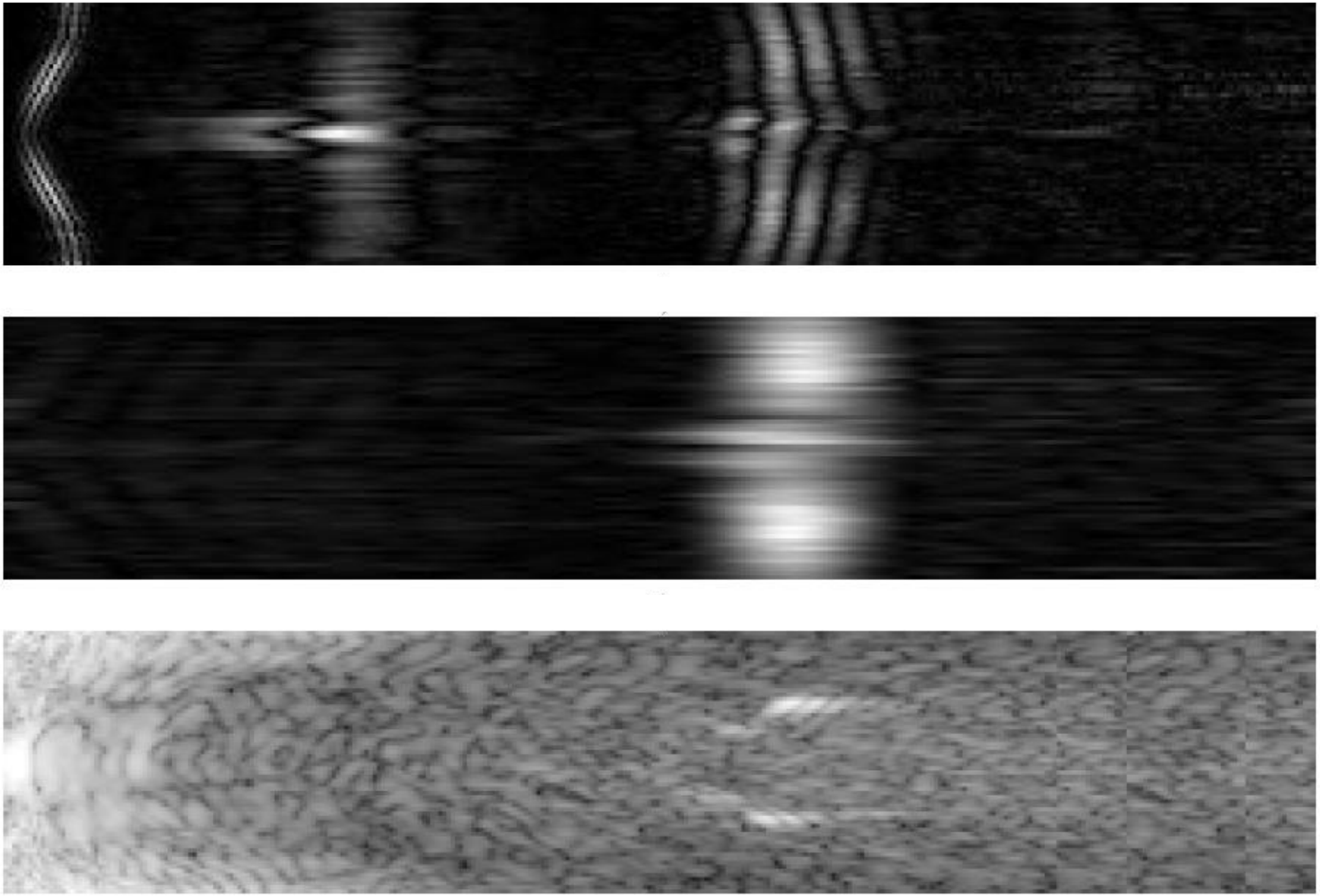


Raw

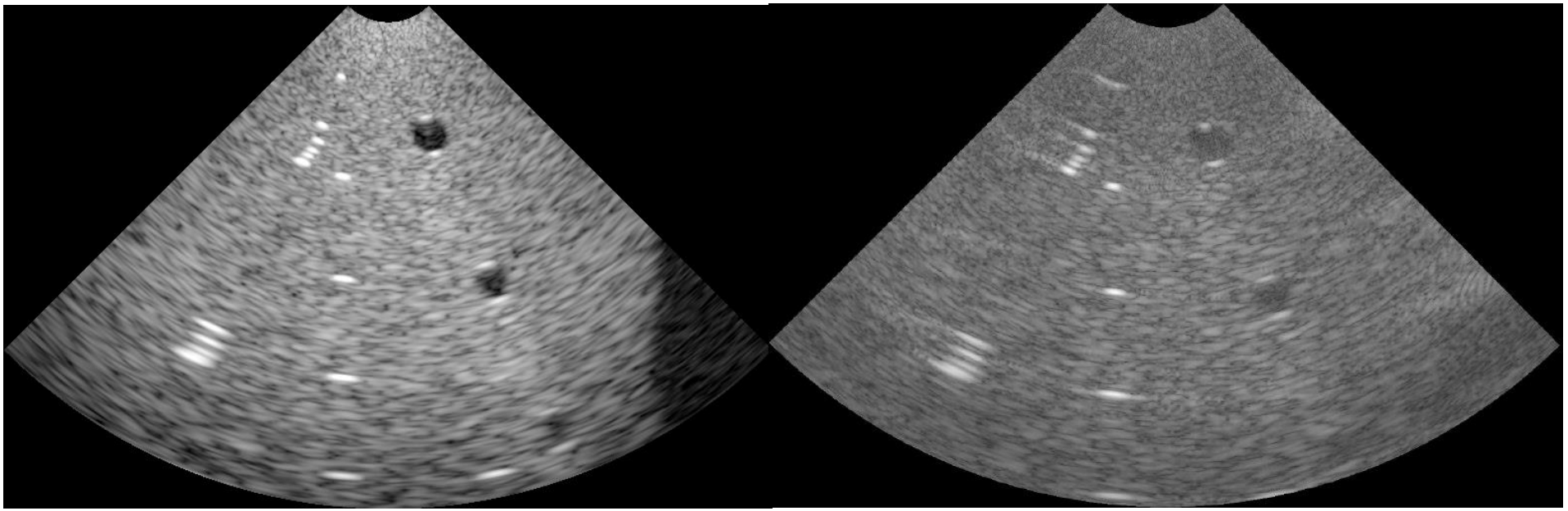
Narrowband filtering

Hilbert transform

GCM: two nylon threads



Experimental B-scans

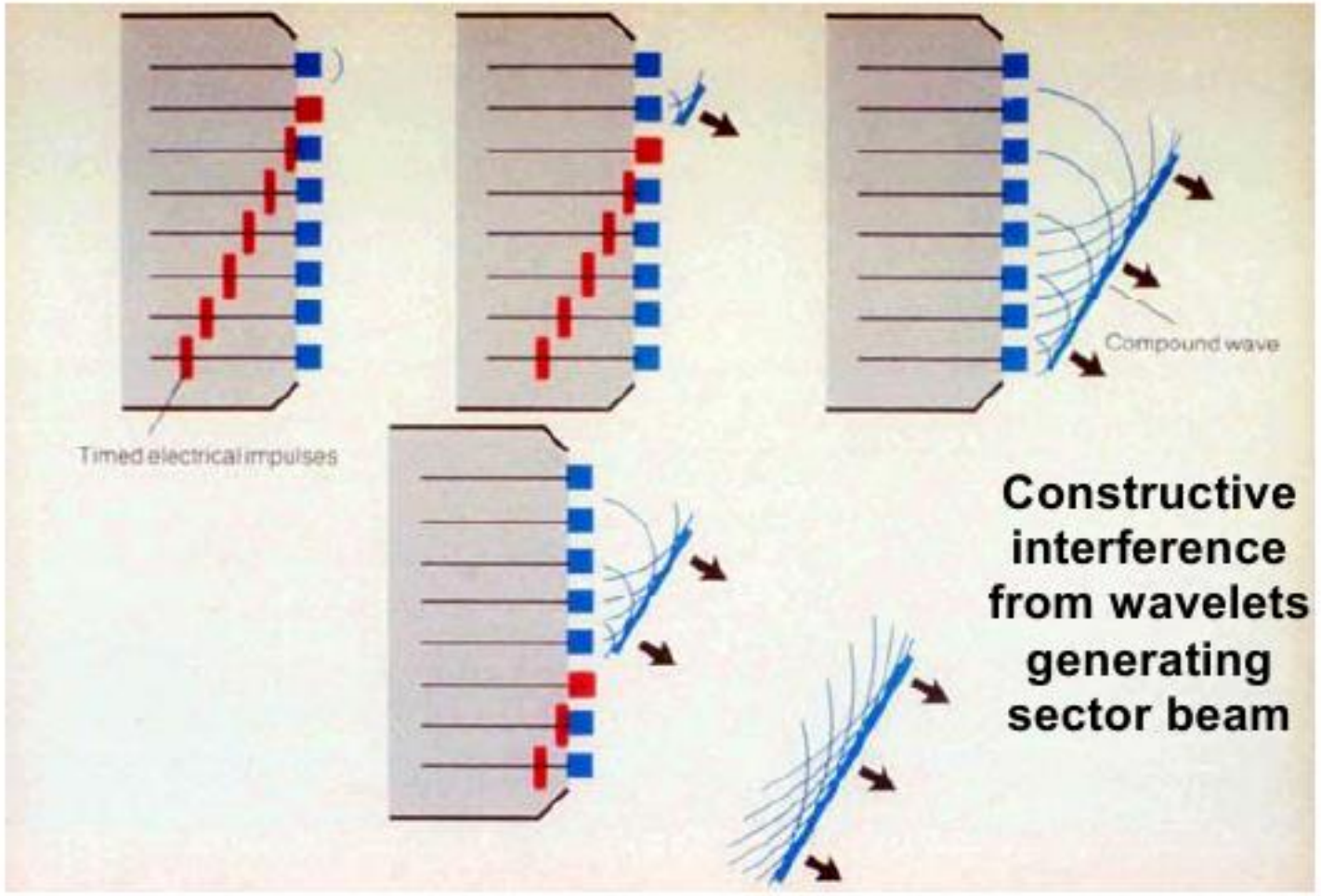


Experimental raw data
+
Original
postprocessing pipeline

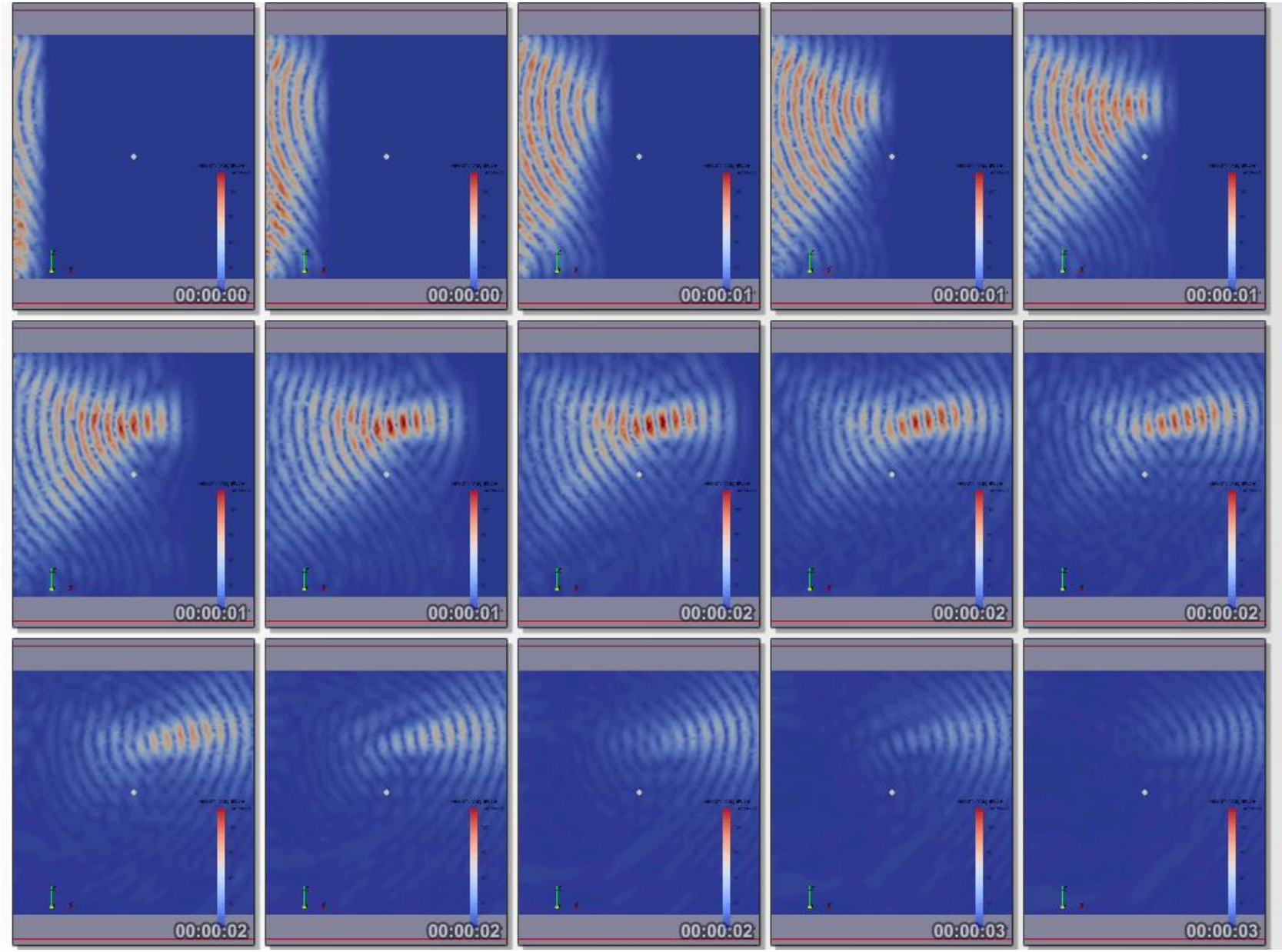
Experimental raw data
+
Numerical
postprocessing pipeline

B-scan generation: phased array

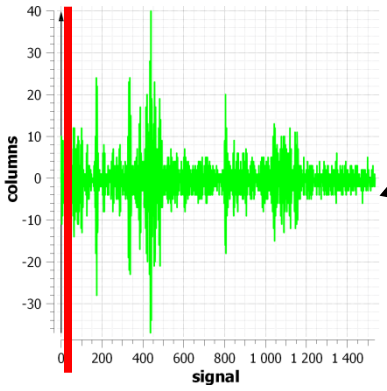
Each waveform merges to form a compound wave, generating a sector beam.



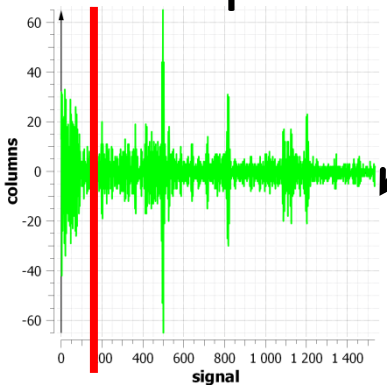
B-scan generation: phased array



B-scan generation



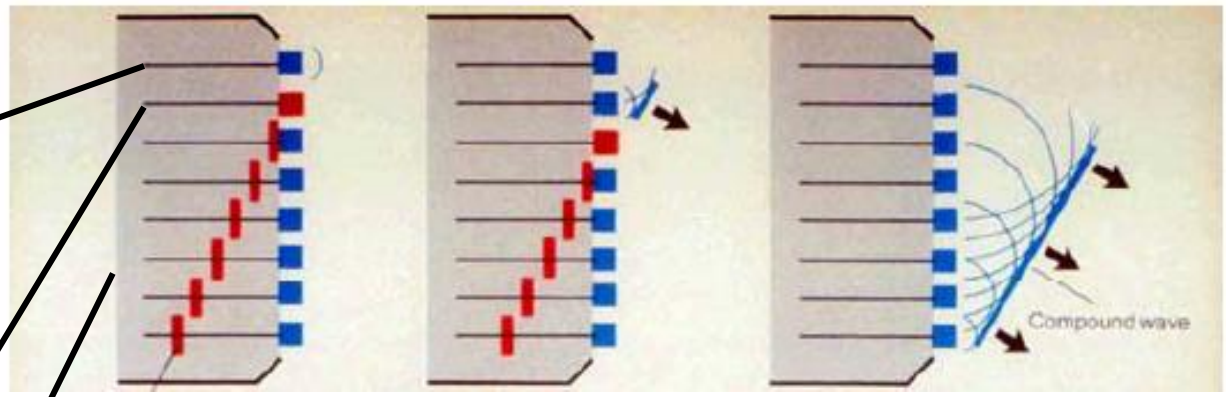
+

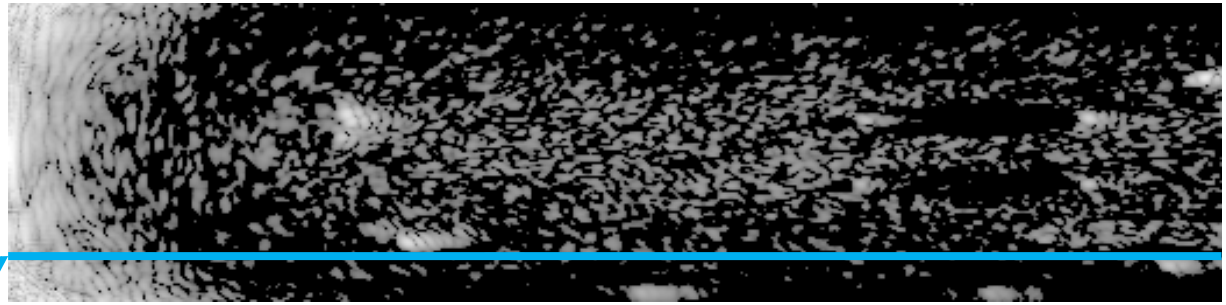


+

...

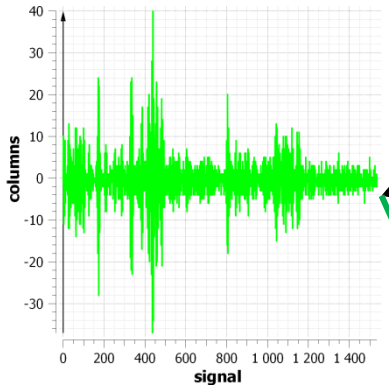
=



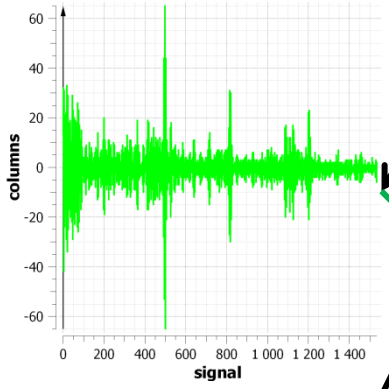


~230 beams => ~230 pixel lines

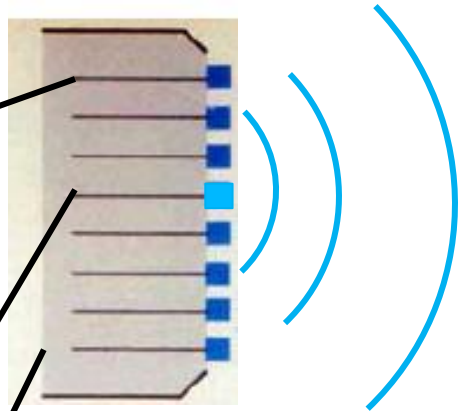
B-scan generation: alternative

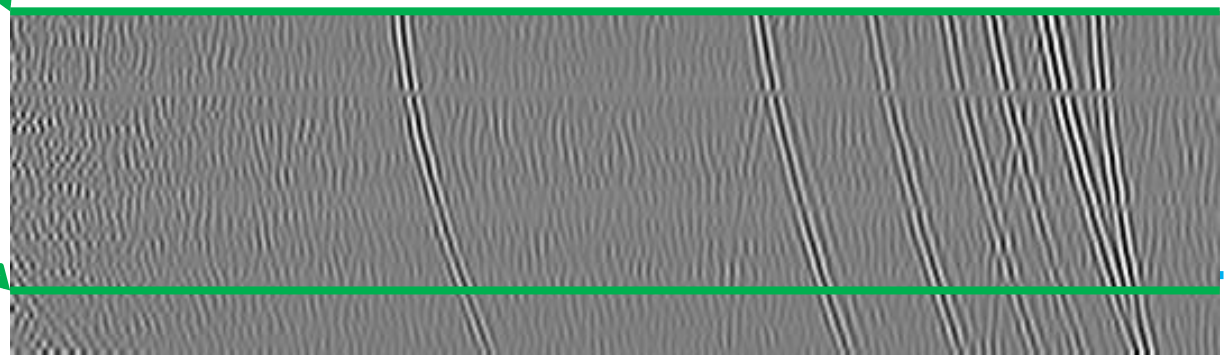


...



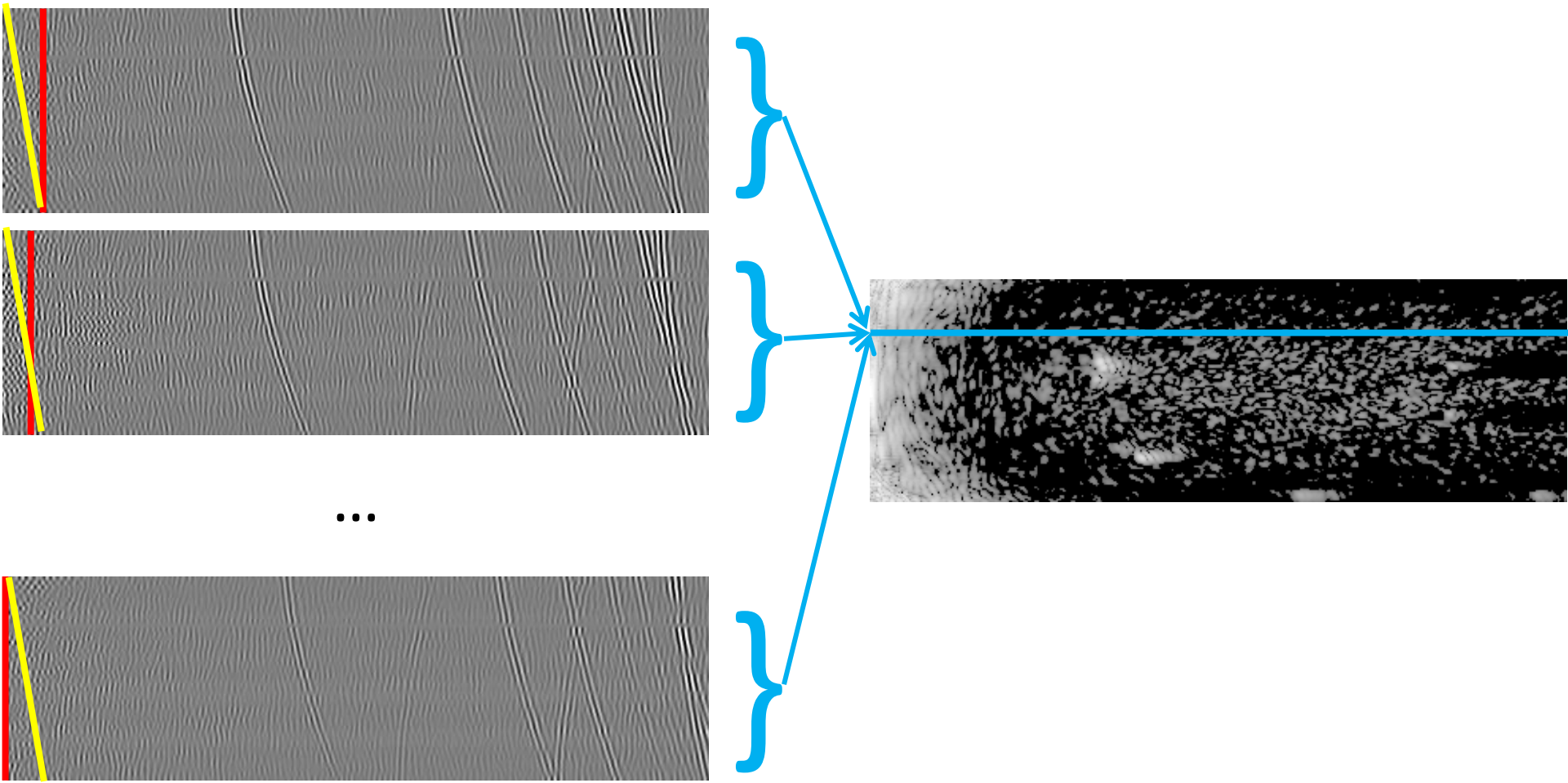
...





48 elements => 48 pixel lines

B-scan generation: alternative



Ray tracing

Direct pulse propagation: grid-characteristic method

Acoustics equations system
Maxwell's viscosity model

$$\rho(\mathbf{x})\frac{\partial \mathbf{v}(\mathbf{x},t)}{\partial t} + \nabla p(\mathbf{x},t) = 0 \qquad \text{in } \Omega,$$

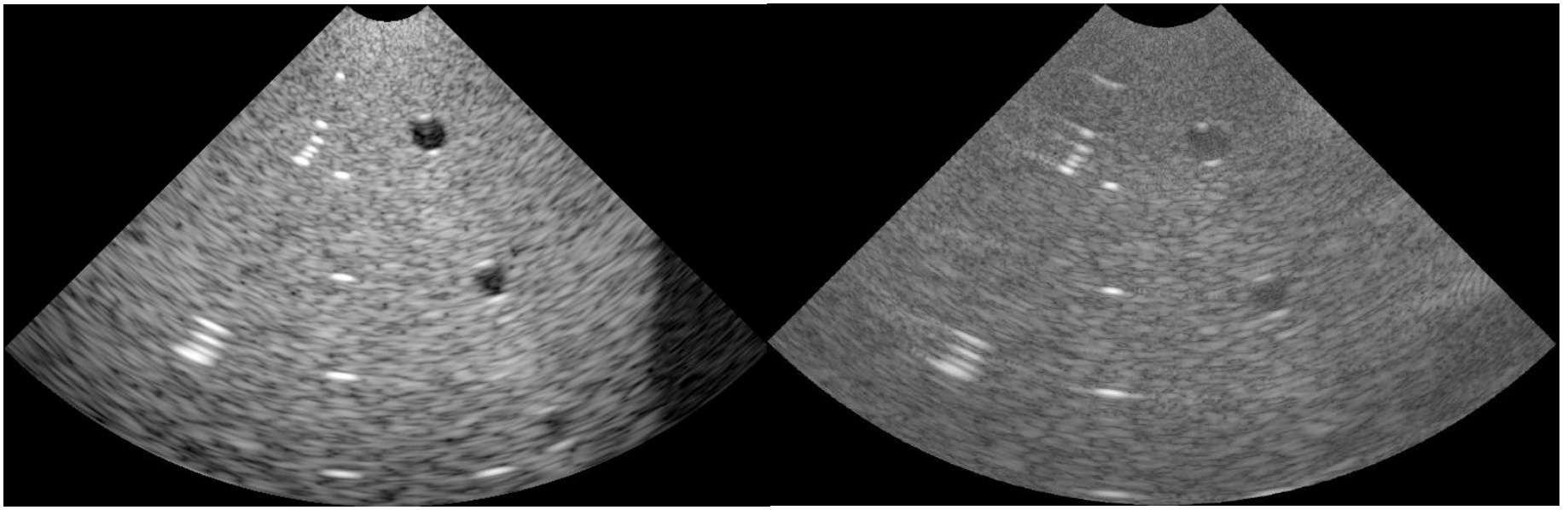
$$\frac{\partial p(\mathbf{x},t)}{\partial t} + \rho(\mathbf{x})c^2(\mathbf{x})\nabla \cdot \mathbf{v}(\mathbf{x},t) = -\alpha(\mathbf{x})c(\mathbf{x})p(\mathbf{x},t) \qquad \text{in } \Omega,$$

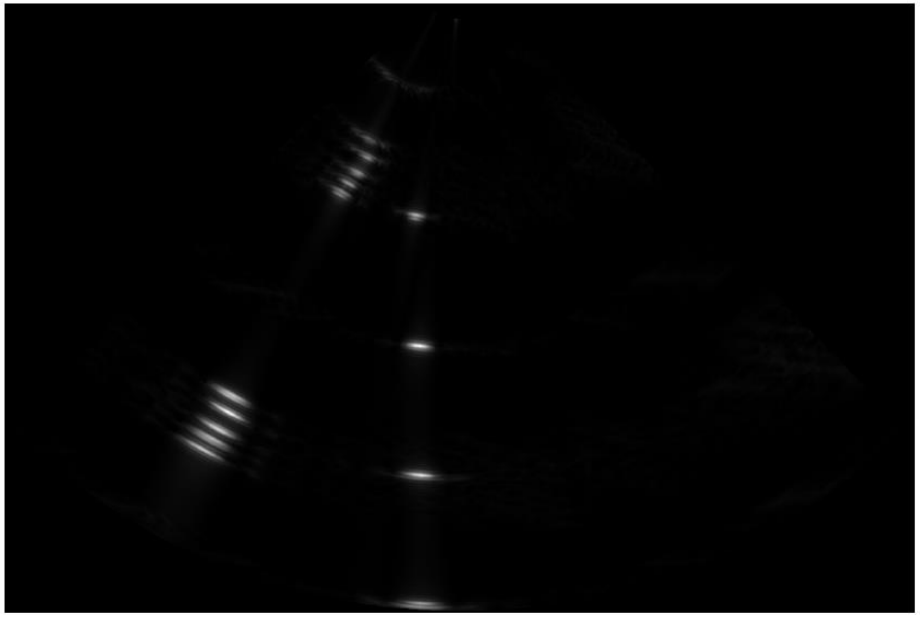
Reflected pulse propagation: ray tracing

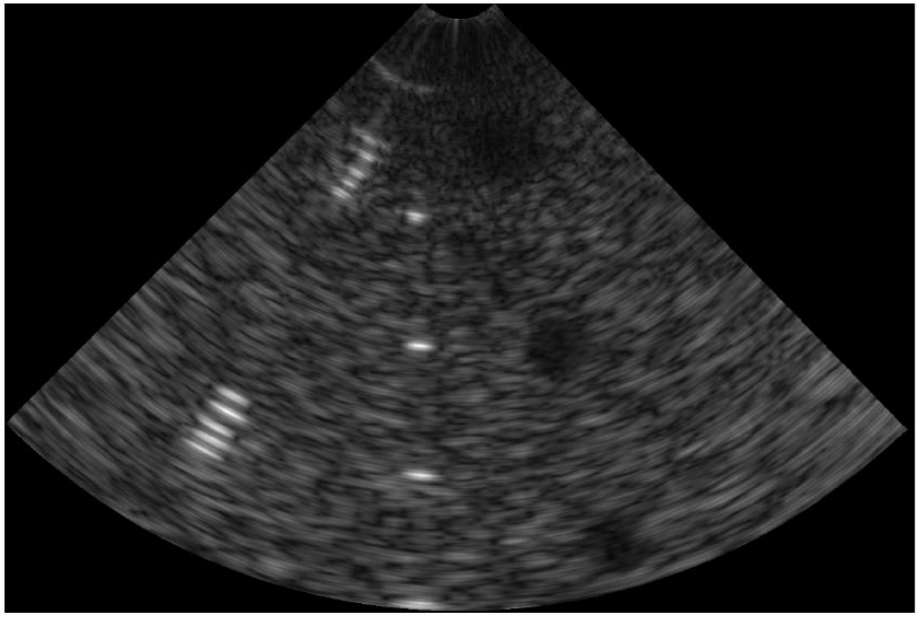
Single element signal

$$p(\mathbf{x},t) = p_0 \int_{\omega_0-\Delta\omega}^{\omega_0+\Delta\omega} \mathrm{e}^{(-\mathrm{i}(\omega t - \mathbf{k}\mathbf{x})} \mathrm{d}\omega.$$

Ray tracing: point reflectors and speckles







Conclusion

- Numerical postprocessing pipeline was implemented and verified on experimental data.
- Alternative method of B-scan generation was developed, implemented and verified on experimental data.
- Ray tracing technique was implemented to model the response from phantom nylon threads and scattered response from the phantom medium. Results were compared with experimental data.

Thank you!