SAMPLLAB Signal Acquisition Modeling Processing and Learning

SAGIVTECH

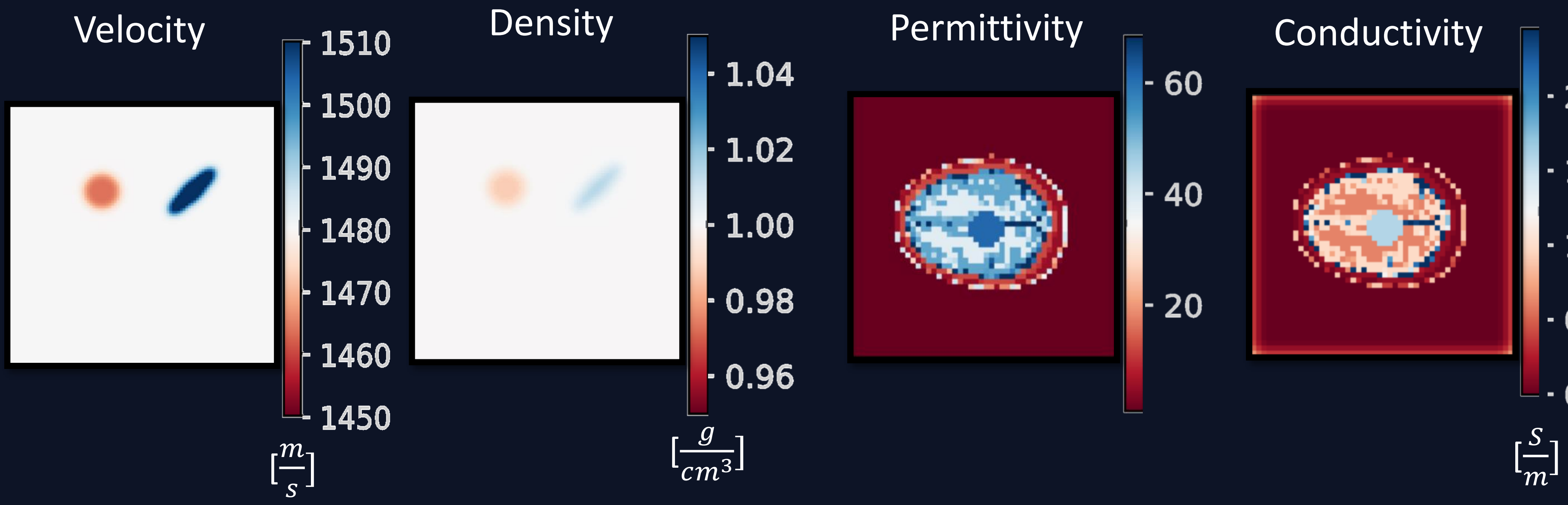
WEIZMANN INSTITUTE OF SCIENCE

IMVC 2024

Model-Based Real Time Quantitative Ultrasound and Radar

Tom Sharon, Yonina C. Eldar

Motivation


Velocity
1510
1500
1490
1480
1470
1460
1450
[m/s]
Density
1.04
1.02
1.00
0.98
0.96
[g/cm³]
Permittivity
60
40
20
Conductivity
2.0
1.5
1.0
0.5
0.0
[S/m]

Motivation

Healthy liver

Fatty liver

Fat percentage [%]

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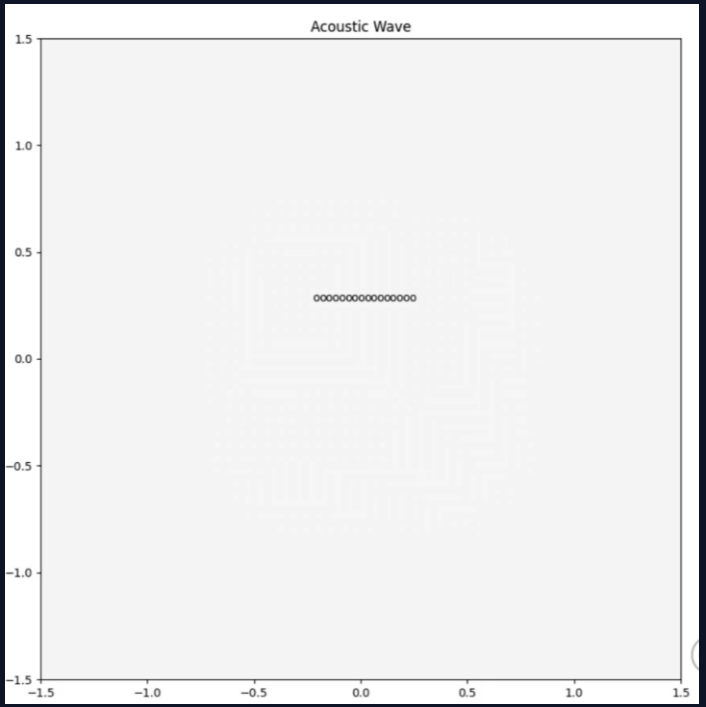
Problem statements



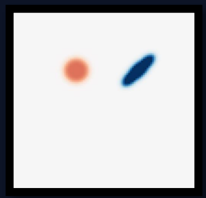
Forward Problem

US wave equation

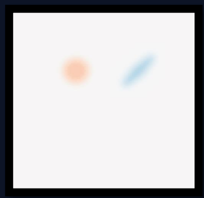
Radar wave equation

US

SoS



density

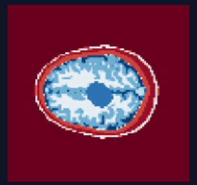


Distinguish between benign and malignant tumors

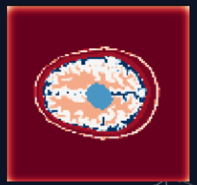
Estimate the fat % in the liver

Radar

permittivity



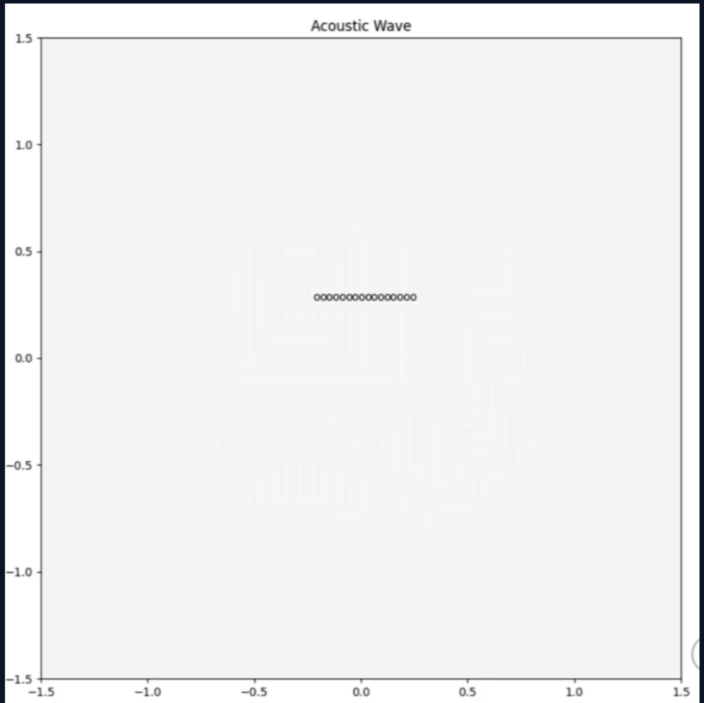
conductivity



Show different organs or properties of the human body in different contrast

Blood spreading in Hemorrhagic stroke

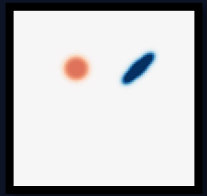
Problem statements



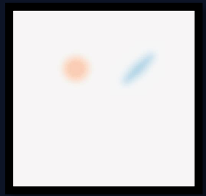
Trained network

US

SoS



density



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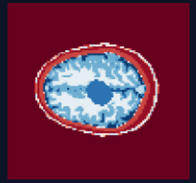
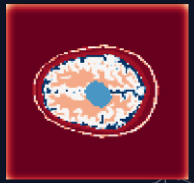


conductivity



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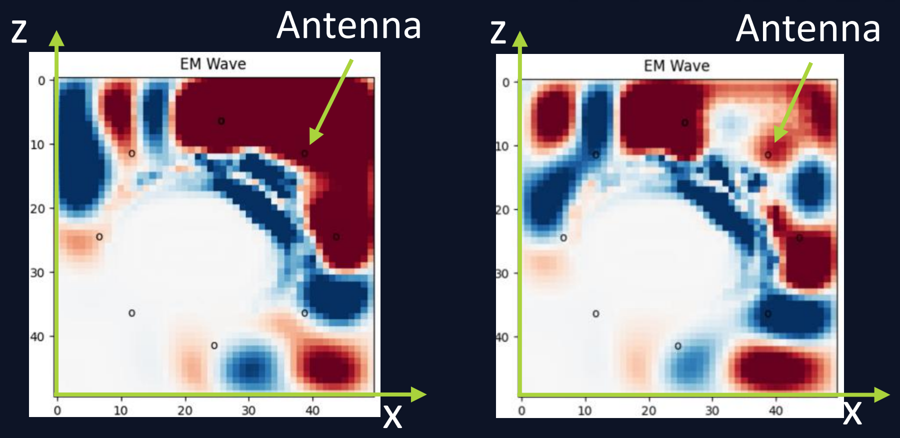
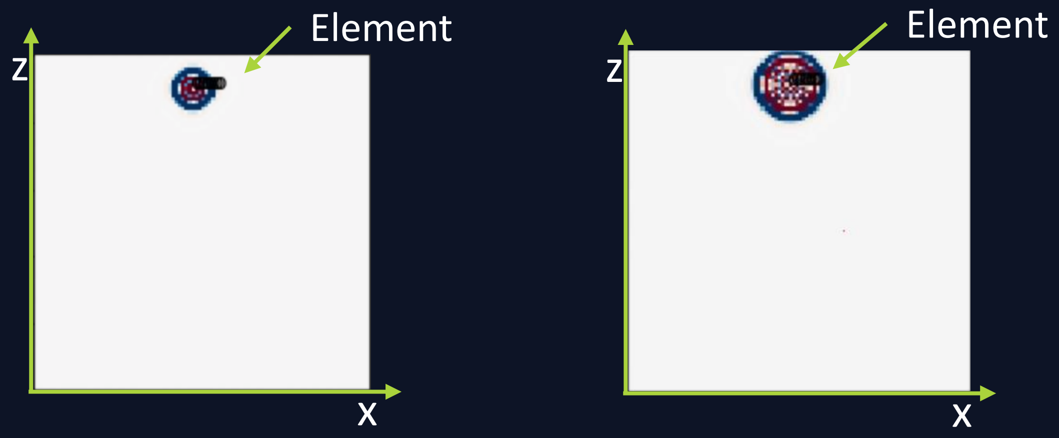
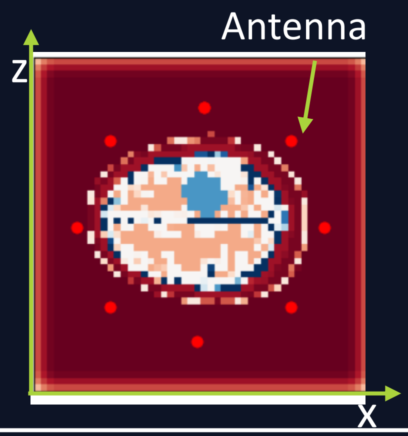
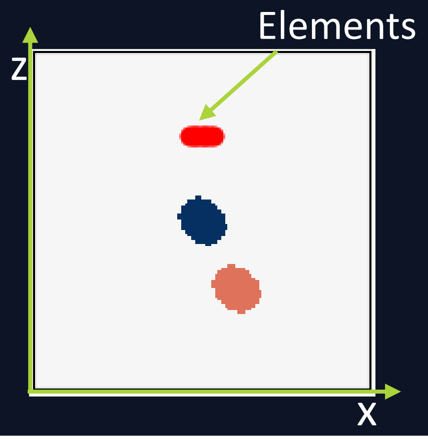






- 8 elements
- 1 transmits – the rest record



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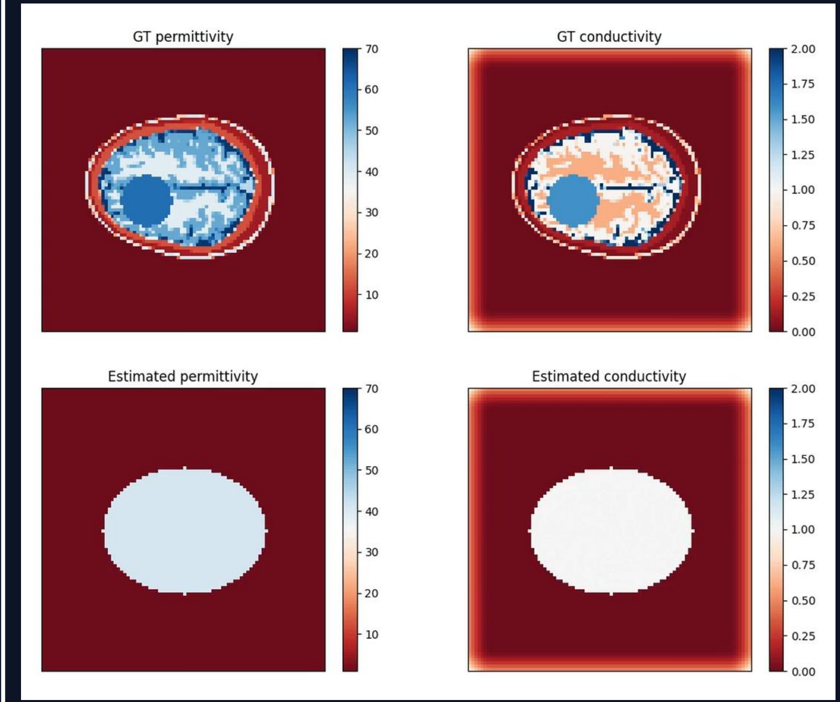
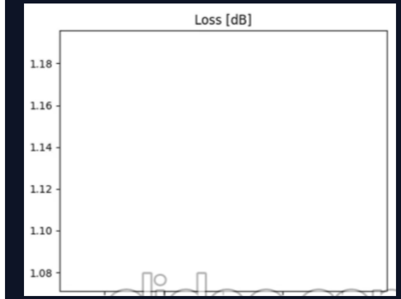
Full Waveform Inversion (FWI) algorithm

An iterative optimization method, based on GD, to achieve quantitative imaging from the signals





Advantages

- No training
- Recovers different physical properties

Disadvantages

- Time consuming
- Tends to converge to a local minima
- Initial guess should be close to true solution

Full Waveform Inversion (FWI) algorithm

An iterative optimization method, based on GD, to achieve quantitative imaging from the signals

$$L\left(\{\theta_j\}_{j=1}^{n_m}\right) = \frac{1}{2}\left\| M - F\left(\{\theta_j\}_{j=1}^{n_m}\right)\right\|_2^2$$

Predicted signals

The update of the physical property in the i+1 iteration:

$$\theta_j^{i+1} = \theta_j^i - \eta \frac{\partial L(\{\theta_j^i\}_{j=1}^{n_m})}{\partial \theta_j}$$

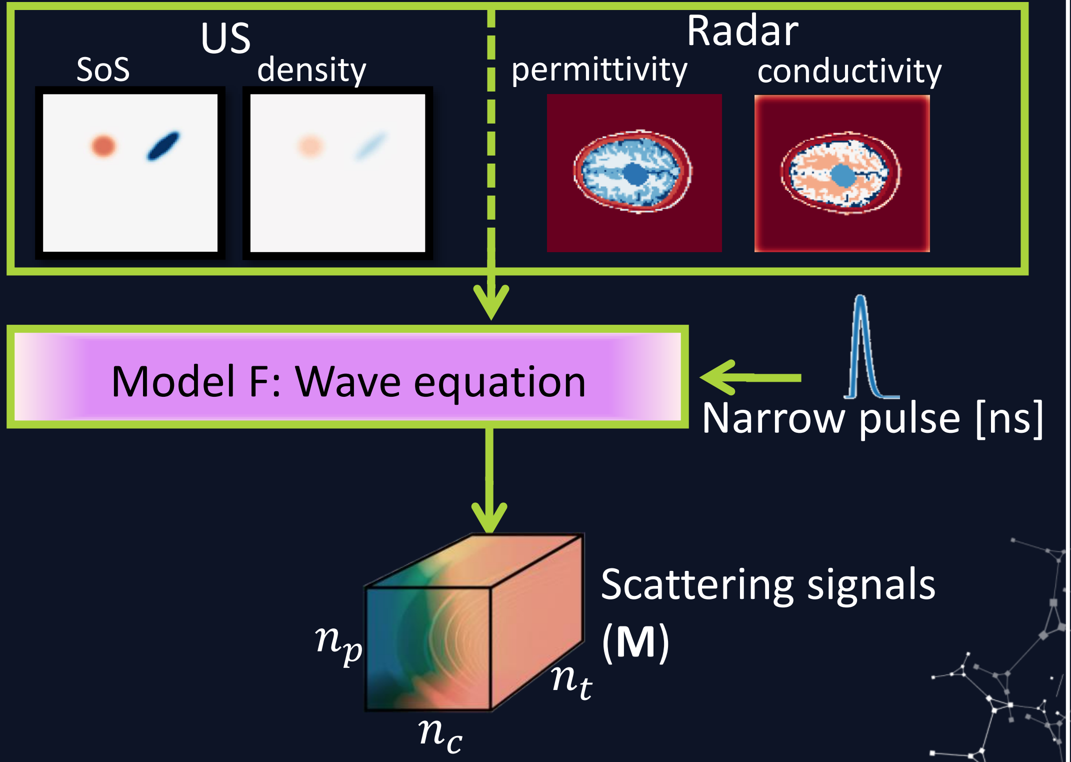
$\theta_j \in \mathbb{R}^{n_x \, X \, n_z}$ is the j'th physical property out of n_m properties
M is the measured signals
F() is the known wave propagation equation

Data creation

MNIST

Overlapping ovals

Simulated scanned medium



Model-based deep learning

Better than **pure analytical** solution

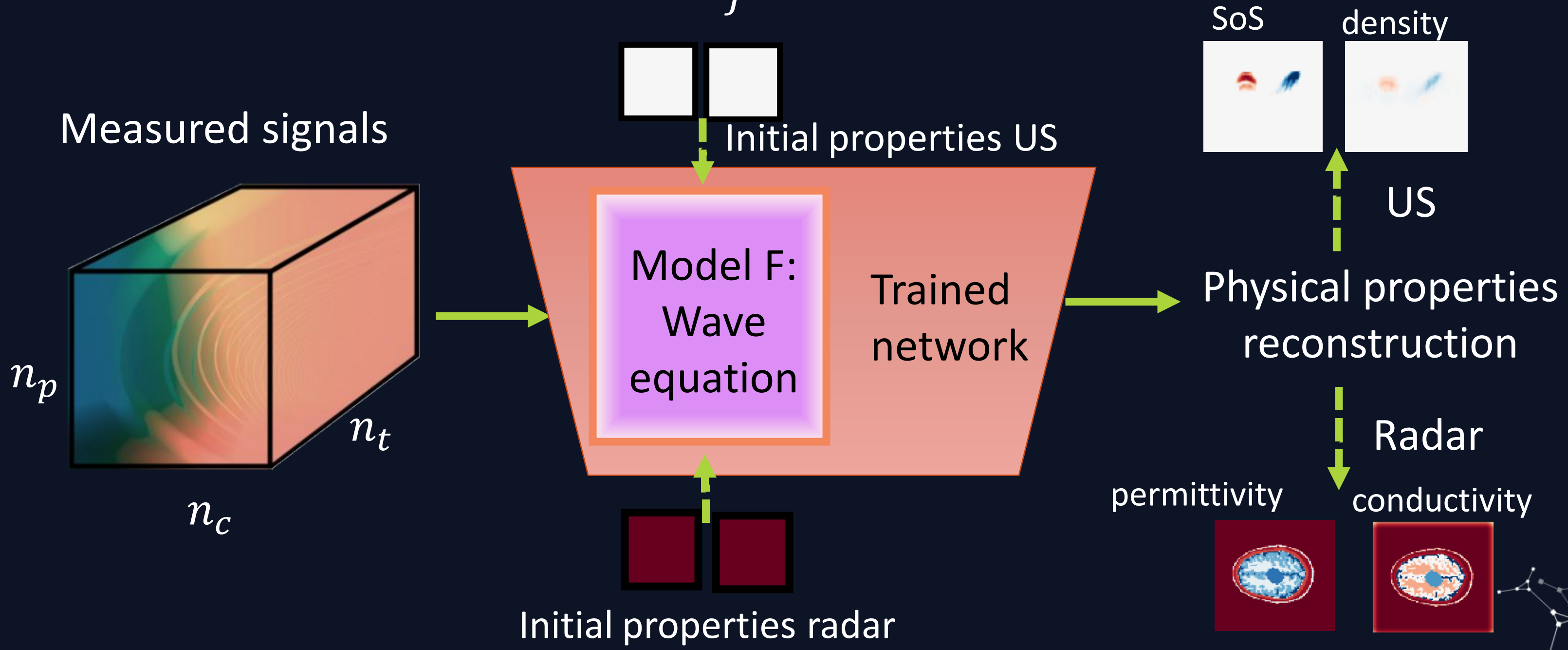
Better than **standard deep** NN

- ✓ Improved inference results
- ✓ Improved inference time

- ✓ Requires less training data
- ✓ Better generalization

Our method: MB-QRUS

- Unfolding of FWI with learned gradients (G = $\frac{\partial L}{\partial \theta_j}$) according to a U-Net based block
- Network input:
  - M
  - $\{\theta_j^0\}_{j=1}^{n_m}$
- Output:
  - $\{\theta_j^L\}_{j=1}^{n_m}$



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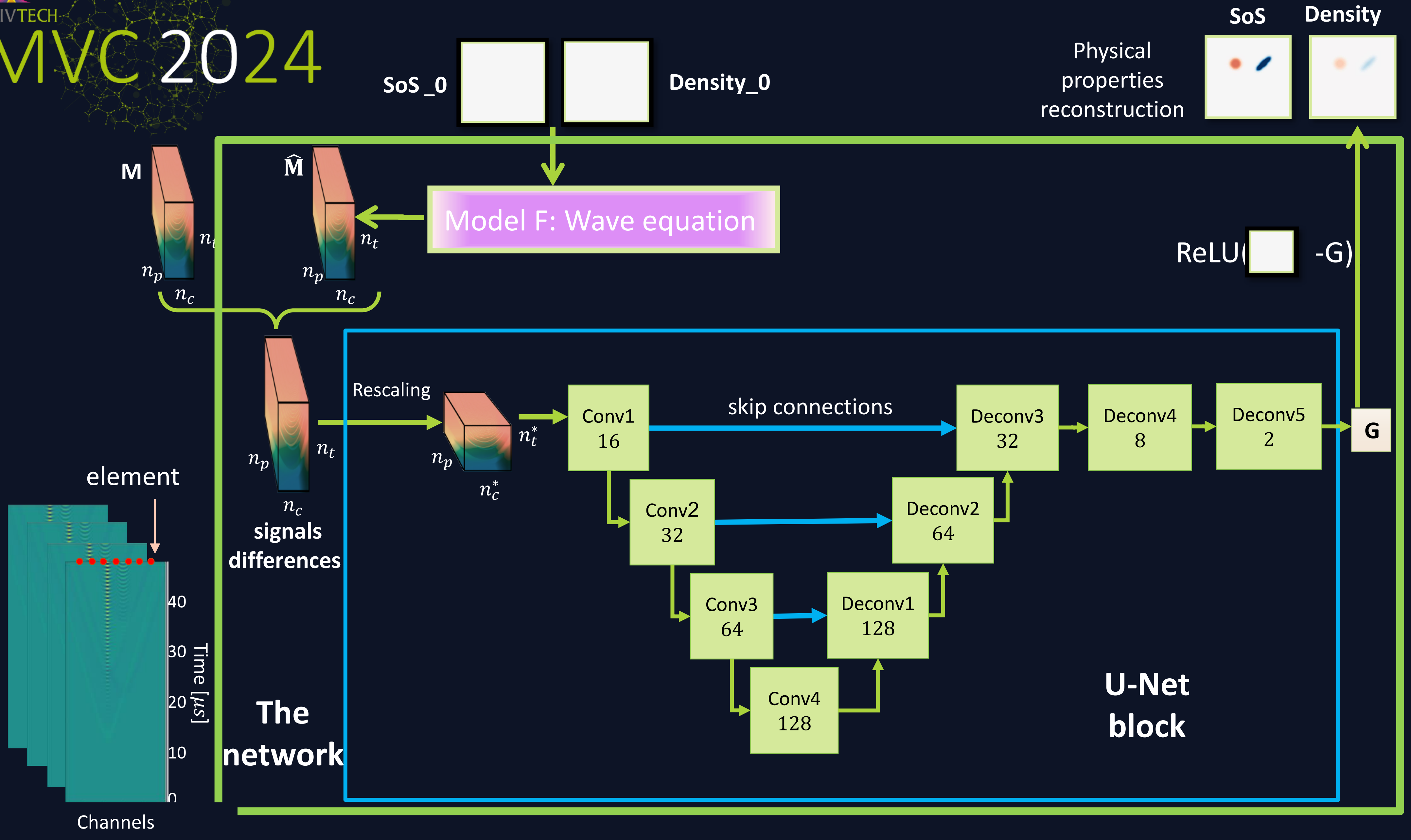

Results

$$NRMSE(\hat{\theta}) = \frac{\sqrt{\left\|\hat{\theta} - \theta_{GT}\right\|_F^2/(n_x n_z)}}{\theta_{max} - \theta_{min}}$$ ↓

$$PSNR(\hat{\theta}) = 20\log_{10}\theta_{max} - \log_{10}\left\|\hat{\theta} - \theta_{GT}\right\|_F^2$$ ↑

$$SSIM(x,y) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)}$$ ↑

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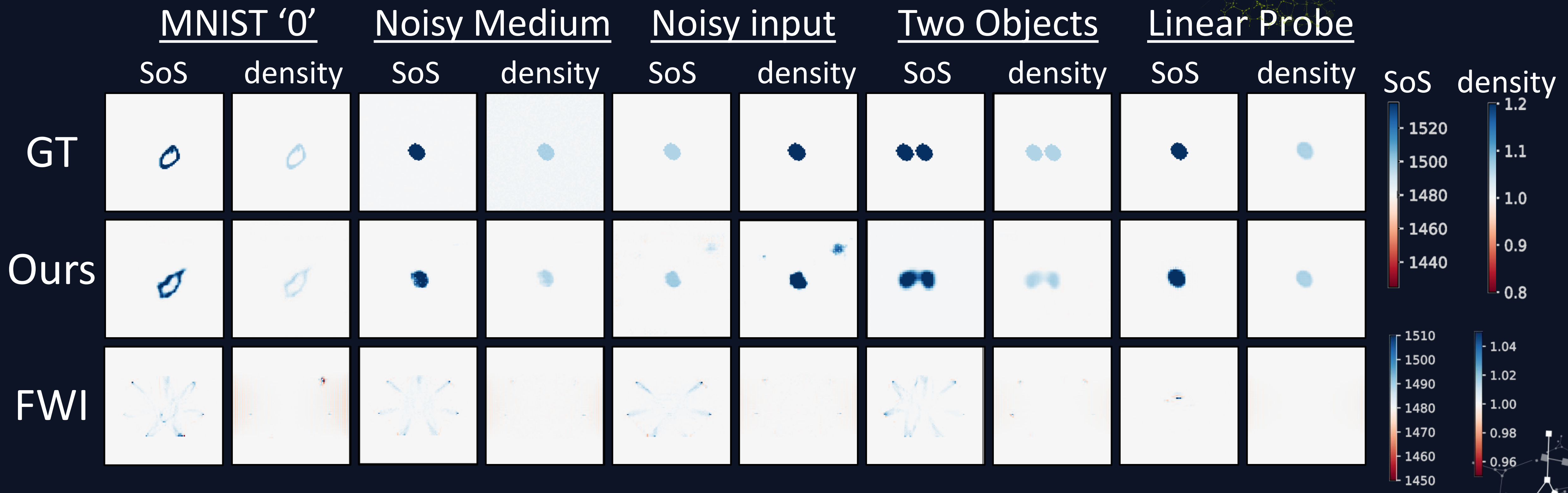
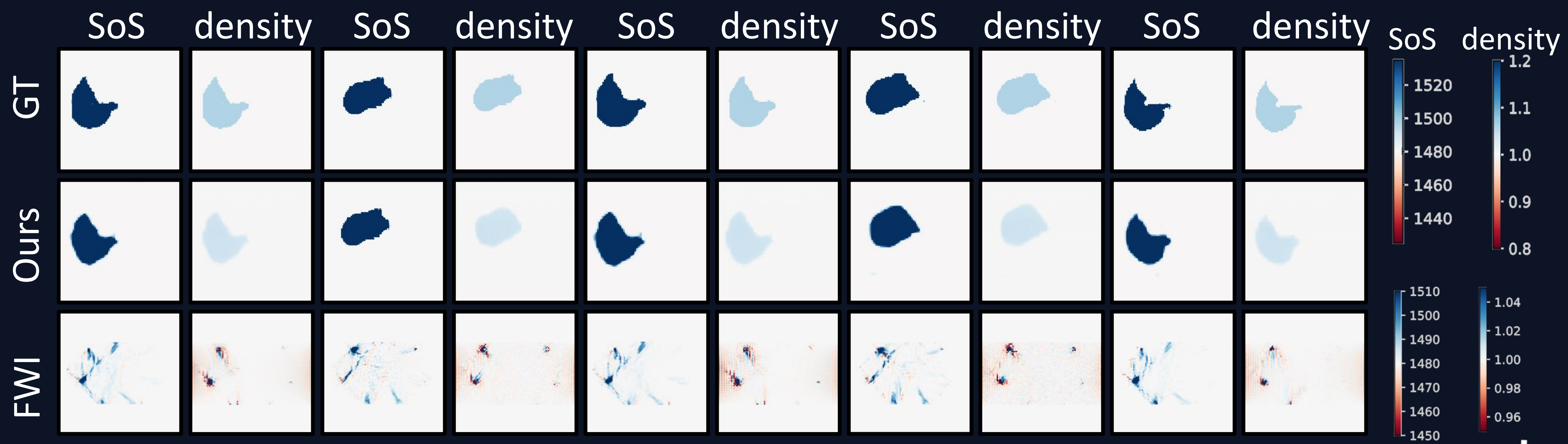


Property	NRMSE	PSNR	SSIM
SoS	-56.33%	1.93%	8.15%
density	-55.43%	13.15%	6.10%

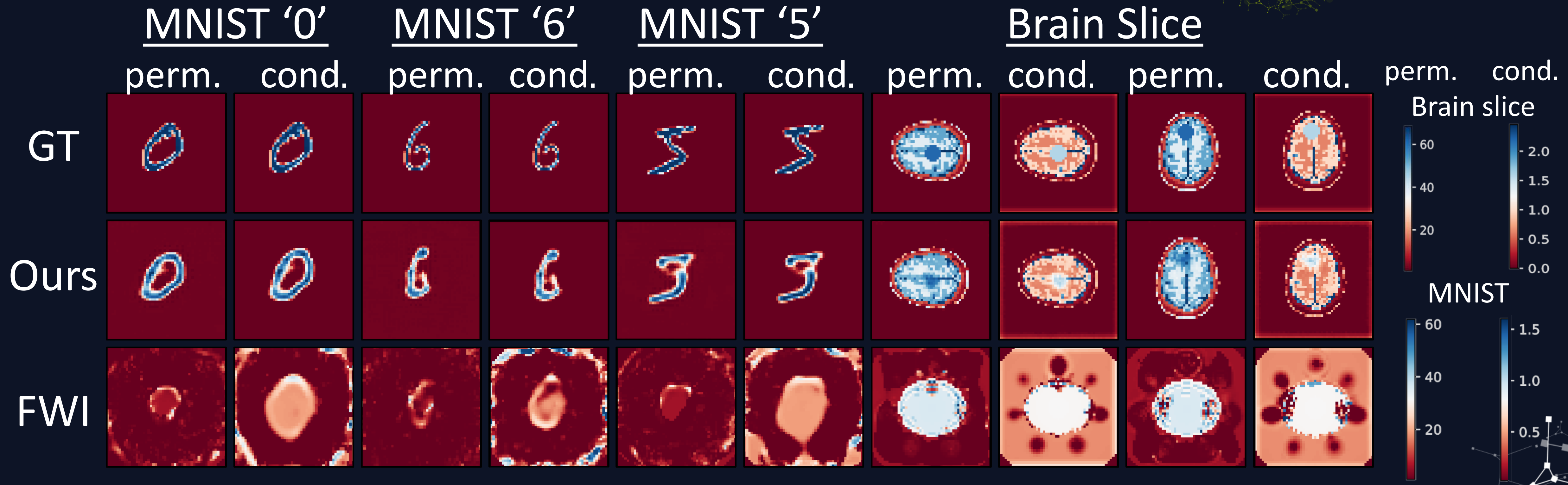
OURS	FWI
< 1 second	> 32 minutes

Realistic liver shapes



Property	NRMSE	PSNR	SSIM
SoS	-62.87%	1.7%	20.72%
density	-62.35%	53.37%	33.63%

OURS	FWI
< 1 second	> 32 minutes

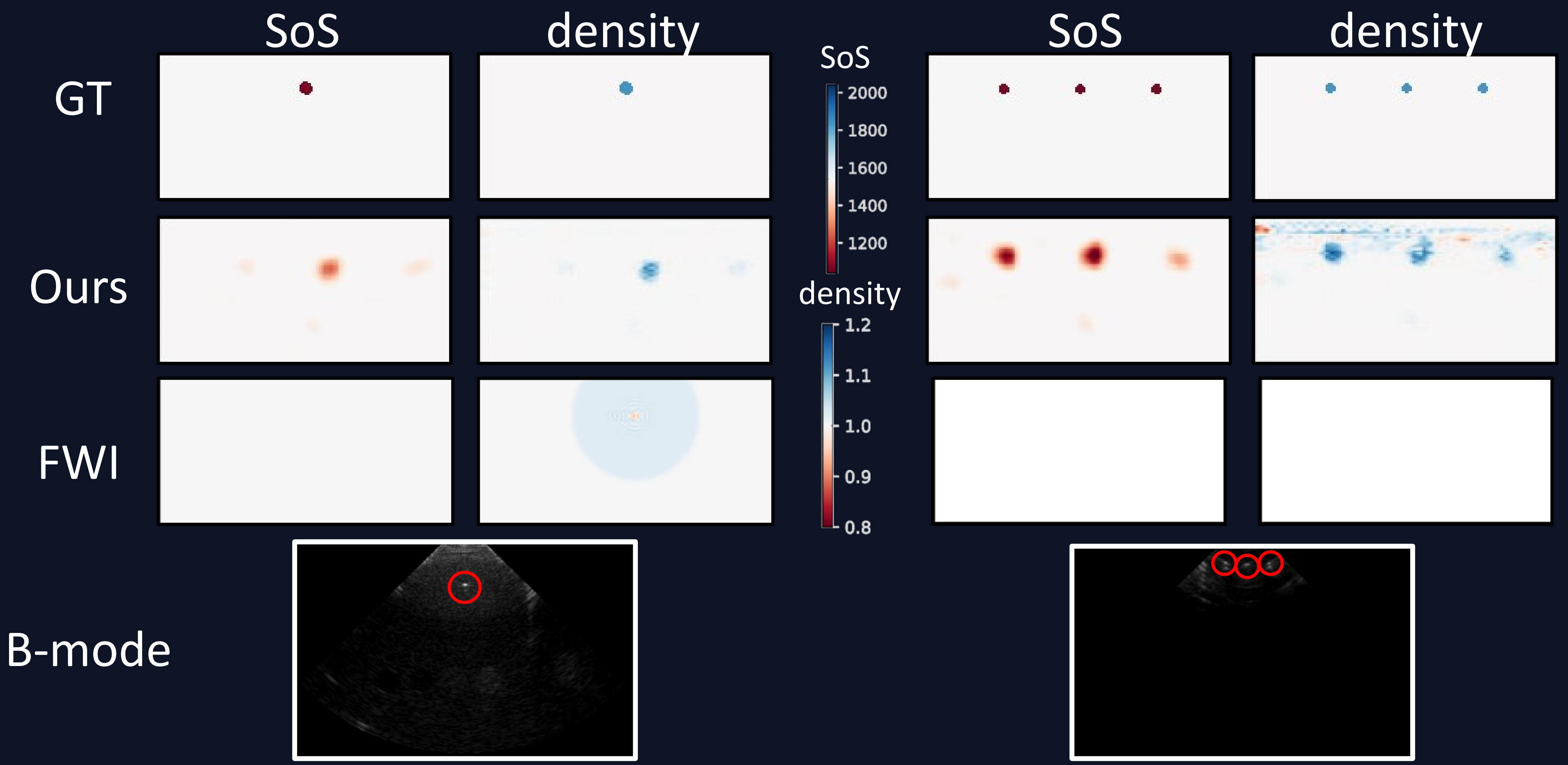


Property	NRMSE	PSNR	SSIM
conductivity	-83.53%	24.61%	1150.35%
permittivity	-79.72%	3.91%	467.33%

OURS	FWI
< 0.3 seconds	13-32 minutes

Real Data

Phantom1 Phantom2



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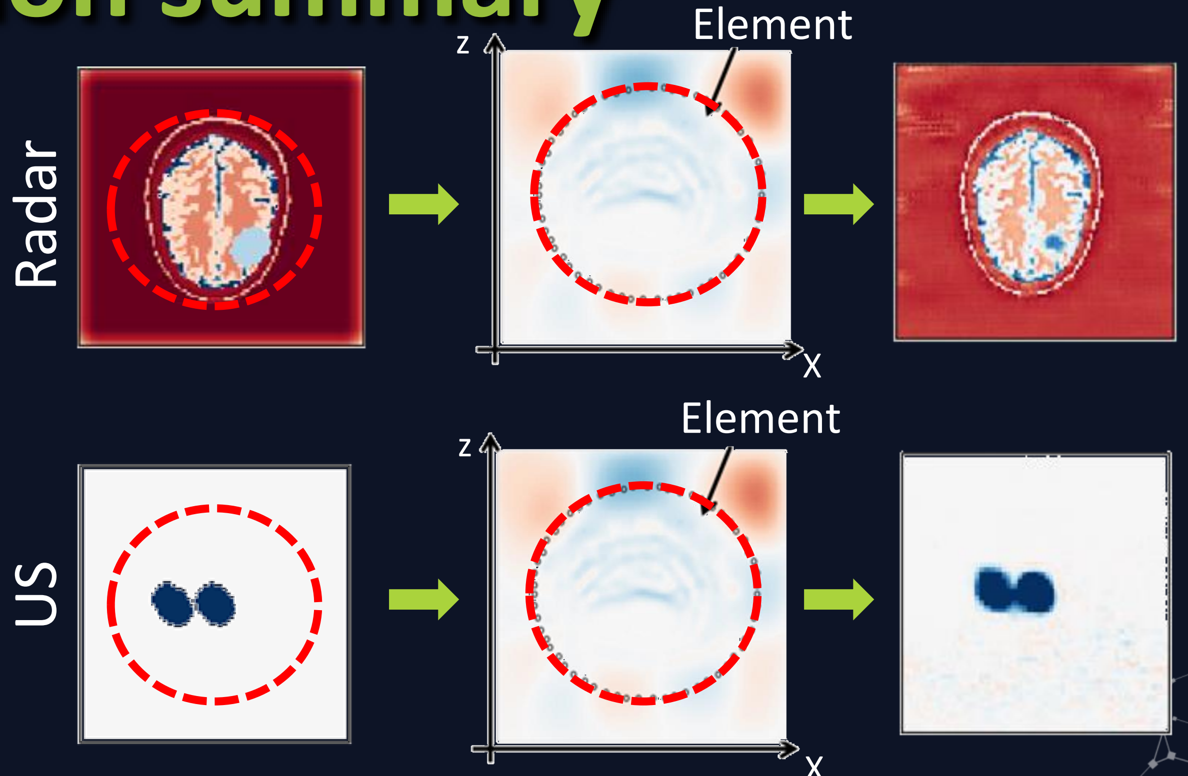
Contribution summary

- ✓ Quantitative results in real time
- ✓ Multiple physical properties reconstruction
- ✓ Works on realistic data with high accuracy results + real recorded data
- ✓ Using data from only 8 elements
- ✓ Suitable for diverse transmission setups including linear probe
- ✓ Reconstruction from either radar or US signals



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