

# Equitable Medical Imaging

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Department of Biomedical Engineering

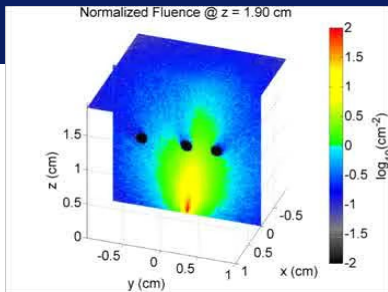
Department of Computer Science

Department of Oncology



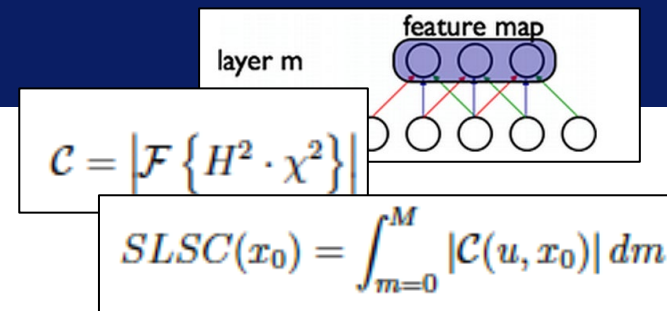


# PULSE Lab Overview



Theory,  
Modeling,  
and  
Simulations

Design  
Beamformers  
and Imaging  
Probes



Photoacoustic (PA)  $\rightleftharpoons$  Ultrasound (US)

Improve  
PA & US

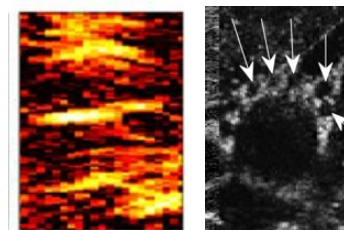
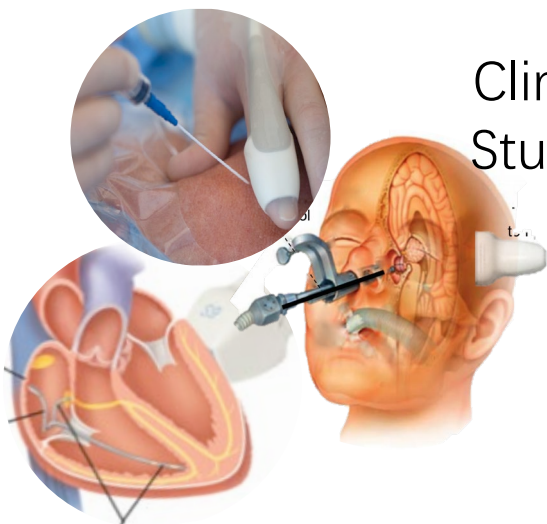


Image Quality

Build and Test  
Prototypes

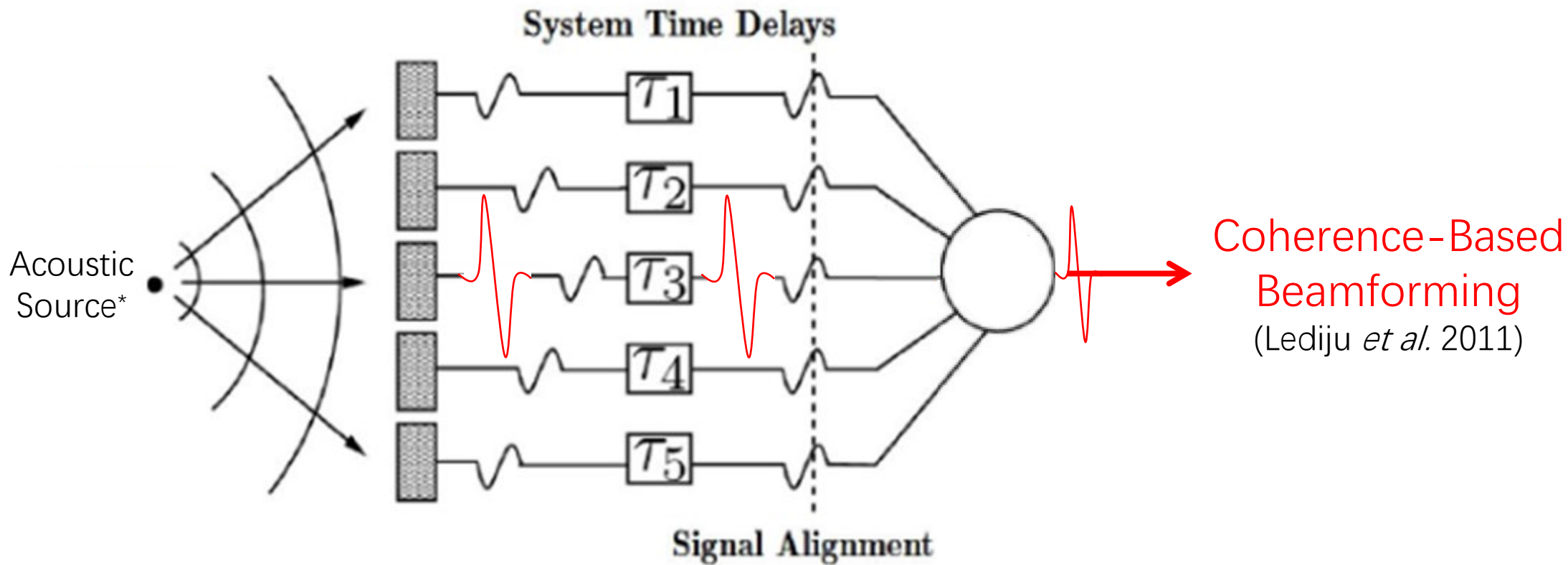
System  
Integration

Clinical  
Studies





# Beamforming



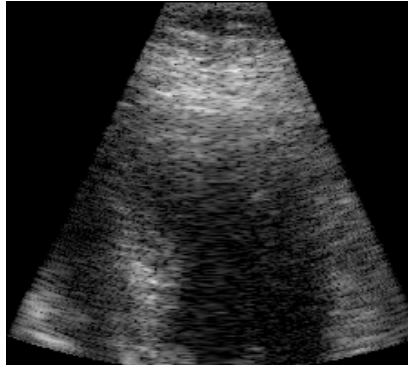
\*generated from light (PA) or sound (US) transmission



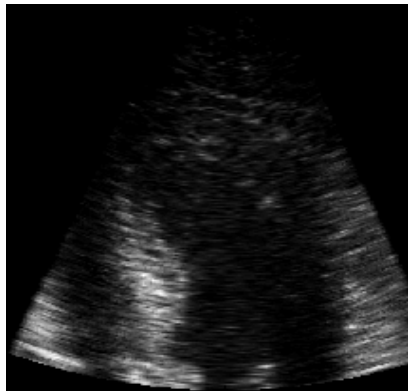
# Improvements with Coherence-Based Beamforming

## Cardiac Images

Amplitude



Coherence



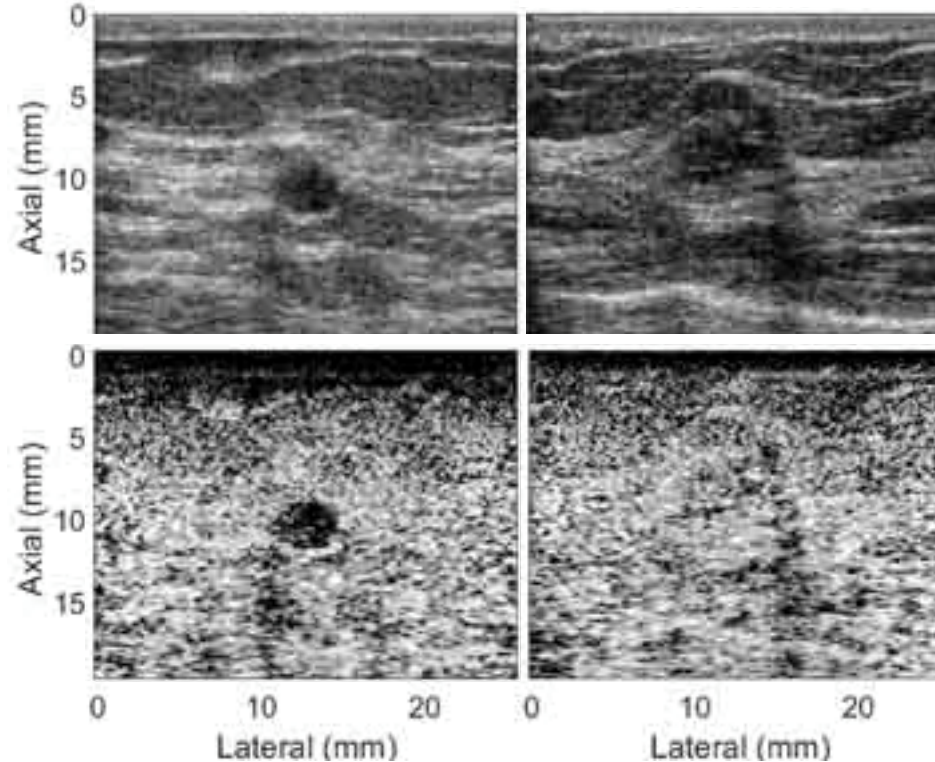
Bell *et al.* 2012

→ Improved image quality in **overweight and obese** patients

## Breast Masses

fluid

solid



Wiacek *et al.*, 2020

Wiacek *et al.*, 2023

Sharma *et al.*, 2024

→ Reduced number of fluid breast masses recommended for biopsy from 43.3% to 13.3%  
→ Promising for **women with dense breast tissue**





# Coherence-Based Photoacoustic Imaging

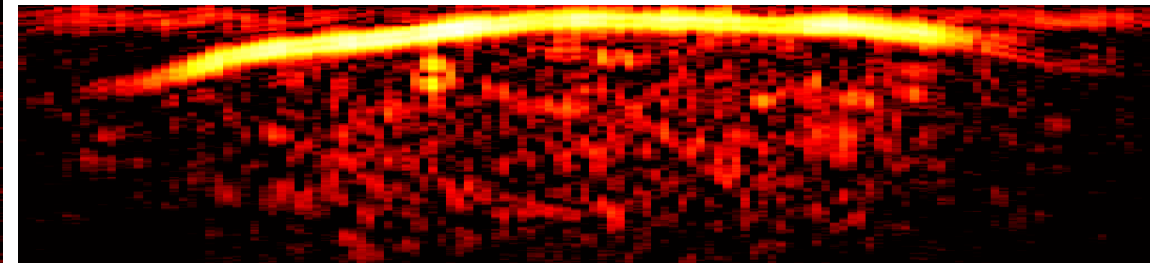
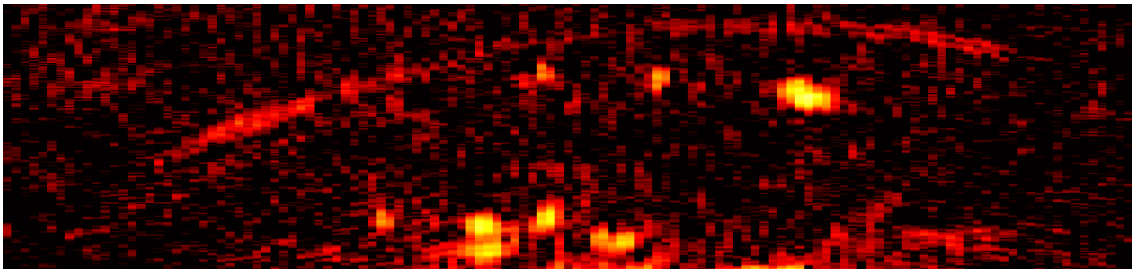
- Optical penetration depths limited by melanin absorbers, which cause acoustic clutter
- Leads to inherent skin tone bias with amplitude-based techniques
- Coherence-based beamforming will reduce clutter in **patients with darker skin tones**



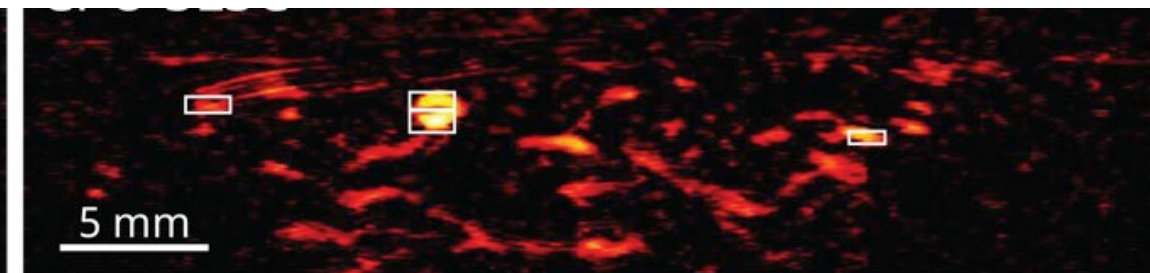
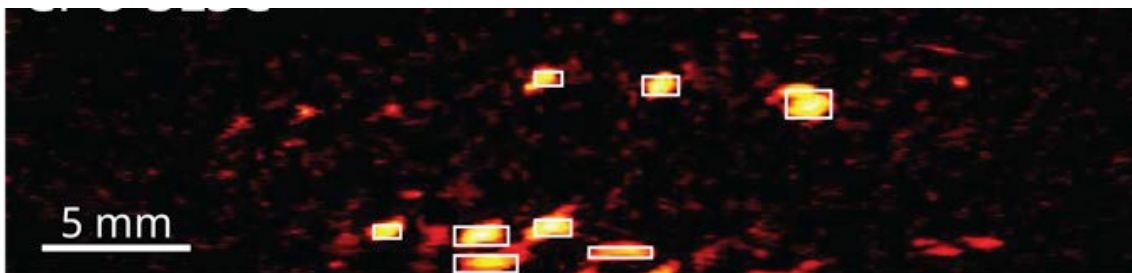
Intermediate Skin Tone

Dark Skin Tone

Amplitude



Coherence



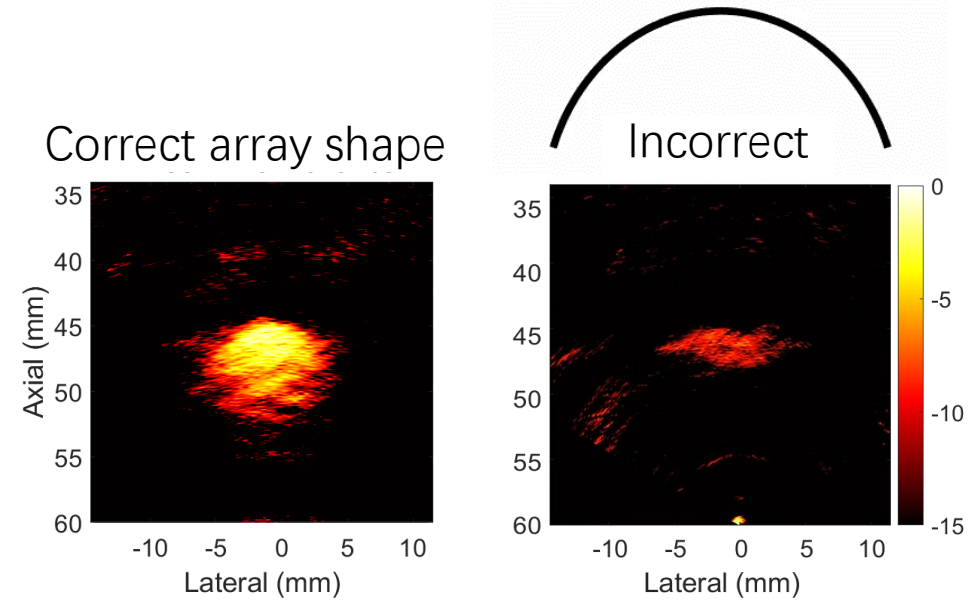
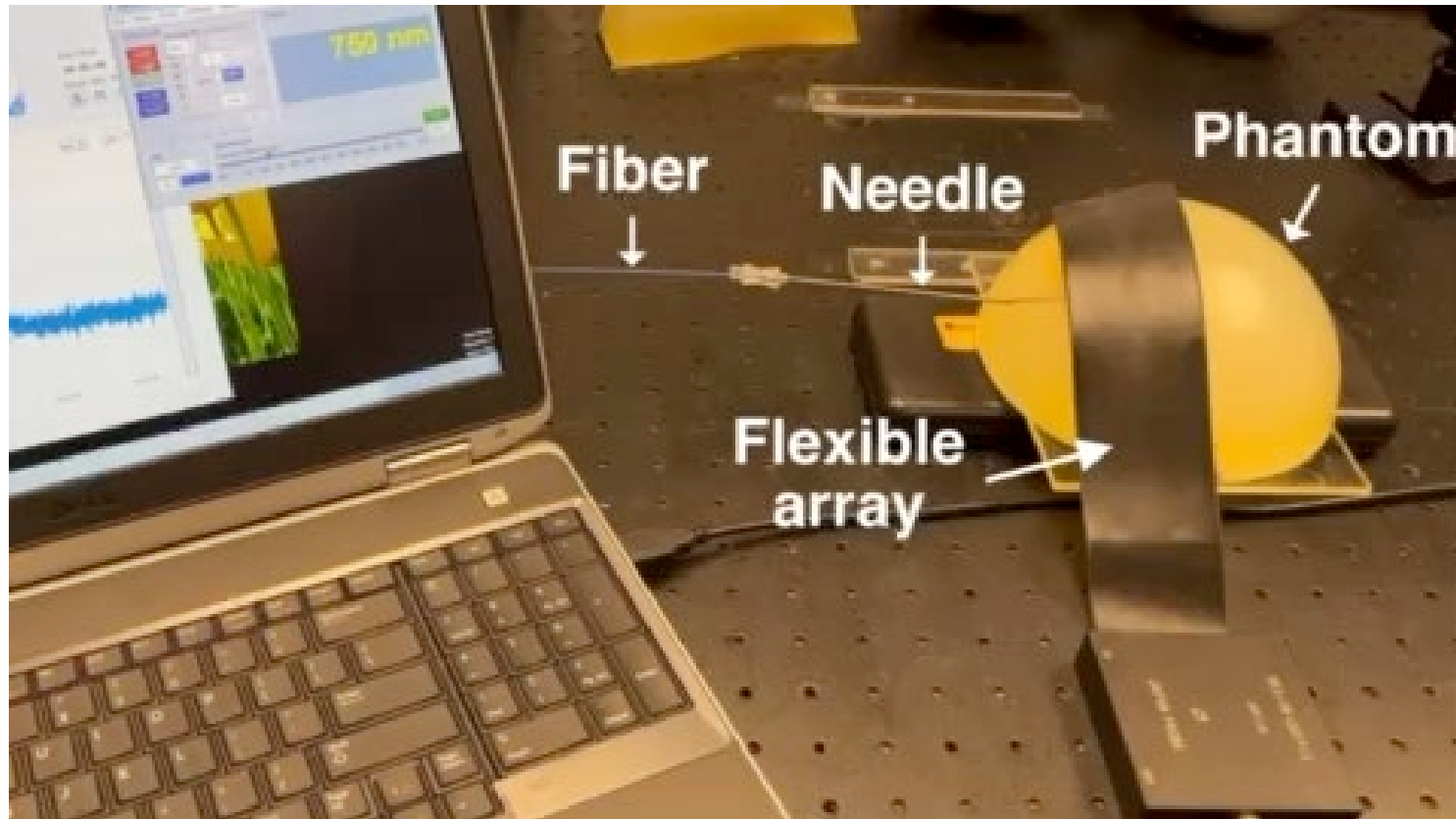
Fernandes *et al.*, *Photoacoustics*, 2023

Featured on 



# Flexible Array for Photoacoustic Guided Surgery

✓ Conforms to **different body shapes**    ✗ Unknown array shape



Bell, *Journal of Applied Physics*, 2020  
Zhang *et al.* *Biomedical Optics Express*, 2023  
Zhang *et al.* *SPIE Photonics West*, 2024



# Summary

- Single signal processing technique enables more equitable medical imaging
- Diversity drives innovation
  - Datasets (e.g., overweight and obese, dense breasts, dark skin tones)
  - Personnel (e.g., 9 current PhD students: 1 BME, 7 ECE, 1 CS)
  - Background (e.g., MechE, BME, CS, Physics, ECE, Oncology)
- Ignore traditional disciplinary silos when innovating new ideas, yet introduce boundaries when grant writing, publishing, etc.



# Acknowledgements

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• **Graduate Students:**

- Alycen Wiacek
- Jiaxin Zhang
- Eduardo González
- Arun Nair
- Michelle Graham
- Mardava Gubbi
- Ole Marius Hoel Rindal
- Guilherme Fernandes
- Ziwei Feng
- Nethra Venkatayogi
- Mahban Golijafari
- Junior Arroyo
- Junhao Zhang

• **Undergraduate Students:**

- Khaijat Kokumo
- Brooke Stephanian
- José Tmaná
- Rhea Rasquina

• **Postdocs:**

- Arunima Sharma
- Md Ashikuzzaman

• **Collaborators:**

- Susan Harvey, MD
- Kelly Fabrega-Foster, MD
- Eniola Falomo, MD
- Kelly Myers, MD
- Emily Ambinder, MD
- Lisa Mullen, MD
- Kai Ding, PhD
- Tiffany Fong, MD
- Theo Pavan, PhD
- Trac D. Tran, PhD



NIH Trailblazer Award  
NIH K99/R00 EB018994  
NIH R01 EB032960  
NIH R01 EB032358



NSF CAREER Award  
ECCS 1751522  
NSF EEC 1852155  
NSF IIS 2014088



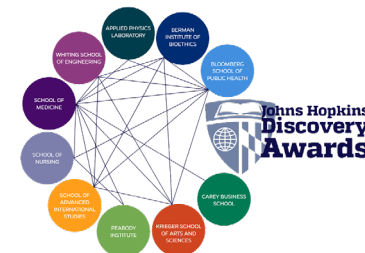
**NVIDIA**



IEEE ULTRASONICS, FERROELECTRICS  
AND FREQUENCY CONTROL SOCIETY



Junior Faculty  
Enhancement  
Award



JHU Discovery Award  
JHU Catalyst Award



**SPIE.**





# Flexible Array Technology for PA-Guided Surgery

✓ **Conforms** to different surfaces

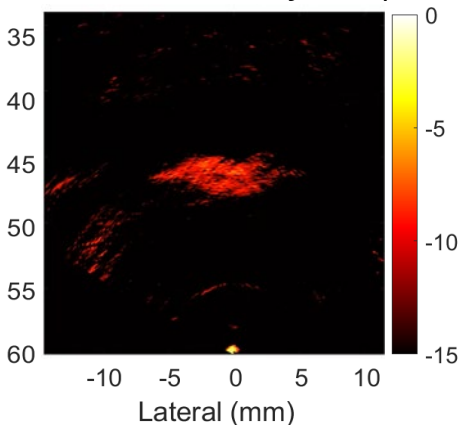
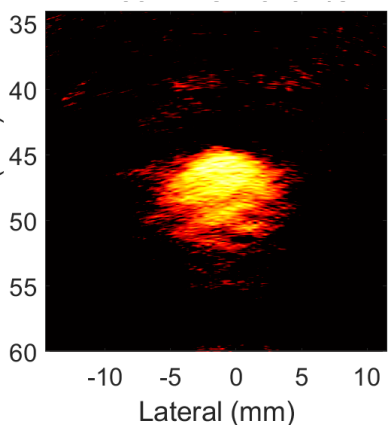
✗ Unknown **array shape**

✗ Unknown **sound speed**

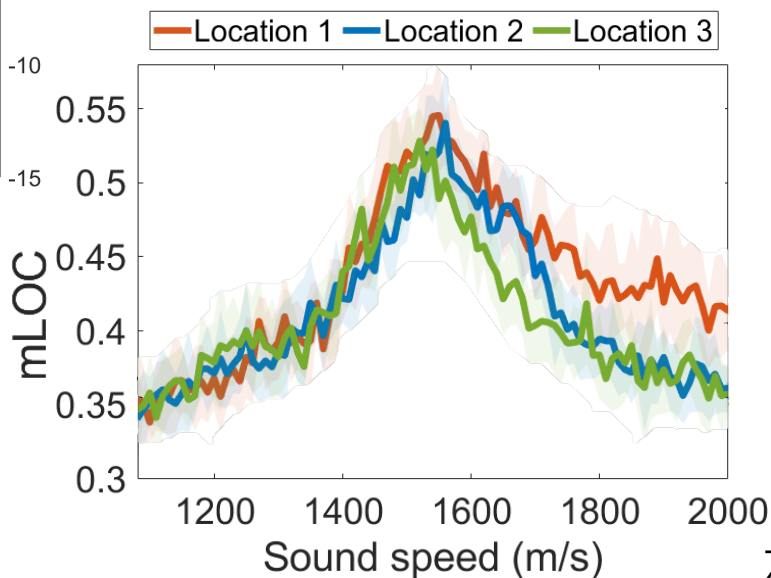
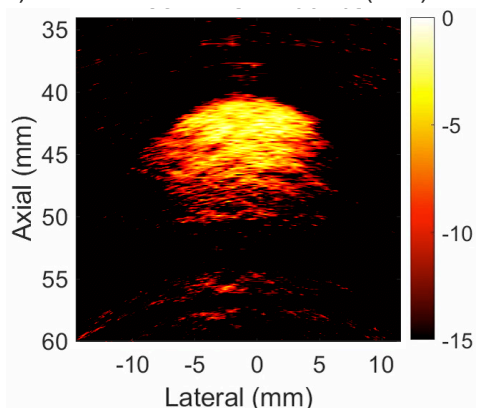
**mLOC** = maximum lag-one coherence within a region of interest surrounding photoacoustic target

Correct array shape

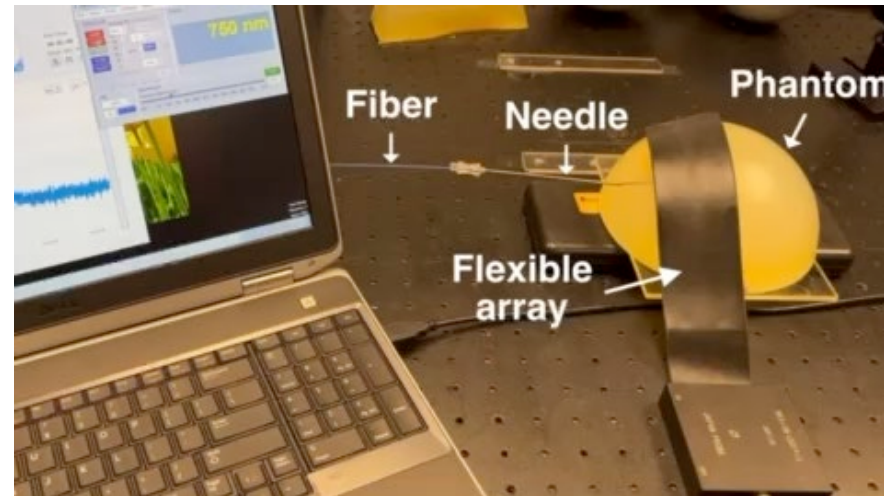
Incorrect array shape



Sound speed  
1400 m/s



**Accuracy range: 97-100%**

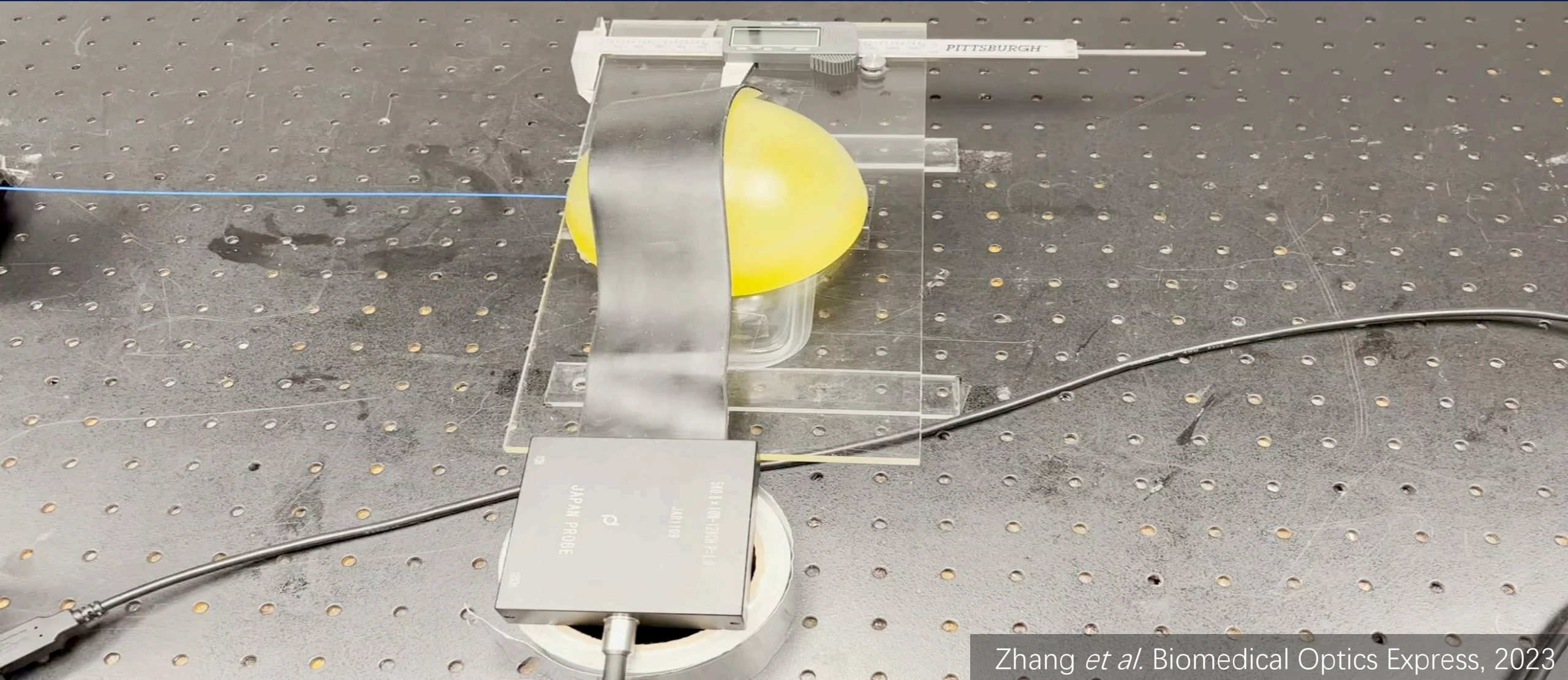


Zhang *et al.* Biomedical Optics Express, 2023  
Zhang *et al.* SPIE Photonics West, 2024





# Flexible Array Technology for PA-Guided Surgery



Zhang *et al.* Biomedical Optics Express, 2023





# Detection of Mass Contents in Dense Breasts

Difficult to distinguish fluid masses (benign) from solid masses (benign or malignant) with **DAS beamforming**

- High false positive rates
- Biopsies, aspiration, follow-up
- Patient anxiety

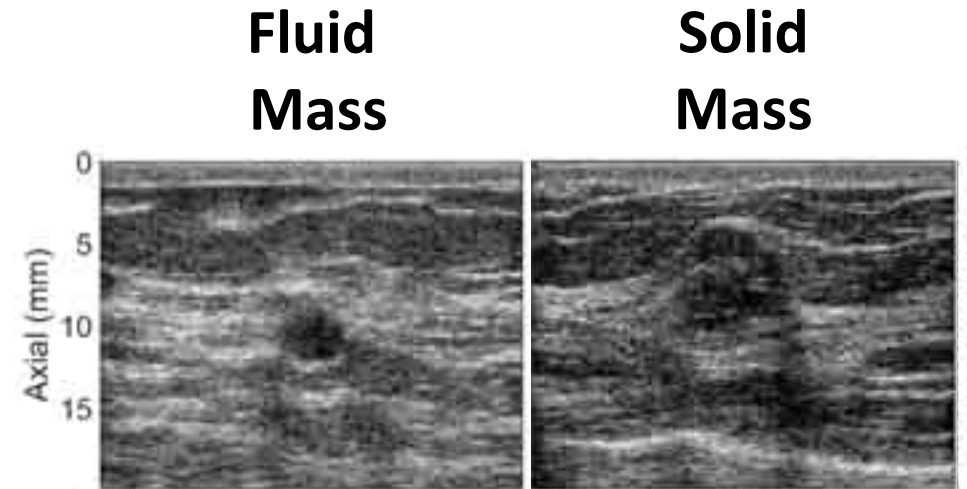
Promising Solution: **Coherence-Based Beamforming**

- Reduced number of fluid masses recommended for biopsy from 43.3% to 13.3%
- Related LOC metric promising for dense breast tissue

Wiacek *et al.*, *Ultrasound in Medicine & Biology*, 2020

Wiacek *et al.*, *Ultrasound in Medicine & Biology*, 2023

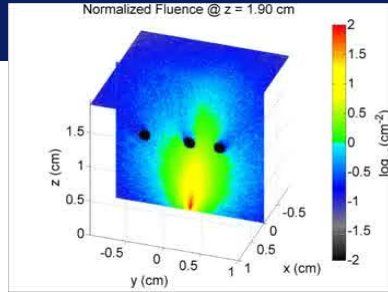
Sharma *et al.*, *IEEE TUFFC*, 2024



(funded by NIH R01 EB032960)

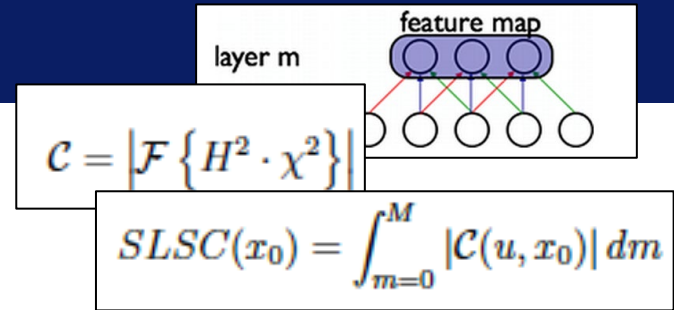


# PULSE Lab Overview

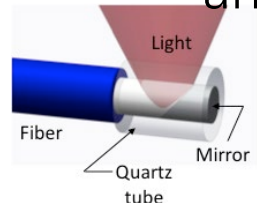


Theory, Modeling, and Simulations

Design Beamformers and Imaging Probes



Photoacoustic (PA)  $\rightleftharpoons$  Ultrasound (US)



Improve PA & US

Build and Test Prototypes

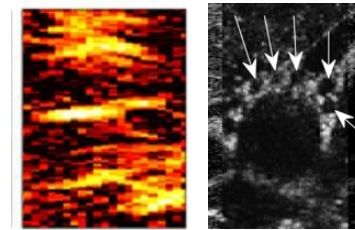


Image Quality

Clinical Studies



System Integration







# Acknowledgements

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Summer 2022



Summer 2023

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NIH Trailblazer Award  
NIH K99/R00 EB018994  
NIH R01 EB032960  
NIH R01 EB032358



NSF CAREER Award  
ECCS 1751522  
NSF EEC 1852155  
NSF IIS 2014088



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AND FREQUENCY CONTROL SOCIETY



Junior Faculty  
Enhancement  
Award



JHU Discovery Award  
JHU Catalyst Award



**SPIE.**

Cutting Edge Surgical, Inc.





# Improved Image Quality in Overweight & Obese Patients

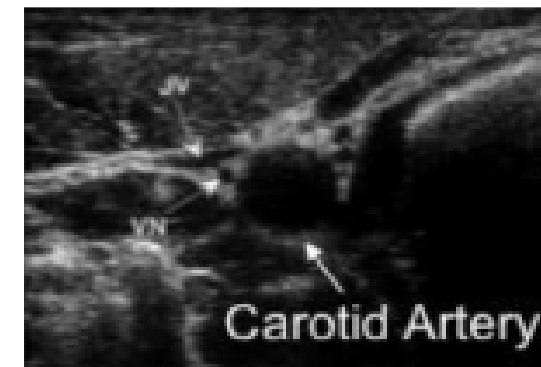
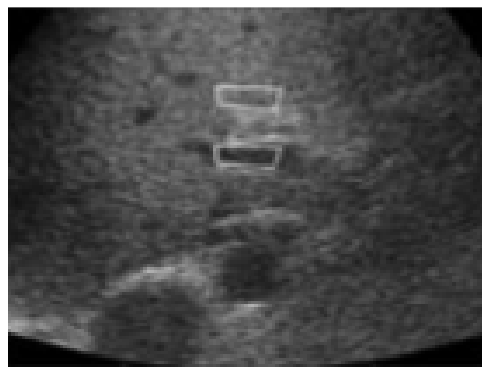
heart

liver

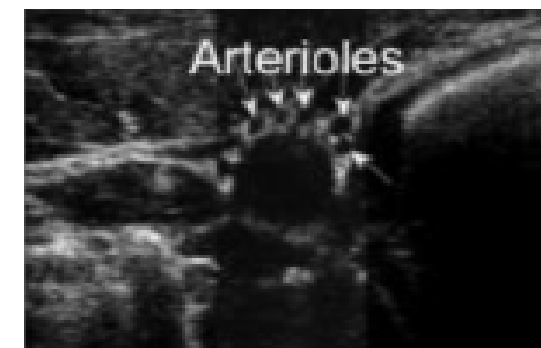
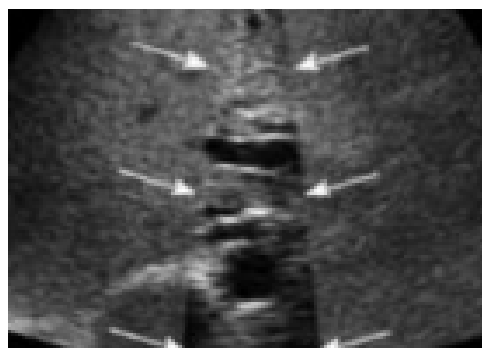
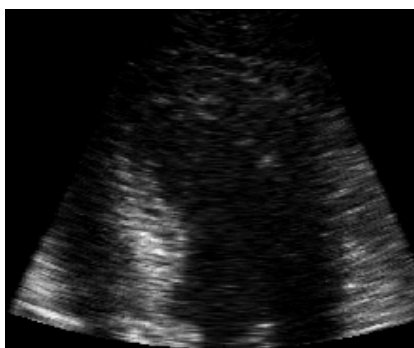
fetus

vessels

Amplitude  
(Delay & Sum)



Coherence  
(SLSC\*)



Bell *et al.* 2012

Jakovljevic *et al.* 2013

Kakkad *et al.* 2015

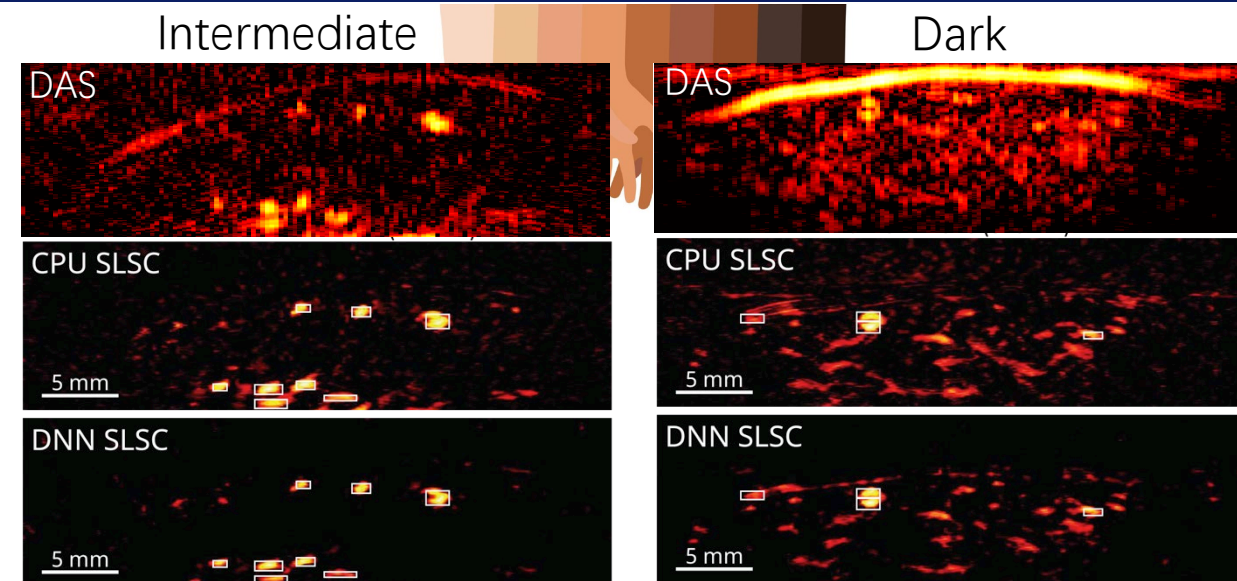
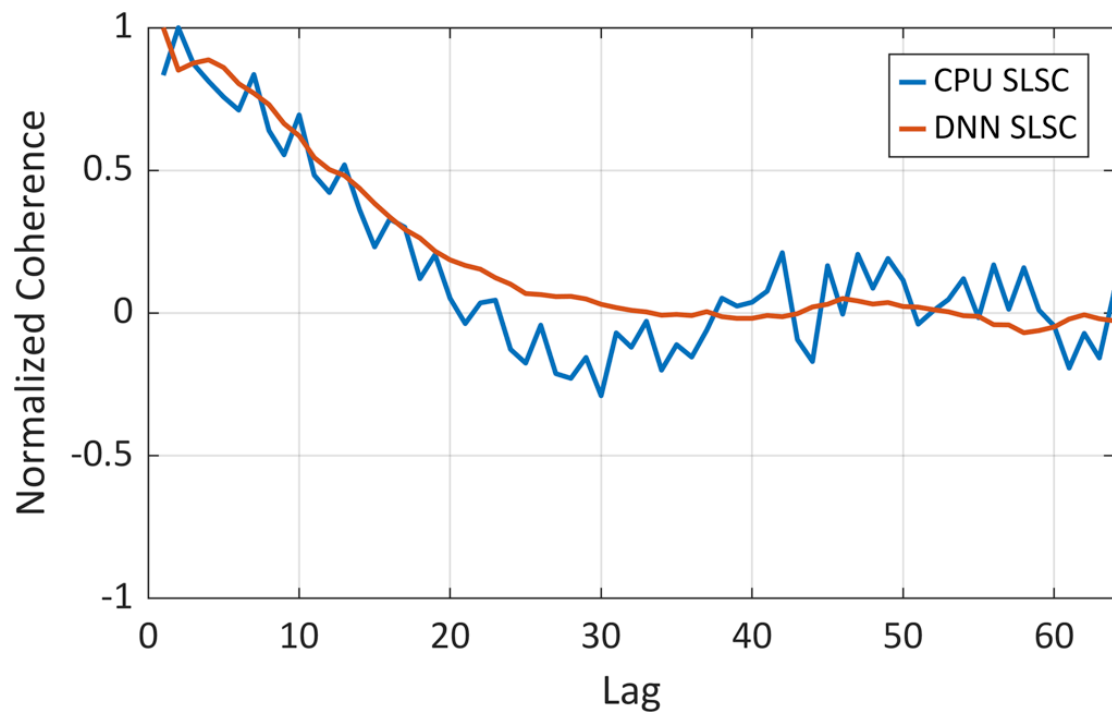
Dahl *et al.* 2011

\*SLSC = Short-Lag Spatial Coherence, **Patented in 2016**

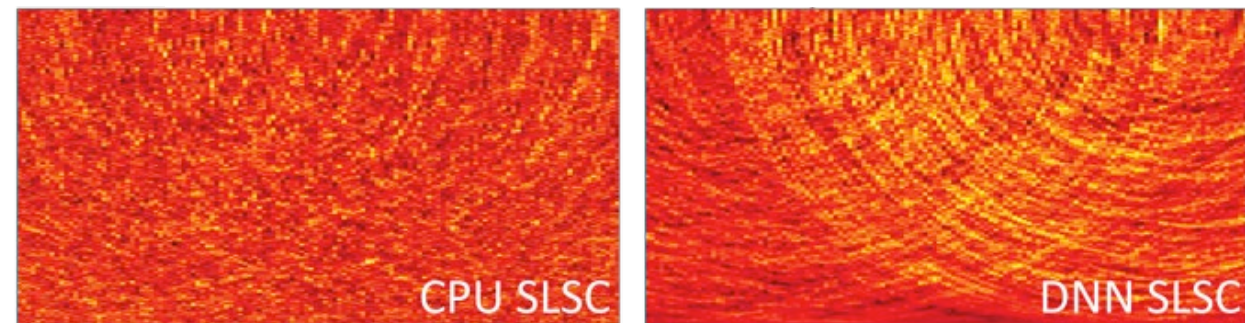


# Applications in Deep Learning

- Photoacoustic coherence functions were learned to provide SLSC images for a diversity of skin tones<sup>1</sup>
- Reduces clutter and skin tone bias present in traditional amplitude-based images<sup>2</sup>



Overfitting detection with Gaussian input<sup>3</sup>



<sup>1</sup>Timaná, Fernandes, Pavan, Bell, *IEEE IUS*, 2023

<sup>2</sup>Fernandes *et al. Photoacoustics*, 2023

<sup>3</sup>Zhang *et al. IEEE IUS* 2022



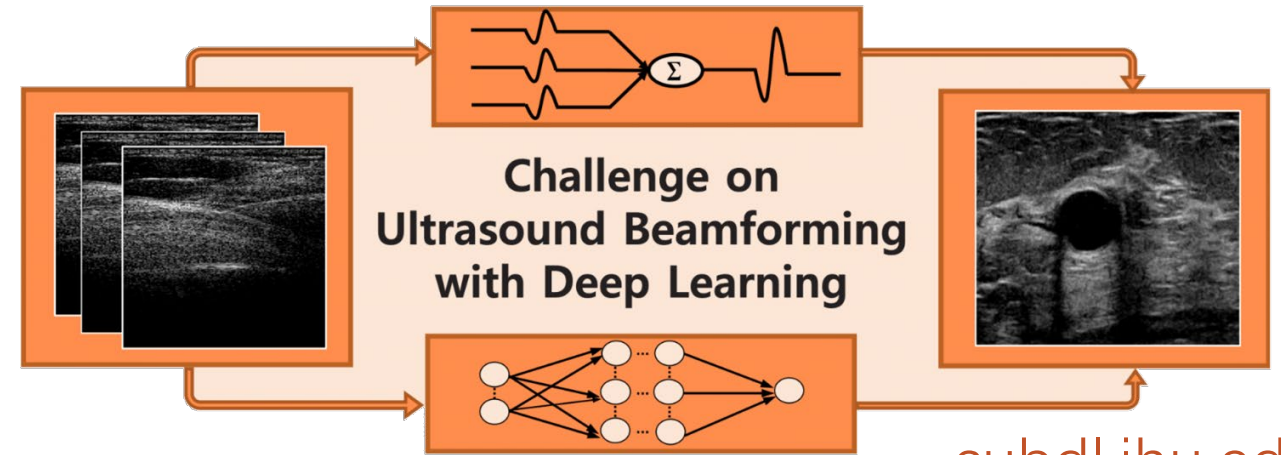
# Open-Source Datasets, Code, Resources



## UltraSound ToolBox

MATLAB toolbox for processing ultrasonic signals

[www.ustb.no](http://www.ustb.no)



[cubdl.jhu.edu](http://cubdl.jhu.edu)

PICMUS is part of the [IEEE IUS 2016, Tours, France](#).

2016 **IUS** INTERNATIONAL ULTRASONICS SYMPOSIUM

September 18-21, 2016, TOURS, FRANCE

[www.creatis.insa-lyon.fr/Challenge/IEEE\\_IUS\\_2016/download](http://www.creatis.insa-lyon.fr/Challenge/IEEE_IUS_2016/download)



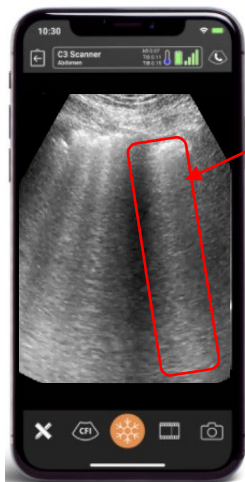


# COVID-19 Detection with Artificial Intelligence

wireless probe

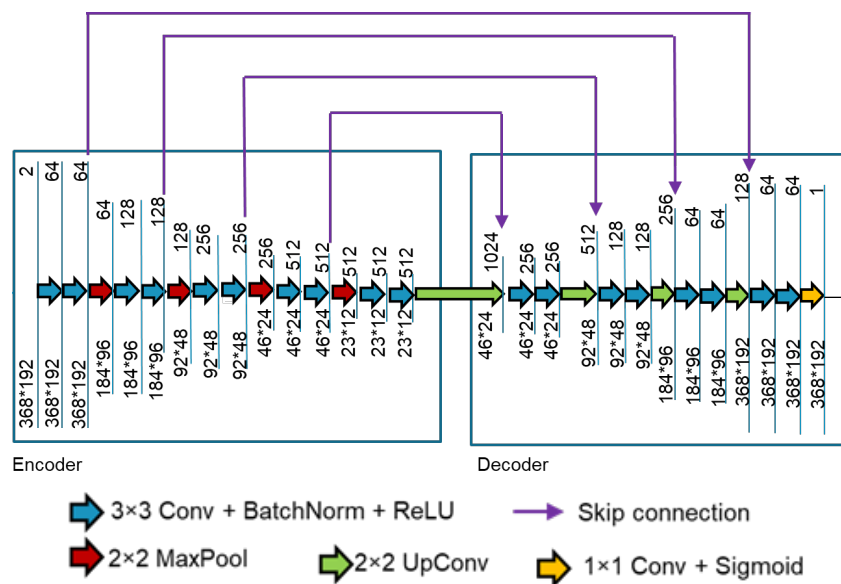


smart phone

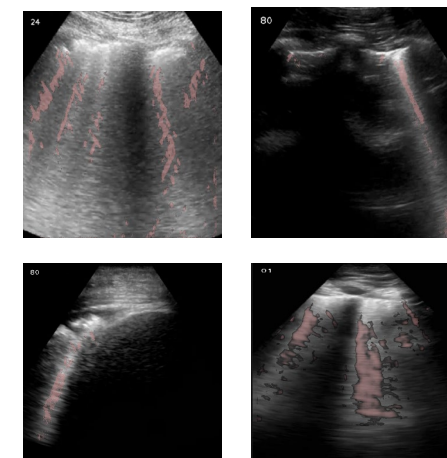


B-lines

+



Example Results  
with Lung Ultrasound Images



(can be deployed in remote locations)

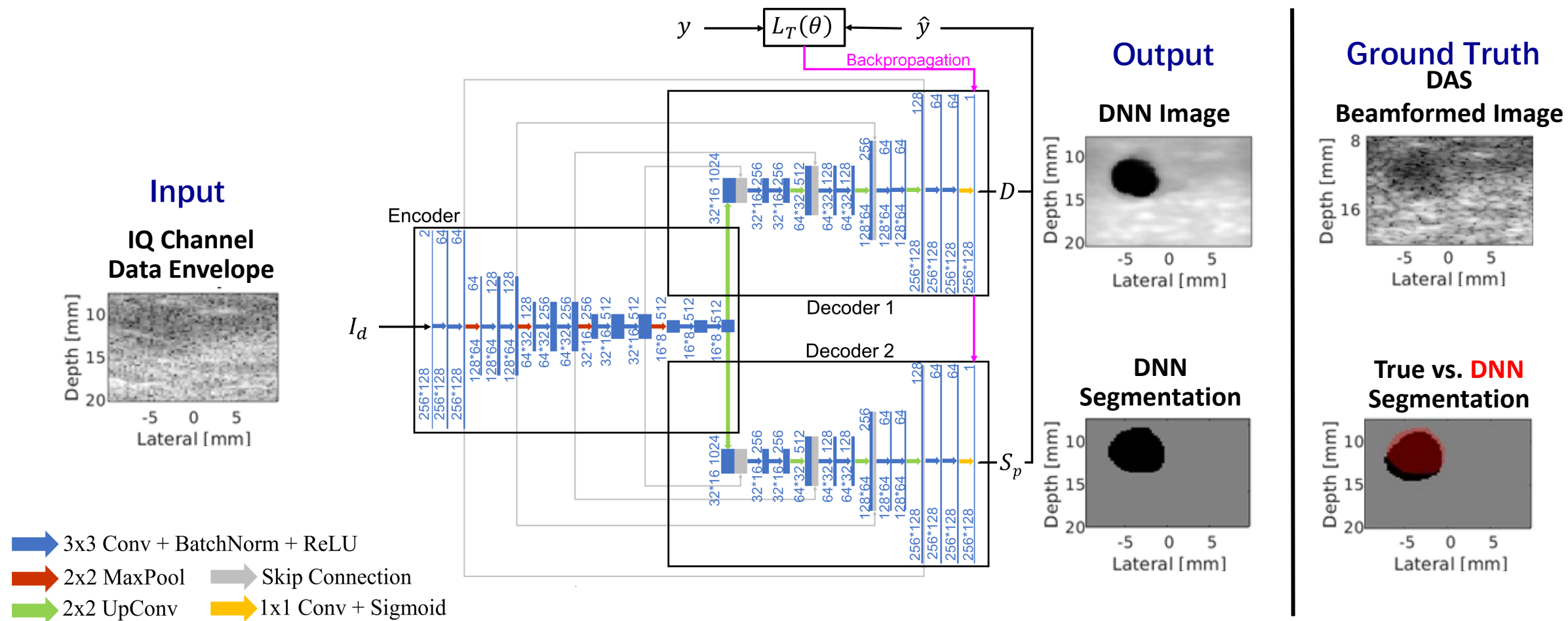
- First to train DNNs with simulated lung ultrasound data
- Accuracy better than training on *in vivo* data when applied to *in vivo* patient images
- Assists with identifying and monitoring COVID-19 and other lung diseases

\*Data, code, and segmentation labels are public:  
<https://gitlab.com/pulselab/covid19>

L Zhao, T Fong, MAL Bell, *Nature Communications Medicine*, 2024  
(funded by NIH Trailblazer Supplement NIH R21 EB025621-03S)



# In Vivo Breast Cyst Detection with Deep Learning



Nair, *et al.* "Deep learning to obtain simultaneous image and segmentation outputs from a single input of raw ultrasound channel data." *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, 2020





Largest database of ultrasound channel data!

Crowd-sourced training & testing data

## IEEE DataPort™

- 1\_CUBDL\_Task1\_Data
- 2\_Post\_CUBDL\_JHU\_Breast\_Data
- 3\_Additional\_CUBDL\_Data
- CUBDL\_Data\_Release\_Agreement.pdf
- CUBDL\_Phantom\_Details.xlsx
- README.txt



Open source evaluation code



## GitLab

Name	Last update
cubdl	4 days ago
datasets	Update README.
images	Added image to README.md.
scoring	Add top submitted networks and make min...
submissions	Add top submitted networks and make min...
.gitignore	Merge development branch into master
README.md	Update README.

**README.md**

CUBDL - Challenge on Ultrasound Beamforming with Deep Learning

Description

This repository is for the 2020 IEEE International Ultrasonics Symposium Challenge on Ultrasound Beamforming with Deep Learning. Example

PyTorch DAS beamformer

# PYTORCH

```
class DAS_PW(torch.nn.Module):
    """ PyTorch implementation of DAS plane wave beamforming.

    This class implements DAS plane wave beamforming as a neural network via a PyTorch
    nn.Module. Subclasses derived from this class can choose to make certain parameters
    trainable. All components can be turned into trainable parameters.
    """
```



Trained network weights from CUBDL winners

- goudarzi
- rothlubbers

Hyun, Wiacek, Goudarzi, RothlÜbbers, Asif, Eickel, Eldar, Huang, Mischi, Rivaz, Sinden, Sloun, Strohm, Bell, *IEEE TUFFC*, 2021



# CUBDL Contributors

## Lead Organizer



MAL Bell

## CUBDL Co-Organizers



D Hyun



J Huang



RJG van Sloun



YC Eldar



M Mischi

## Post-CUBDL Evaluator & Data Curator



A Wiacek

- **CUBDL Winners:** S Goudarzi, S Rothlübbers, A Asif, K Eickel, H Rivaz, D Sinden, H Strohm
- **CUBDL Data Contributors**
  - A Wiacek, J Huang, MAL Bell, E Oluyemi, and E Ambinder (Johns Hopkins University, **USA**)
  - Ping Gong and Shigao Chen (Mayo Clinic, **USA**)
  - Alessandro Ramalli and Piero Tortoli (University of Florence, **Italy**)
  - Ben Luijten and Massimo Mischi (Eindhoven University of Technology, **The Netherlands**)
  - Ole Marius Hoel Rindal (University of Oslo, **Norway**)
  - Vincent Perrot and Hervé Liebgott (CREATIS, INSA, University of Lyon, **France**)
  - Xi Zhang and Jianwen Luo (Tsinghua University, **China**)

## Sponsors



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