Use of structural priors in multi-modal optical breast imaging

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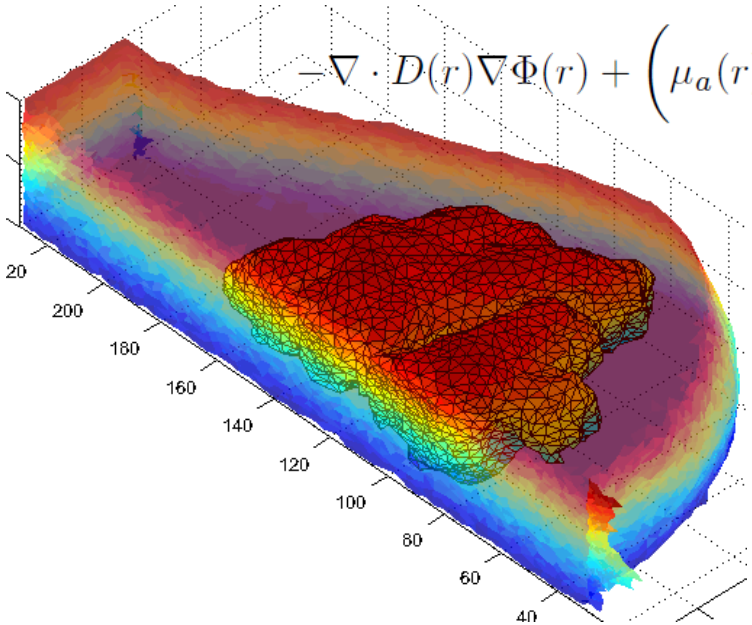
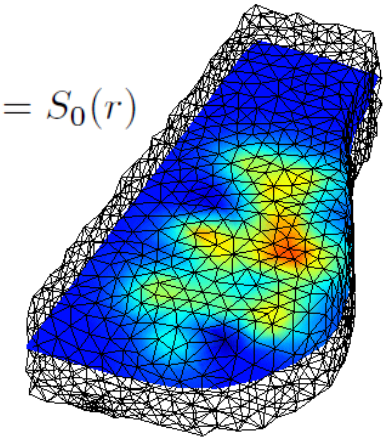
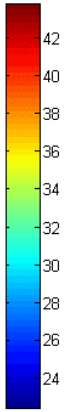
$$-\nabla \cdot D(r)\nabla\Phi(r) + \left(\mu_a(r) + \frac{j\omega}{c}\right)\Phi(r) = S_0(r)$$







Outline and conclusions

- A multimodality breast imager
- Data analysis pipeline
- Clinical study and results
- New approach to fuse structural priors

- Conclusion:
  - Solving inverse problems with structural priors can enhance resolution and contrast in a functional imaging modality

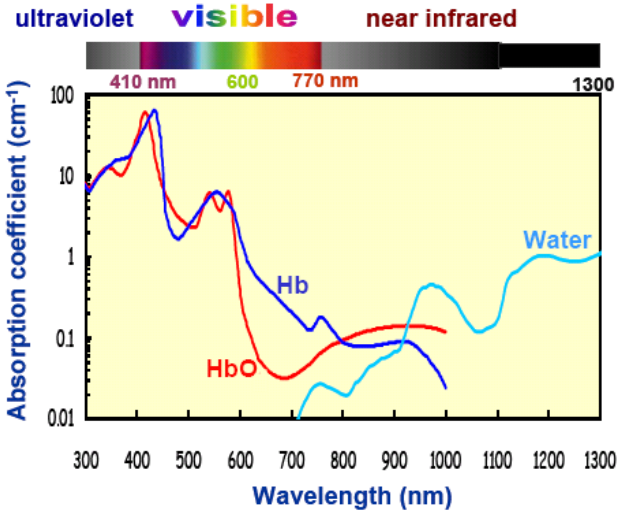
Breast imaging: clinical challenges

- Breast cancer results in ~40,000 death per year in the US
- Mammography discovers 80% of the cancers, but also results in unnecessary biopsy 70~80%
- Mammography misses 44% early cancers (DCIS)
- Difficulty in dense breasts (in younger people)

- Good penetration and high contrast makes optical imaging a promising candidate

Tissue absorption and chromophores

- Low absorption between 600nm-1000nm (near-infrared)
- Distinct absorption spectra:
  - Oxygenated hemoglobin (HbO)
  - Deoxygenated hemoglobin (HbR)
  - Water
  - Lipids



- By measuring absorptions at multiple wavelengths, one can calculate the concentrations of the chromophores

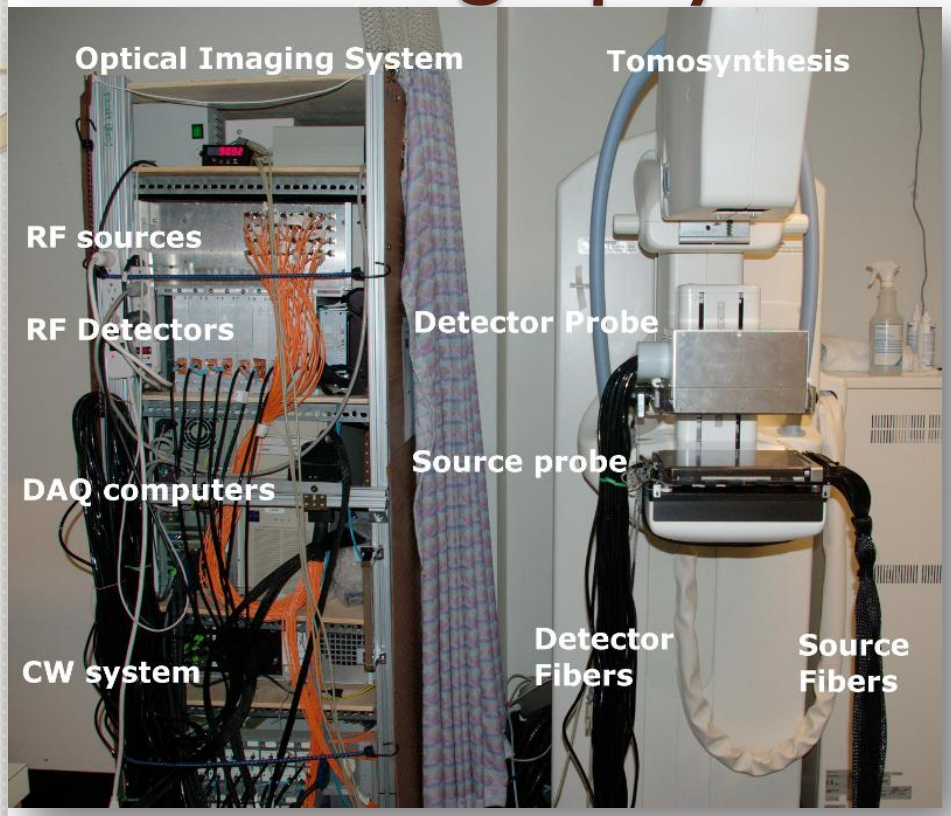
Near-infrared spectroscopy for the study of biological tissue
Angelo Sassaroli, et al. Tufts Univ

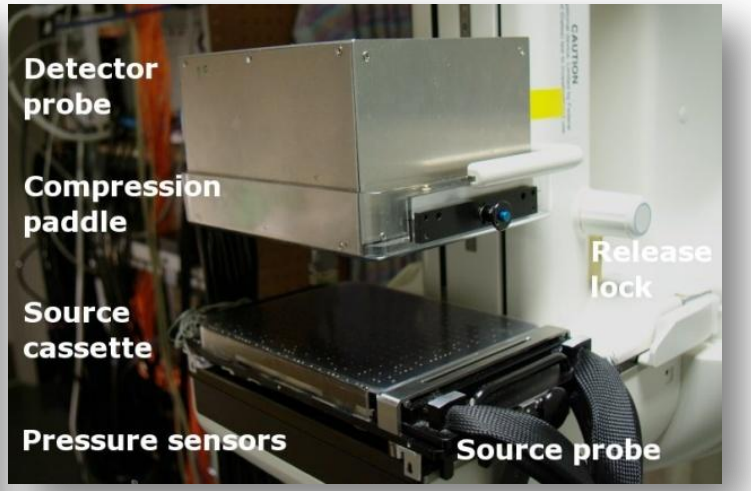
Difficulties in optical image reconstructions

- Photon transport is highly non-linear
  - Must use advanced computational models
- Inverse problem is ill-posed: sensitive to noise
  - Must smooth the solution to gain stability
- Sparse source/detector locations
  - Limited sampling of the target domain
- Generally resulting in functional images with poor resolution

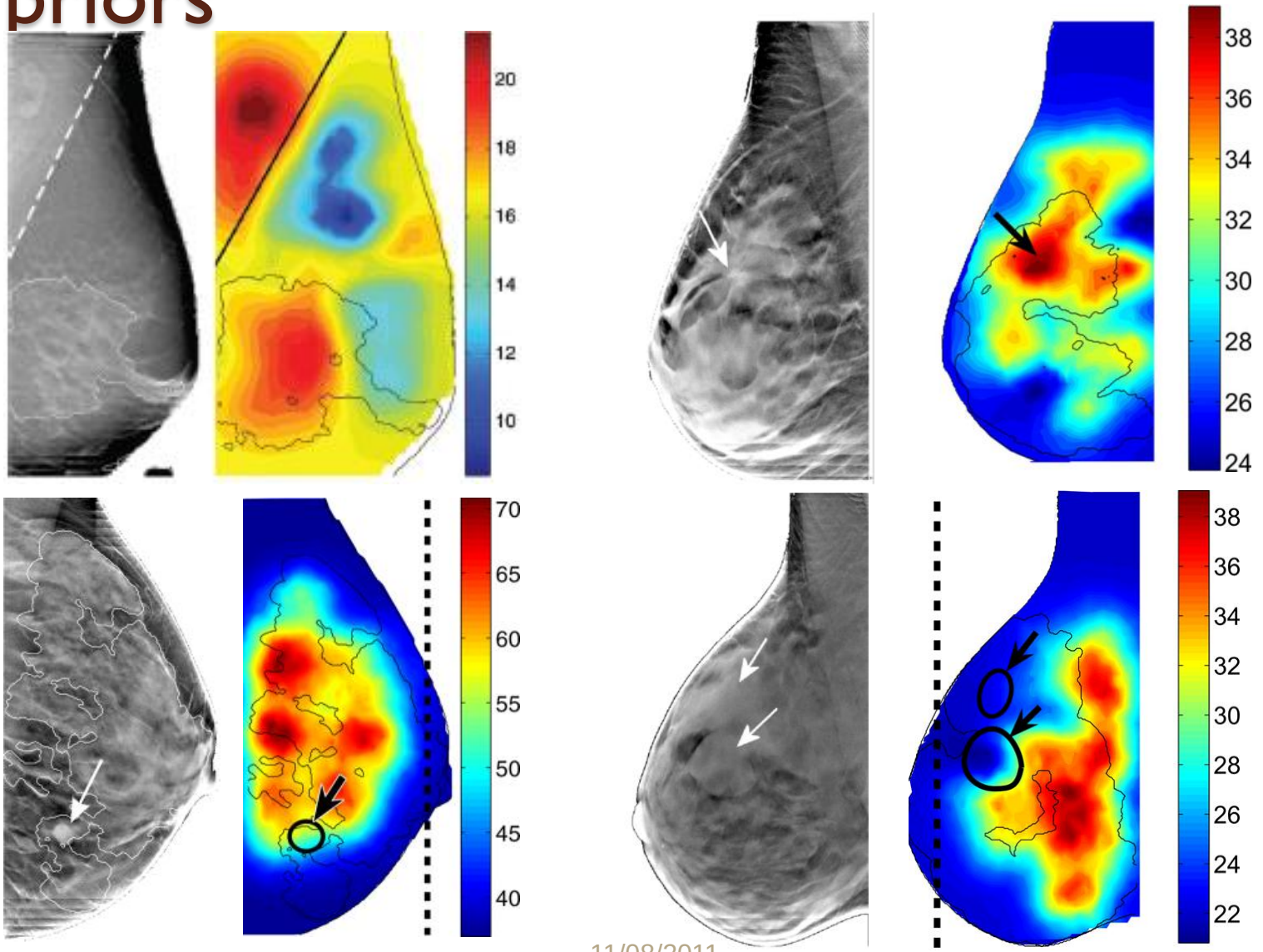
- **Win-win**: Data fusion from X-ray structure

Combined DOT with mammography



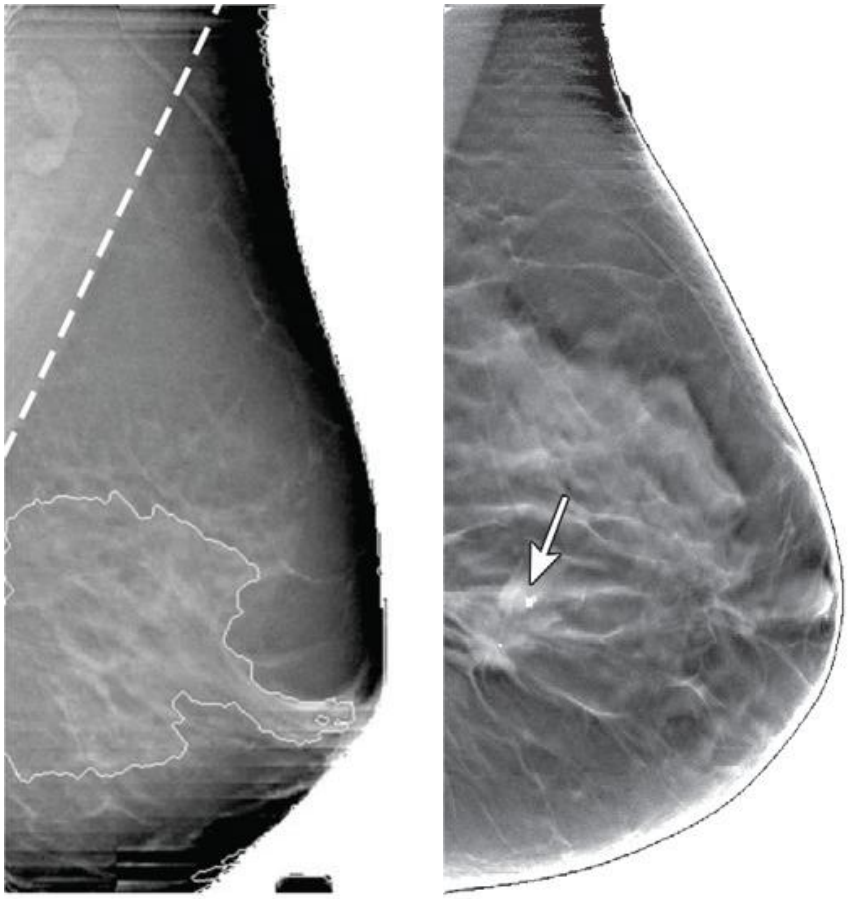


Reconstruction without structural priors



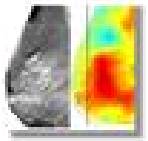
Fang Q, et al., Radiology, 258(1): 89-97, 2011.

Limitations of binary segmentation



- Not all tissues can be well separated
- Fine structure info is lost
- Introduces segmentation error, sometimes it counter-weights the benefit of the prior

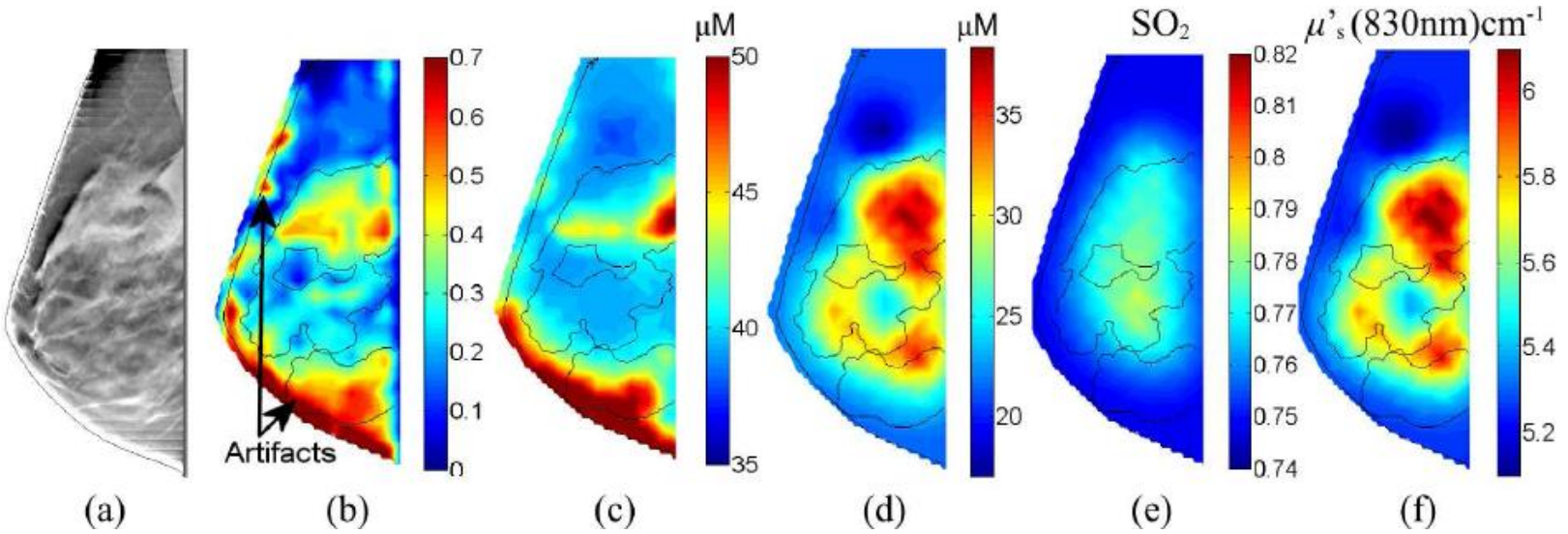
Compositional-prior-guided image reconstruction algorithm for multi-modality imaging



Abstract | Full Text: PDF (1608 KB) | XHTML

- Biomedical Optics Express Vol. 1, Iss. 1, pp. 223–235 (2010)
- Qianqian Fang, Richard H. Moore, Daniel B. Kopans, and David A. Boas

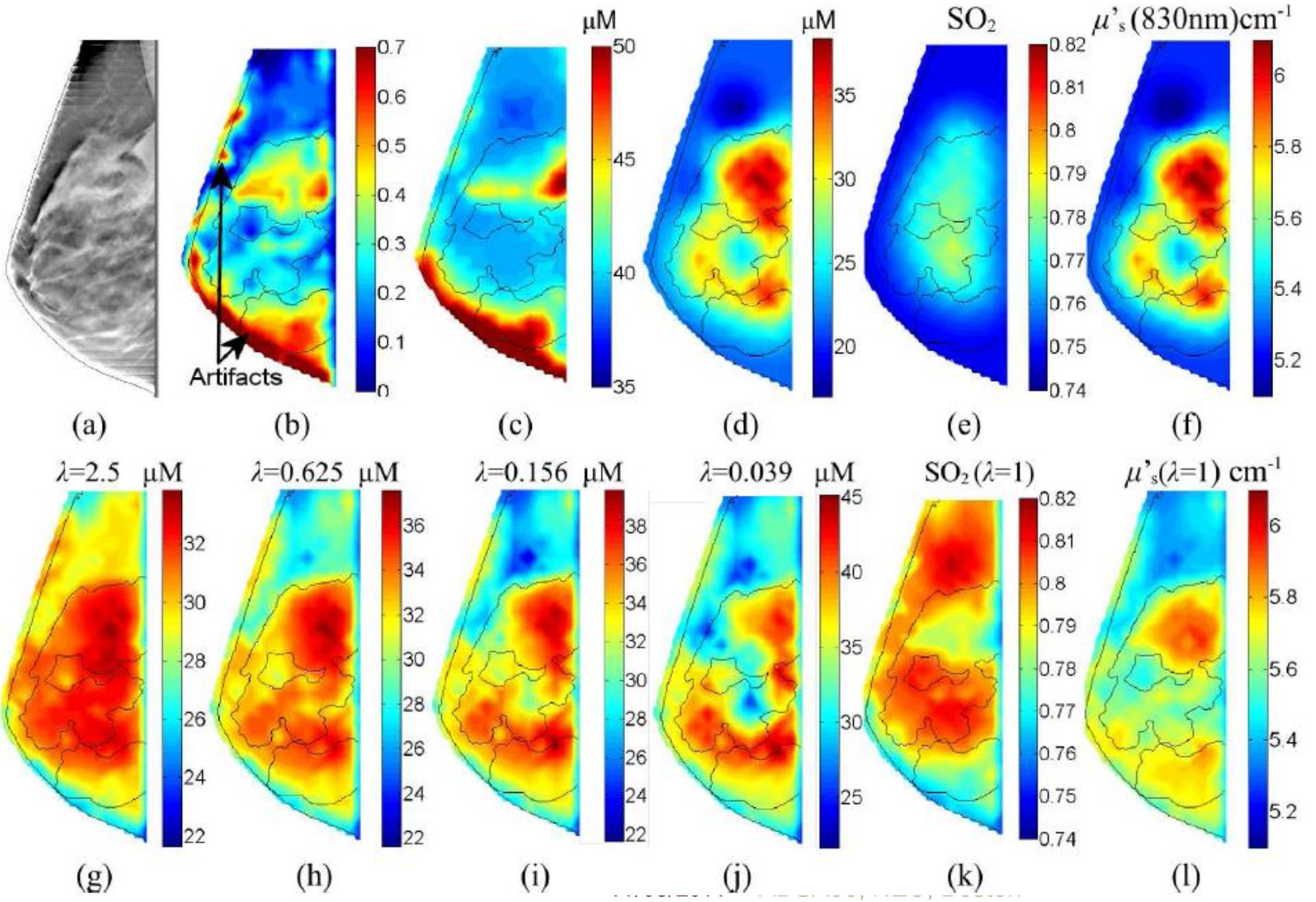
A healthy breast with priors



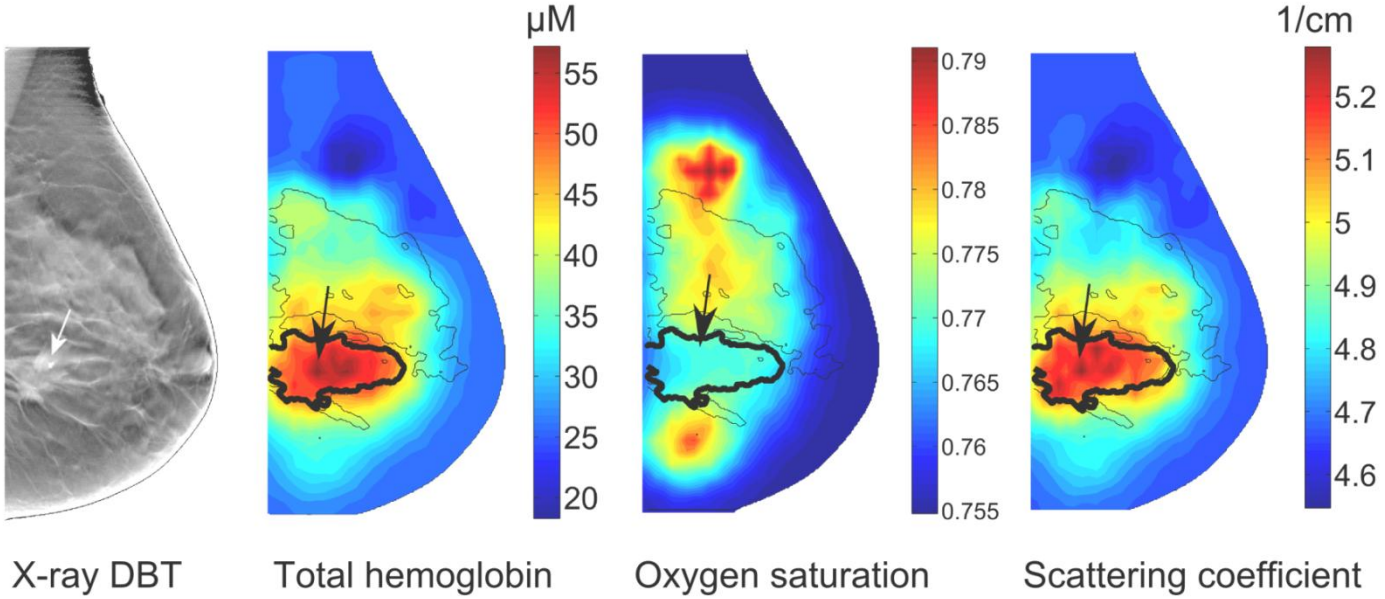
Soft-prior
HbT

No prior

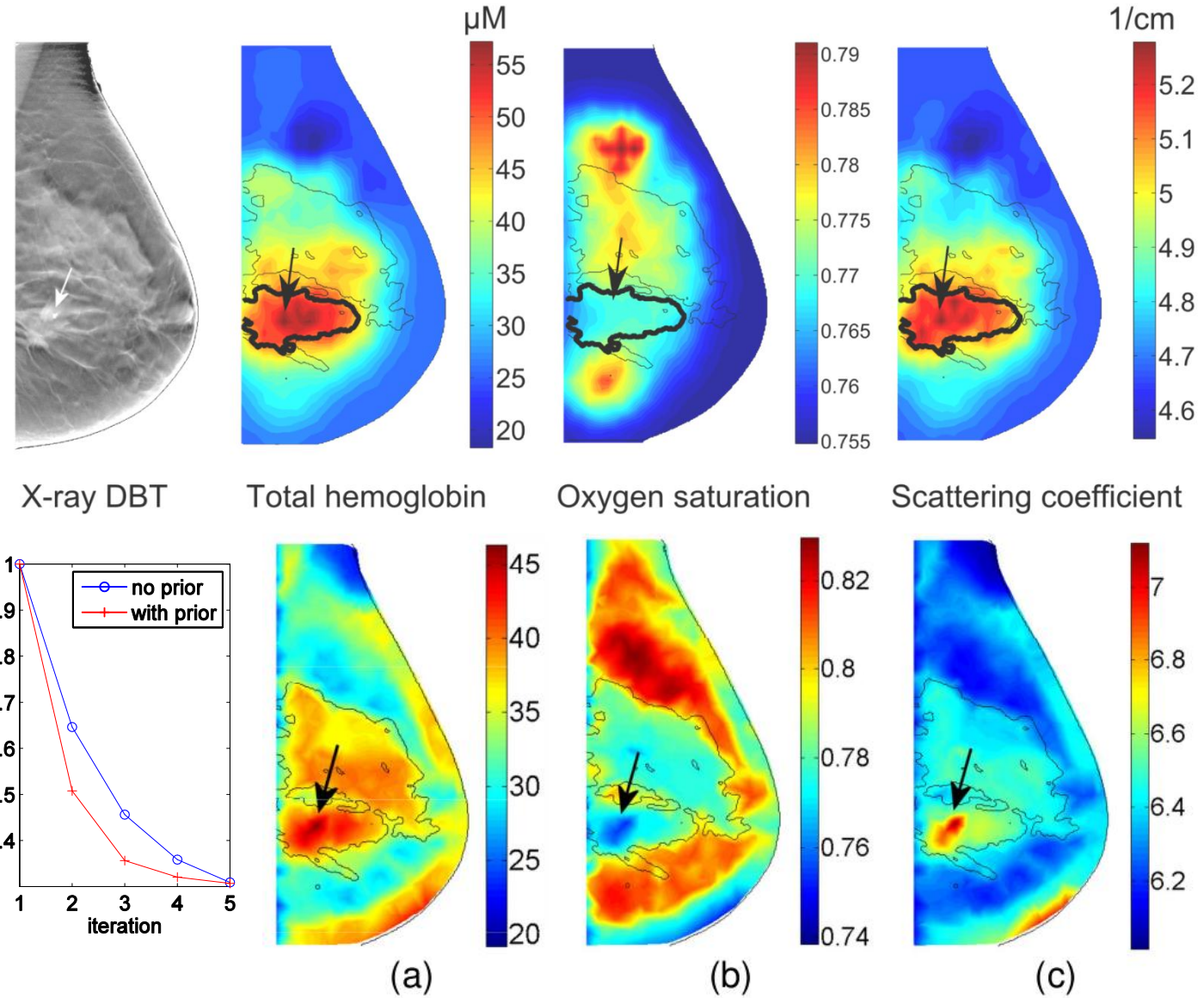
A healthy breast with priors



Tumor with healthy-tissue priors



Tumor with healthy-tissue priors



Observations:

1.+ better spatial details
2.+ better image consistency
3.+ comparable residual
4.--- lower contrast

Statistical tests (p-values)

Optical Property and Tissue Type	Malignant Tumor	Solid Benign Lesion	Cyst	Fibroglandular Tissue: Breast with Lesion*	Fibroglandular Tissue: Normal Breast†
Hb_T					
Malignant tumor	. . .	.025‡	.0033‡	.0062‡	.25
Solid benign lesion	. . .	. . .	.11	.017‡	.017‡
Cyst	. . .	. . .	. . .	.0032‡	.0012‡
So_2					
Malignant tumor	. . .	.47	<.0005‡	.11	.16
Solid benign lesion	. . .	. . .	.026‡	.33	.22
Cyst	. . .	. . .	. . .	.038‡	<.0001‡
μ_s' at 830 nm					
Malignant tumor	. . .	.24	.11	.064	.0083‡
Solid benign lesion	. . .	. . .	.24	.46	.15
Cyst	. . .	. . .	. . .	.049‡	.02‡

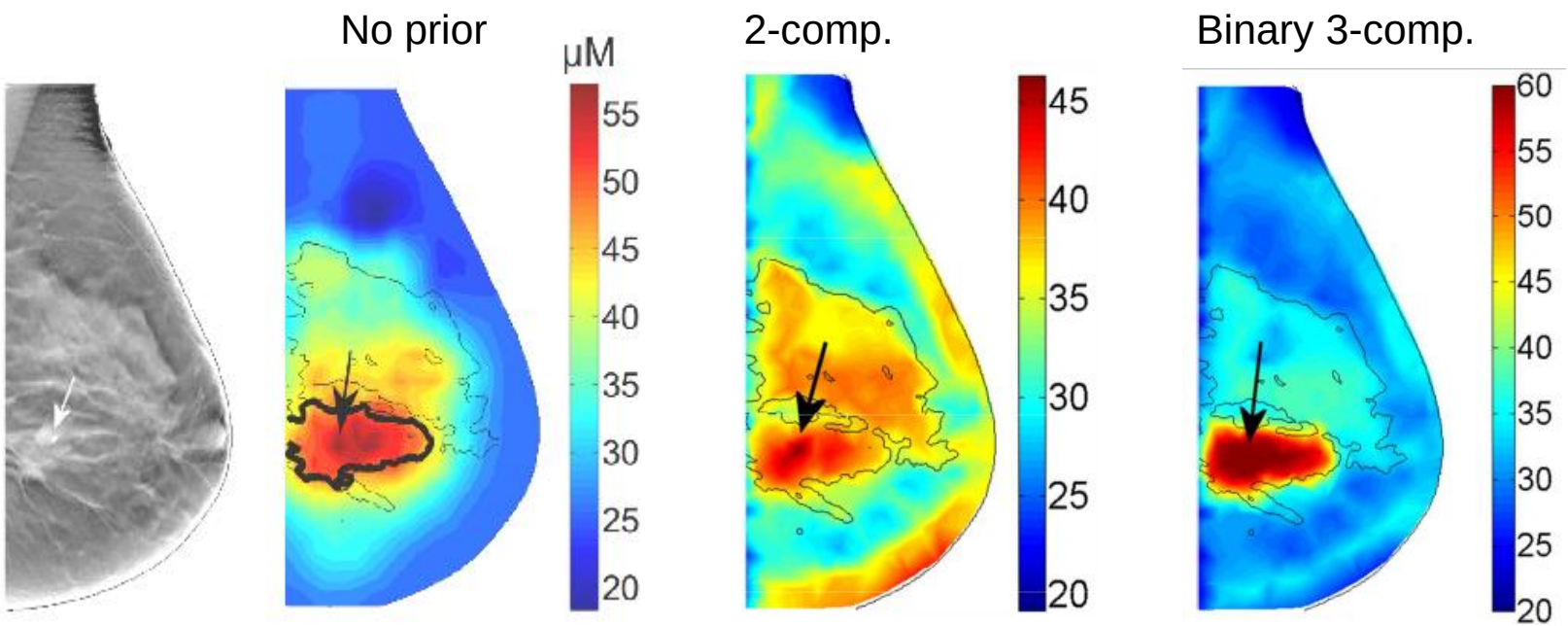
HbT	Malignant	Solid Benign	Cyst	Fibrogland.	Fibrogland.
Malignant (26)		0.04	0.13 x	0.08 x	0.48
Solid Benign (17)			0.49	0.07 x	0.19 x
Cyst (8)				0.03	0.02
SO_2					
Malignant (26)		0.23	0.35 x	0.36	0.46
Solid Benign (17)			0.19	0.26	0.46
Cyst (7)				0.06	0.44 x
μ_s' at 830nm					
Malignant (26)		0.41	0.24	0.008 v	0.46 x
Solid Benign (17)			0.41	0.13	0.21
Cyst (7)				0.04	0.24 x

Using only the healthy tissue structures reduces tumor contrast and statistical significance

Add additional tumor priors

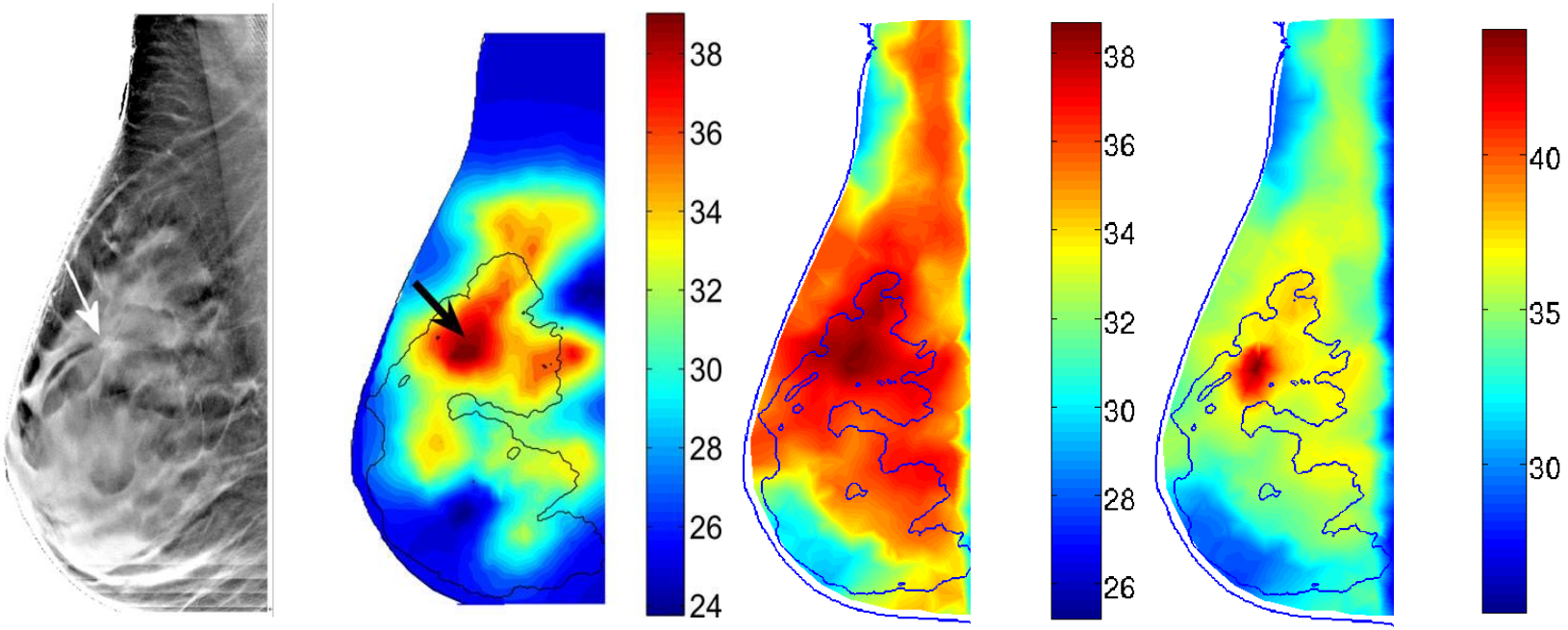
$$\mathbf{c} = \{C_a,\ C_f,\ C_t\}$$

$$\begin{matrix} A_1 & F_1 & 0 \\ 0 & 0 & 1 \\ A_3 & F_3 & 0 \end{matrix} \quad \rightarrow \text{inside tumor ROI}$$



Another malignant tumor (60165L)

- No prior 2-comp. Binary 3-comp.

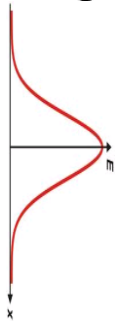


Add statistical tumor priors

C={Ca, Cf, Ct}

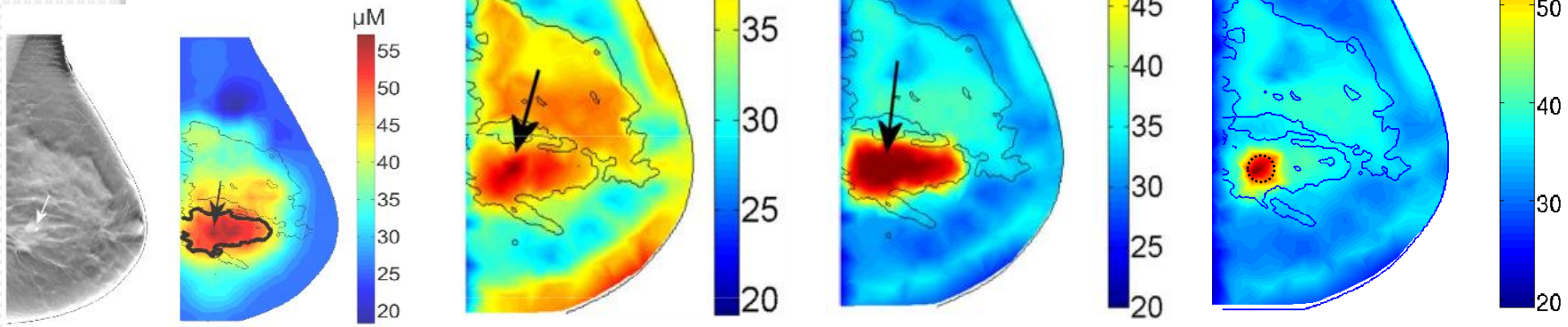
A_1 F_1

A_3 F_3



→ inside tumor ROI, center: p_0, σ

2-comp. Binary 3-comp. Gaussian 3-comp.



Conclusions

- Optically derived physiological parameters correlate with tumor malignancy and can be potentially used to differentiate malignant from benign lesions and reduce false positives.
- Fusing x-ray tissue structure into optical image reconstruction is highly beneficial by dramatically improving the spatial resolution and contrast of the tumors.

- TODO:
  - Statistical tests for tumor-prior reconstructions
  - Interactive diagnosis powered by real-time reconstruction
  - Efficient algorithm to define tumor priors (as part of the optimization, search algorithm, multi-foci, shape-based)

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