

PET-enabled Dual-energy CT:

*Exploring a New Way of Spectral Imaging Using
Synergistic Reconstruction*

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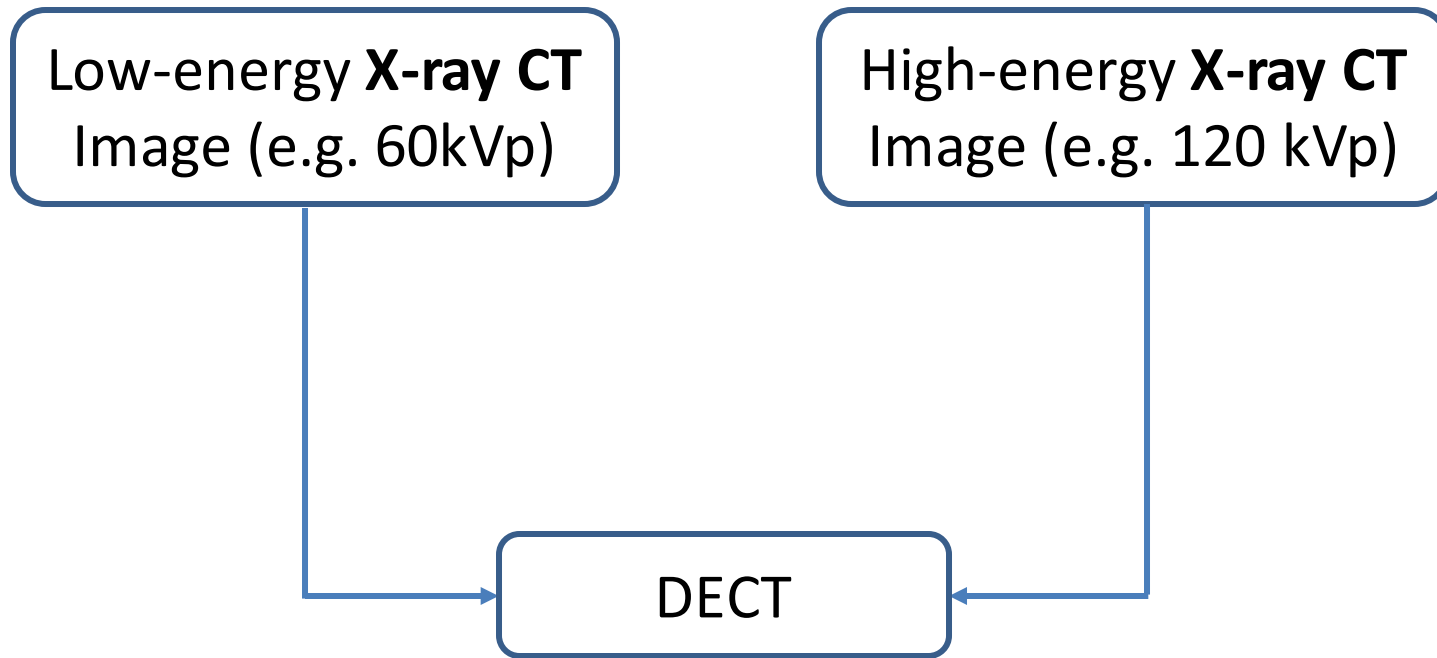
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Dual-energy (DE) CT for Quantitative Imaging

- DECT uses two different energies to obtain quantitative material decomposition
- First introduced in late 1970's
- Renewed interests since ~2005
 - *New implementations*: fast kVp switching, dual-source, spectral detectors

Existing X-ray DECT Paradigm

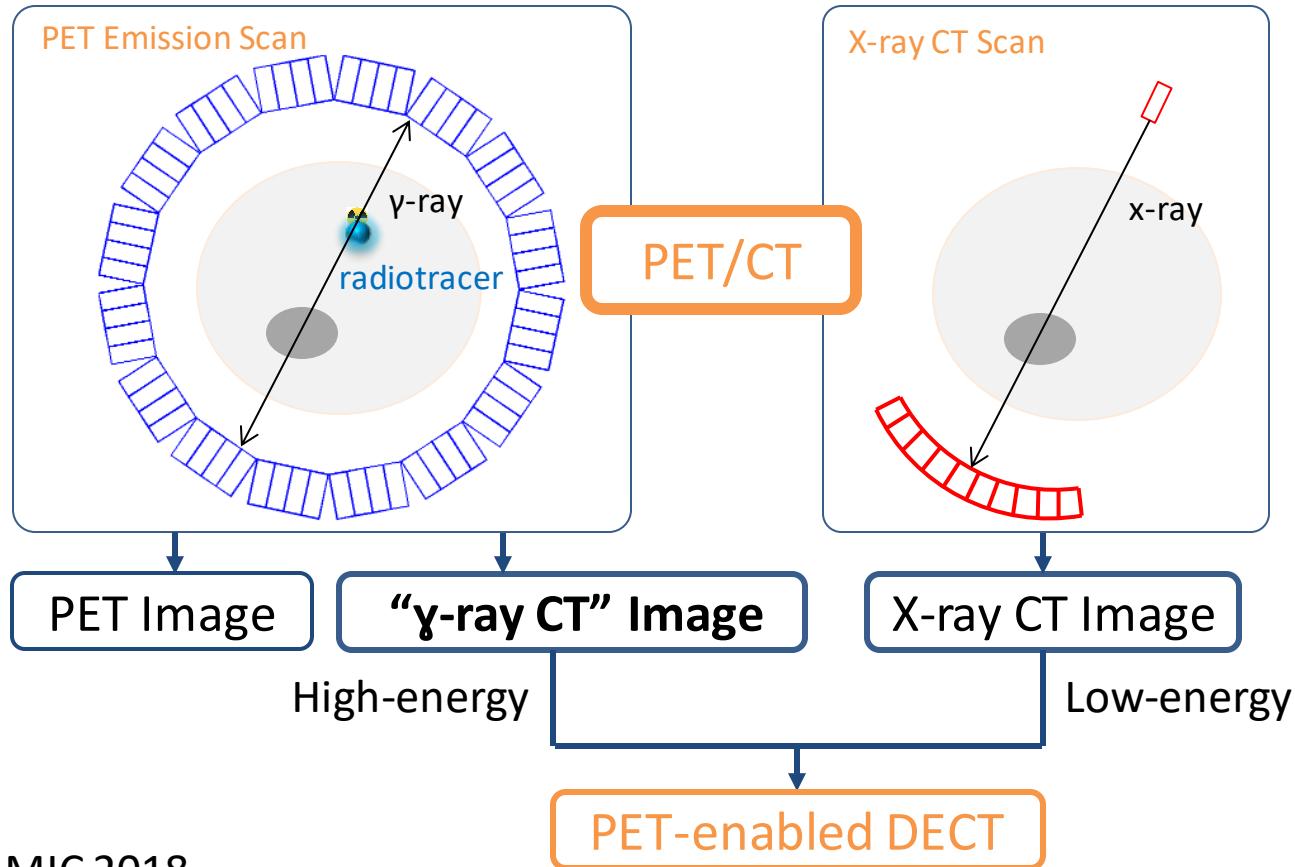


Implementation on PET/CT Scanners?

- PET/DECT

would require hardware upgrade
or increase radiation dose

Our Proposed Method: PET-enabled DECT



Two Ways to Obtain “ γ -ray CT” from PET Data

- Method 1: Synergistic reconstruction of PET activity and γ -ray CT attenuation at 511 keV - known as “MLAA”

Phys. Med. Biol. **57** (2012) 885–899

Time-of-flight PET data determine the attenuation sinogram up to a constant

Michel Defrise¹, Ahmadreza Rezaei² and Johan Nuyts²

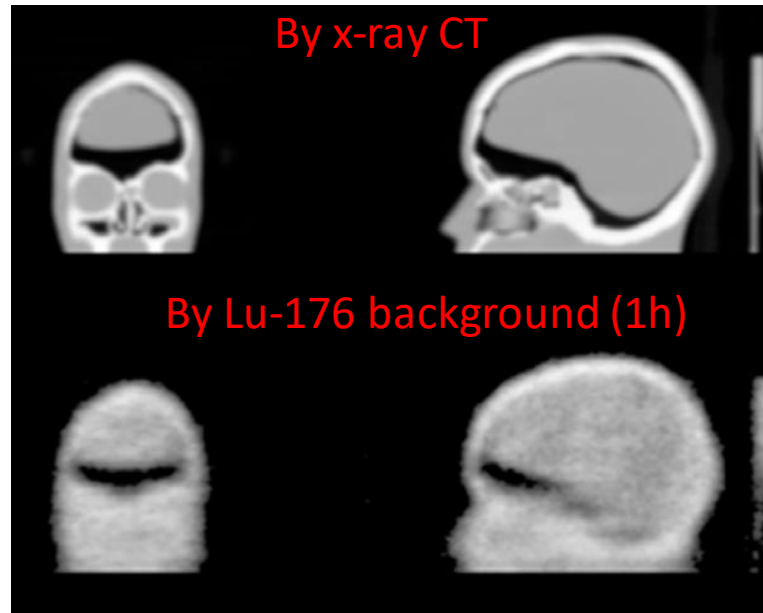
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MLAA implementation: Rezaei *et al* 2012; Erdogan & Fessler 1999

Two Ways to Obtain “ γ -ray CT” from PET Data

- Method 2: Reconstruction of γ -ray CT attenuation from intrinsic background radiation of PET LSO scintillators



Comparison with Previous Works in PET/CT

- Previous attention: To break up with x-ray CT

Transmission-less PET **attenuation correction**

- Our interest: To keep the x-ray CT

PET-enabled **DECT** imaging

Quantitative Material Decomposition

- Example: 3-material decomposition (*fat, soft tissue, and calcium*)

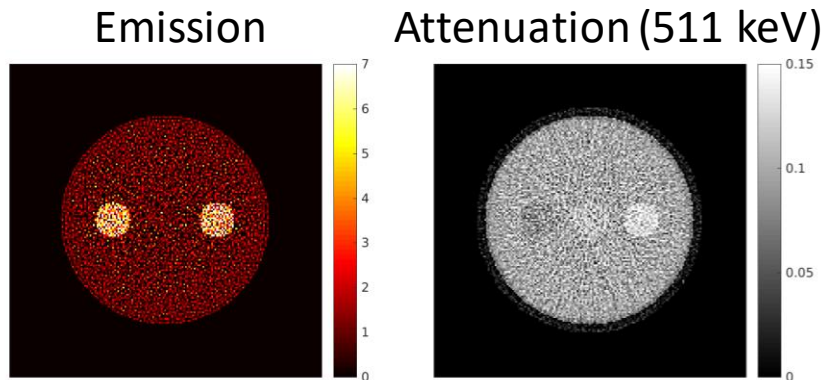
$$\begin{array}{ccc} \begin{bmatrix} u^L \\ u^H \end{bmatrix} & = & \begin{bmatrix} u_F^L & u_S^L & u_C^L \\ u_F^H & u_S^H & u_C^H \end{bmatrix} \begin{bmatrix} \rho_F \\ \rho_S \\ \rho_C \end{bmatrix} \\ \mathbf{u} & & \mathbf{B} \quad \boldsymbol{\rho} \\ \text{DECT} & & \text{Basis Functions} \quad \text{Fraction} \end{array}$$

- Material fraction $\boldsymbol{\rho}$ is estimated using optimization

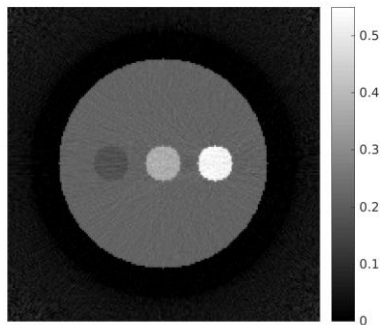
$$\hat{\boldsymbol{\rho}} = \operatorname{argmin}_{\boldsymbol{\rho}} ||\mathbf{u} - \mathbf{B}\boldsymbol{\rho}||^2$$

Preliminary Simulation Results for Proof of Concept

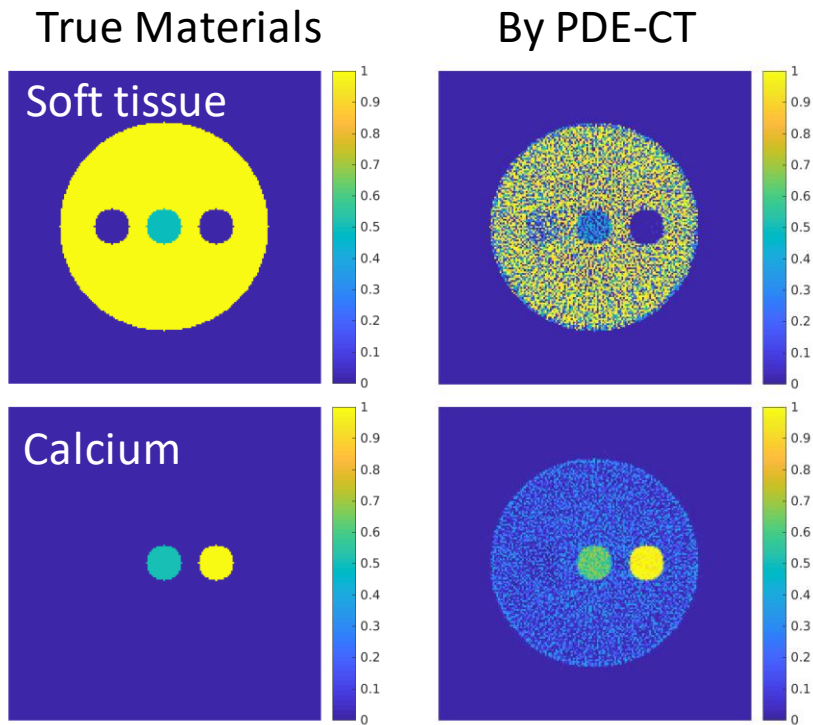
A. MLAA reconstruction of TOF-PET data



B. X-ray CT (60 keV)



C. Material Decomposition



Noise Challenge and Solution

- Challenge

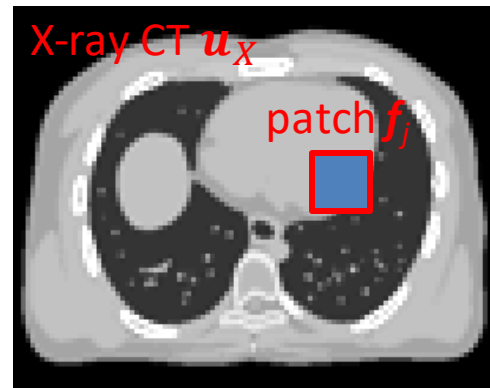
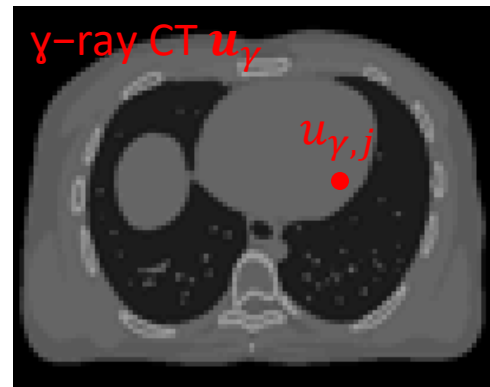
High noise associated with PET emission data

- Solution: Guide the reconstruction of γ -ray CT from PET data using the available **x-ray CT** data
 - Good initial estimate
 - Anatomical prior

Kernel Representation for γ -ray CT Image

- Pixel j of a γ -ray image \mathbf{u}_γ is associated with a feature vector \mathbf{f}_j on the x-ray CT image \mathbf{u}_x
- Describe the intensity (“label”) $u_{\gamma,j}$ as a linear function in the kernel space using “kernel trick”

$$u_{\gamma,j} = \sum_{l=1}^N \alpha_l \kappa(\mathbf{f}_j, \mathbf{f}_l) = [\mathbf{K}\boldsymbol{\alpha}]_j$$



Kernelized MLAA

- Standard MLAA (maximum likelihood estimation of activity and attenuation) for time-of-flight PET emission data

$$\hat{\mathbf{x}}, \hat{\mathbf{u}} = \arg \max_{\mathbf{x}, \mathbf{u}} L(\mathbf{y}^{\text{TOF}} | \bar{\mathbf{y}}(\mathbf{x}, \mathbf{u}))$$

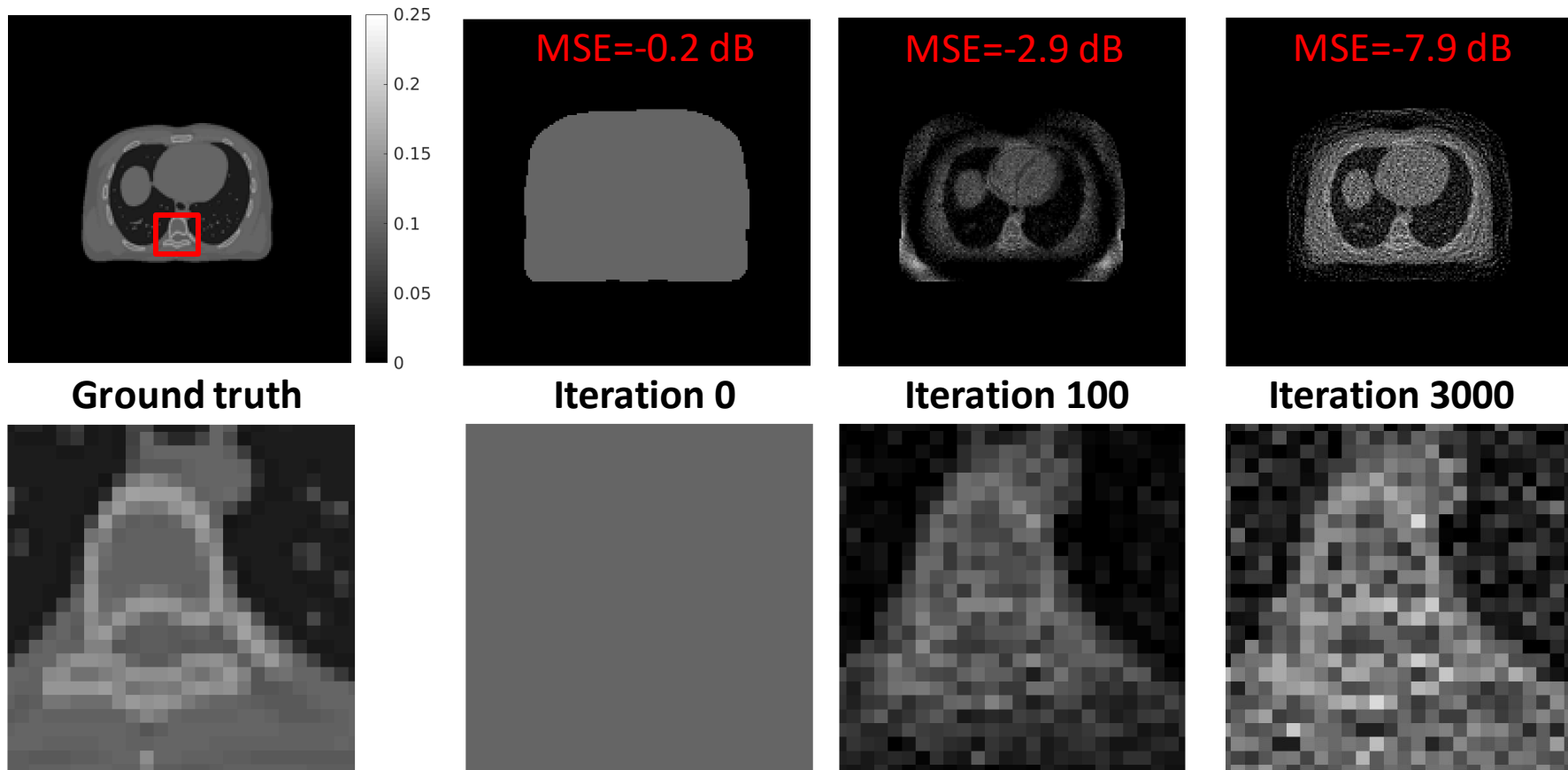
- Kernelized MLAA

$$\hat{\mathbf{x}}, \hat{\boldsymbol{\alpha}} = \arg \max_{\mathbf{x}, \boldsymbol{\alpha}} L(\mathbf{y}^{\text{TOF}} | \bar{\mathbf{y}}(\mathbf{x}, \mathbf{K}\boldsymbol{\alpha}))$$

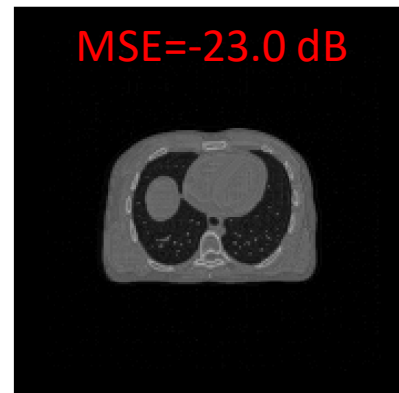
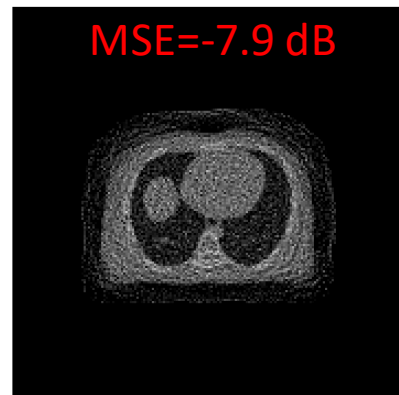
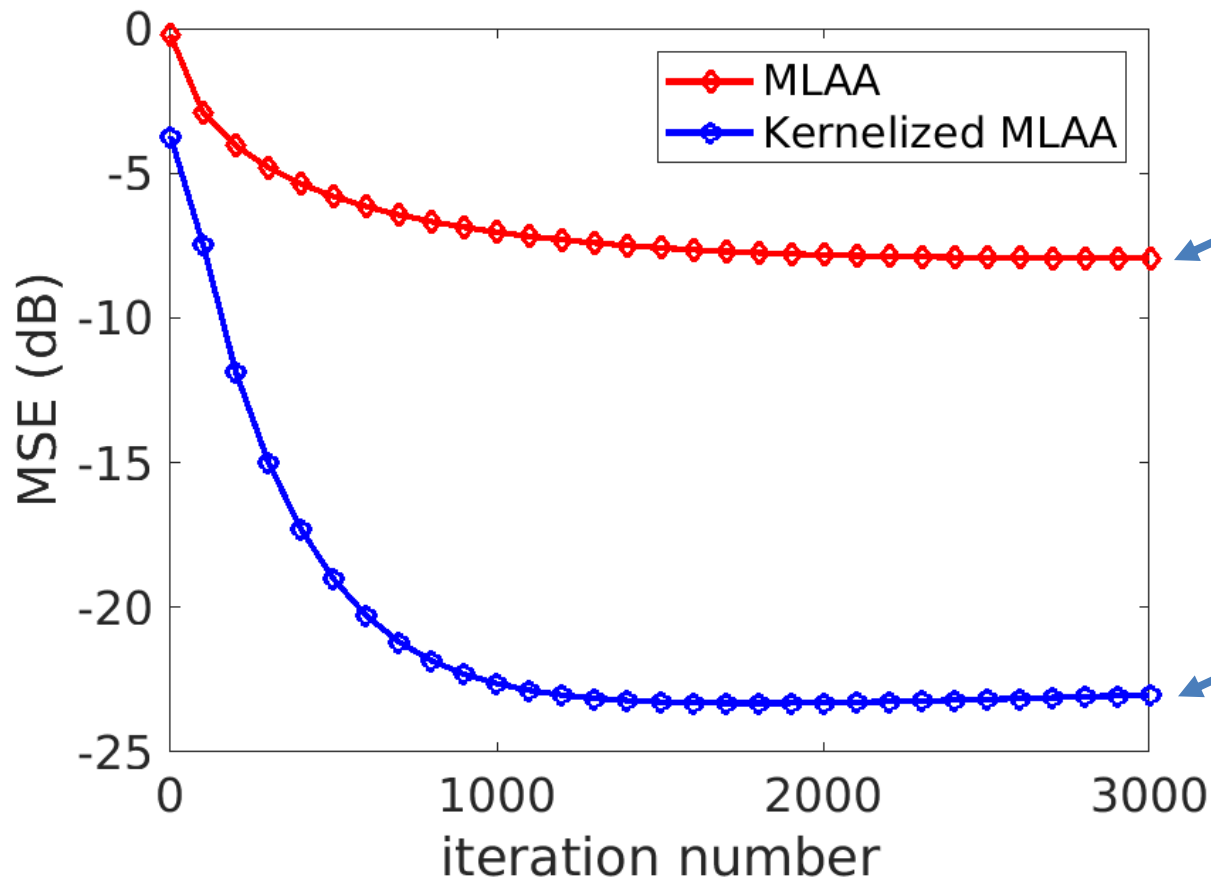
where the kernel matrix \mathbf{K} is derived from x-ray CT image.

- Final image estimate from K-MLAA is $\hat{\mathbf{u}} = \mathbf{K}\hat{\boldsymbol{\alpha}}$

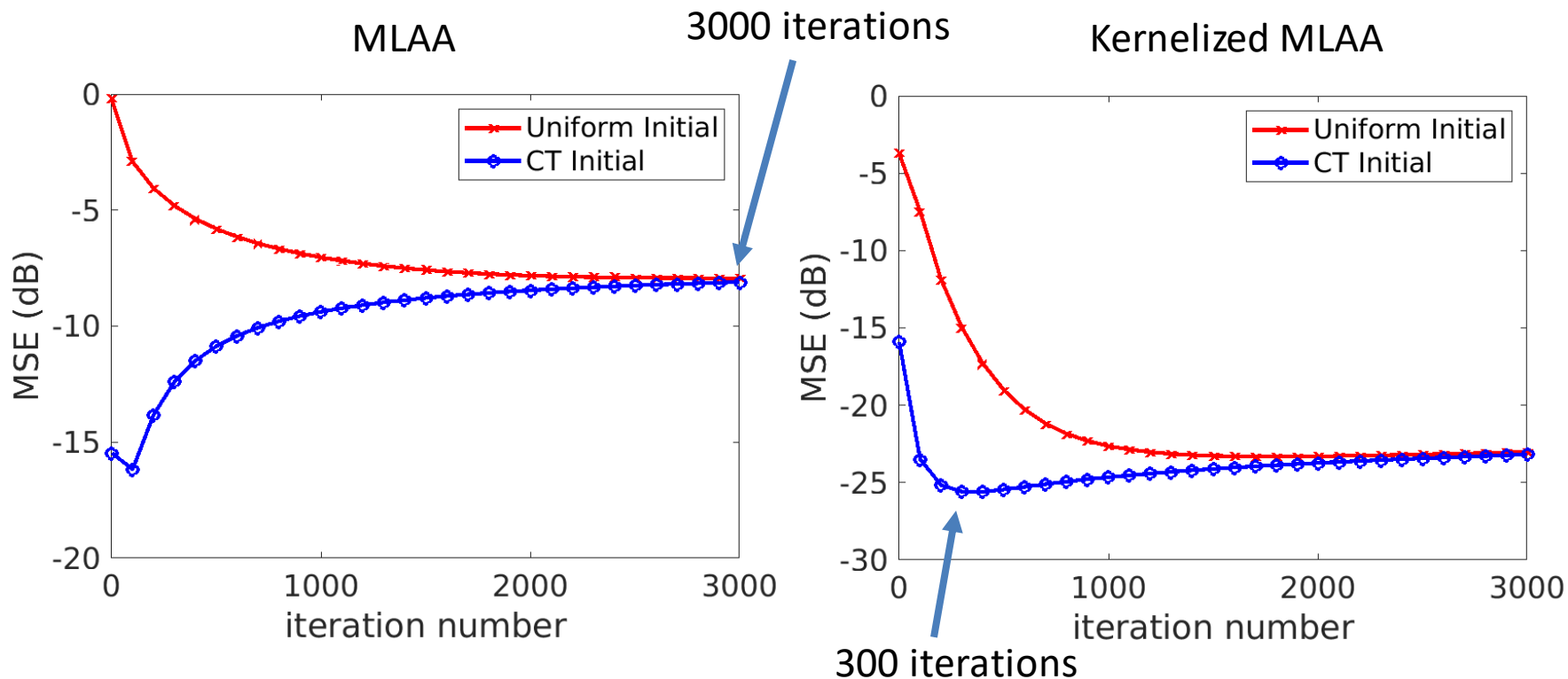
Results from a Computer Simulation: MLAA



Kernelized MLAA Dramatically Improves Image Quality

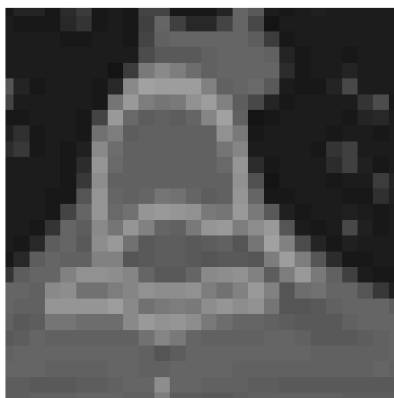
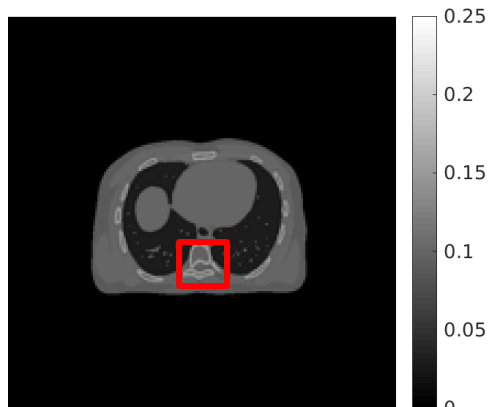


Use of CT Initial Accelerates Kernelized MLAA

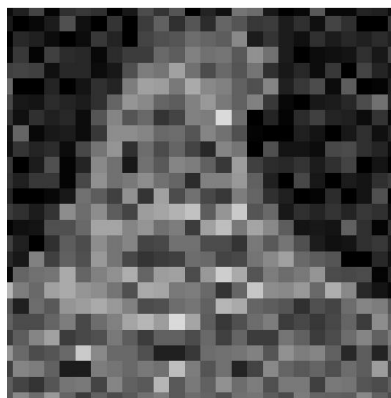
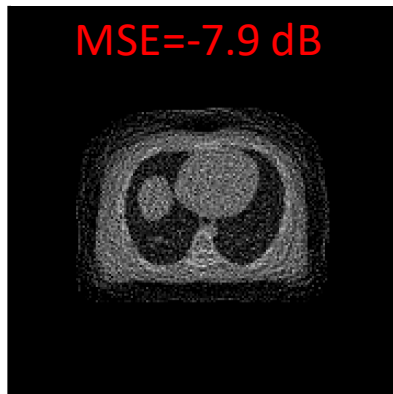


Demonstration of Improved Image Quality

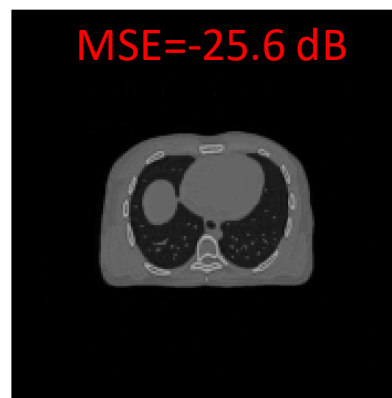
Ground truth



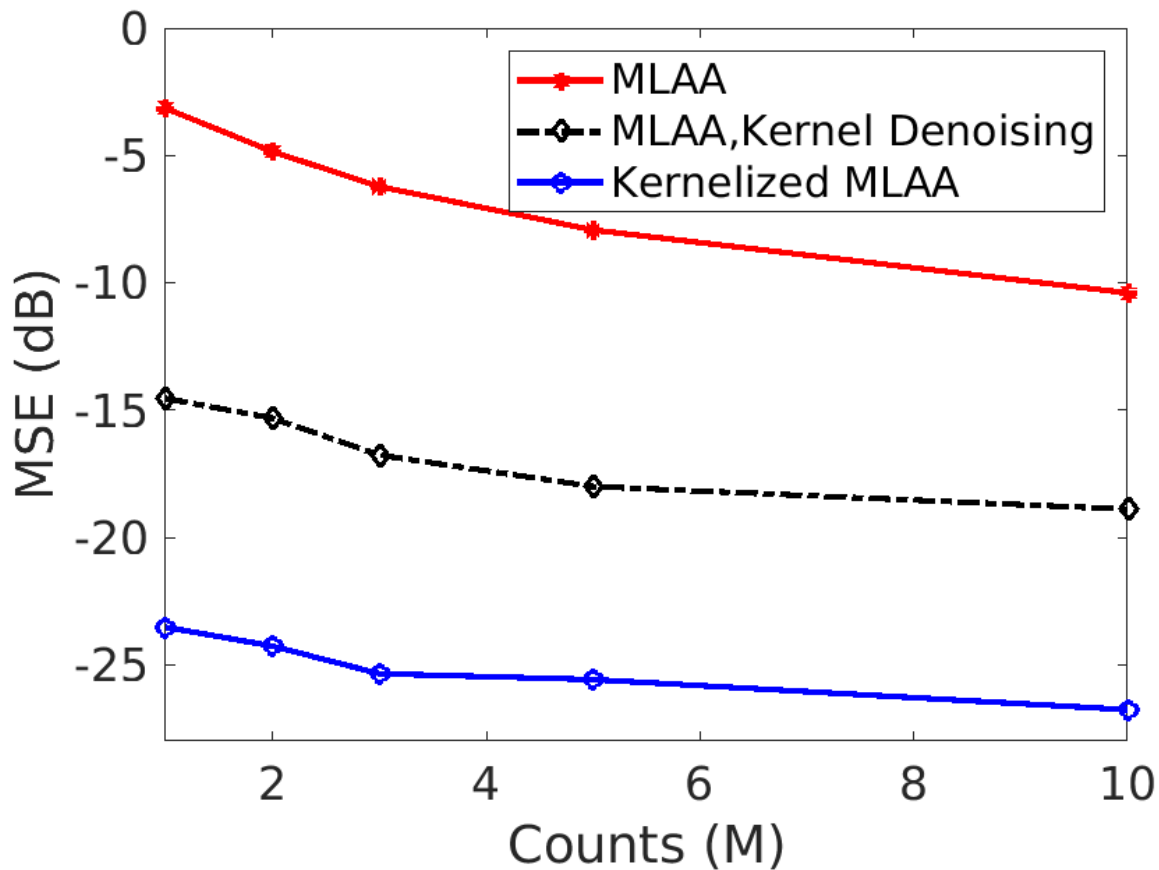
Existing Method



Proposed Method



Quality Improvement Across Different Count Levels



Summary and Future Directions

- We have shown the feasibility of a PET-enabled dual-energy spectral CT imaging method
- Many more algorithm development opportunities
 - PET-enabled spectral CT (PS-CT) imaging (511 keV, 307 keV, 202 keV γ -rays and ≤ 140 keV x-ray)
 - Super-resolution PS-CT
 - Synergistic and direct reconstructions

Acknowledgements

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- MATLAB code to be released at:

<https://wanglab.faculty.ucdavis.edu/code>