Structure-Preserving Dual-Energy CT (SPDE)

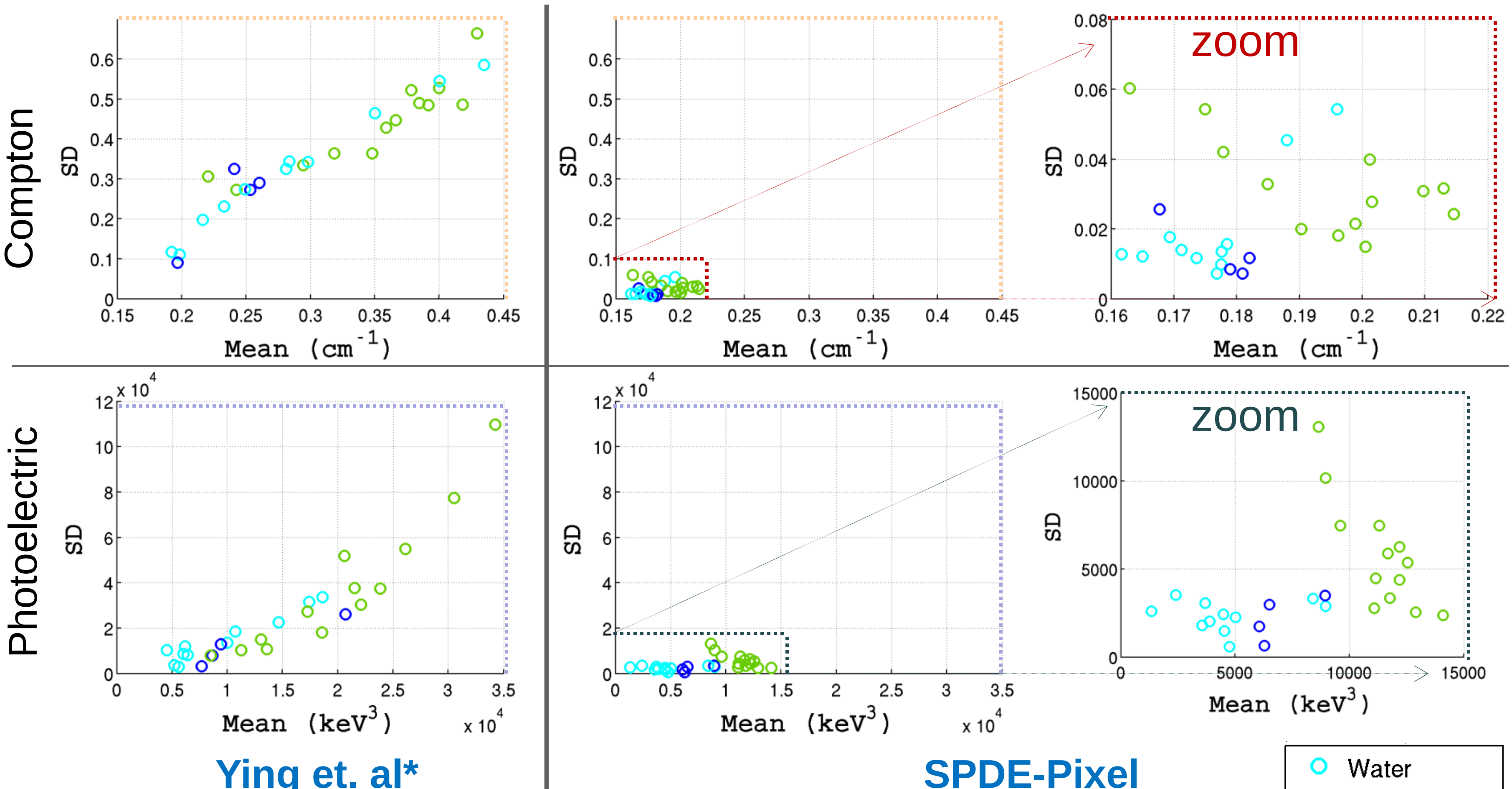
Limor Martin and W. Clem Karl

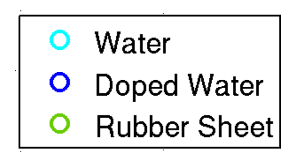
TO3 Project Review

Oct. 24th 2013

BOSTON UNIVERSITY

SPDE-Pixel Performance: SD vs. Mean of Compton and Photoelectric

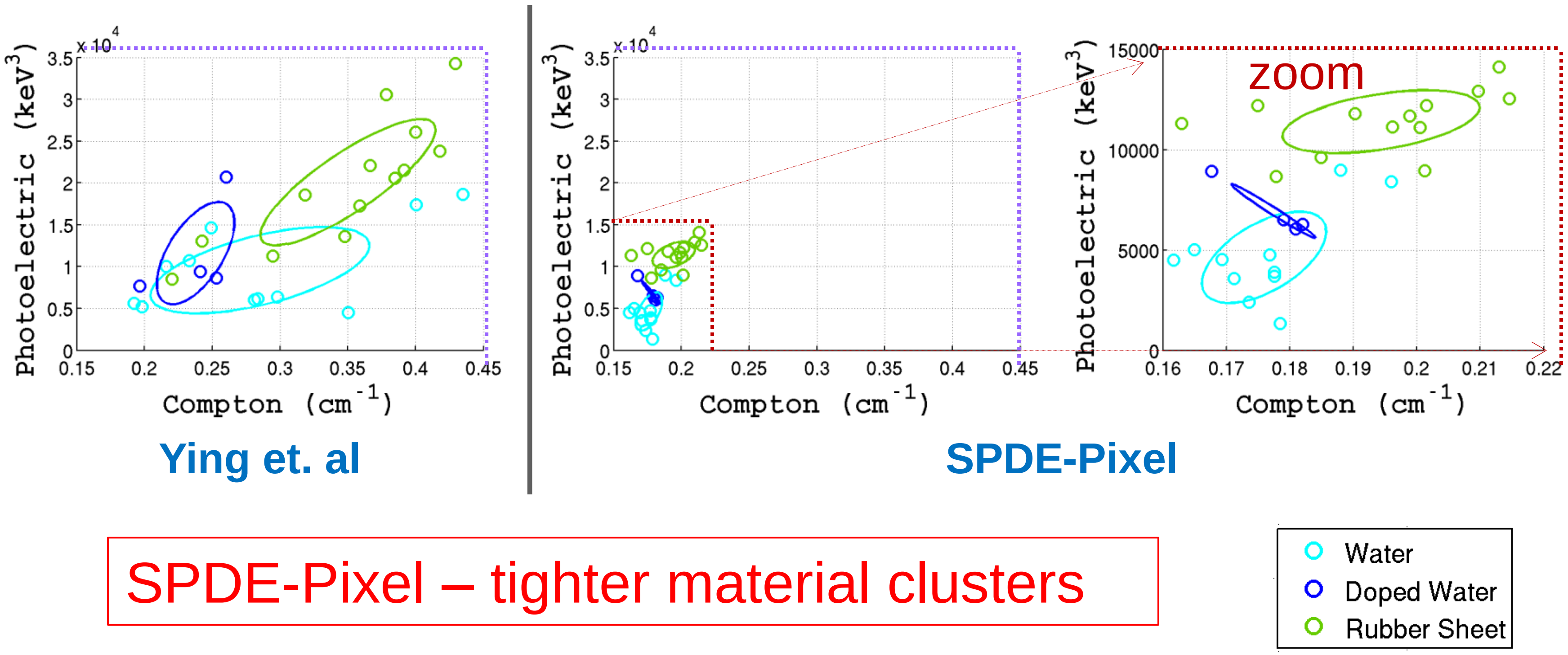




SPDE-Pixel - lower SD, better mean separation

* Z. Ying, R. Naidu and C. Crawford, �Dual Energy Computed Tomography for Explosive Detection,� Journal of X-ray Science and Technology 14 (2006), pp 235-256.

SPDE-Pixel Performance: Photoelectric mean vs. Compton mean



SPDE-Pixel – tighter material clusters

SPDE-Pixel Results

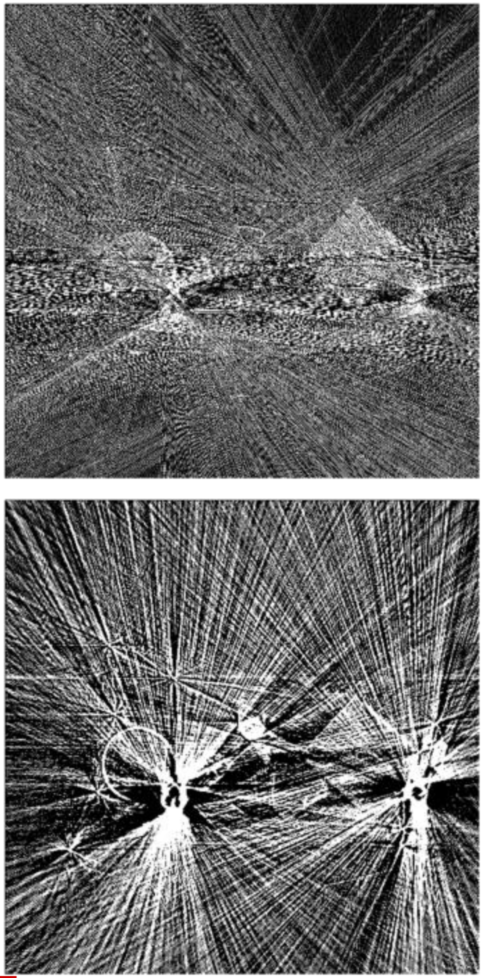
Ying et. al | **SPDE-Pixel**

Compton

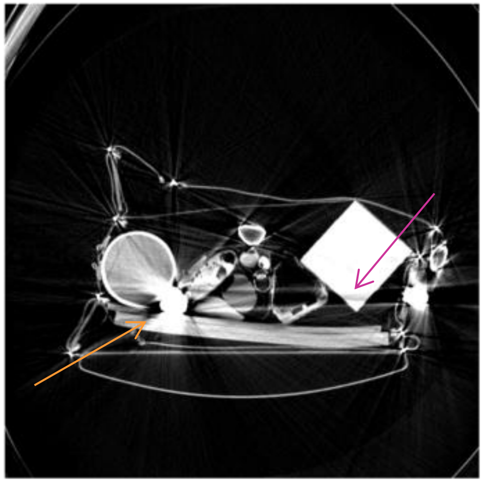
WL/WW
0.15/0.3

Photoelectric

WL/WW
5500/9000



Xrec 130KV



WL/WW
-250/1500

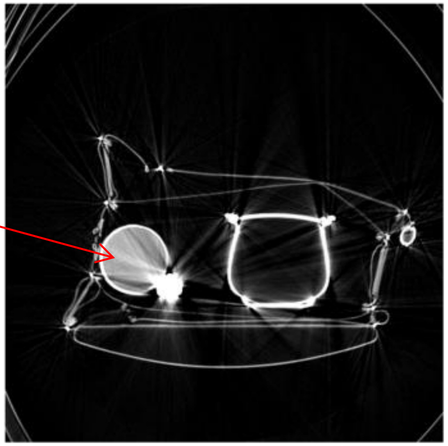
SPDE-Pixel - Reduced noise and metal artifacts

(High Clutter 1 Slice 220)

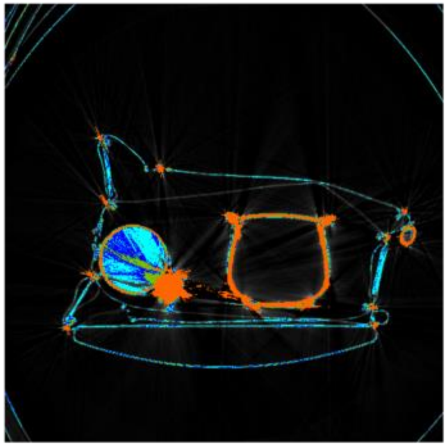
SPDE Direct Object-based labeling

Metal corrupts nearby object properties

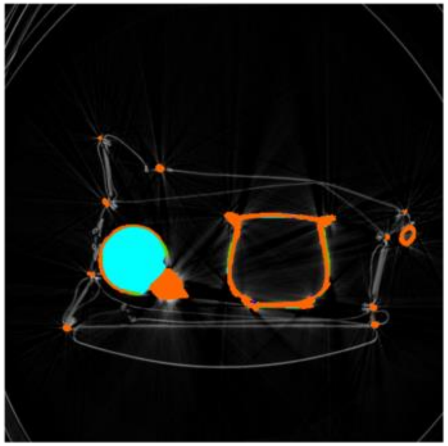
130KV Xrec image



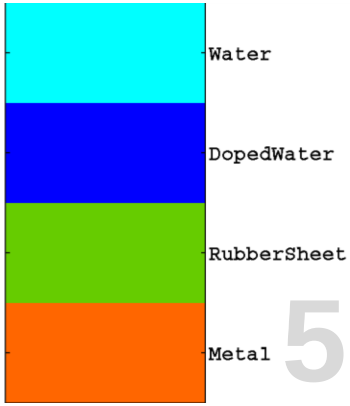
DE likelihood based labeling



SPDE-Object



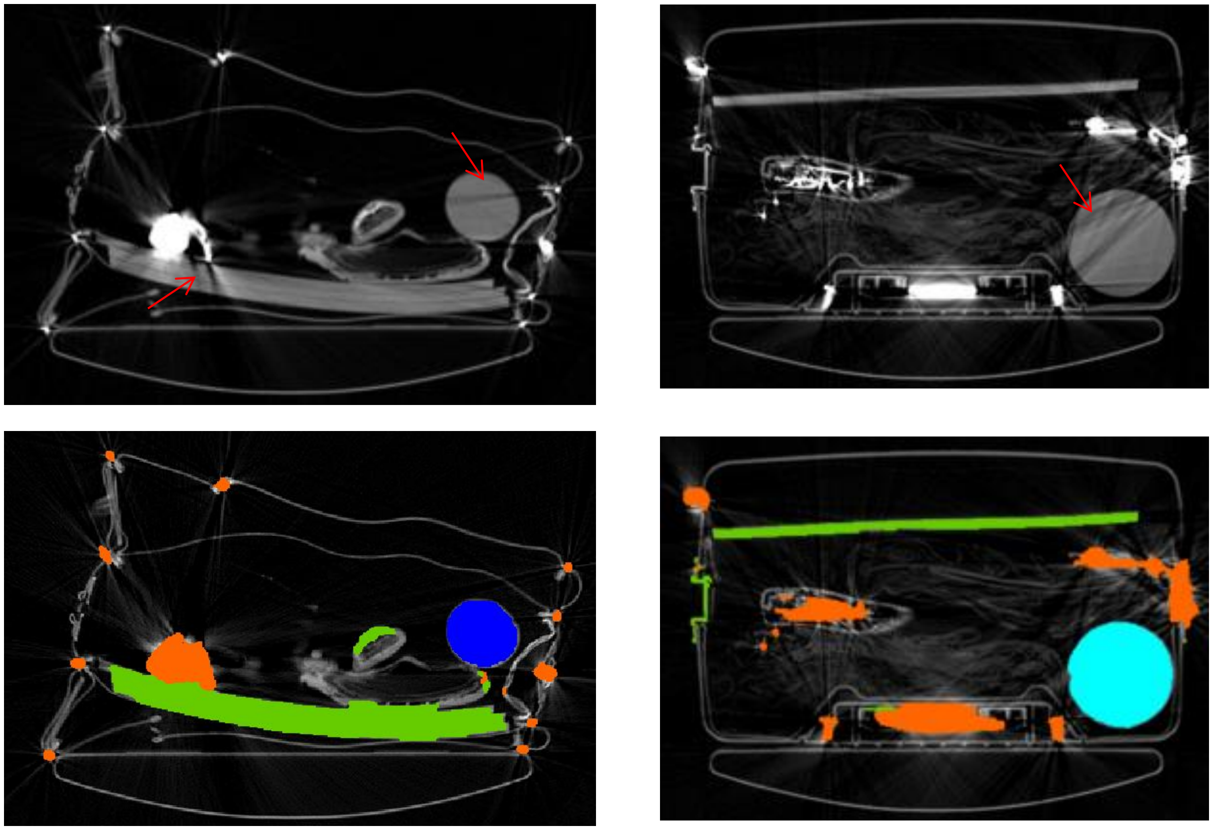
- In general, Photo-Compton images not used for segmentation
- Idea: Directly estimate object labels and boundaries from dual-energy data
- Approach: metal class, explicit boundary model, homogeneous object model, downweight data near metal



SPDE-Object Results

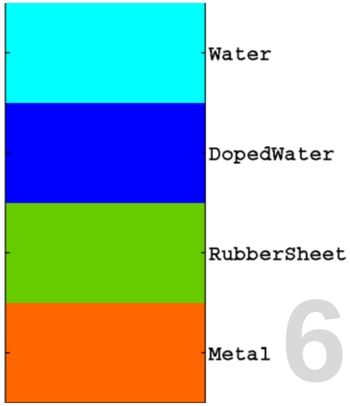
Xrec 130KV

SPDE-Object



(High Clutter 1 Slice 299) (Medium Clutter 1 Slice 281)

Object localization and labeling robust to streaks and presence of metal



BU Team

Limor Martin, M.S.
Ph.D. Candidate
Expected graduation: Jan. 2014

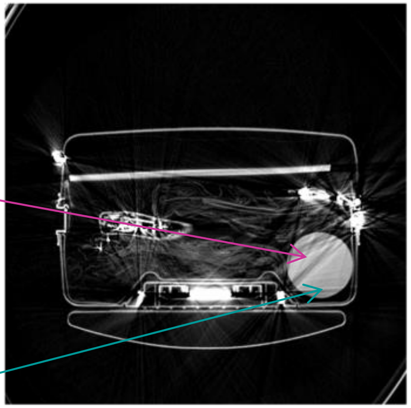
W. Clem Karl, Ph.D.
Prof. of Electrical and Computer Engineering

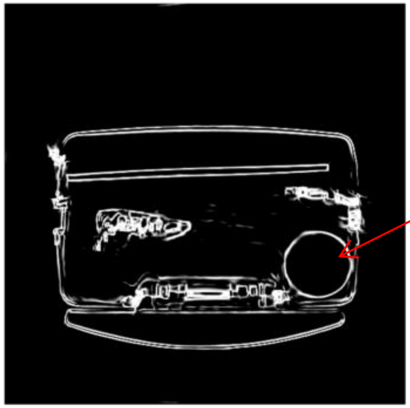
Information Sciences and Research (ISS) Group
Research, education, and technology transfer in all areas related to the sensing, communication, and processing of information

SPDE Method Description

Data weighting for metal effect mitigation

Markov field for smooth properties





Explicit boundary field to improve localization, reduce artifacts

Pixel-Based	**Object-Based**
▪ Form photoelectric and Compton pixel property images ▪ Nonlinear tomographic inversion	▪ Direct formation of material-label image from dual-energy images ▪ Learn appearance models from training data ▪ Efficient graph-cut framework for optimization

Formulation of SPDE-Pixel

Observed 130 and 95 data sinograms — Photoelectric and Compton sinograms — Photoelectric and Compton images

$$\underset{(y_p, y_c, x_p, x_c, s)}{\text{minimize}} \quad \underbrace{||z_1 - f_1(y_p, y_c)||_2^2 + ||z_2 - f_2(y_p, y_c)||_2^2 + ||y_p - Tx_p||_{W_z}^2 + ||y_c - Tx_c||_{W_z}^2}_{\text{Data}}$$

$$+ \underbrace{\lambda_1 ||Dx_p||_{W_s}^2 + \lambda_2 ||Dx_c||_{W_s}^2 + \lambda_3 ||x_p||_2^2 + \lambda_4 ||x_c||_2^2 + \lambda_5 ||Ds||_2^2 + \lambda_6 ||s||_2^2}_{\text{Prior}}$$

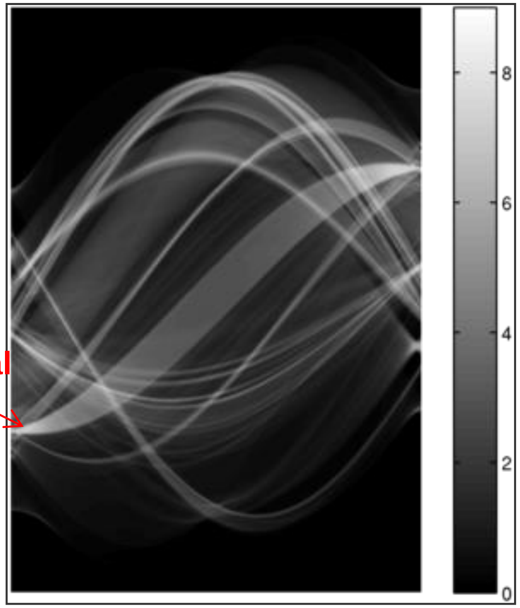
$$\text{subject to } y_p, y_c, x_p, x_c \geq 0$$

Mutual object boundary

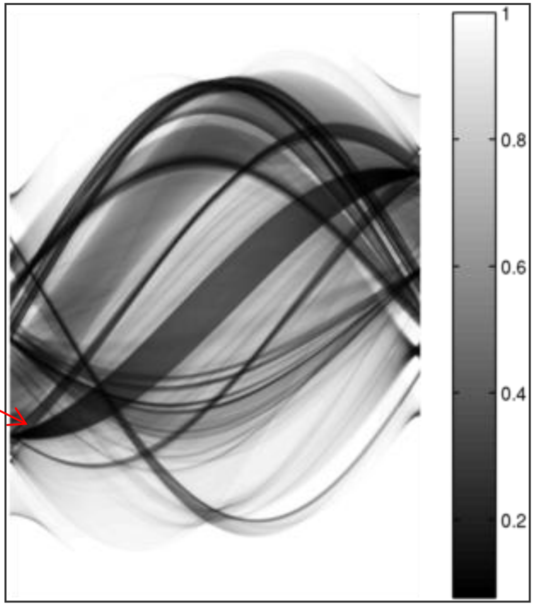
- Edge-preserving prior
- Iterative solution via coordinate descent
- Splitting-based, using auxiliary variables

Low weights to rays through metal

Ray going
through metal

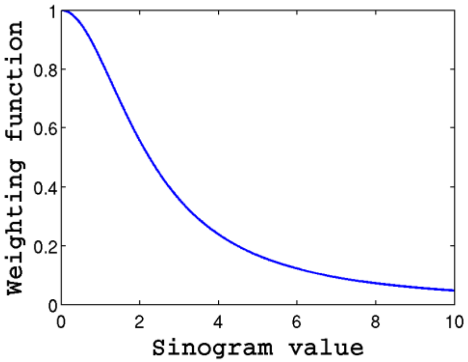


130KV sinogram

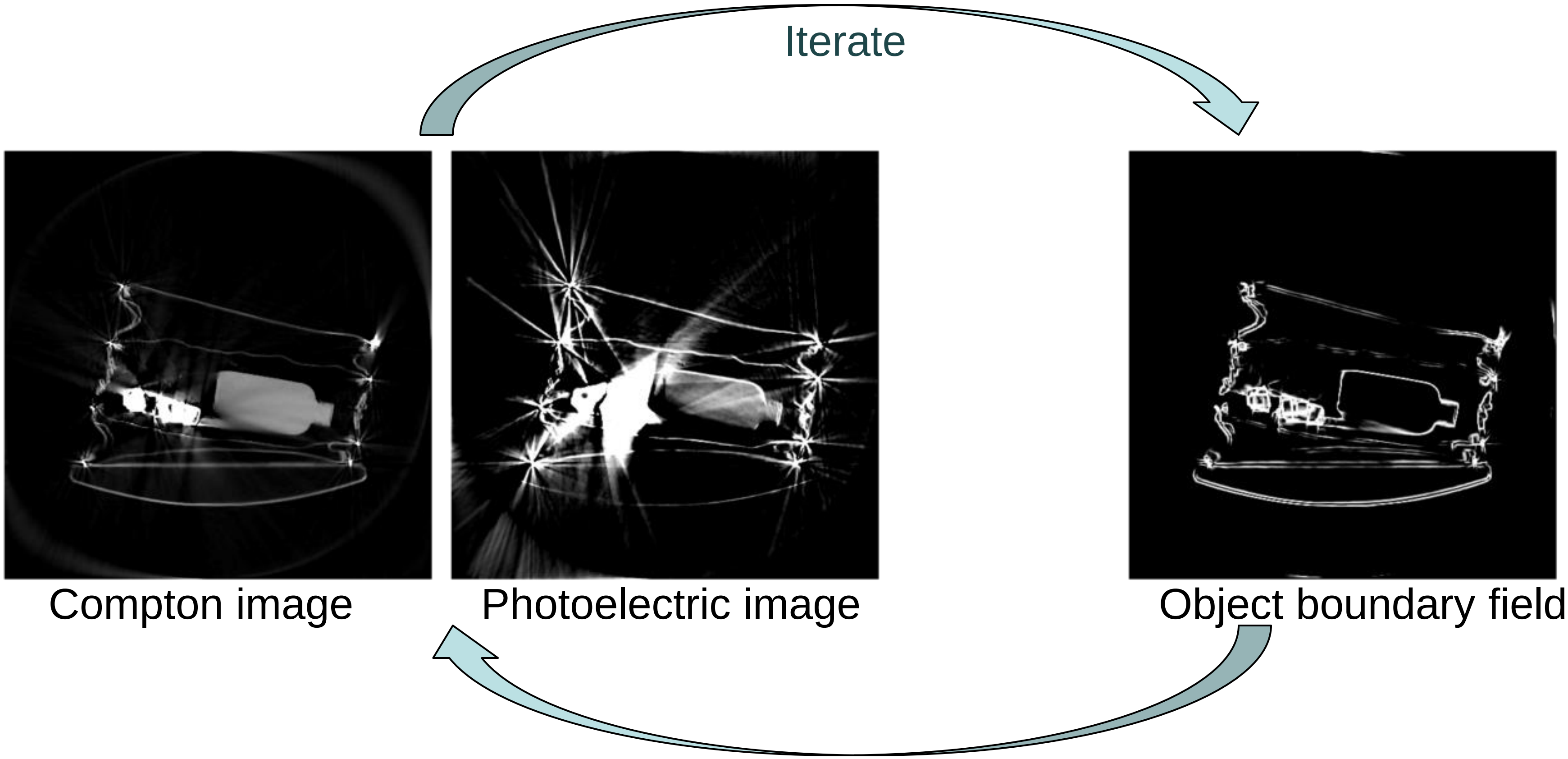


Corresponding data weights

Data-weighting function



Smoothing with mutual object boundary

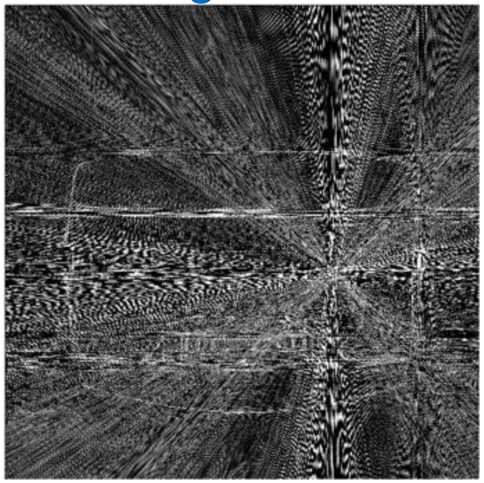


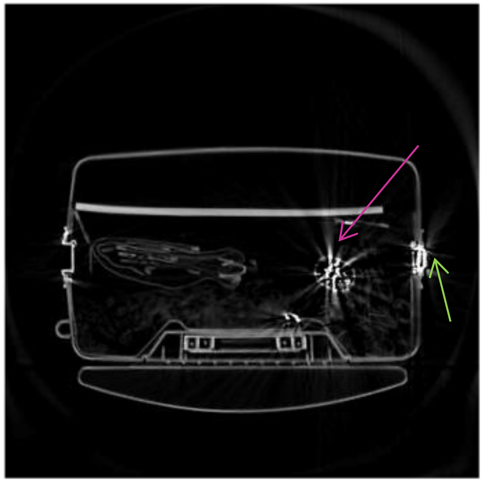
Smooth inside objects while retaining object boundaries

SPDE-Pixel Results

Ying et. al | **SPDE-Pixel**

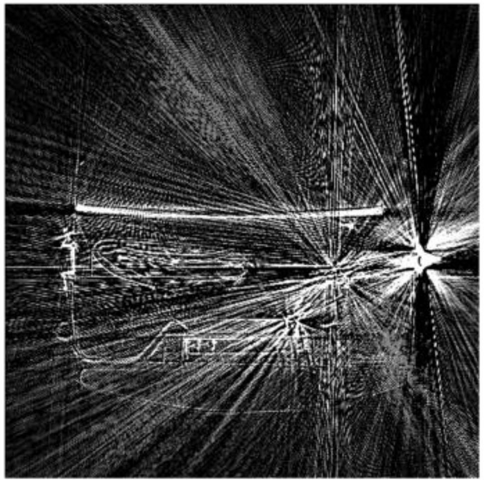
Compton





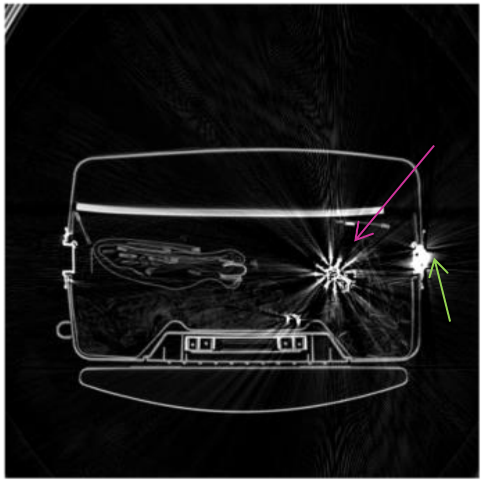
WL/WW
0.15/0.3

Photoelectric



WL/WW
5500/9000

Xrec 130KV



WL/WW
-250/1500

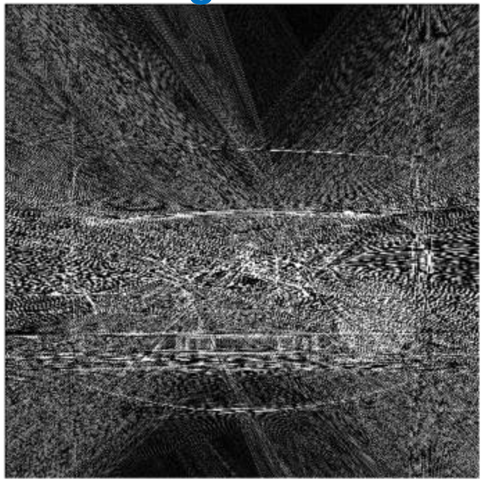
Metal is more contained

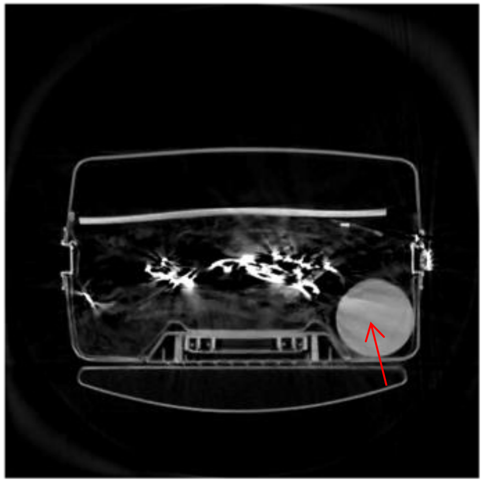
(Medium Clutter 1 Slice 123)

SPDE-Pixel Results

Ying et. al | **SPDE-Pixel**

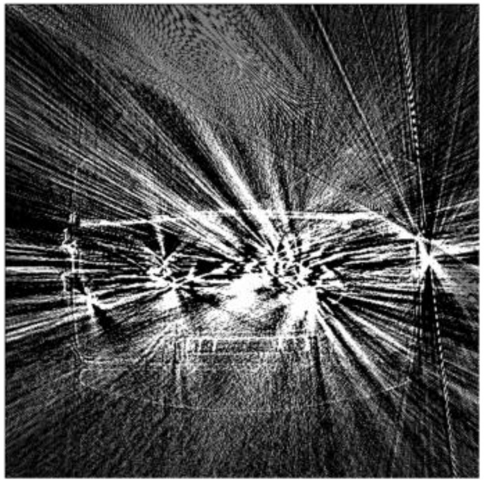
Compton

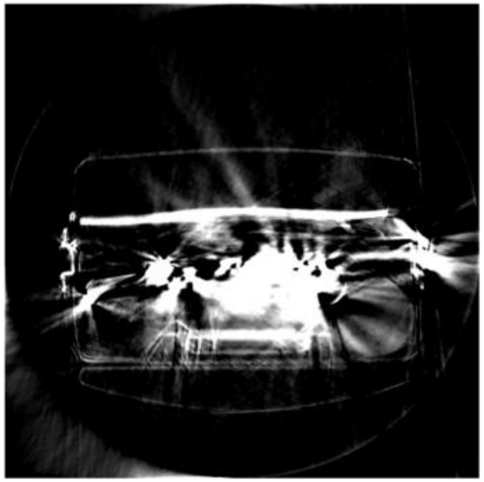




WL/WW
0.15/0.3

Photoelectric





WL/WW
5500/9000

Xrec 130KV

WL/WW
-250/1500

Reduced streaks

(Medium Clutter 1 Slice 231)

SPDE-Pixel Results

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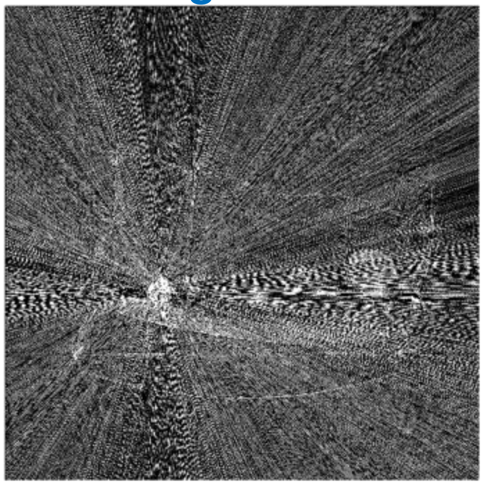
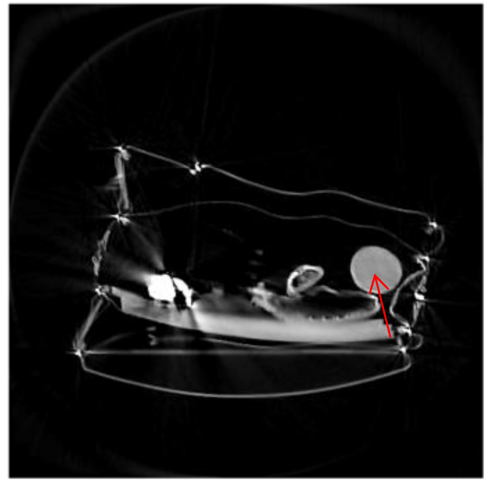
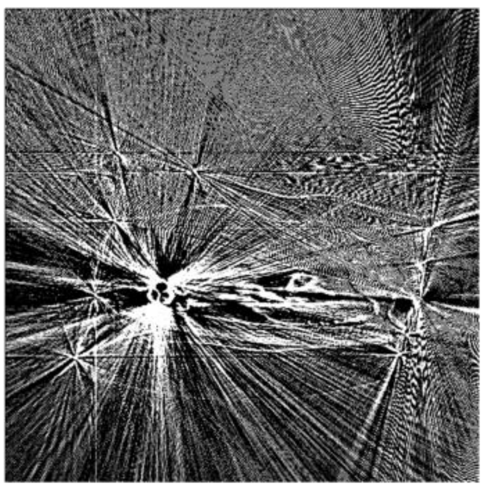
Compton

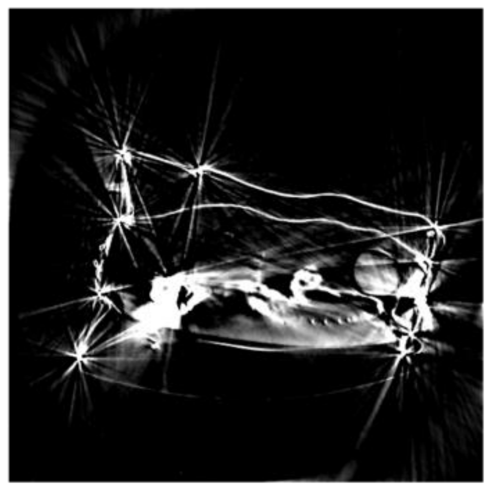




WL/WW
0.15/0.3

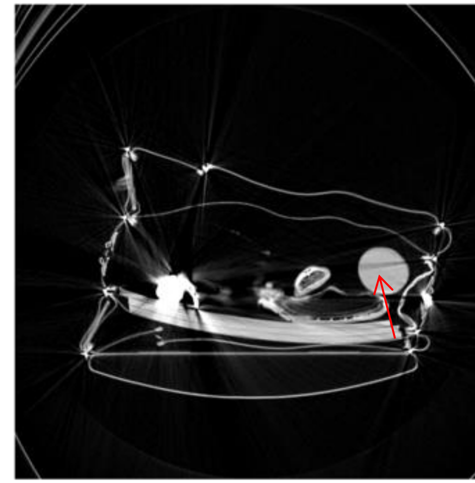
Photoelectric





WL/WW
5500/9000

Xrec 130KV



WL/WW
-250/1500

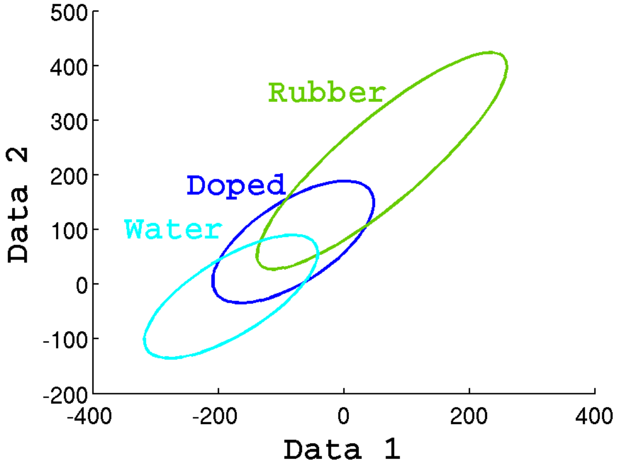
Smoothing inside objects while retaining boundaries

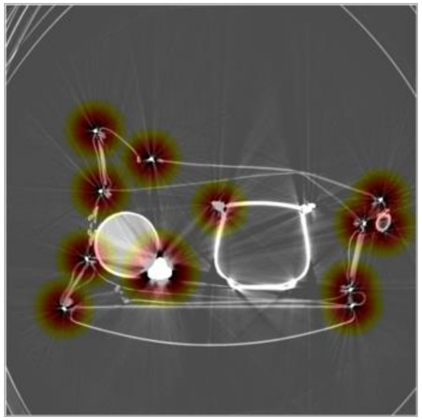
(High Clutter 1 Slice 299)

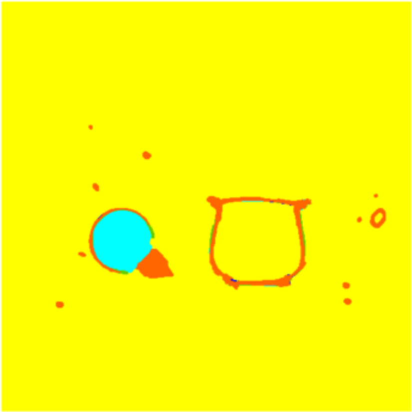
Formulation of SPDE-Object

1) Learn appearance models from dual-energy data

2) Down-weight data close to metal







$$\underset{l}{\text{minimize}} \sum_{i=1}^{n} v_i \left(-\ln p(u_i|l_i)\right) + \lambda \sum_{\{i,j\}\in\mathcal{N}} \mathbb{1}\{l_i \neq l_j\} \left(\frac{1}{|s_i - s_j|}\right)$$

such that $l_i \in \{1, ..., m\}$

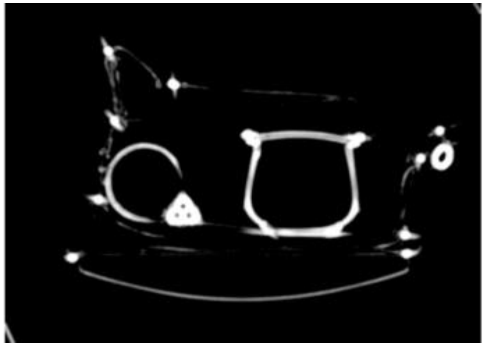
Formulation of SPDE-Object

3) Object boundary controls smoothing:

- Smooth in areas far from an edge
- Don't smooth across an edge

4) Efficient solution using Graph-Cuts

Boundary-field



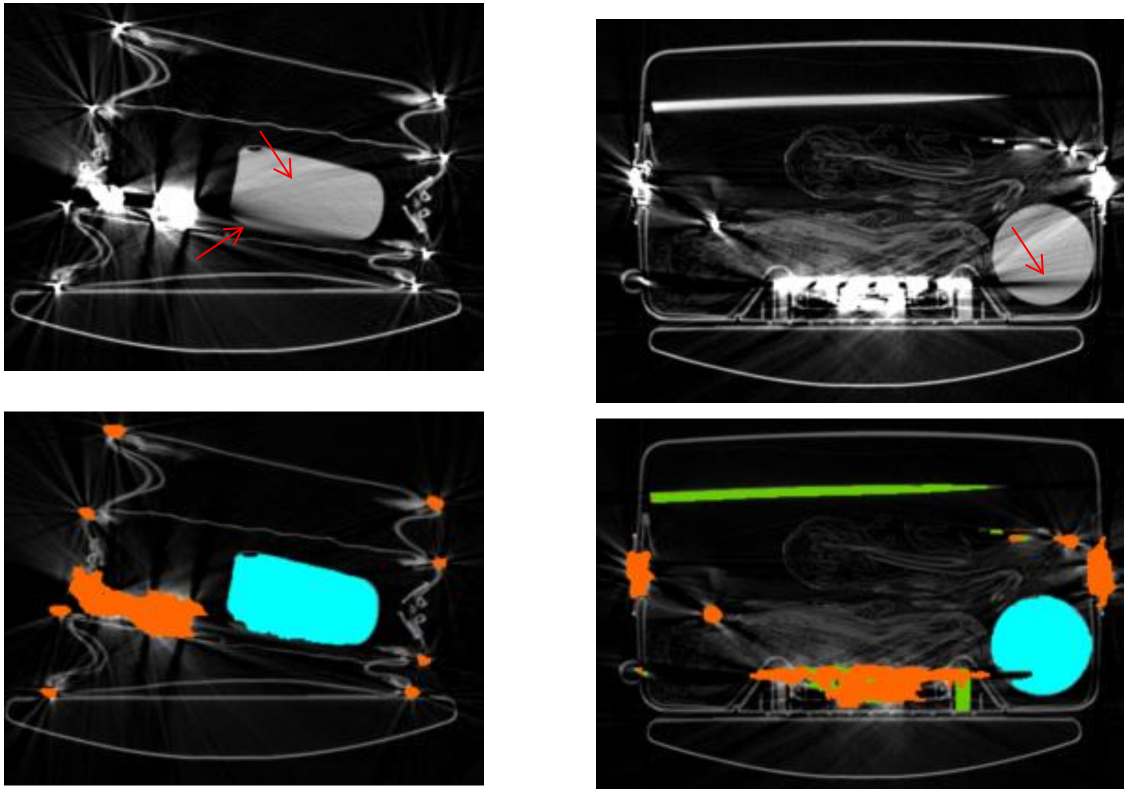
$$\underset{l}{\text{minimize}} \quad \sum_{i=1}^{n} v_i \left(-\ln p(u_i|l_i)\right) + \lambda \sum_{\{i,j\}\in\mathcal{N}} \mathbb{1}\{l_i \neq l_j\} \left(\frac{1}{|s_i - s_j|}\right)$$

$$\text{such that } l_i \in \{1, ..., m\}$$

SPDE-Object Results

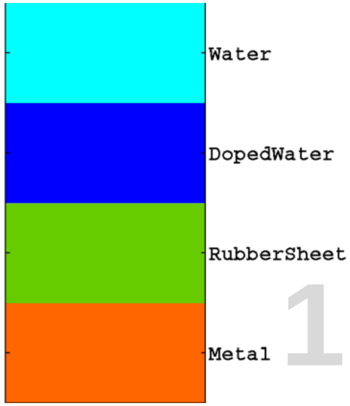
Xrec 130KV

SPDE-Object



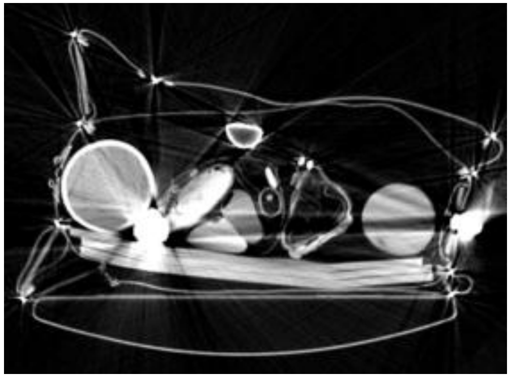
(High Clutter 1 Slice 362) (Medium Clutter 1 Slice 295)

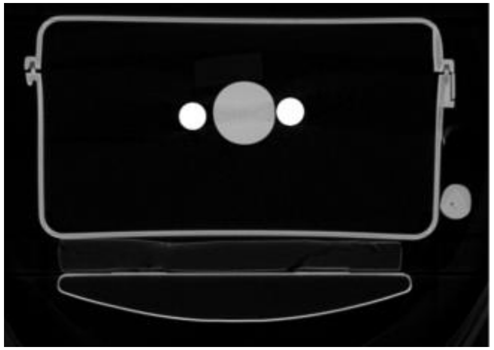
Successful direct labeling from dual energy data in presence of metal, shading, streaking



SPDE-Object Results

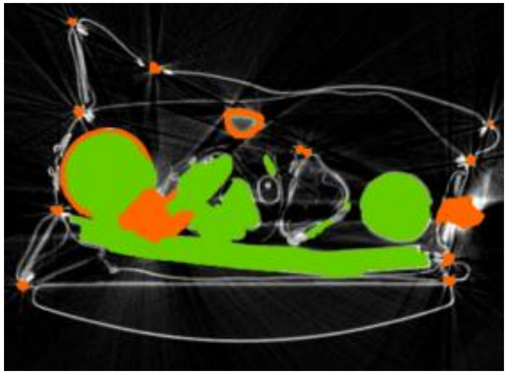
Xrec 130KV

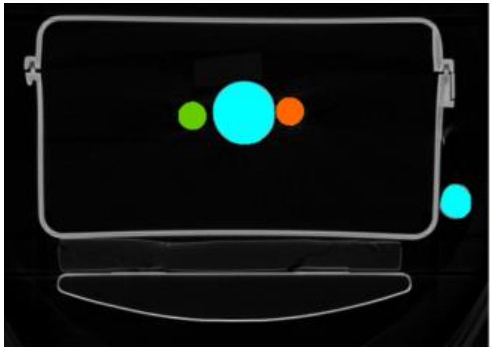


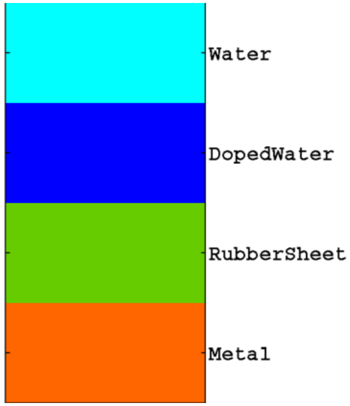


In presence of artifacts objects may be mislabeled, but localization is still good.

SPDE-Object







(High Clutter 1 Slice 239)

(LLNLPC 1b Slice 090)

SPDE Strengths and Weaknesses

Strengths:

- Pixel-based method reduces noise and metal artifacts in photoelectric and Compton coefficient images while keeping boundary localization
- Object-based method provides and accurate object segmentation and labeling even in the presence of significant streaks

Weaknesses:

- Parameter tuning is time consuming
- Need accurate tomographic model
- SPDE-Pixel is computationally expensive
- Need sufficient training data

Recommendation for Future Work

- Combine pixel-based and object-based methods in unified framework for improved image quality and accurate material labeling
- Study performance with features different than photoelectric and Compton (e.g. learned features)
- Extend method to more than two energies and other sensing modalities

Acknowledgements

- Collaborators at BU: Dr. Prakash Ishwar and Ahmet Tuysuzoglu.
- Imatron forward projection matrix provided by Pengchong Jin, Purdue.
- Imatron source spectra provided by Dr. Taly Gilat Schmidt, Marquette.