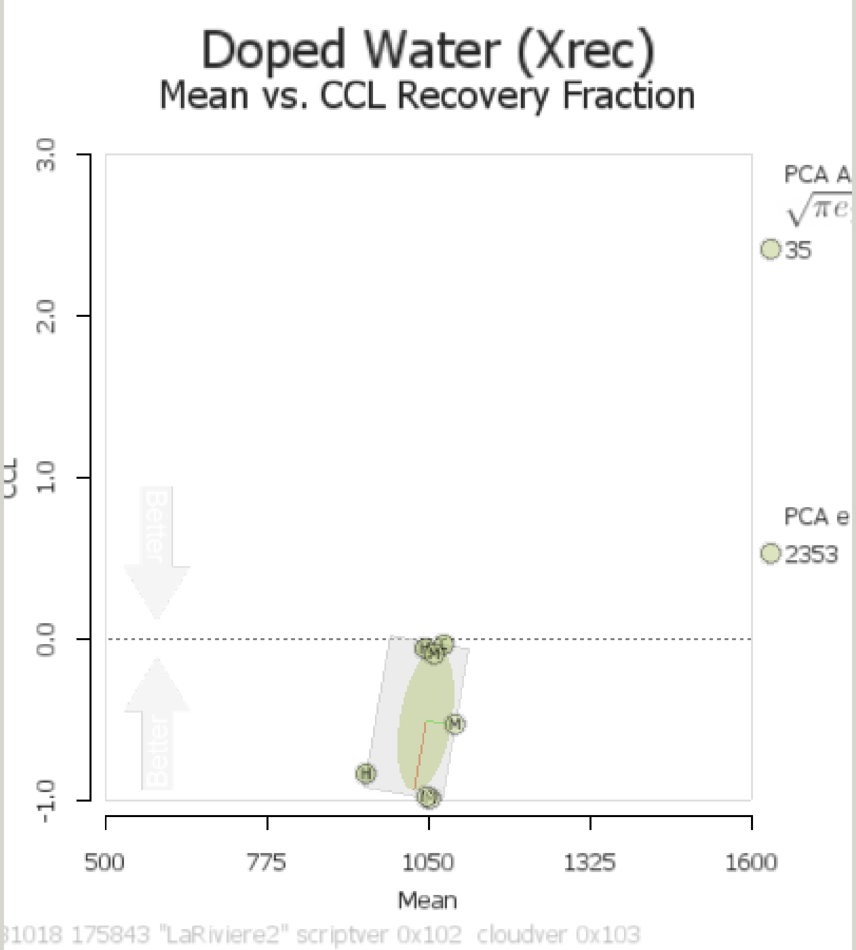
ALERT Reconstruction Initiative TO#3: Sinogram processing

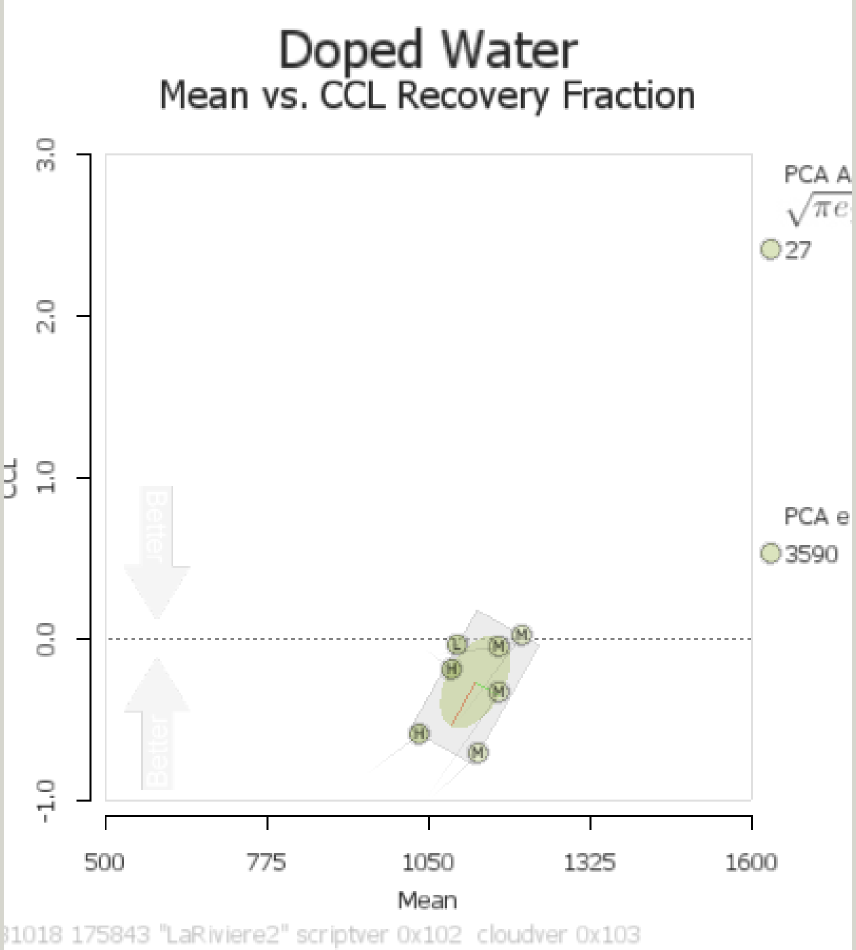
Patrick J. La Rivière and Phillip A. Vargas

October 24, 2013

Doped water CCL



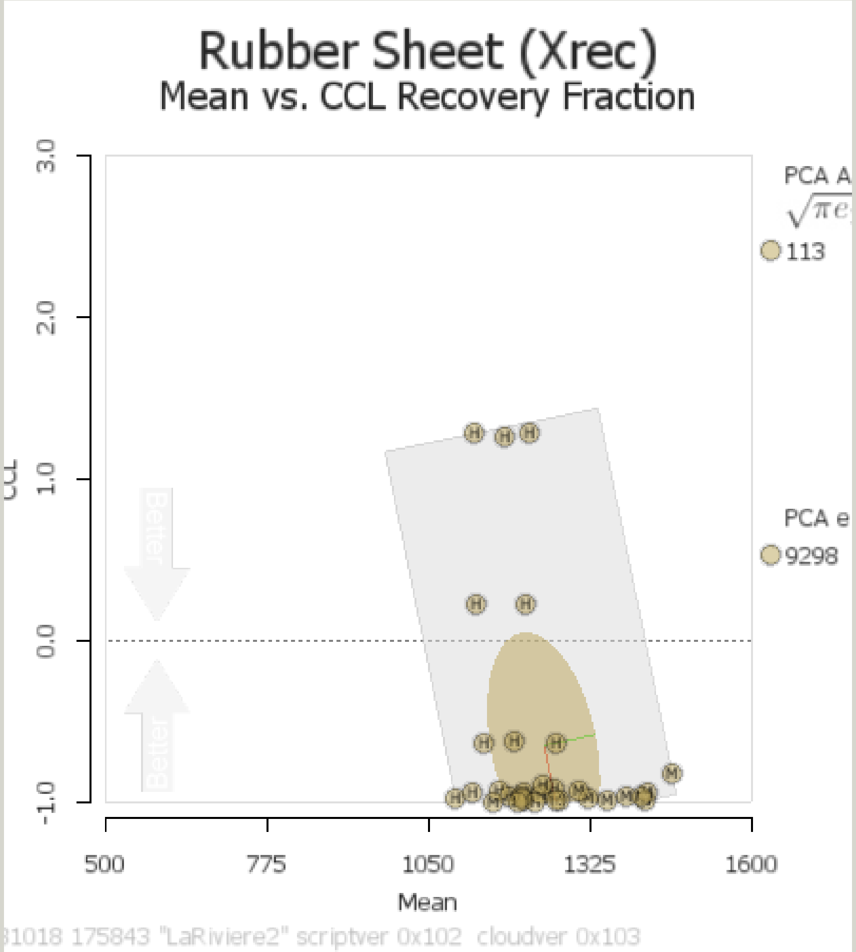
Doped Water (Xrec)
Mean vs. CCL Recovery Fraction

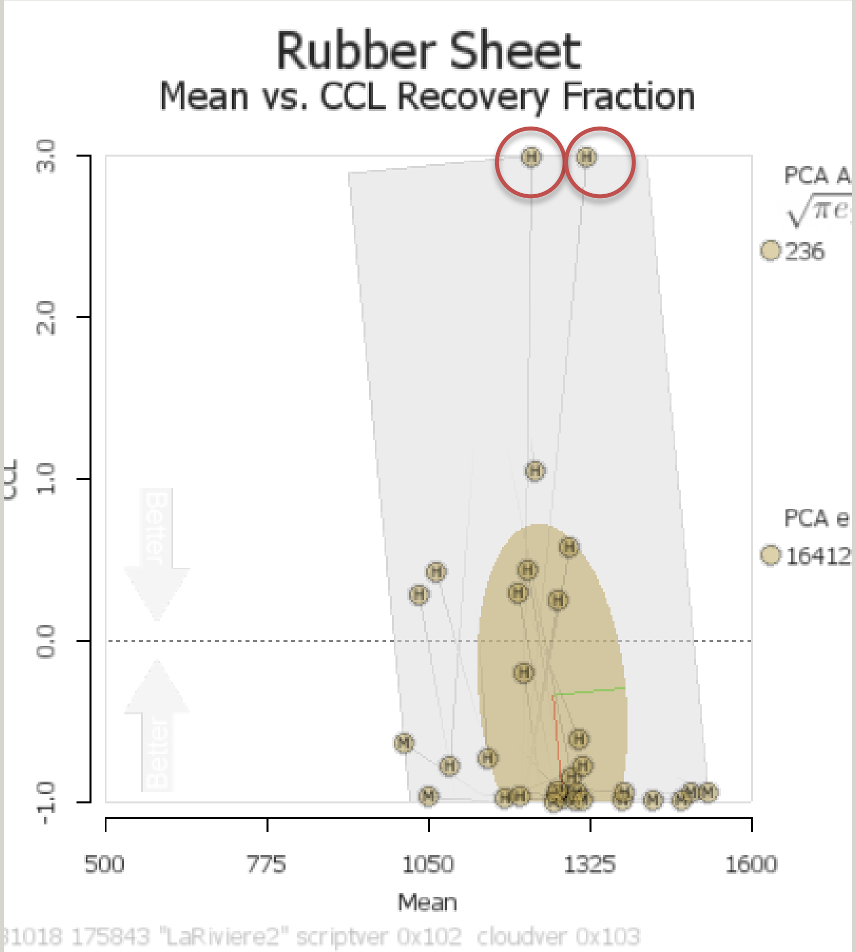


Doped Water
Mean vs. CCL Recovery Fraction

Doper water CCL segmentation is improved.

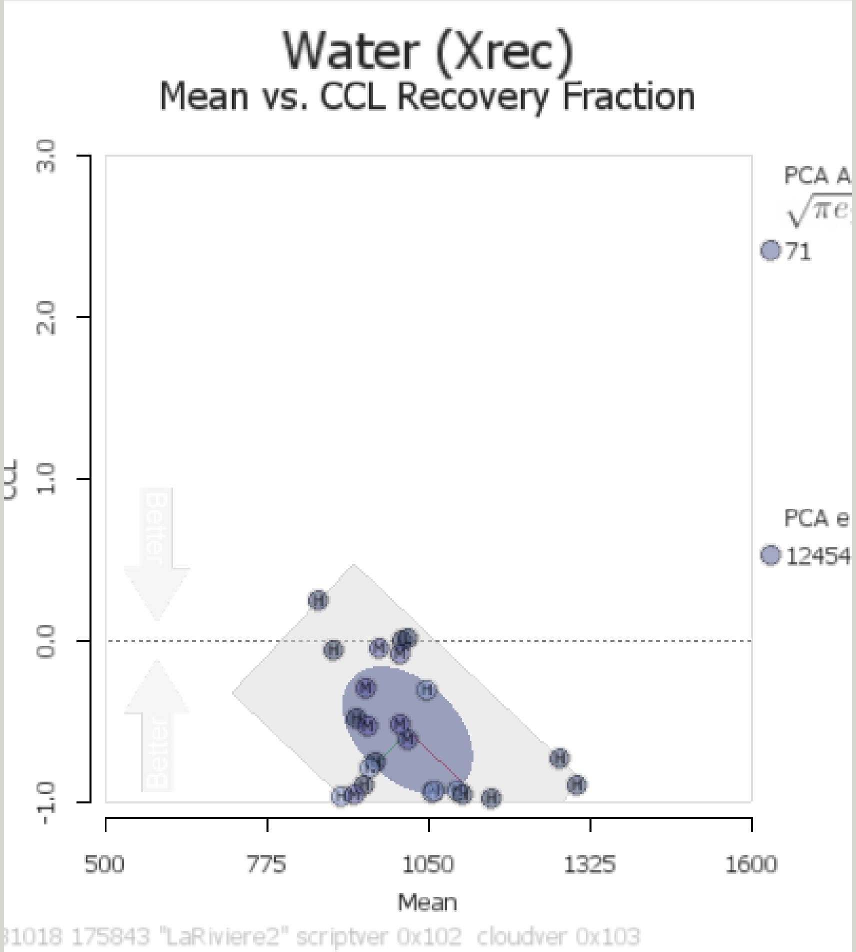
Rubber sheet CCL

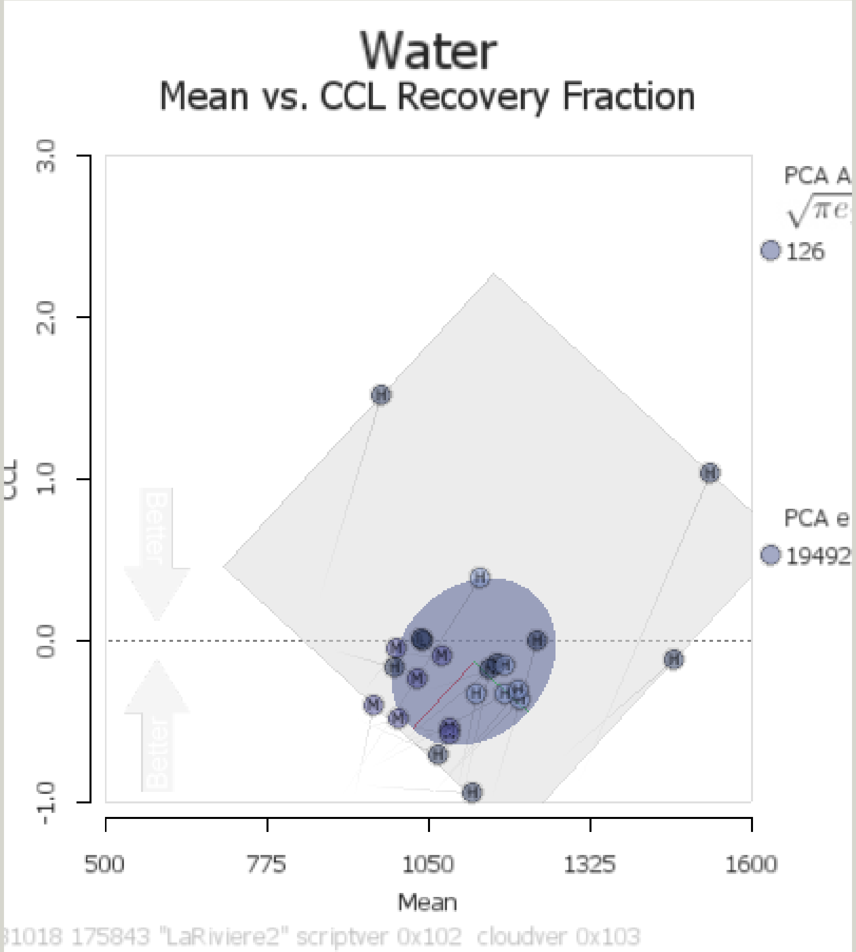




Sheet CCL seems to suffer from two outliers (red circles).

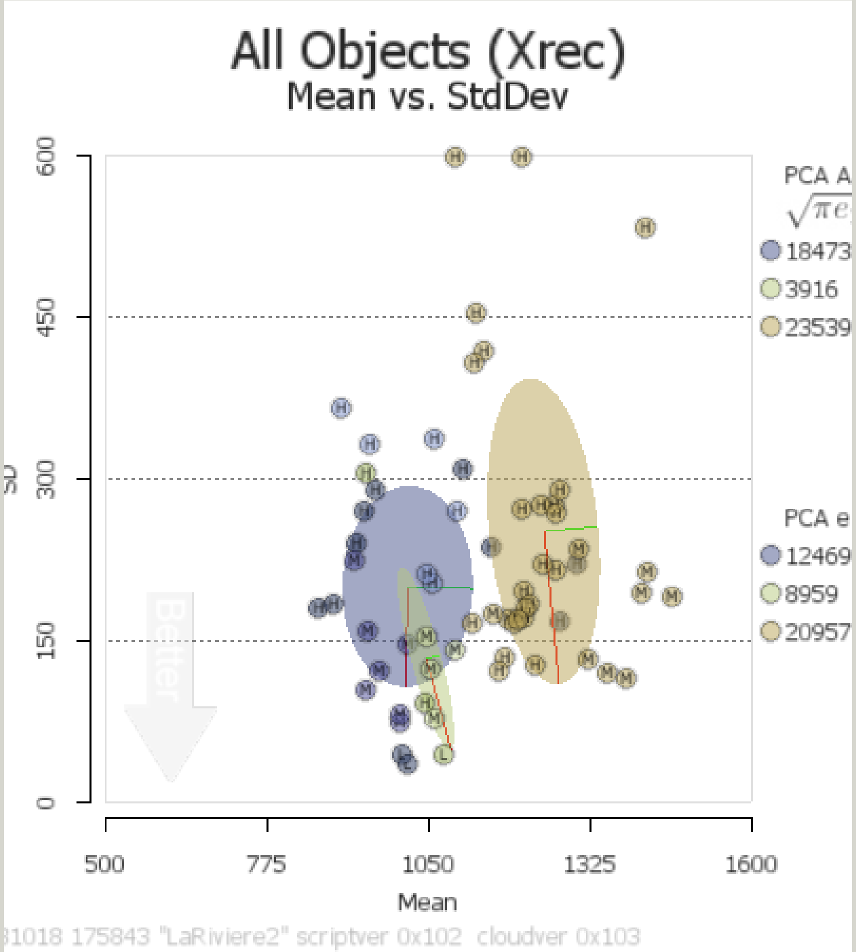
Water CCL

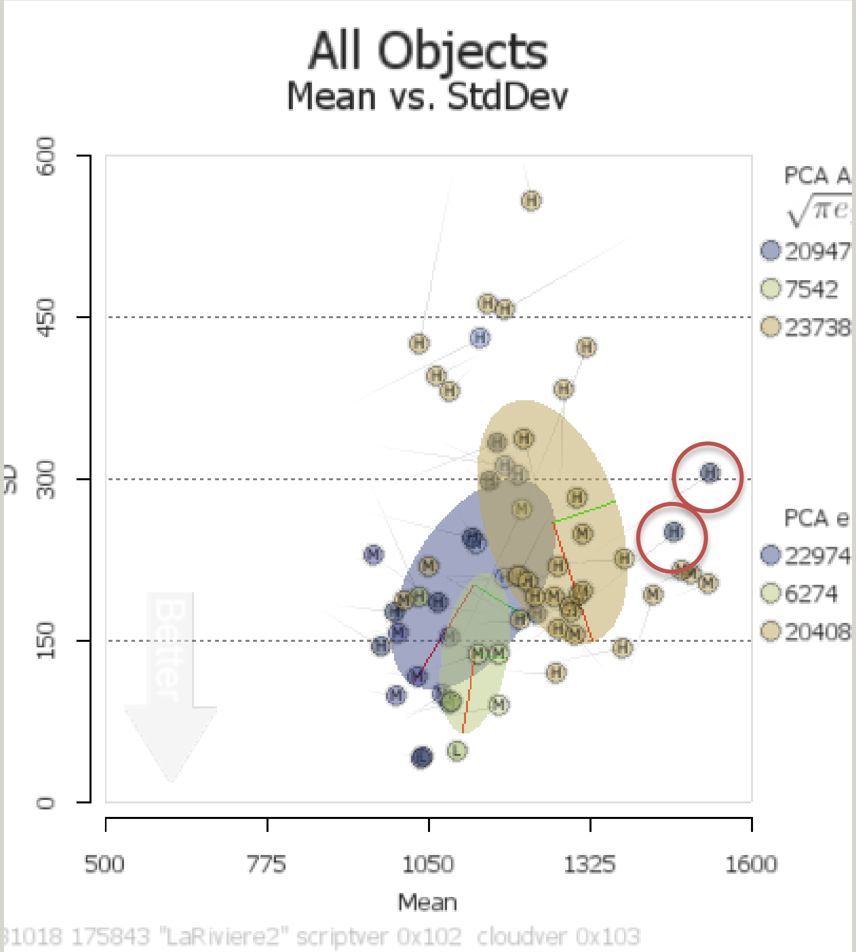




Water CCL performance is improved.

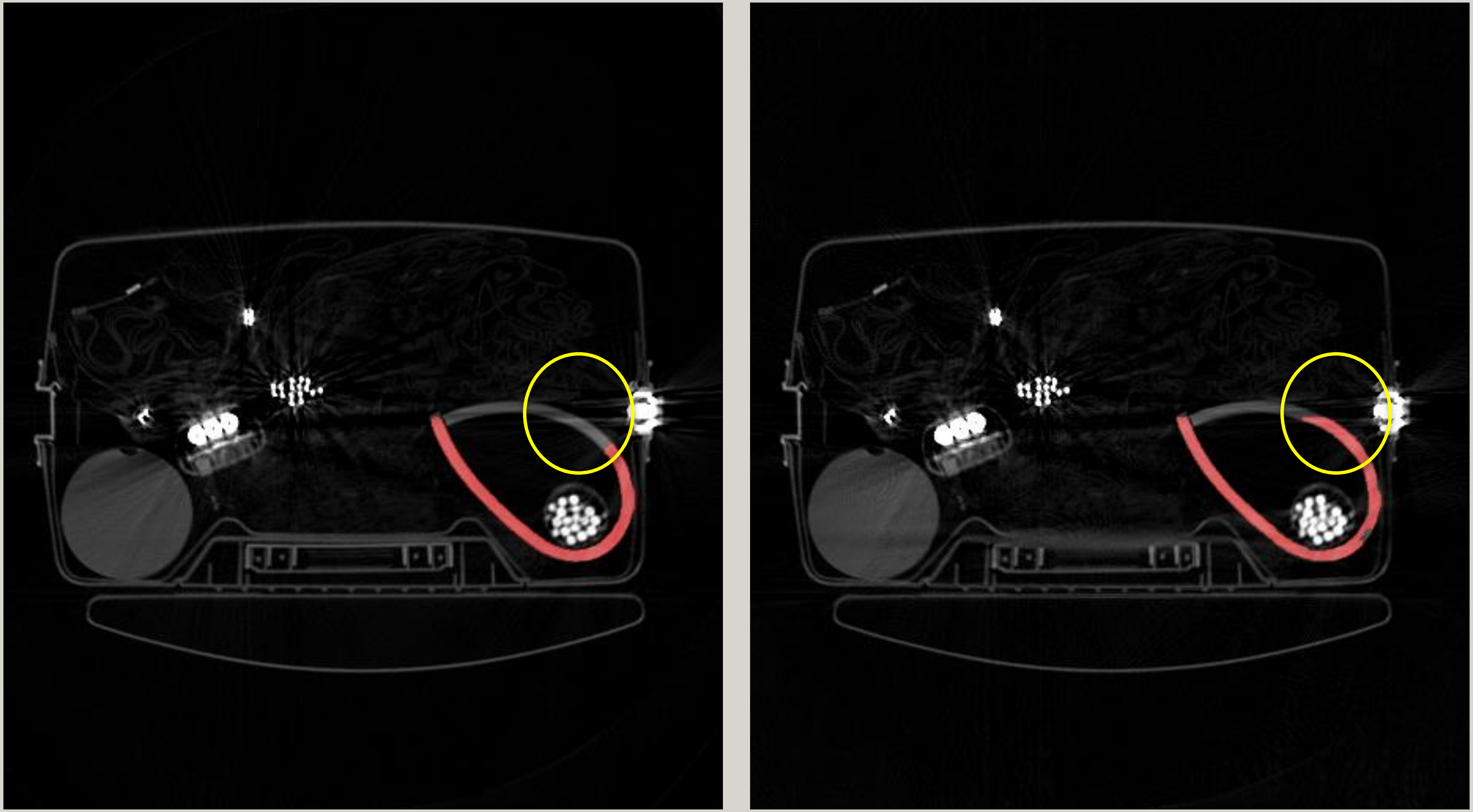
Mean vs Std Dev.





Our water cloud suffers from two outliers (red circles).

Sheet Segmentation improvement

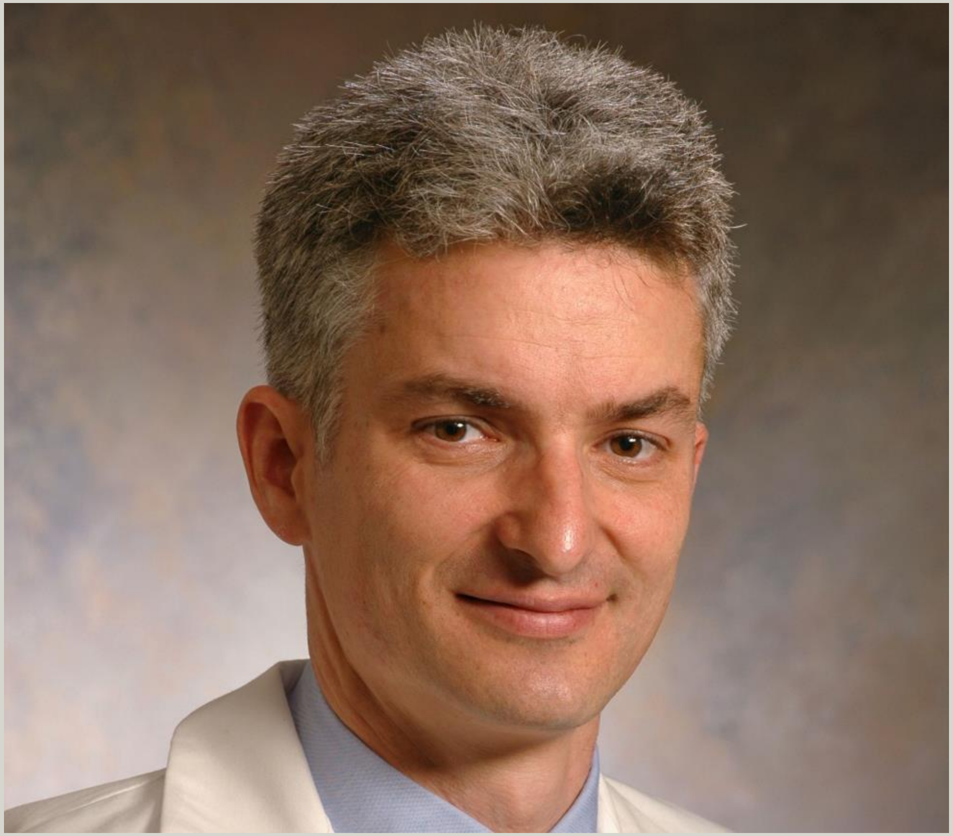


XREC

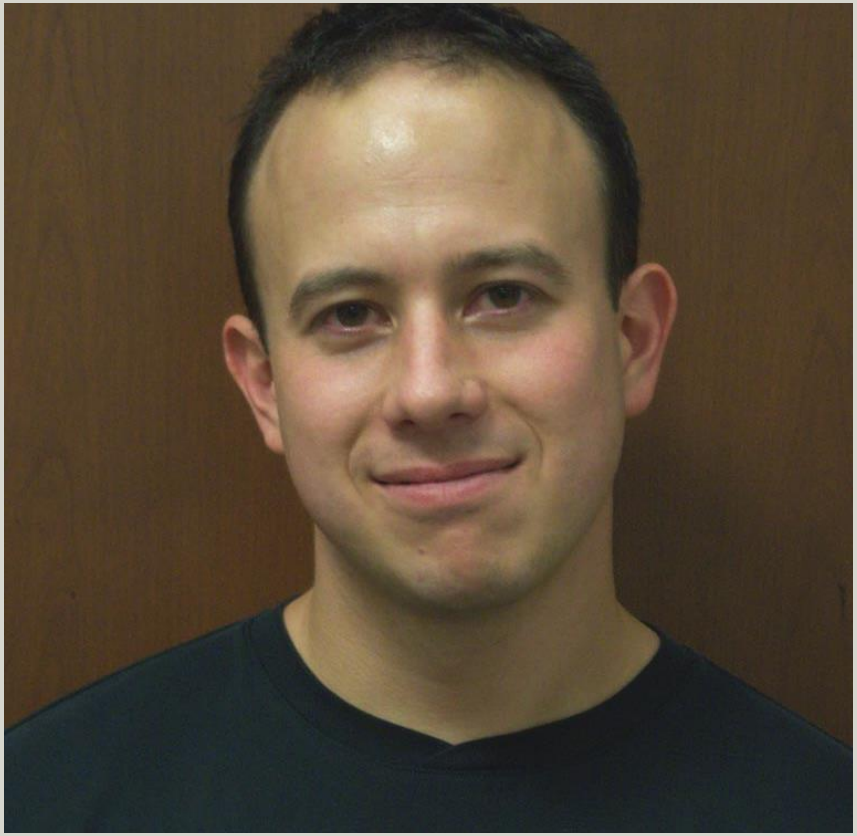
Sinogram prcessing

Medium clutter 4, slice 134

Institution and Researchers



- Patrick La Riviere, Ph.D.
- Associate Professor of Radiology
- The University of Chicago



- Phillip Vargas, M.S.
- Assistant Professor, Harold Washington Community College
- Part-time research specialist, U of Chicago

Algorithm

Adaptive Filter

FSMAR

Sinogram Restoration

Analytic recon

Generalized multi-dimensional adaptive filter

- Mark Kachelriess, et al., Med. Phys., 28:475.
- Noise reduction

Frequency Split Metal Artifact Reduction

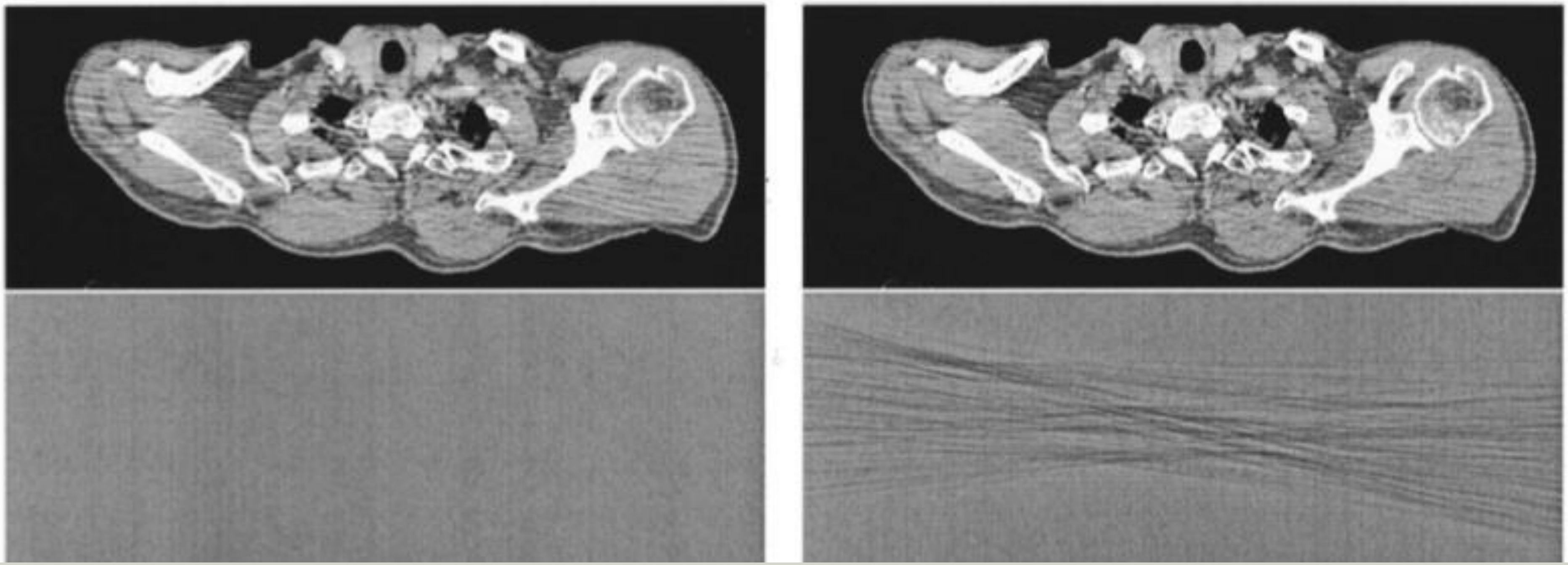
- Esther Meyer et al., Med. Phys., 39, p. 1904.
- Streak reduction

Sinogram restoration

- Patrick La Rivière et al., IEEE TMI, 25, p. 1022.

Analytic reconstruction (grdding-based)

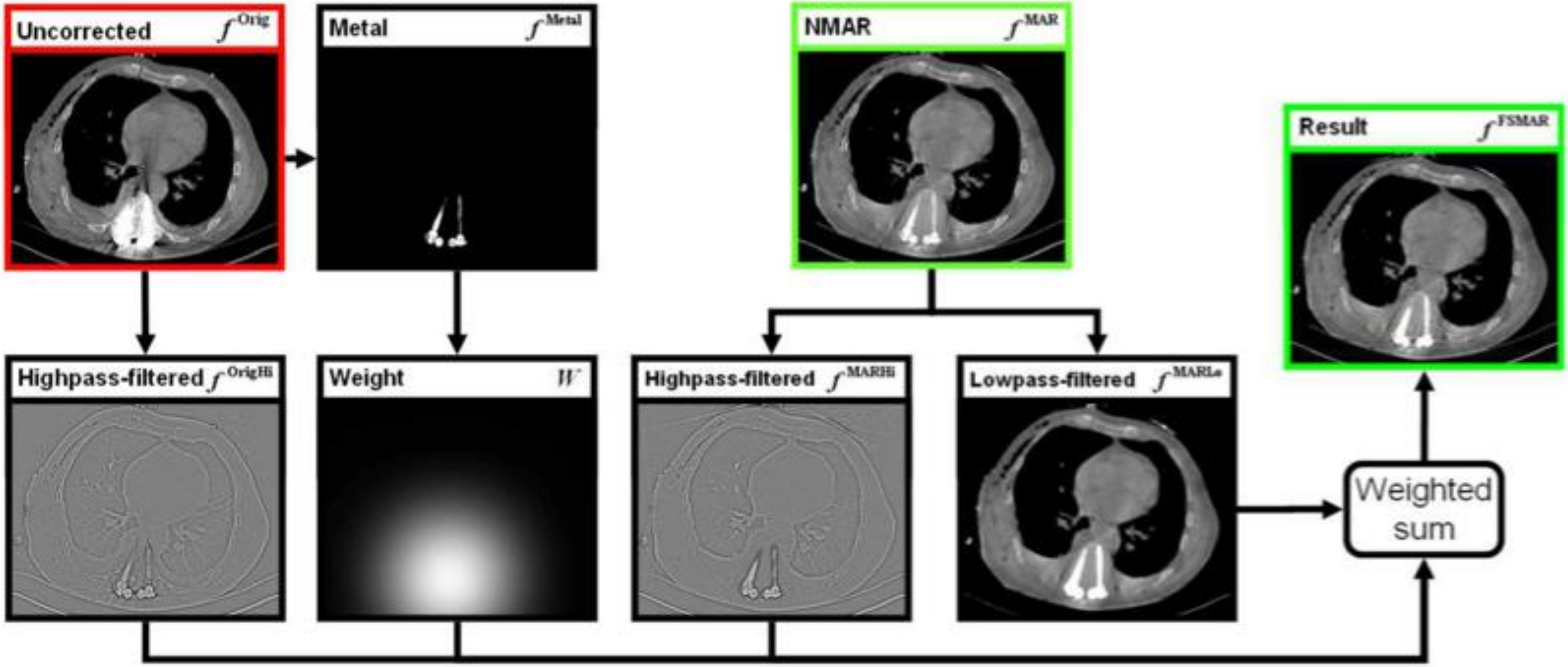
Adaptive filtering



Removes worst noise spikes from line integrals by neighborhood smoothing.

Figure from: Mark Kachelriess, et al., Med. Phys., 28:475.

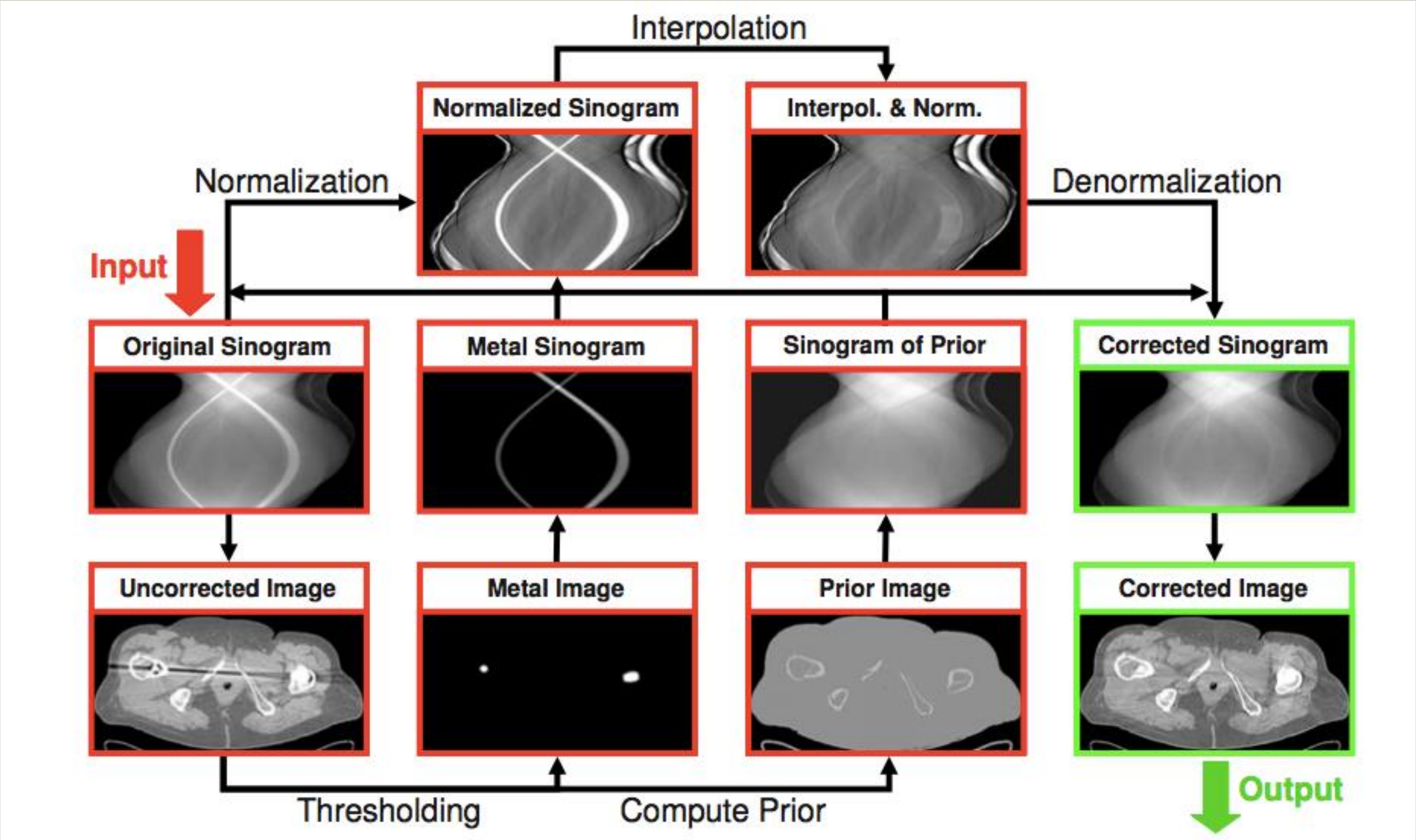
Frequency-split Metal Artifact Reduction



Combines the high frequencies of an uncorrected image with the more reliable low frequencies of an image which was corrected with an inpainting-based MAR method.

Fig from: Esther Meyer et al., Med. Phys., 39, p. 1904.

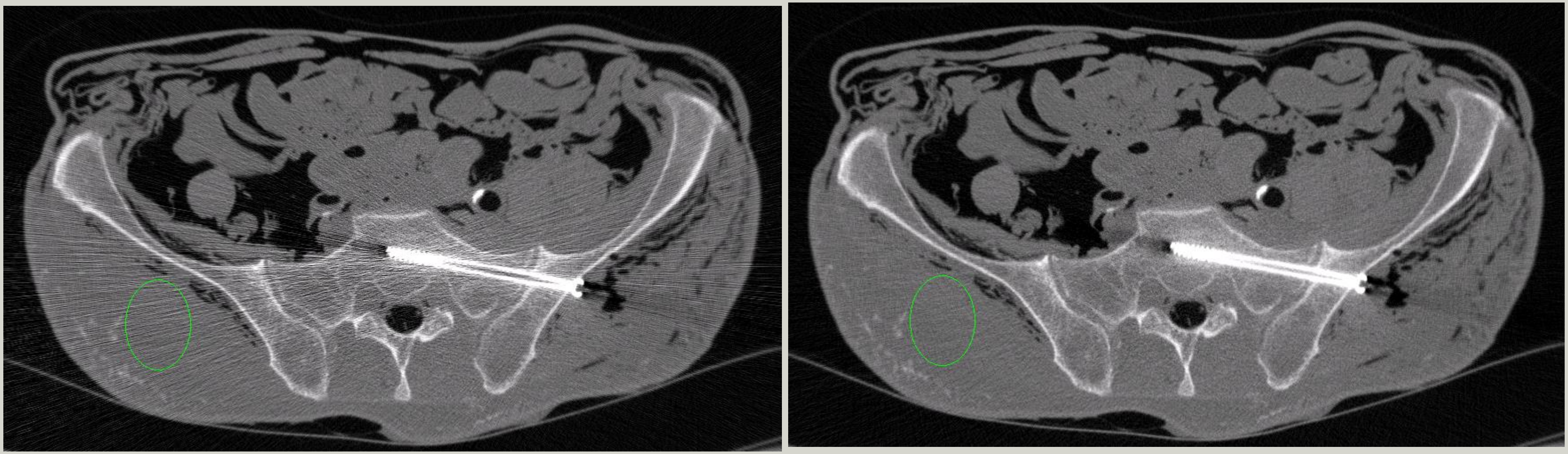
Normalized Metal Artifact Reduction



Combines the high frequencies of an uncorrected image with the more reliable low frequencies of an image which was corrected with an inpainting-based MAR method.

Fig from: Meyer et al., Med Phys 37, p 5482.

Sinogram restoration



Modeling of Poisson-dominated noise behavior and potentially many other effects including anode angle, off-focal radiation, afterglow, crosstalk.

Four potential reconstruction strategies

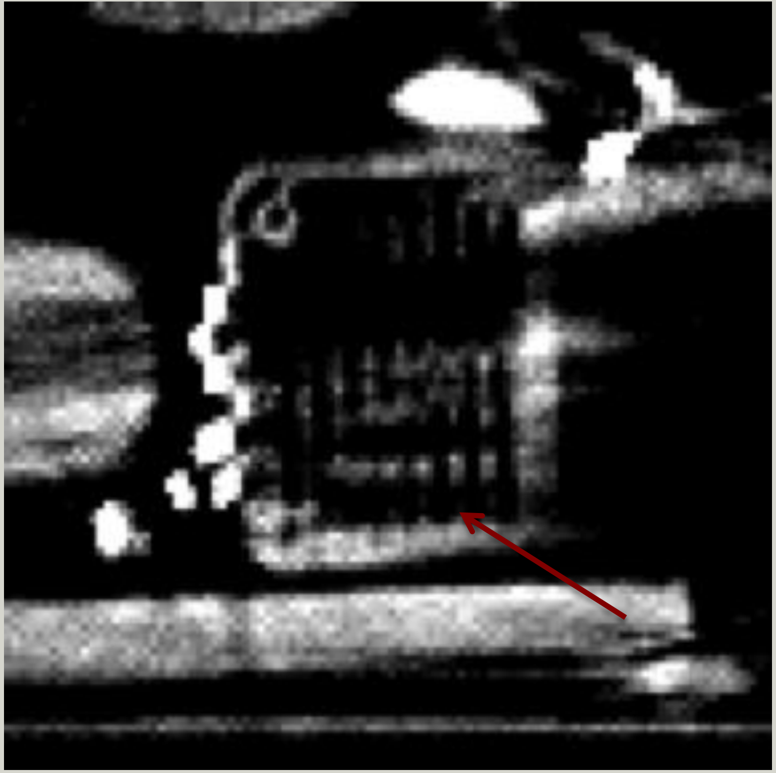
1. **Current commercial approach**: Attempt to estimate the line integrals from the data by standard sinogram preprocessing/calibration techniques and then use analytic reconstruction to obtain the image.
2. **Promising iterative approach**: Attempt to estimate the line integrals from the data by standard sinogram preprocessing/calibration techniques and then use iterative reconstruction with statistical modeling to obtain the image.
3. **Pipe dream iterative approach**: Use iterative reconstruction to estimate the image directly from the transmission measurements by modeling all effects.
4. **Our approach**: Use iterative methods with statistical modeling to estimate the line integrals and then use analytic reconstruction to obtain the image.

Our approach to sinogram processing

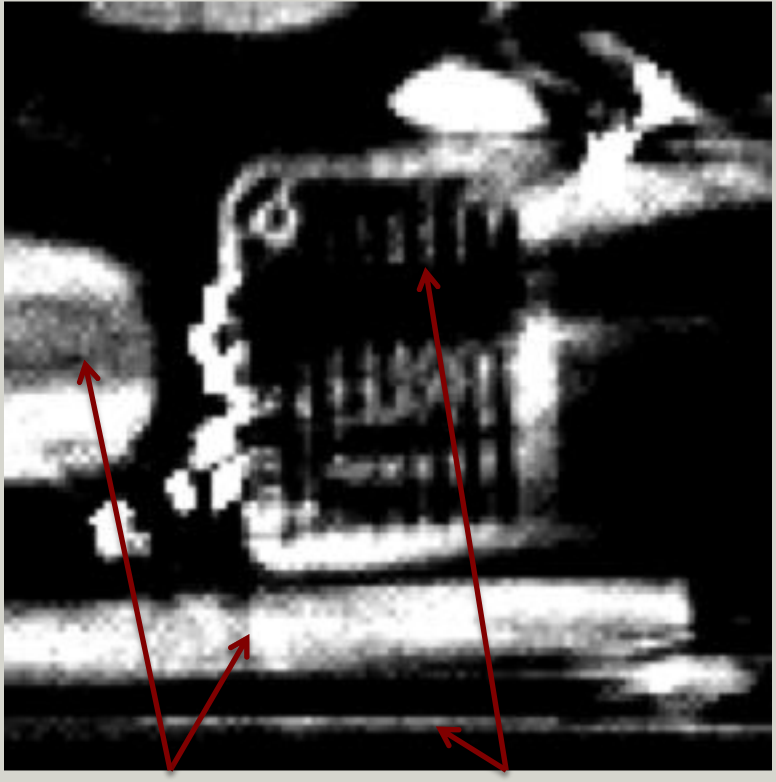
- We have formulated CT sinogram preprocessing as a statistical restoration problem.
  - The goal is to estimate as accurately as possible the attenuation line integrals needed for reconstruction from the set of noisy, degraded measurements.
  - We do so by maximizing a penalized-likelihood objective function.
  - Reconstruction is then done by use of existing methods.
- The hope is that one could achieve reduced noise and artifact levels relative to existing approaches, especially in low-dose and non-contrast scans.

MAR alone vs MAR + Restoration

High Clutter 3 – 130kV – Slice 222
FSMAR
Window [-500, 700]



High Clutter 3 – 130kV – Slice 222
FSMAR and SPS
Window [-500, 700]



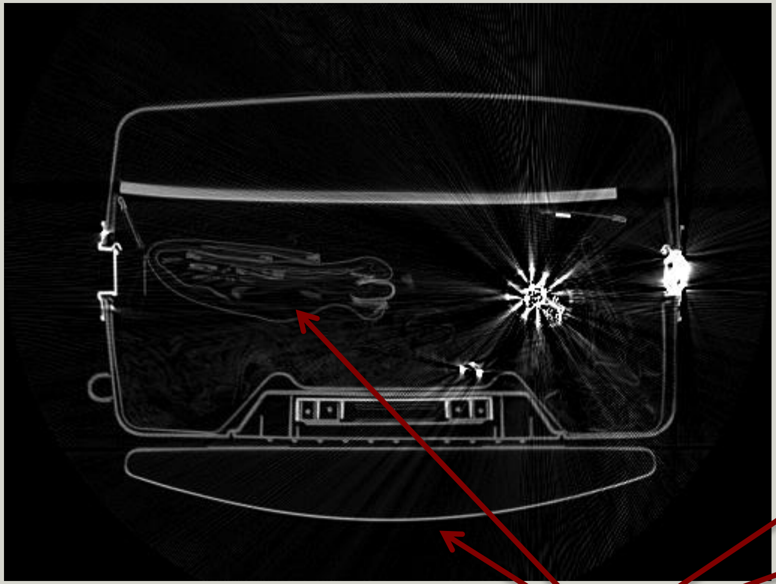
Improved Uniformity

Improved Resolution

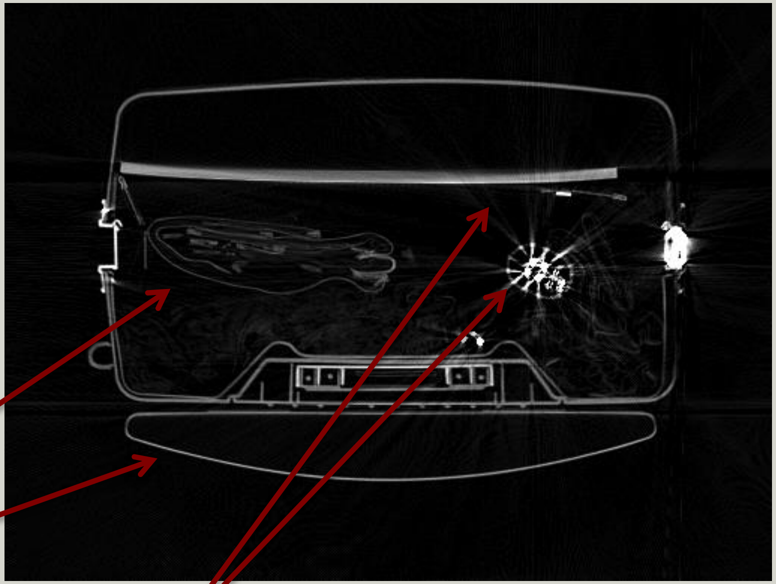
This result shows synergy of two algorithms.

Results – Retains Resolution

Medium Clutter 1 – 130kV – Slice 123
Uncorrected Image
Window [-1000, 1000]



Medium Clutter 1 – 130kV – Slice 123
Corrected Image
Window [-1000, 1000]



Retention in resolution for fine lines and small objects

Reduction in streak artifacts

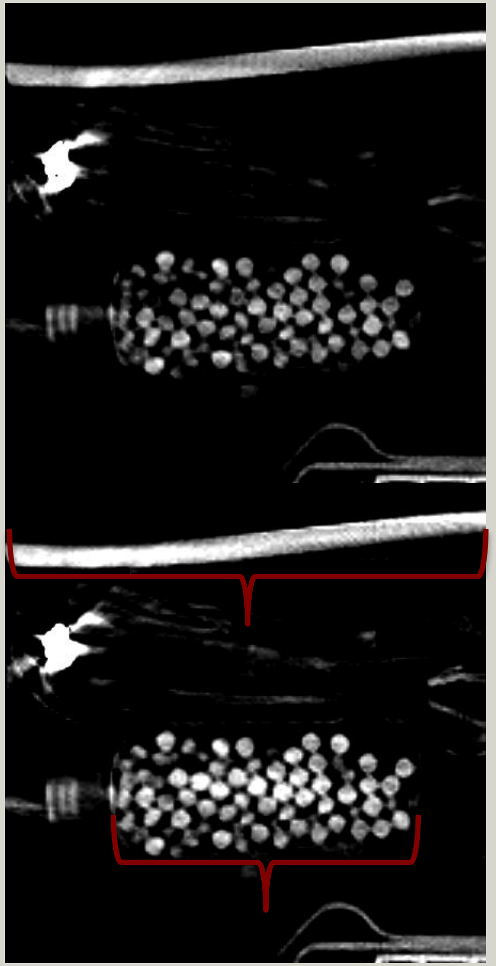
NOTE: Retaining resolution can aid in segmentation.

Results – Improves Uniformity

Uncorrected Image
Window [250, 600]
ROI Variance =

Medium Clutter 1
130kV Slice 202

Corrected Image
Window [250, 600]
ROI Variance =

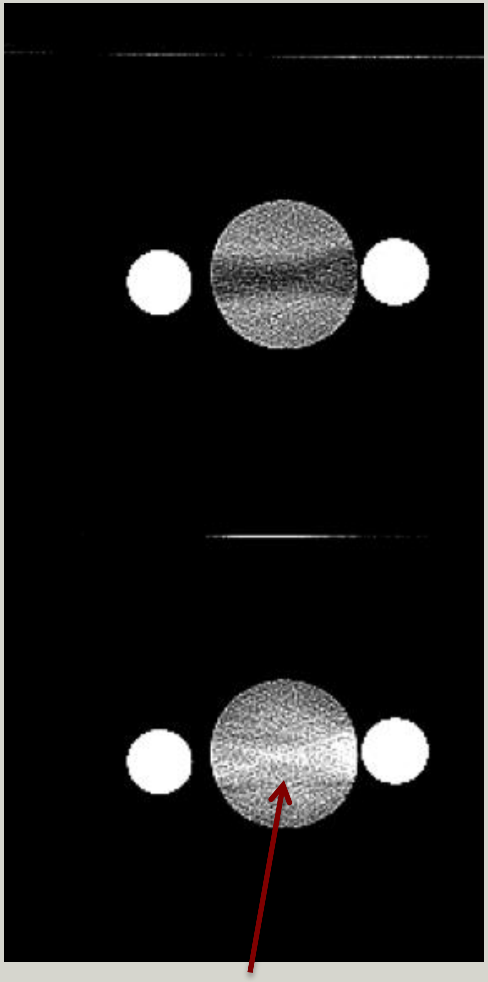


Improved circularity, uniformity and volume

Uncorrected Image
Window [-100, 100]
ROI Variance =

LLNLPC 1b
130kV Slice 90

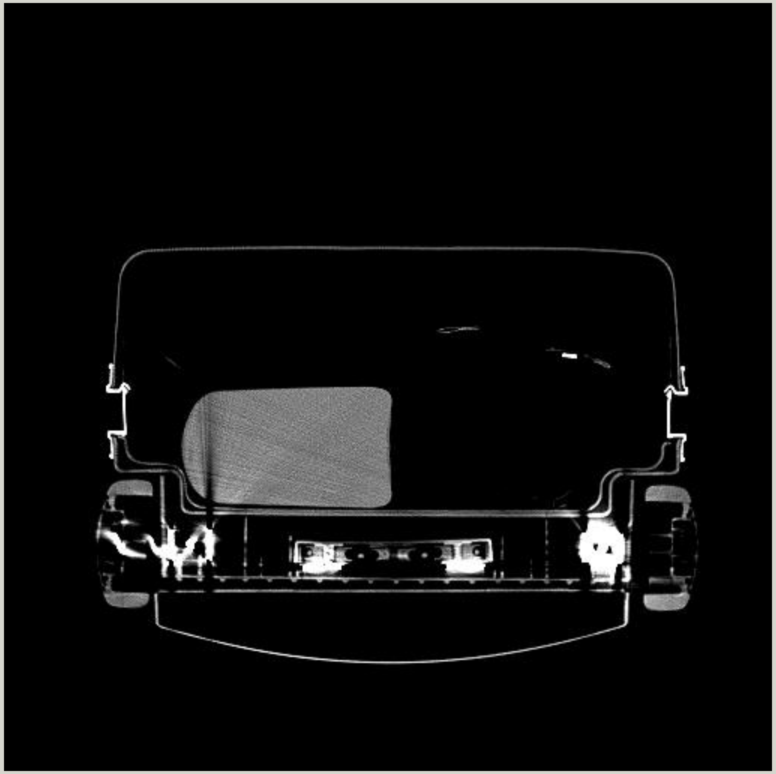
Corrected Image
Window [-100, 100]
ROI Variance =



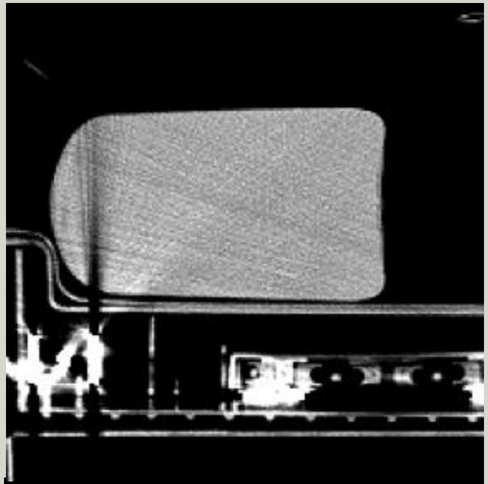
Improved circularity

Results – Mitigates Object Splitting

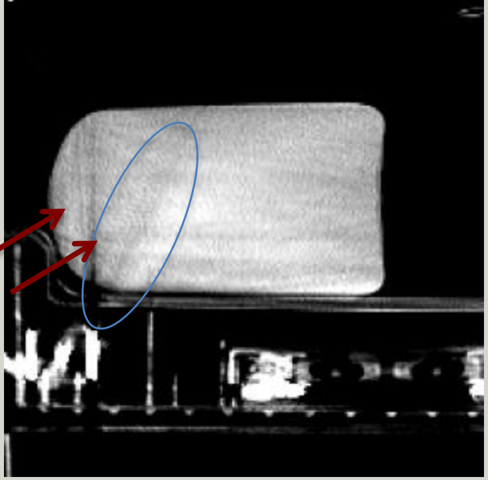
Medium Clutter 1 – 130kV – Slice 38
Uncorrected Image
Window [-500, 500]



Uncorrected
Image



Corrected
Image



Reduction in
streak artifacts
splitting objects

Some increase
in secondary
streak

Strength and Weaknesses

- Strengths
  - Acts upon sinogram; no need for backprojection and reprojection.
  - This makes it fast.
- Weaknesses
  - Multiple free parameters to optimize.
  - Hard to implement edge preserving priors in sinogram domain.

Future Research

- Apply to real security scanner data.
- See if metal artifact reduction step can be incorporated directly into the objective function being used.
- Perhaps feed these results into fully iterative reconstruction.

ALERT Reconstruction Initiative TO#3:
Sinogram processing
Backup slides

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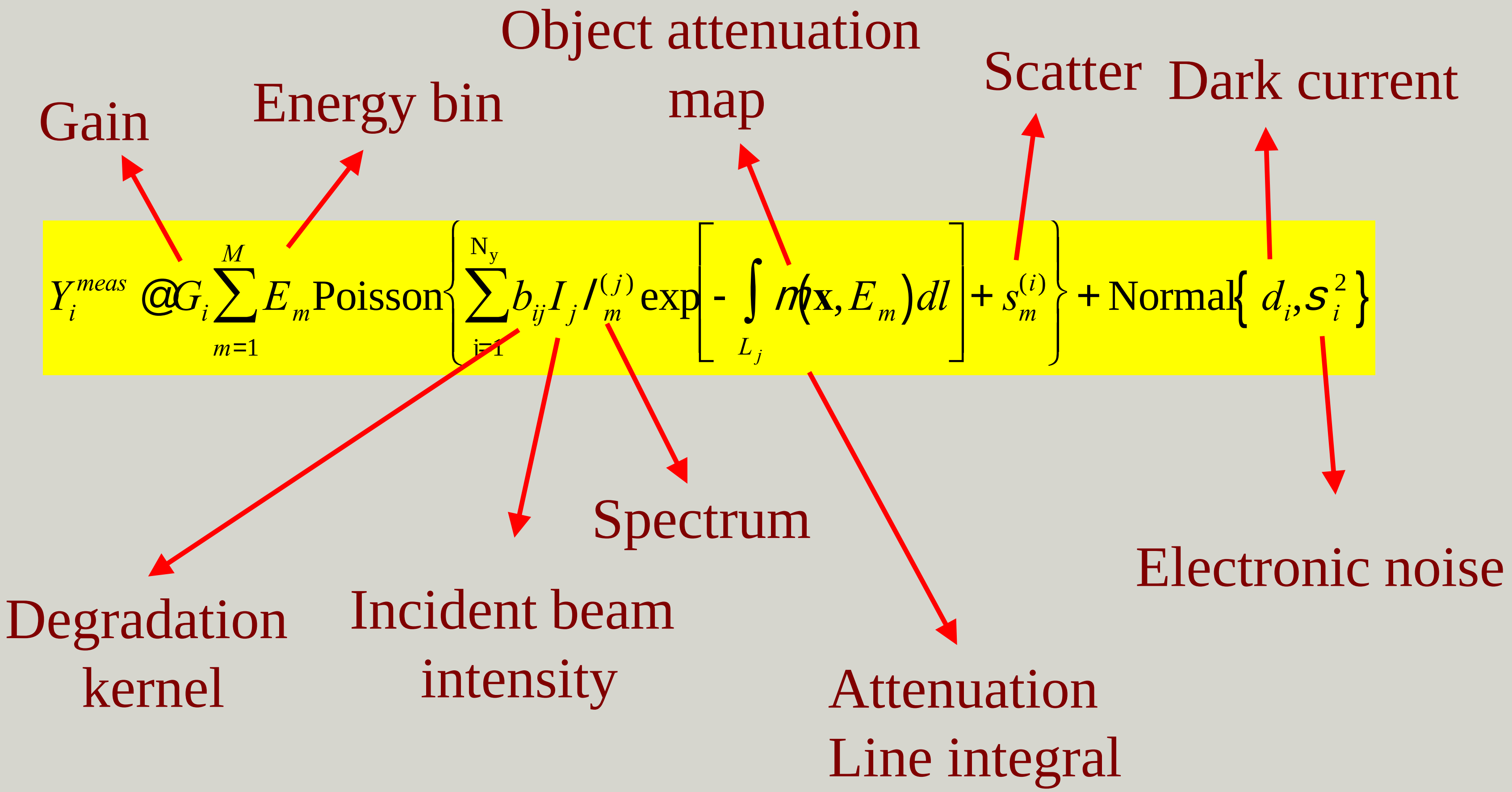
Sinogram restoration imaging model

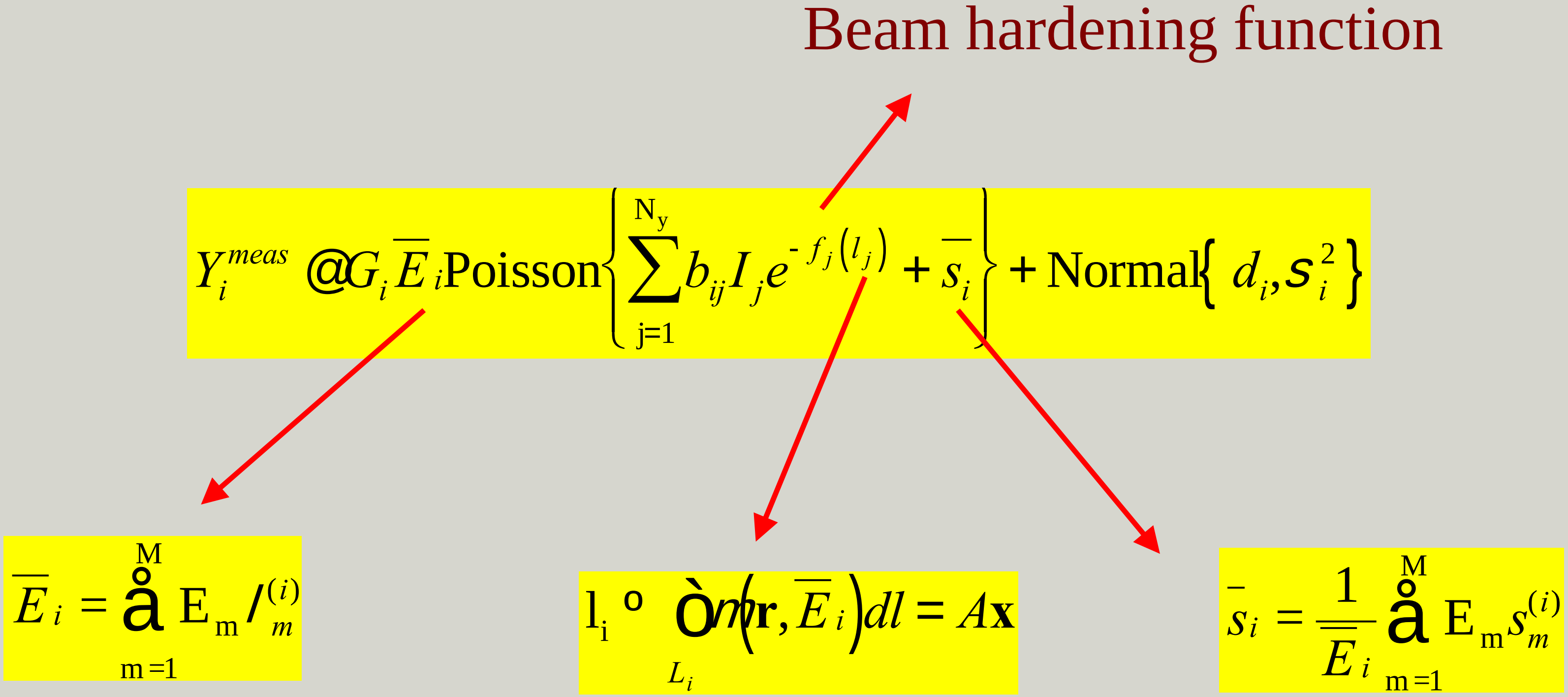
- We assume the CT scan produces a set of measurements that are realizations of random variables:



$$Y_i^{meas} \cong G_i \sum_{m=1}^{M} E_m \mathrm{Poisson}\left\{ \sum_{j=1}^{N_y} b_{ij} I_j \lambda_m^{(j)} \exp\left[- \int_{L_j} \mu(\mathbf{x}, E_m)\, dl \right] + s_m^{(i)} \right\} + \mathrm{Normal}\left\{ d_i, \sigma_i^2 \right\}$$

Sinogram restoration simplified imaging model

- More practically, we assume the CT scan produces a set of measurements that are realizations of random variables:



Beam hardening function

$$Y_i^{meas} \cong G_i \bar{E}_i \,\text{Poisson}\left\{ \sum_{j=1}^{N_y} b_{ij} I_j e^{-f_j(\lambda_j)} + \bar{s}_i \right\} + \text{Normal}\{ d_i, \sigma_i^2 \}$$

$$\bar{E}_i = \sum_{m=1}^{M} E_m /_m^{(i)}$$

$$\lambda_i \equiv \int_{L_i} \mu(\mathbf{r}, \bar{E}_i)\, dl = A\mathbf{x}$$

$$\bar{s}_i = \frac{1}{\bar{E}_i} \sum_{m=1}^{M} E_m s_m^{(i)}$$

Objective function

- We find the undegraded attenuation line integrals by

$$\hat{\mathbf{l}} = \arg\max_{\mathbf{l} \geq 0} \left[L(\mathbf{l};\mathbf{y}) - \beta R(\mathbf{l}) \right]$$

- Here *L*(**l**;**y**) is the Poisson likelihood for the adjusted measurements **y** and *R*(**l**) is the roughness penalty.
- To maximize we make use of an update derived by use of the optimization transfer approach (Fessler, 2000) adapting some tricks due to DePierro (1995).

The update

$$l_j^{(n+1)} = \left[l_j^{(n)} - \frac{n_j - b\sum_{k=1}^{N_y} c_{kj} w_k \left[C l^{(n)} \right]_k}{c_j^{(n)} + b v_j} \right]_+$$

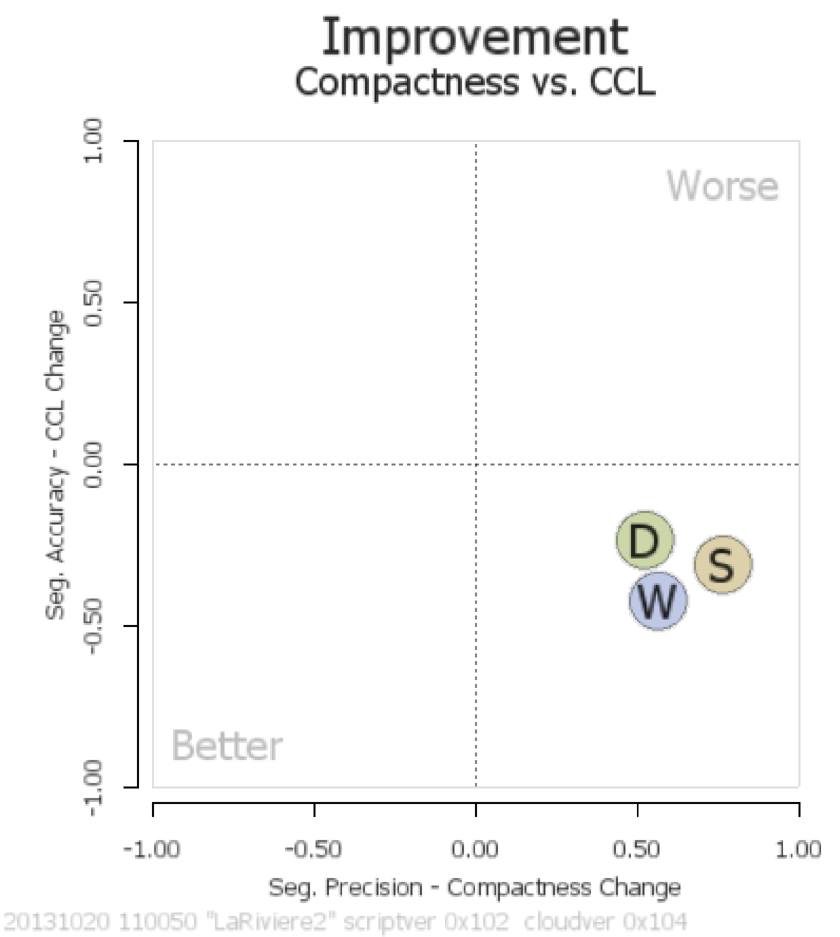
where

$$n_j \equiv \sum_{\mathrm{i=1}}^{\mathrm{N_y}} I_j b_{ij} \dot{g}_i \left(\sum_{\mathrm{j=1}}^{\mathrm{N_y}} I_j b_{ij} e^{-f\left(l_j^{(n)}\right)} + s_i + \frac{s_i^2}{G_i^2} \right) e^{-f\left(l_j^{(n)}\right)} \dot{f}\left(l_j^{(n)}\right)$$

and

$$\dot{g}_i(x)^{\circ} \frac{y_i}{x} - 1$$

Segmentation performance



Improvement
Compactness vs. CCL

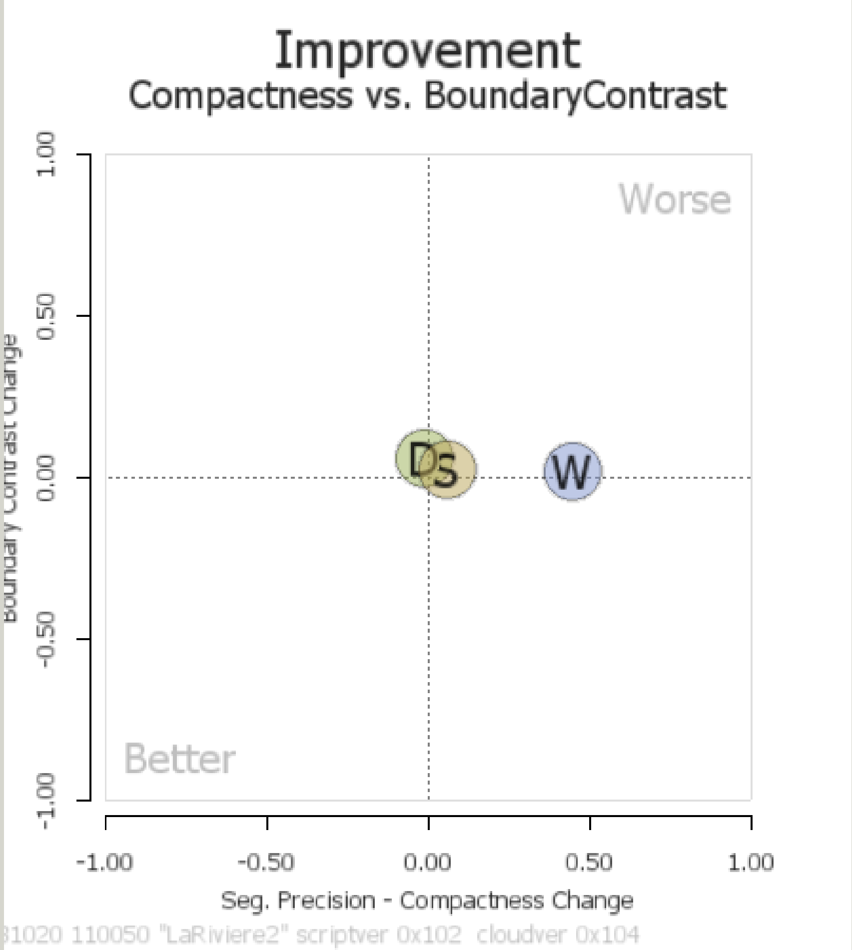
20131020 110050 "LaRiviere2" scriptver 0x102 cloudver 0x104

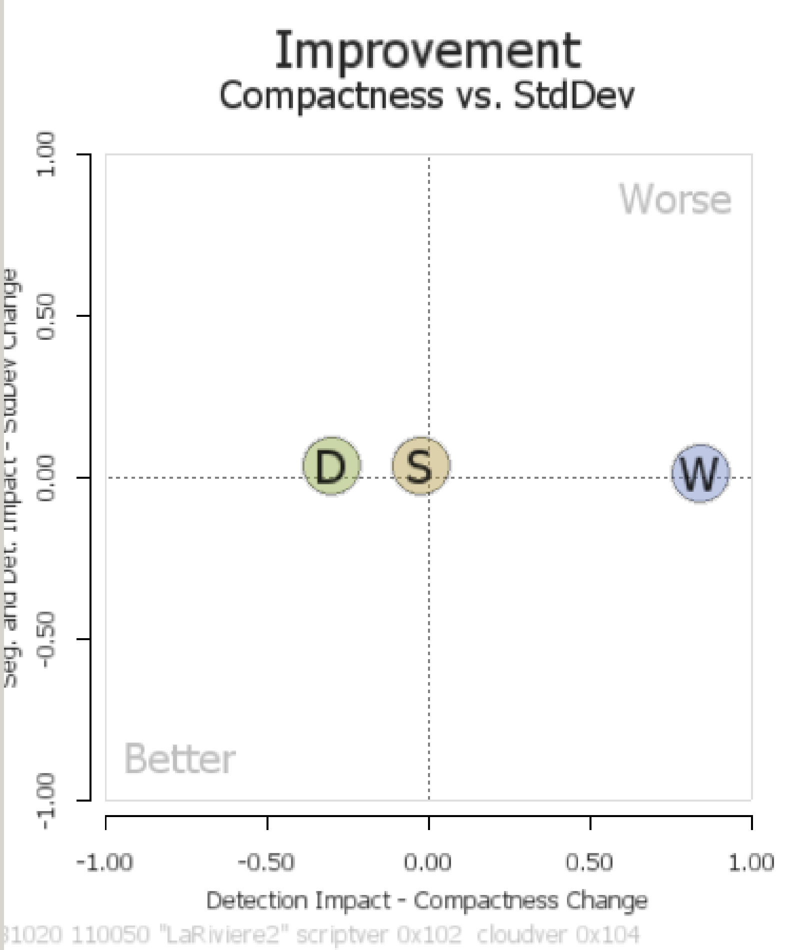
Improvement
Compactness vs. Tumbler

31020 110050 "LaRiviere2" scriptver 0x102 cloudver 0x104

Improved segmentation accuracy but at some cost in segmentation precision.

Compactness





Improved detection impact compactness for doped water.