Estimating the High Scatter Frequencies Caused by Coarse Anti-Scatter Grids in X-Ray CT

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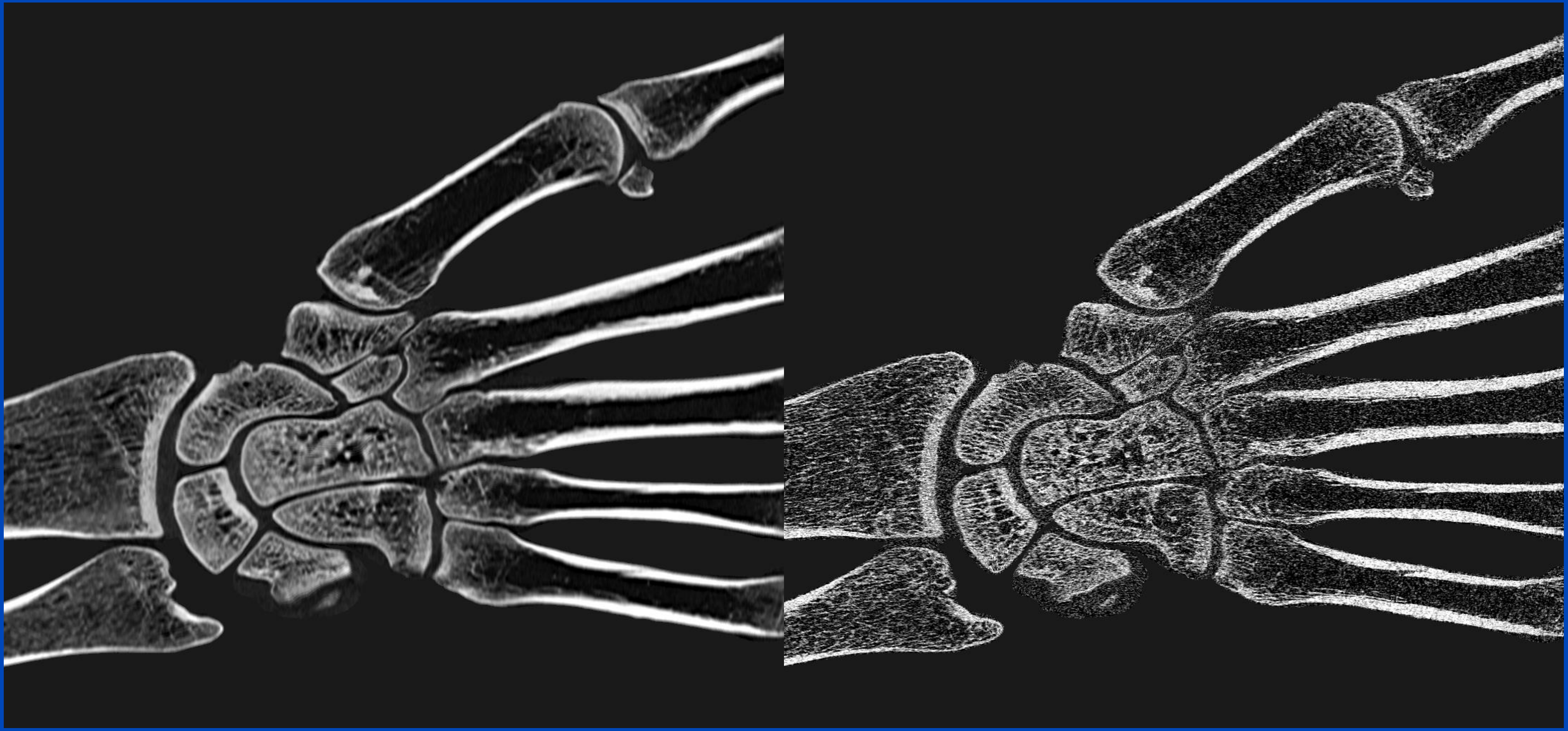
Photon-Counting enables Visualization of Small Details



Reconstruction to mimick conventional energy-integrating CT, e.g. Somatom Flash

Reconstruction of data scanned at photon-counting CT Naoetom Alpha

Properties of Photon-Counting Detectors

- **Smaller detector pixels**
  - can deliver ultra high resolution imaging
  - less dose due for conventional spatial resolution[1] ("small pixel effect")
- **No electronic noise**
  - advanced image quality in obese patients and low-dose scans
- **No downweighting of lower energy quanta**
  - improved image contrast
  - less dose due to increased iodine CNR[2] ("iodine effect")
- **Intrinsic spectral sensitivy**
  - established dual energy applications available in any scan

[1] Klein, Kachelrieß, Sawall et al. "Effects of Detector Sampling on Noise Reduction in Clinical Photon-Counting Whole-Body Computed Tomography." *Investigative Radiology* vol. 55(2): 111-119, 2020.
[2] Sawall, Kachelrieß et al. "Iodine Contrast-to-Noise Ratio Improvement at Unit Dose and Contrast Media Volume Reduction in Whole-Body Photon-counting CT." *European Journal of Radiology* vol. 126: 108909, 2020.

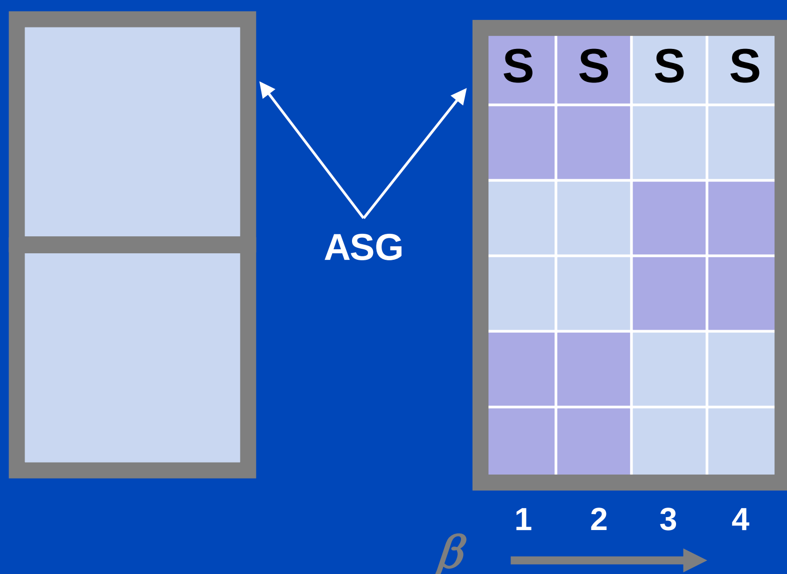
Scatter for Coarse ASG

Energy-integrating detector

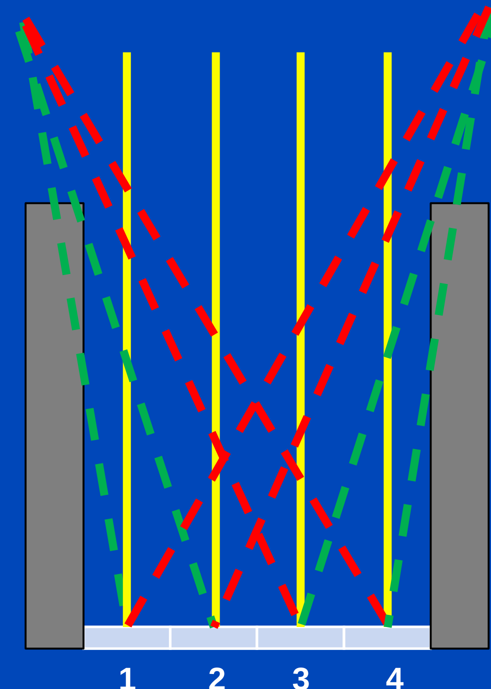
Conventional ASG
Each pixel surrounded by ASG

Photon-counting detector

Coarse ASG
Several subpixel surrounded by ASG



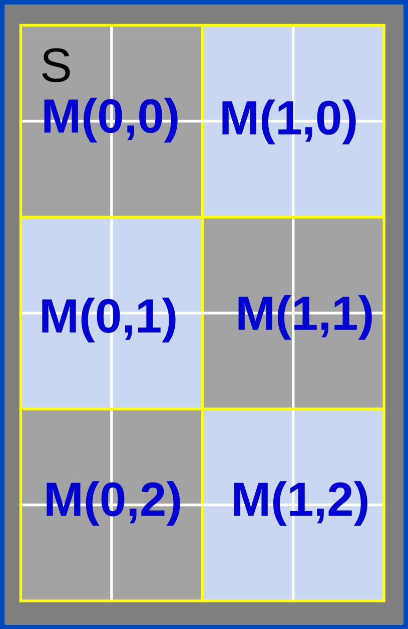
Primary radiation
Scatter measured by the detector
Scatter attenuated by the ASG

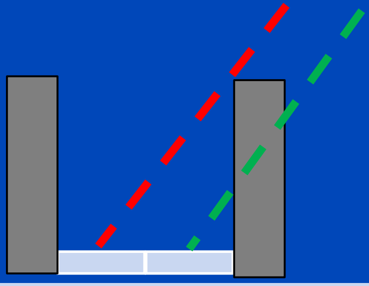


Coarse ASG leads to changing scatter intensity between neighboring pixel depending on the incident angle of the photon

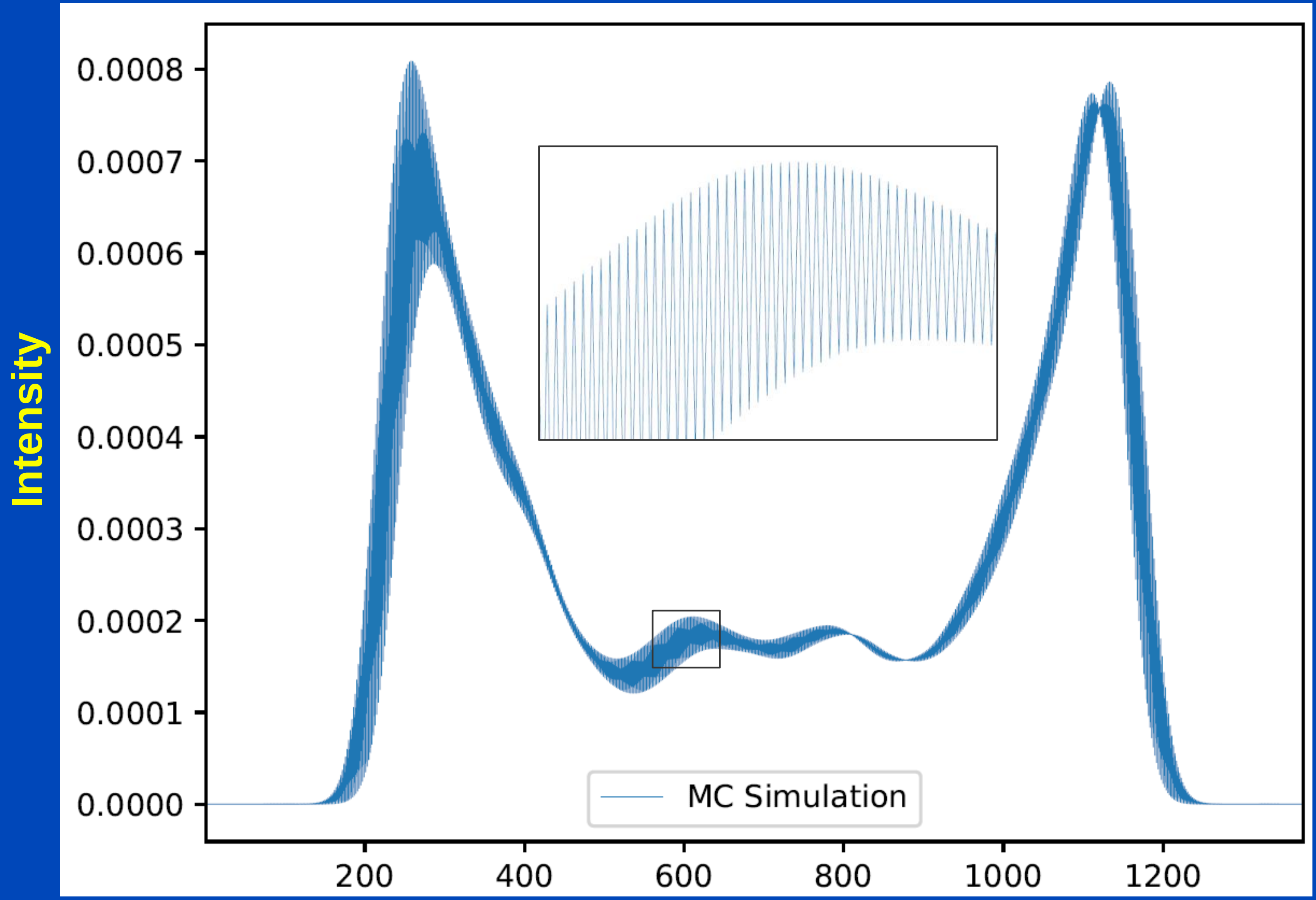
Scatter for Coarse ASG

Four subpixel (S) merged to one macropixel (M)

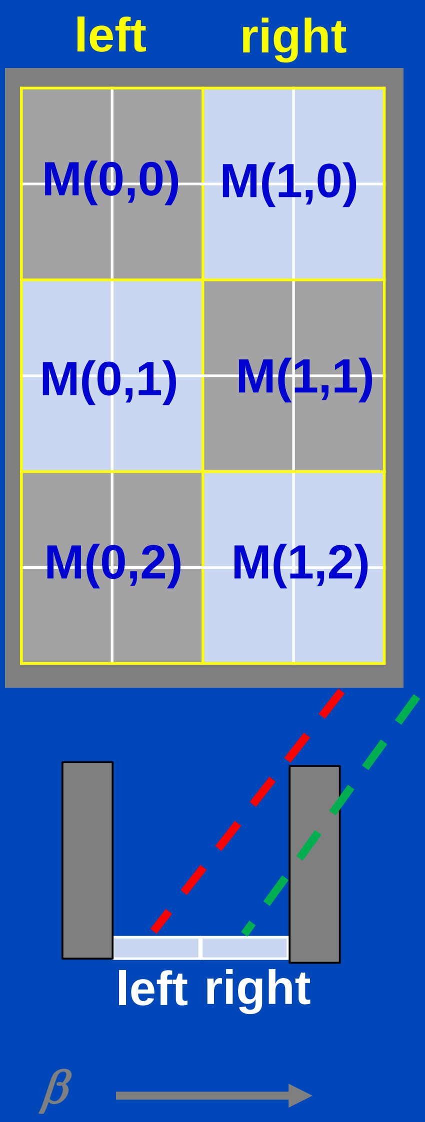




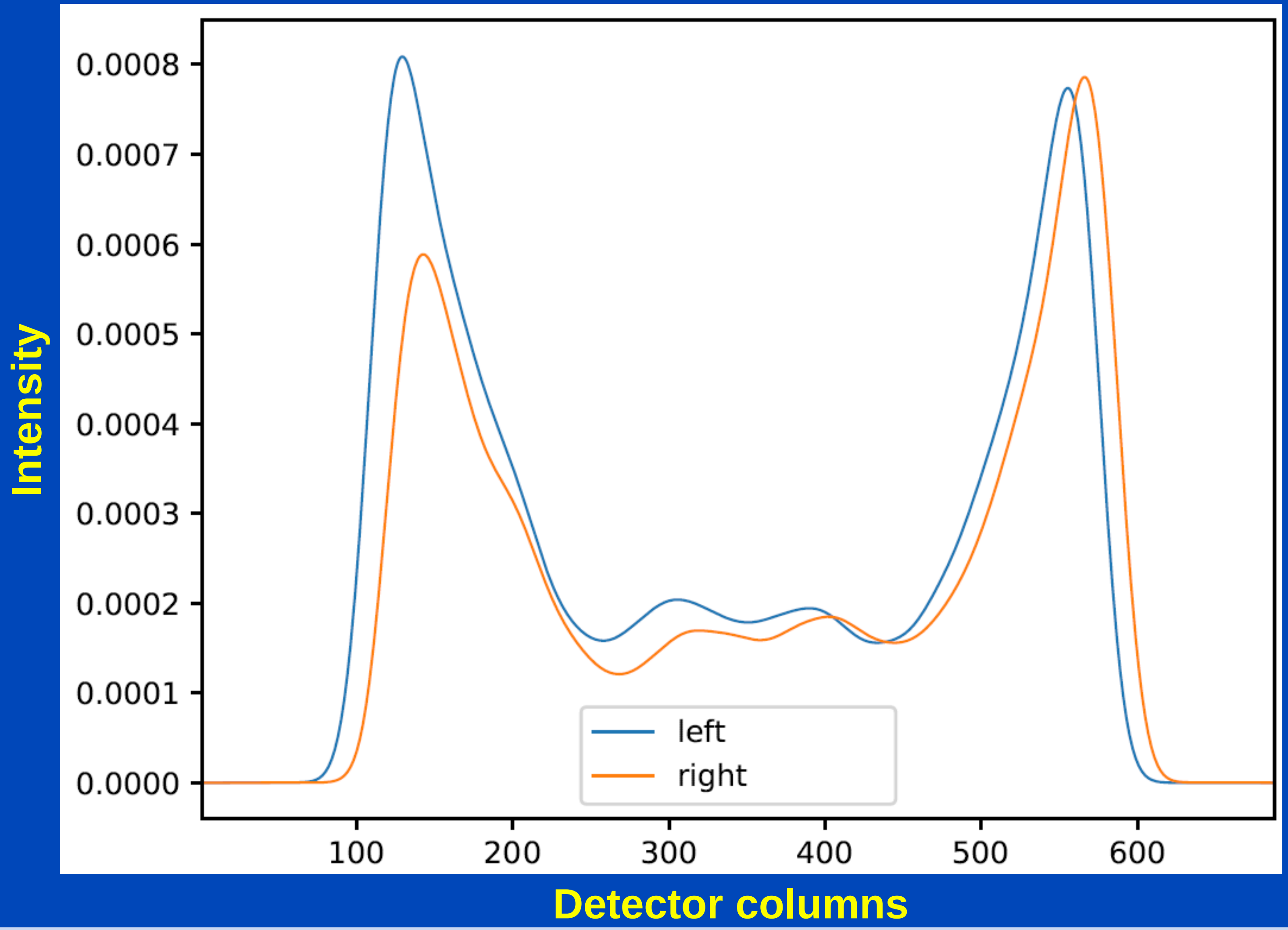
Scatter distribution averaged over all detector rows



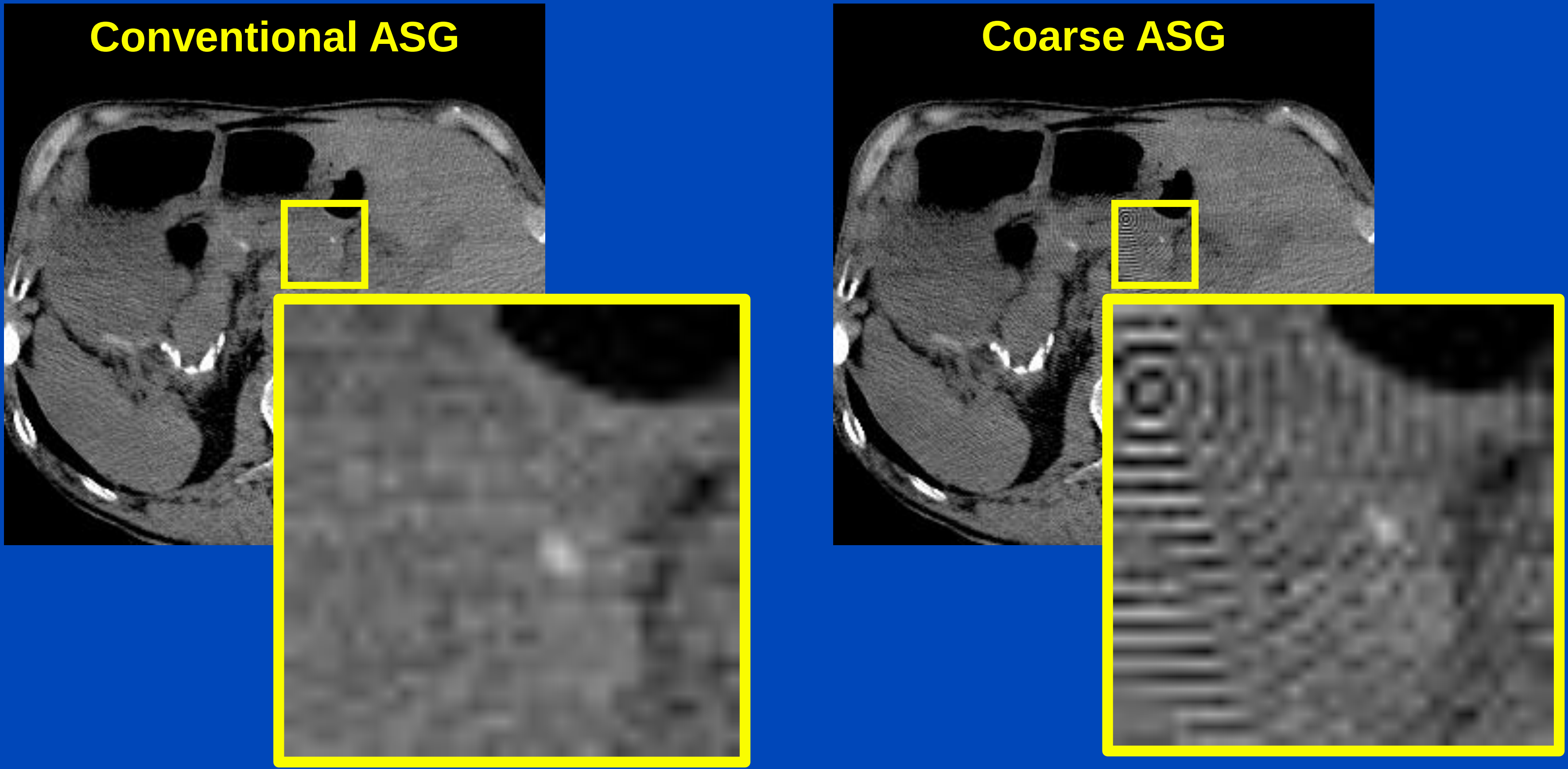
Scatter for Coarse ASG



Scatter distribution averaged over all detector rows



Scatter Artifacts of Coarse ASG



Coarse ASG can lead to scatter-induced moiré artifacts.

Deep Scatter Estimation (DSE)

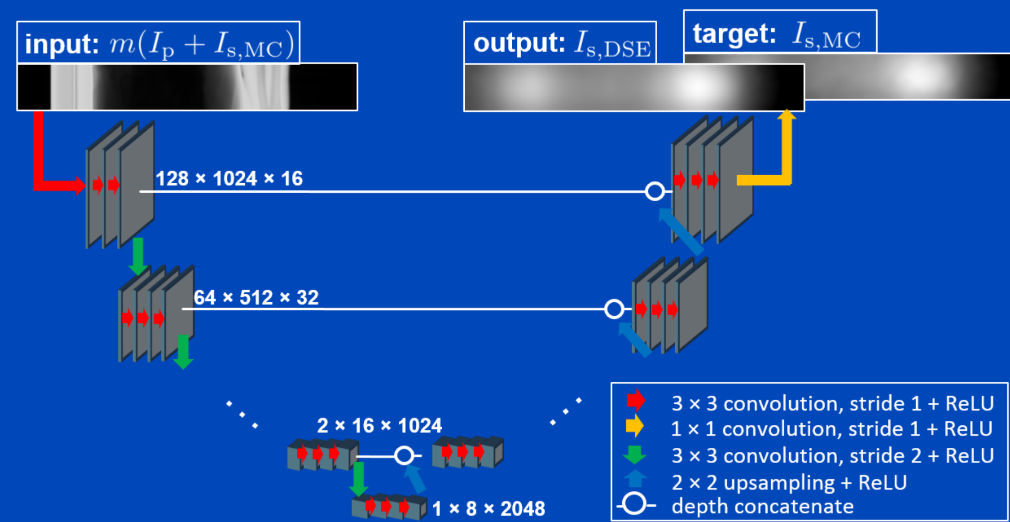
- Use a deep convolutional neural network to estimate scatter using the acquired projection data as input.[1,2]
- Train the network to predict Monte Carlo scatter estimates based on the acquired projection data.[1,2]
- DSE outperforms other scatter estimation techniques.[1,2,4,5]
- DSE is much faster than the Monte Carlo simulation.[1,2,5]
- DSE can also be trained with measured scatter data.[3]
- DSE shows great potential to correct for cross-scatter in dual source CT.[4,5]

Scatter profile from Monte Carlo simulation

Time: 65 s per projection = 14 h per circle scan

Scatter prediction from deep scatter estimation

Time: 3.3 ms per projection = 4 s per circle scan



[1] J. Maier, M. Kachelrieß et al. “Deep Scatter Estimation (DSE)“, SPIE 2017 and J. of Nondest. Eval. 37:57, July 2018.
[2] J. Maier, M. Kachelrieß et al. “Robustness of DSE“, Med. Phys. 46(1):238-249, January 2019.
[3] J. Erath, M. Kachelrieß et al “Monte-Carlo-Free Deep Scatter Estimation (DSE) for X-Ray CT and CBCT”, RSNA 2019
[4] J. Erath, T. Vöth, J. Maier, E. Fournié, M. Petersilka, K. Stierstorfer, and M. Kachelrieß, “Deep Scatter Correction in DSCT”, CT Meeting August 2020.
[5] J. Erath, T. Vöth, J. Maier, E. Fournié, M. Petersilka, K. Stierstorfer, and M. Kachelrieß, “Deep Learning-Based Forward and Cross-Scatter Correction in DS CT” Med. Phys. 2021

Matrix Multiplication

- To obtain scatter via MC simulation for every subpixel comes with high computational costs
- How accurate can neural network estimate scatter with additional pattern on it?
- Idea: multiply scatter data with pattern matrix
- 1. Matrix multiplication with ones:
  - e, b, a, d, c = 1
- 2. Matrix multiplication with constant values:
  - e = b = 1, a = d = 0.8, c = 0.6
- 3. Matrix multiplication with random values :
  - e = b = 1, 0.7 < a = d < 0.9, 0.4 < c < 0.7
  - After each projection new random matrix
- Detector size 1024 × 128
- First and last row multiplied with 1 (126 divisible by 6)

	a	b	b	a
c	c×a	c×b		
d	d×a	d×b		
e		1	1	
e		1	1	
d				
c				

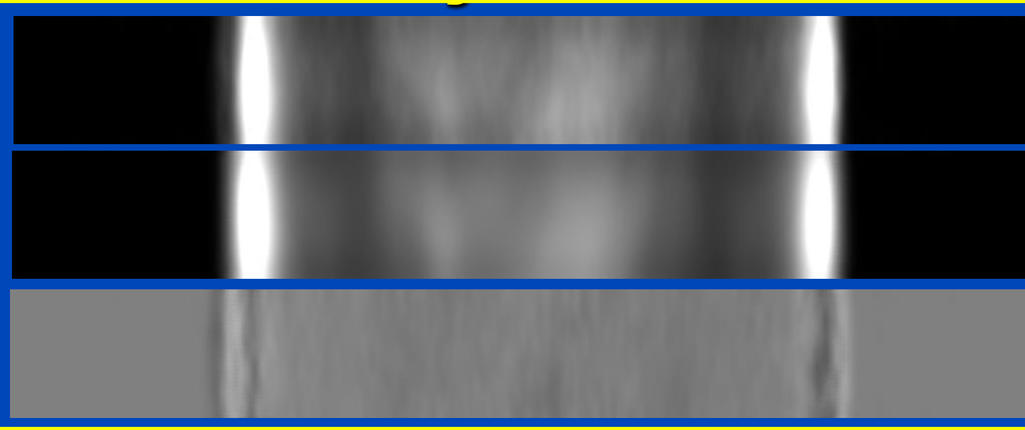
Results in Projection Domain

Matrix ones

GT

Prediction

Difference
GT - Prediction

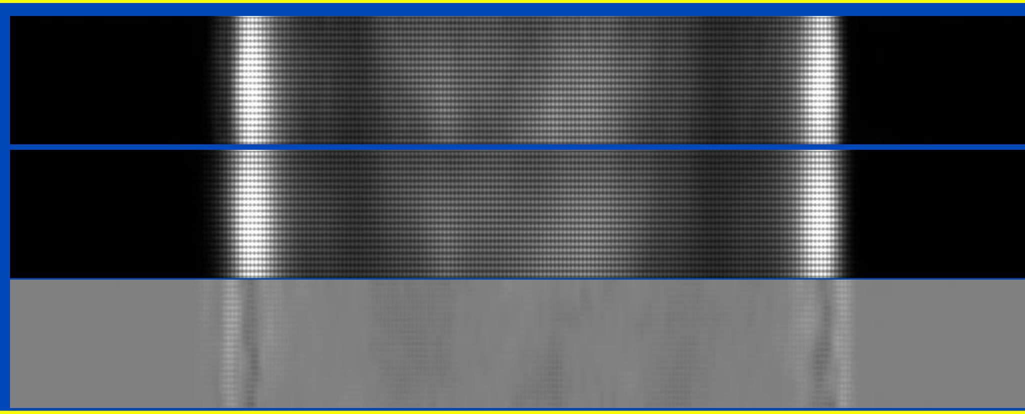


Matrix constant

GT

Prediction

Difference
GT - Prediction

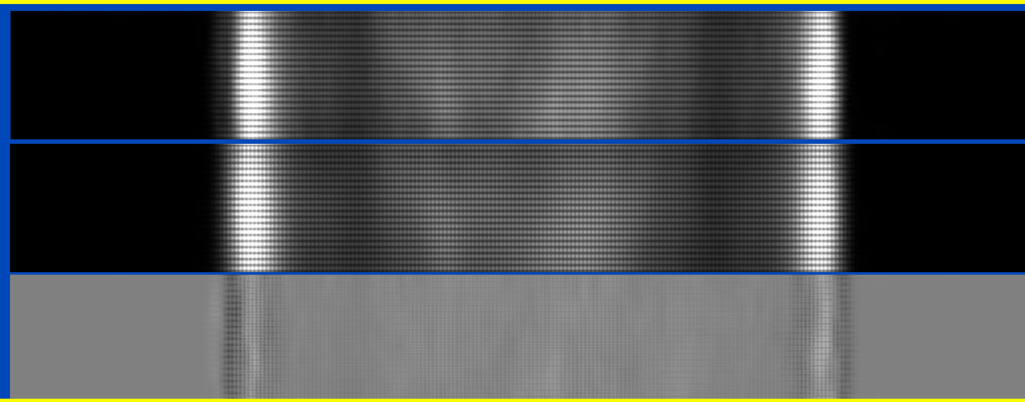


Matrix random

GT

Prediction

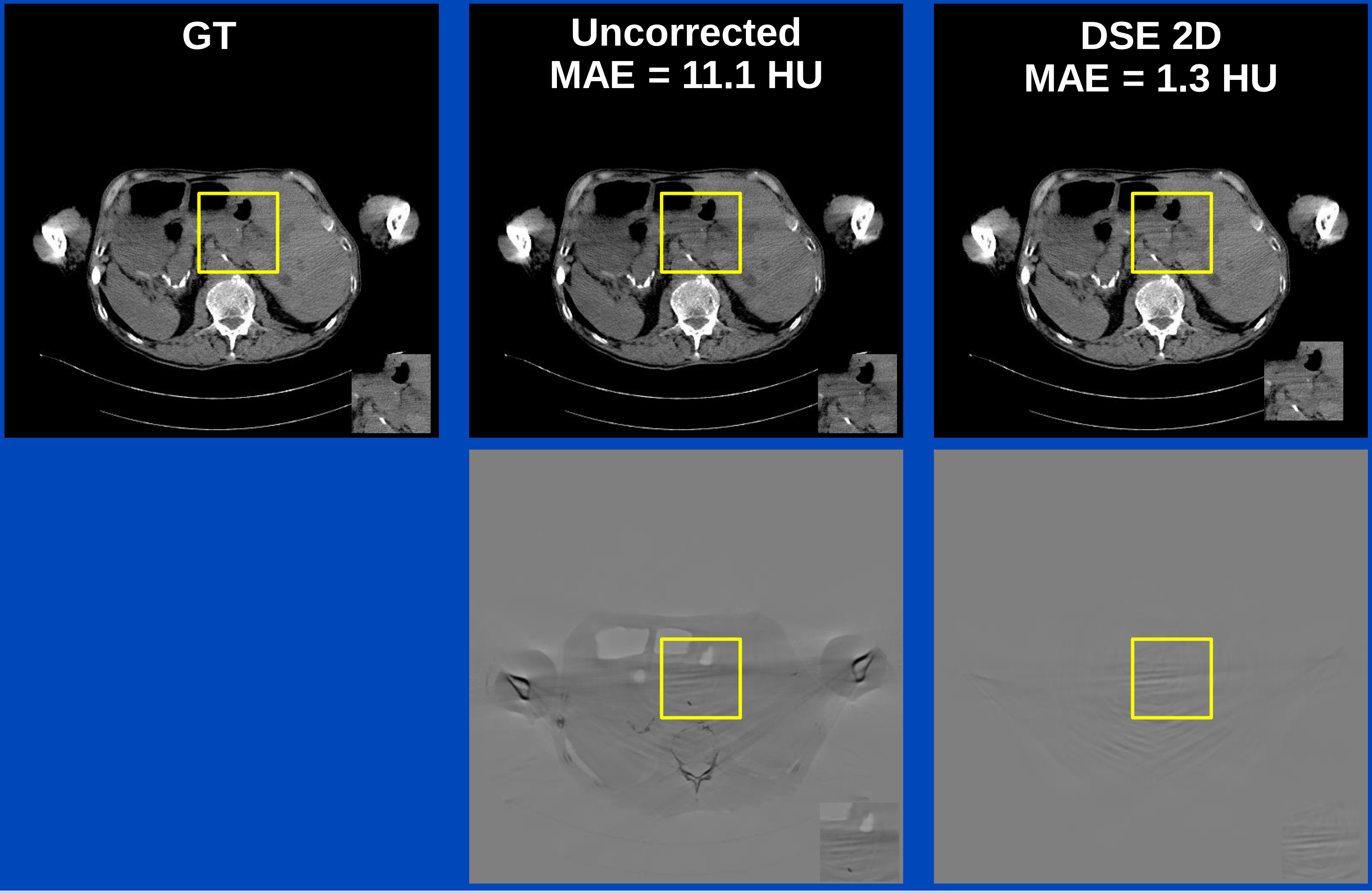
Difference
GT - Prediction



GT & Prediction: C = 0.0004, W = 0.0008

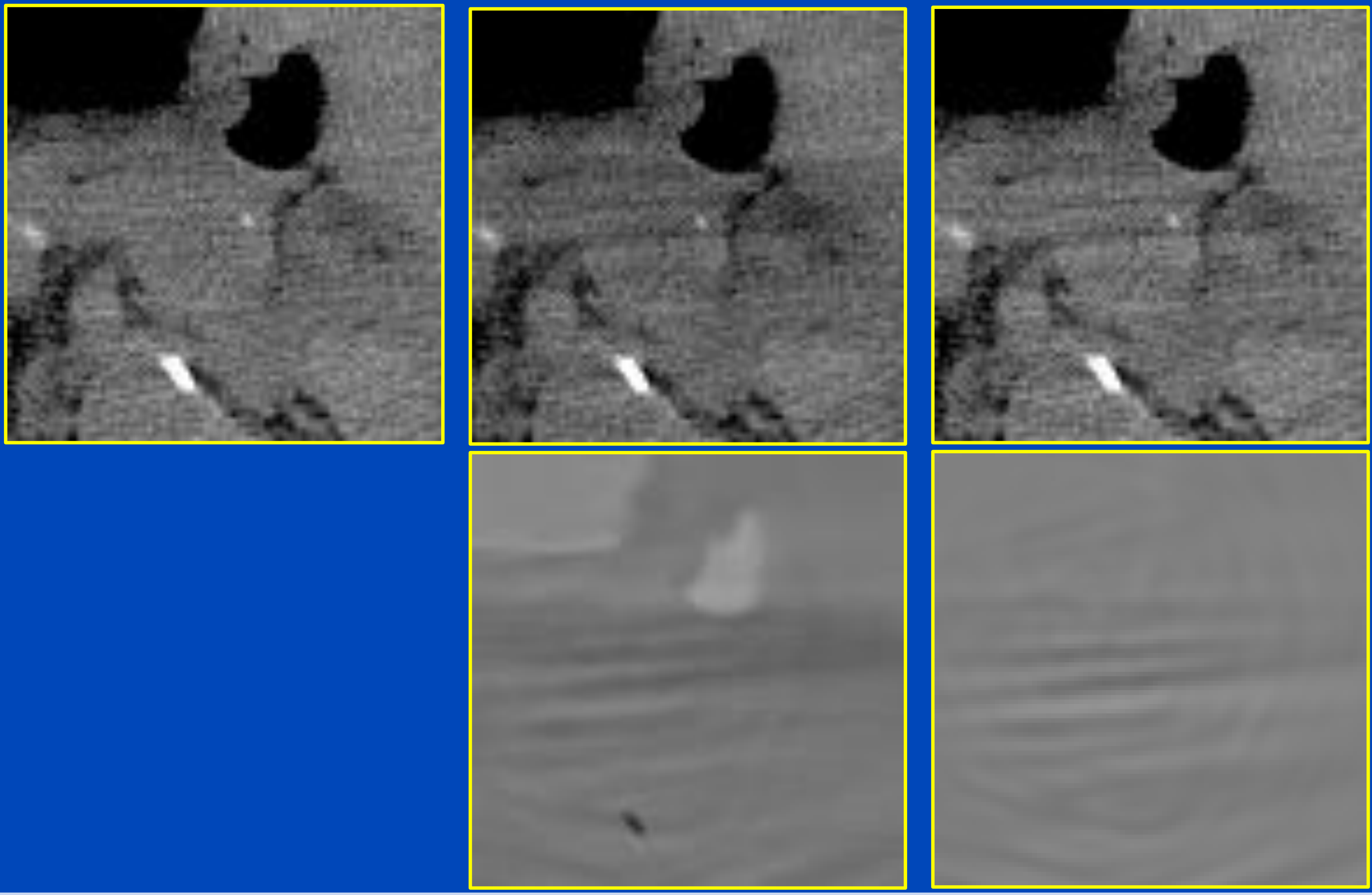
Difference: C = 0.0000, W = 0.0008

Results Matrix = 1



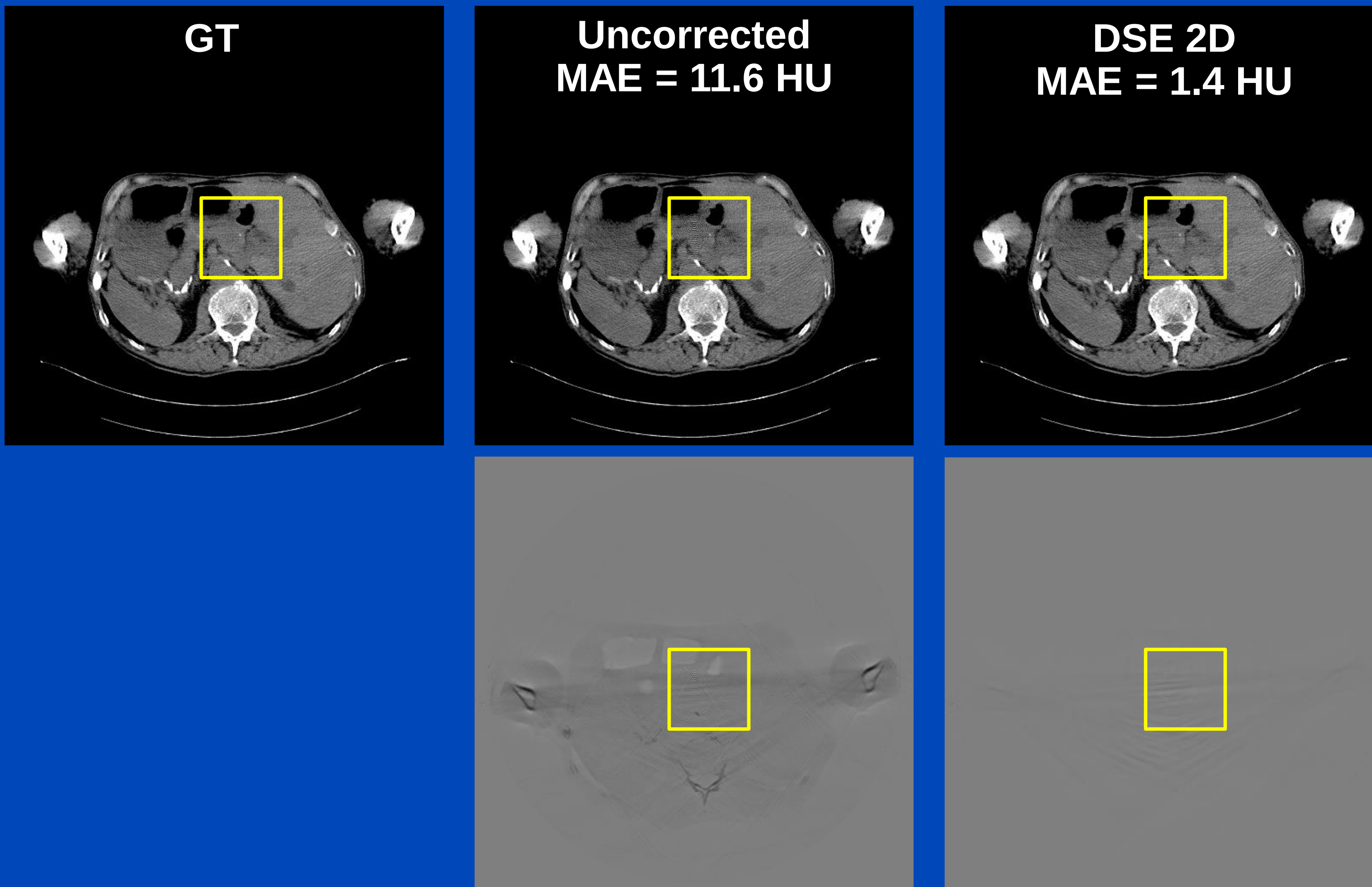
 Images: *C* = 40 HU, *W* = 300 HU Differences: *C* = 0 HU, *W* = 300 HU

Results Matrix = 1



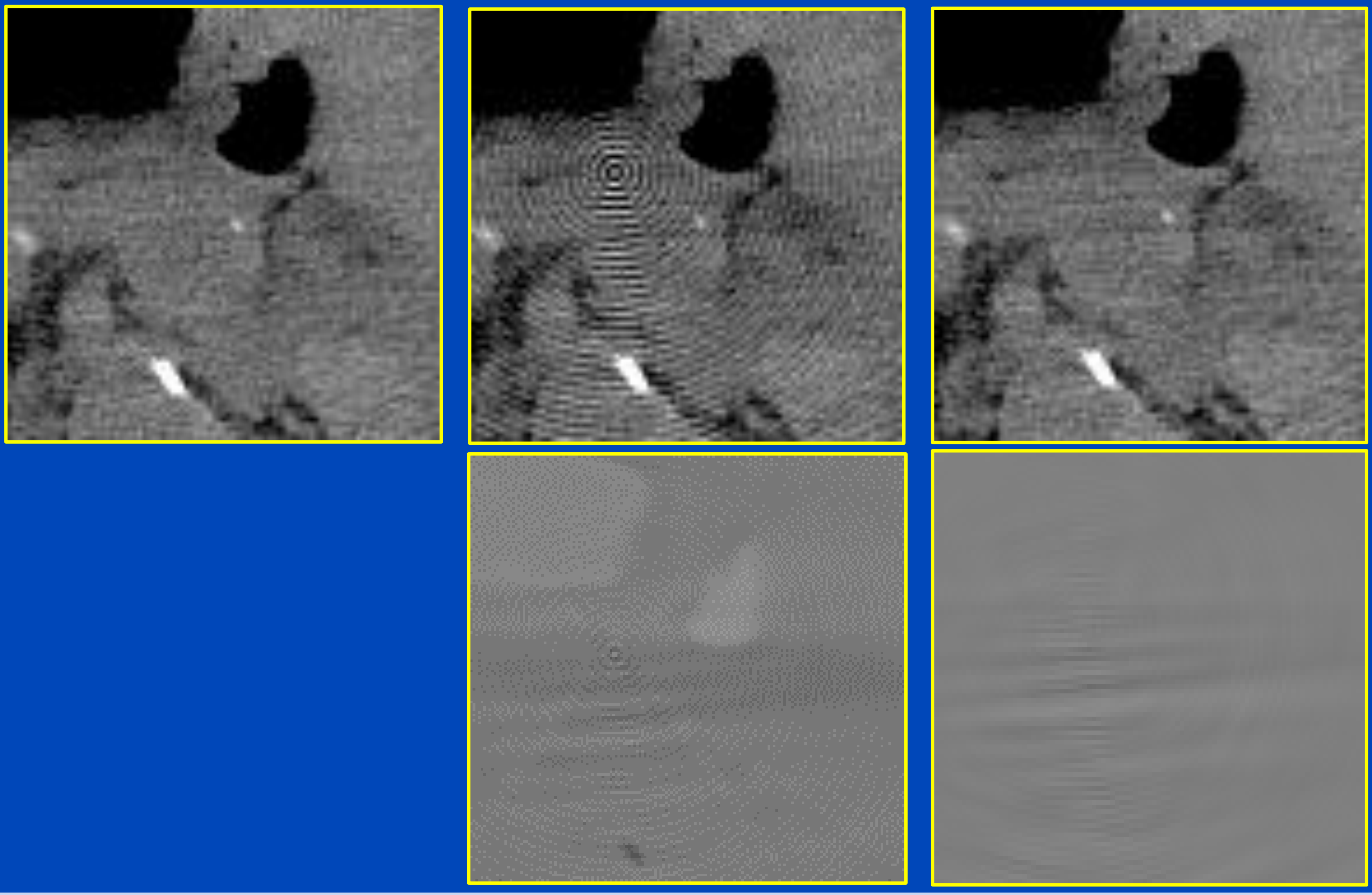
Images: *C* = 40 HU, *W* = 300 HU   Differences: *C* = 0 HU, *W* = 300 HU

Results Matrix Constant



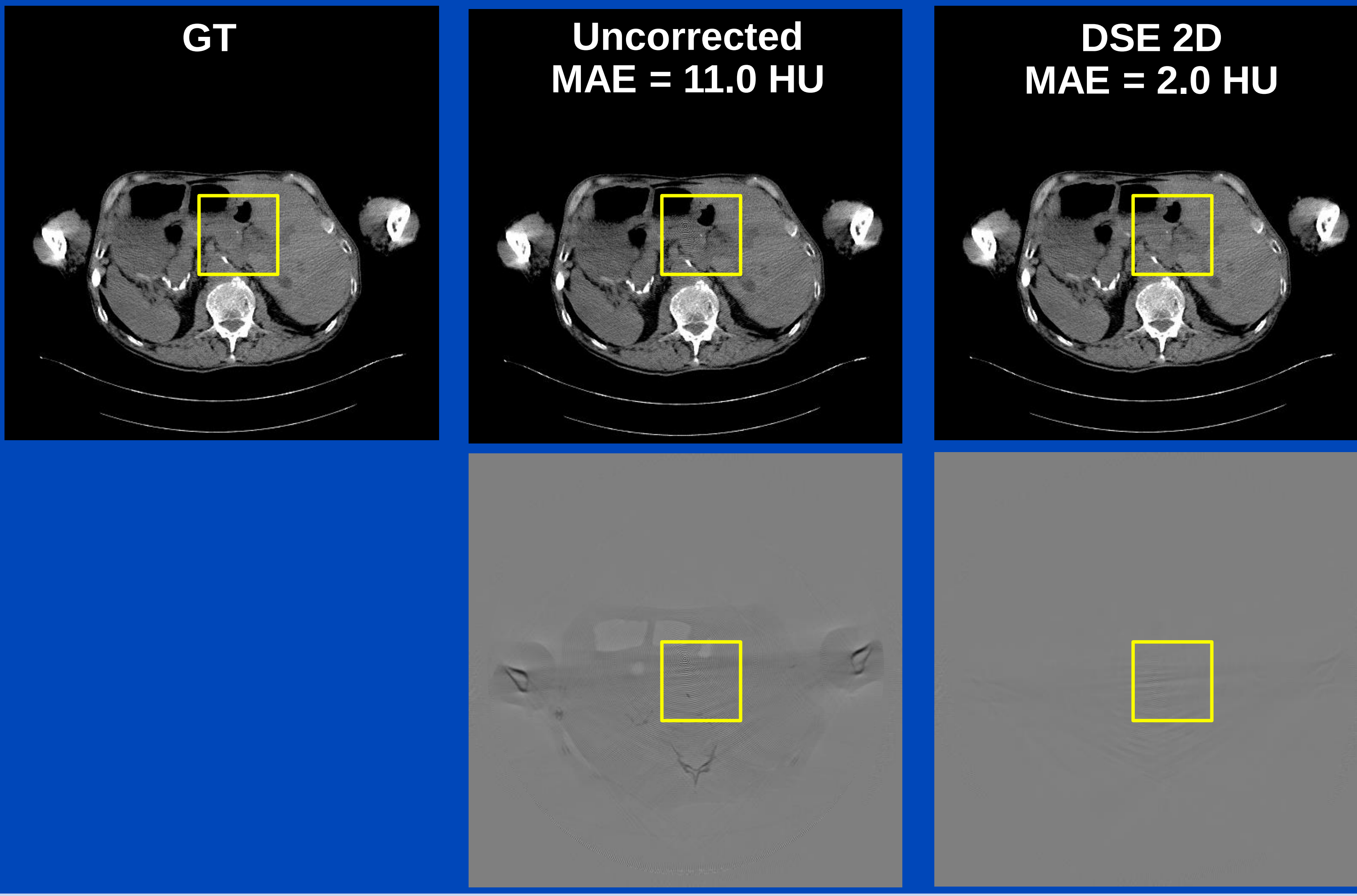
Images: C = 40 HU, W = 300 HU   Differences: C = 0 HU, W = 300 HU

Results Matrix Constant



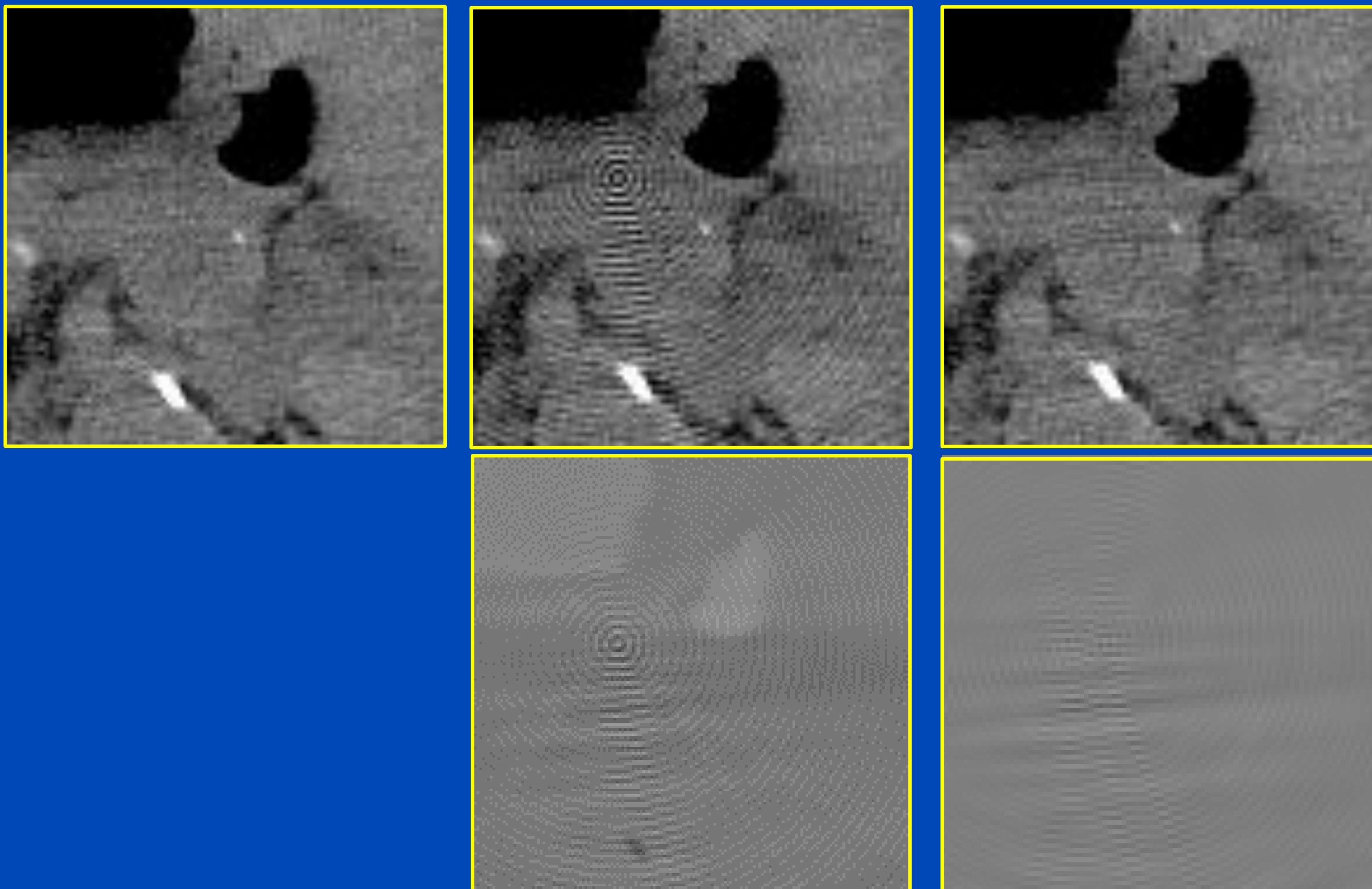
Images: *C* = 40 HU, *W* = 300 HU   Differences: *C* = 0 HU, *W* = 300 HU

Results Matrix Random



Images: *C* = 40 HU, *W* = 300 HU   Differences: *C* = 0 HU, *W* = 300 HU

Results Matrix Random



Images: *C* = 40 HU, *W* = 300 HU   Differences: *C* = 0 HU, *W* = 300 HU

Conclusions

- Smaller detector pixel and coarse anti-scatter grid can lead to moiré artifacts.
- Scatter induced moiré effect can be corrected with deep learning-based scatter correction.
- Neural network is able to detect additional pattern on scatter.
- With the proposed algorithm the mean absolute error (MAE) could be reduced from uncorrected about 10 HU to about 1 HU.
- The amplitude of the scatter induced moiré effect can be corrected from 20 HU to less than 1 HU.
- Next step: apply matrix deep-learning based correction for measurements.

Thank You!

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