Artifacts and Pitfalls in CT

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Artifact List

- …glow artifacts
- Aliasing artifacts
- Beam hardening artifacts
- Blooming artifacts
- Calibration artifacts
- Cone-beam artifacts
- Correction artifacts
- Cross-talk artifacts
- Cupping and capping artifacts
- Defect detector pixel artifacts
- Display artifacts
- Electronic noise artifacts
- Ghost artifacts
- Limited angle artifacts
- Linear partial volume artifacts
- Metal artifacts
- Misalignment artifacts
- Missing data artifacts
- Motion artifacts
- Non-linear partial volume aritifacts
- Photon starvation artifacts
- Quantum noise artifacts
- Ring artifacts
- Sampling artifacts
- Scatter artifacts
- Streak artifacts
- Truncation artifa…
- Windmill a…

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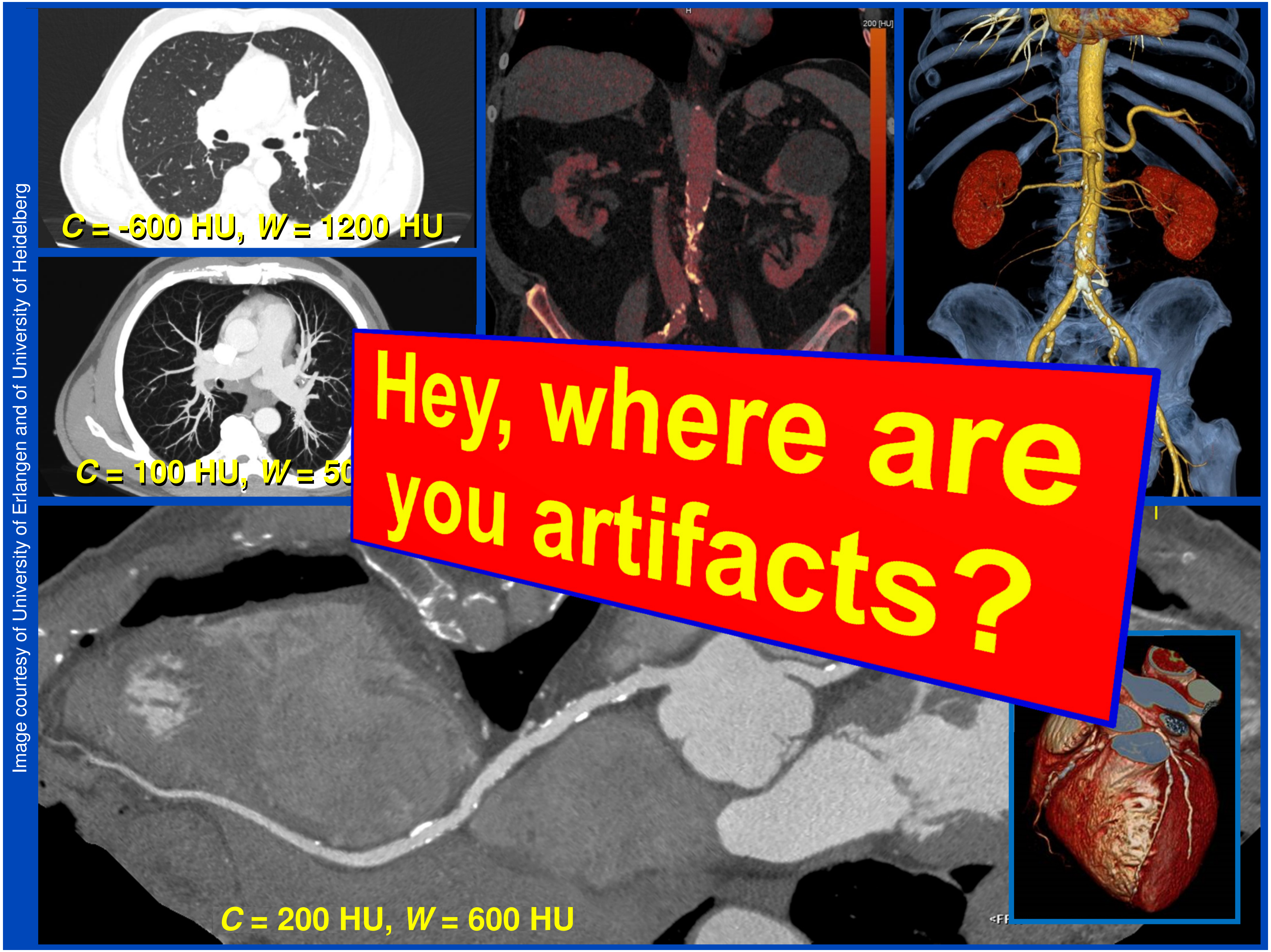
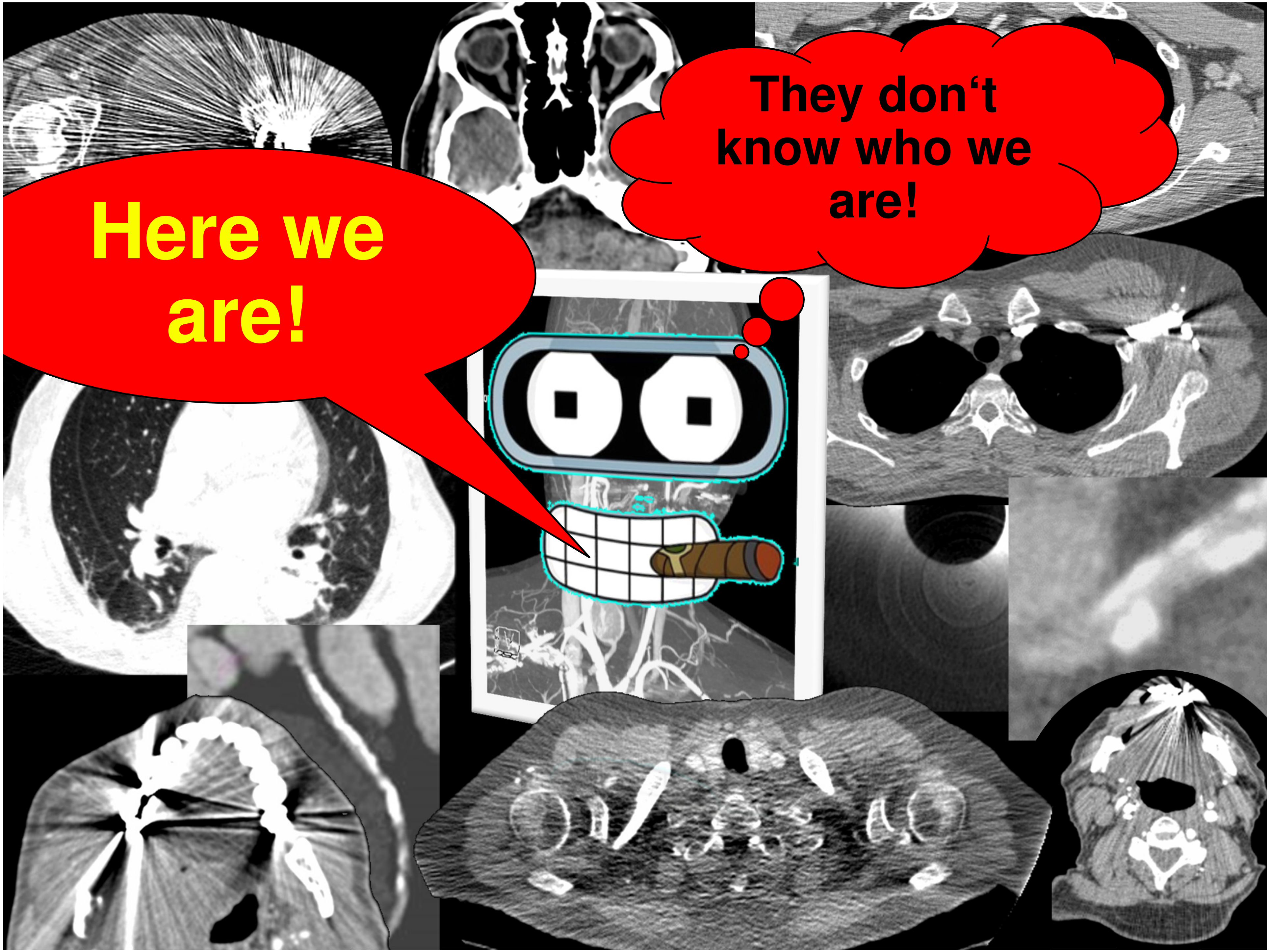
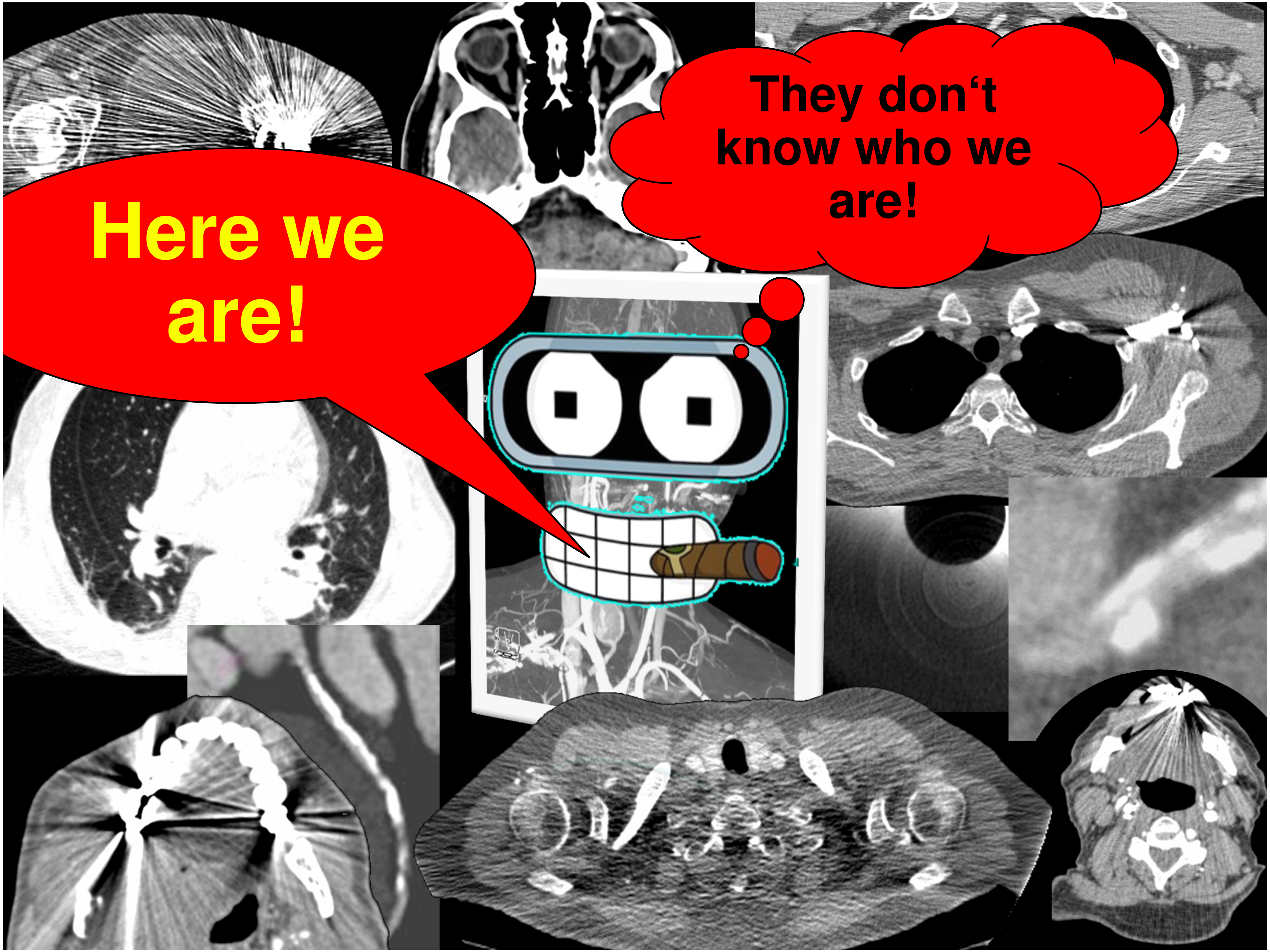


Image courtesy of University of Erlangen and of University of Heidelberg


Here we are!
They don‘t know who we are!


Here we are!
They don‘t know who we are!

GE Revolution CT

Philips IQon Spectral CT

Siemens Somatom Force

Toshiba Aquilion ONE Vision

In-plane resolution: 0.4 … 0.7 mm

Nominal slice thickness: S = 0.5 … 1.5 mm

Tube (max. values): 120 kW, 150 kV, 1300 mA

Effective tube current: $\mathrm{mAs}_{\mathrm{eff}}$ = 10 mAs … 1000 mAs

Rotation time: T_{rot} = 0.25 … 0.5 s

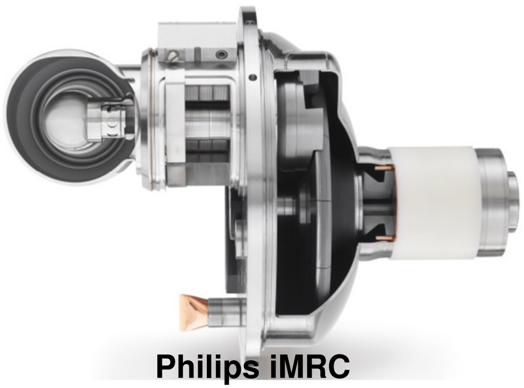
Simultaneously acquired slices: M = 16 … 320

Table increment per rotation: d = 1 … 183 mm

Scan speed: up to 73 cm/s

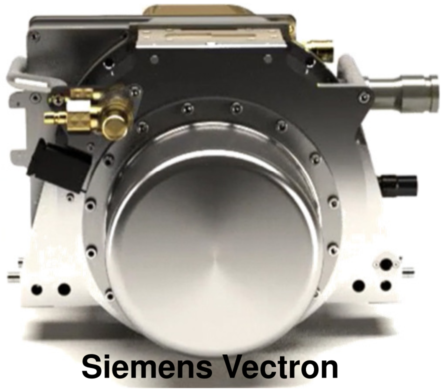
Temporal resolution: 50 … 250 ms

GE Performix HDw

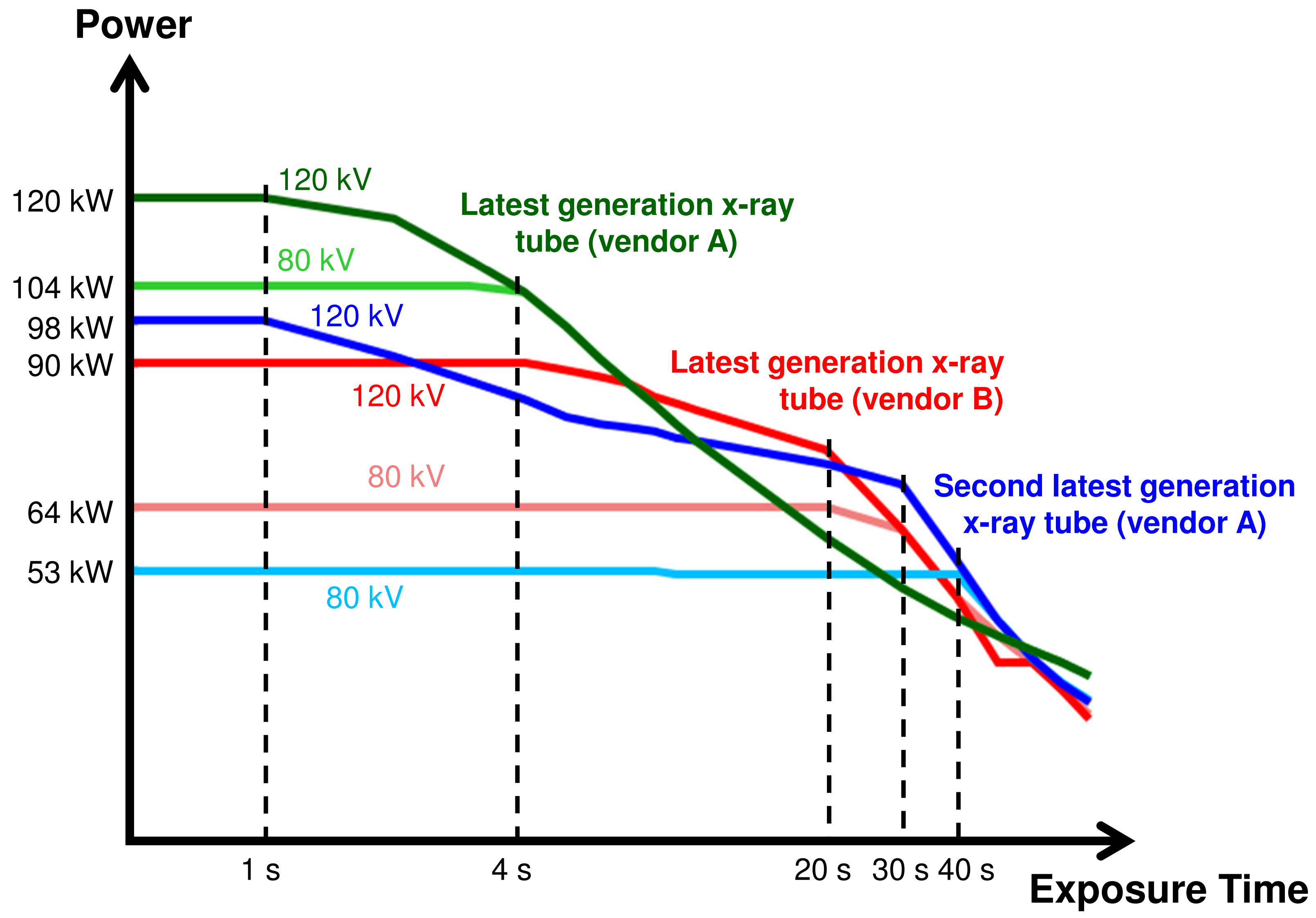


Philips iMRC

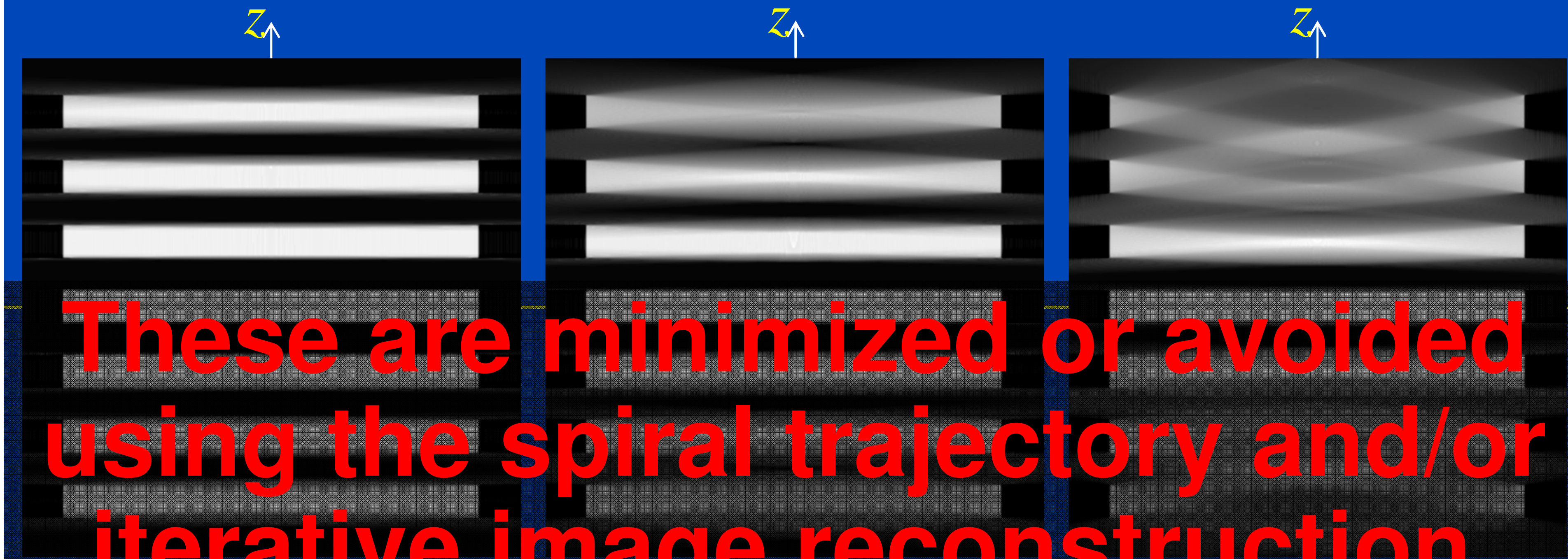
Siemens Straton



Siemens Vectron

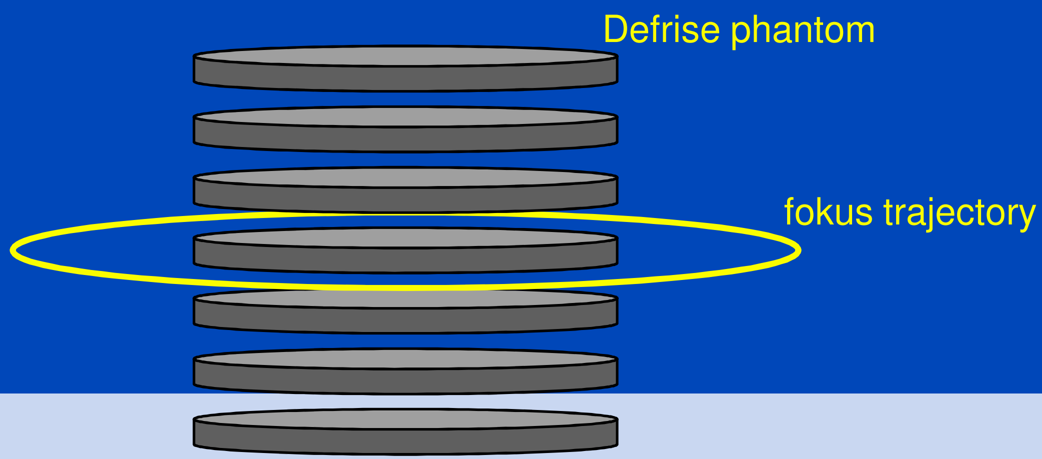

Power
120 kW
104 kW
98 kW
90 kW
64 kW
53 kW
120 kV
80 kV
120 kV
120 kV
80 kV
80 kV
Latest generation x-ray tube (vendor A)
Latest generation x-ray tube (vendor B)
Second latest generation x-ray tube (vendor A)
1 s
4 s
20 s
30 s
40 s
Exposure Time

Cone-Beam Artifacts



These are minimized or avoided using the spiral trajectory and/or iterative image reconstruction.

Cone-angle Γ = 6° Cone-angle Γ = 14° Cone-angle Γ = 28°



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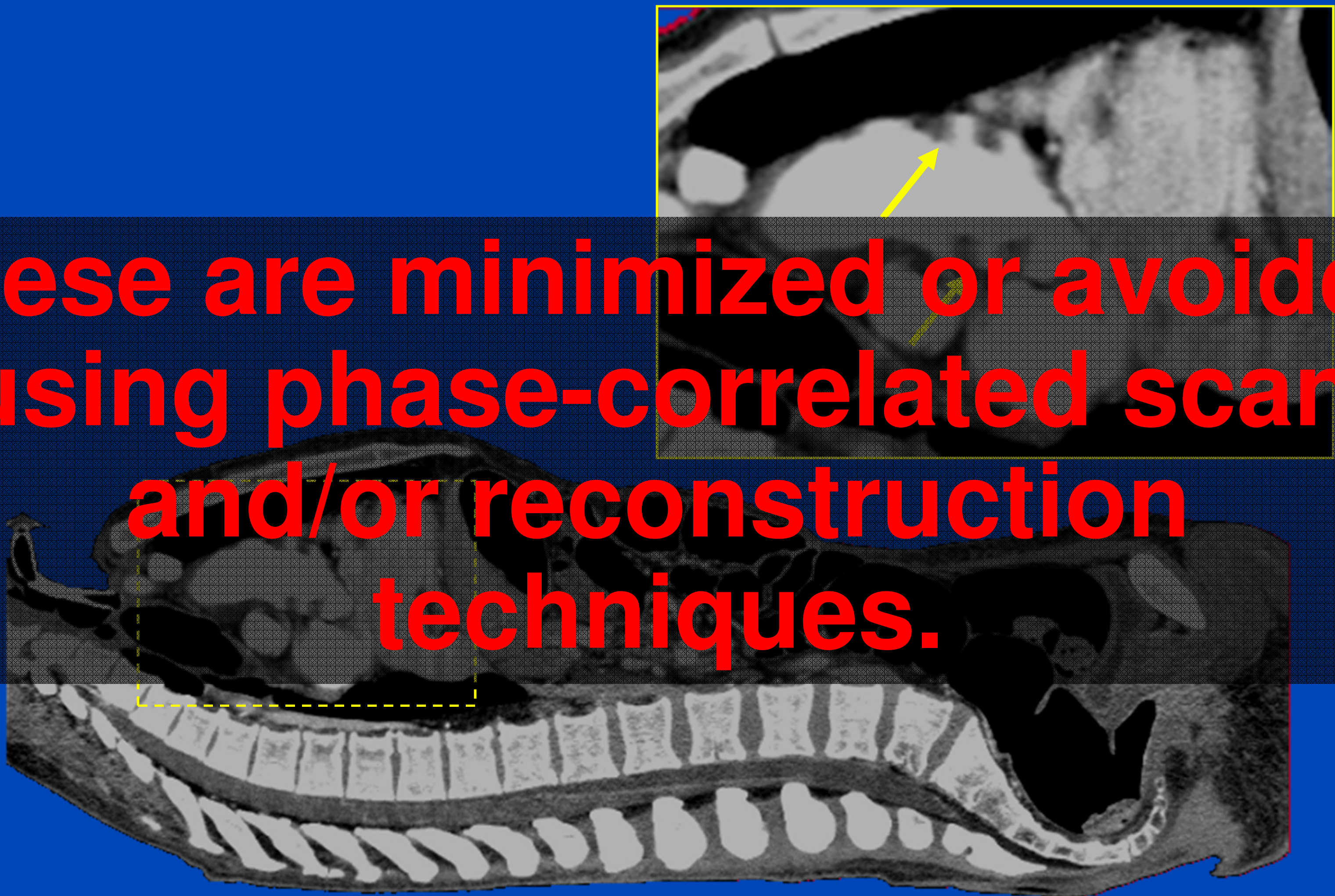
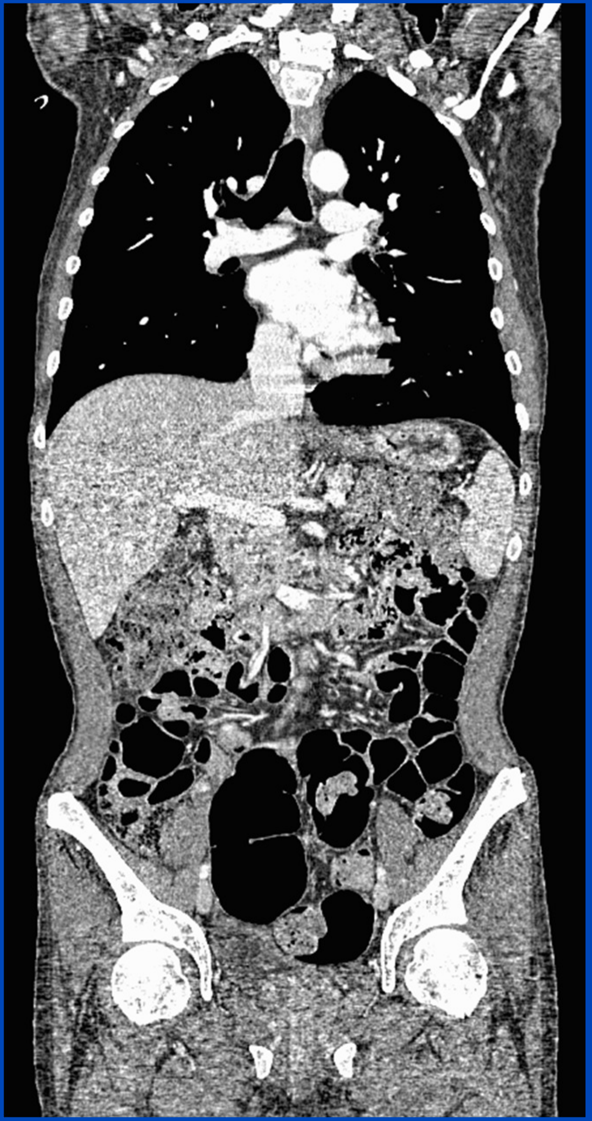
Motion Artifacts of the Heart



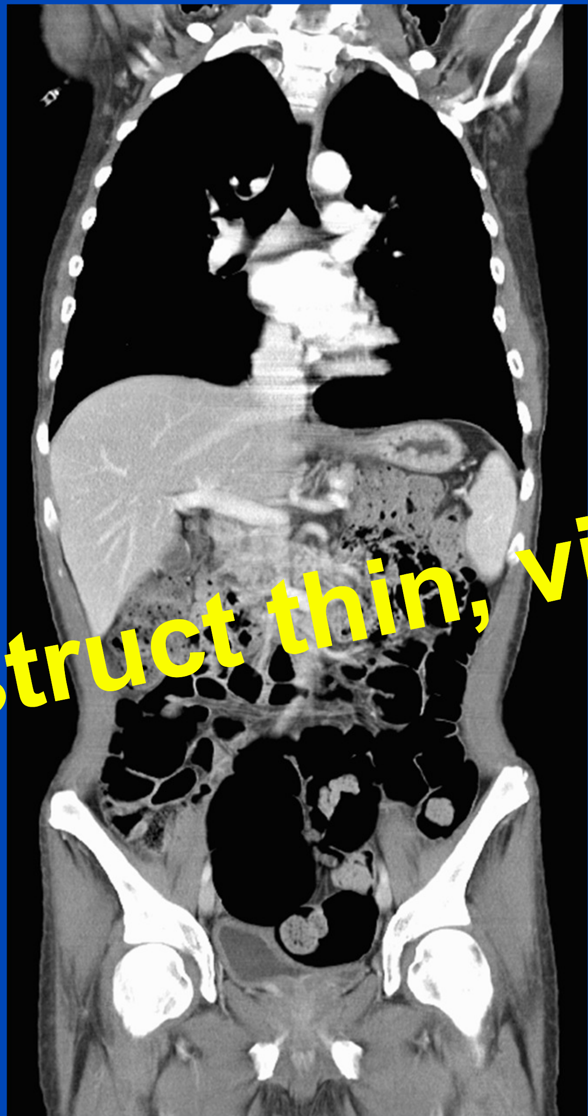
These are minimized or avoided using phase-correlated scan and/or reconstruction techniques.

Standard Display

0,5×0,5×0,5 mm^3
C = 50 HU, W = 400 HU



Sliding Thin Slab (STS) Display



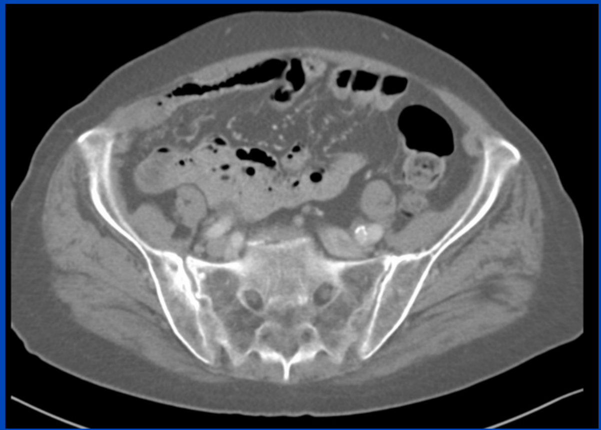
“Reconstruct thin, view thick!”

0,5×0,5×10 mm^3
C = 50 HU, W = 400 HU

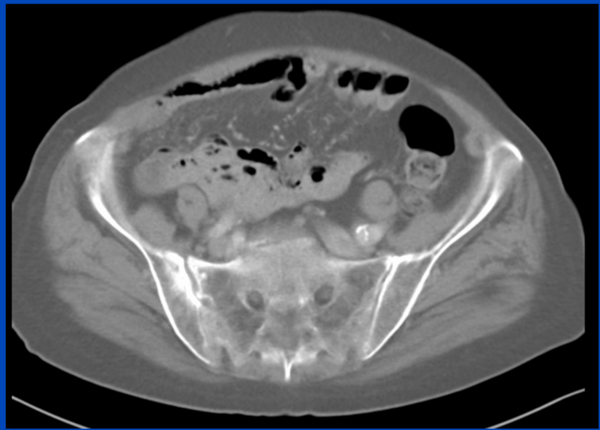
Linear Partial Volume Effect

S = 1 mm

S = 5 mm

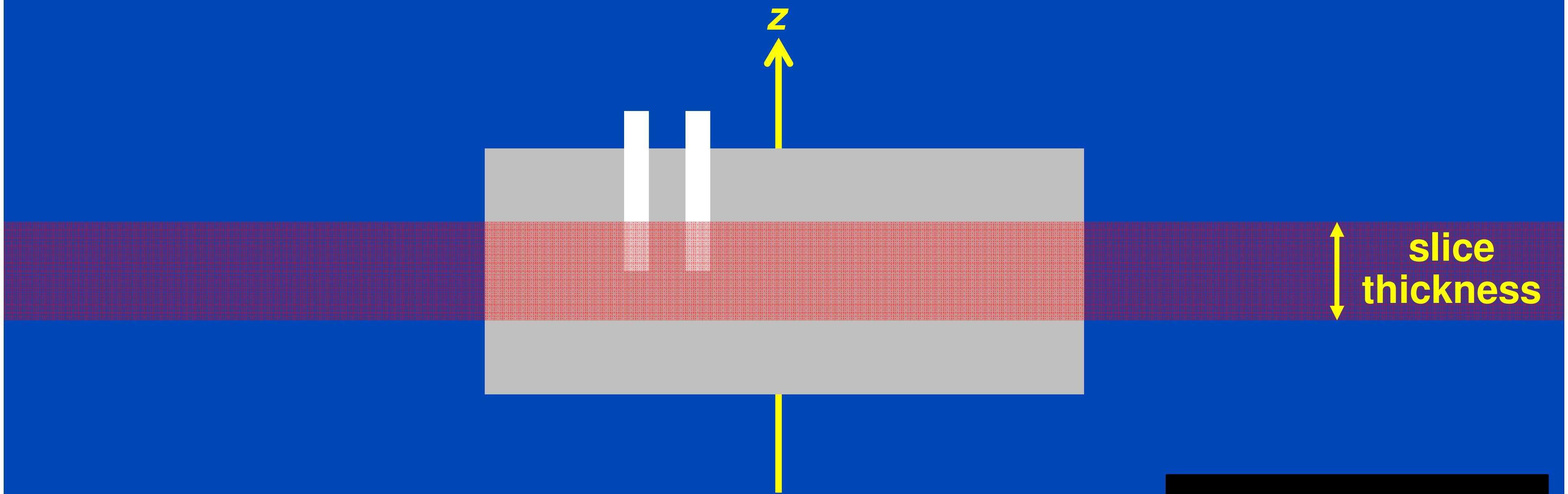


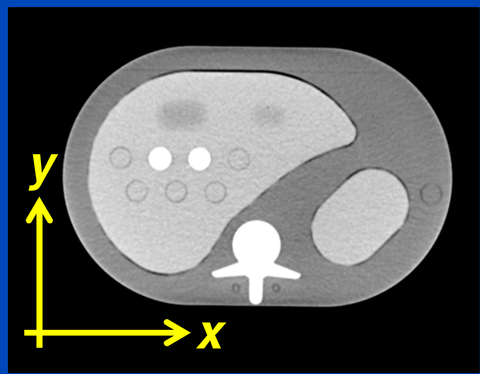
S = 10 mm



C = 0 HU, *W* = 800 HU

Partial Volume Effect: Experiment





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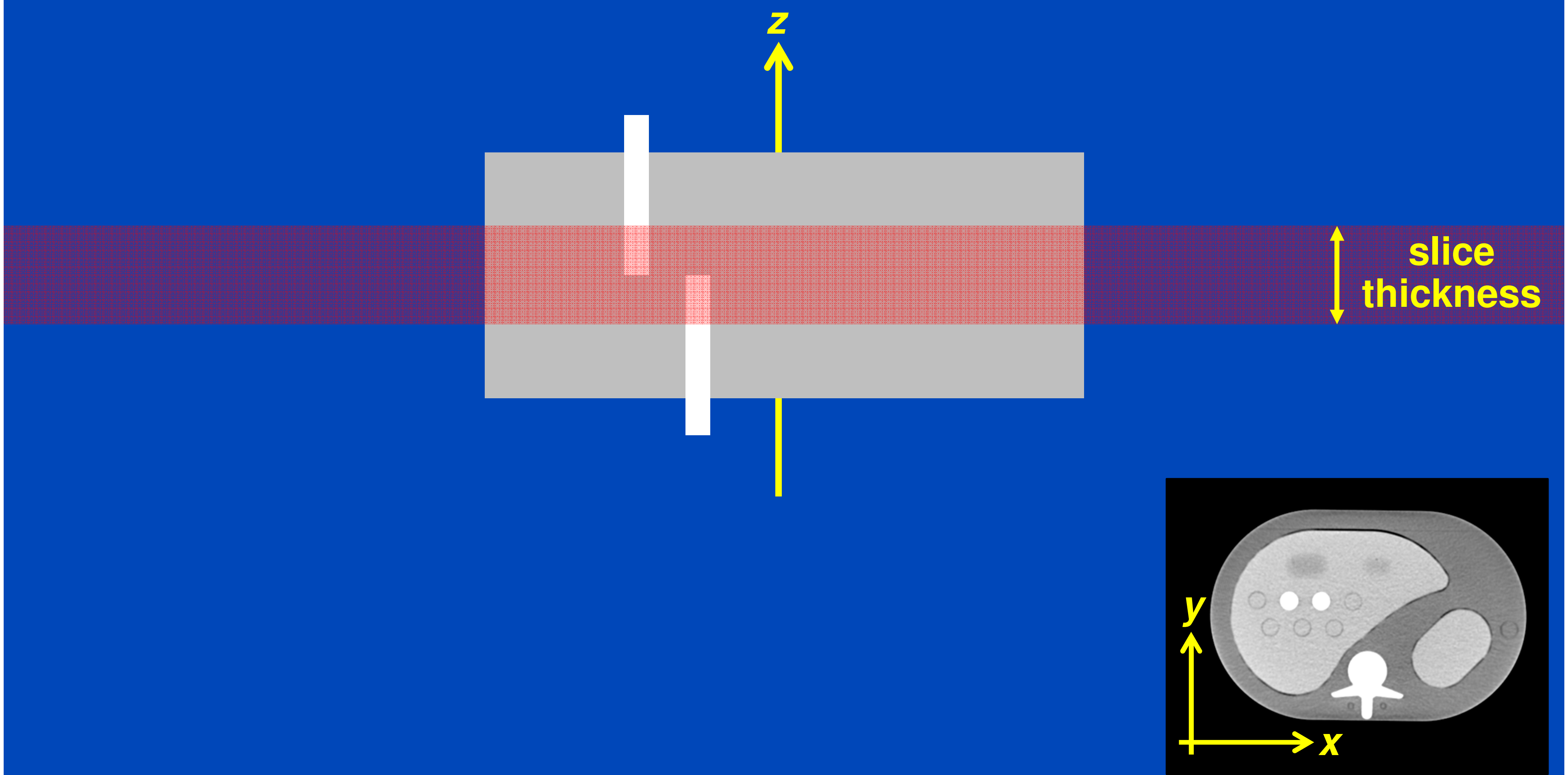
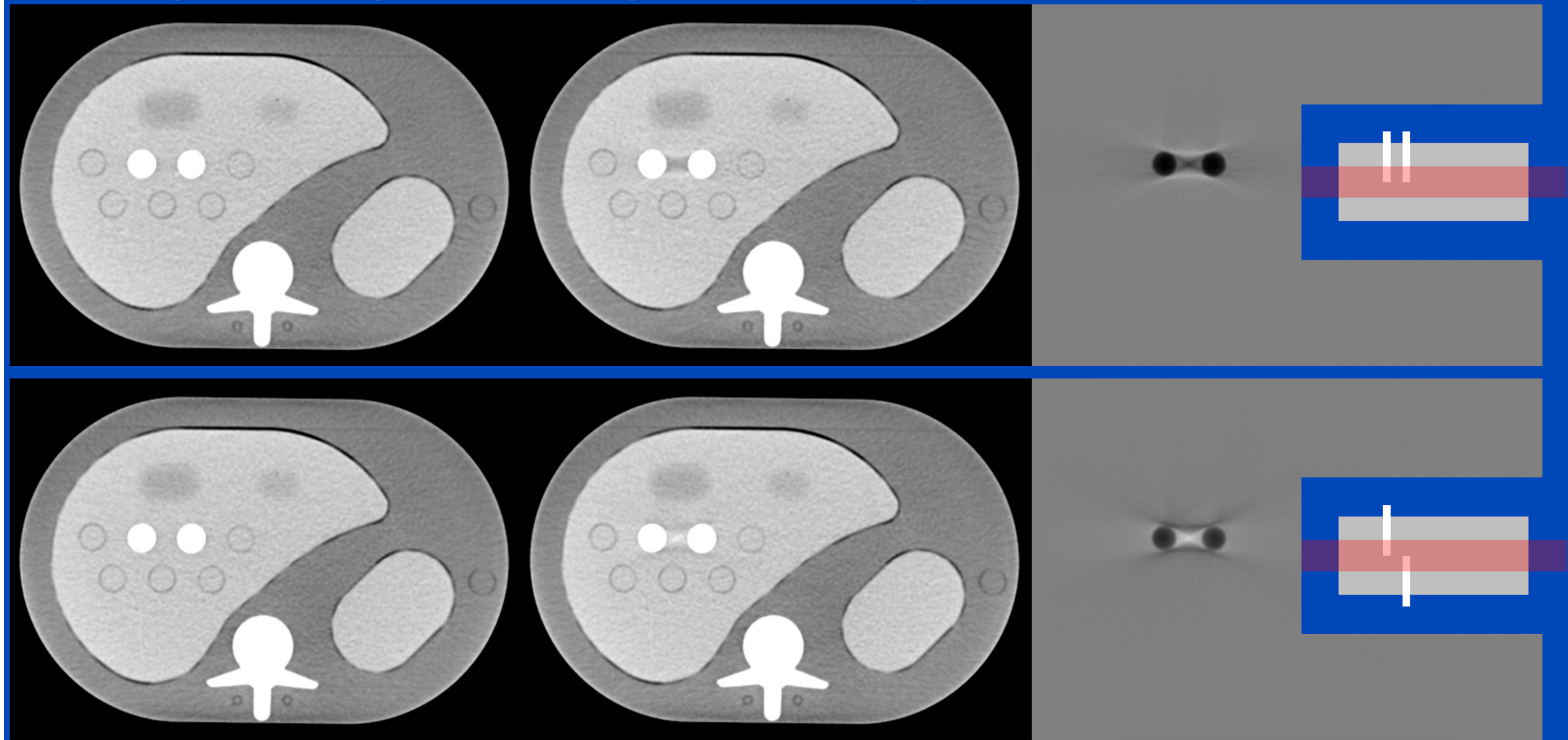
Partial Volume Effect: Experiment



Linear and Non-Linear Partial Volume Effect

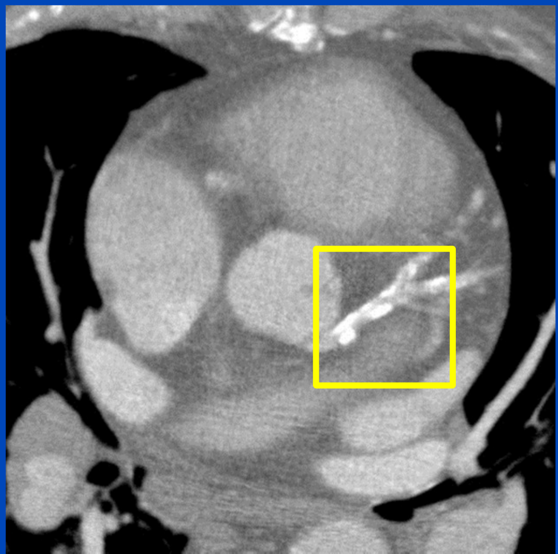
Log domain average (linear PVE) | Intensity domain average (non-linear PVE) | Intensity minus log domain average



C = 40 HU, *W* = 200 HU | *C* = 0 HU, *W* = 100 HU

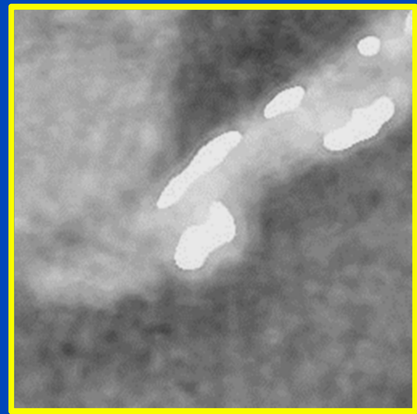
Blooming Artifacts and their Reduction

Cardiac reconstruction



Calcification
+ Blooming

Estimated
calcification

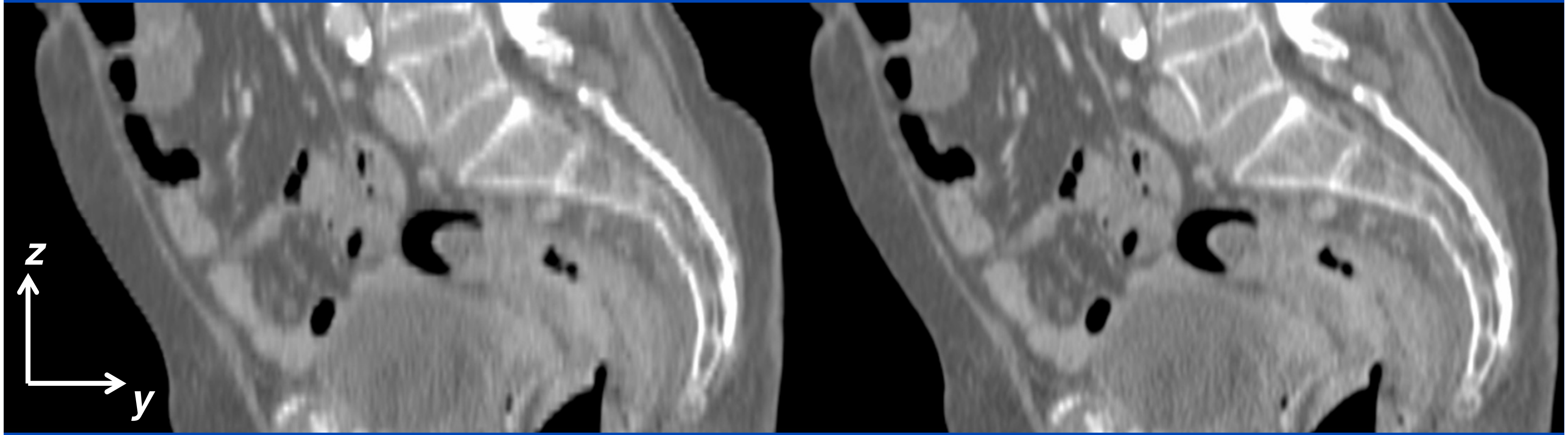


- This shows a dedicated blooming artifact reduction approach based on a discrete tomography reconstruction technique.
- Blooming artifacts are also suppressed by today‘s iterative reconstruction algorithms.

C = 0 HU, W = 1000 HU

Sampling Artifacts and their Removal

S_{eff} = 3 mm, RI = 3 mm | S_{eff} = 3 mm, RI = 1 mm



Always perform Overlapping Recons!

C = 0 HU, *W* = 800 HU

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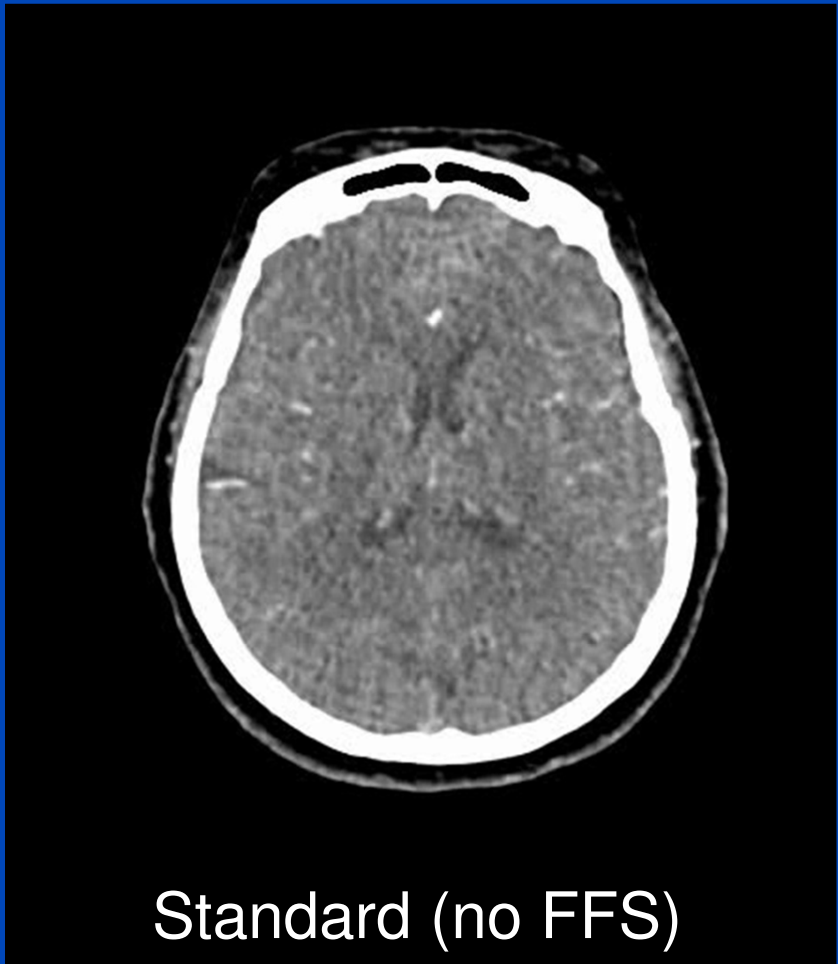
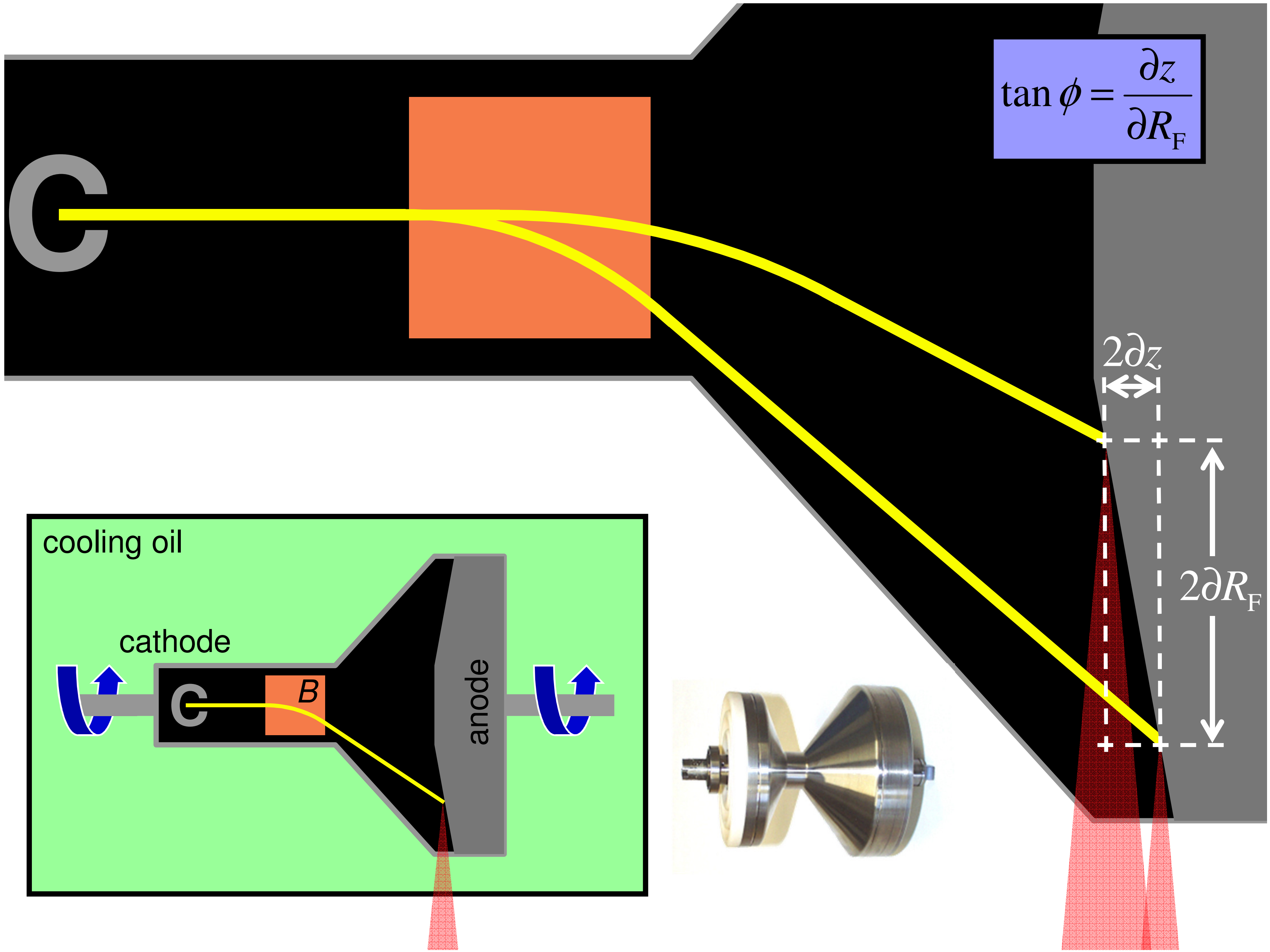
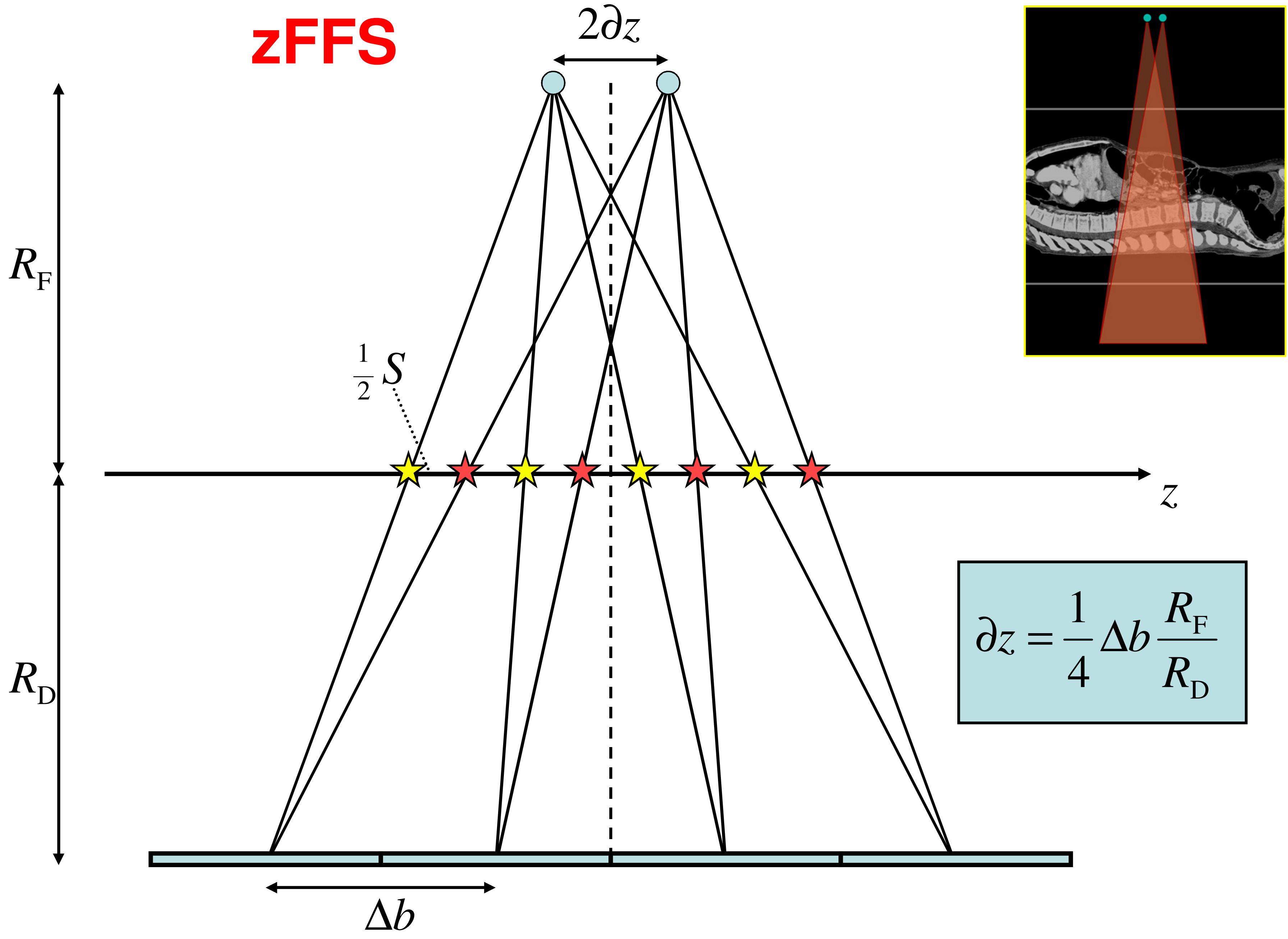
Windmill Artifacts and their Removal



ASSR reconstruction, $p = 1.0$, ($C = 0$ HU, $W = 200$ HU)

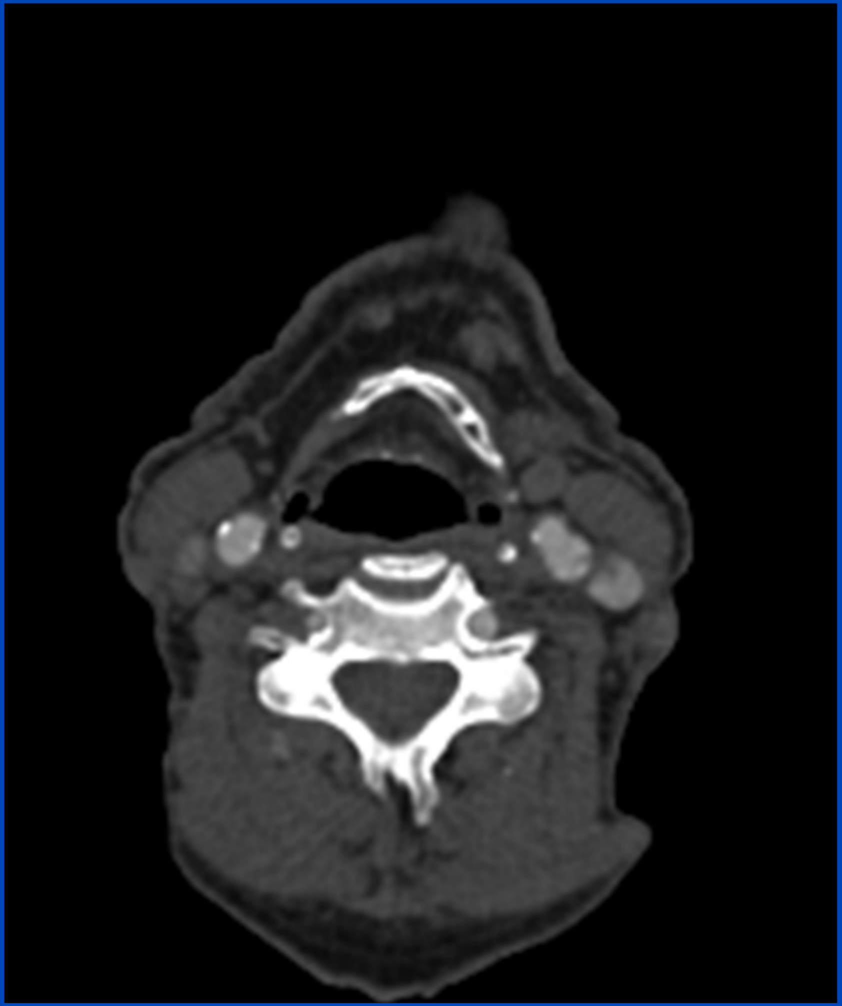


$\tan\phi = \frac{\partial z}{\partial R_F}$
C
$2\partial z$
$2\partial R_F$
cooling oil
cathode
C
B
anode



zFFS
$2\partial z$
R_F
R_D
$\frac{1}{2}S$
z
Δb
$\partial z = \frac{1}{4}\Delta b \frac{R_F}{R_D}$

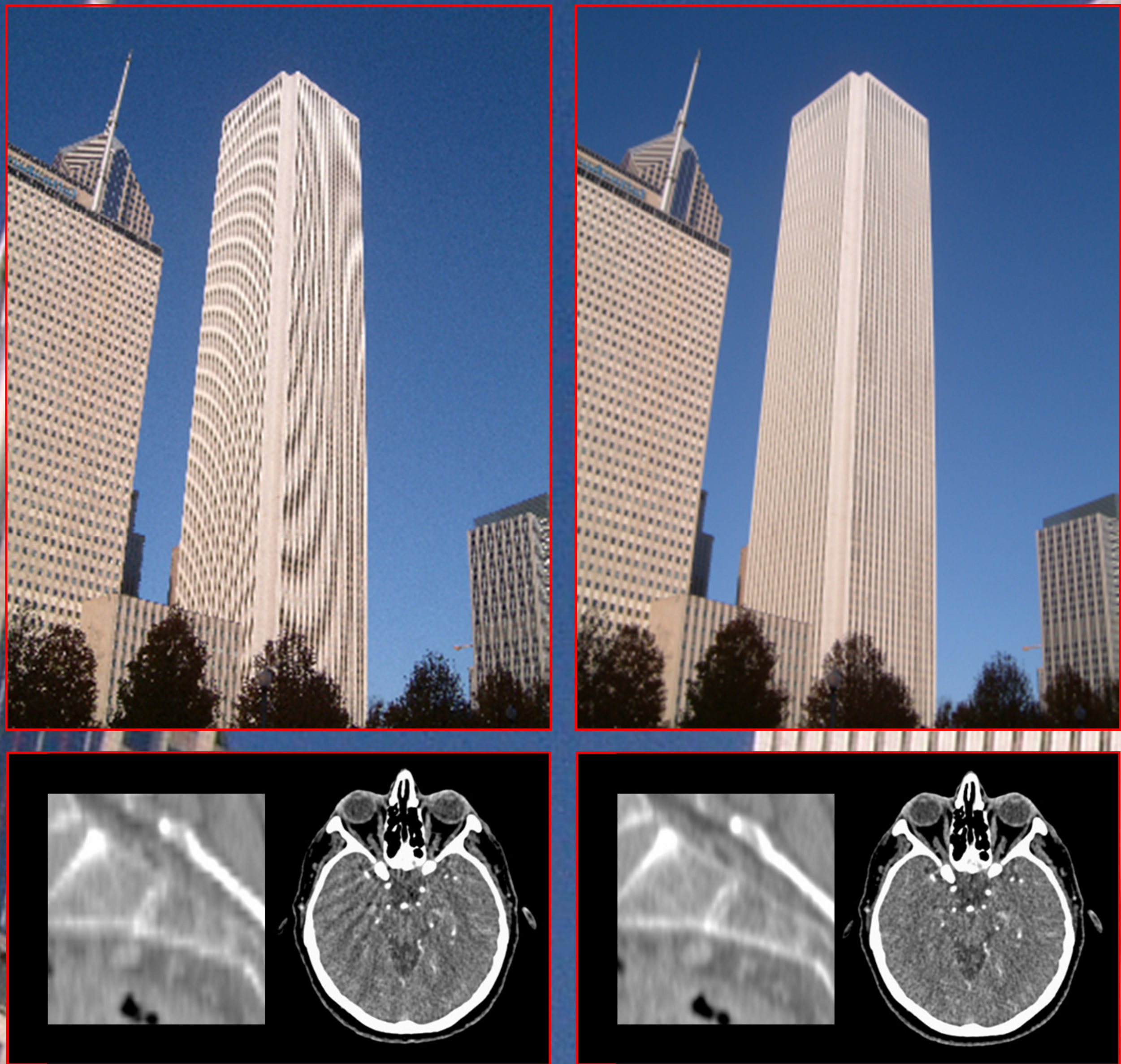
Windmill Artifacts in Spiral Shuttle Mode



- Siemens SOMATOM Force
- Perfusion measurement
- Pitch $p = 1$
- Δ_{xy} =0.93 mm
- Δ_z =1.25 mm

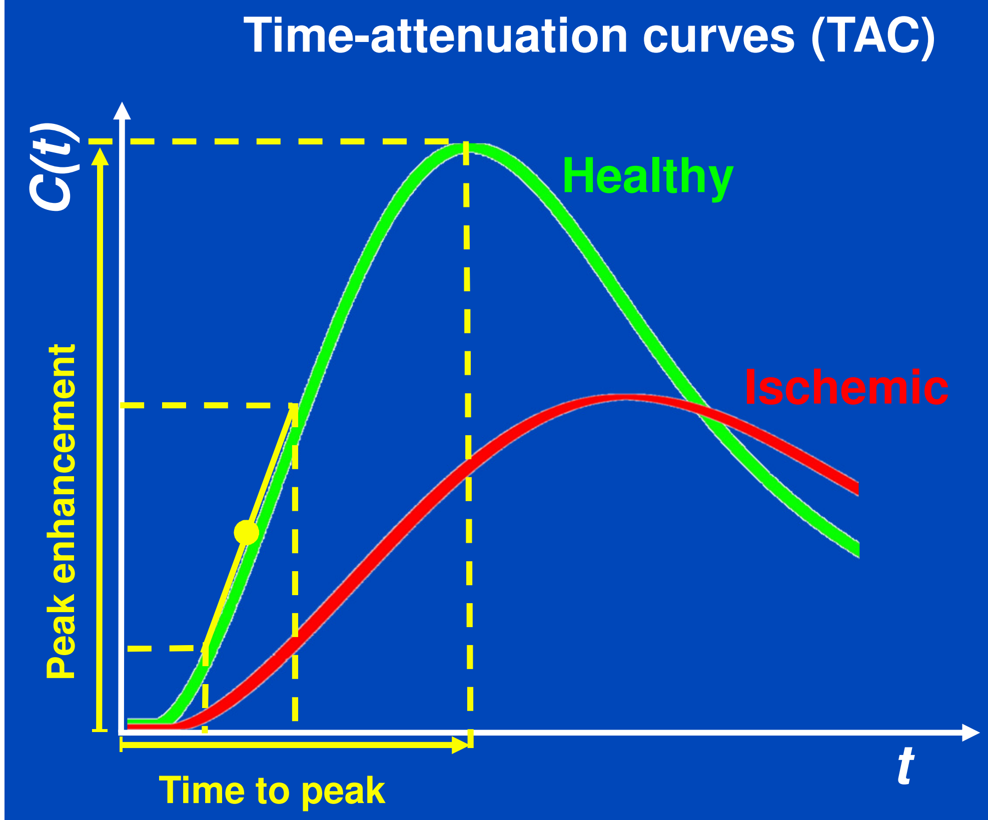
C = 300 HU, W = 1000 HU

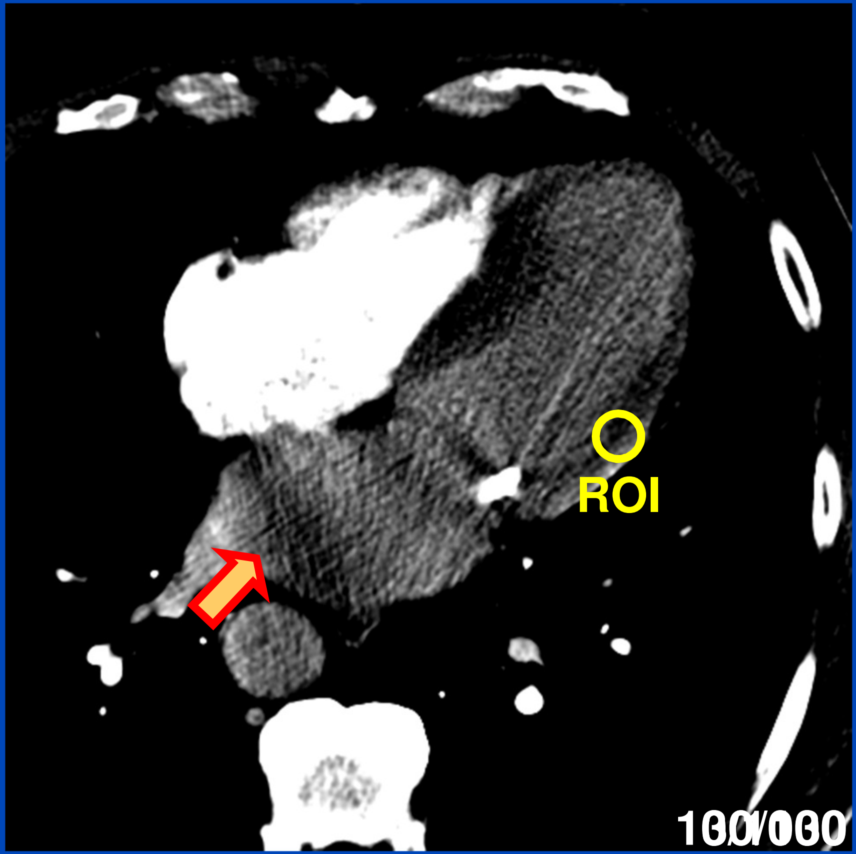
Sampling, Aliasing, Nyquist-Condition



Edward Durell Stone, Amoco building, Chicago, 1973

BH: Perfusion Analysis in CT





Beam hardening artifacts cause an underestimation of the CT-values leading to incorrect perfusion parameters!

Beam Hardening

- **Measurement**

$$q = -\ln \int dE\, w(E) e^{-\int dL\, \mu(\boldsymbol{r}, E)}$$

- **Single material approximation:** $\mu(\boldsymbol{r}, E) = f_1(\boldsymbol{r})\psi_1(E)$

$$q = -\ln \int dE\, w(E) e^{-p_1 \psi_1(E)}$$

→ cupping artifacts, first order BH artifacts → cupping correction (water precorrection)

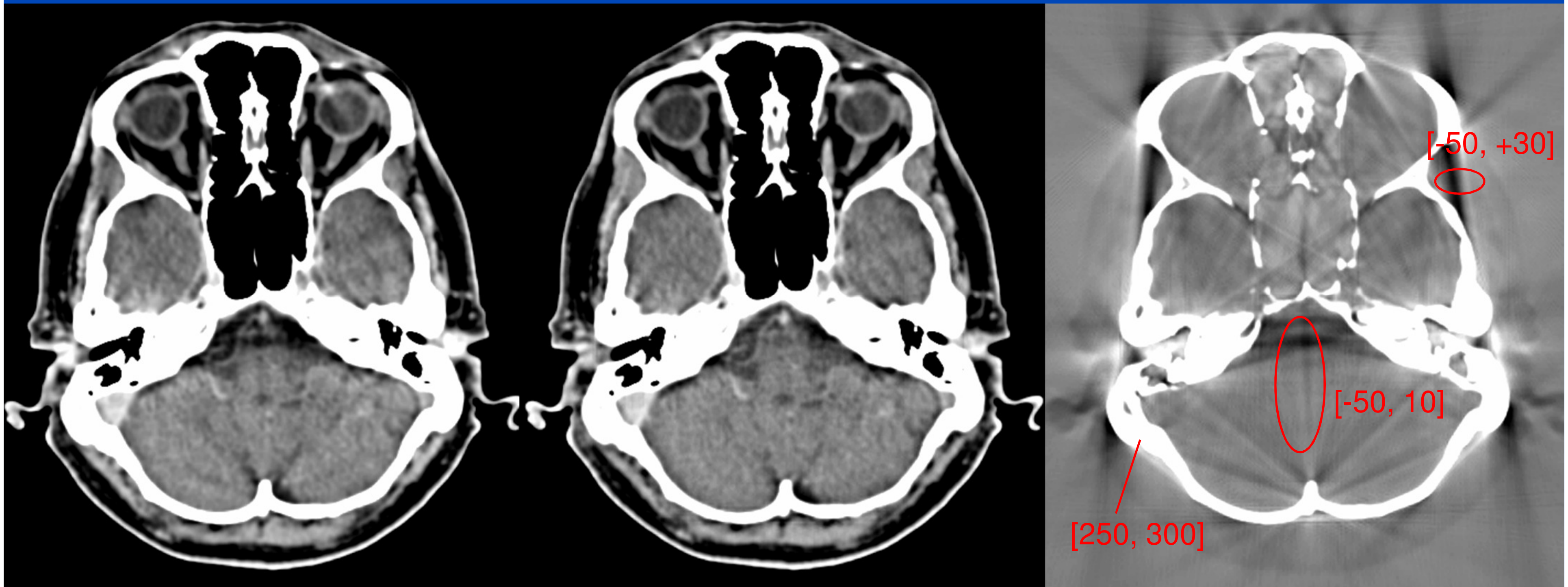
- **Two material case:** $\mu(\boldsymbol{r}, E) = f_1(\boldsymbol{r})\psi_1(E) + f_2(\boldsymbol{r})\psi_2(E)$

$$q = -\ln \int dE\, w(E) e^{-p_1 \psi_1(E) - p_2 \psi_2(E)}$$

→ banding artifacts, higher order BH artifacts → higher order BH correction

Patient Data
Spiral 4-Slice CT Scan at 120 kV

Original Image | **BHC Image** | **Original minus BHC**

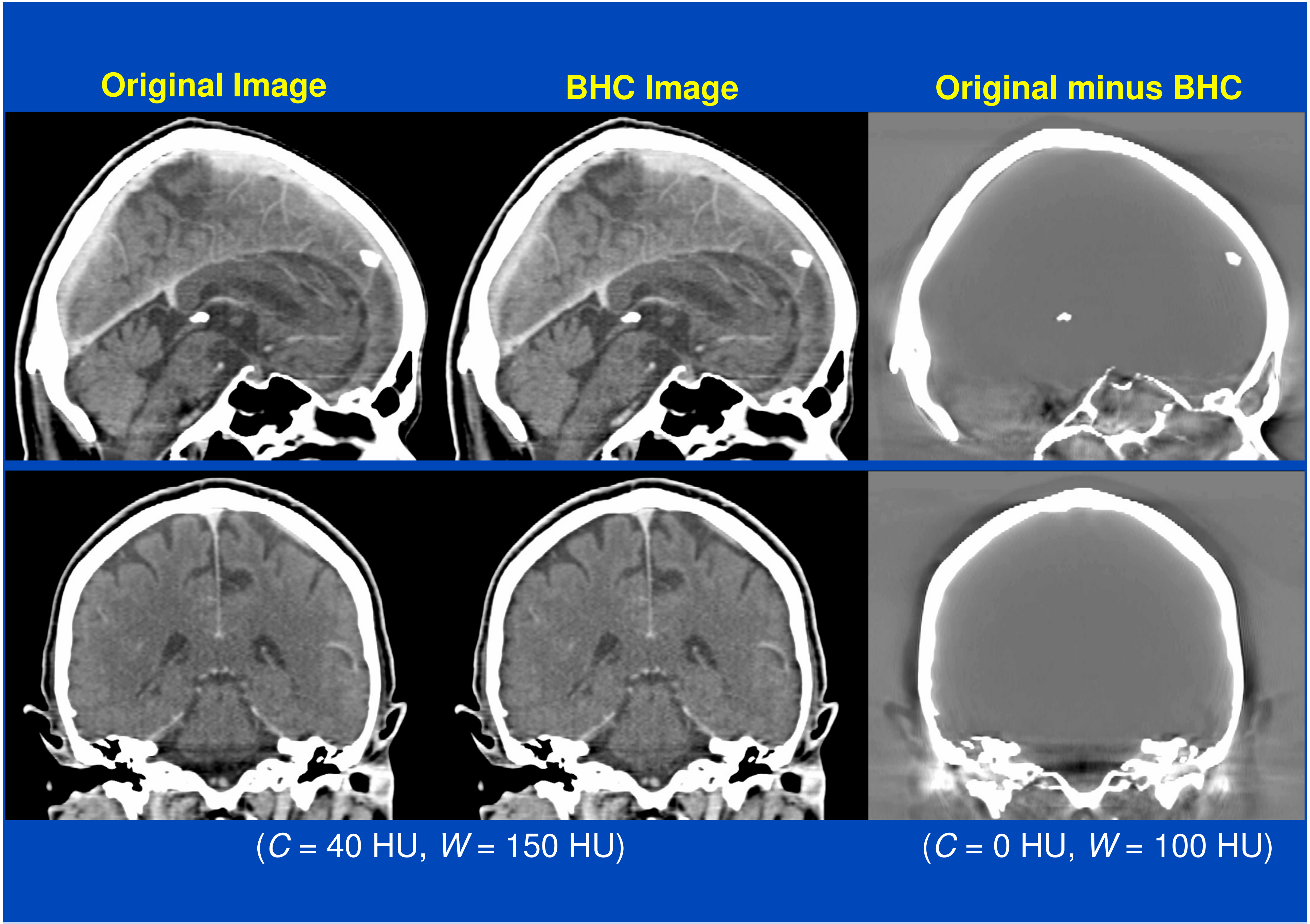


(C = 40 HU, W = 150 HU)

(C = 0 HU, W = 100 HU)

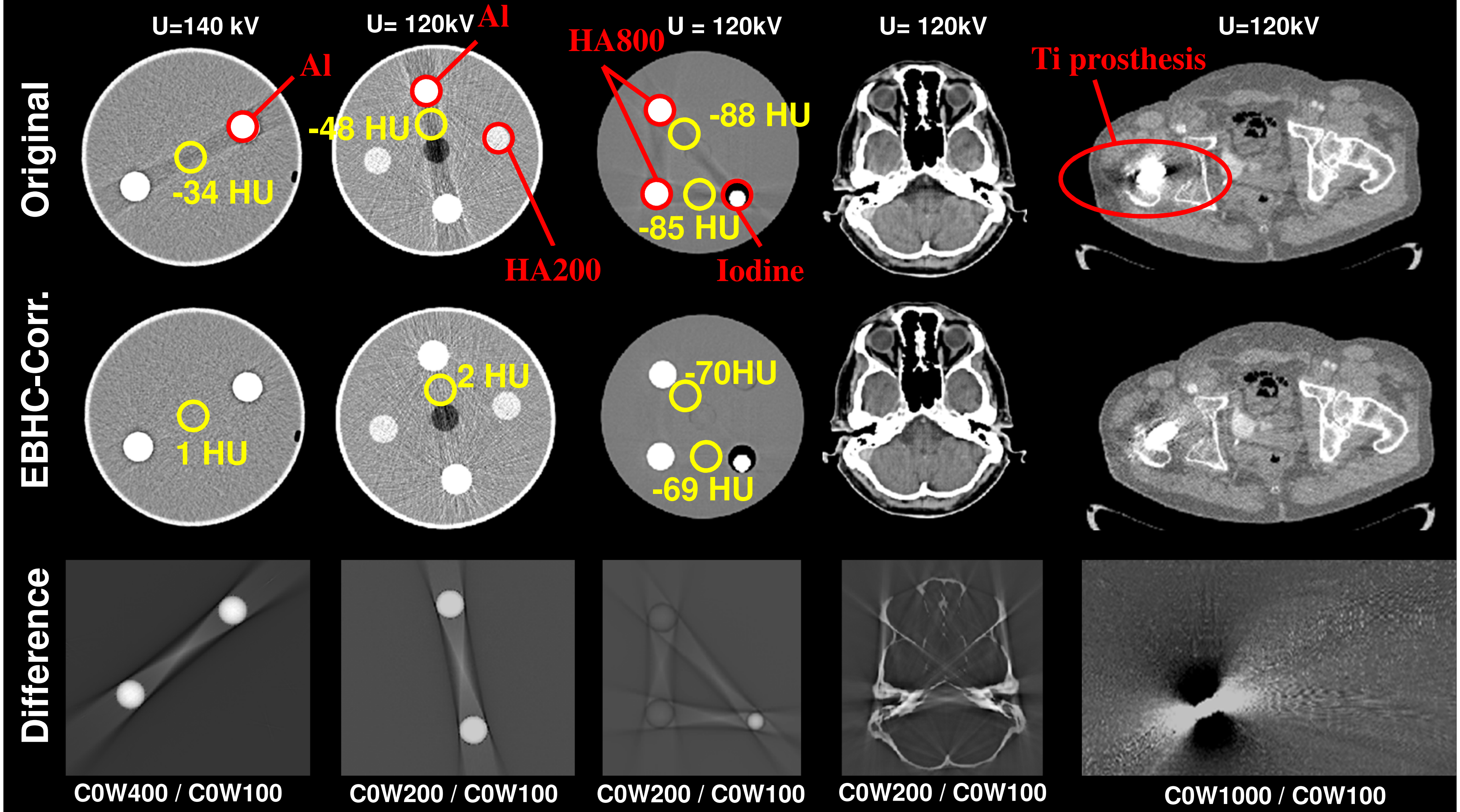
Red values indicate the range of CT-values within the corresponding ROI in HU

M. Kachelrieß, and W.A. Kalender, "Improving PET/CT attenuation correction with iterative CT beam hardening correction," IEEE Medical Imaging Conference Program, M04-5, October 2005.



M. Kachelrieß, and W.A. Kalender, "Improving PET/CT attenuation correction with iterative CT beam hardening correction," IEEE Medical Imaging Conference Program, M04-5, October 2005.

Beam Hardening Artifacts (and their Correction with EBHC)



Y. Kyriakou, E. Meyer, D. Prell, and M. Kachelrieß, "Empirical beam hardening correction (EBHC) for CT," Med. Phys. 37(10):5179-5187, October 2010.

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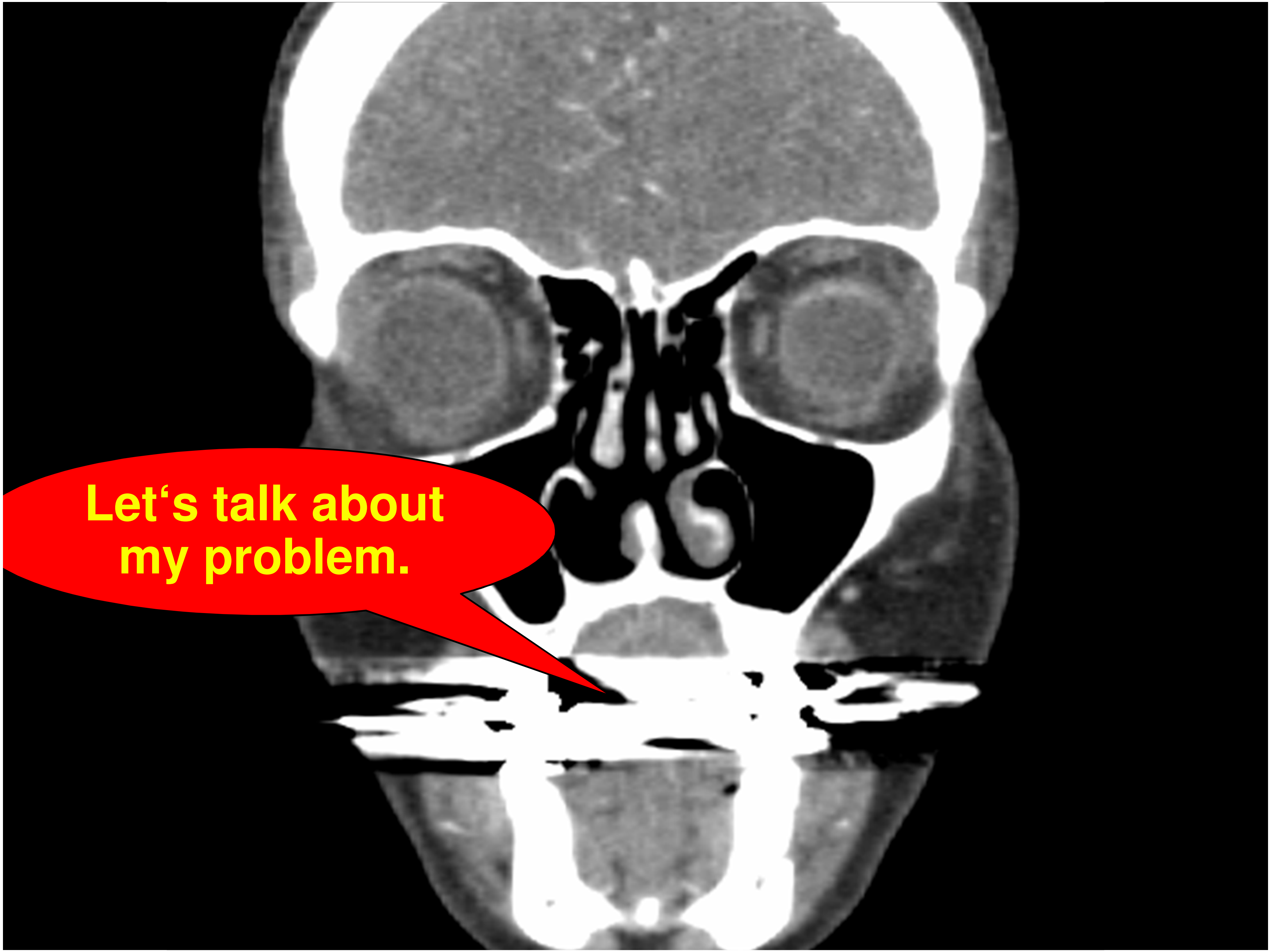
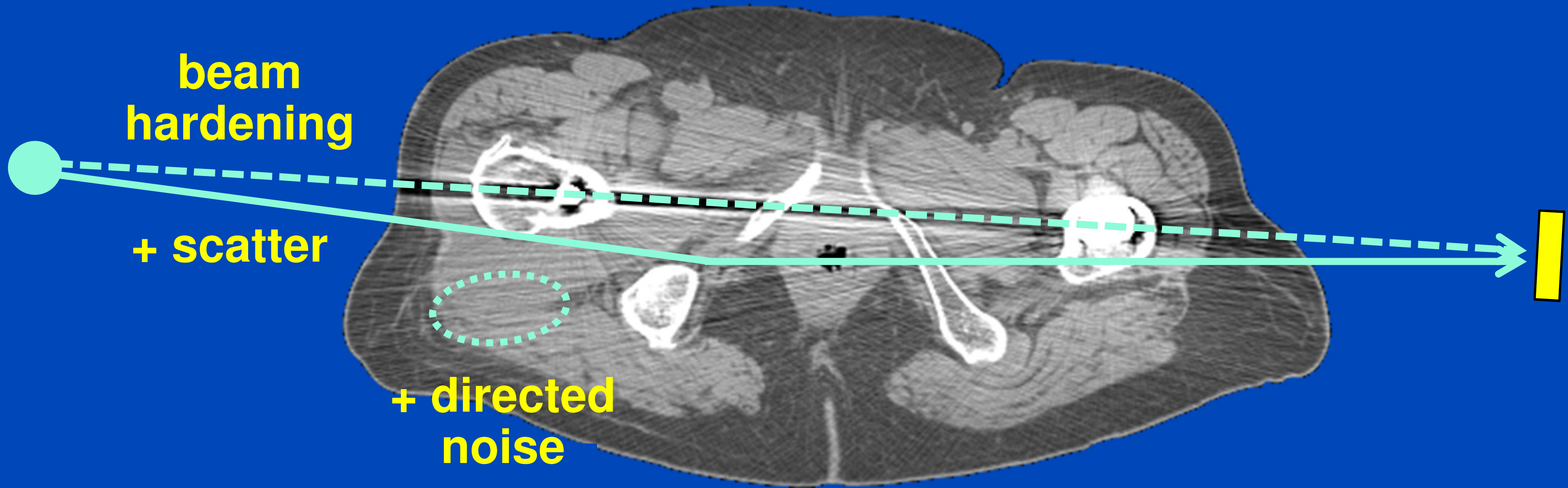
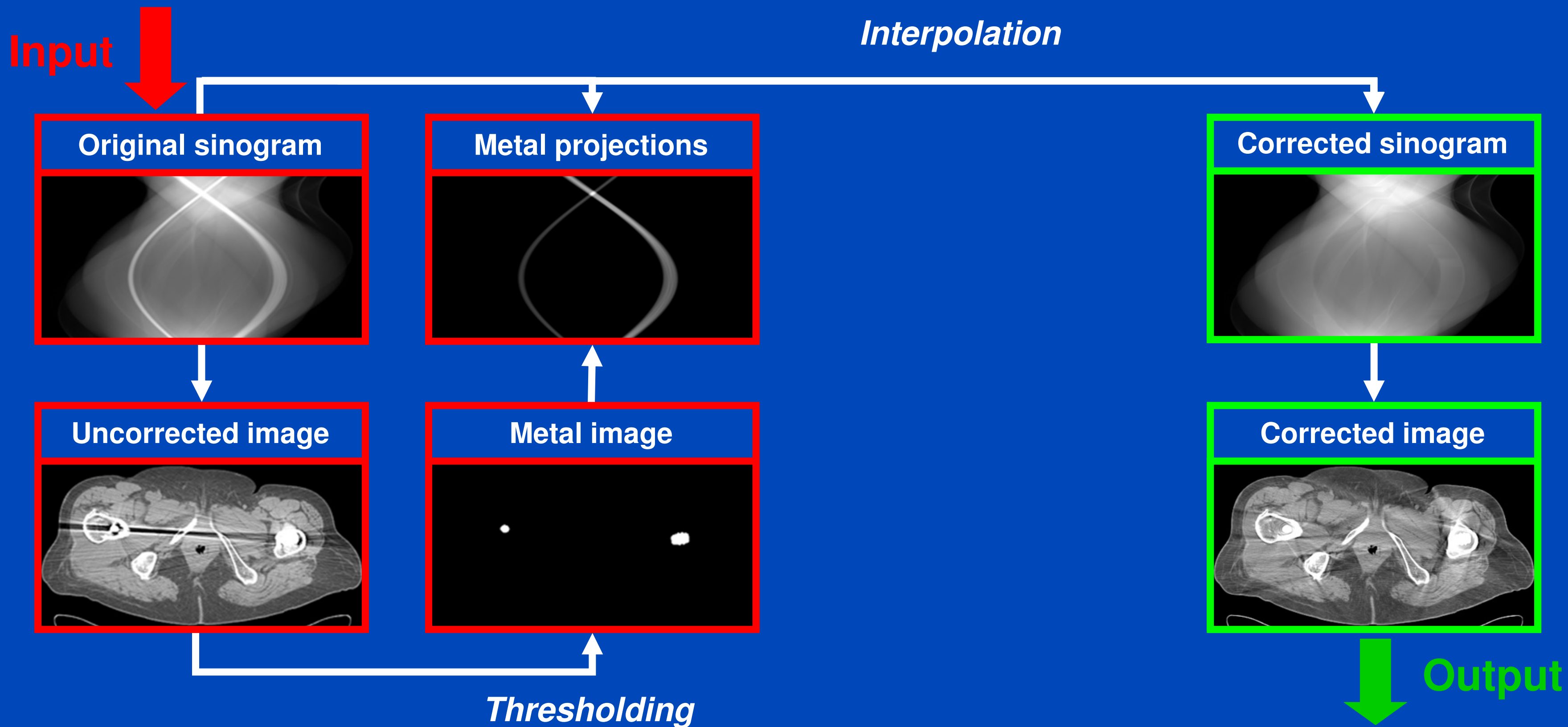

Let‘s talk about
my problem.

Metal artifacts are



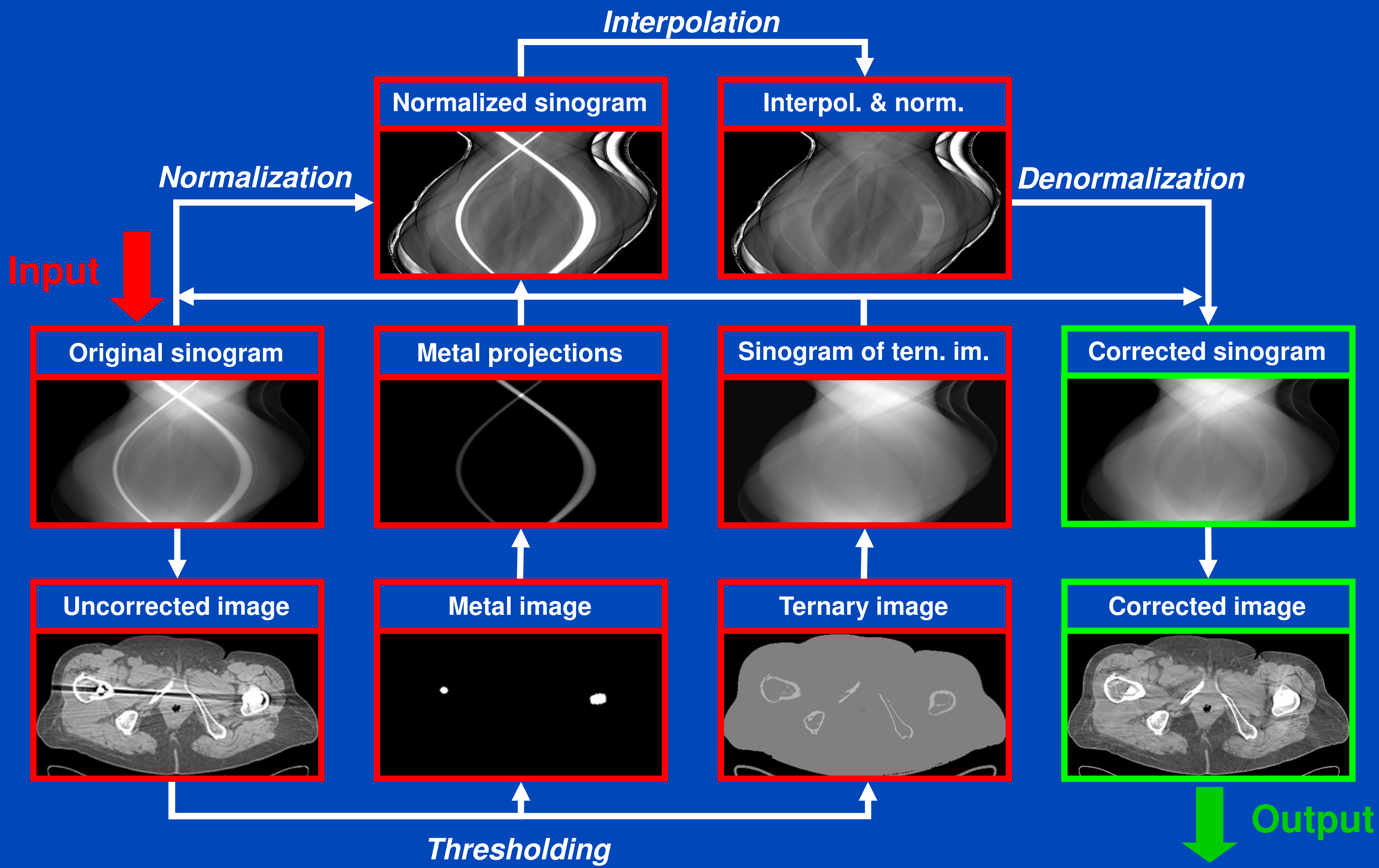
+ increased susceptibility to sampling artifacts and motion.

Linear Interpolation MAR (LIMAR)



W. A. Kalender, R. Hebel, and J. Ebersberger, "Reduction of CT artifacts caused by metallic implants," Radiology 164(2): 576–577, 1987.

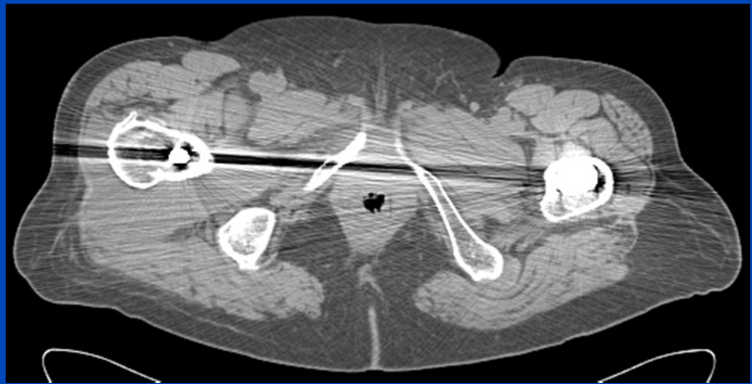
Normalized MAR (NMAR)



Meyer, Raupach, Lell, Schmidt, and Kachelrieß, “Normalized metal artifact reduction (NMAR) in computed tomography”, Med. Phys. 37(10):5482-5493, 2012.

Results and Comparison: Patient Data

Uncorrected



LIMAR

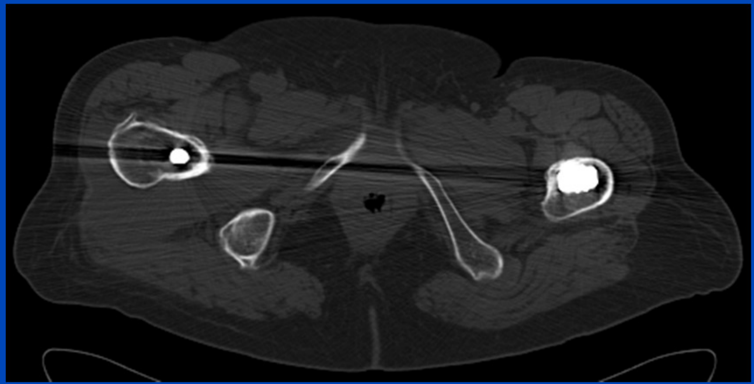
NMAR

Patient with hip implants, Sensation 16, 140 kV, (C = 0 HU, W = 500 HU)

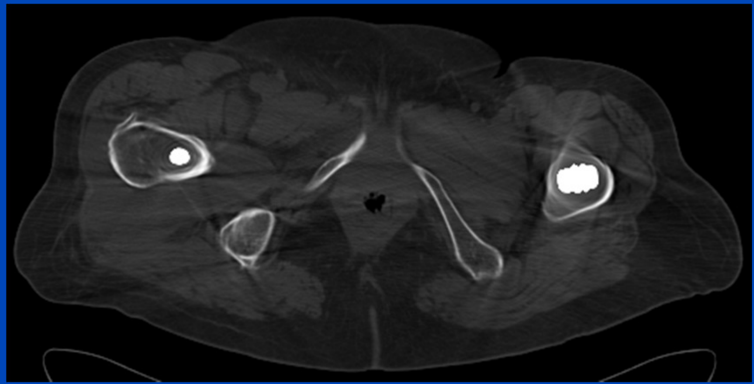
Meyer, Raupach, Lell, Schmidt, and Kachelrieß, “Normalized metal artifact reduction (NMAR) in computed tomography”, Med. Phys. 37(10):5482-5493, 2012.

Results and Comparison: Patient Data

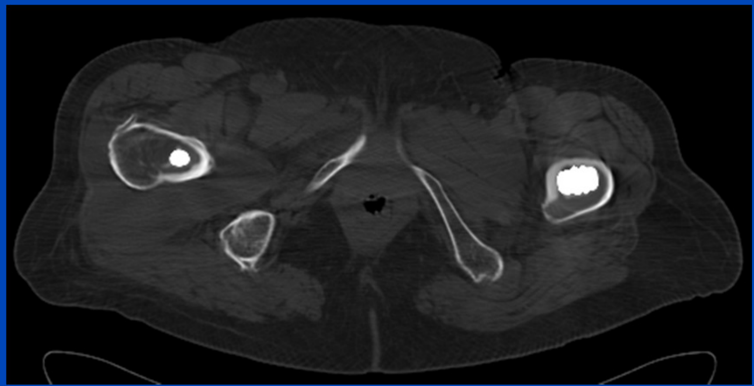
Uncorrected



LIMAR

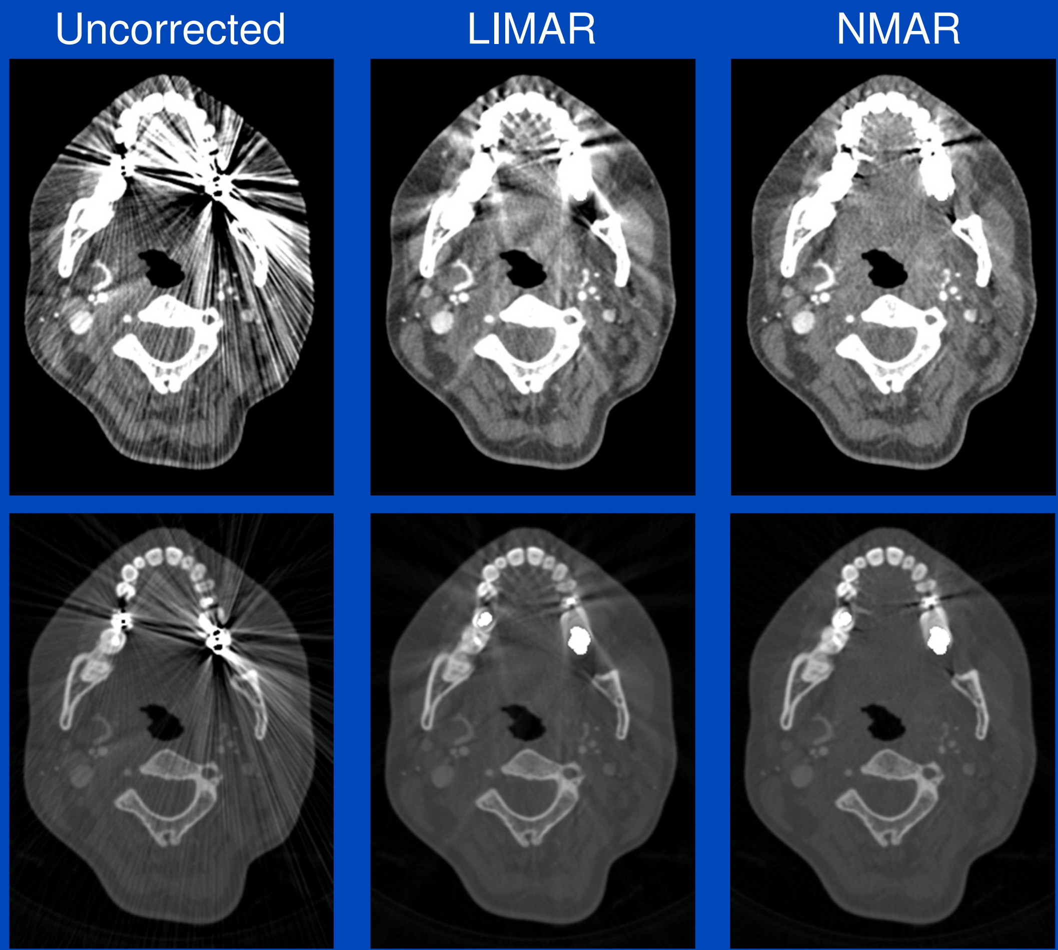


NMAR



Patient with hip implants, Sensation 16, 140 kV, (C = 0 HU, W = 500 HU)

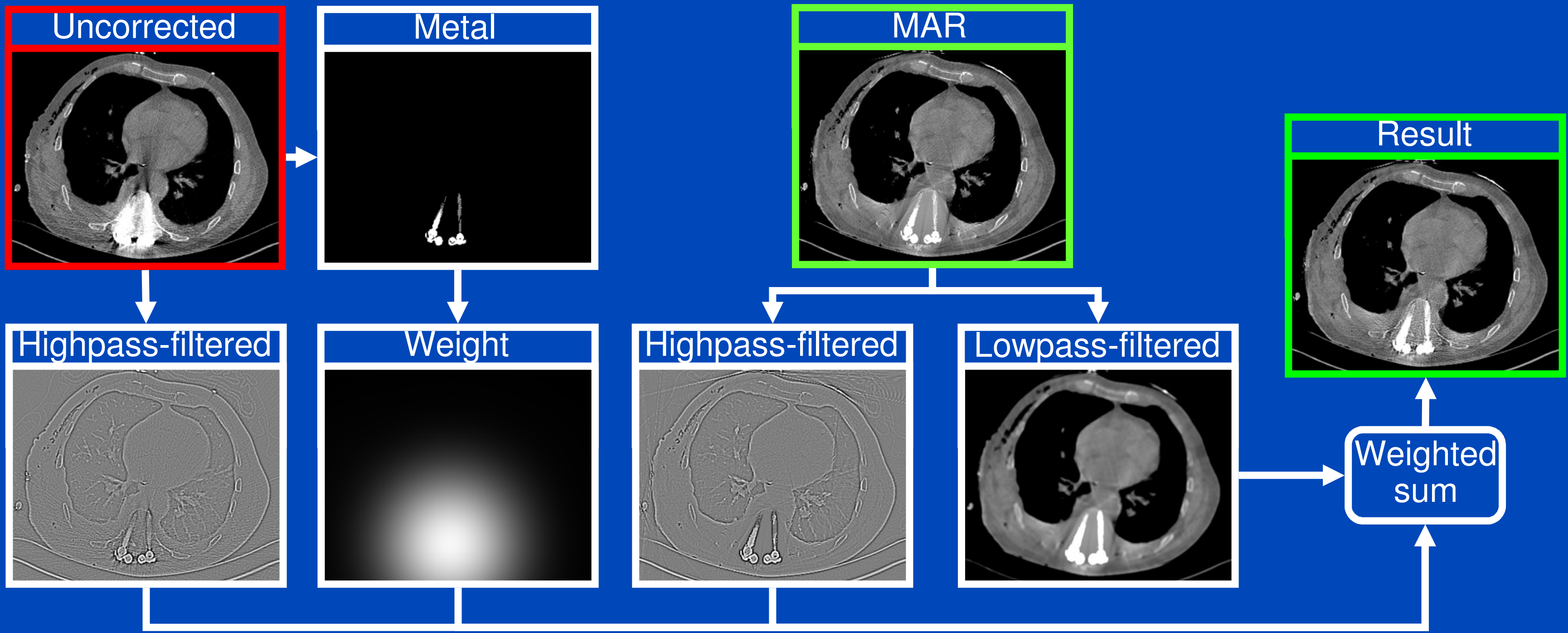
Results and Comparison: Patient Data



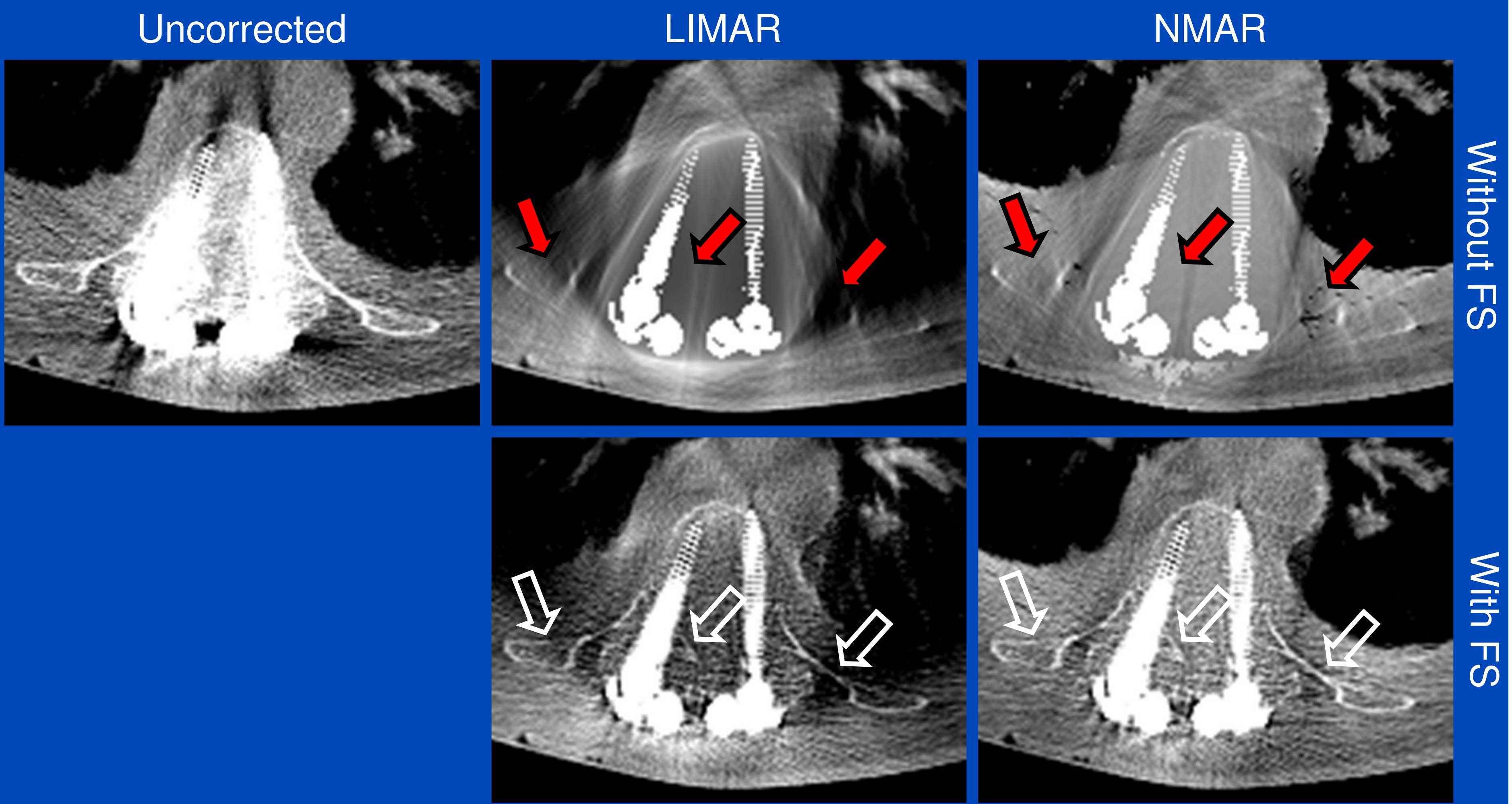
Patient dental fillings, slice 110, Somatom Definition Flash, pitch 0.9.
Top row: (C = 100 HU, W = 750 HU). Bottom row: (C = 1000 HU, W = 4000 HU)

Meyer, Raupach, Lell, Schmidt, and Kachelrieß, "Normalized metal artifact reduction (NMAR) in computed tomography", Med. Phys. 37(10):5482-5493, 2012.

FSMAR: Scheme



FSMAR: Results

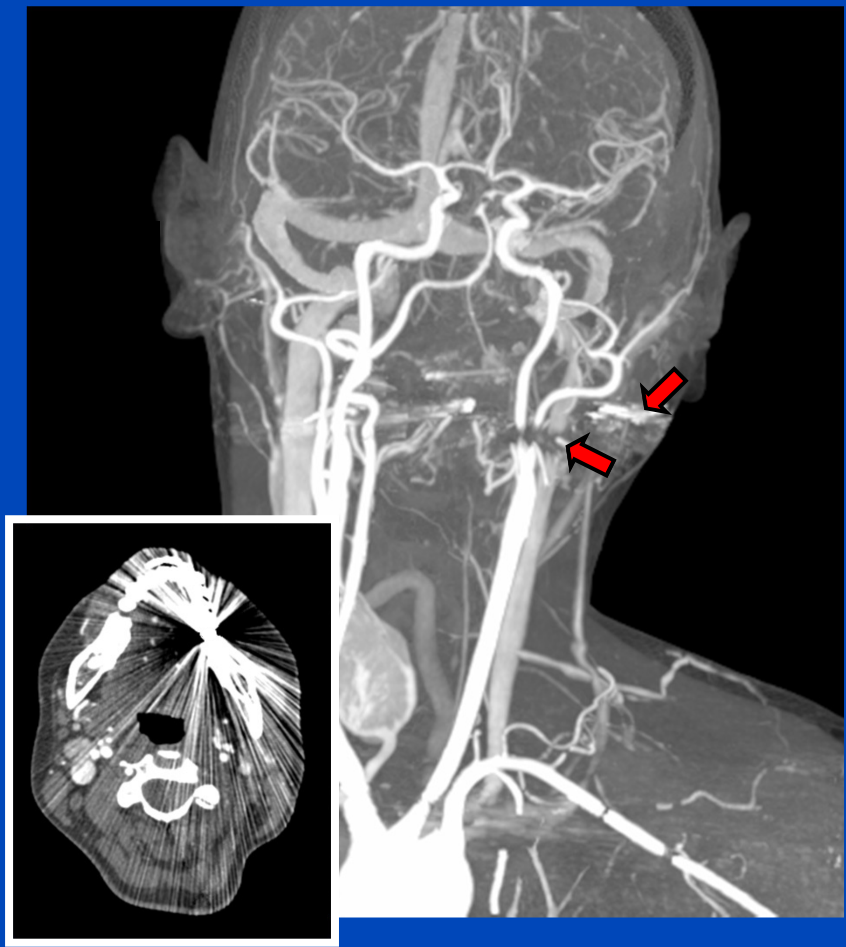


Patient with spine fixation, Somatom Definition, (C=100/W=1000).

Meyer, Raupach, Lell, Schmidt, and Kachelrieß, "Frequency split metal artifact reduction (FSMAR) in computed tomography", Med. Phys. 39(4):1904-1916, 2012.

NMAR: Results

Uncorrected



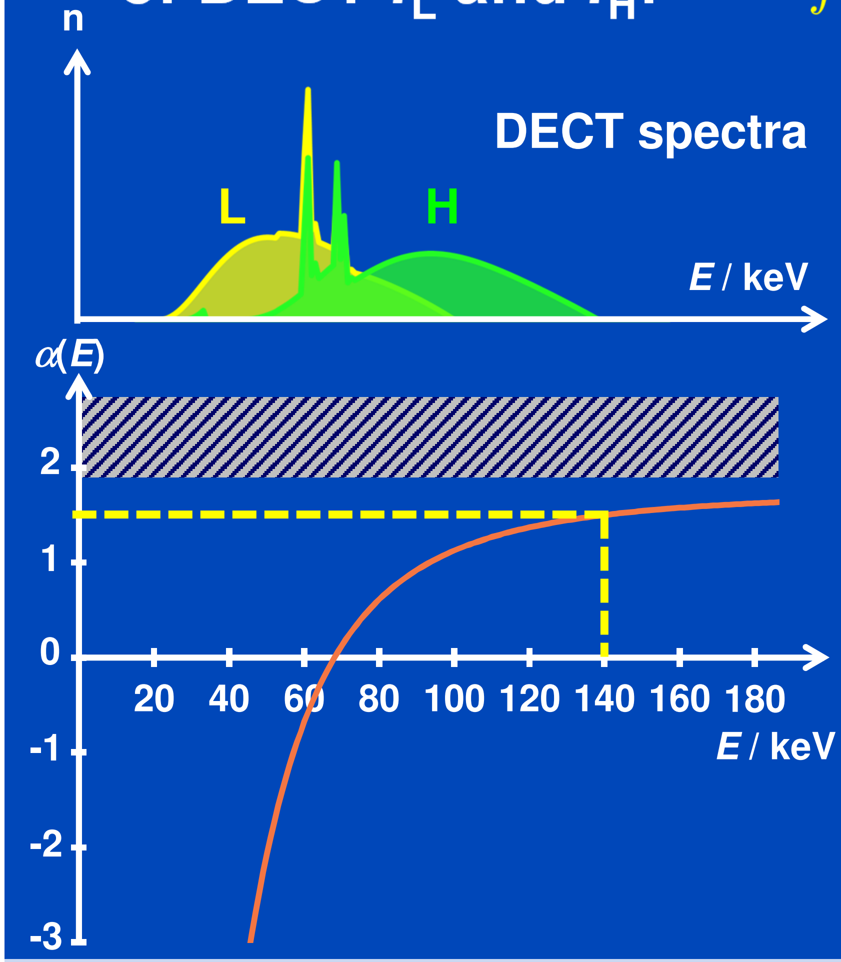
NMAR

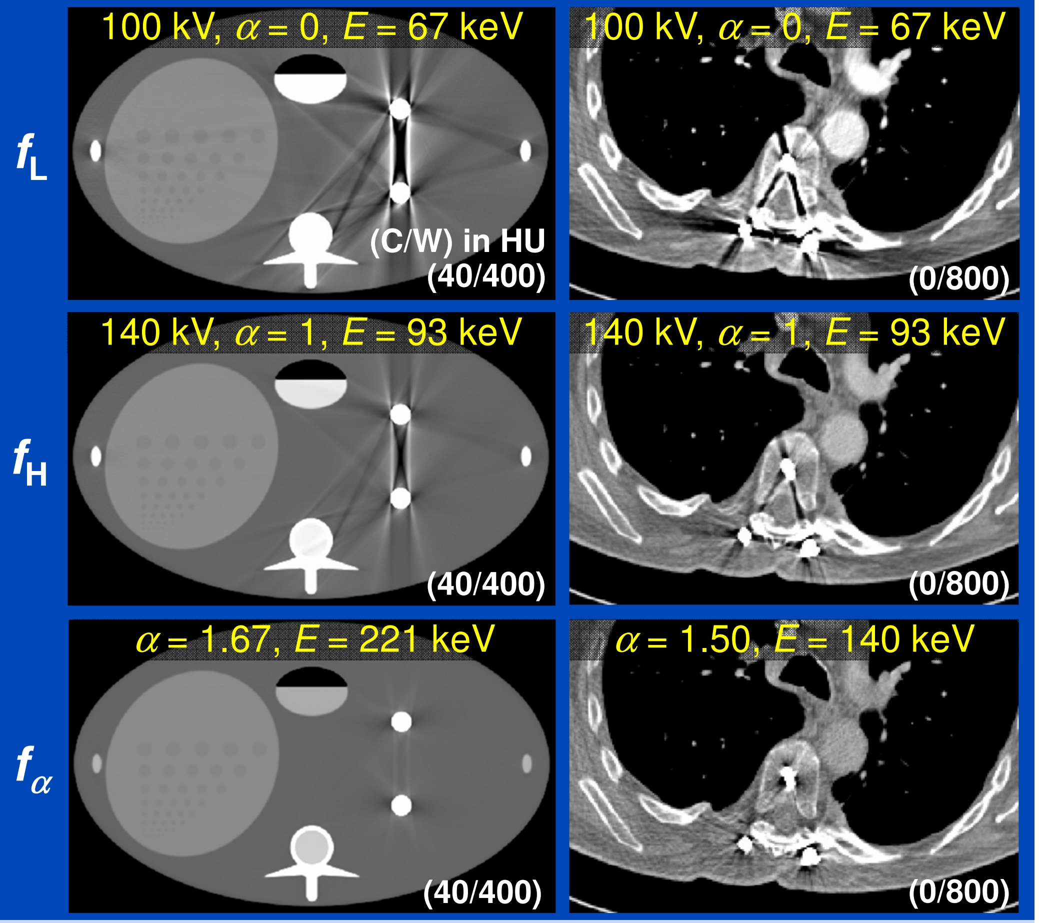
Bone removal (with scanner software), (C=40/W=500).

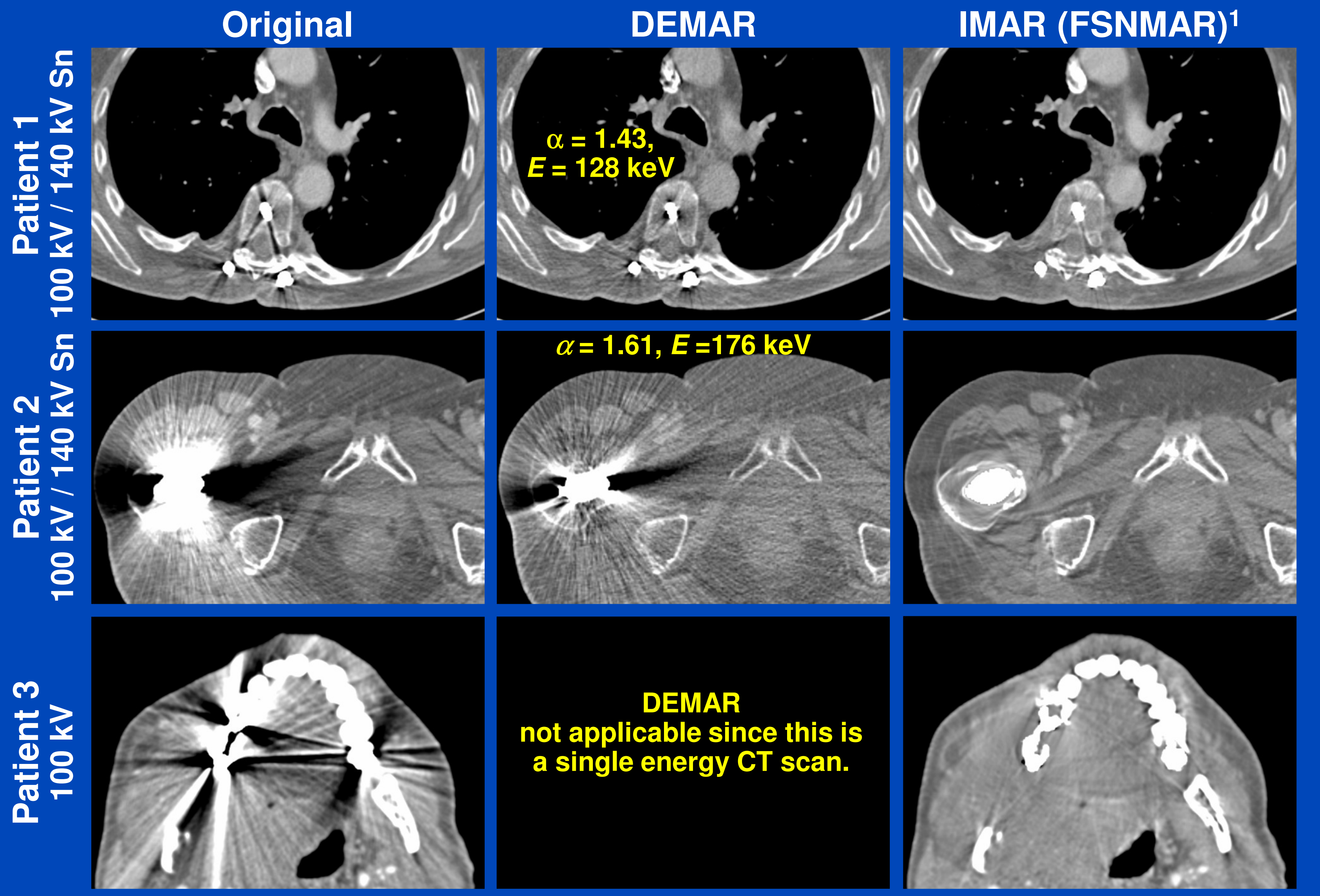
Meyer, Raupach, Lell, Schmidt, and Kachelrieß, “Normalized metal artifact reduction (NMAR) in computed tomography”, Med. Phys. 37(10):5482-5493, 2012.

DECT and Pseudo Monochromatic Imaging

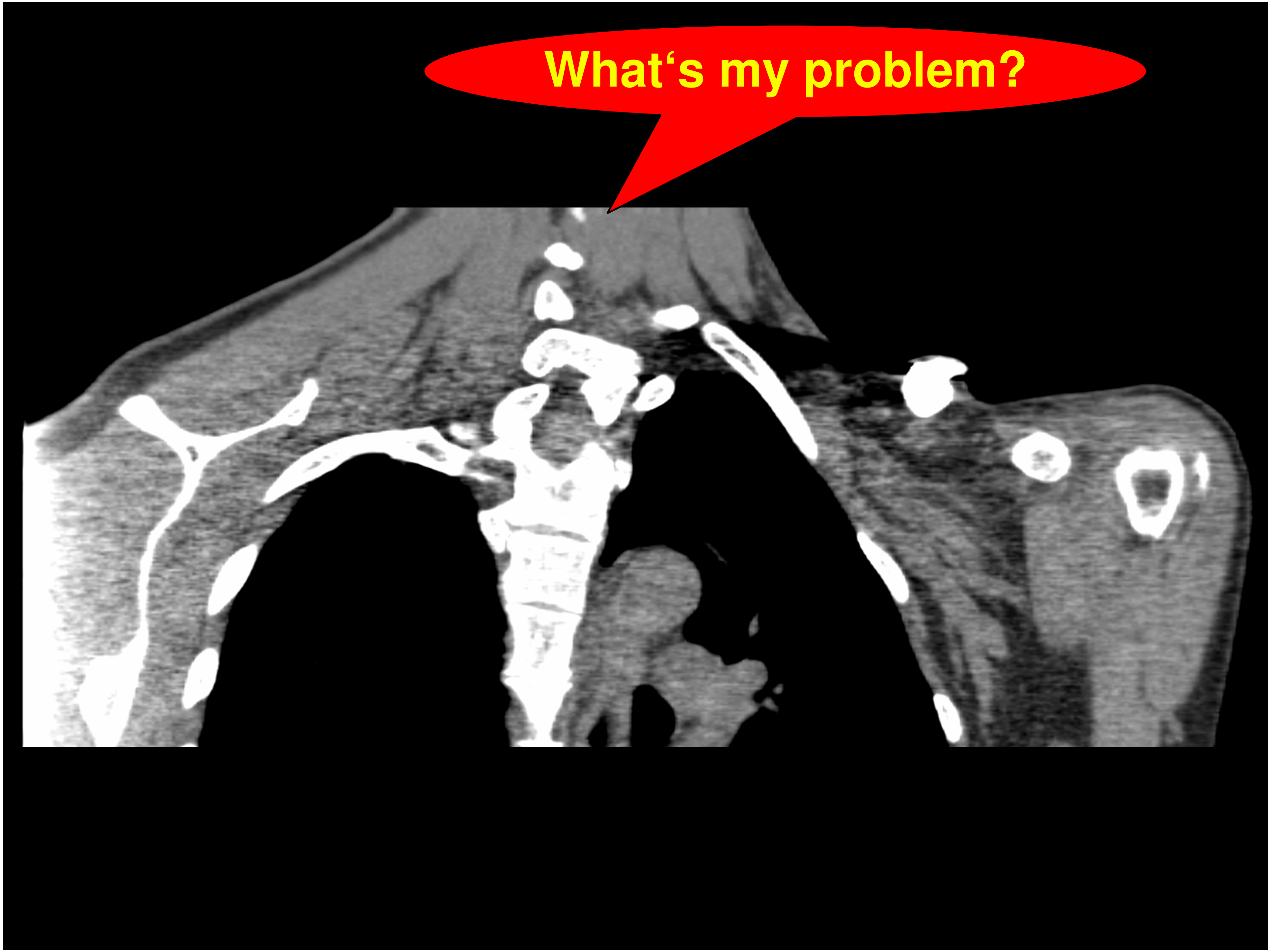
Pseudo monochromatic imaging is a linear combination of DECT f_L and f_H: $f_\alpha = (1-\alpha)\, f_\mathrm{L} + \alpha\, f_\mathrm{H}$



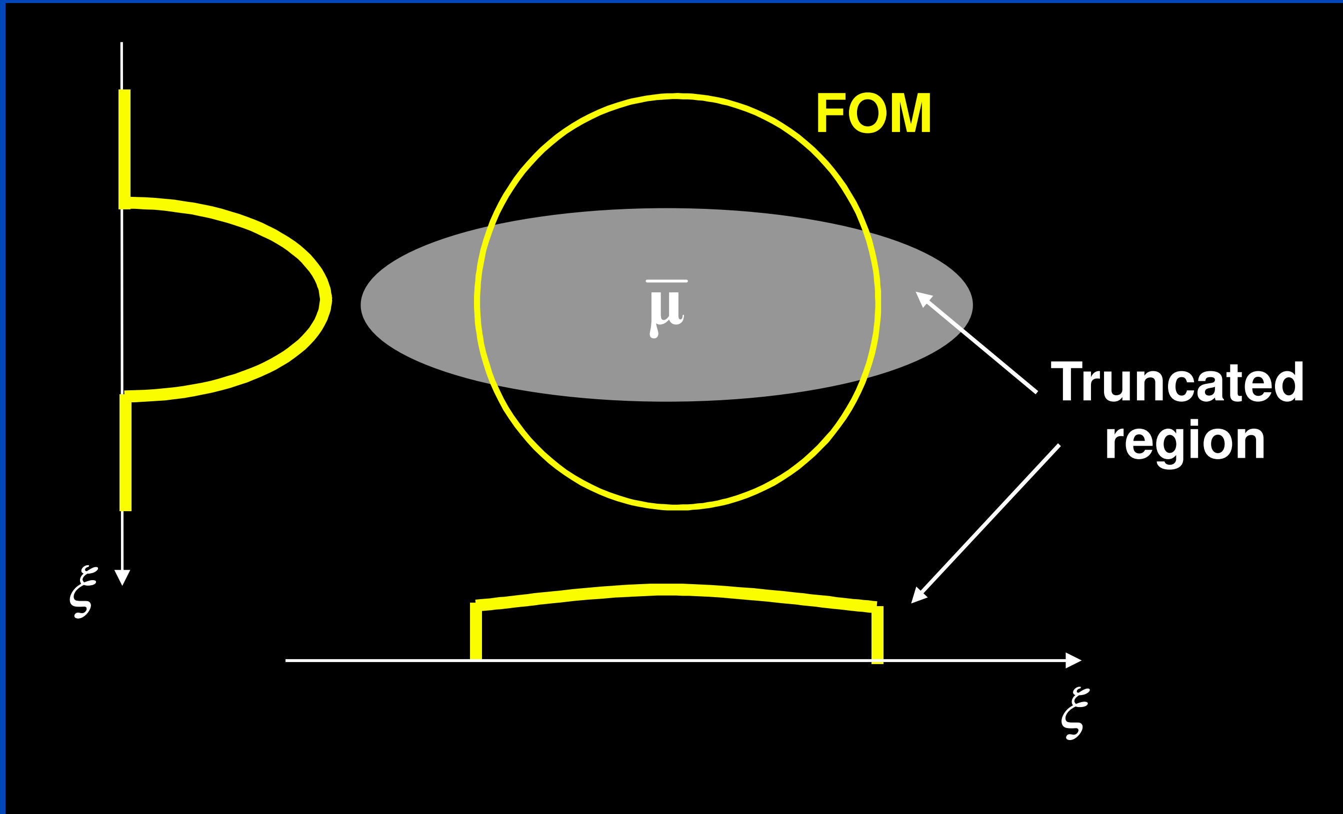




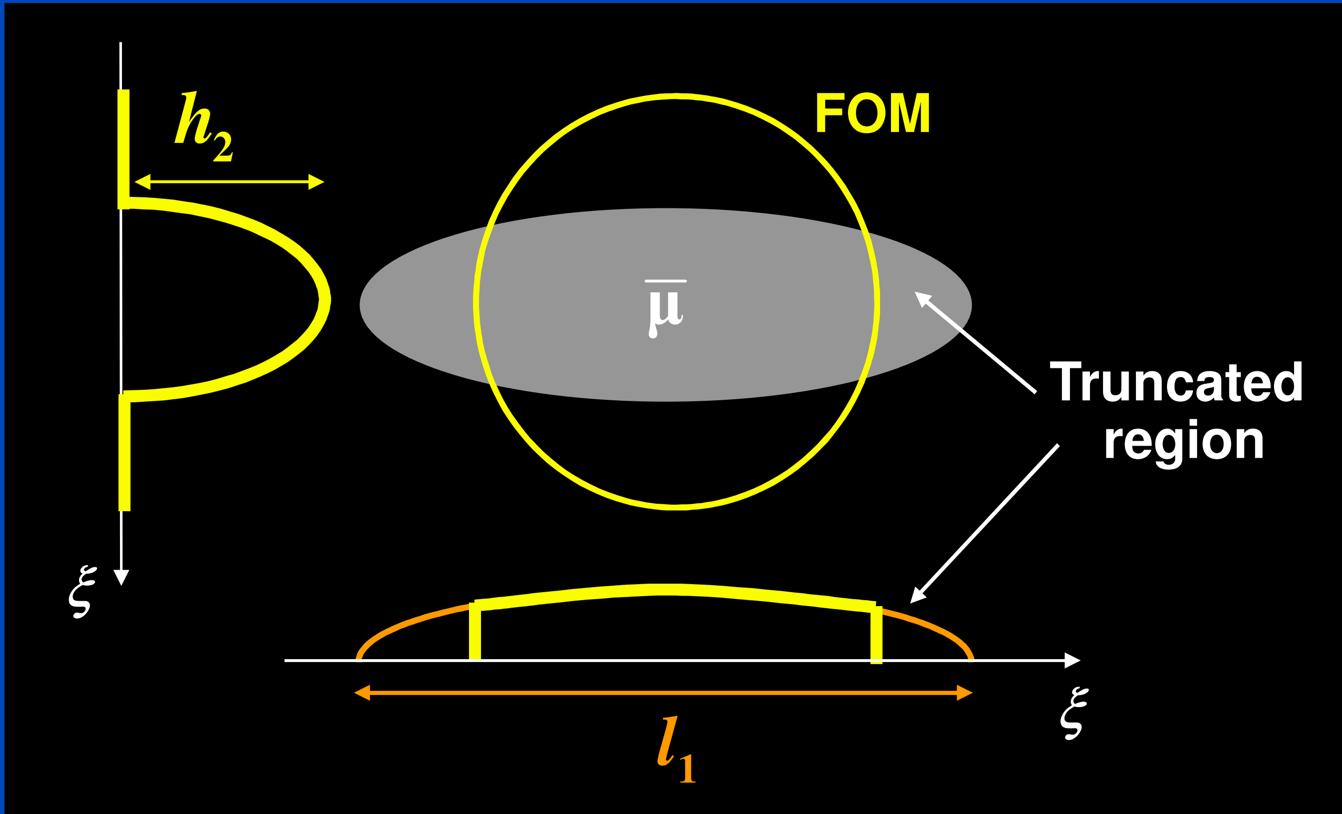
[1]Iterative metal artifact reduction (IMAR) is the Siemens product implementation of FSNMAR.


What‘s my problem?

Adaptive Detruncation Method (ADT)



Adaptive Detruncation Method (ADT)



Data consistency

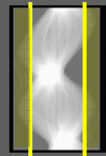
$$l_1 = h_2 / \bar{\mu}$$

$$A_1 = A_2$$

Smooth extrapolation

$$\sqrt{a\xi^2 + b\xi + c}$$

Example :
2 × 100 suppressed columns

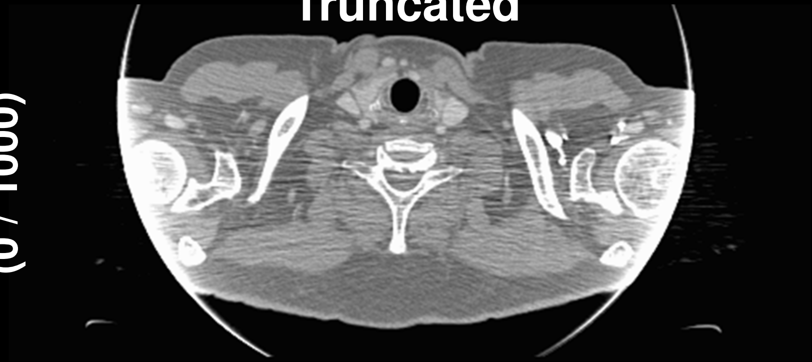


Original

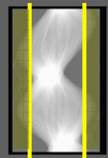
(0 / 1000)

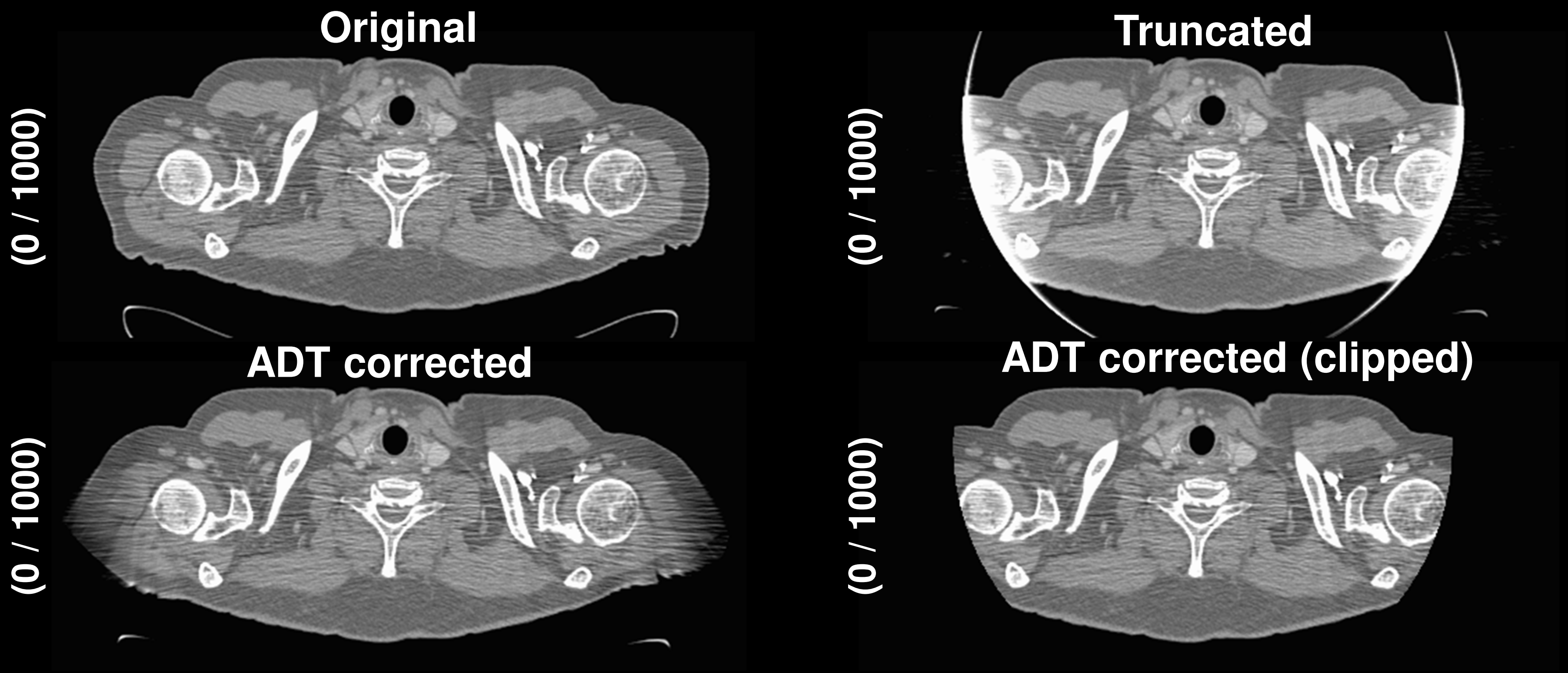
Truncated

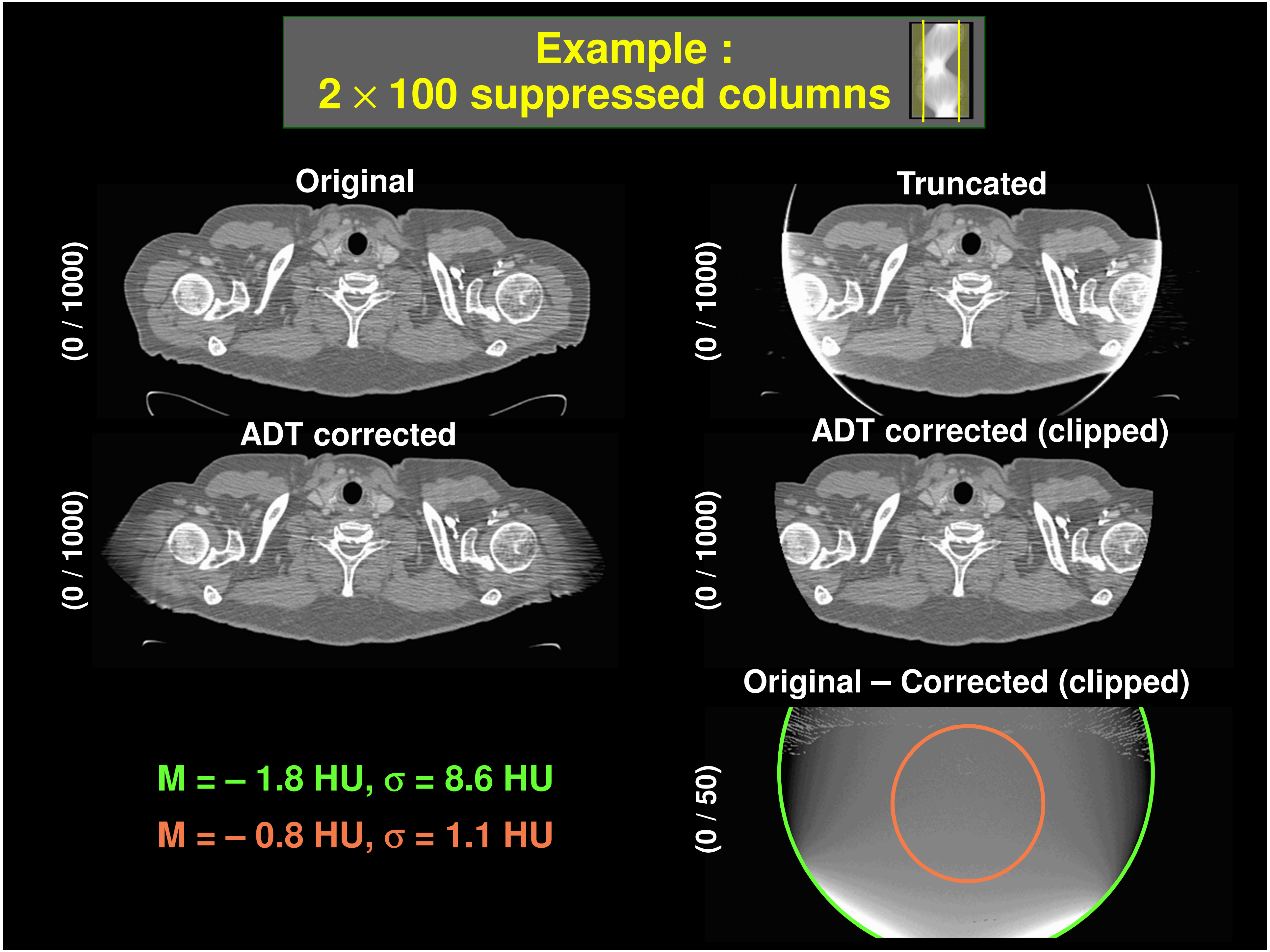
(0 / 1000)



Example : 2 × 100 suppressed columns






Example :
2 × 100 suppressed columns
Original
(0 / 1000)
Truncated
(0 / 1000)
ADT corrected
(0 / 1000)
ADT corrected (clipped)
(0 / 1000)
Original – Corrected (clipped)
(0 / 50)
M = – 1.8 HU, σ = 8.6 HU
M = – 0.8 HU, σ = 1.1 HU

Thank You!

The 4th International Conference on

Image Formation in X-Ray Computed Tomography

Conference Chair

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This presentation will soon be available at www.dkfz.de/ct.
Parts of the reconstruction software were provided by RayConStruct® GmbH, Nürnberg, Germany.