Bin-Combination-Based Noise Reduction for Metal Artifact Reduction in Photon Counting CT

Philip Trapp[1,2], Achim Byl[1,2], Laura Klein[1,2], Sarah Heinze[2], Heinz-Peter Schlemmer[1], Stefan Sawall[1], and Marc Kachelrieß[1]

[1]German Cancer Research Center (DKFZ), Heidelberg, Germany
[2]University of Heidelberg, Germany

DEUTSCHES KREBSFORSCHUNGSZENTRUM IN DER HELMHOLTZ-GEMEINSCHAFT

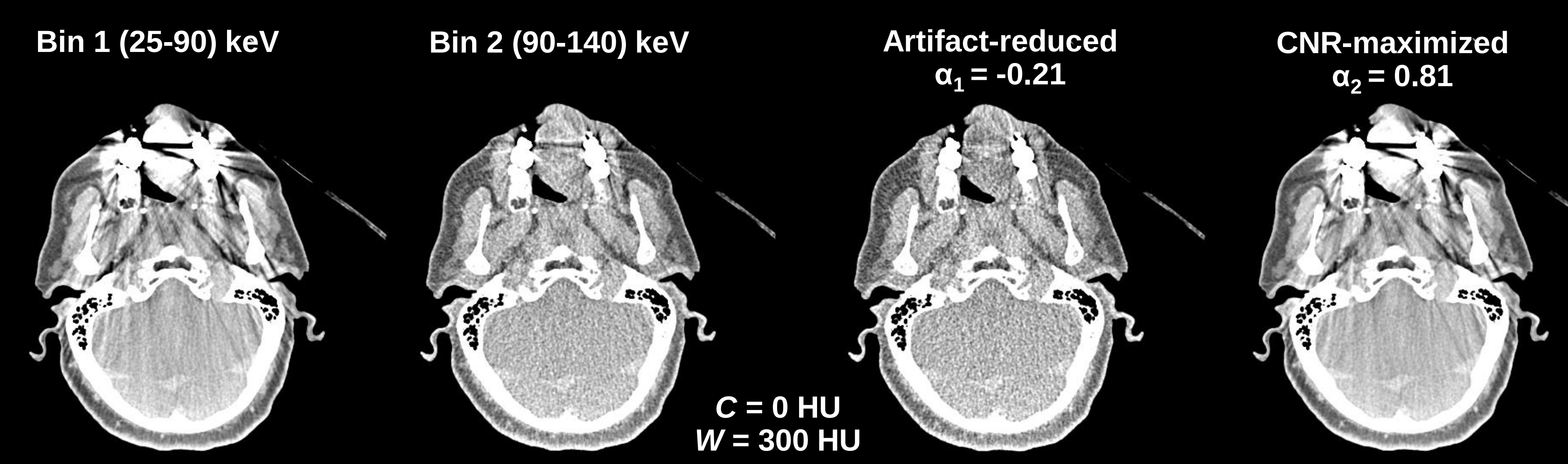
Motivation

- When using a photon counting (PC) detector, energy thresholds allow for spectral separation of data.
- Combined images can be constructed out of energy bin images e.g. via linear combinations, α-blending:

$$f_\alpha(\boldsymbol{r}) = \alpha f_{\mathrm{Bin1}}(\boldsymbol{r}) + (1-\alpha) f_{\mathrm{Bin2}}(\boldsymbol{r})$$

$\alpha_1 < 0$: Low level of artifacts, low contrast-to-noise ratio (CNR)

$0 < \alpha_2 < 1$: High level of artifacts, high CNR



Aim

To obtain a high CNR image with least artifacts.

Prior work:

[1] Yang et al., *Dual-energy CT Reconstruction using Guided Image Filtering*, 2016 IEEE Nuclear Science Symposium
[2] Manhart et al., *Guided Noise Reduction for Spectral CT with Energy-Selective Photon Counting Detectors,* Proc. CT Meeting 2014:91–94
[3] Müller et al., *Towards Material Decomposition on Large Field-of-View Flat Panel Photon-Counting Detectors — First in-vivo Results*, Proc. CT Meeting 2016:479–482
[4] Li et al., *An effective noise reduction method for multi-energy CT images that exploits spatio-spectral features*, Med. Phys. 44(5):1610–1623, 2017
[5] Allner et al., *Bilateral filtering using the full noise covariance matrix applied to x-ray phase-contrast computed tomography*, Phys. Med. Biol. 61(10):3867-3884, 2016

Method

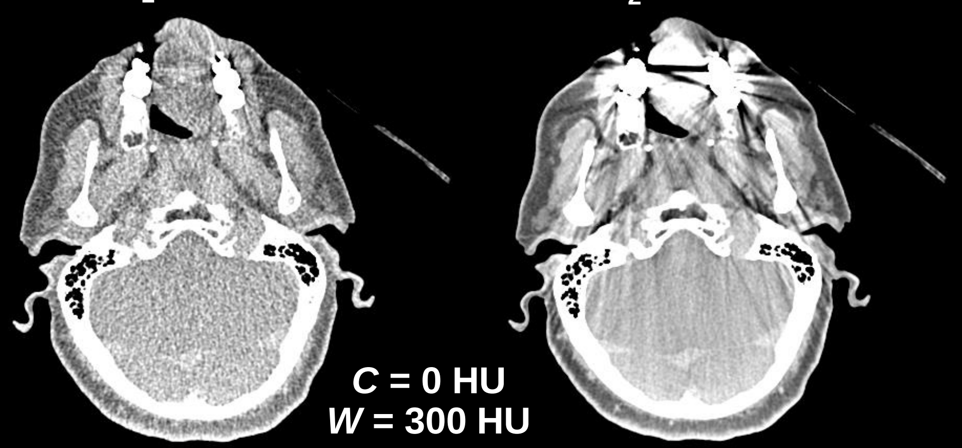
- **Proposed method: guided bilateral filter**

$$\underbrace{f_{\mathrm{filt}}(\boldsymbol{r})}_{\substack{\text{filtered}\\ \text{image}}} \propto \sum_{\boldsymbol{\rho} \in \boldsymbol{R}} \underbrace{f_{\alpha_1}(\boldsymbol{\rho})}_{\substack{\text{original}\\ \text{image}}} \underbrace{R_1(|f_{\alpha_1}(\boldsymbol{\rho}) - f_{\alpha_1}(\boldsymbol{r})|)}_{\substack{\text{range kernel 1}\\ \text{intensity-dependent}\\ \text{kernel}}} \underbrace{R_2(|f_{\alpha_2}(\boldsymbol{\rho}) - f_{\alpha_2}(\boldsymbol{r})|)}_{\substack{\text{range kernel 2}\\ \text{intensity-dependent}\\ \text{kernel (guide)}}} \underbrace{D(|\boldsymbol{\rho} - \boldsymbol{r}|)}_{\substack{\text{domain kernel}\\ \text{spatially-dependent}\\ \text{kernel}}}$$

- **The filter kernels R_1, R_2, and D are chosen to be of truncated Gaussian shape with filter parameters σ_{r1}, σ_{r2}, and σ_d.**

Artifact-reduced
α_1 = -0.21

CNR-maximized
α_2 = 0.81



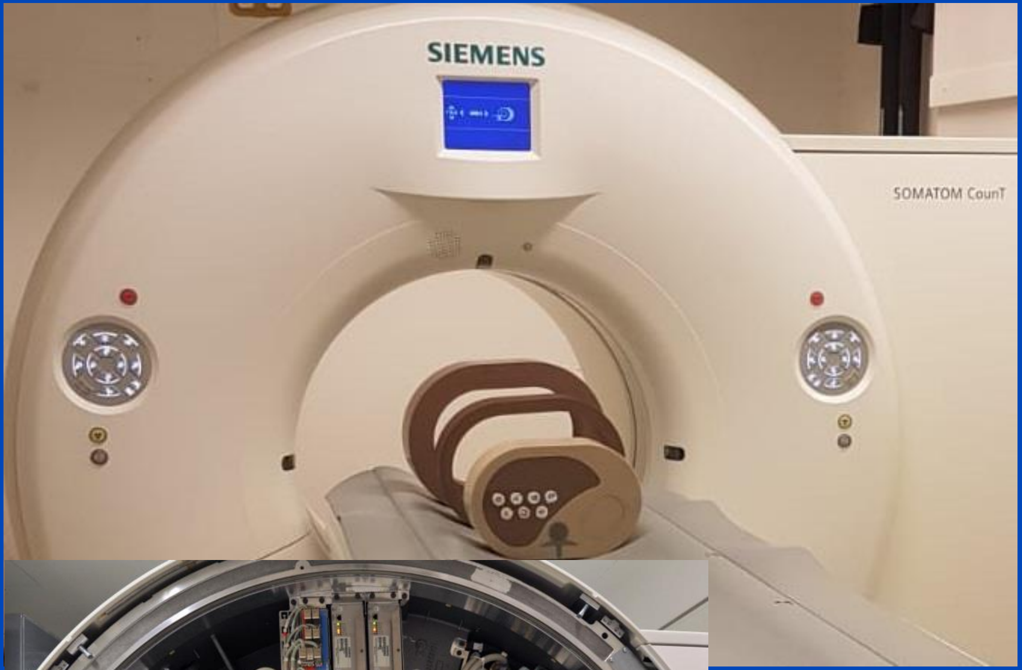
CounT CT System at the DKFZ

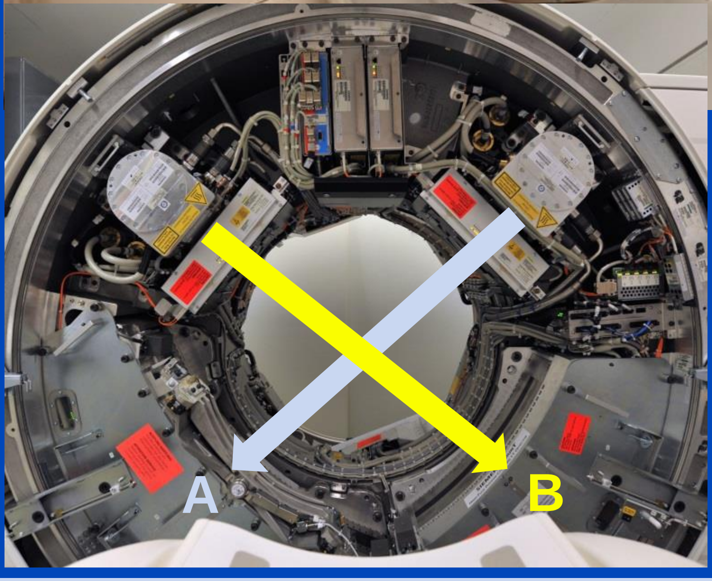
Gantry from a clinical dual source scanner

- Ultra-high-resolution (UHR) mode with two energy thresholds (25 and 90 keV)
- Head scan of a human corpse with dental implants (140 kV, 150 mAs)
- Torso scan of a pig cadaver with manually inserted hip total endoprostheses (TEPs) (140 kV, 225 mAs)

A: conventional CT detector (500 mm FOV)

B: Photon counting detector (275 mm FOV)

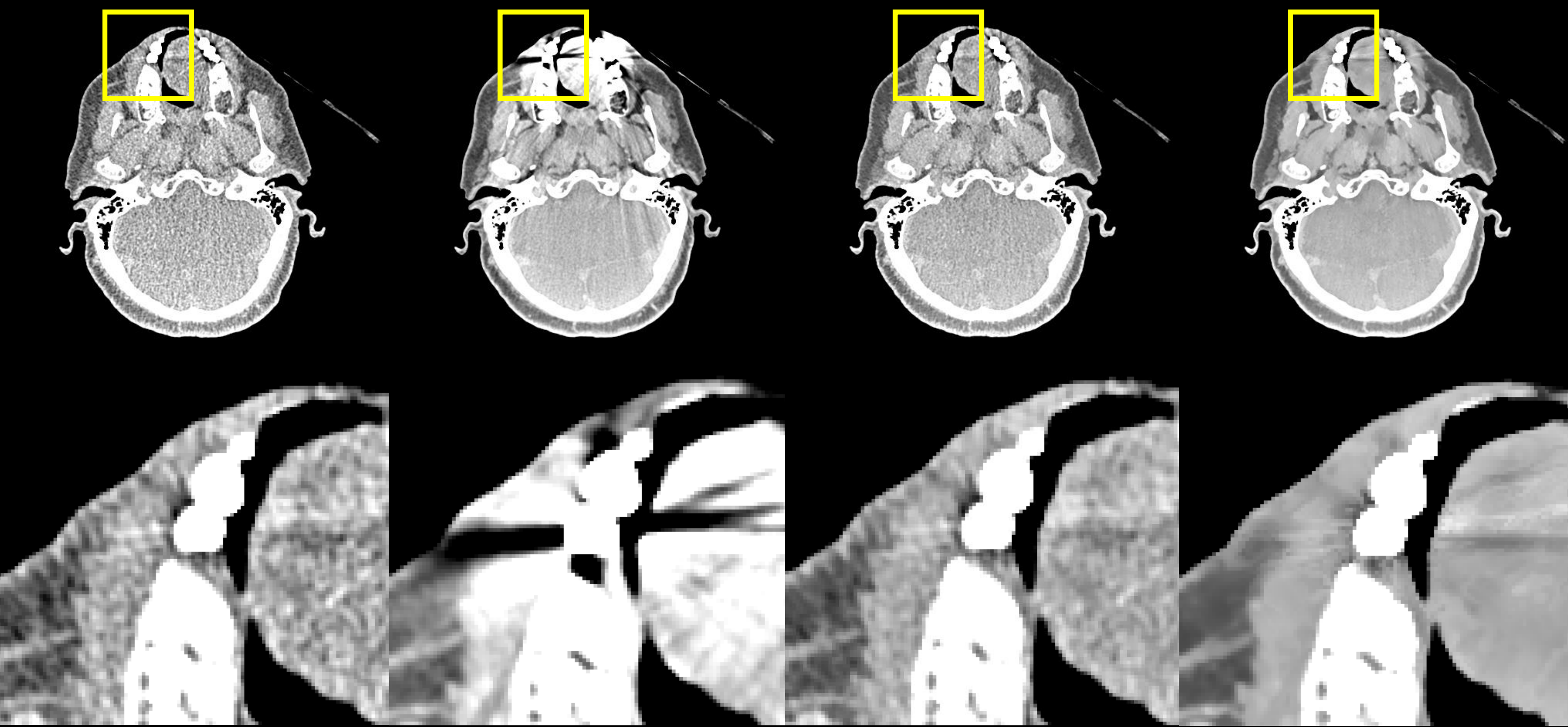




Experimental CT system, not commercially available.

Results: Reduced Artifacts with Improved CNR

A) Artifact-reduced α_1 = -0.21	B) CNR-maximized α_2 = 0.81	Bilateral filtered A) (self-guided)	Proposed method on A) (guide: B))



		σ_{r1} = 25 HU σ_d = 4 px	σ_{r1} = 200 HU σ_{r2} = 10 HU σ_d = 4 px

C = 0 HU, *W* = 300 HU

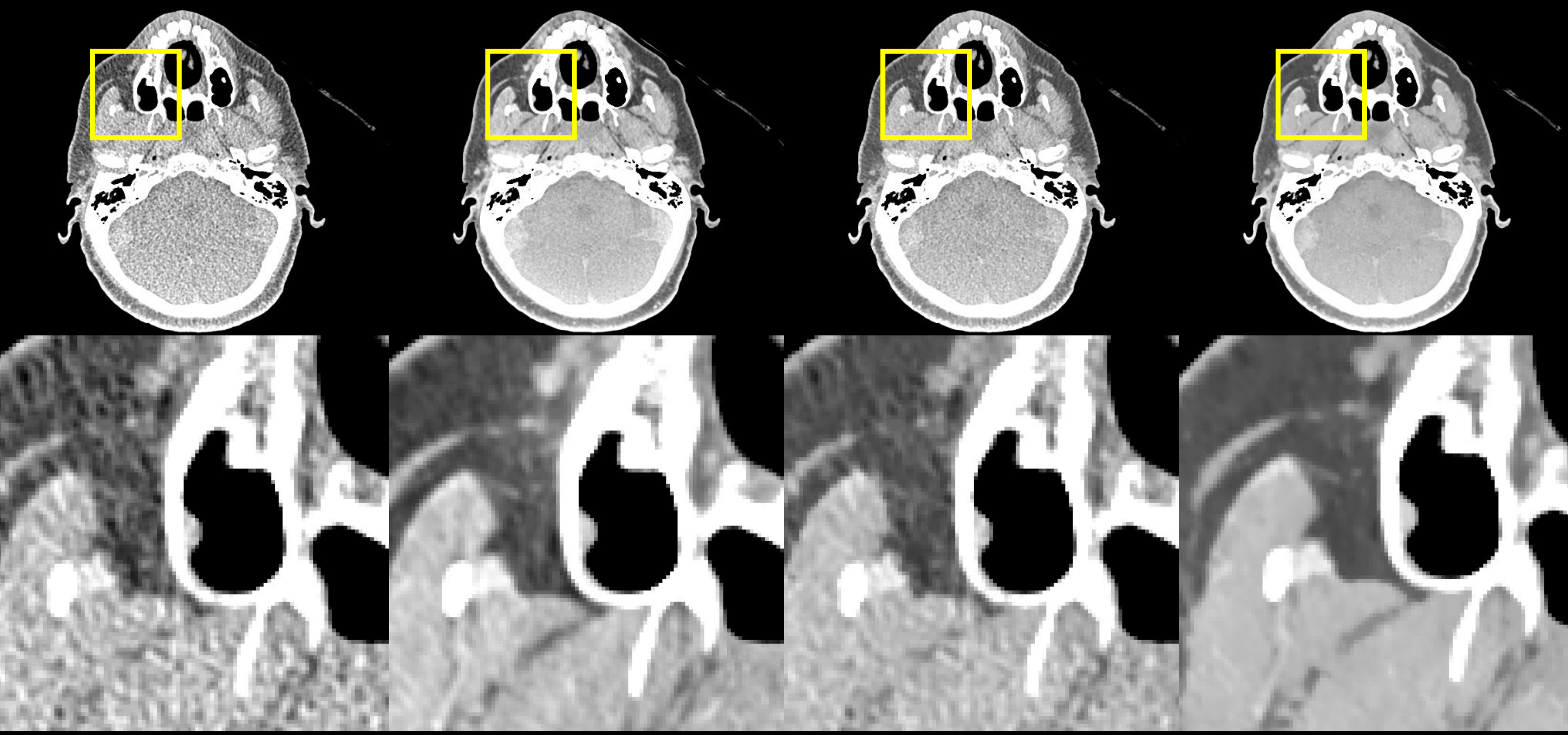
Results: Conservation of Spatial Resolution

A) Artifact-reduced α_1 = -0.21

B) CNR-maximized α_2 = 0.81

Bilateral filtered A) (self-guided)

Proposed method on A) (guide: B))



Bilateral filtered A): σ_{r1} = 25 HU, σ_d = 4 px

Proposed method: σ_{r1} = 200 HU, σ_{r2} = 10 HU, σ_d = 4 px

C = 0 HU, *W* = 300 HU

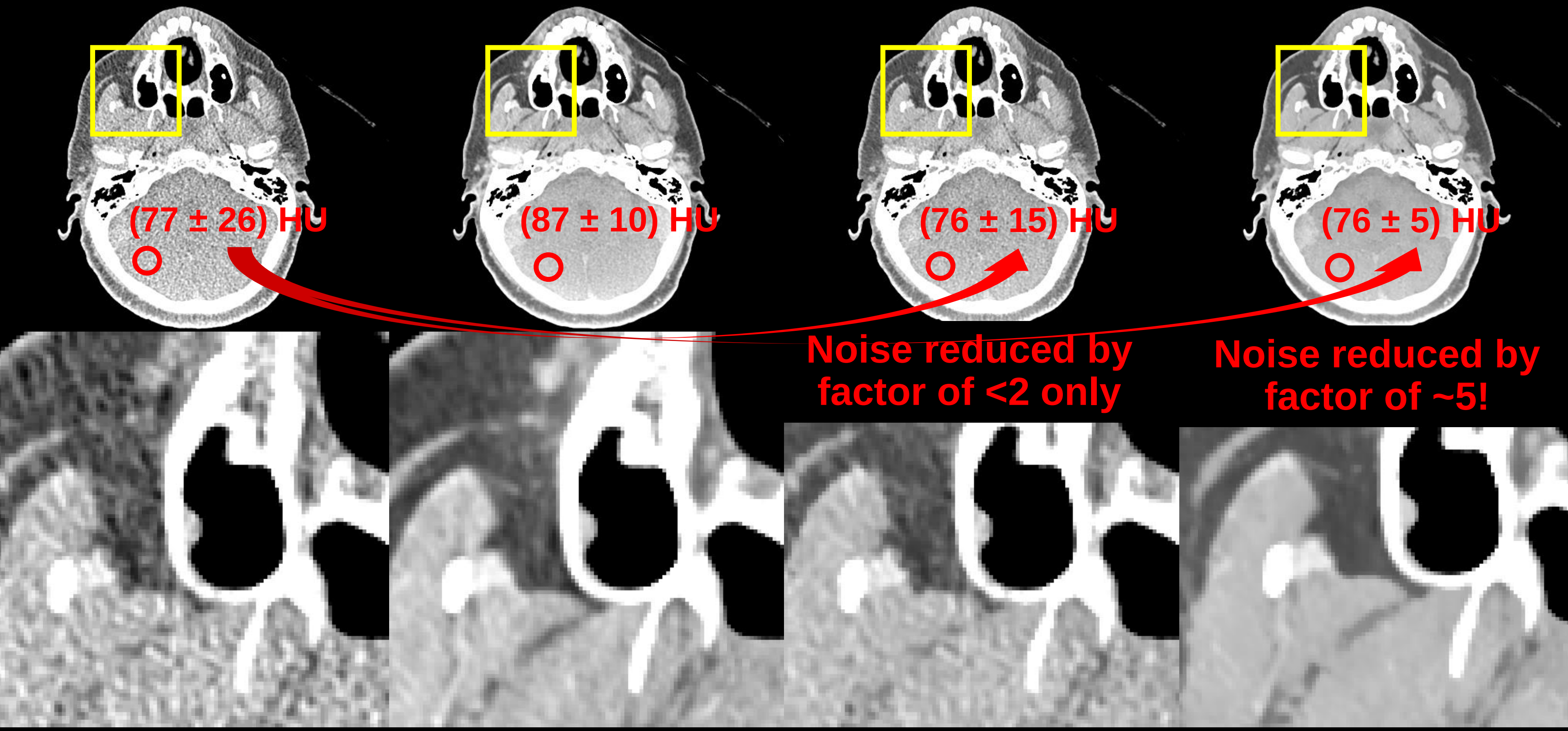
Results: Comparison of Image Noise

A) Artifact-reduced $\alpha_1 = -0.21$

B) CNR-maximized $\alpha_2 = 0.81$

Bilateral filtered A) (self-guided)

Proposed method on A) (guide: B))



Bilateral filtered: $\sigma_{r1} = 25$ HU, $\sigma_d = 4$ px

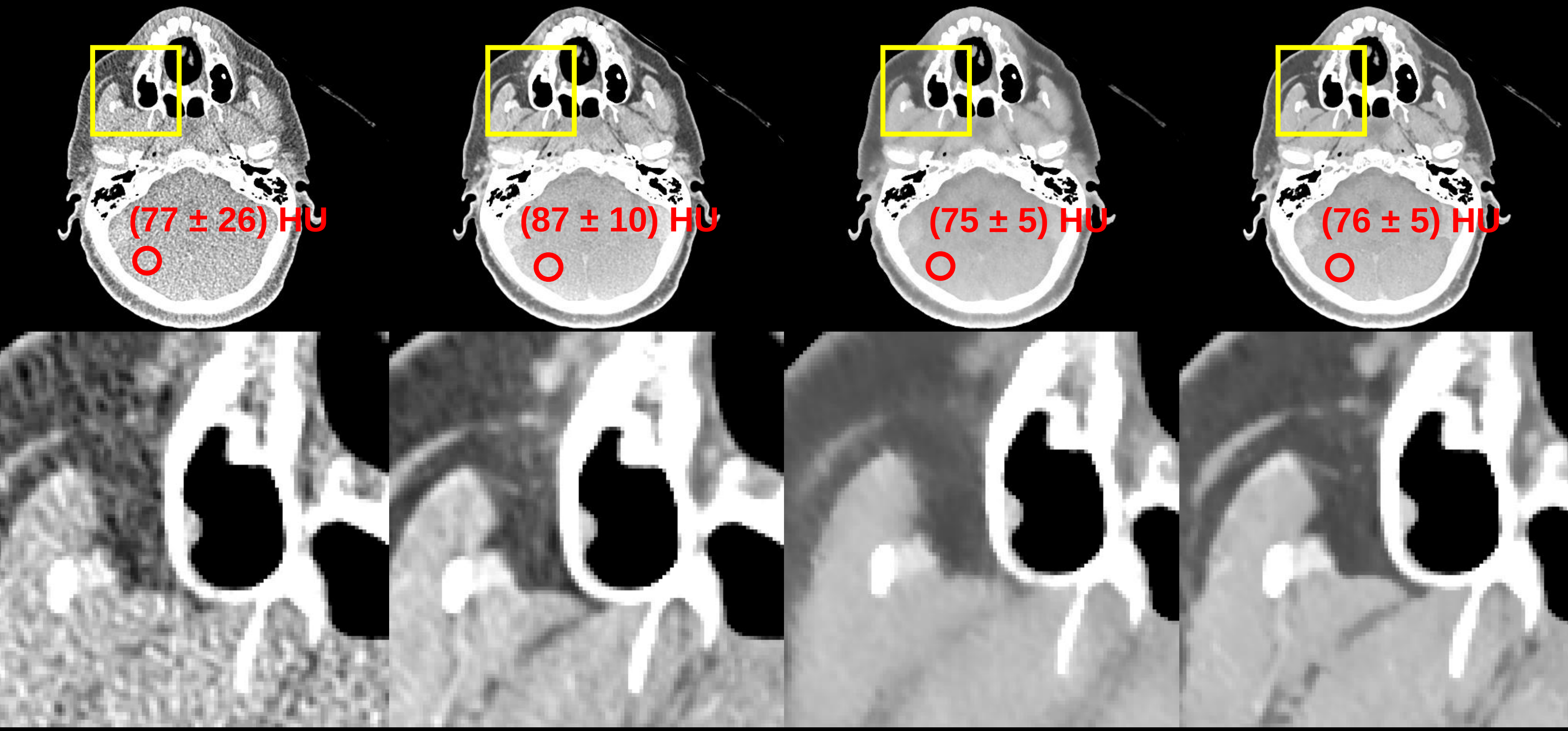
Proposed method: $\sigma_{r1} = 200$ HU, $\sigma_{r2} = 10$ HU, $\sigma_d = 4$ px

$C = 0$ HU, $W = 300$ HU

dkfz.

Results: Self-Guided Filter at Same Noise Level

A) Artifact-reduced $\alpha_1 = -0.21$	B) CNR-maximized $\alpha_2 = 0.81$	Bilateral filtered A) (self-guided)	Proposed method on A) (guide: B))

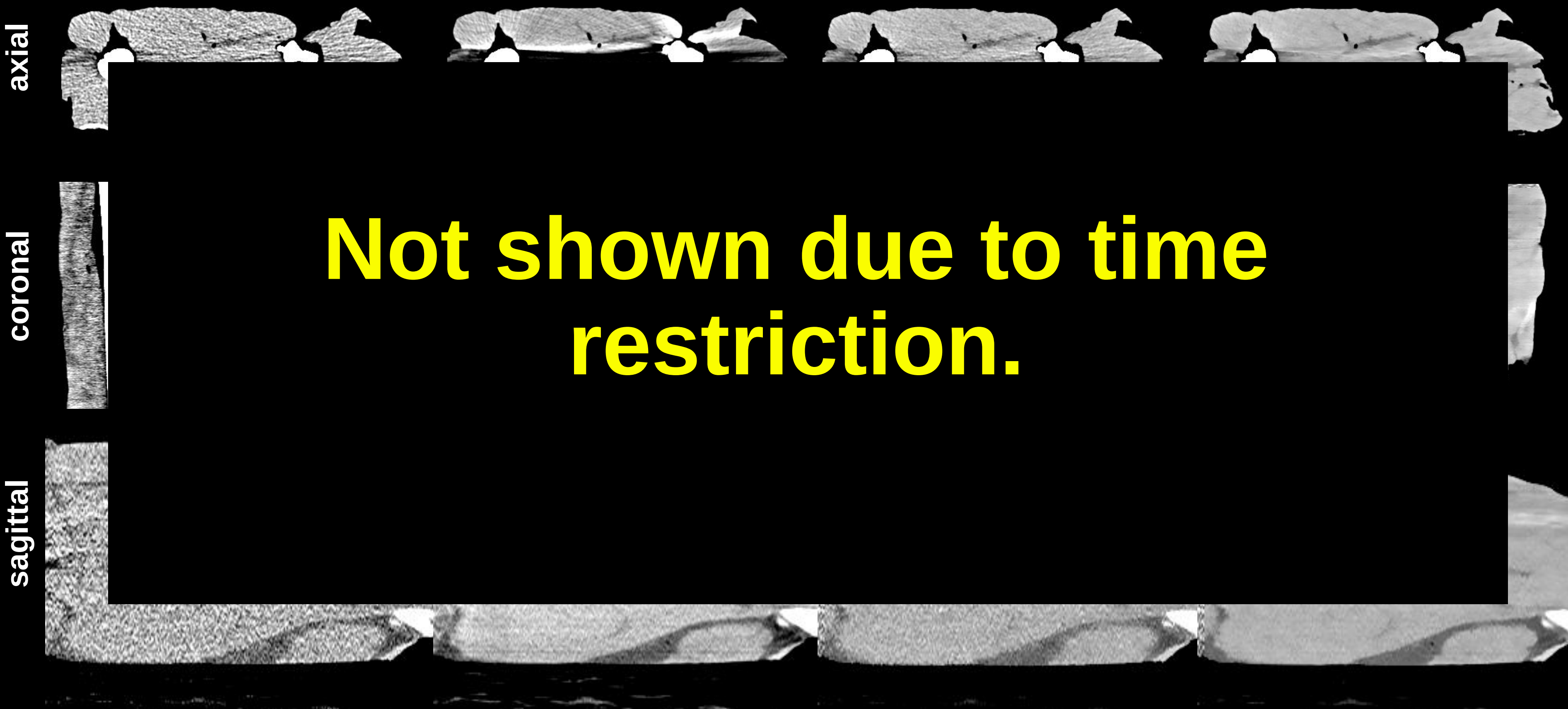


		σ_{r1} = 75 HU σ_d = 4 px	σ_{r1} = 200 HU σ_{r2} = 10 HU σ_d = 4 px

C = 0 HU, *W* = 300 HU

Results: Increasing Artifact and Noise Levels in the Pig Measurement

A) Artifact-reduced $\alpha_1 = -0.20$	B) CNR-maximized $\alpha_2 = 0.81$	Bilateral filtered A) (self-guided)	Proposed method on A) (guide: B))



		σ_{r1} = 65 HU σ_d = 4 px	σ_{r1} = 200 HU σ_{r2} = 25 HU σ_d = 4 px

C = 0 HU, *W* = 300 HU

Conclusions

- A guided bilateral filter is a useful tool to combine the possible benefits of spectral data (high CNR, low amount of artifacts).
- Image noise could be reduced by a factor of 5 while a low level of metal artifacts and a high spectral resolution is maintained.
- This improvement of image noise can be traded for a reduction of patient dose.
- The method of is not limited to PC CT but can be used whenever aligned spectral data is available (e.g. dual energy CT).

Thank You!

This work was supported in parts by the BMBF under grant number 13N14804.

This presentation is available at www.dkfz.de/ct

Job opportunities through DKFZ’s international PhD or Postdoctoral Fellowship programs (www.dkfz.de), or directly through Prof. Dr. Marc Kachelrieß (marc.kachelriess@dkfz.de).

Parts of the reconstruction software were provided by RayConStruct® GmbH, Nürnberg, Germany.