ISMRM/SCMR co-provided Workshop on the Emerging Role of Machine Learning in CMR, Seattle, WA, Feb 6-7, 2019

dnoiseNET: Deep CNN for image denoising

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Declaration of Financial Interests or Relationships

Speaker Name: Hung Do

Company Name: Canon Medical Systems USA, Inc. (formerly Toshiba Medical)

Type of Relationship: Employee

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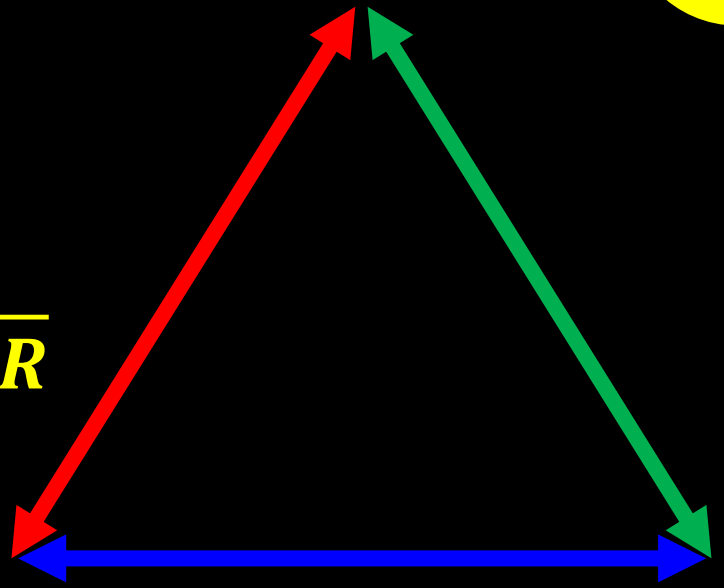
SNR in MRI

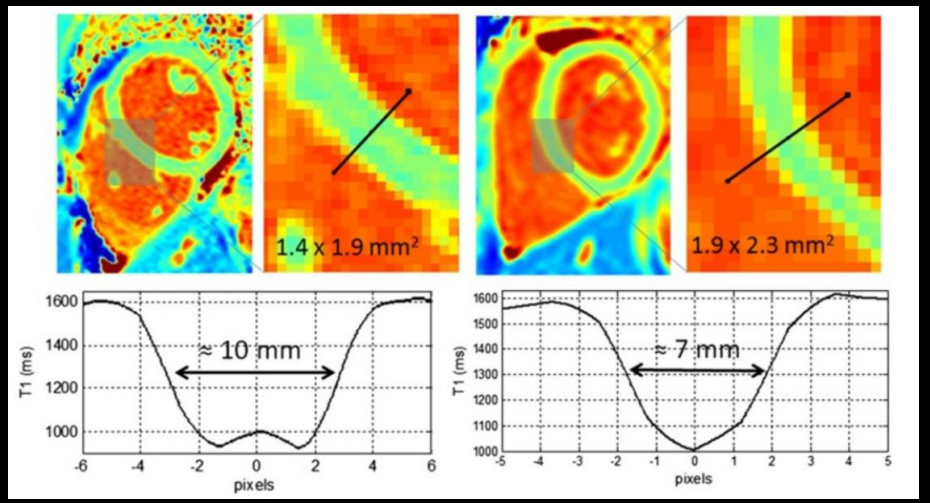
Shorter acquisition time
- Shorter breath-hold
- Less sensitive to motions

$$\textbf{Uncertainty} \sim \frac{1}{SNR}$$



Higher SNR
- Image quality
- Visualization
- Down-stream post-processing

Higher resolution
- Less partial volume effects

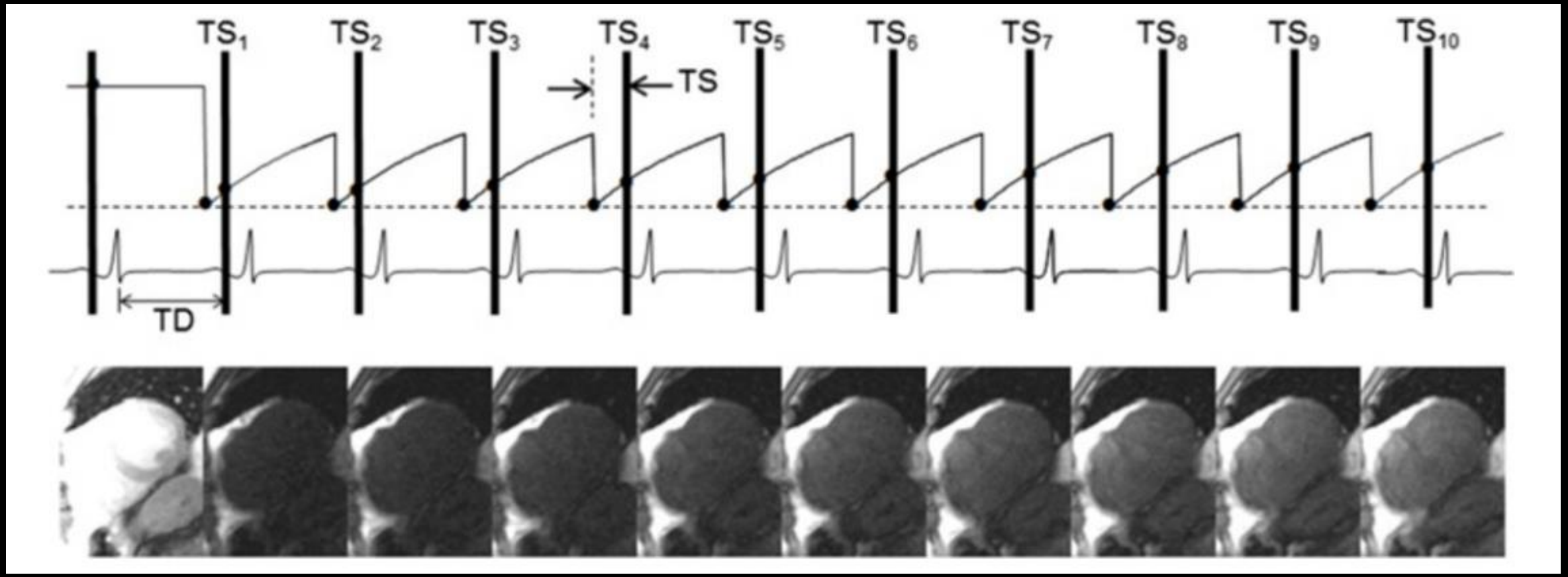


Quantitative CMR

- Relaxometry: T1, T2, T2*, T1rho
- Diffusion: DWI, DTI, IVIM
- Perfusion: ASL
- Water-Fat: PDFF

Improved SNR → lower uncertainty

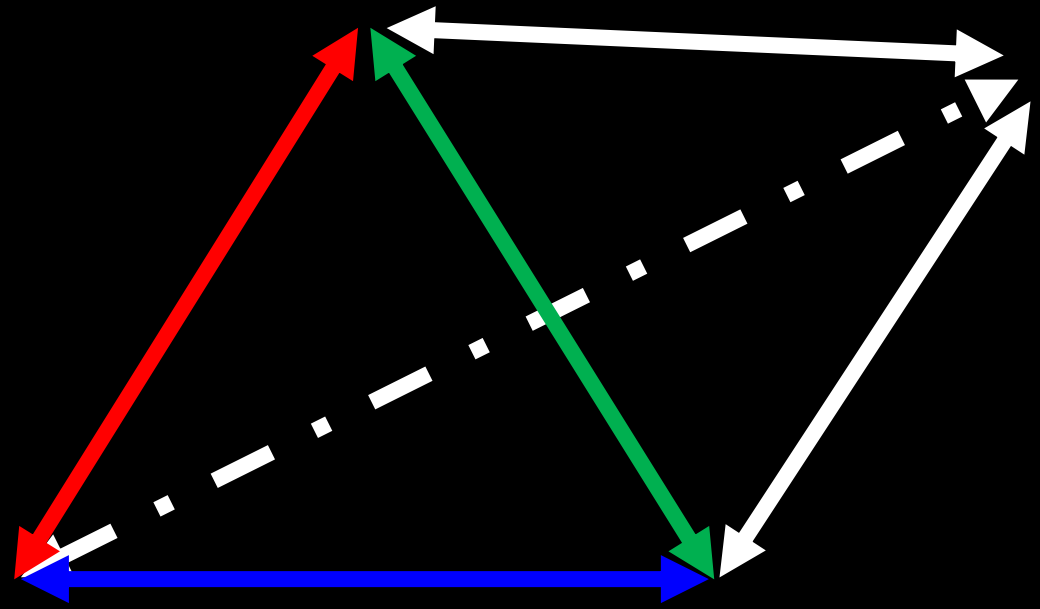
SASHA T1 Mapping



Low-field MRI

$$\text{SNR} \sim B_0^{\frac{3}{2}}$$

Shorter acquisition time

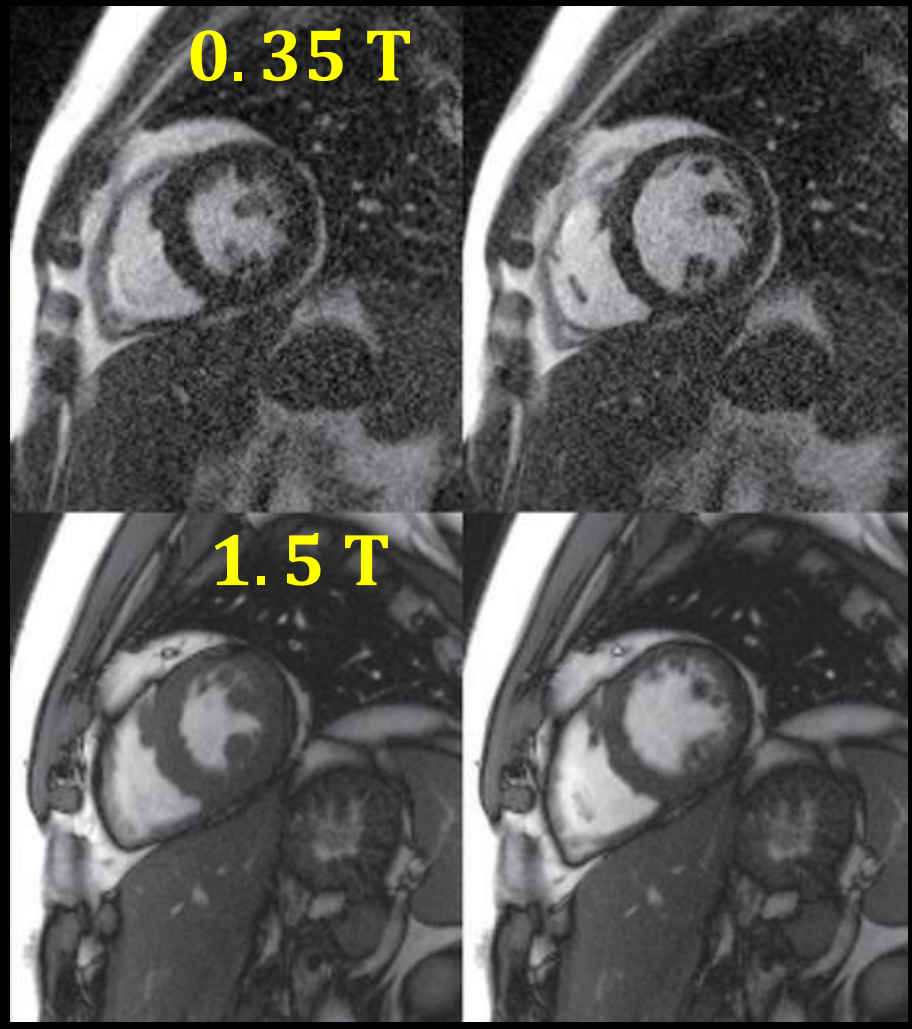


Lower field strength

- Reduced cost
- Patient comfort
- Field homogeneities

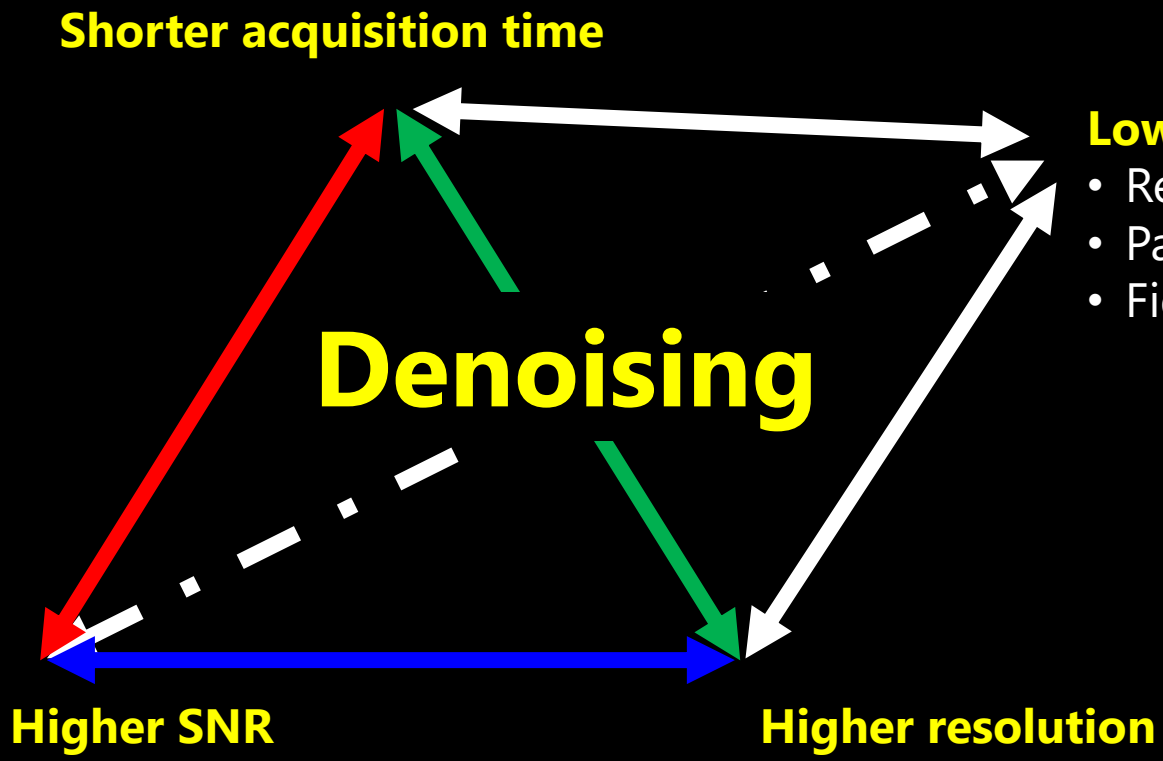
Higher SNR

Higher resolution



1. **Shams Rashid**, et al. "Cardiac bSSFP MRI at 0.35 T." *Quant Imaging Med Surg* **2018;8(7):627-636**
2. **Jose Marques**, et al., "Low-field MRI: An MR Physics Perspective." *Journal of Magnetic Resonance Imaging* **2019**

Motivation

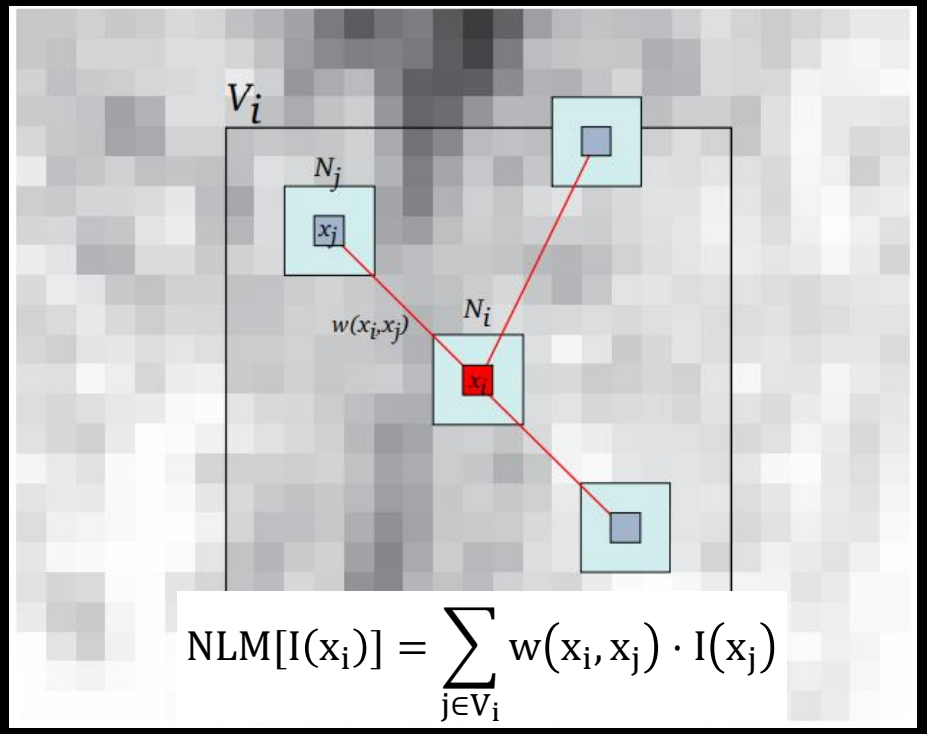


Lower field strength

- Reduced cost
- Patient comfort
- Field homogeneities

1. **Shams Rashid**, et al. "Cardiac bSSFP MRI at 0.35 T." *Quant Imaging Med Surg* **2018;8(7):627-636**
2. **Jose Marques**, et al., "Low-field MRI: An MR Physics Perspective." *Journal of Magnetic Resonance Imaging* **2019**

NLM and BM3D



$$\mathrm{NLM}[\mathrm{I}(\mathrm{x_i})] = \sum_{\mathrm{j}\in\mathrm{V_i}} \mathrm{w}(\mathrm{x_i},\mathrm{x_j}) \cdot \mathrm{I}(\mathrm{x_j})$$

Non-local Mean (MLM)

- Average based on self-similarity instead of distance (i.e. “non-local”)

Limitations

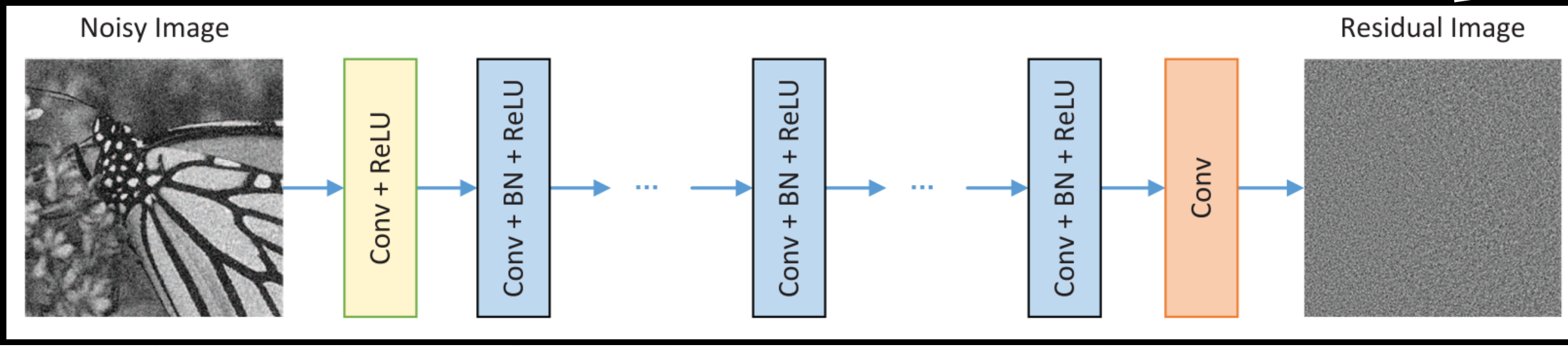
- Slow
- Required human inputs

BM3D algorithm

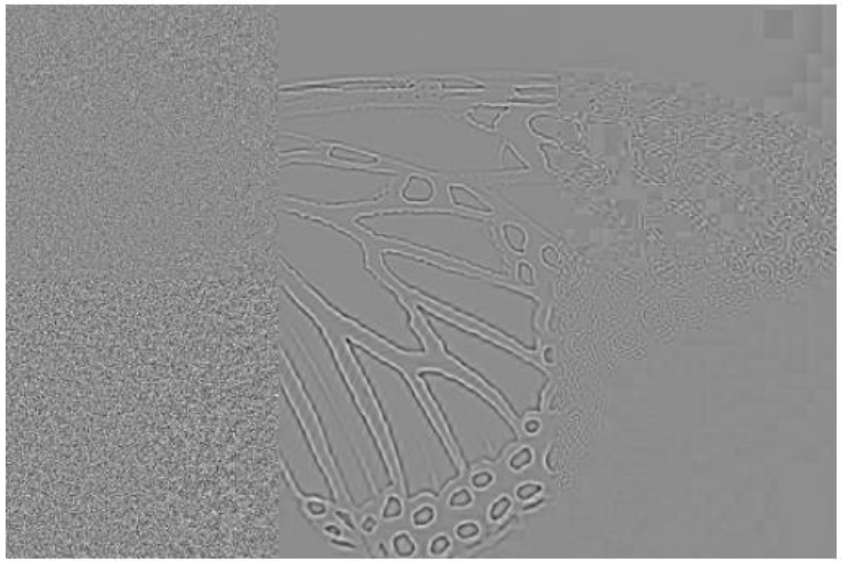
- Block matching -> 3D stack
- Shrinkage in the sparse 3D transformed domain (Wavelet)

1. **Antoni Buades,** et al. “Non-local Mean.” *Computer Vision and Pattern Recognition* **CVPR 2005.**
2. **Kostadin Dabov,** et al. “BM3D.” *IEEE Transactions on image processing* **2007;16(8):2080-2095.**

dnCNN (residual learning)



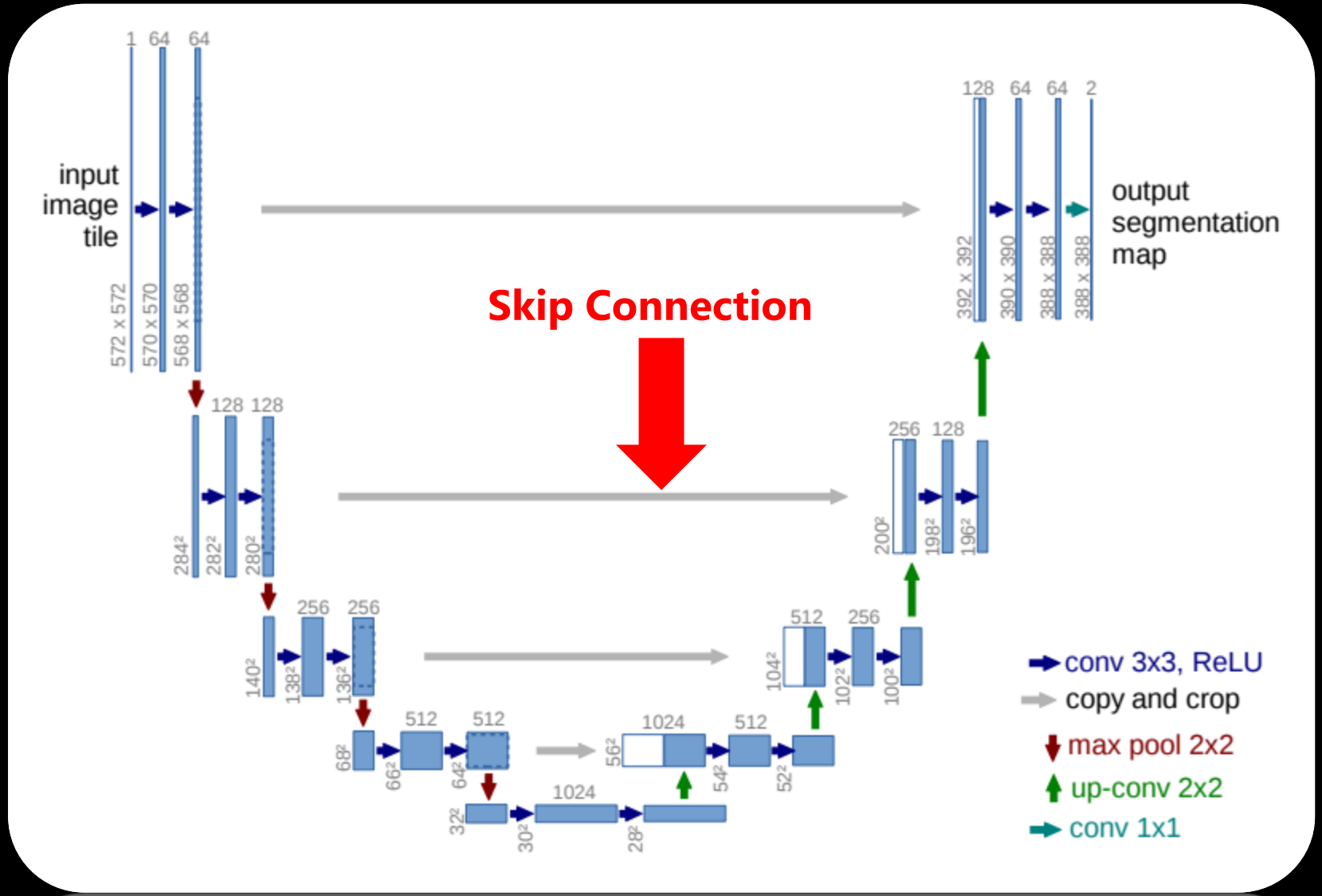
(a) Input Image



(b) Output Residual Image

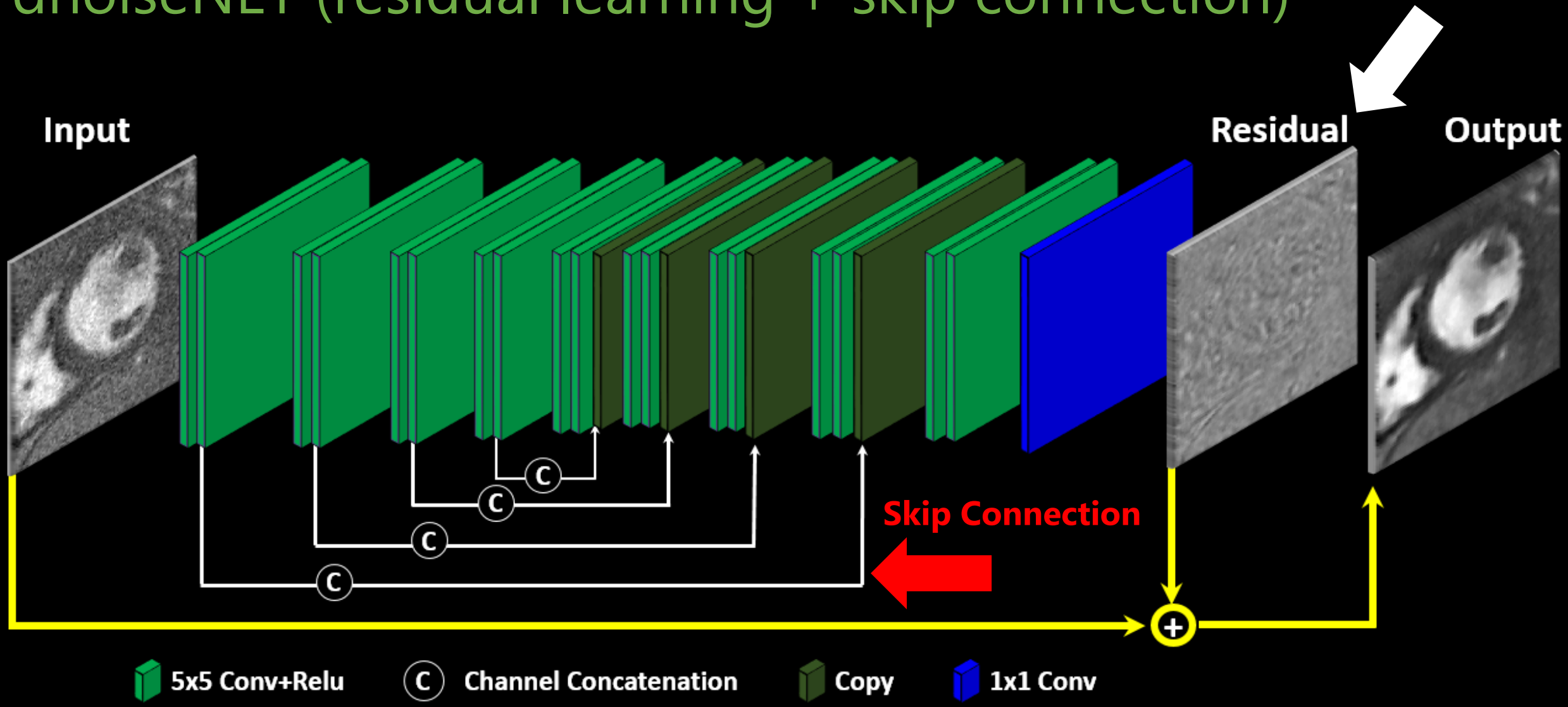
(c) Restored Image

U-NET (skip connection)



1. **Olaf Ronneberger**, et al. "U-NET." *MICCAI*, Springer, Cham, **2015;p234-241.**

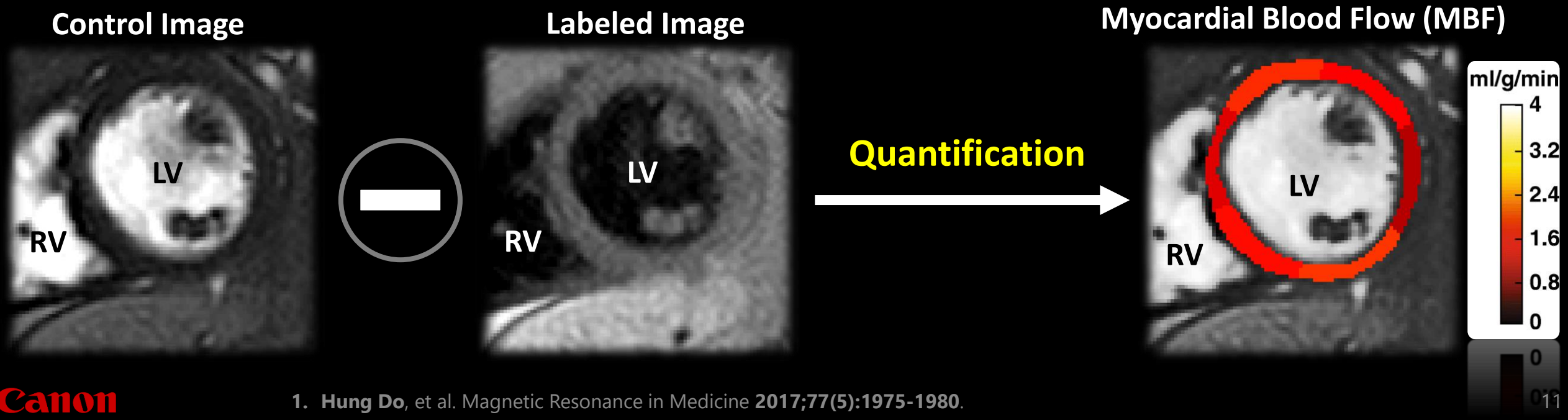
dnoiseNET (residual learning + skip connection)



1. **Kai Zhang**, et al. "dnCNN." *IEEE Transactions on Image Processing* **2017;26(7):3142-3155.**
2. **Olaf Ronneberger**, et al. "U-NET." *MICCAI*, Springer, Cham, **2015;p234-241.**

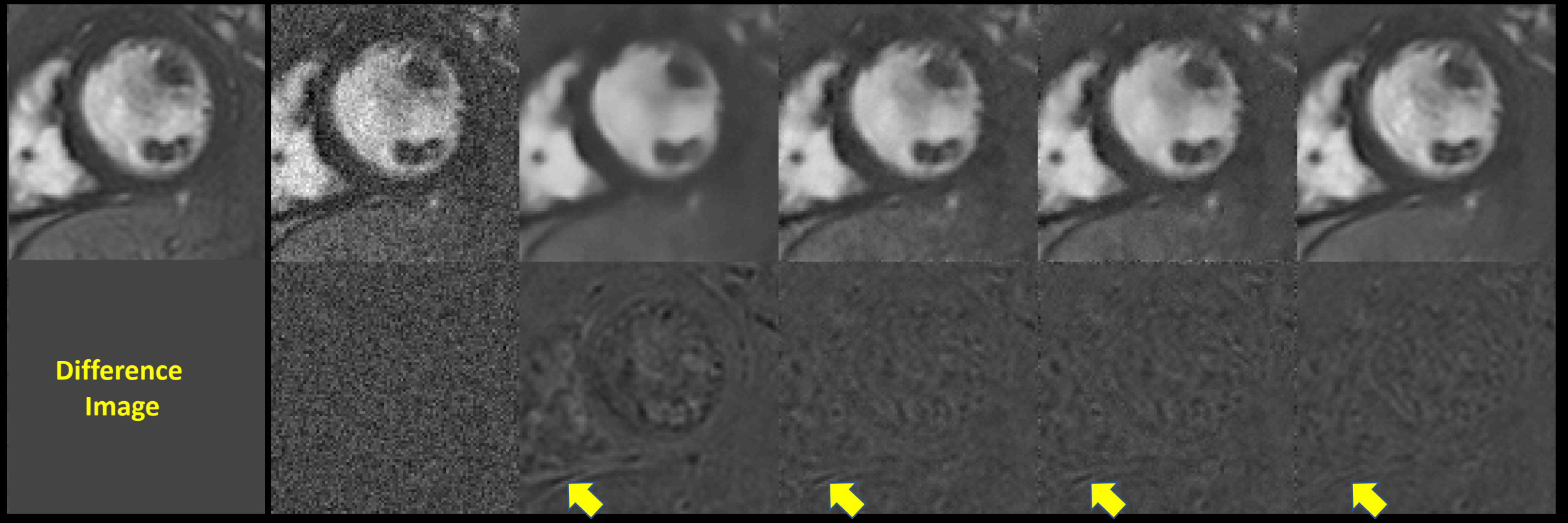
Myocardial ASL Data

- Training and validation data[1]:
  - From 22 subjects: 438/40 images for training/validation
- Test data[1]:
  - From 6 heart transplant patients: 144 images for testing
- i.i.d Gaussian noise was added to magnitude images



1. **Hung Do**, et al. Magnetic Resonance in Medicine **2017;77(5):1975-1980**.

Quality assessment: MSE, SSIM, and PSNR



Mean ± SD from 144 images in the test set

	Noisy	NLM	U-NET	dnCNN	dnoiseNET
MSE = 10^{-3} x	29.4 ± 40.0	4.8 ± 5.7	3.8 ± 4.3	4.2 ± 4.9	2.7 ± 2.6
SSIM =	0.40 ± 0.15	0.62 ± 0.10	0.67 ± 0.12	0.66 ± 0.12	0.72 ± 0.10
PSNR =	18.6 ± 5.5	25.2 ± 4.1	26.4 ± 4.3	26.0 ± 4.5	27.6 ± 4.1

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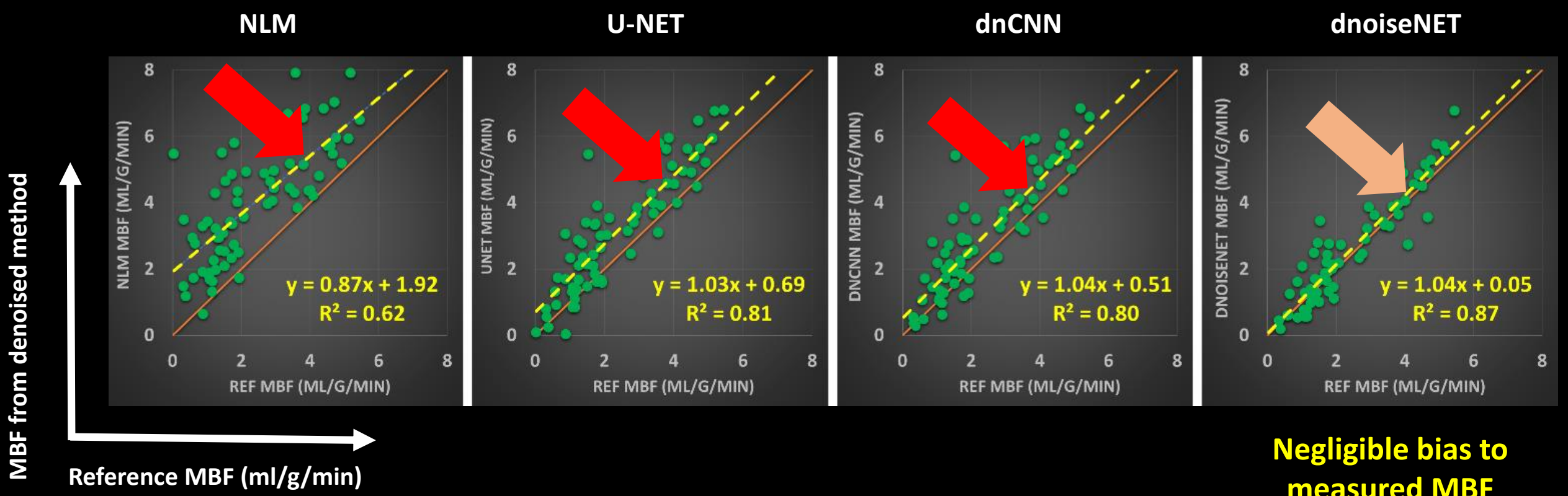
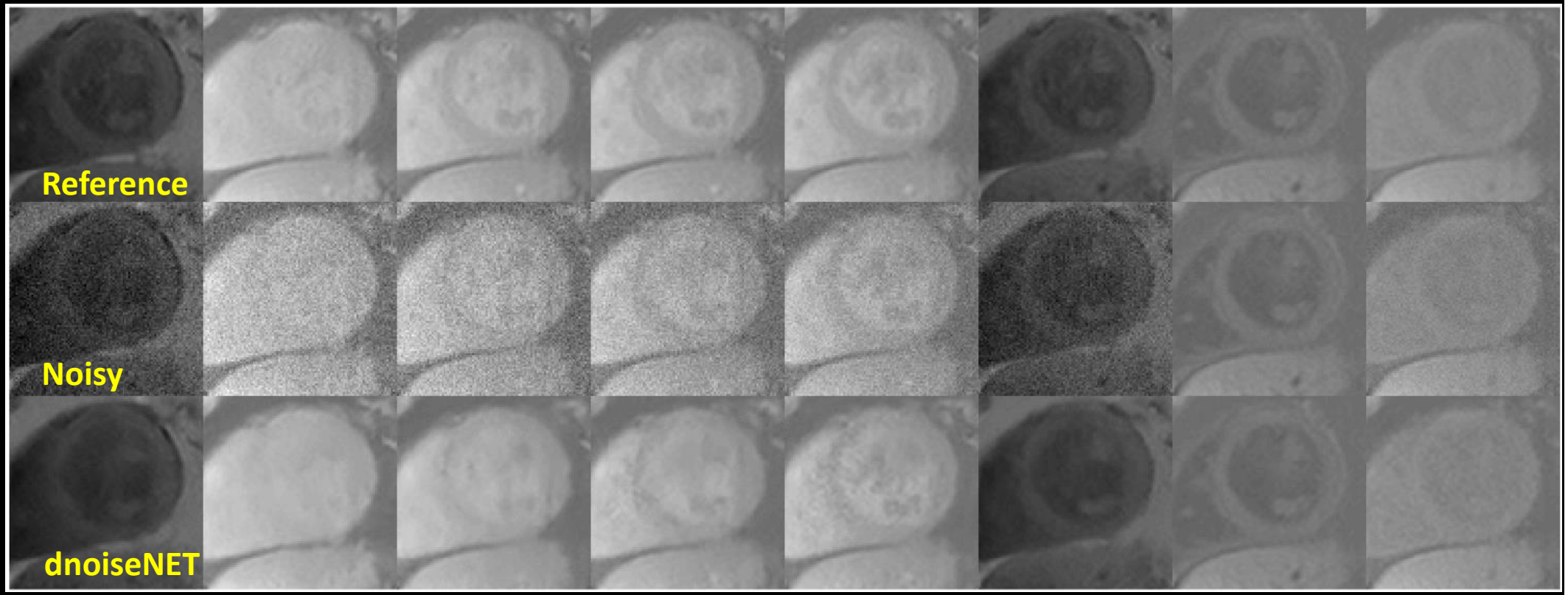
Task-specific quality assessment



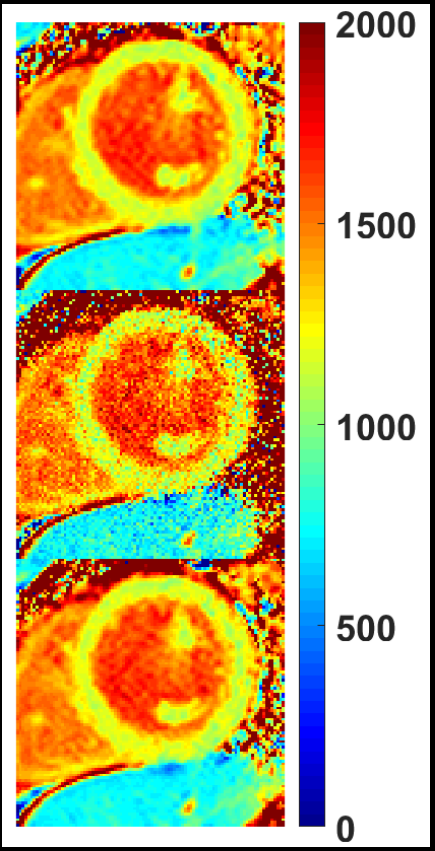
Negligible bias to measured MBF

T1 mapping

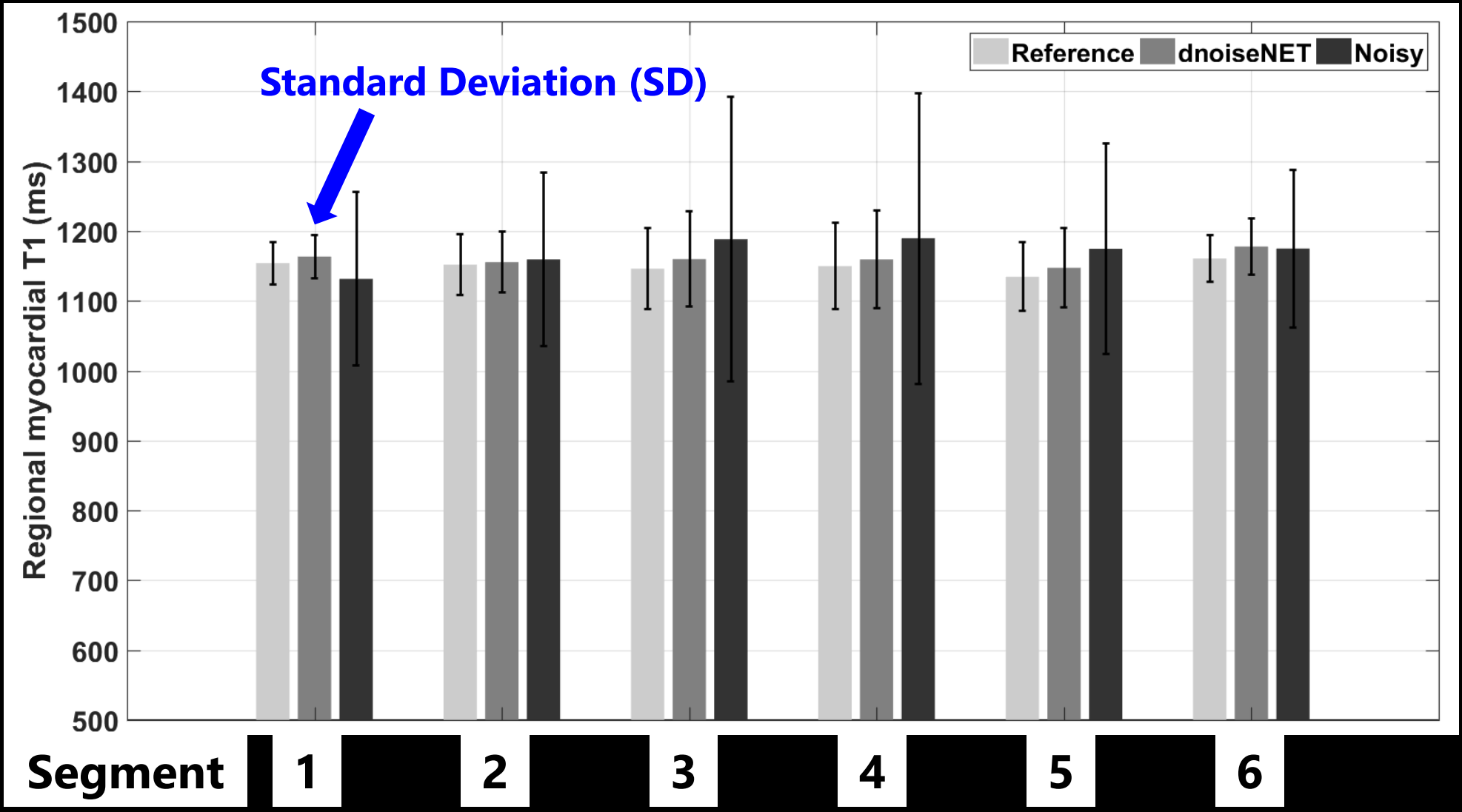
Raw MR images from MOLLI 5(3s)3

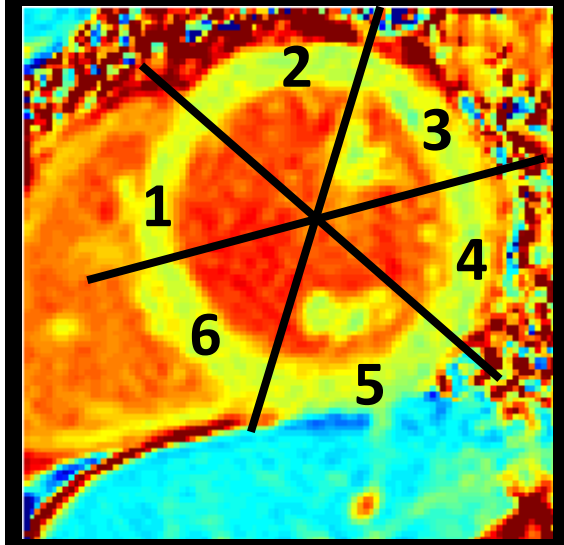


T1 map (ms)

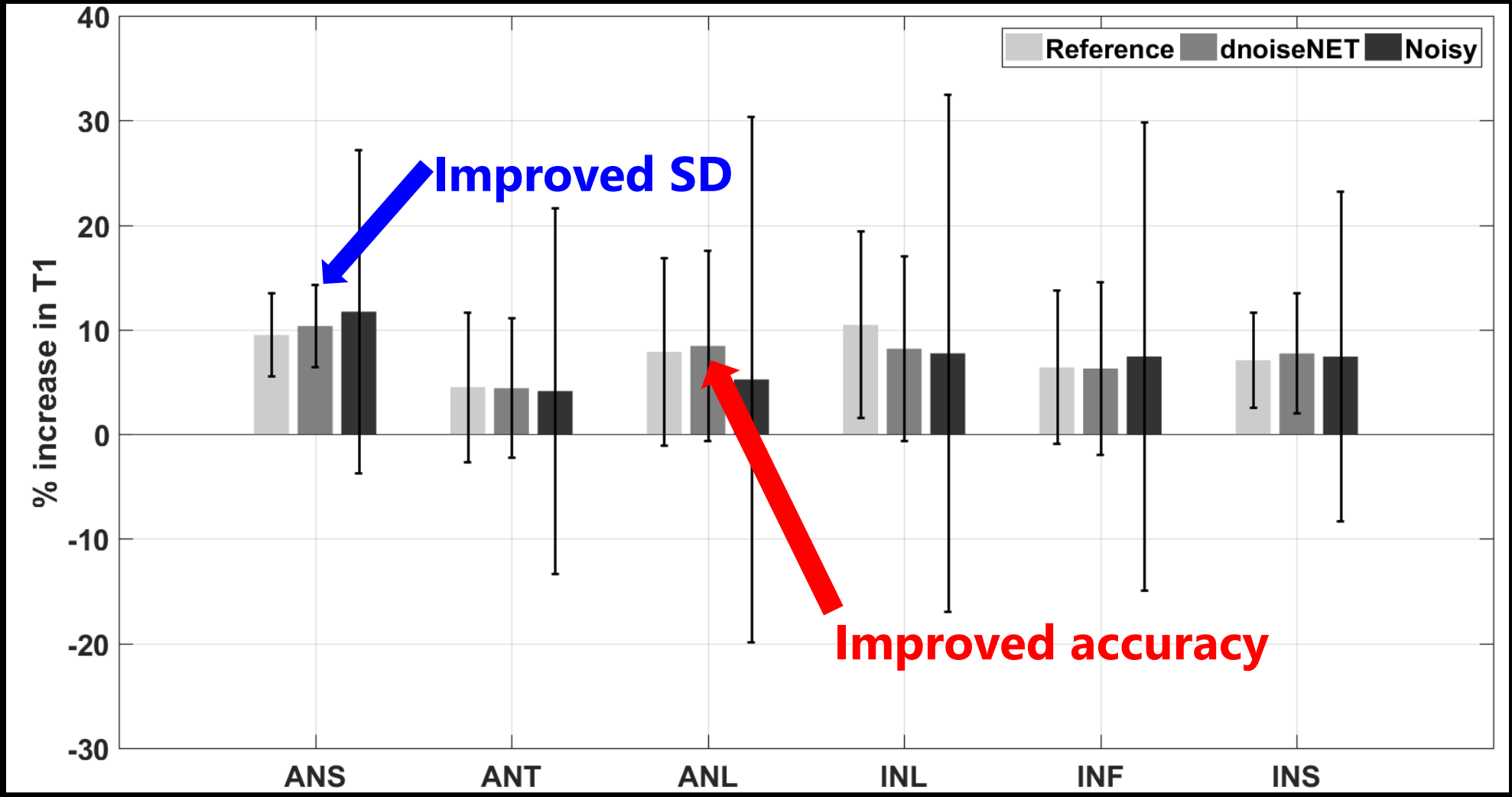


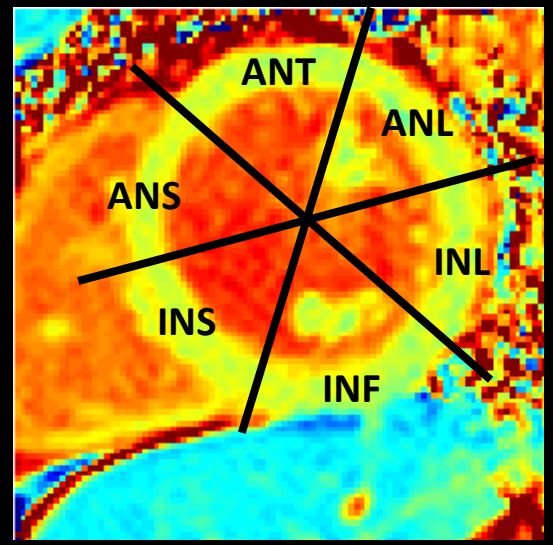
Improved SNR → lower uncertainty





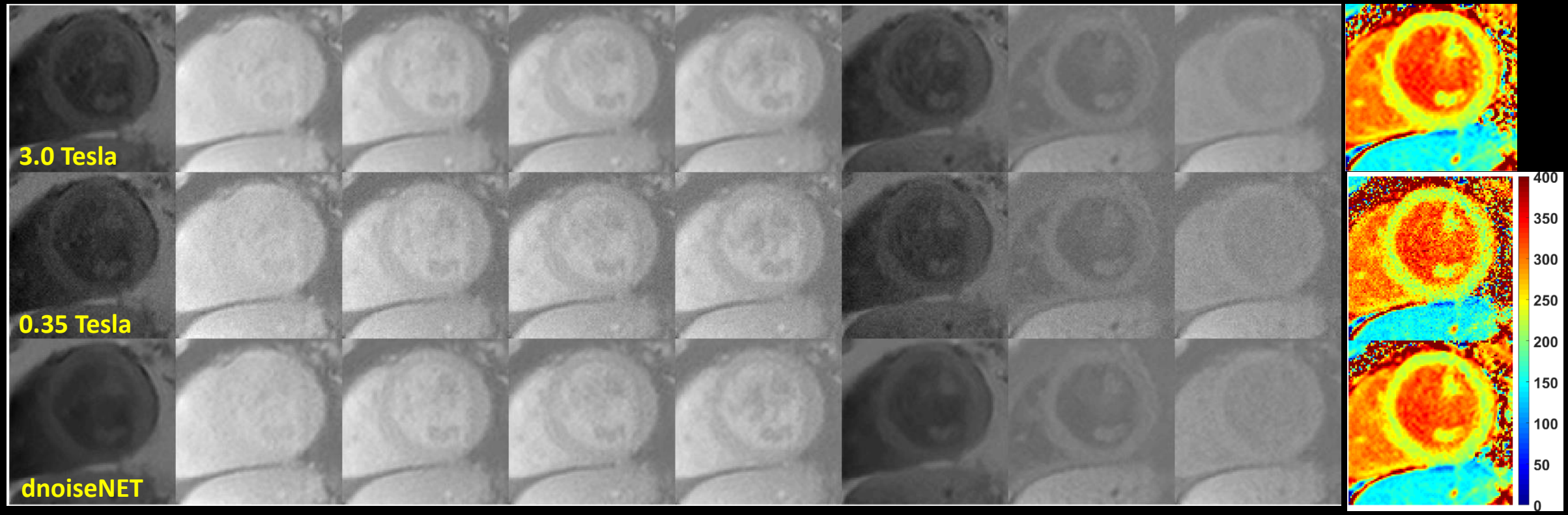
% increase in T1 – rest and stress T1



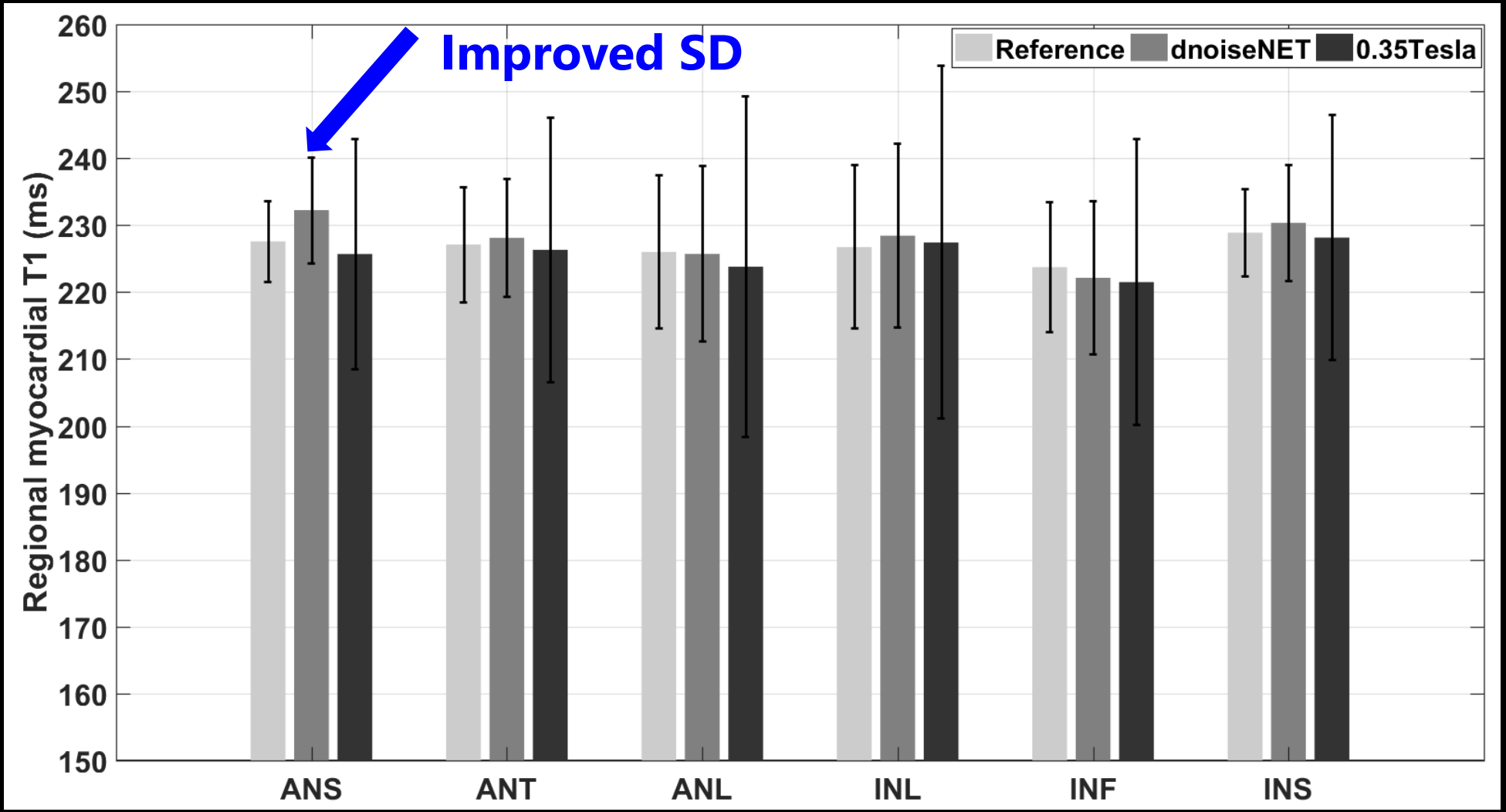


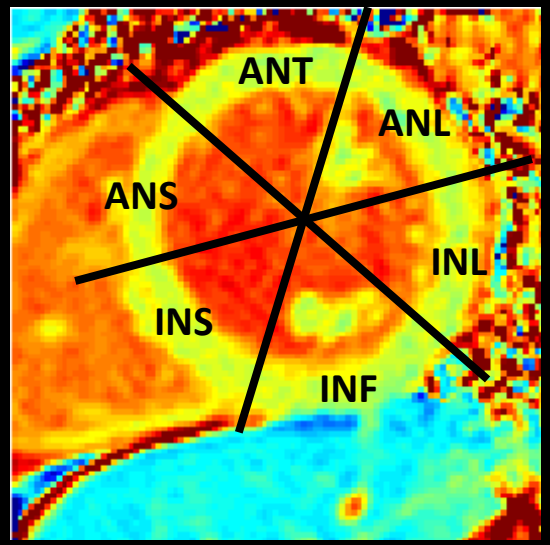
$$\%\ increase\ in\ T_1 = 100 \cdot \frac{(T_{1stress} - T_{1rest})}{T_{1rest}}$$

T1 Mapping at simulated 0.35 Tesla



T1 Mapping at simulated 0.35 Tesla





Conclusions

dnoiseNET: Residual learning and skip connections

- Superior performance in term of MSE, PSNR, SSIM
- More importantly, it does not introduce any significant bias to quantitative MBF

Quality Assessment:

- MSE, PSNR, SSIM may not be sufficient for quality assessment
- Task-specific quality assessment is desired (MBF in this work)

Future works:

- Low-field MRI
- Other type of noise distributions (Rician, Parallel Imaging Noise, and residual artifacts from under sampled data, etc.)

Acknowledgements

Funding:

- Whittier Foundation
- NIH/NHLBI, #1R01HL130494-01A1

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USC University of Southern California

Made For life

For over 100 years, the Canon Medical Systems `Made for Life' philosophy prevails as our ongoing commitment to humanity. Generations of inherited passion creates a legacy of medical innovation and service that continues to evolve as we do. By engaging the brilliant minds of many, we continue to set the benchmark, because we believe quality of life should be a given, not the exception.

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Accuracy vs. Precision

1. Spatial average over ROI → $\underline{T_1^{REF}}$
2. Spatial average over ROI → $\underline{T_1^{PROP}(t_n)}$
3. Spatial SD over ROI → $SD(T_1^{PROP}(t_n))$
4. Accuracy = time average of $abs(\underline{T_1^{REF}} - \underline{T_1^{PROP}(t_n)})$
5. Bias = $\underline{T_1^{REF}}$ – time average of $\underline{T_1^{PROP}(t_n)}$
6. Precision = time average of $SD(T_1^{PROP}(t_n))$
7. Reproducibility = SD of $\underline{T_1^{PROP}(t_n)}$

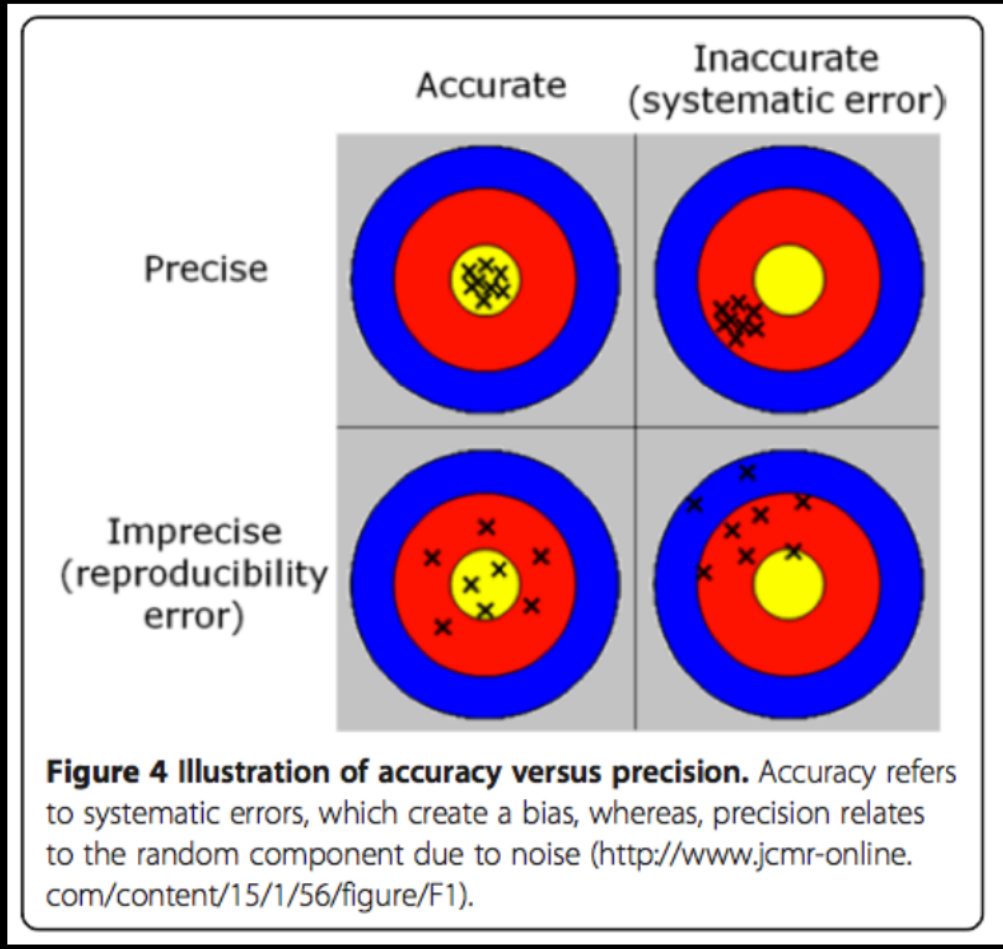
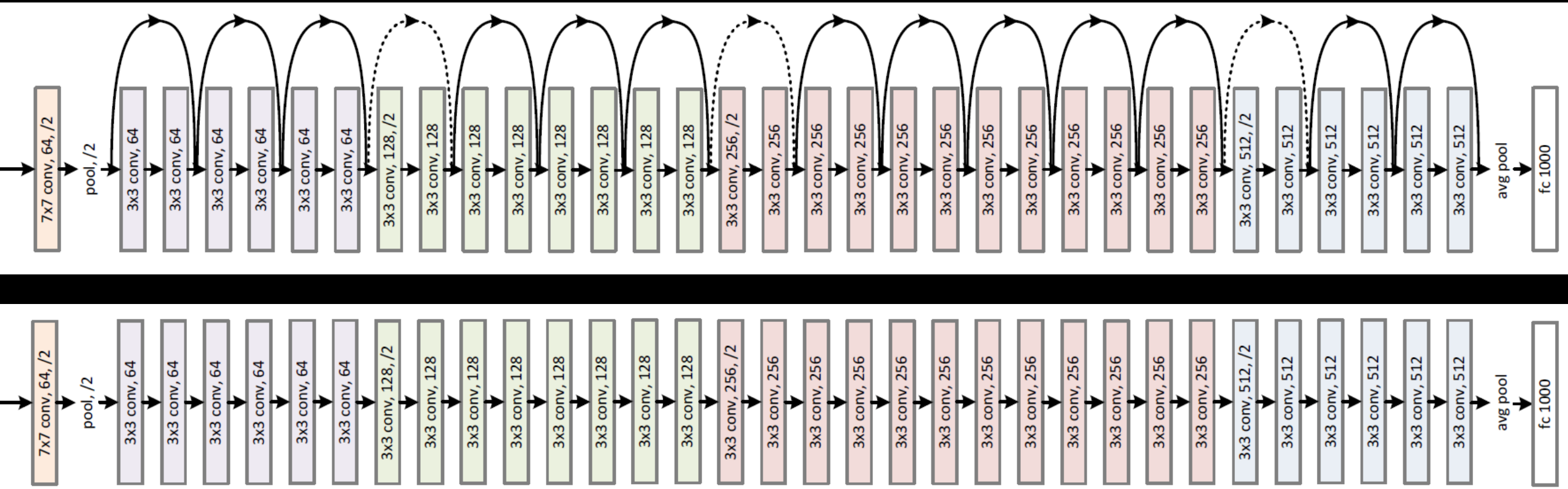
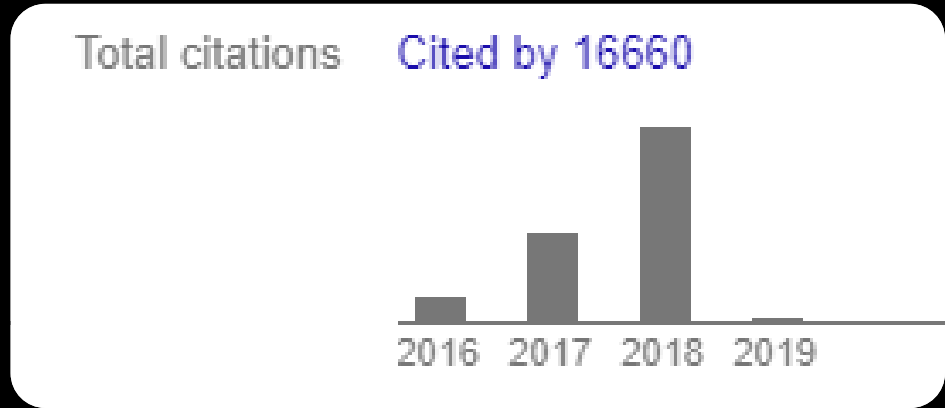


Figure 4 Illustration of accuracy versus precision. Accuracy refers to systematic errors, which create a bias, whereas, precision relates to the random component due to noise (http://www.jcmr-online.com/content/15/1/56/figure/F1).

Skip connection





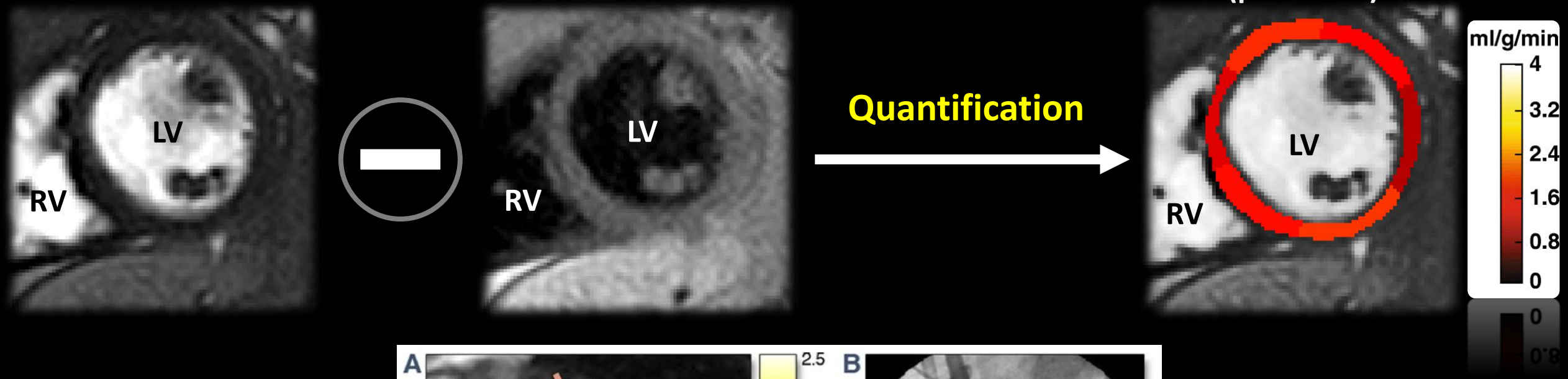
1. **Kaiming He**, et al. "ResNet." **CVPR 2016;p770-778.**

Methods(1): Myocardial Arterial Spin Labeling (ASL)

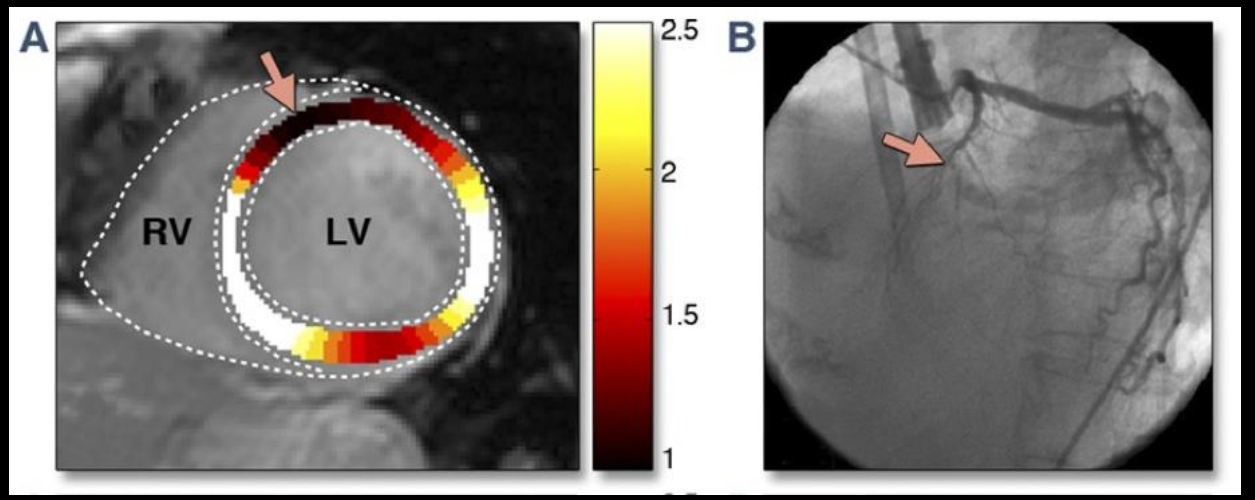
Control Image

Labeled Image

Myocardial Blood Flow (MBF)
(perfusion)



Coronary artery disease (CAD)



1. **Kober, Frank** et al. "*Myocardial arterial spin labeling*." Journal of Cardiovascular Magnetic Resonance 2016; 18:22.
2. **Zun, Zungho** et al., " *ASL-CMR Detects Clinically Relevant Increases in Myocardial Blood Flow With Vasodilation*." iJACC 2011; 4(12):1253-1261.