Self-gated self-supervised ADMM unrolling enables mesoscale high-resolution motion-robust diffusion-weighted imaging

Zhengguo Tan [1], Patrick A Liebig [2], Annika Hofmann [3], Michael Jaroszewicz [1], Yun Jiang [1], Vikas Gulani [1], Frederik B Laun [4], Florian Knoll [3]

1. Michigan Institute for Imaging Technology and Translation (MIITT), Radiology, University of Michigan, Ann Arbor, Michigan, USA
2. Siemens Healthcare GmbH, Erlangen, Germany
3. Artificial Intelligence in Biomedical Engineering (AIBE), Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany
4. Radiology, Universitätsklinikum Erlangen, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany

Declaration of Financial Interests or Relationships

Z Tan:

I have no financial interests or relationships to disclose with regard to the subject matter of this presentation.

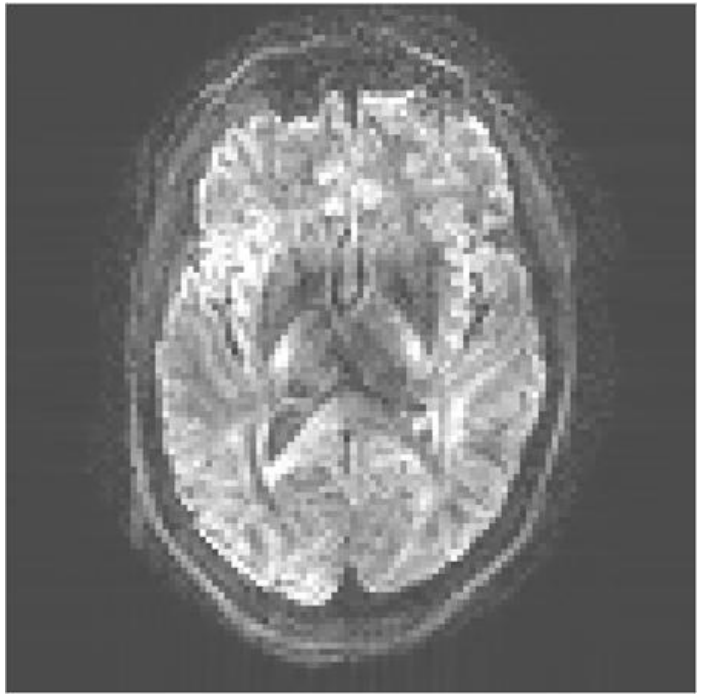
INTRODUCTION

Diffusion-Weighted Imaging (DWI) [1]

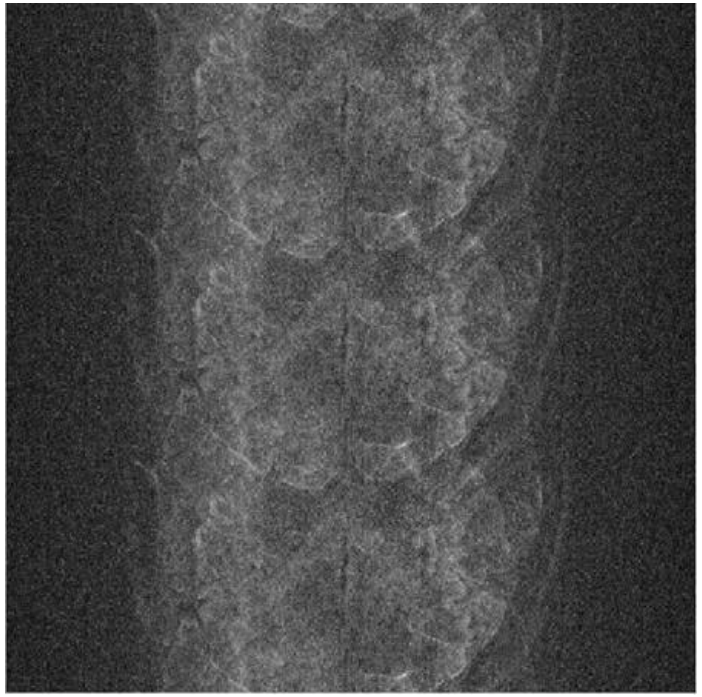
- **Powerful tool for acute stroke diagnosis, fiber tracking, cancer staging, …**

- **Challenges:**

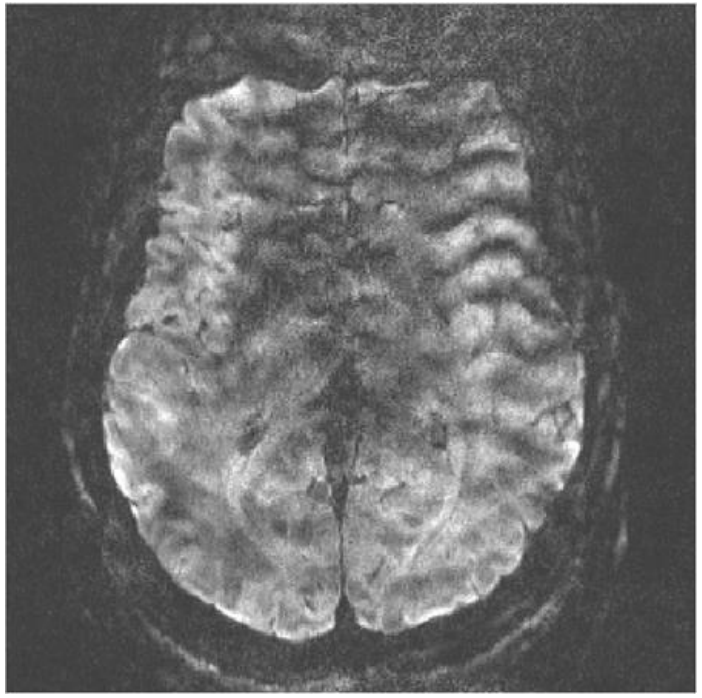
Low spatial resolution



Shot-to-shot phase variation

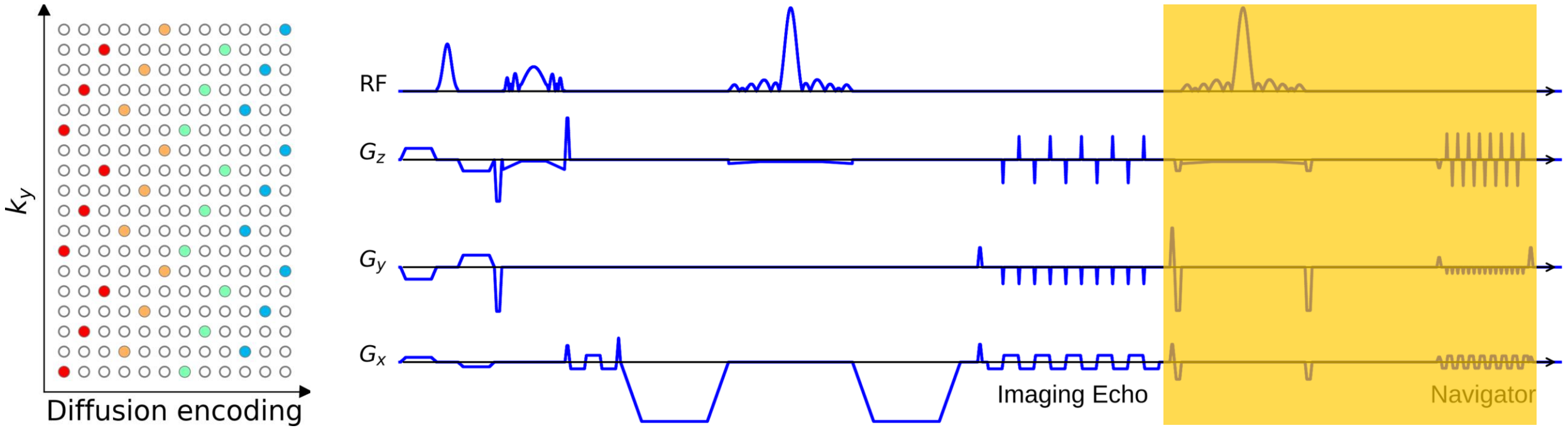


Motion



1. Le Bihan D. From brownian motion to virtual biopsy: a historical perspective from 40 years of diffusion MRI. *Jpn J Raiol* (2024).

Previous Work: Mesoscale High-Resolution DWI Acquisition with NAViEPI [2]



Brain DWI Protocol: 0.7 mm ISO

Shots: 3; Acceleration: 2 x 2; Matrix size: 286 x 286 x 176; 1 x b0 & 20 x b1000; TEs/TR: 58/98/15000 ms;

TA: 16 minutes.

TA reduced to 10 minutes w/o navigators.

Question: Selfgated reconstruction for accelerated DWI?

2. Tan Z, et al. JETS-NAViEPI. *Imaging Neuroscience* (2024).

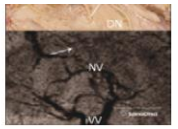
State-of-the-Art Selfgated DWI Reconstruction

- MUltiplexed Sensitivity-Encoding (**MUSE**): simultaneous multi-slice (SMS) multi-shot SENSE

ELSEVIER

NeuroImage

journal homepage: www.elsevier.com/locate/ynimg



Technical Note

A robust multi-shot scan strategy for high-resolution diffusion weighted MRI enabled by multiplexed sensitivity-encoding (MUSE)

Nan-kuei Chen *, Arnaud Guidon, Hing-Chiu Chang, Allen W. Song

Brain Imaging and Analysis Center, Duke University Medical Center, Box 2737, Hock Plaza, Durham, NC 27710, USA

- **Low Rankness**

  > **MUSSELS**: low-rankness among shots

Magnetic Resonance in Medicine 78:494–507 (2017)

Multi-Shot Sensitivity-Encoded Diffusion Data Recovery Using Structured Low-Rank Matrix Completion (MUSSELS)

Merry Mani,[1] Mathews Jacob,[2]* Douglas Kelley,[3] and Vincent Magnotta[1,4,5]

  > **LLR**: Locally low rank of spatial-diffusion matrices

FULL PAPER

Magnetic Resonance in Medicine

Multi-shot diffusion-weighted MRI reconstruction with magnitude-based spatial-angular locally low-rank regularization (SPA-LLR)

Yuxin Hu[1,2] | Xiaole Wang[1] | Qiyuan Tian[1,2] | Grant Yang[1,2] | Bruce Daniel[2,3] | Jennifer McNab[2] | Brian Hargreaves[1,2,3]

Inspiration: Self2Self & Zero-Shot Learning

- **Self2Self** [3]

  A denoising neural network can be learned from one single image.

- **Zero-shot learning** [4,5]

  The regularization in iterative reconstructions can be learned without full-sampled k-space data.

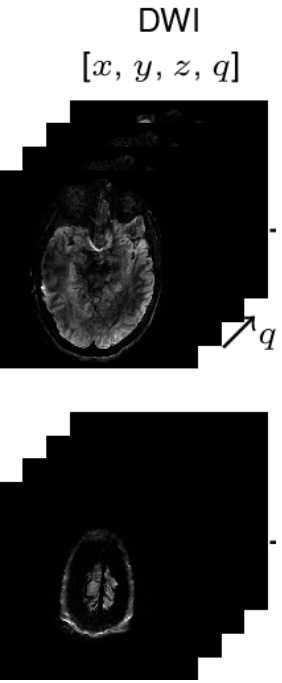
- **Question: Self-supervised learning for high-resolution joint DWI reconstruction?**

3. Quan Y, et al. Self2Self with dropout: Learning self-supervised denoising from single image. *CVPR* (2020).
4. Yaman B, et al. Zero-shot self-supervised learning for MRI reconstruction. *ICLR* (2022).
5. Heydari A, et al. Joint MAPLE: Accelerated joint T1 and T2* mapping with scan specific self-supervised networks. *Magn Reson Med* (2024).

METHODS

Joint k-q-Slice Reconstruction

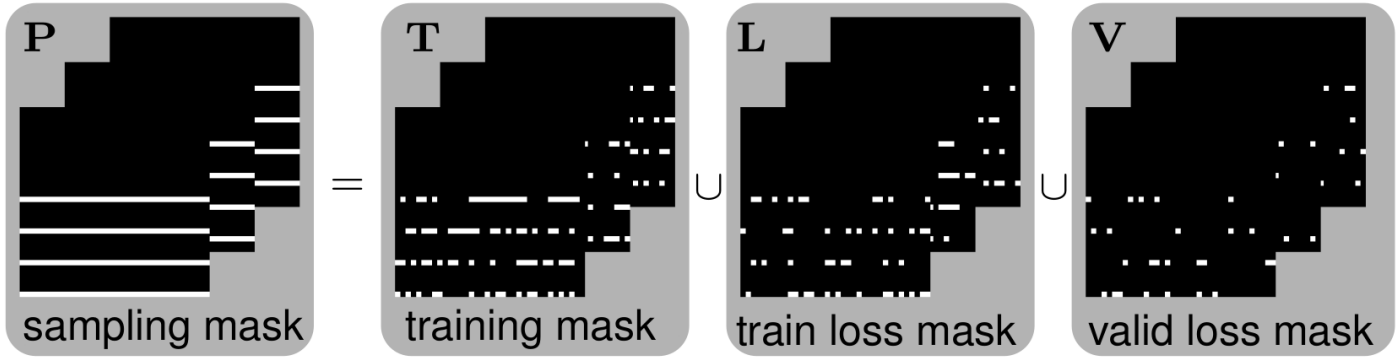
- Joint k-q-slice forward model (github.com/ZhengguoTan/NAViEPI)



$$\underset{\mathbf{x}}{\operatorname{argmin}} \|\mathbf{A}\mathbf{x} - \mathbf{y}\|_2^2 + \lambda \mathcal{D}_\omega(\mathbf{x})$$

Self-Supervised ADMM Unrolling Reconstruction

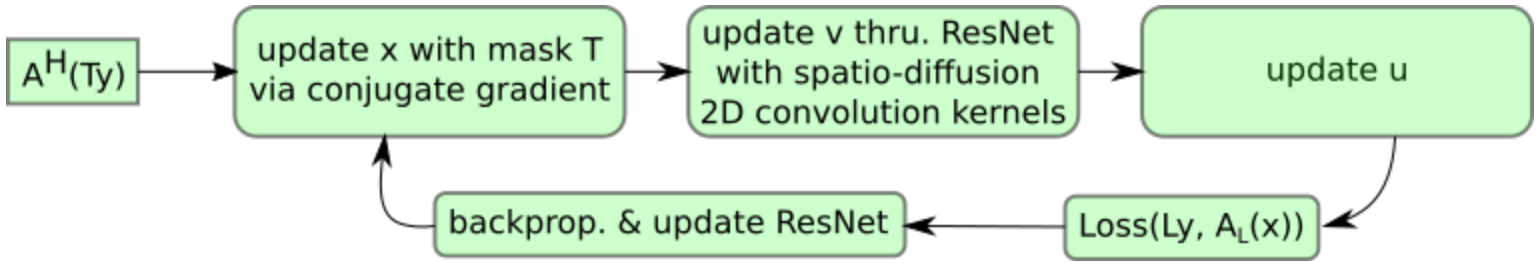
(a) sampling mask splitting



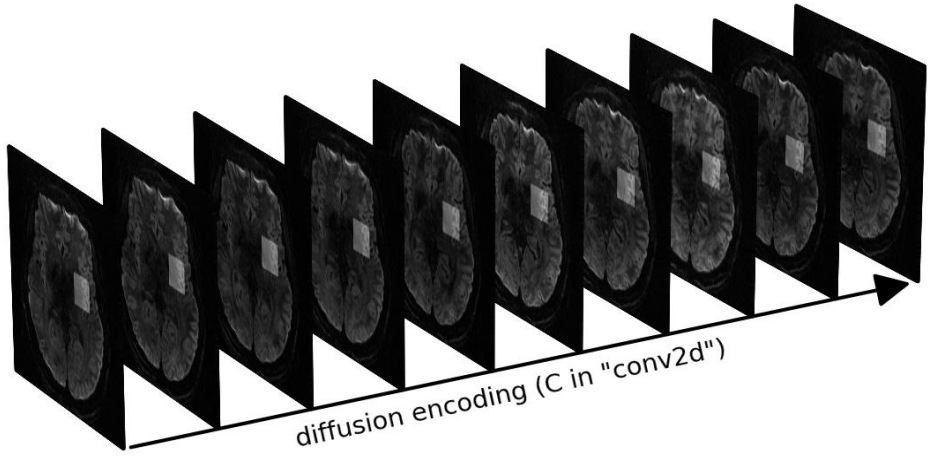
(b) ADMM [6] unrolling

$$\begin{cases} \mathbf{x}^{(k+1)} = \underset{\mathbf{x}^{(k)}}{\operatorname{argmin}} \left\| \mathbf{y} - \mathcal{A}(\mathbf{x}^{(k)}) \right\|_2^2 \\ \qquad\qquad + \frac{\rho}{2} \left\| \mathbf{x}^{(k)} - \mathbf{v}^{(k)} + \mathbf{u}^{(k)} \right\|_2^2 \\ \mathbf{v}^{(k+1)} = (\lambda/\rho) \cdot \mathcal{D}_\omega(\mathbf{x}^{(k+1)} + \mathbf{u}^{(k)}) \\ \mathbf{u}^{(k+1)} = \mathbf{u}^{(k)} + \mathbf{x}^{(k+1)} - \mathbf{v}^{(k+1)} \end{cases}$$

(c) training



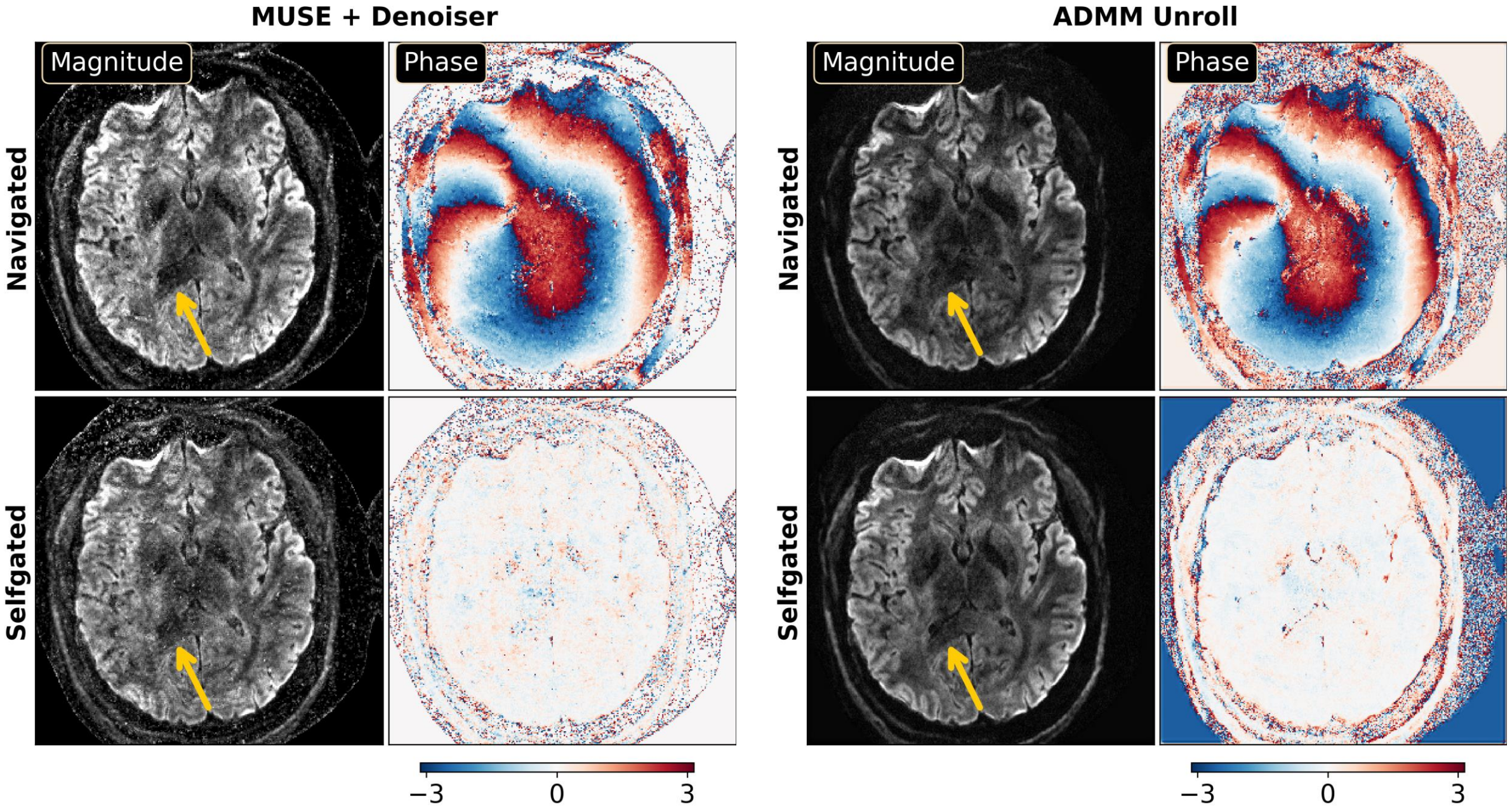
(d) spatial-diffusion convolution



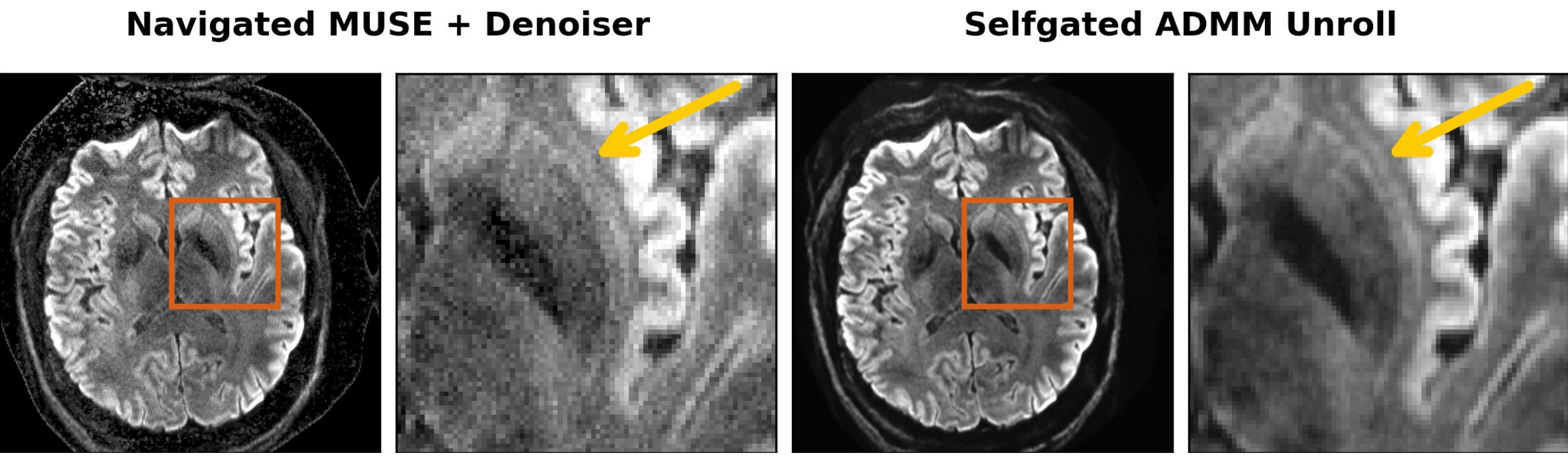
6. Boyd S, et al. Distributed optimization and statistical learning via the alternating direction method of multipliers. *Found Trends Mach Learn* (2010).

RESULTS

Joint k-q-Space ADMM Unroll Enables Selfgated DWI Reconstruction



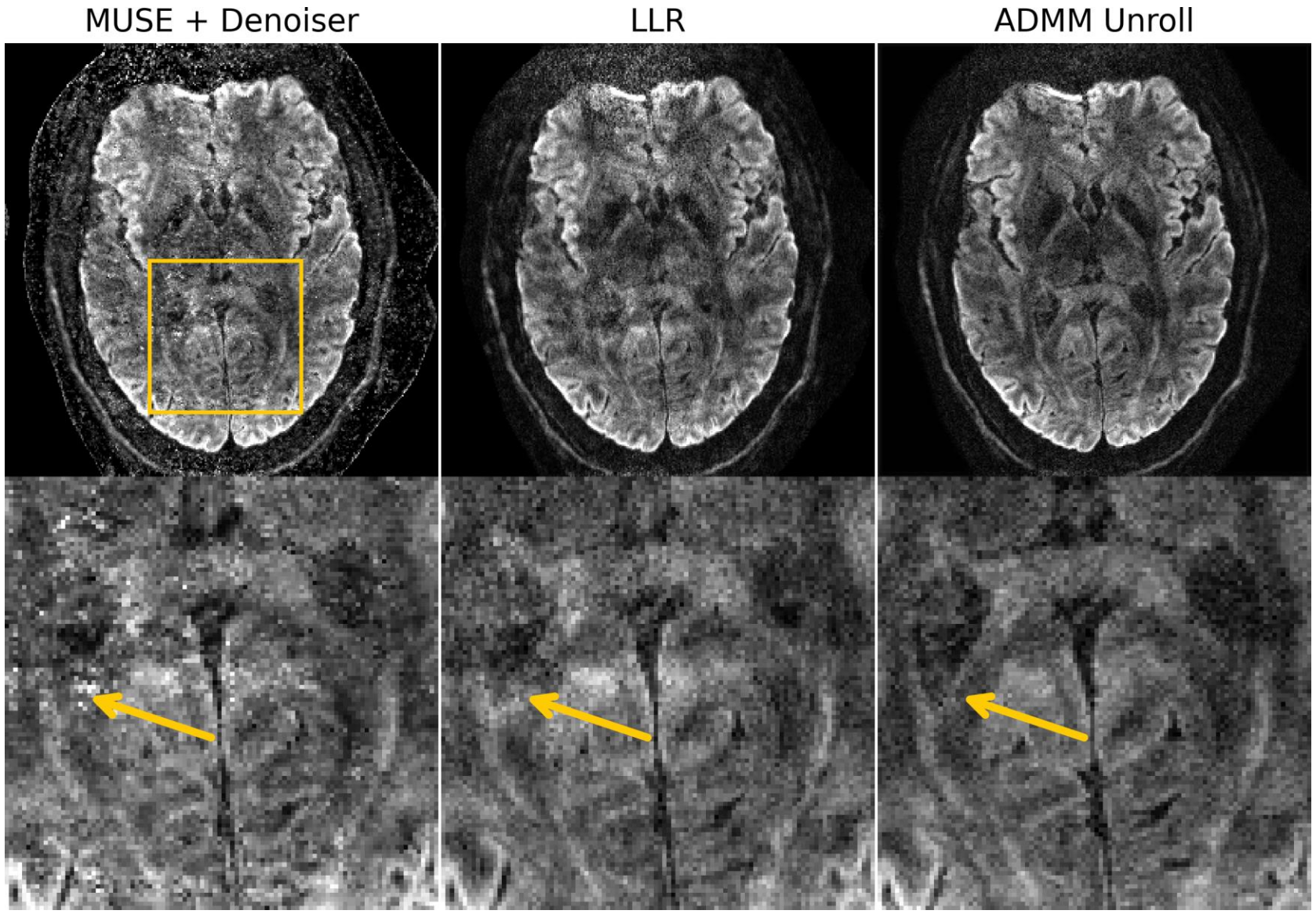
0.7 mm DWI Enables Visualization of the "Hidden-Away" Claustrum



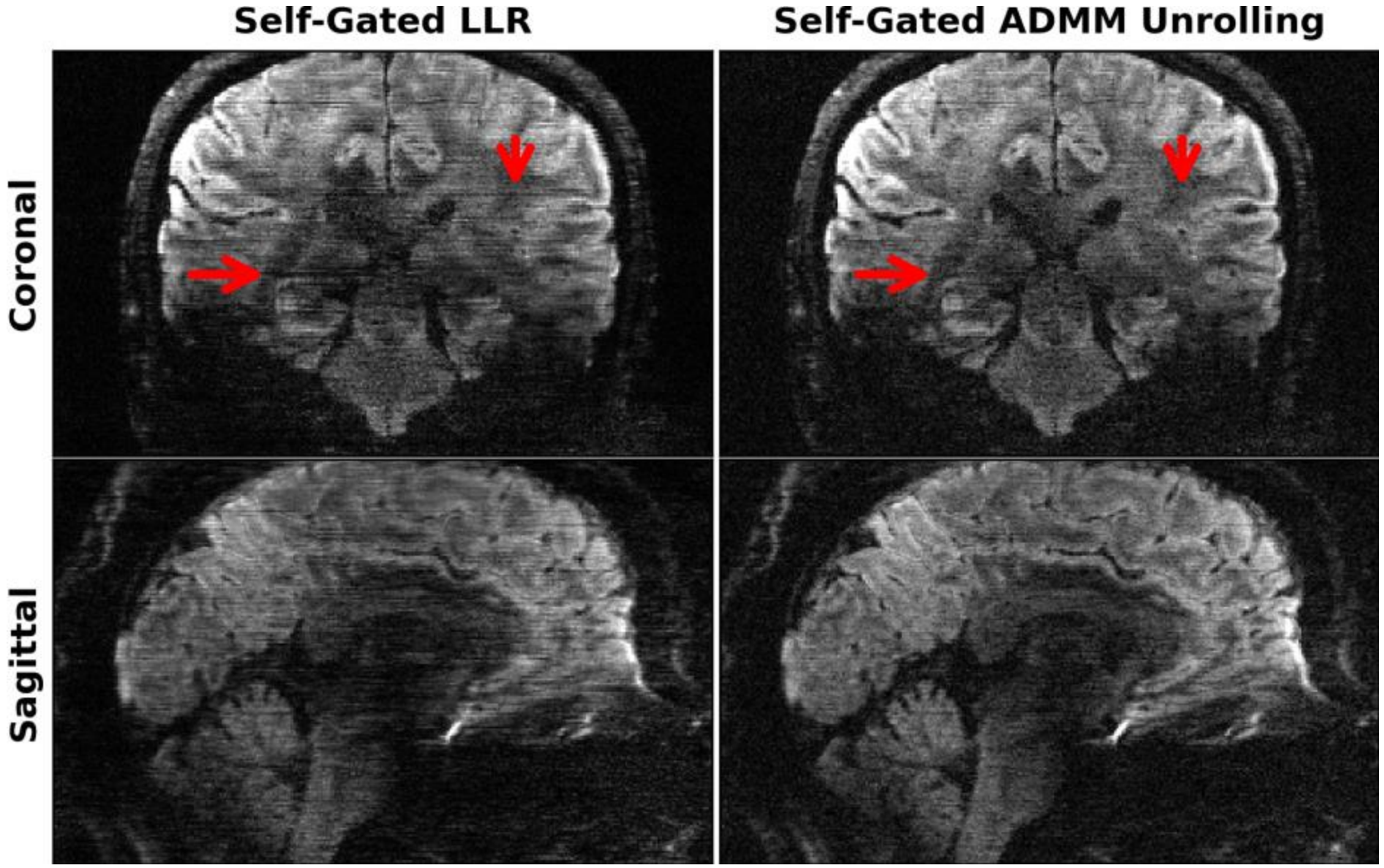
- Mean diffusion-weighted images from 20 directions at b = 1000 s/mm^2 are displayed

Joint k-q-Space ADMM Unroll Enables Selfgated DWI Reconstruction

0.7 mm ISO with 150 slices and 21 diffusion volumes with b = 1000 s/mm^2 at 10 minutes



Motion Robustness



SUMMARY

Summary

- **Self-supervised ADMM unrolling enables mesoscale DWI at short scan time.**