



# DEEPQSM

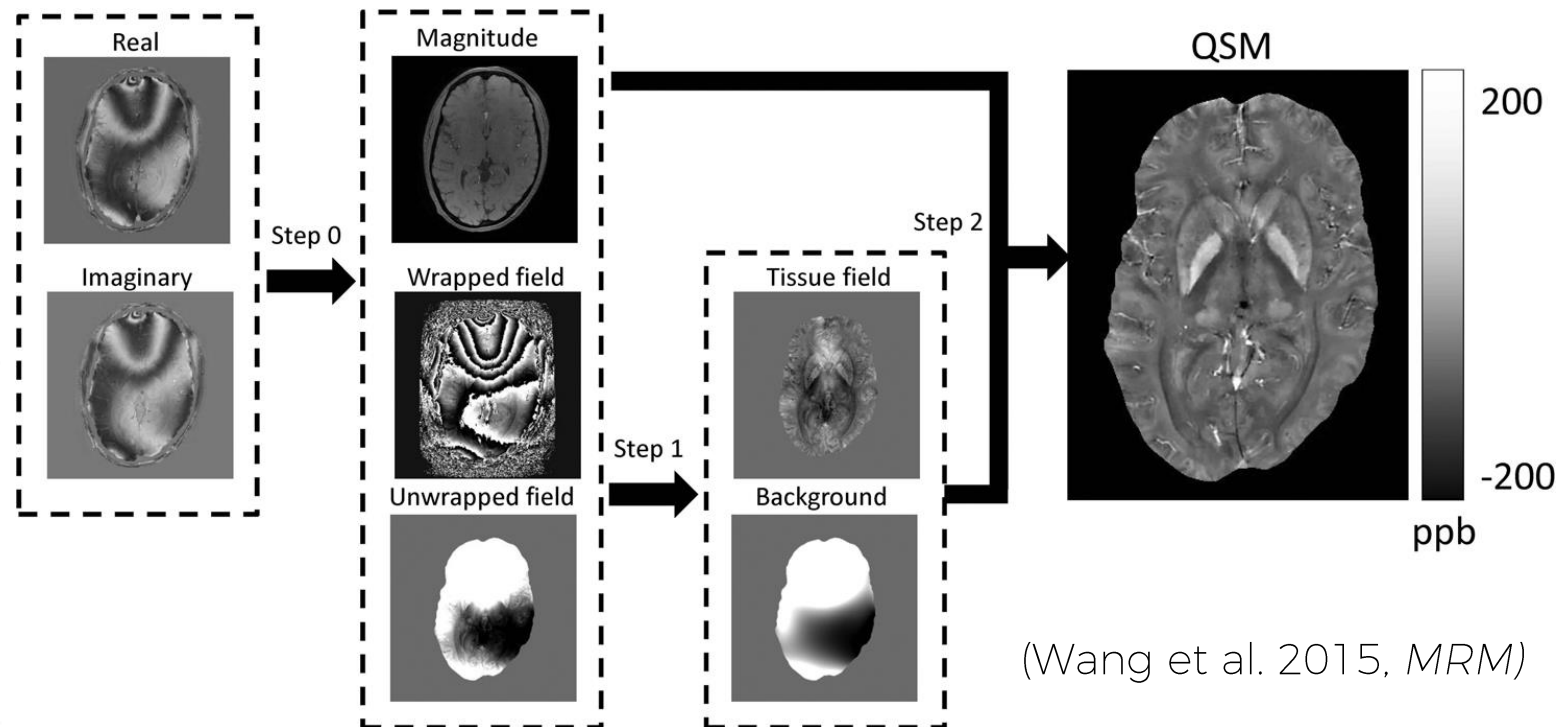
USING DEEP LEARNING TO SOLVE  
THE DIPOLE INVERSION FOR MRI SUSCEPTIBILITY

Steffen Bollmann  
Centre for Advanced Imaging  
The University of Queensland  
Australia



# QUANTITATIVE SUSCEPTIBILITY MAPPING (QSM)

- Magnetic Susceptibility = degree of magnetization of a material in a magnetic field
- computed based on the MRI signal phase of GRE

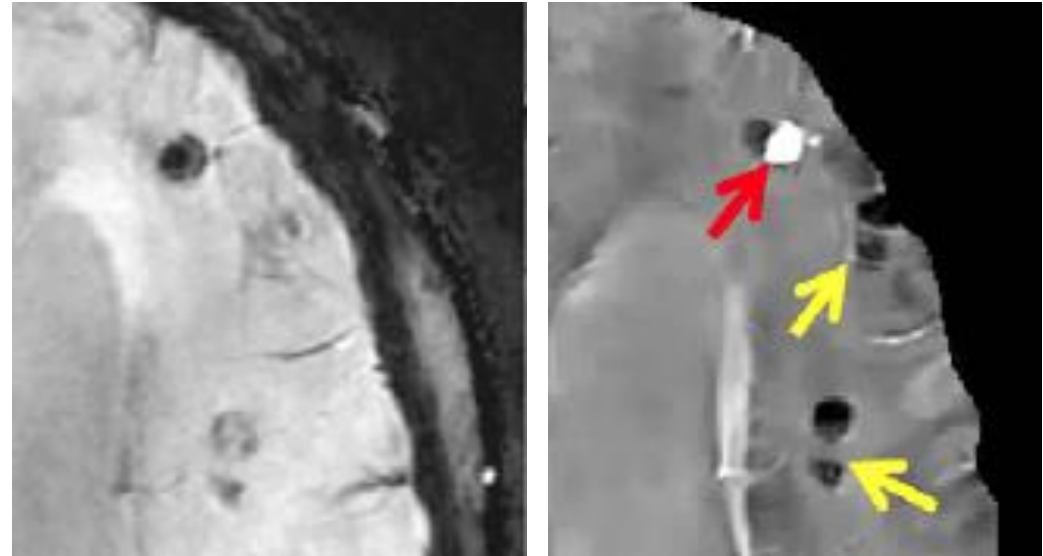


(Wang et al. 2015, *MRM*)

# APPLICATIONS OF QSM

- sensitive to bio-metals
- micro-bleeds
- calcification
- contrast agent biodistribution
- demyelination

(Chen et al. 2014 Radiology)



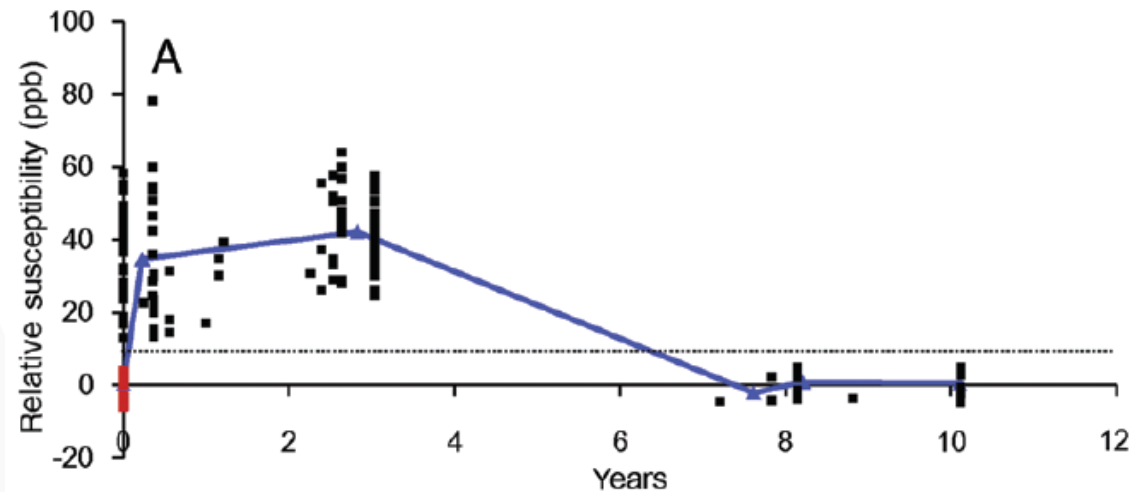
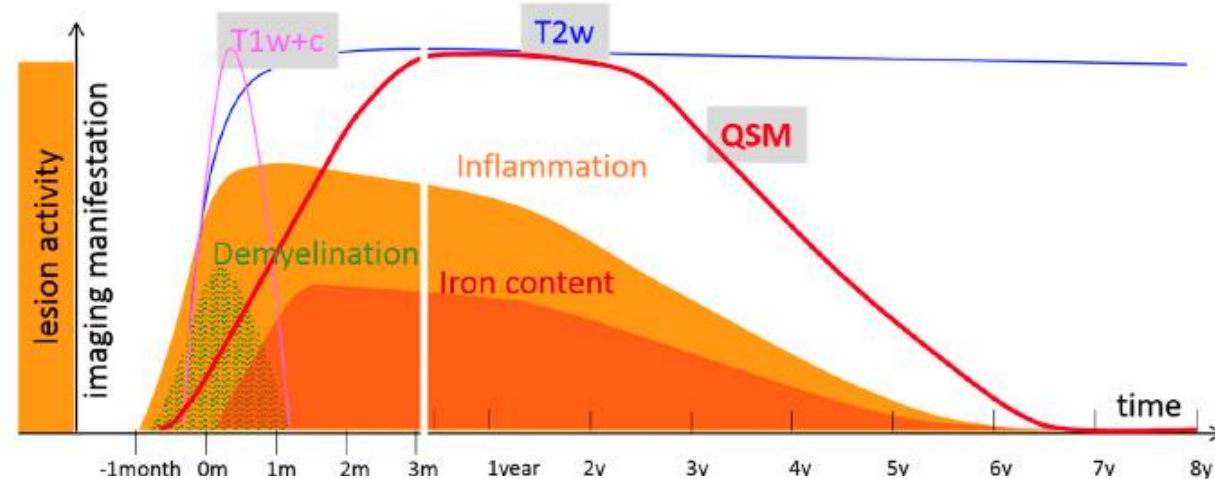
T2\* weighting

QSM

Example: QSM shows active lesions with positive susceptibilities (red arrow) and calcified lesions with negative susceptibilities (yellow arrows)

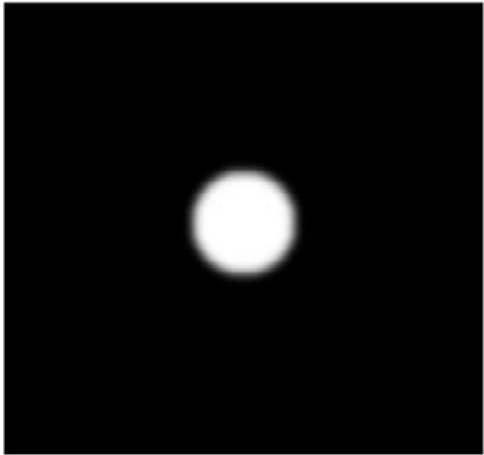
# APPLICATIONS OF QSM

- Multiple Sclerosis
- iron accumulates after demyelination in microglia
- slow iron-depletion from normal appearing white matter



# INVERSE PROBLEM

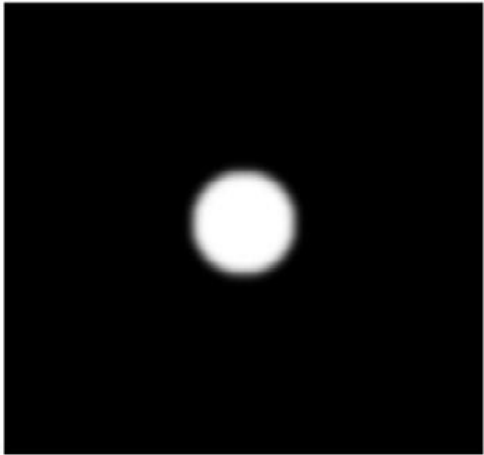
magnetic susceptibility  
distribution



Schweser, F., Deistung, A., Reichenbach, J.R., 2015. Foundations of MRI phase imaging and processing for Quantitative Susceptibility Mapping (QSM). Zeitschrift für Medizinische Physik.

# INVERSE PROBLEM

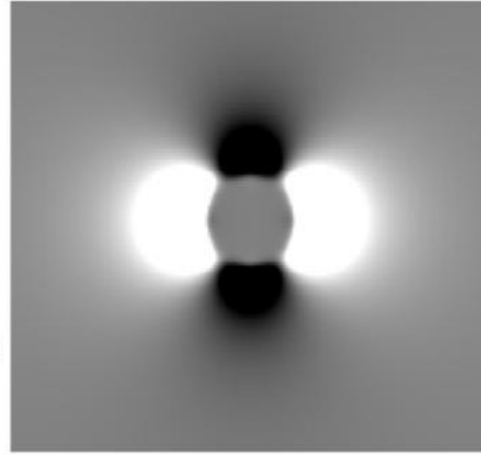
magnetic susceptibility  
distribution



applied  
magnetic field

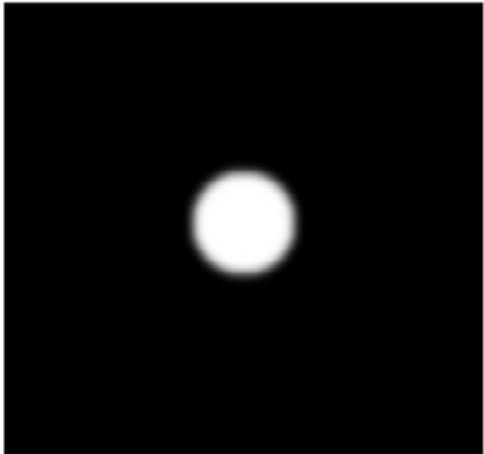


magnetic field  
perturbation



# INVERSE PROBLEM

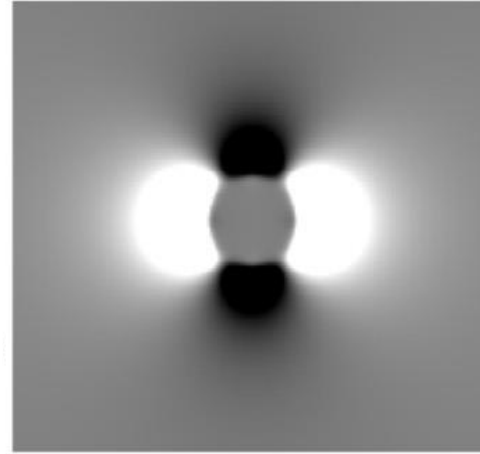
magnetic susceptibility  
distribution



applied  
magnetic field



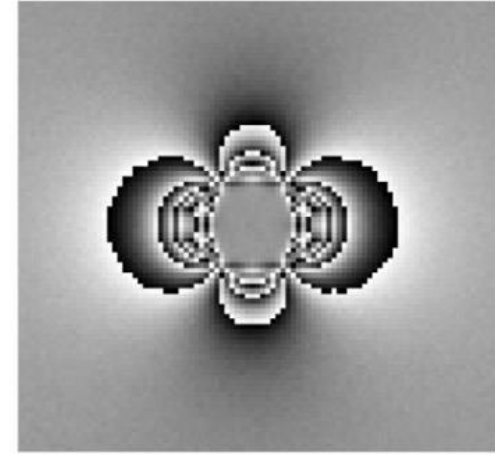
magnetic field  
perturbation



MRI measurement

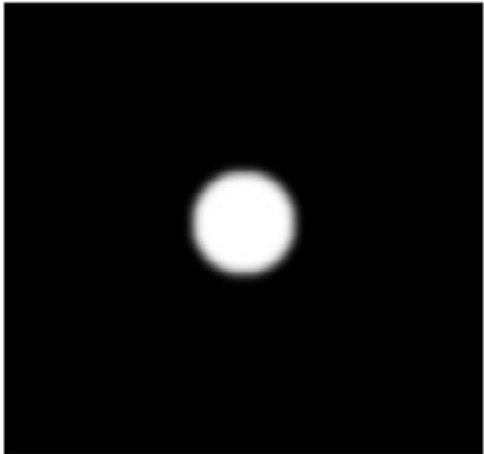


measured (noisy)  
wrapped MRI phase



# INVERSE PROBLEM

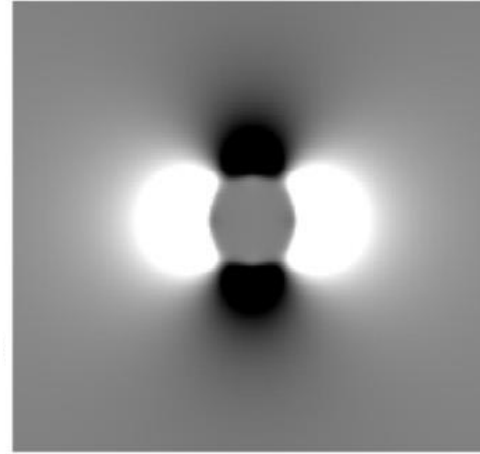
magnetic susceptibility  
distribution



applied  
magnetic field



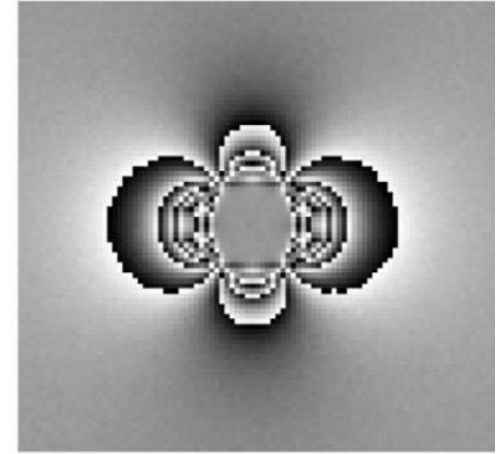
magnetic field  
perturbation



MRI measurement



measured (noisy)  
wrapped MRI phase

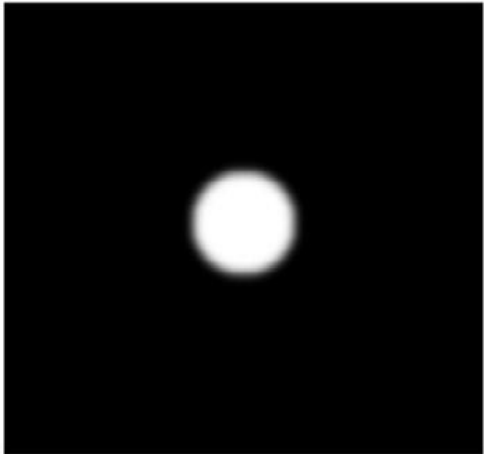


phase unwrapping



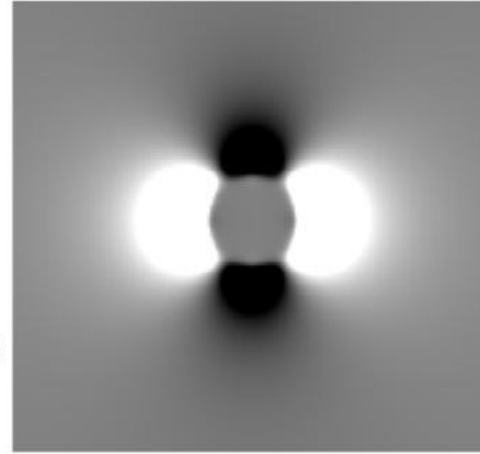
# INVERSE PROBLEM

magnetic susceptibility  
distribution



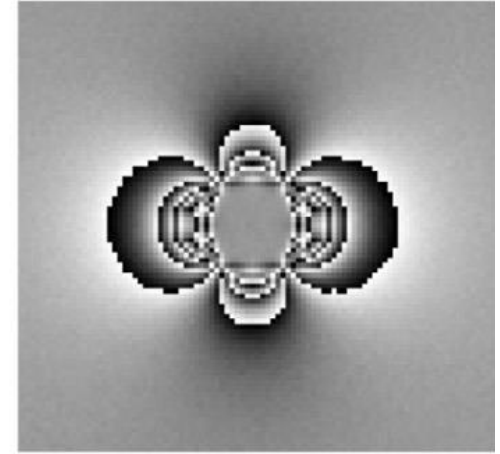
applied  
magnetic field  
→  
←  
inverse field-to-source  
problem

magnetic field  
perturbation



MRI measurement  
→  
←  
phase unwrapping

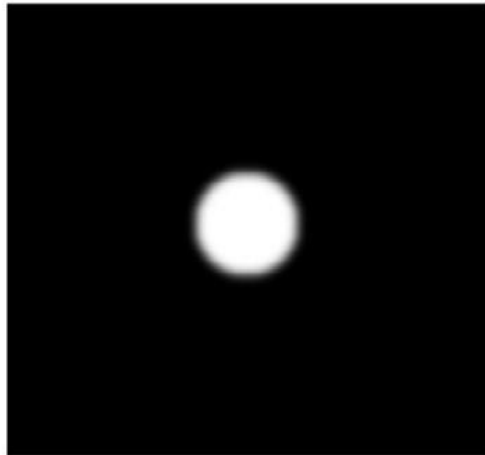
measured (noisy)  
wrapped MRI phase



# INVERSE PROBLEM

Forward Problem

magnetic susceptibility  
distribution

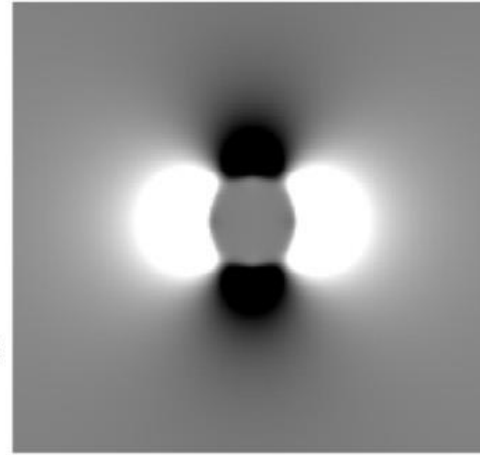


applied  
magnetic field



inverse field-to-source  
problem

magnetic field  
perturbation

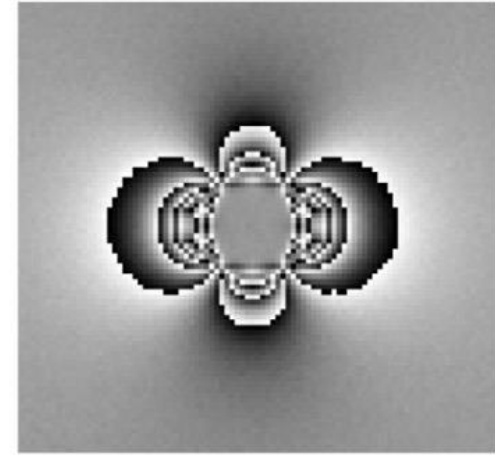


MRI measurement



phase unwrapping

measured (noisy)  
wrapped MRI phase



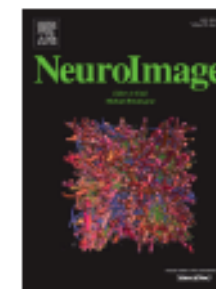
Inverse Problem

Schweser, F., Deistung, A., Reichenbach, J.R., 2015. Foundations of MRI phase imaging and processing for Quantitative Susceptibility Mapping (QSM). Zeitschrift für Medizinische Physik.





# NeuroImage

Volume 195, 15 July 2019, Pages 373-383



## DeepQSM - using deep learning to solve the dipole inversion for quantitative susceptibility mapping

Steffen Bollmann <sup>a</sup>  , Kasper Gade Bøtger Rasmussen <sup>b</sup>, Mads Kristensen <sup>b</sup>, Rasmus Guldhammer Blendal <sup>b</sup>, Lasse Riis Østergaard <sup>b</sup>, Maciej Plochanski <sup>b</sup>, Kieran O'Brien <sup>a, c</sup>, Christian Langkammer <sup>d</sup>, Andrew Janke <sup>a, 1</sup>, Markus Barth <sup>a, 1</sup>

Received 8 March 2018, Revised 3 March 2019, Accepted 26 March 2019, Available online 29 March 2019.



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Imaging  
Facility

 @sbollmann\_MRI



Create change

Slide 11

# GENERATE DATA AND TRAIN

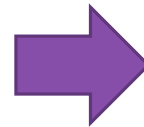
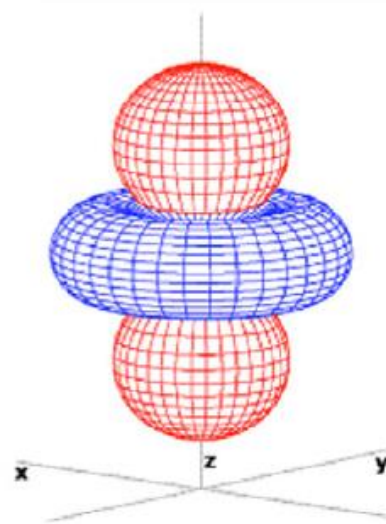
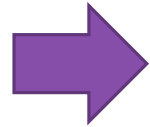
Simulated Magnetic Susceptibilities

Convolve with dipole Kernel

Magnetic Field Perturbation



(n=91600)



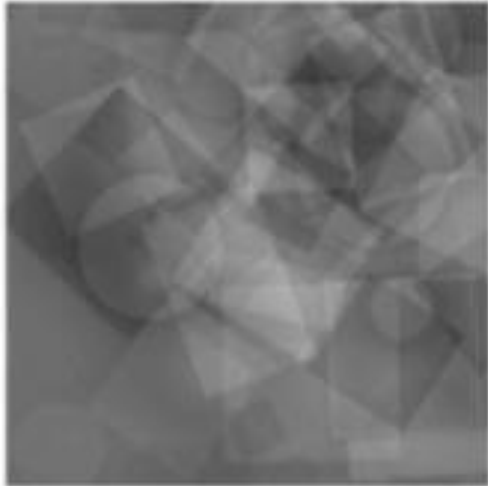
$$FT(d) = \frac{1}{3} - \frac{k_z^2}{k_x^2 + k_y^2 + k_z^2}$$

TRAIN

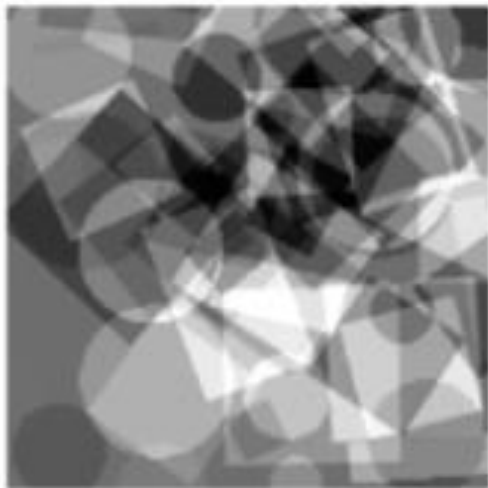


# SIMPLE SHAPES

Phase

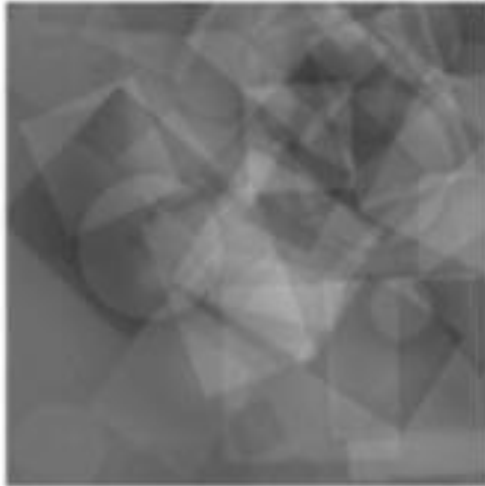


Simulation

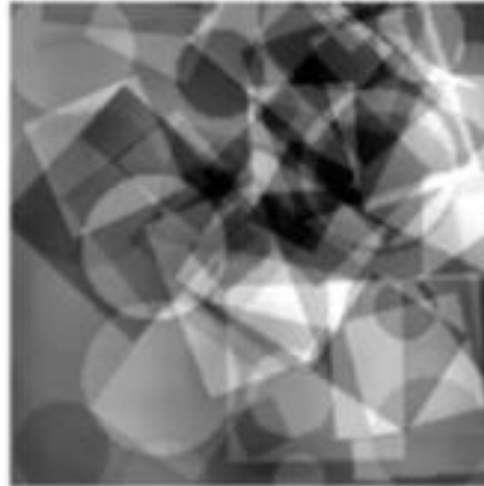


# SIMPLE SHAPES

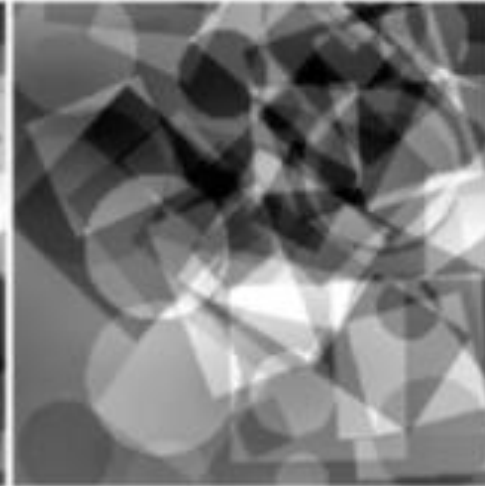
Phase



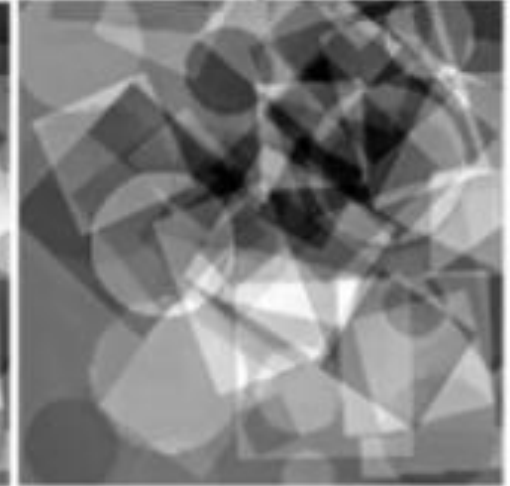
STI iLSQR



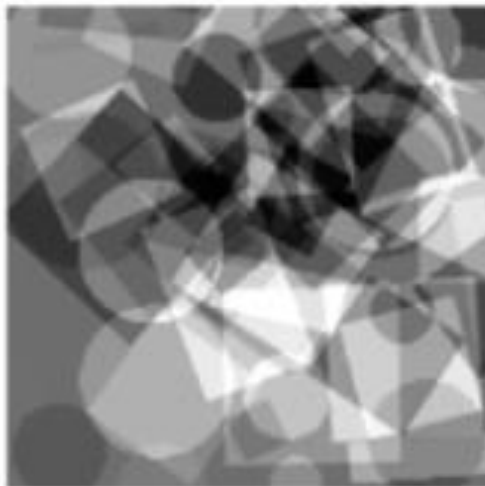
MEDI



DeepQSM

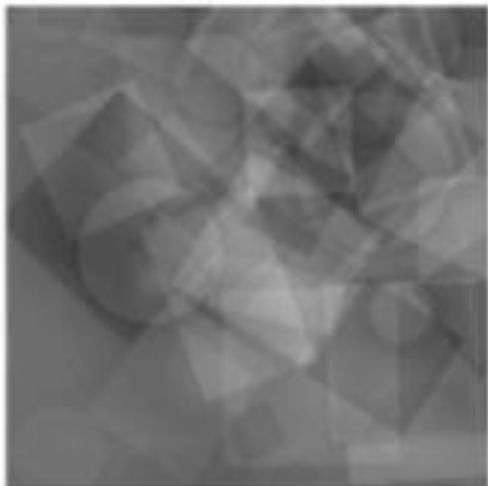


Simulation

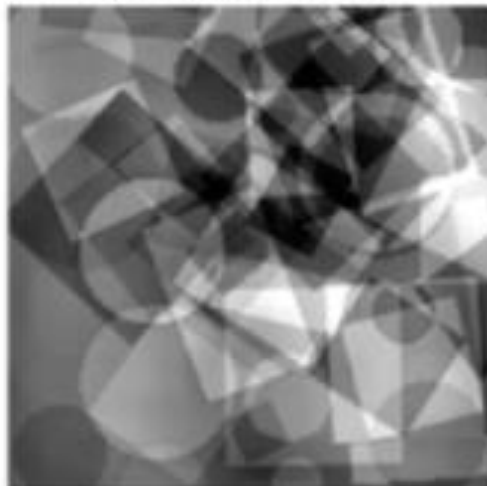


# SIMPLE SHAPES

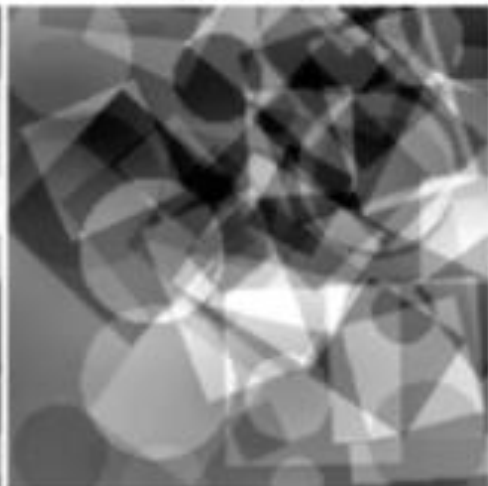
Phase



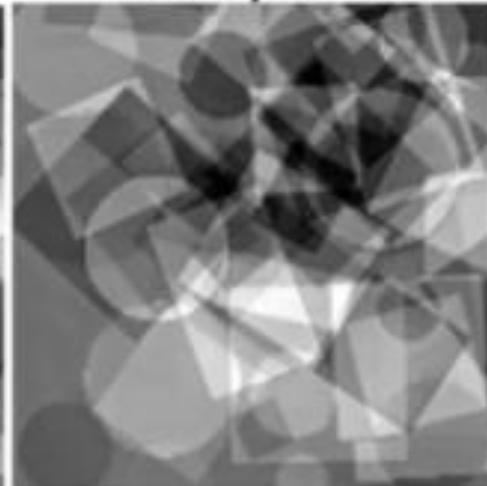
STI iLSQR



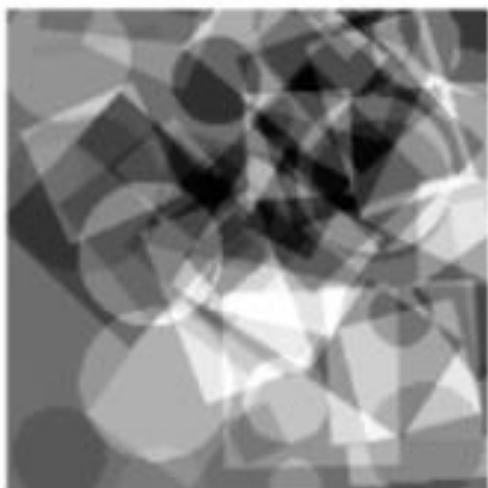
MEDI



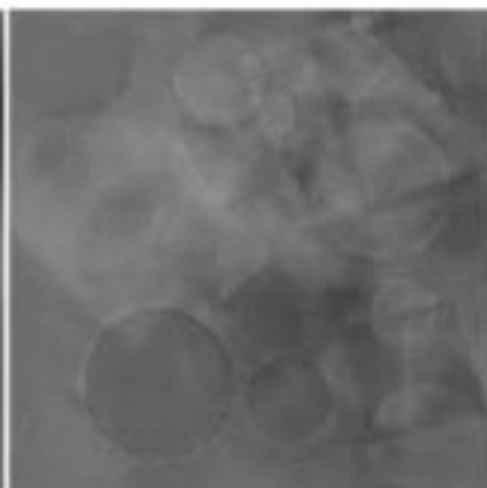
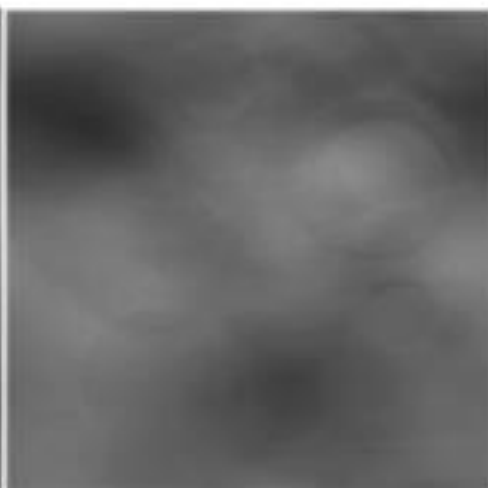
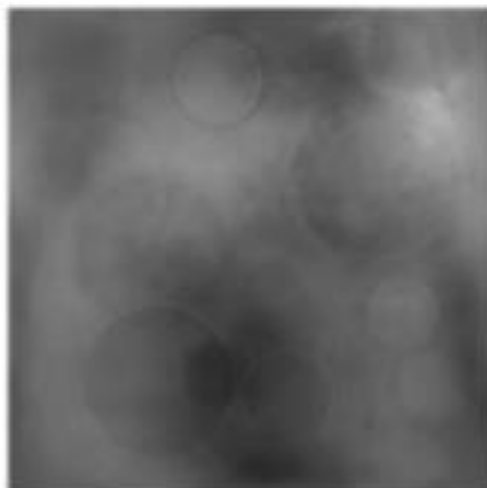
DeepQSM



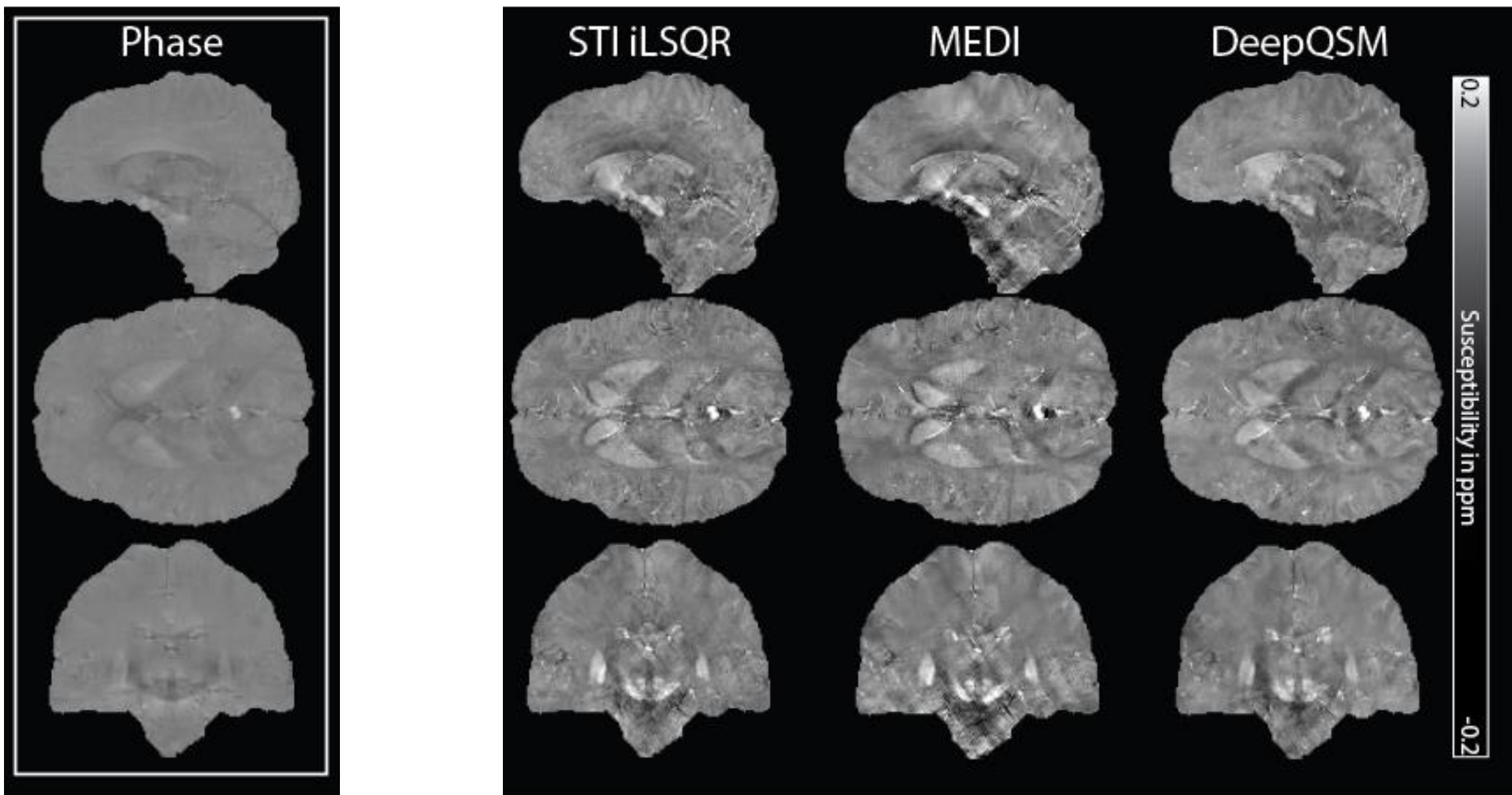
Simulation



Difference to Simulation

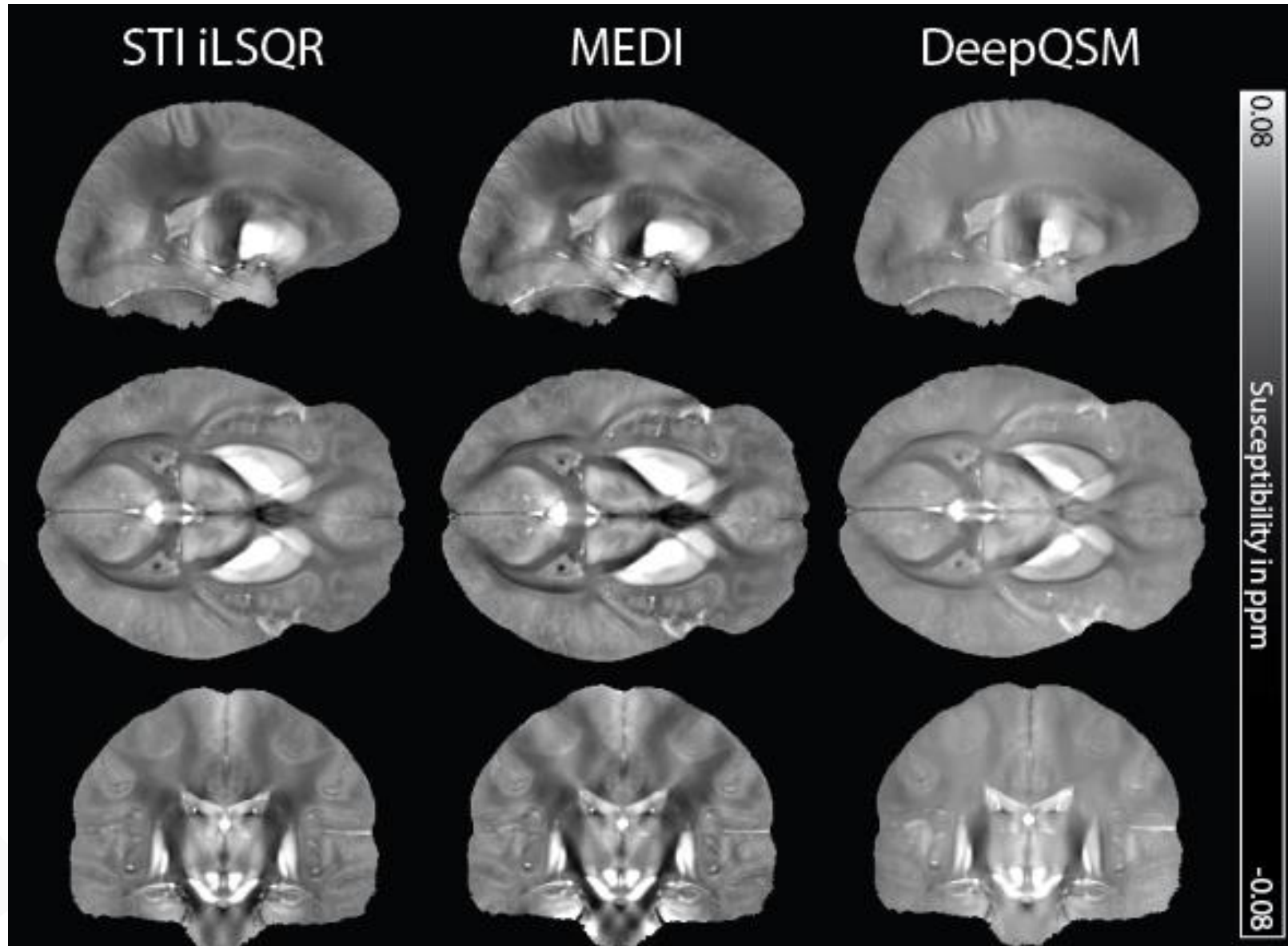


# IN VIVO BRAIN DATA





# GROUP RESULTS (N=27)



# BACKGROUND FIELD CORRECTION





Zeitschrift für Medizinische Physik

Volume 29, Issue 2, May 2019, Pages 139-149



Original Paper

## SHARQnet – Sophisticated harmonic artifact reduction in quantitative susceptibility mapping using a deep convolutional neural network

Steffen Bollmann <sup>a</sup>  , Matilde Holm Kristensen <sup>b</sup>, Morten Skaarup Larsen <sup>b</sup>, Mathias Vassard Olsen <sup>b</sup>, Mads Jozwiak Pedersen <sup>b</sup>, Lasse Riis Østergaard <sup>b</sup>, Kieran O'Brien <sup>a, c</sup>, Christian Langkammer <sup>d</sup>, Amir Fazlollahi <sup>e</sup>, Markus Barth <sup>a</sup>

# TRAINING DATA

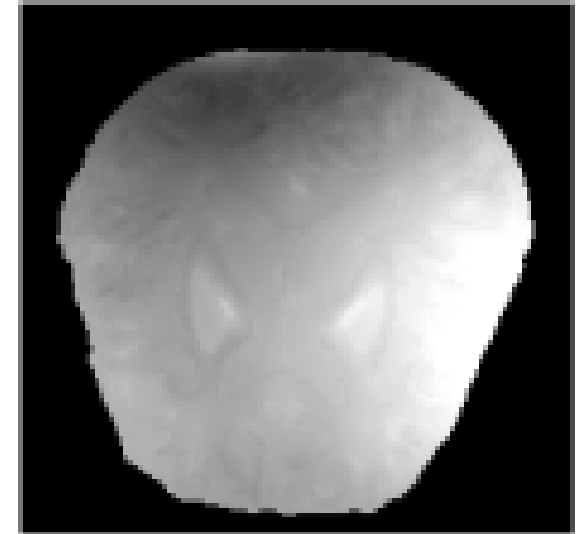
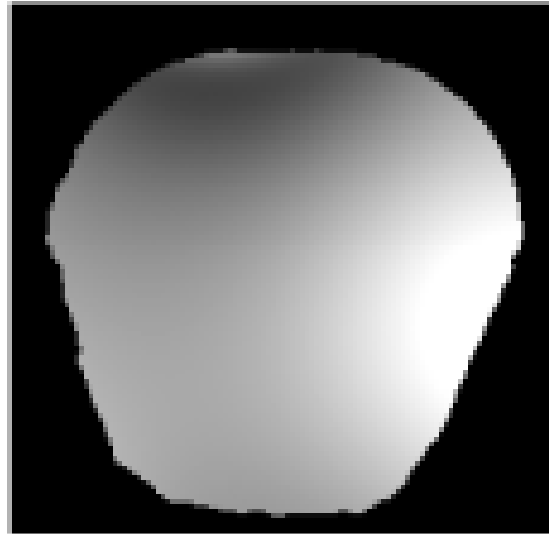
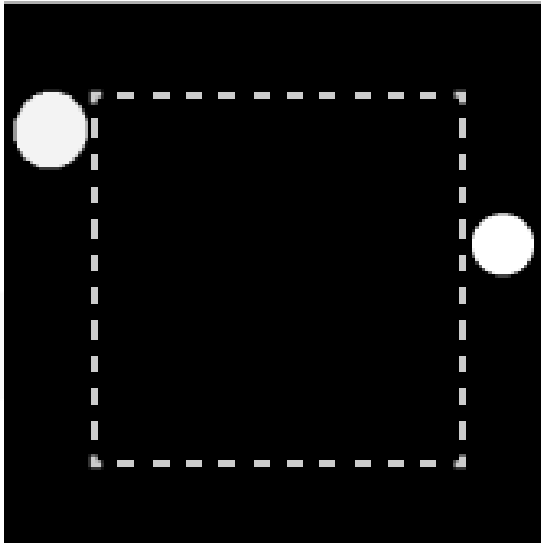
Simulated  
background sources



dipole convolution +  
brain mask



overlaid on synthetic  
brain



# TRAINING DATA

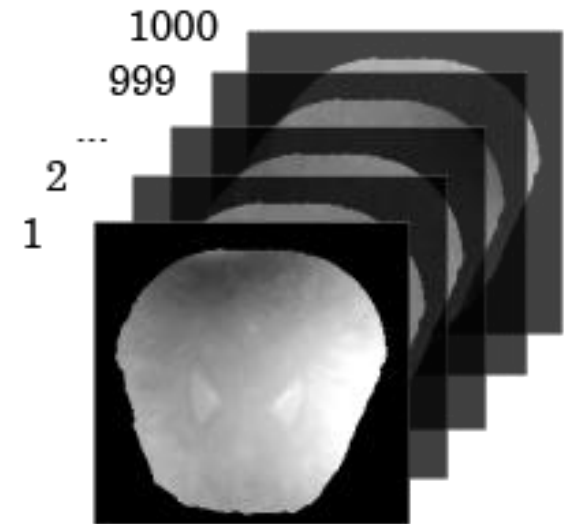
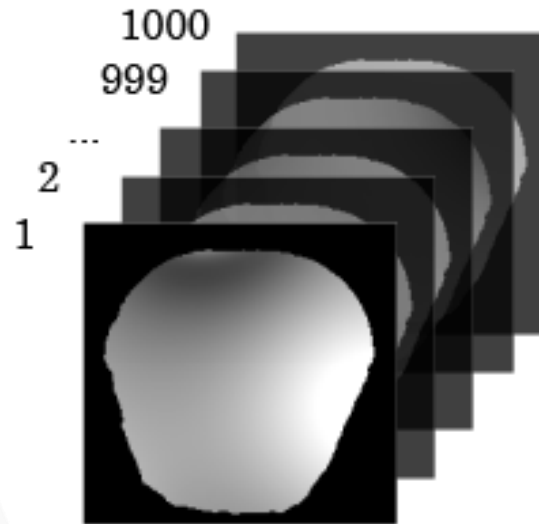
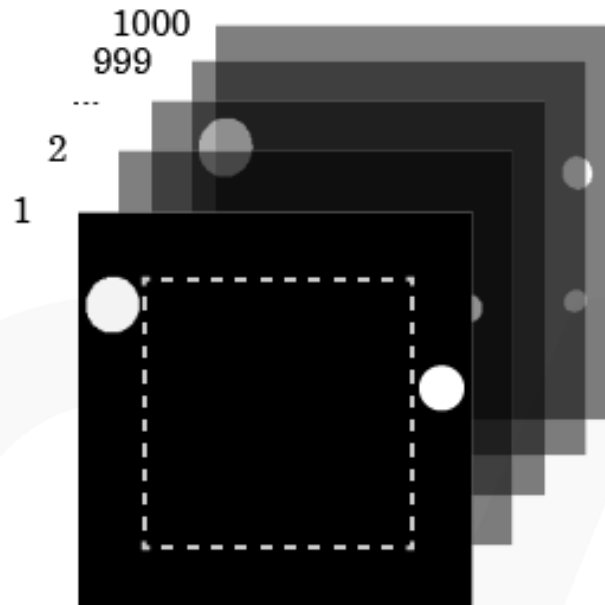
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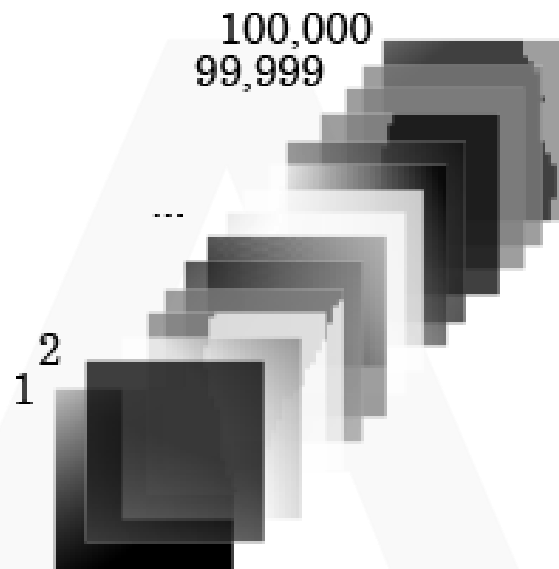
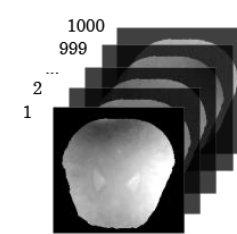
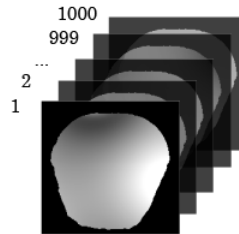
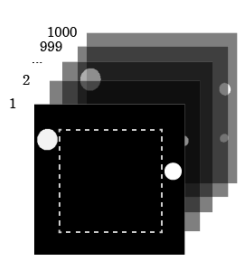


# TRAINING DATA

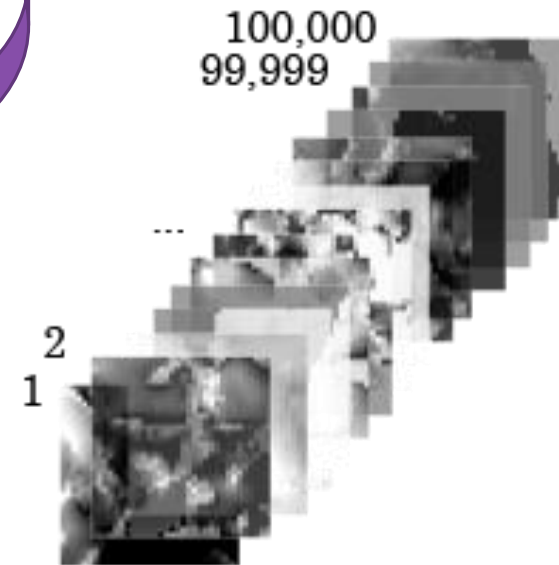
Simulated  
background sources

dipole convolution +  
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brain

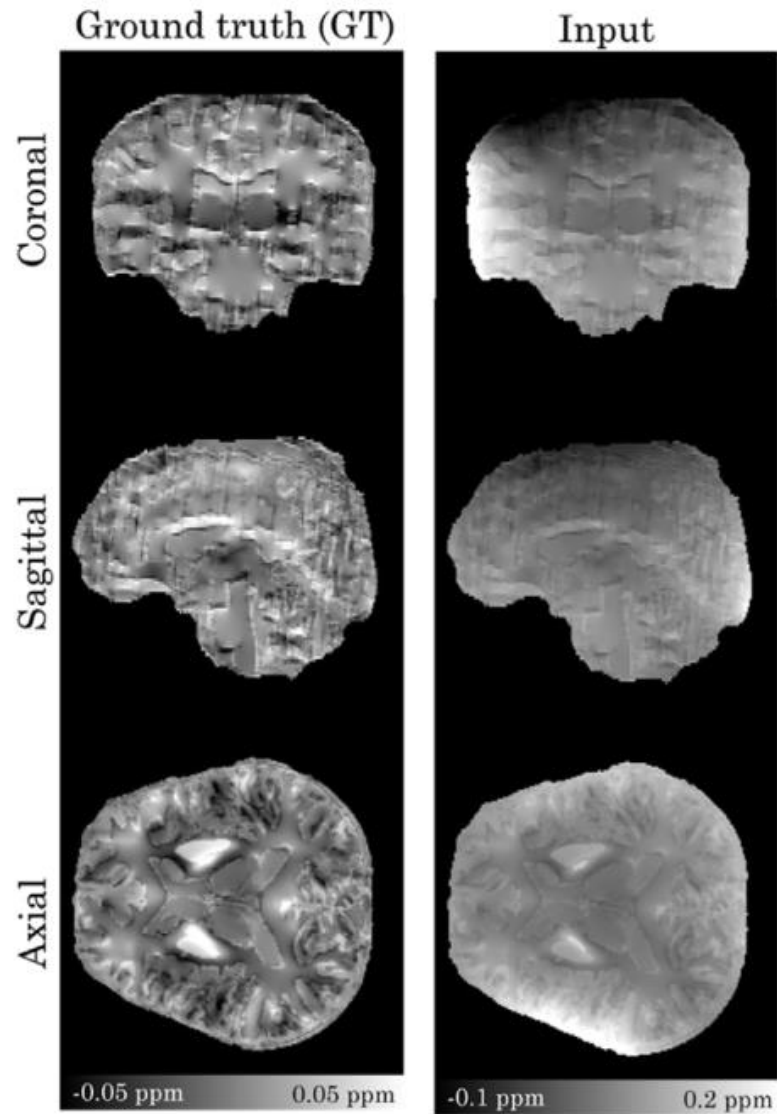


1000  
crops

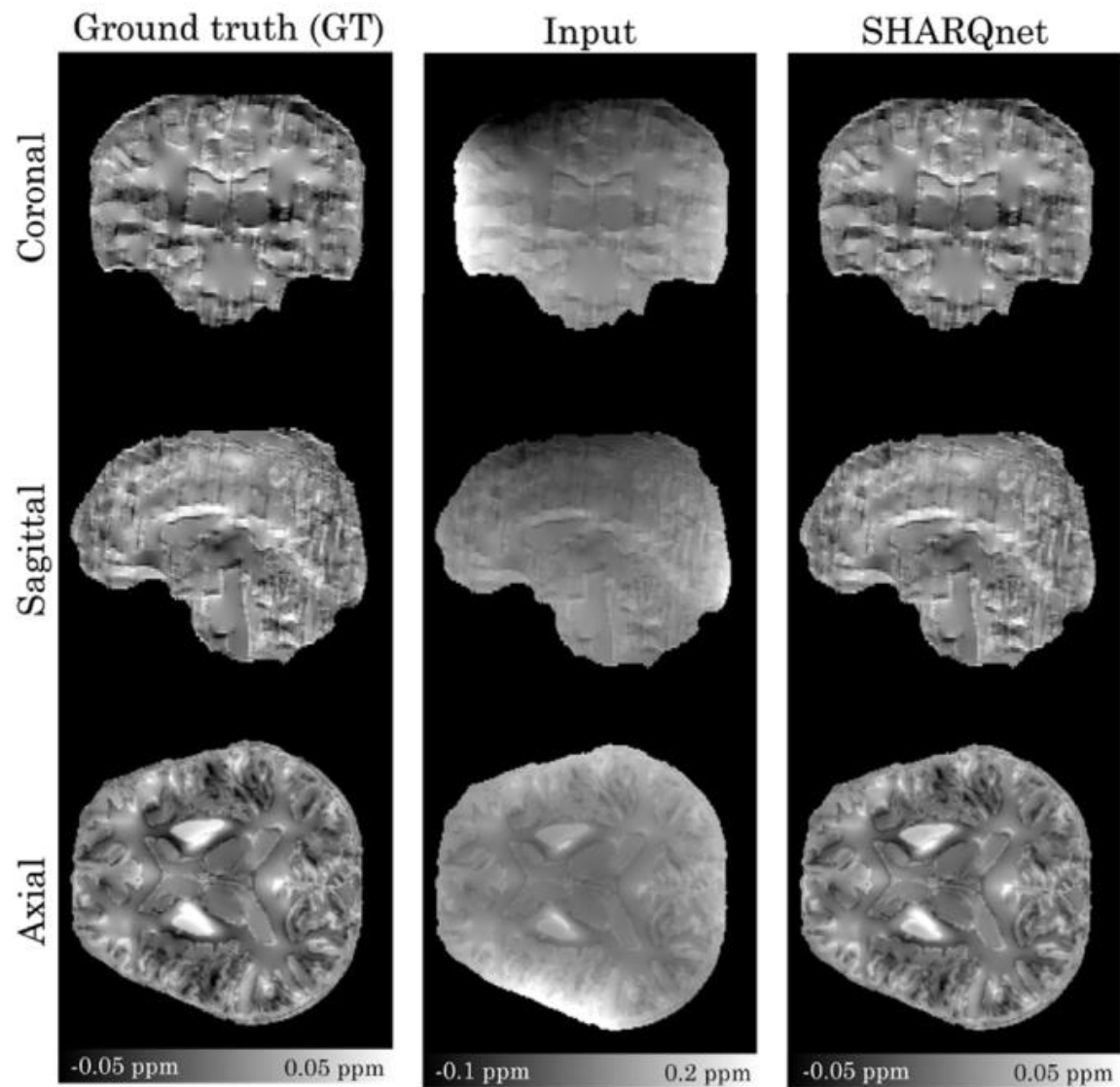


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crops

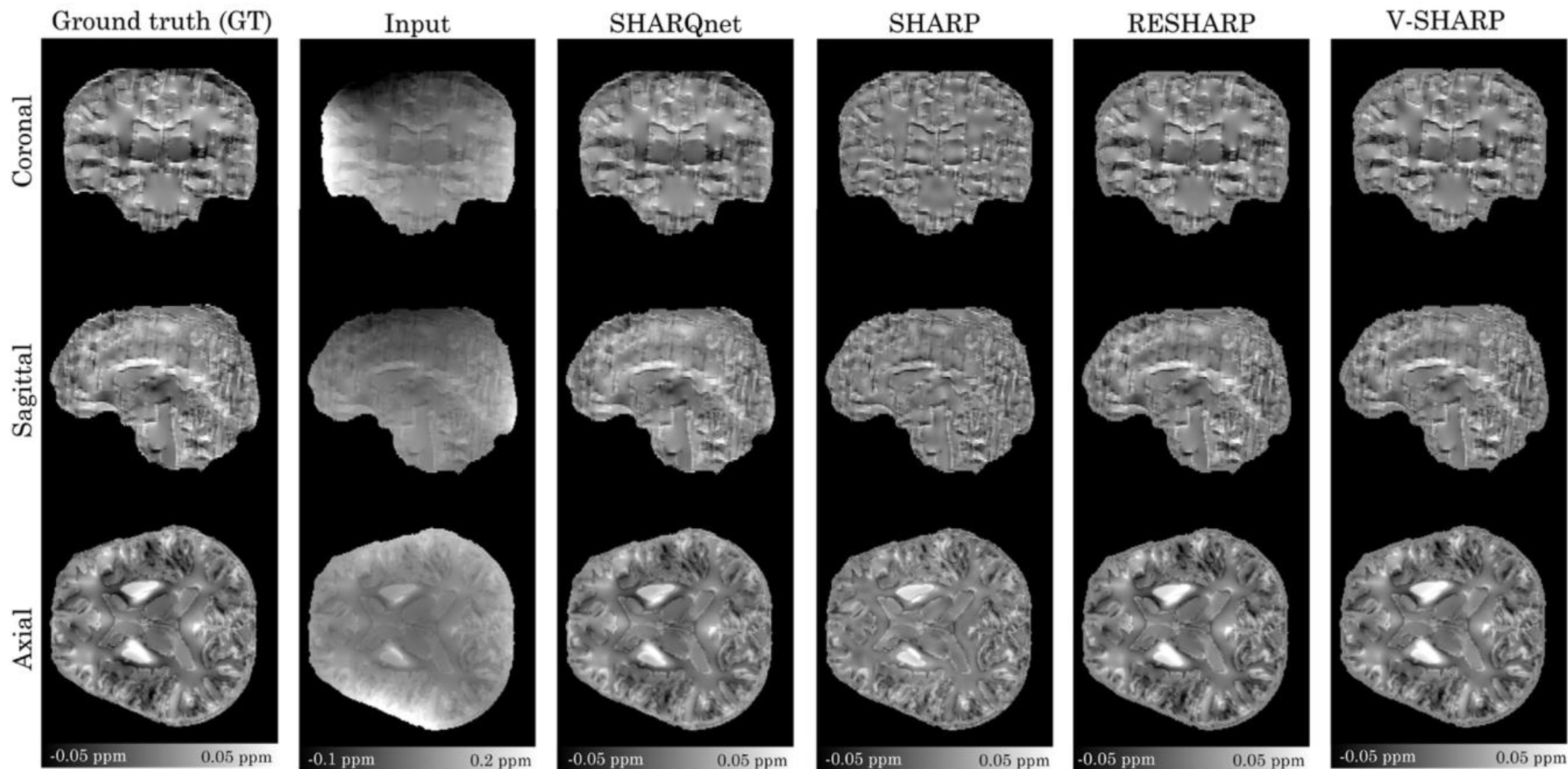
# SIMULATED BACKGROUND FIELDS



# SIMULATED BACKGROUND FIELDS

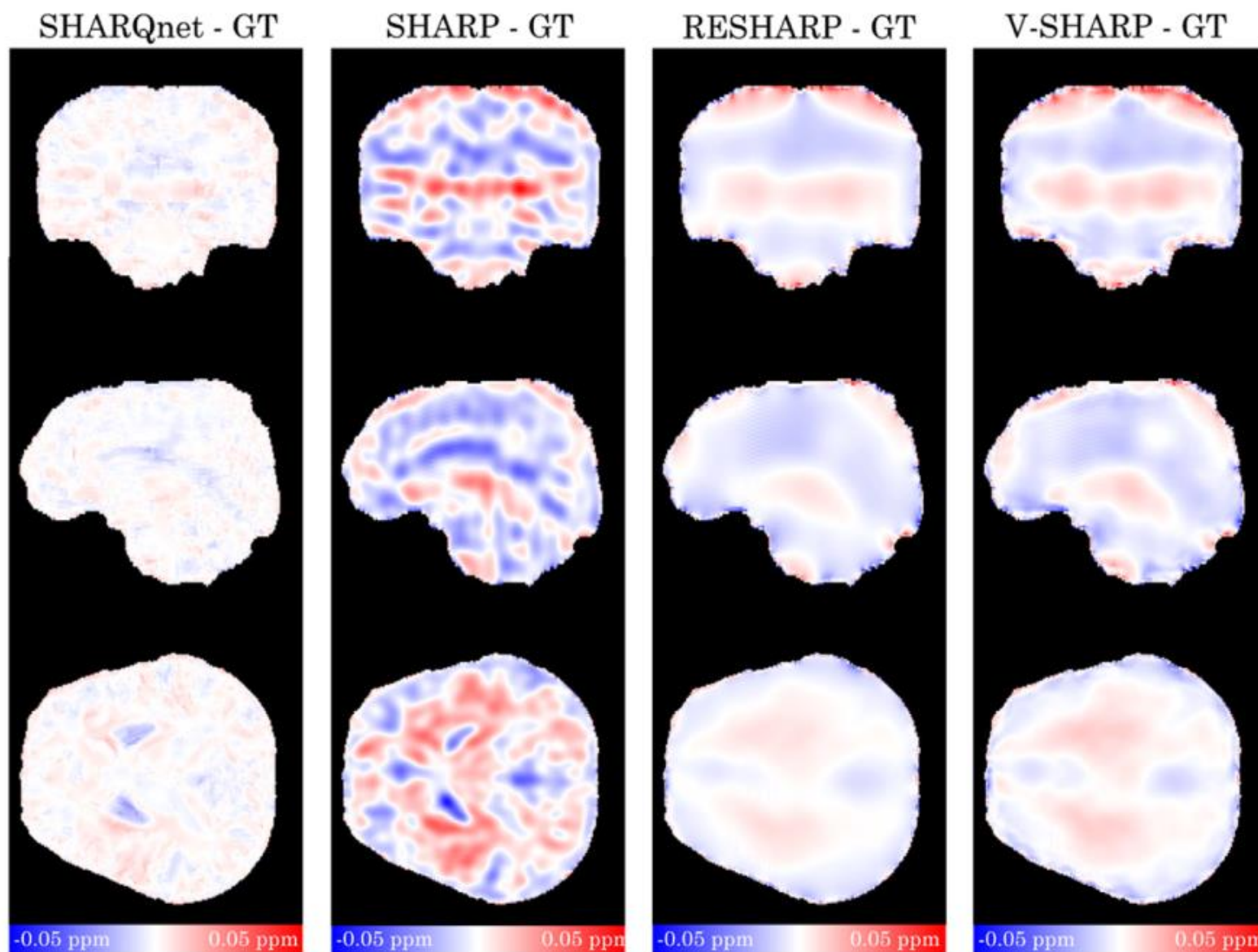


# SIMULATED BACKGROUND FIELDS





# SIMULATED BACKGROUND FIELDS



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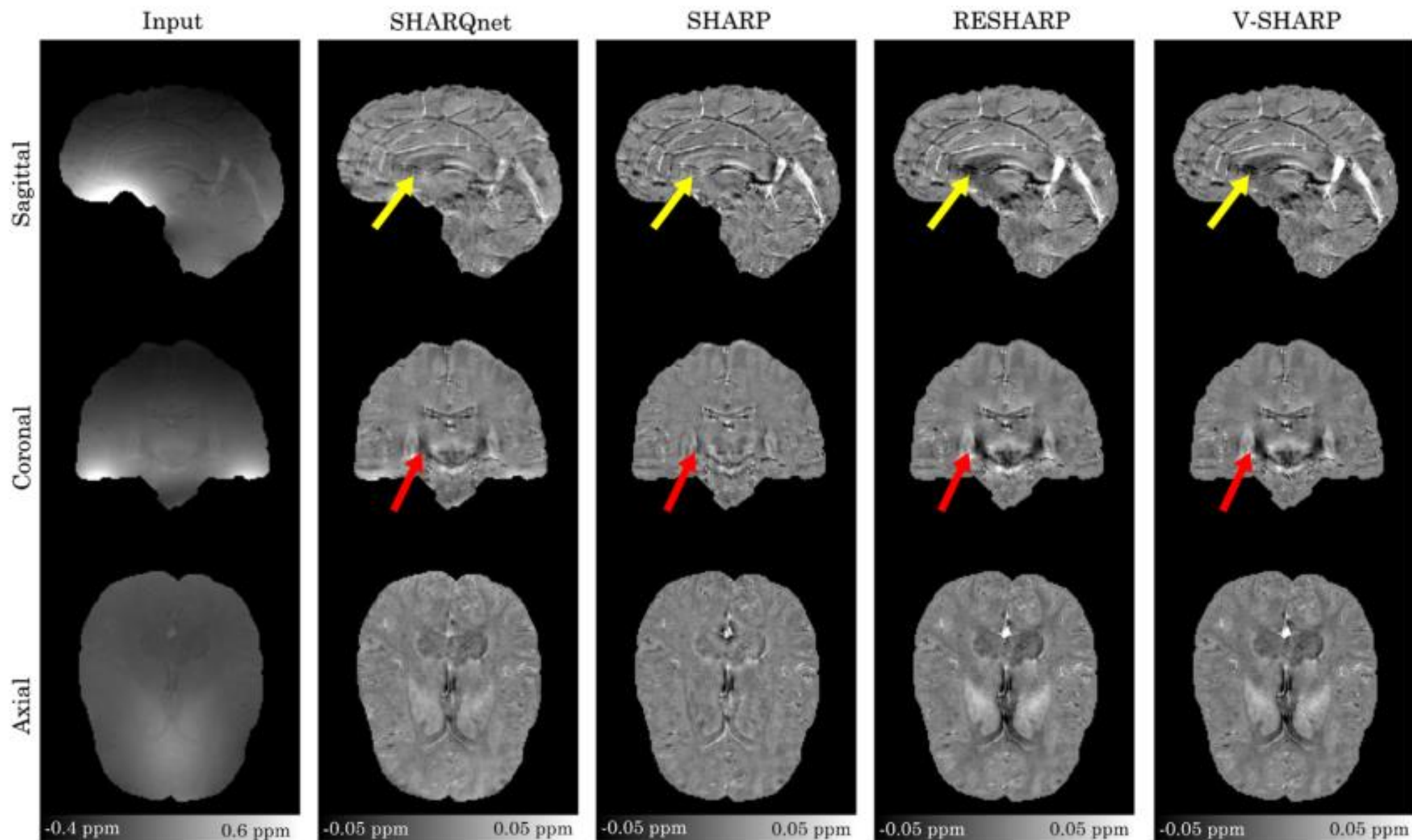


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OF QUEENSLAND  
AUSTRALIA

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# IN VIVO BRAIN DATA





# DEMO

<http://bit.ly/qsmohbm>



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AUSTRALIA

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Slide 27



# Thank you



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[steffen.bollmann@cai.uq.edu.au](mailto:steffen.bollmann@cai.uq.edu.au)

