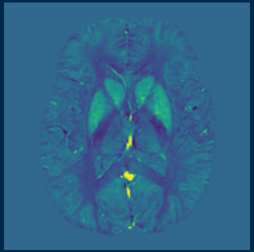
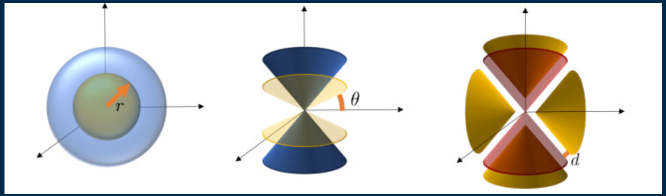
Klinikum rechts der Isar
Technische Universität München

322 One-Dimensional k-Space Metrics on Cone Surfaces for Quantitative Susceptibility Mapping

Maximilian N. Diefenbach[1], Christof Böhm[1], Jakob Meineke[2], Chunlei Liu[3], Dimitrios C. Karampinos[1]





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[2]Philips Research, Hamburg, Germany
[3]Department of Electrical Engineering and Computer Sciences, & Helen Wills Neuroscience Institute, University of California, Berkeley, Berkeley, CA, United States

Declaration of Financial Interests or Relationships

Speaker Name: Maximilian N. Diefenbach

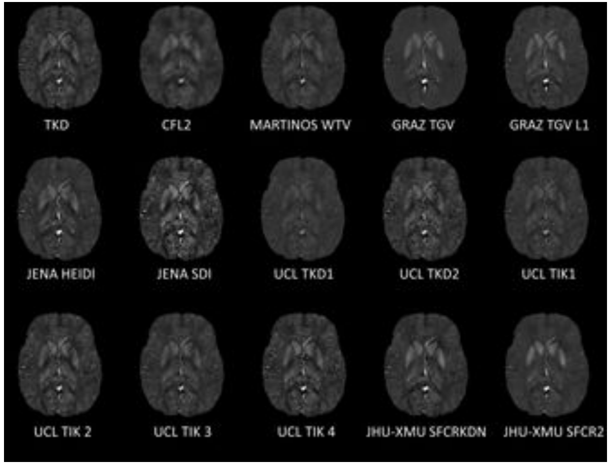
I have the following financial interest or relationship to disclose with regard to the subject matter of this presentation:

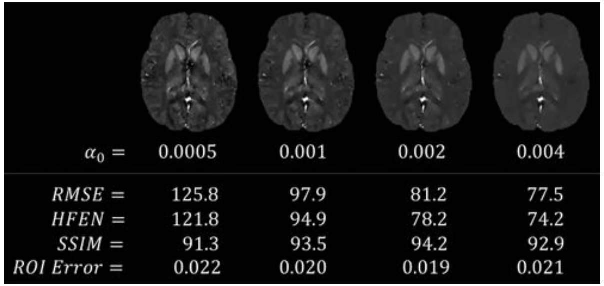
Company Name: Philips Healthcare
Type of Relationship: Grant Support

Motivation I

How to compare QSM reconstruction results?

How to choose hyper parameters?





Quantitative Susceptibility Mapping:
Report from the 2016 reconstruction challenge,
MRM, 79(3), 1661–1673 (2017).

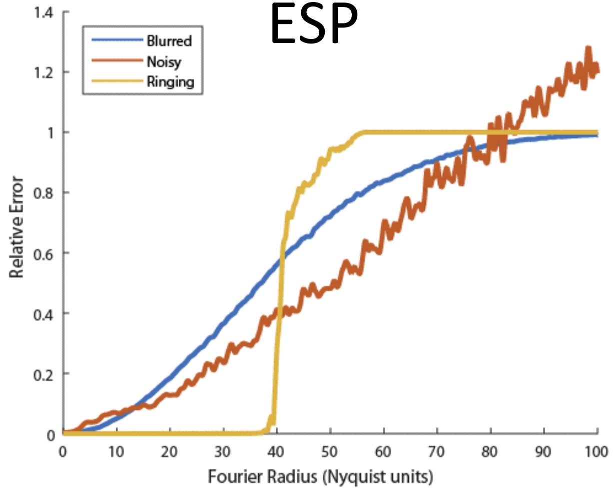
Motivation II

ISMRM 2018 Paris, #249

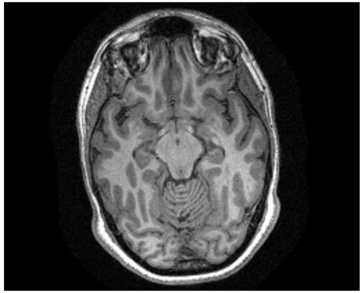
Kim, T. H., & Haldar, J. P.

"Assessing MR image reconstruction quality using the Fourier radial ***error spectrum plot [(ESP)]****"*

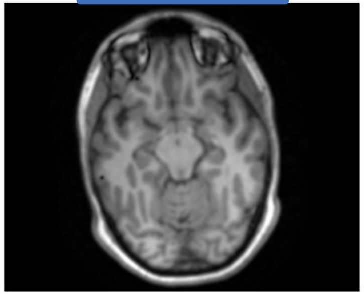
ESP



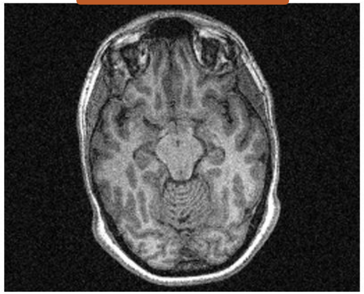
Gold Standard



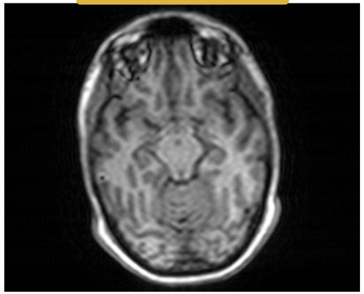
Blurred



Noisy



Ringing



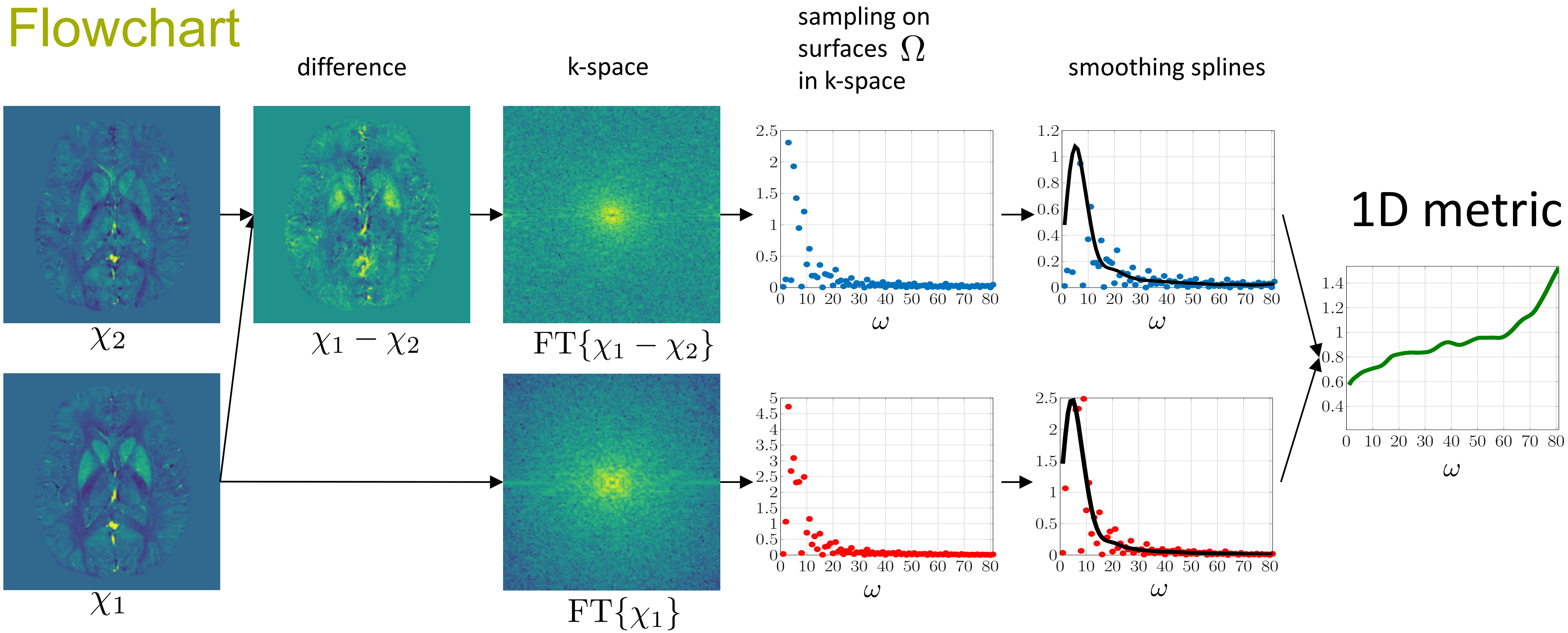
Purpose

to ...

1. Apply the **Error Spectrum Plot** concept in **QSM**

2. Explore **different parametrizations** suited to the intrinsic k-space geometries in QSM

Flowchart



$$E_\Omega(\omega(\vec{k}), \chi_1, \chi_2) = \sqrt{\frac{S(||\mathrm{FT}\{\chi_1(\omega) - \chi_2(\omega)\}||_2)}{S(||\mathrm{FT}\{\chi_1(\omega))\}||_2)}}$$

$$E_\Omega(\omega(\vec{k}), \chi_1, \chi_2) = \sqrt{\frac{S(||\mathrm{FT}\{\chi_1(\omega) - \chi_2(\omega)\}||_2)}{S(||\mathrm{FT}\{\chi_1(\omega))\}||_2)}}, \qquad \omega \in \Omega$$

Parametrizations

$\vec{B}_0$

Recon challenge data

- tissue field after background field removal: **phs_tissue**
- reference: **chi_33**

Baseline reconstruction:

$$b = d * \chi \xrightarrow{\text{FFT}} B = DX$$

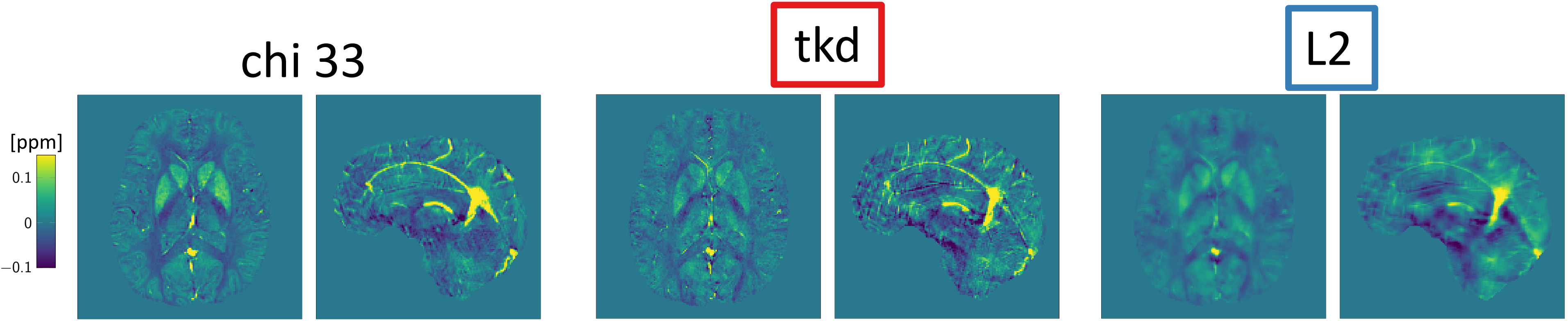
- **tkd** "Truncated k-space division" Shmueli et al., MRM, 62(6), 1510–1522 (2009). doi: 10.1002/mrm.22135

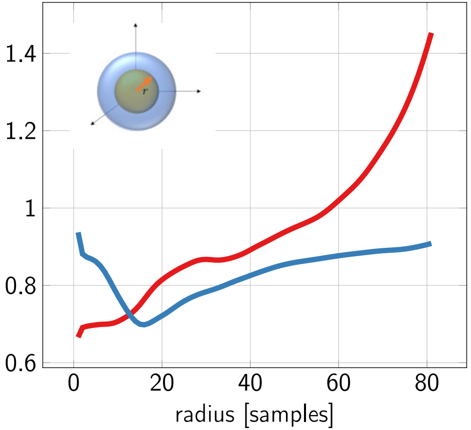
$$X = B/D' \qquad D' = \operatorname{sgn}(D(k))\ \max(|D(k)|, \tau)$$

- **L2** "close form L2 regularized solution" Bilgic et al., JMRI 40(1), 181–191 (2013). doi: 10.1002/jmri.24365

$$X = B/D'' \qquad D'' = (D^2(k) + \lambda k^2)/D(k)$$

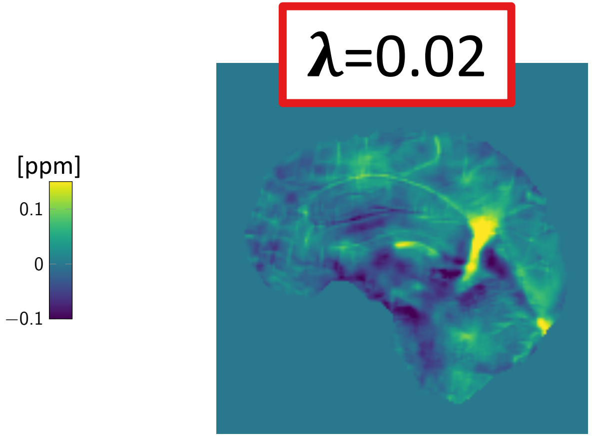
Comparison of QSM reconstruction results

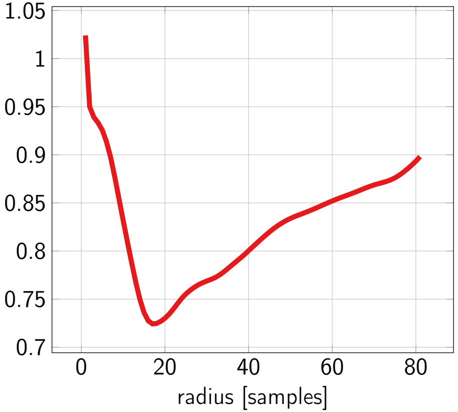


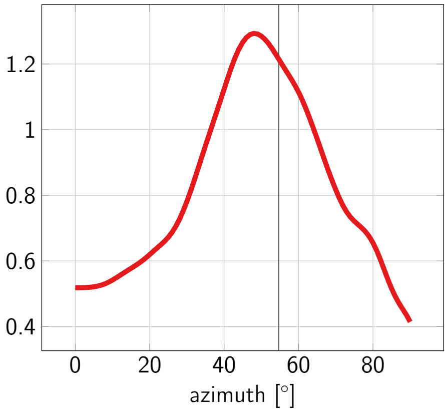


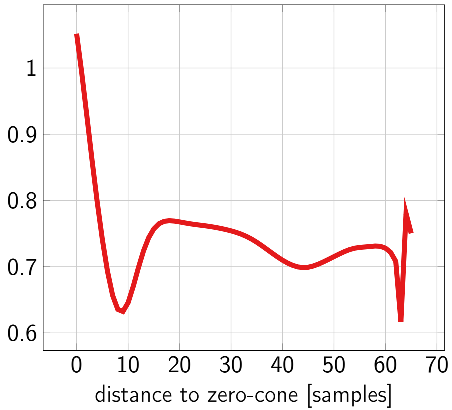
	rmse	hfen	ssim
tkd	86.50	81.97	0.77
L2	81.23	75.49	0.81

Selection of hyper parameters: L2 regularization parameter λ



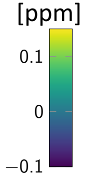


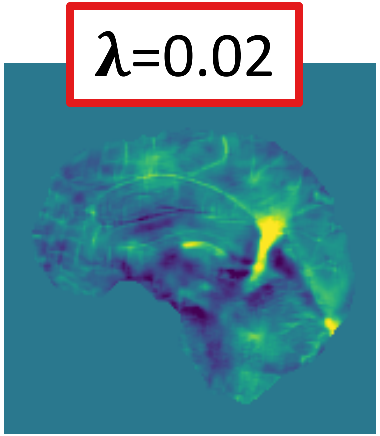


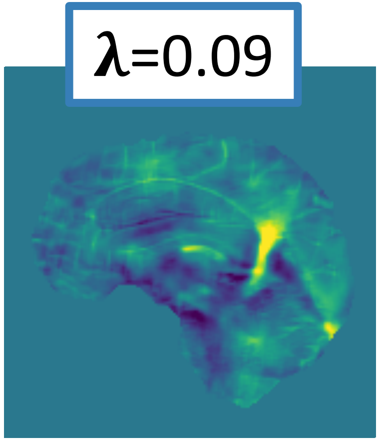


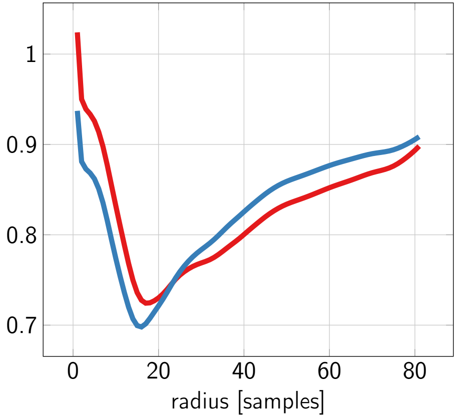
λ	rmse	hfen	ssim
0.02	83.54	76.26	0.81

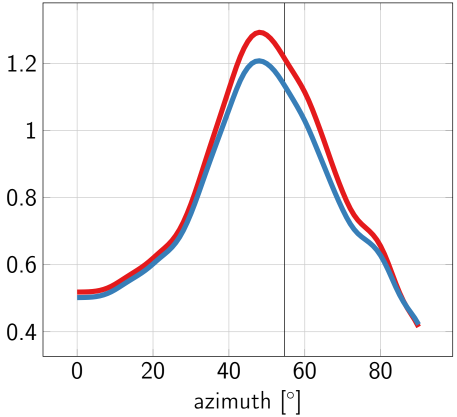
Selection of hyper parameters: L2 regularization parameter λ

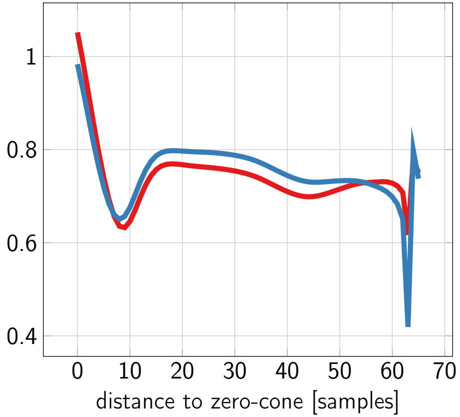






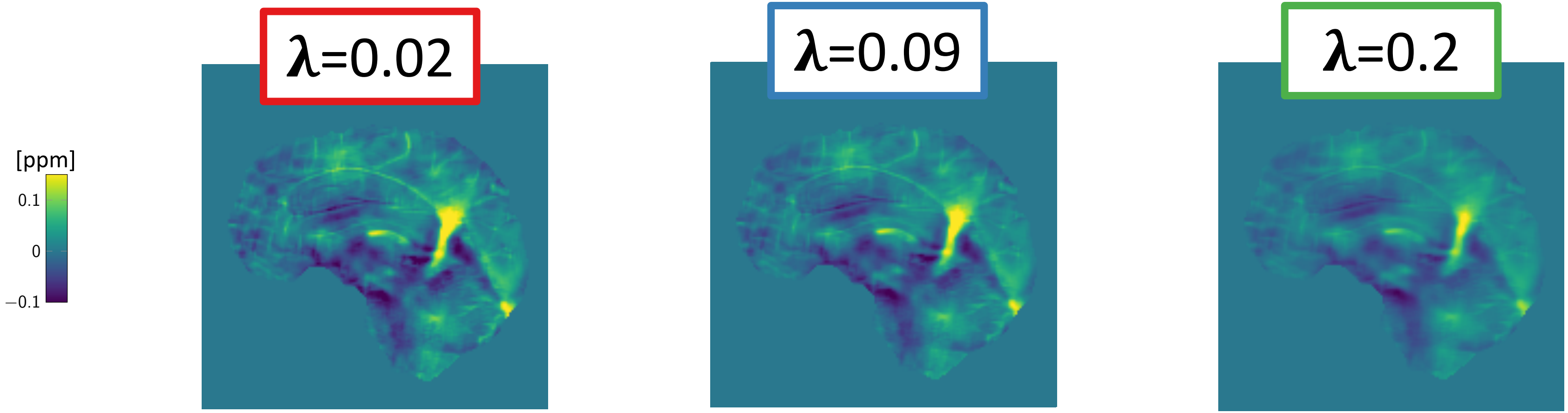


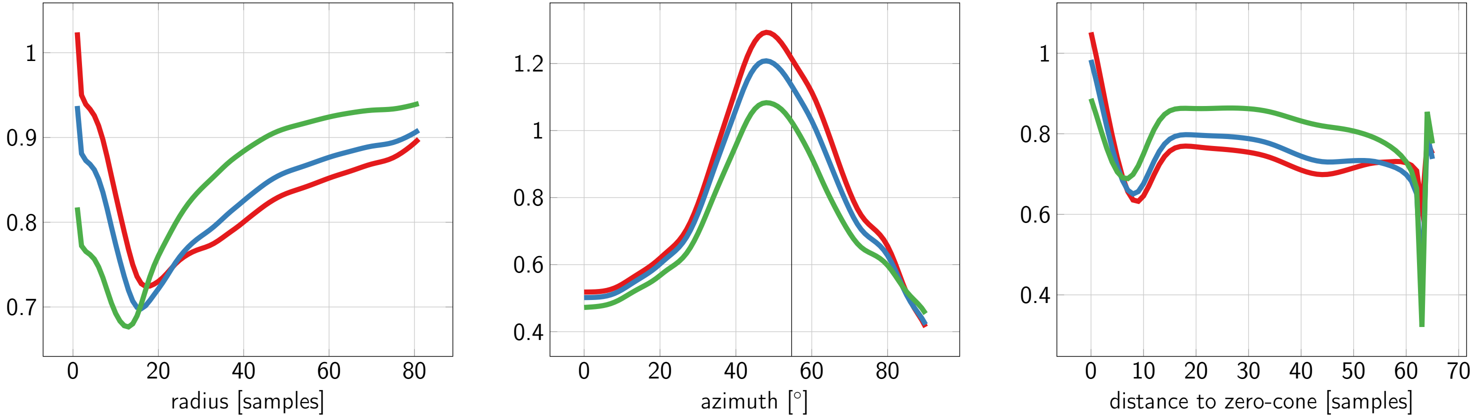




λ	rmse	hfen	ssim
0.02	83.54	76.26	0.81
0.09	81.23	75.49	0.81

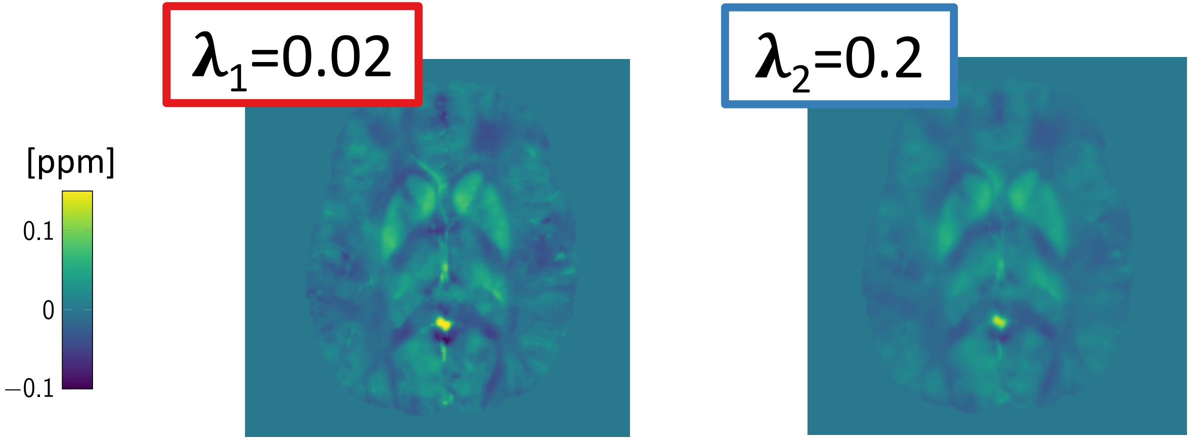
Selection of hyper parameters: L2 regularization parameter λ

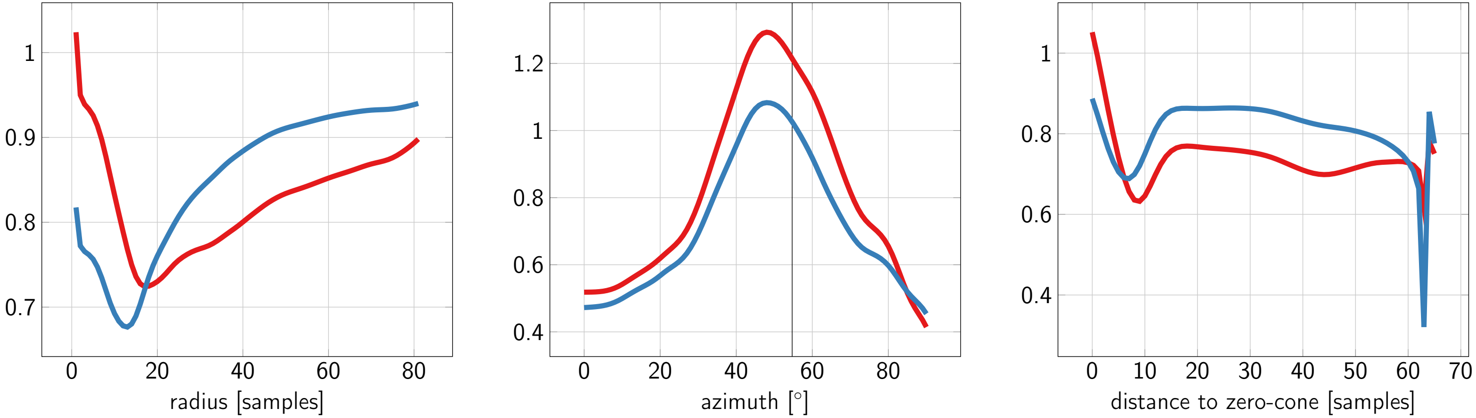




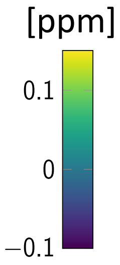
λ	rmse	hfen	ssim
0.02	83.54	76.26	0.81
0.09	81.23	75.49	0.81
0.2	**79.66**	78.20	0.79

Fusion of QSM maps: L2(λ_1) ⇔ L2(λ_2)

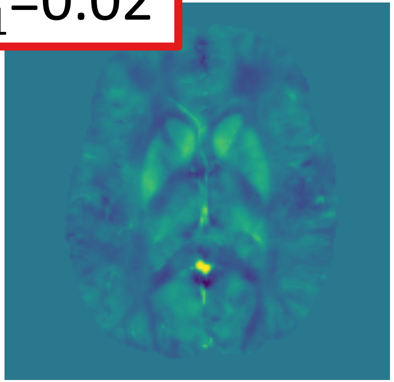




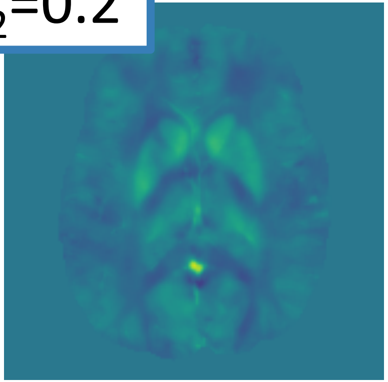
Fusion of QSM maps: L2(λ_1) ⇔ L2(λ_2)



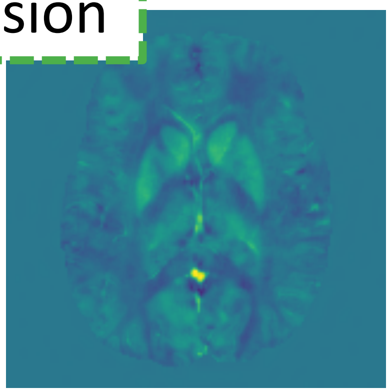
λ_1=0.02

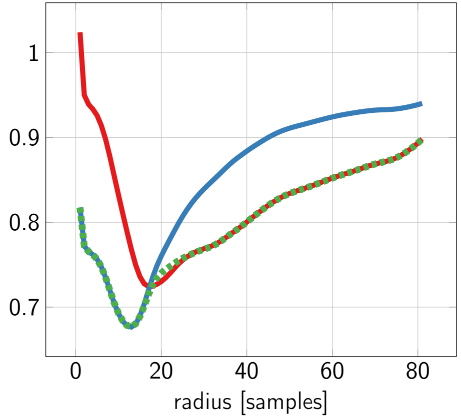


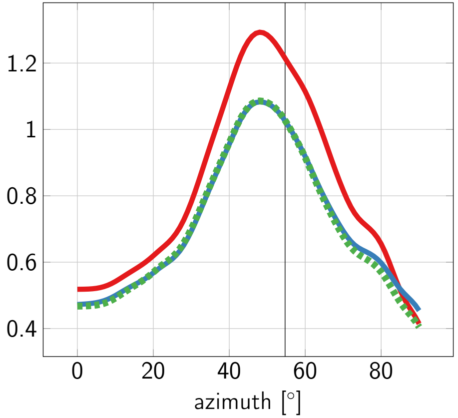
λ_2=0.2

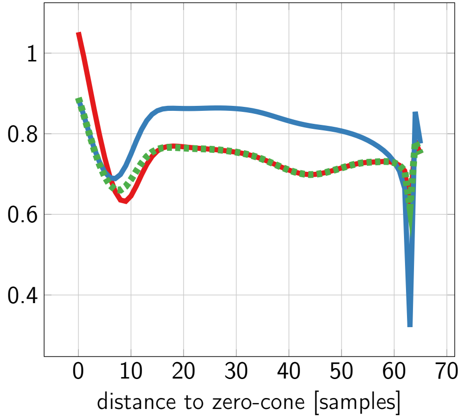


fusion



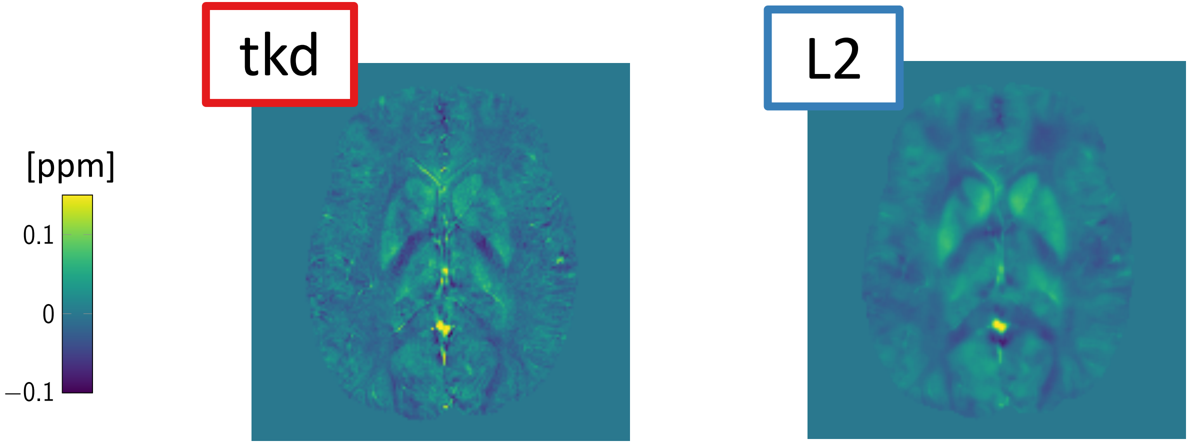


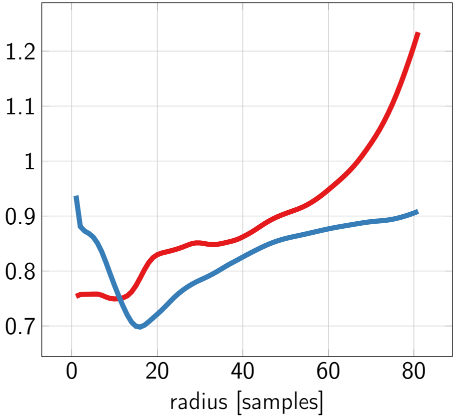


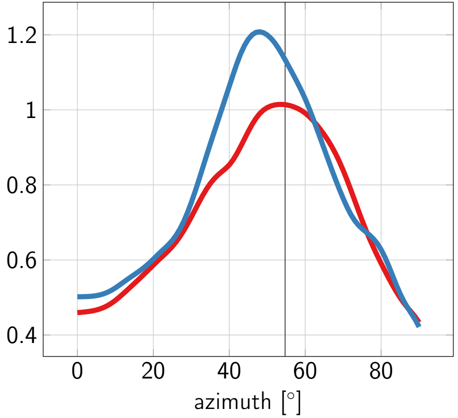


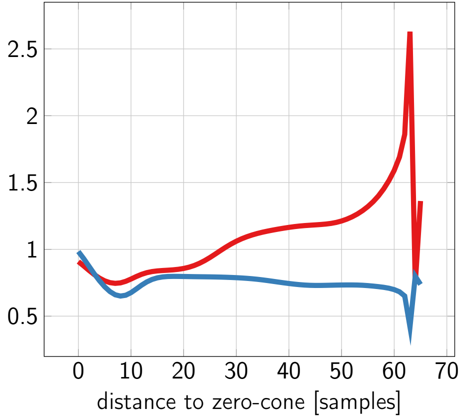
ssim drops (?)

Fusion of QSM maps: tkd ⇔ L2

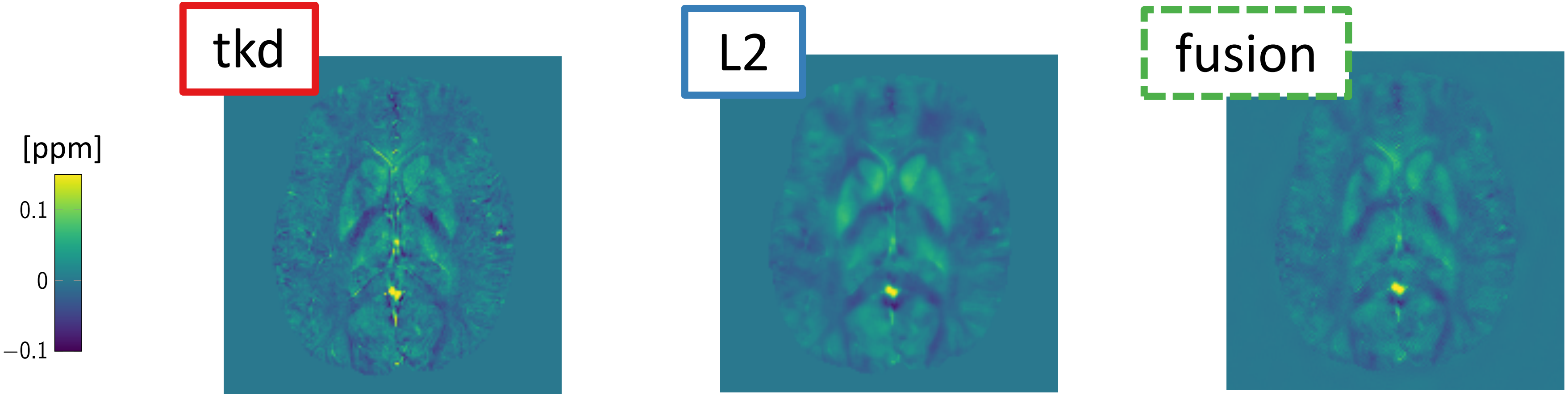


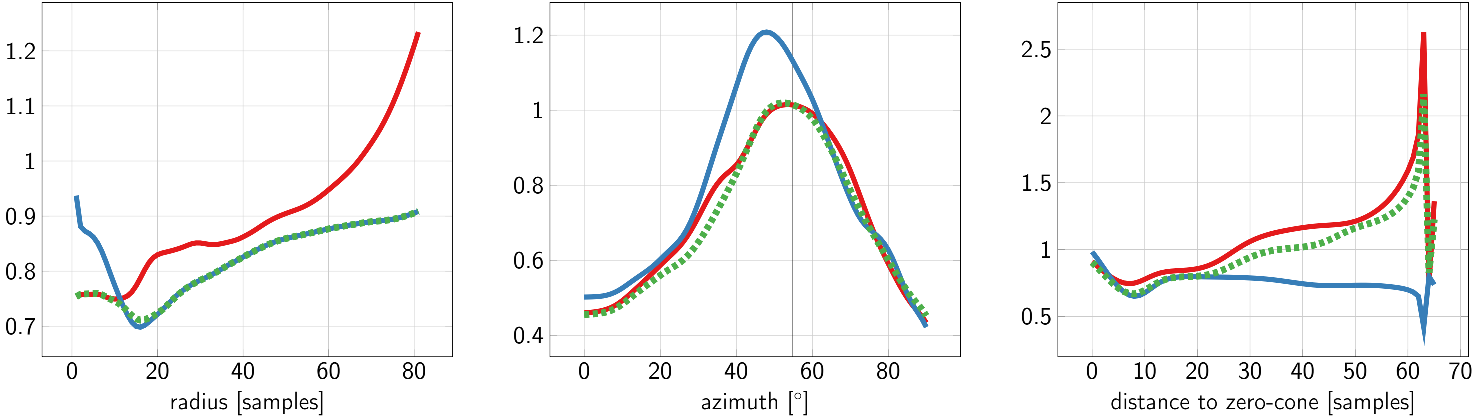






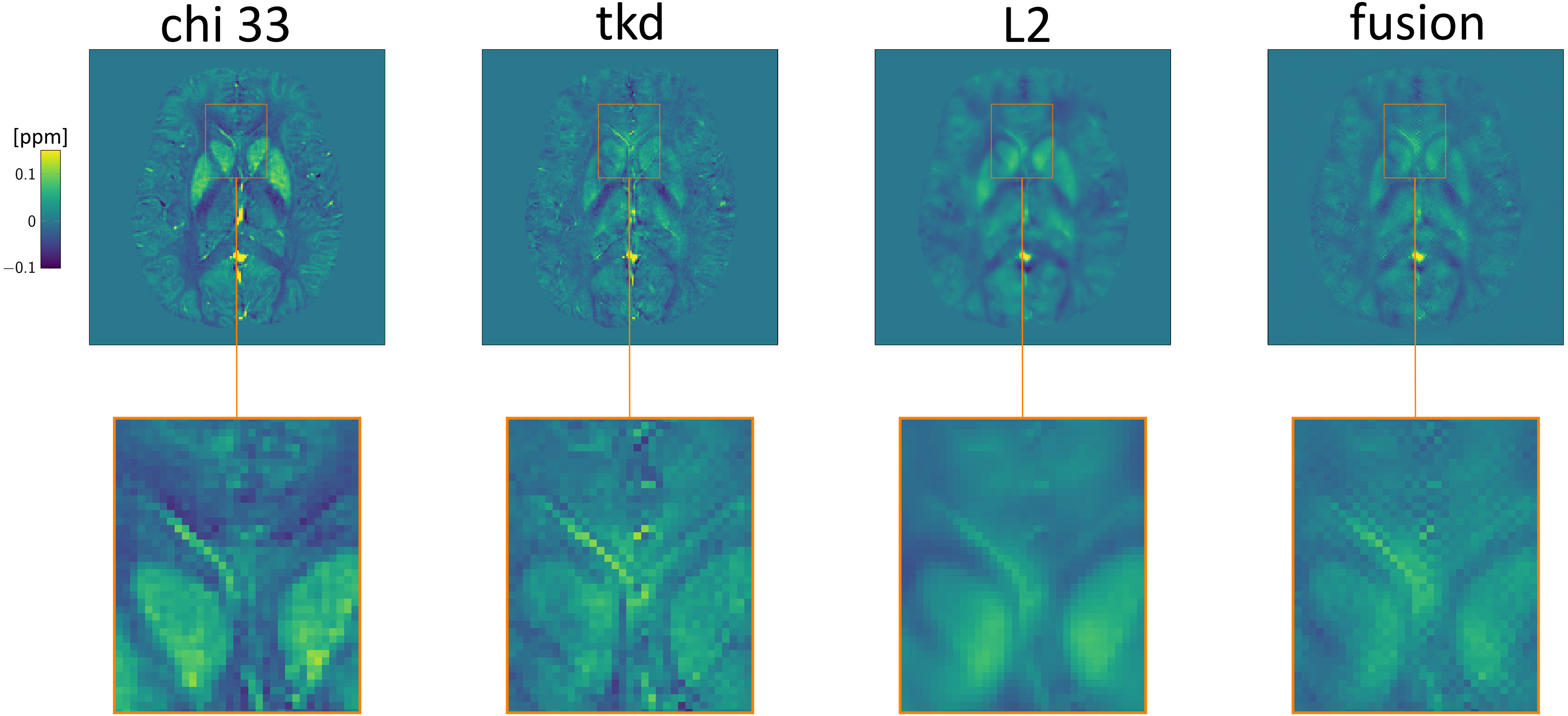
Fusion of QSM maps: tkd ⇔ L2



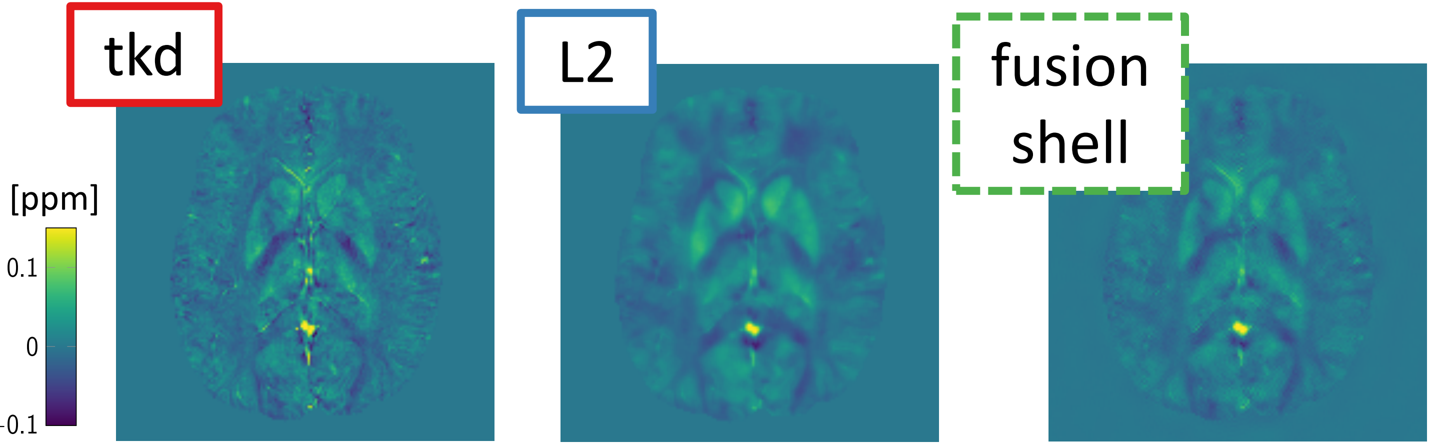


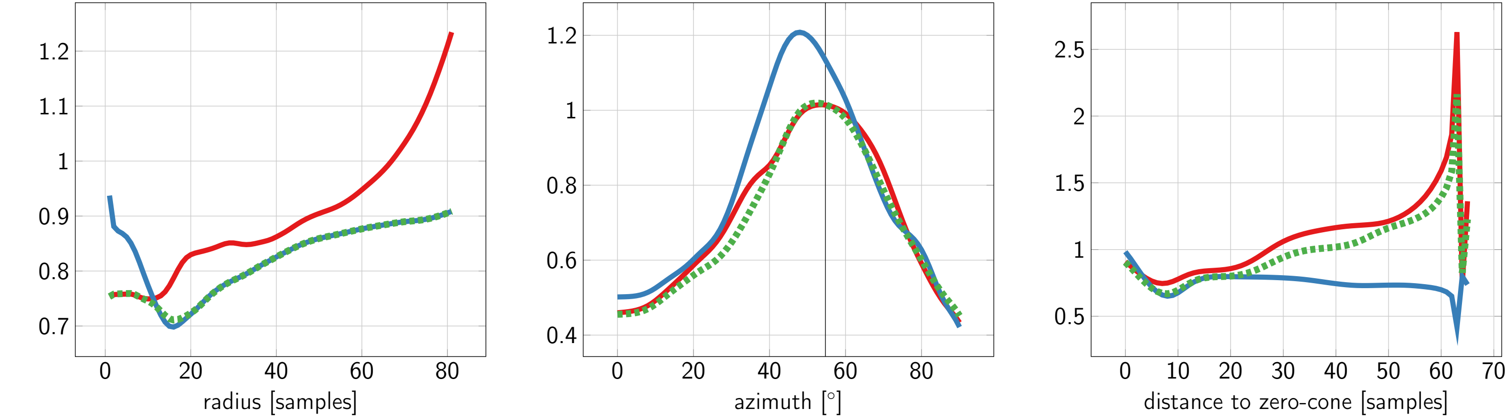
	rmse	hfen	ssim
tkd	84.52	82.28	0.79
L2	81.23	75.49	0.81
fusion	**79.97**	**75.42**	0.15

Fusion of QSM maps: tkd ⇔ L2



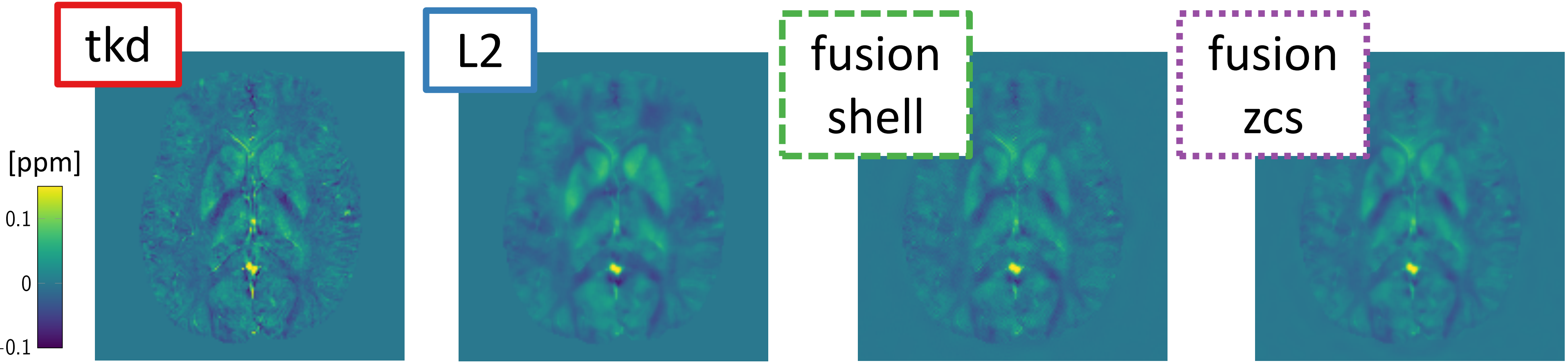
Fusion of QSM maps: tkd ⇔ L2, cone surfaces!

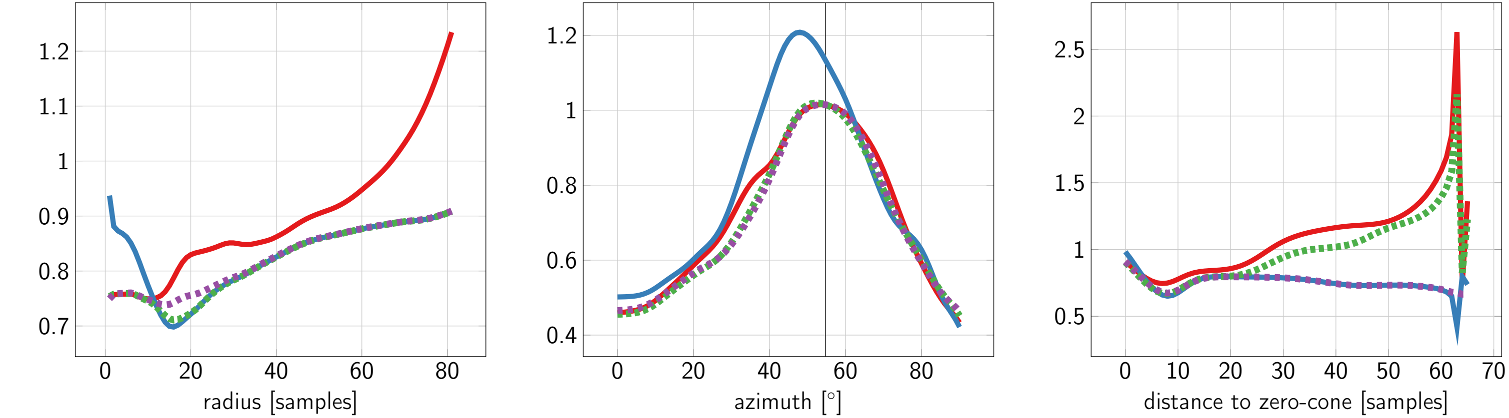




	rmse	hfen	ssim
tkd	84.52	82.28	0.79
L2	81.23	75.49	0.81
fusion shell	79.97	75.42	0.15

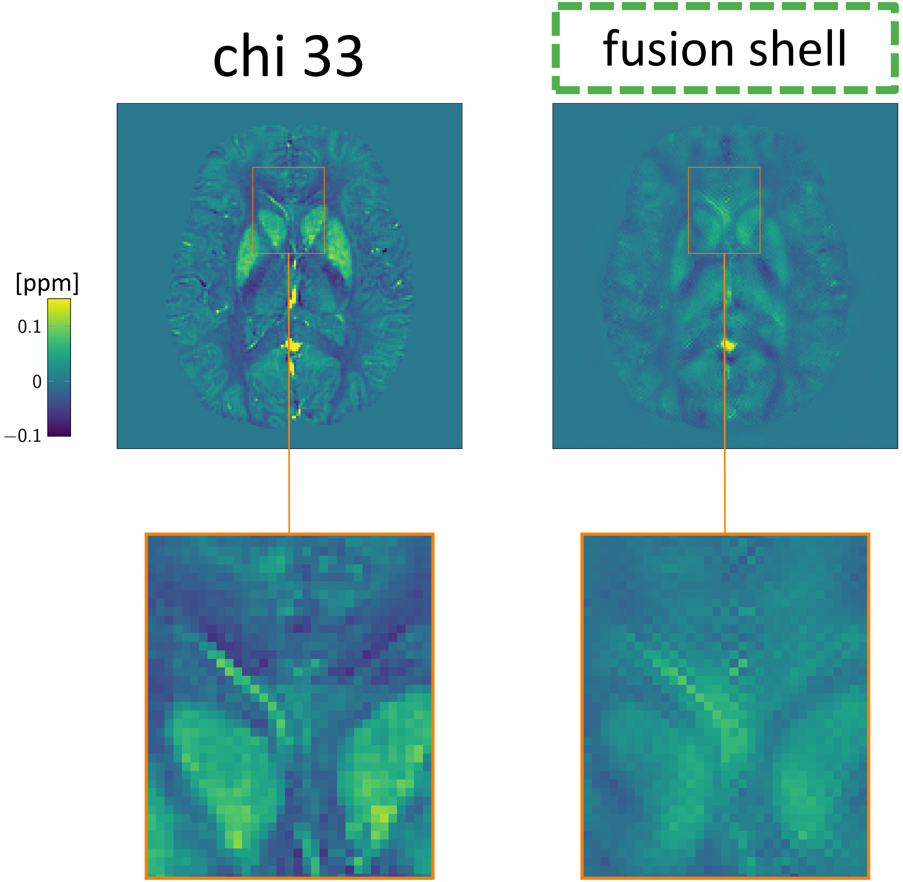
Fusion of QSM maps: tkd ⇔ L2, cone surfaces!



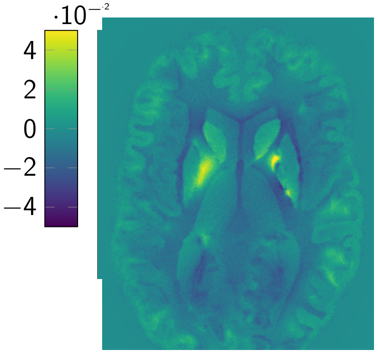


	rmse	hfen	ssim
tkd	84.52	82.28	0.79
L2	81.23	75.49	0.81
fusion shell	79.97	75.42	0.15
fusion zcs	**79.09**	76.97	0.15

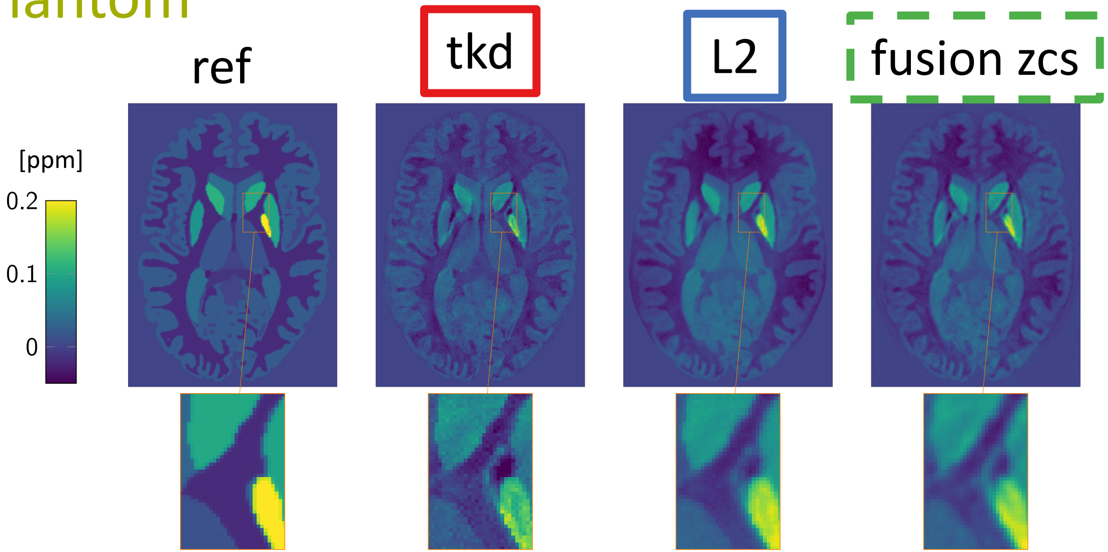
Fusion of QSM maps: tkd ⇔ L2, cone surfaces!

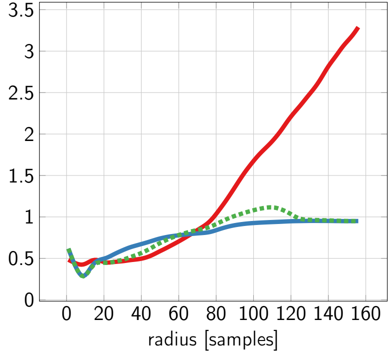


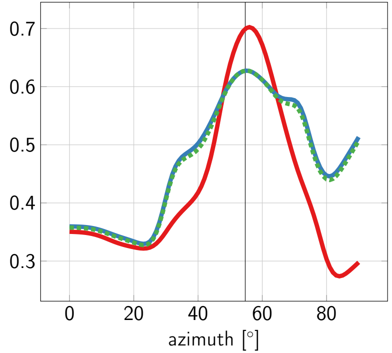
Validation numerical brain phantom

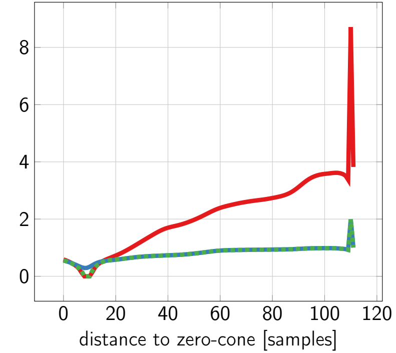


tissue field (SNR=100)









	rmse	hfen	ssim
tkd	54.32	48.35	0.66
L2	49.10	56.64	0.74
fusion zcs	**47.41**	49.18	0.30

Limitations

- Relation 1D to scalar metrics not clear (ssim)

	rmse	hfen	ssim
tkd	84.52	82.28	0.79
L2	81.23	75.49	0.81
fusion	**79.97**	**75.42**	0.15

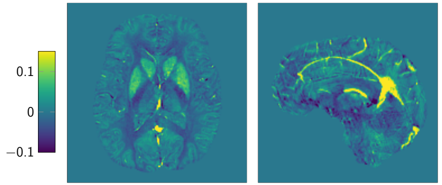
- Focus on baseline methods (tkd, L2) not state-of-the-art

$$D' = \mathrm{sgn}(D(k))\ \max(|D(k)|, \tau)$$

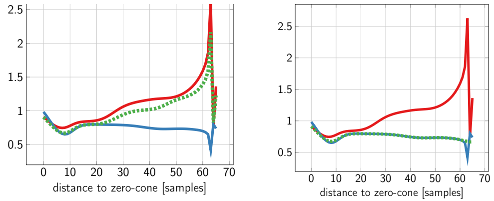
$$D'' = (D^2(k) + \lambda k^2)/D(k)$$

- 1D metrics still reference-based

chi 33

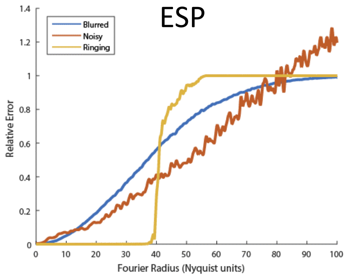


- No clear prospective fusion strategy

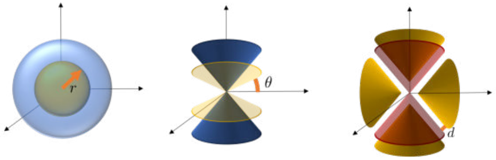


Conclusion

- **ESP** applicable in QSM



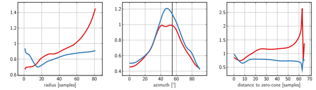
- **Conic parametrizations** allow visualization of differences between QSM methods



- **Complementary** to standard error metrics

	rmse	hfen	ssim
tkd	86.50	81.97	0.77
L2	81.23	75.49	0.81

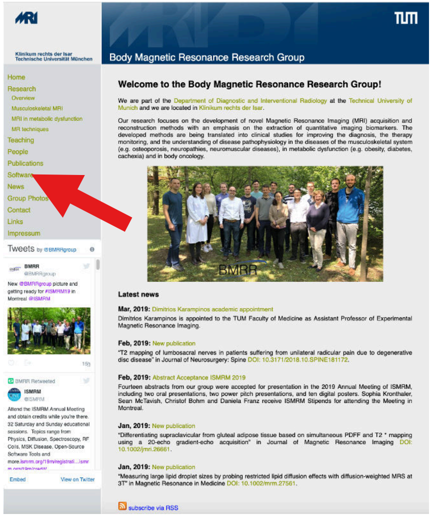
↔



- **Fusion** of different QSM methods can yield can improve results

Software available

„qsm_esp“



http://bmrr.de/software

MATLAB (& python)

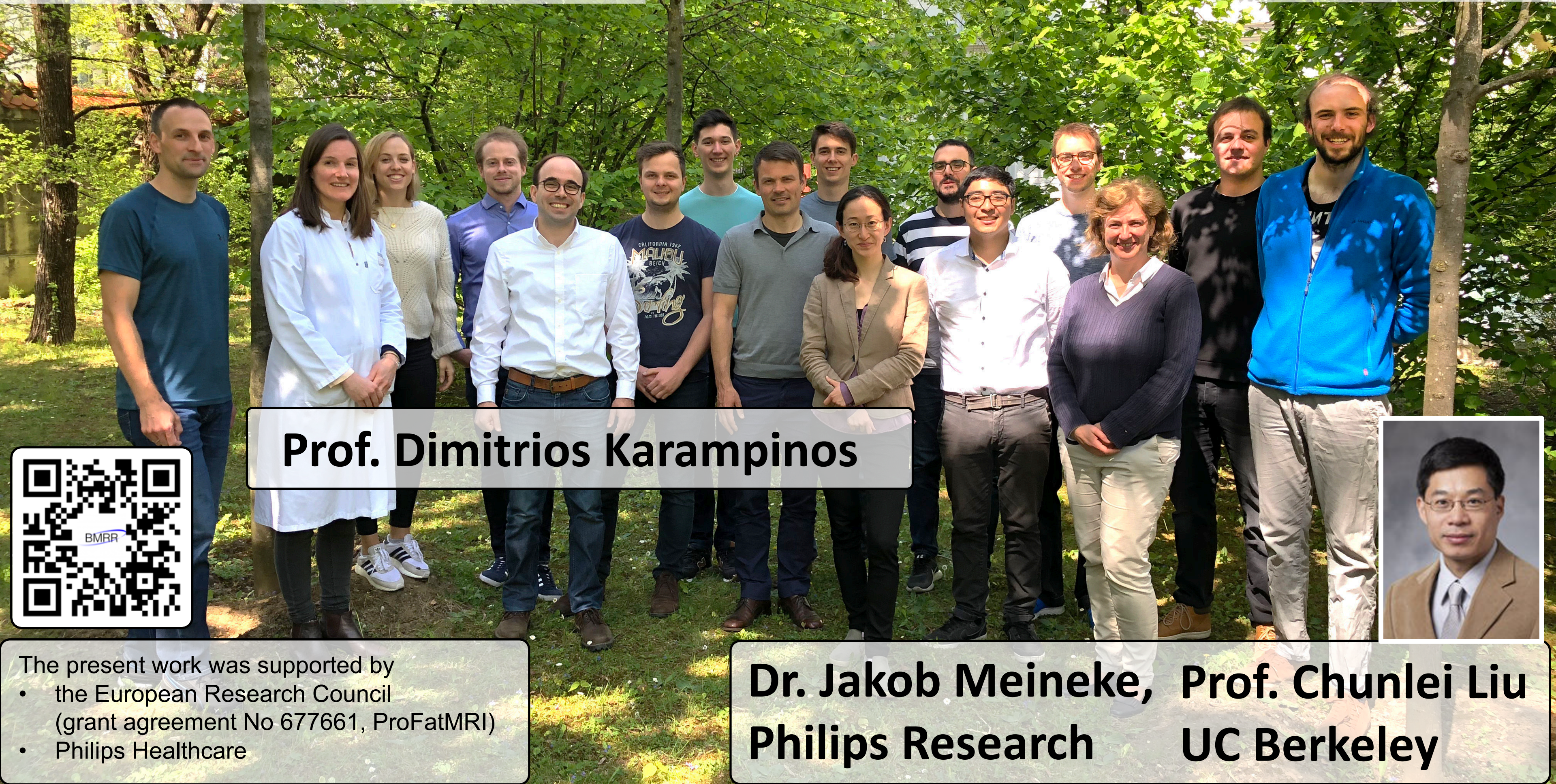
```
% addpath(genpath('qsm_esp/'))

metrics = compute_metrics(chi_ref, chi);

plot_metrics(metrics);
```

+ functions for fusion

Acknowledgements



Prof. Dimitrios Karampinos

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Dr. Jakob Meineke, Philips Research

Prof. Chunlei Liu UC Berkeley