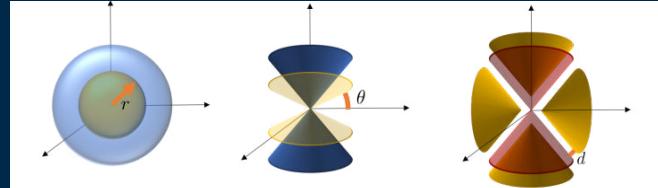
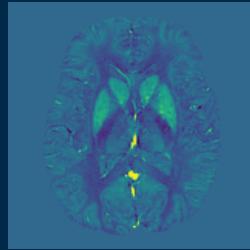


322 One-Dimensional k-Space Metrics on Cone Surfaces for Quantitative Susceptibility Mapping

Maximilian N. Diefenbach¹, Christof Böhm¹, Jakob Meineke², Chunlei Liu³, Dimitrios C. Karampinos¹



¹Department of Diagnostic & Interventional Radiology, Technical University of Munich, Munich, Germany

²Philips Research, Hamburg, Germany

³Department of Electrical Engineering and Computer Sciences, & Helen Wills Neuroscience Institute, University of California, Berkeley, Berkeley, CA, United States



ISMRM 27TH ANNUAL MEETING & EXHIBITION

Palais des congrès de Montréal  Montréal, QC, Canada  11–16 May 2019

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:

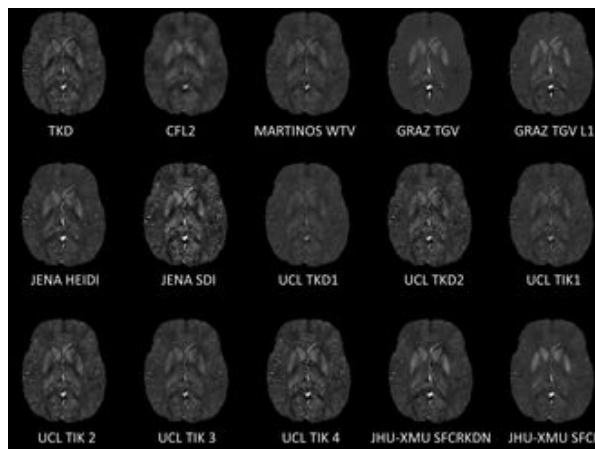
Company Name: Philips Healthcare

Type of Relationship: Grant Support

Motivation I

How to compare QSM
reconstruction results?

How to choose
hyper parameters?



$\alpha_0 =$	0.0005	0.001	0.002	0.004
$RMSE =$	125.8	97.9	81.2	77.5
$HFEN =$	121.8	94.9	78.2	74.2
$SSIM =$	91.3	93.5	94.2	92.9
$ROI\ Error =$	0.022	0.020	0.019	0.021

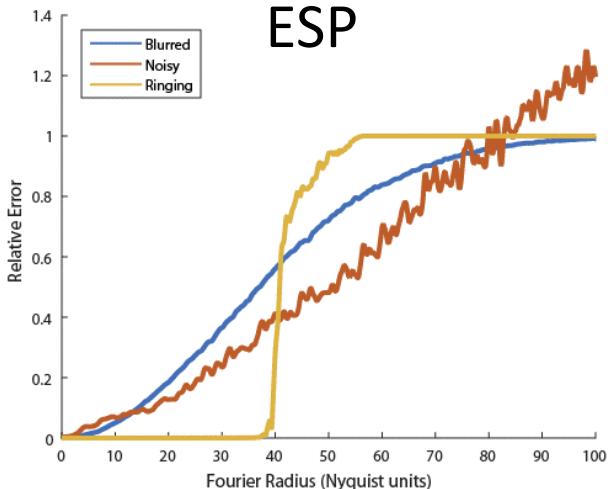
Quantitative Susceptibility Mapping:
Report from the 2016 reconstruction challenge,
MRM, 79(3), 1661–1673 (2017).

Motivation II

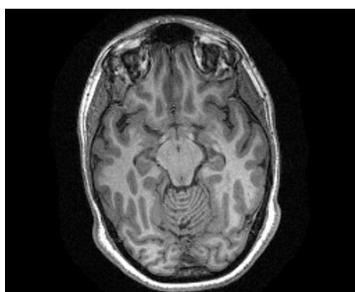
ISMRM 2018 Paris, #249

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

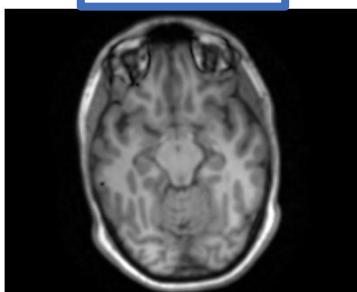
*"Assessing MR image reconstruction quality using the Fourier radial **error spectrum plot** [(ESP)]"*



Gold Standard



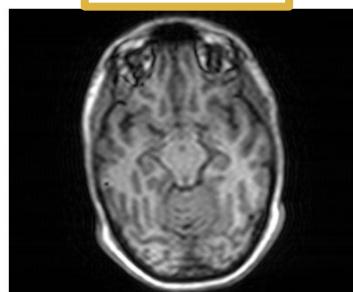
Blurred



Noisy



Ringing

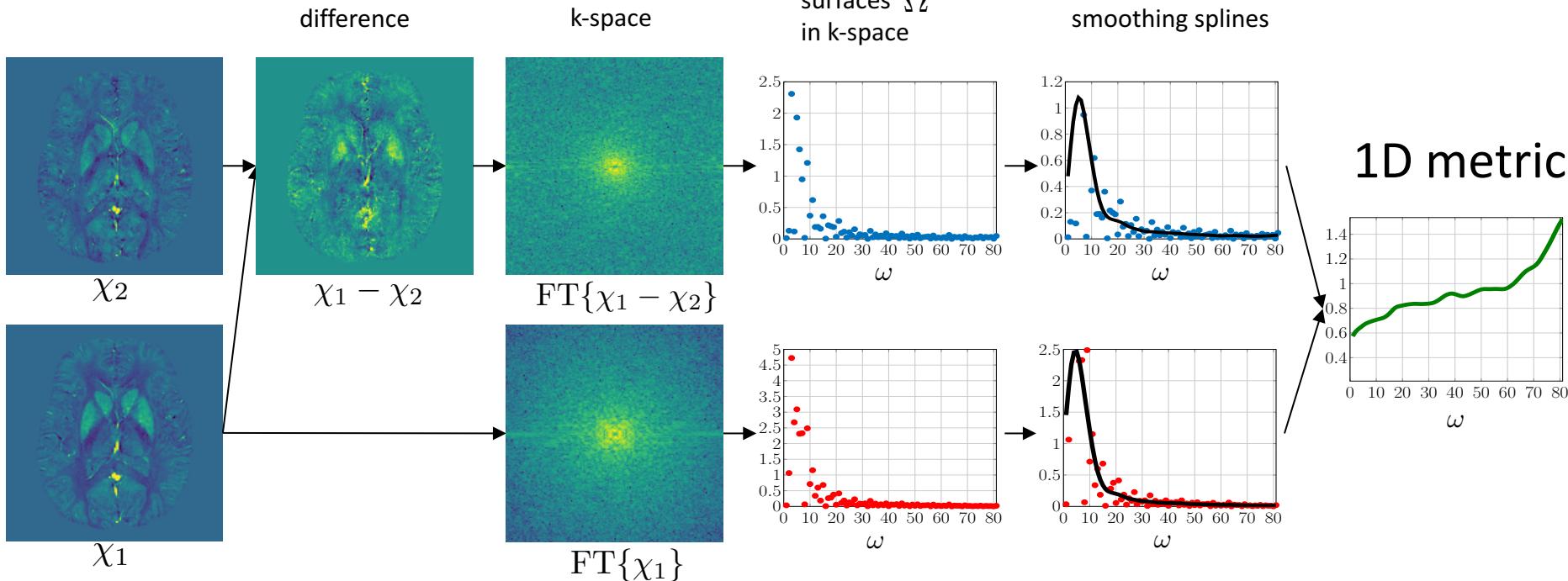


Purpose

to ...

1. Apply the **Error Spectrum Plot** concept in QSM
2. Explore **different parametrizations** suited to
the intrinsic k-space geometries in QSM

Flowchart



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

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

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

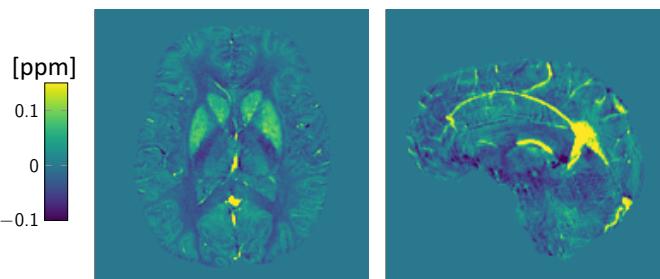
$$X = B/D' \quad D' = \text{sgn}(D(k)) \max(|D(k)|, \tau)$$

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

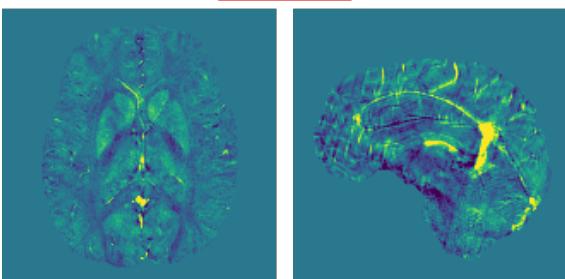
$$X = B/D'' \quad D'' = (D^2(k) + \lambda k^2)/D(k)$$

Comparison of QSM reconstruction results

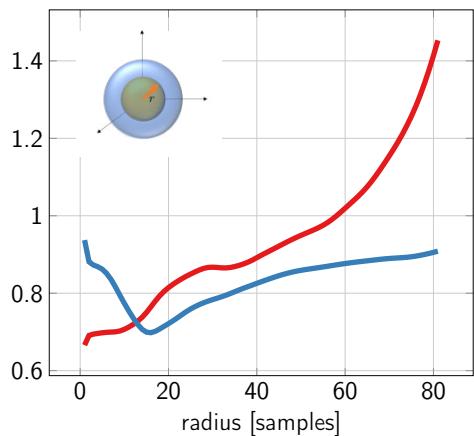
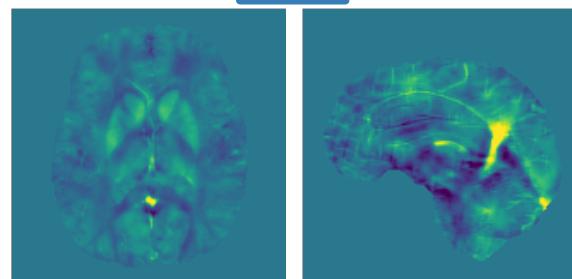
chi 33



tkd

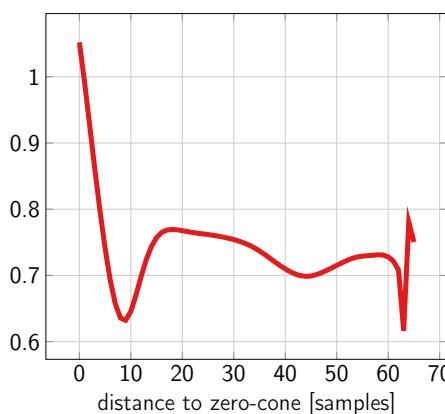
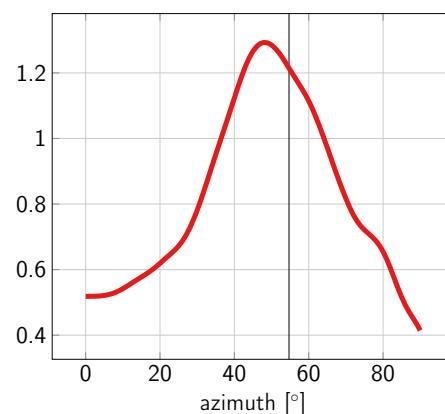
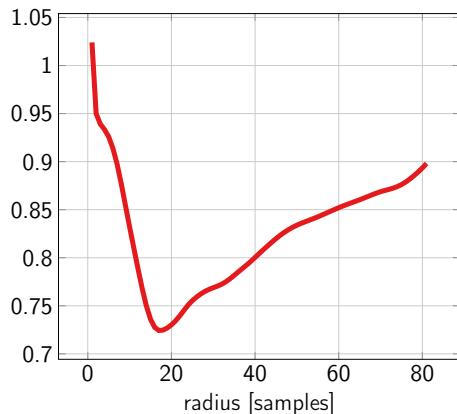
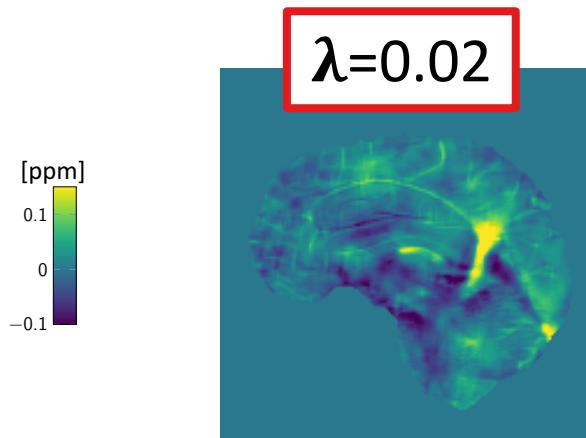


L2



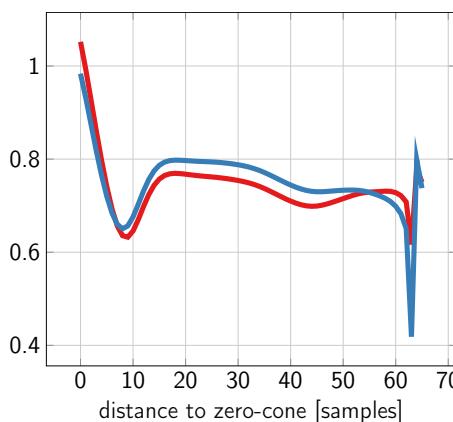
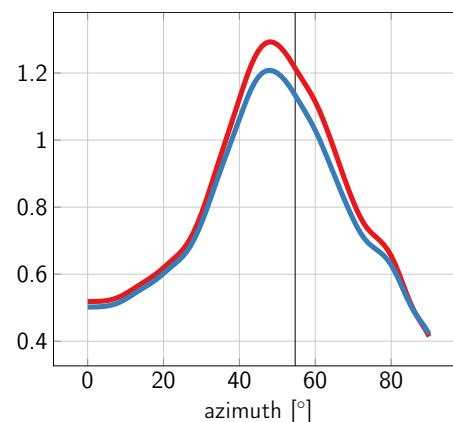
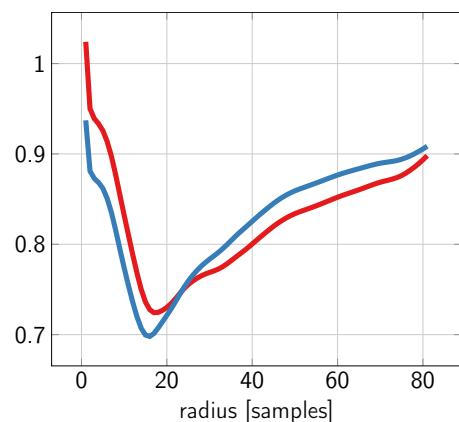
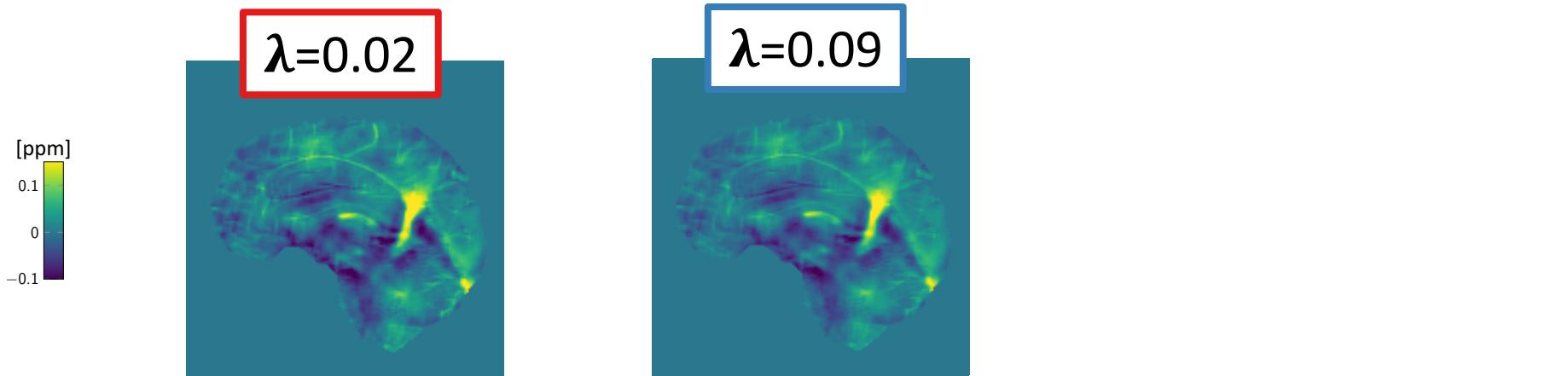
	rmse	hfen	ssim
tkd	86.50	81.97	0.77
L2	81.23	75.49	0.81

Selection of hyper parameters: L2 regularization parameter λ



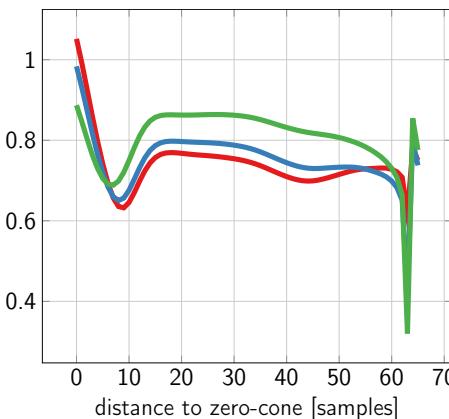
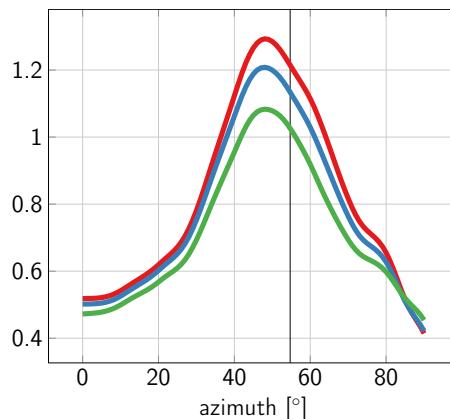
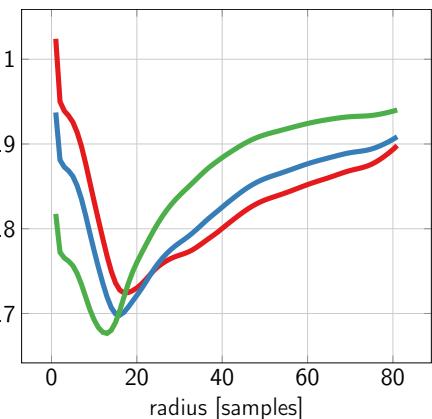
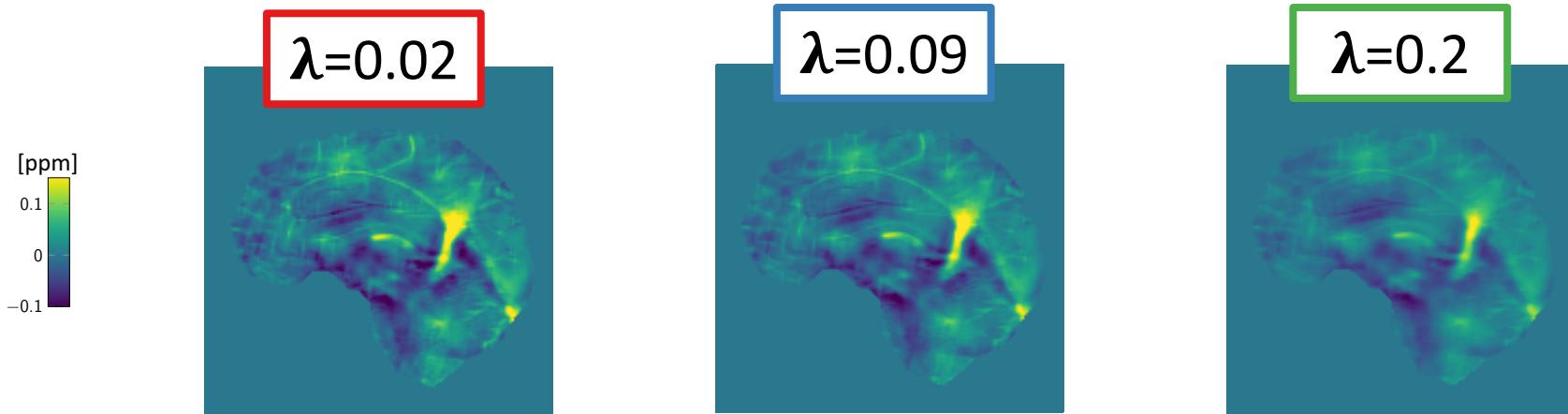
λ	rmse	hfen	ssim
0.02	83.54	76.26	0.81

Selection of hyper parameters: L2 regularization parameter λ



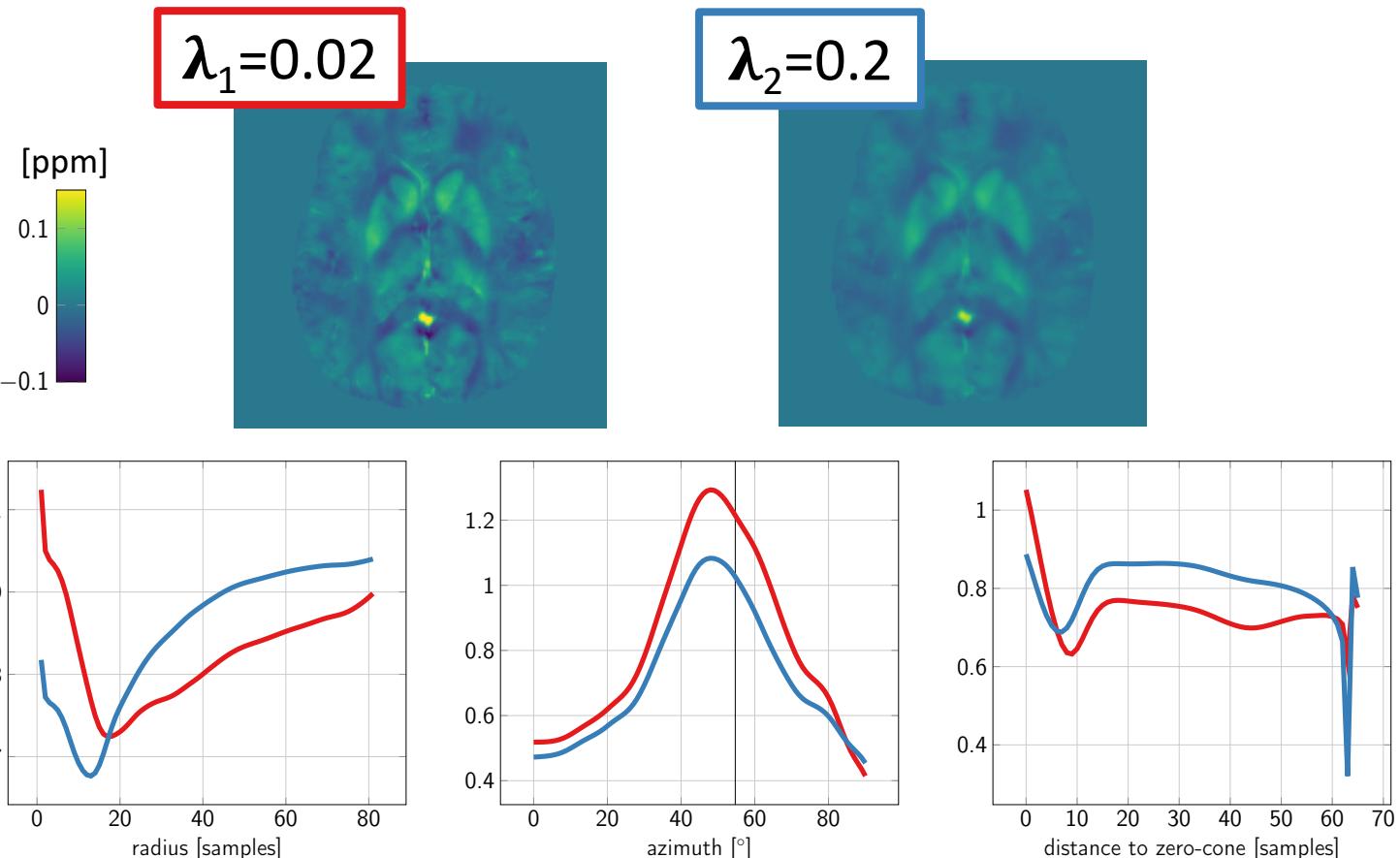
λ	rmse	hfen	ssim
0.02	83.54	76.26	0.81
0.09	81.23	75.49	0.81

Selection of hyper parameters: L2 regularization parameter λ

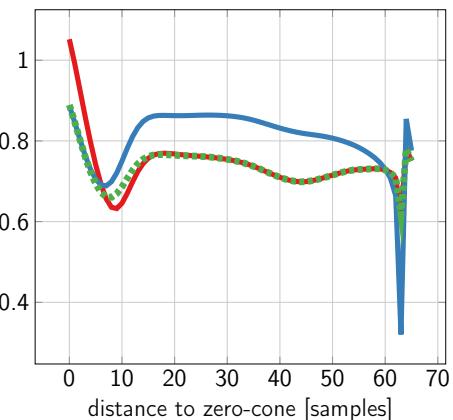
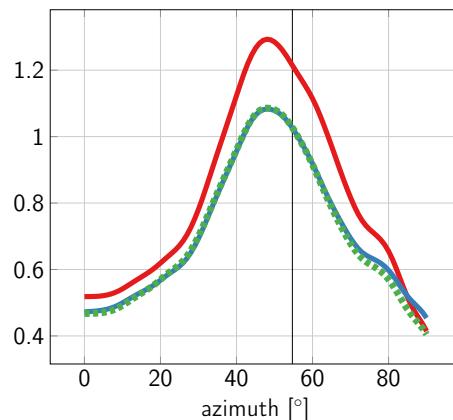
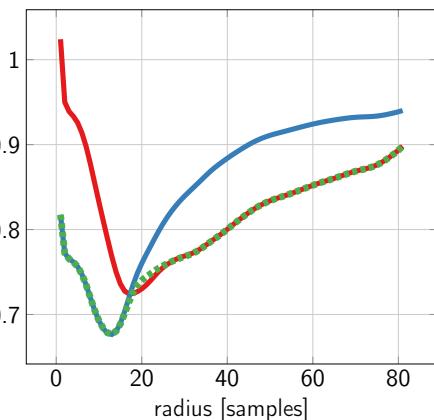
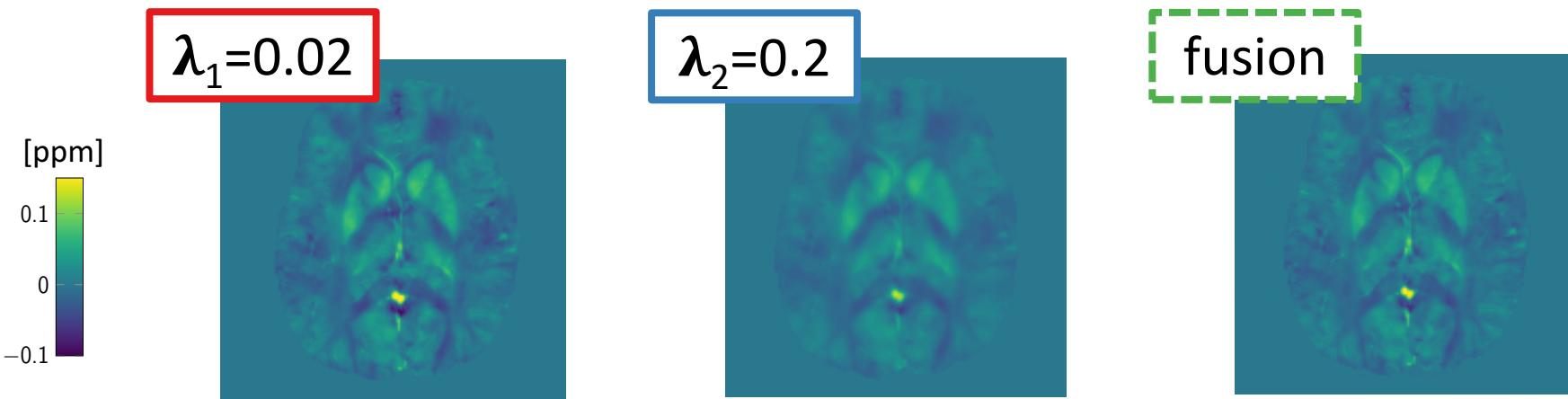


λ	rmse	hfen	ssim
0.02	83.54	76.26	0.81
0.09	81.23	75.49	0.81
0.2	79.66	78.20	0.79

Fusion of QSM maps: $L_2(\lambda_1) \Leftrightarrow L_2(\lambda_2)$

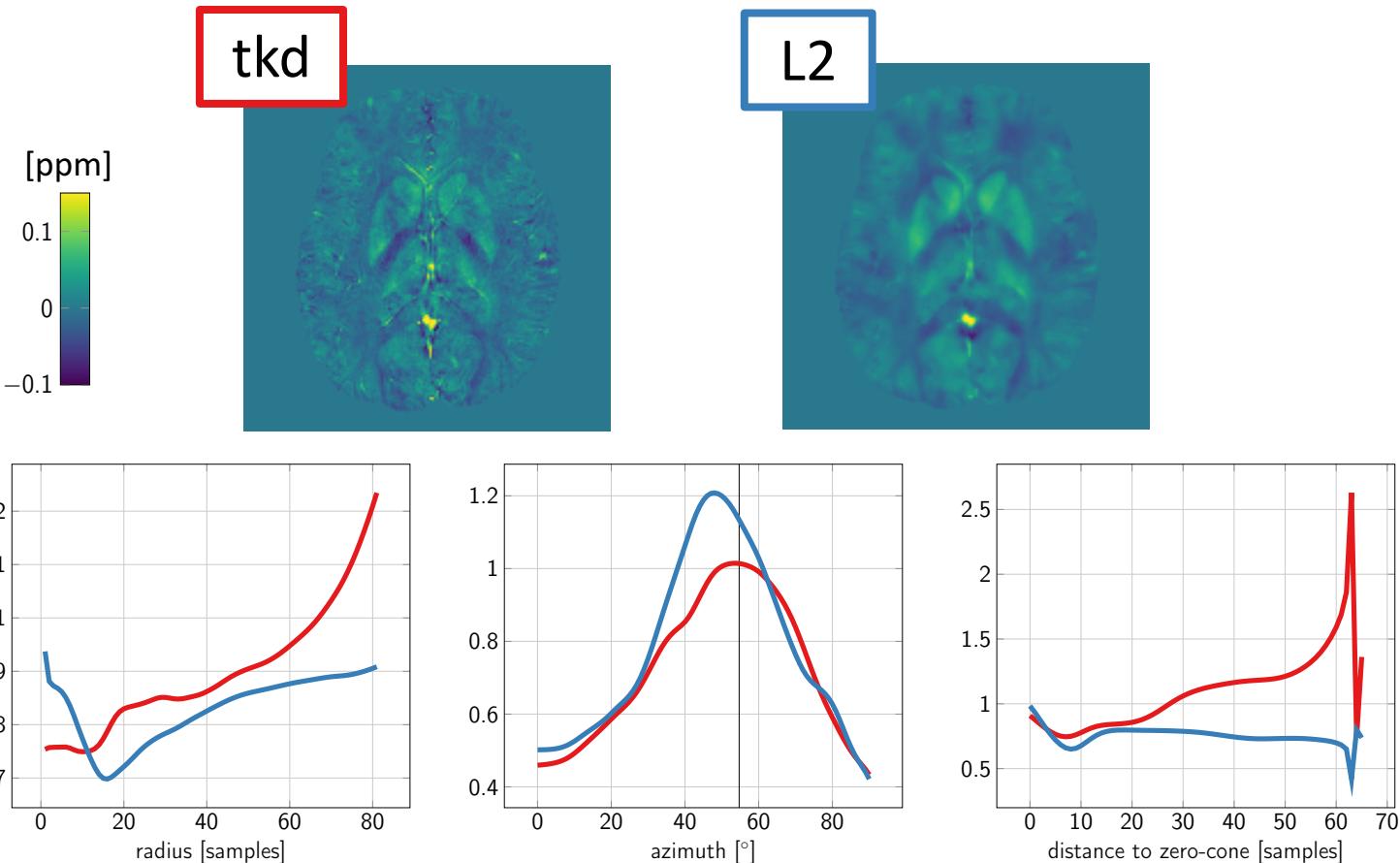


Fusion of QSM maps: $L_2(\lambda_1) \Leftrightarrow L_2(\lambda_2)$

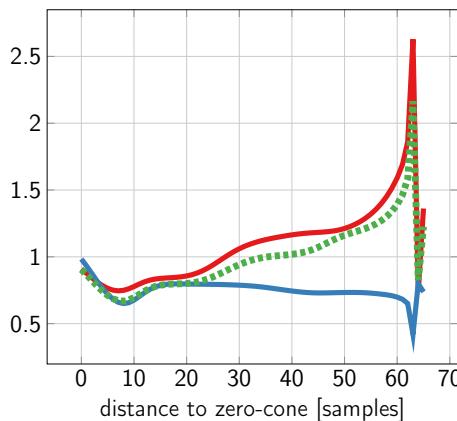
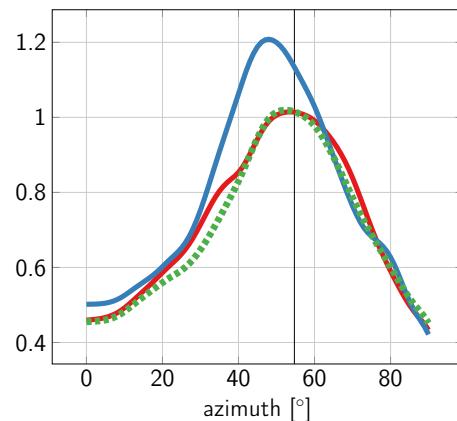
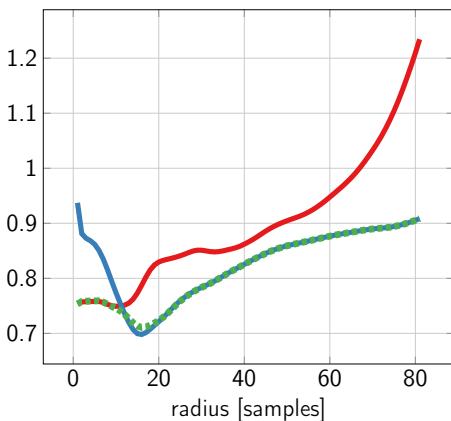
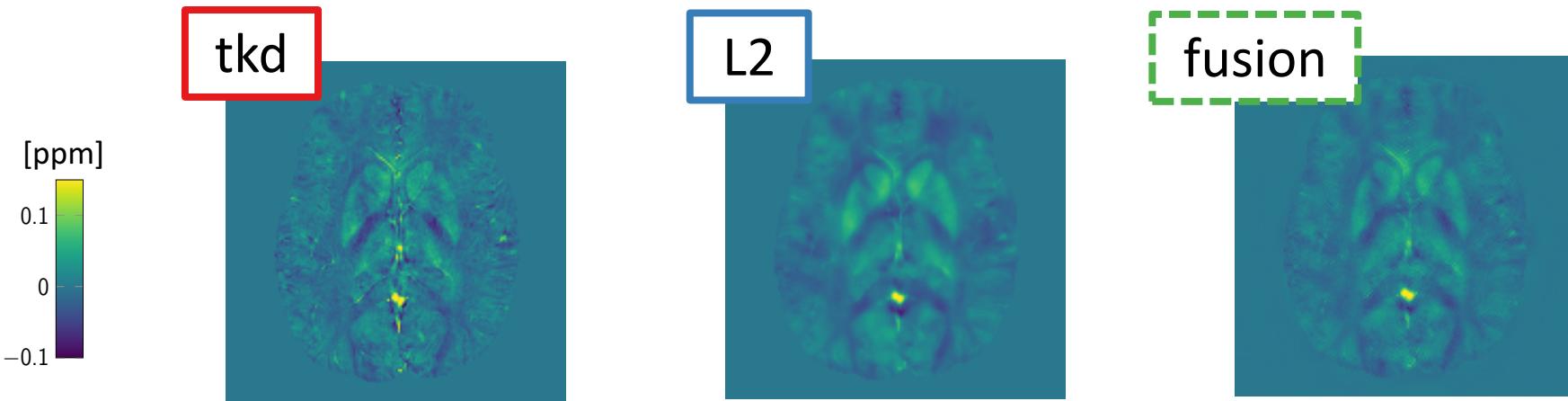


ssim
drops (?)

Fusion of QSM maps: tkd \leftrightarrow L2



Fusion of QSM maps: tkd \leftrightarrow L2



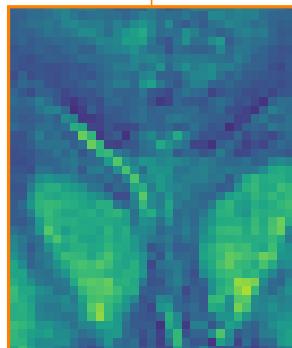
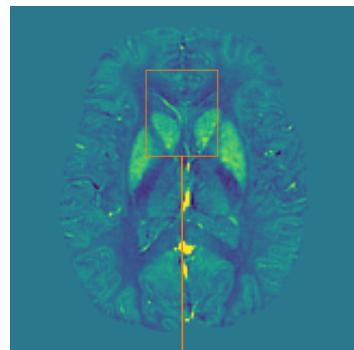
	rmse	hfen	ssim
tkd	84.52	82.28	0.79
L2	81.23	75.49	0.81
fusion	79.97	75.42	0.15

Fusion of QSM maps: tkd \leftrightarrow L2

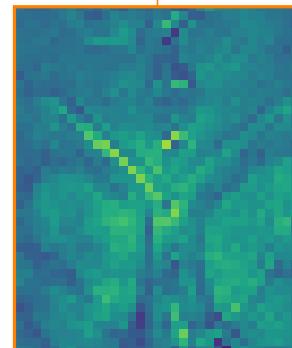
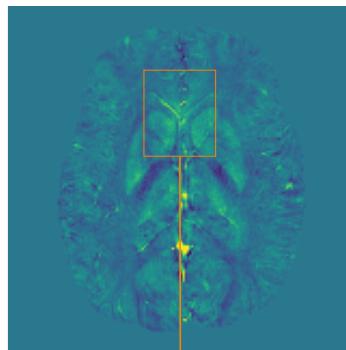
chi 33

[ppm]

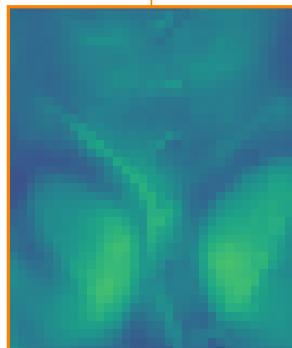
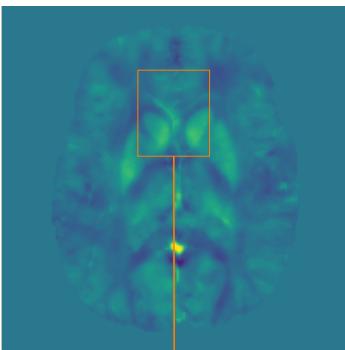
0.1
0
-0.1



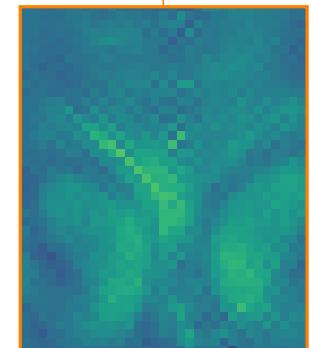
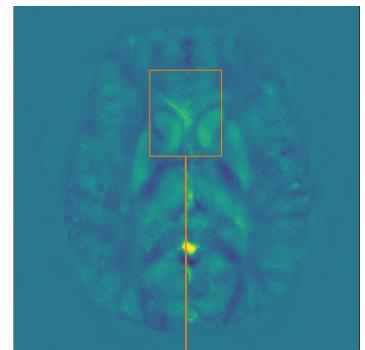
tkd



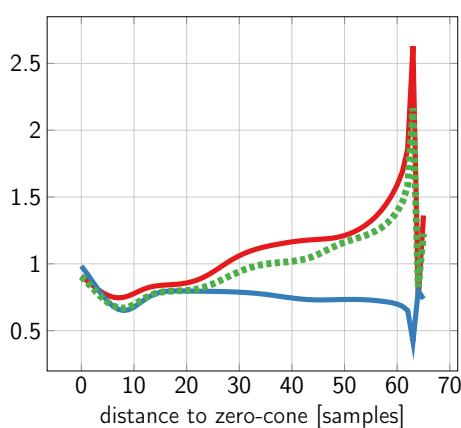
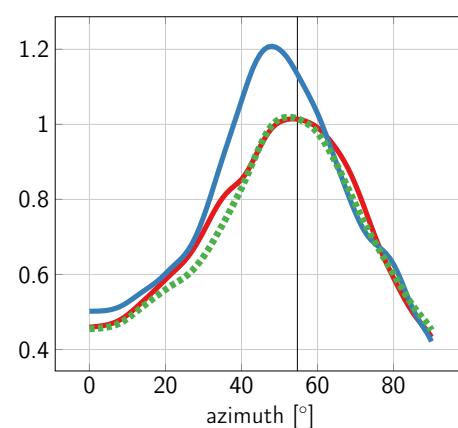
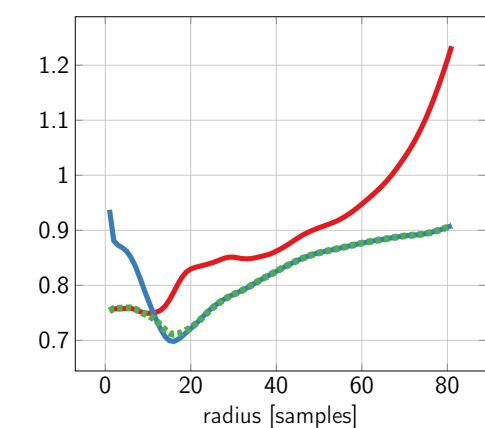
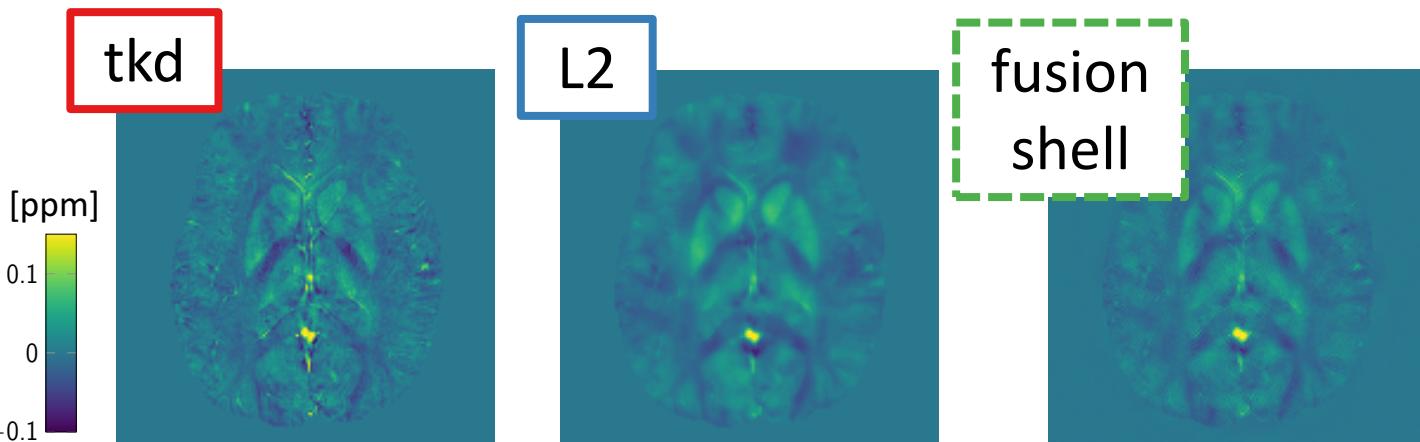
L2



fusion

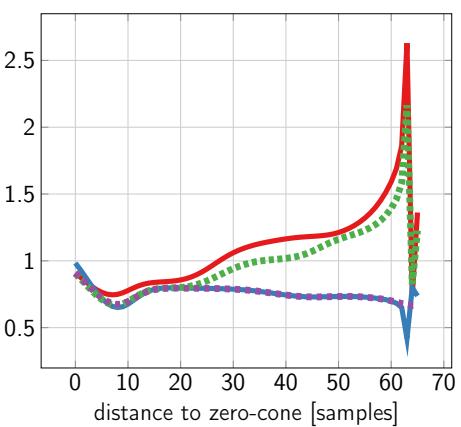
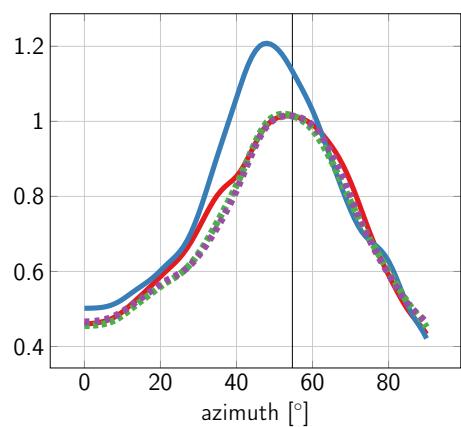
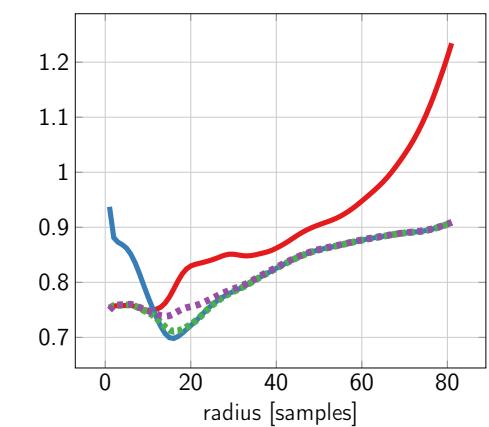
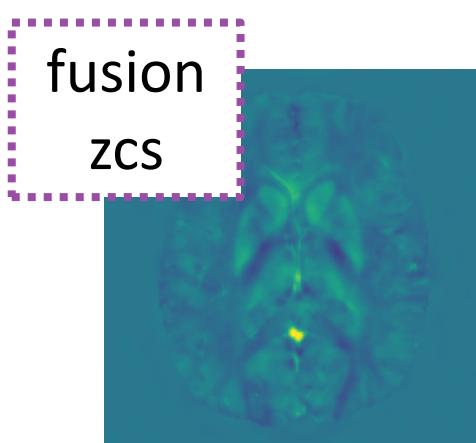
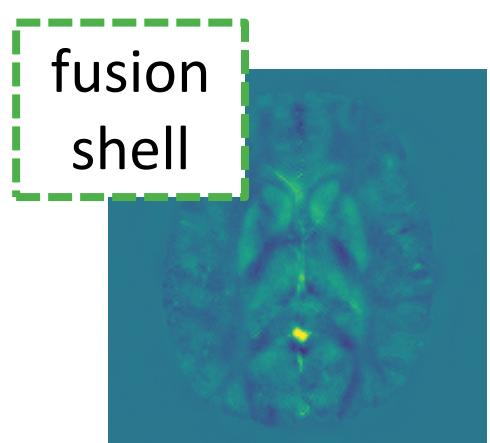
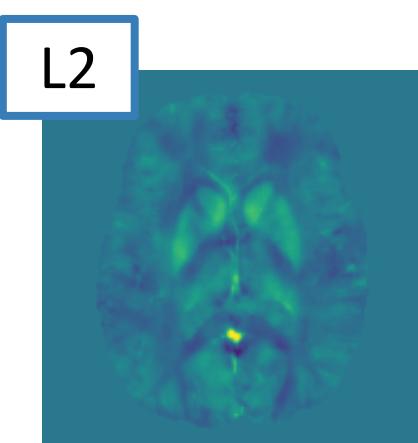
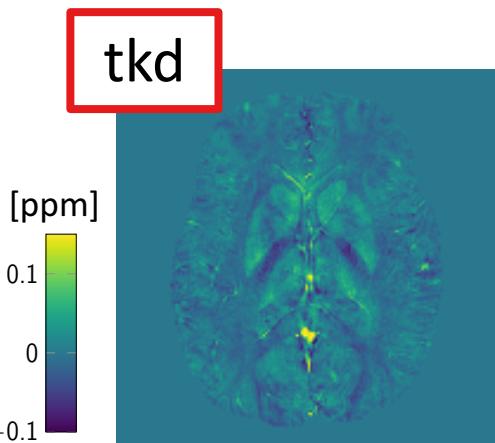


Fusion of QSM maps: tkd \Leftrightarrow L2, cone surfaces!



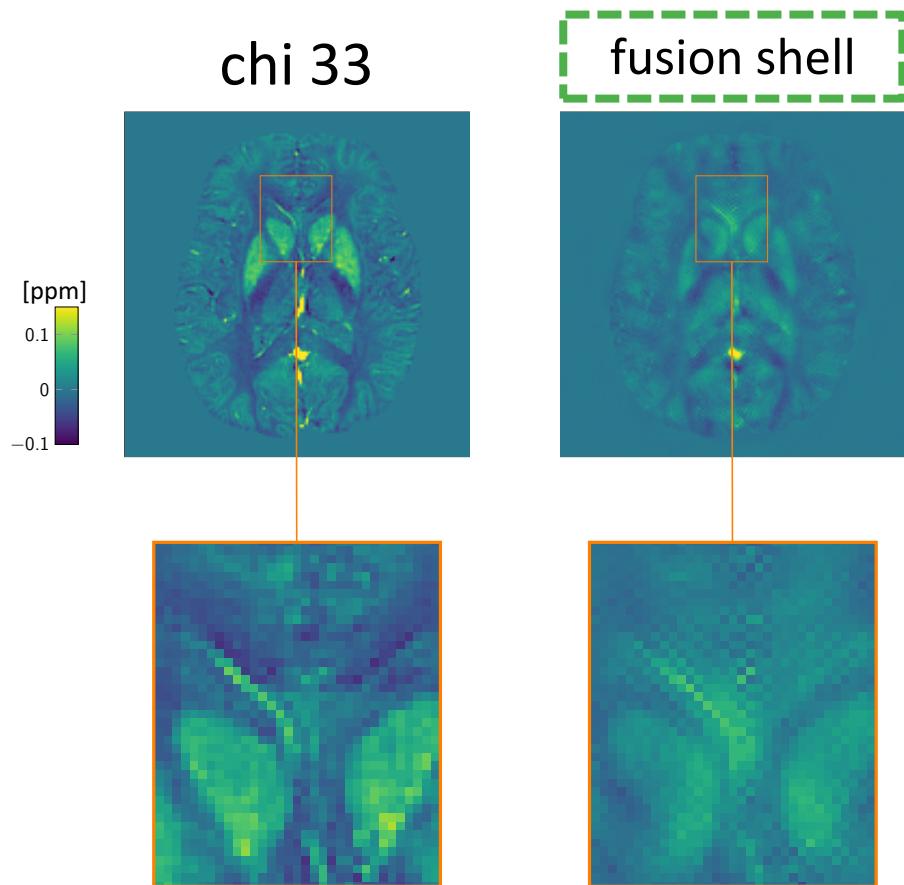
	rmse	hfen	ssim
tkd	84.52	82.28	0.79
L2	81.23	75.49	0.81
fusion shell	79.97	75.42	0.15

Fusion of QSM maps: tkd \leftrightarrow L2, cone surfaces!

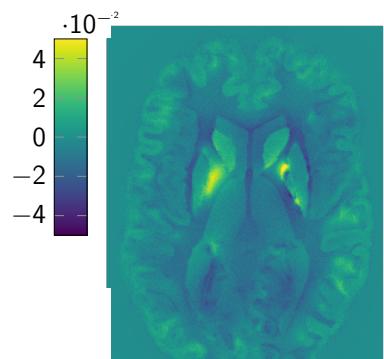


	rmse	hfen	ssim
tkd	84.52	82.28	0.79
L2	81.23	75.49	0.81
fusion shell	79.97	75.42	0.15
fusion zcs	79.09	76.97	0.15

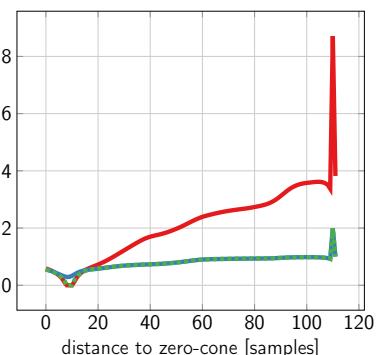
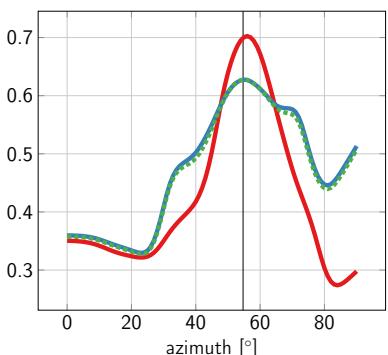
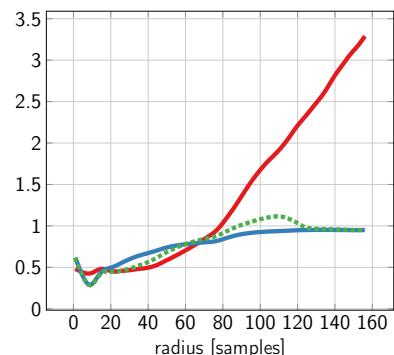
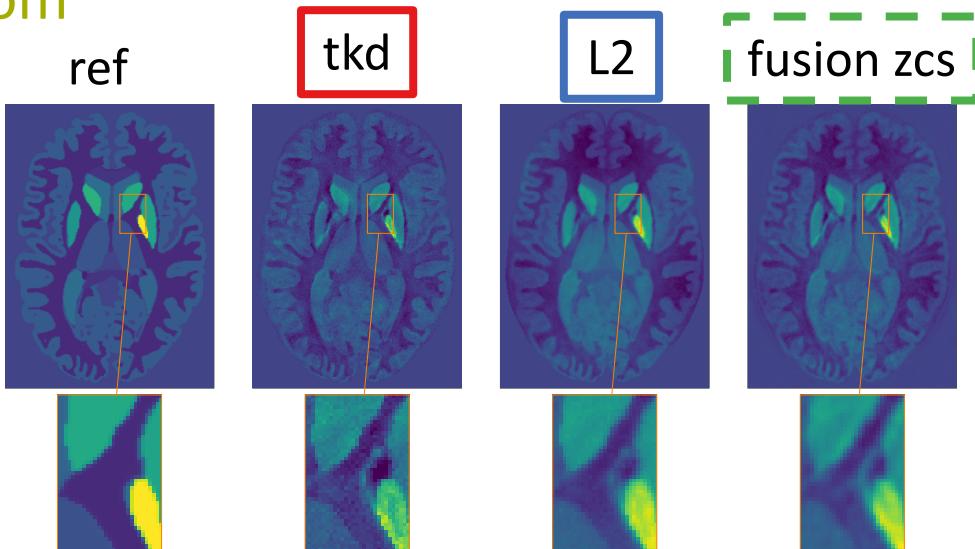
Fusion of QSM maps: tkd \Leftrightarrow L2, cone surfaces!



Validation numerical brain phantom



ref



	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

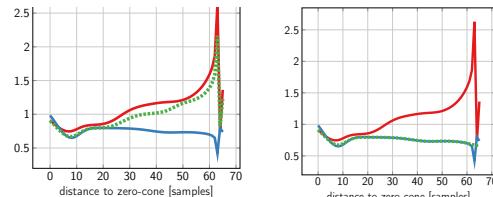
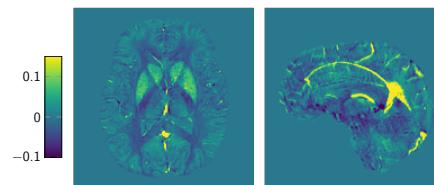
Limitations

- Relation 1D to scalar metrics not clear (ssim)
- Focus on baseline methods (tkd, L2) not state-of-the-art
- 1D metrics still reference-based
- No clear prospective fusion strategy

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

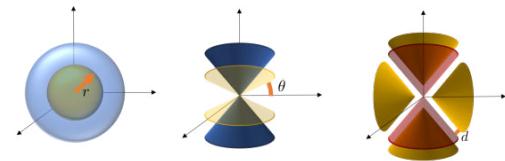
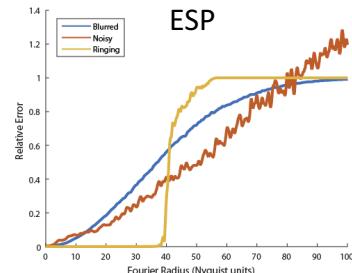
$$D' = \text{sgn}(D(k)) \max(|D(k)|, \tau)$$
$$D'' = (D^2(k) + \lambda k^2)/D(k)$$

chi 33

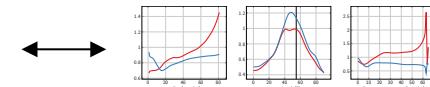


Conclusion

- **ESP** applicable in QSM
- **Conic parametrizations** allow visualization of differences between QSM methods
- **Complementary** to standard error metrics
- **Fusion** of different QSM methods can yield can improve results



	rmse	hfen	ssim
tkd	86.50	81.97	0.77
L2	81.23	75.49	0.81



Software available

„qsm_esp“



The screenshot shows the homepage of the "Body Magnetic Resonance Research Group" at the Technical University of Munich. The page features a dark header with the TUM logo and the group's name. Below the header is a large photograph of a group of people standing outdoors. On the left side, there is a sidebar with various links: Home, Research, Overview, Magnetometers MRI, MRI in metabolic syndrome, MRI in muscle diseases, Teaching, People, Publications, Software (which is highlighted with a red arrow), News, Group Photos, Contact, Links, Impressum, and Tweets. The main content area includes sections for Welcome to the Body Magnetic Resonance Research Group!, Latest news, and a footer with social media links and a subscribe button via RSS.

<http://bmrr.de/software>

MATLAB (& python)

```
% addpath(genpath('qsm_esp/'))  
  
metrics = compute_metrics(chi_ref, chi);  
  
plot_metrics(metrics);
```

+ functions for fusion

Acknowledgements



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- the European Research Council
(grant agreement No 677661, ProFatMRI)
- Philips Healthcare

Dr. Jakob Meineke, Prof. Chunlei Liu
Philips Research **UC Berkeley**