Highly Accelerated Brain DCE MRI with Direct Estimation of Pharmacokinetic Parameter Maps

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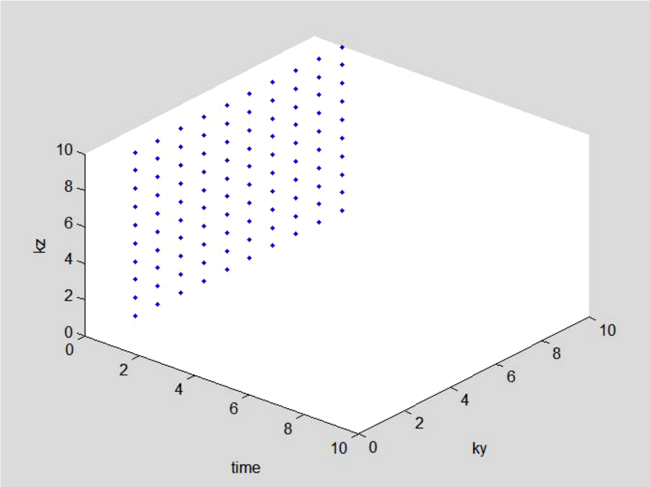
Declaration of
Financial Interests or Relationships

Speaker Name: Yi Guo

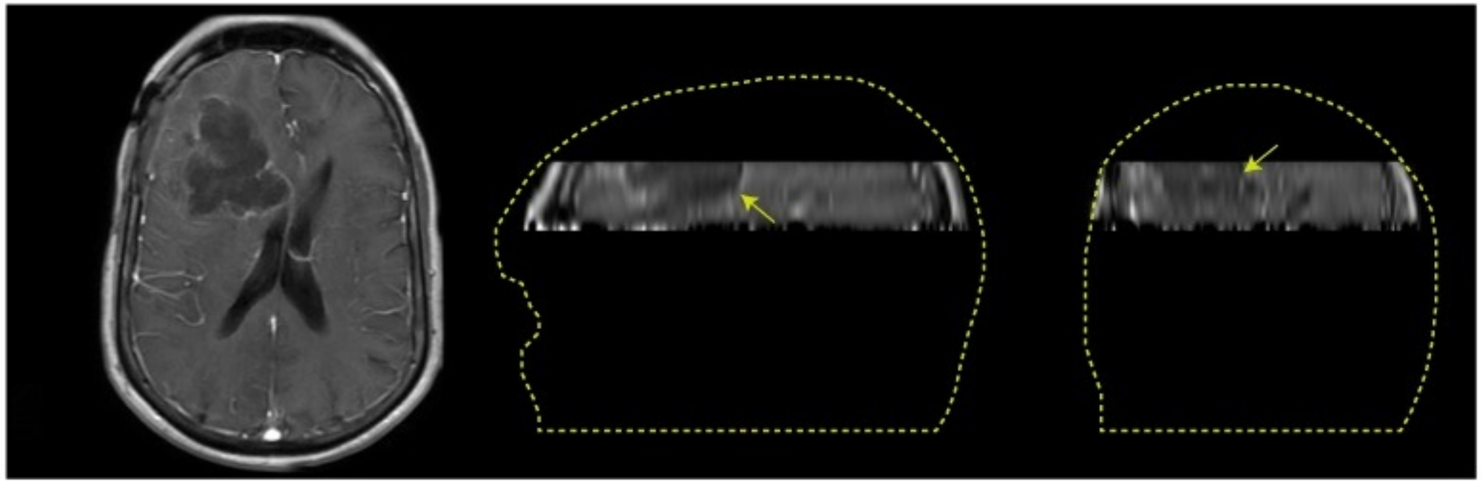
I have no financial interests or relationships to disclose with regard to the subject matter of this presentation.

Introduction

- Sub-optimal coverage and resolution for Dynamic Contrast Enhanced (DCE) MRI by Nyquist sampling.



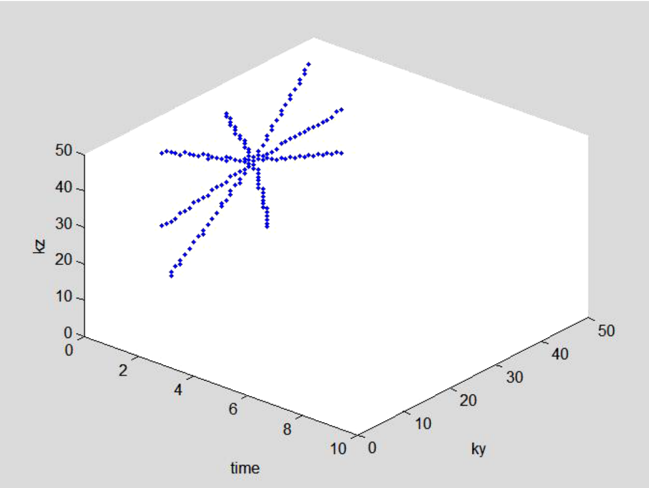
Cartesian Nyquist sampling



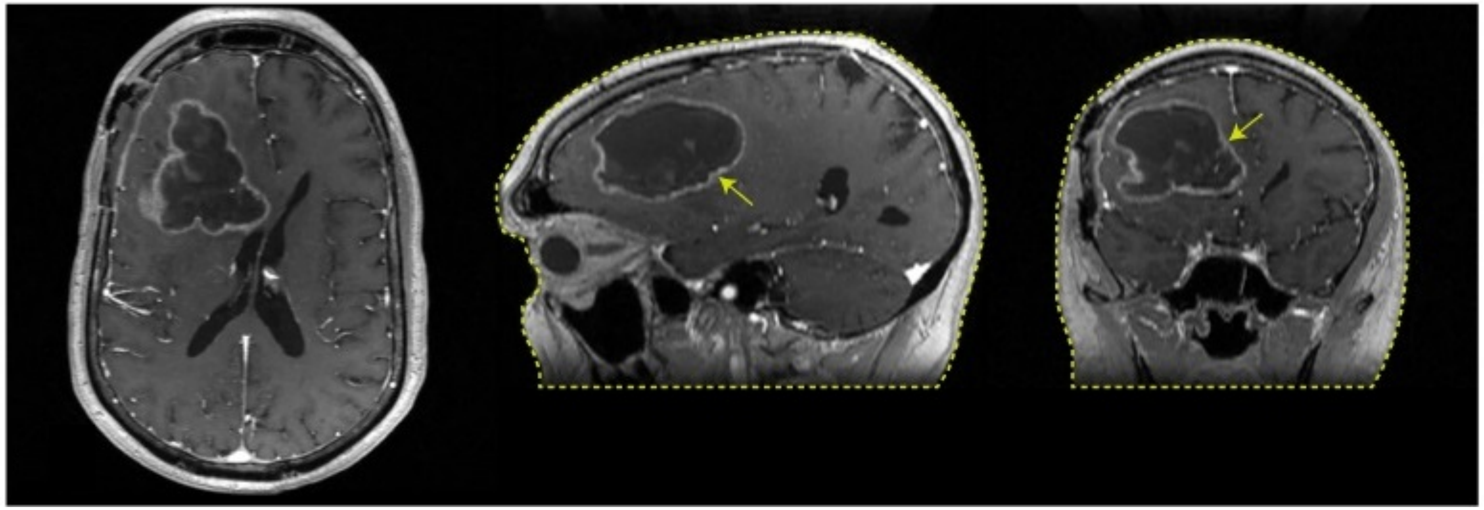
Limited coverage and resolution

Introduction

- Sub-optimal coverage and resolution for Dynamic Contrast Enhanced (DCE) MRI by Nyquist sampling.
- Whole-brain coverage high-resolution enabled by constrained reconstruction from under-sampled kt-space[1,2].



Cartesian Golden-angle radial sampling



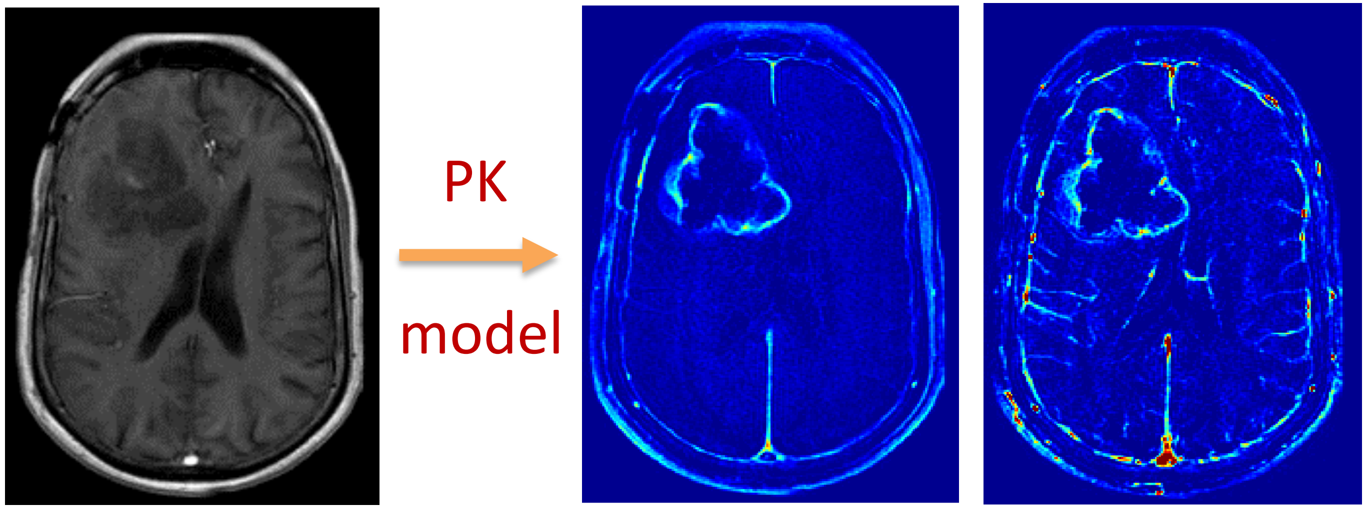
Whole-brain coverage

[1]RM Lebel, et al. MRM 71(2): 635–644, 2014. [2]Y Guo, et al. ISMRM p374, 2015.

Introduction

- Sub-optimal coverage and resolution for Dynamic Contrast Enhanced (DCE) MRI by Nyquist sampling.
- Whole-brain coverage high-resolution enabled by constrained reconstruction from under-sampled kt-space[1,2].
- Important pathological information from pharmacokinetic(PK) maps (K^{trans}, v_p, v_e etc.).

Reduced dimensionality: from 4D dynamic images to 3D static PK maps.



Dynamic images K^{trans} v_p

Goal

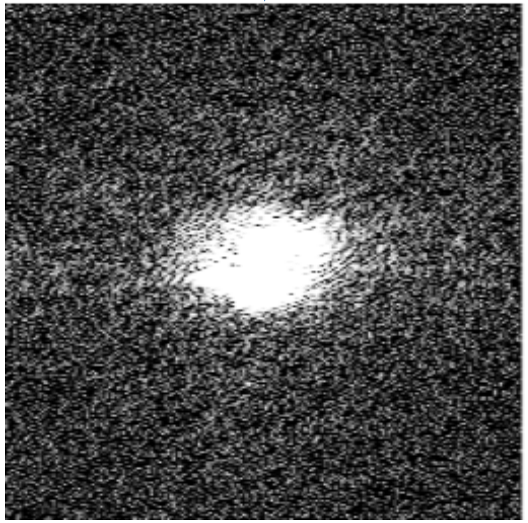
- Direct reconstruction of PK maps with PK model integrated in reconstruction process

- This may enable higher acceleration rate and better fidelity of PK maps.

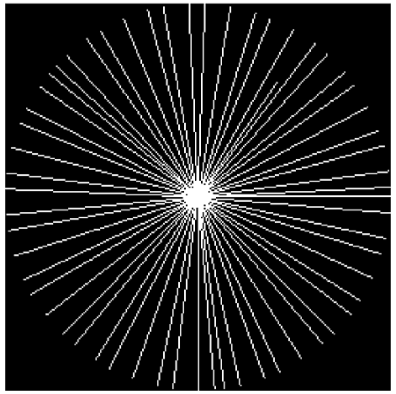
Conventional estimation of PK maps

Under-sampled kt-space data: $k_u(t)$ → Anatomical Images: S(t) → Contrast Agent Concentration: CA(t) → PK Parameters: K^{trans}, v_p

Constrained reconstruction using sensitivity maps, under-sampling pattern,
with some sparsity constraints.



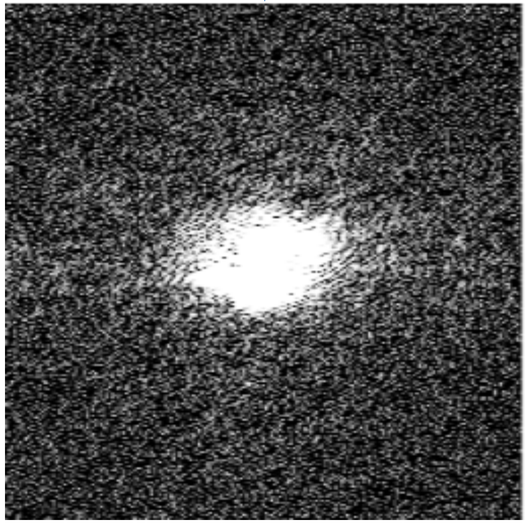
Sensitivity

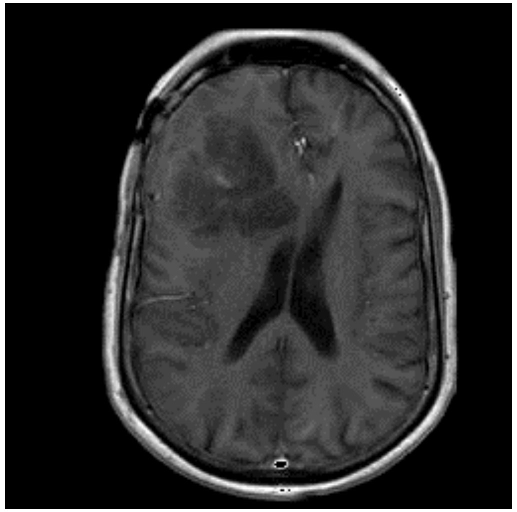


Sampling pattern

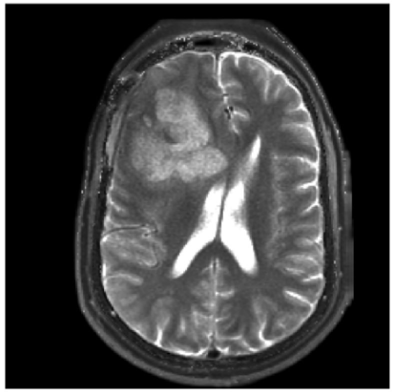
Conventional estimation of PK maps

Under-sampled kt-space data: $k_u(t)$ → Anatomical Images: S(t) → Contrast Agent Concentration: CA(t) → PK Parameters: K^{trans}, v_p

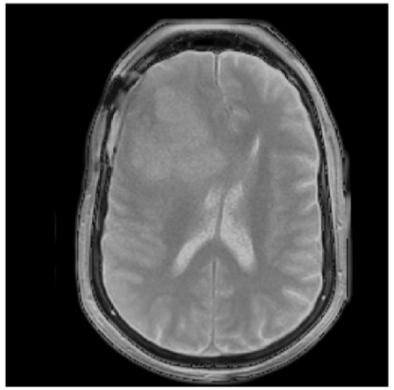




Use T1w signal equation to estimate contrast concentration changes over time with T1 maps and M0 maps.



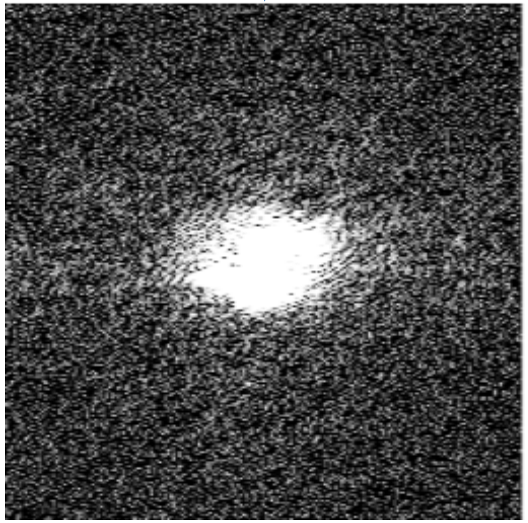
T1

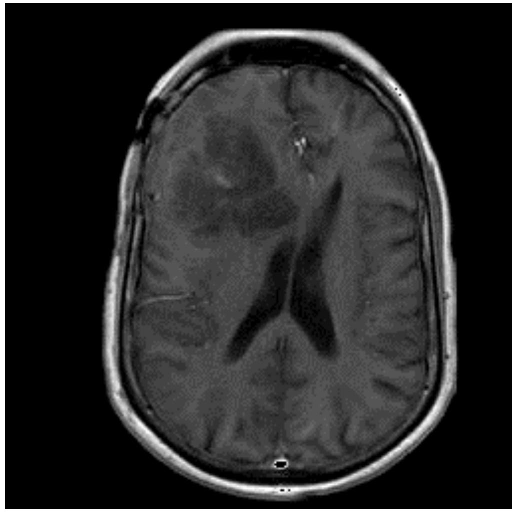


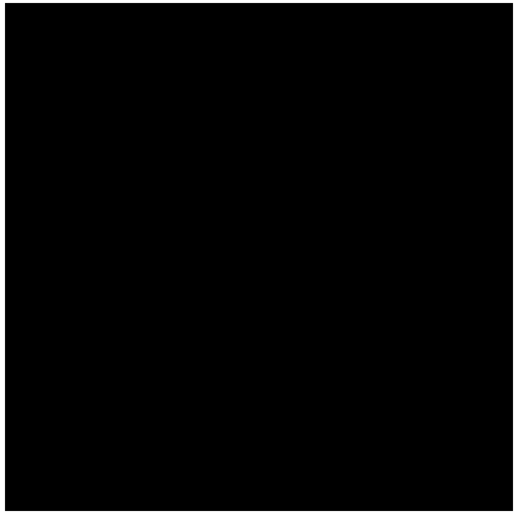
M0

Conventional estimation of PK maps

Under-sampled kt-space data: $k_u(t)$ → Anatomical Images: $S(t)$ → Contrast Agent Concentration: $CA(t)$ → PK Parameters: K^{trans}, v_p



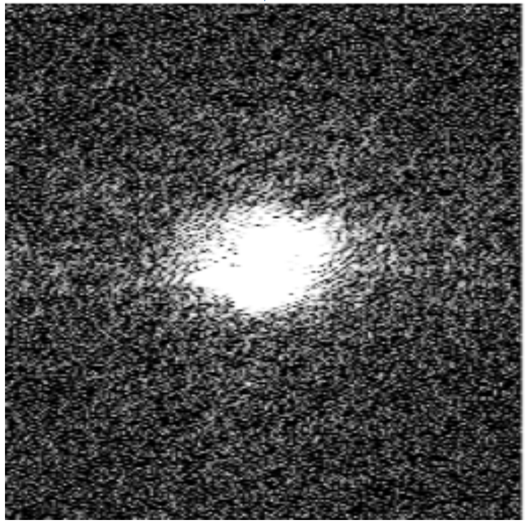


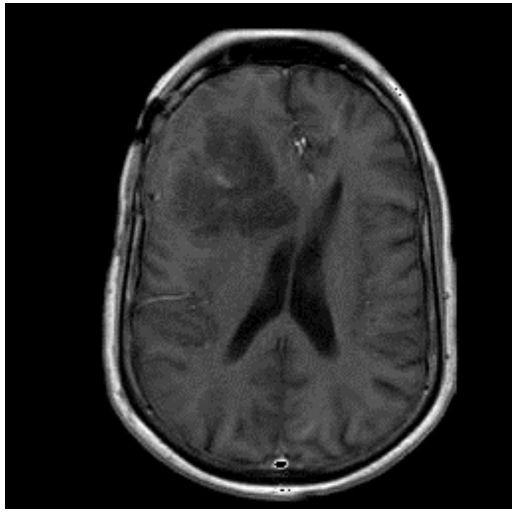


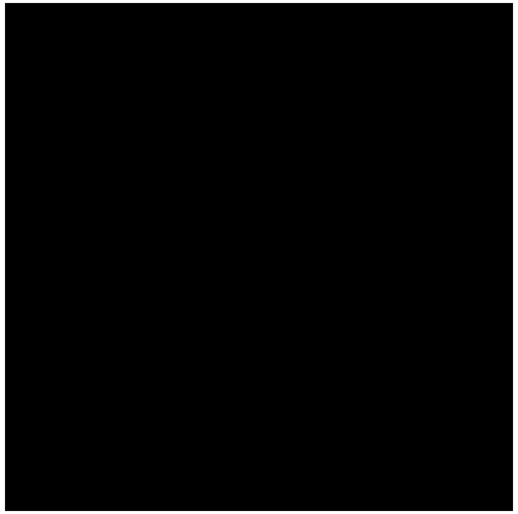
Use PK model (Patlak model in our study) to estimate PK parameters from contrast concentration changes C(t)

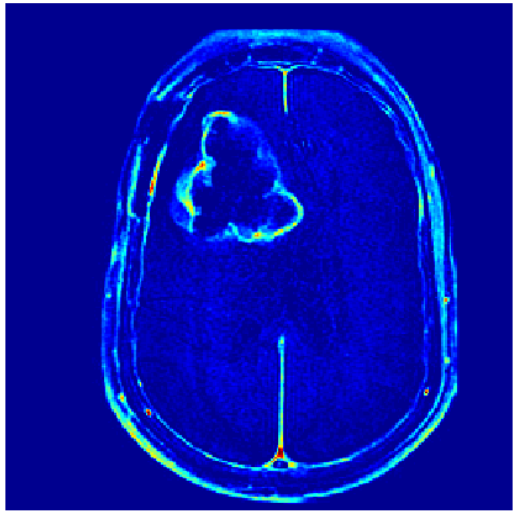
Conventional estimation of PK maps

Under-sampled kt-space data: $k_u(t)$ → Anatomical Images: S(t) → Contrast Agent Concentration: CA(t) → PK Parameters: K^{trans}, v_p







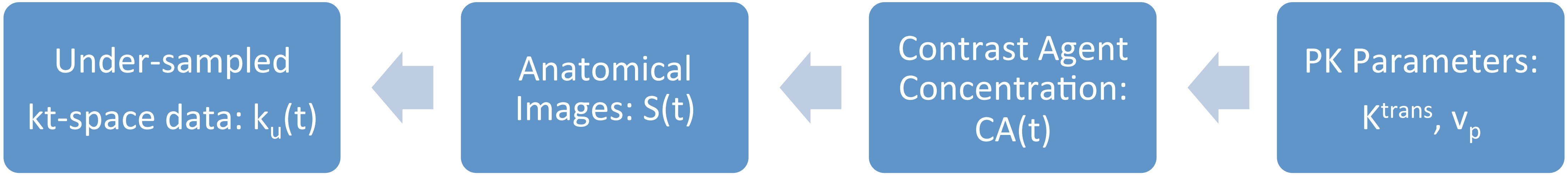


Reduced dimension!

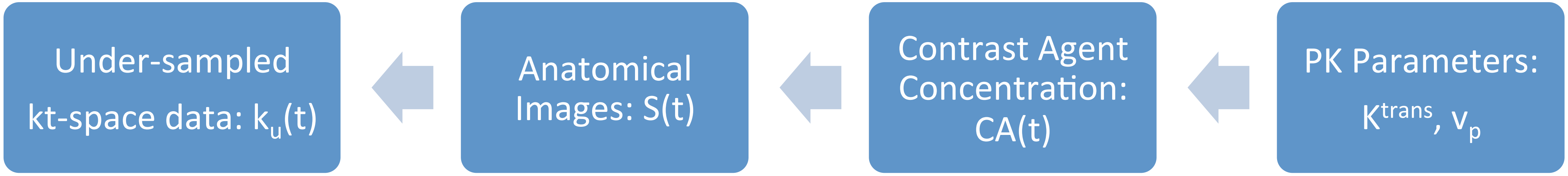
Conventional estimation of PK maps

Under-sampled kt-space data: $k_u(t)$ → Anatomical Images: $S(t)$ → Contrast Agent Concentration: $CA(t)$ → PK Parameters: K^{trans}, v_p

Forward modeling



Direct estimation



If a general function f is used:

$$k_u(t) = f(\mathrm{K}^{\mathrm{trans}}, v_p)$$

Can sovle PK maps with an optimization problem:

$$(K^{trans}, v_p) = \underset{K^{trans}, v_p}{\operatorname{argmin}} \| k_u(t) - f(K^{trans}, v_p) \|_2^2$$

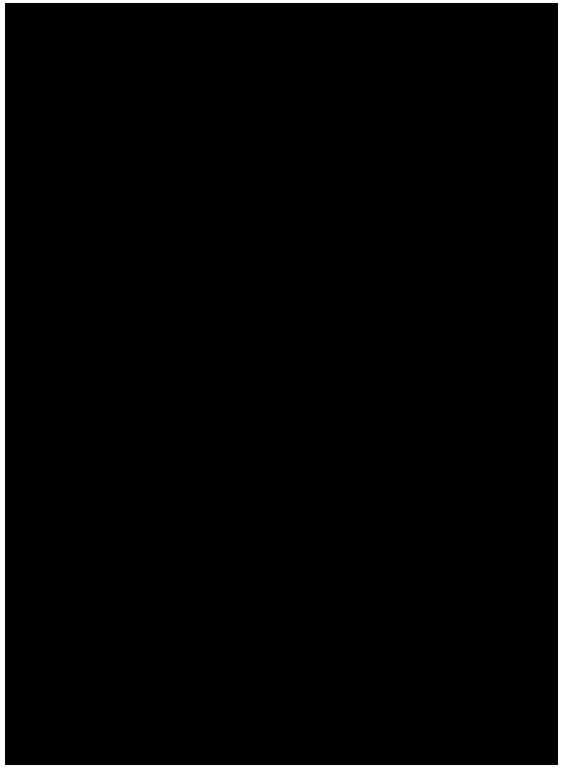
Direct estimation

- Solve: $(K^{trans}, v_p) = \underset{K^{trans}, v_p}{\operatorname{argmin}} \| k_u(t) - f(K^{trans}, v_p) \|_2^2$
- No constraint is needed, a parameter-free reconstruction!
- Gradient is calculated for the objective function to use a efficient l-BFGS algorithm.

	Conventional	Direct
Sparsity constraint	Temporal finite difference on anatomic images	None!
Algorithms	Alternating Direction Methods of Multipliers (ADMM)	Limited memory Broyden–Fletcher–Goldfarb–Shanno (l-BFGS)
Reconstruction time (2D case)	265s	296s

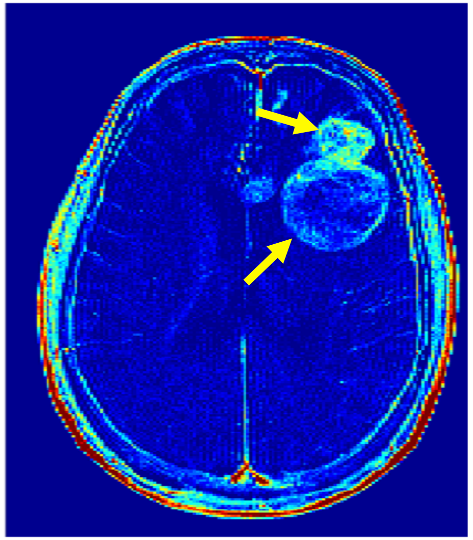
Retrospective study

- Fully-sampled DCE from brain tumor patients
- Randomized golden-angle radial sampling[1,2]
- Retrospectively down-sampled 10x ~ 100x

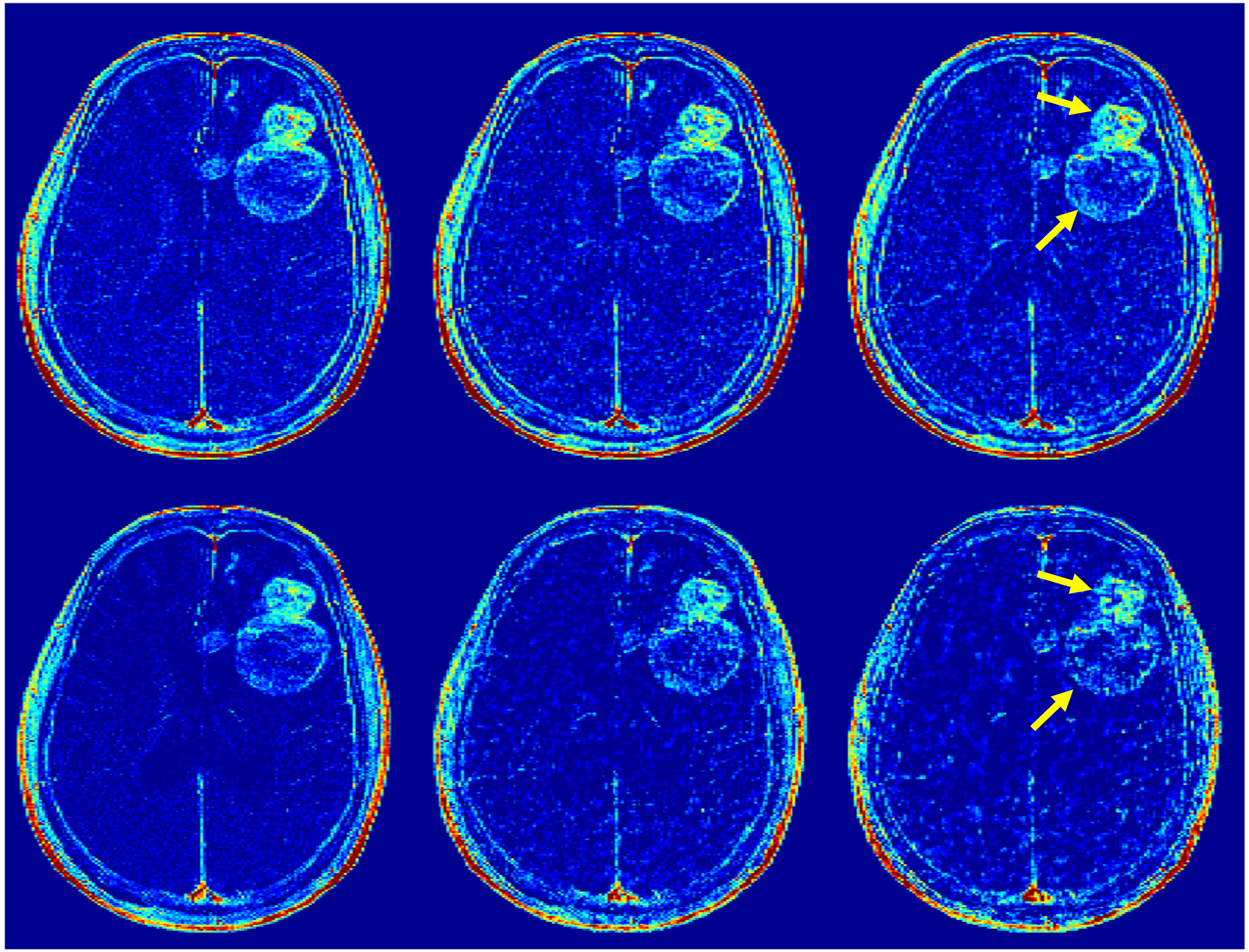


[1]Y Zhu et al. p4365, ISMRM 2014
[2]Y Zhu et al. p2535, ISMRM, 2015

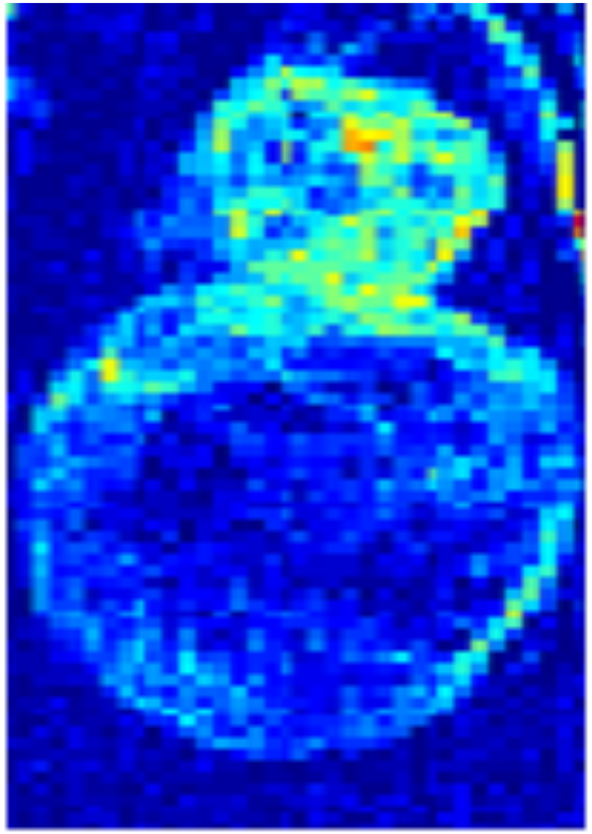
K^{trans} maps



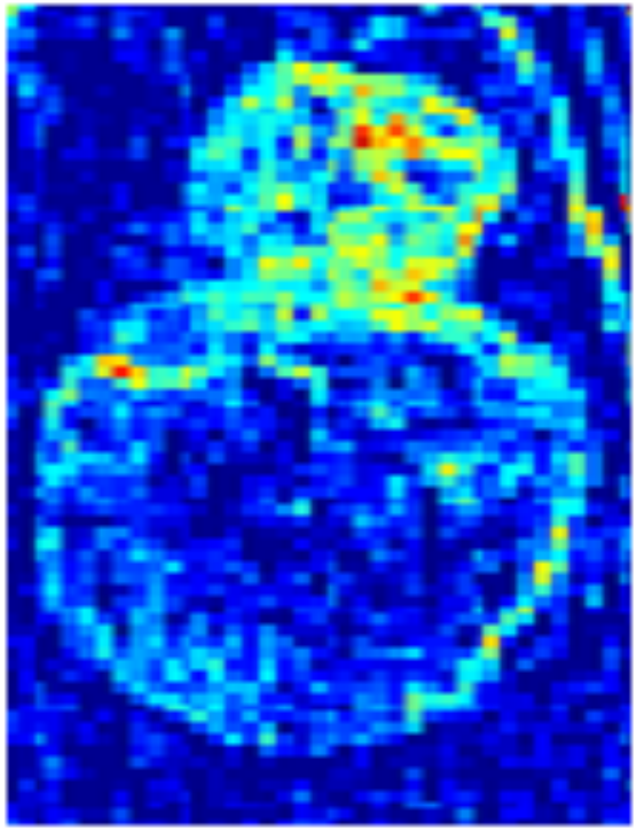
Fully sampled



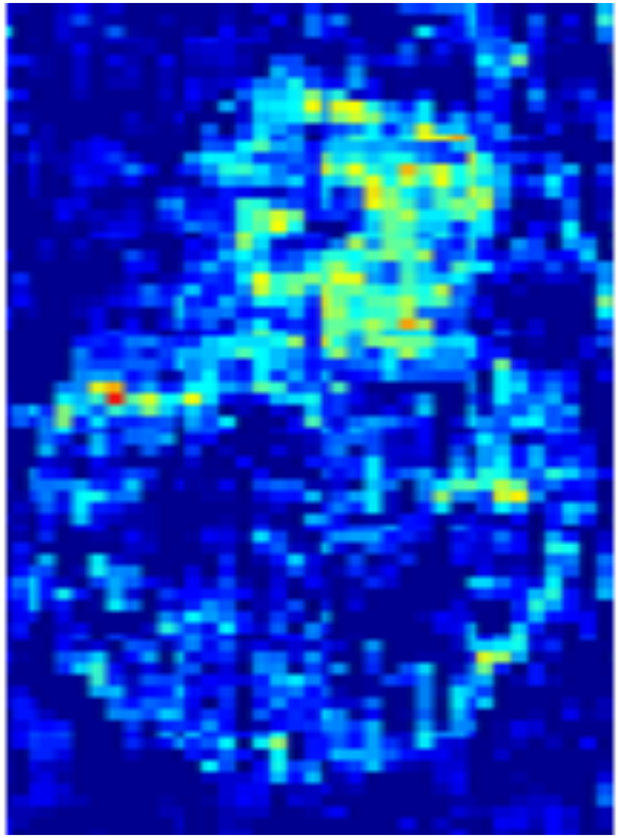
Zoom-in on tumor, 100x



Fully-sampled

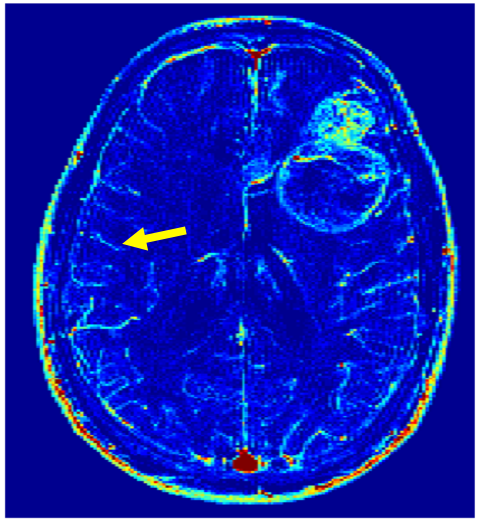


Direct

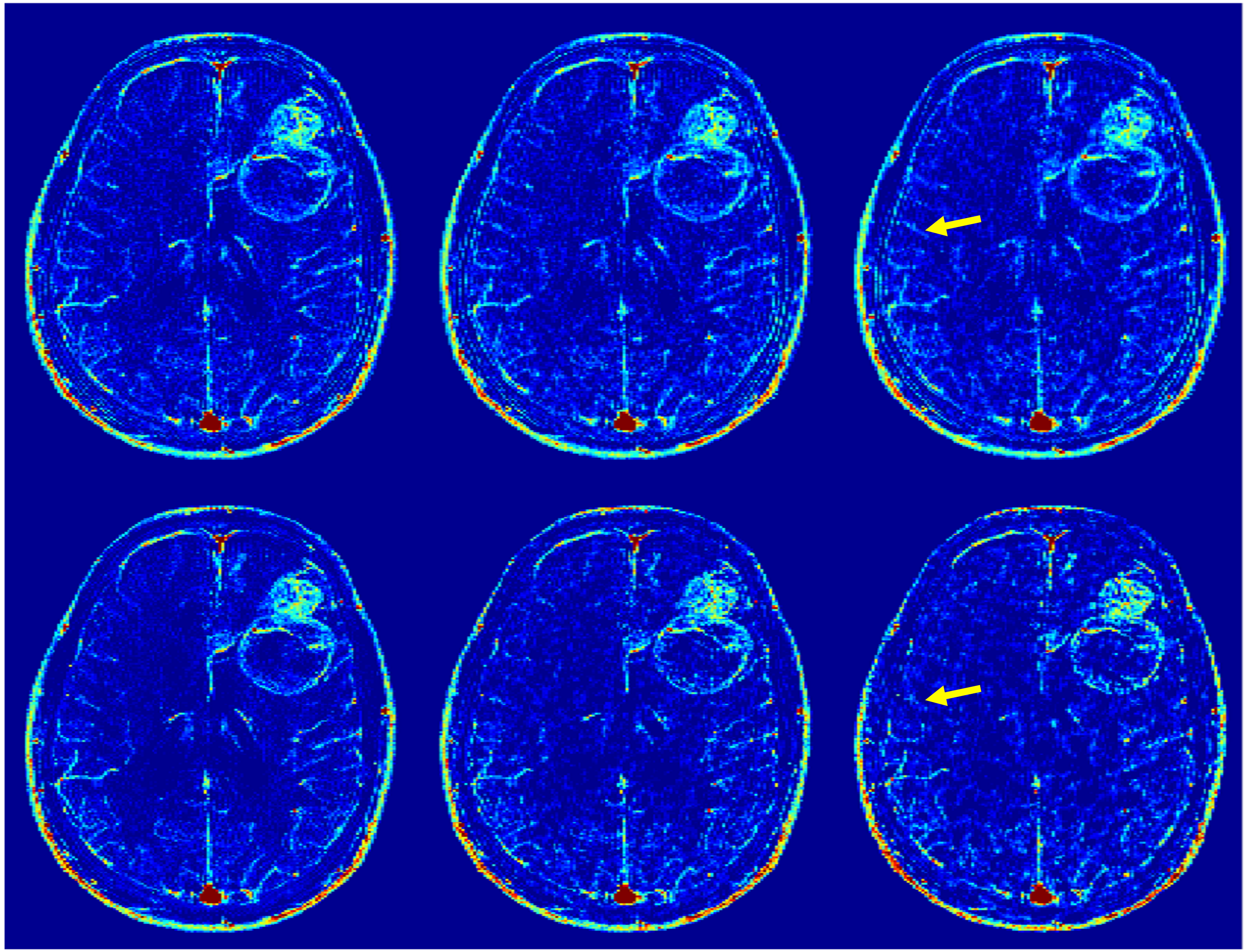


Conventional

v_p maps



Fully sampled

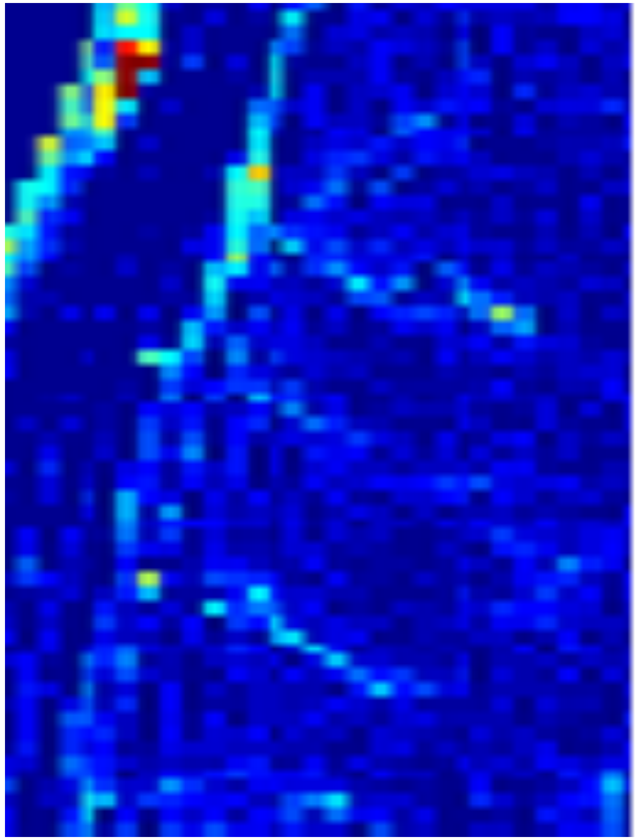


Direct

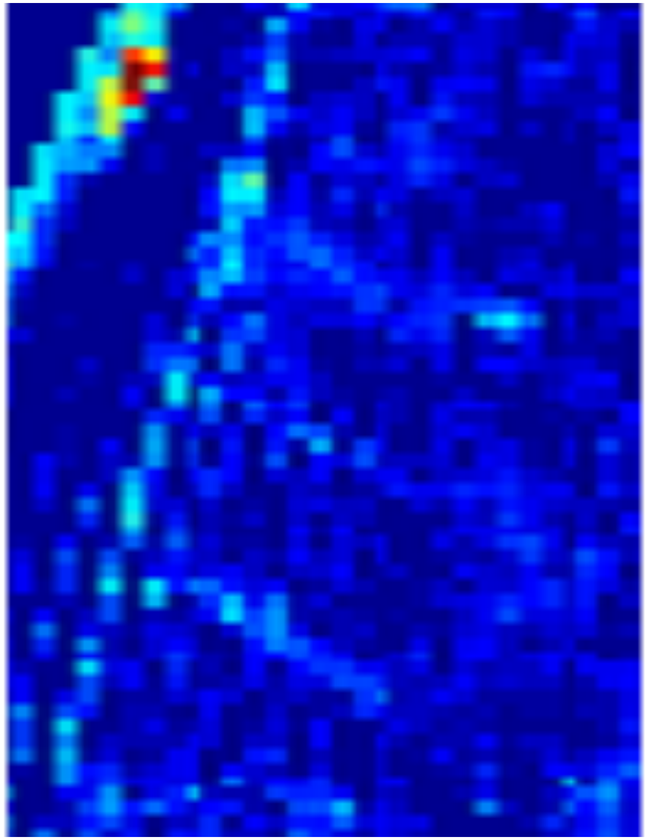
Conventional

20x 60x 100x

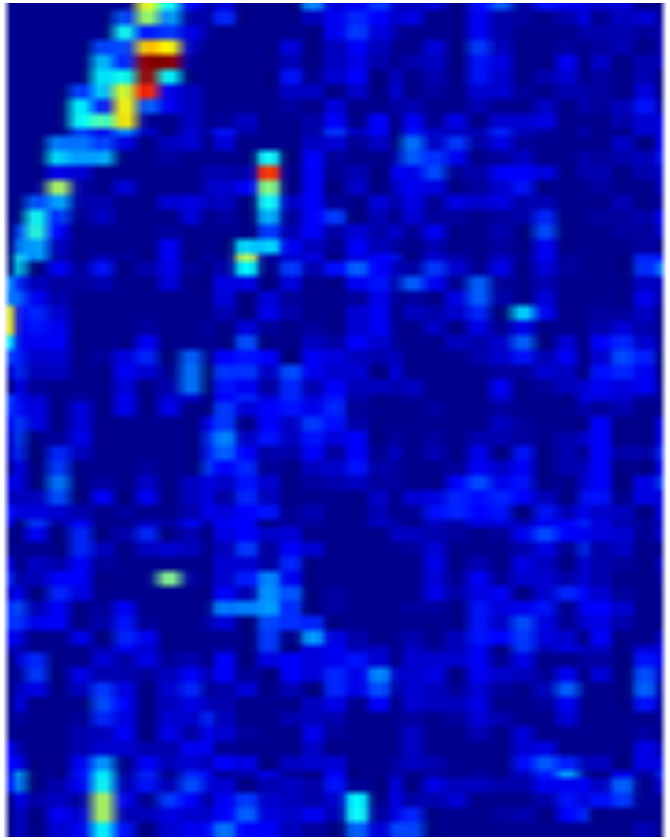
Zoom-in on vessels, 100x



Fully-sampled

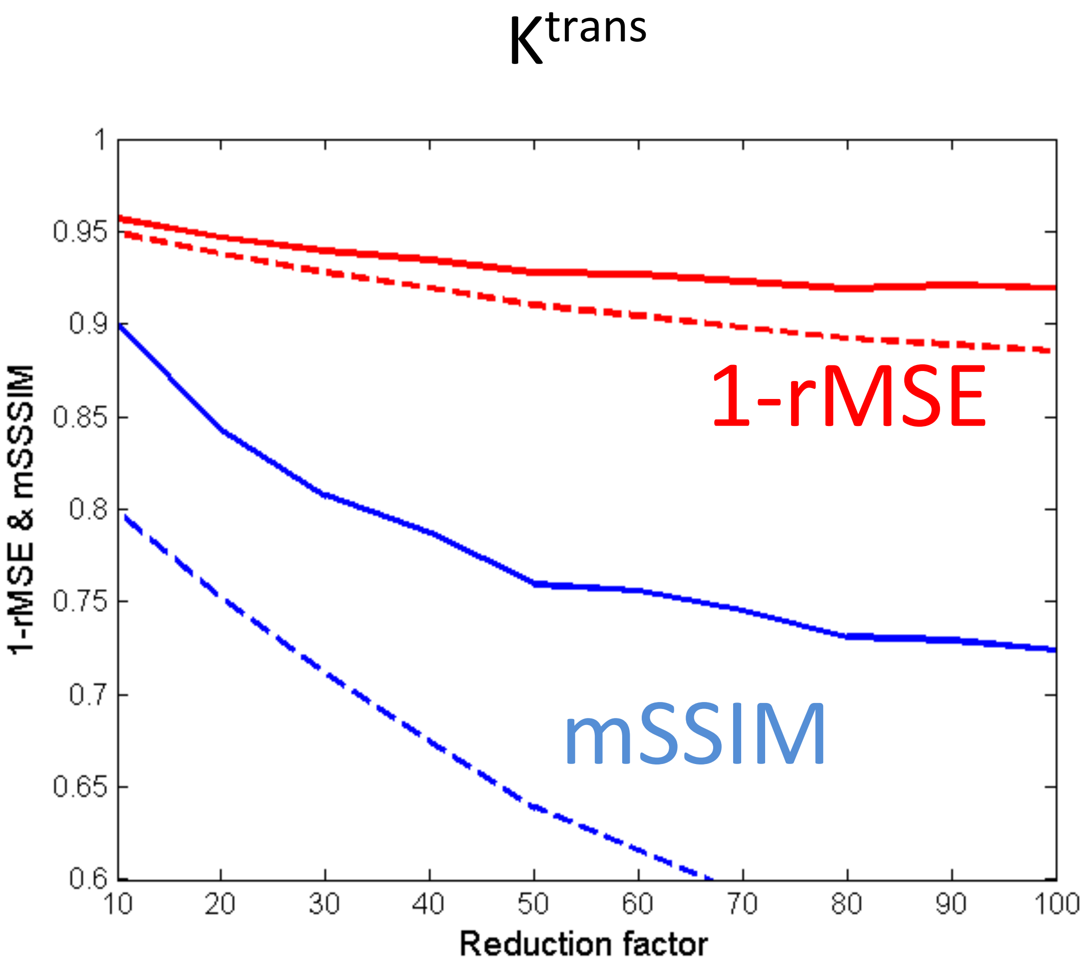


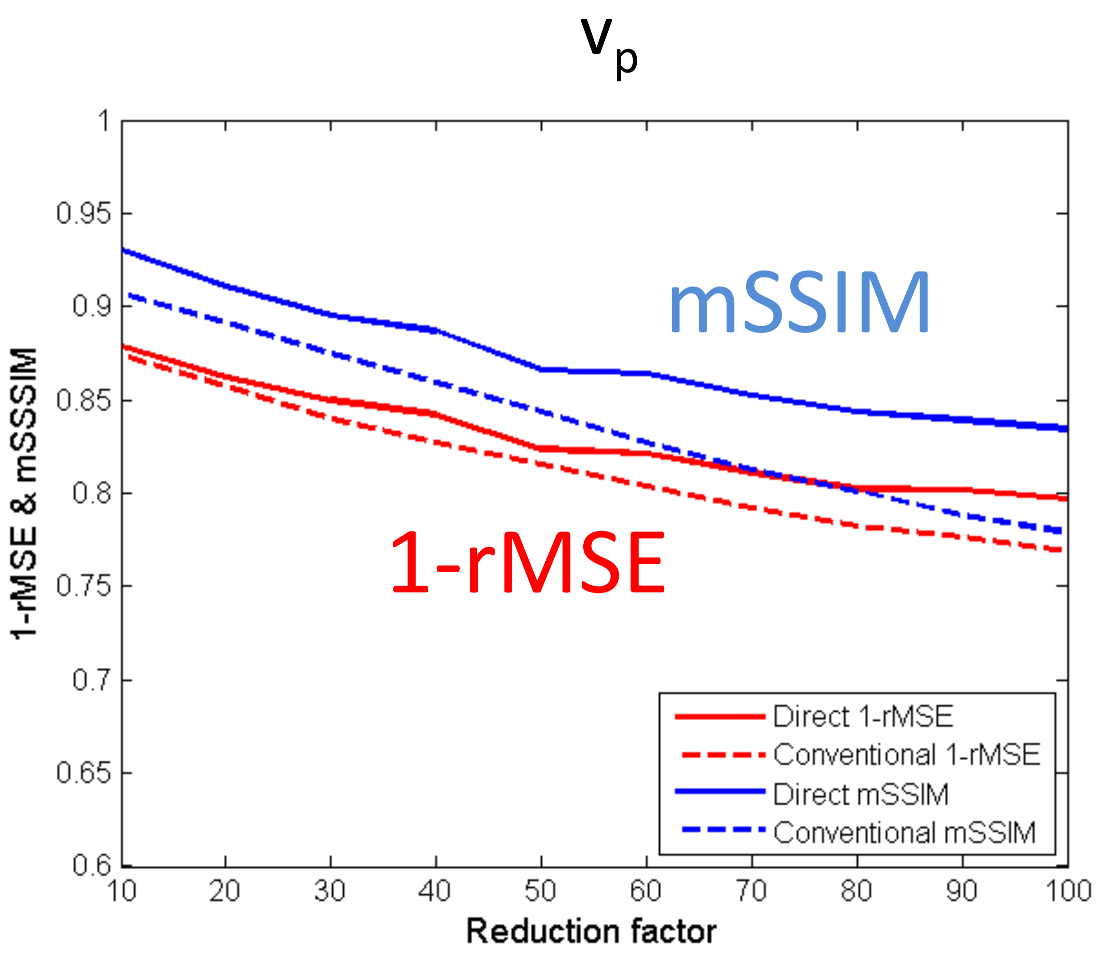
Direct



Conventional

1-rMSE and mSSIM

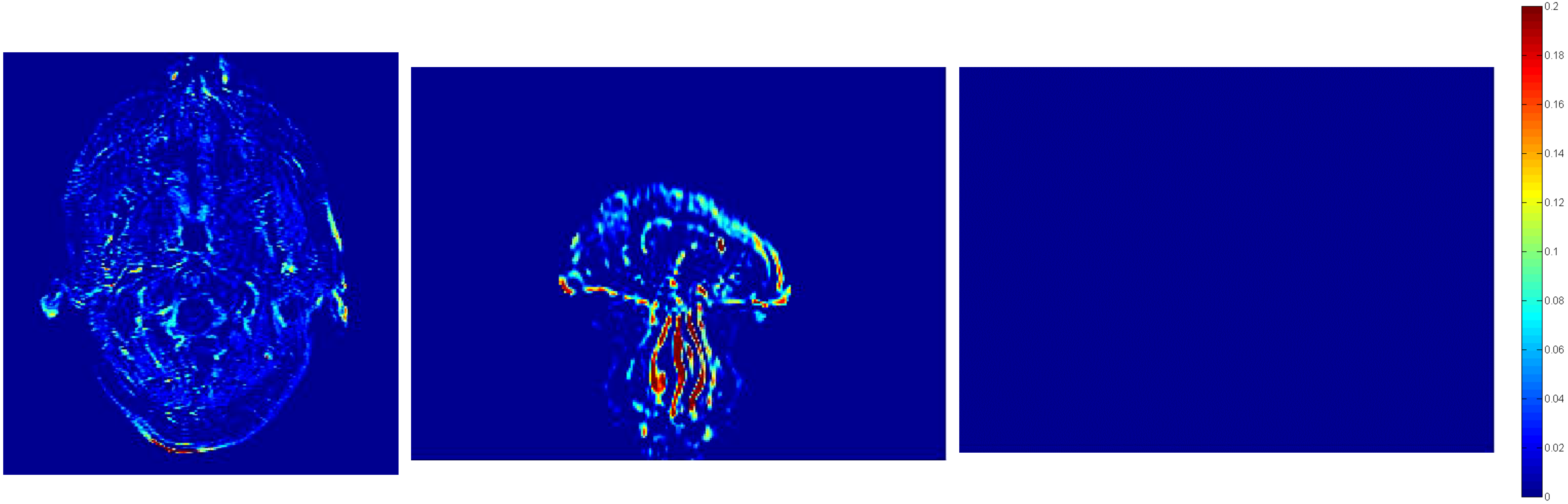




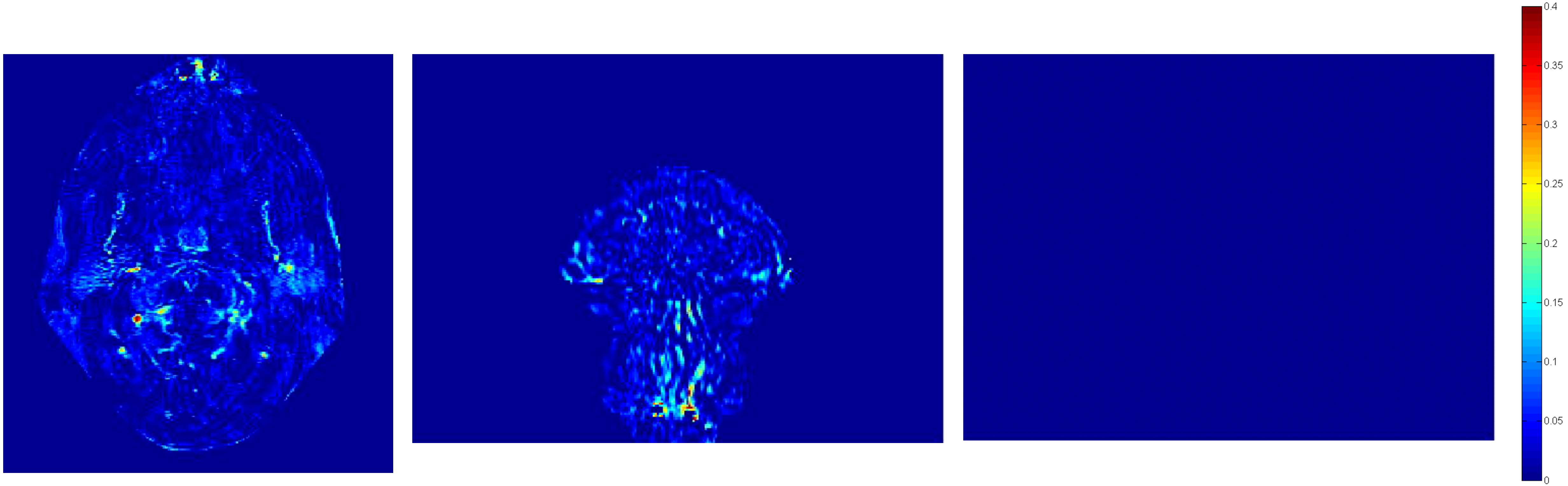
Prospective study

- Direct reconstruction from prospective under-sampled data:
  - A whole-brain FOV: $22 \times 22 \times 19 cm^3$
  - Spatial resolution: $0.9 \times 0.9 \times 1.9 mm^3$
  - Temporal resolution: 5s
  - Traditional golden-angle radial sampling
  - Prospective under-sampled in ky-kz plane
  - Reduction factor 30x

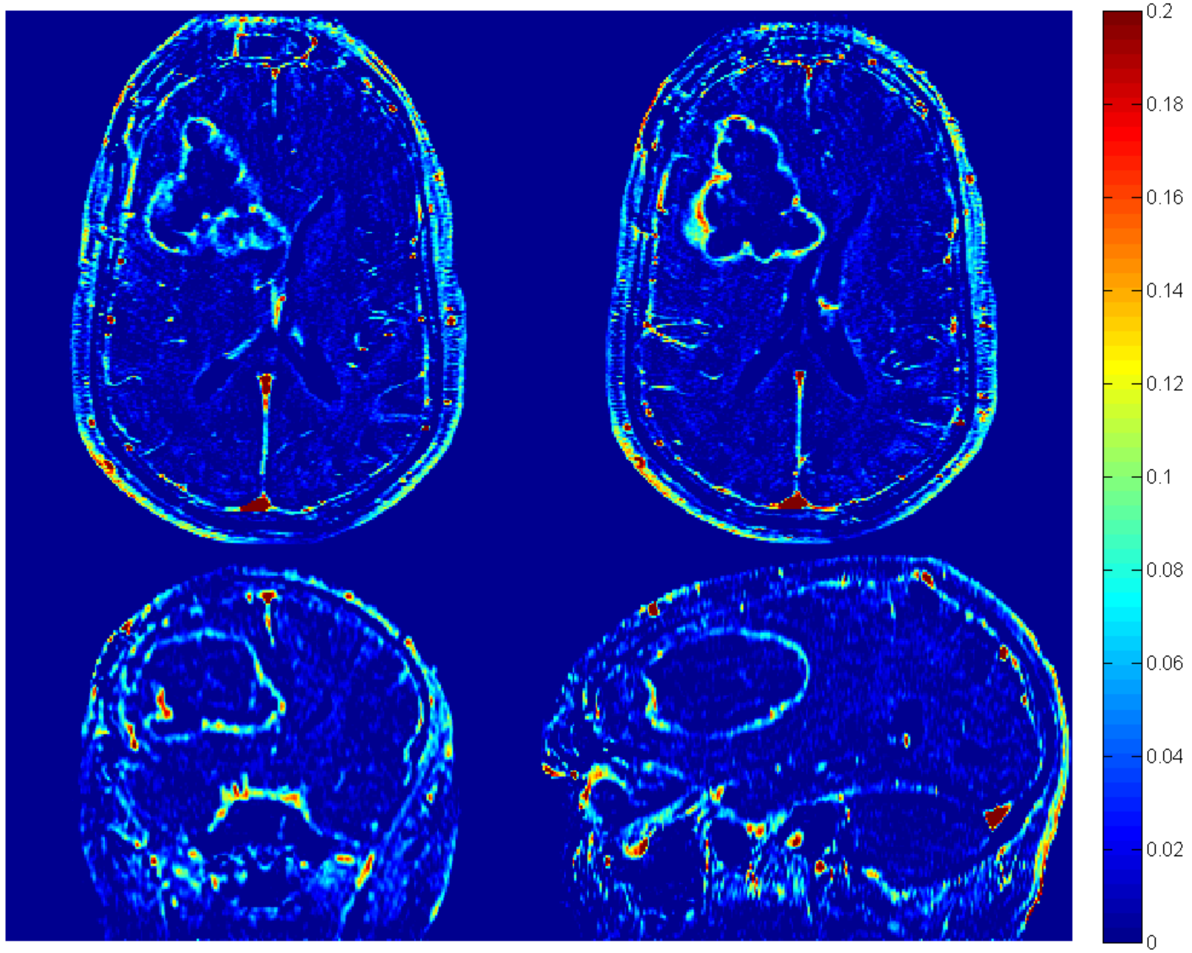
Whole-brain K^{trans} maps



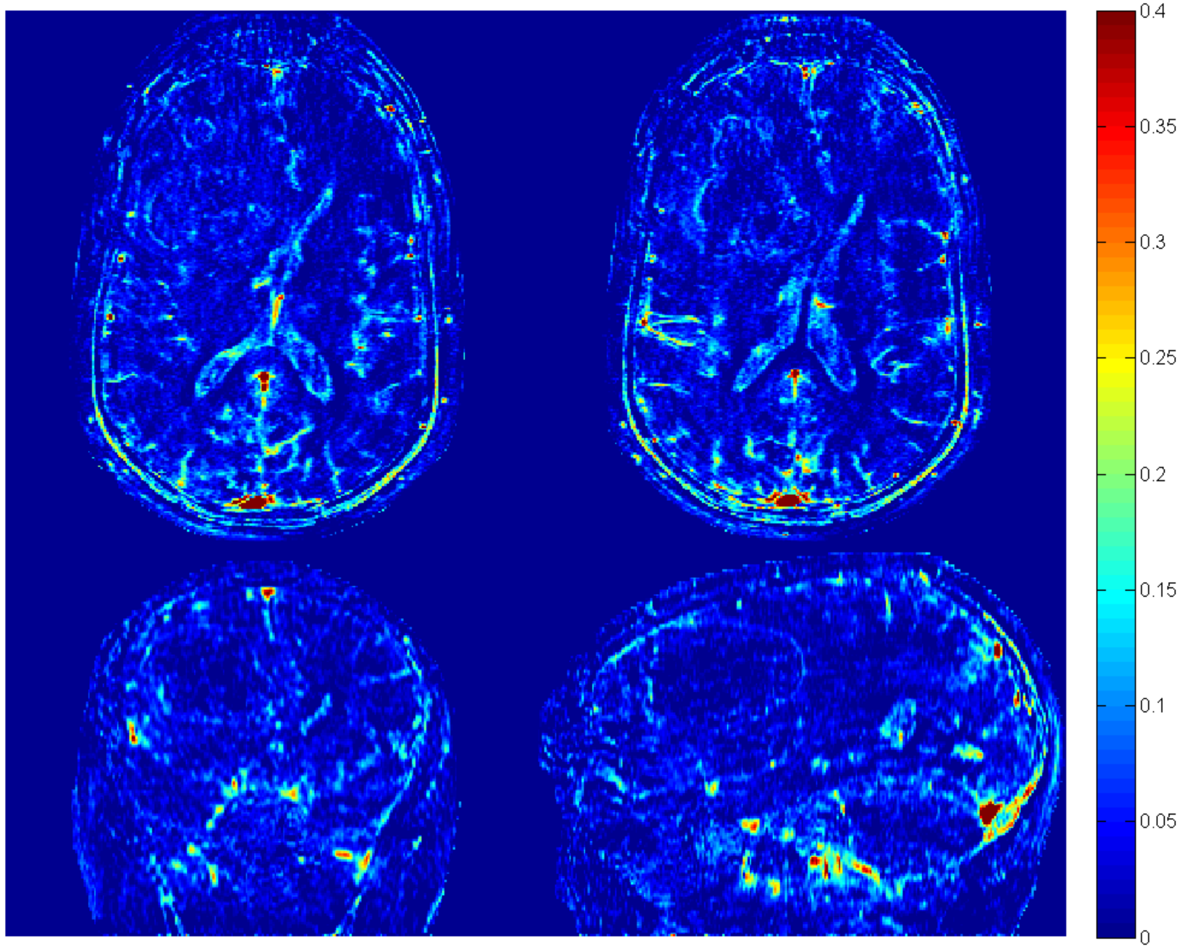
Whole-brain v_p maps



A three-plane view



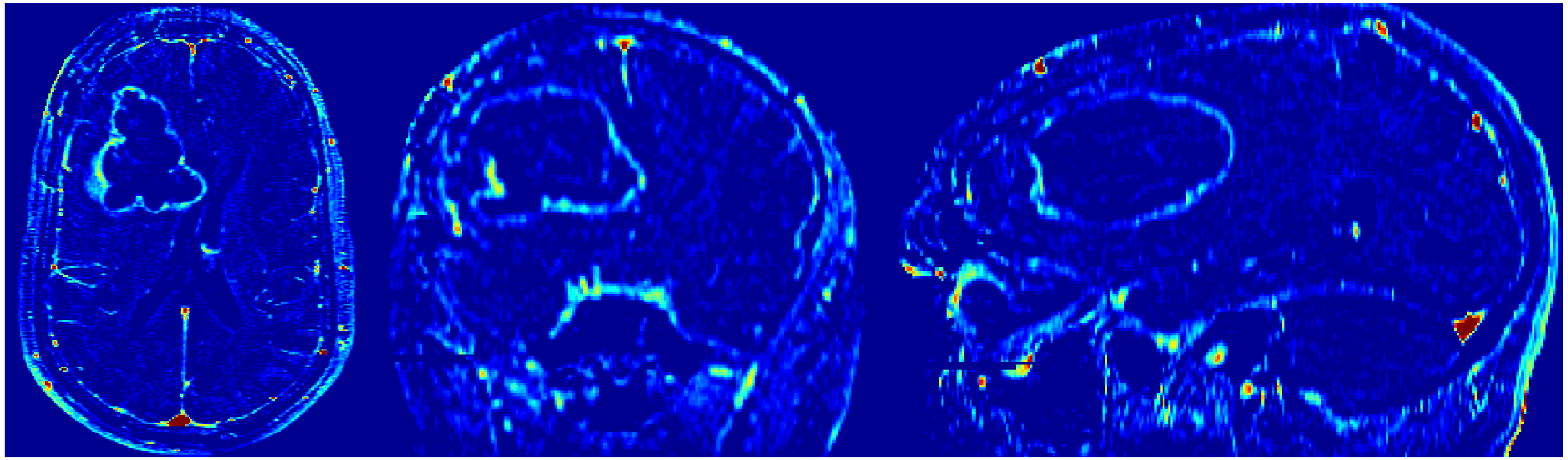
K^{trans}



v_p

Summary

- Direct reconstruction of PK maps is feasible.
- Superior accuracy up to reduction factor of 100x.
- No significant difference in reconstruction time.
- Parameter free reconstruction!
- Applied successfully to whole-brain DCE-MRI in brain tumor patients.



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- Keck Hospital of USC
- Other posters and talks

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