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Diffusion-Relaxation Correlation Spectroscopic Imaging (DR-CSI): A Multidimensional Approach for Probing Microstructure

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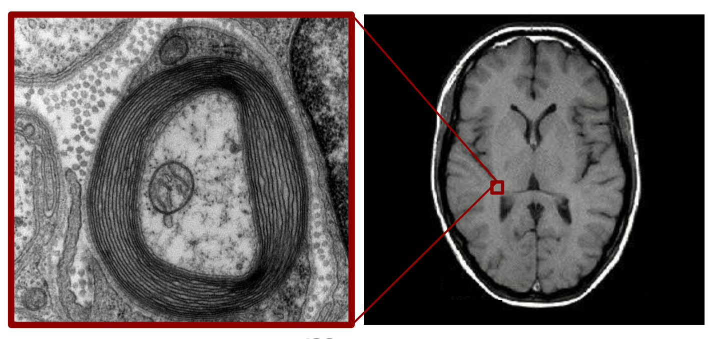
Introduction

- **Microstructure and MRI**
  Millimeter resolution
  Diffusometry and relaxometry
  - Multi-compartment model
- **DR-CSI**
  2D diffusion-relaxation spectroscopy Imaging
  Better compartmental separation

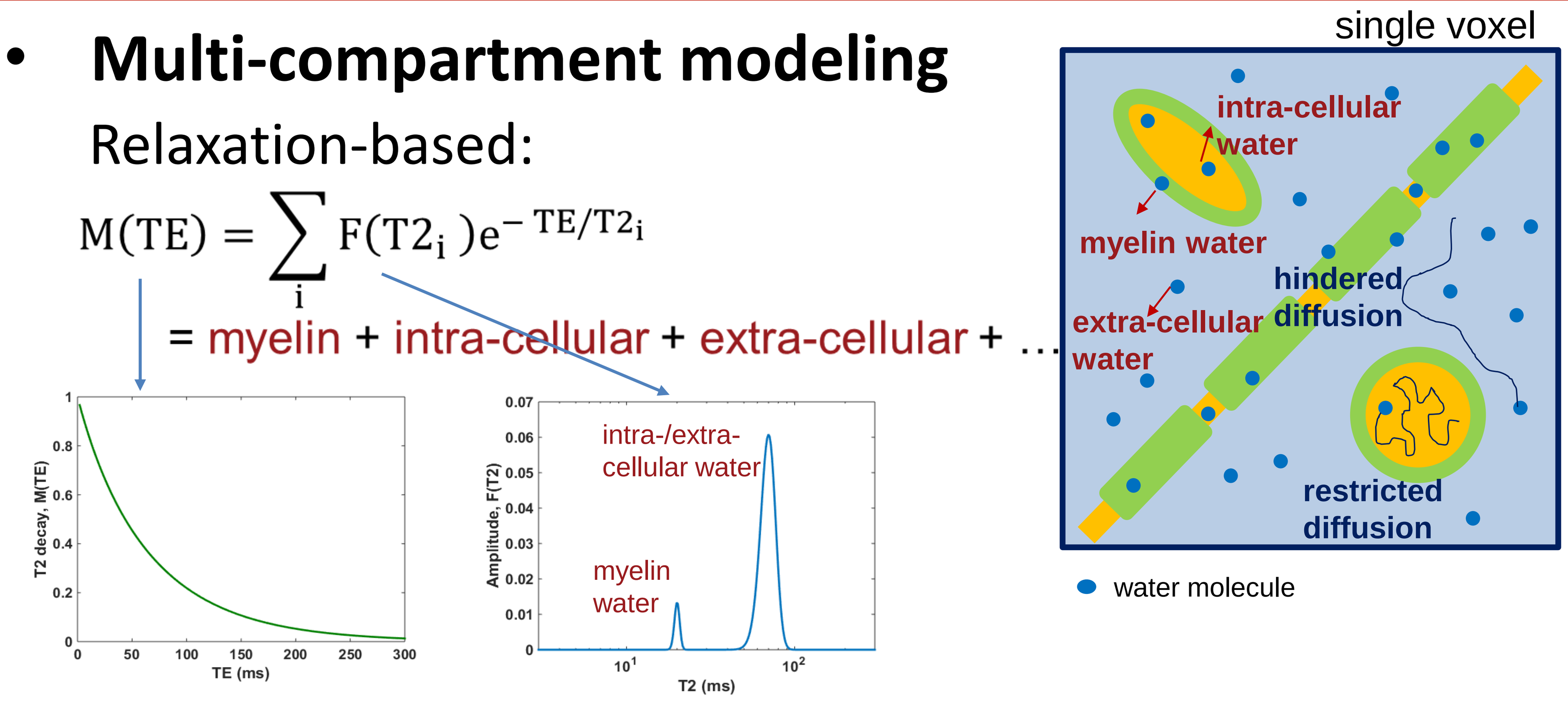


Diffusometry and Relaxometry

- **Multi-compartment modeling**
  Relaxation-based:

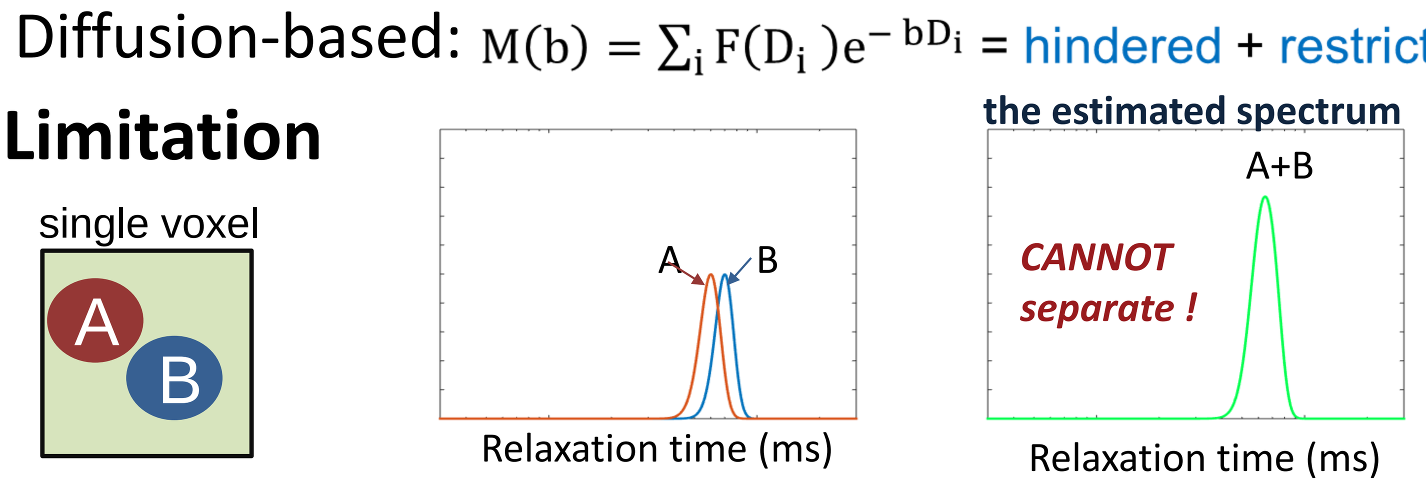
$$M(TE) = \sum_i F(T2_i)e^{-TE/T2_i}$$

= myelin + intra-cellular + extra-cellular + …



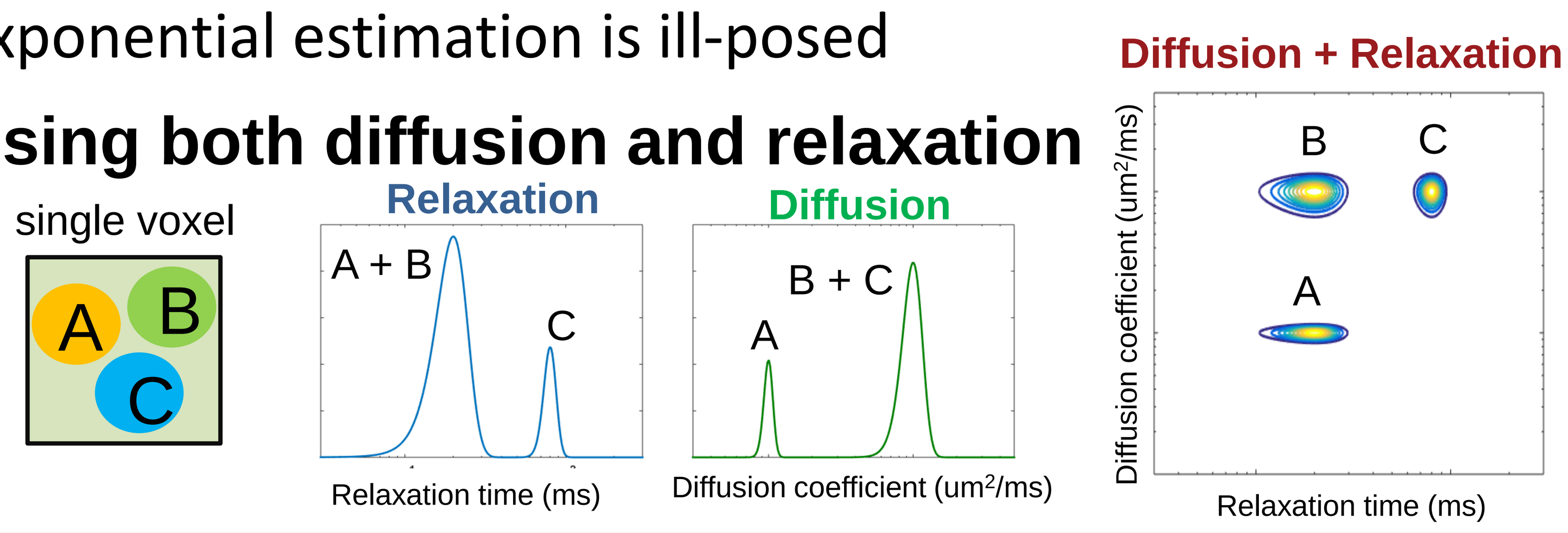
Diffusion-based: $M(b) = \sum_i F(D_i)e^{-bD_i}$ = hindered + restricted + …

- **Limitation**



Compartmental ambiguities
Exponential estimation is ill-posed

- **Using both diffusion and relaxation**



Proposed method: DR-CSI

- **Advanced contrast encoding -** 2D diffusion-relaxation
- **Advanced estimation -** Improved conditioning

Lin et al., IEEE TMI 2014, Hwang et al., JMR 2009, Kumar et al., MRM 2012

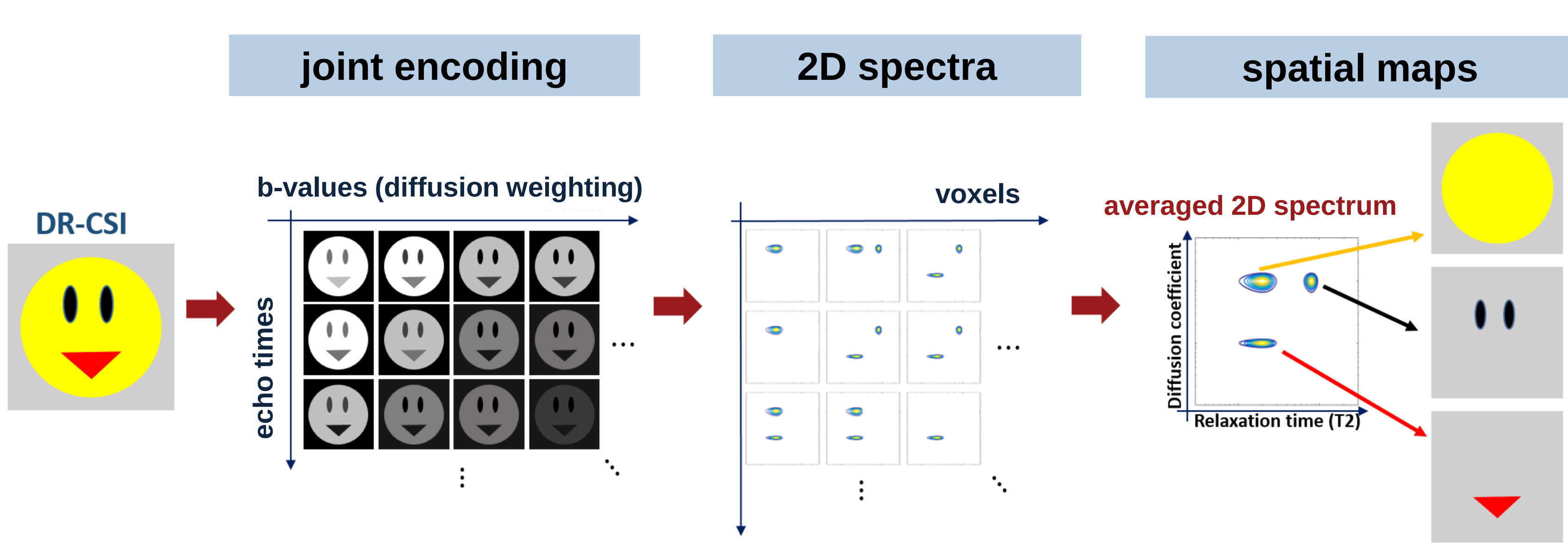
- **2D multi-exponential model**

$$M(x,y,b,TE) = \sum_i \sum_j F(x,y,D_i,T2_j)e^{-TE/T2_j}e^{-bD_i}$$

- **Dictionary-based constrained optimization**

$$\underbrace{\{\mathbf{f}_i\}_{i=1}^N}_{\text{2-D spectra at } i\text{-th voxel}} = \underset{\underbrace{\{\mathbf{f}_i\}_{i=1}^N > 0}_{\text{Nonnegativity}}}{\operatorname{argmin}} \sum_{i=1}^N \left[\underbrace{\|\mathbf{m}_i - \mathbf{K}\mathbf{f}_i\|_2^2}_{\text{Data consistency}} + \underbrace{\lambda \sum_{j \in \Delta i} \|\mathbf{f}_j - \mathbf{f}_i\|_2^2}_{\text{Spatial smoothness}} \right]$$

Optimization: ADMM Afonso et al., IEEE TIP 2010



Numerical simulation

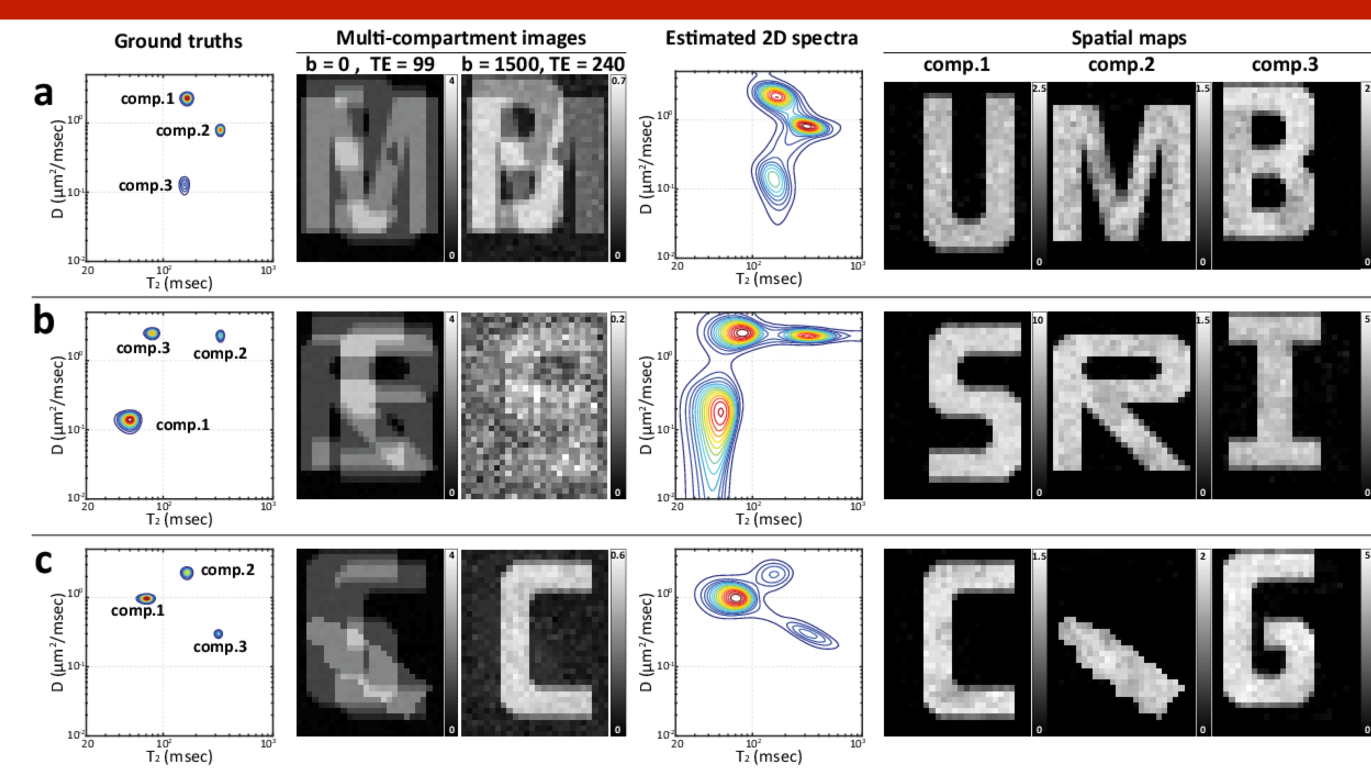


Fig. 1: (a-c) Numerical simulation setup and estimation results for three different multicompartment datasets with different diffusion-relaxation correlation characteristics

Phantom experiment

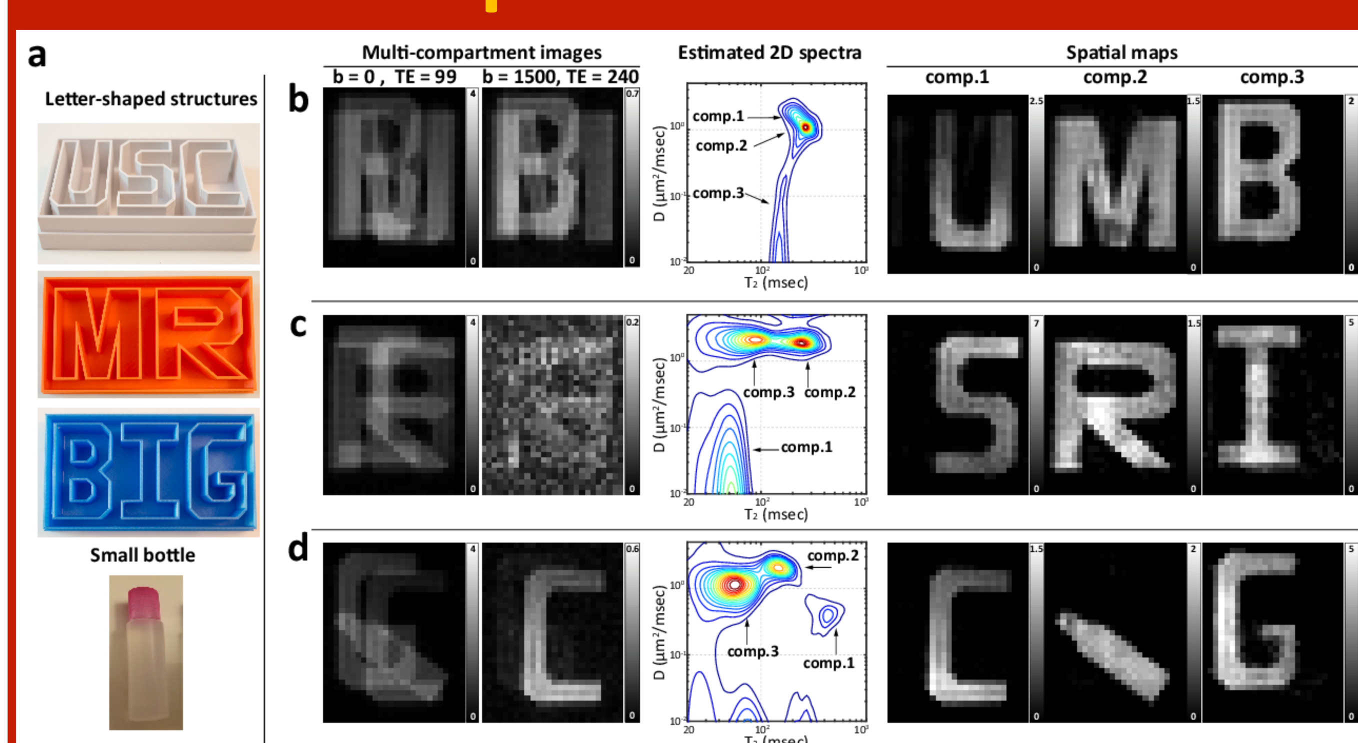


Fig. 2: (a) Structural components used to assemble the custom-built diffusion-relaxation phantom. (b-c) Example data and DR-CSI estimation results obtained with this phantom.

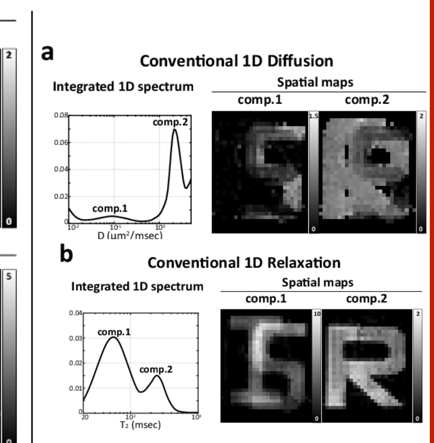


Fig. 3: Estimation results from (a) conventional 1D diffusion, (b) conventional 1D relaxation

Ex-vivo mouse spinal cord experiment

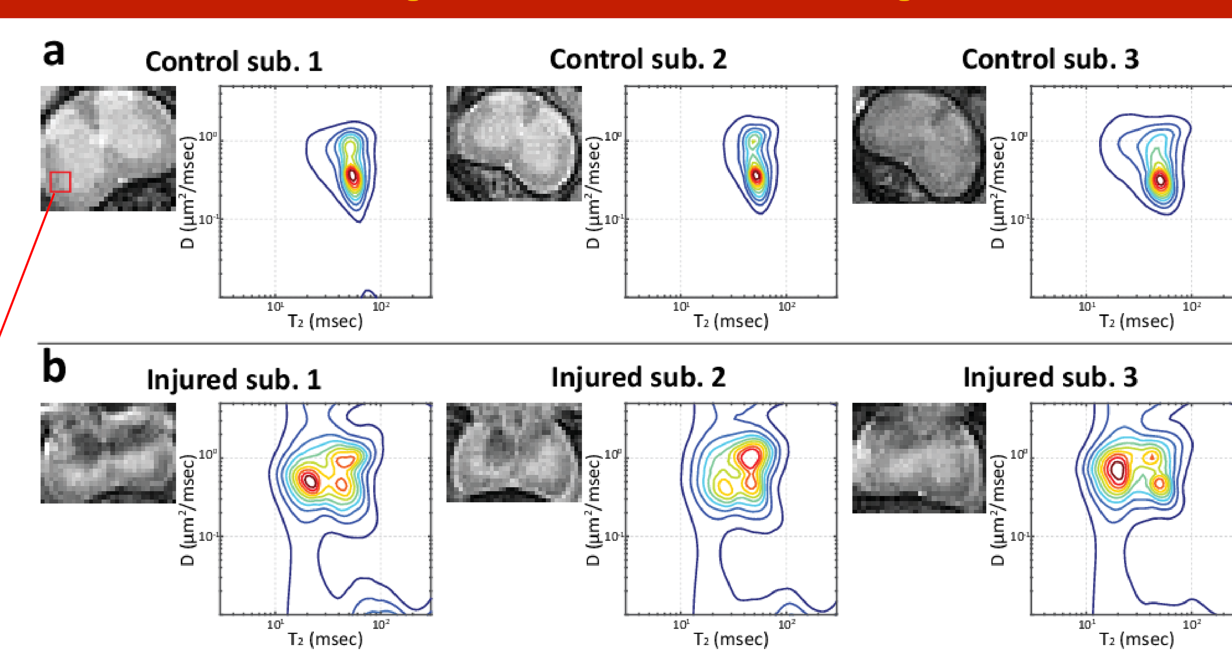


Fig. 4: Reference images and spatially-averaged DR-CSI spectra

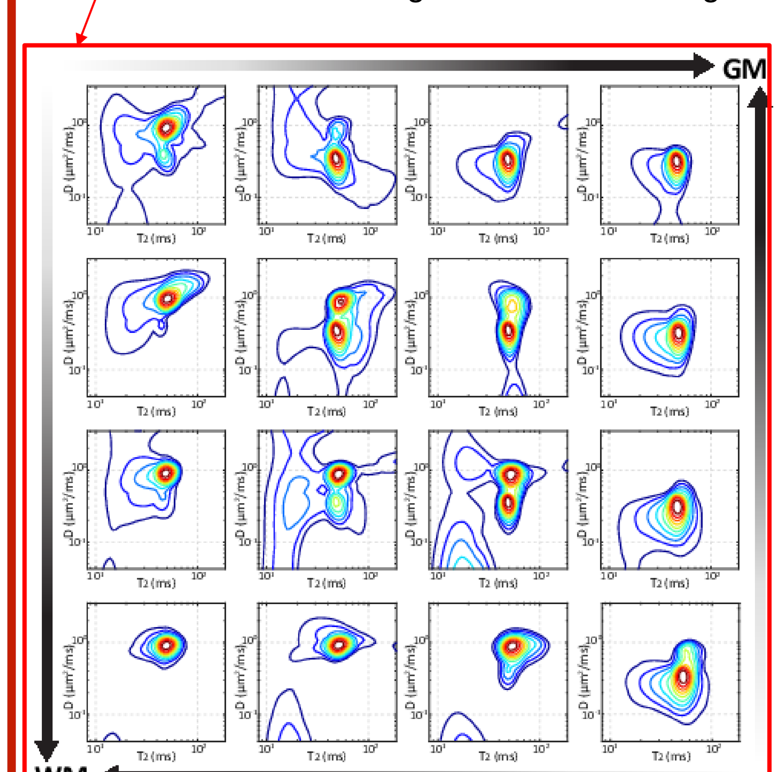


Fig. 5: Spatially-varying DR-CSI spectra from the boundary between WM and VGM in the control cord (subject 1)

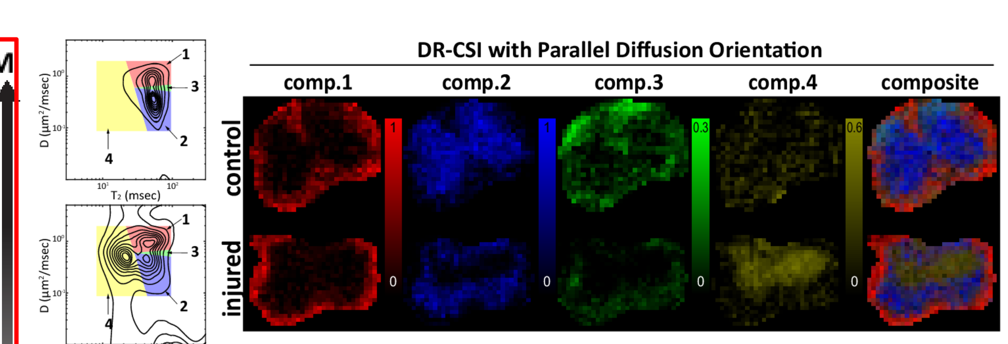


Fig. 6: Spatial maps of the integrated spectral peaks from the DR-CSI reconstruction

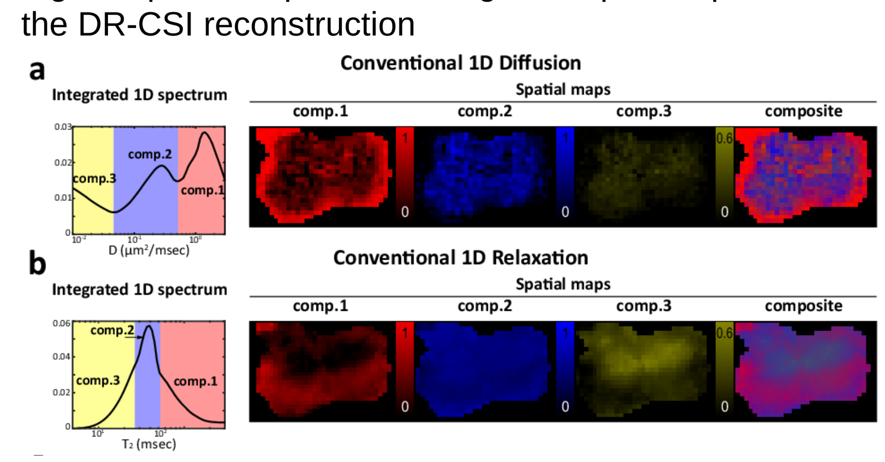


Fig. 7: Spatially-averaged spectra and spatial maps of the integrated spectral peaks from conventional 1D methods

Conclusion

2D diffusion-relaxation spectroscopy + imaging
Substantial advantages over traditional 1D multi-compartment estimation
- Less compartmental ambiguity
- Better-posed inverse problem

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