Quantifying human gray matter microstructure using NEXI and 300 mT/m gradients

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#0685

ISMRM & ISMRT Annual Meeting & Exhibition 2023
03-08 June 2023

UNIL | Université de Lausanne
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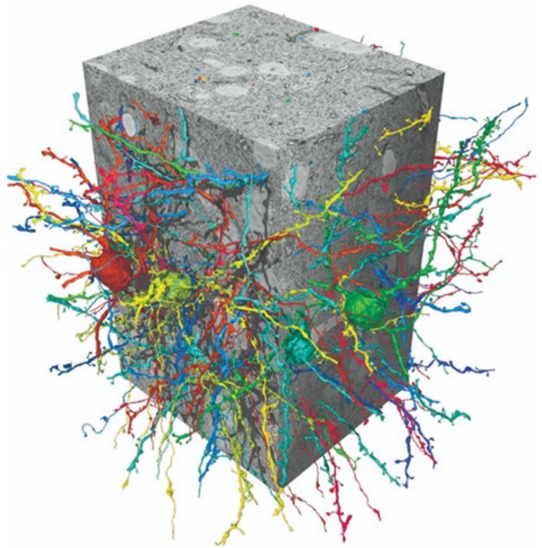
Declaration of Financial Interests or Relationships

Speaker Name: Quentin Uhl

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

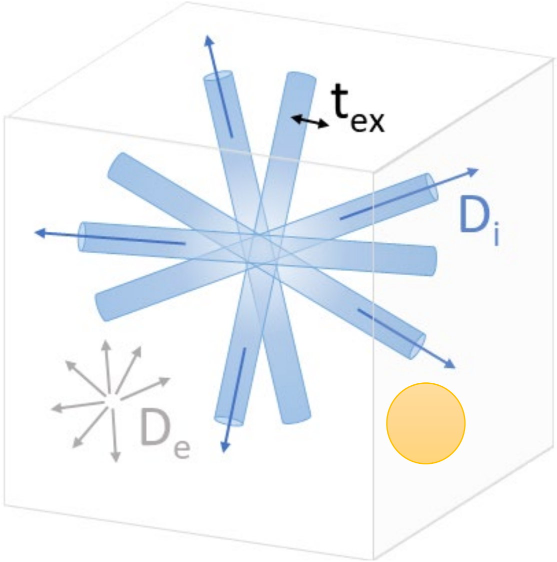
Modeling Gray Matter: Neurite Exchange Imaging (NEXI)



Gray matter microstructure models require:

- Water exchange across the cell membrane
- Signal contribution from cell bodies
- Non-Gaussian diffusion → structural disorder

$[t_{ex}, Di, De, f]$



Volume fraction

Intra-neurite space	f
Extra-neurite space	$1-f$
Dot compartment	f_{dot}

f and $1-f$: $1-f_{dot}$

Sources : Jelescu et al. 2022. NeuroImage
Olesen et al. 2022. NeuroImage
Tax et al. 2020, NeuroImage

NEXI & its variants

NEXI

Kernel:	$\mathcal{K}(q,t,\mathbf{g}\cdot\mathbf{n};\ f, D_{i,\parallel}, D_e, t_{ex}) = f' e^{-q^2 t D_i'} + (1-f') e^{-q^2 t D_e'}$
Where: "apparent" diffusivities	$D_{i/e}' = \frac{1}{2}\left\{ D_{i,\parallel}(\mathbf{g}\cdot\mathbf{n})^2 + D_e + \frac{1}{q^2 t_{ex}} \mp \left[\left[D_e - D_{i,\parallel}(\mathbf{g}\cdot\mathbf{n})^2 + \frac{2f-1}{q^2 t_{ex}}\right]^2 + \frac{4f(1-f)}{q^4 t_{ex}^2}\right]^{\frac{1}{2}} \right\}$
"apparent" fraction	$f' = \frac{1}{D_i' - D_e'}\left[f D_{i,\parallel}(\mathbf{g}\cdot\mathbf{n})^2 + (1-f)D_e - D_e'\right]$
Powder average (over directions):	$S_{NEXI}(q,t) = S\big\rvert_{q=0} \cdot \int_0^1 \mathcal{K}(q,t,\mathbf{g}\cdot\mathbf{n};\mathbf{p})\,d(\mathbf{g}\cdot\mathbf{n})$

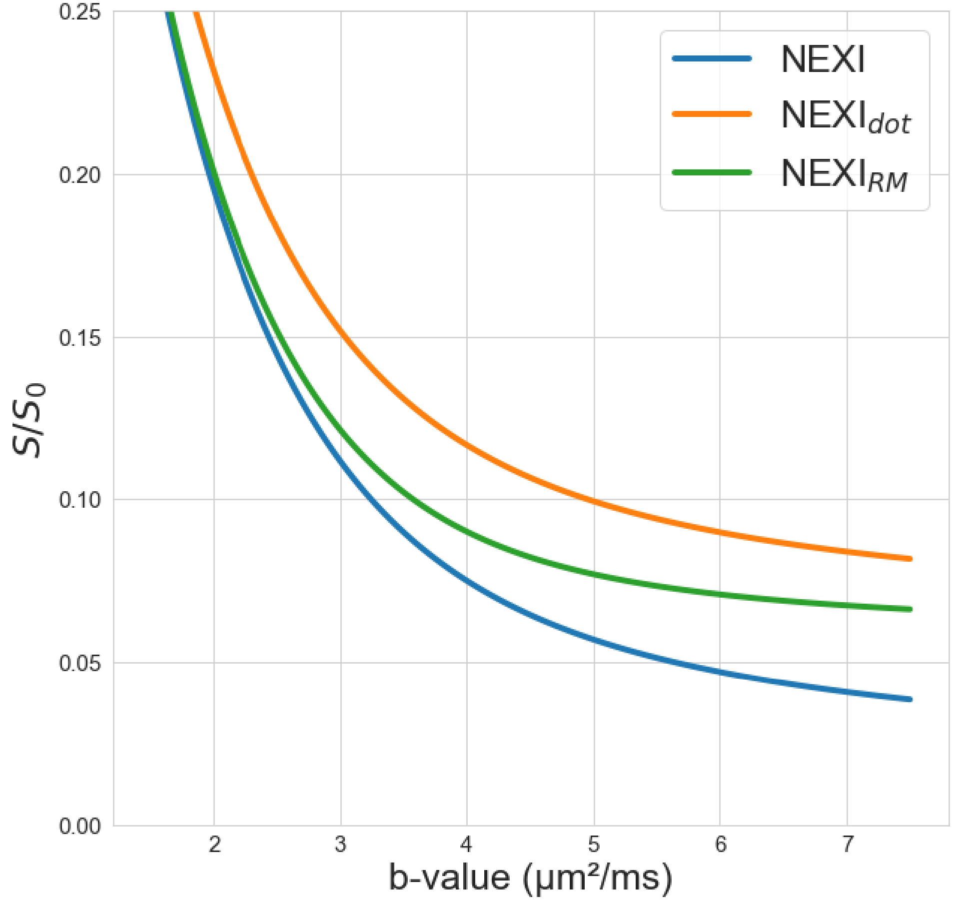
NEXI$_{RM}$

$$\overline{S_{NEXI_{RM}}} = \sqrt{\frac{\pi}{2}}.\sigma.L_{1/2}\left(-\frac{1}{2}\left(\frac{\overline{S_{NEXI}}}{\sigma}\right)^2\right)$$

NEXI$_{dot}$

$$\overline{S_{NEXI_{dot}}} = (1 - f_{dot}).\overline{S_{NEXI}} + f_{dot}$$

At fixed diffusion time (t_d)



Sources : Jelescu et al. 2022. NeuroImage
Olesen et al. 2022. NeuroImage
Tax et al. 2020, NeuroImage

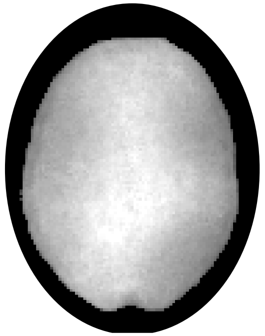
Preprocessing

Raw data

- 3T, 300mT/m gradients, PGSE EPI sequences
- 4 subjects; 3 with a rescan
- 5 b-values: from 1 to 7.5 µm²/ms
- 4 diffusion times: from 20 to 49 ms
- δ = 9 ms, TE = 76ms
- 1.8 mm isotropic resolution

MP-PCA Denoising[1] → Gibbs ringing correction[2] → Topup[3] → Eddy currents correction[4] → Powder average → Input for NEXI fit

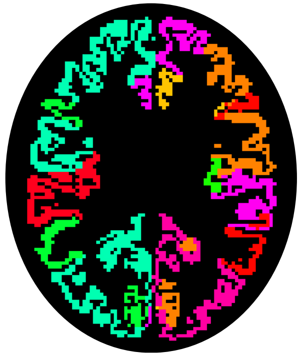
MP-PCA Denoising[1] → Noisemap



Eddy currents correction[4] → DKT Atlas segmentation[5,6]

T1 → DKT Atlas segmentation[5,6]

DKT Atlas segmentation[5,6] → Regions Of Interest (ROI)



Sources : [1] Veerart, NeuroImage 2016 [2] Kellner, MRM 2016 [3] Andersson, NeuroImage 2003
[4] Andersson, NeuroImage 2016 [5] Henschel, NeuroImage 2020 [6] Avants et al., Insight j, 2009

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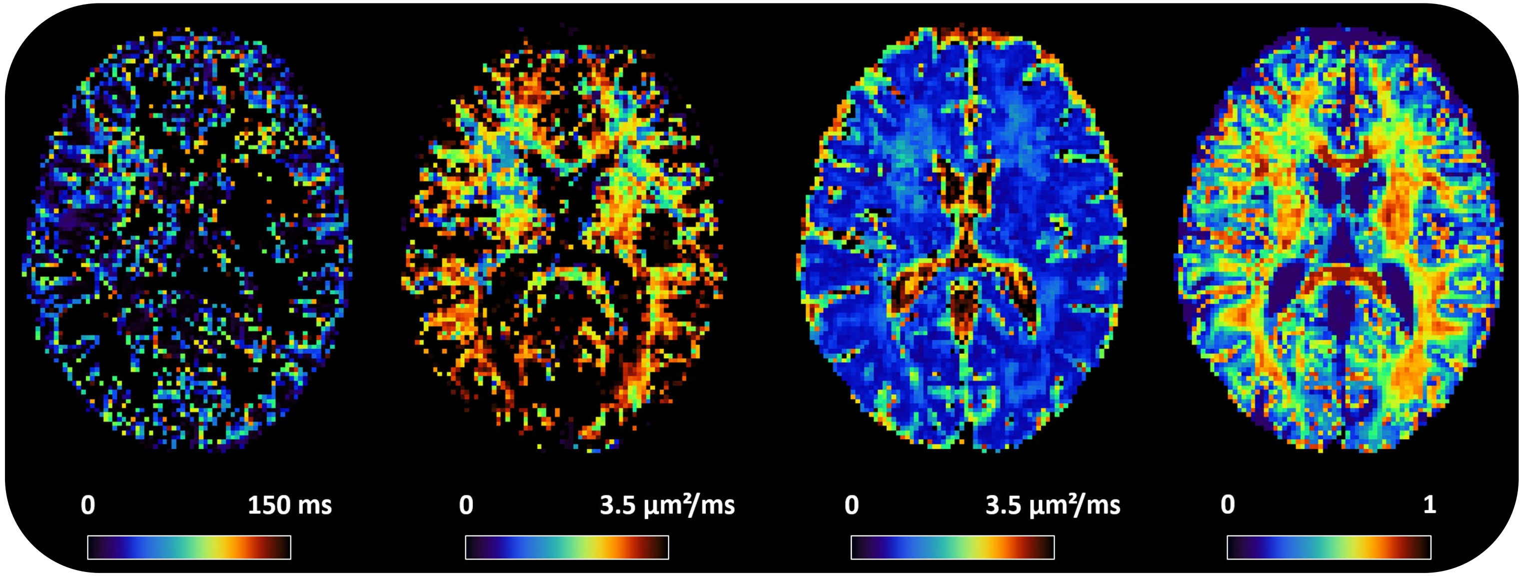
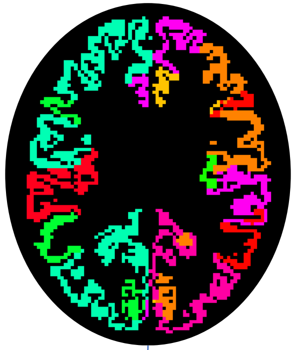
NEXI$_{RM}$





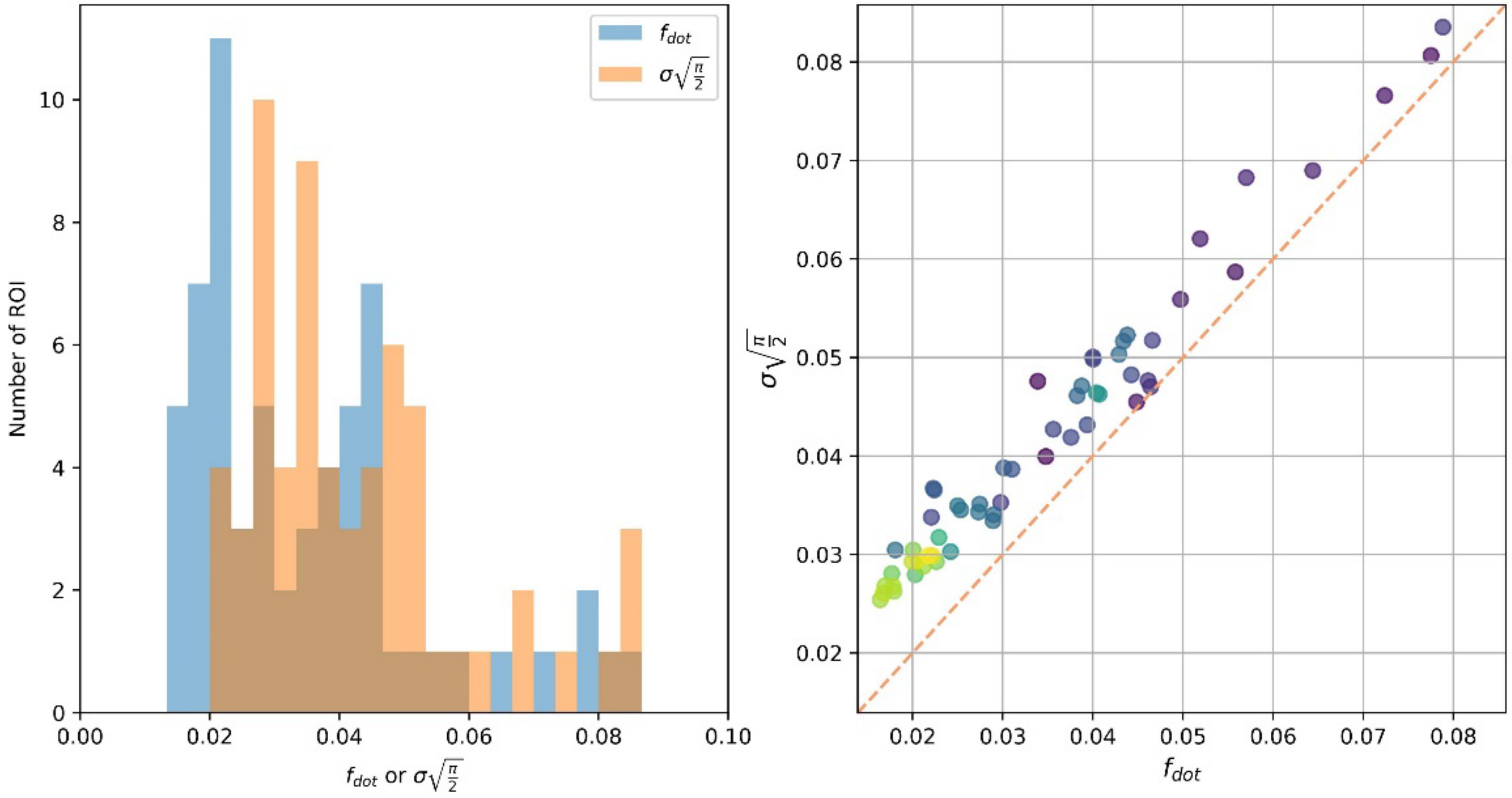
Mean of ROI medians

	t_{ex} (ms)	Di (µm²/ms)	De (µm²/ms)	f	f_{dot}	AICc
NEXI	**103.91** [100.29, 107.53]	**2.79** [2.71, 2.88]	**0.95** [0.94, 0.96]	**0.32** [0.318, 0.325]	-	**42.49** ± 5.62
NEXI$_{dot}$	**14.27** [12.25, 16.29]	**3.36** [3.32, 3.40]	**1.00** [0.99, 1.01]	**0.36** [0.35, 0.37]	**0.03** [0.033, 0.037]	**38.08** ± 6.18
NEXI$_{RM}$	**42.34** [40.00, 44.68]	**3.35** [3.32, 3.38]	**0.92** [0.91, 0.93]	**0.38** [0.379, 0.389]	-	**45.45** ± 5.69
NEXI$_{dot, RM}$	**2.90** [2.71, 3.09]	**3.36** [3.34, 3.39]	**1.03** [1.01, 1.04]	**0.47** [0.47, 0.48]	**0.01** [0.009, 0.010]	**48.24** ± 6.19

- NEXI$_{RM}$ and NEXI$_{dot,RM}$ AICc includes both the error of the model and the error on the noisemap
- NEXI$_{dot}$ is preferred over NEXI while NEXI$_{RM}$ is preferred over NEXI$_{dot,RM}$ …

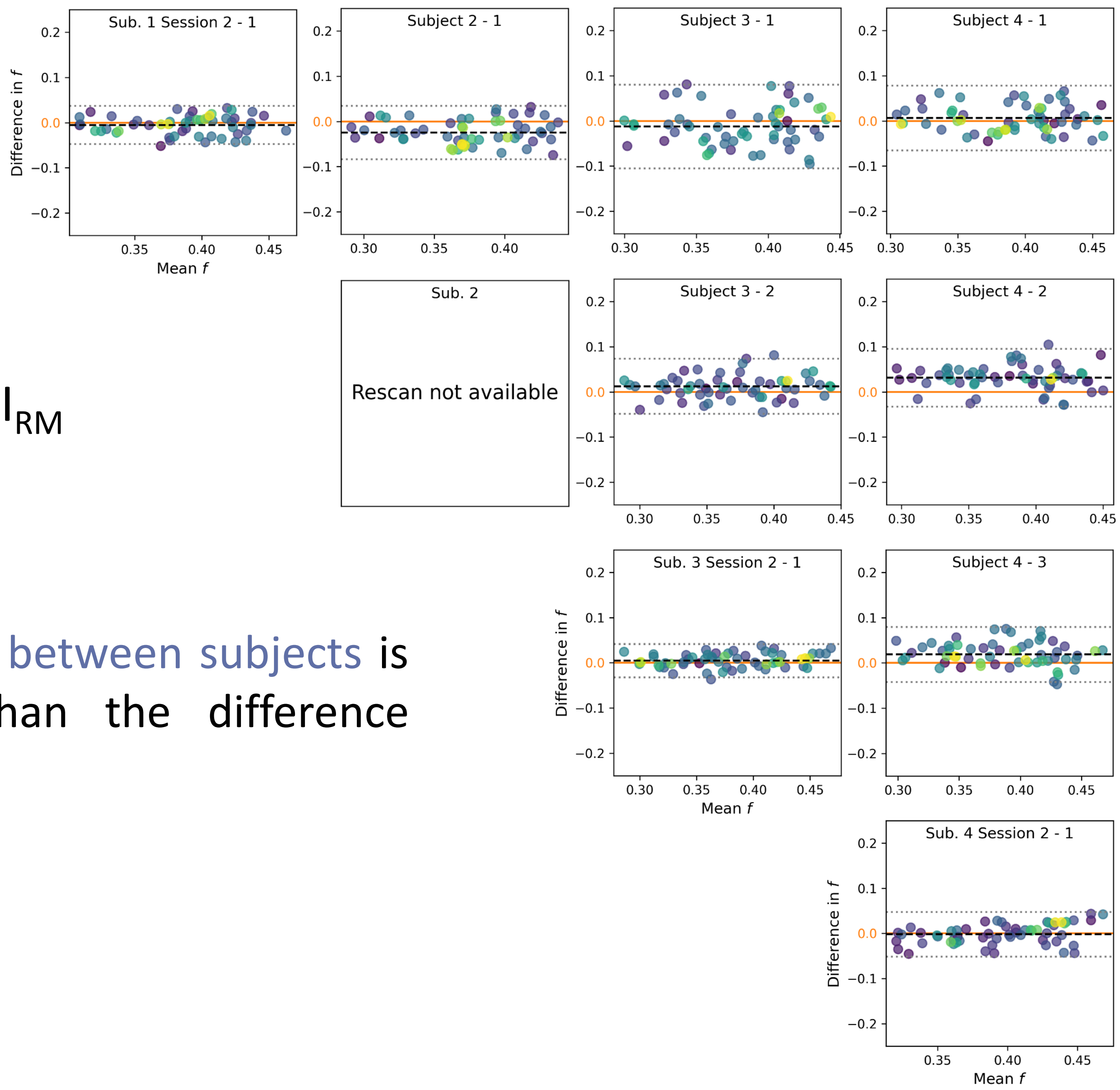
* 95% CI

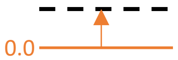
Agreement between the dot fraction estimate of NEXI_{dot} and the Rician floor



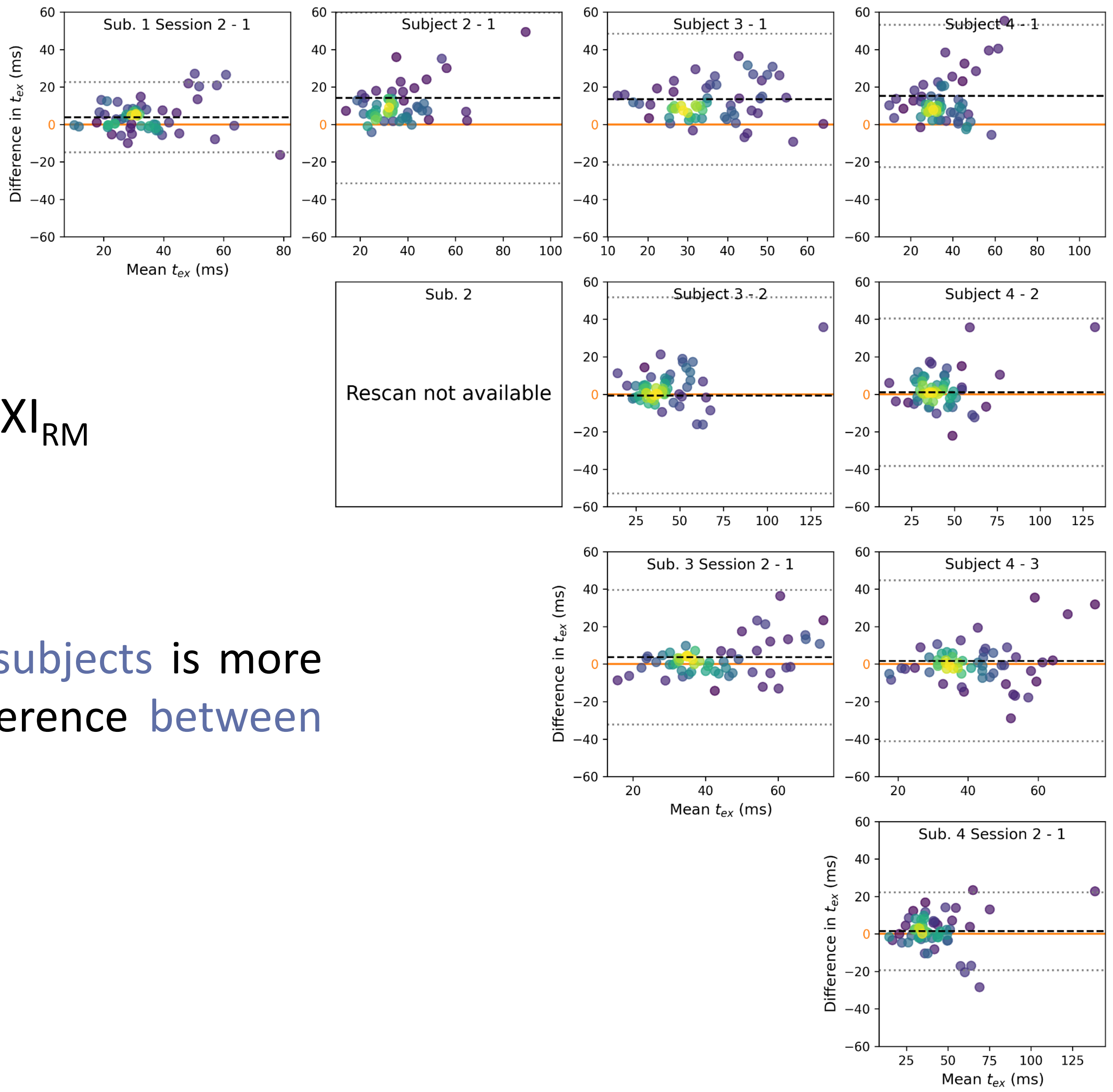
- NEXI_{dot} essentially captures the Rician noise floor as a dot compartment.

Bland-Altman plots of the *f* estimations agreement from $\mathrm{NEXI}_{\mathrm{RM}}$



➢ The mean difference () in *f* between subjects is more than 4.4 times greater than the difference between sessions

Bland-Altman plots of the t_{ex} estimations agreement from NEXI$_{RM}$



- ➢ The mean difference in t_{ex} between subjects is more than 2.5 times greater than the difference between sessions

Take-home message

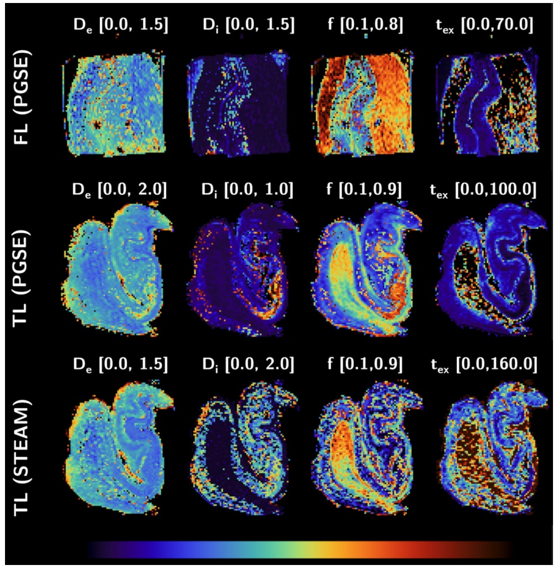
- The first NEXI parametric maps in the human cortex in-vivo.
- The addition of a dot compartment to the NEXI model is not necessary.
- Correcting the Rician floor in the fit is more appropriate.

- Our results are consistent with previous studies conducted in the rat cortex in vivo. Notably, t_{ex} ~ 30-40 ms.
- Good scan-rescan reproducibility + sensitivity to variations among subjects

Take-home message

Quantifying features of human gray matter microstructure postmortem using Neurite Exchange Imaging (NEXI) at ultra-high field

Andreea Hertanu et al.

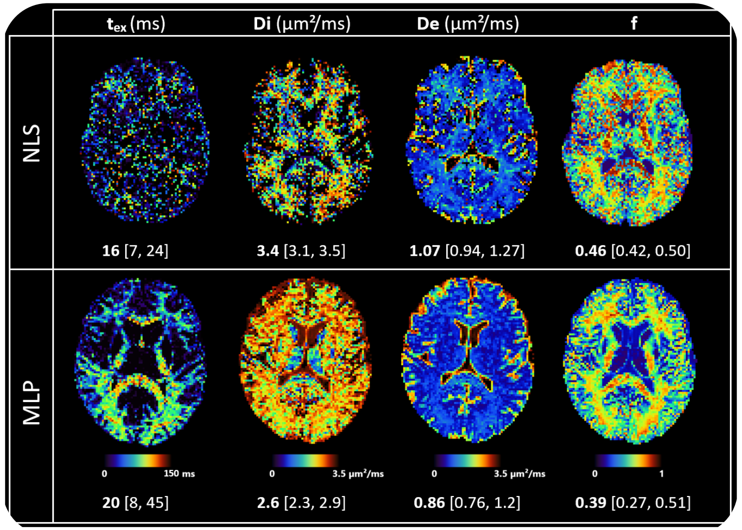


Computer #38

Getting the Best Out of Diffusion MRI
Power Pitch Theatre 2
Wednesday, 07 June 2023 13:30 - 14:30

Optimizing the NEXI acquisition protocol for quantifying human gray matter microstructure on a clinical MRI scanner using Explainable AI

Quentin Uhl et al.



Computer #10

Machine Learning
Power Pitch Theatre 1
Wednesday, 07 June 2023 13:30 - 14:30

Acknowledgments

Microstructure Mapping Lab

The **Microstructure Mapping** team (Lausanne, Switzerland):

- Ileana O. Jelescu
- Tommaso Pavan
- Yujian Diao
- Andreea Hertanu
- Jasmine Nguyen-Duc
- Inès de Riedmatten
- Saina Asadi

Collaborators from **CUBRIC** (Cardiff, UK):

- Marco Palombo
- Derek K. Jones
- Malwina Molendowska

CUBRIC

Our funding:

Swiss National Science Foundation

PCEFP2_194260

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