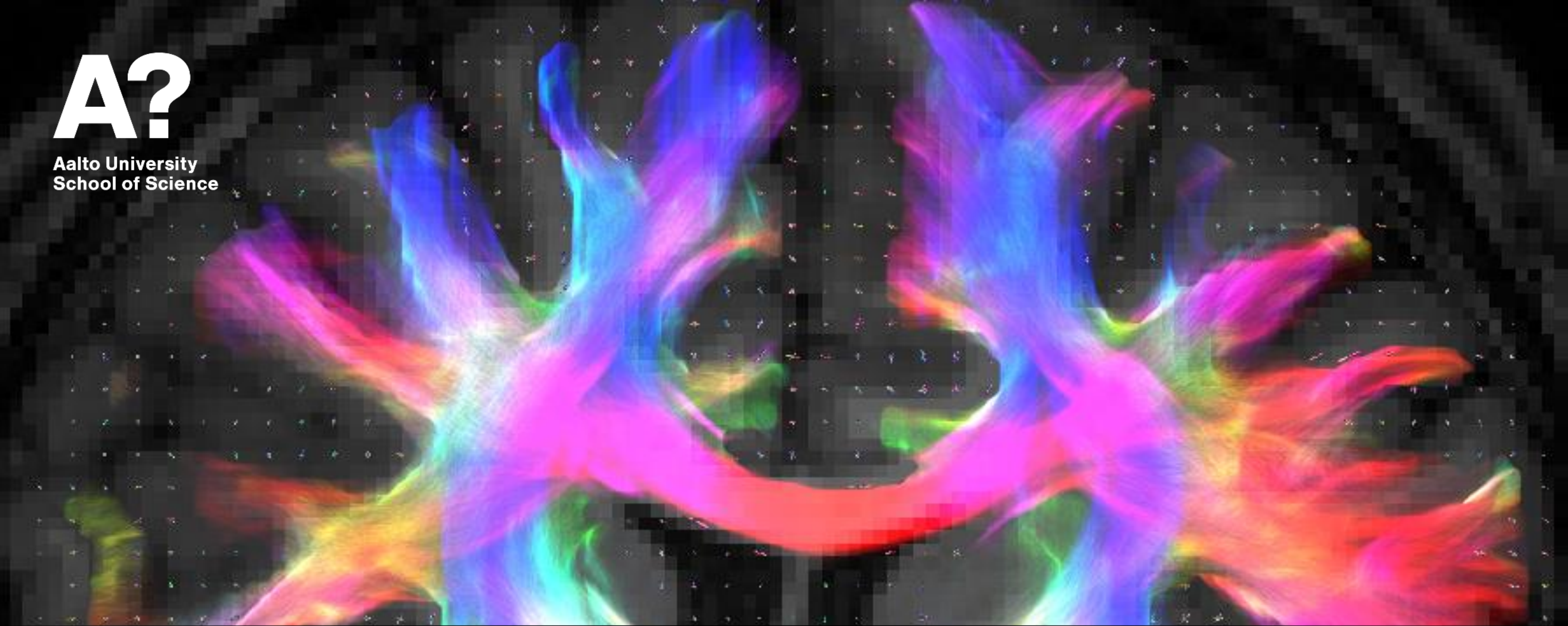


Aalto University
School of Science

Session 5:

Connectivity networks and microstructural models

NBE-E453001 - Special Course in Human Neuroscience V D:

Imaging Brain Microstructure and Connectivity with Diffusion MRI

Dr. Timo ROINE - timo.roine@aalto.fi

Session 3 outline

Summary: networks and microstructure

Group discussion in Flinga

Quiz (10 min)

Break (5 min)

Practical demonstration

Discussion and feedback

Assignments before session 5

Intended learning outcomes

By completing the course, the student can

- understand diffusion MRI acquisition and analysis methods
- describe applications of these methods
- explain the principles of investigating brain microstructure and structural brain connectivity with diffusion MRI
- recognize issues in applying these methods in research and clinic
- apply diffusion MRI methods to investigate brain microstructure and structural brain connectivity (e.g., analyze a dataset or design a project)

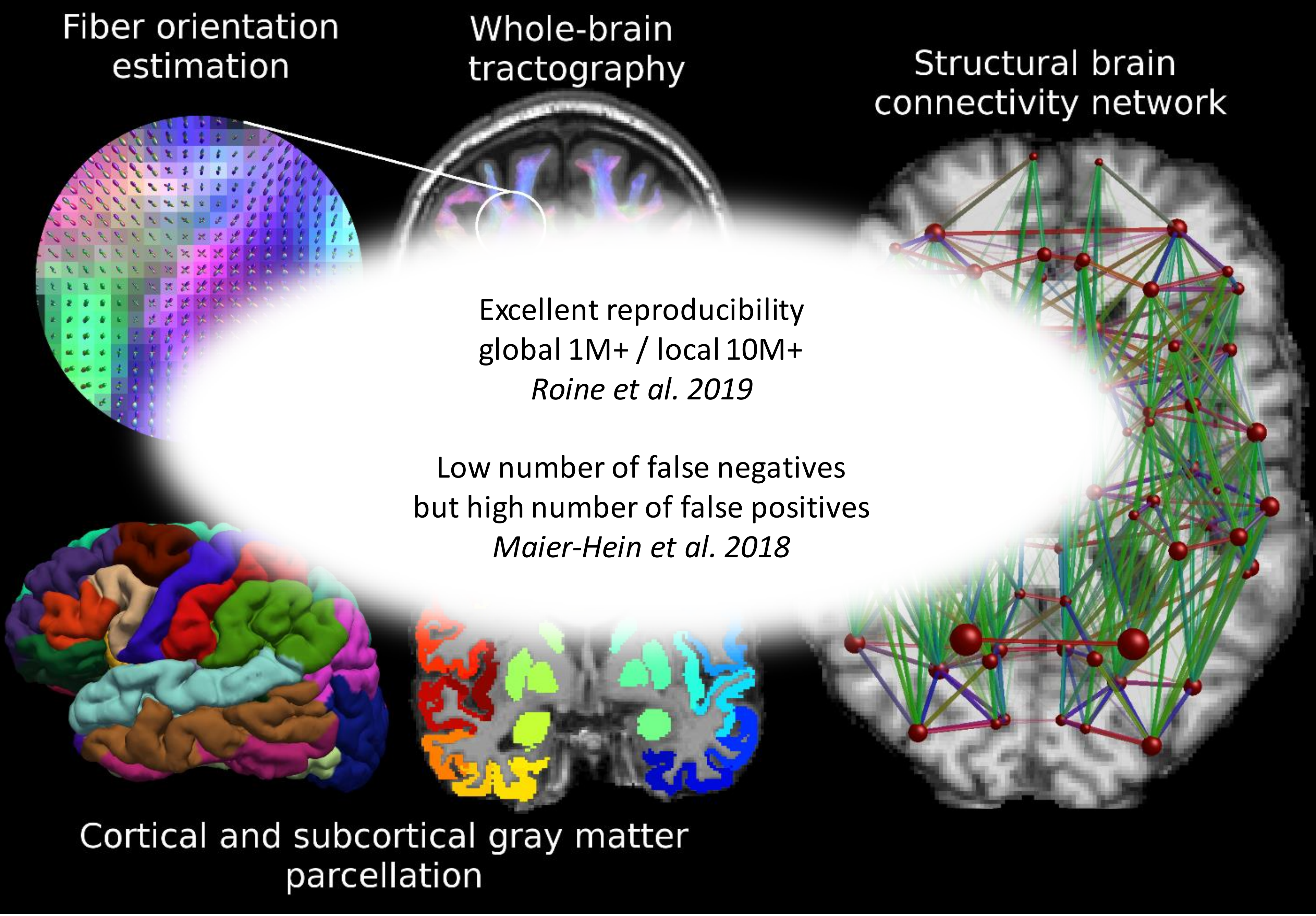
Course outline

Session 5: Connectivity networks and microstructural analyses (30.5.)

Self-study, lecture, practical demonstrations, group discussion, individual reflection, quiz

Assignments: learning log (DL 6.6.), project work report (DL 6.6.), prepare the project work presentation

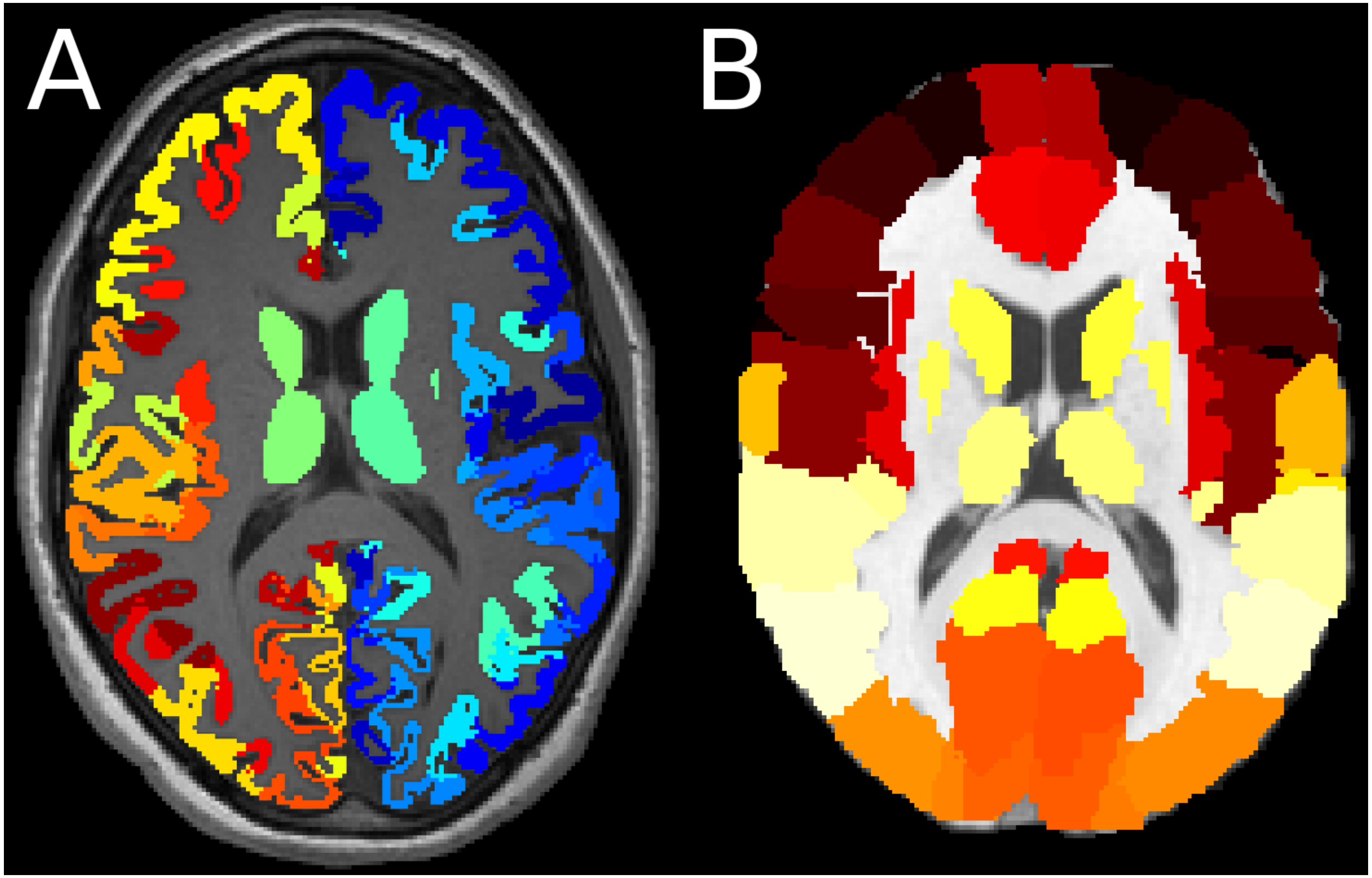
Session 6: Summary of the course, presentations of project works (7.6. 12:15-14:00)
Seminar presentations, lecture, group discussion, feedback, individual reflection



Excellent reproducibility
global 1M+ / local 10M+
Roine et al. 2019

Low number of false negatives
but high number of false positives
Maier-Hein et al. 2018

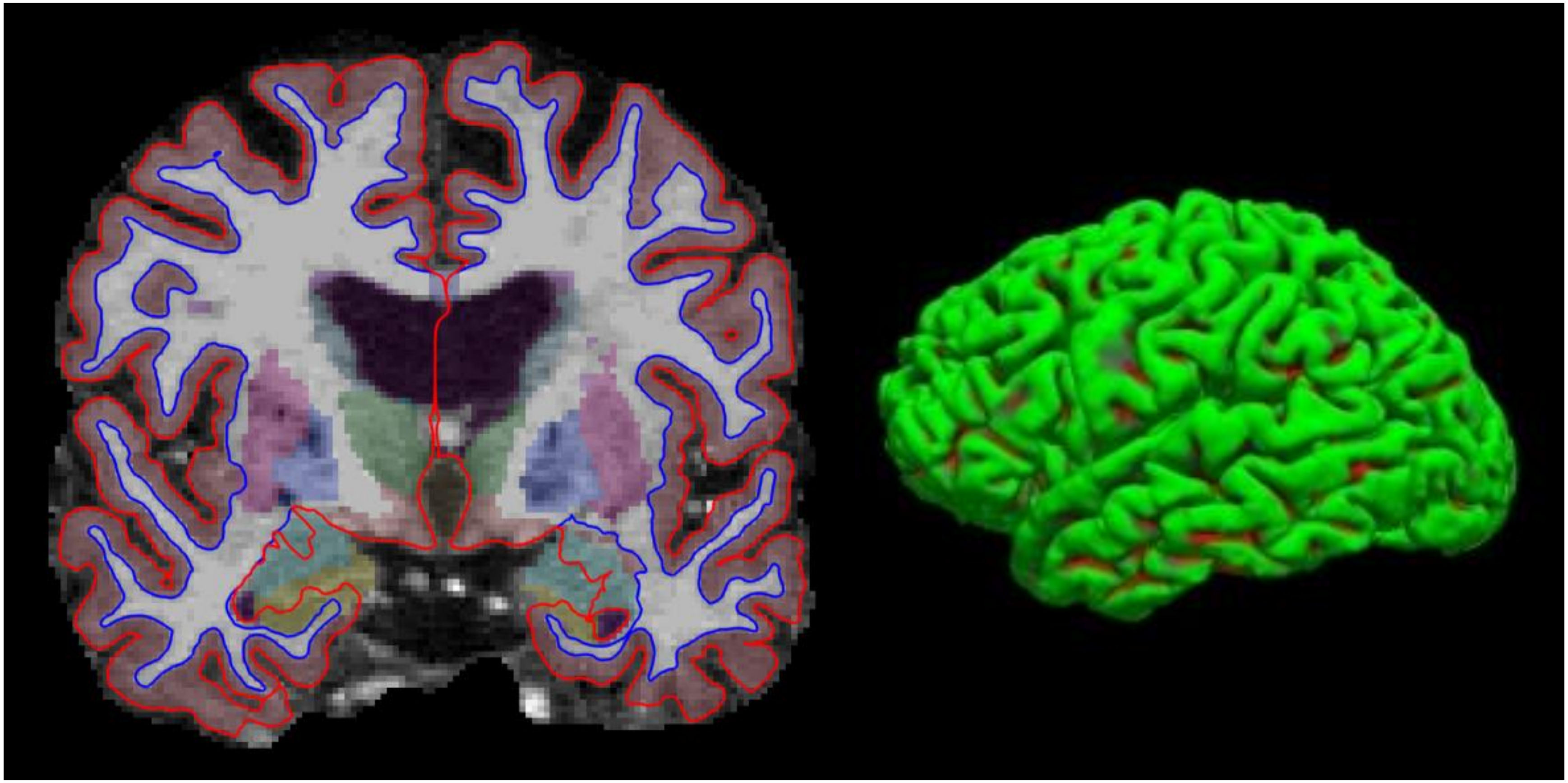
Anatomical parcellation of the T_1-weighted MRIs



Surface-based (FreeSurfer)

Volume-based (e.g. Automated Anatomical Labeling)

FreeSurfer cortical reconstruction

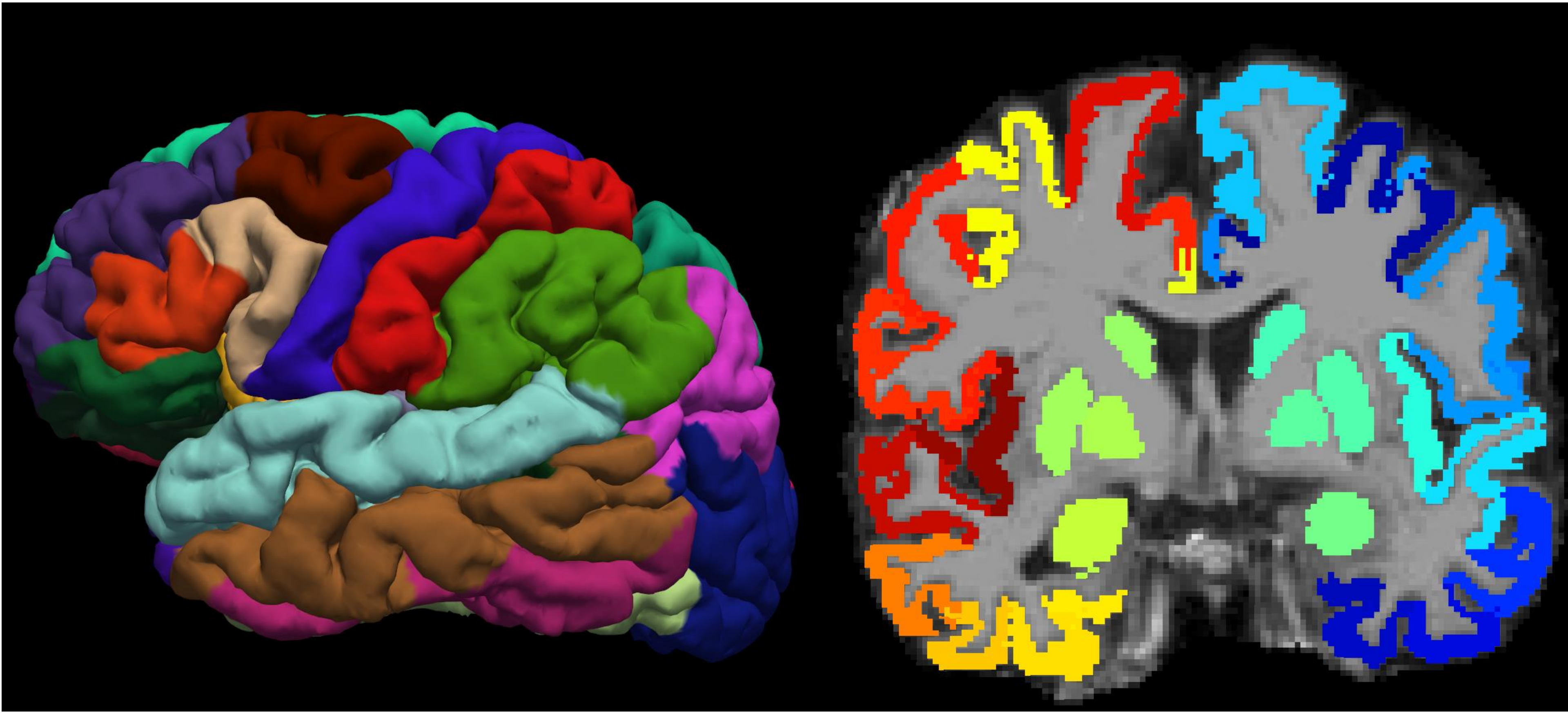


Visually check the surfaces for all subjects (and correct if necessary), especially if cortical thickness is measured/used in models

https://surfer.nmr.mgh.harvard.edu/fswiki/RecommendedReconstruction

https://surfer.nmr.mgh.harvard.edu/fswiki/FsTutorial/OutputData_freeview

FreeSurfer cortical parcellation

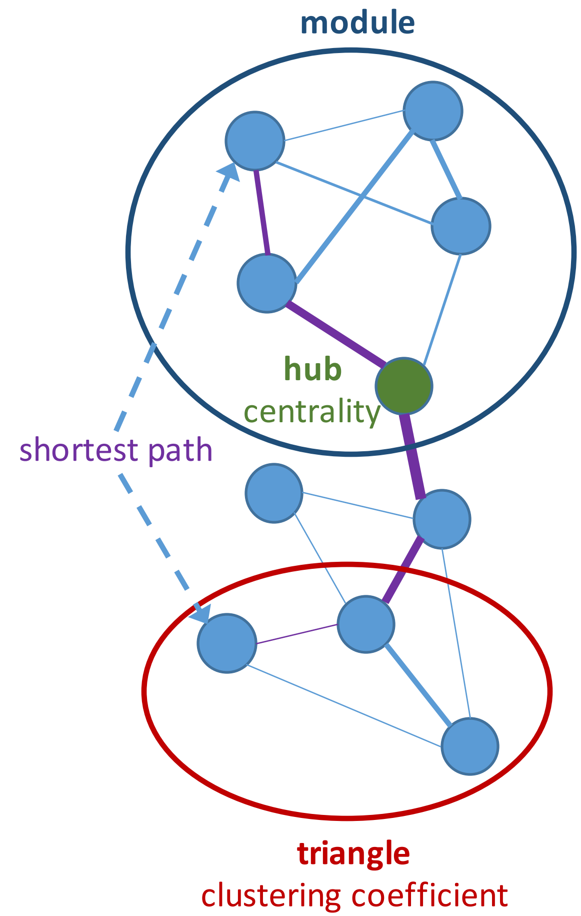


Note: Subcortical parcellation may be better with FIRST in FSL
→ Replace subcortical structures?

https://fsl.fmrib.ox.ac.uk/fsl/fslwiki/FIRST

Graph theoretical analysis

- Global and local properties of complex networks
- Integration metrics
  - Global efficiency, characteristic path length
- Segregation metrics
  - Clustering coefficient, local efficiency
- Centrality metrics
  - Betweenness centrality, strength, degree
- Small-world topology



Bullmore & Sporns, 2009; Rubinov & Sporns, 2010

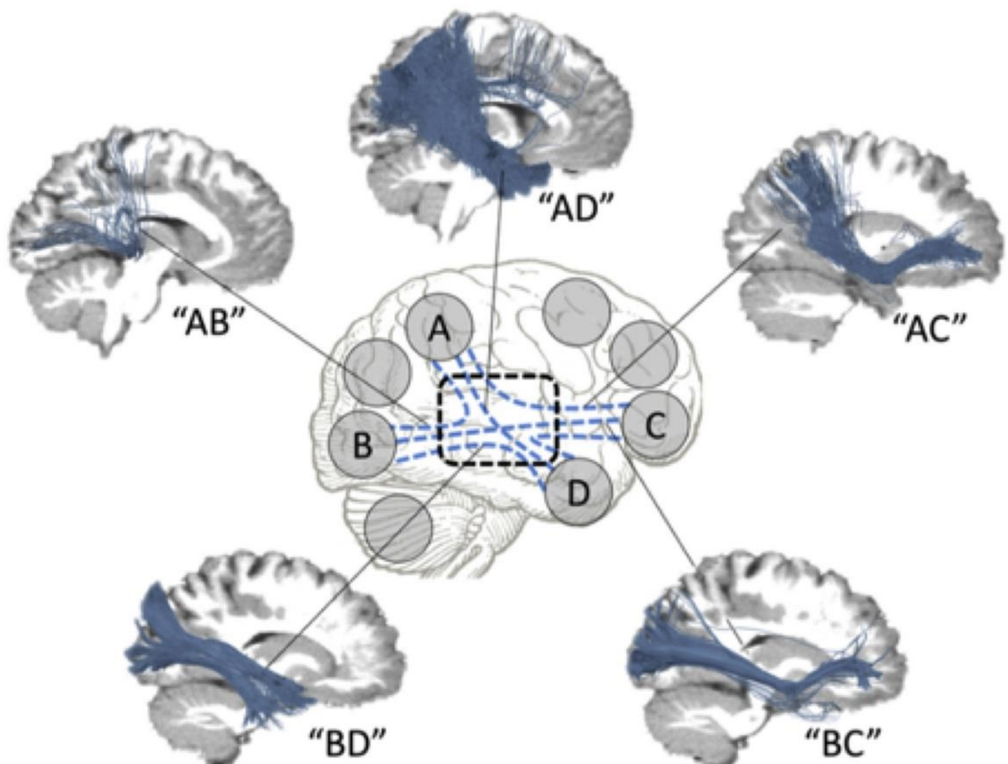
Methodological challenges

- Reliable measures for structural connectivity
  - Longer and thicker tracts are overrepresented due to more seeds
  - Larger seed areas
  - Crossing fibers largely solved
  - Kissing and branching are the main problems
- Reducing the number of false positive connections (Maier-Hein et al. 2018)

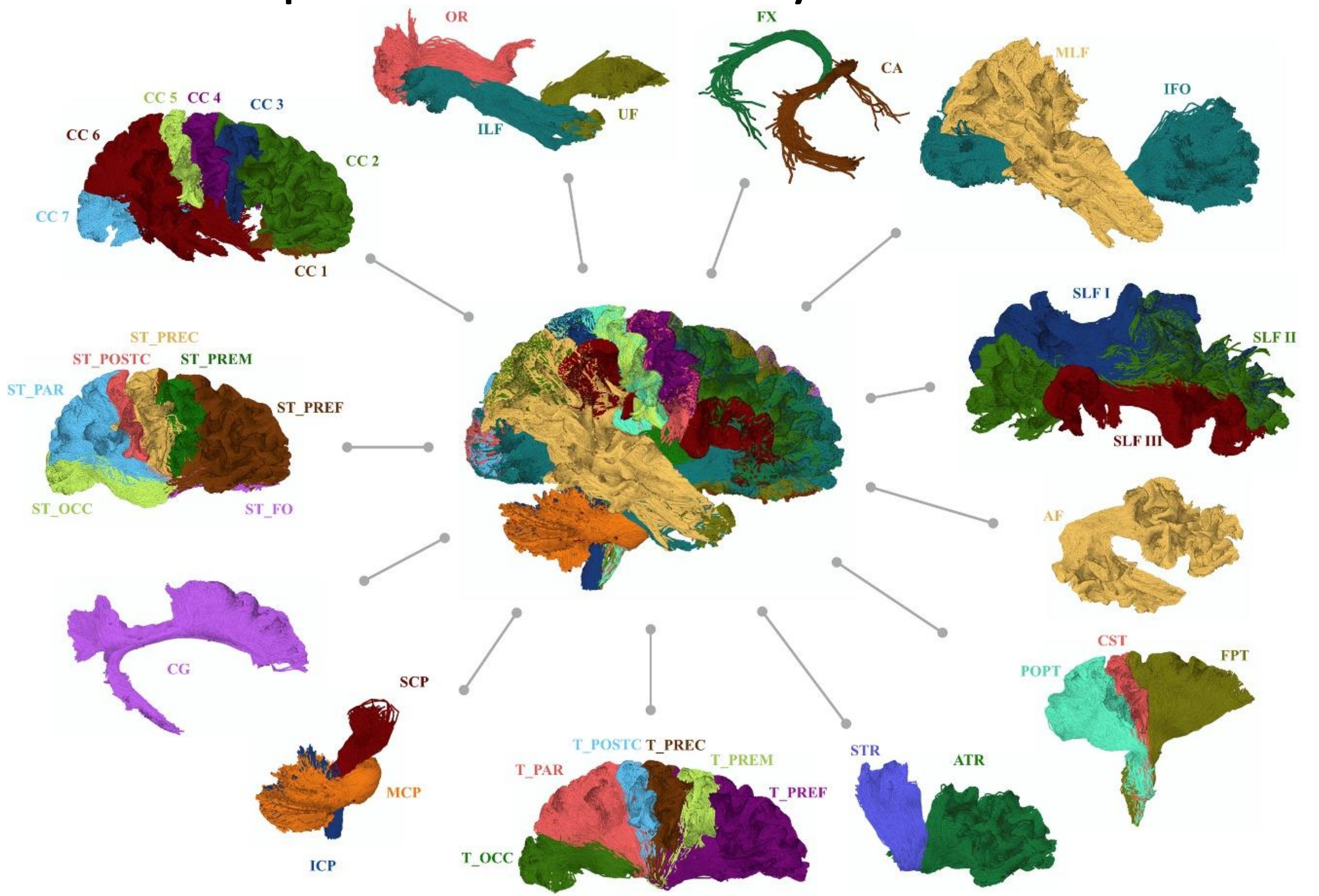
Maxime Descoteaux, 2017:
”My false positives seem to be different from your false positives”

False positives – any solutions?

- Bundle segmentation, TractSeg (Wasserthal et al. 2018)
- Spherical deconvolution informed filtering of tractograms (Smith et al. 2013)
- Microstructure-informed tractography (Girard et al. 2018, Schiavi et al. 2020)



False positives – any solutions?



Microstructural properties

- Tensor-based FA describes e.g. myelination, fiber density, axon diameter, dispersion, and complexity → not specific
- Fixel-based analysis (Raffelt et al. 2017)

→ fiber density and cross-section

- Neurite orientation dispersion and density imaging (NODDI) (Zhang et al. 2012)

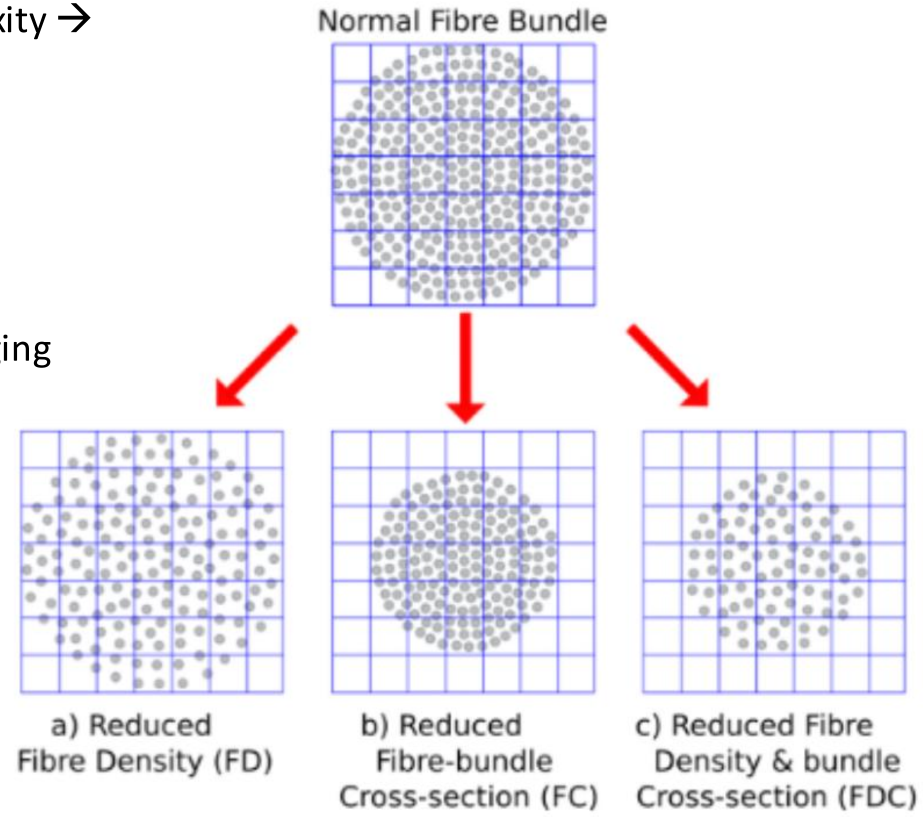
→ intra-cellular and isotropic volume fractions, orientation dispersion

- B-tensor encoding (Westin et al., 2016)

→ Linear, spherical, and planar encoding

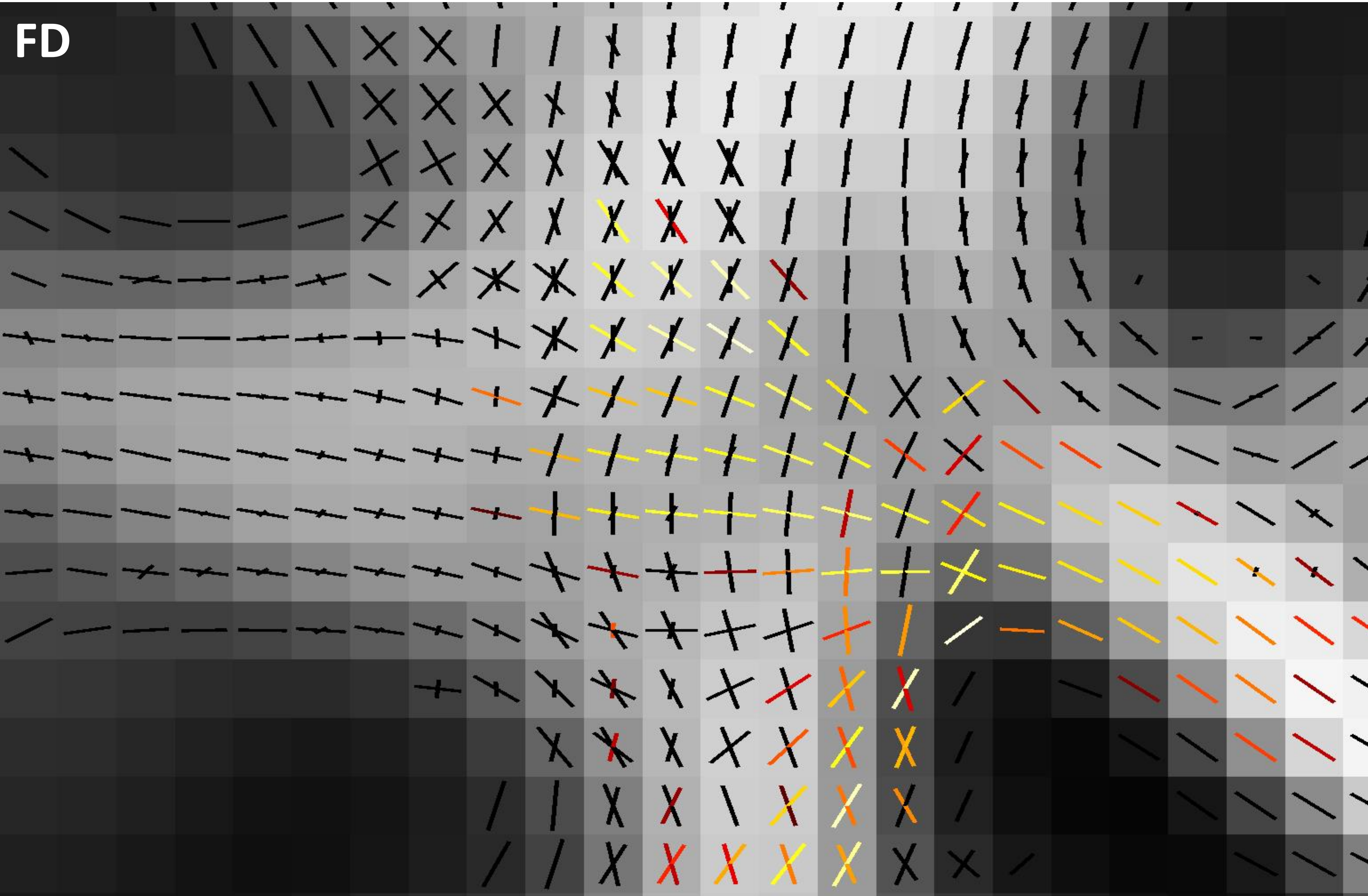
- Diffusion kurtosis imaging (DKI)

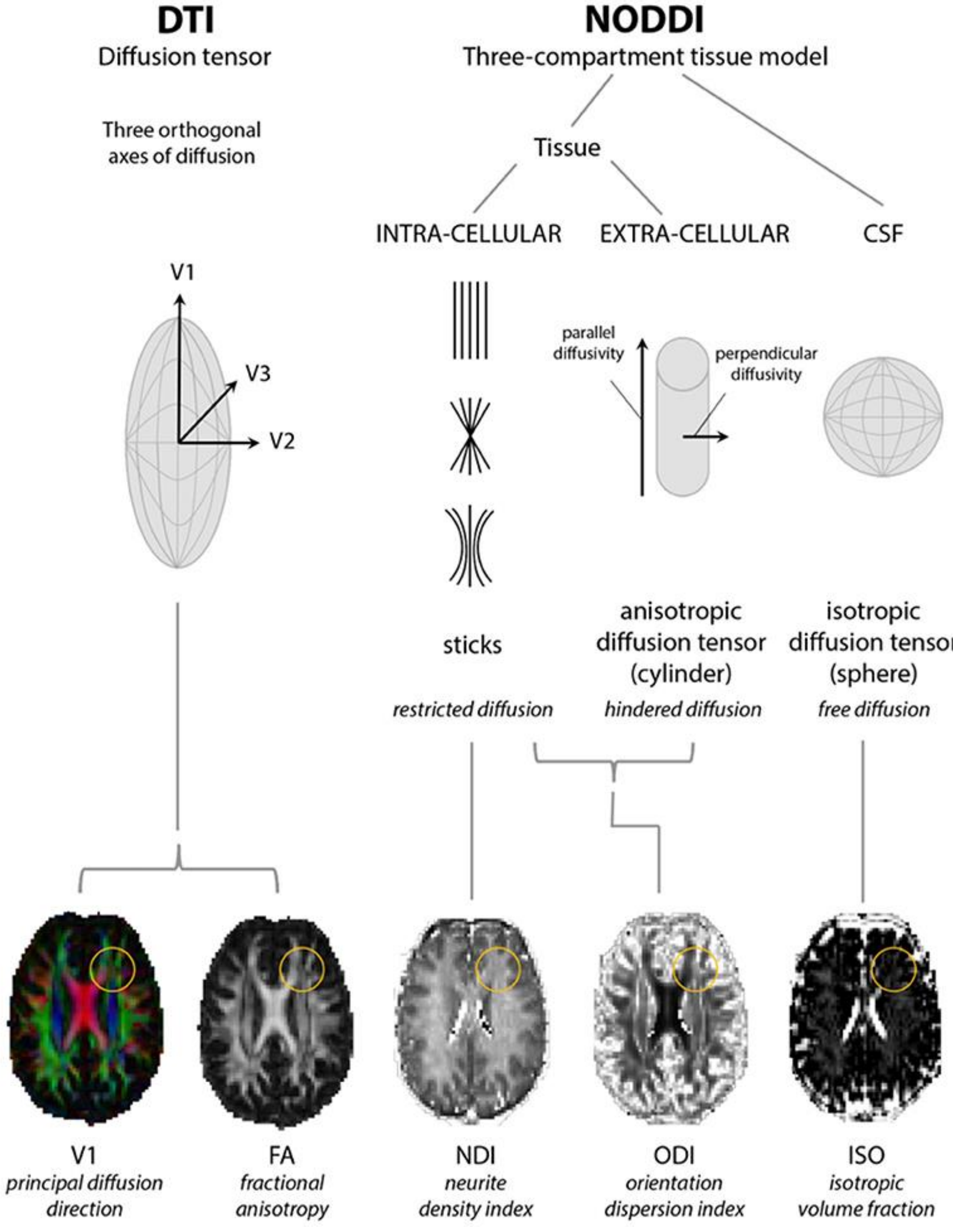
→ Non-Gaussian diffusion (mean kurtosis, anisotropy)



Fixel-based analysis (FBA)

Raffelt et al. 2017

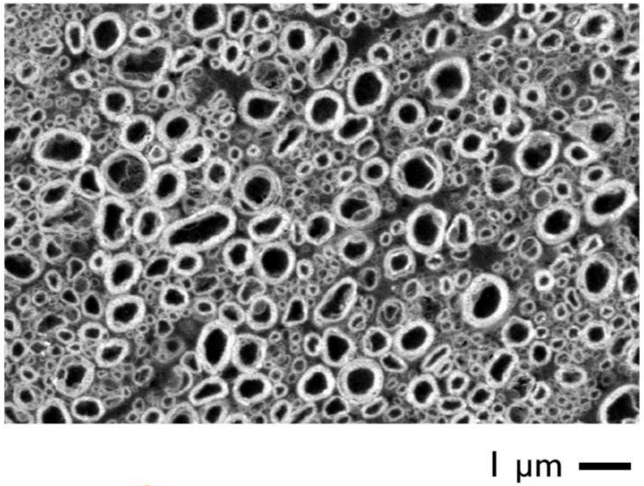


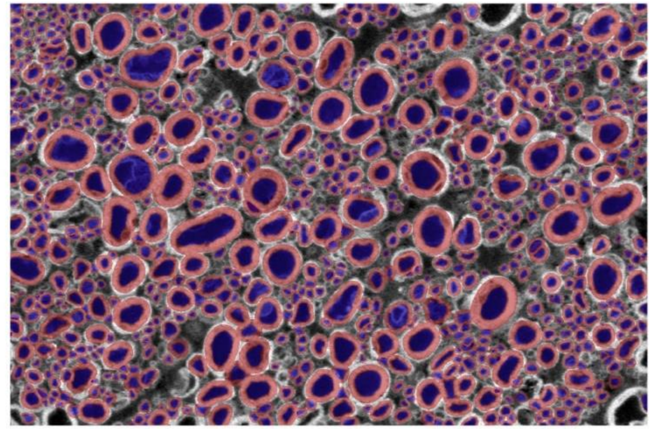


Zhang et al. 2012

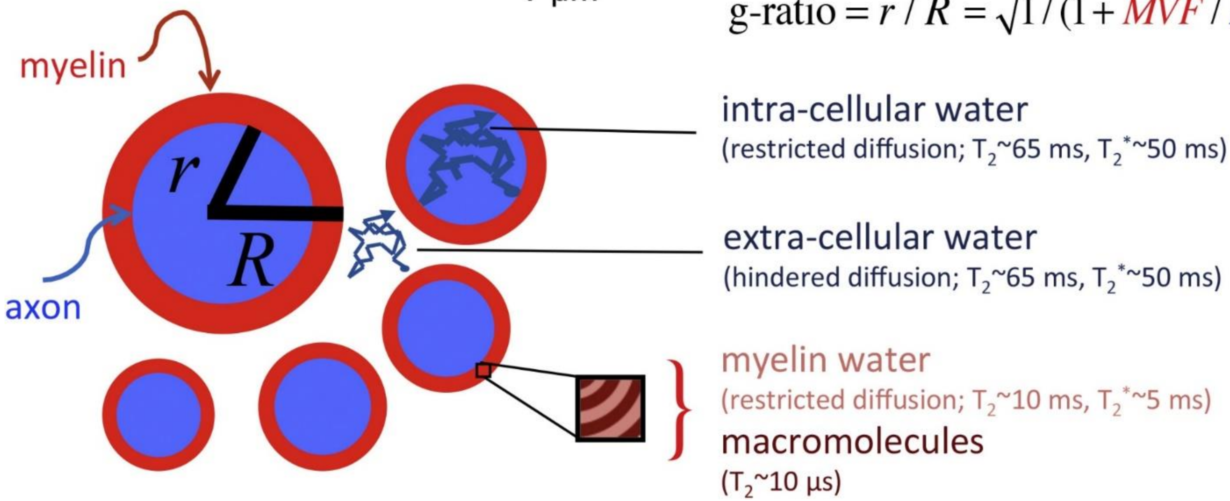
Figure from:
Barritt et al. 2018

G-ratio imaging and conduction velocity





$$\text{g-ratio} = r / R = \sqrt{1/(1 + MVF / AVF)}$$



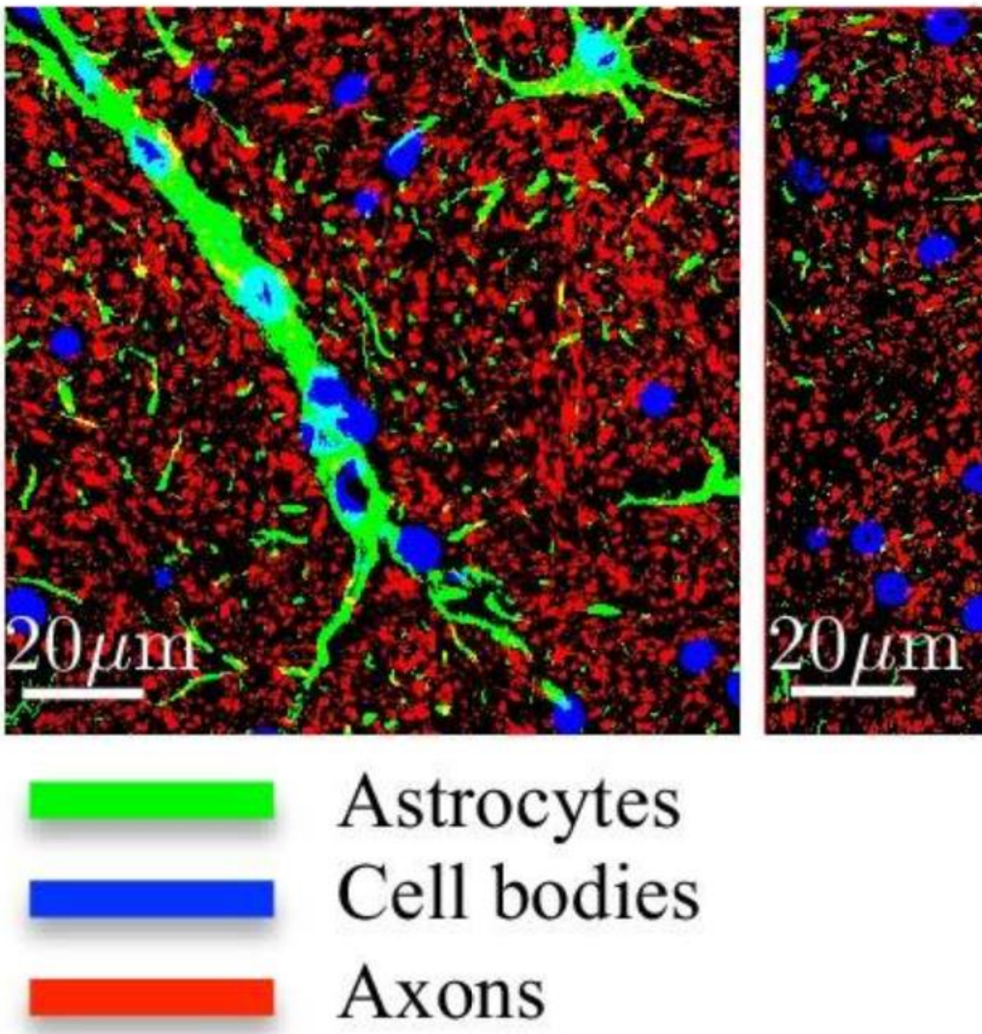
$$v = pd\sqrt{\ln g}$$

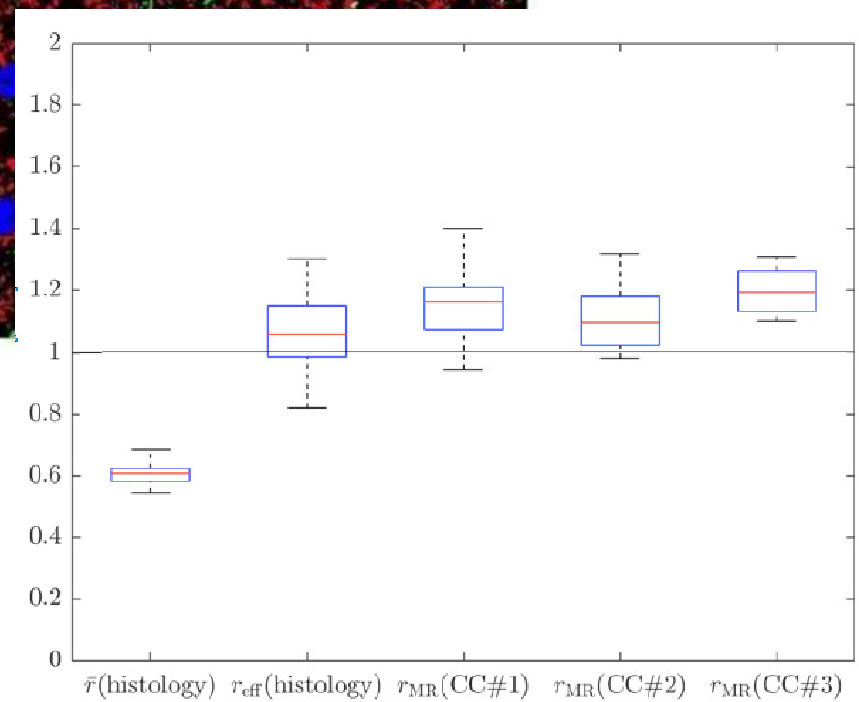
v: conduction velocity
p: proportionality factor
d: axon diameter
g: g-ratio

Requires:
- multi-shell diffusion MRI
- magnetization transfer imaging

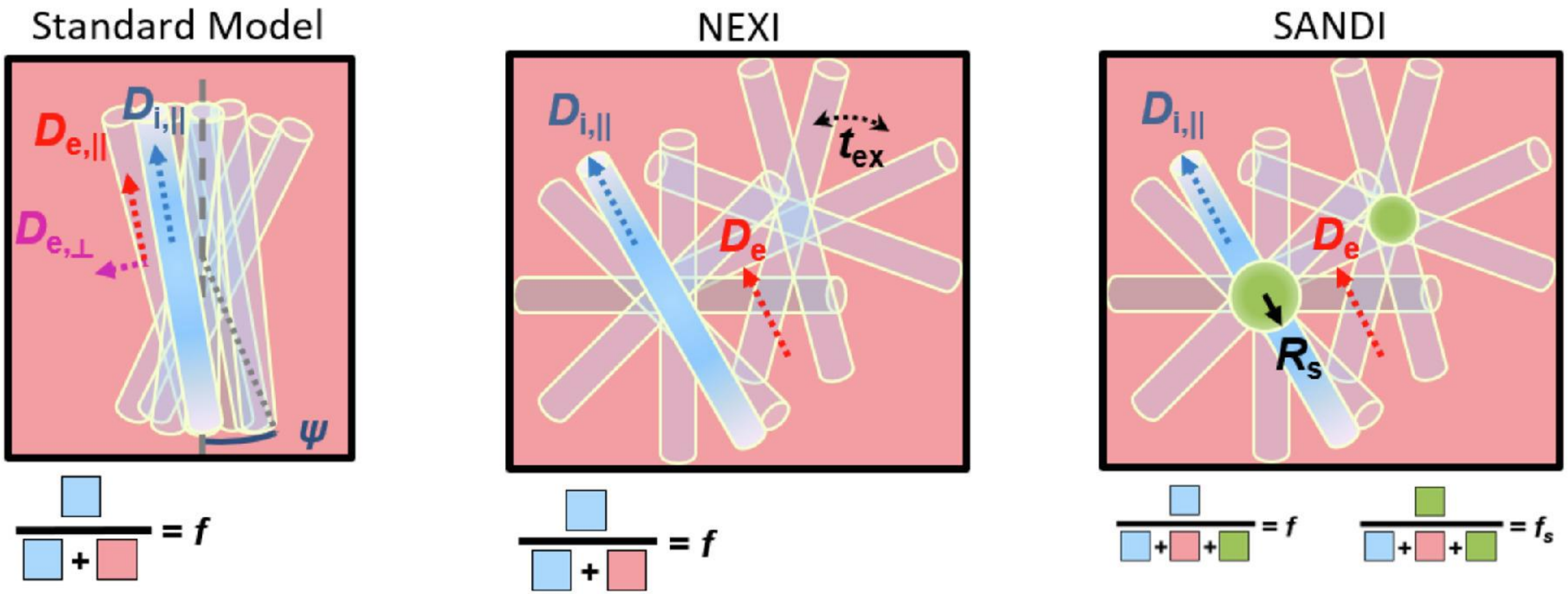
Stikov et al. 2015 https://doi.org/10.1016/j.neuroimage.2015.05.023
Campbell et al. 2018 https://doi.org/10.1016/j.neuroimage.2017.08.038

Axon radii / diameter estimation





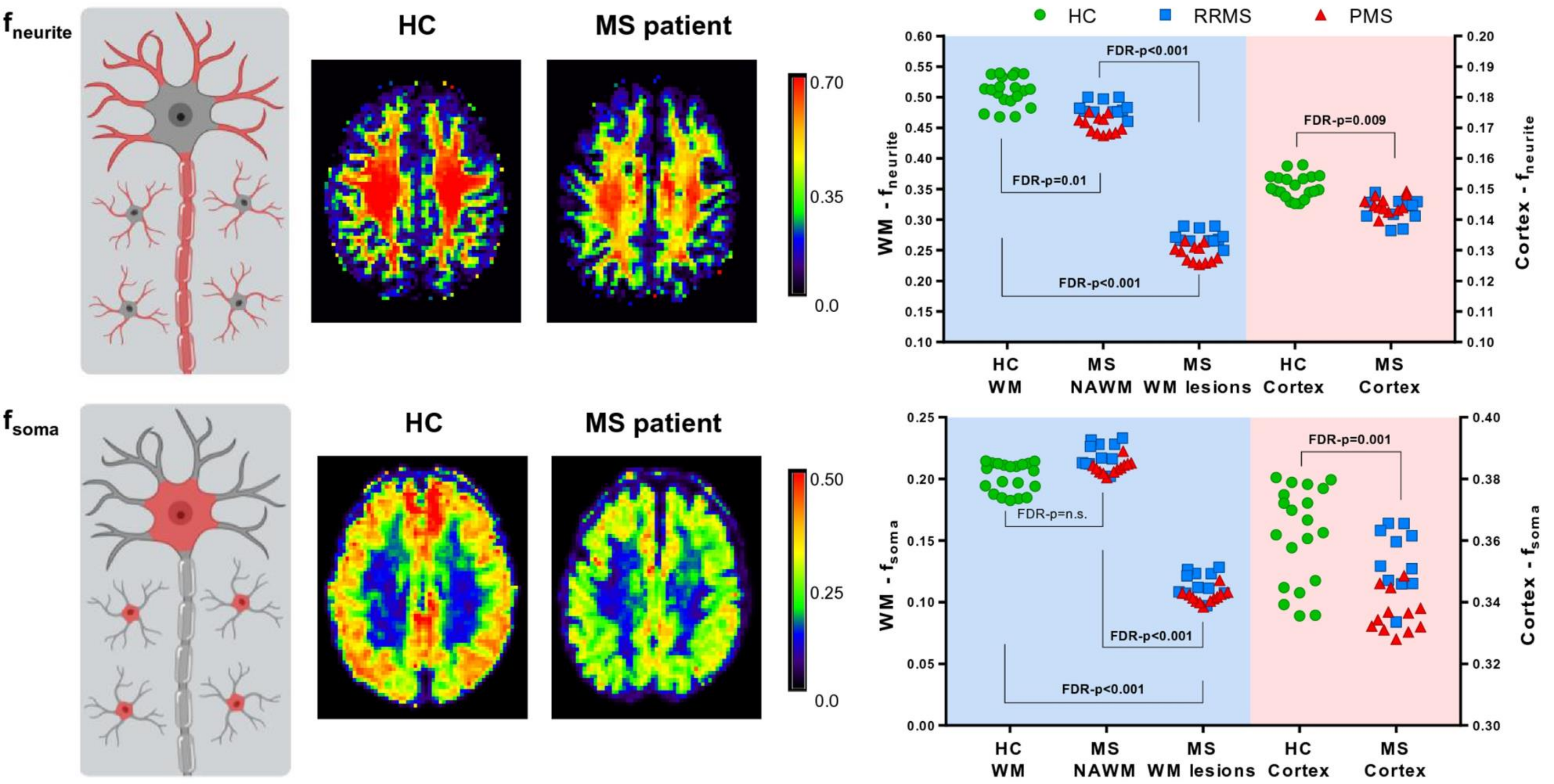
Veraart et al. 2020 https://doi.org/10.7554/eLife.49855



$D = \text{const}$	$D = \text{const}$	$D\Big\vert_{t\to\infty} = A + \frac{B}{t}$
$K = \text{const}$	$K\Big\vert_{t\to\infty} = \frac{A}{t} + B$	?
$\bar{S}\Big\vert_{b\to\infty} = \frac{A}{\sqrt{b}}$	$\bar{S}\Big\vert_{b\to\infty} = \frac{A}{\sqrt{b}}\left[1 + \frac{B}{b}\right]$	$\bar{S}\Big\vert_{b\to\infty} = \frac{A}{\sqrt{b}}$

Palombo et al., 2020 https://doi.org/10.1016/j.neuroimage.2020.116835
Jelescu et al., 2022 https://doi.org/10.1016/j.neuroimage.2022.119277

In vivo quantification of brain soma and neurite density abnormalities in multiple sclerosis



Palombo et al., 2020 https://doi.org/10.1016/j.neuroimage.2020.116835
Jelescu et al., 2022 https://doi.org/10.1016/j.neuroimage.2022.119277

Assignments (obligatory to pass)

- Participation in sessions:
  - 6 x session attendance (pass/fail)
  - 5 x quizzes (40% of grade)
  - 5 x learning log (20% of grade)
  - substitute assignment to replace if absent (12% of grade)
- Project work report (20% of grade) + presentation (20% of grade)
- Peer feedback on the draft report of other groups (pass/fail)

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