Contrôle qualité et analyse des données IRM de diffusion (DWI)

exemples d'outils performants et standardisés

Réunion Mensuelle de Neuro-Imagerie

23 / 11/ 2023

Julien Sein (INT)

int institut de neurosciences de la timone

IRMf

Introduction / Motivation for this talk

- Diffusion weighted MRI is one of the oldest MRI technique

Stejskal EO, Tanner JE. 1965
Le Bihan et al. 1986
Moseley et al. 1990

- Many choices in acquisition
- Complicated preprocessing/ analysis steps and many ways and tools to do so
- Functional MRI much more used in the MRI Center – INT @ CERIMED:
  tools in place: SPM, FSL, fmriprep, nilearn
- Acquisition shorter for DWI experiments than fMRI in general
- 3T Siemens Prisma scanner (and soon Cima.X) is particularly performant for DWI with strong gradients and limited Tx bias and susceptibility distorsion.

- Can we get more studies using DWI at the MRI Center / Can we analyse now studies that already acquired DWI ?

QSIPREP: Standardized Preprocessing and reconstruction tool for DWI

- **Documentation**: https://qsiprep.readthedocs.io/en/latest/
- **BIDSApp**: understands your dataset
- Integrates **cutting edge tools** from different software: MRTrix, FSL, Dipy, pyAFQ, DSI Studio, AMICO, …
- Very **versatile**: able to deal automatically with different sampling schemes: DTI, HARDI, DSI, single shell, multi-shells, multi-runs…
- Very **modular**: possibility to remove some steps, or use very advanced step (eddy_cuda available with almost all its options)
- **Well maintained**, good support (github and neurostars), frequent releases
- **Easy installation**: Docker and Singularity images

QSIPREP: Standardized Preprocessing and reconstruction tool for DWI

- Usage on the mesocentre (SLURM):

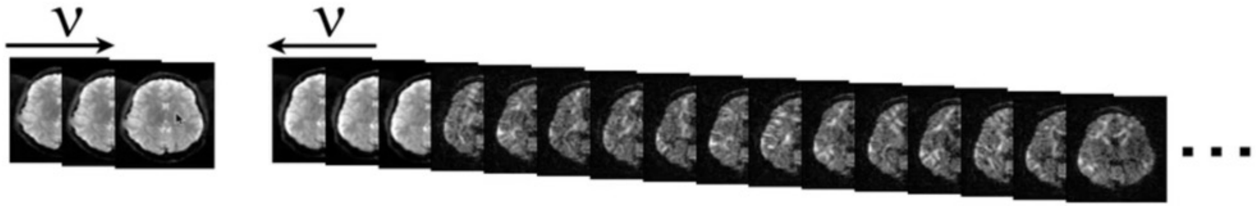
```
singularity run --cleanenv -B /scratch/jsein/BIDS:/work \
 --nv /scratch/jsein/my_images/qsiprep-0.18.1.sif /work/$study  \
 /work/$study/derivatives participant --participant_label $sub     \
 -w /work/temp_data_${study}_test  --output-resolution 1.8  --fs-license-file /work/freesurfer/license.txt \
  --eddy-config /work/$study/code/qsiprep/eddy_params.json   \
 --b0-threshold 50 --unringing-method mrdegibbs  --denoise-method dwidenoise  \
 --anat-modality T1w --distortion-group-merge none --recon-spec
/work/qsirecon_custom/mrtrix_multishell_msmt_pyafq_tractometry_JS.json  \
 --freesurfer-input /work/$study/derivatives/fmriprep/sourcedata/freesurfer
```

- 8h execution

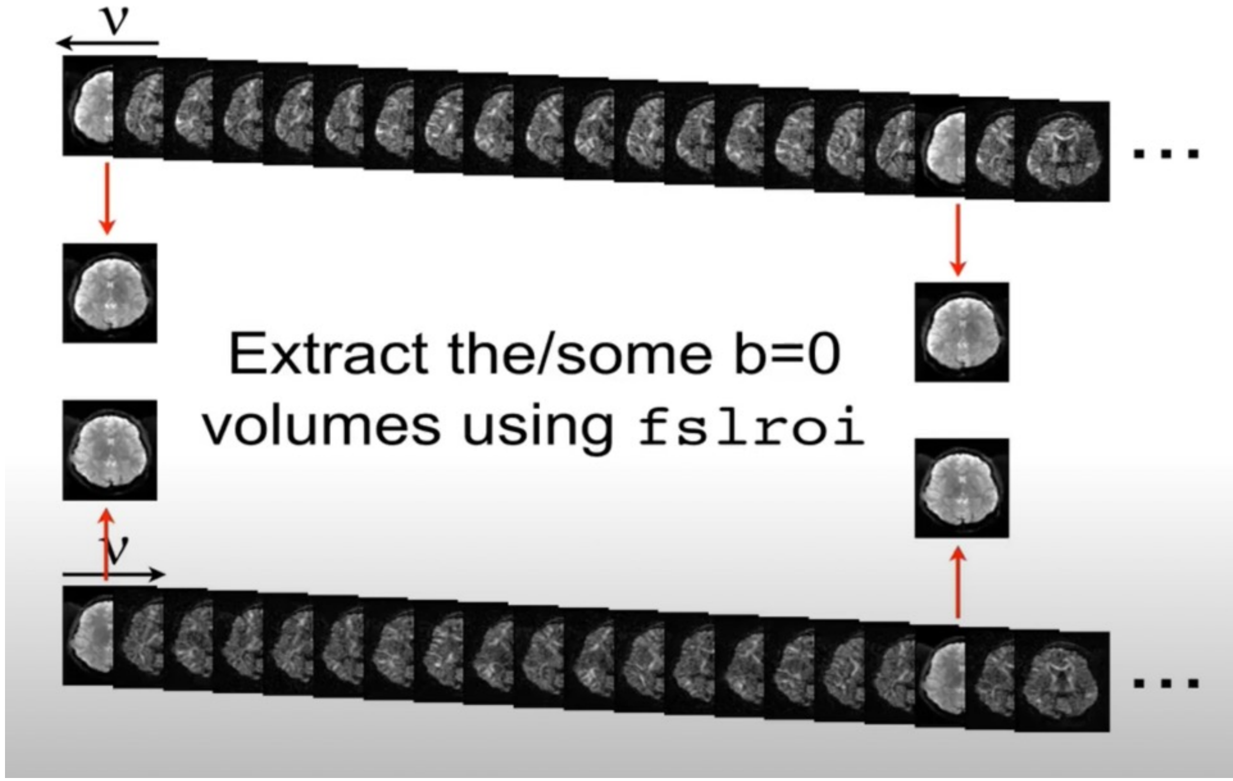
FreeSurfer run by FMRIPREP

Organization of BIDS dataset for DWI
(BIDS valid)

- Several acquisition cases:



Few b0 volumes in one direction and all diffusion volumes in the opposite direction (UK BioBank- style)



All the diffusion volumes (along with extra b0s) in both phase encoding direction (HCP-style)

Organization of BIDS dataset for DWI (BIDS validation necessary)

- **Several acquisition schemes, all automatically understood by QSIPREP**

DWI in one direction + external fieldmap

```
sub-test
├── anat
│   ├── sub-test_T1w.json
│   └── sub-test_T1w.nii.gz
└── dwi
    ├── sub-test_dir-AP_dwi.bval
    ├── sub-test_dir-AP_dwi.bvec
    ├── sub-test_dir-AP_dwi.json
    ├── sub-test_dir-AP_dwi.nii.gz
    ├── sub-test_dir-PA_dwi.bval
    ├── sub-test_dir-PA_dwi.bvec
    ├── sub-test_dir-PA_dwi.json
    └── sub-test_dir-PA_dwi.nii.gz
```

or

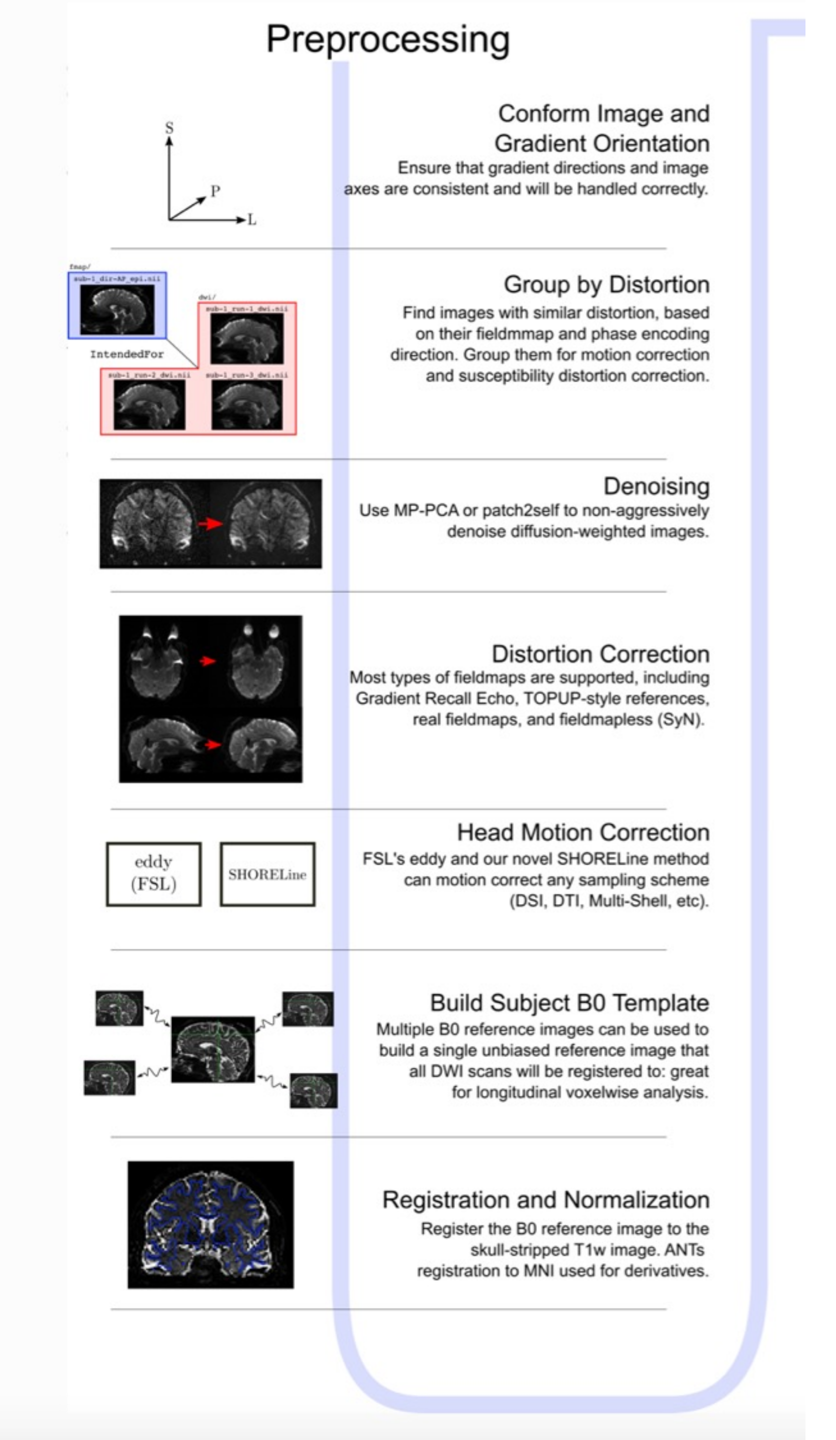
```
sub-test
├── anat
│   ├── sub-test_T1w.json
│   └── sub-test_T1w.nii.gz
├── dwi
│   ├── sub-test_dir-AP_dwi.bval
│   ├── sub-test_dir-AP_dwi.bvec
│   ├── sub-test_dir-AP_dwi.json
│   └── sub-test_dir-AP_dwi.nii.gz
└── fmap
    ├── sub-test_dir-PA_epi.json
    └── sub-test_dir-PA_epi.nii.gz
```

Full PEPOLAR: DWI repeated in AP and PA

+ other more “exotic schemes: DSI, CS-DSI, …

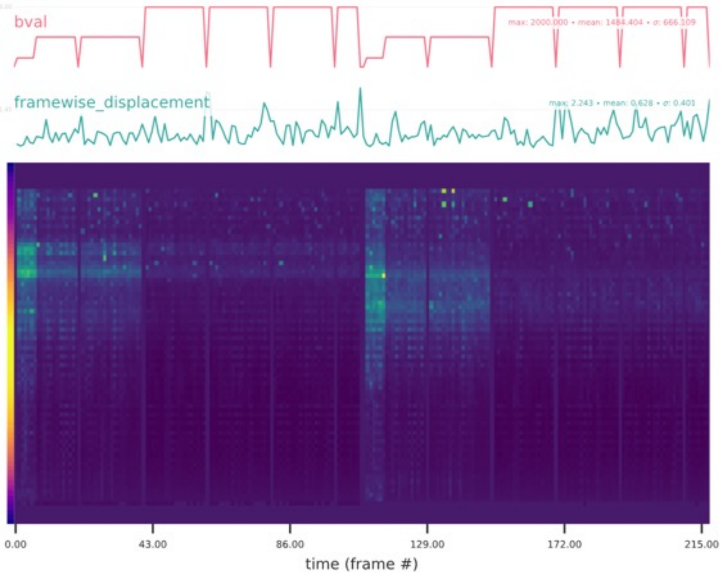
QSIPREP: Preprocessing

- Each preprocessing step is modular and scalable
- BIDS organization is essential
- Possibility to use and configure eddy_cuda (with GPU) with specific parameters defined in a JSON configuration file.
- Output in T1w-ACPC space
- QC measures provided at the end of the preprocessing

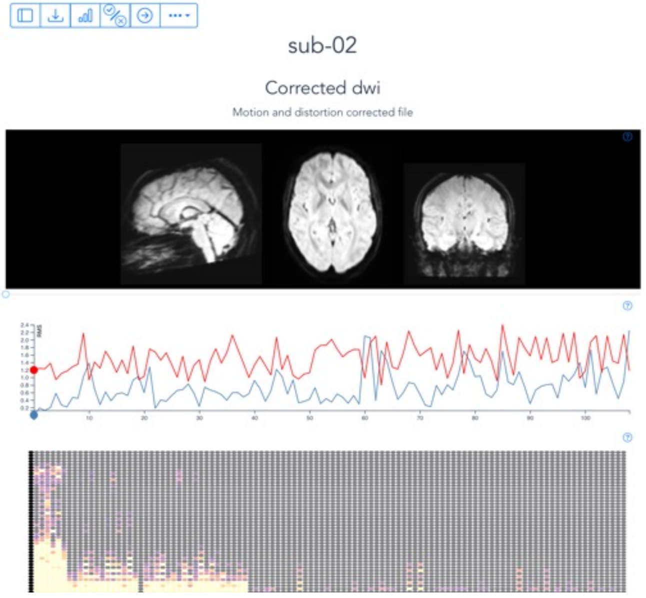


QSIPREP: QC

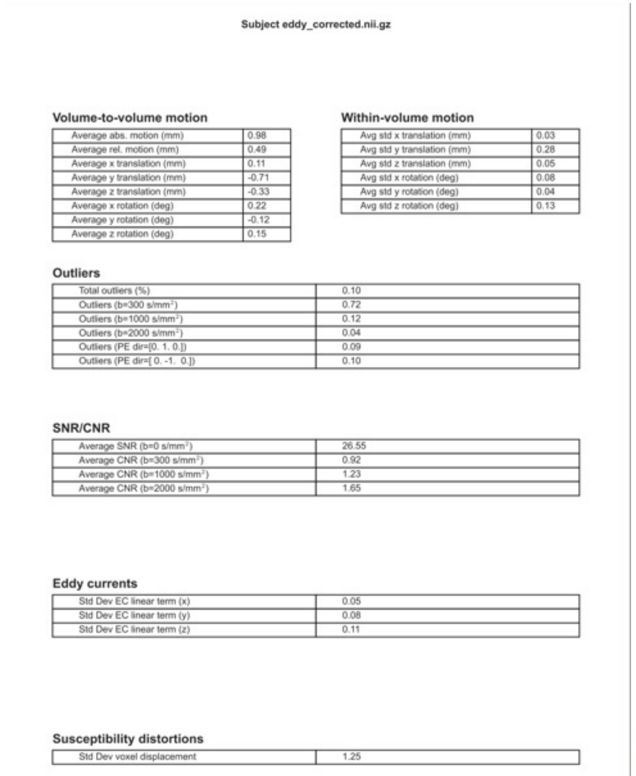
- HTML report (similar to FMRIPREP report)
- `dwiqc.json` file to be read by dmiprep-viewer http://www.nipreps.org/dmriprep-viewer/#/
- Possibility to run EddyQc by saving temporary nipype files



QSIPREP-HTML



Dmriprep-viewer



Subject eddy_corrected.nii.gz

Volume-to-volume motion

Average abs. motion (mm)	0.98
Average rel. motion (mm)	0.49
Average x translation (mm)	0.11
Average y translation (mm)	-0.71
Average z translation (mm)	-0.33
Average x rotation (deg)	0.22
Average y rotation (deg)	-0.12
Average z rotation (deg)	0.15

Within-volume motion

Avg std x translation (mm)	0.03
Avg std y translation (mm)	0.28
Avg std z translation (mm)	0.05
Avg std x rotation (deg)	0.08
Avg std y rotation (deg)	0.04
Avg std z rotation (deg)	0.13

Outliers

Total outliers (%)	0.10
Outliers (b=300 s/mm²)	0.72
Outliers (b=1000 s/mm²)	0.12
Outliers (b=2000 s/mm²)	0.04
Outliers (PE dir=[0. 1. 0.])	0.09
Outliers (PE dir=[0. -1. 0.])	0.10

SNR/CNR

Average SNR (b=0 s/mm²)	26.55
Average CNR (b=300 s/mm²)	0.92
Average CNR (b=1000 s/mm²)	1.23
Average CNR (b=2000 s/mm²)	1.65

Eddy currents

Std Dev EC linear term (x)	0.05
Std Dev EC linear term (y)	0.08
Std Dev EC linear term (z)	0.11

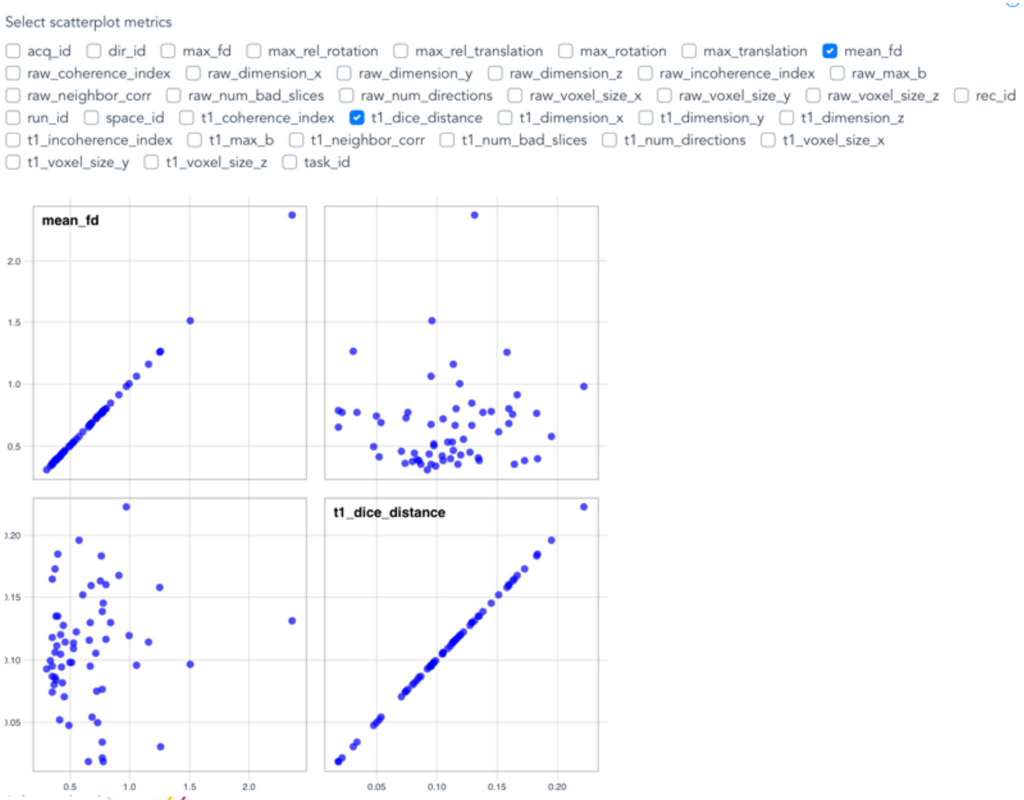
Susceptibility distortions

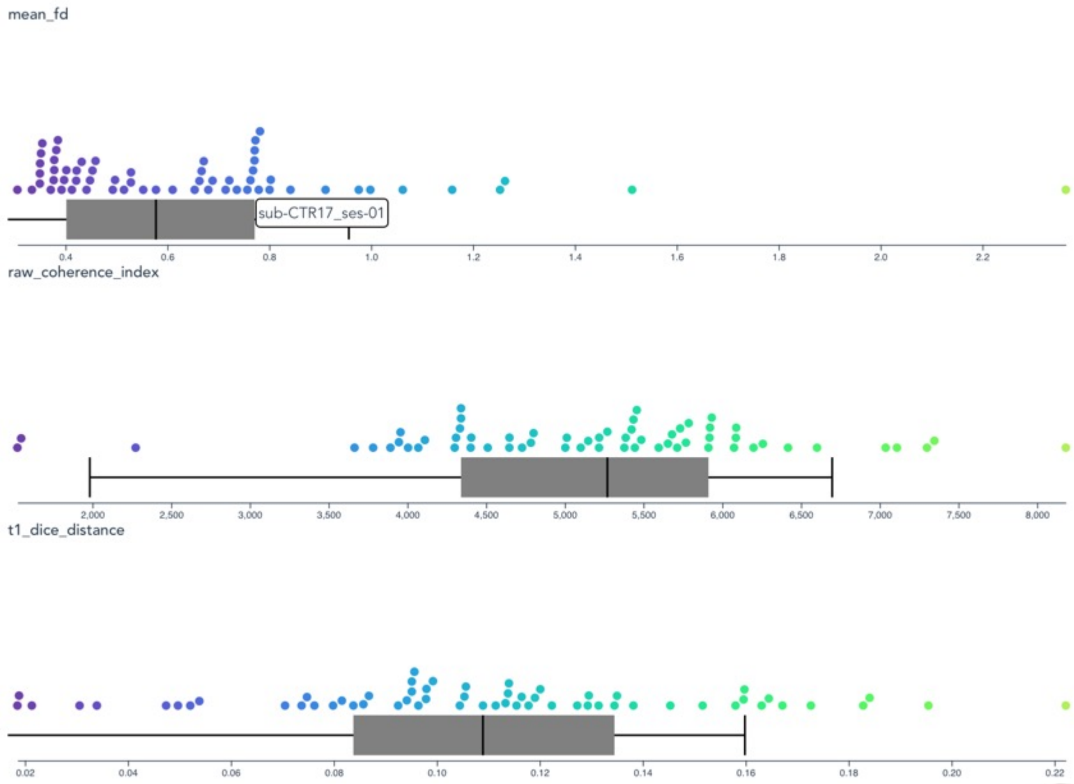
Std Dev voxel displacement	1.25

EddyQC

dmriprep-viewer : group QC

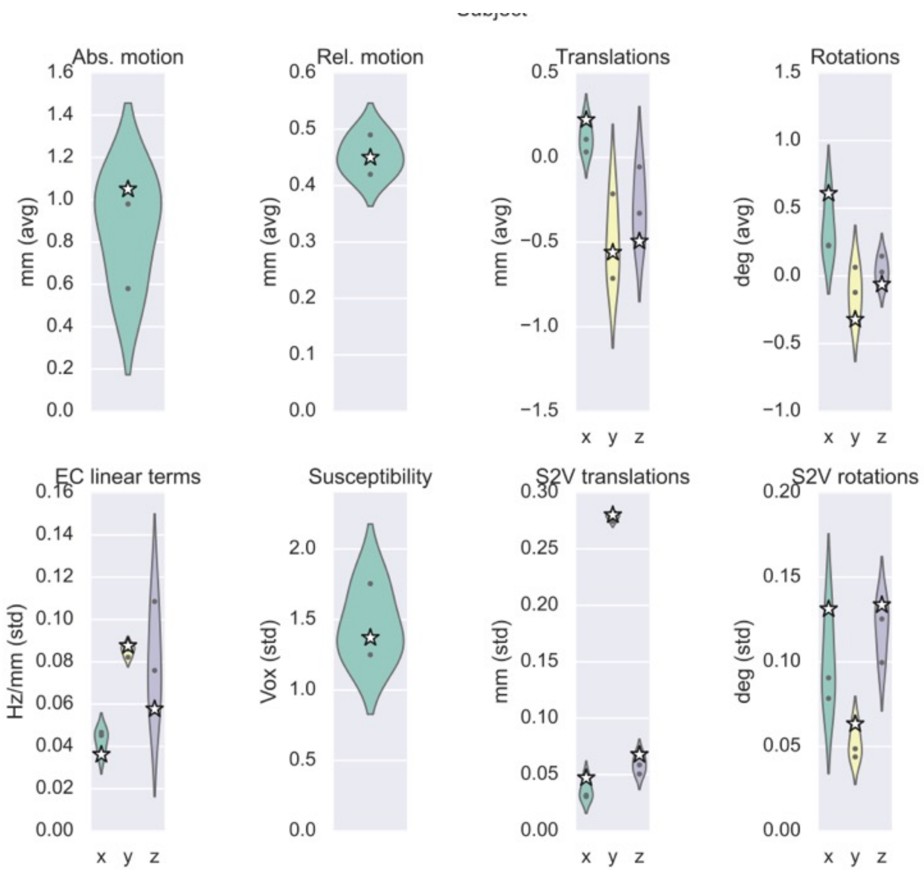
- dmiprep-viewer http://www.nipreps.org/dmriprep-viewer/#/

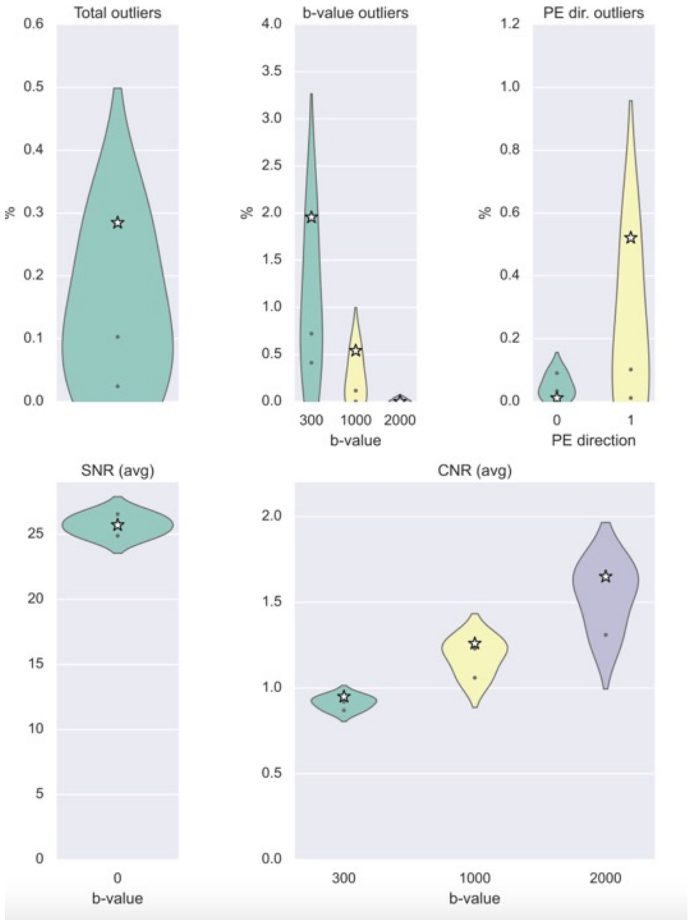




EddyQC : group QC

- EddyQC: command squad

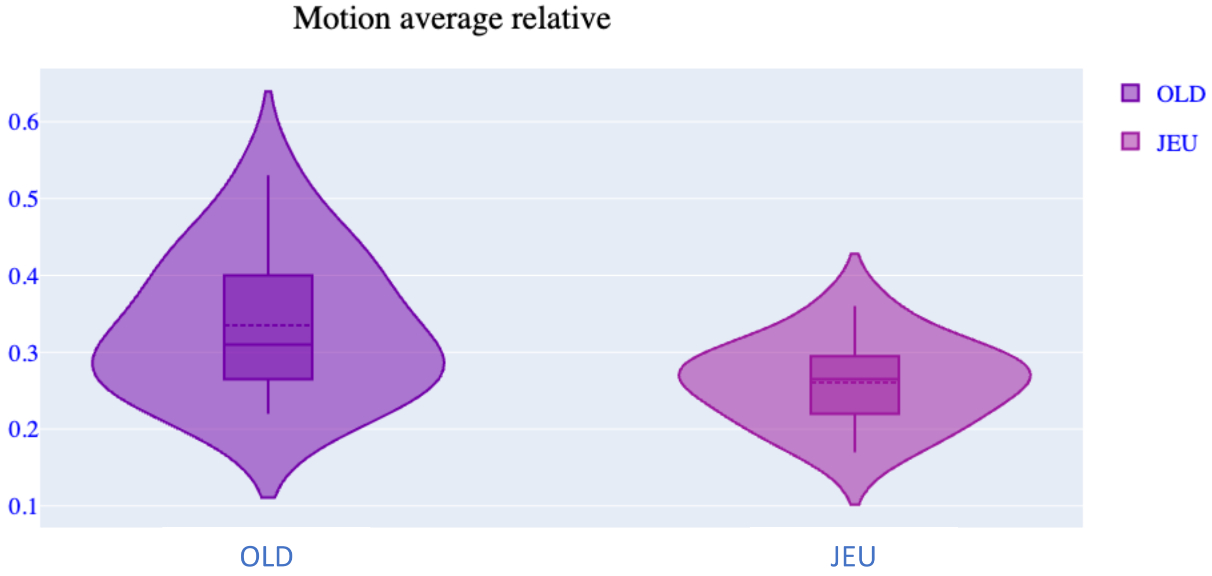


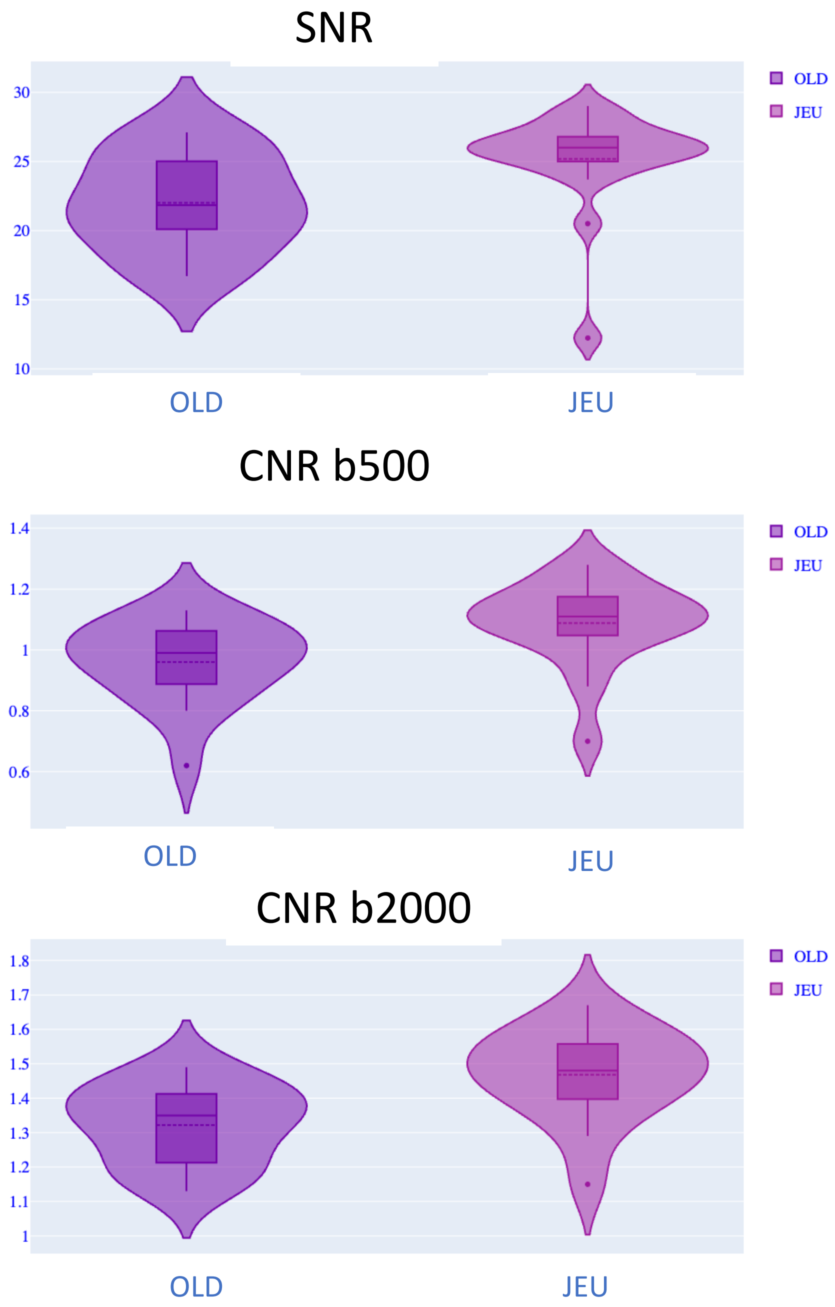


EddyQC : group QC

Example with Aging study (Kavounoudias et al.) :

- two populations: Young (JEU) and Elderly (OLD)
- 2 b-values: 500 (6 dir) and 2000 (64 dir) s/mm²





Open question: impact on Tractography and Tractometry?

DWI Reconstruction with qsiprep

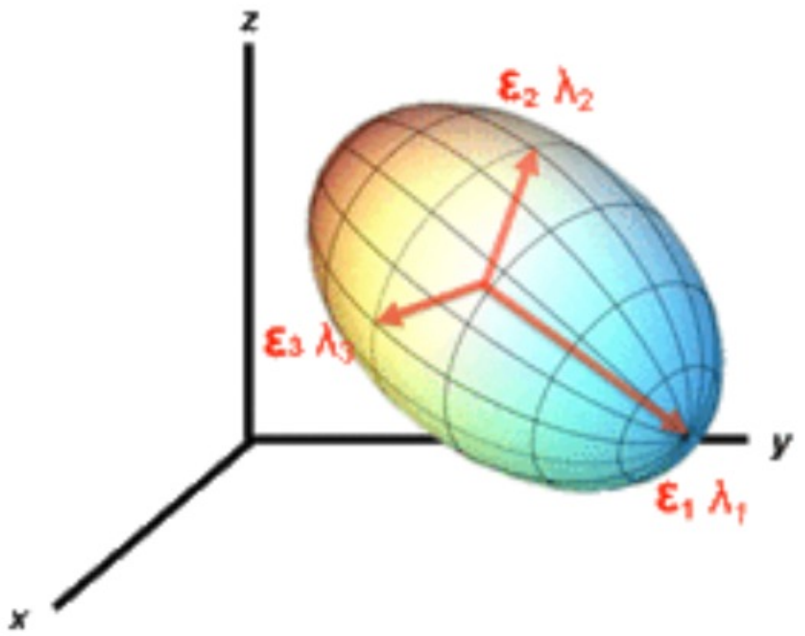
Option	MultiShell	DSI	DTI	Tractography
mrtrix_multishell_msmt_ACT-fast*	Yes	No	No	Probabilistic
mrtrix_multishell_msmt_ACT-hsvs	Yes	No	No	Probabilistic
mrtrix_multishell_msmt_noACT	Yes	No	No	Probabilistic
mrtrix_singleshell_ss3t_noACT	No	No	Yes	Probabilistic
mrtrix_singleshell_ss3t_ACT-hsvs	No	No	Yes	Probabilistic
mrtrix_multishell_msmt_ACT-fast*	No	No	Yes	Probabilistic
pyafq_tractometry	Yes	No	Yes	Both
mrtrix_multishell_msmt_pyafq_tractometry	Yes	No	Yes	Both
amico_noddi	Yes	No	No	None
dsi_studio_gqi	Yes	Yes	Yes*	Deterministic
dipy_mapmri	Yes	Yes	No	Both
dipy_3dshore	Yes	Yes	No	Both
csdsi_3dshore	Yes	Yes	No	Both
reorient_fslstd	Yes	Yes	Yes	None

+ custom reconstruction through configuration files !

DTI metrics

DTI scalar metrics:

- FA = $\sqrt{\frac{(\lambda_1-\lambda_2)^2+(\lambda_2-\lambda_3)^2+(\lambda_1-\lambda_3)^2}{2(\lambda_1^2+\lambda_2^2+\lambda_3^2)}}$
- MD = $(\lambda_1 + \lambda_2 + \lambda_3)/3)$
- RD = $(\lambda_2 + \lambda_3)/2)$
- AxD = λ_1



Representation of the diffusion as an ellipsoid with three unit eigenvectors, ($\boldsymbol{\varepsilon_1}$, $\boldsymbol{\varepsilon_2}$, and $\boldsymbol{\varepsilon_3}$), with corresponding lengths (λ_1, λ_2, *and* λ_3), the eigenvalues.

DTI metrics and usage

DTI scalar metrics interpretation

- Increased FA: higher fiber density, lower membrane permeability, greater myelination, …

- MD : more robust than FA, RD and AxD to crossing fibers

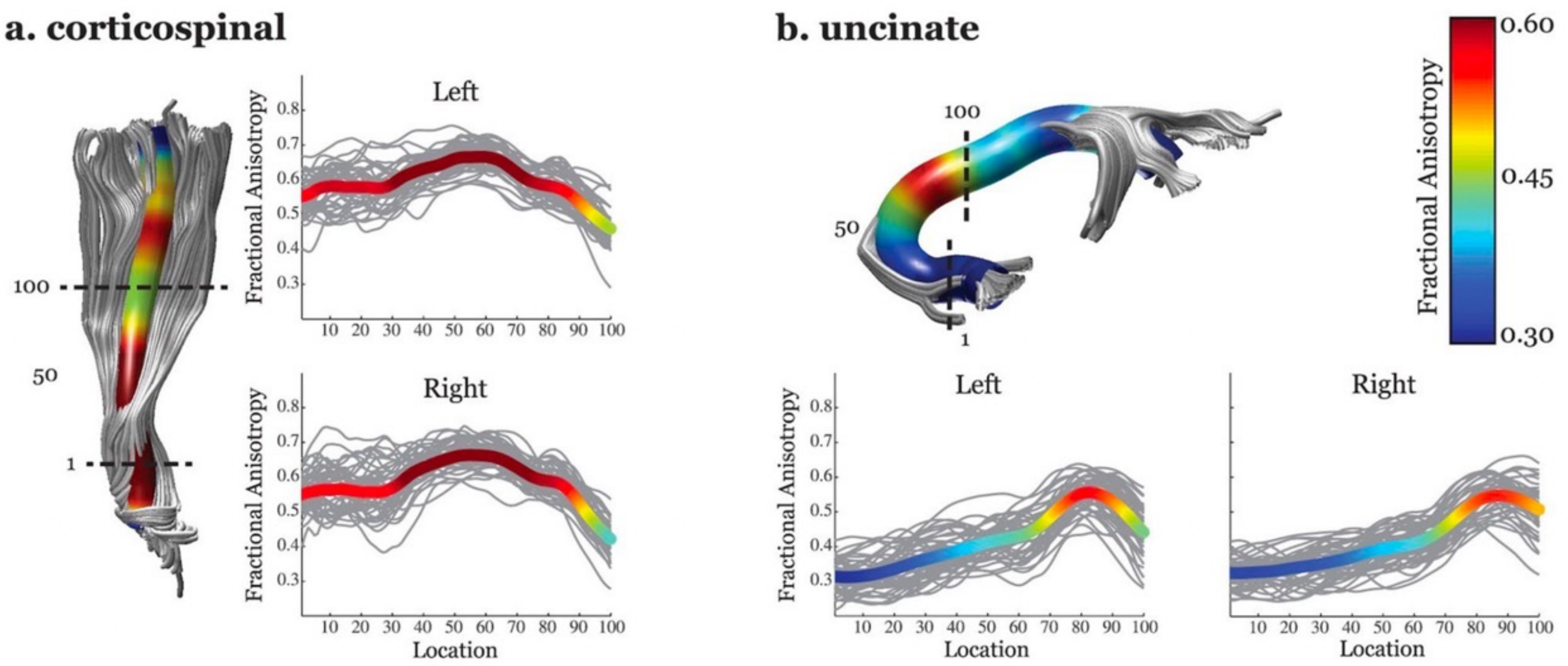
Figley et al. **Potential Pitfalls of Using Fractional Anisotropy, Axial Diffusivity, and Radial Diffusivity as Biomarkers of Cerebral White Matter Microstructure.** *(2022)*

Recommends complimented measures:
- **DKI**, **CSD**, **NODDI**, **Fixel Based Analysis**
- other than DWI: **T1w/T2w**, **ihMT**, **MWF**

DWI Reconstruction : Tractometry

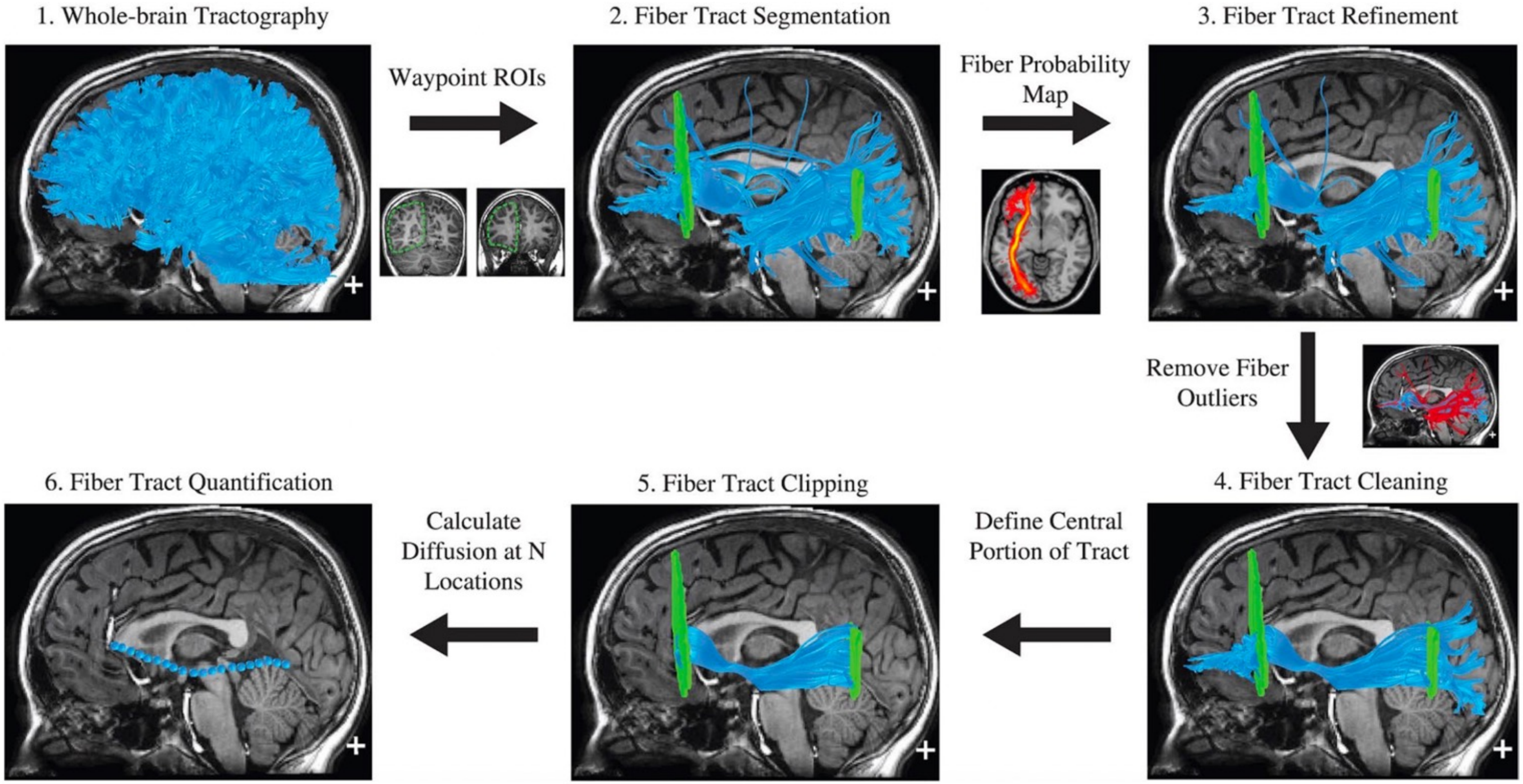
“Taken together, **computational tractography**, **bundle recognition**, and **diffusion modeling** provide so-called **<u>tract profiles</u>**: estimates of microstructural properties of tissue along the length of major pathways. This is the basis of **tractometry**: statistical analysis that compares different groups or assesses individual variability in brain connection structure”

Kruper et al. *Aperture Neuro* **2021**



Andica et al.
Automated Three-Dimensional Major White Matter Bundle Segmentation Using Diffusion Magnetic Resonance Imaging.
Anat Sci Int **2023**

pyAFQ Reconstruction within qsiprep



Andica et al. 2021, Yeatman et al. 2012

pyAFQ Reconstruction within qsiprep


```
 "description": "Use pyAFQ to perform the Tractometry pipeline, with tractography from qsiprep with DKI in addition",
    "space": "T1w",
    "name": "mrtrix_multishell_msmt_pyafq_tractometry_JS",
    "atlases": [],
    "nodes": [
        {
            "name": "msmt_csd",
            "software": "MRTrix3",
            "action": "csd",
            "output_suffix": "msmtcsd",
            "input": "qsiprep",
            "parameters": {
                "mtnormalize": true,
                "response": {
                "algorithm": "dhollander"
                },
                "fod": {
                "algorithm": "msmt_csd",
                "max_sh": [8, 8, 8]
```

```
"name": "track_ifod2",
"software": "MRTrix3",
"action": "tractography",
"output_suffix": "ifod2",
"input": "msmt_csd",
"parameters": {
   "use_5tt": false,
   "use_sift2": true,
   "tckgen":{
   "algorithm": "iFOD2",
   "select": 1e6,
   "max_length": 250,
   "min_length": 30,
   "power":0.33
   },
   "sift2":{}
```

```
"name": "pyafq_tractometry",
"software": "pyAFQ",
"action": "pyafq_tractometry",
"input": "track_ifod2",
"output_suffix": "PYAFQ_TRACTOMETRY_ET",
"parameters": {
   "use_external_tracking": true,
   "export": "all",
   "directions": "prob",
   "max_angle": 30.0,
   "sphere": "",
   "seed_mask": "",
   "seed_threshold": 0,
   "n_seeds": 1,
   "random_seeds": false,
   "rng_seed": "",
   "stop_mask": "",
   "stop_threshold": 0,
   "step_size": 0.5,
   "min_length": 50,
   "max_length": 250,
   "odf_model": "CSD",
   "tracker": "local",
   "nb_points": false,
   "nb_streamlines": false,
   "seg_algo": "AFQ",
   "
```

pyAFQ Reconstruction within qsiprep

Specific option in pyAFQ (through QSIPREP):

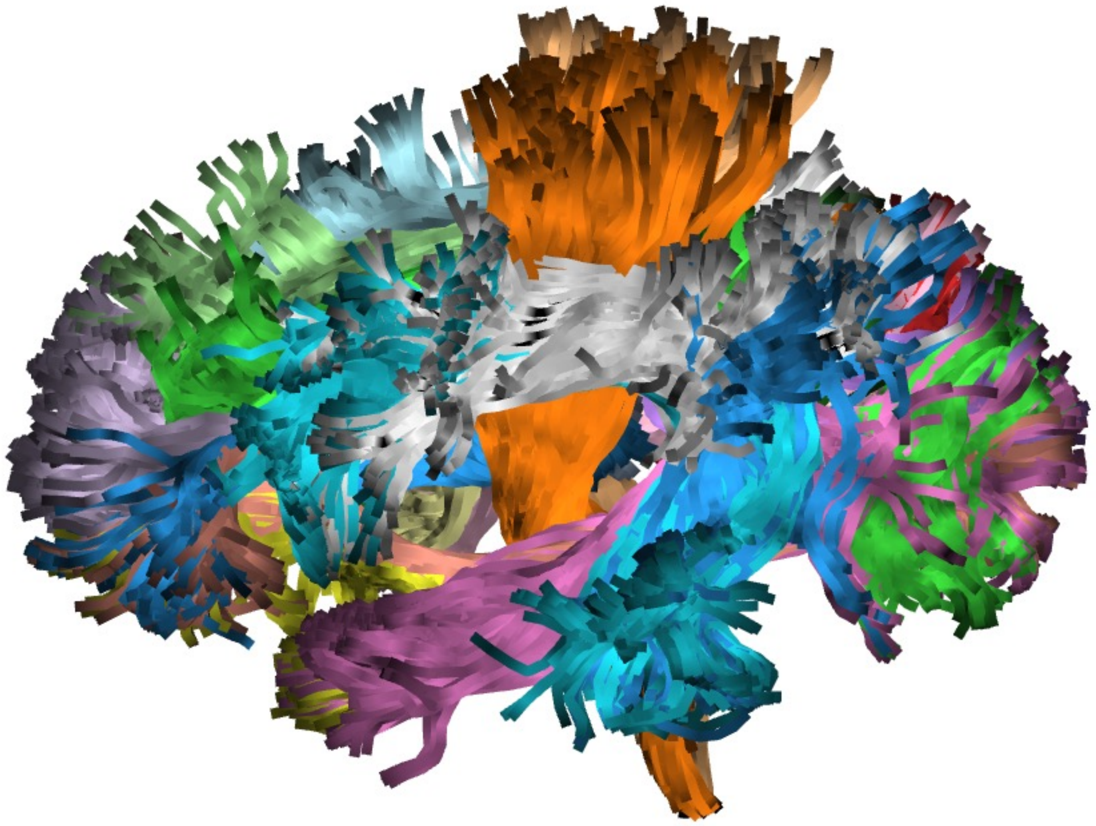
```
"scalars":
"['dti_fa','dti_md','dti_rd','dti_ad','dki_fa','dki_md']",
```

sub-SUB_space-T1w_desc-preproc_dwi_space-RASMM_model-probCSD_algo-AFQ_desc-profiles_dwi.csv

	tractID	nodeID	dti_fa	dti_md	dti_rd	dti_ad	dki_fa	dki_md
0	ATR_L	0	0.20570933854551643	0.000686916065784494	0.0006151699570349627	0.0008304082832835536	0.23724199868892912	0.0008574057502554258
1	ATR_L	1	0.235723937038021	0.0006726244134407995	0.0005910810428346782	0.000835711154653046	0.2701782451199084	0.0008293609318190809
2	ATR_L	2	0.2692432407500829	0.000666069032143725	0.0005716939706152982	0.000854819155200578	0.3007053672774038	0.0008210591738175878
3	ATR_L	3	0.30230813333267226	0.0006621957152211032	0.0005541436993604519	0.0008782997469424069	0.3280628871756977	0.000819582586150776
4	ATR_L	4	0.33778103072740817	0.0006571018774746051	0.0005342394656032334	0.0009028267012173492	0.35847578610972647	0.000817585508623988
5	ATR_L	5	0.3720022284451804	0.0006507187349331651	0.0005137055316980438	0.0009247451414034052	0.38877468371008156	0.0008151938069753821
6	ATR_L	6	0.4053563495129063	0.0006440213266363467	0.0004931299407467528	0.0009458040984155365	0.41807084685300433	0.0008144467516062641
7	ATR_L	7	0.43423053017046875	0.0006383732725740044	0.0004752454445847734	0.0009646289285524639	0.44181102793176036	0.0008156335089100516
8	ATR_L	8	0.45619211389941133	0.0006341570153181982	0.00046208220224638847	0.000978306641461819	0.458830337790342	0.0008187808832119736
9	ATR_L	9	0.47142632821755165	0.000631969647024736	0.0004538612617678625	0.0009881864175384824	0.47025880763211164	0.0008232013445819059

Table S1. Abbreviations of the major white matter pathways recognized by pyAFQ.

ARC L	Left arcuate
ARC R	Right arcuate
ATR L	Left thalamic radiation
ATR R	Right thalamic radiation
CGC L	Left cingulum cingulate
CGC R	Right cingulum cingulate
CST L	Left corticospinal
CST R	Right corticospinal
FA	Callosum forceps minor
FP	Callosum forceps major
IFO L	Left inferior fronto-occipital fasciculus
IFO R	Right inferior fronto-occipital fasciculus
ILF L	Left inferior longitudinal fasciculus
ILF R	Right inferior longitudinal fasciculus
SLF L	Left superior longitudinal fasciculus
SLF R	Right superior longitudinal fasciculus
UNC L	Left uncinate
UNC R	Right uncinate

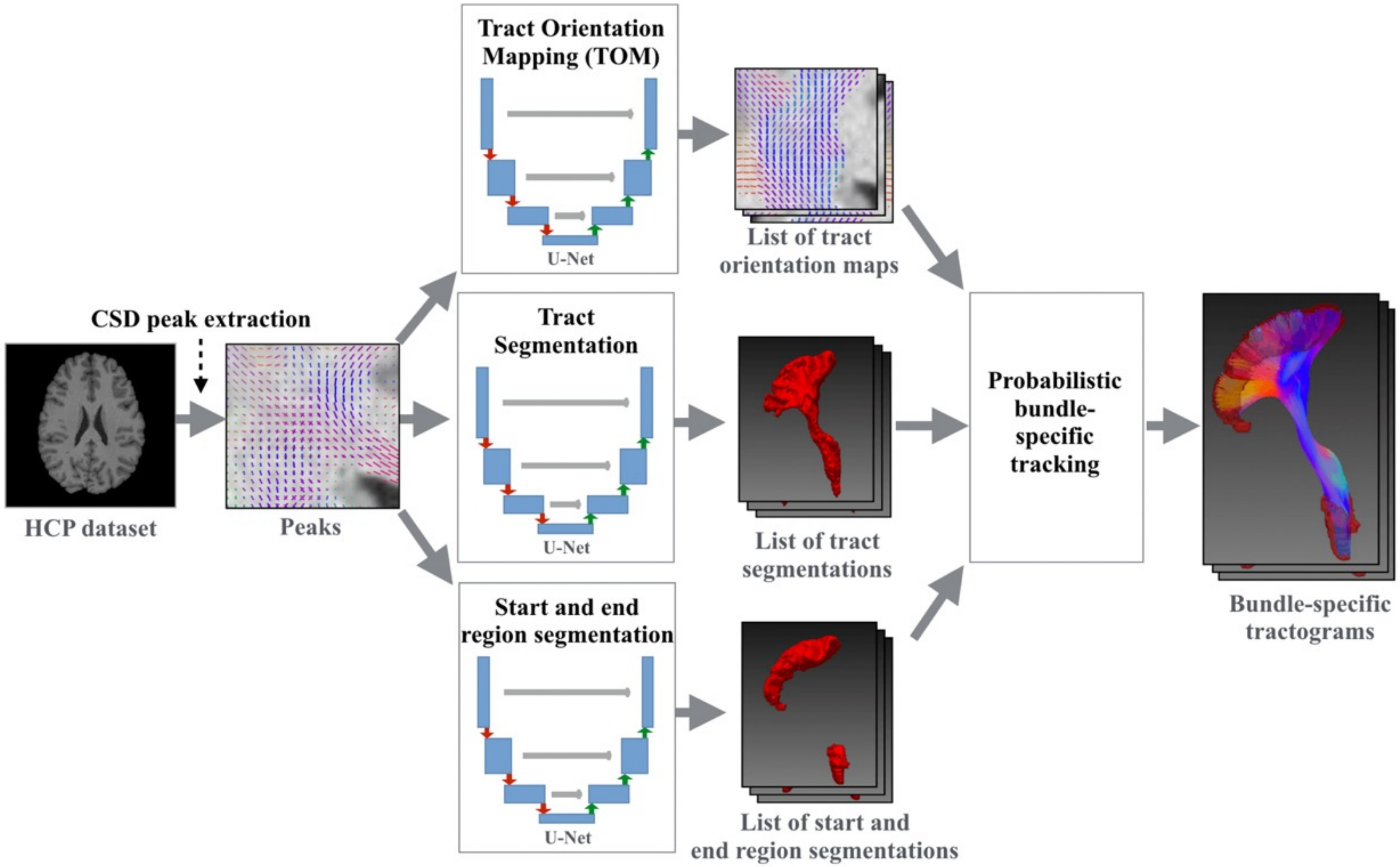


Andica et al. 2021, Yeatman et al. 2012

Demo on Web browser and image viewers

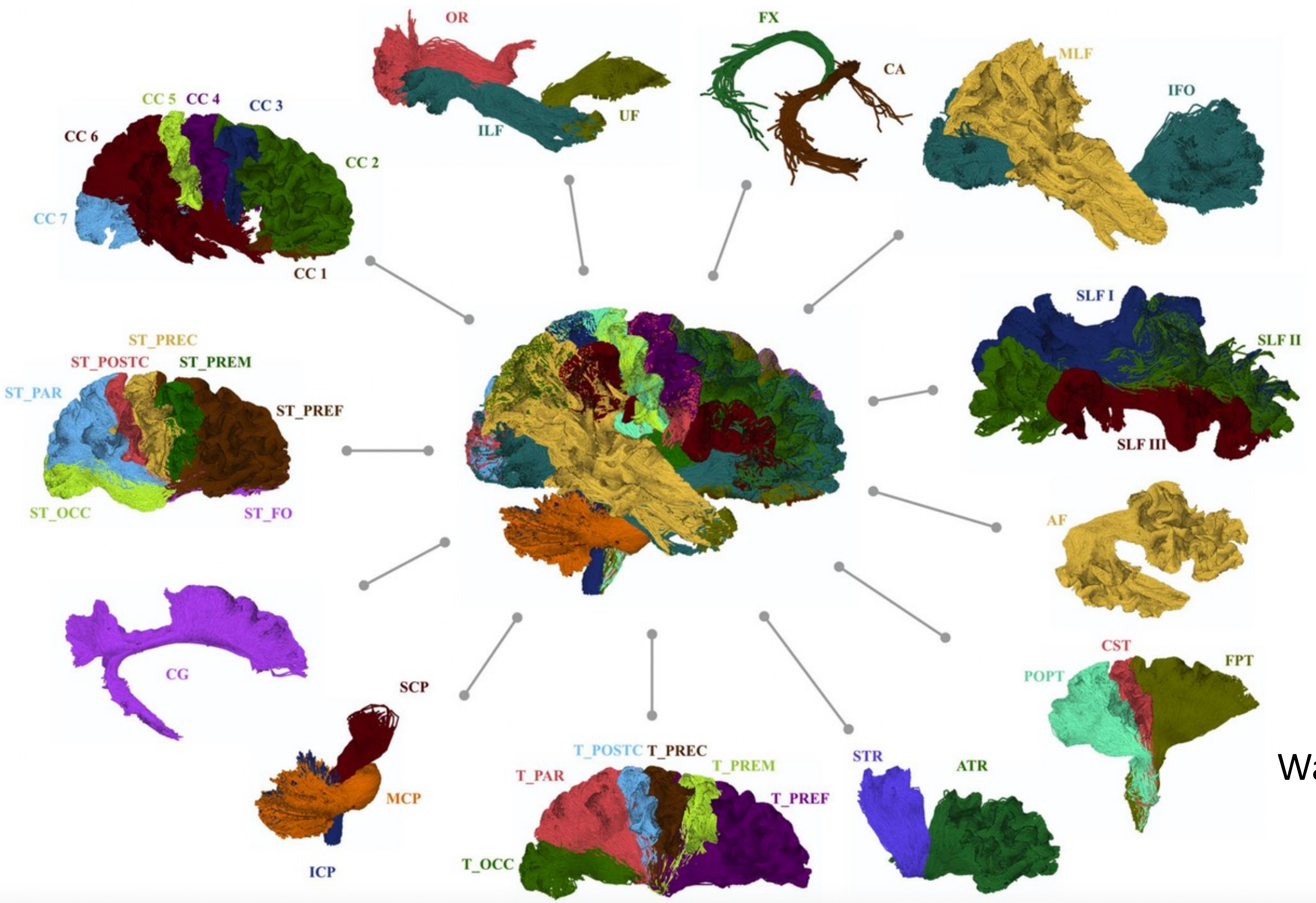
Another Tractometry tool: TractSeg

- https://github. com/MIC-DKFZ/TractSeg/
- 72 white matter tracts automatically segmented



Another Tractometry tool: TractSeg

- https://github. com/MIC-DKFZ/TractSeg/
- 72 white matter tracts automatically segmented



Wasserthal et al. 2018

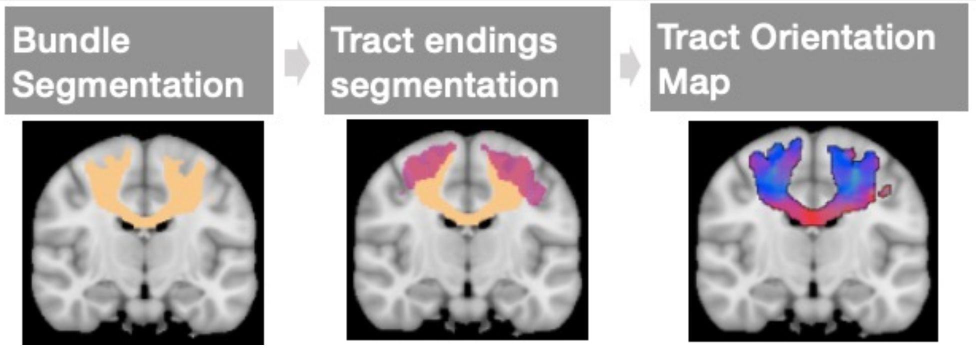
```
0: AF_left          (Arcuate fascicle)
1: AF_right
2: ATR_left         (Anterior Thalamic Radiation)
3: ATR_right
4: CA               (Commissure Anterior)
5: CC_1             (Rostrum)
6: CC_2             (Genu)
7: CC_3             (Rostral body (Premotor))
8: CC_4             (Anterior midbody (Primary Motor))
9: CC_5             (Posterior midbody (Primary Somatosensory))
10: CC_6            (Isthmus)
11: CC_7            (Splenium)
12: CG_left         (Cingulum left)
13: CG_right
14: CST_left        (Corticospinal tract)
15: CST_right
16: MLF_left        (Middle longitudinal fascicle)
17: MLF_right
18: FPT_left        (Fronto-pontine tract)
19: FPT_right
20: FX_left         (Fornix)
21: FX_right
22: ICP_left        (Inferior cerebellar peduncle)
23: ICP_right
24: IFO_left        (Inferior occipito-frontal fascicle)
25: IFO_right
26: ILF_left        (Inferior longitudinal fascicle)
27: ILF_right
28: MCP             (Middle cerebellar peduncle)
29: OR_left         (Optic radiation)
30: OR_right
```

```
31: POPT_left       (Parieto-occipital pontine)
32: POPT_right
33: SCP_left        (Superior cerebellar peduncle)
34: SCP_right
35: SLF_I_left      (Superior longitudinal fascicle I)
36: SLF_I_right
37: SLF_II_left     (Superior longitudinal fascicle II)
38: SLF_II_right
39: SLF_III_left    (Superior longitudinal fascicle III)
40: SLF_III_right
41: STR_left        (Superior Thalamic Radiation)
42: STR_right
43: UF_left         (Uncinate fascicle)
44: UF_right
45: CC              (Corpus Callosum - all)
46: T_PREF_left     (Thalamo-prefrontal)
47: T_PREF_right
48: T_PREM_left     (Thalamo-premotor)
49: T_PREM_right
50: T_PREC_left     (Thalamo-precentral)
51: T_PREC_right
52: T_POSTC_left    (Thalamo-postcentral)
53: T_POSTC_right
54: T_PAR_left      (Thalamo-parietal)
55: T_PAR_right
56: T_OCC_left      (Thalamo-occipital)
57: T_OCC_right
58: ST_FO_left      (Striato-fronto-orbital)
59: ST_FO_right
60: ST_PREF_left    (Striato-prefrontal)
61: ST_PREF_right
62: ST_PREM_left    (Striato-premotor)
```

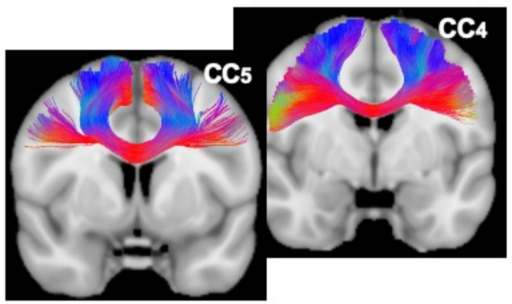
```
63: ST_PREM_right
64: ST_PREC_left    (Striato-precentral)
65: ST_PREC_right
66: ST_POSTC_left   (Striato-postcentral)
67: ST_POSTC_right
68: ST_PAR_left     (Striato-parietal)
69: ST_PAR_right
70: ST_OCC_left     (Striato-occipital)
71: ST_OCC_right
```

TractSeg bundles
Wasserthal et al. 2018

Exemple with TractSeg: project Aging (A. Kavounoudias)

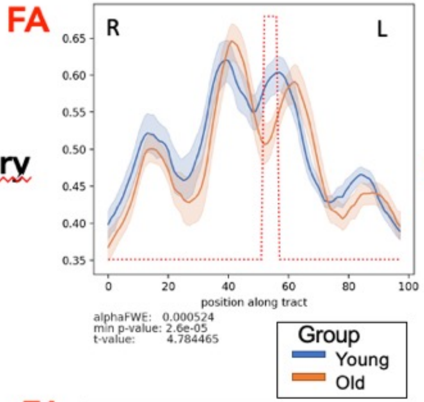


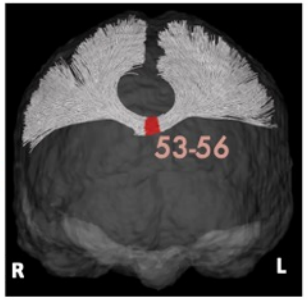
Tractometry



Tractography: age-related changes within the interhemispheric motor and somatosensory tract.

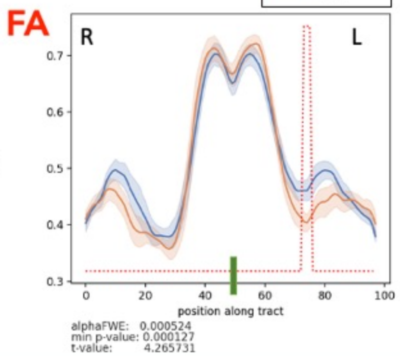
Somatosensory Tract

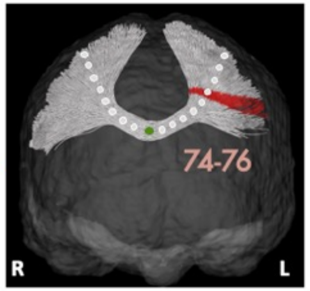




significant

Motor Tract

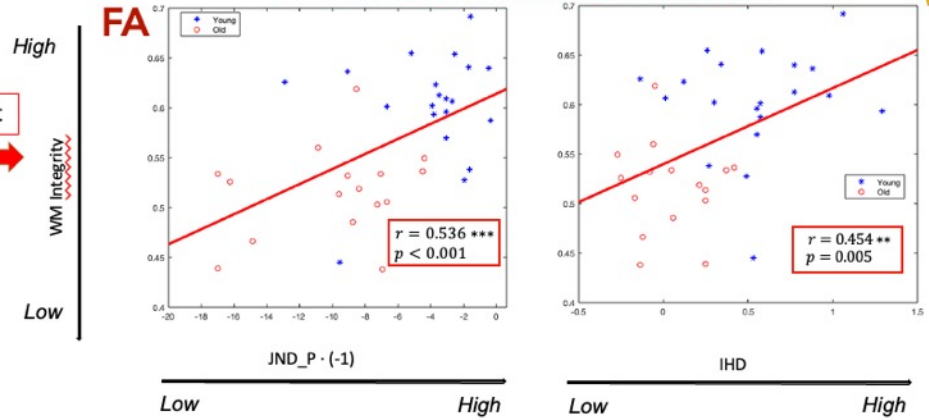


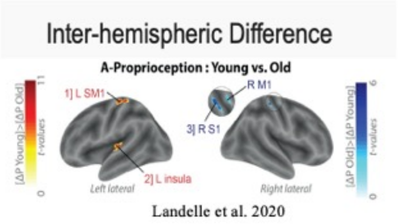


not significant

Pinzon et al.
OHBM 2022

Correlations with functional indices



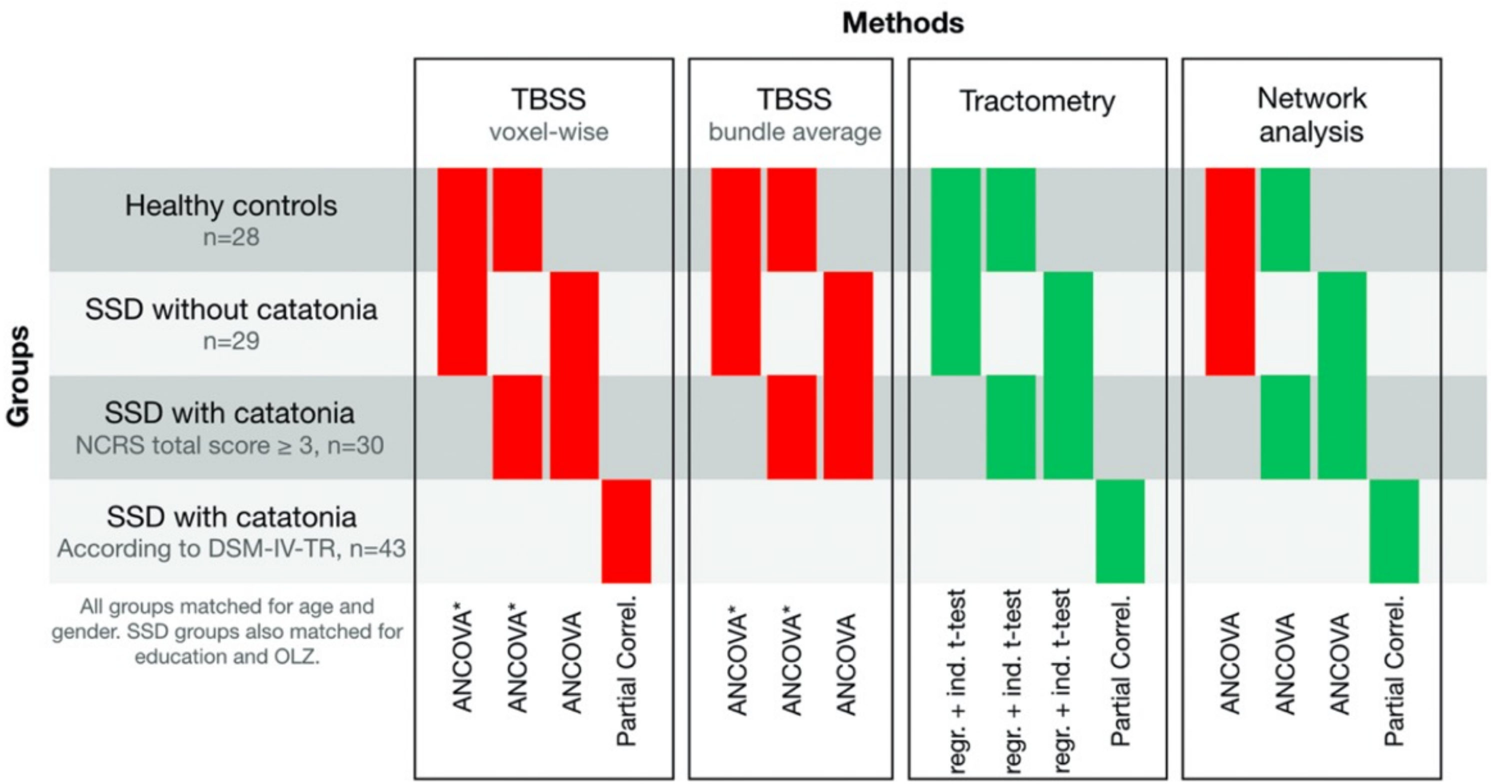


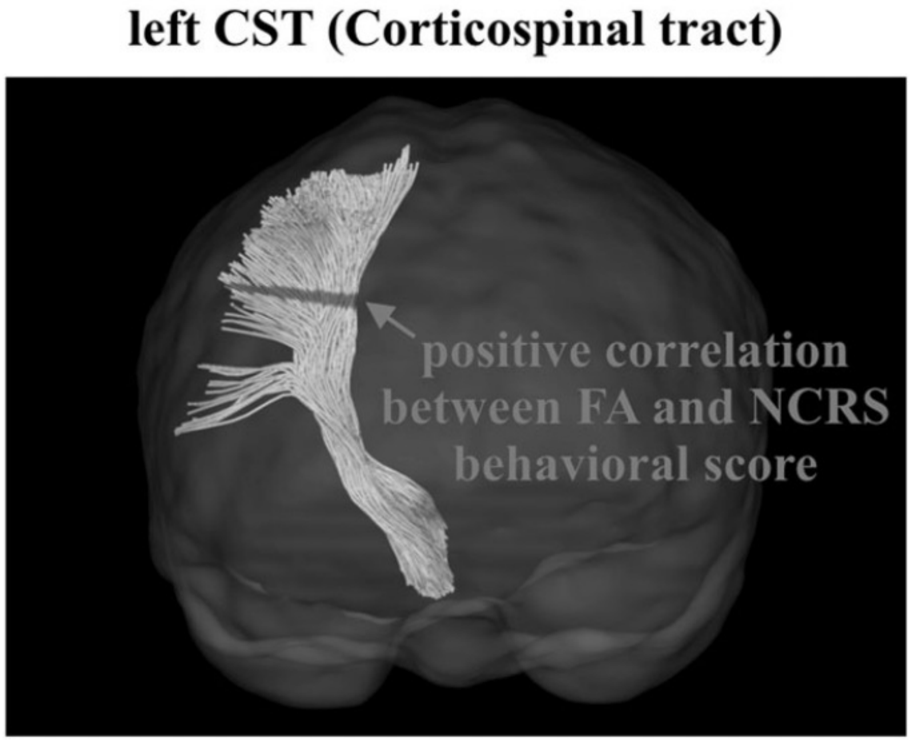
RD in the sensory tract significantly correlated with the functional indices

Examples of Tractometry studies

(TractSeg)

Wasserthal et al. **Multiparametric Mapping of White Matter Microstructure in Catatonia.** *Neuropsychopharmacol.* **2020**

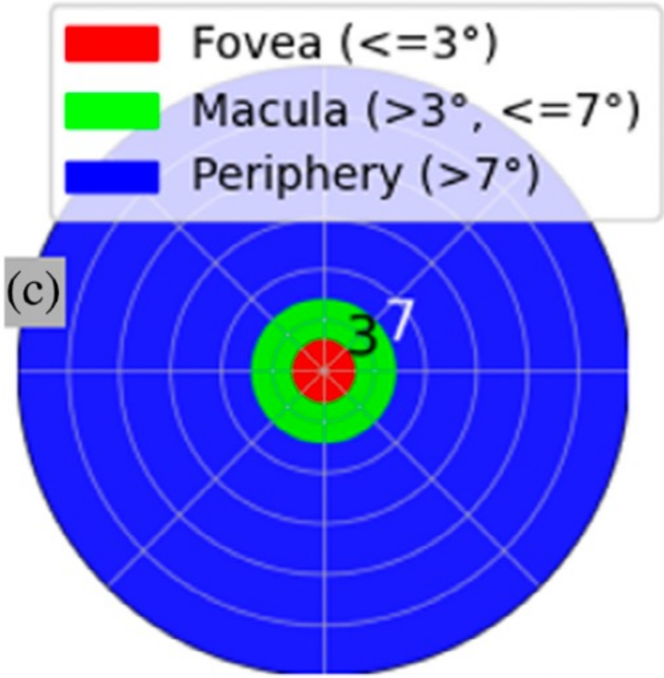


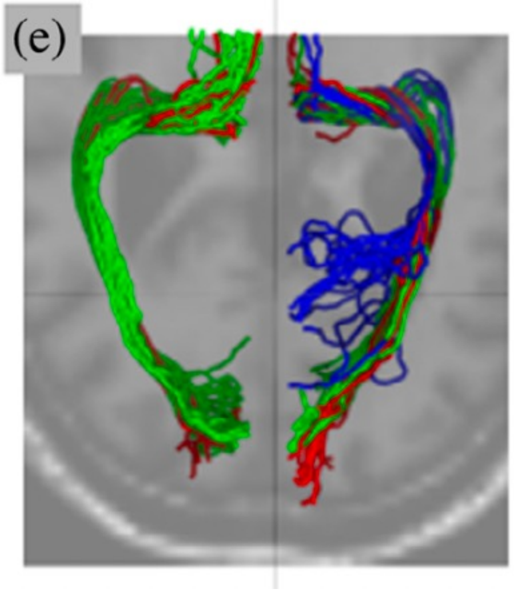


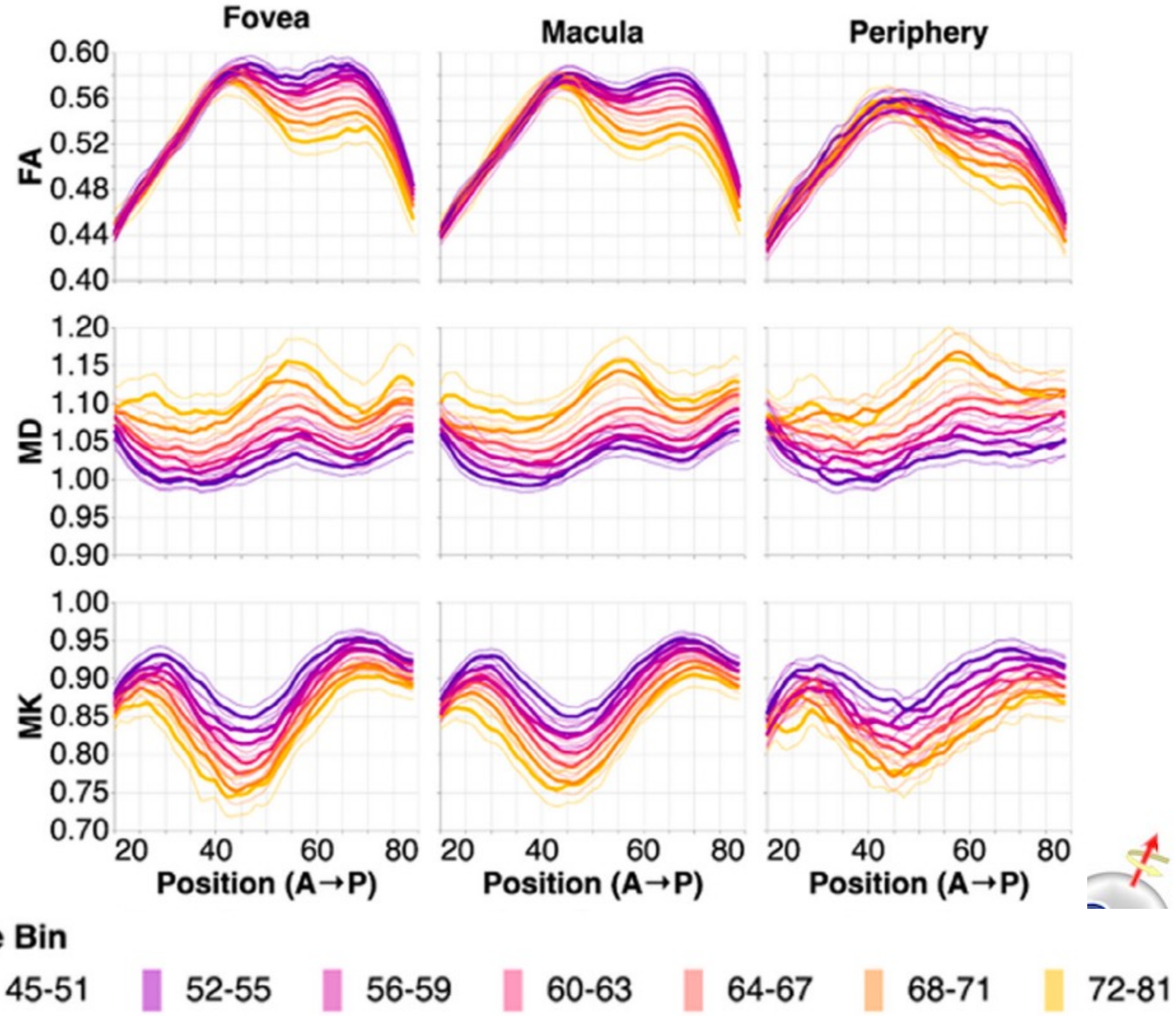
Examples of Tractometry studies
(pyAFQ)

Kruper et al. **Optic Radiations Representing Different Eccentricities Age Differently.** *Human Brain Mapping* **2023**

dMRI data from 5382 subjects of UK BioBank , age 45-81

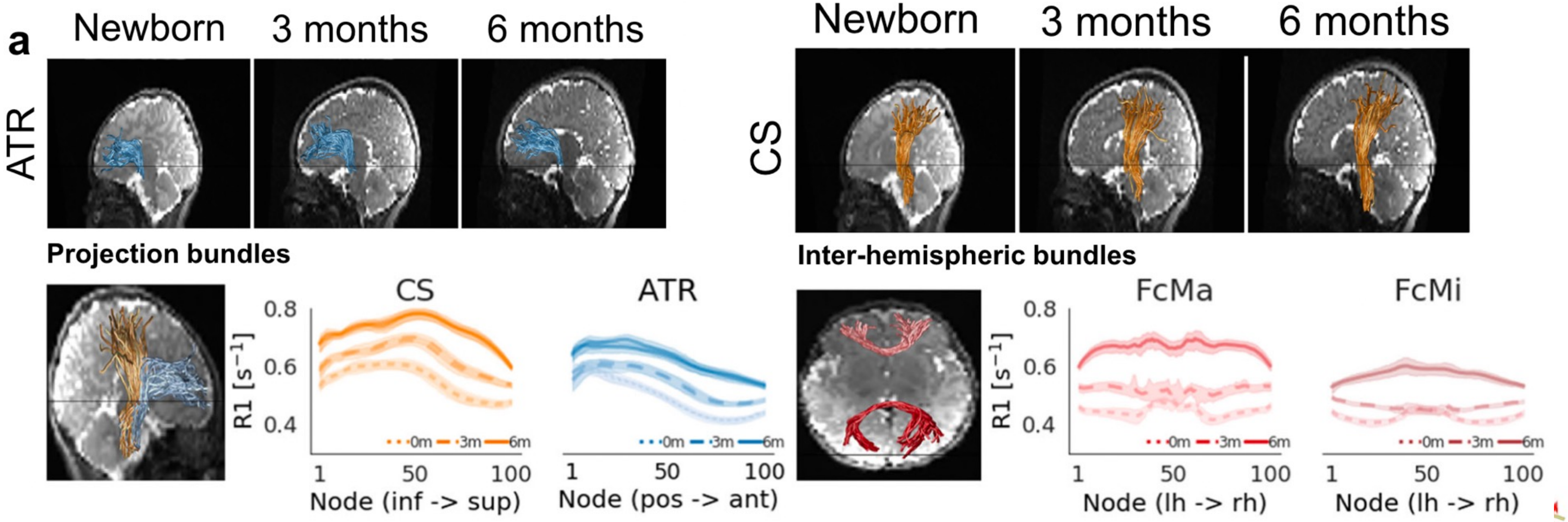






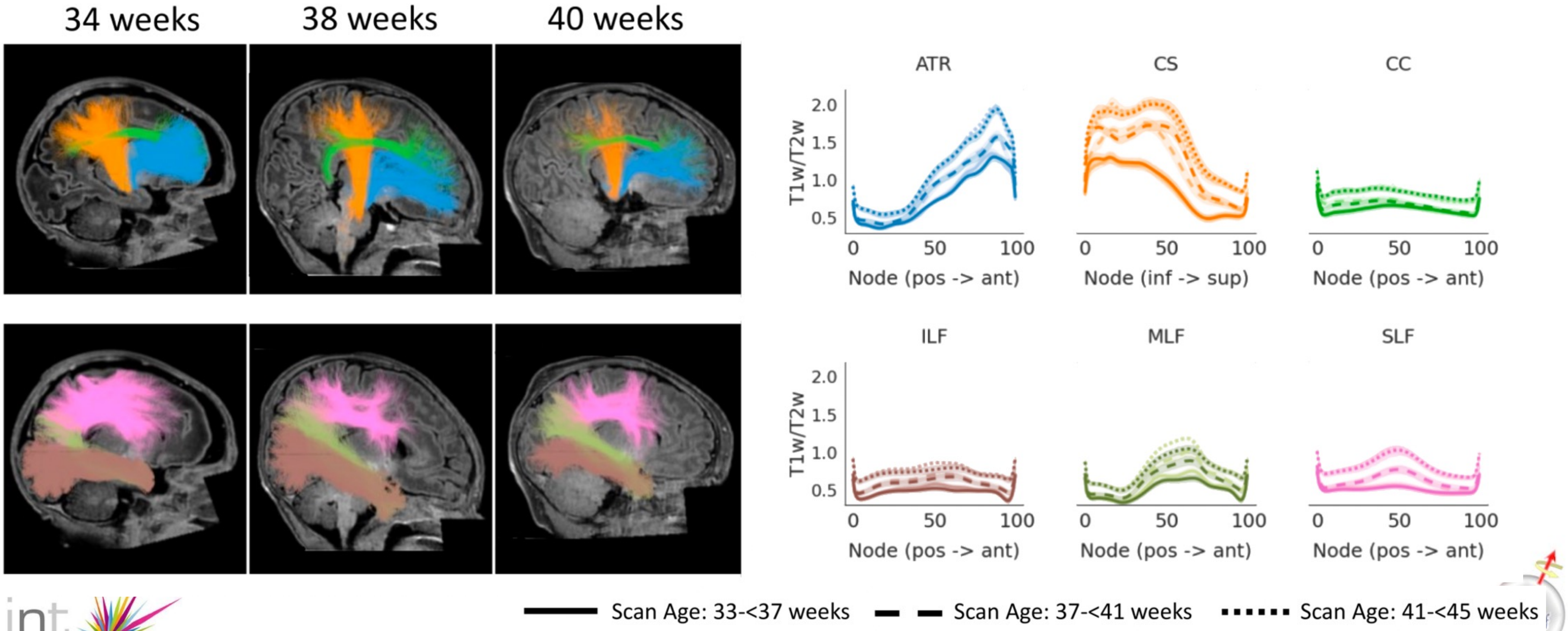
Examples of Tractometry studies
(Baby AFQ)

Grotheer et al. **Matter Myelination during Early Infancy Is Linked to Spatial Gradients and Myelin Content at Birth.** *Nat Commun* **2022**



Examples of Tractometry studies
(Baby AFQ)

- Grotheer et al. . **Human White Matter Myelination Rate Slows down at Birth**; preprint; Neuroscience, 2023.



Tractometry tools

- **AFQ** (matlab) and its successor pyAFP (python) (implemented within QSIPREP)

Yeatman et al. **Tract Profiles of White Matter Properties: Automating Fiber-Tract Quantification.** *PLOS ONE* **2012**.
Kruperet al. **Evaluating the Reliability of Human Brain White Matter Tractometry**. *Aperture Neuro* **2021**

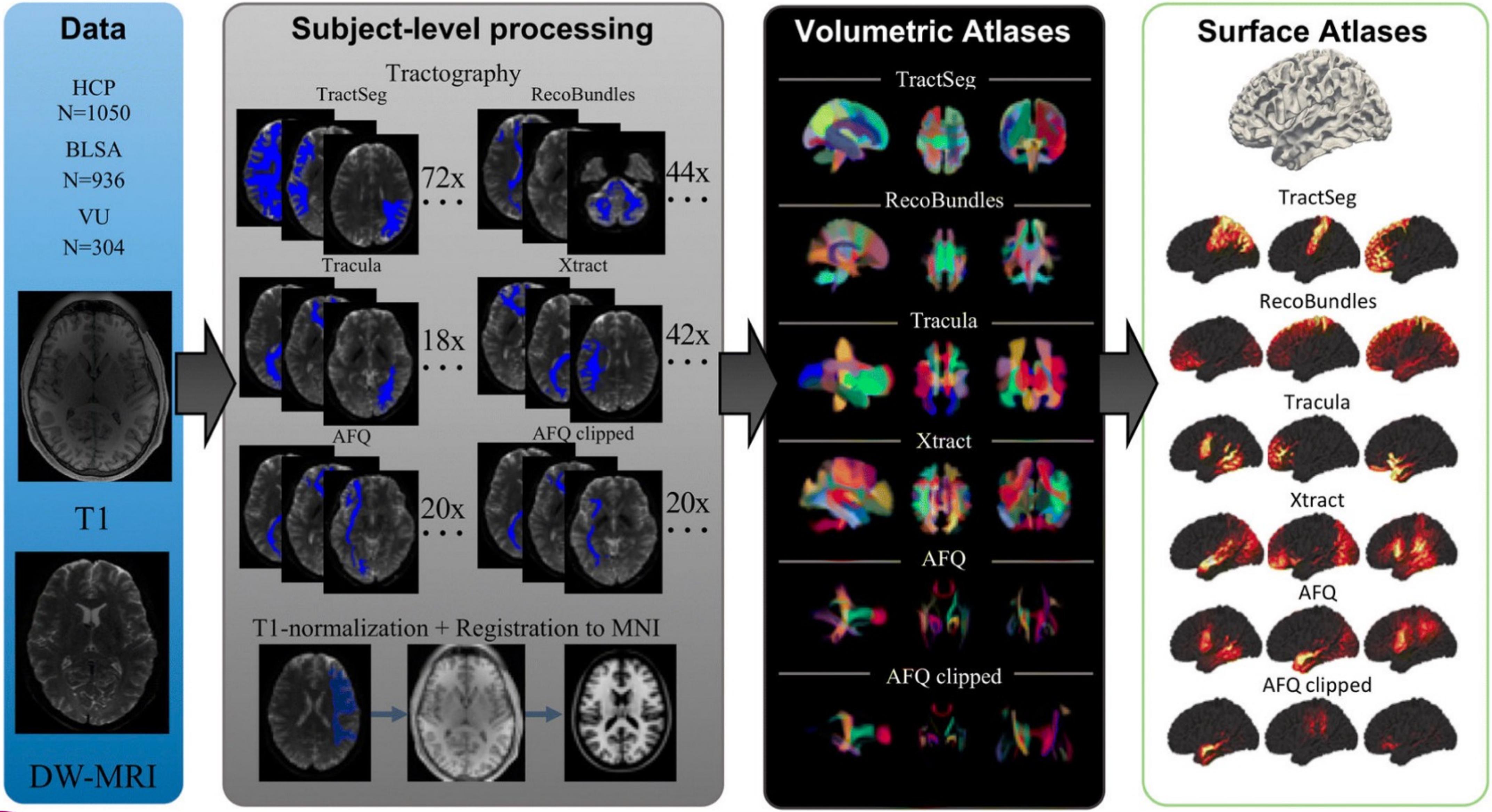
- Comparison between **TRACULA**, **AFQ** and **TractSeg** :

Andica et al. **Automated Three-Dimensional Major White Matter Bundle Segmentation Using Diffusion Magnetic Resonance Imaging**. *Anat Sci Int* **2023**, *98* (3), 318–336. https://doi.org/10.1007/s12565-023-00715-9

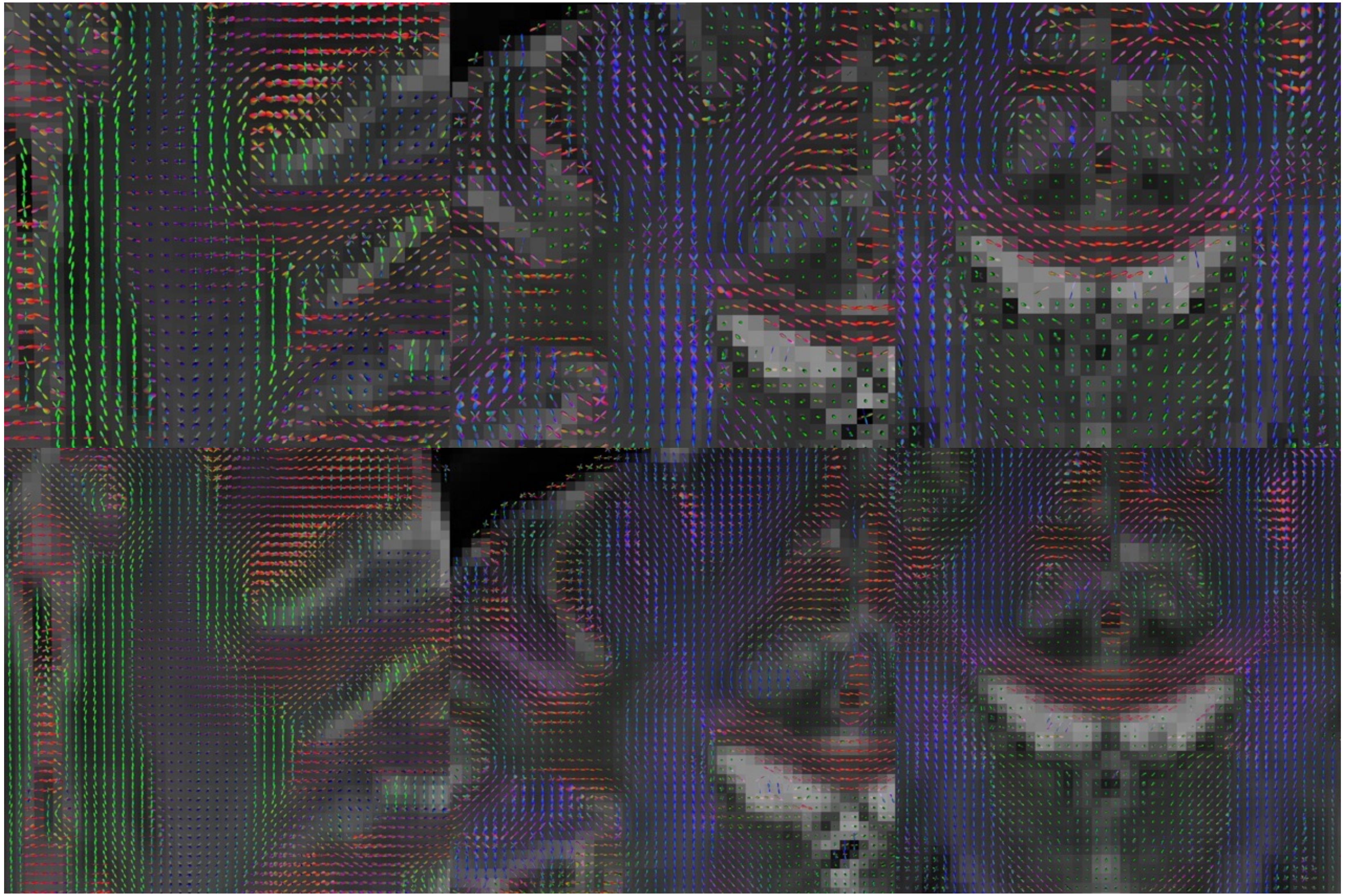
- Atlas based on different Bundle Segmentation Algorithms: **TRACULA**, **AFQ**, **XTRACT**, **RecoBundles**, **TractSeg**

Hansen et al. **Pandora: 4-D White Matter Bundle Population-Based Atlases Derived from Diffusion MRI Fiber Tractography.** *Neuroinformatics* **2021**

Pandora atlas



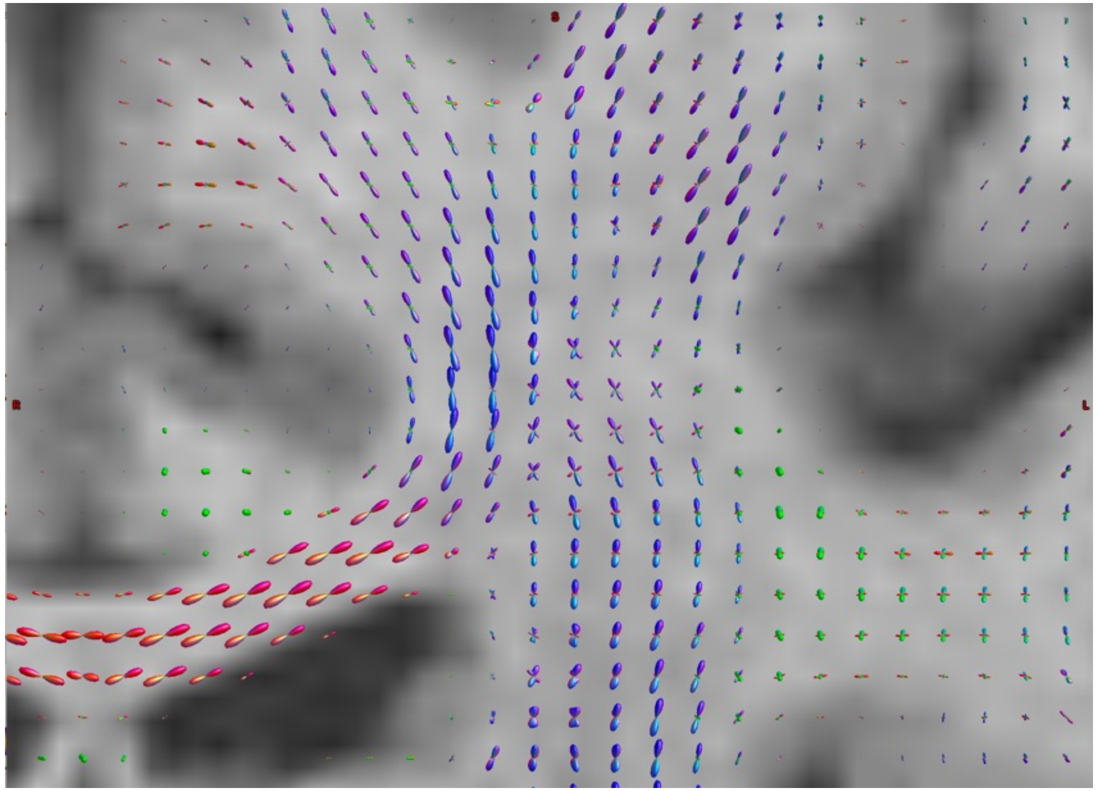
Methodological use case: Upsampling during preprocessing?



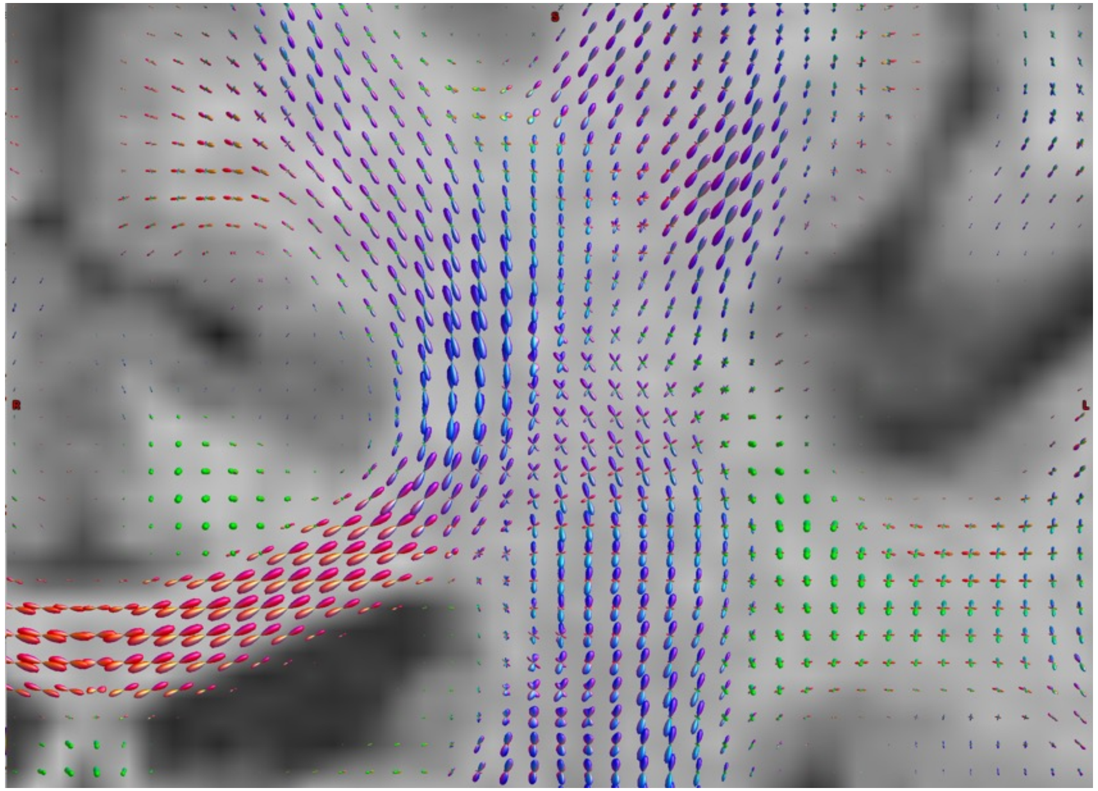
ODFs after preprocessing at original resolution: **1.8mm iso**

ODFs after preprocessing at upsampled resolution: **1.2mm iso**

Upsampling during preprocessing?

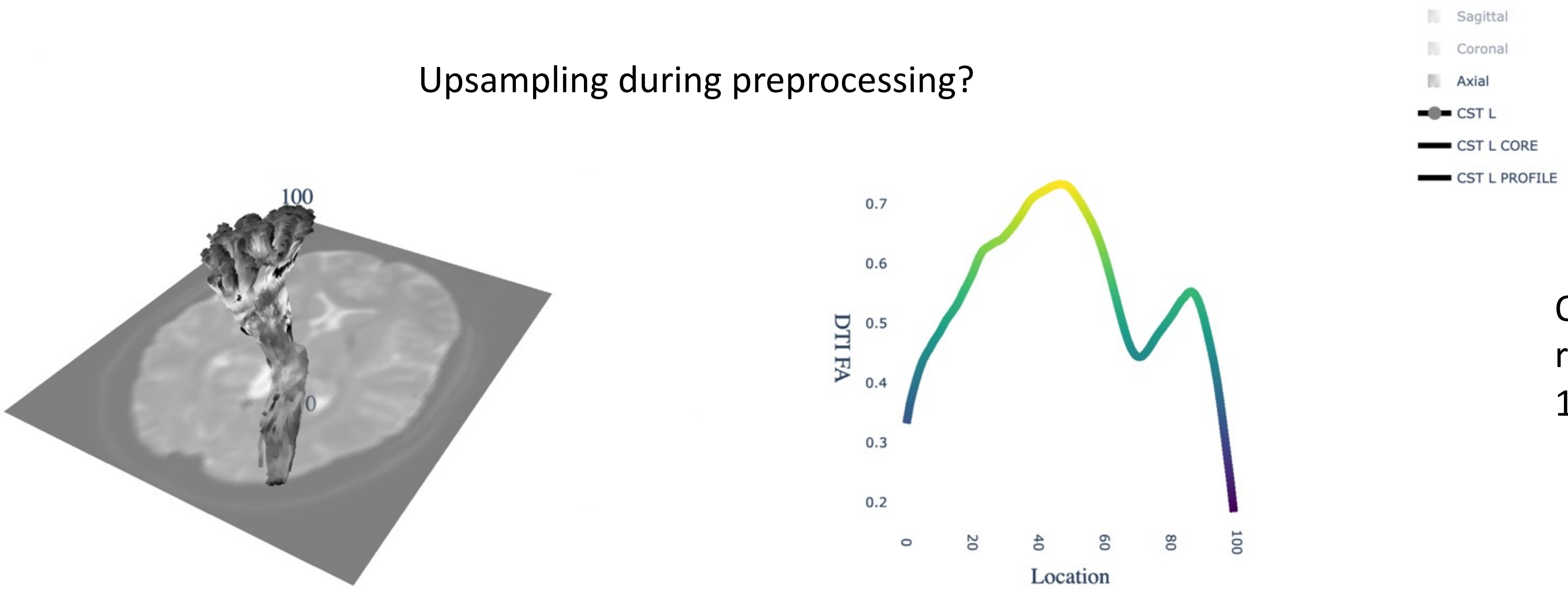


ODFs after preprocessing at
original resolution: 1.8mm iso

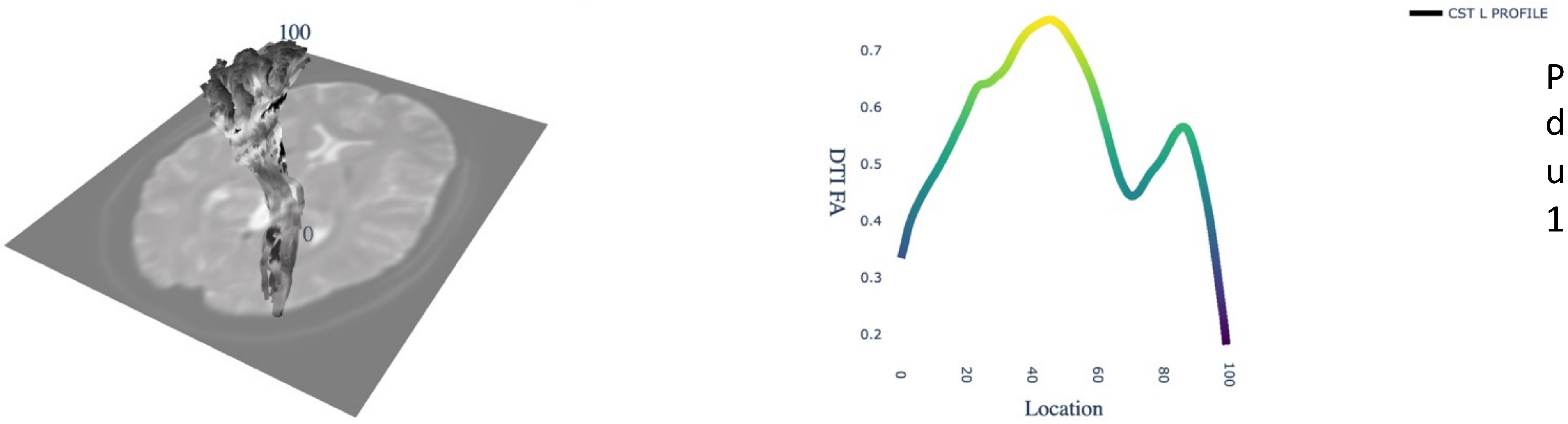


ODFs after preprocessing at
upsampled resolution: 1.2mm iso

Upsampling during preprocessing?

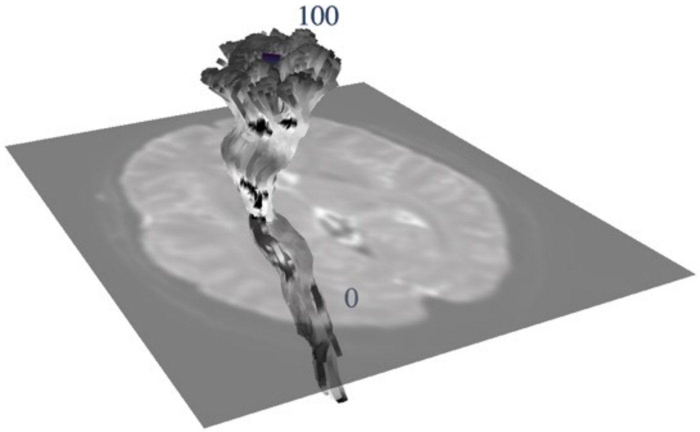


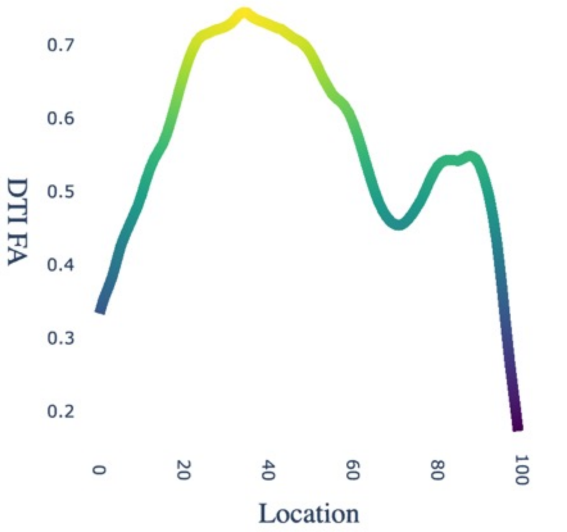
Original resolution: 1.8mm iso



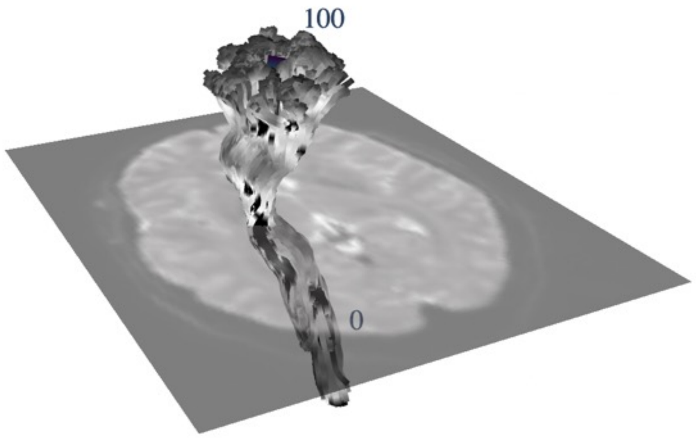
Preprocessed data upsampled at 1.2mm iso

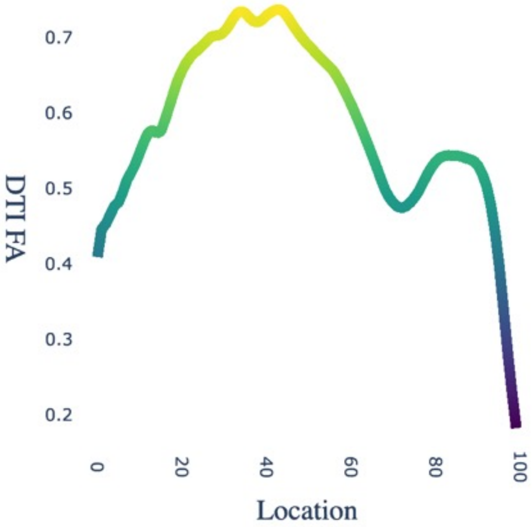
DWI acquisition with only bvec in AP?





Full PEPOLAR acquisition

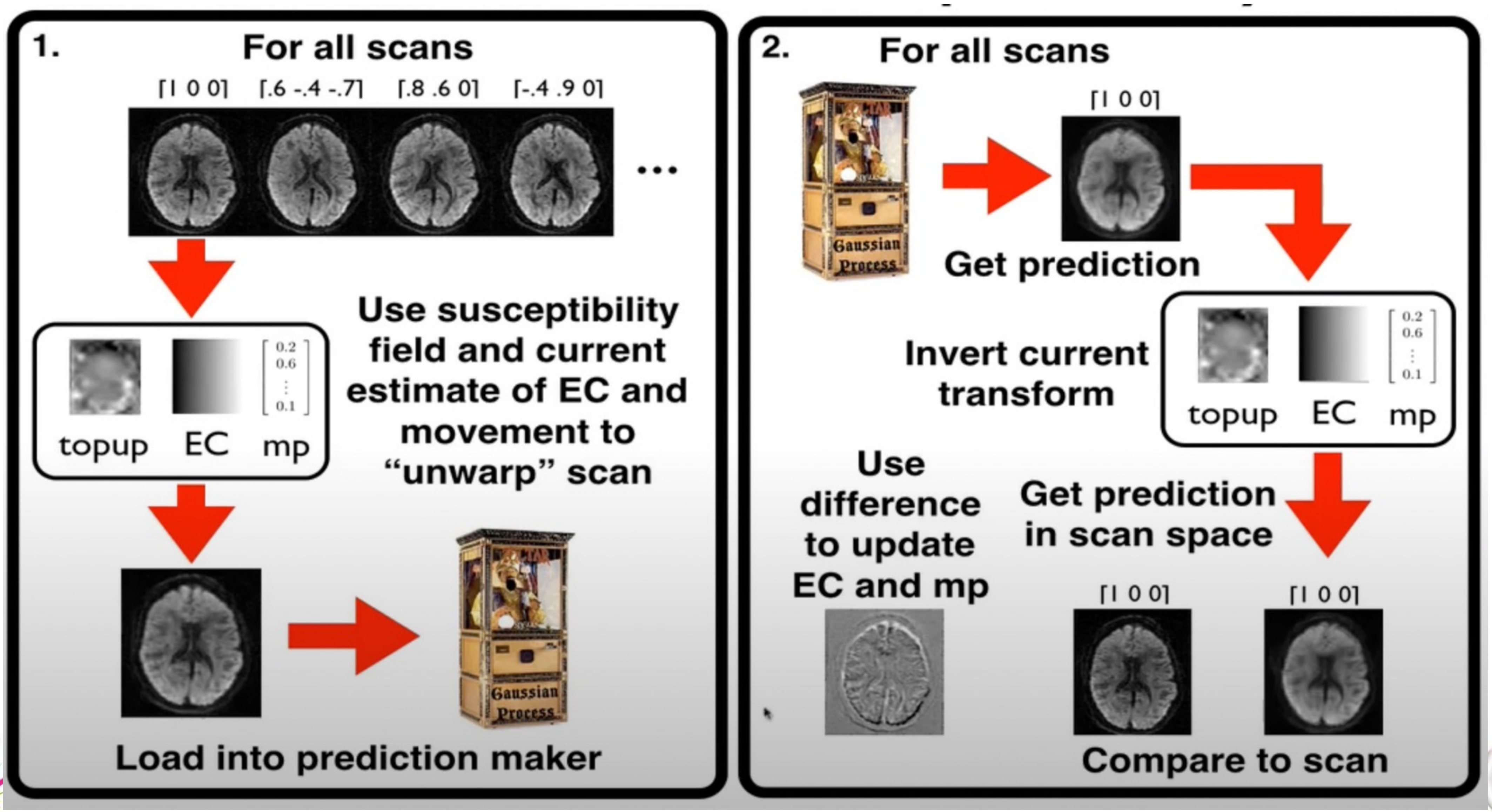




Only Diffusion direction in AP

FSL course:
fsl.fmrib.ox.ac.uk/fslcourse

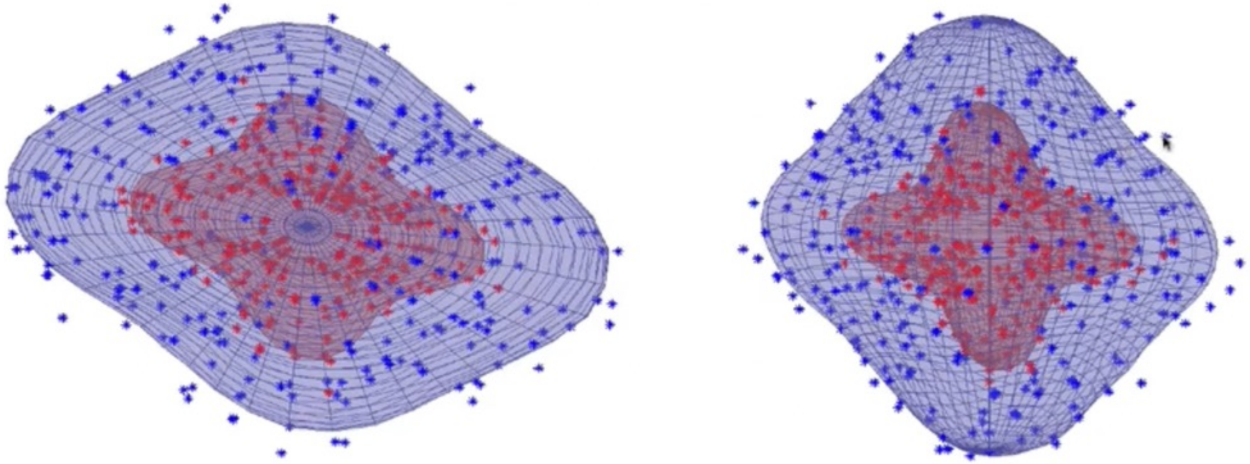
Extra slice on Eddy definition of CNR



FSL course:
fsl.fmrib.ox.ac.uk/fslcourse

Extra slice on Eddy definition of CNR

How are the predictions made?



A Gaussian process that simply assumes that the signal varies smoothly as we move in Q-space

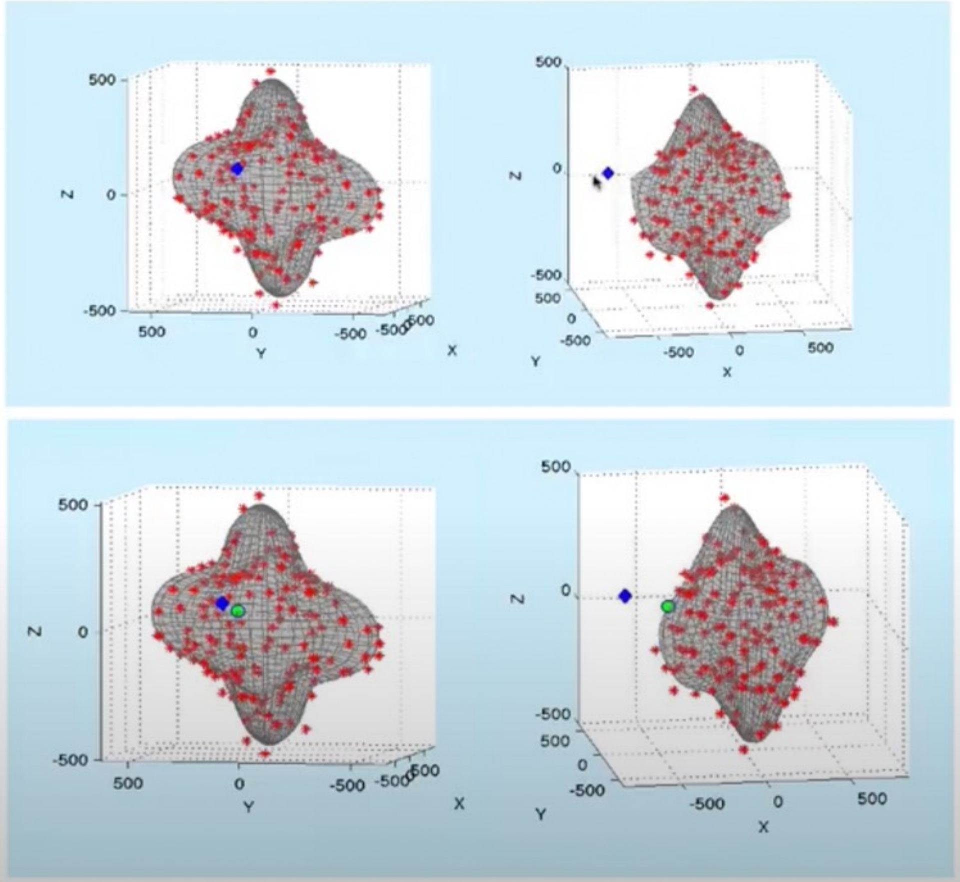
Very few assumptions. Hyperparameters calculated by leave-one-out.

$$\hat{y}_{\mathbf{g}} = K(\mathbf{g}, \mathbf{G}) \left[K(\mathbf{G}, \mathbf{G}) + \sigma^2 \mathbf{I} \right]^{-1} \mathbf{y}$$

FSL course:
fsl.fmrib.ox.ac.uk/fslcourse

Extra slice on Eddy definition of CNR

How to make the "right" prediction



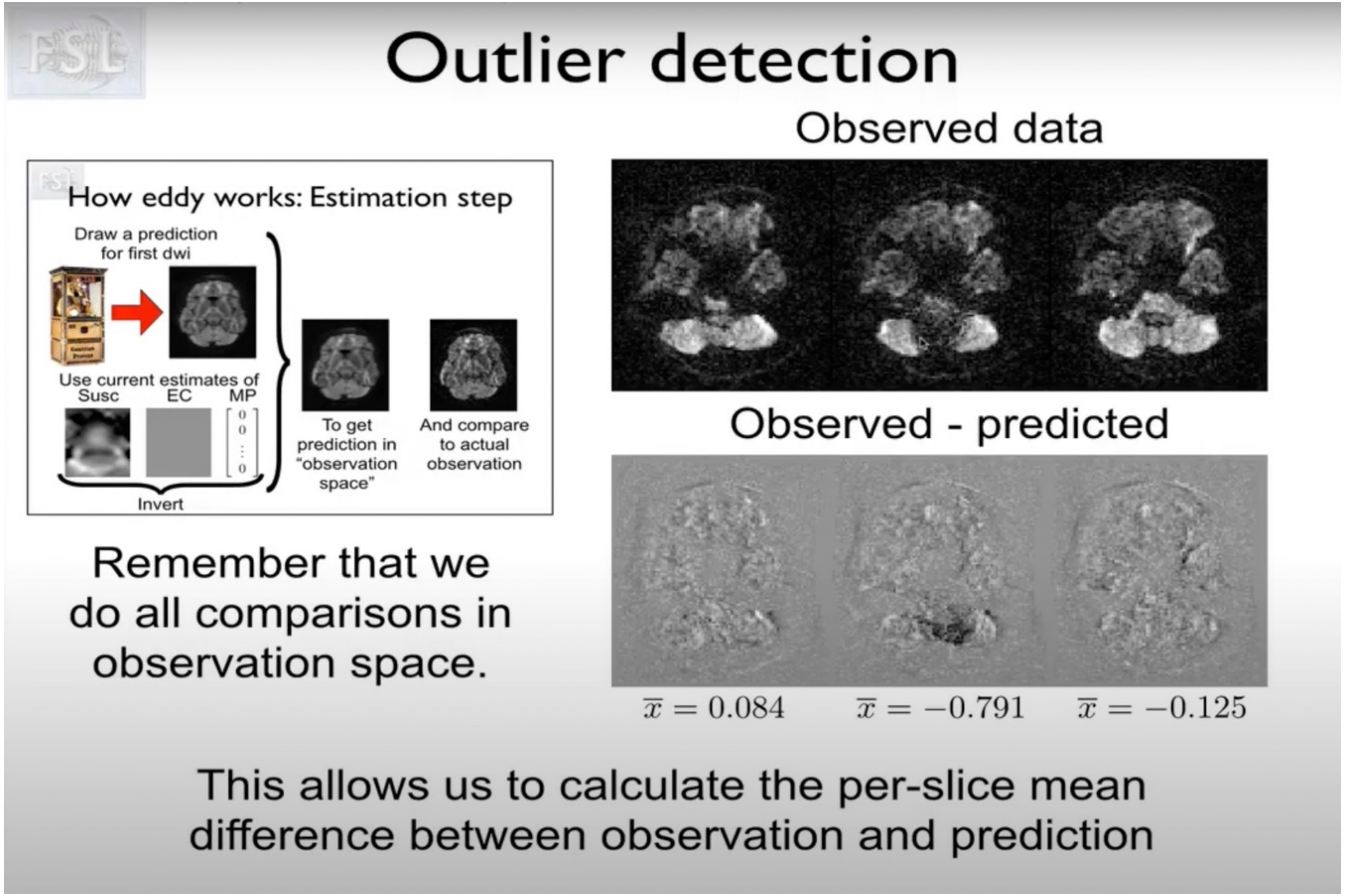
The outlier skews the predictions, but is still recognisable as an outlier

↓

Remove the outlier and recalculate the "model". The prediction is taken from this new "model".

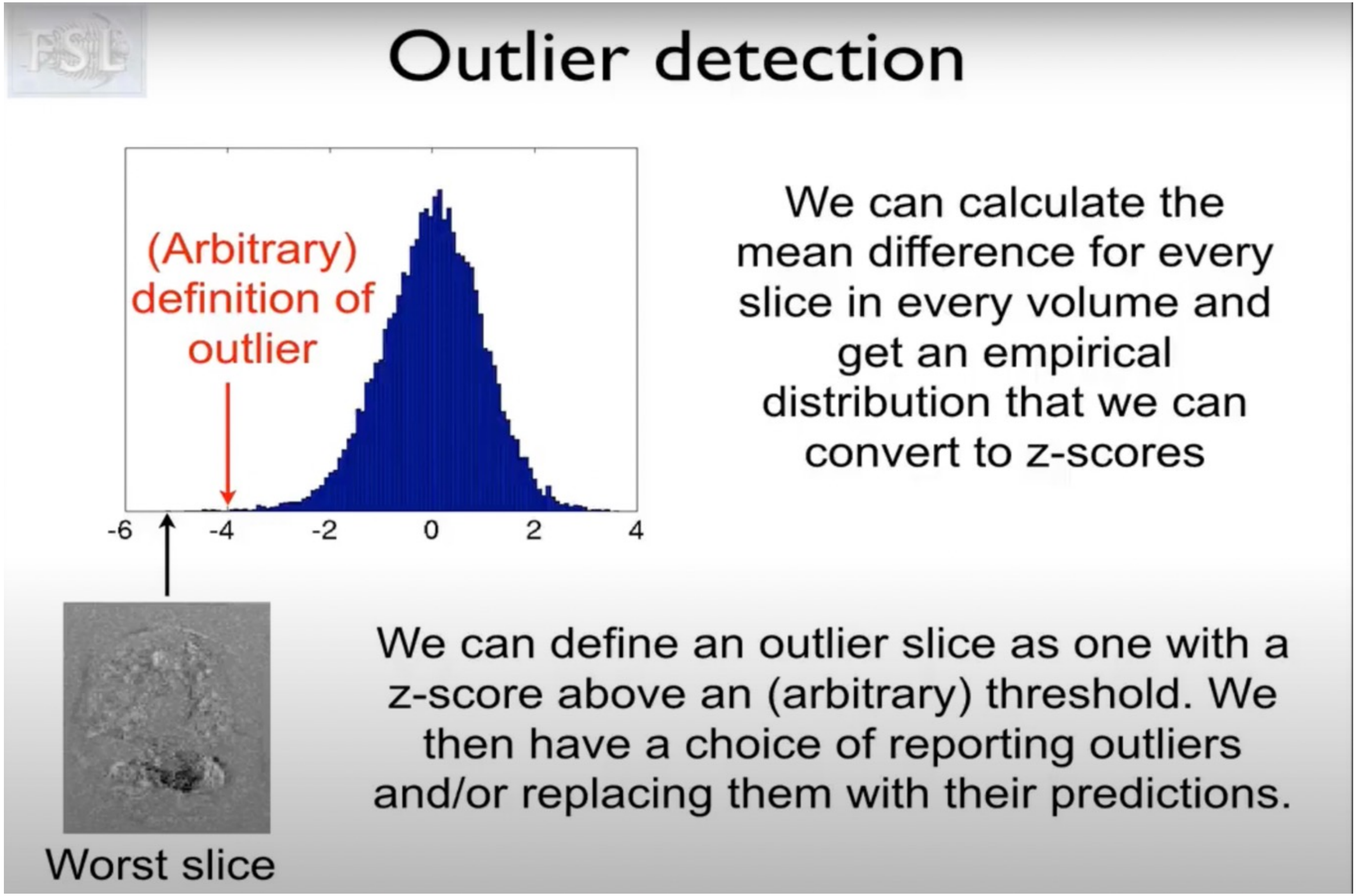
FSL course:
fsl.fmrib.ox.ac.uk/fslcourse

Extra slice on Eddy definition of CNR



FSL course:
fsl.fmrib.ox.ac.uk/fslcourse

Extra slice on Eddy definition of CNR



Recent Tractometry litterature

(1)
Zhang, S.; Zhao, F.; Yang, X.; Tan, Q.; Li, S.; Shao, H.; Su, X.; Gong, Q.; Yue, Q. Multiparametric Mapping of White Matter Reorganizations in Patients with Frontal Glioma-Related Epilepsy. *CNS Neuroscience & Therapeutics* **2023**, *29* (8), 2366–2376. https://doi.org/10.1111/cns.14322.

(2)
Morita, T.; Takemura, H.; Naito, E. Functional and Structural Properties of Interhemispheric Interaction between Bilateral Precentral Hand Motor Regions in a Top Wheelchair Racing Paralympian. *Brain Sci* **2023**, *13* (5), 715. https://doi.org/10.3390/brainsci13050715.

(3)
Lerma-Usabiaga, G.; Liu, M.; Paz-Alonso, P. M.; Wandell, B. A. Reproducible Tract Profiles 2 (RTP2) Suite, from Diffusion MRI Acquisition to Clinical Practice and Research. *Sci Rep* **2023**, *13* (1), 6010. https://doi.org/10.1038/s41598-023-32924-7.

(4)
Kruper, J.; Benson, N. C.; Caffarra, S.; Owen, J.; Wu, Y.; Lee, A. Y.; Lee, C. S.; Yeatman, J. D.; Rokem, A.; UK Biobank Eye and Vision Consortium. Optic Radiations Representing Different Eccentricities Age Differently. *Human Brain Mapping* **2023**, *44* (8), 3123–3135. https://doi.org/10.1002/hbm.26267.

(5)
Grotheer, M.; Bloom, D.; Kruper, J.; Richie-Halford, A.; Zika, S.; Aguilera González, V. A.; Yeatman, J. D.; Grill-Spector, K.; Rokem, A. *Human White Matter Myelination Rate Slows down at Birth*; preprint; Neuroscience, 2023. https://doi.org/10.1101/2023.03.02.530800.

(6)
Fuelscher, I.; Hyde, C.; Thomson, P.; Vijayakumar, N.; Sciberras, E.; Efron, D.; Anderson, V.; Hazell, P.; Silk, T. J. Longitudinal Trajectories of White Matter Development in Attention-Deficit/Hyperactivity Disorder. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging* **2023**, *8* (11), 1103–1112. https://doi.org/10.1016/j.bpsc.2023.03.008.

(7)
Clemente, A.; Attyé, A.; Renard, F.; Calamante, F.; Burmester, A.; Imms, P.; Deutscher, E.; Akhlaghi, H.; Beech, P.; Wilson, P. H.; Poudel, G.; Domínguez D, J. F.; Caeyenberghs, K. Individualised Profiling of White Matter Organisation in Moderate-to-Severe Traumatic Brain Injury Patients. *Brain Research* **2023**, *1806*, 148289. https://doi.org/10.1016/j.brainres.2023.148289.

(8)
Chen, Q.; Wang, M.; Wu, G.; Li, W.; Ren, X.; Wang, Y.; Wei, X.; Wang, J.; Yang, Z.; Li, X.; Li, Z.; Tang, L.; Zhang, P.; Wang, Z. Characteristics of White Matter Alterations along Fibres in Patients with Bulimia Nervosa: A Combined Voxelwise and Tractography Study. *European Journal of Neuroscience* **2023**, *58* (3), 2874–2887. https://doi.org/10.1111/ejn.16077.

(9)
Bianco, K. M.; Fuelscher, I.; Lum, J. A. G.; Singh, M.; Enticott, P. G.; Caeyenberghs, K.; Hyde, C. Individual Differences in Procedural Learning Are Associated with Fiber Specific White Matter Microstructure of the Superior Cerebellar Peduncles in Healthy Adults. *Cortex* **2023**, *161*, 1–12. https://doi.org/10.1016/j.cortex.2023.01.006.

(10)
Andica, C.; Kamagata, K.; Aoki, S. Automated Three-Dimensional Major White Matter Bundle Segmentation Using Diffusion Magnetic Resonance Imaging. *Anat Sci Int* **2023**, *98* (3), 318–336. https://doi.org/10.1007/s12565-023-00715-9.

(11)
Muncy, N. M.; Kimbler, A.; Hedges-Muncy, A. M.; McMakin, D. L.; Mattfeld, A. T. General Additive Models Address Statistical Issues in Diffusion MRI: An Example with Clinically Anxious Adolescents. *NeuroImage: Clinical* **2022**, *33*, 102937. https://doi.org/10.1016/j.nicl.2022.102937.

(12)
Grotheer, M.; Rosenke, M.; Wu, H.; Kular, H.; Querdasi, F. R.; Natu, V. S.; Yeatman, J. D.; Grill-Spector, K. White Matter Myelination during Early Infancy Is Linked to Spatial Gradients and Myelin Content at Birth. *Nat Commun* **2022**, *13* (1), 997. https://doi.org/10.1038/s41467-022-28326-4.

(13)
Kruper, J.; Yeatman, J. D.; Richie-Halford, A.; Bloom, D.; Grotheer, M.; Caffarra, S.; Kiar, G.; Karipidis, I. I.; Roy, E.; Chandio, B. Q.; Garyfallidis, E.; Rokem, A. Evaluating the Reliability of Human Brain White Matter Tractometry. *Aperture Neuro* **2021**, *2021* (1), 25. https://doi.org/10.52294/e6198273-b8e3-4b63-babb-6e6b0da10669.

(14)
Grotheer, M.; Rosenke, M.; Wu, H.; Kular, H.; Querdasi, F. R.; Natu, V.; Yeatman, J. D.; Grill-Spector, K. *White Matter Myelination during Early Infancy Is Explained by Spatial Gradients and Myelin Content at Birth*; preprint; Neuroscience, 2021. https://doi.org/10.1101/2021.03.29.437583.

(15)
Chamberland, M.; Genc, S.; Tax, C. M. W.; Shastin, D.; Koller, K.; Raven, E. P.; Cunningham, A.; Doherty, J.; van den Bree, M. B. M.; Parker, G. D.; Hamandi, K.; Gray, W. P.; Jones, D. K. Detecting Microstructural Deviations in Individuals with Deep Diffusion MRI Tractometry. *Nat Comput Sci* **2021**, *1*, 598–606. https://doi.org/10.1038/s43588-021-00126-8.