# Advanced MR techniques DTI

Turku PET Centre 4.6.2018
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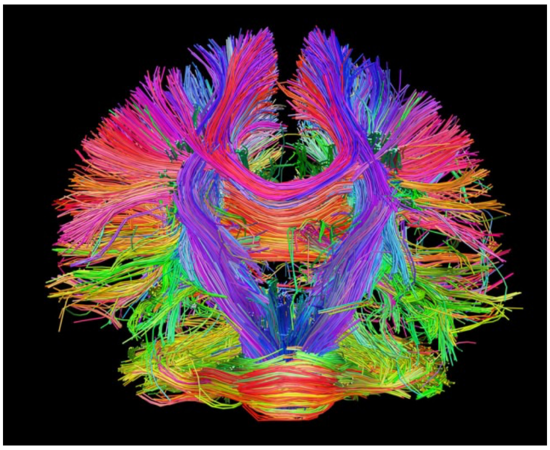
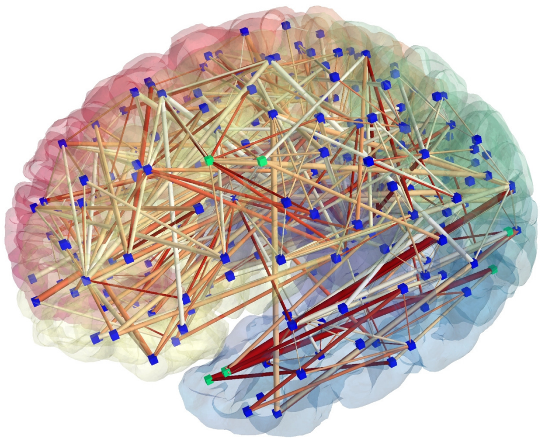
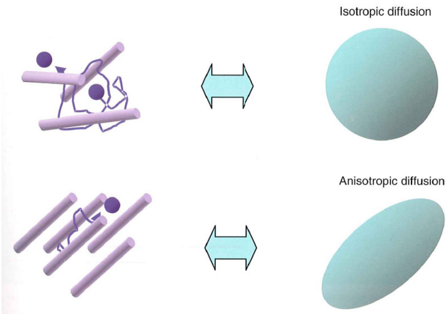
## Why image diffusion?





# Isotropic and anisotropic diffusion

water diffusion is sensitive to the underlying tissue microstructure

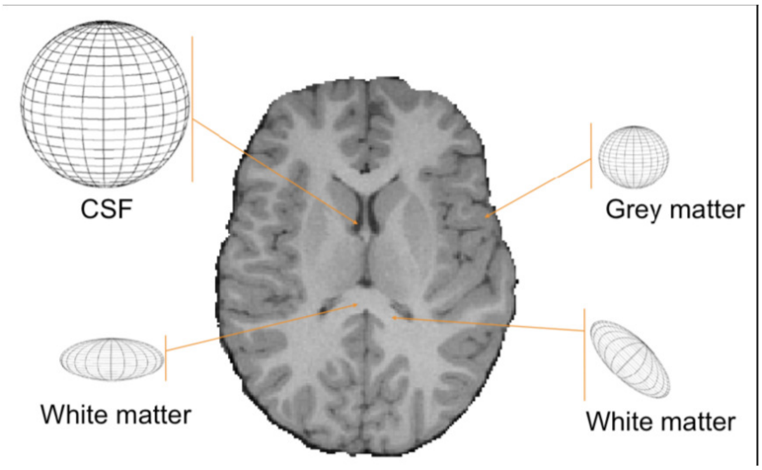



Isotropic diffusion:
**diffusion constant**

Anisotropic diffusion:
**diffusion tensor**

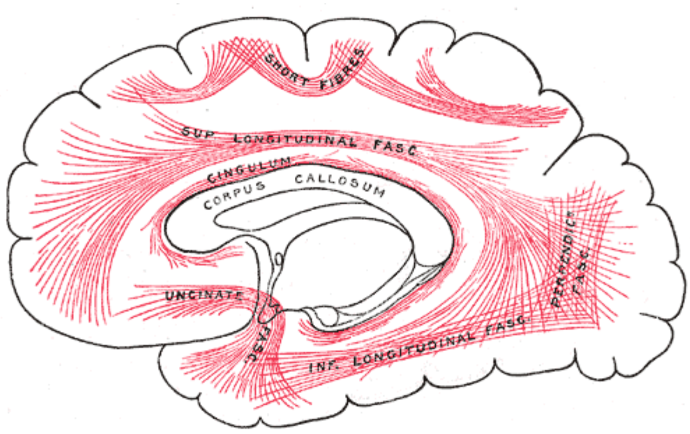
Biological tissues are highly anisotropic. This means that the diffusion rates are *not* the same in every direction

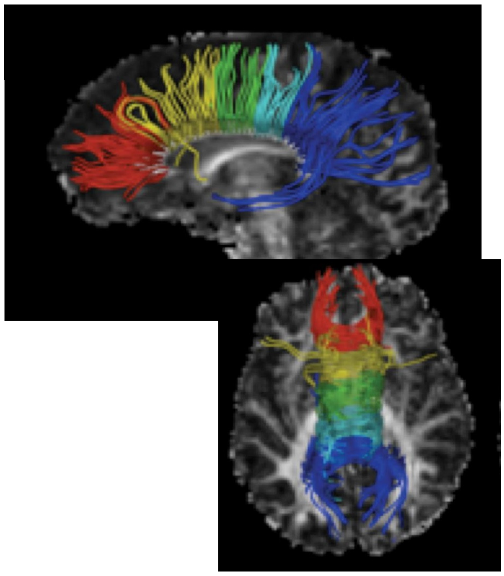
# Types of diffusion




T1 weighted image

# White matter = Highways



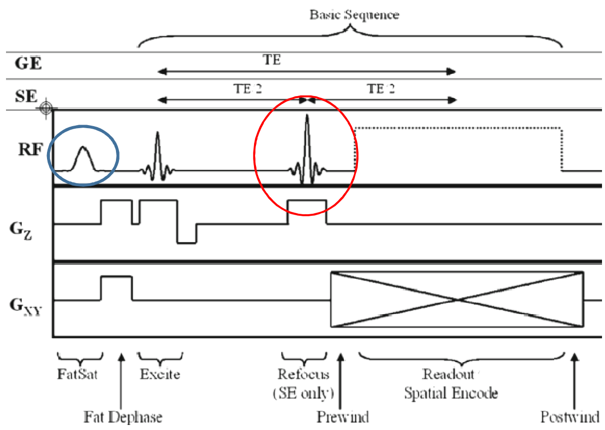



# How to image diffusion?

# DTI– how to image

A fat saturation pulse

Excitation and refocus pulse

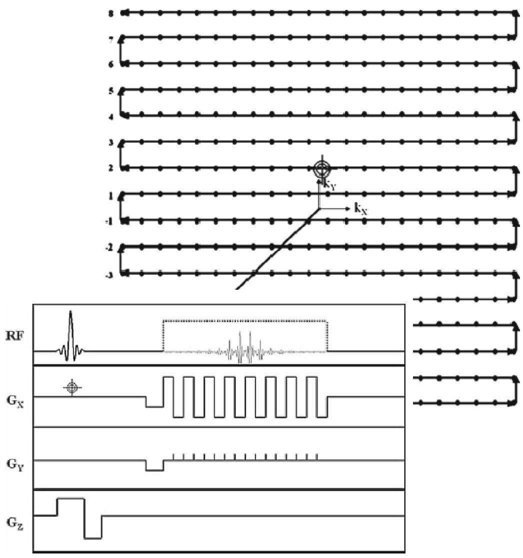



# DWI Readout = fMRI Readout

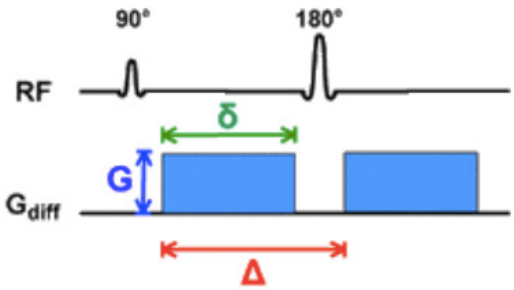
**Single-shot sequences**: an entire slice are acquired in one readout window after one excitation.

Blipped echo-planar imaging (EPI) pulse sequence. Readout gradients are reversed following readout of each kx line, along with a small increment of k-space in ky direction, or a "blip" in Gy.

**Limited resolution** from T2 and T2∗ signal decay during the signal readout

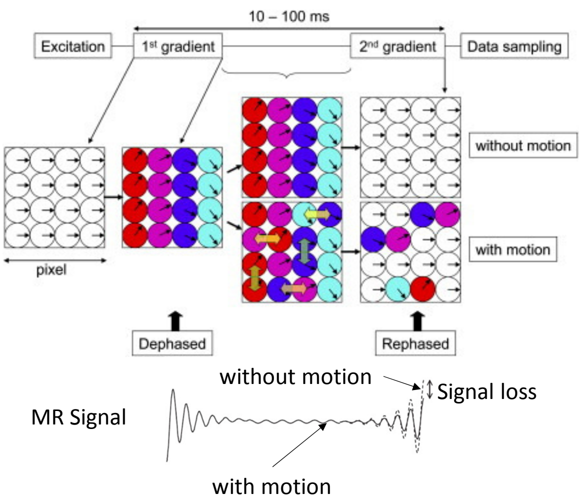


# But how is this sensitive to diffusion?



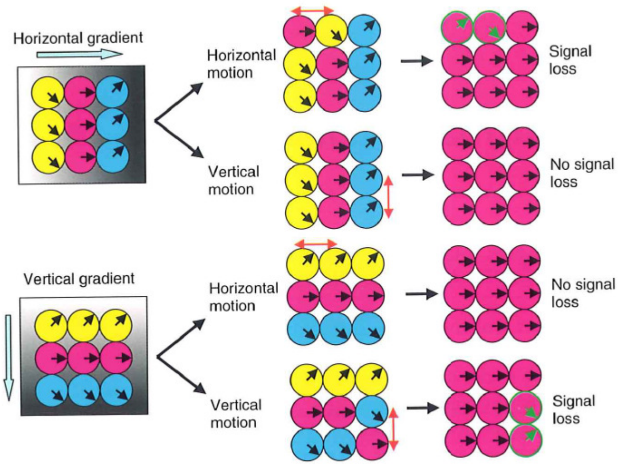

Stejskal-Tanner pulsed gradient diffusion method.

$$b = \gamma^2 G^2 \delta^2 (\Delta - \delta/3)$$




Susumu M, Jiangyang Z. **Principles of Diffusion Tensor Imaging and Its Applications to Basic Neuroscience Research.** null, Volume 51, Issue 5, 2006, 527–539 http://dx.doi.org/10.1016/j.neuron.2006.08.012

# diffusion direction



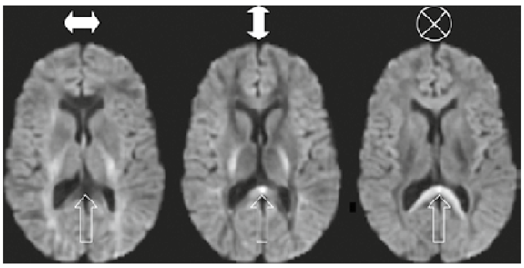

# DTI - contrast formation

Dark areas = high apparent diffusivity

lighter areas represent lower apparent diffusivity.

Unfilled arrows: splenium of the corpus callosum

- LR (a): the apparent diffusivity is high
- AP(b) and FH(c): low



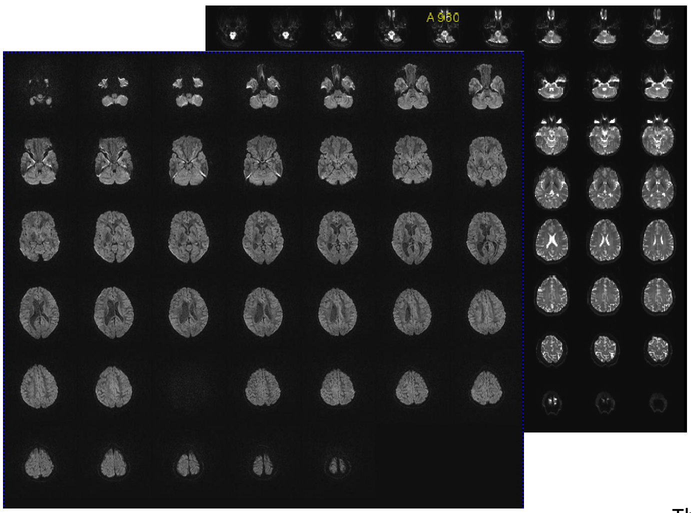

Jones D. 2009. Gaussian Modeling of the Diffusion Signal. In: Johansen-Berg, Behrens ed. Diffusion MRI. Academic Press, p. 41

# Imaging sequence

- Diffusion tensor estimation:
  - high b-values (e.g., 1000s/mm2) along at least 6 non-collinear diffusion encoding directions & one image with b-value (b = 0s/mm2)
  - high b-value (e.g., 1000s/mm2) along 60 non-collinear diffusion encoding directions & one image with b-value (b = 0s/mm2)
  - Super high b-value (e.g., 3000s/mm2) and high b-value (e.g., 1000s/mm2) along 60 non-collinear diffusion encoding directions & 10 images with b-value (b = 0s/mm2)

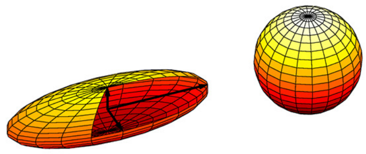
# Imaging sequence: one direction

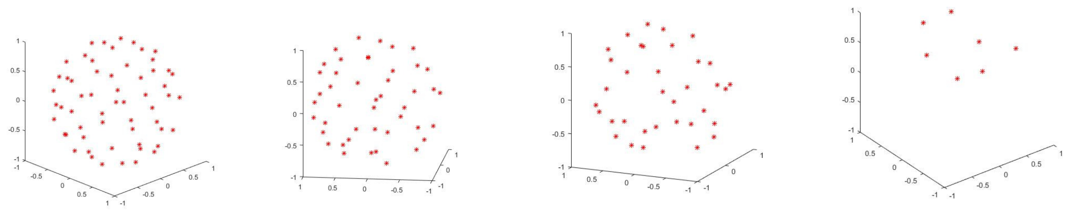
high b-value (e.g., 1000s/mm2) along 60 non-collinear diffusion encoding directions & one image with b-value (b = 0s/mm2)



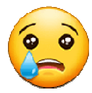
Thanks for the case:
Jani Saunavaara

# Gradient volumes





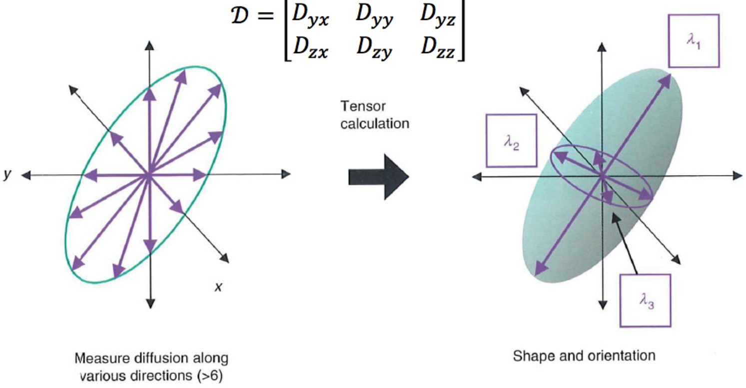
57 44 34 6



https://emojipedia.org

# Diffusion tensor

$$\mathcal{D} = \begin{bmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{yx} & D_{yy} & D_{yz} \\ D_{zx} & D_{zy} & D_{zz} \end{bmatrix}$$




- λ, eigenvalue
- υ, eigenvector

http://mriquestions.com/diffusion-tensor.html

# Output, Fractional anisotropy, FA

**Outputs of dtifit**

- `<basename>_V1` - 1st eigenvector
- `<basename>_V2` - 2nd eigenvector
- `<basename>_V3` - 3rd eigenvector
- `<basename>_L1` - 1st eigenvalue
- `<basename>_L2` - 2nd eigenvalue
- `<basename>_L3` - 3rd eigenvalue
- `<basename>_MD` - mean diffusivity
- `<basename>_FA` - fractional anisotropy
- `<basename>_MO` - mode of the anisotropy (oblate ~ -1; isotropic ~ 0; prolate ~ 1)
- `<basename>_S0` - raw T2 signal with no diffusion weighting

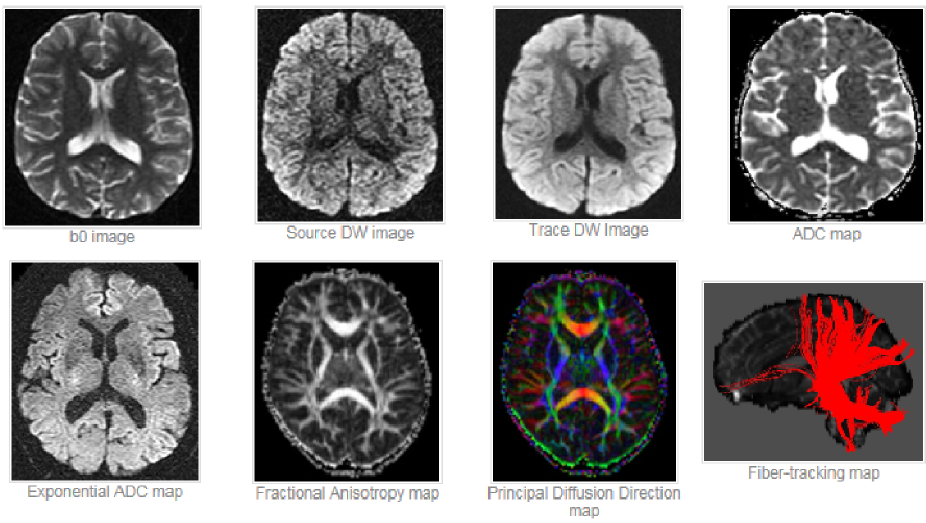
**optional output**

- `<basename>_sse` - Sum of squared error
- `<basename>_tensor` - tensor as a 4D file in this order: Dxx,Dxy,Dxz,Dyy,Dyz,Dzz

$$\mathrm{FA} = \sqrt{\frac{1}{2}}\frac{\sqrt{\left((\lambda_1-\lambda_2)^2+(\lambda_2-\lambda_3)^2+(\lambda_3-\lambda_1)^2\right)}}{\sqrt{\lambda_1^2+\lambda_2^2+\lambda_3^2}}$$

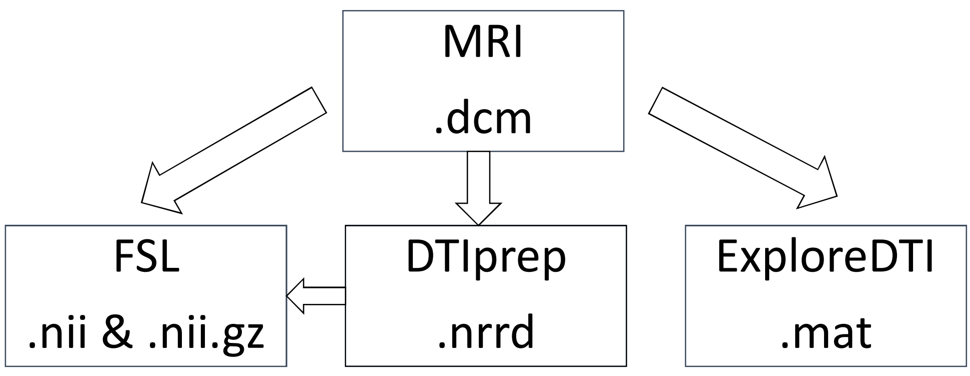
Isotropic diffusion FA = 0

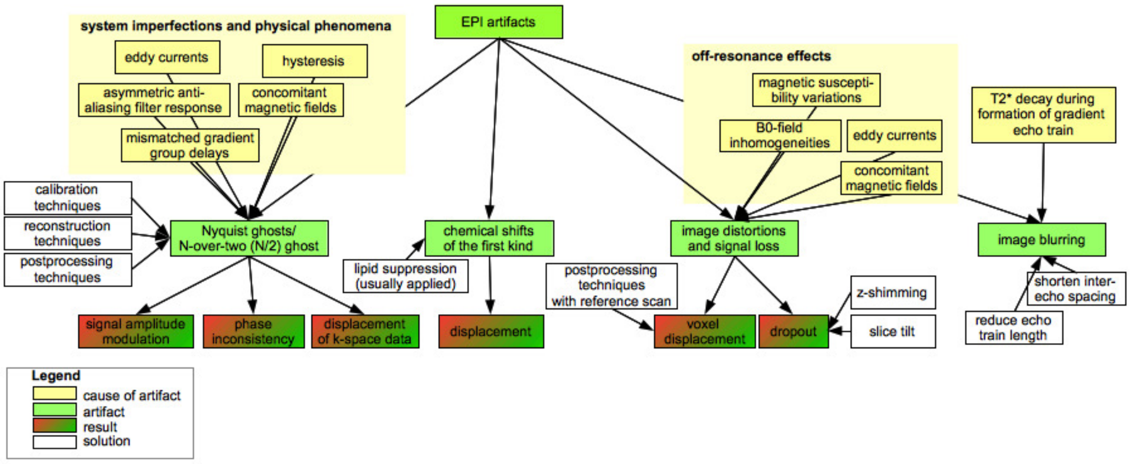
Anisotropic diffusion FA =1




http://mriquestions.com/making-a-dw-image.html

How to process the data?






Chapter 16.1.4 of Bernstein et al (2004) *Handbook of MRI pulse sequences*

# Preprosessing

**Artefacts: Head motion**

diffusion of protons: ~10 µm

subject motion: ~ millimetre

severe ghosting (shifted image duplications)

signal attenuation

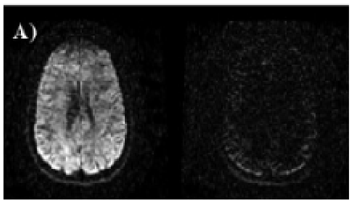
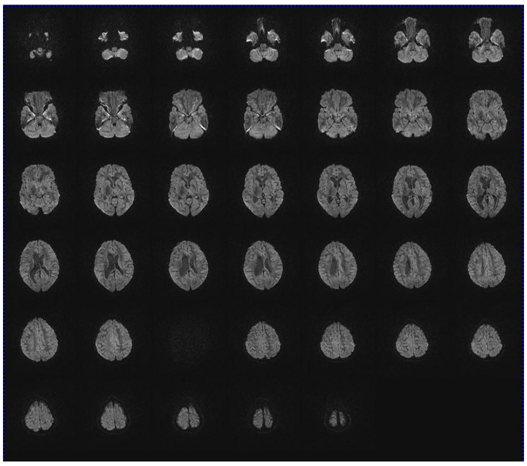
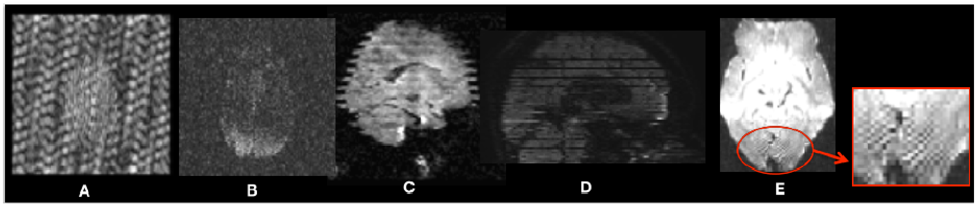



Image: Liu B et al. Comparison of quality control software tools
for diffusion tensor imaging 2015 (33), 3, 276-285

# Motion artifact



# Artifacts



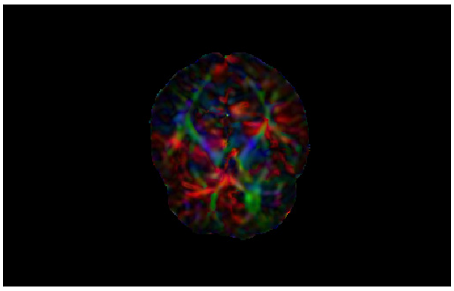

. (A) An electromagnetic interference-like artifact, (B) severe signal loss in the anterior and middle regions, (C) venetian blind artifact, (D) inter-slice and intra-slice intensity artifact, and (E) checkerboard artifact.

DTIPrep: quality control of diffusion-weighted images. Frontiers in neuroinformatics 2014 (8) 4 Oguz et al.

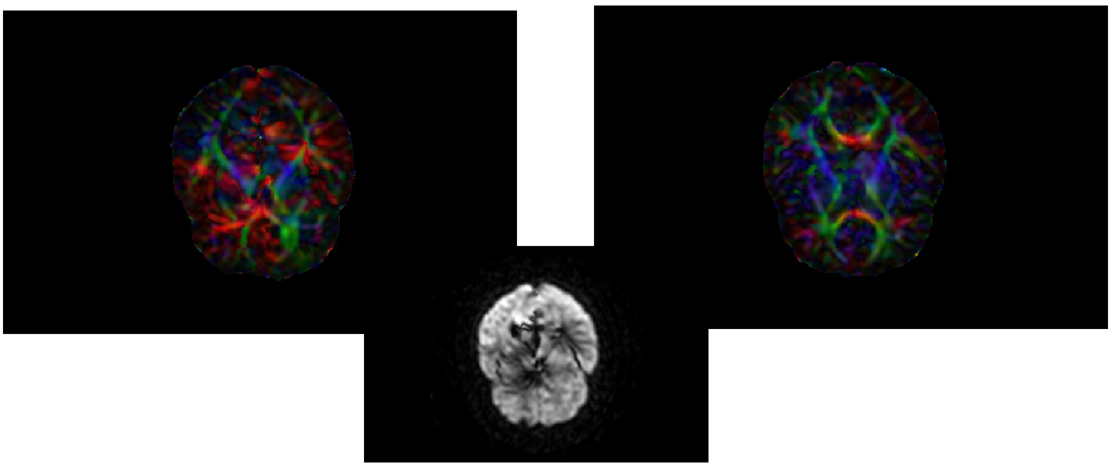
# DTI preprosessing

Exclude:

- Limit the analysis to regions without artifacts
- single slice
- affected subject
- gradient volume



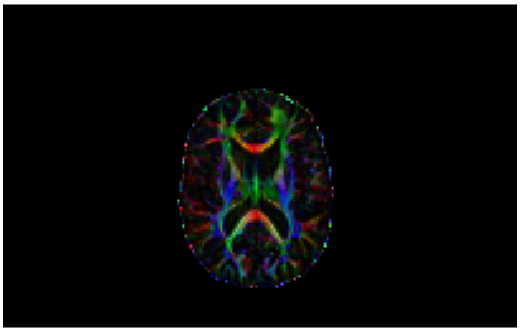
# DTI preprosessing



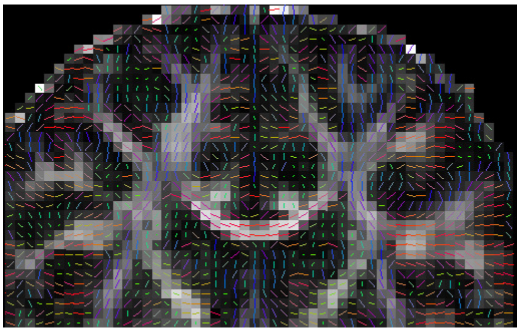
Patient was excluded from the study.

# Is my data OK? Original data

**RGB (FA-modulated)**

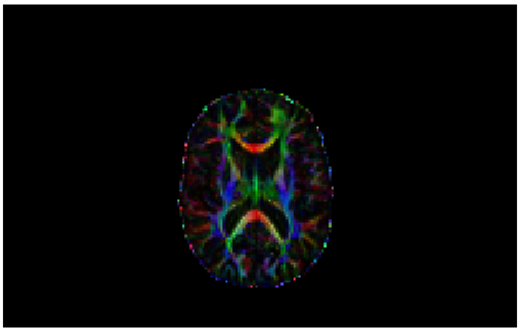


**Glyps (COR)**

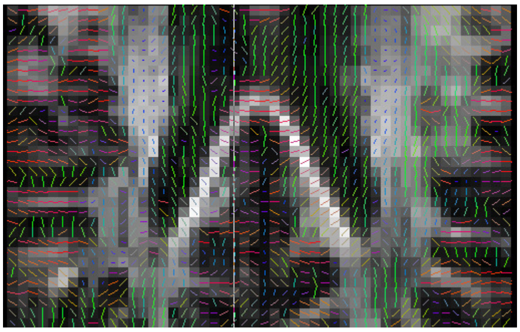


# Is my data OK? Original data

**RGB (FA-modulated)**

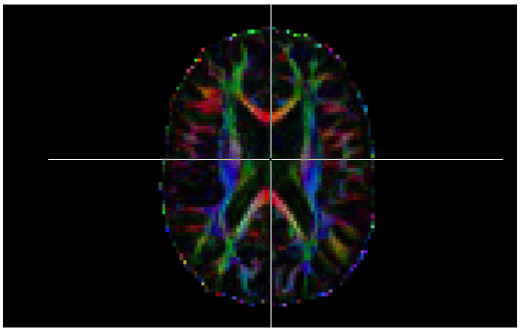


**Glyps (axial slice)**

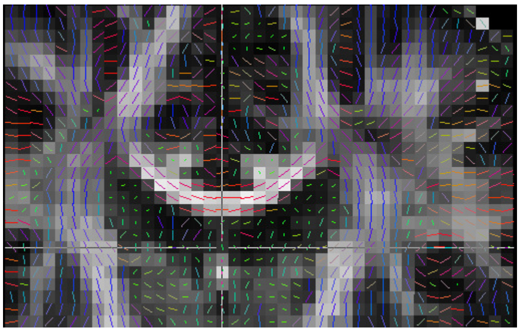


# Is my data OK?
# Corrected data

**RGB (FA-modulated)**

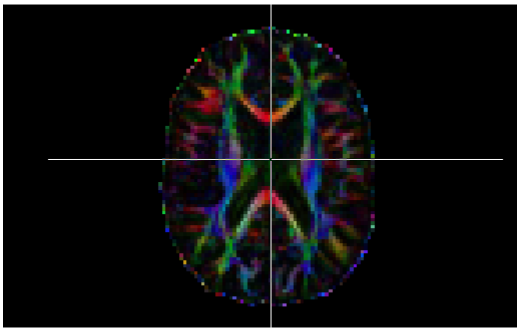


**Glyps (COR)**

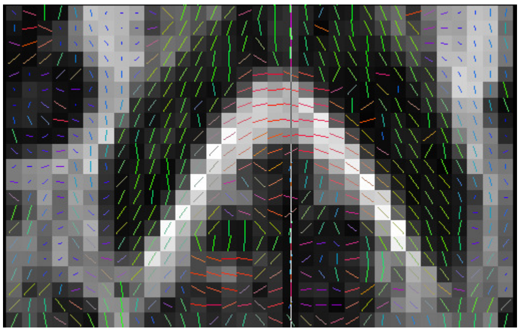


# Is my data OK?
# Corrected data

**RGB (FA-modulated)**



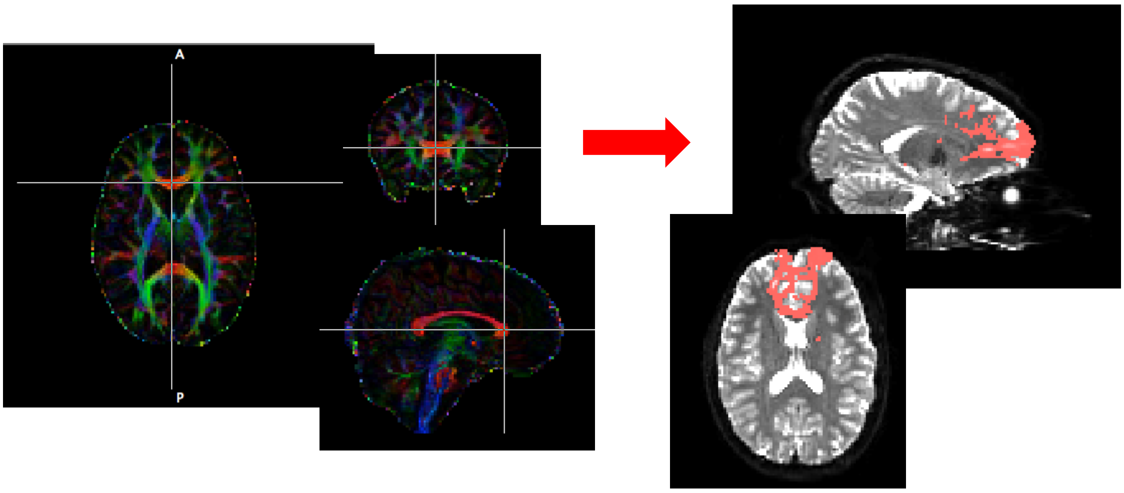
**Glyps**



# After preprosessing

- **BEDPOSTX -**Fitting of the probabilistic diffusion model on corrected data
- **PROBTRACKX** - probabilistic tracking

# Tractography – single point



# Tractography – mask from fMRI