OHBM 2019 Annual Meeting – Educational Course: “Taking Control of Your Neuroimaging Data: Understanding artefacts and quantifying quality”, Rome, IT

Identifying and Correcting Physiological and Systematic Artifacts in Diffusion MRI

Alexander Leemans

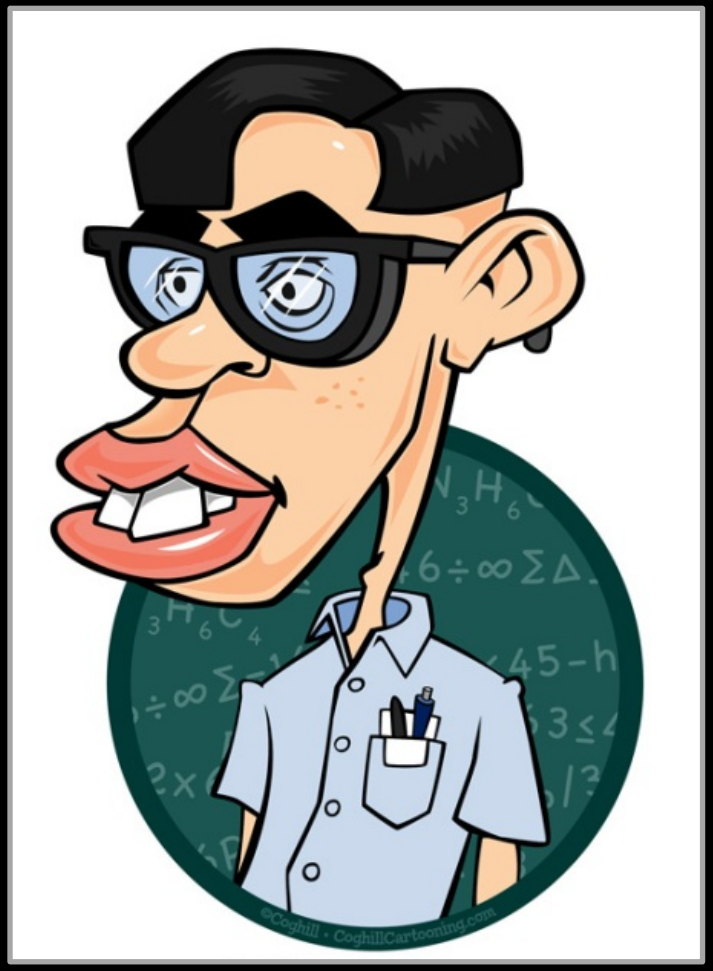
PROVIDI Lab
PROcessing & VIsualization in Diffusion Imaging

@Alex_Leemans

University Medical Center
Utrecht, the Netherlands

A typical day at the office…

Hi Alex, I have been collecting “advanced DTI data”. Can you help me with the analysis?*



** Read: “Can you do the analysis for me?”*

@Alex_Leemans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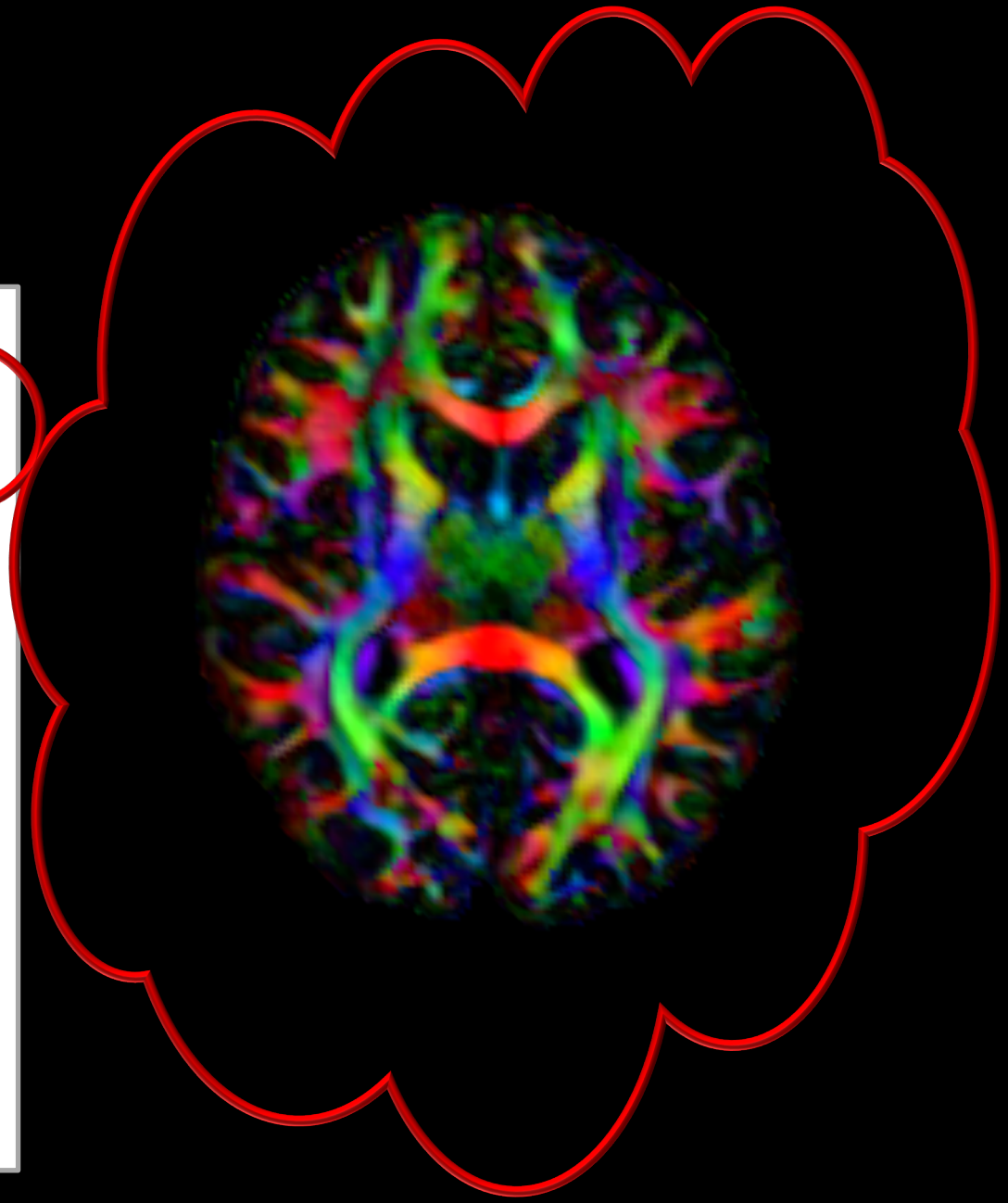


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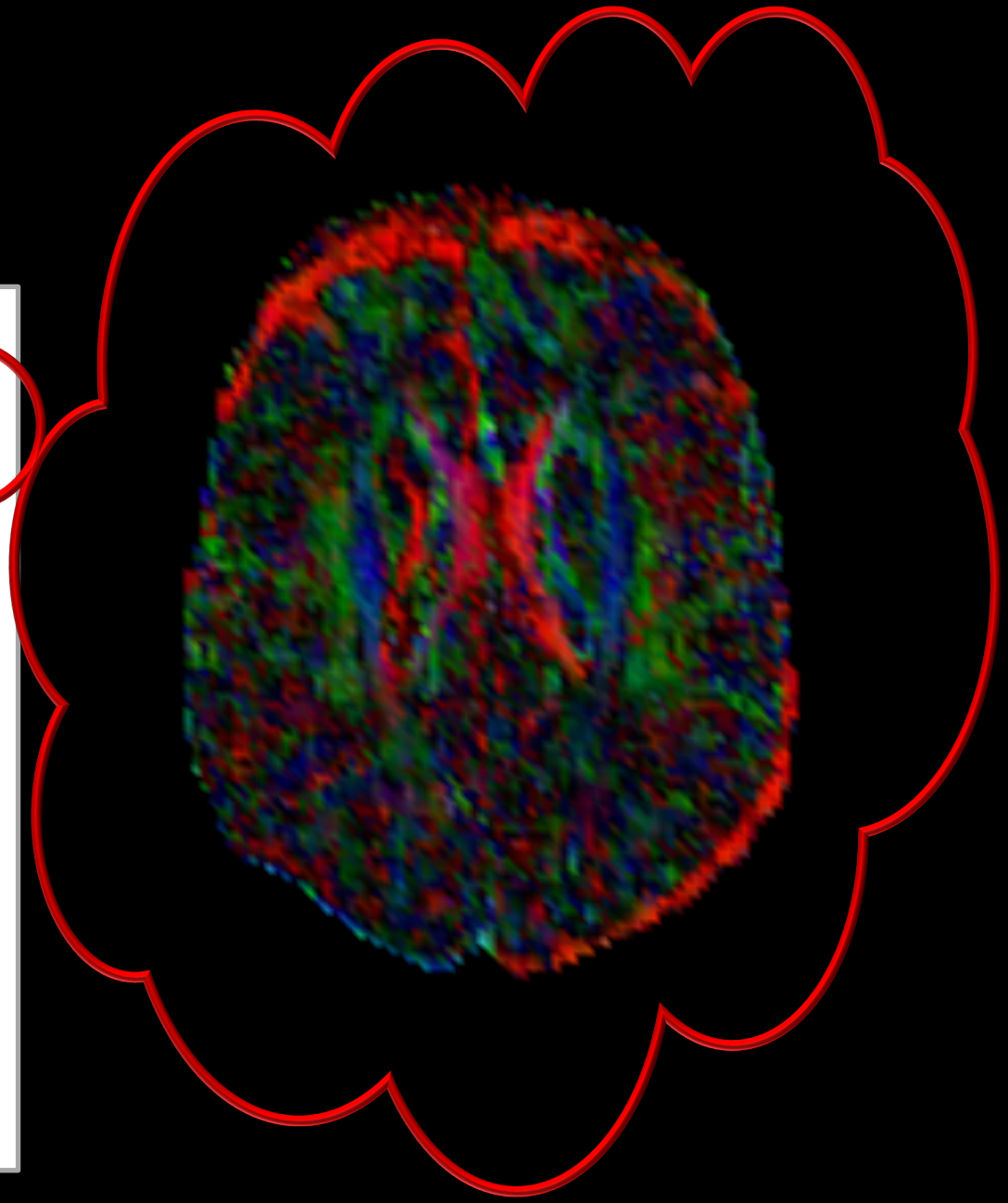
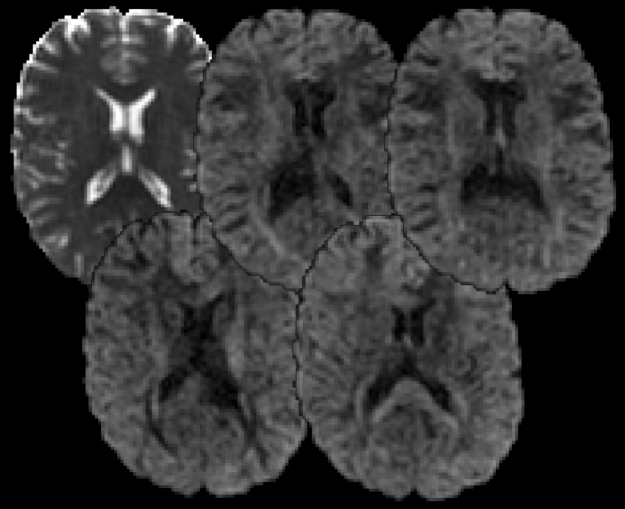
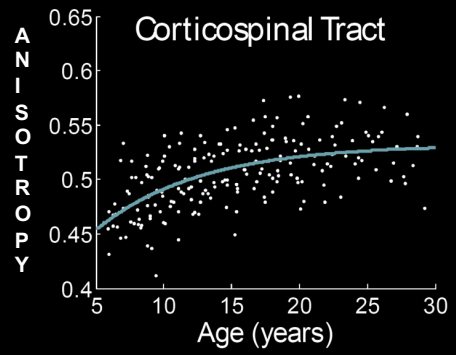
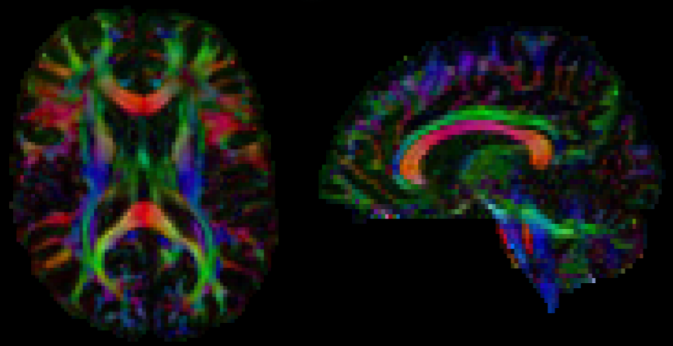
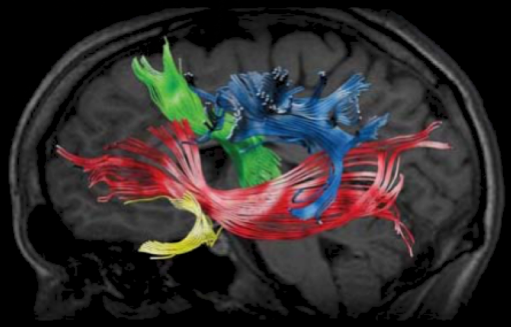


The pipeline ...









Lebel C. et al, NeuroImage (2008)

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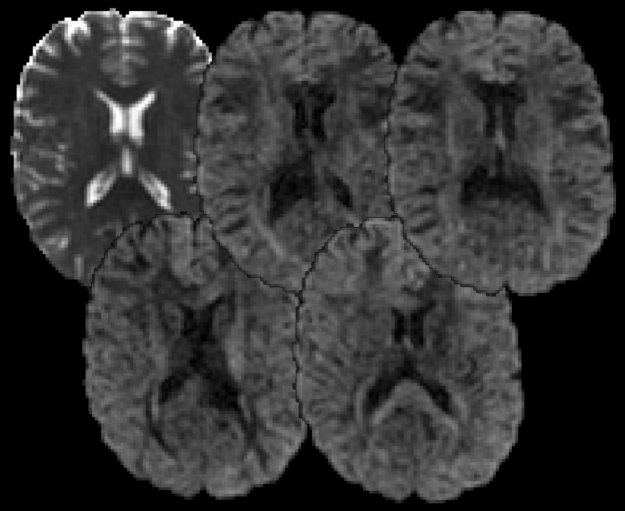
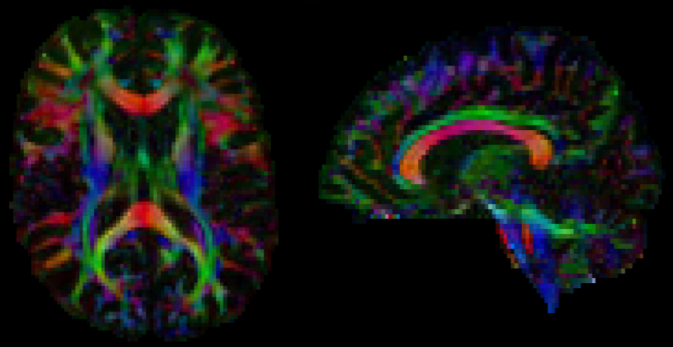
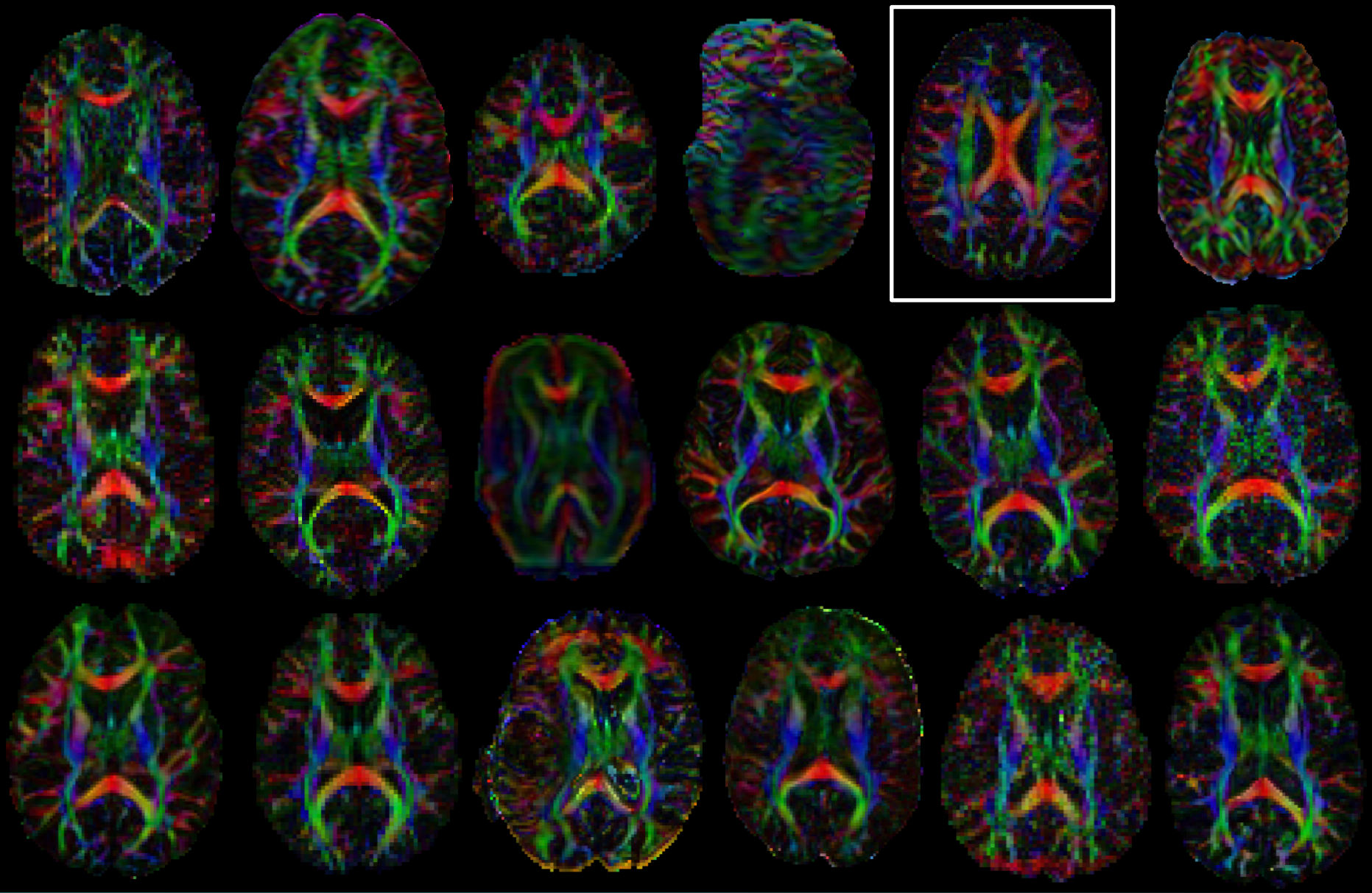
Data quality assessment ...





Data quality assessment ...



Tournier J.-D. et al, Magn Reson Med (2011)

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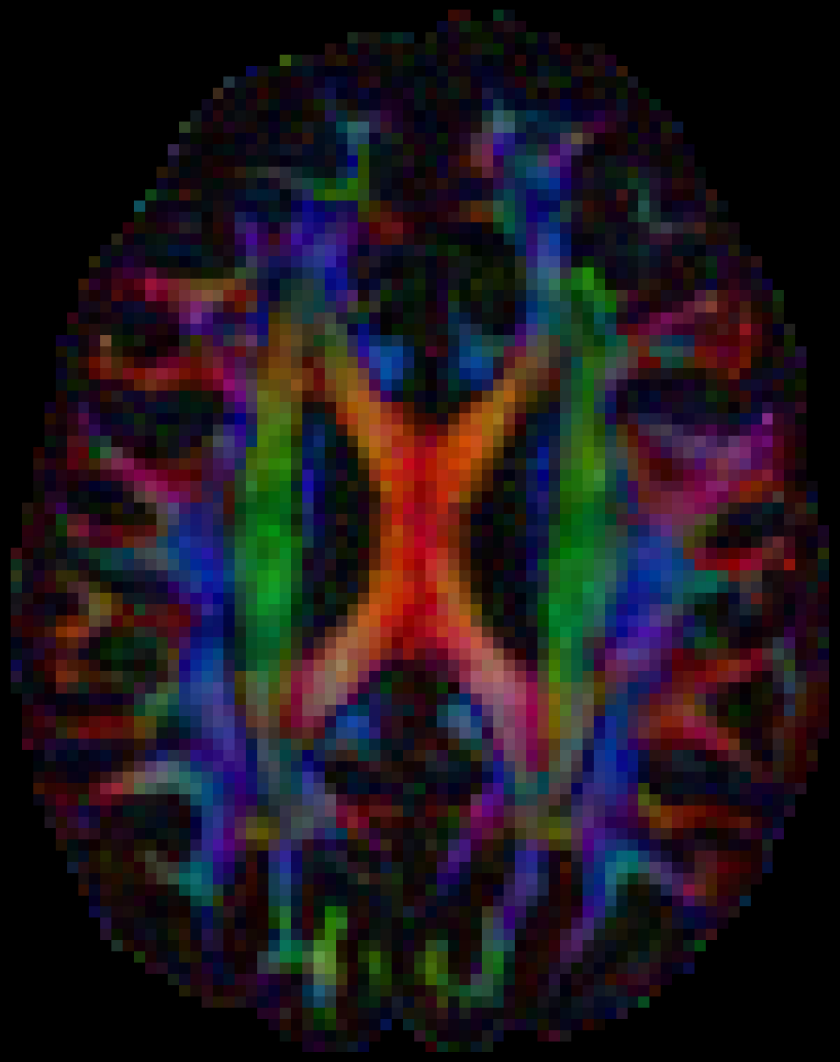
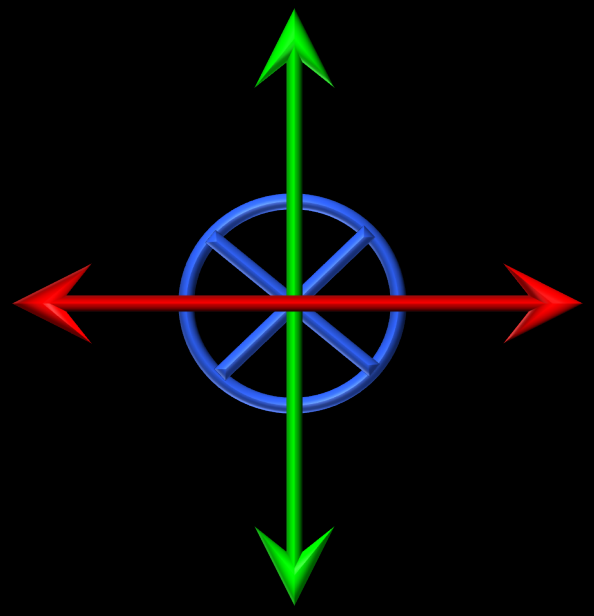
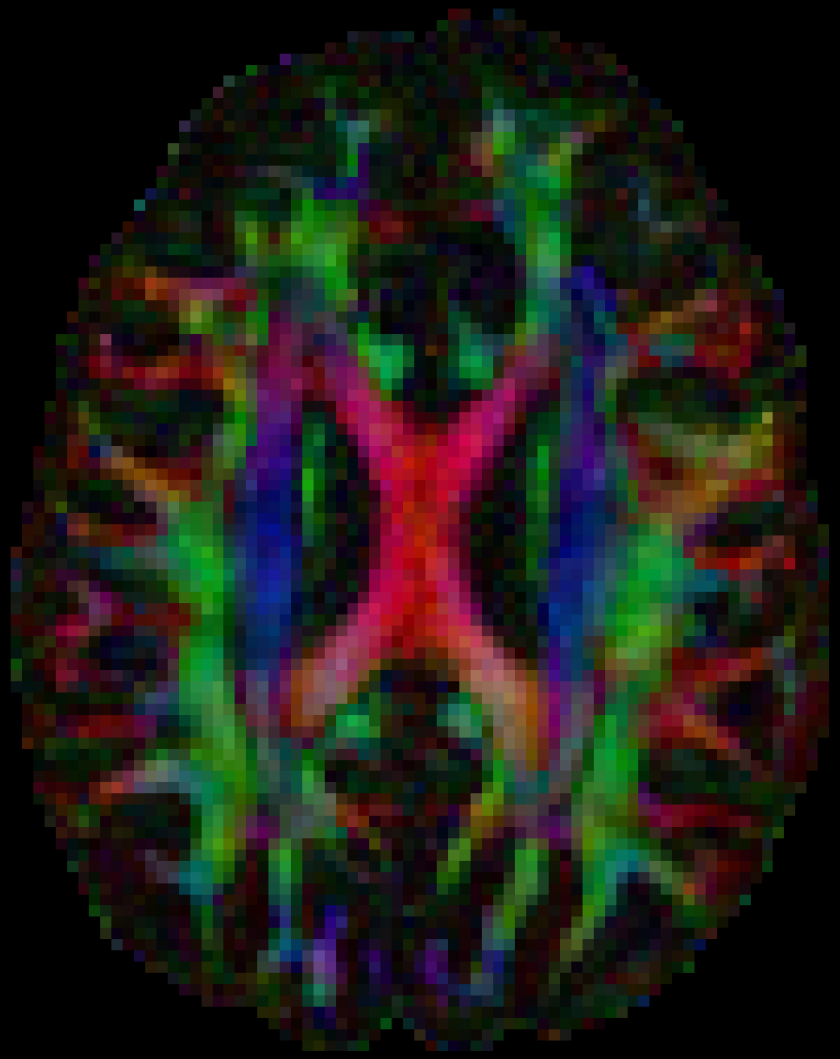
Data quality assessment ...

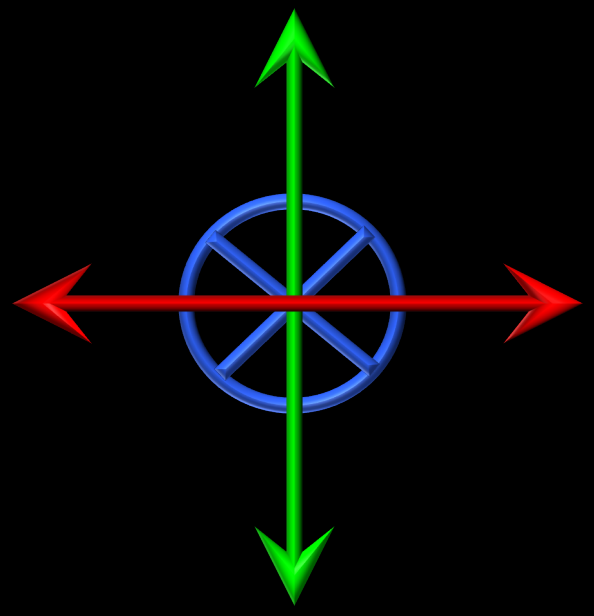




Color-encoding is not conventional

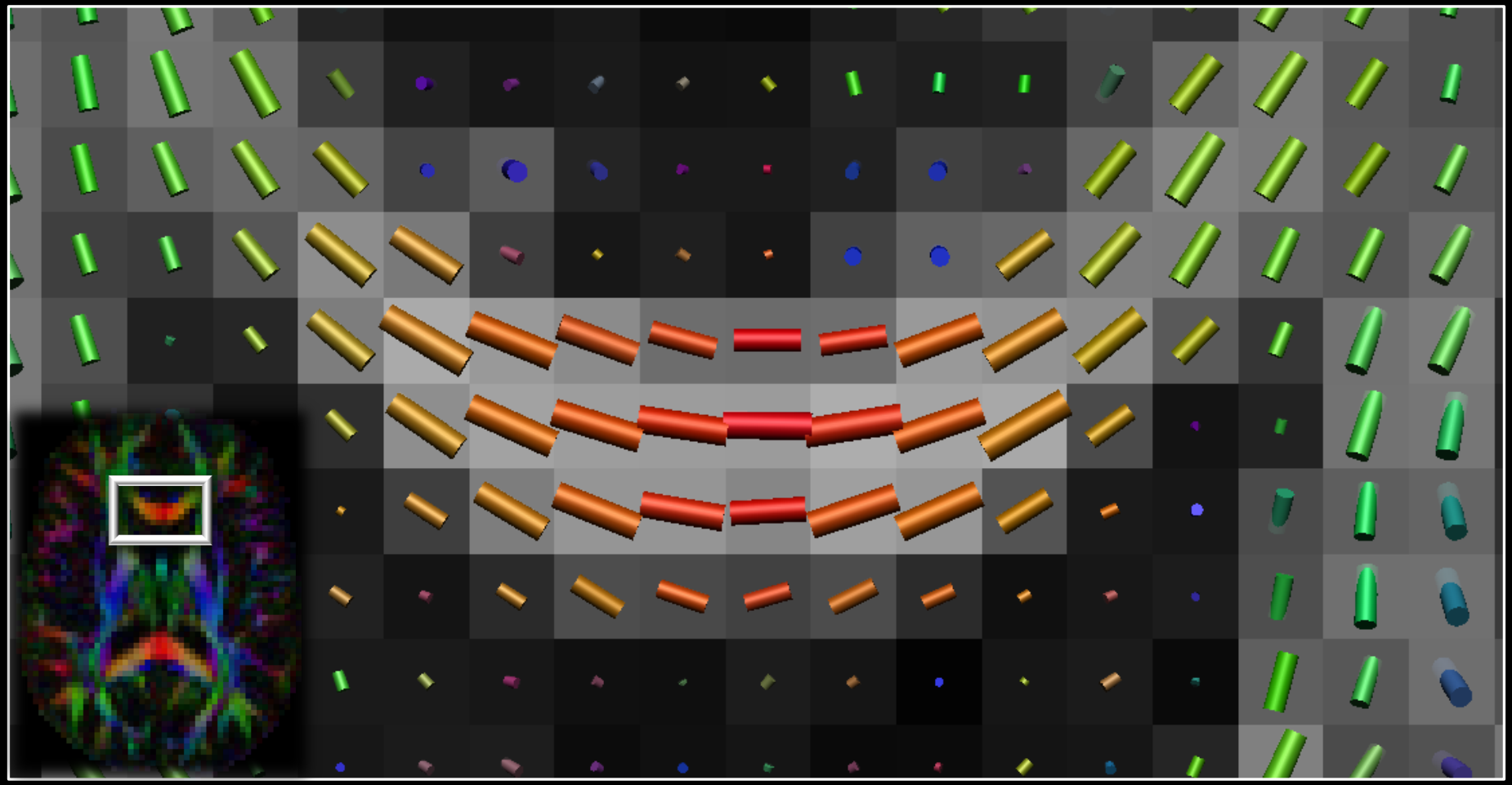
Data quality assessment ...





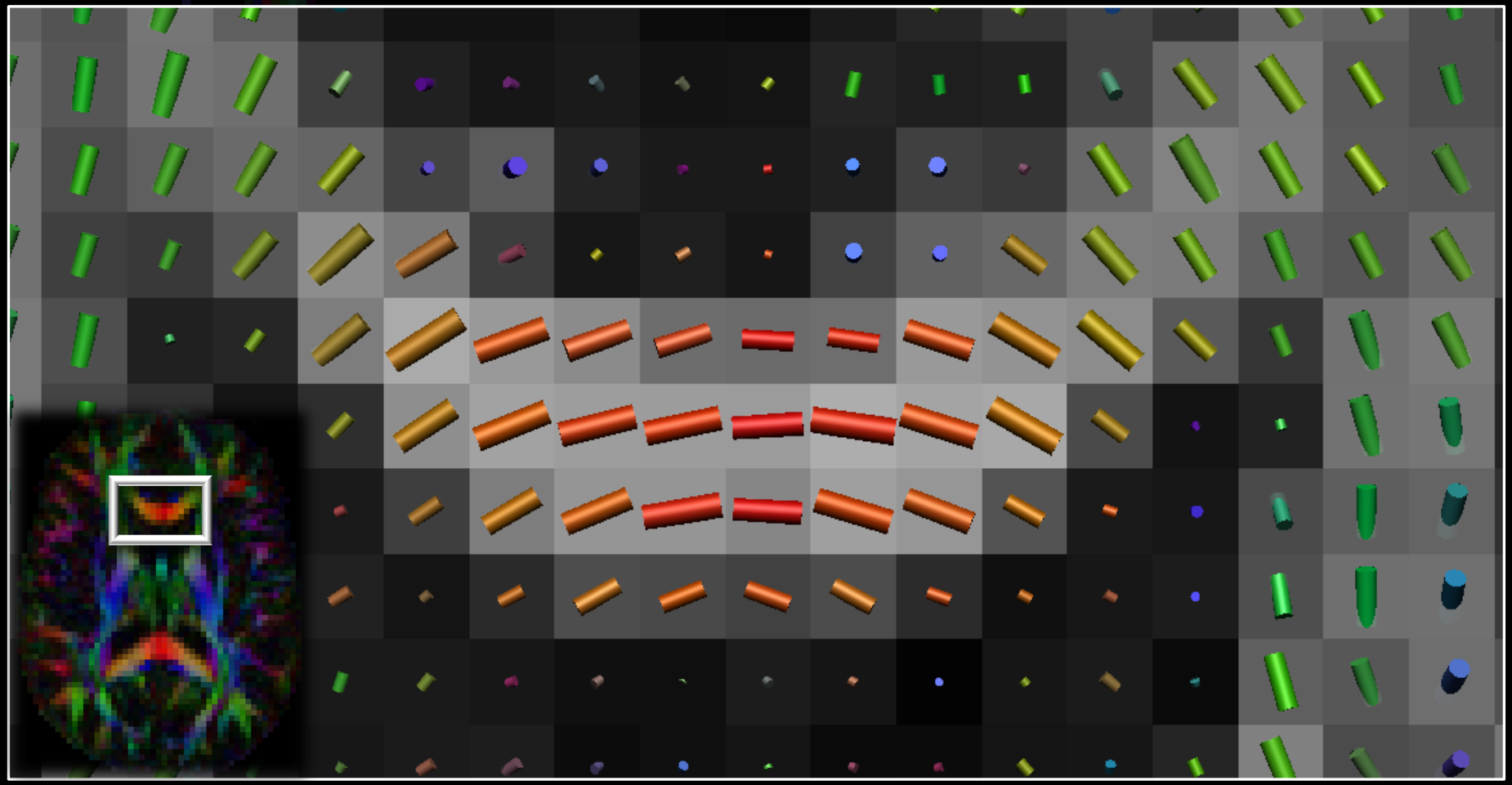
Conventional Color-encoding

Data quality assessment ...



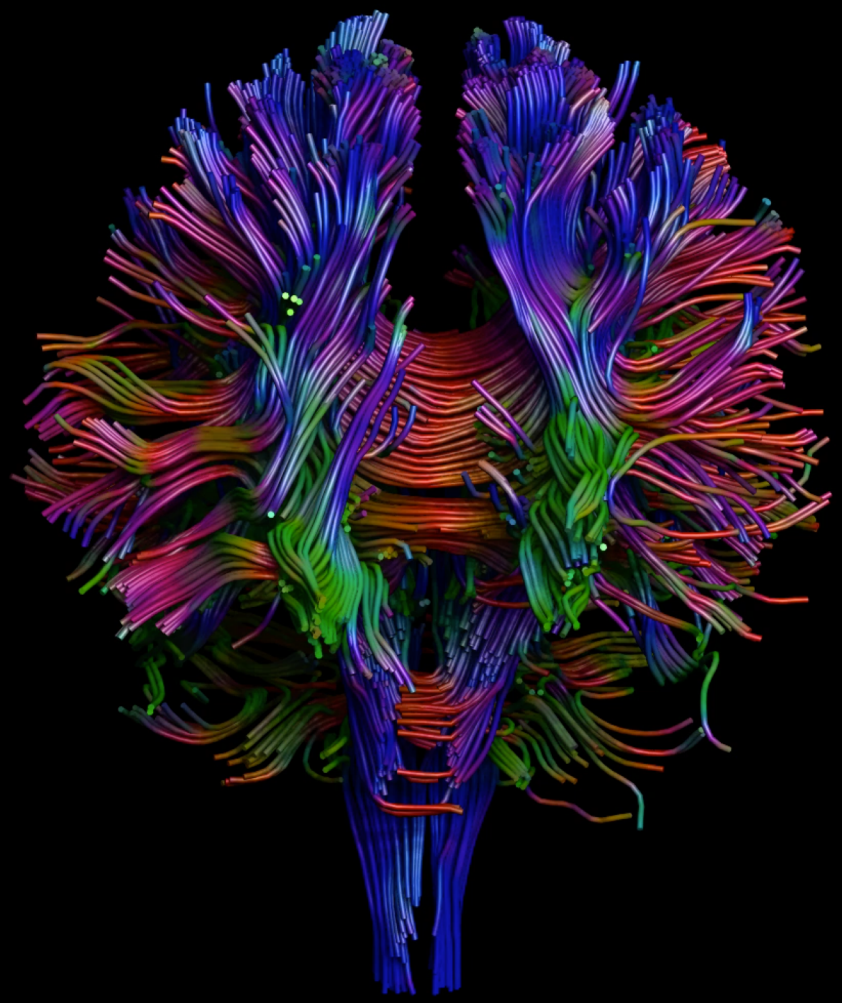
Correct diffusion gradient orientations

Data quality assessment ...



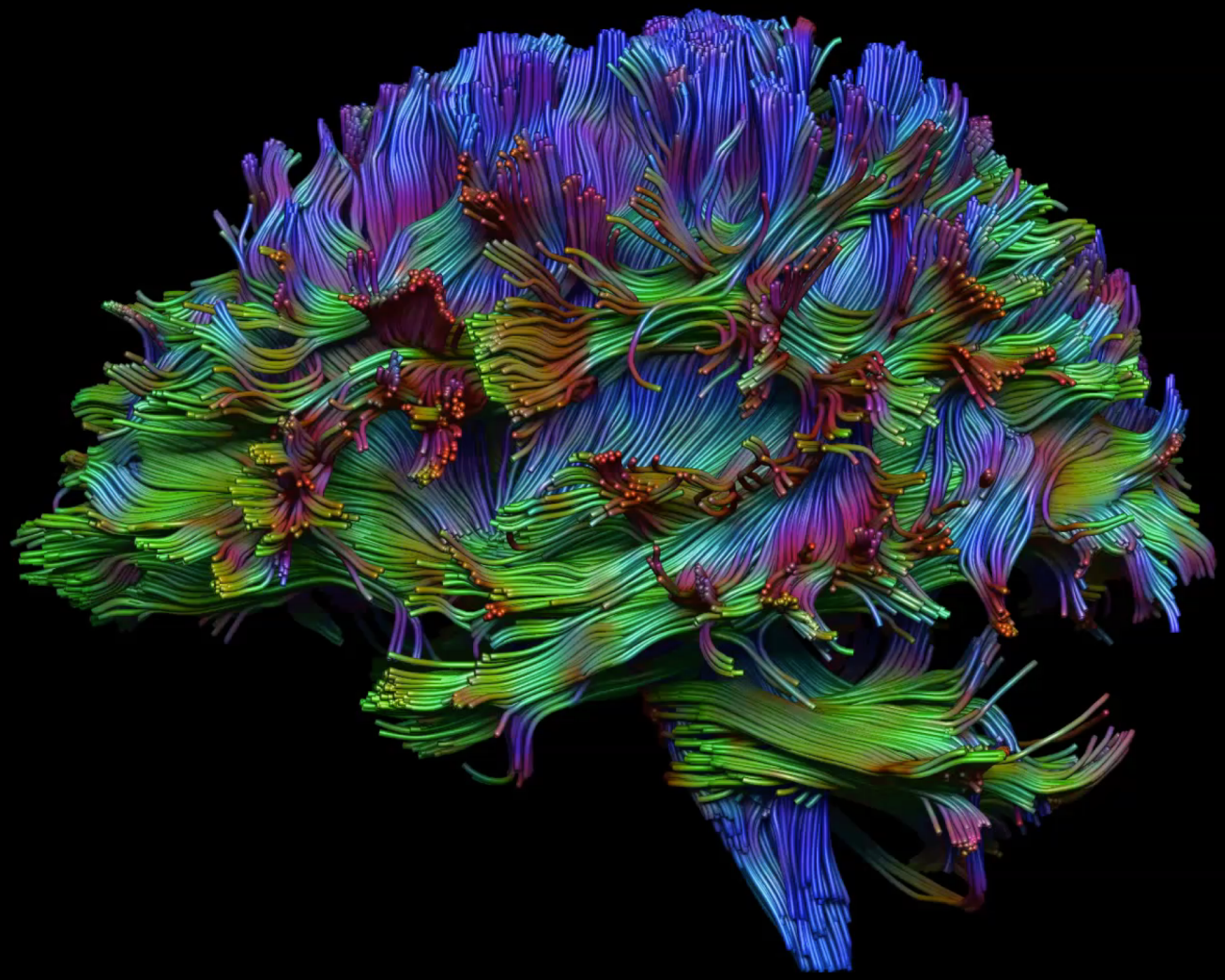
Incorrect diffusion gradient orientations

Data quality assessment ...



Incorrect diffusion gradient orientations

Data quality assessment ...



Correct diffusion gradient orientations

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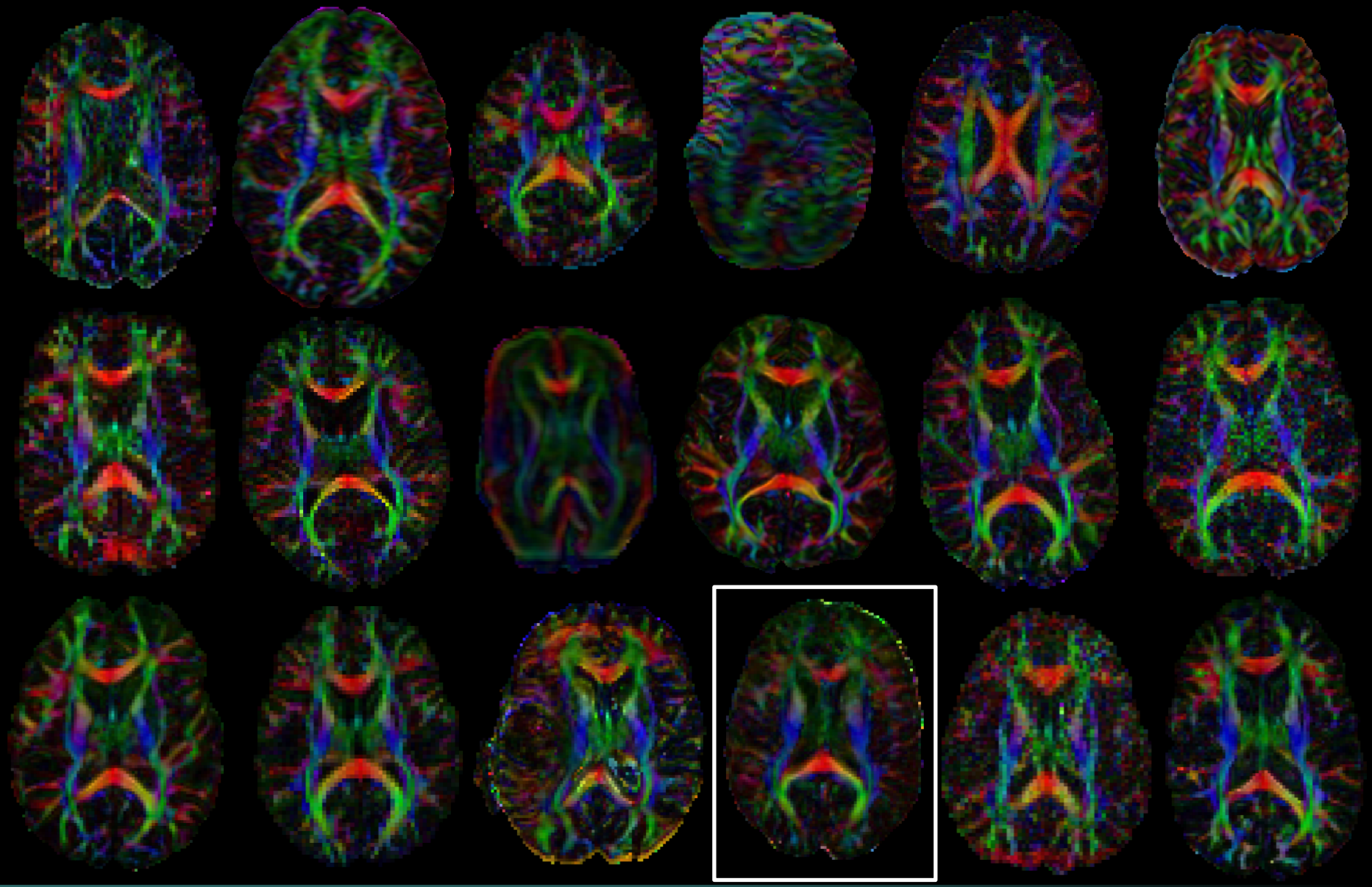

Tournier J.-D. et al, Magn Reson Med (2011)

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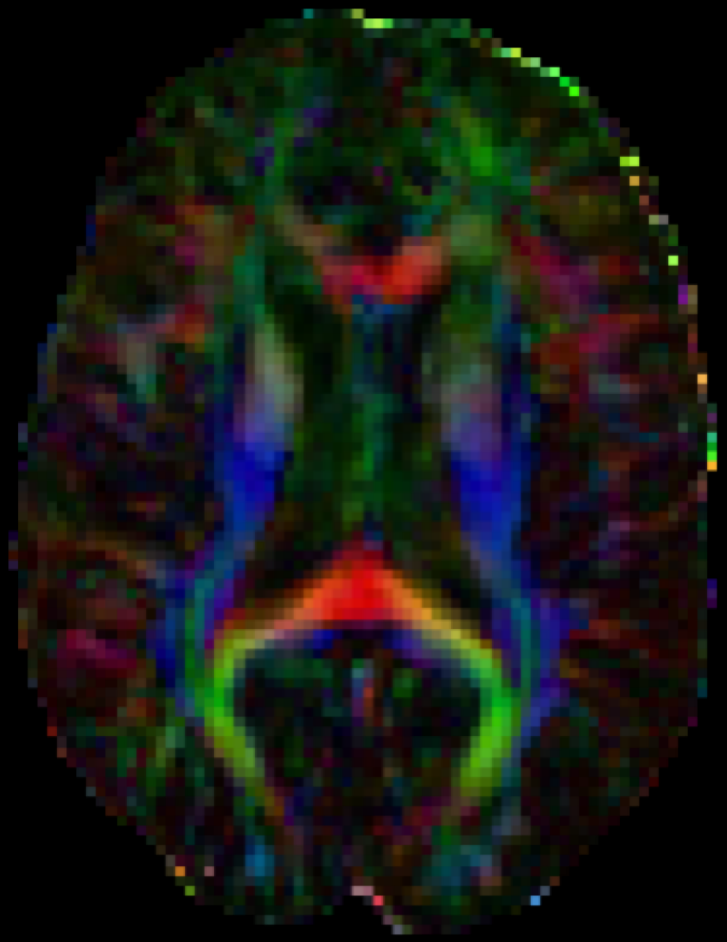
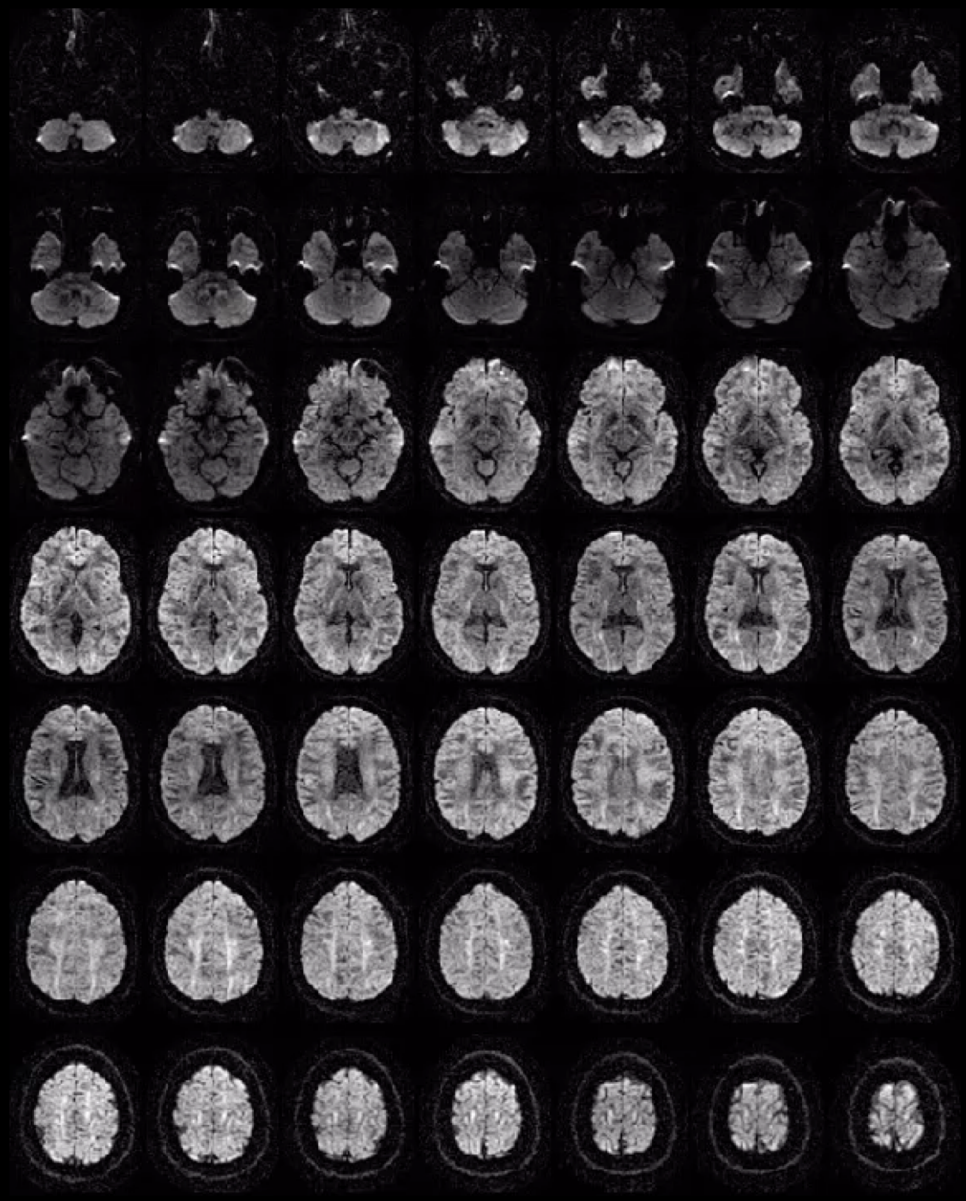
Data quality assessment ...

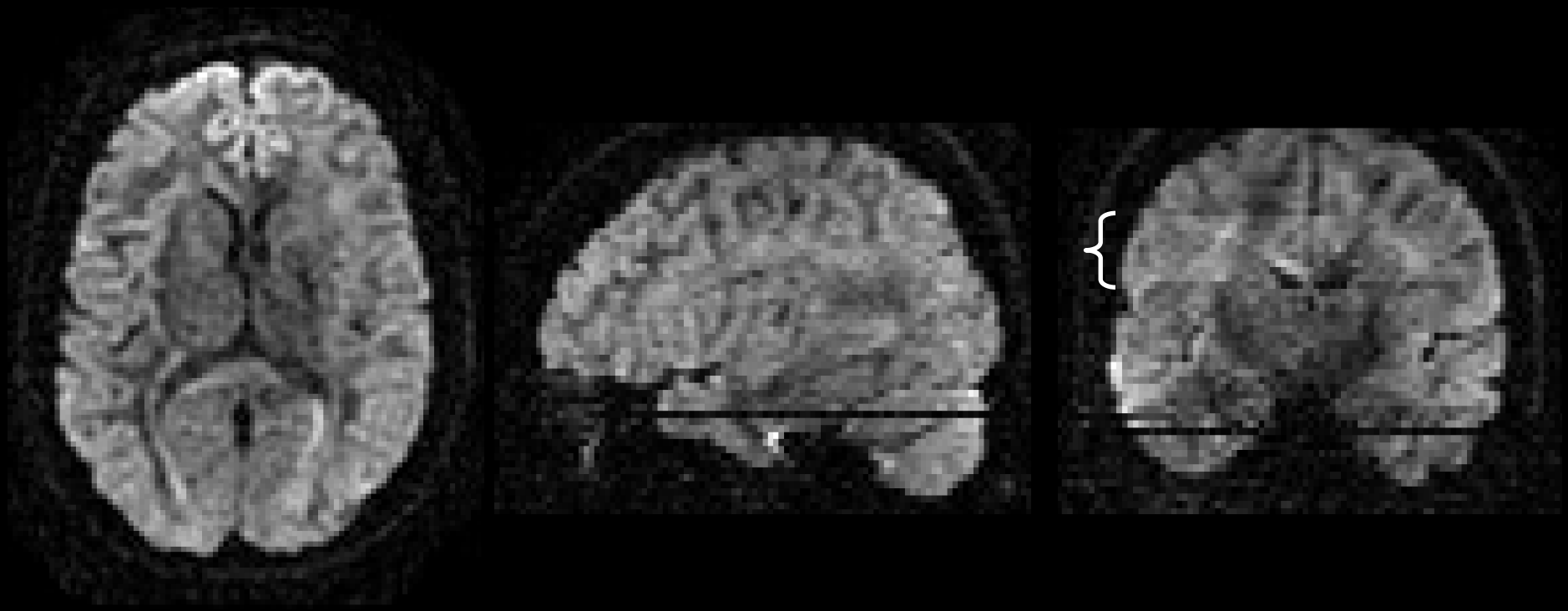




Look at your raw data!
Make a movie loop…

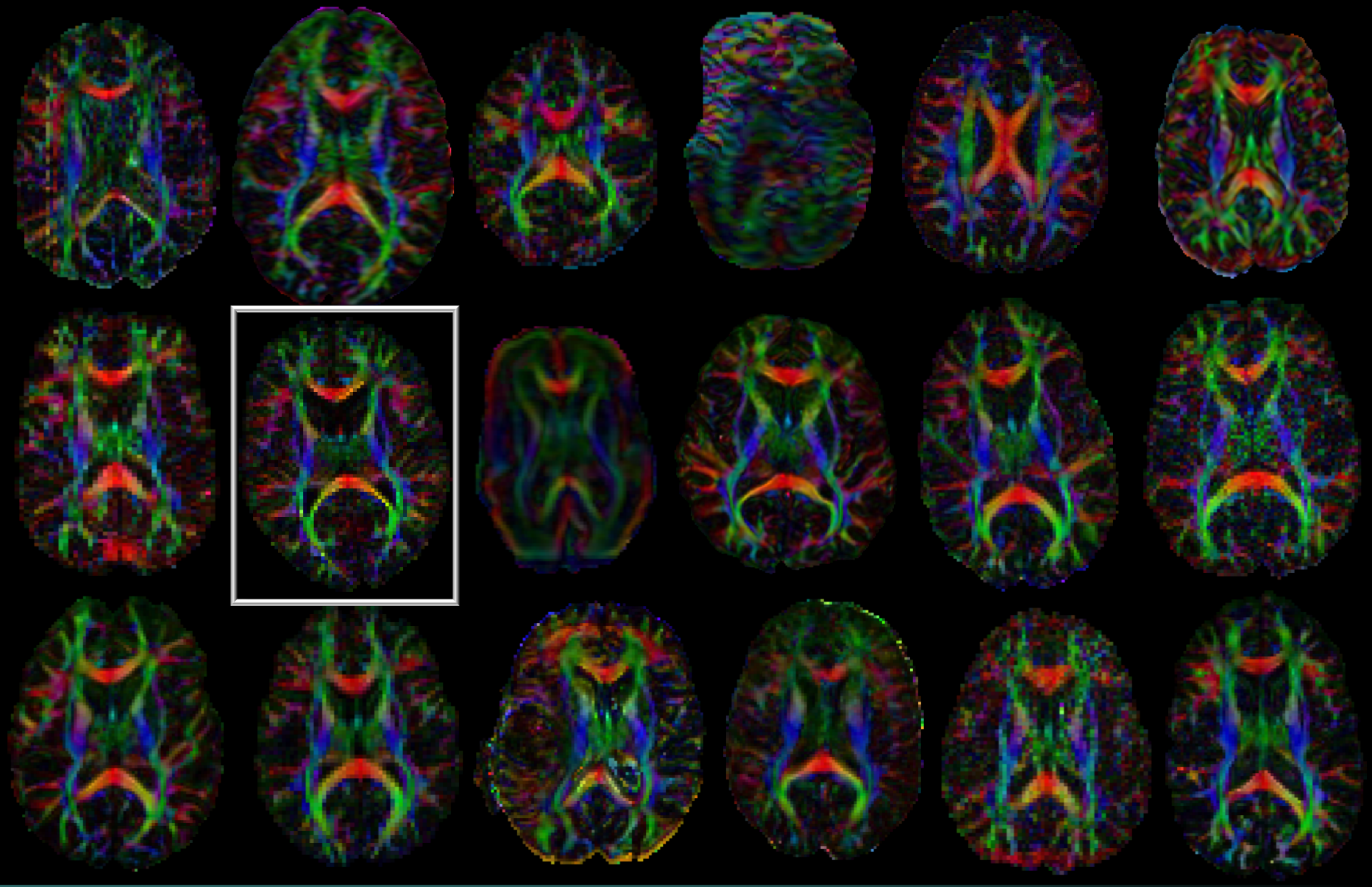
Data quality assessment ...

Different views!



Axial Sagittal Coronal

Data quality assessment ...



Tournier J.-D. et al, Magn Reson Med (2011)

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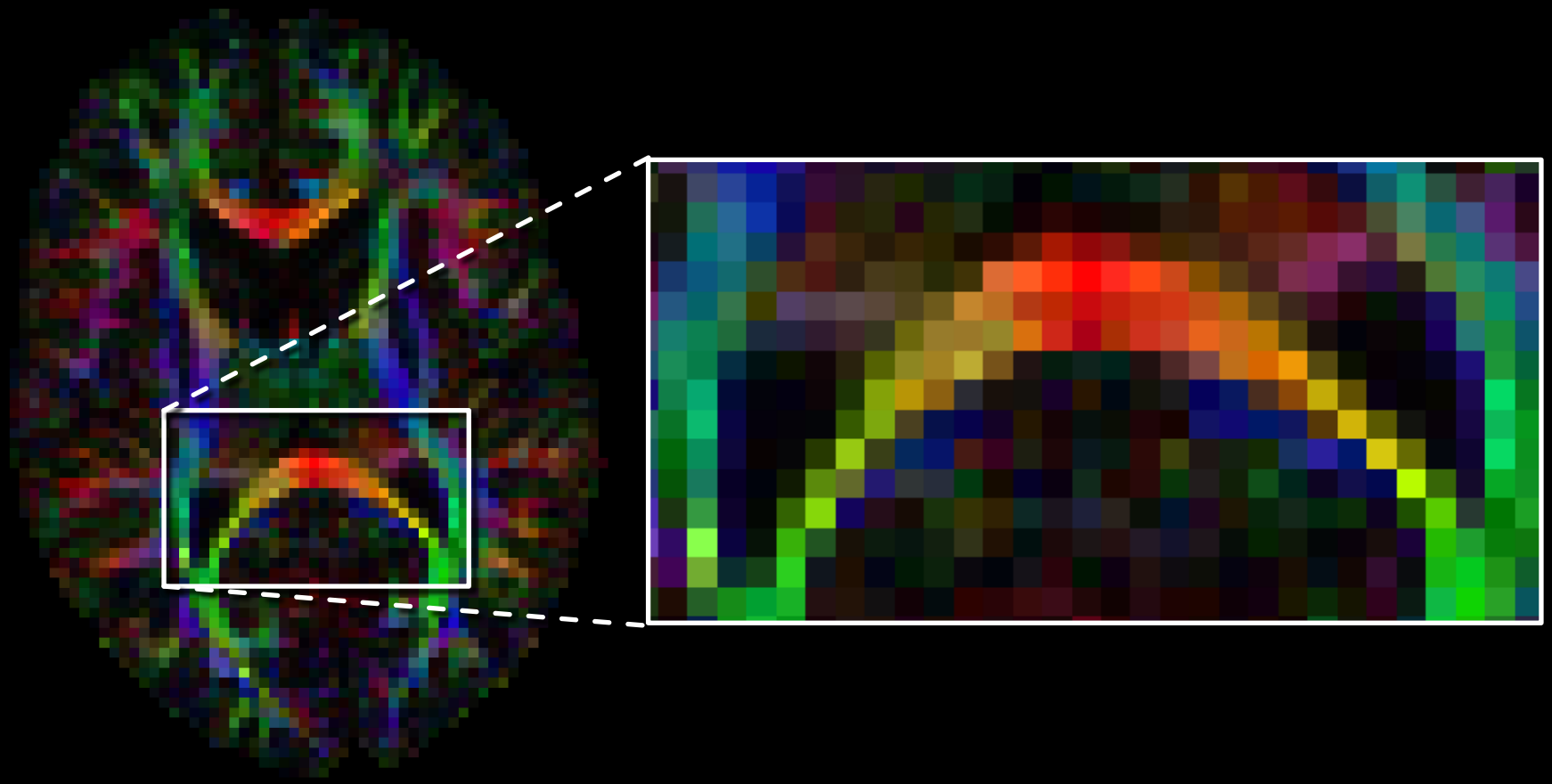
Data quality assessment ...



Data quality assessment ...

"Physically Implausible Signals" (PIS)

$$S = S_0 e^{-b \cdot D}$$

S = diffusion weighted signal

S_0 = non-diffusion weighted signal

b = diffusion weighting

D = diffusion coefficient

Data quality assessment …

"Physically Implausible Signals" (PIS)

$$S = S_0 \underbrace{e^{-b \cdot D}}_{< 1}$$

$$\rightarrow S < S_0$$

S = diffusion weighted signal

S_0 = non-diffusion weighted signal

b = diffusion weighting

D = diffusion coefficient

Data quality assessment …

"Physically Implausible Signals" (PIS)

The painful reality …

$$S > S_0$$

S = diffusion weighted signal

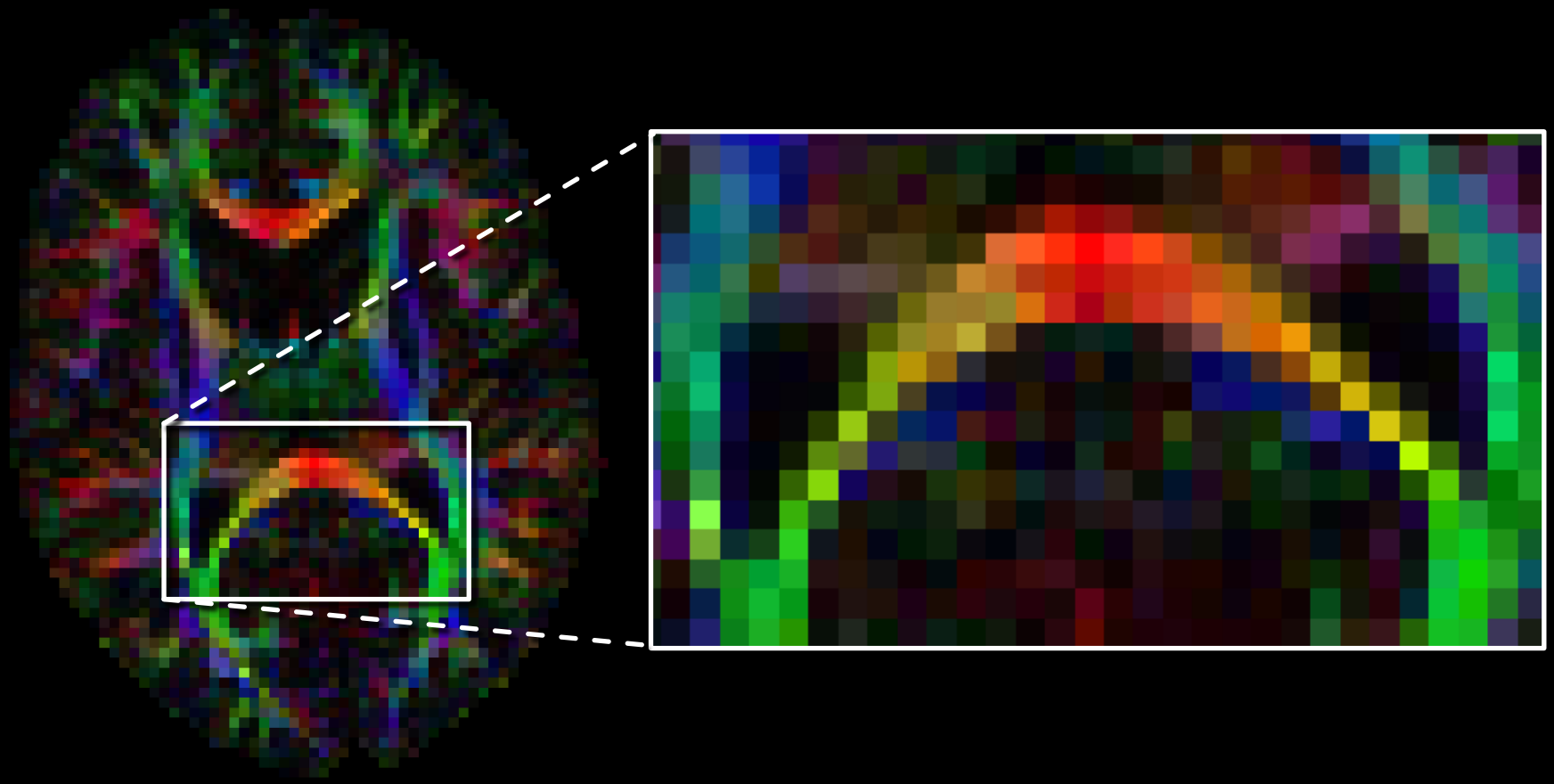
S_0 = non-diffusion weighted signal

b = diffusion weighting

D = diffusion coefficient

Data quality assessment ...

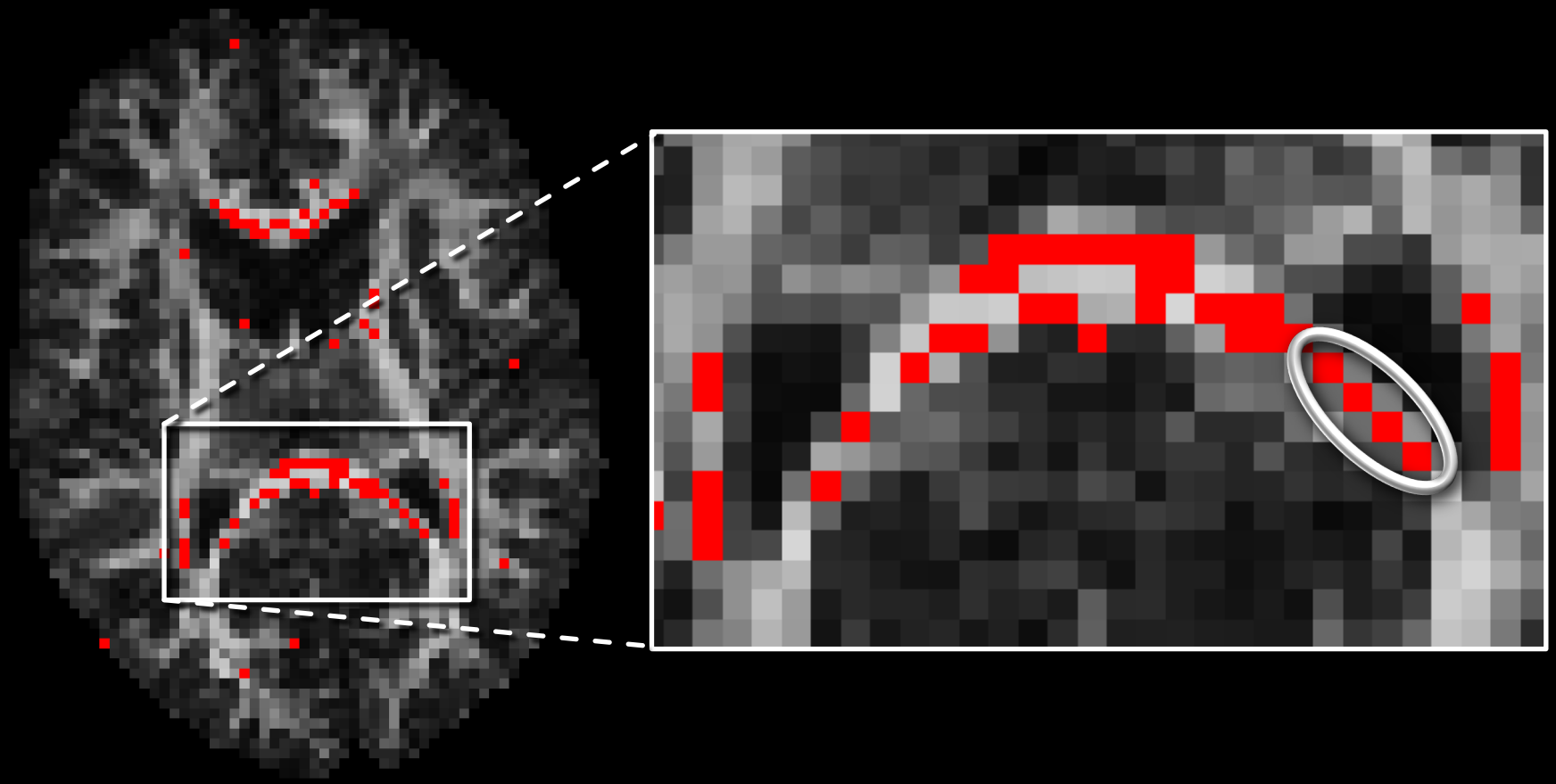
"Physically Implausible Signals" (PIS)



Color-coded fractional anisotropy (FA)

Data quality assessment ...

"Physically Implausible Signals" (PIS)



Regions with "PIS" ($S > S_0$) overlaid on FA!!!

Perrone D. et al, NeuroImage (2015)

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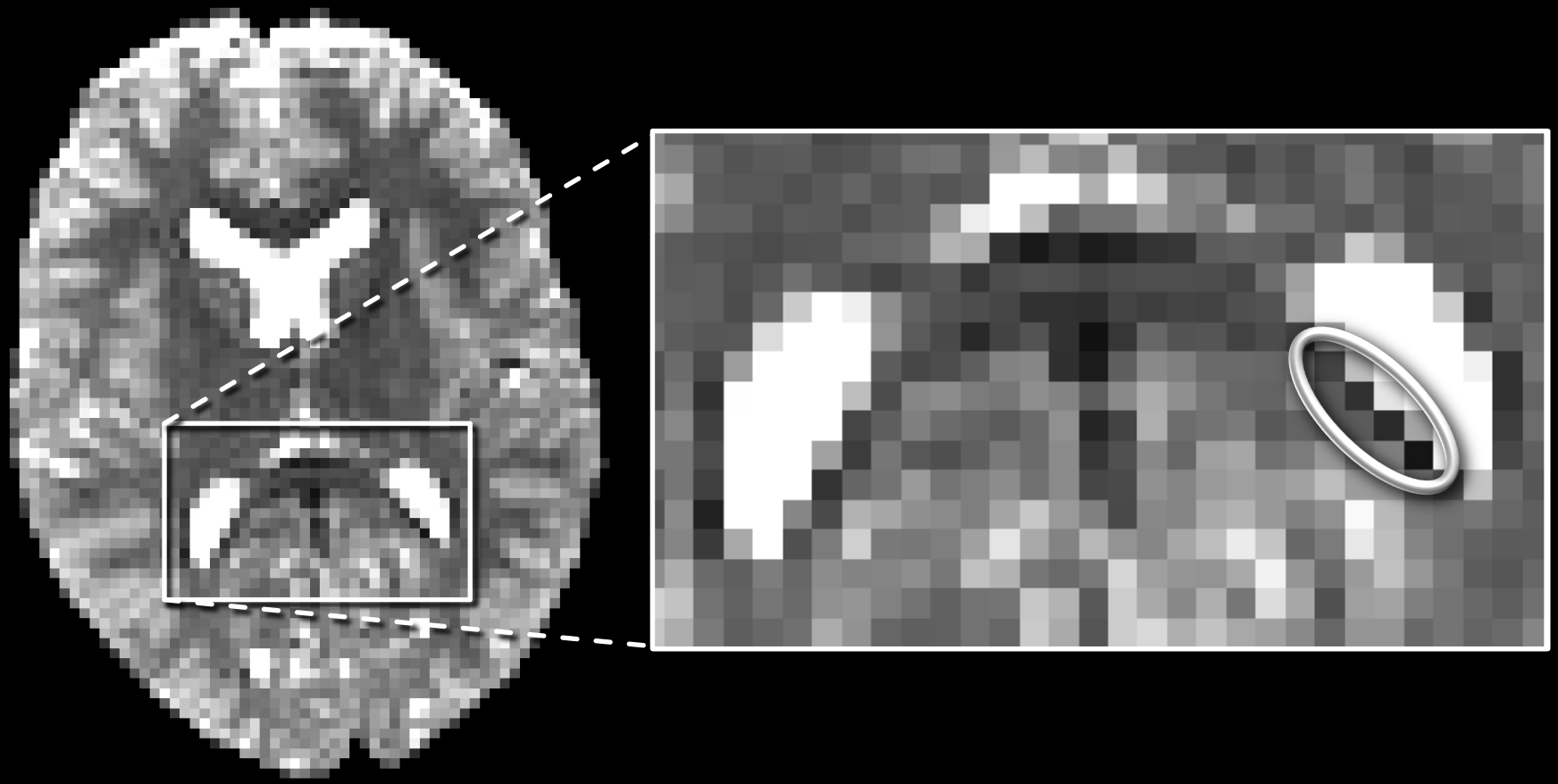
Data quality assessment ...

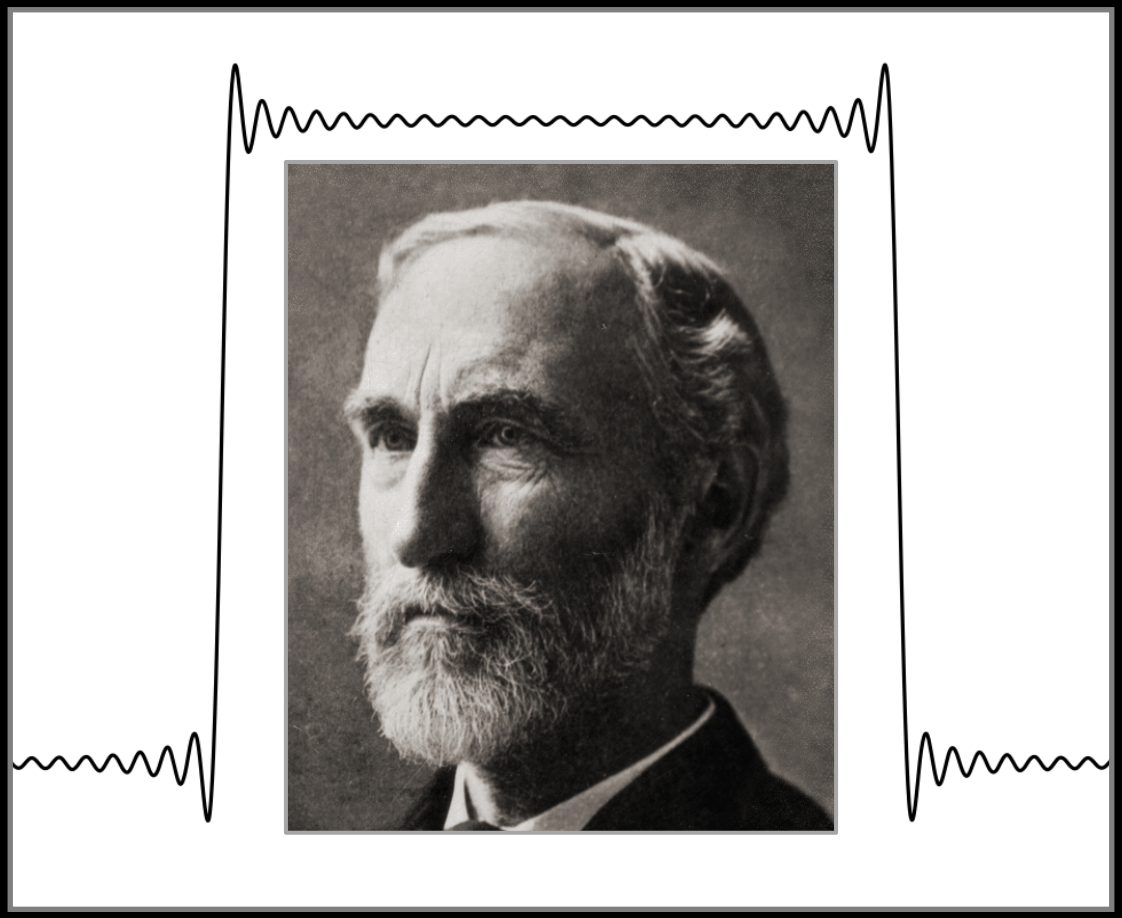
"Physically Implausible Signals" (PIS)



"PIS" → in regions with low S_0 values

Data quality assessment ...

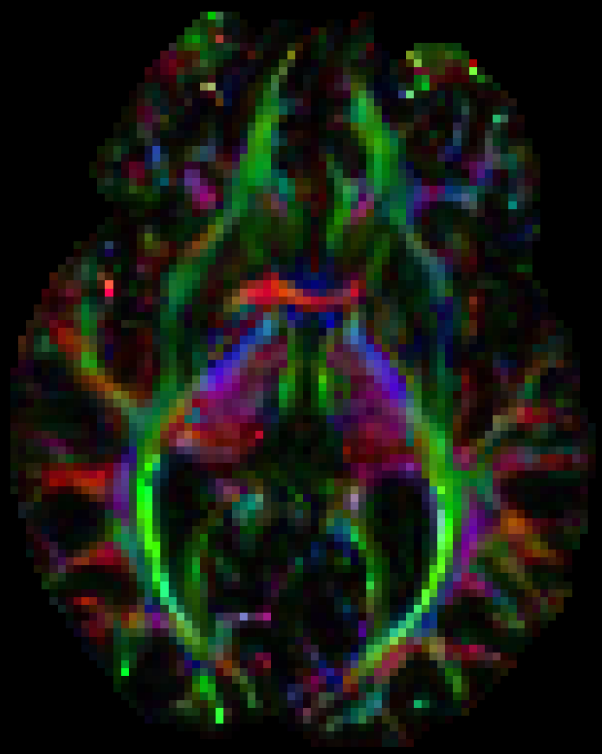
"Physically Implausible Signals" (PIS)



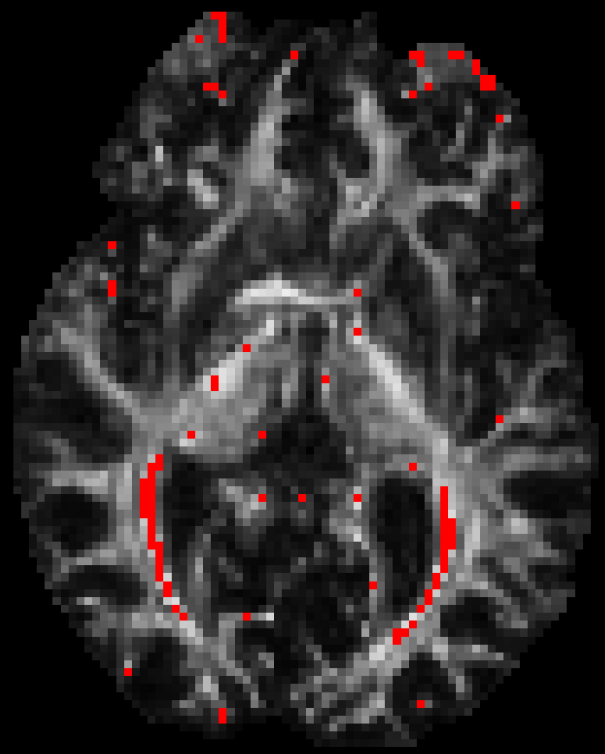
Josiah W. Gibbs

Data quality assessment ...

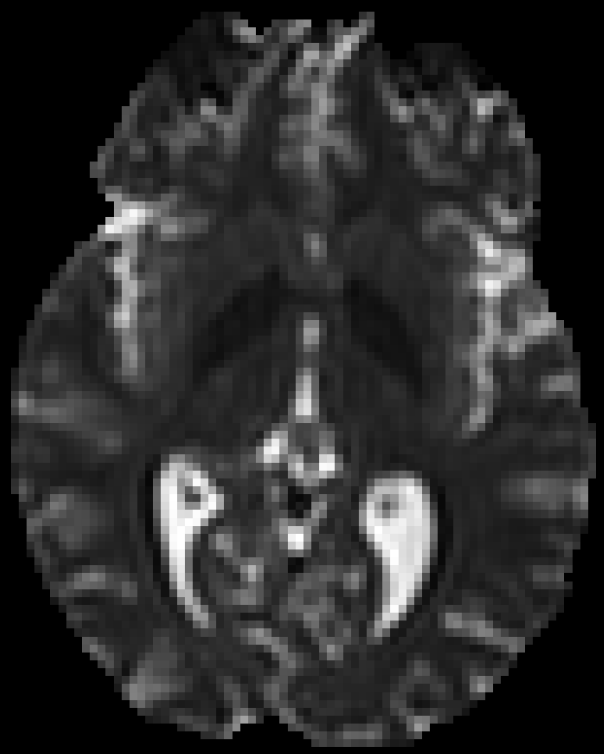
"Physically Implausible Signals" (PIS)



Color-coded FA



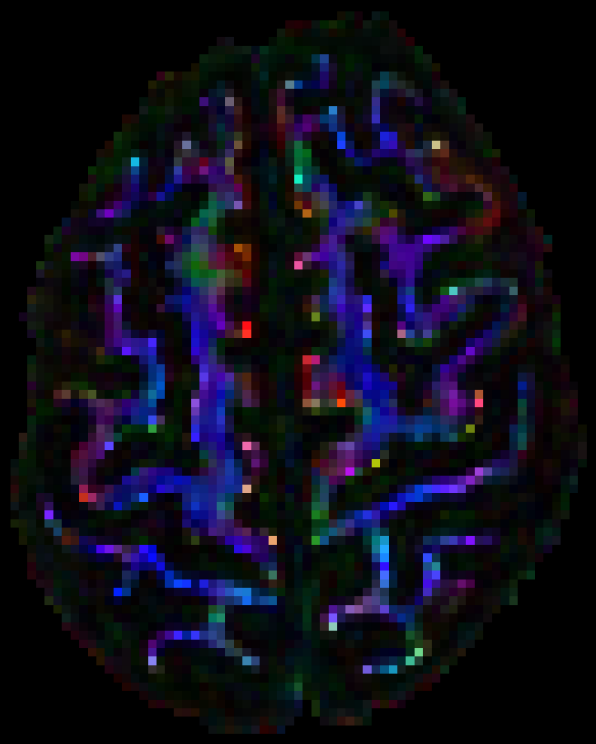
"PIS" on FA



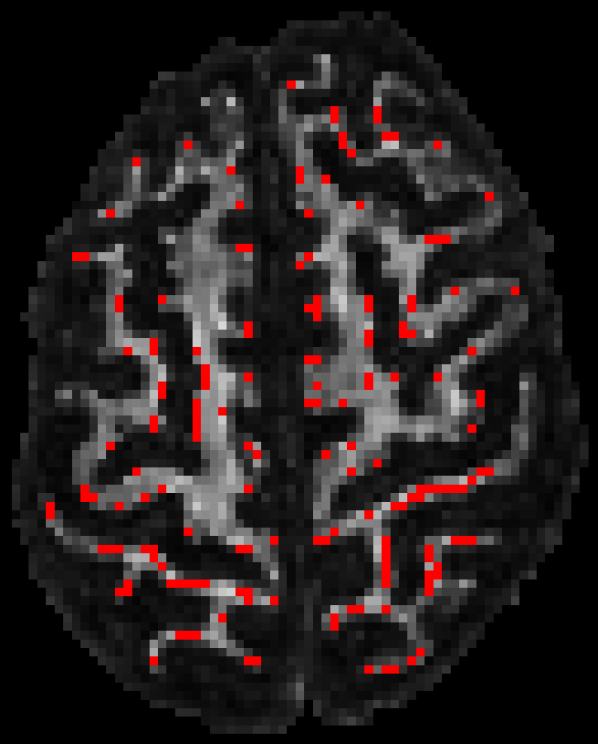
S_0

Data quality assessment ...

"Physically Implausible Signals" (PIS)



Color-coded FA

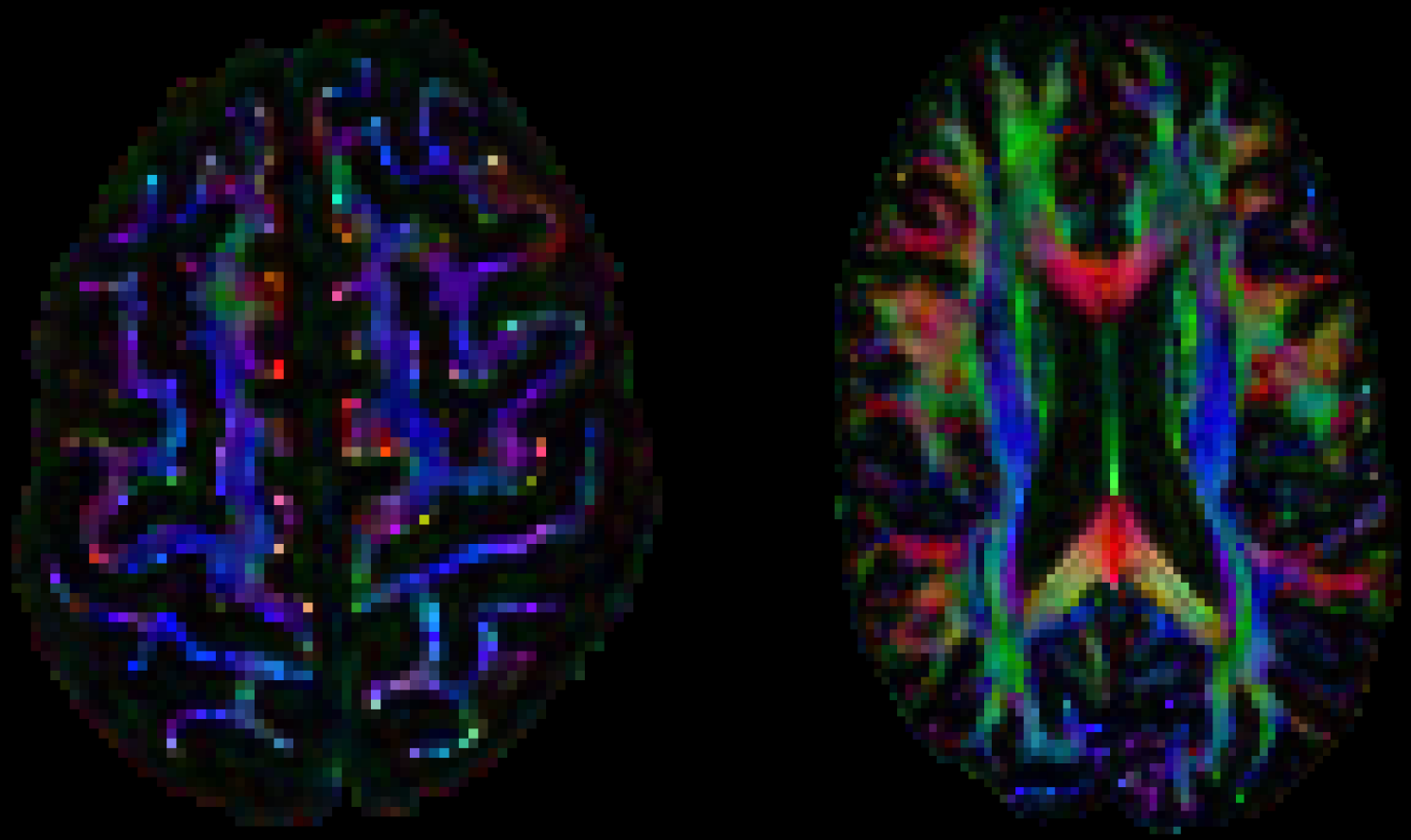


"PIS" on FA

S_0

Data quality assessment ...

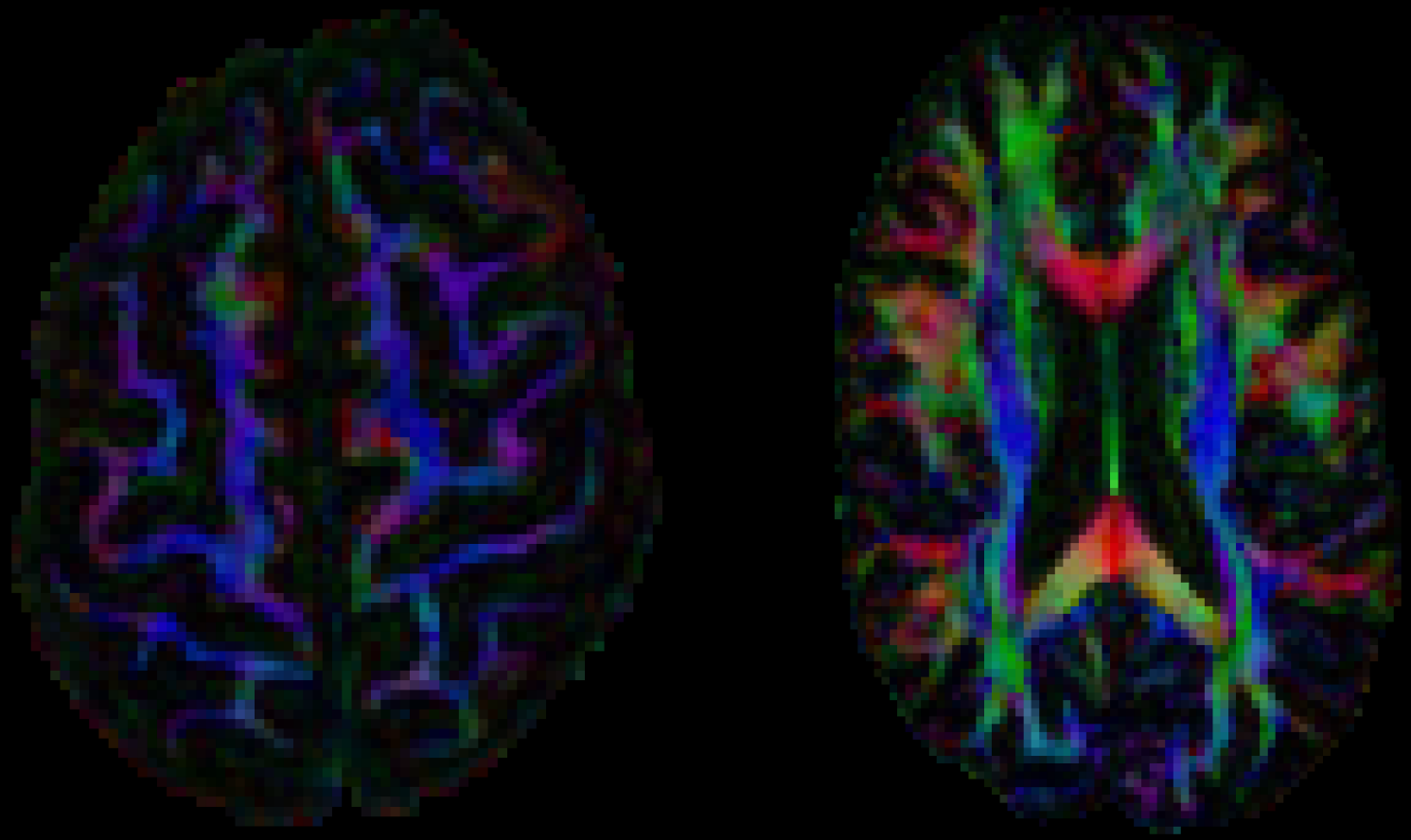
"Physically Implausible Signals" (PIS)



Before correcting for Gibbs ringing artifacts

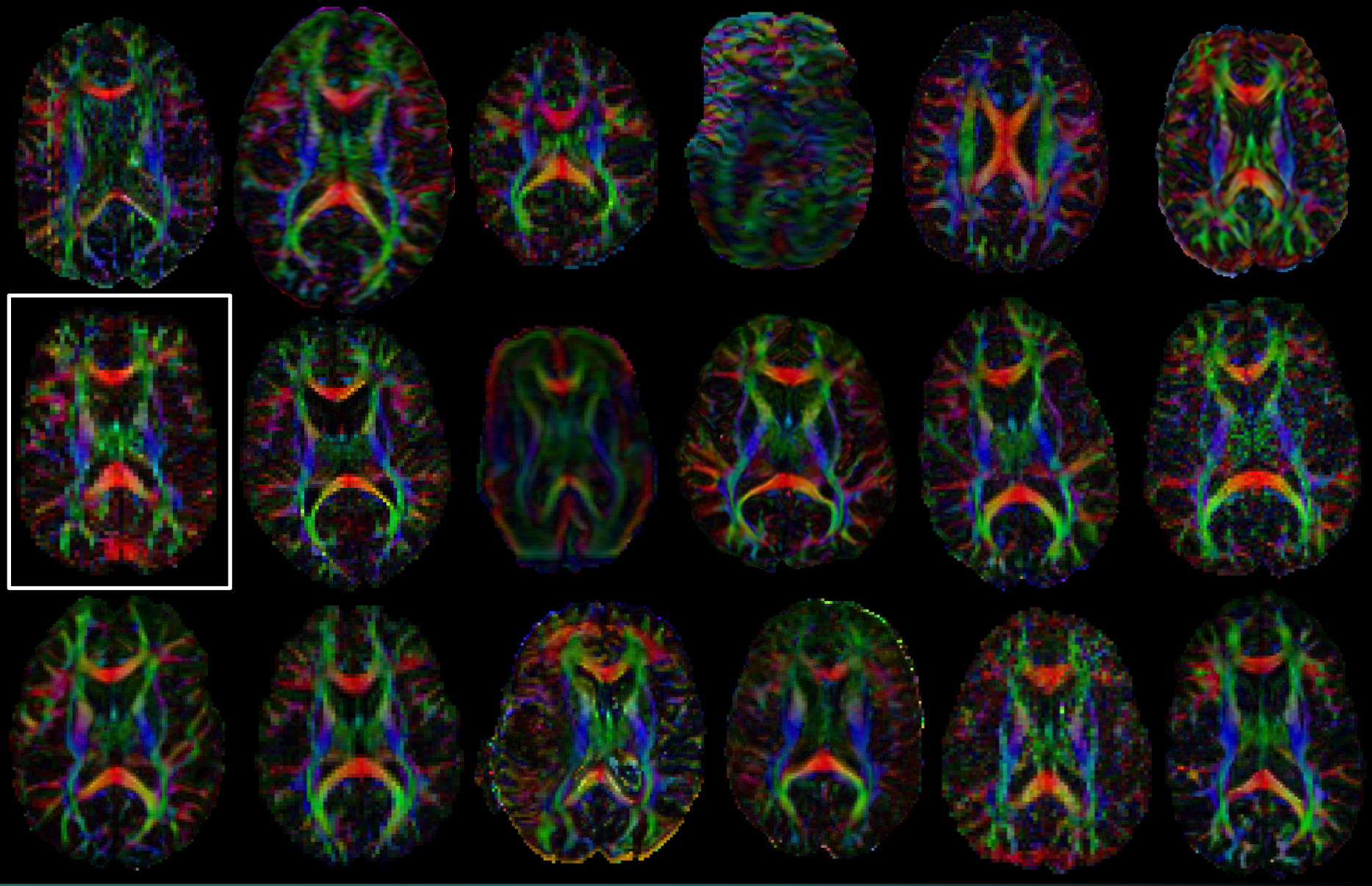
Data quality assessment ...

"Physically Implausible Signals" (PIS)



After correcting for Gibbs ringing artifacts

Data quality assessment ...



Tournier J.-D. et al, Magn Reson Med (2011)

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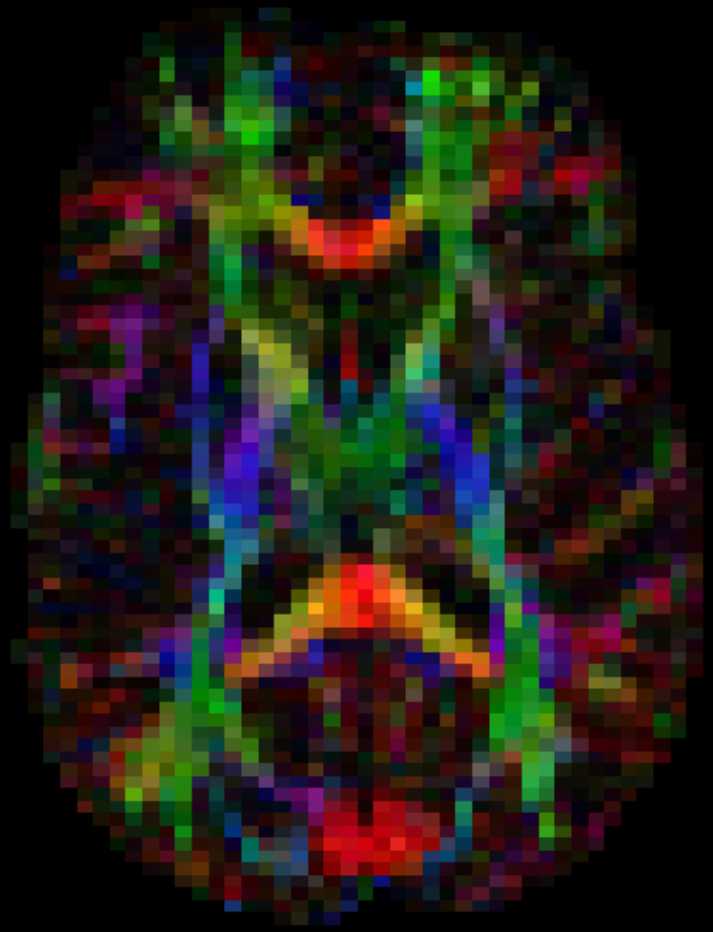
Data quality assessment ...

Residuals from the model estimation



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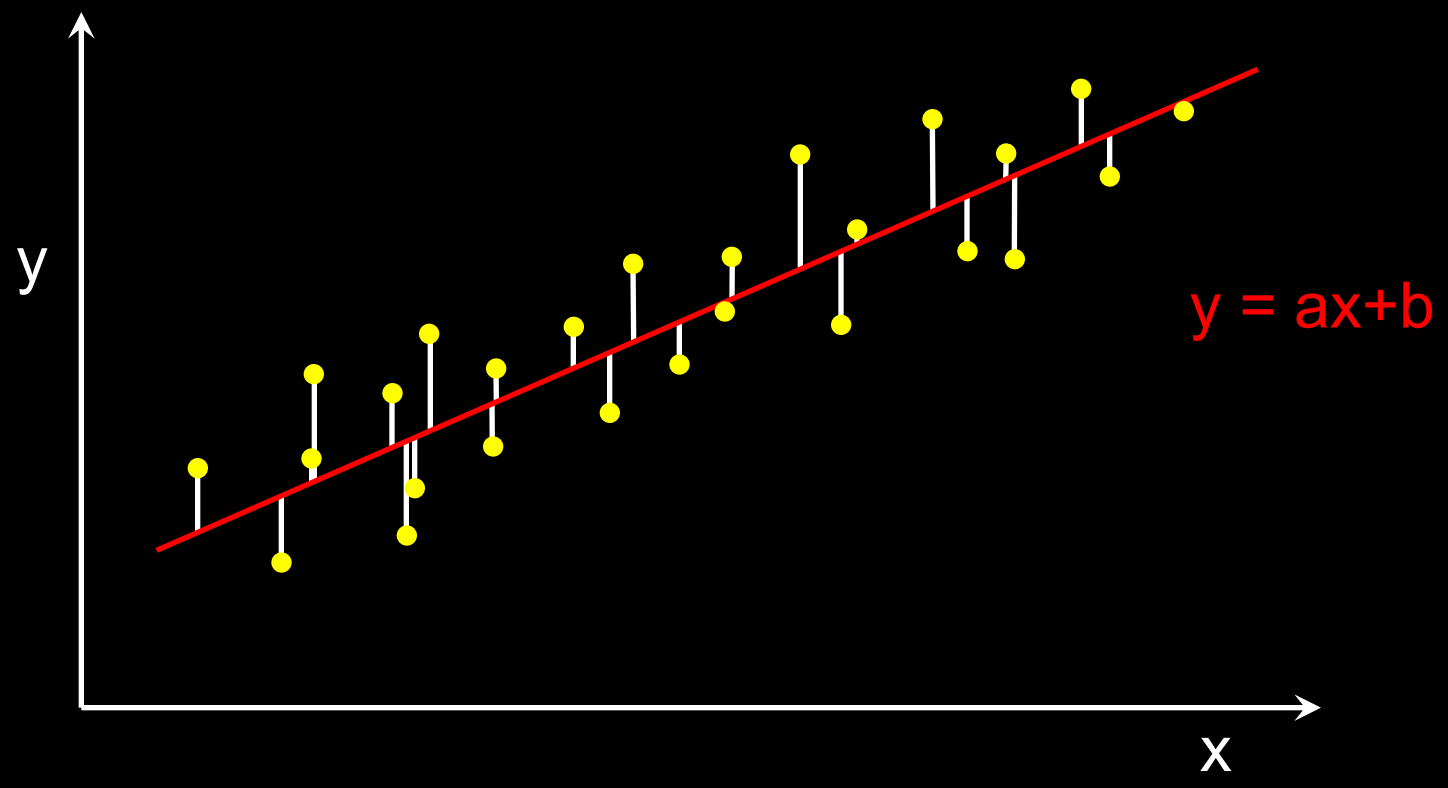
Data quality assessment ...

Residuals from the model estimation

Data quality assessment ...

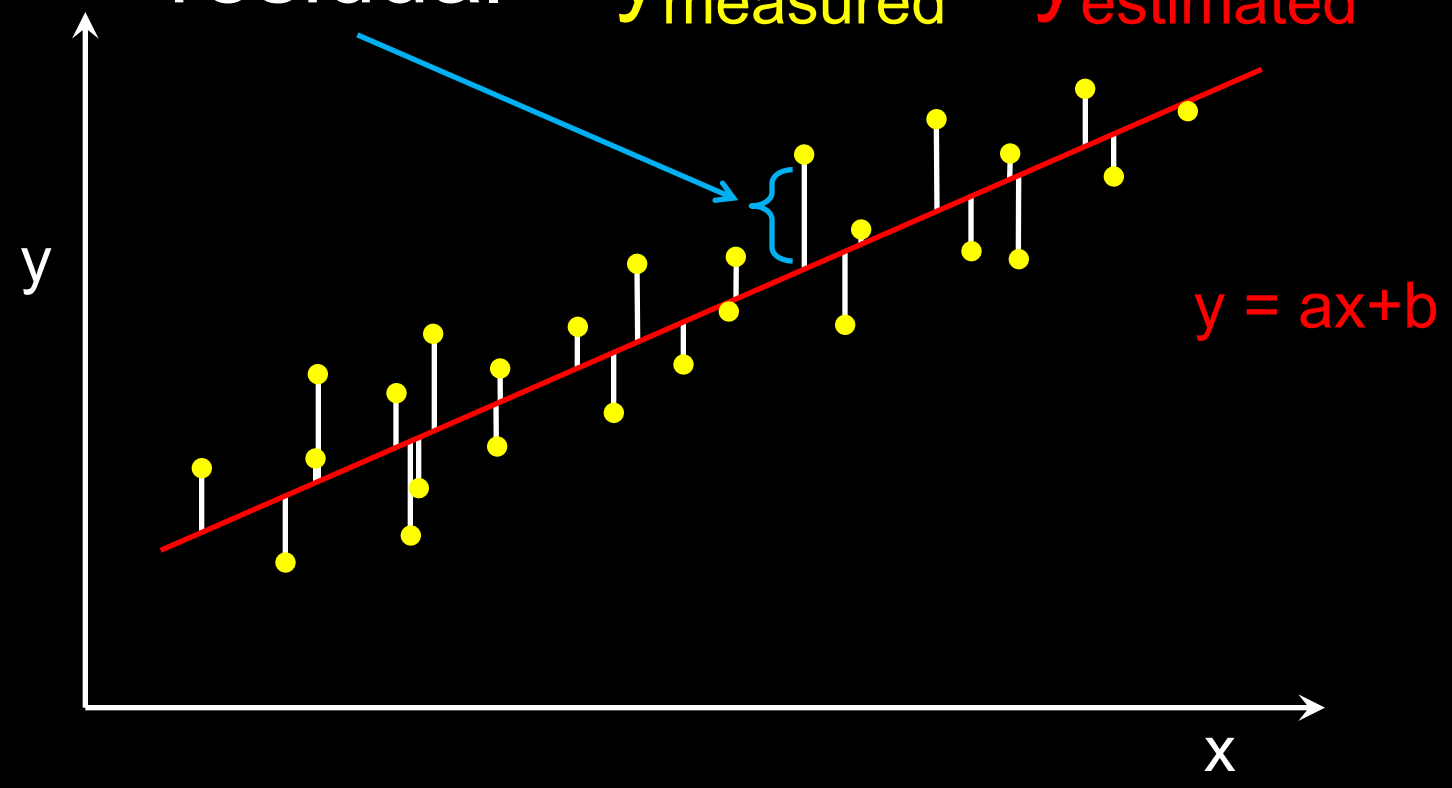
Residuals from the model estimation



Data quality assessment ...

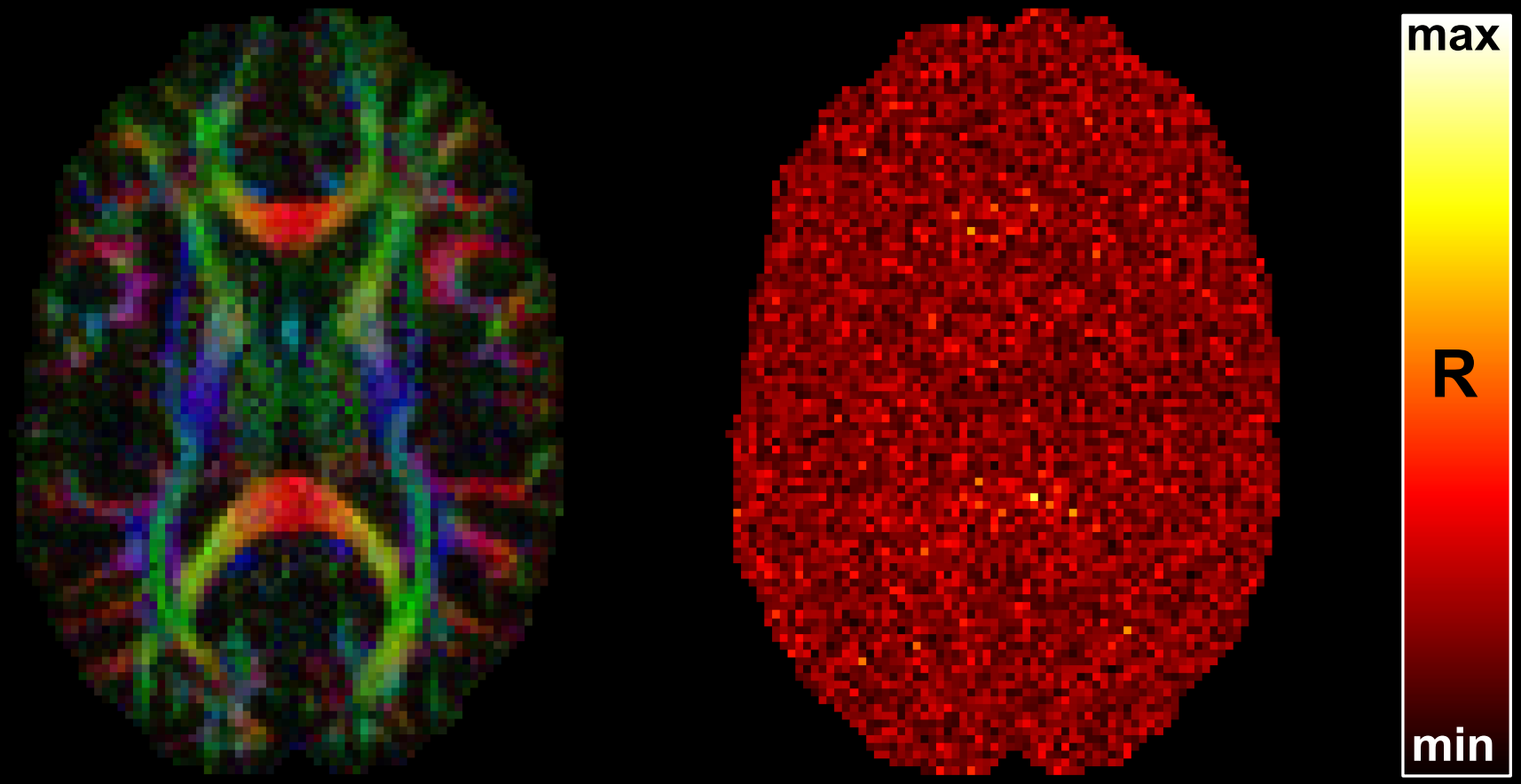
Residuals from the model estimation

residual = $y_{measured}$ - $y_{estimated}$



Data quality assessment ...

Residuals from the model estimation



Good quality ⟺ Low values / uniformity

Tournier J.-D. et al, Magn Reson Med (2011)

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Data quality assessment ...

Residuals from the model estimation

◆ Human Brain Mapping 31:193–202 (2010) ◆

Addressing a Systematic Vibration Artifact in Diffusion-Weighted MRI

Daniel Gallichan,[1]* Jan Scholz,[1] Andreas Bartsch,[2] Timothy E. Behrens,[1] Matthew D. Robson,[3] and Karla L. Miller[1]

[1]*Centre for Functional Magnetic Resonance Imaging of the Brain, John Radcliffe Hospital, University of Oxford, Oxford, United Kingdom*
[2]*Department of Neuroradiology, University of Würzburg, Würzburg, Germany*
[3]*University of Oxford Centre for Clinical Magnetic Resonance Research, Oxford, United Kingdom*

Tournier J.-D. et al, Magn Reson Med (2011)

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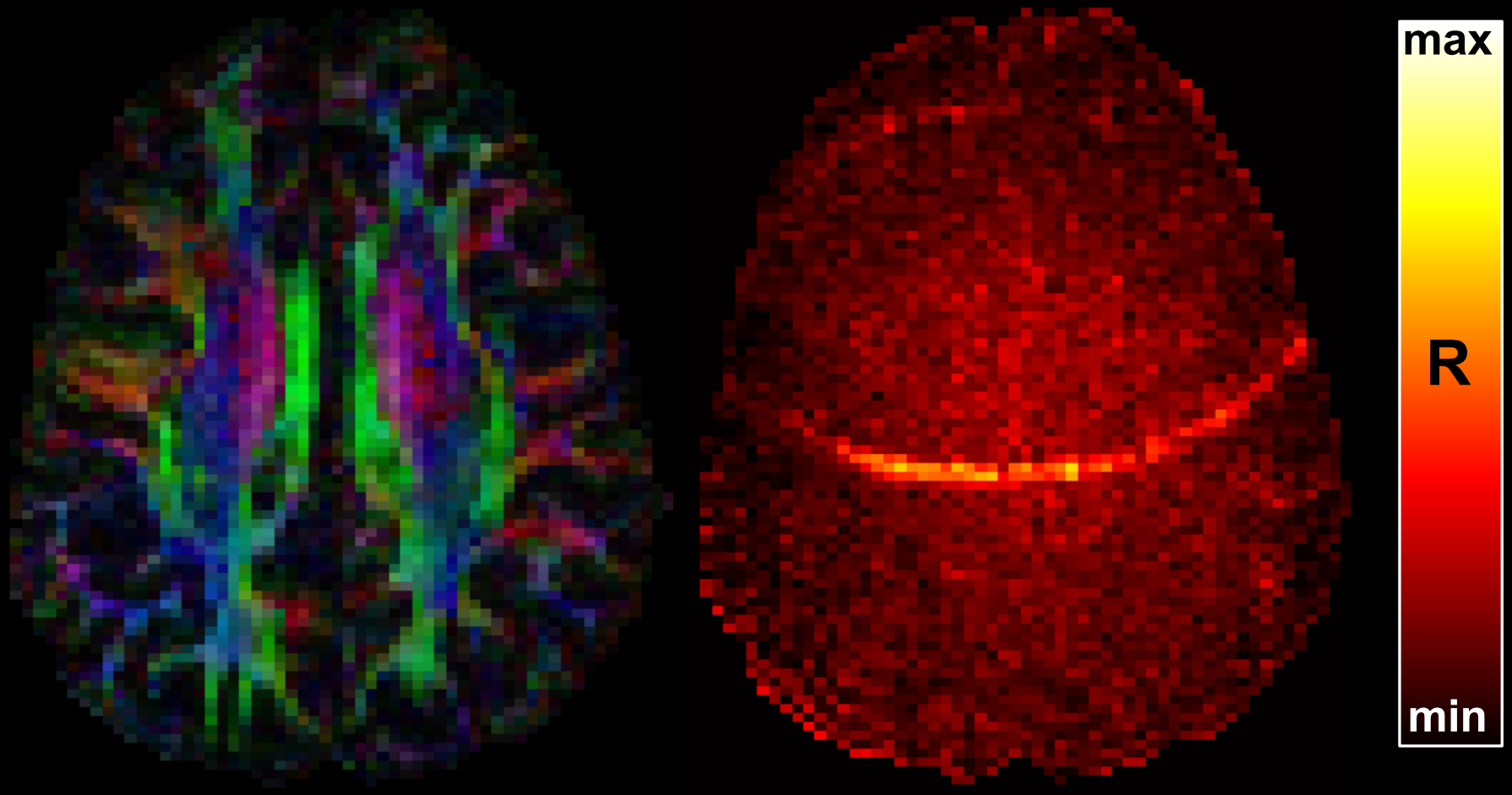
Data quality assessment ...

Residuals from the model estimation

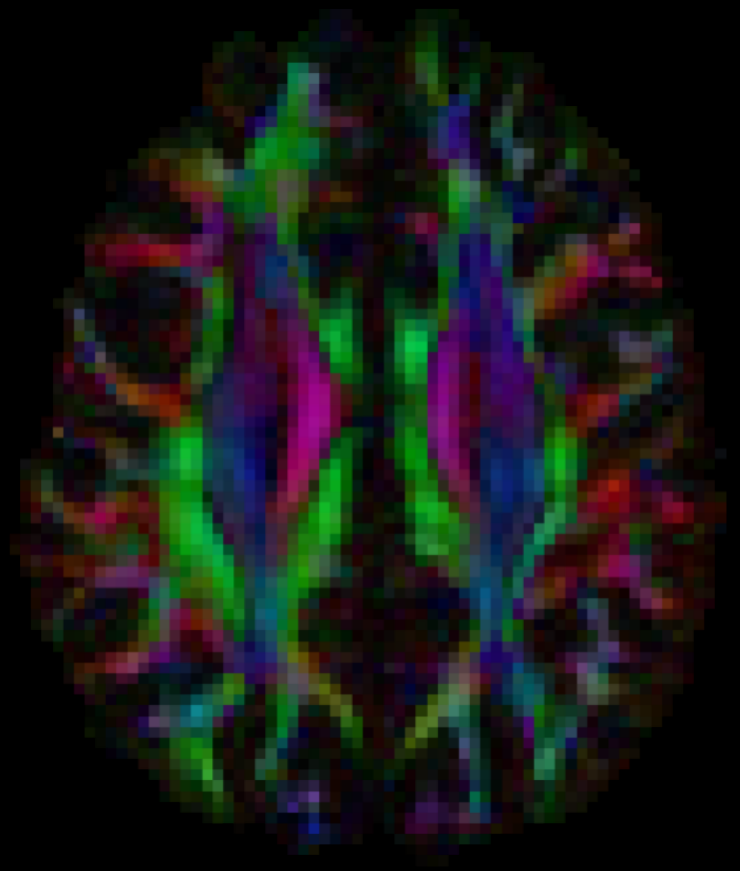


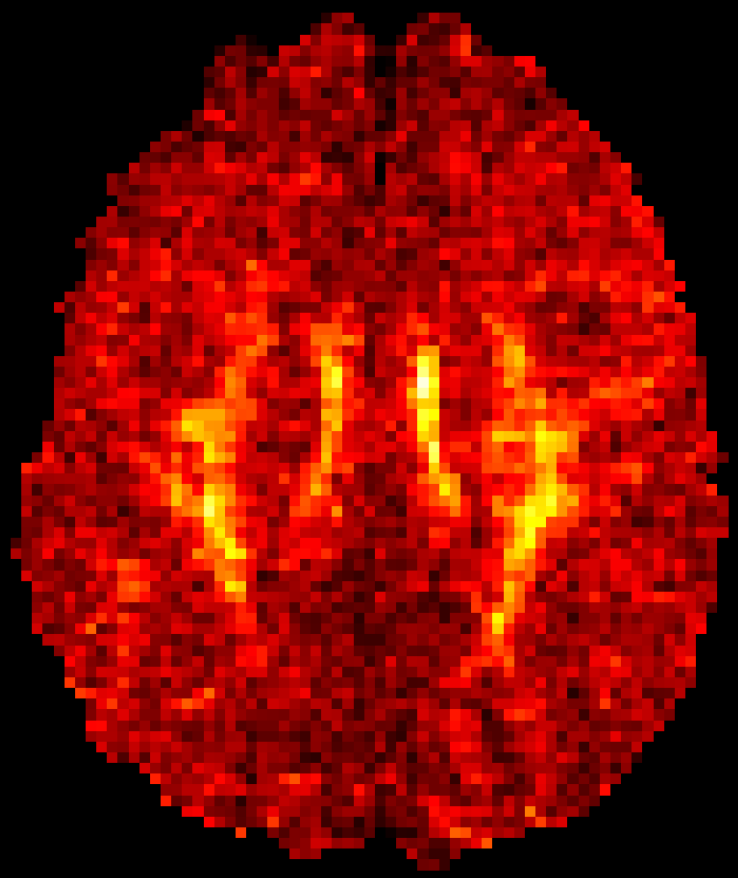
Tournier J.-D. et al, Magn Reson Med (2011)

@Alex_Leemans

Data quality assessment ...

Residuals from the model estimation





Tournier J.-D. et al, Magn Reson Med (2011)

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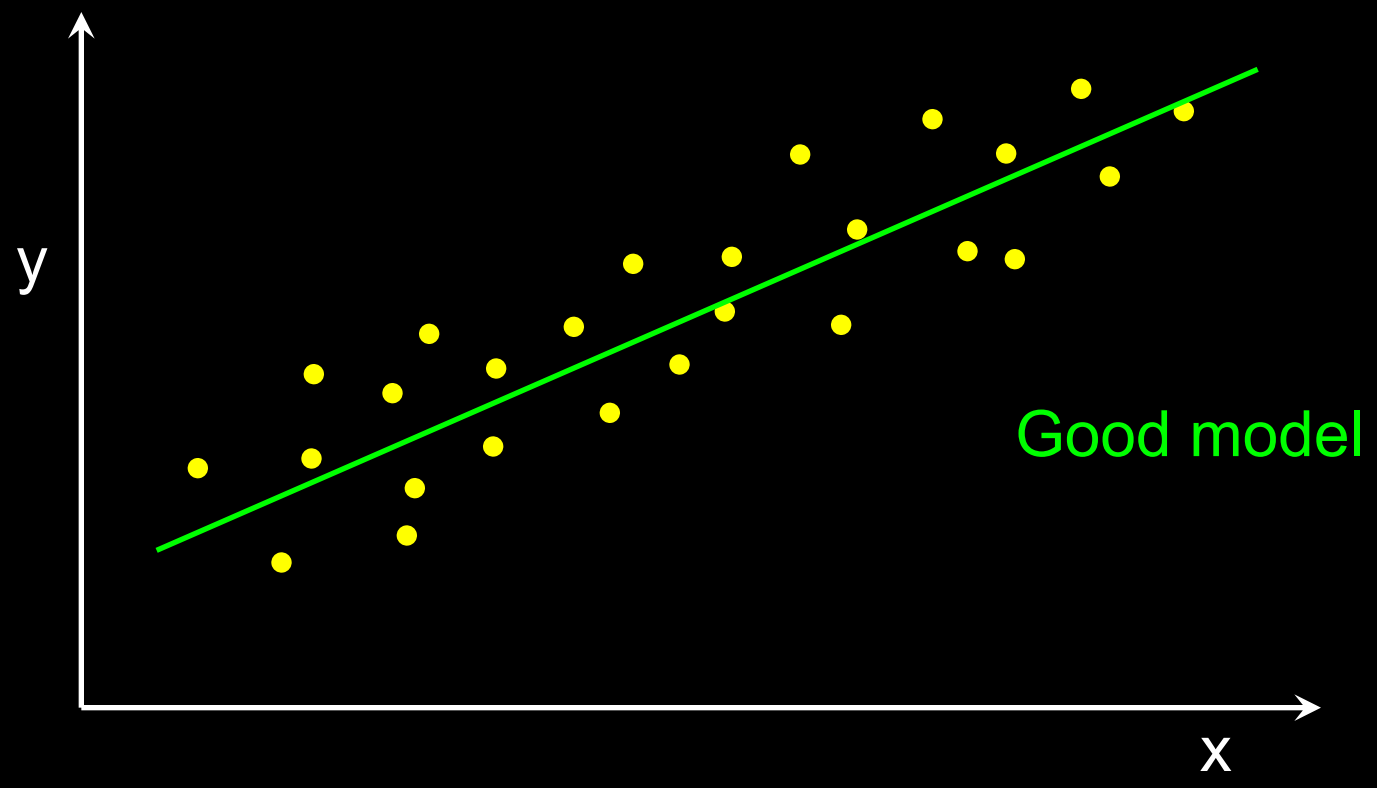
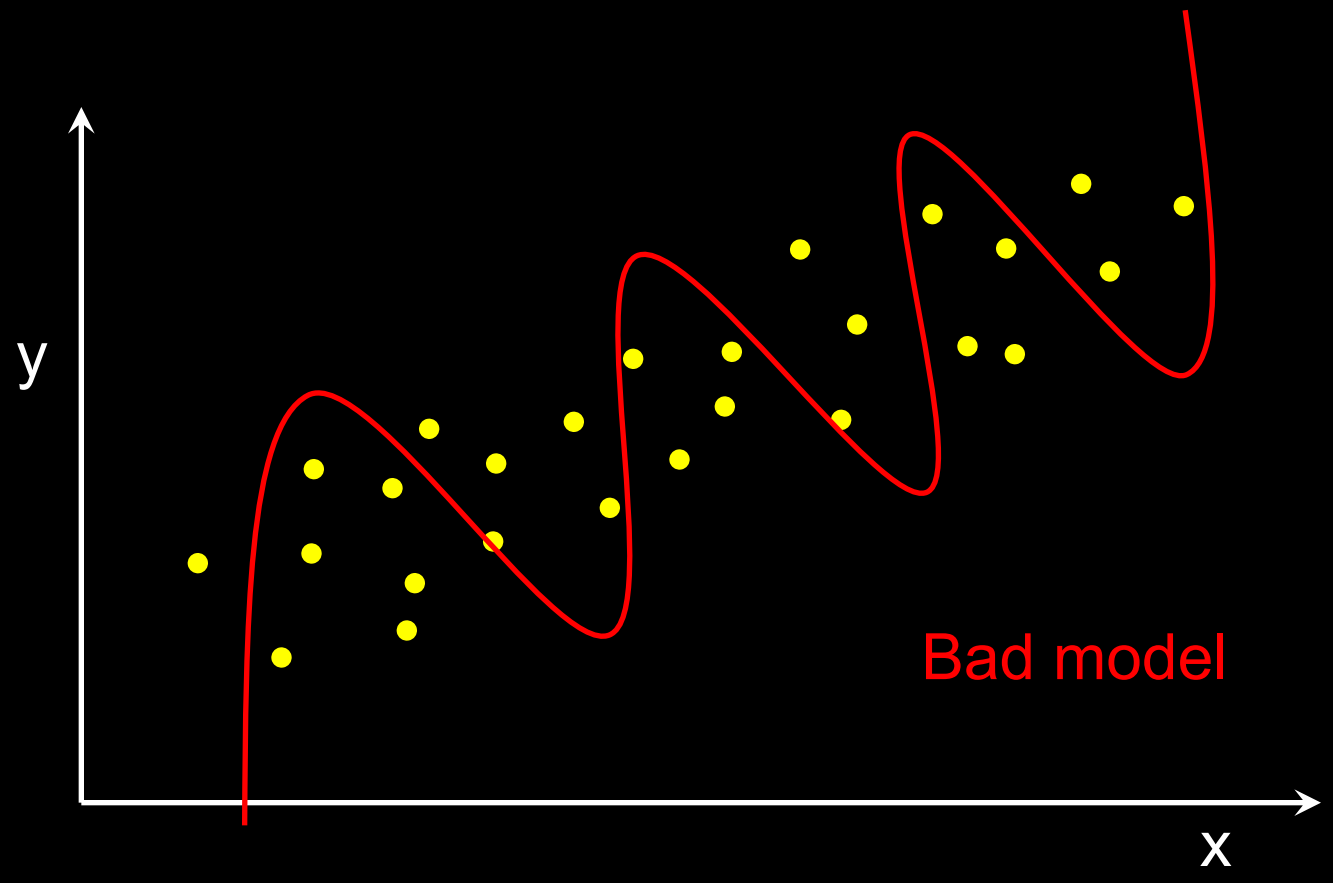
Data quality assessment ...

Residuals from the model estimation



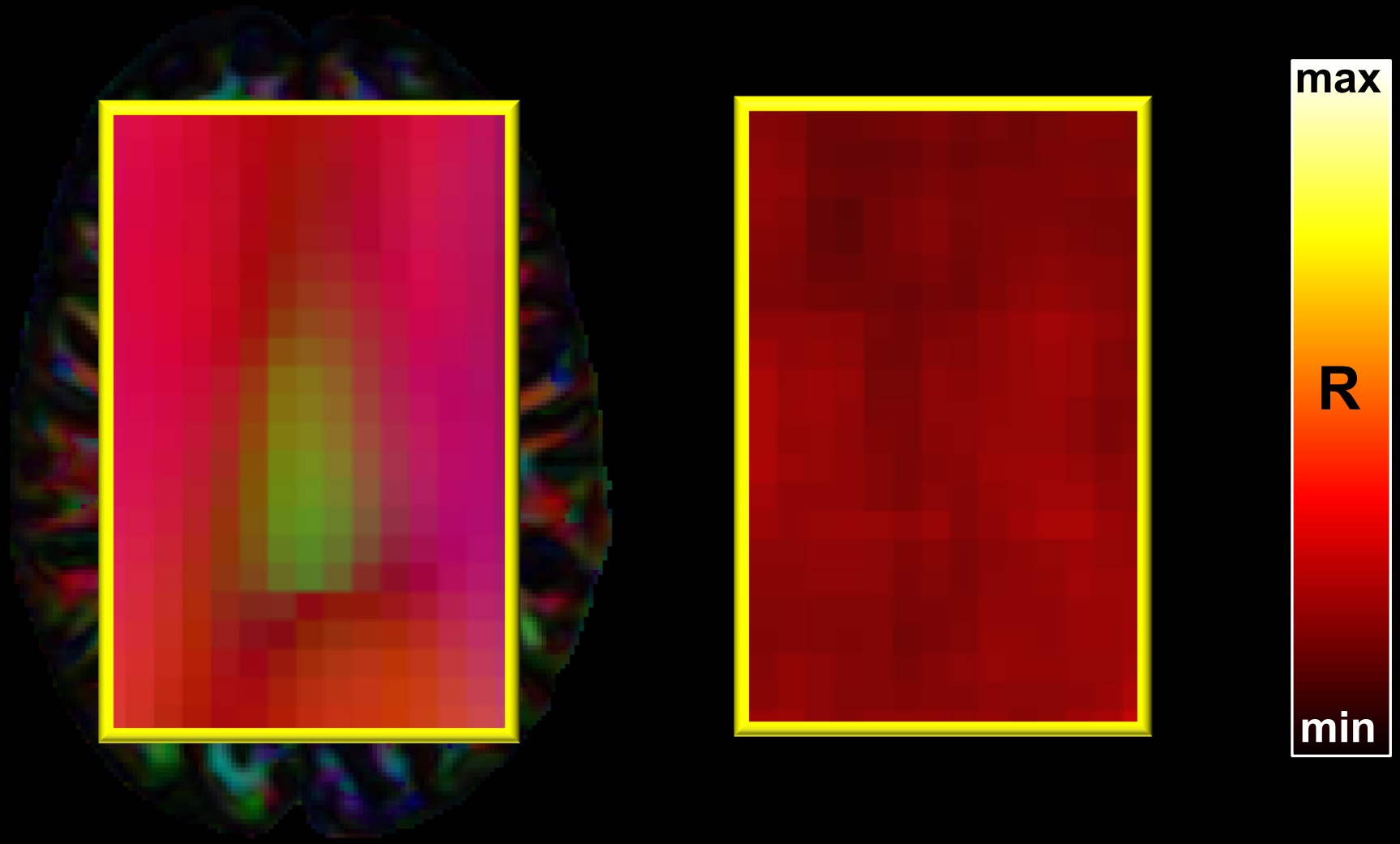
Data quality assessment ...

Residuals from the model estimation



Data quality assessment ...

Residuals from the model estimation



Poldrack R.A. et al, Nature Communications (2015)

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QA DIFFUSION

Data processing steps

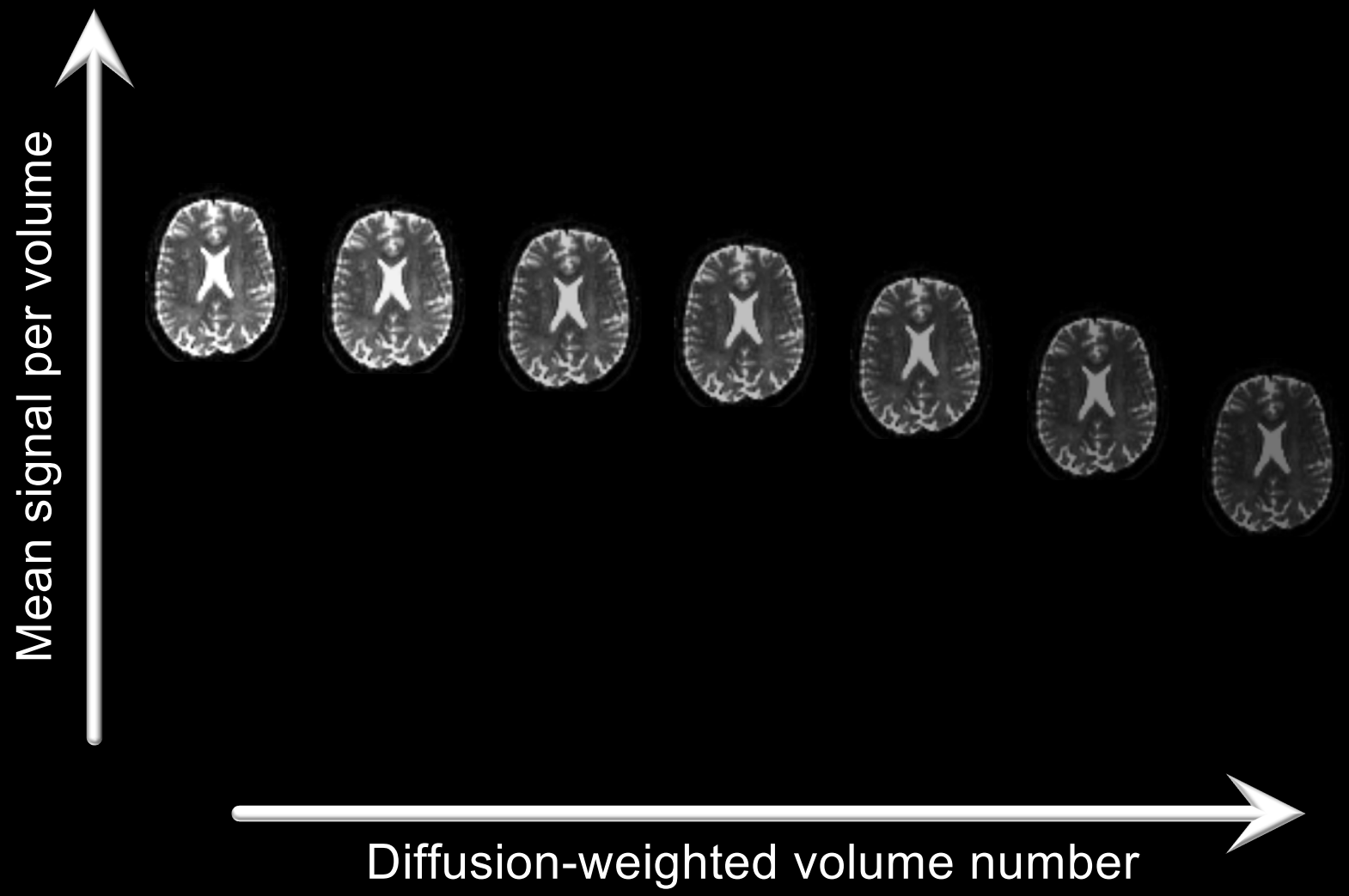
1. Correction for signal intensity drift
2. Correction for subject motion and eddy current induced distortions
3. Correction for EPI deformations
4. Diffusion model *estimation* approaches

A confession by a dMRI scientist...

Data processing steps

1. Correction for signal intensity drift
2. Correction for subject motion and eddy current induced distortions
3. Correction for EPI deformations
4. Diffusion model *estimation* approaches

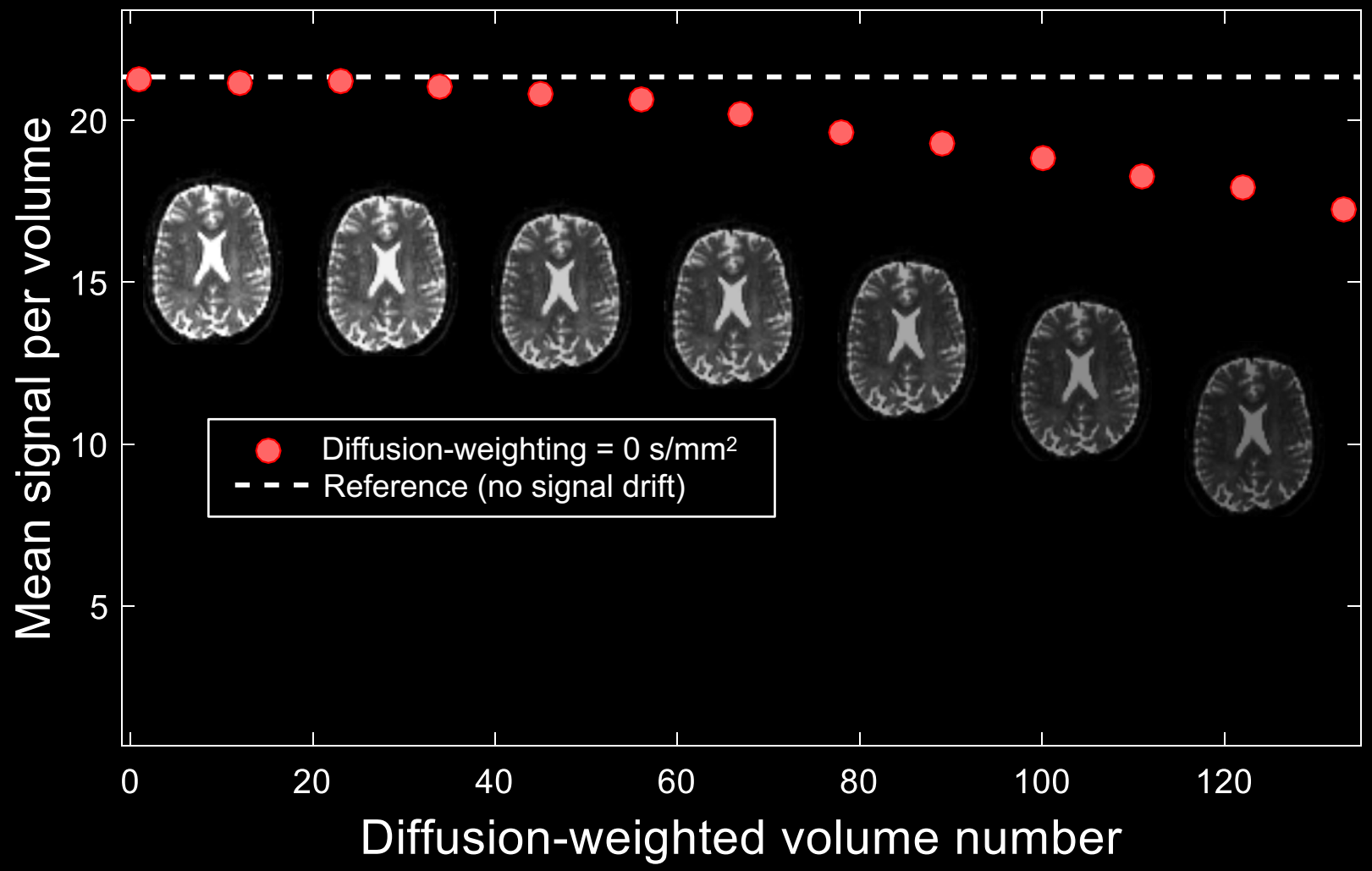
1. Correction for signal intensity drift



Vos S.B. et al, Magnetic Resonance in Medicine, 2016

@Alex_Leemans

1. Correction for signal intensity drift



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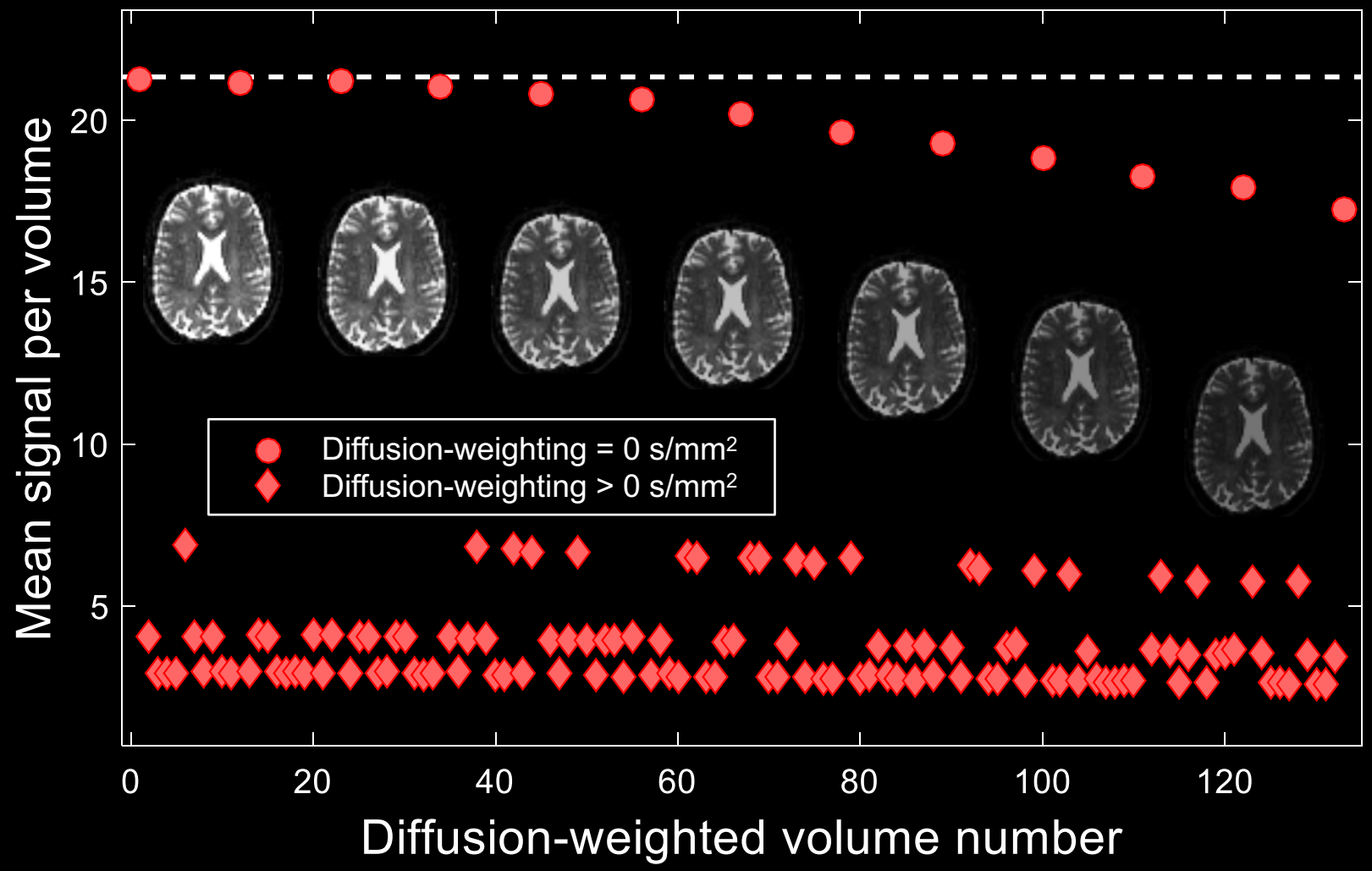
1. Correction for signal intensity drift



Vos S.B. et al, Magnetic Resonance in Medicine, 2016

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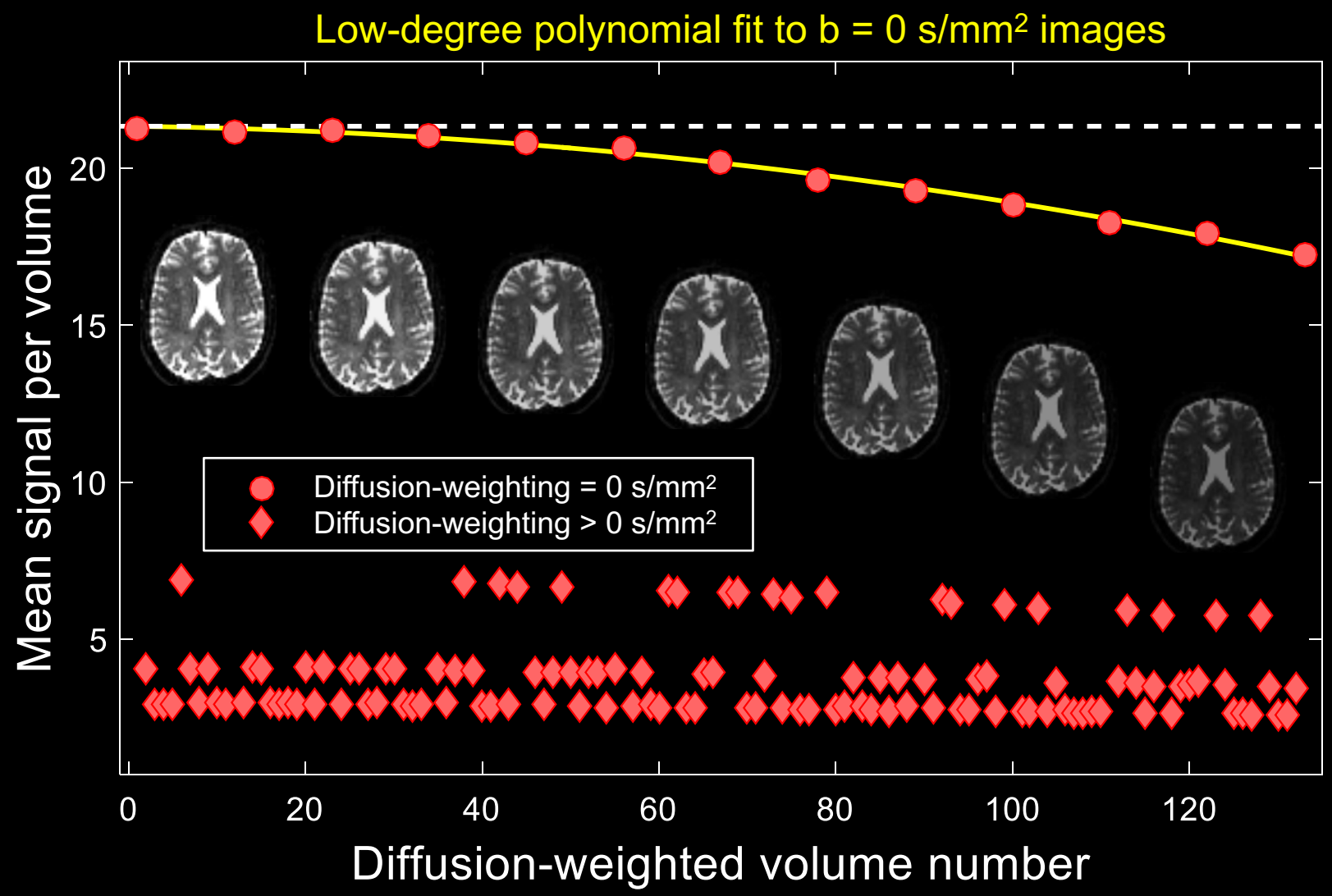
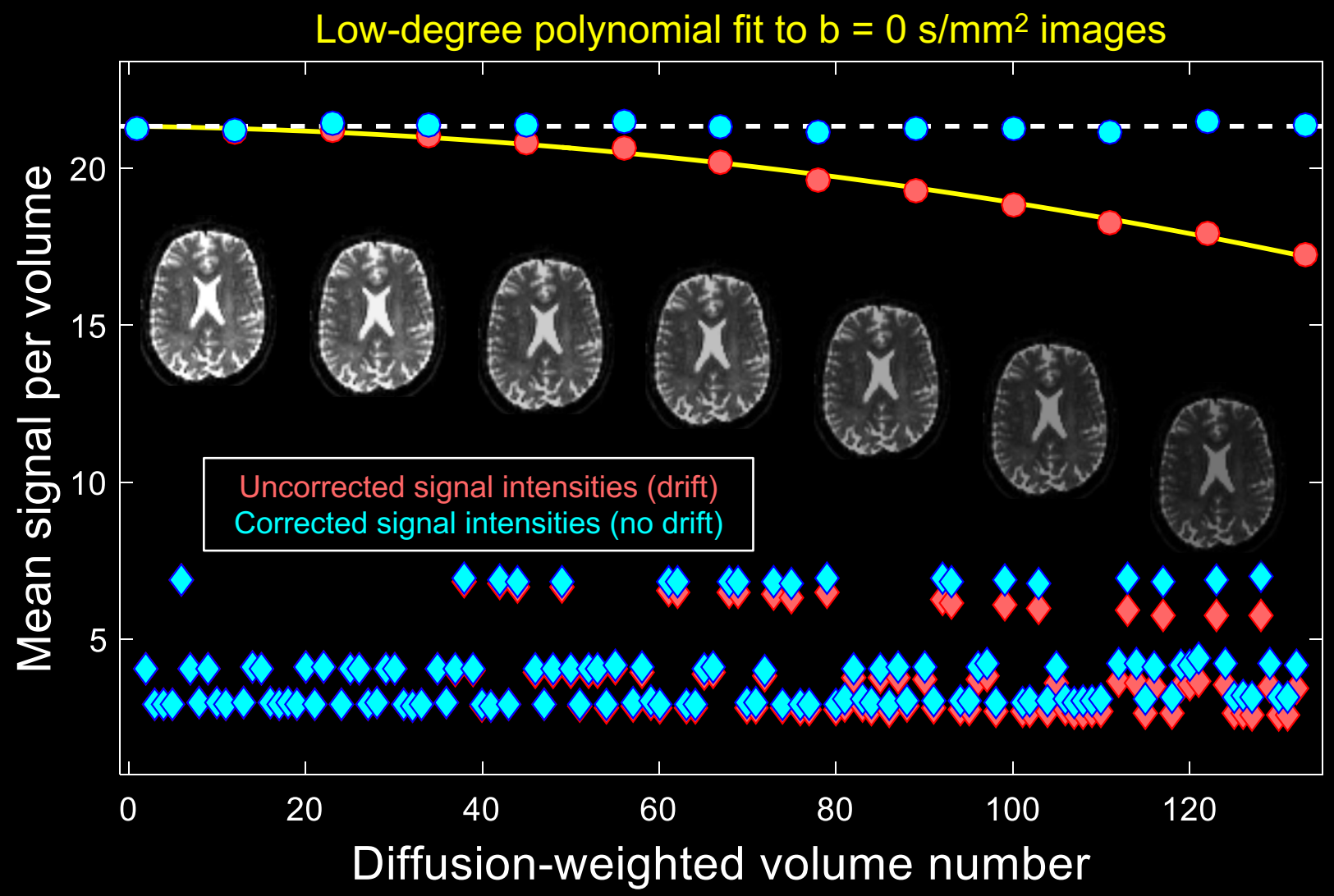
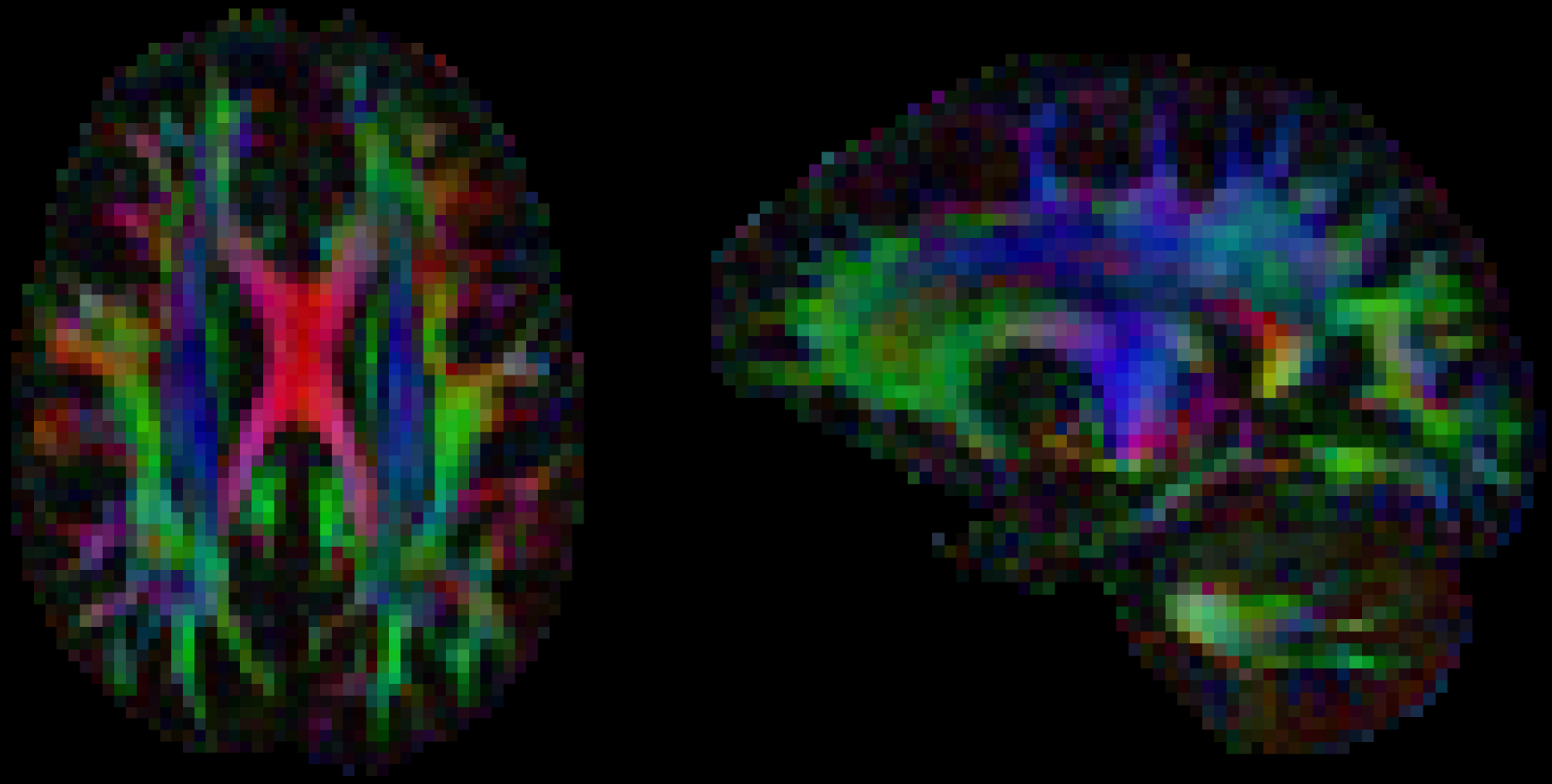
1. Correction for signal intensity drift



1. Correction for signal intensity drift

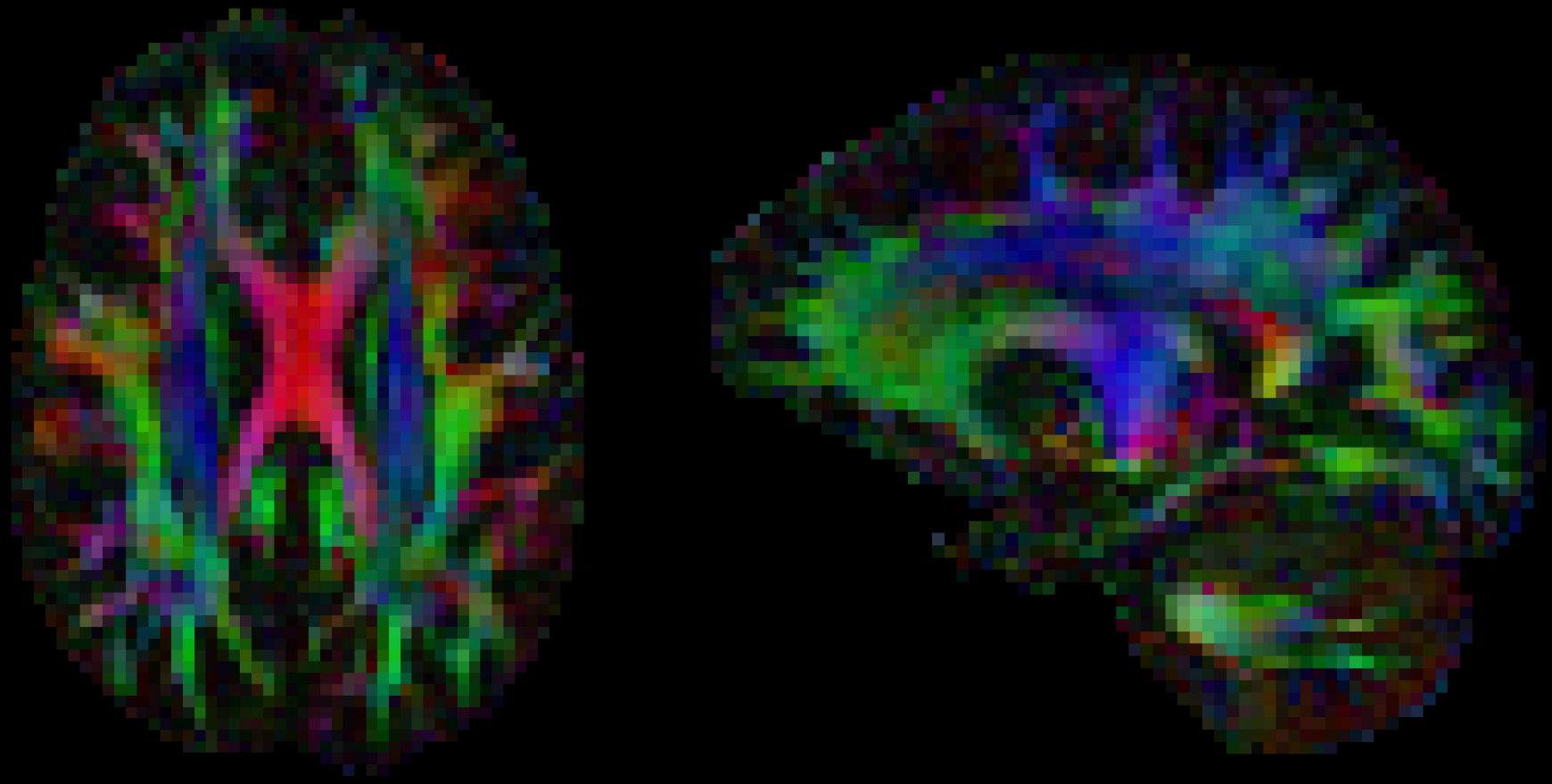


1. Correction for signal intensity drift



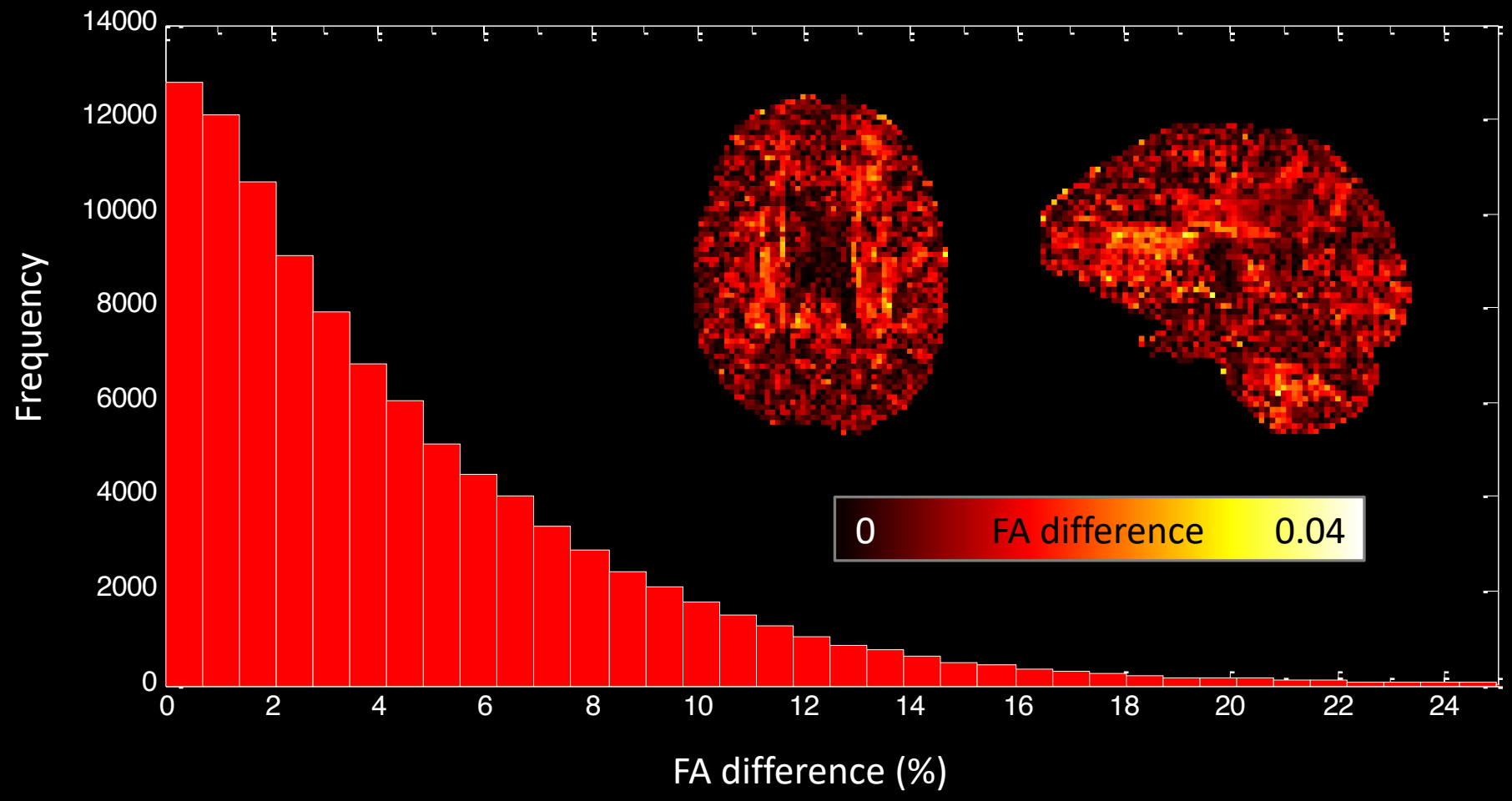
Before correcting for signal intensity drift

1. Correction for signal intensity drift



After correcting for signal intensity drift

1. Correction for signal intensity drift



Vos S.B. et al, Magnetic Resonance in Medicine, 2017

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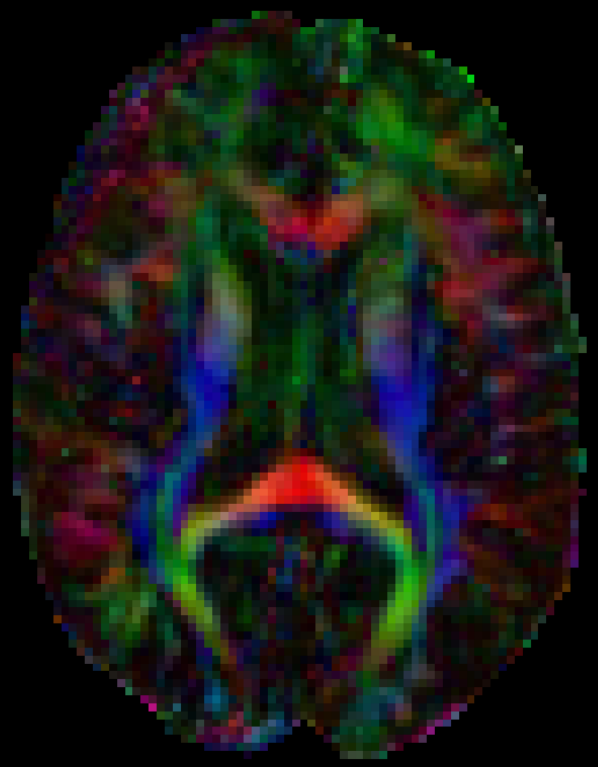
2. Correction for subject motion and eddy current induced distortions

Not corrected for subject motion

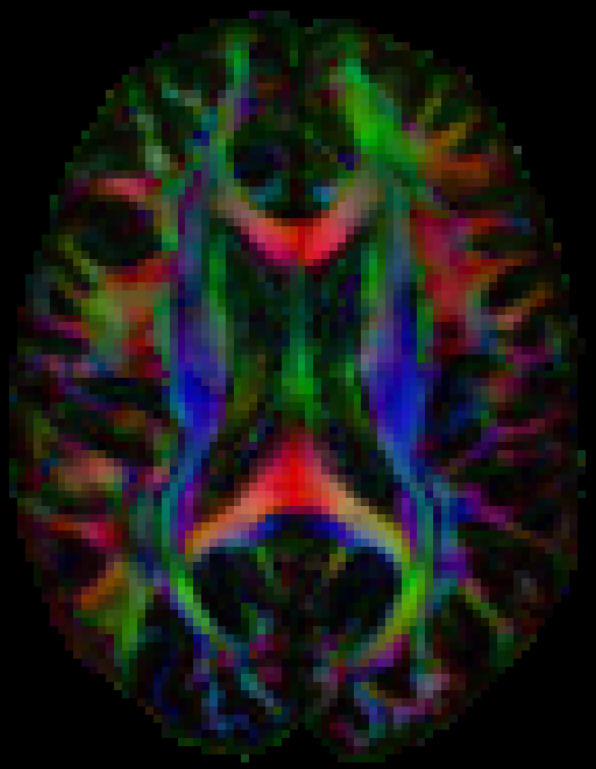


Leemans A. & Jones D.K., Magn Reson Med (2009)

@Alex_Leemans

2. Correction for subject motion and eddy current induced distortions

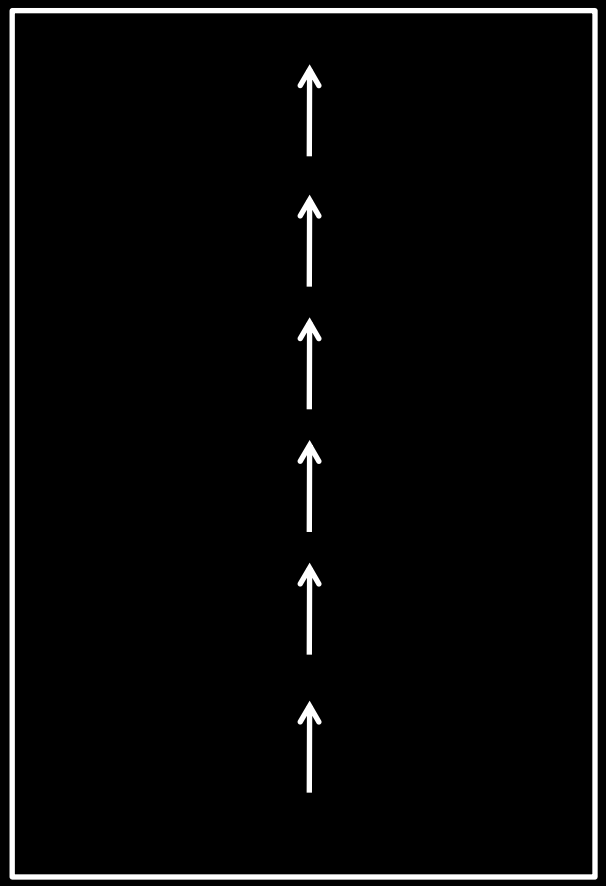
Corrected for subject motion



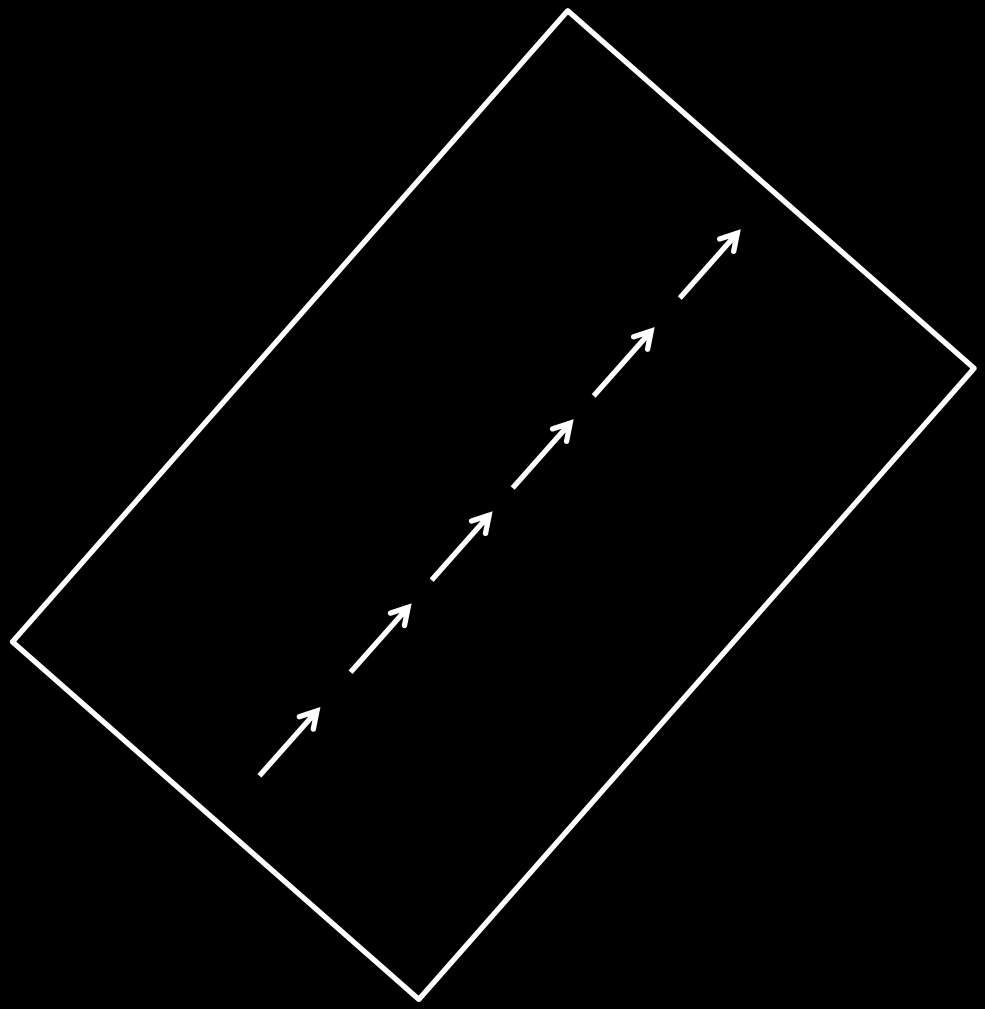
Leemans A. & Jones D.K., Magn Reson Med (2009)

@Alex_Leemans

2. Correction for subject motion and eddy current induced distortions

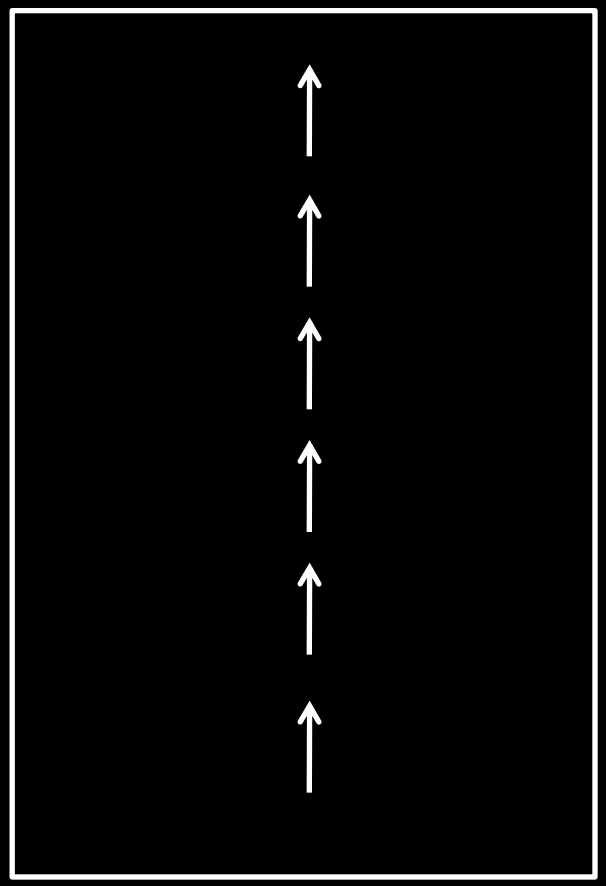


"Reference image"



"Image with subject motion"

2. Correction for subject motion and eddy current induced distortions



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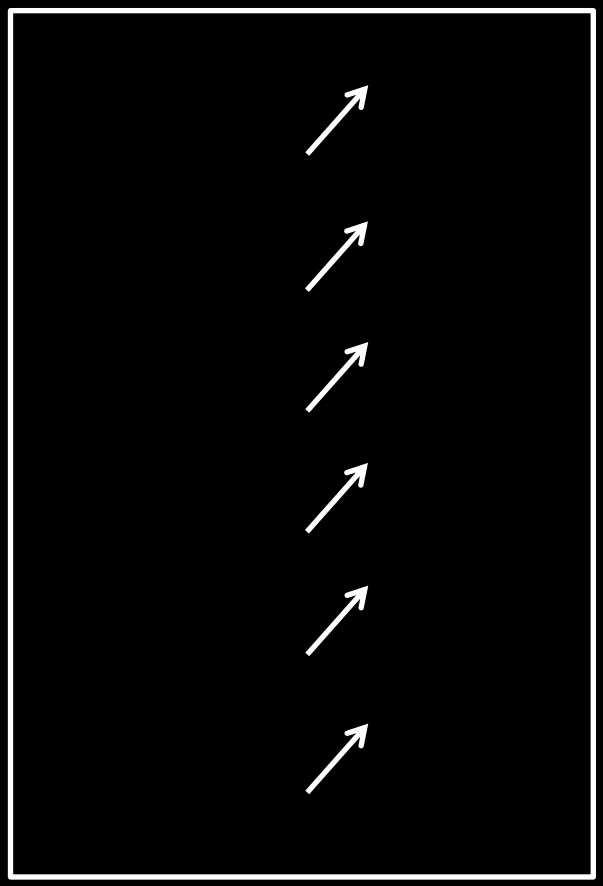
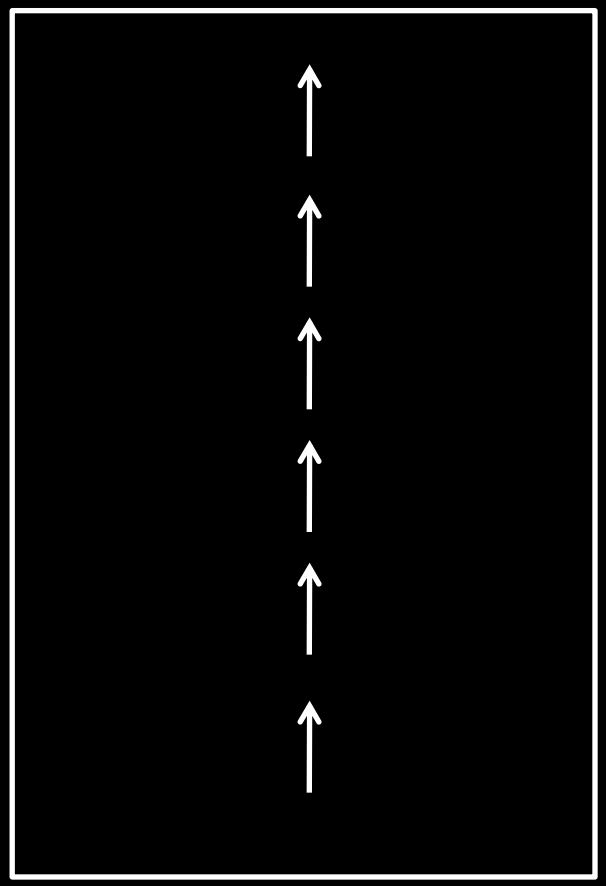


"Corrected image"
(**no** B-matrix rotation)

2. Correction for subject motion and eddy current induced distortions



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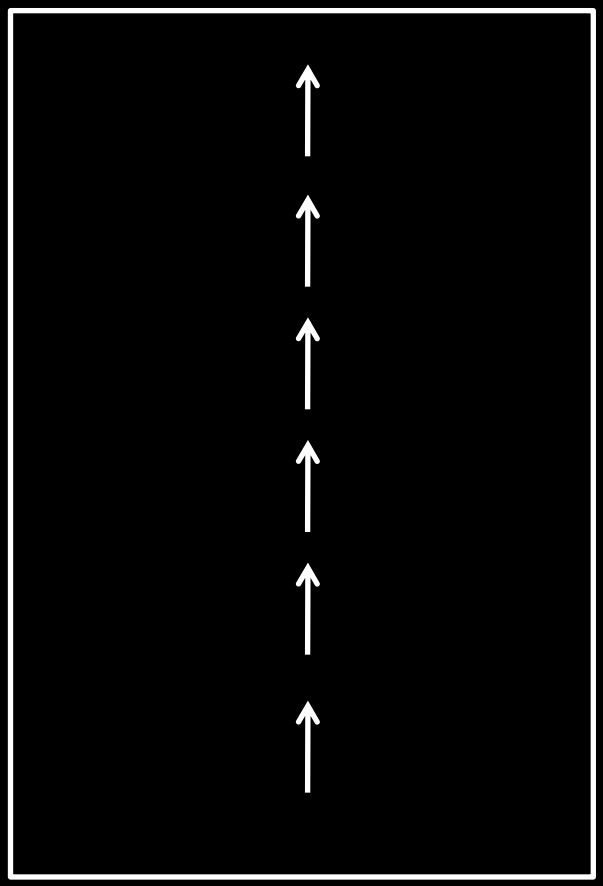
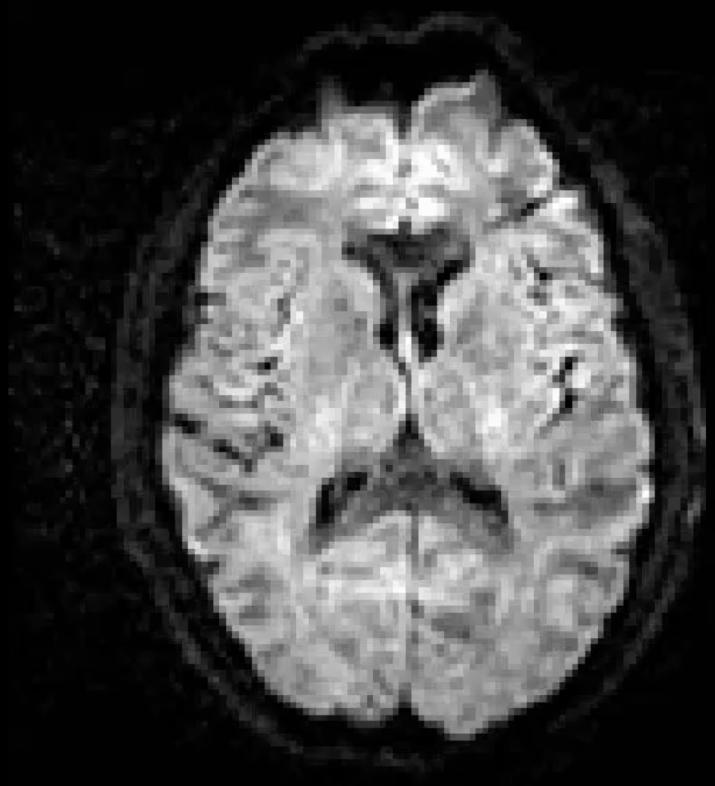
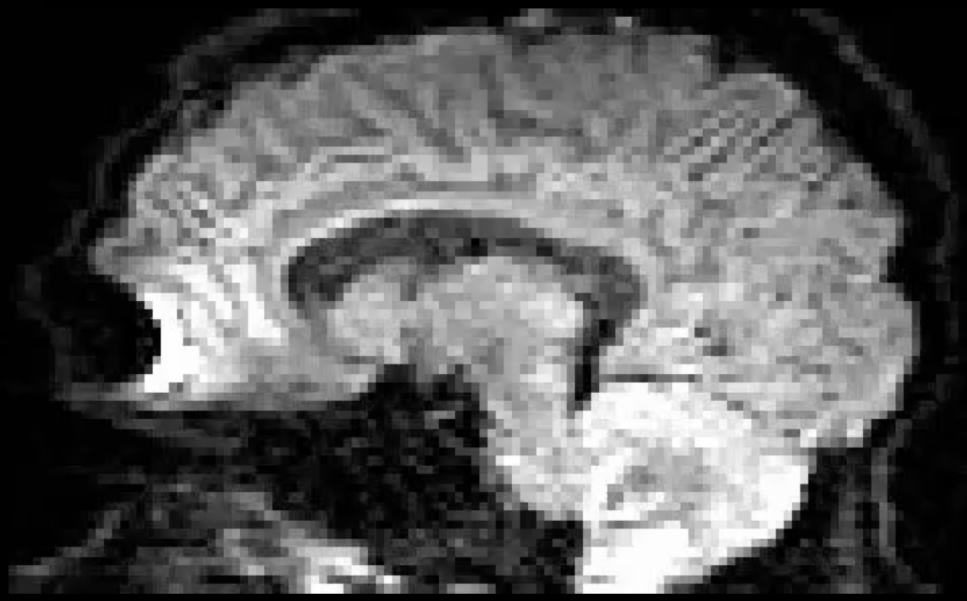


"Corrected image"
(**with** B-matrix rotation)

2. Correction for subject motion and eddy current induced distortions

"Eddy currents"





Leemans A. & Jones D.K., Magn Reson Med (2009)

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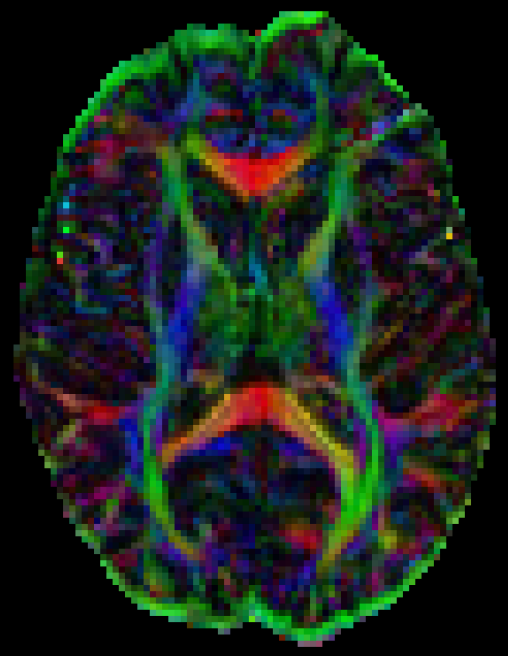
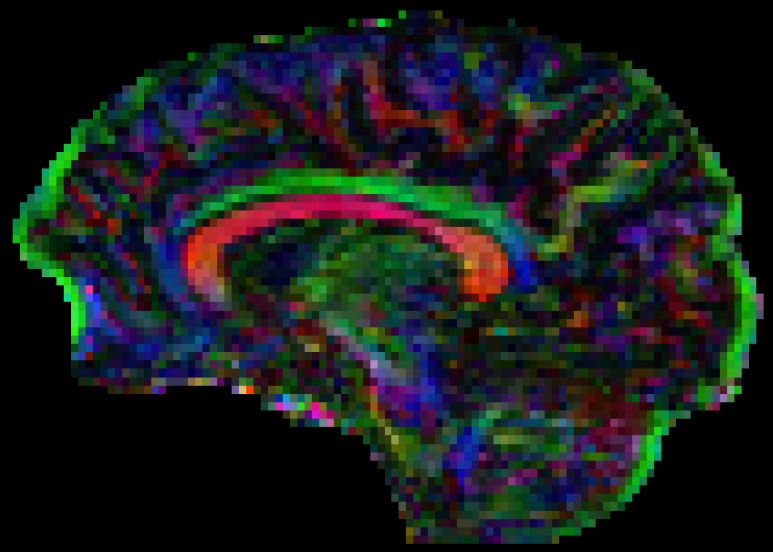
2. Correction for subject motion and eddy current induced distortions

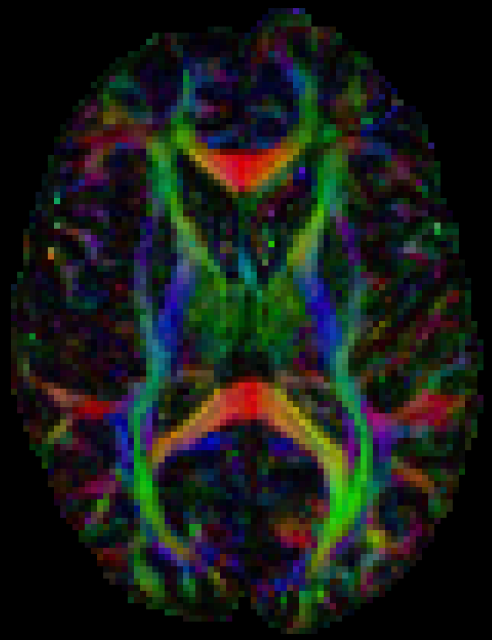
Without eddy currents correction

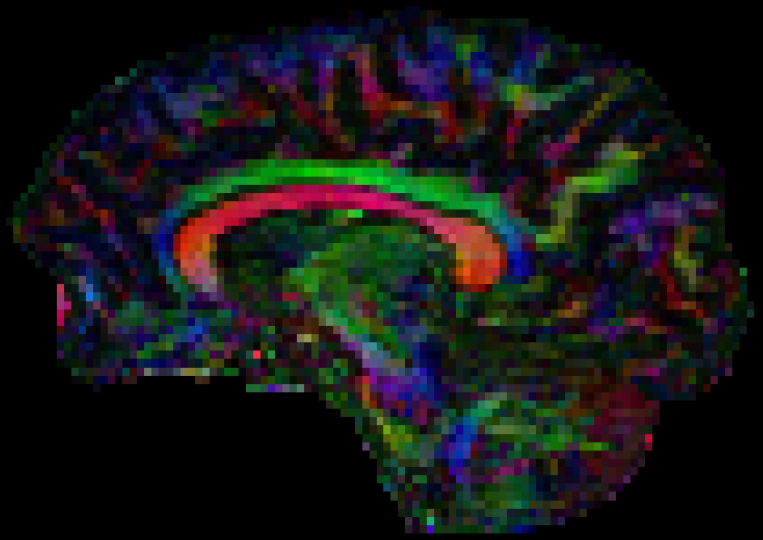




2. Correction for subject motion and eddy current induced distortions

With eddy currents correction





Leemans A. & Jones D.K., Magn Reson Med (2009)

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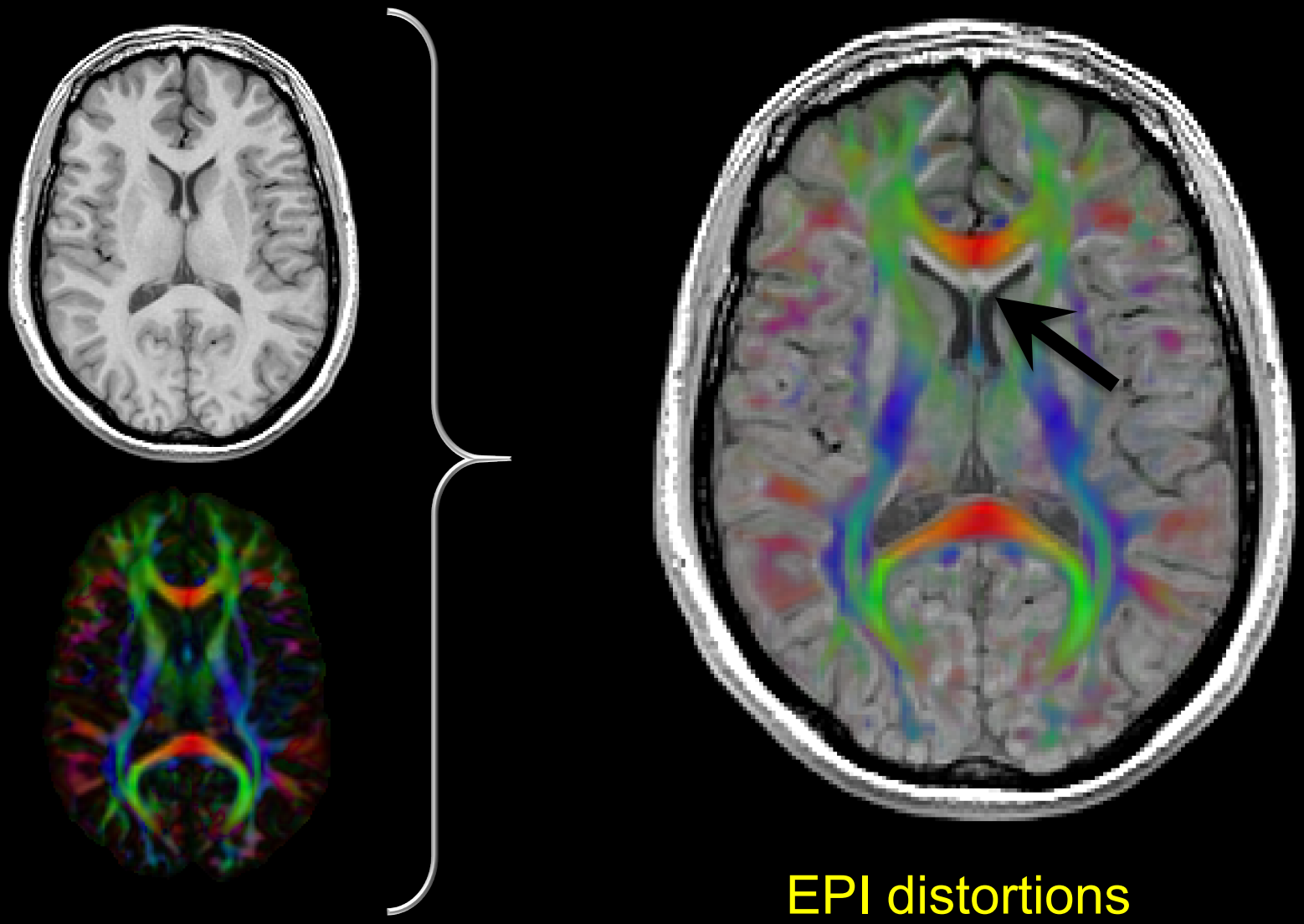
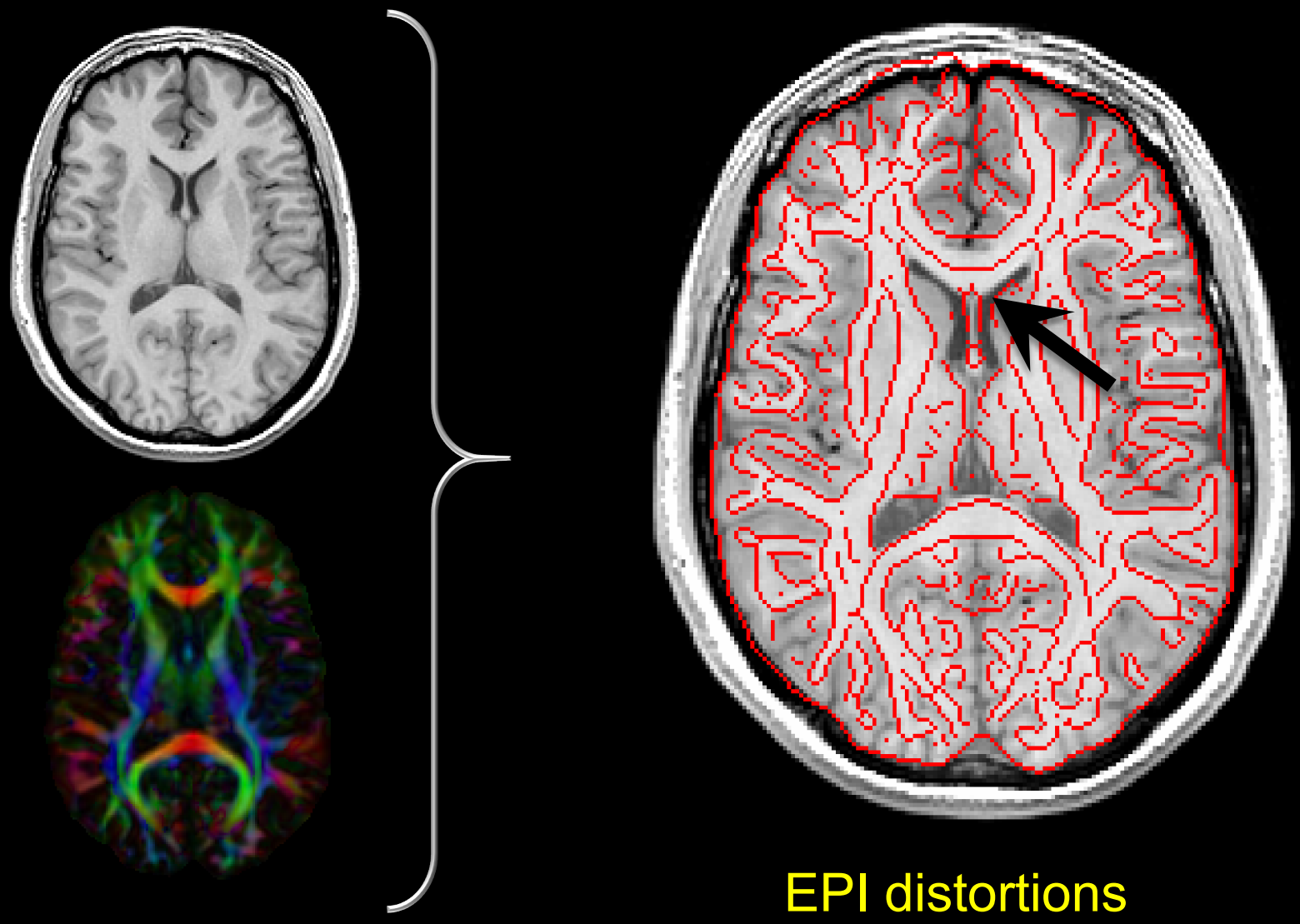
3. Correction for EPI deformations



Huang et al, MRI 2008; Tournier et al, MRM 2011; Irfanoglu et al, NeuroImage 2012

3. Correction for EPI deformations



Huang et al, MRI 2008; Tournier et al, MRM 2011; Irfanoglu et al, NeuroImage 2012

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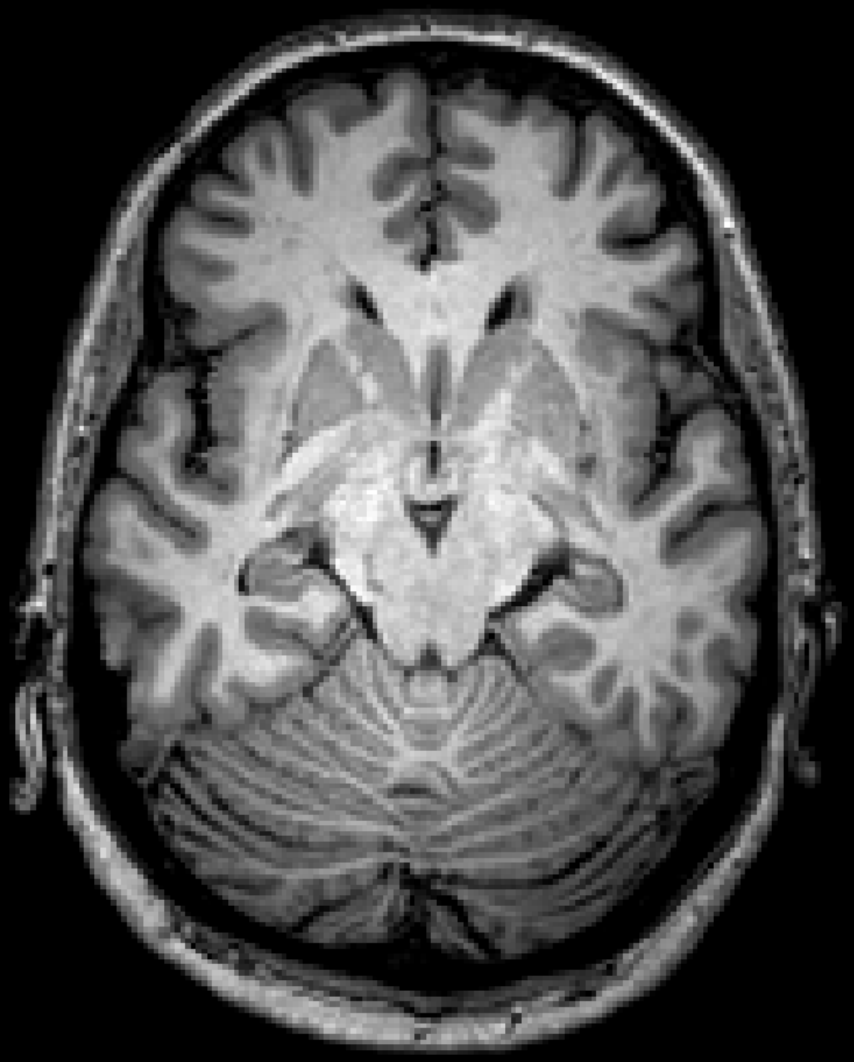
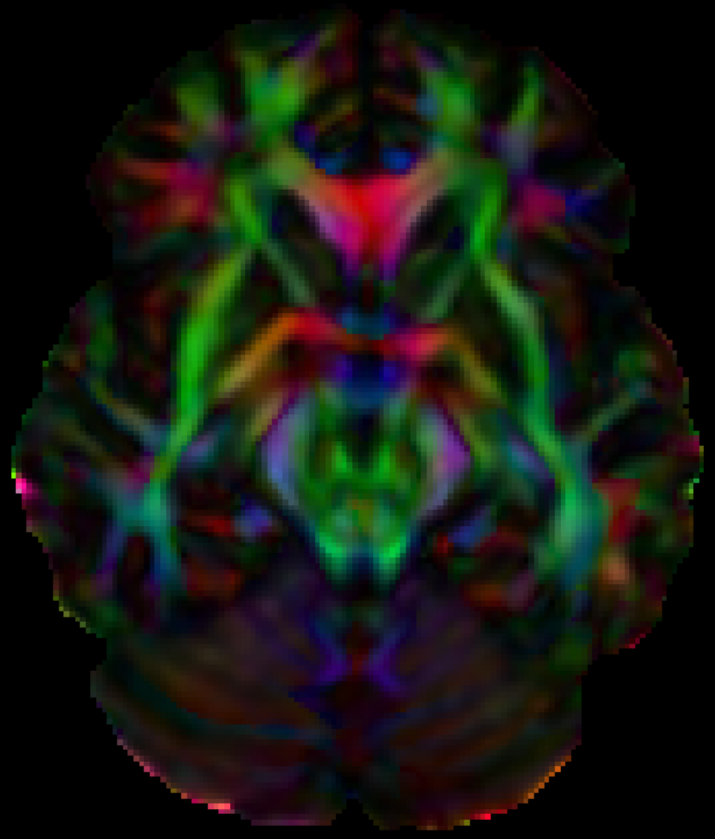
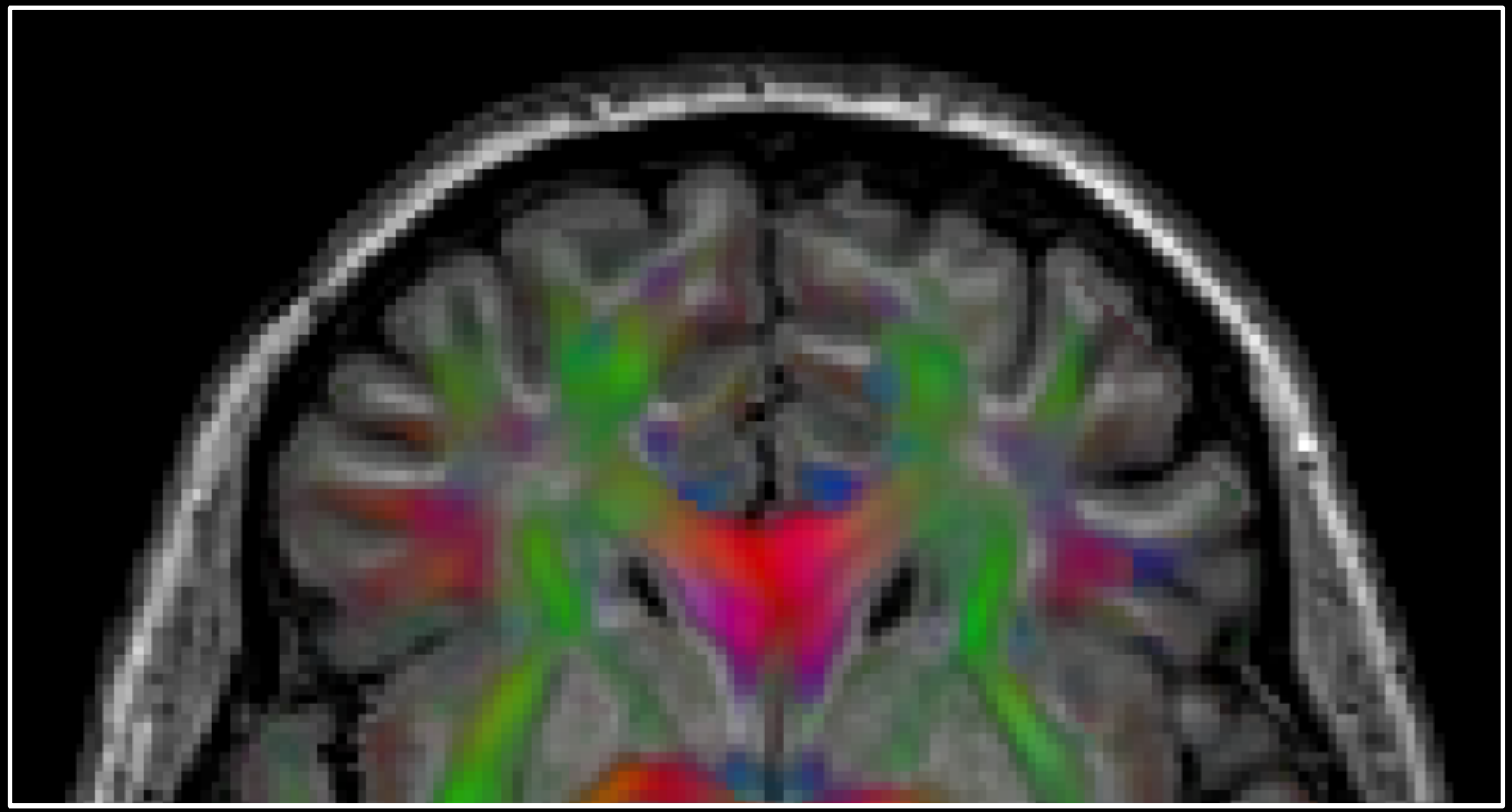
3. Correction for EPI deformations





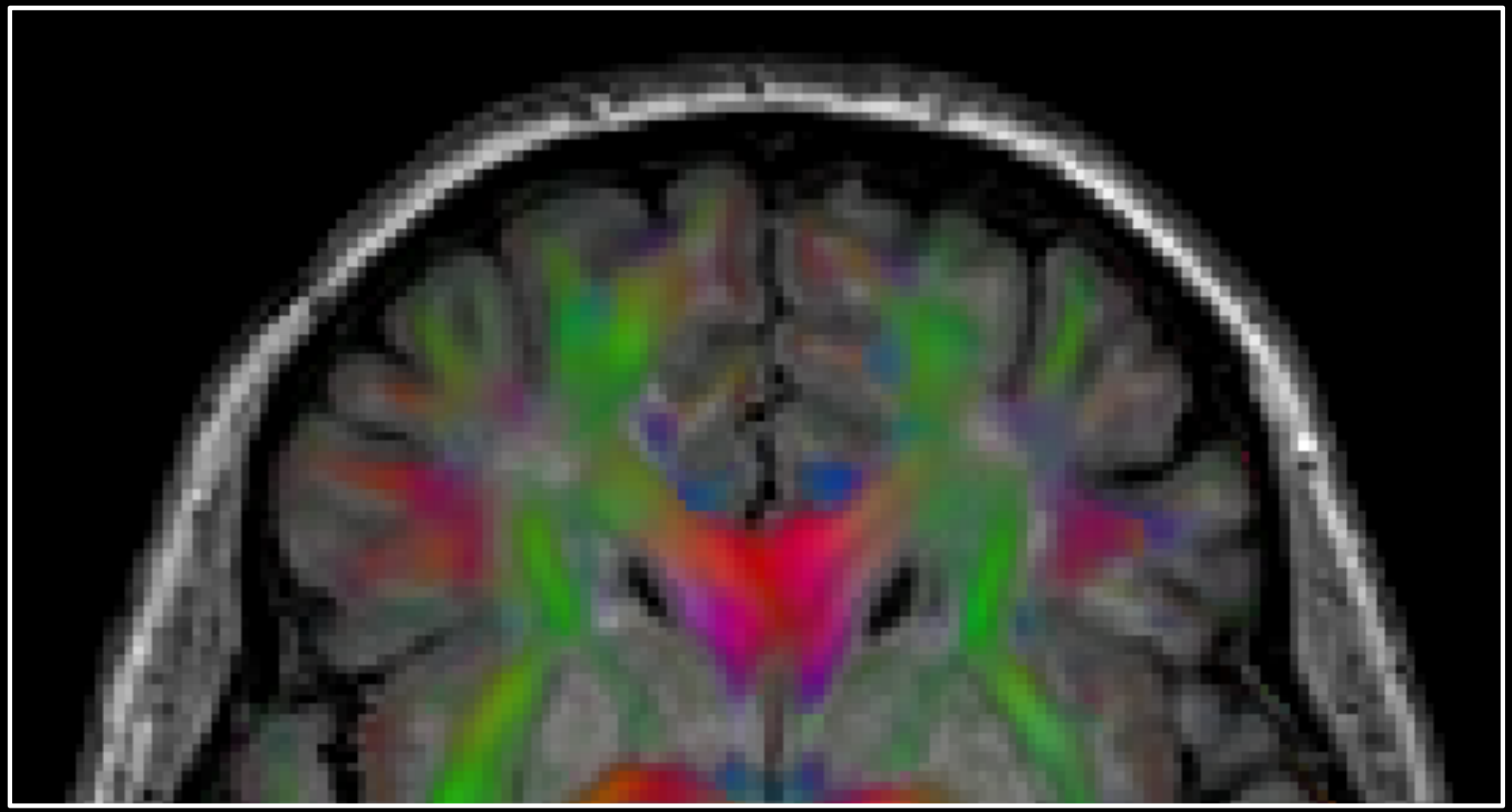
Huang et al, MRI 2008; Tournier et al, MRM 2011; Irfanoglu et al, NeuroImage 2012

3. Correction for EPI deformations



Without EPI distortion correction

3. Correction for EPI deformations



With EPI distortion correction

Huang et al, MRI 2008; Tournier et al, MRM 2011; Irfanoglu et al, NeuroImage 2012

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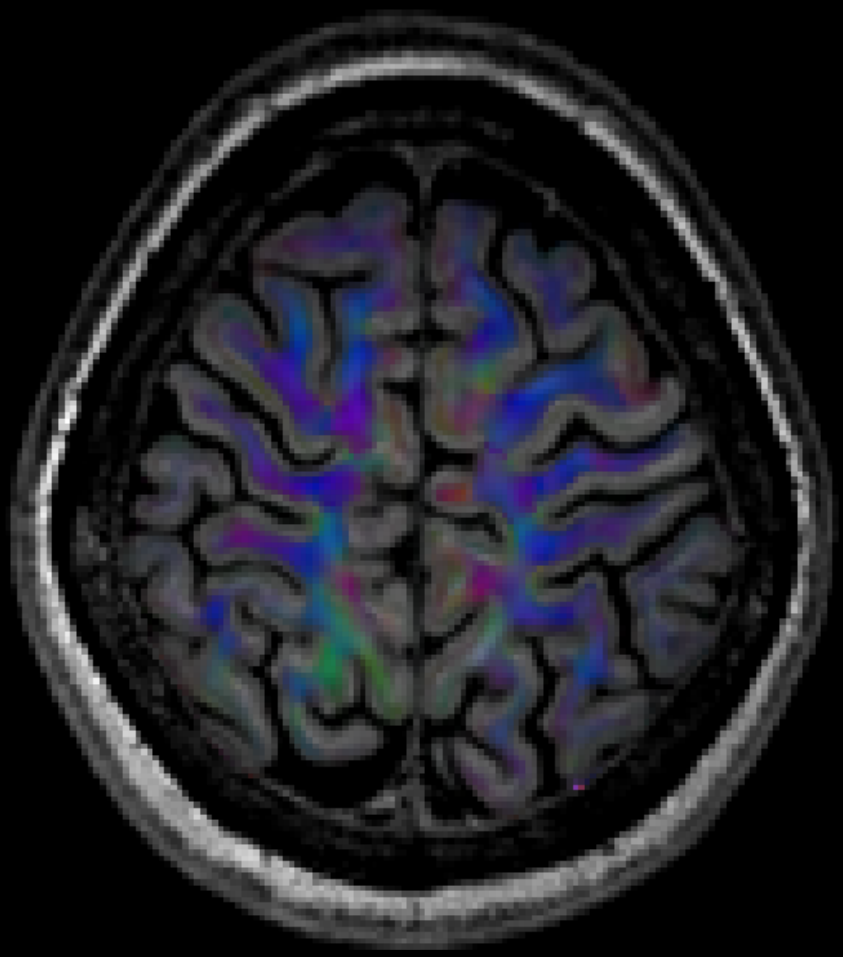
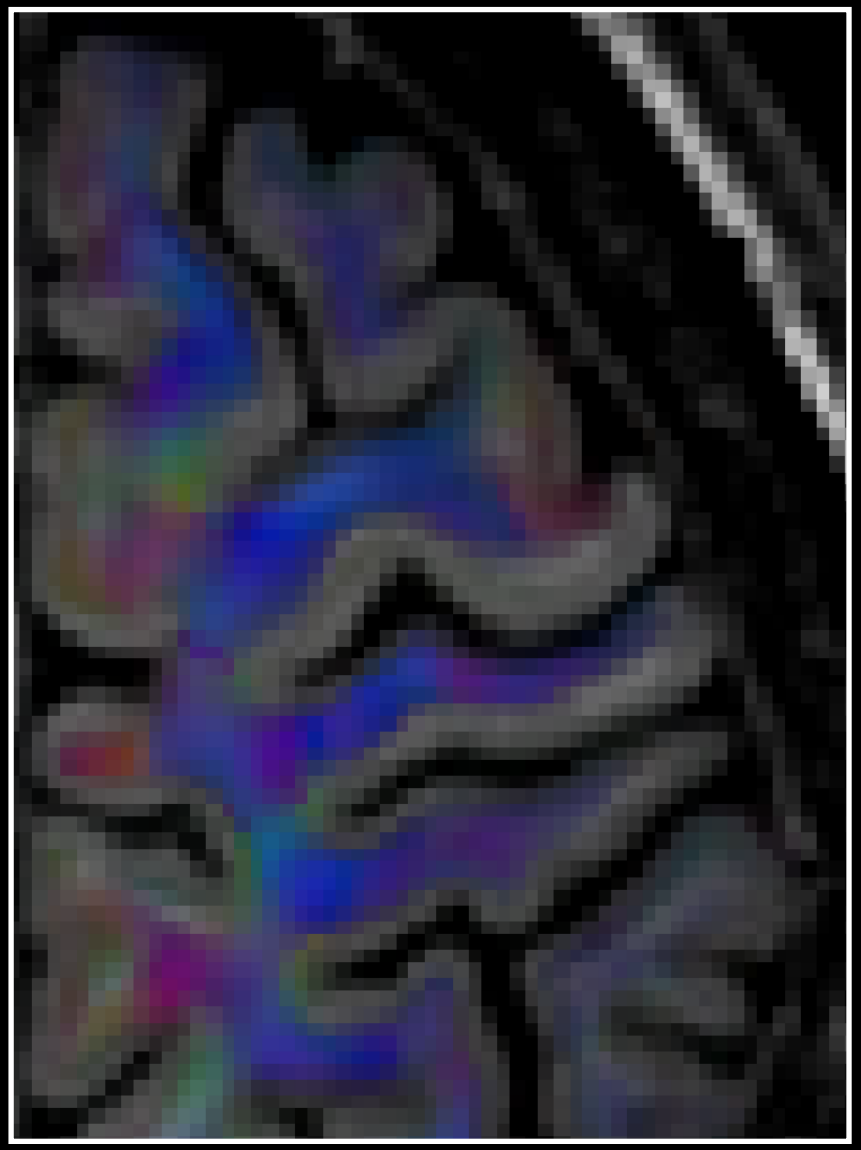
3. Correction for EPI deformations





Without EPI distortion correction

Huang et al, MRI 2008; Tournier et al, MRM 2011; Irfanoglu et al, NeuroImage 2012

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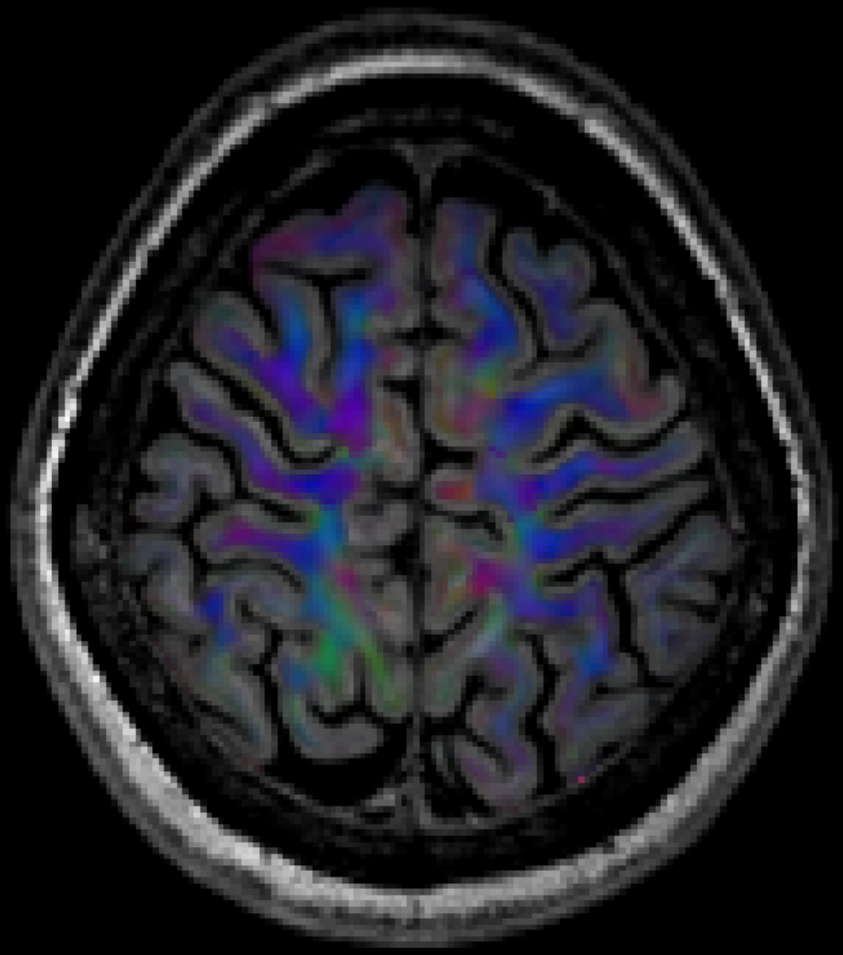
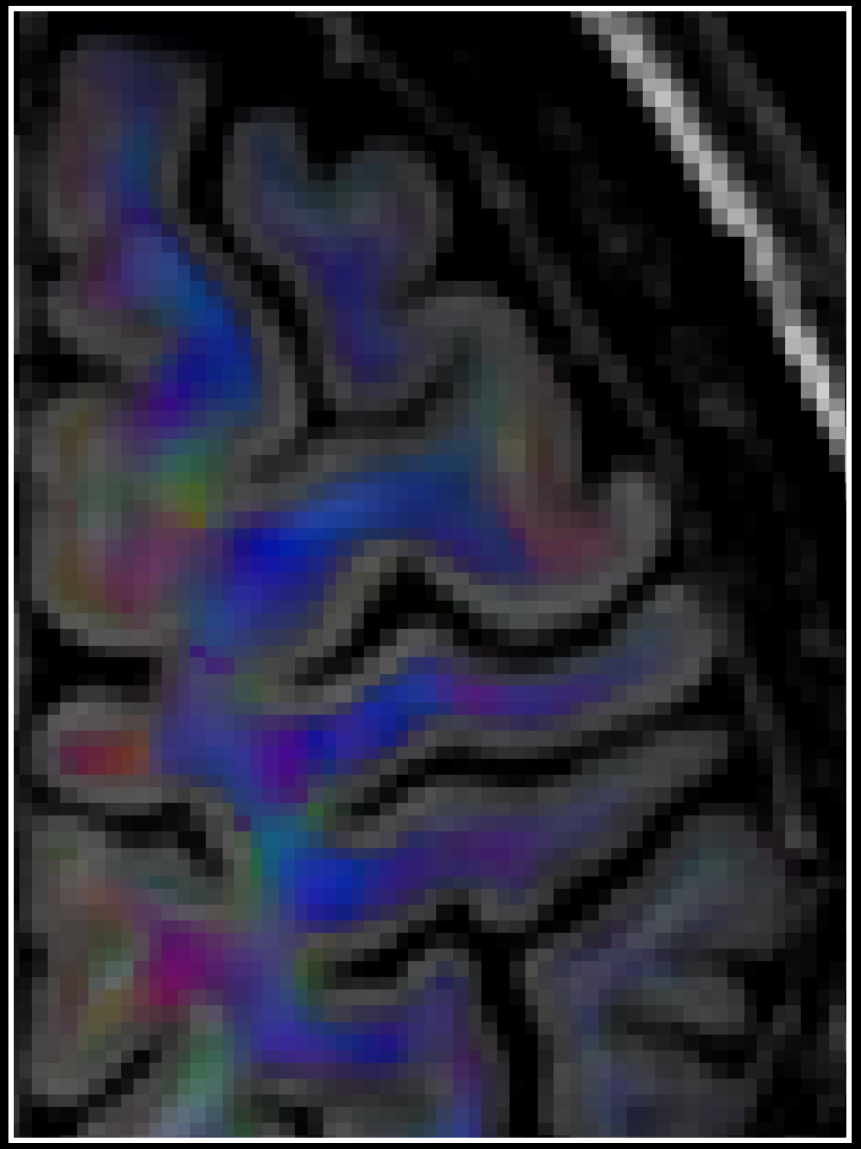
3. Correction for EPI deformations

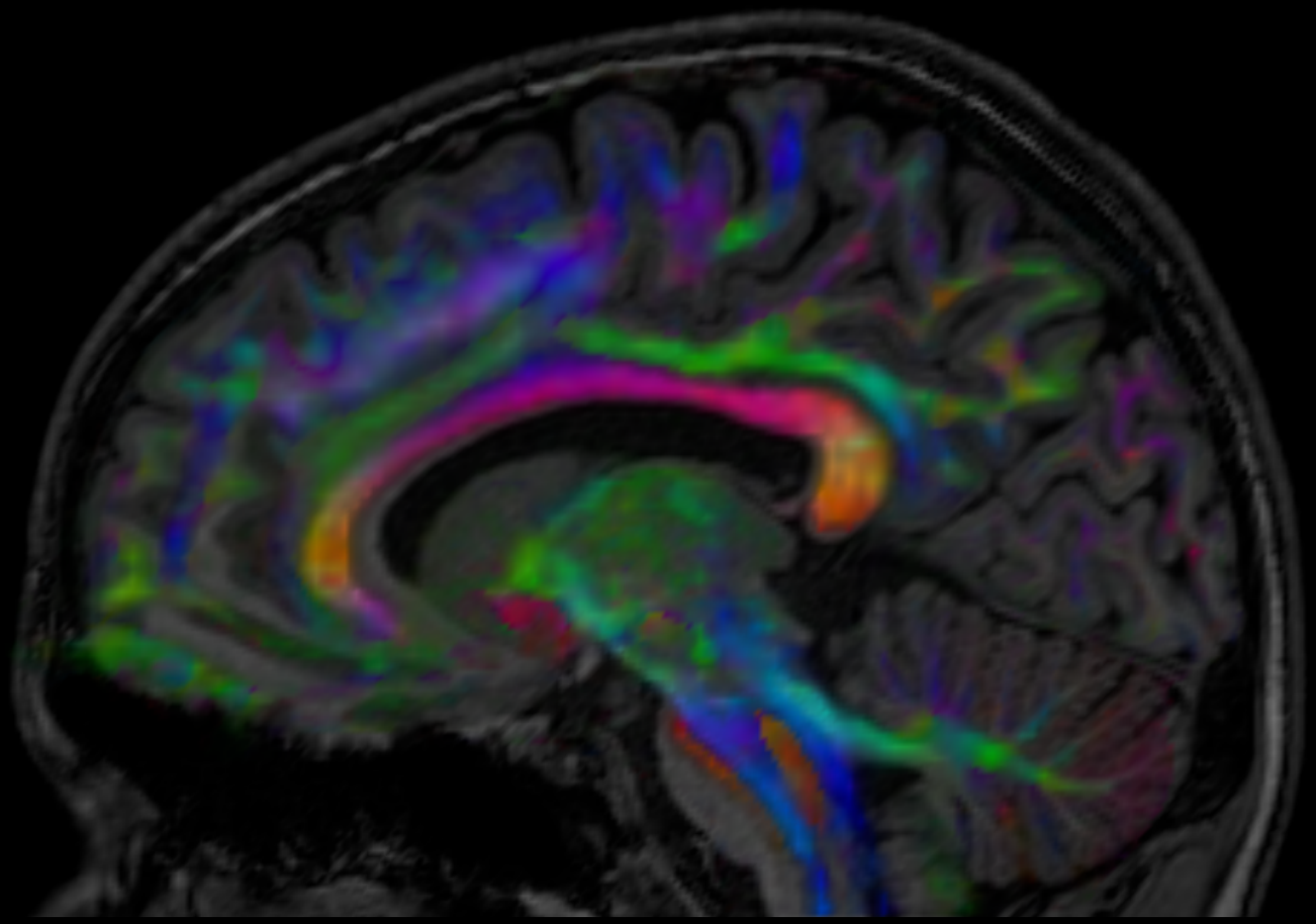


With EPI distortion correction



Huang et al, MRI 2008; Tournier et al, MRM 2011; Irfanoglu et al, NeuroImage 2012

3. Correction for EPI deformations



Without EPI distortion correction

Huang et al, MRI 2008; Tournier et al, MRM 2011; Irfanoglu et al, NeuroImage 2012

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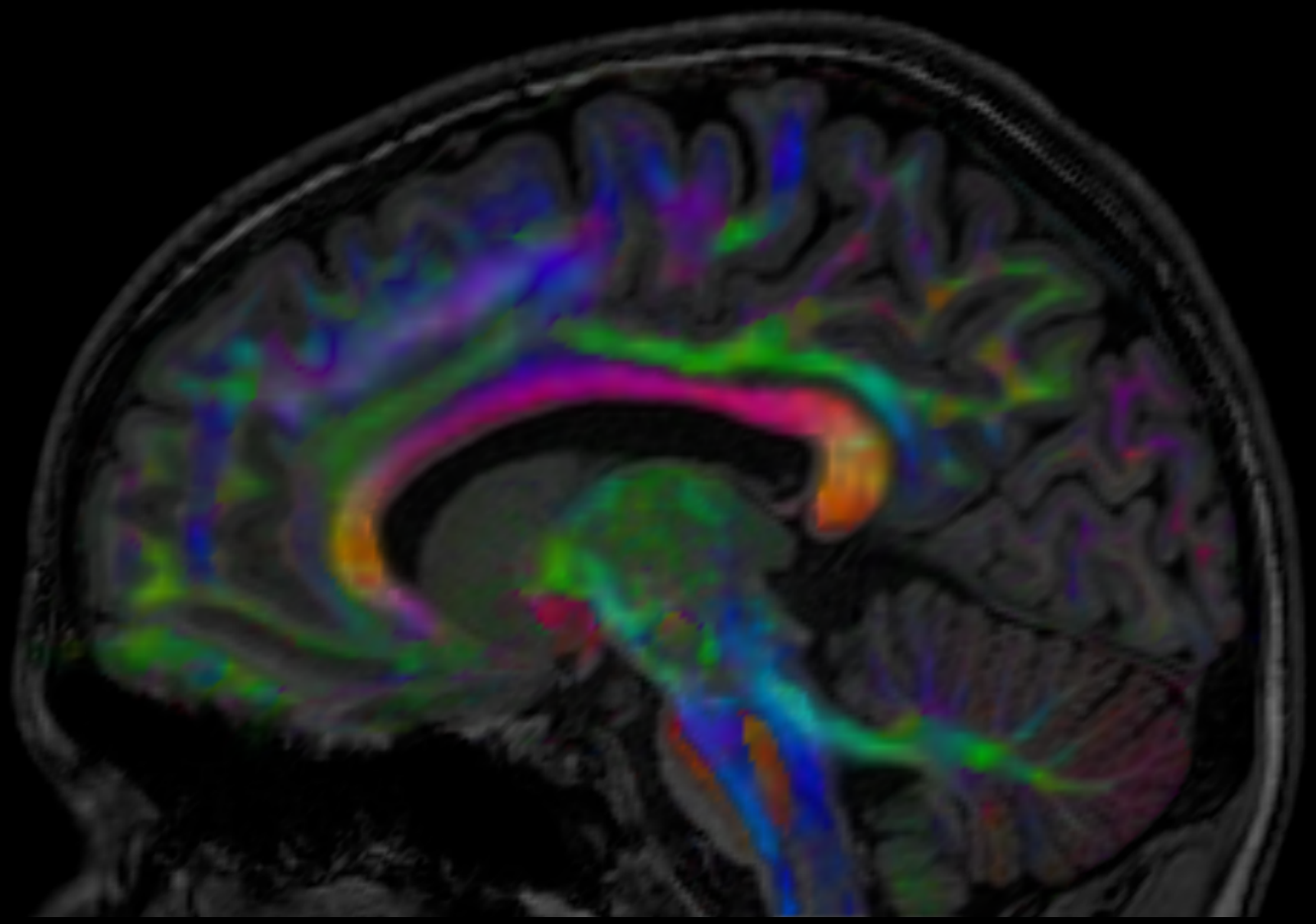
3. Correction for EPI deformations



With EPI distortion correction

Huang et al, MRI 2008; Tournier et al, MRM 2011; Irfanoglu et al, NeuroImage 2012

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Correction for combined subject motion + EC + EPI distortions

NeuroImage 171 (2018) 277–295

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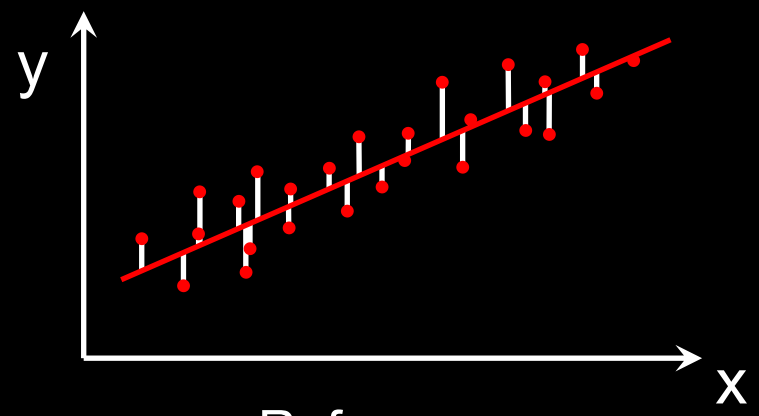
Susceptibility-induced distortion that varies due to motion: Correction in diffusion MR without acquiring additional data

Jesper L.R. Andersson [a,*], Mark S. Graham [b], Ivana Drobnjak [b], Hui Zhang [b], Jon Campbell [a]

[a] FMRIB, Wellcome Centre for Integrative Neuroimaging, Nuffield Department of Clinical Neurosciences, University of Oxford, Oxford, United Kingdom
[b] Centre for Medical Image Computing & Department of Computer Science, University College London, London, United Kingdom

4. Diffusion model estimation approaches



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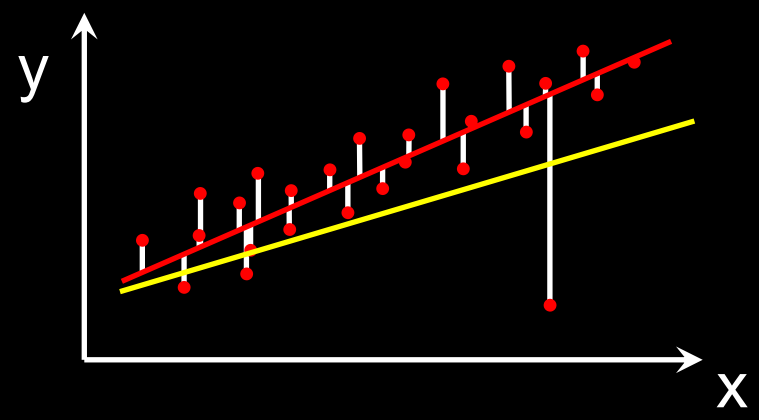
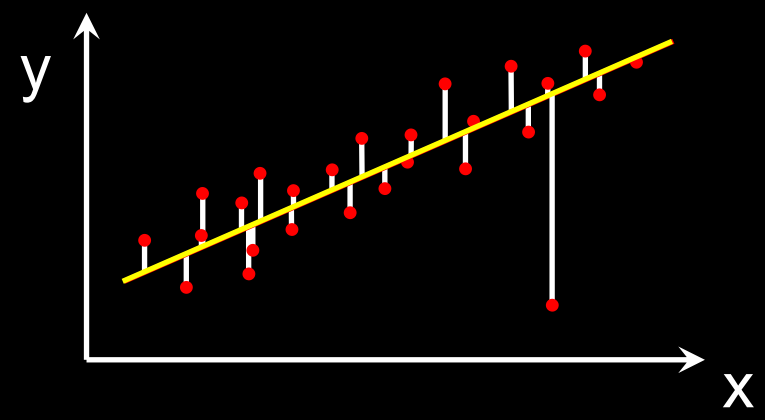
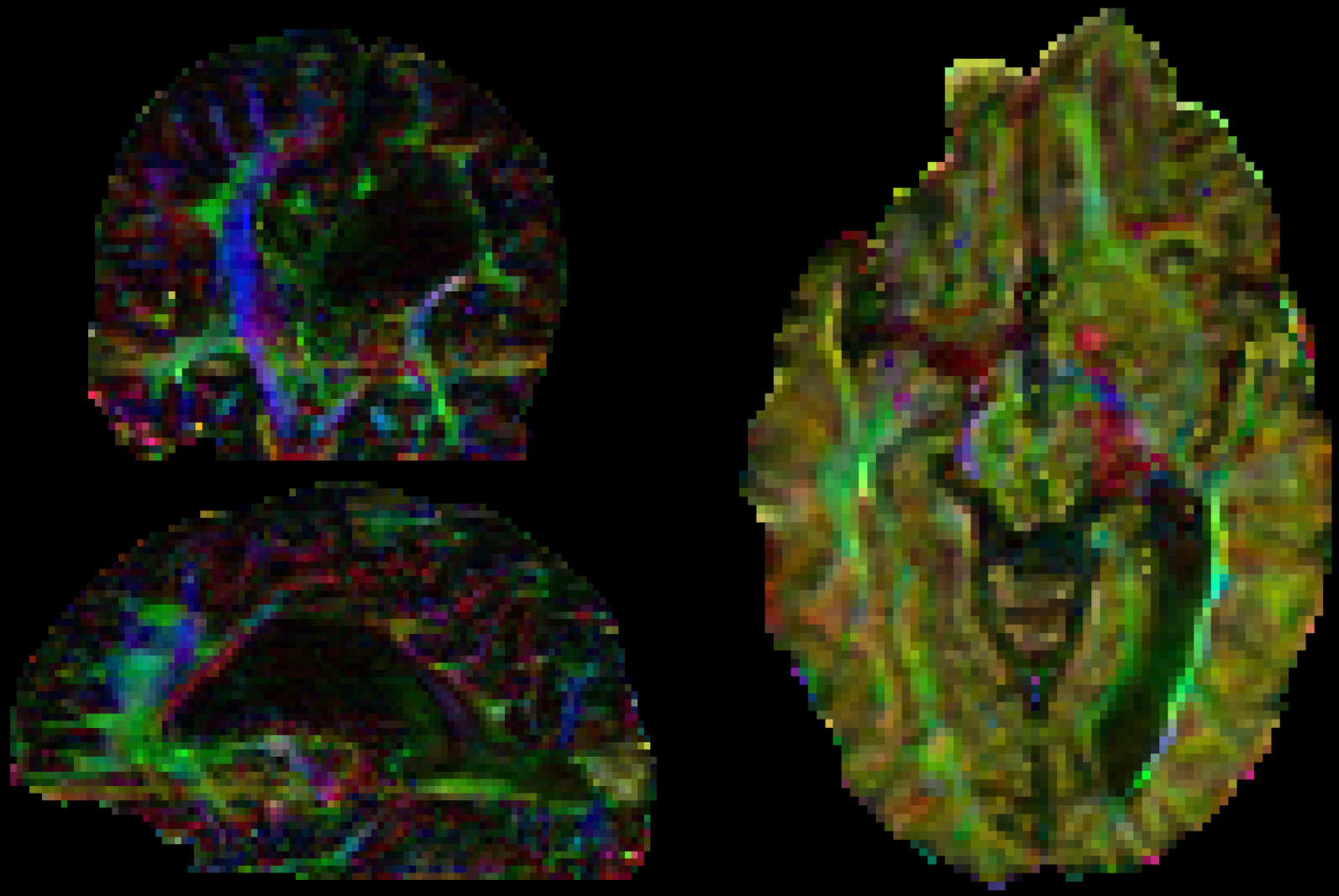


Ordinary least squares estimation



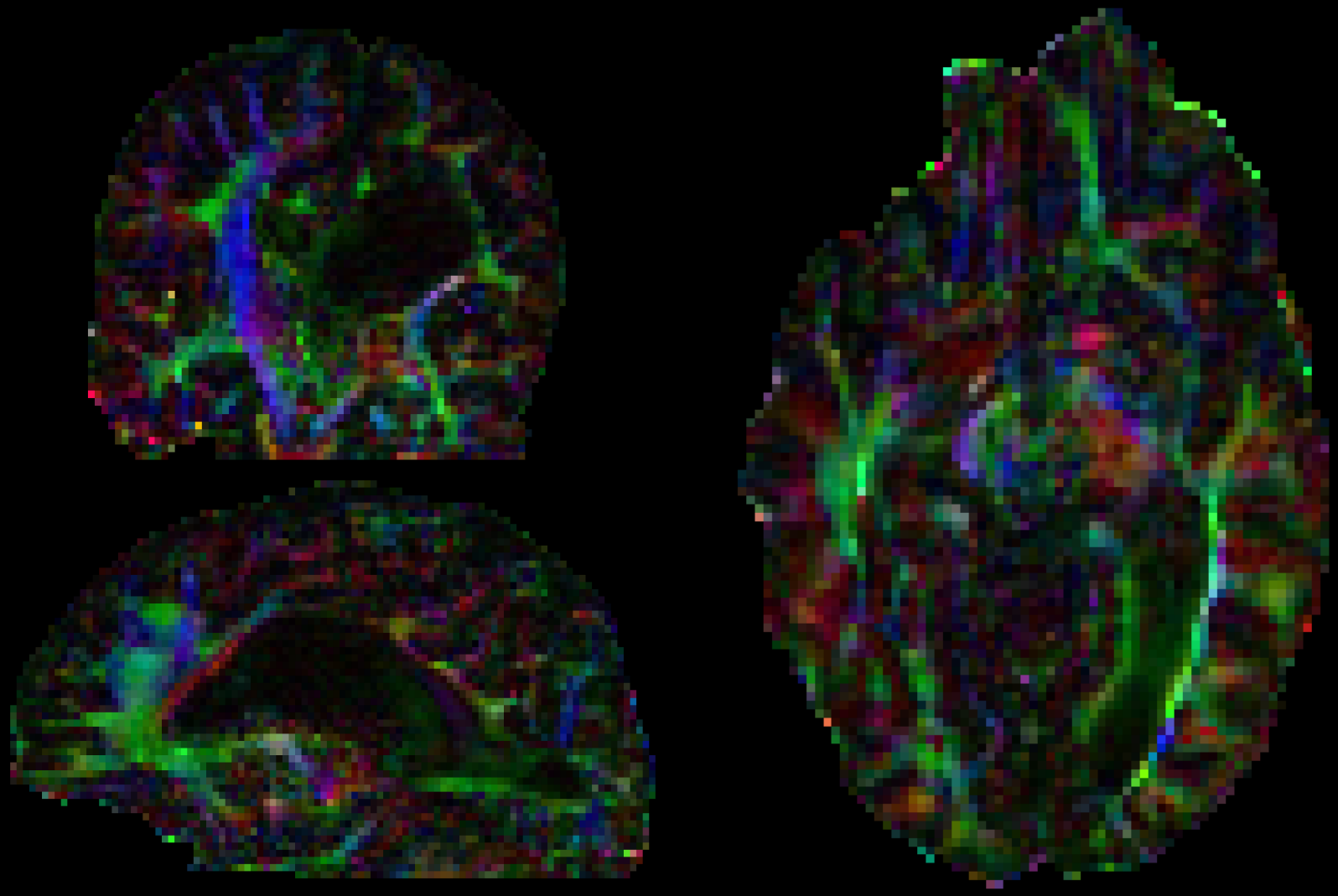
Robust estimation

4. Diffusion model estimation approaches



Ordinary least squares estimation

4. Diffusion model estimation approaches



Robust estimation

Acknowledgements

www.ExploreDTI.com

9-11 December in Costa Rica!

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Niek van der Aa
Yael Reijmer
Martijn Froeling
Karen Caeyenberghs

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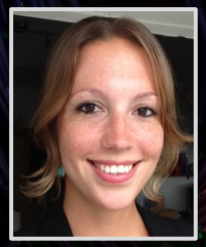
J. Kok


H.M. Hulshof


H. Mesri


S. Dávid


O. Odish


E. O'Hanlon

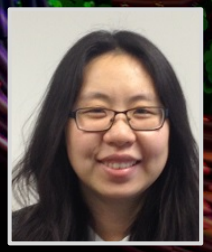

I. Vos


E. Christiaanse


B. Robalo


D. Aquino

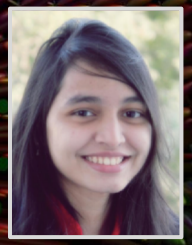

A. De Luca


F. Guo


U. Roine


S. St-Jean


A. Van Rijn

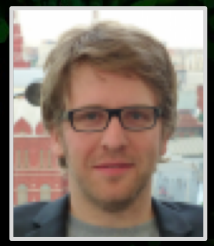

S. Ishrat


A. Zhylka

Alumni who moved on to bigger & better…


W. Haakma


W. Van Hecke


B. Jeurissen

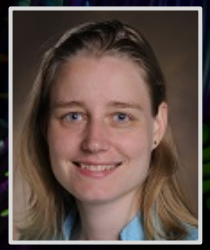

S.B. Vos


J.-L. Hsu


J. Gooijers


C.M.W. Tax


D. Perrone


A. Heemskerk


T. Roine

Thank you for your attention!