Donders Institute
for Brain, Cognition and Behaviour

OHBM
SEATTLE 2013

m.kleinnijenhuis@donders.ru.nl

Detailed laminar characteristics of the human neocortex revealed by NODDI and histology

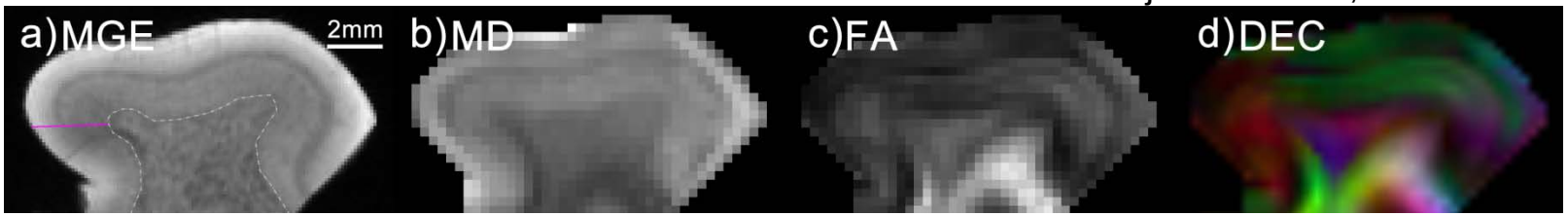
Donders Institute, Nijmegen, NL ---------- Michiel Kleinnijenhuis
University College Londen, UK ---------- Hui Zhang
Max Planck Institute, Cologne, D ---------- Dirk Wiedermann
UMC St. Radboud, Nijmegen, NL ---------- Benno Küsters
UMC St. Radboud, Nijmegen, NL -- Anne-Marie van Cappellen van Walsum
Donders Institute, Nijmegen, NL ---------- David Norris

Radboud University Nijmegen Medical Centre

Towards in vivo cytoarchitecture

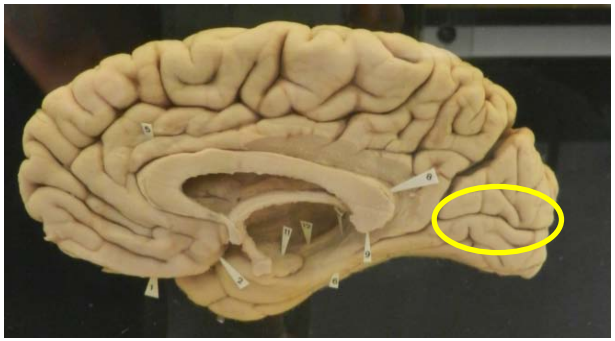
- Diffusion can be used as structural probe
- Tensor metrics vary over cortical layers

Kleinnijenhuis et al., Cortex 2012



- Extension to multishell

Samples of human V1



- post-mortem interval (< 24 h)
- fixed in formalin (> 1 month)
- 1 cm^3 calcarine sulcus (V1)

- soaked in phosphate buffered saline (> 72 h)
- scanned in proton-free liquid

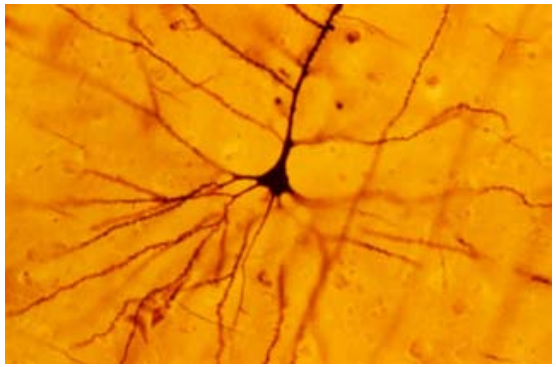
Diffusion Weighted Imaging

- System:
  - 9.4T Bruker BioSpec; G_{max} = 660 mT/m
  - cryogenic mouse brain coil (20-30 K)
- PGSE with segmented EPI readout
- TR/TE = 6750/26 ms
- 0.2 mm isotropic voxels
- 8 shells x 384 (sample A) / 54 directions (sample B)
  - b = [0 1000 3000 4000 8000 12000 16000 20000] smm^{-2}
  - δ/Δ = 8/12 ms

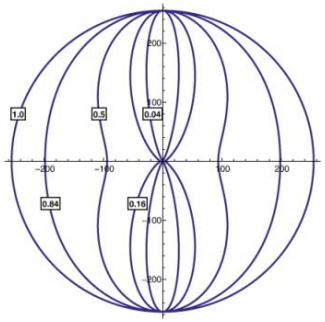
Neurite Orientation Dispersion and Density Imaging

- NODDI multicompartment tissue model (Zhang et al., NI 2012)

  1. neurite volume fraction
  2. extra-cellular volume fraction
  3. isotropic volume fraction
  4. isotropic restriction compartment
     ➔ ex vivo only (Alexander et al, 2010)



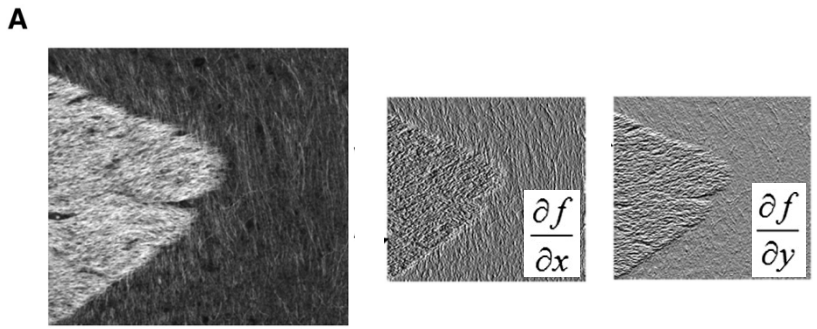
  – Watson distribution
     ➔ mean orientation **μ** and concentration **κ**
     ➔ modeling WM & GM

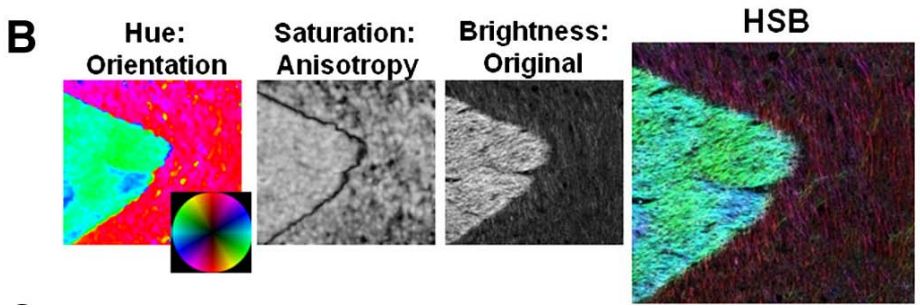


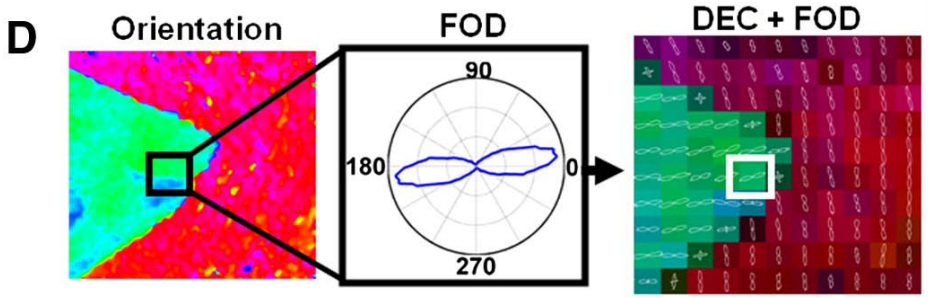
Histology

- Samples bisected and embedded in parafin
- Stains on consecutive 5 µm sections:
  - Hematoxylin & Eosin (cell bodies)
  - Luxol Fast Blue (myelin)
  - Bodian (axons)

- Structure tensor analysis (Budde and Frank, 2012)





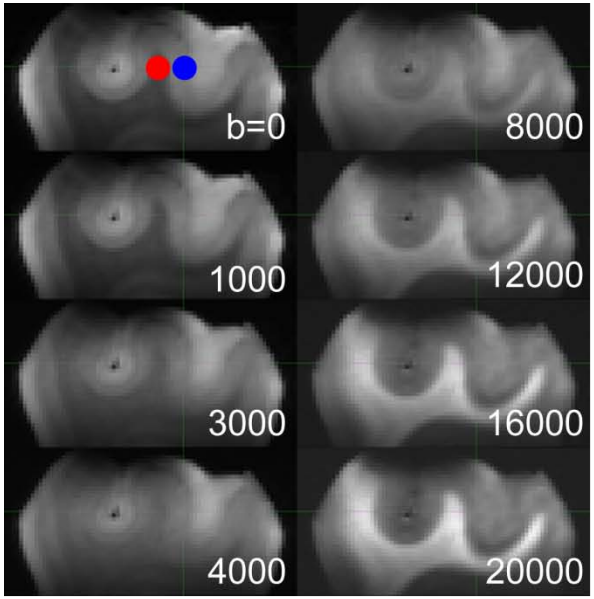


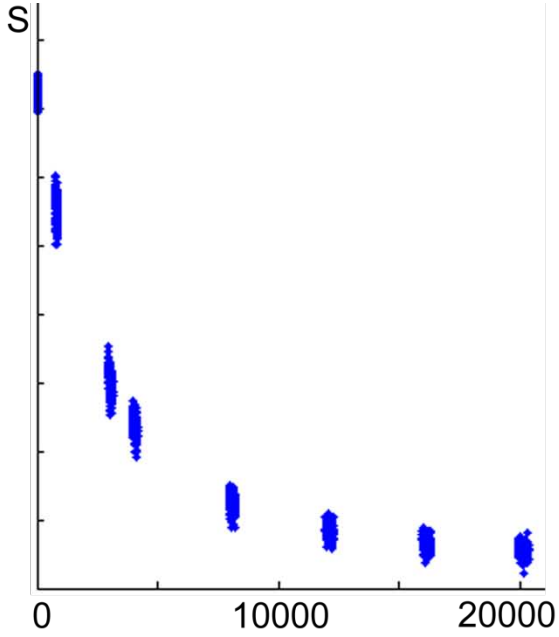
Data impression

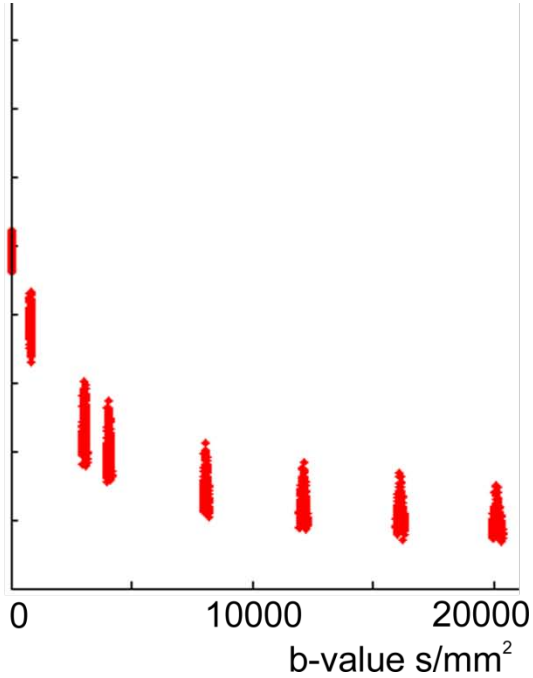
Normalized shell means

GM voxel

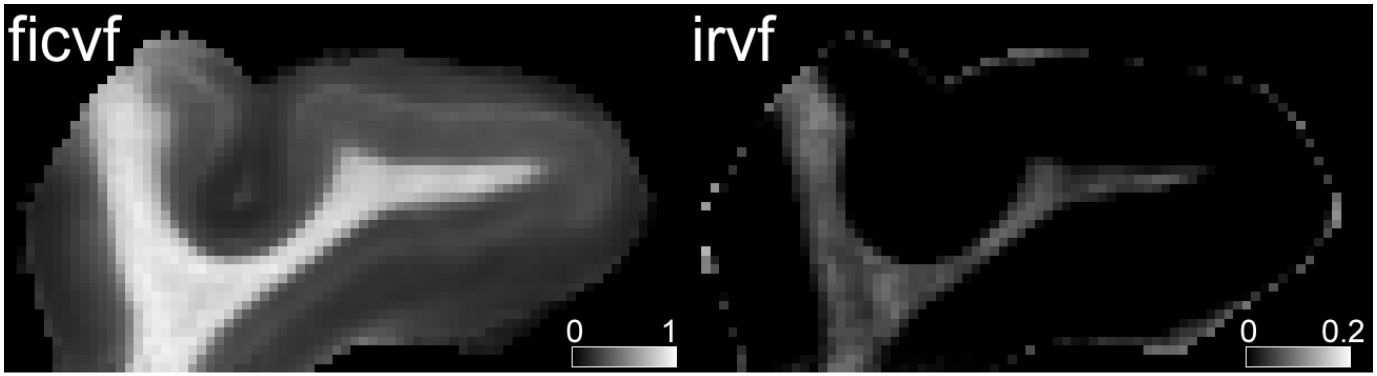
WM voxel

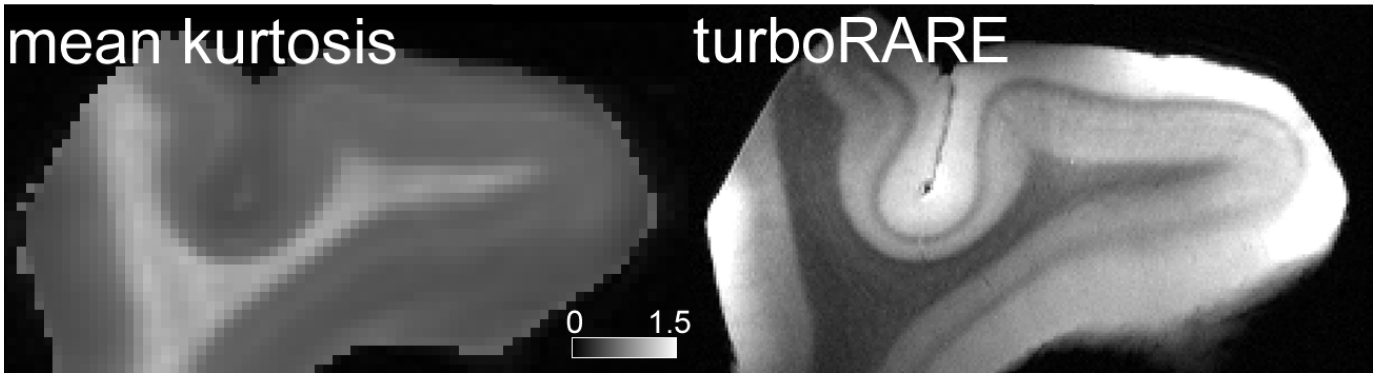


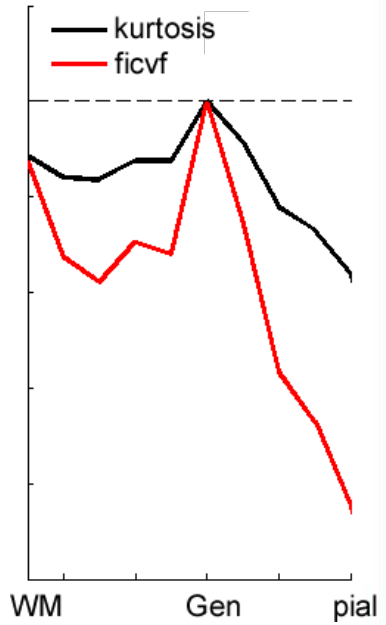




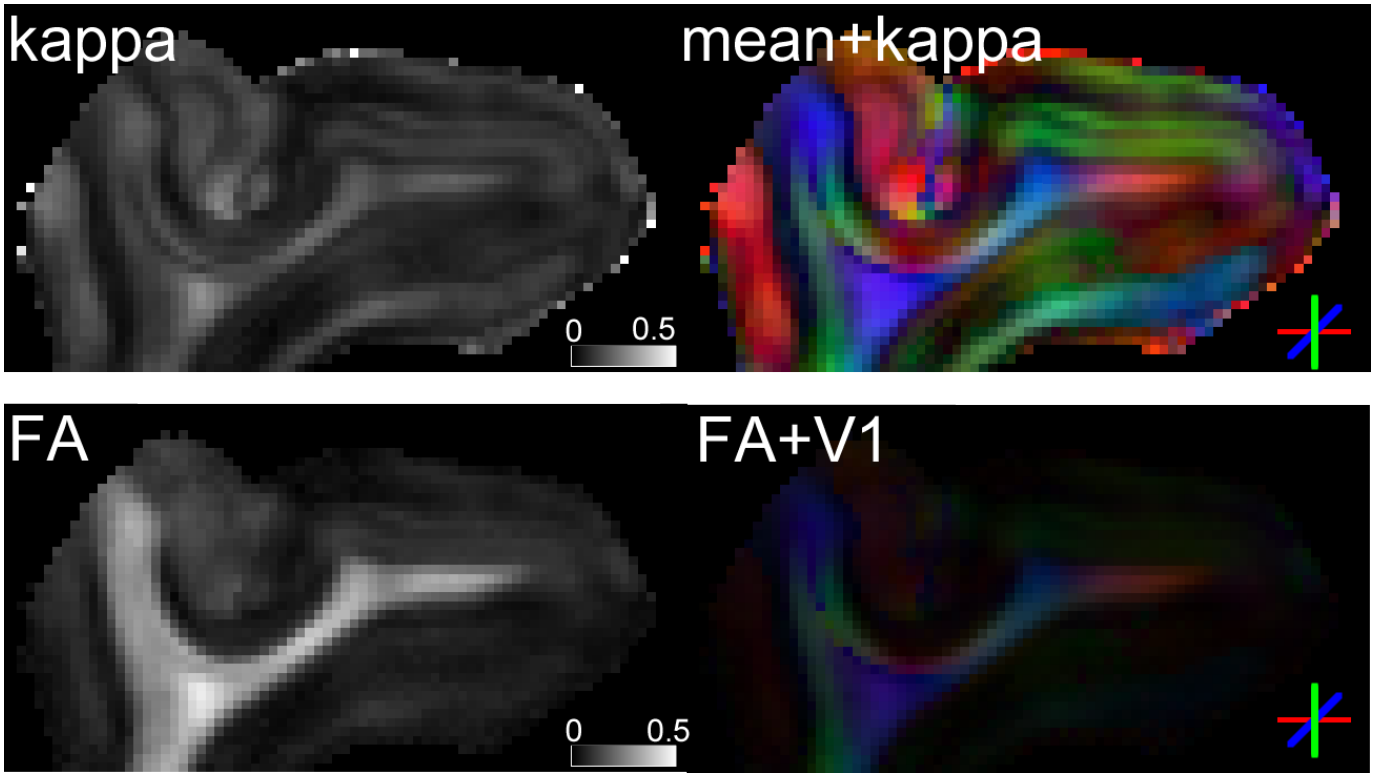
Volume fractions

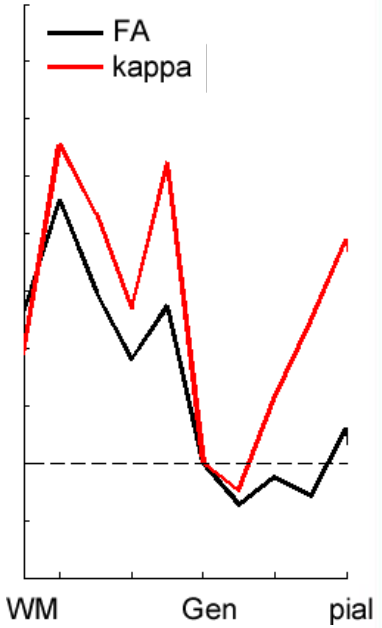




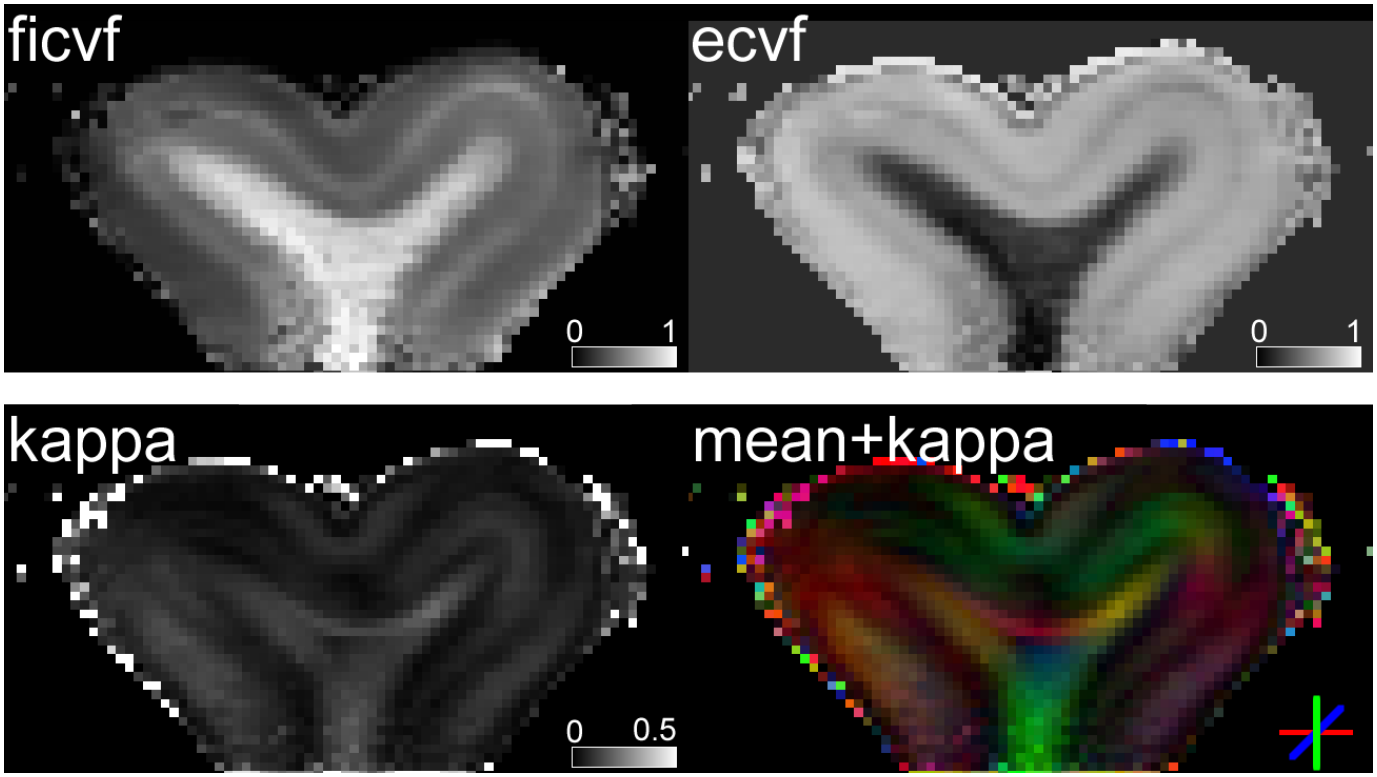


Orientation dispersion



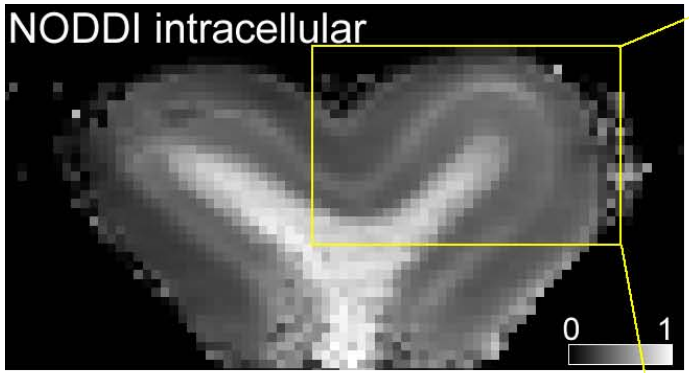


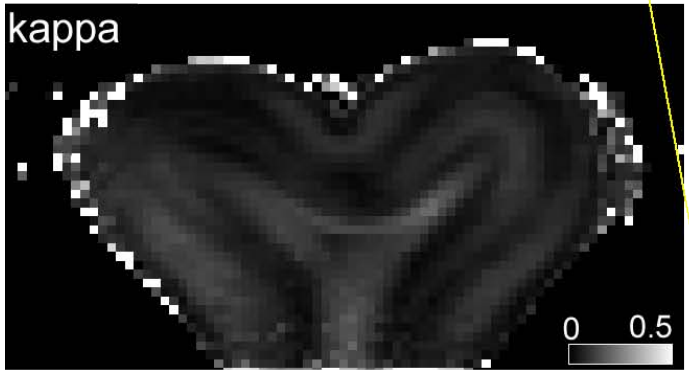
Sample B (54 directions)

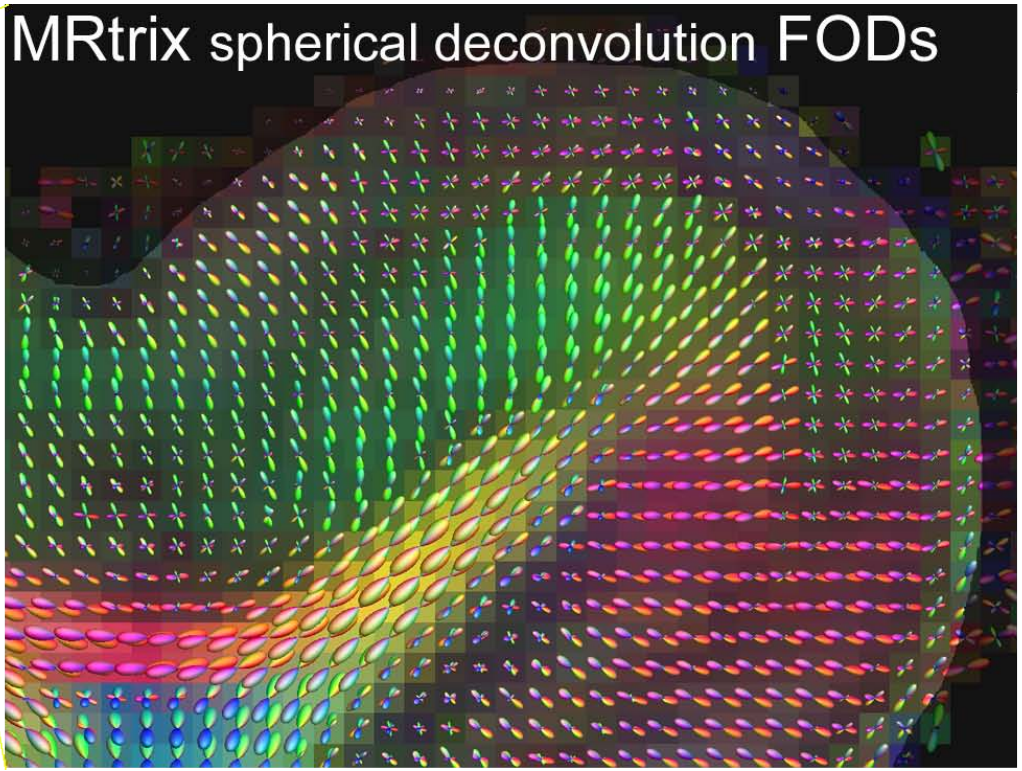


Orientation

- Areas of high orientation dispersion coincide with multicomponent fibre orientation distributions (FODs)

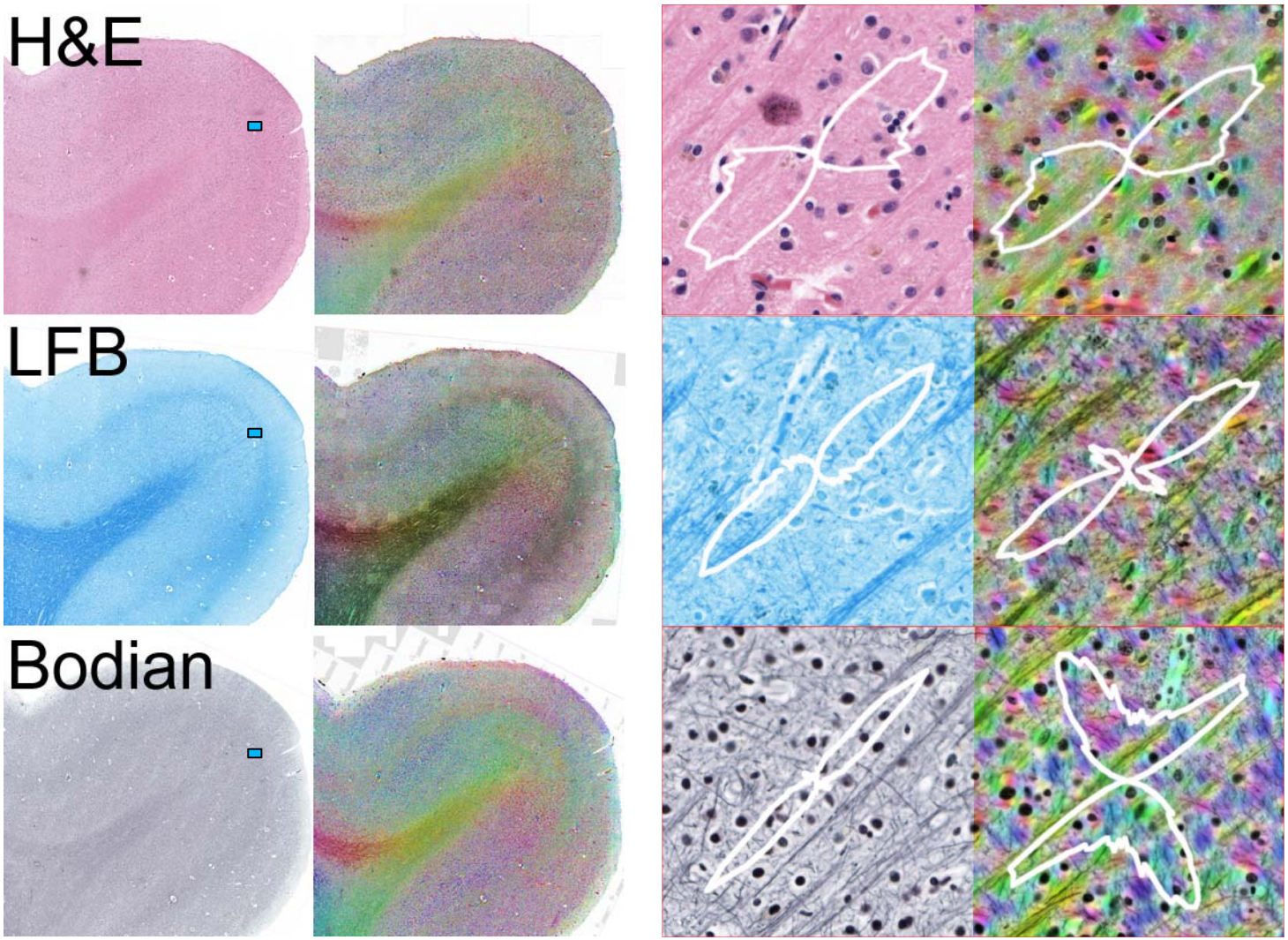




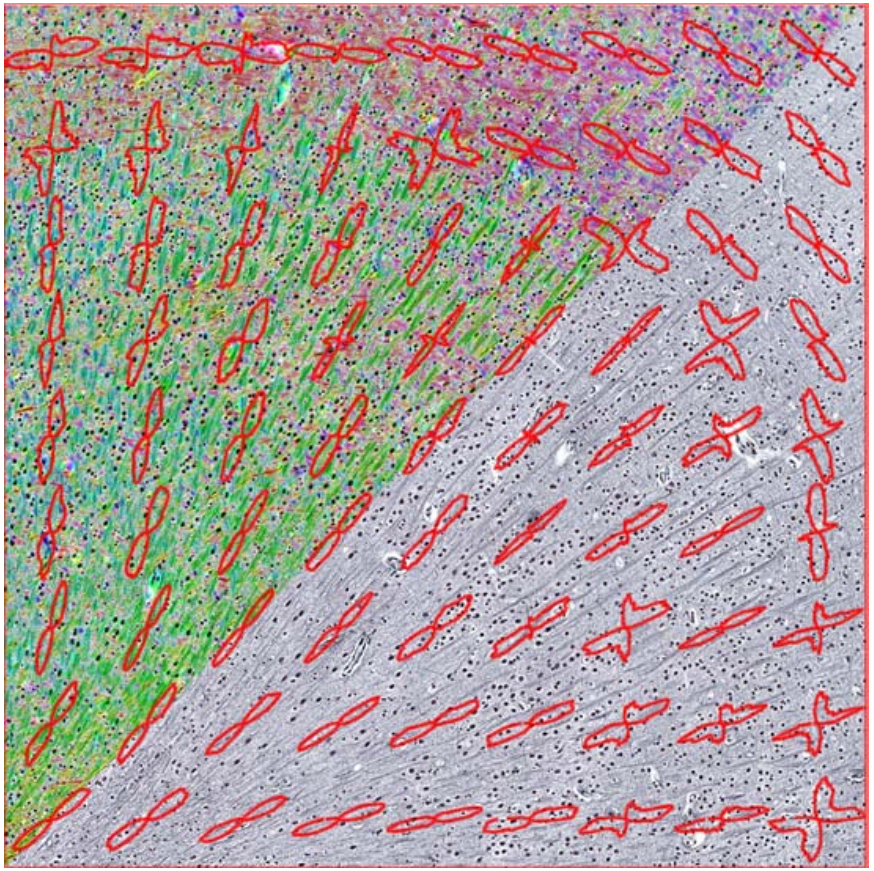


3D Diffusion data

Histology



Bodian



Conclusions

- High layer discriminability
- Sharp delineation of layer boundaries in GM and WM
- Interpretable measures
- Cortical *in vivo* investigations feasible in clinical scan times

m.kleinnijenhuis@donders.ru.nl

Thank you

Anatomy: Valerio Zerbi
Dirk Ruiter
Jos Dederen
Pathology: Ine Mamor-Cornelissen
MPI Köln: Matthias Hoehn
DCCN: Markus Barth
Marcel Zwiers

VIP Brain Networks
MIRA INSTITUTE FOR BIOMEDICAL TECHNOLOGY AND TECHNICAL MEDICINE
provincie Overijssel
provincie Gelderland
Ministerie van Economische Zaken

Discussion

- Cortical *in vivo* investigations feasible in clinical scan times?
  - The number of directions can be limited
  - *In vivo* eliminates the need for b=20000
  - CRLB optimization[1] suggests 4 shells: b=[0 1000 4000 12000]
  - Equates to b=[0 300 1000 3000] *in vivo*

- Neurite dispersion might vary with cortical curvature

Neurite Orientation Dispersion and Density Imaging

- NODDI multicompartment tissue model (Zhang et al., NI 2012)