Donders Institute
for Brain, Cognition and Behaviour

Radboud Universiteit Nijmegen

Radboudumc

# Laminar characteristics of gyrencephaly using high resolution DTI *in vivo* at 7T

Michiel Kleinnijenhuis [1,2,3]
Tim van Mourik [1]
David Norris [1,4,5]
Dirk Ruiter [2]
Anne-Marie van Cappellen van Walsum [2,1,5]
Markus Barth [1,4,6]

[1] *Donders Institute for Brain, Cognition and Behaviour, Nijmegen, Netherlands*
[2] *Department of Anatomy, Radboudumc, Nijmegen, Netherlands*
[3] *Oxford Centre for Functional MRI of the Brain, Oxford, United Kingdom*
[4] *Erwin L. Hahn Institute for Magnetic Resonance Imaging, Essen, Germany*
[5] *MIRA Institute, University of Twente, Enschede, Netherlands*
[6] *The University of Queensland, Centre for Advanced Imaging, Brisbane, Australia*

**10 June 2014**

HBM
HAMBURG 2014

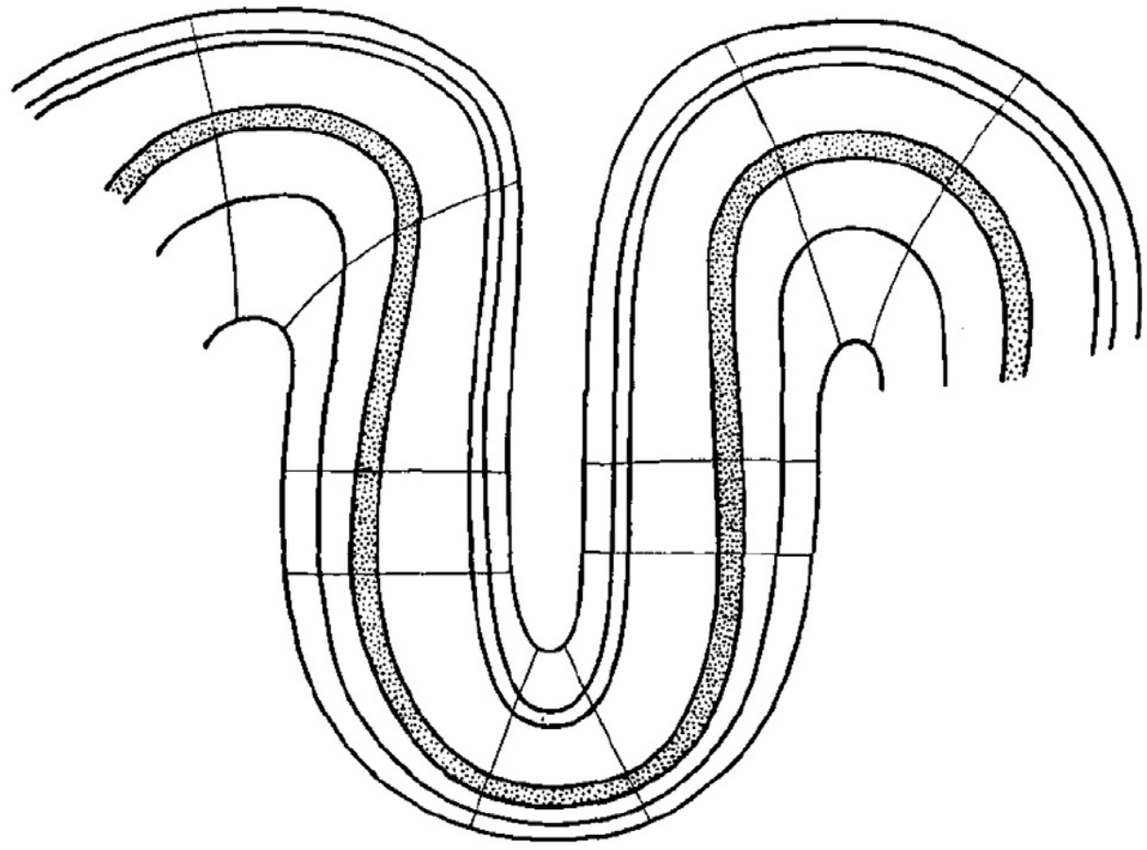
# Cortical anatomy

1. *Laminar* organization

2. Cortical *curvature*

   layer thickness variation

- How does this relate to fibre architecture?



*

**Fig. 1.** Sketch from Bok (1929) of a cortical cross section depicting six cytoarchitectonic layers. Principal dendrites divide each layer into segments. The volume fraction of a segment is constant across the whole layer. This is possible because the thickness of the layer changes to compensate the curvature. At locations of high curvature a layer is relatively thick, at locations of low curvature it is comparably thin.

* sketch from Bok (1929), reproduced from Waehnert et al. (2013), 'Anatomically motivated modeling of cortical laminae', NeuroImage vol. 93(2), pp. 210-220.

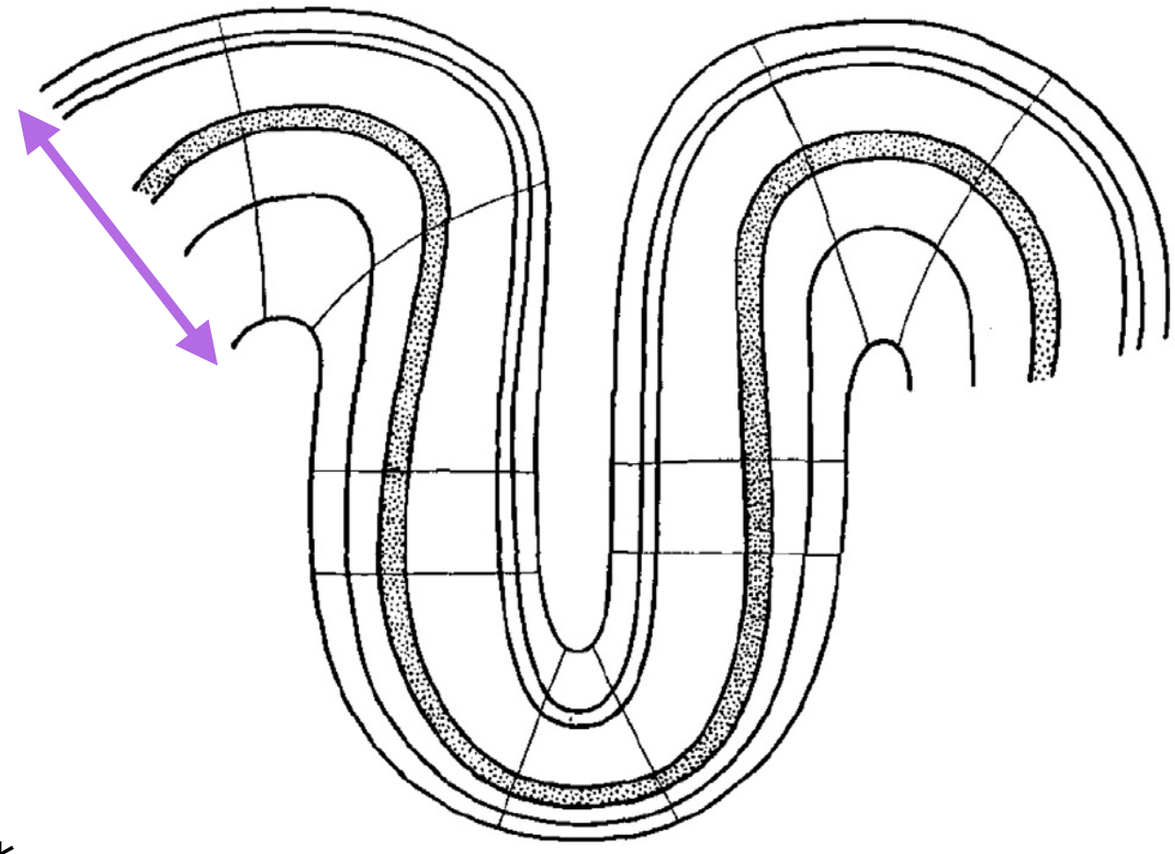
# Cortical anatomy

1. *Laminar* organization

2. Cortical *curvature*

   layer thickness variation

- How does this relate to fibre architecture?



*

**Fig. 1.** Sketch from Bok (1929) of a cortical cross section depicting six cytoarchitectonic layers. Principal dendrites divide each layer into segments. The volume fraction of a segment is constant across the whole layer. This is possible because the thickness of the layer changes to compensate the curvature. At locations of high curvature a layer is relatively thick, at locations of low curvature it is comparably thin.

* sketch from Bok (1929), reproduced from Waehnert et al. (2013), 'Anatomically motivated modeling of cortical laminae', NeuroImage vol. 93(2), pp. 210-220.

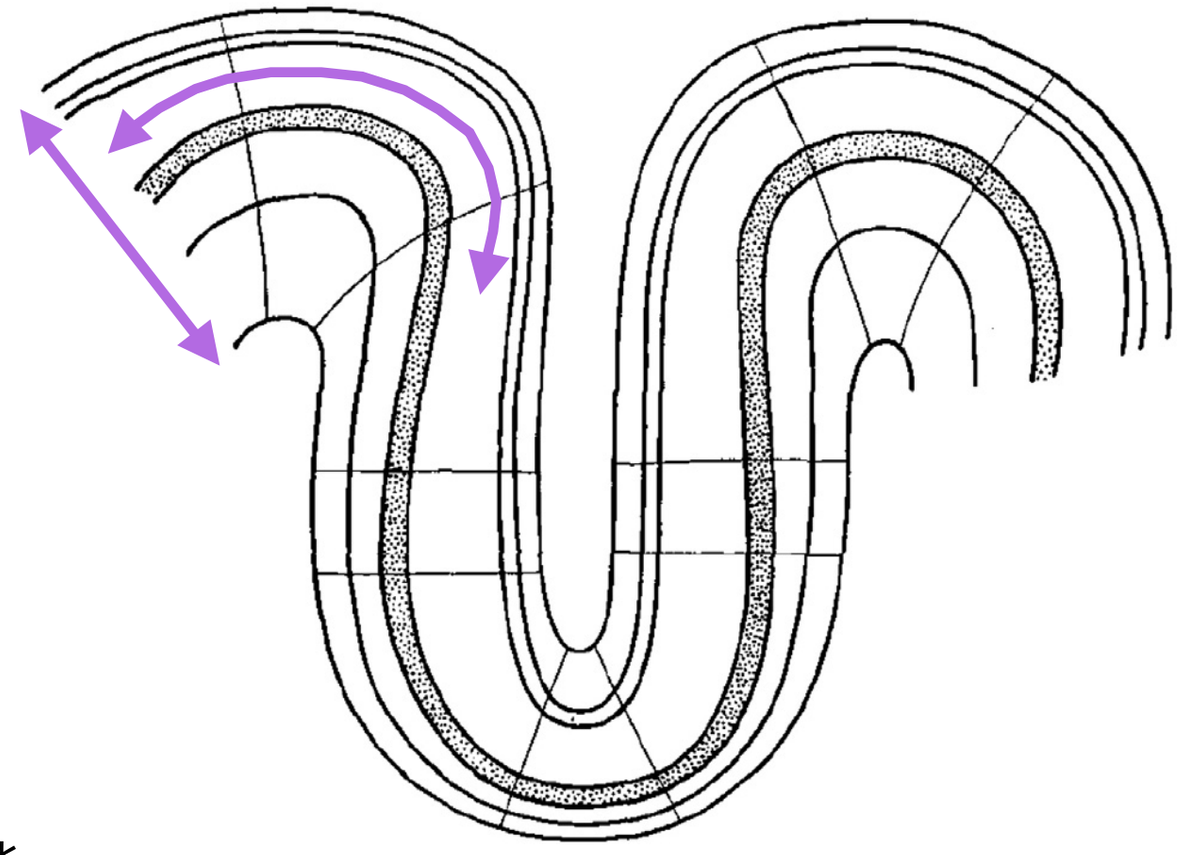
# Cortical anatomy

1. *Laminar* organization

2. Cortical *curvature*

   layer thickness variation

- How does this relate to fibre architecture?



*

**Fig. 1.** Sketch from Bok (1929) of a cortical cross section depicting six cytoarchitectonic layers. Principal dendrites divide each layer into segments. The volume fraction of a segment is constant across the whole layer. This is possible because the thickness of the layer changes to compensate the curvature. At locations of high curvature a layer is relatively thick, at locations of low curvature it is comparably thin.

* sketch from Bok (1929), reproduced from Waehnert et al. (2013), 'Anatomically motivated modeling of cortical laminae', NeuroImage vol. 93(2), pp. 210-220.

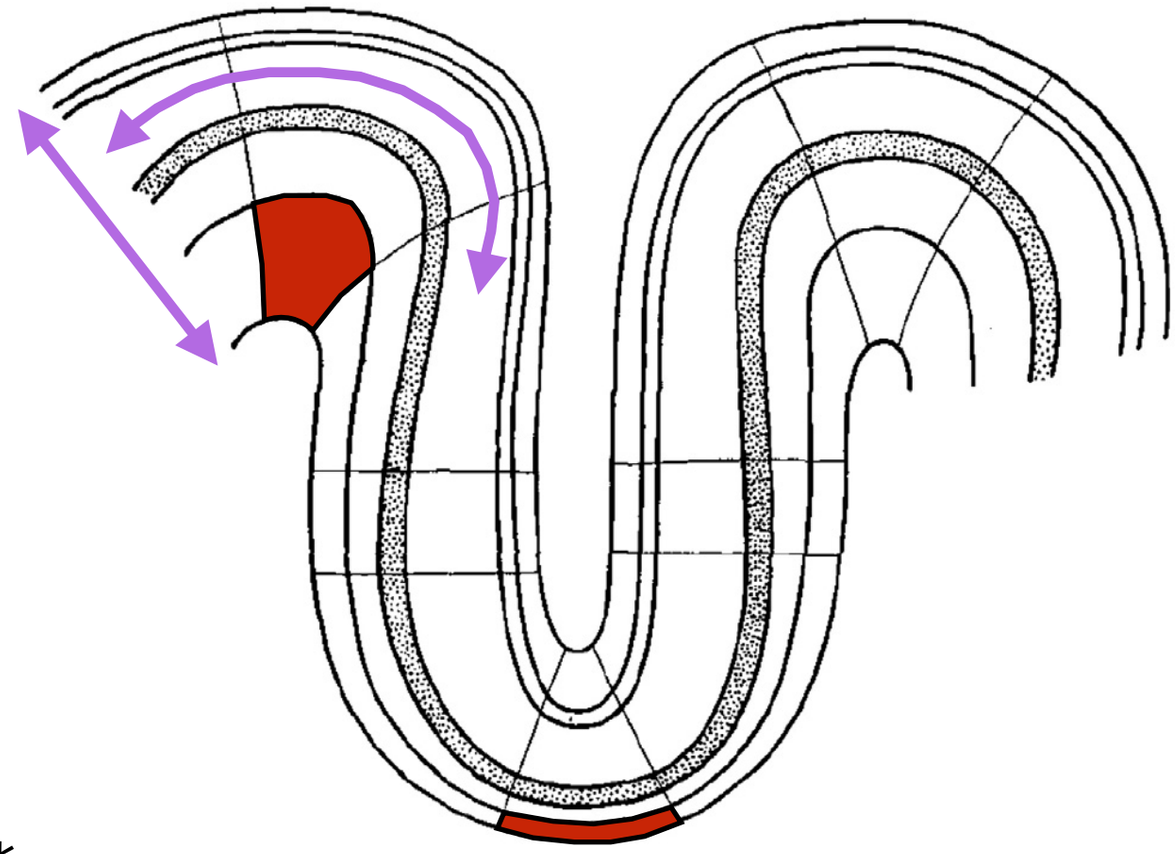
# Cortical anatomy

1. *Laminar* organization

2. Cortical *curvature*

   layer thickness variation

- How does this relate to fibre architecture?



*

**Fig. 1.** Sketch from Bok (1929) of a cortical cross section depicting six cytoarchitectonic layers. Principal dendrites divide each layer into segments. The volume fraction of a segment is constant across the whole layer. This is possible because the thickness of the layer changes to compensate the curvature. At locations of high curvature a layer is relatively thick, at locations of low curvature it is comparably thin.

* sketch from Bok (1929), reproduced from Waehnert et al. (2013), 'Anatomically motivated modeling of cortical laminae', NeuroImage vol. 93(2), pp. 210-220.

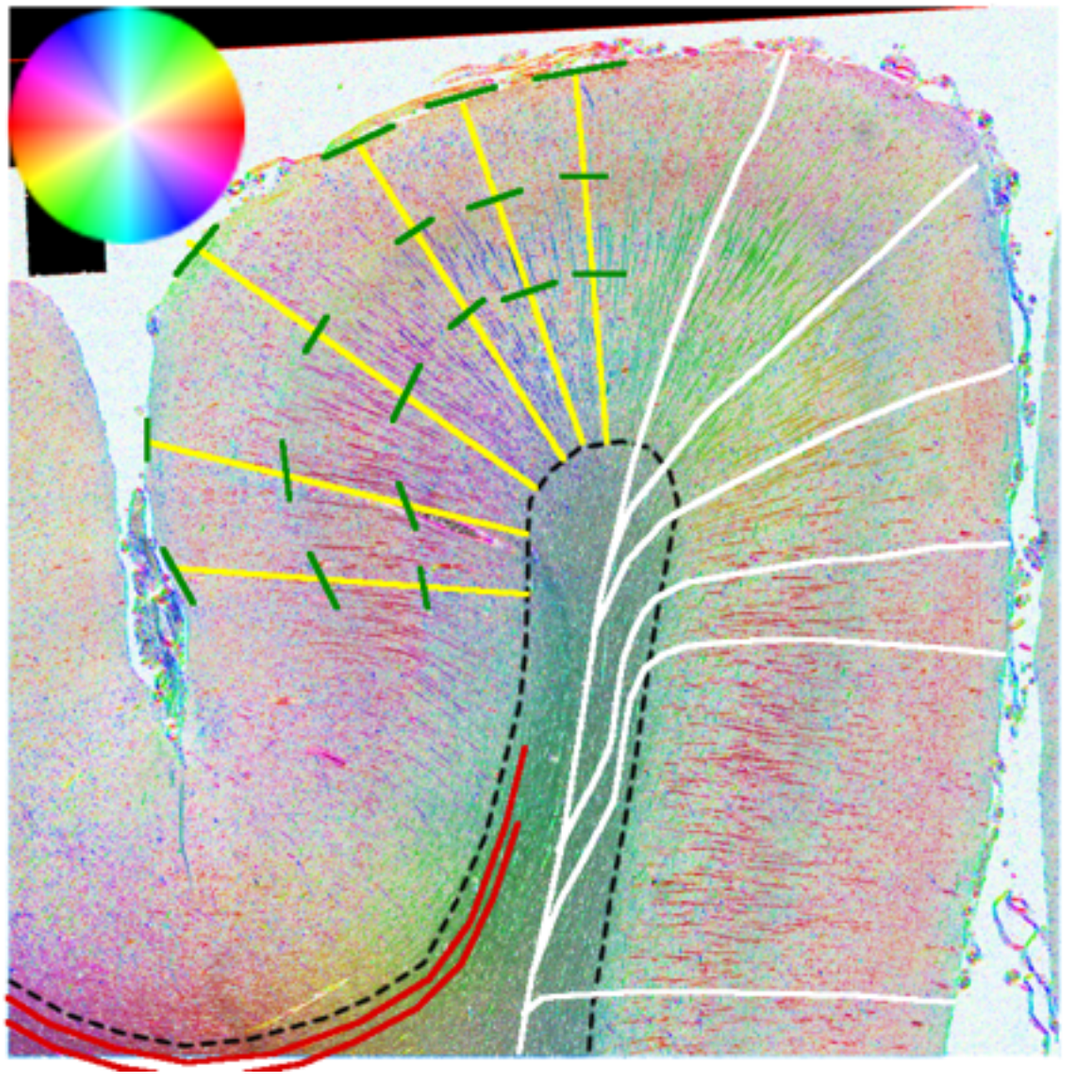
# Gyral fibres

- essential for progress in diffusion MRI:
  - ⋆ structural connectomics
  - ⋆ cortical microstructure
- investigated with diffusion:
  - radial organisation[1]
  - regional[2] and laminar[3,4] variation
  - fibre insertion patterns[5,6,7]
  - superficial WM (e.g. u-fibres)

**GM**

↓

**WM**

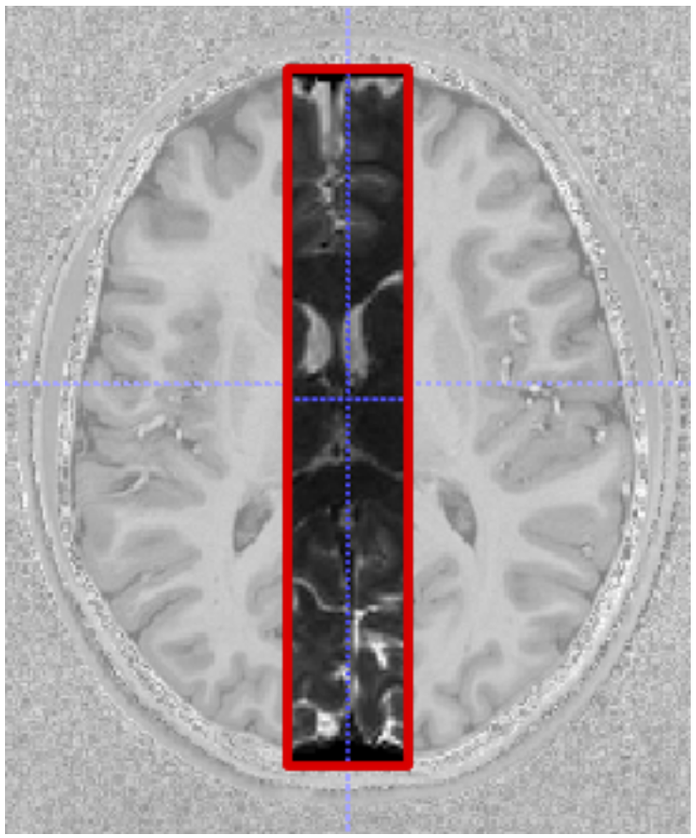


Structure tensor analysis of Bodian stain[5]

1) McNab et al., NI 2009; 2) McNab et al., NI 2013; 3) Kleinnijenhuis et al., OHBM 2011; 4) Leuze et al., OHBM 2011; 5) Kleinnijenhuis et al., OHBM 2013; 6) Sotiropoulos et al., OHBM 2013; 7) Bastiani et al. OHBM 2013

# Methods: MRI

- 5 healthy participants



- 7T DTI

  ➡ RESOLVE* at $1mm^3$

  ➡ 61 directions at b = 1000 $s/mm^2$

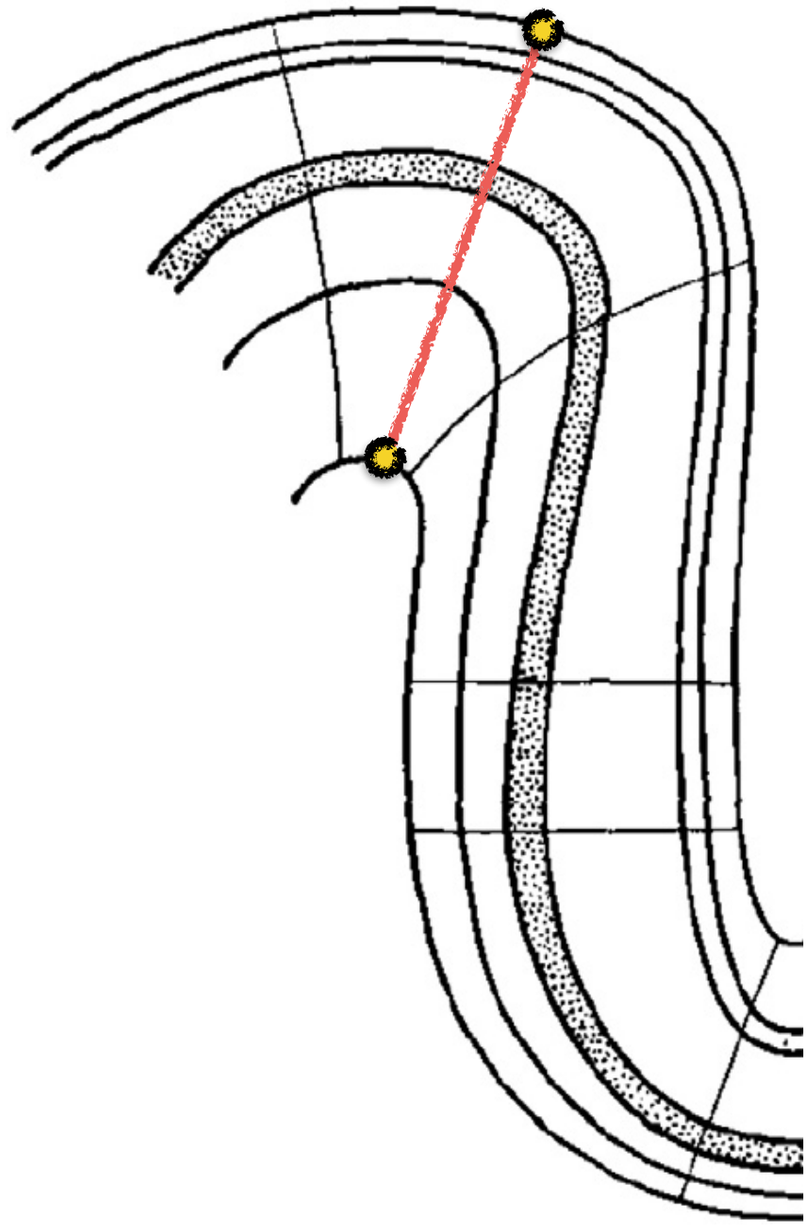
  ➡ sagittal slab centred on midline

- MP2RAGE for cortical surface reconstruction

* Porter et al. (2009) 'High resolution diffusion-weighted imaging using readout-segmented echo-planar imaging, parallel imaging and a two- dimensional navigator-based reacquisition', Magnetic Resonance in Medicine, vol.62, pp. 468–475.

# Methods: sampling

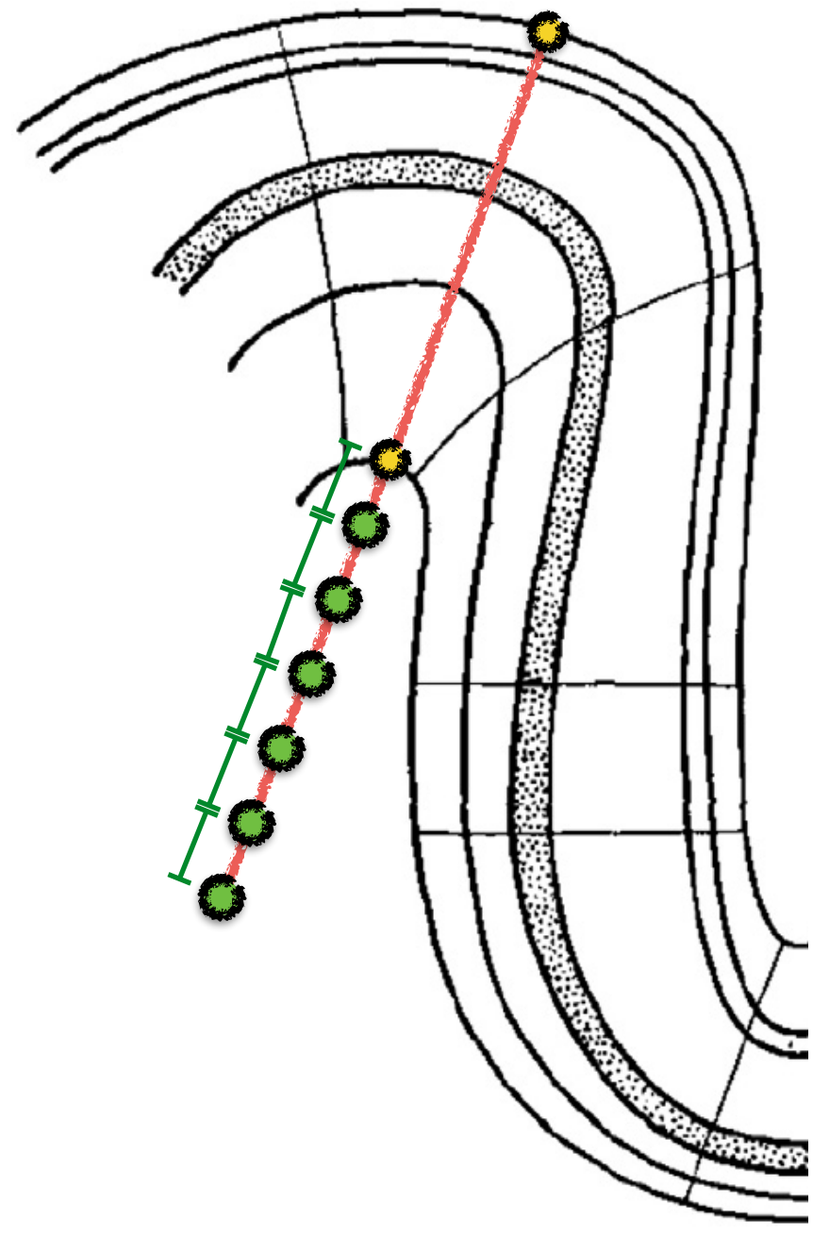
- 13 surfaces:
  - gm-wm, pial (FreeSurfer)
  - WM => **6** equi*distant* (1 cortical thickness)
  - GM => **5** equi*volume*[1] (curvature and thickness)
- maps of T1, FA, DT radiality[2] (Camino)
- 10 curvature bins
  - profiles with similar curvature averaged



1) Waehnert et al. (2013), 'Anatomically motivated modeling of cortical laminae', NeuroImage vol. 93(2), pp. 210-220.
2) McNab et al. (2013), 'Surface based analysis of diffusion orientation for identifying architectonic domains in the in vivo human cortex', NeuroImage, vol.69, pp. 87–100

# Methods: sampling

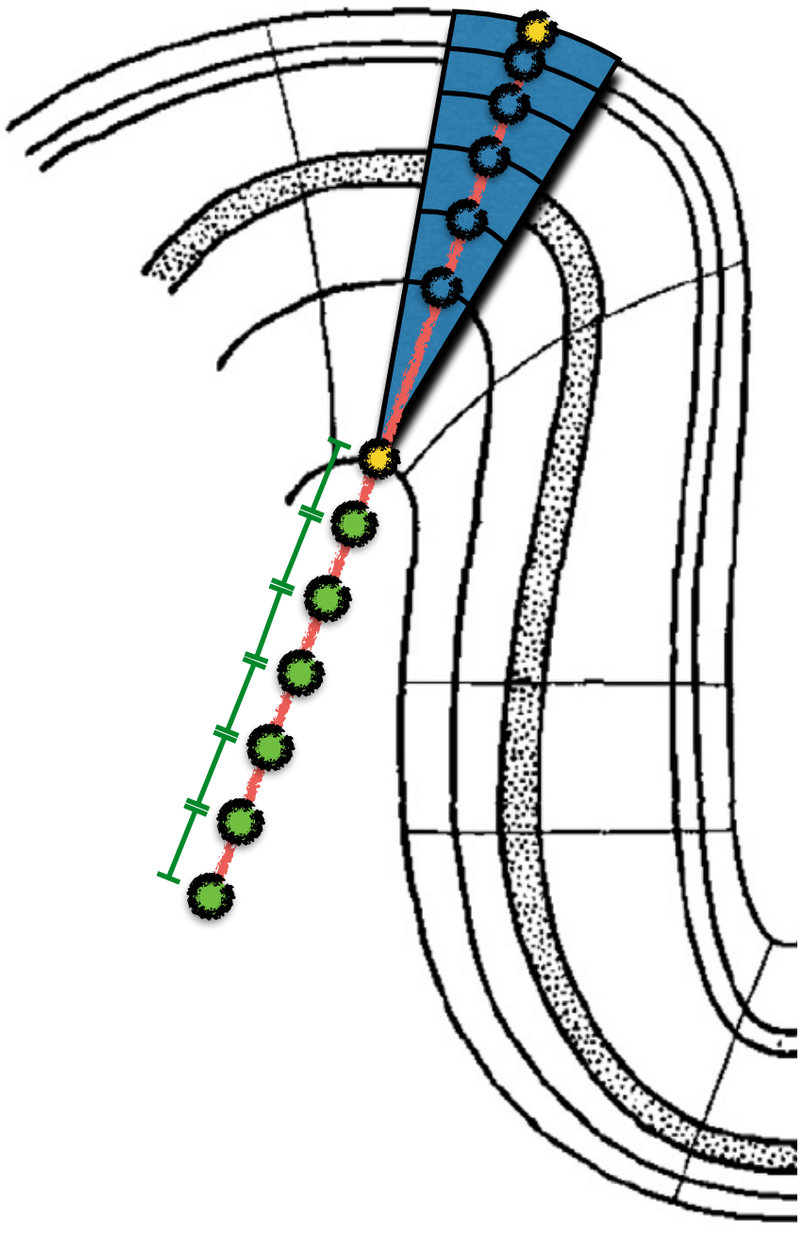
- 13 surfaces:
  - gm-wm, pial (FreeSurfer)
  - WM => **6** equi*distant* (1 cortical thickness)
  - GM => **5** equi*volume*[1] (curvature and thickness)
- maps of T1, FA, DT radiality[2] (Camino)
- 10 curvature bins
  - profiles with similar curvature averaged



1) Waehnert et al. (2013), 'Anatomically motivated modeling of cortical laminae', NeuroImage vol. 93(2), pp. 210-220.
2) McNab et al. (2013), 'Surface based analysis of diffusion orientation for identifying architectonic domains in the in vivo human cortex', NeuroImage, vol.69, pp. 87–100

# Methods: sampling

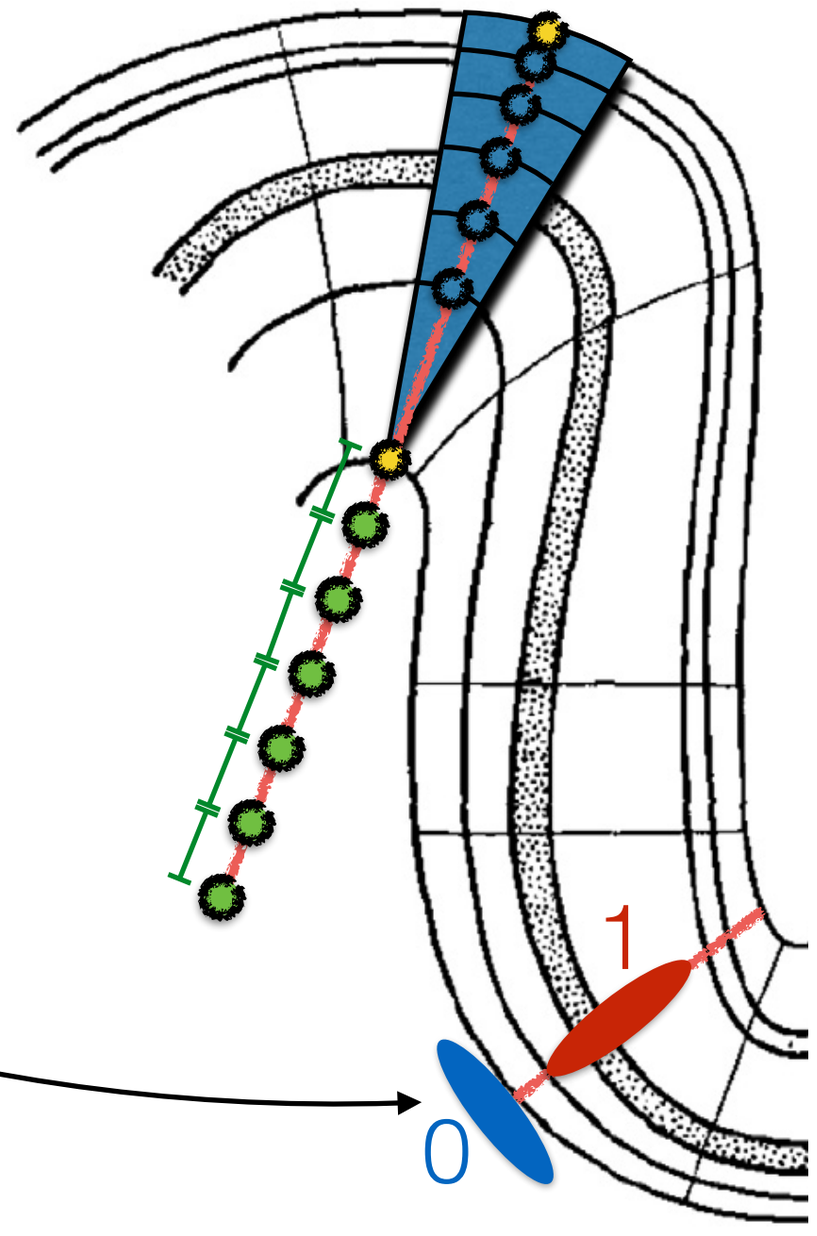
- 13 surfaces:
  - gm-wm, pial (FreeSurfer)
  - WM => **6** equi*distant* (1 cortical thickness)
  - GM => **5** equi*volume*[1] (curvature and thickness)
- maps of T1, FA, DT radiality[2] (Camino)
- 10 curvature bins
  - profiles with similar curvature averaged



1) Waehnert et al. (2013), 'Anatomically motivated modeling of cortical laminae', NeuroImage vol. 93(2), pp. 210-220.
2) McNab et al. (2013), 'Surface based analysis of diffusion orientation for identifying architectonic domains in the in vivo human cortex', NeuroImage, vol.69, pp. 87–100

# Methods: sampling

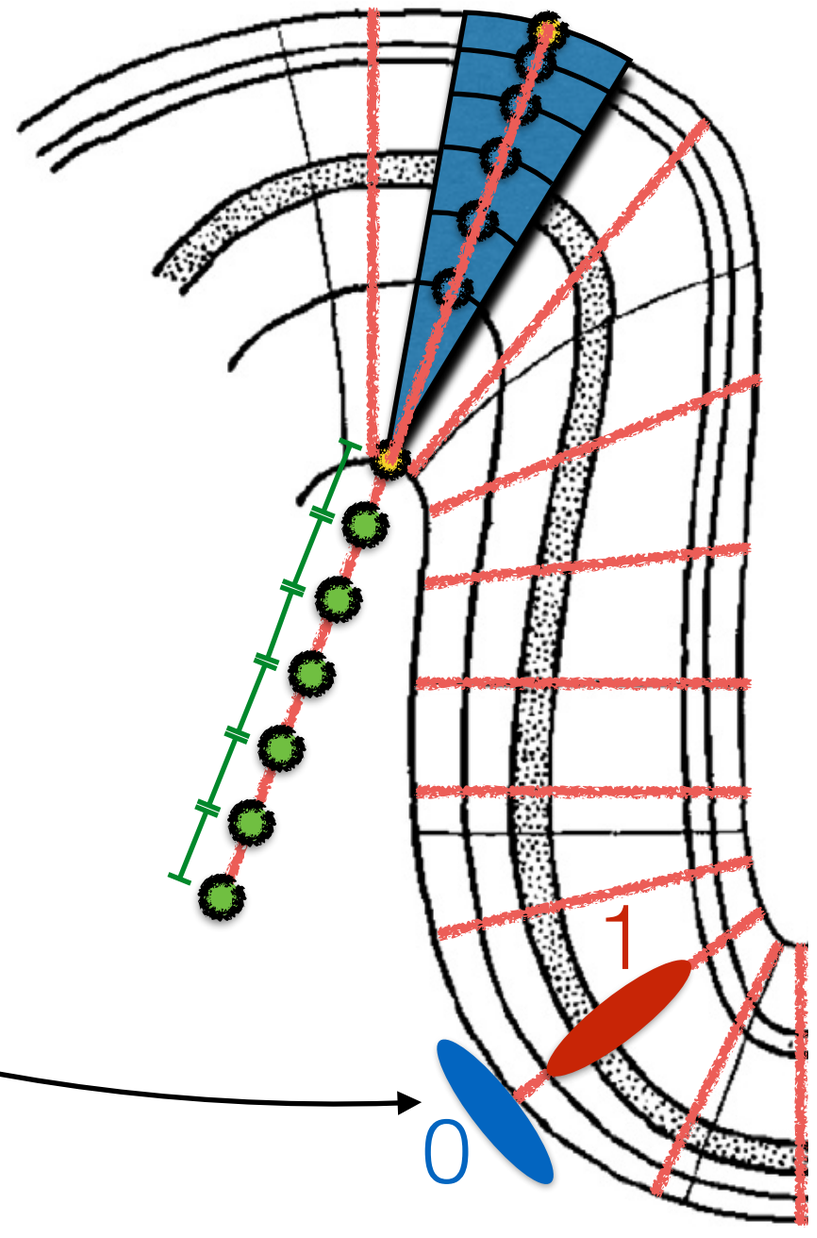
- 13 surfaces:
  - gm-wm, pial (FreeSurfer)
  - WM => **6** equi*distant* (1 cortical thickness)
  - GM => **5** equi*volume*[1] (curvature and thickness)
- maps of T1, FA, DT radiality[2] (Camino)
- 10 curvature bins
  - profiles with similar curvature averaged




1) Waehnert et al. (2013), 'Anatomically motivated modeling of cortical laminae', NeuroImage vol. 93(2), pp. 210-220.
2) McNab et al. (2013), 'Surface based analysis of diffusion orientation for identifying architectonic domains in the in vivo human cortex', NeuroImage, vol.69, pp. 87–100

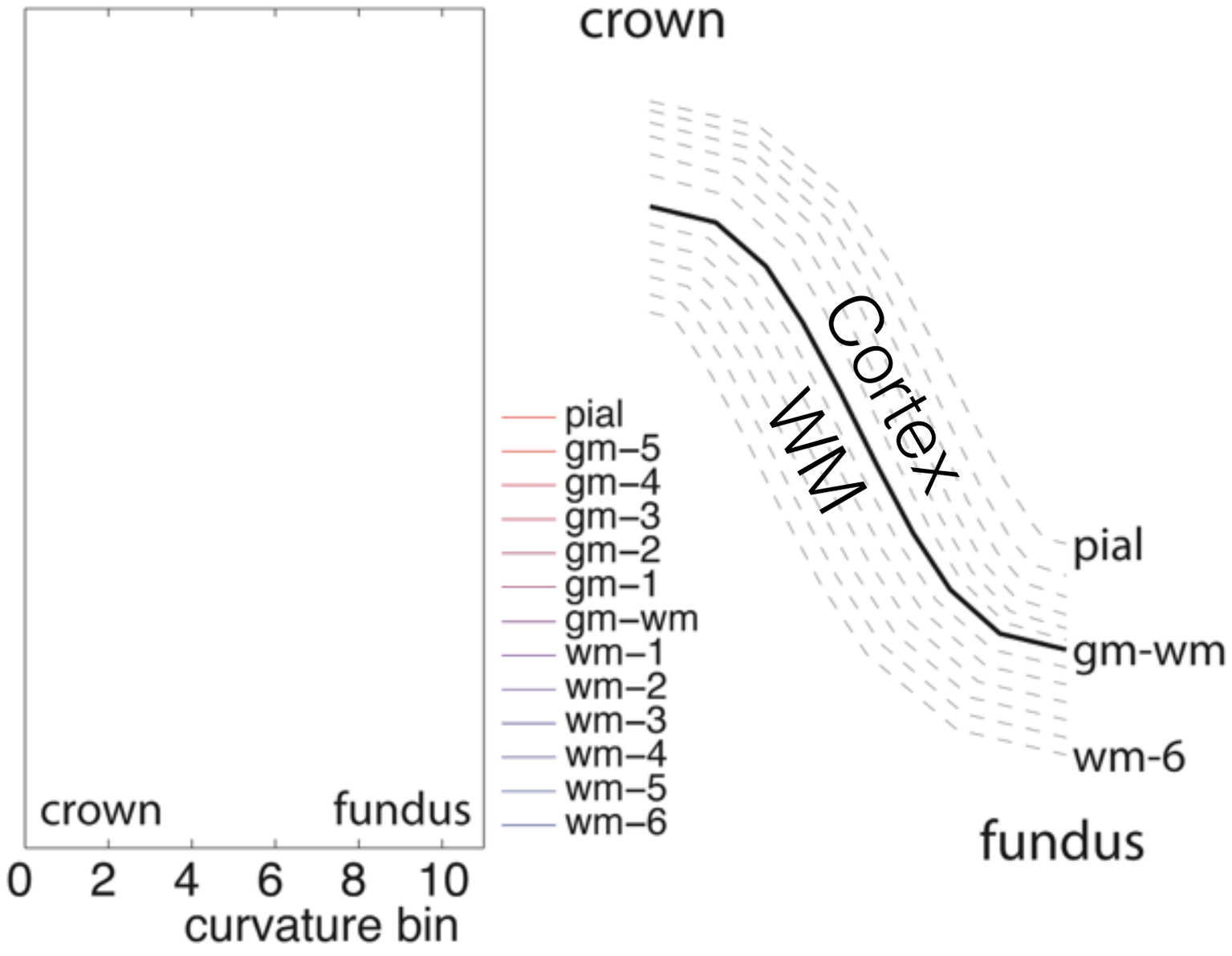
# Methods: sampling

- 13 surfaces:
  - gm-wm, pial (FreeSurfer)
  - WM => **6** equi*distant* (1 cortical thickness)
  - GM => **5** equi*volume*[1] (curvature and thickness)
- maps of T1, FA, DT radiality[2] (Camino)
- 10 curvature bins
  - profiles with similar curvature averaged

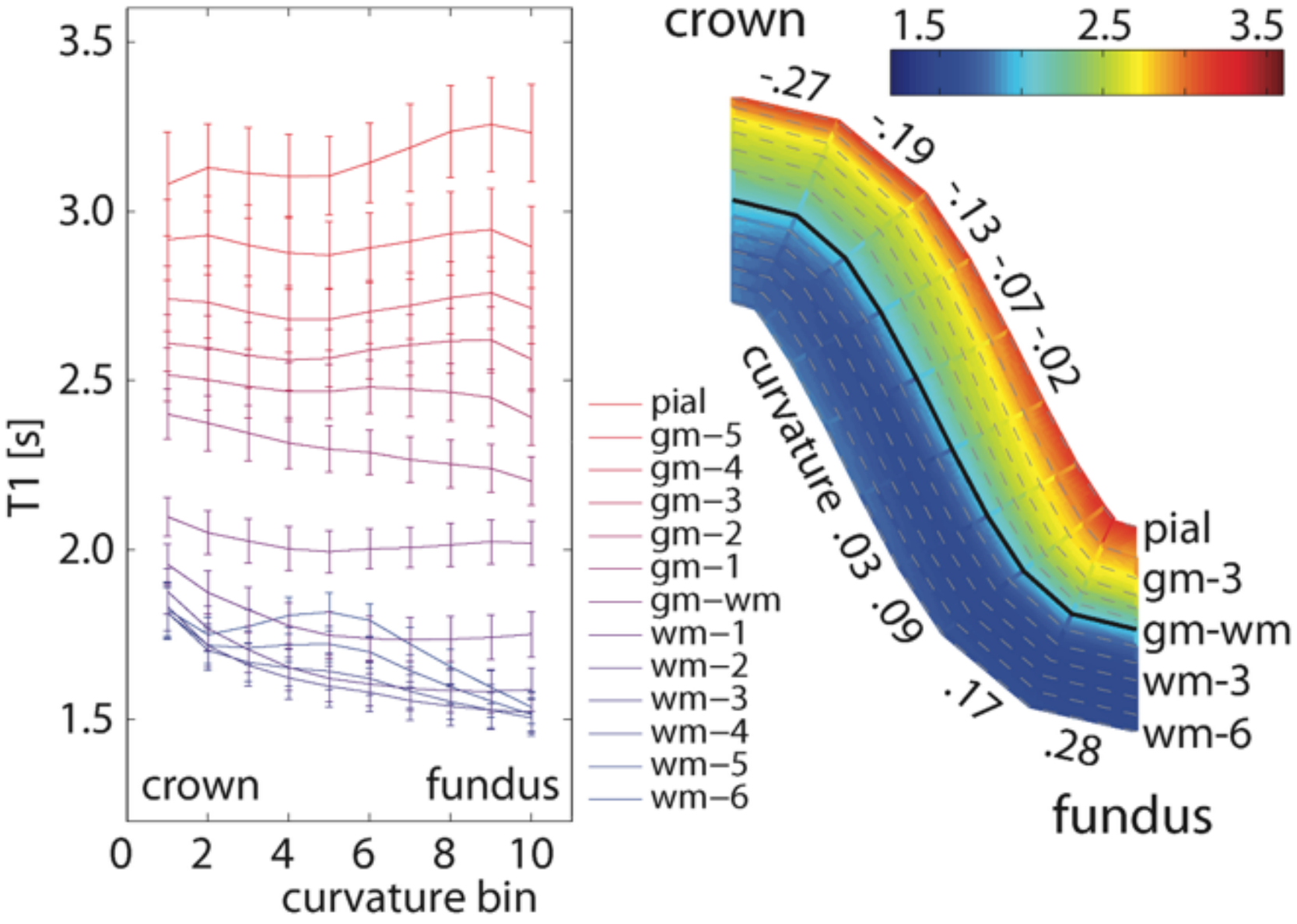


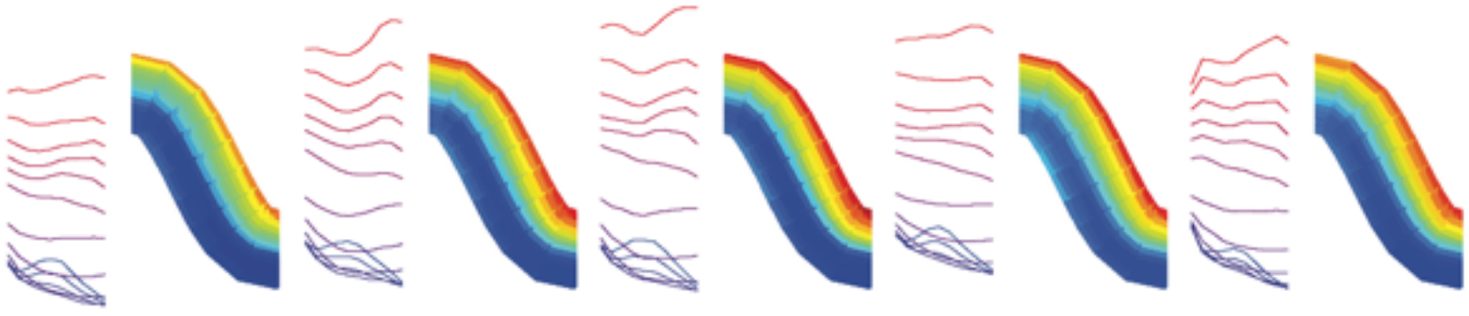

1) Waehnert et al. (2013), 'Anatomically motivated modeling of cortical laminae', NeuroImage vol. 93(2), pp. 210-220.
2) McNab et al. (2013), 'Surface based analysis of diffusion orientation for identifying architectonic domains in the in vivo human cortex', NeuroImage, vol.69, pp. 87–100

# Gyrus model




individual subjects

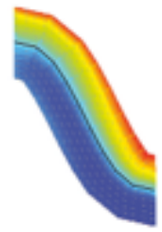


individual subjects

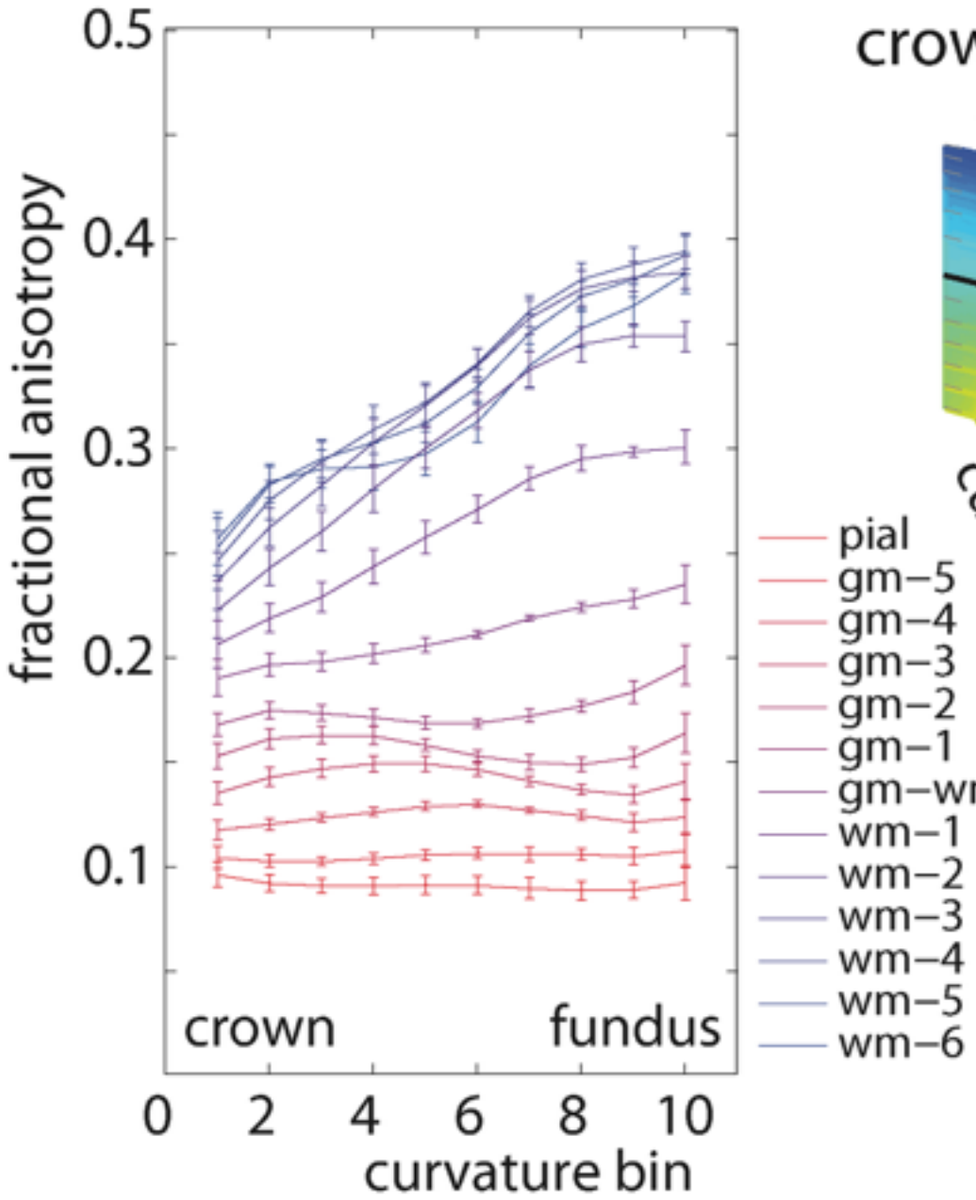
## Gyrus model

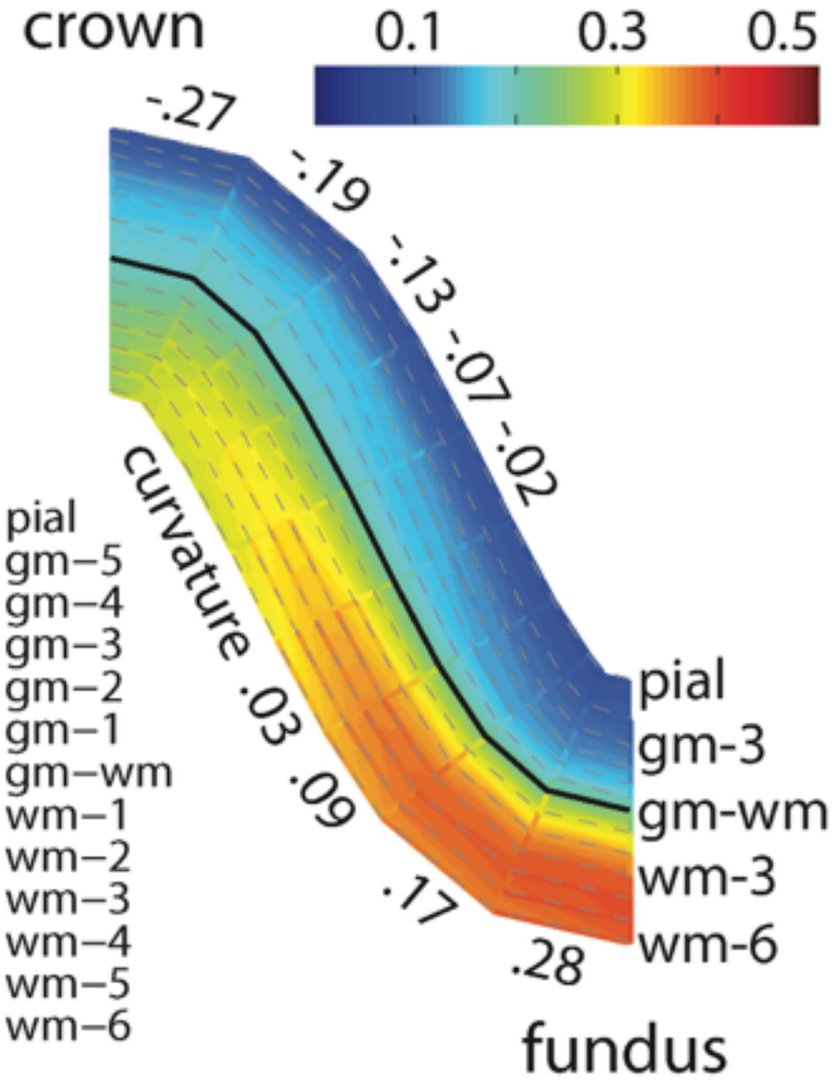
- T1:

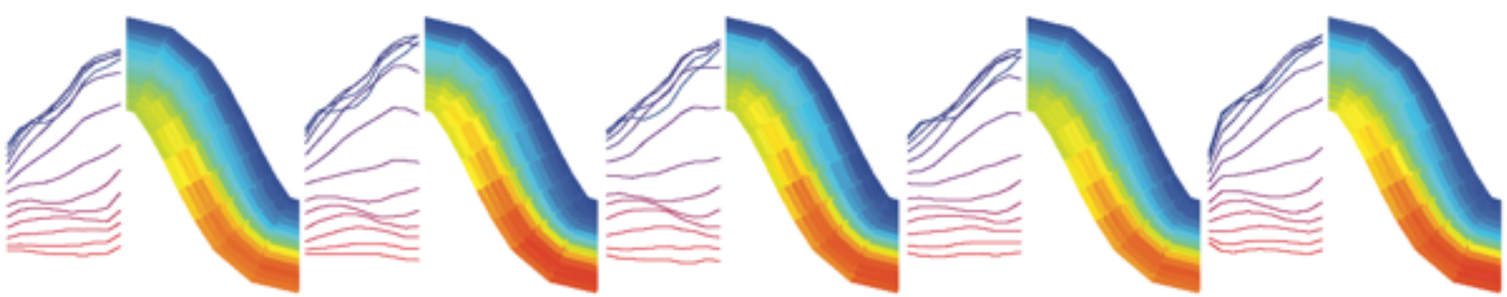


GM-WM contrast

laminar gradient



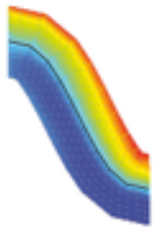



individual subjects

## Gyrus model

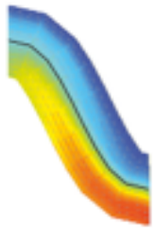
- T1:



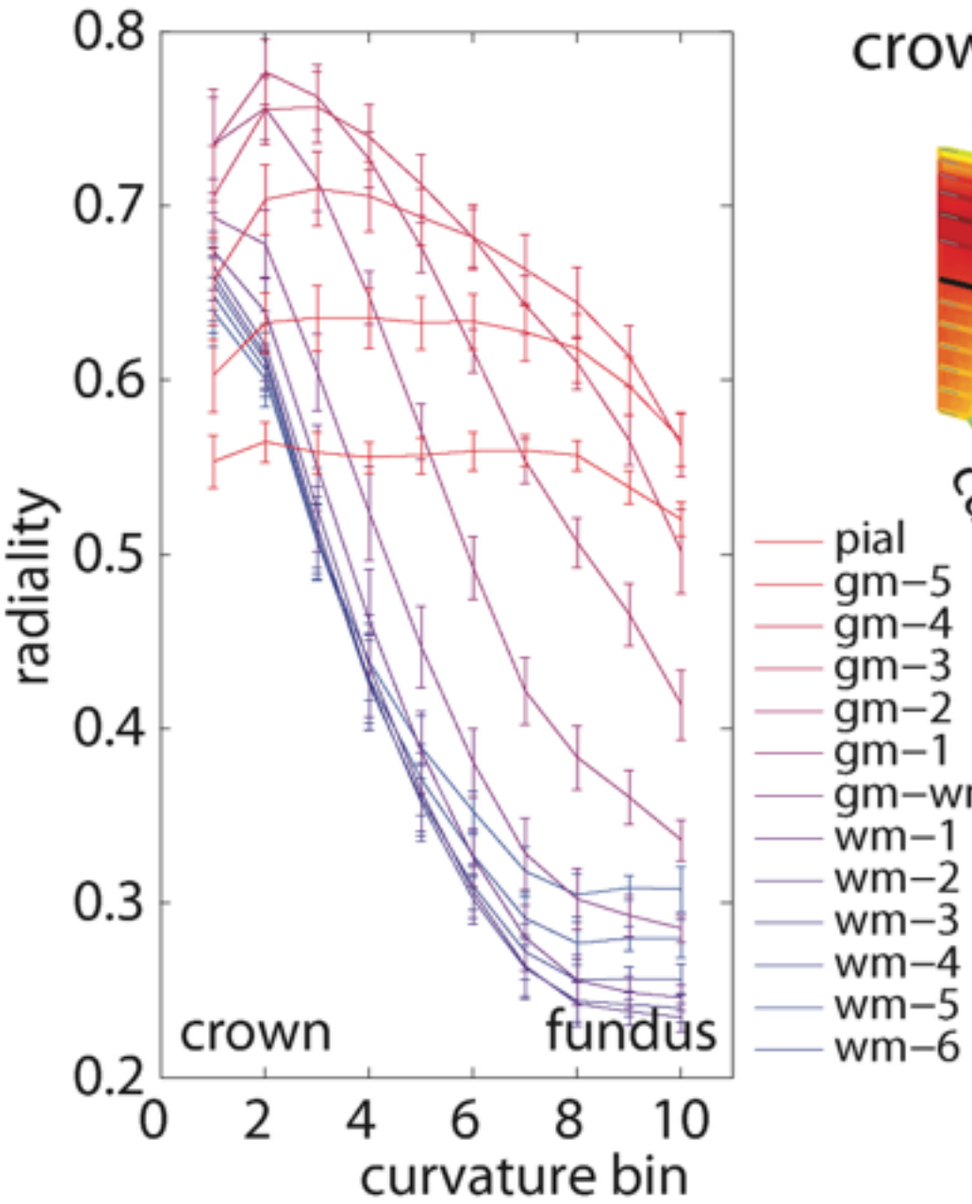
GM-WM contrast

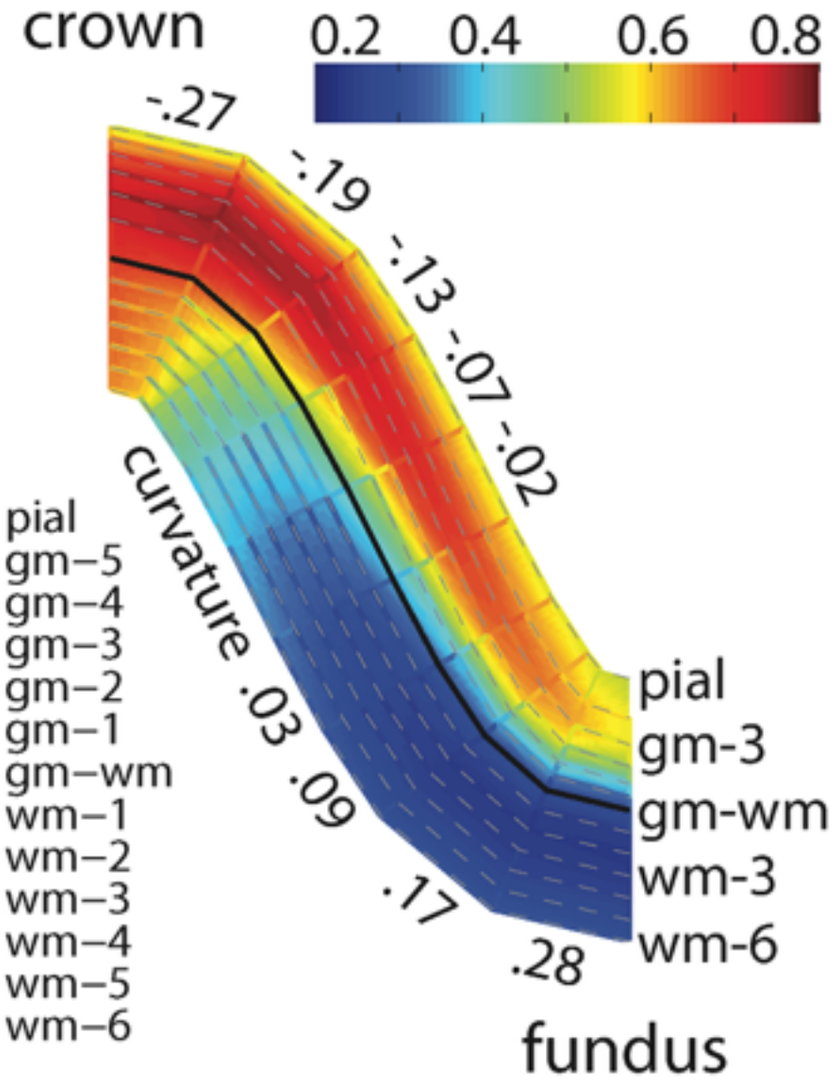
laminar gradient

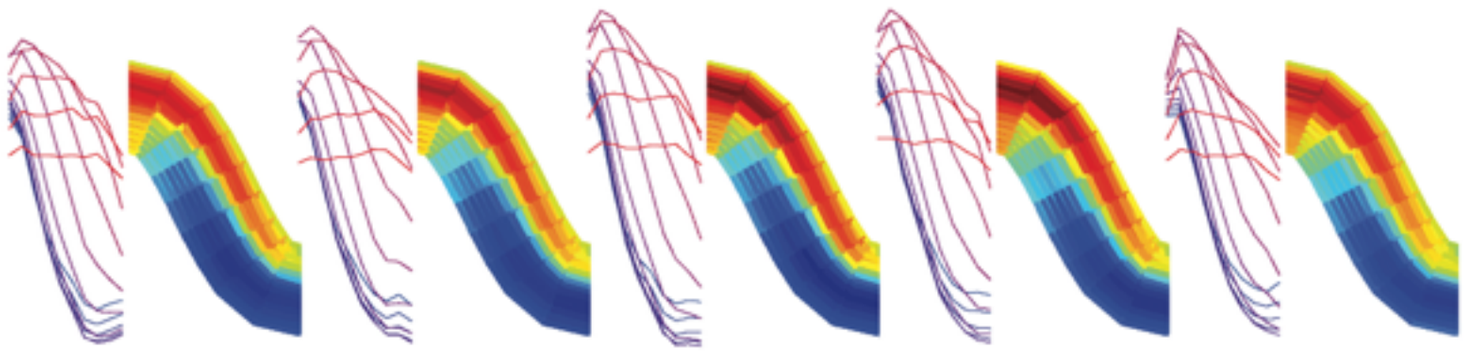
- FA:



WM: increase towards fundus



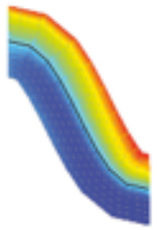



individual subjects

## Gyrus model

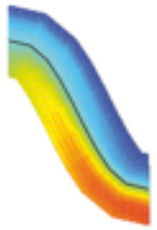
- T1:



GM-WM contrast

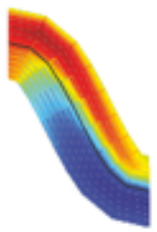
laminar gradient

- FA:



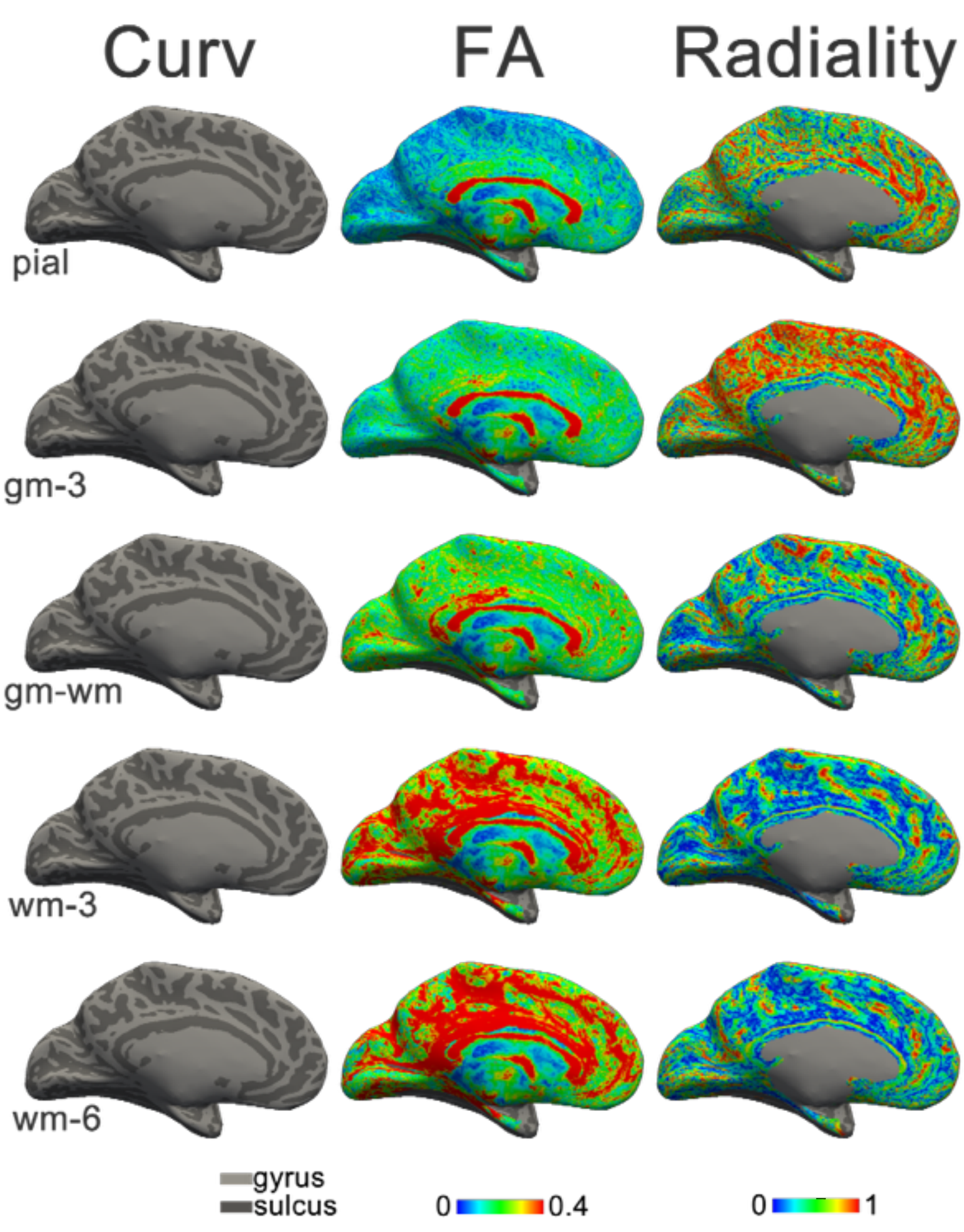
WM: increase towards fundus

- Radiality:



crown: radial

fundus: tangential




## single-subject maps

- FA:

  low on pial surface

  0.1-0.2 in cortex

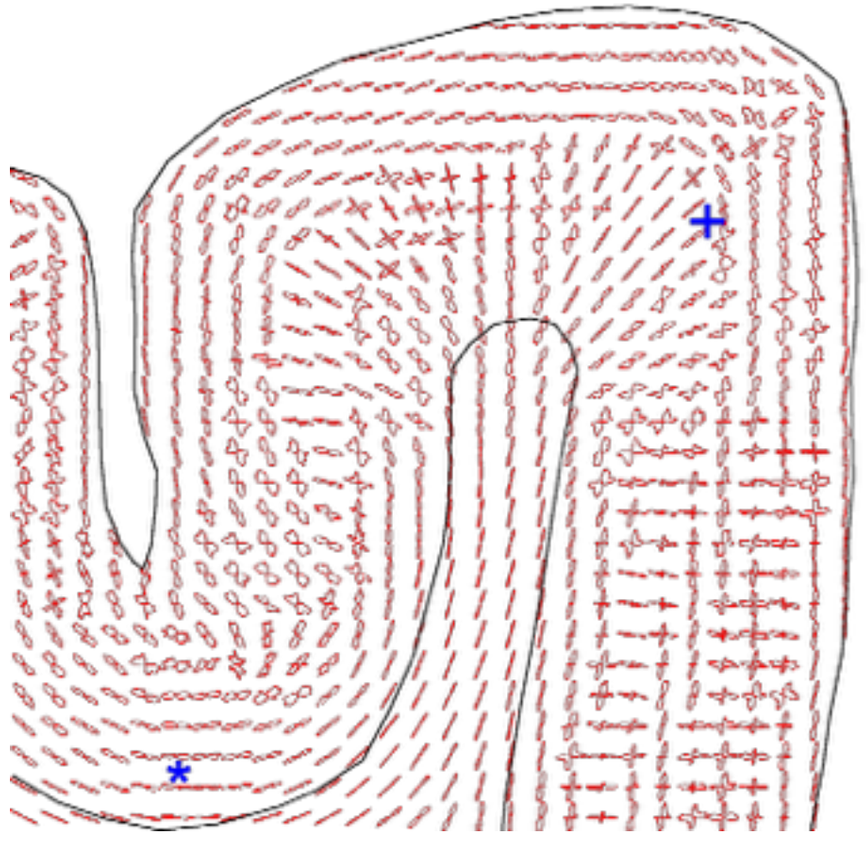
  low under crowns

- Radiality:

  radial midcortex gm-3, but oblique in fundi

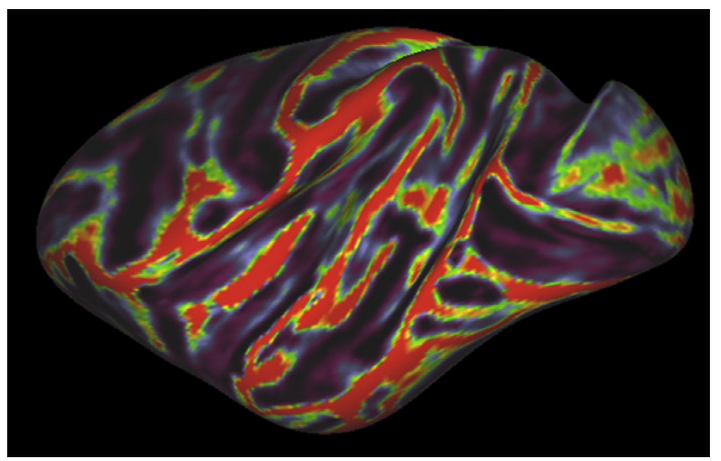
  tangential under fundi

# Discussion



- Histology, *ex vivo* & *in vivo* MRI:
  - peak radiality in crown (+)
  - tangential DTs in deep layers of the fundus (*)

- Tractography bias towards crown[1]
  - result of the gyral fibre pattern
  - seen in macaque and human data
  - model / algorithm improvements



Van Essen et al. (2014)

[1] for a discussion: Van Essen et al. (2014), 'Mapping Connections in Humans and Non-Human Primates: Aspirations and Challenges for Diffusion Imaging', In: Johansen-Berg, H., Behrens, T.E.J. (Eds.), 'Diffusion MRI: From Quantitative Measurement to In-vivo Neuroanatomy', pp. 337–358.

FMRIB
Oxford Centre for Functional MRI of the Brain

ERWIN L. HAHN INSTITUTE FOR MAGNETIC RESONANCE IMAGING

VIP Brain Networks

provincie overijssel

provincie Gelderland

Ministerie van Economische Zaken

MIRA
INSTITUTE FOR BIOMEDICAL TECHNOLOGY AND TECHNICAL MEDICINE

HBM HAMBURG 2014

# Thank you!

Lena Schäfer

Emil Nijhuis

Saad Jbabdi

Stam Sotiropoulos

Karla Miller

DCCN MR techniques

FMRIB Physics

Donders Institute
for Brain, Cognition and Behaviour

Radboud Universiteit Nijmegen

Radboudumc