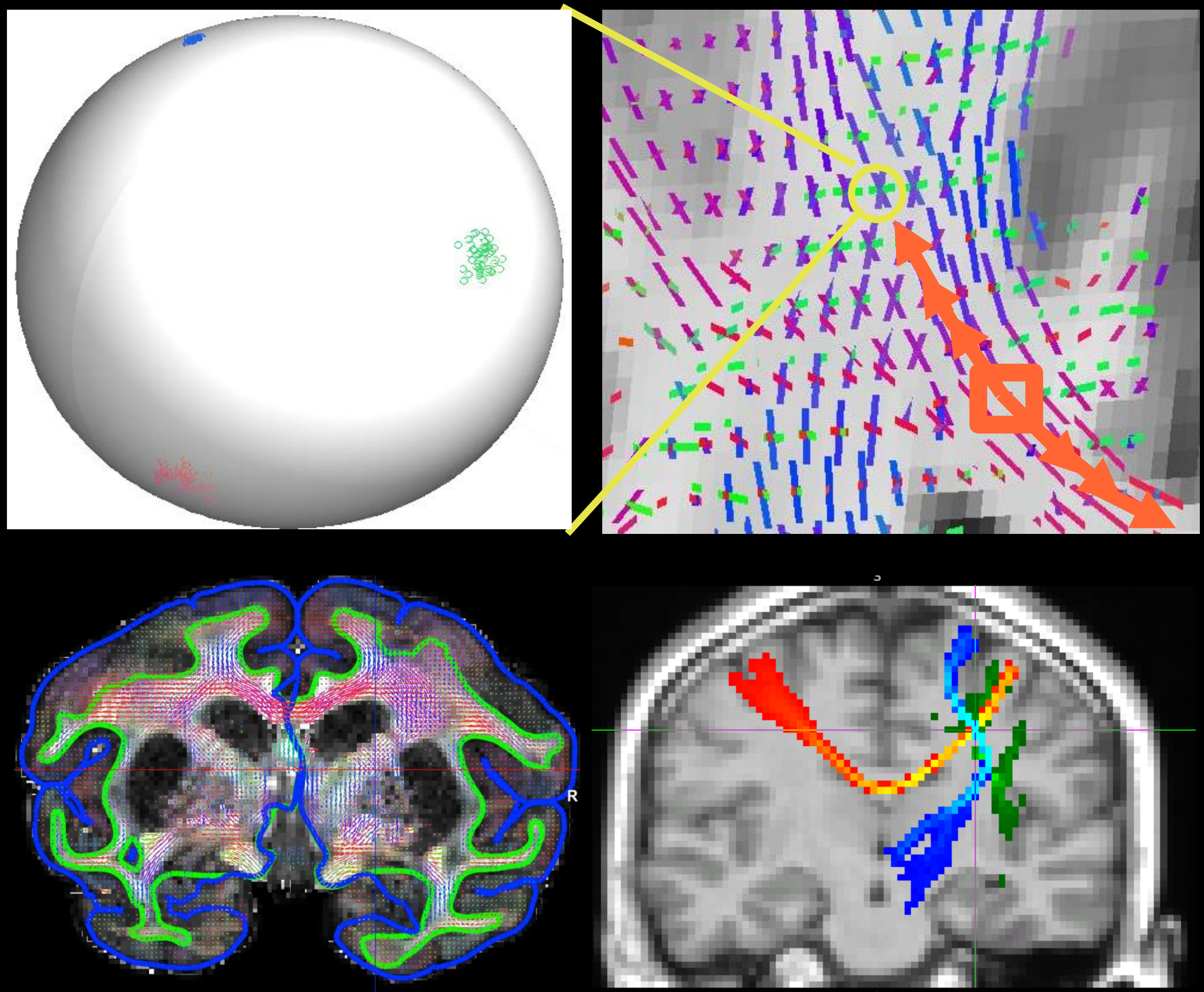
# Fiber orientations from diffusion MRI and histology in the macaque brain

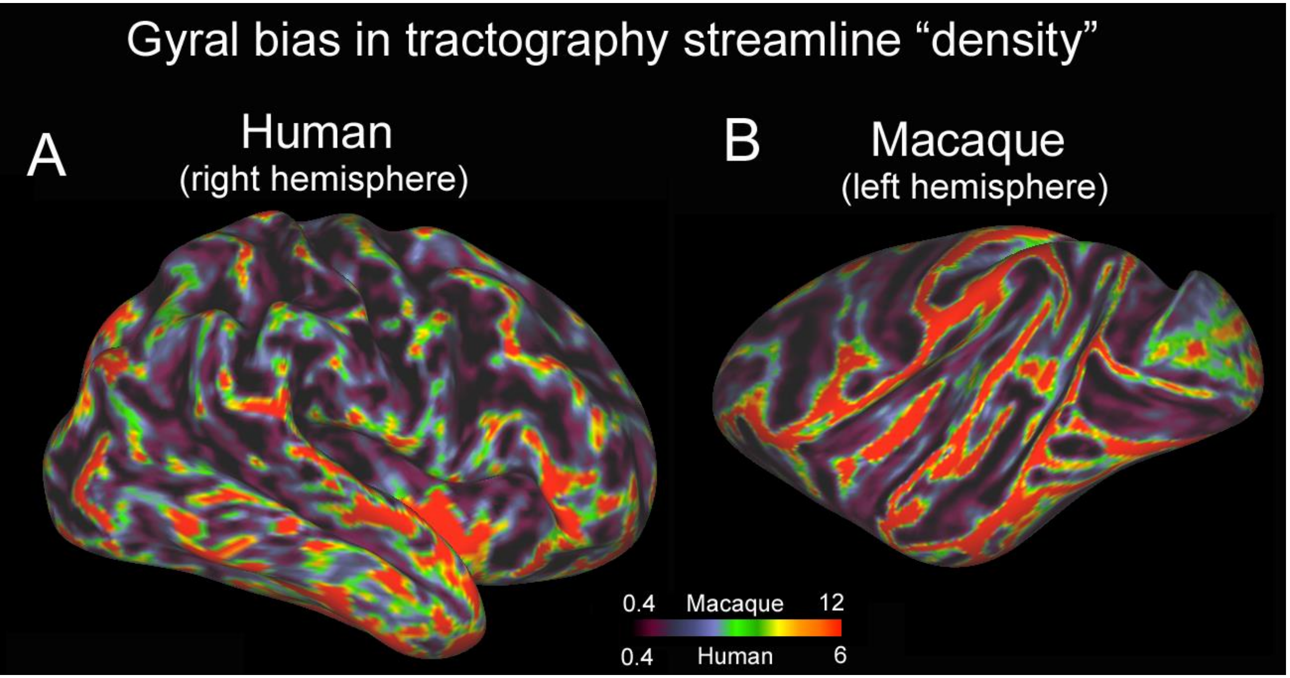
Charles Chen[1], Stamatios N. Sotiropoulos[2], Krikor Dikranian[1], David C. Van Essen[1], and Matthew F. Glasser[1]

1 Washington University in St. Louis

2 FMRIB, University of Oxford

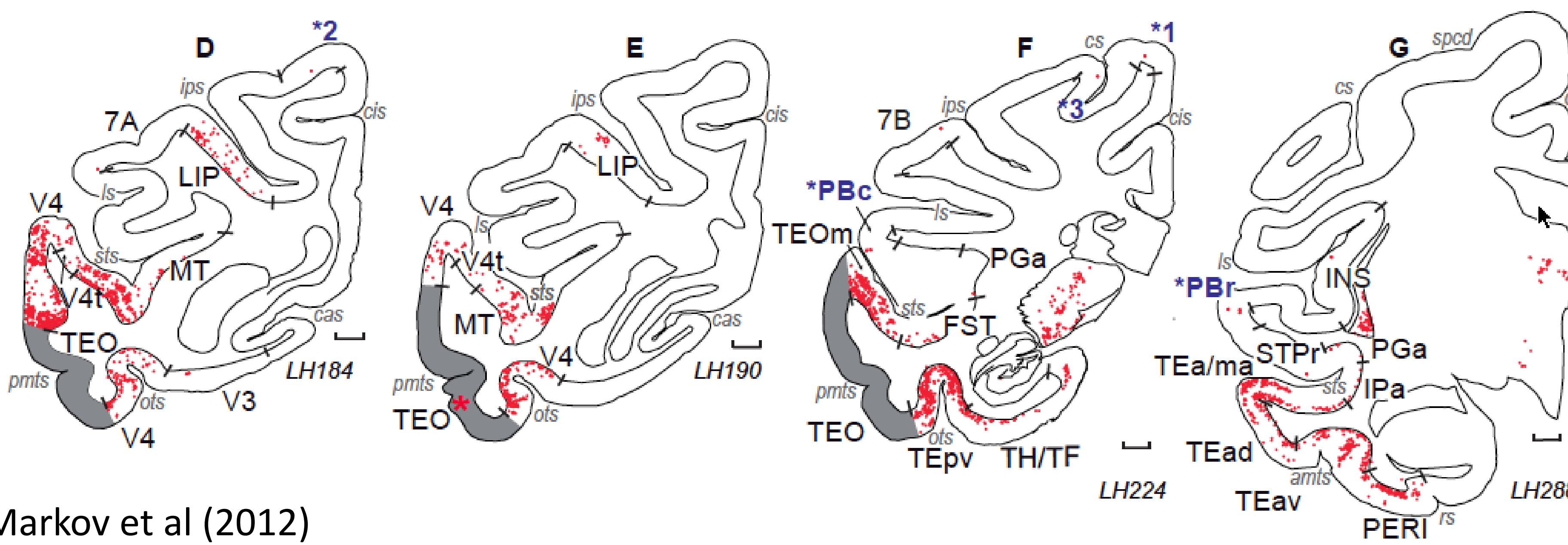
# Diffusion MRI and tractography





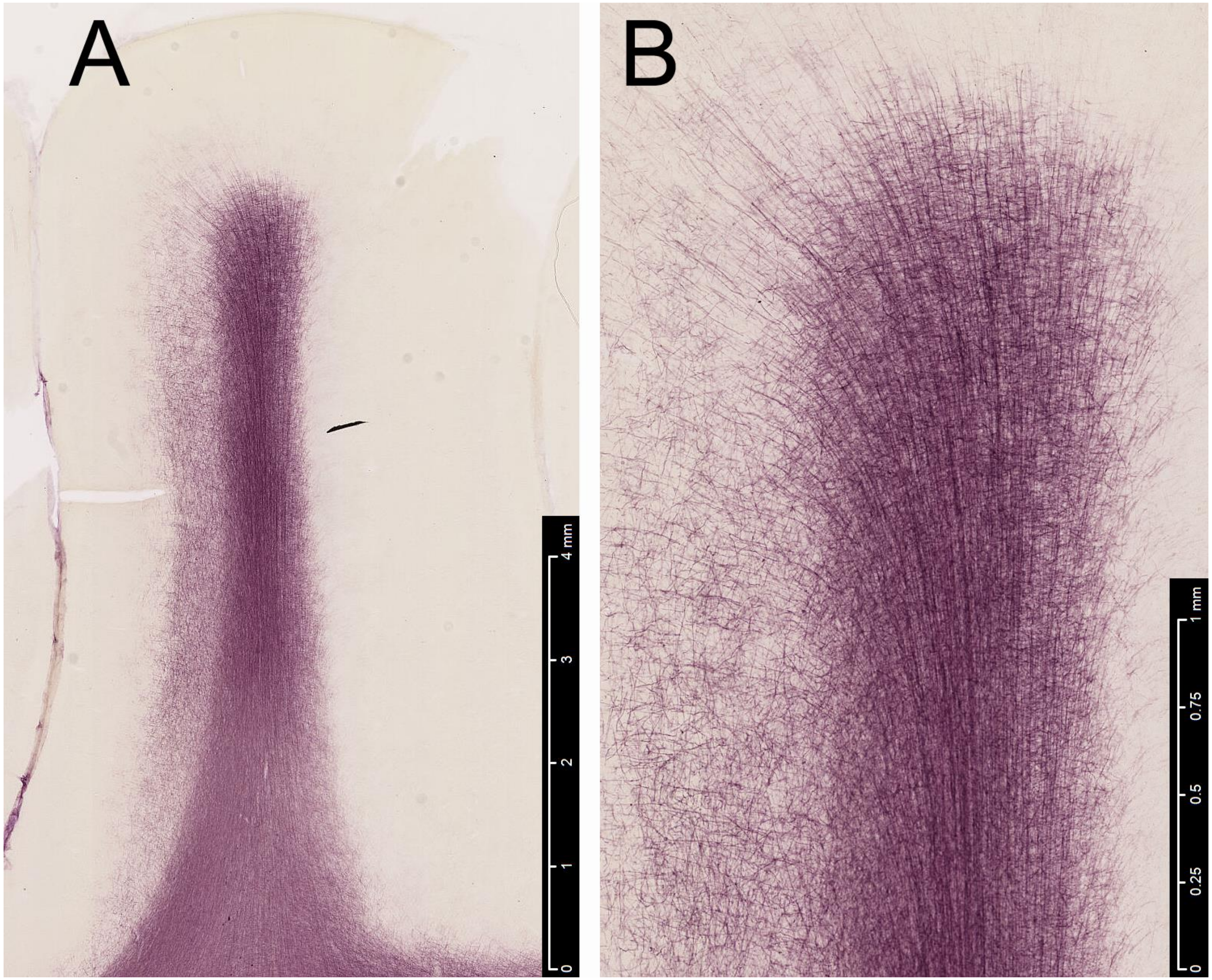

- Top : Streamline density maps from human and post-mortem macaque
- Bottom : Tracer injections from macaque

Van Essen et al (2013), in press



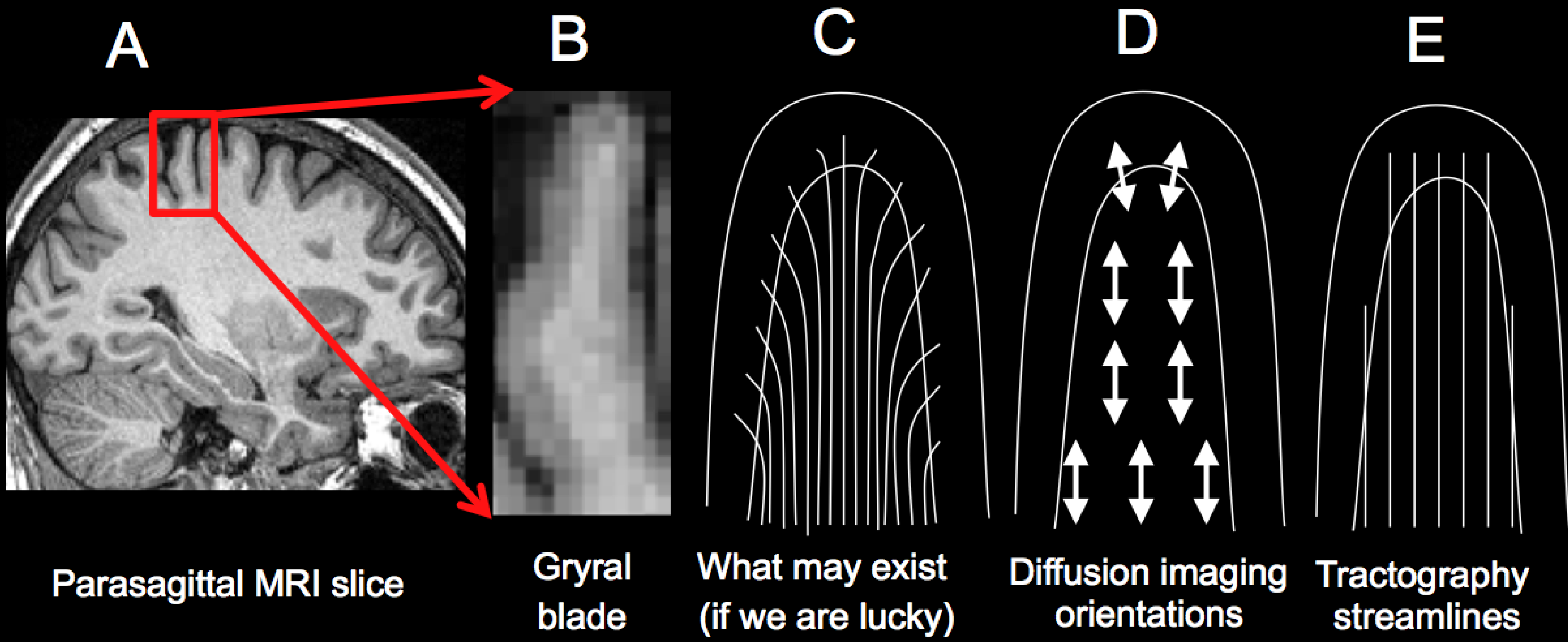

Markov et al (2012)

# Insights from histology

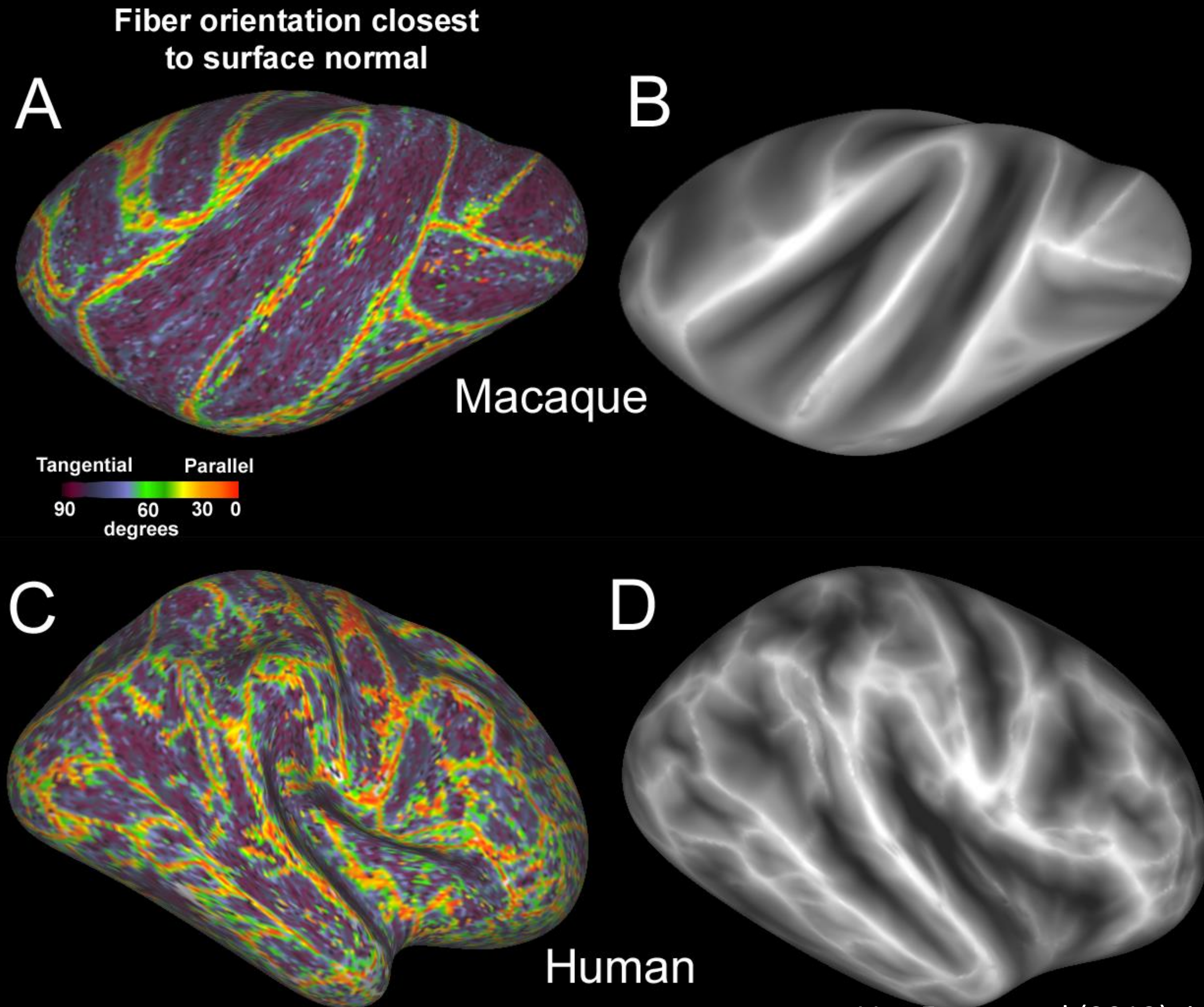



Van Essen et al (2013), in press

# Tractography predictions

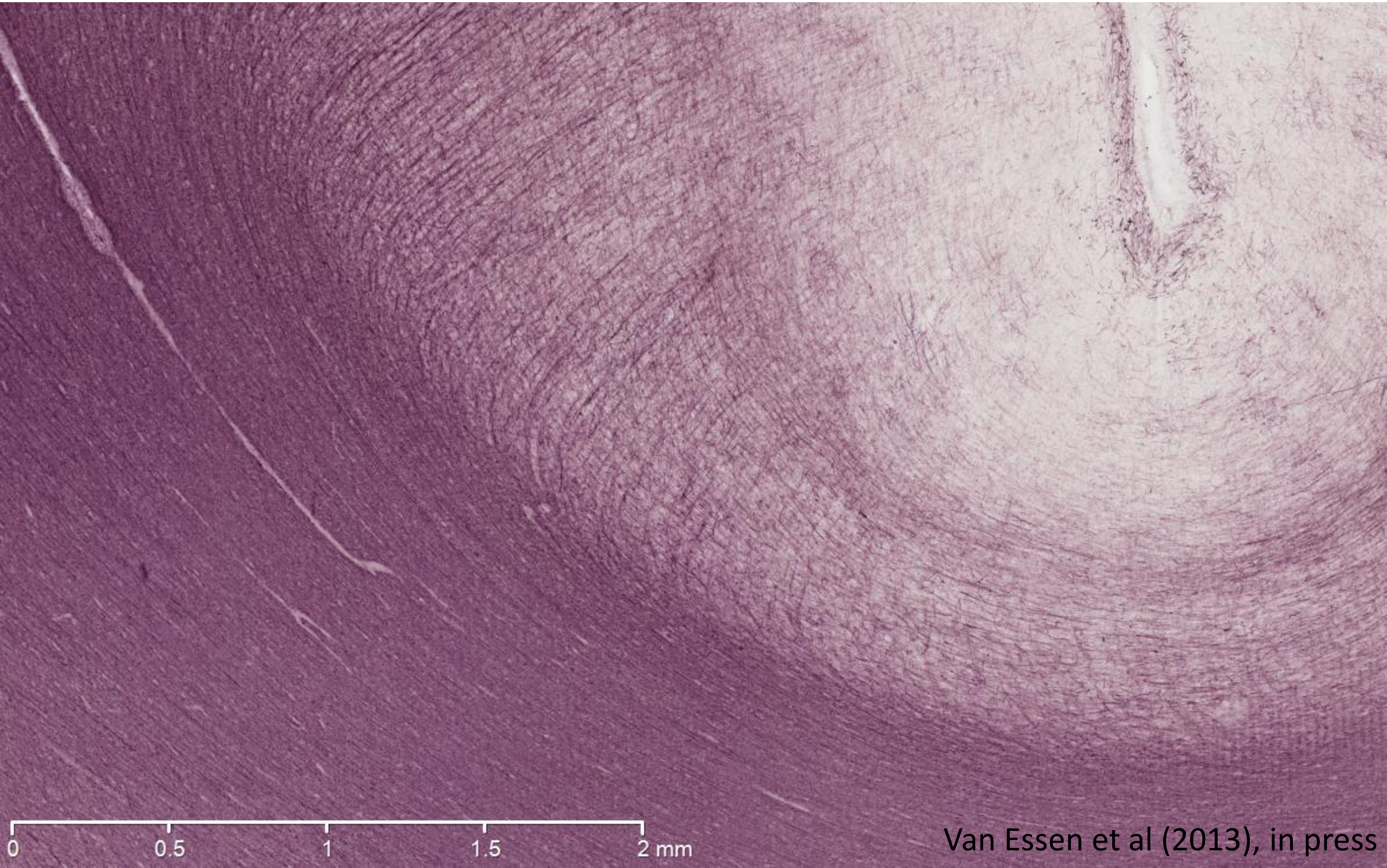



Van Essen et al (2013), in press



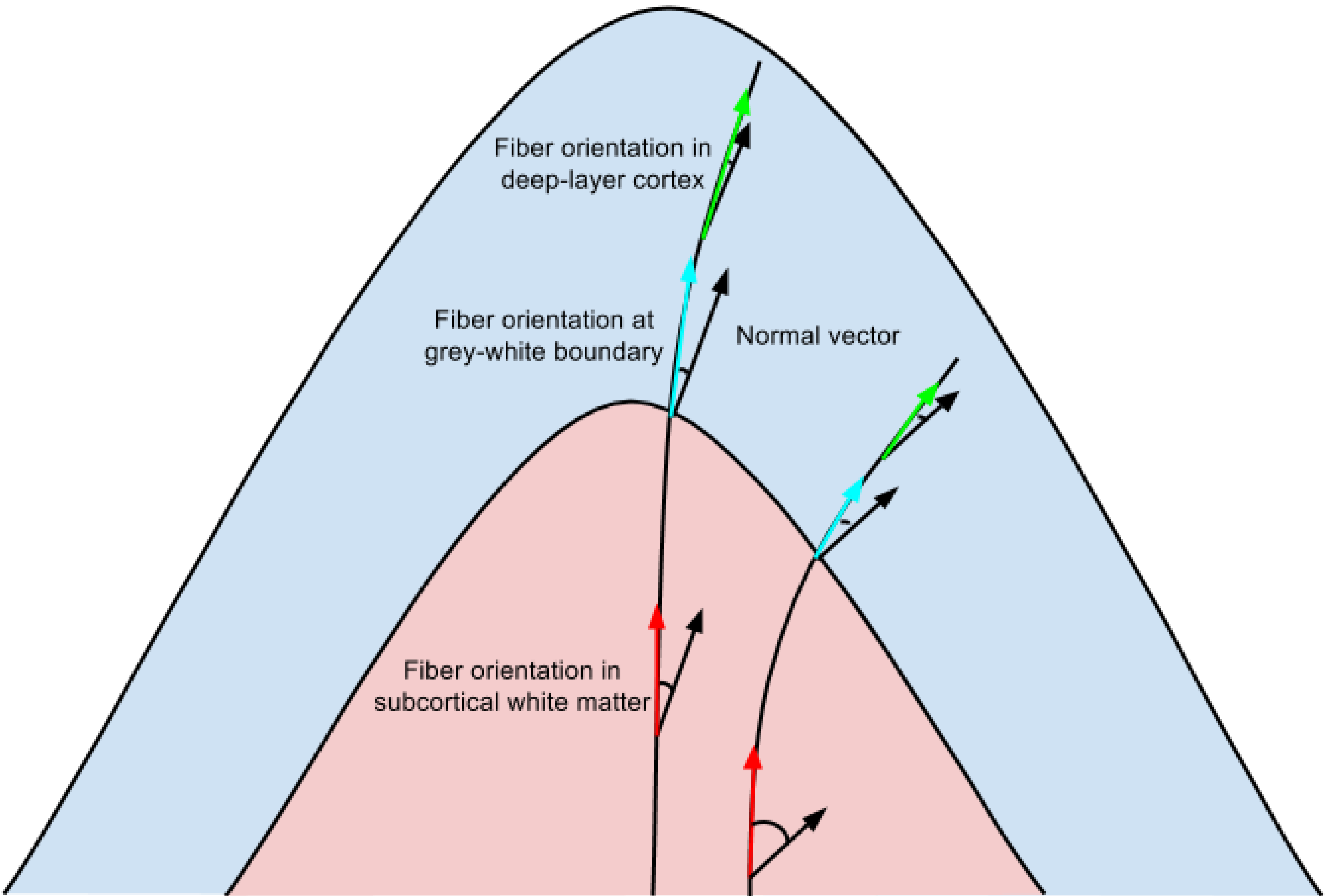

Van Essen et al (2013), in press

# Insights from histology

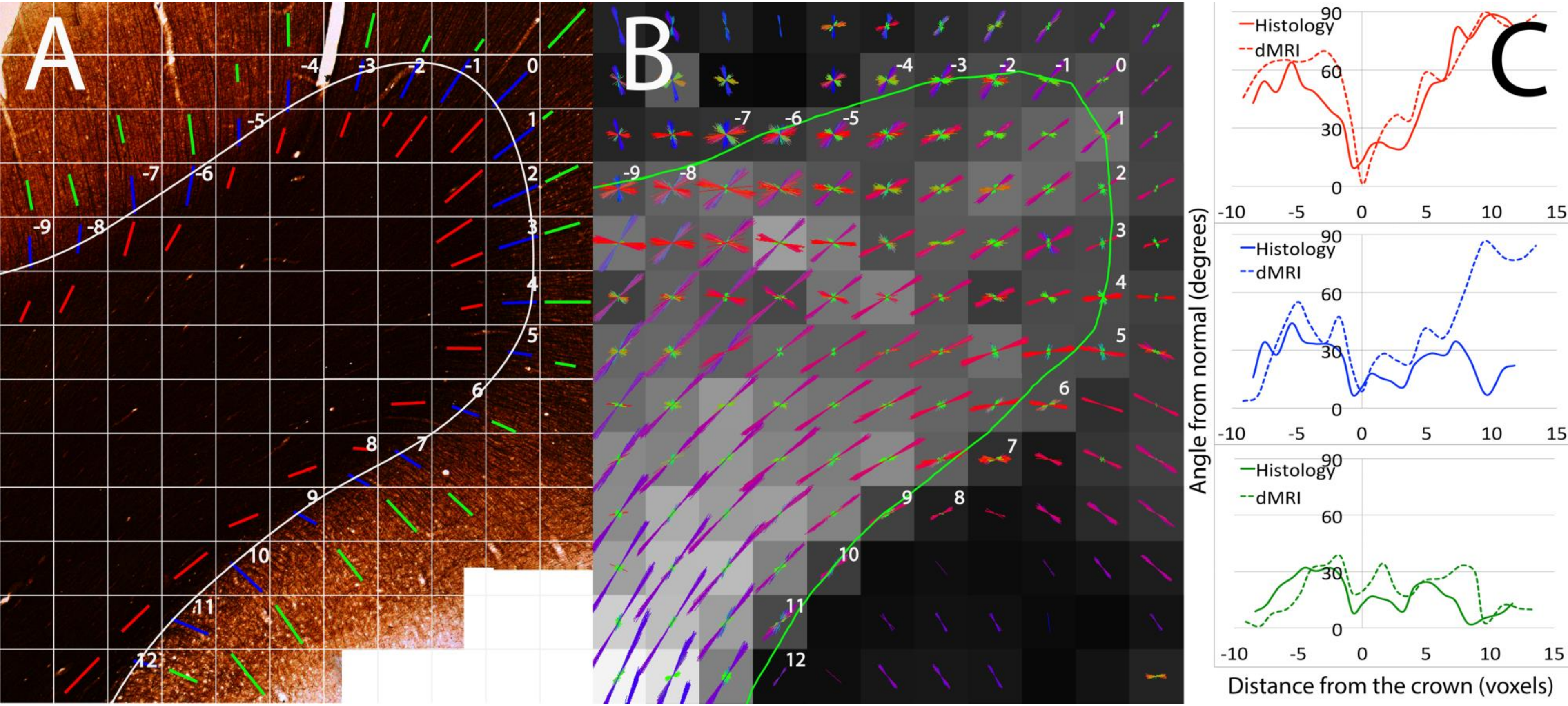



Van Essen et al (2013), in press

# Fiber orientations near cortex



# Comparing DTI and histology




Van Essen et al (2013), in press

# Summary

- Diffusion MRI and tractography are powerful tools for generating connectomes
- However, they suffer from technical limitations, such as resolving gyral biases
- Tractography algorithms can be informed through histological data
- Fiber estimates can only be improved through better acquisition

# Supplementary Slides

# Imaging Methods

- Histology

  A postnatal day 6 macaque brain. Sections were immunostained with antibody to myelin basic protein (MBP, MAB395, Millipore) and scanned on a NanoZoomer 2 (Hamamatsu) scanning microscope equipped with Olympus lens at 20X (0.9225 um x 0.9225 $um^2$ resolution).

  A modified Gallyas myelin stained section from an adult macaque brain was also digitized in a similar fashion*.

- Post-mortem Diffusion MRI**

  A diffusion-weighted MRI dataset of a perfusion-fixed adult macaque brain was acquired using a 4.7 T Bruker scanner.

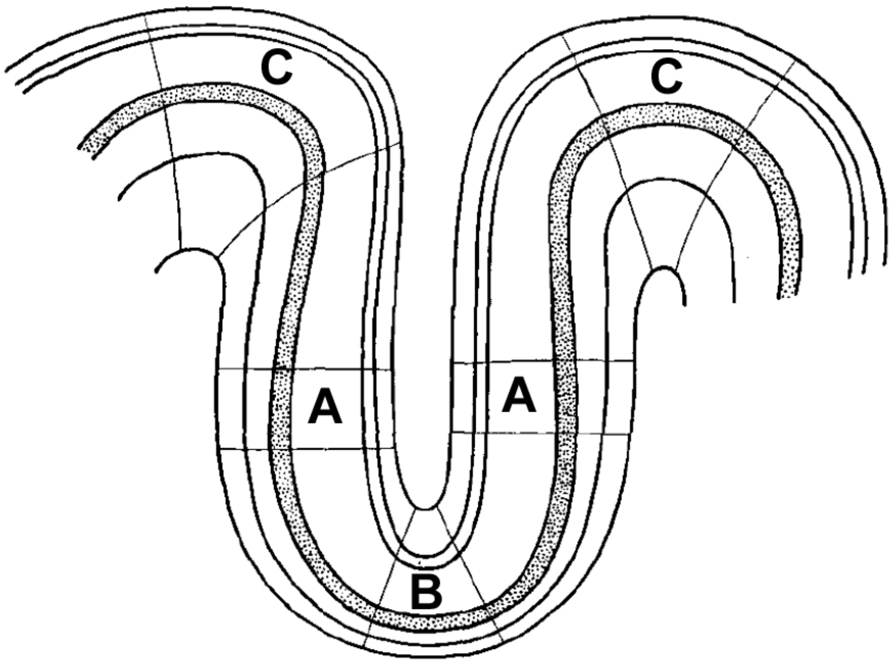
  Scans were performed using a 3D multi-shot, spin-echo sequence (with in-plane resolution 430 × 430 $um^2$, TE = 33 ms, TR = 350 ms)

  120 DW directions at b=8000 $s/mm^2$ , 17 b=0 $s/mm^2$ , 128 slices with a thickness of 430 um.

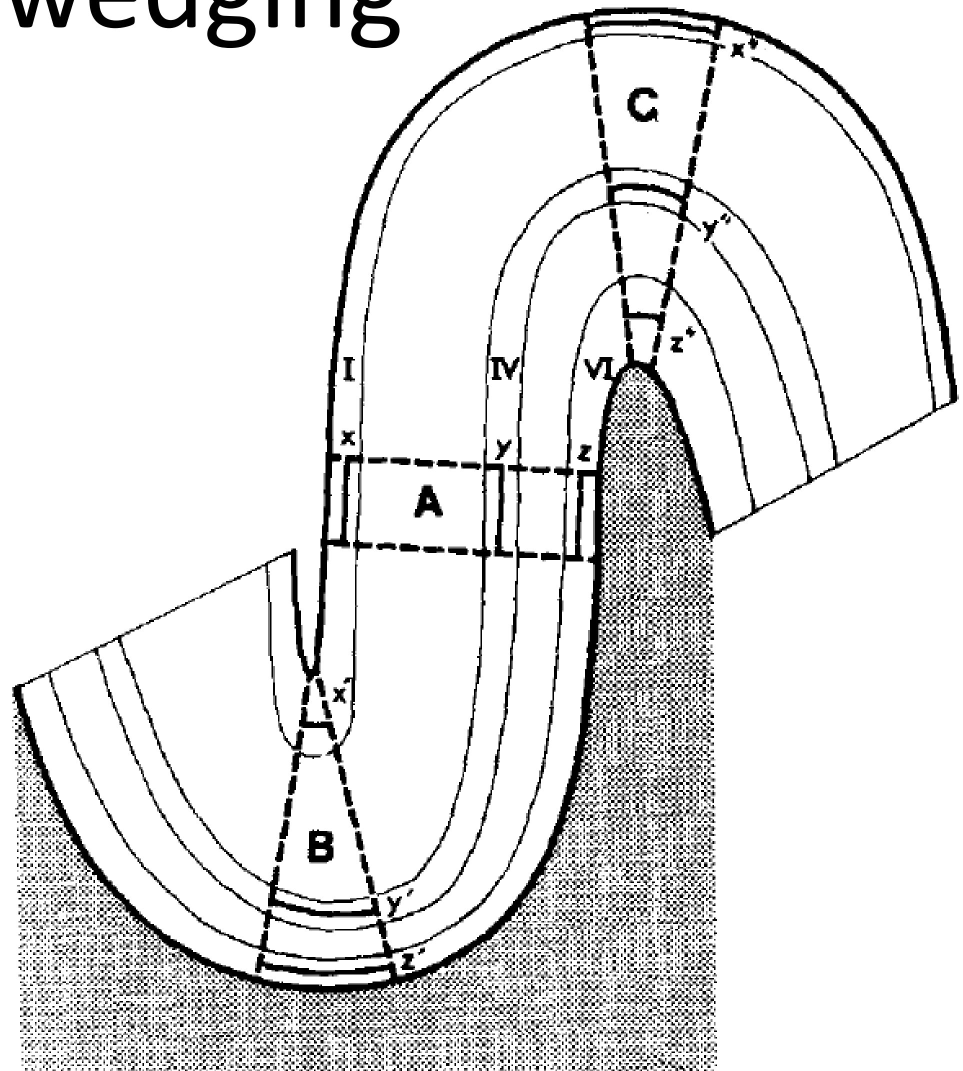
* Data are courtesy of JL Price, WashU, School of Medicine

** Data from [D'Arceuil et al, NeuroImage 35:553-565, 2007]

# Cortical wedging

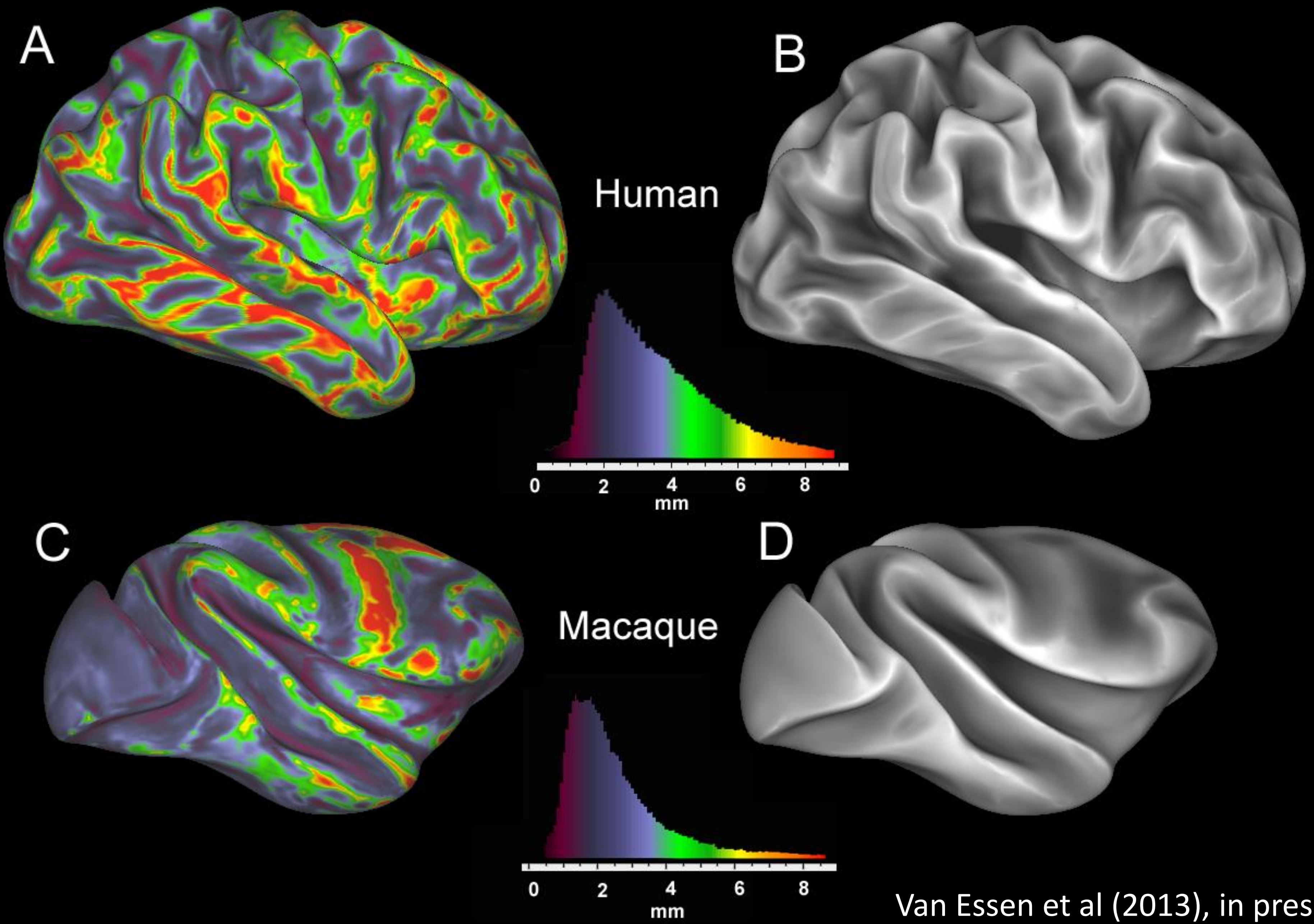



Bok (1929) (via Waehnert et al., 2013)




Van Essen and Maunsell, (1980)

# Gyral vs sulcal wedges:
## Cortical volume per unit area of gray/white surface

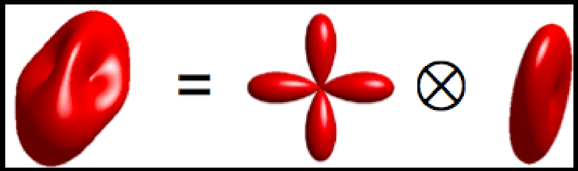



Van Essen et al (2013), in press

# Parametric Spherical Deconvolution

- Assuming mono-exponential decay in q-space:
  [Behrens et al, MRM 2003], [Kaden et al, NeuroImage 2007]

$$S_k = S_0 \left[ (1-f)\exp(-b_k d) + f \int_0^{2\pi}\int_0^{\pi} H(\theta,\phi)\exp(-b_k d(\mathbf{g}_k^T \mathbf{v})^2)\sin\theta d\theta d\phi \right]$$



- If the fODF is modelled as a Delta function (or sum of Delta functions), we get the *ball & stick model* [Behrens et al, MRM 2003, NeuroImage 2007]:

$$S_k = S_0 \left[ (1-f)\exp(-b_k d) + f\exp(-b_k \boldsymbol{g}_k^T \boldsymbol{v})^2) \right]$$

# Structure Tensor Analysis

Given an image $I(x, y)$ and its spatial gradient vector

$$\nabla I = [I_x \;\; I_y]^T$$

spatial partial derivative along $y$

(Gaussian smoothed)

The 2x2 *gradient tensor* is: $Q = \nabla I \cdot \nabla I^T = [q_{ij}]$

The 2x2 *structure tensor* is: $S = [s_{ij}], \;\; s_{ij} = g_{\sigma,w} * \{q_{ij}\}$

Gaussian filter with window size $w$

and spatial scale $\sigma$

The eigenvector of the structure tensor associated with the smallest eigenvalue gives the *coherence* direction.

[Weickert, Int J Comp Vis, 1999]

# Comparing DTI and Histology