(Modern) Brain anatomy for cognitive neuroscientists

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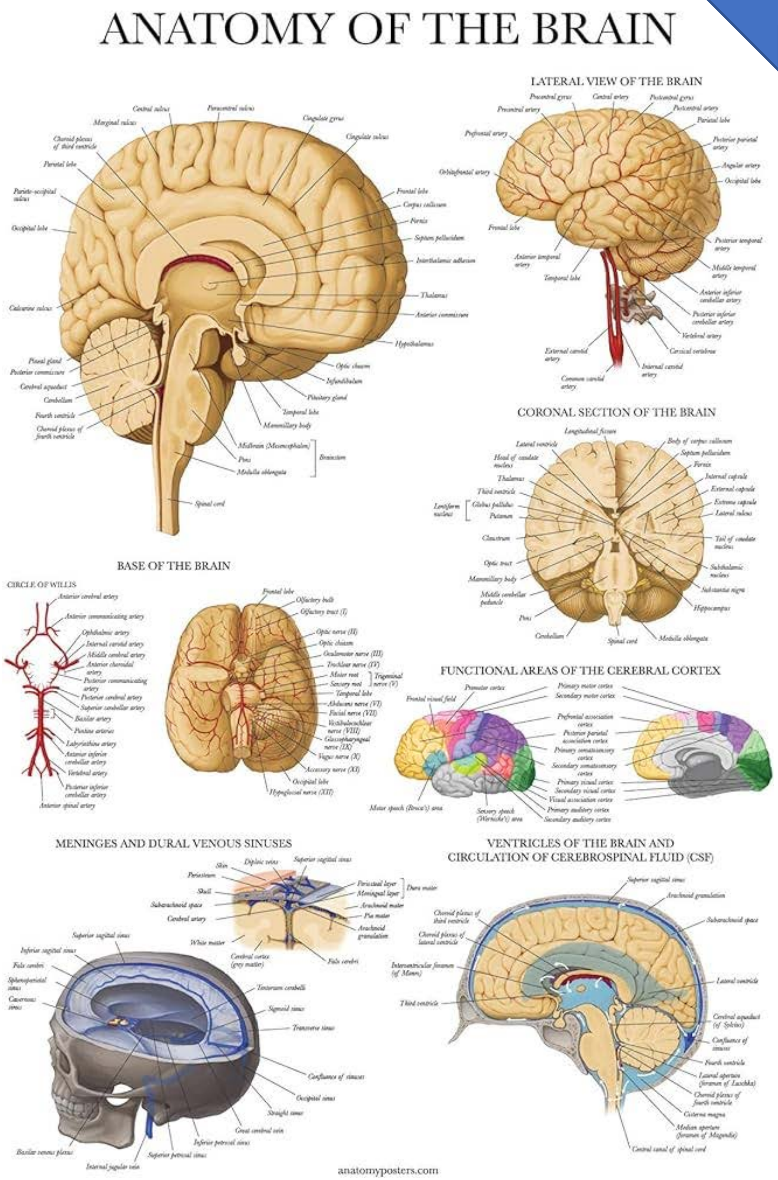
University of Cambridge

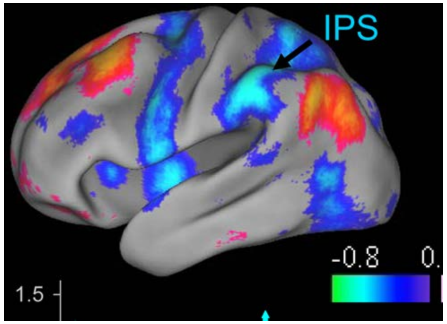
Textbook

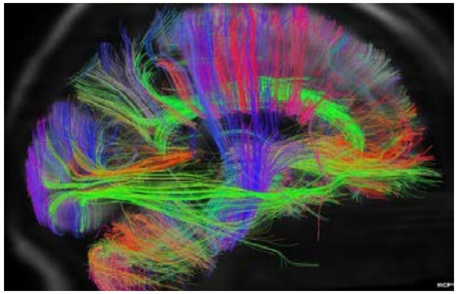


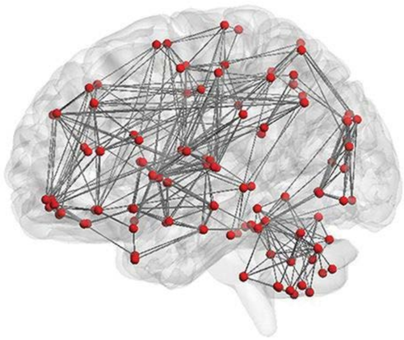
How to link them?

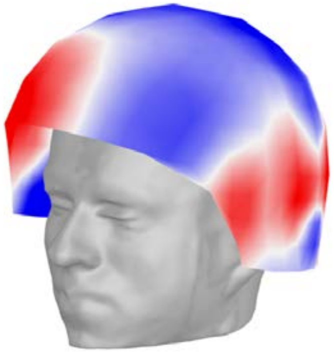
Modern

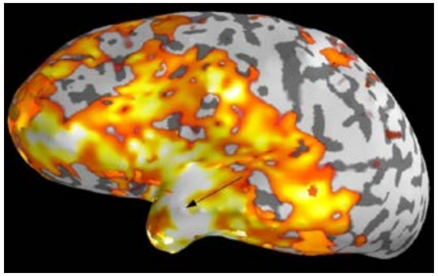
Brain imaging



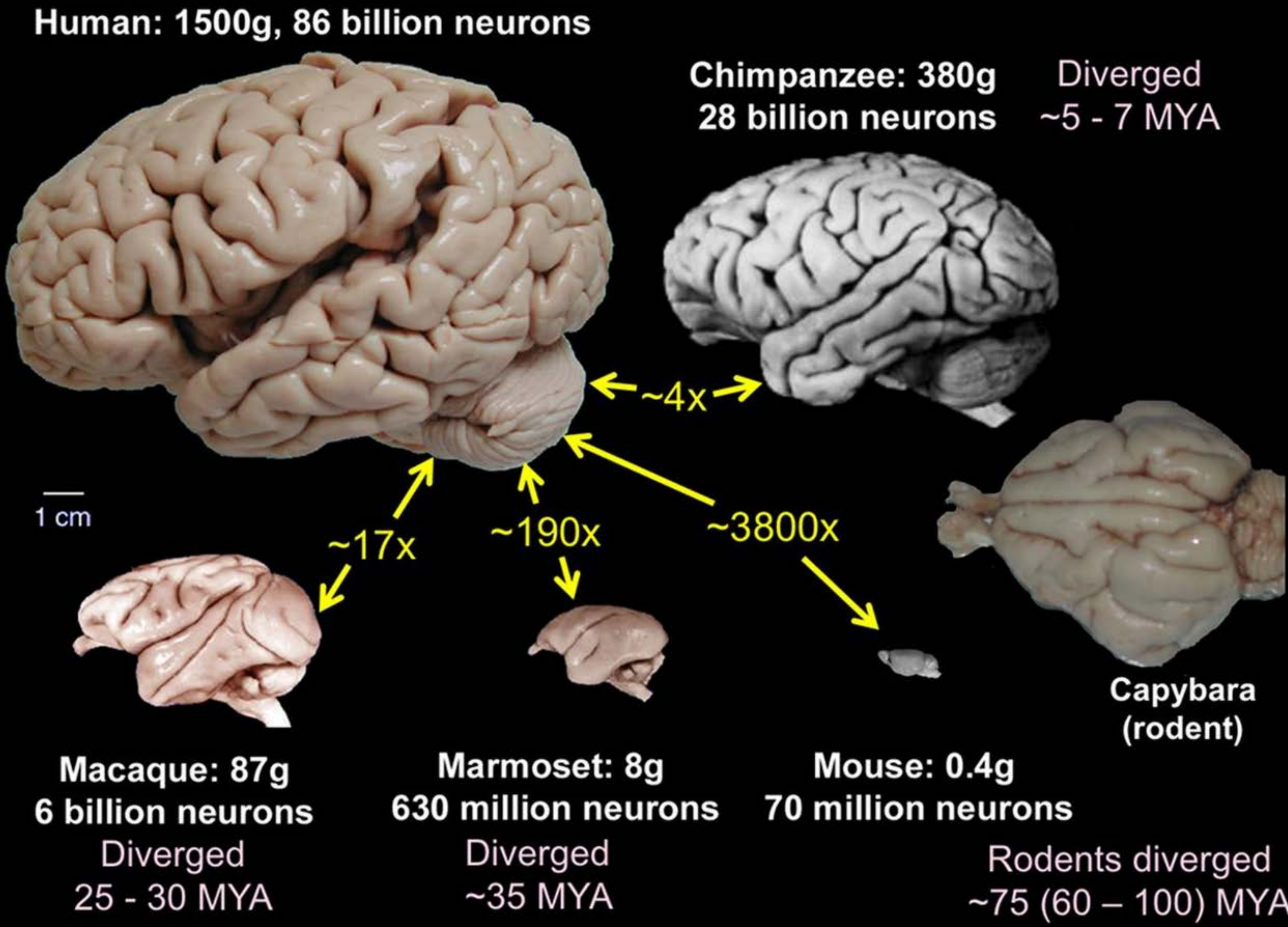








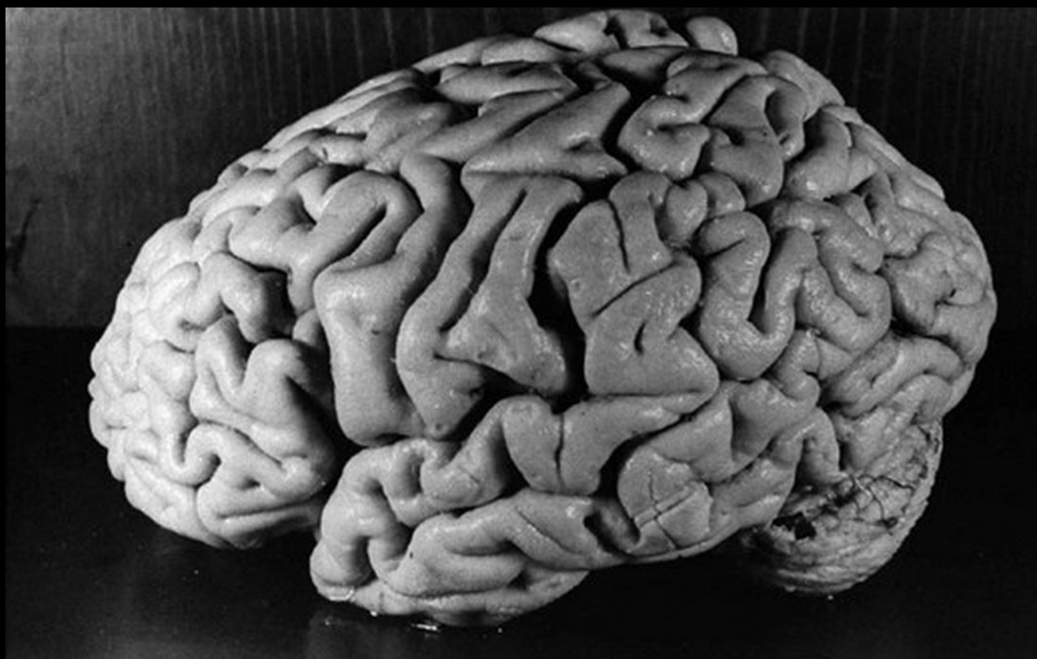
Evolutionary context



Van Essen et al PNAS 2019

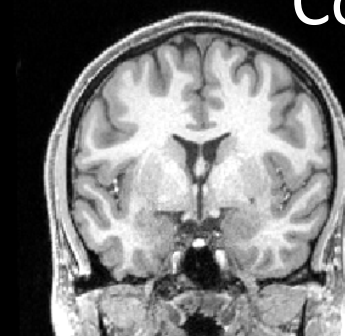
Cortex

Basic MRI landmarks

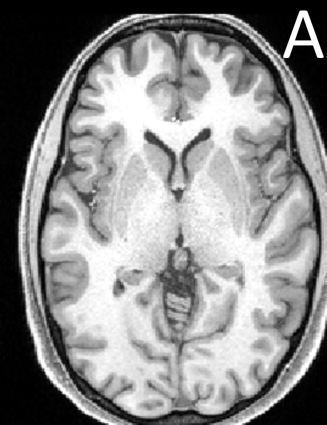


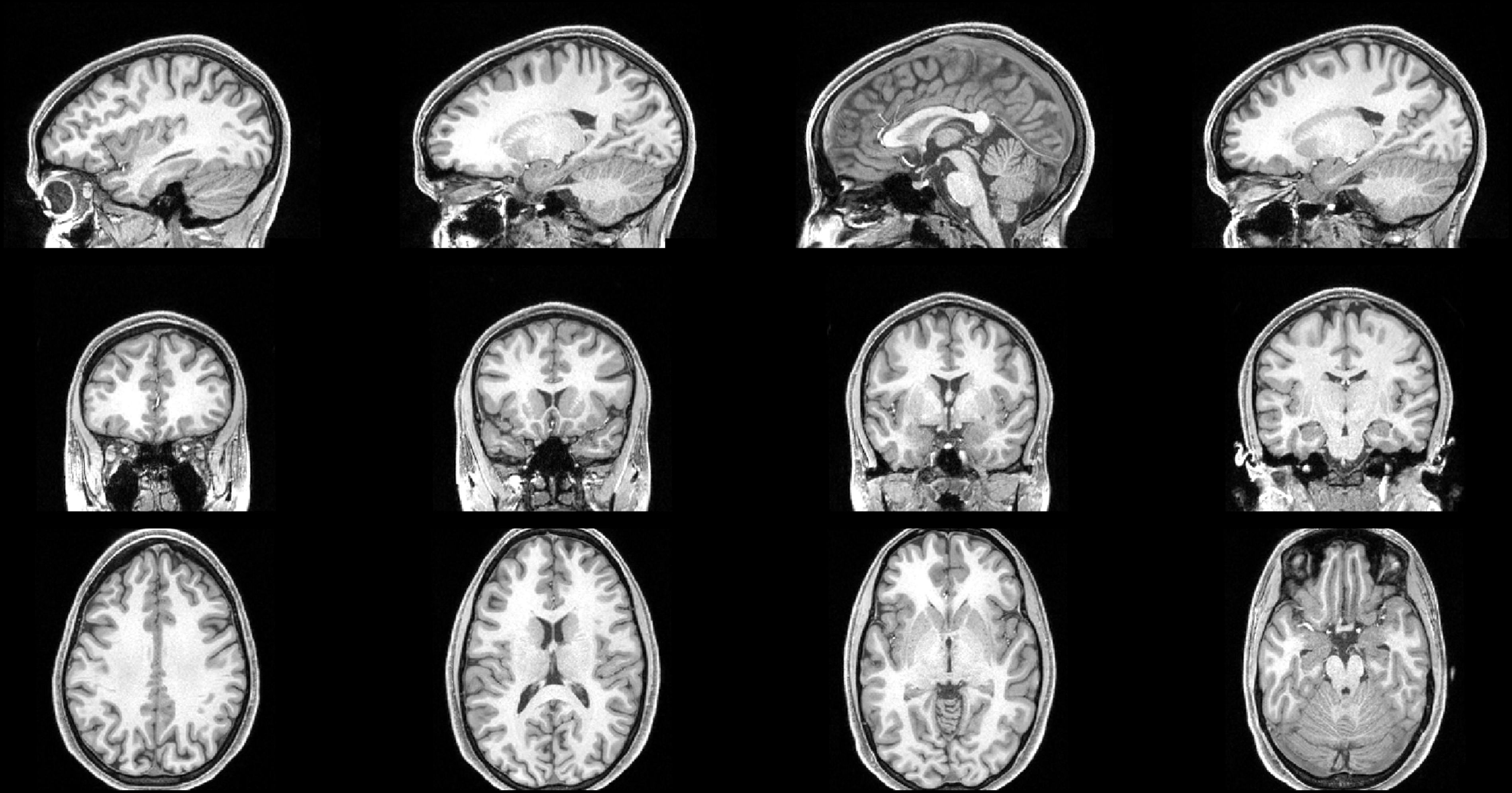
Sagittal

Coronal

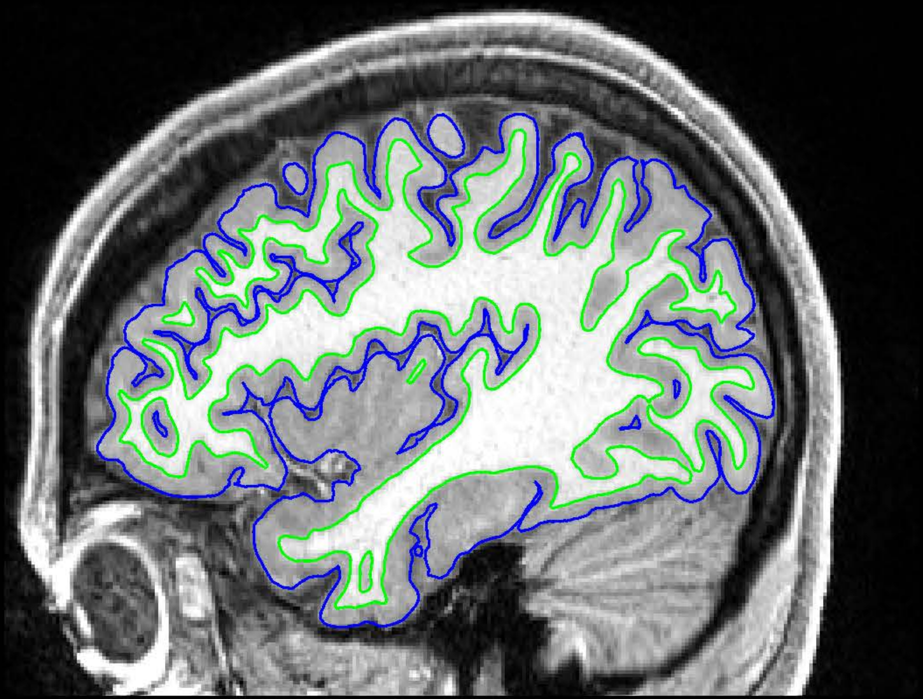


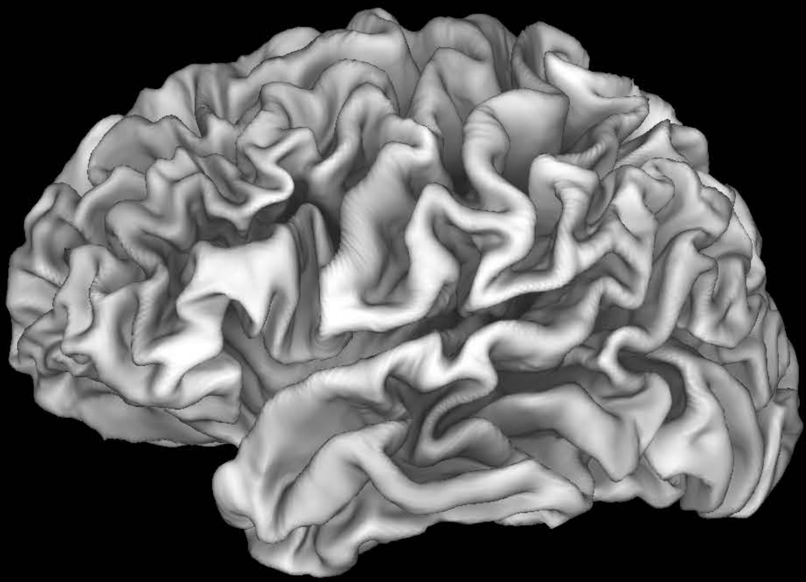
Axial





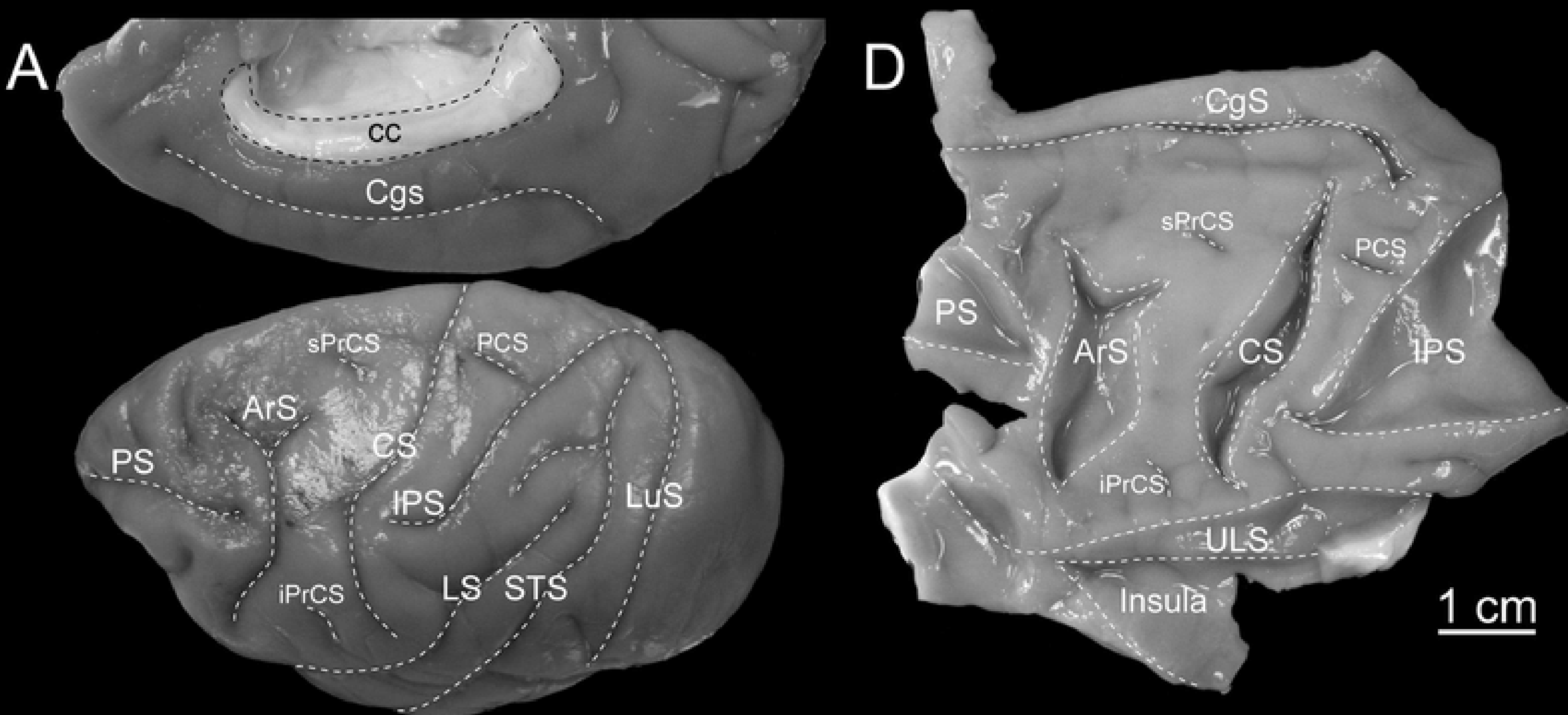
Cortical surface 3D reconstruction



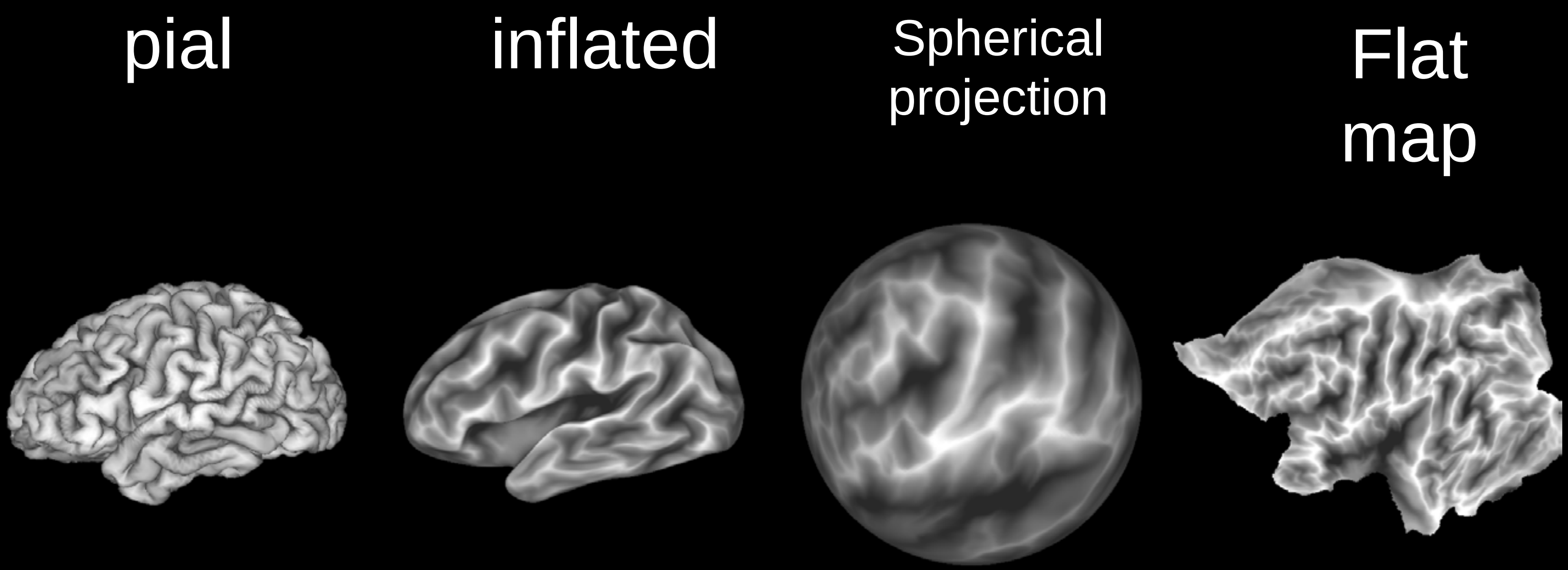


Example subject from HCP-style data scanned at CBU

Non-human primate flat cortical surface



Human example



Cortical layers

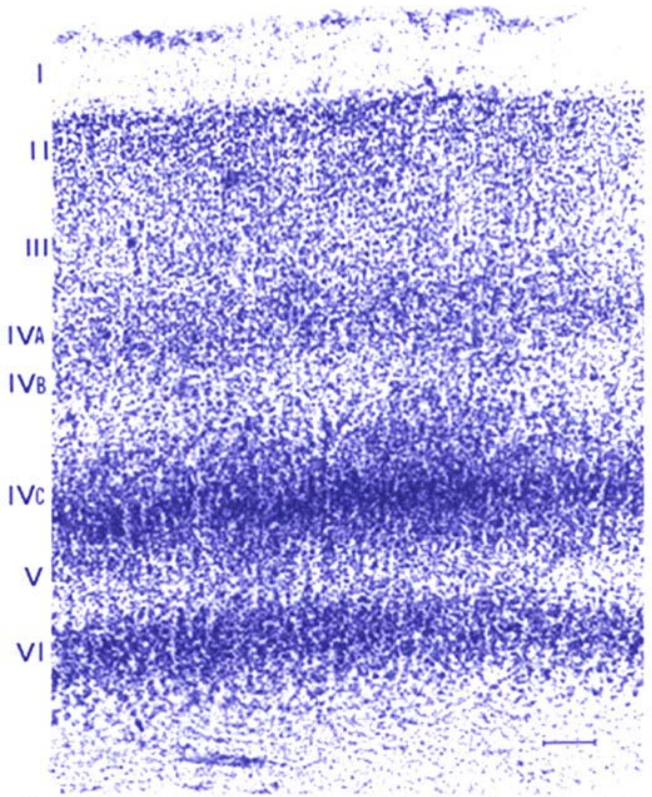
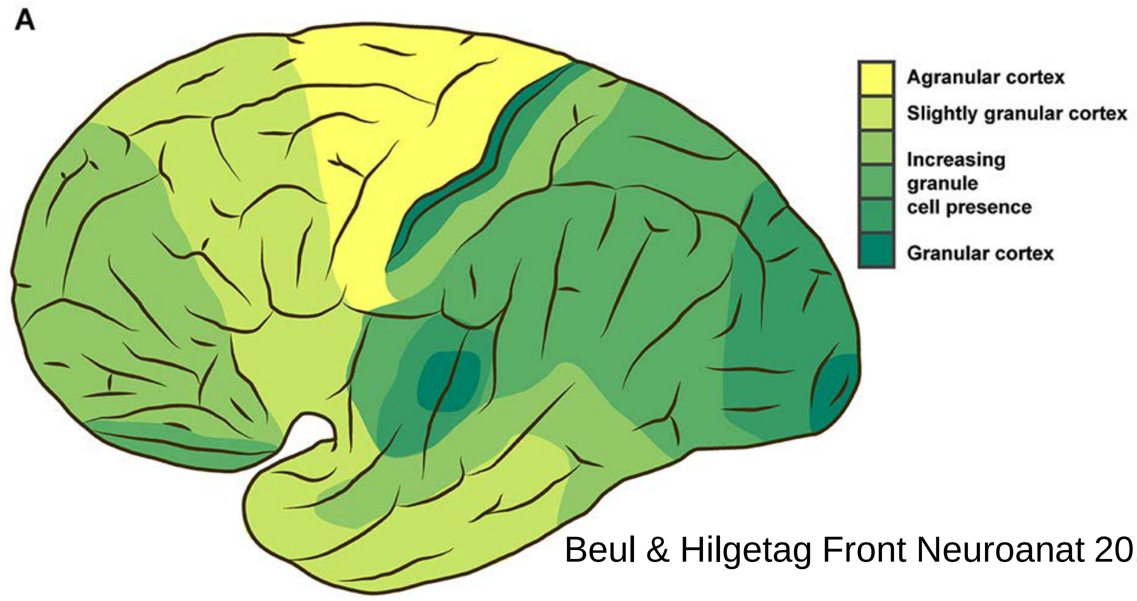


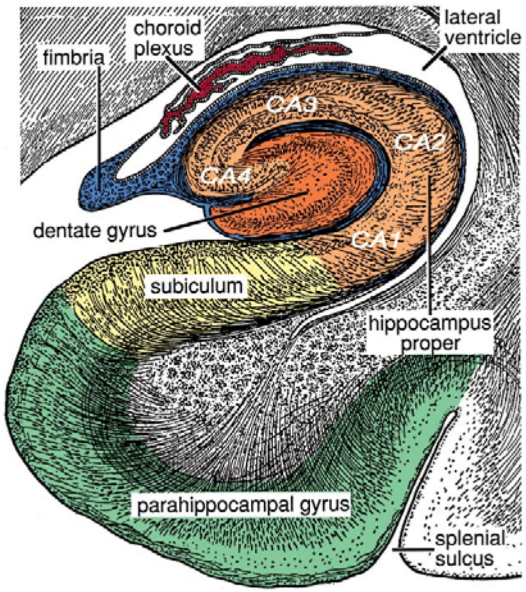
Figure 13. Nissl stain of the visual cortex reveals the different layers I through VI quite clearly.

https://webvision.med.utah.edu/

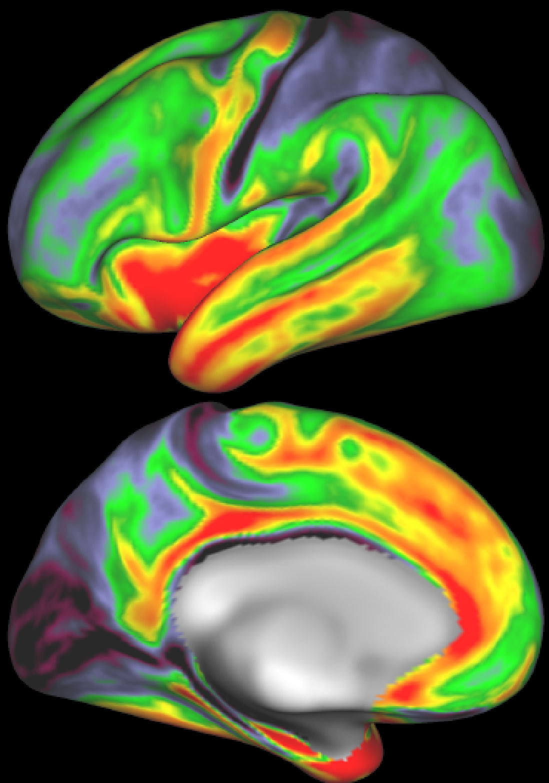


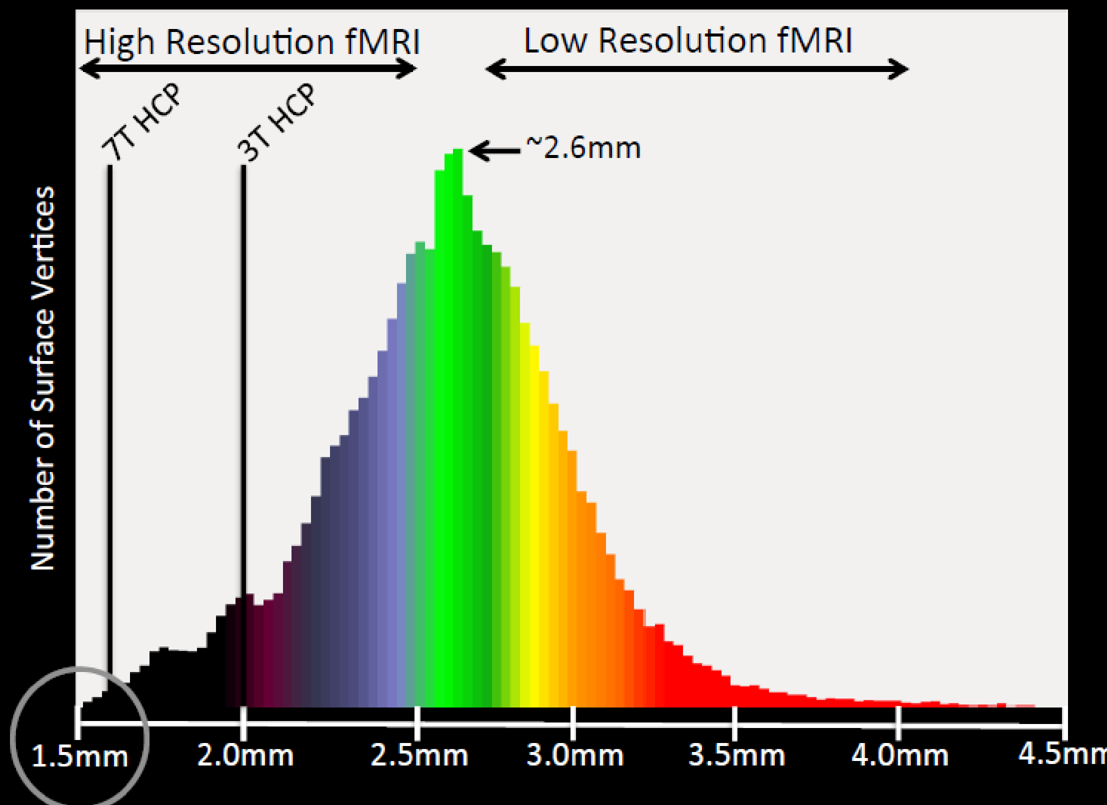
Beul & Hilgetag Front Neuroanat 2015

Hippocampus is a cortical structure



Cortical Neuroanatomy Drives Spatial Resolution Choices for Acquiring HCP-style MRI Data

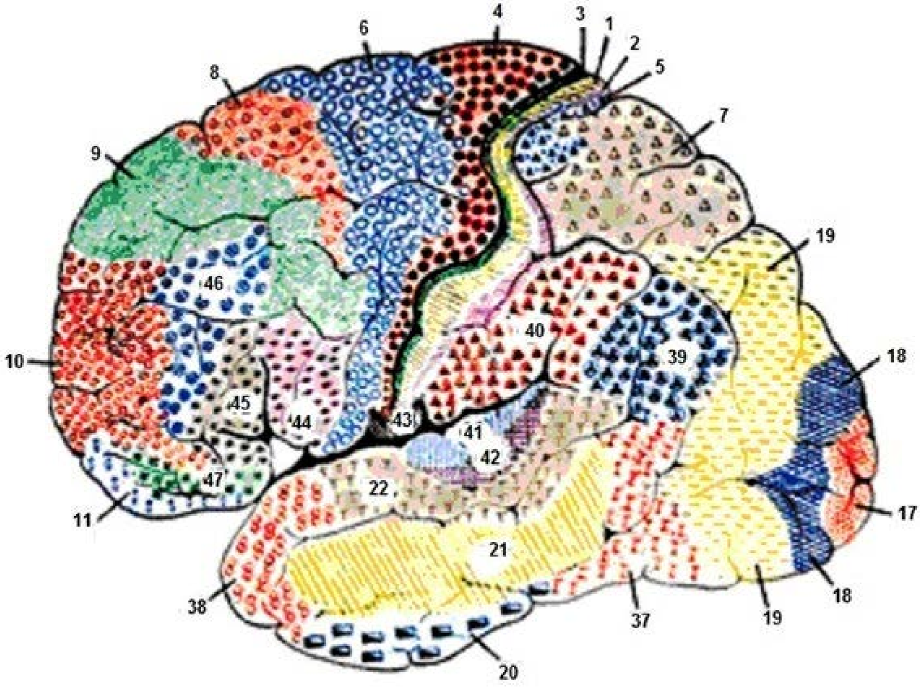




- Mean thickness of cortex: ~2.6mm
- Minimum thickness of cortex: ~1.6mm
- HCP 3T: 2.0mm resolution, 1 frame / 0.72s
- HCP 7T: 1.6mm resolution, 1 frame / 1.0s

- Other Useful Reference Points
  - 1.3mm (two lamina analysis possible)
  - 0.8mm (2 voxels for all of cortex)
- High temporal resolution is ~1.0s or less

Defining a cortical area: Cytoarchitecture



Brodmann (1909)

Area V1 (17)

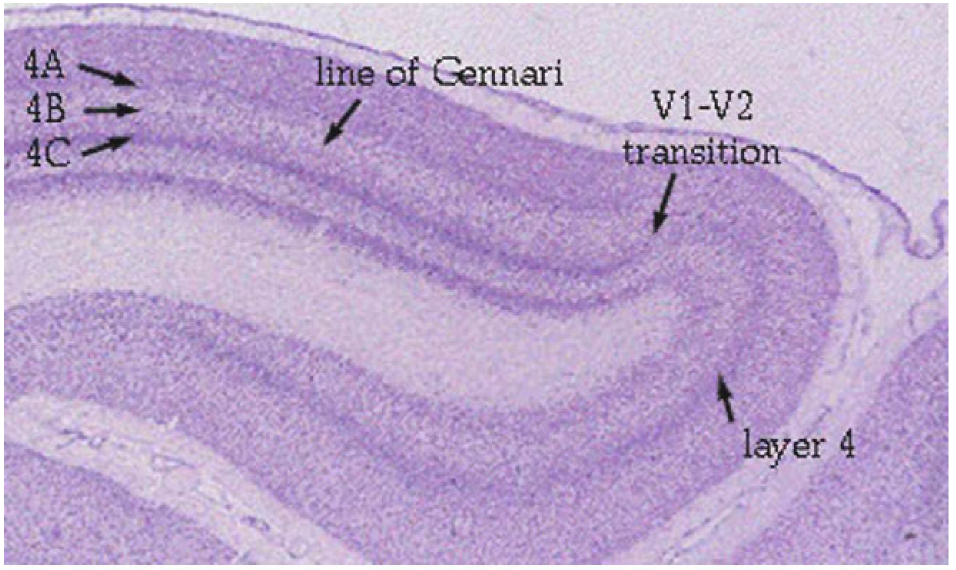
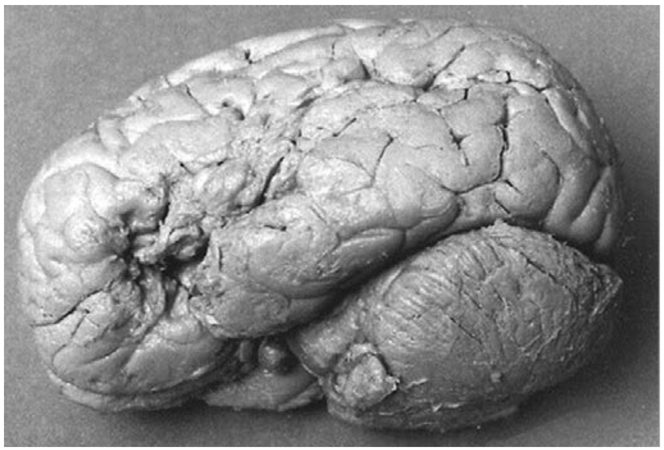
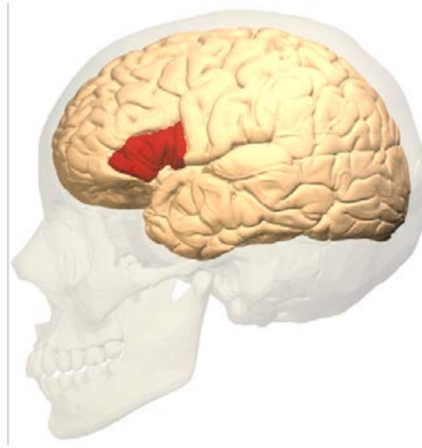


Figure 9. Nissl stained section of the visual cortex to show the border between area 17 (V1) and area 18 (V2).

https://webvision.med.utah.edu/

Functional lesions: Broca's area



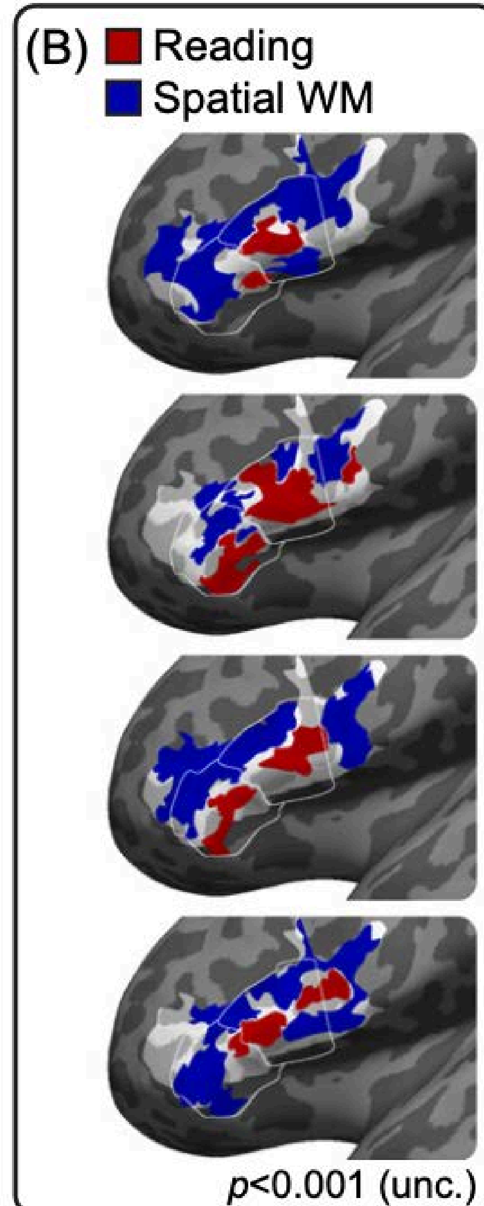


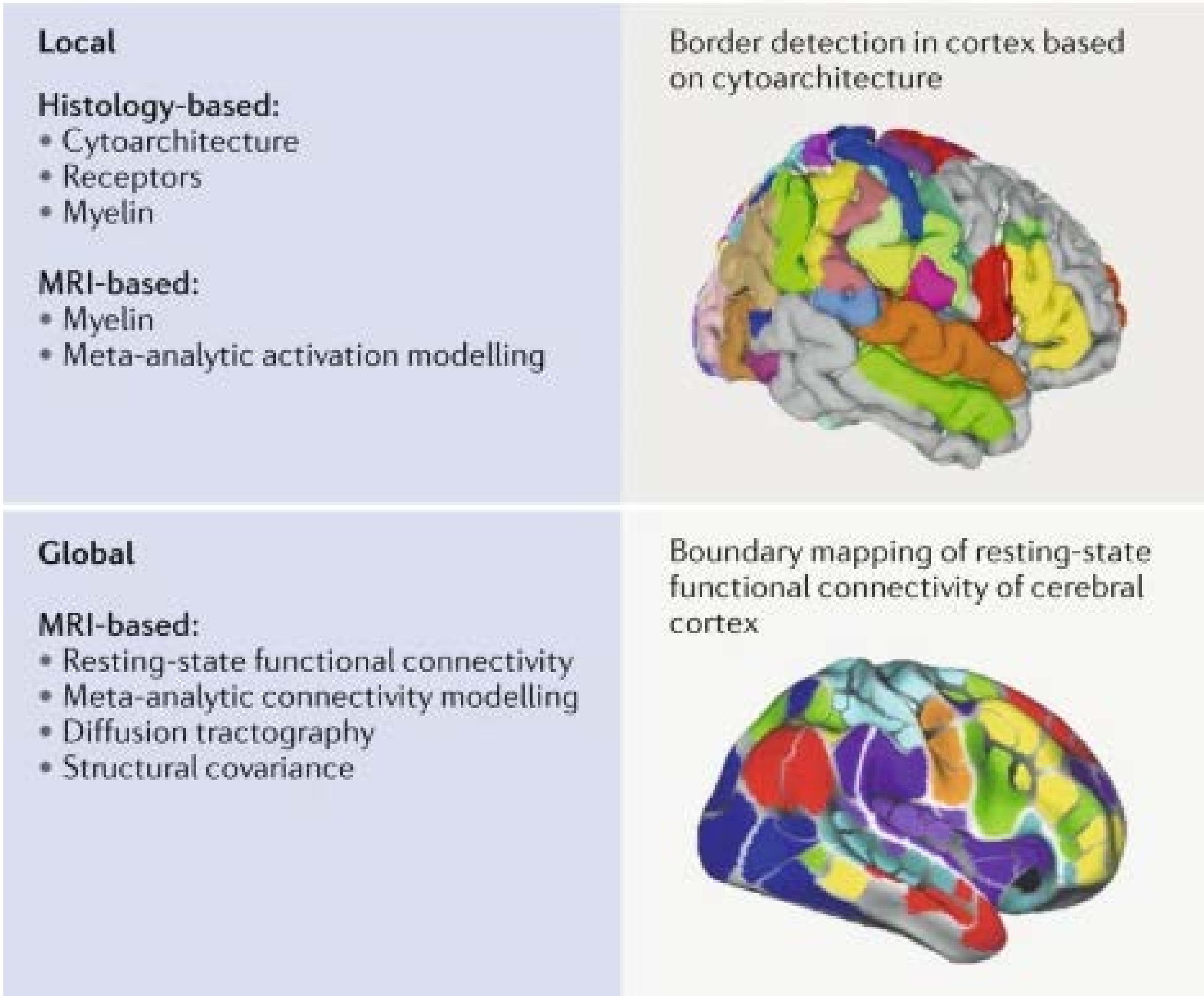
Trends in Cognitive Sciences

Opinion

Broca's Area Is Not a Natural Kind

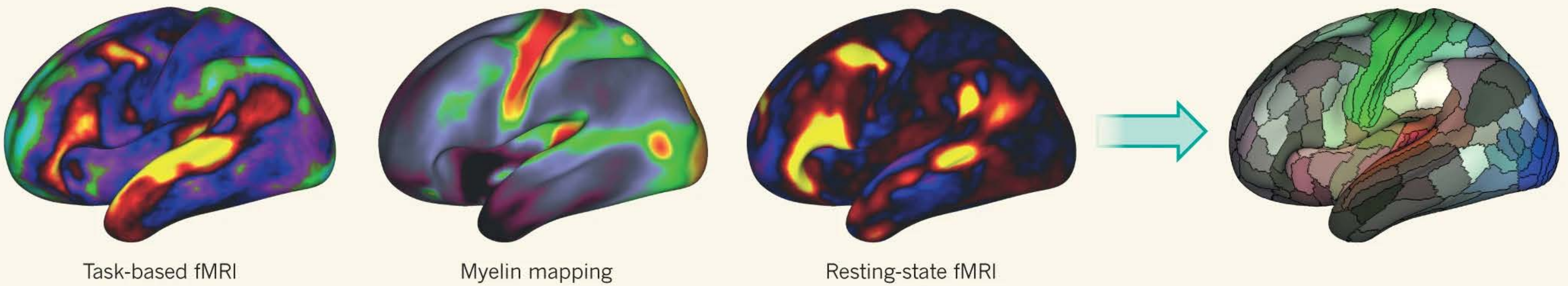
Evelina Fedorenko[1,*] and Idan A. Blank[2,*]

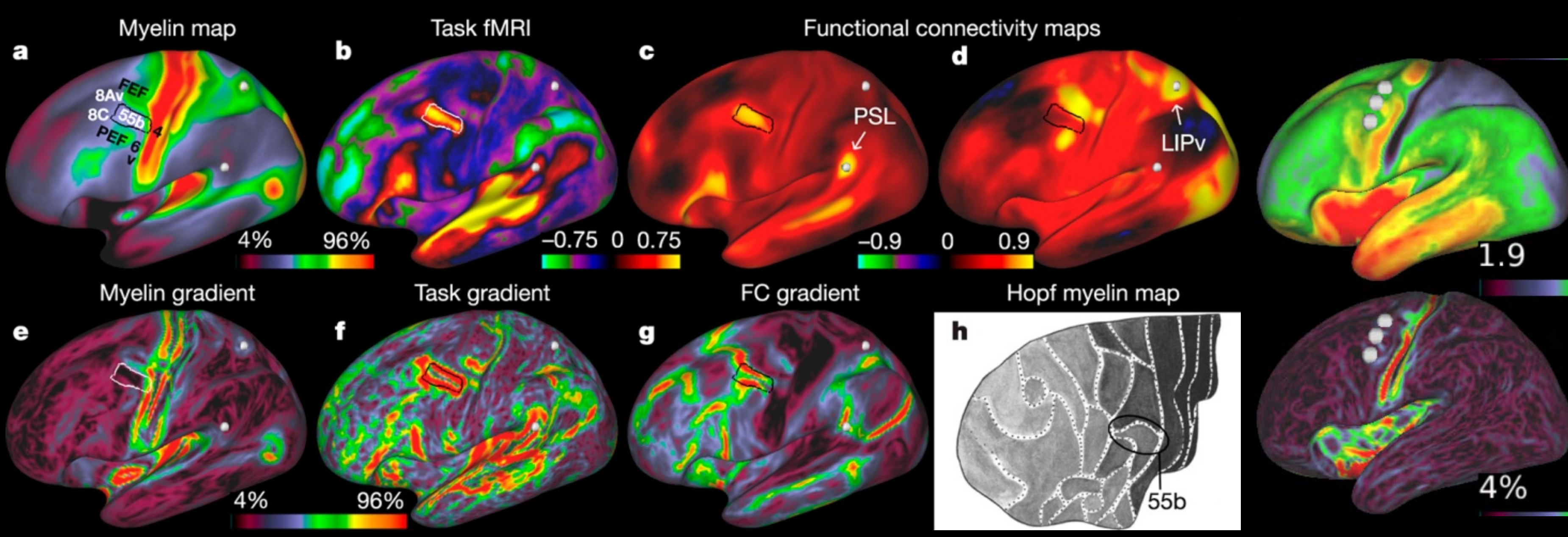




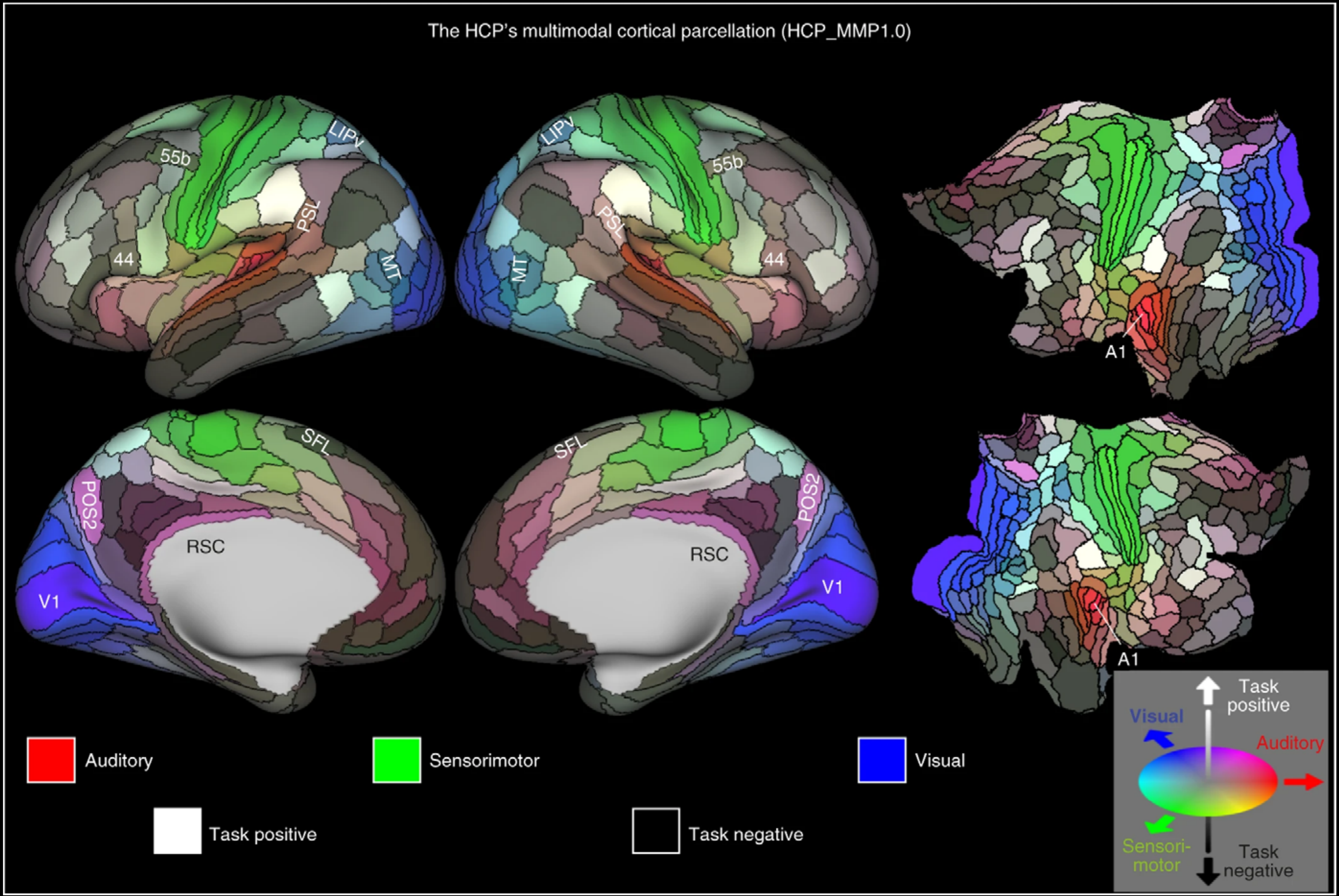
Eickhoff et al Nature Rev Neuro 2018

Multimodal atlases

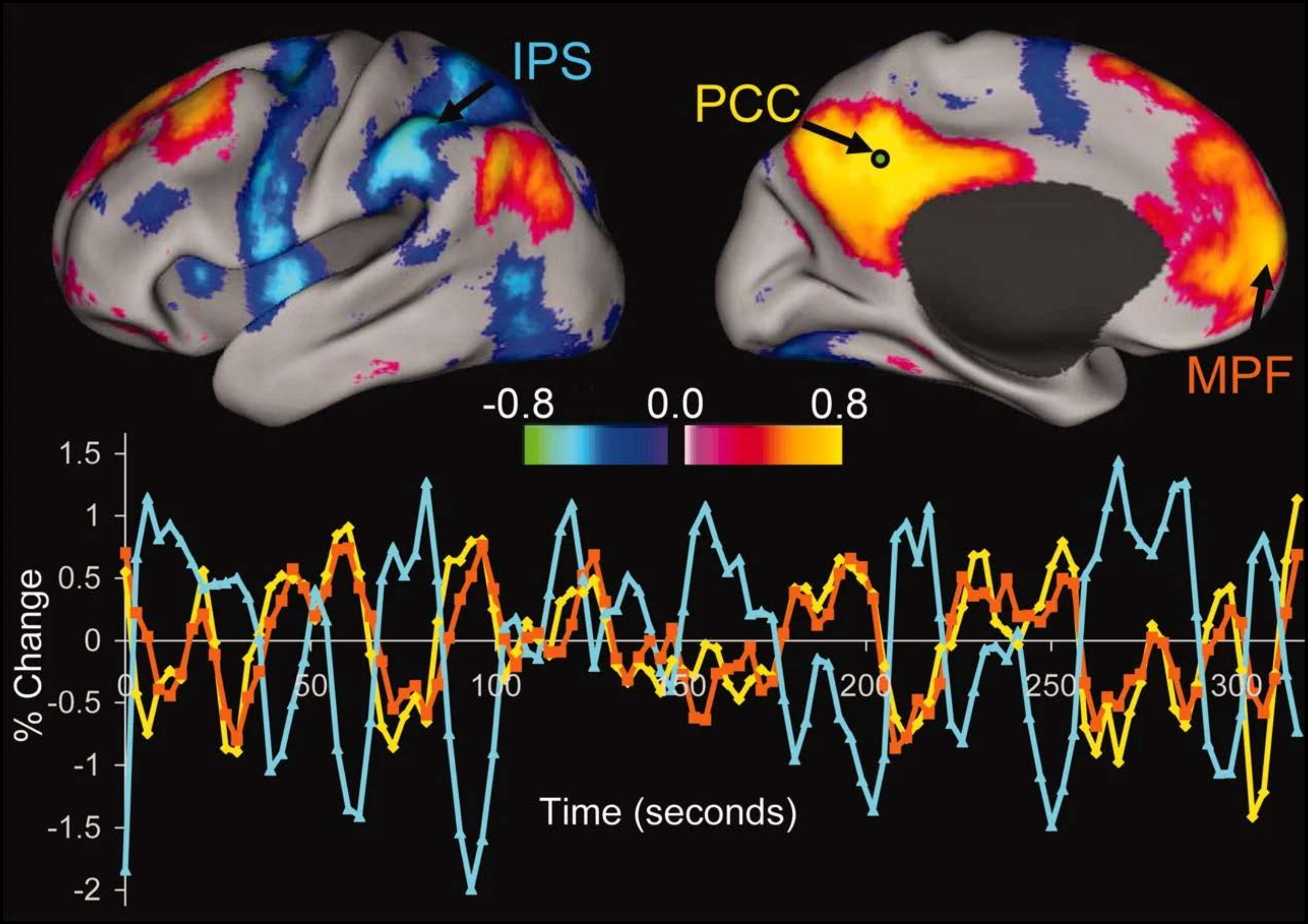




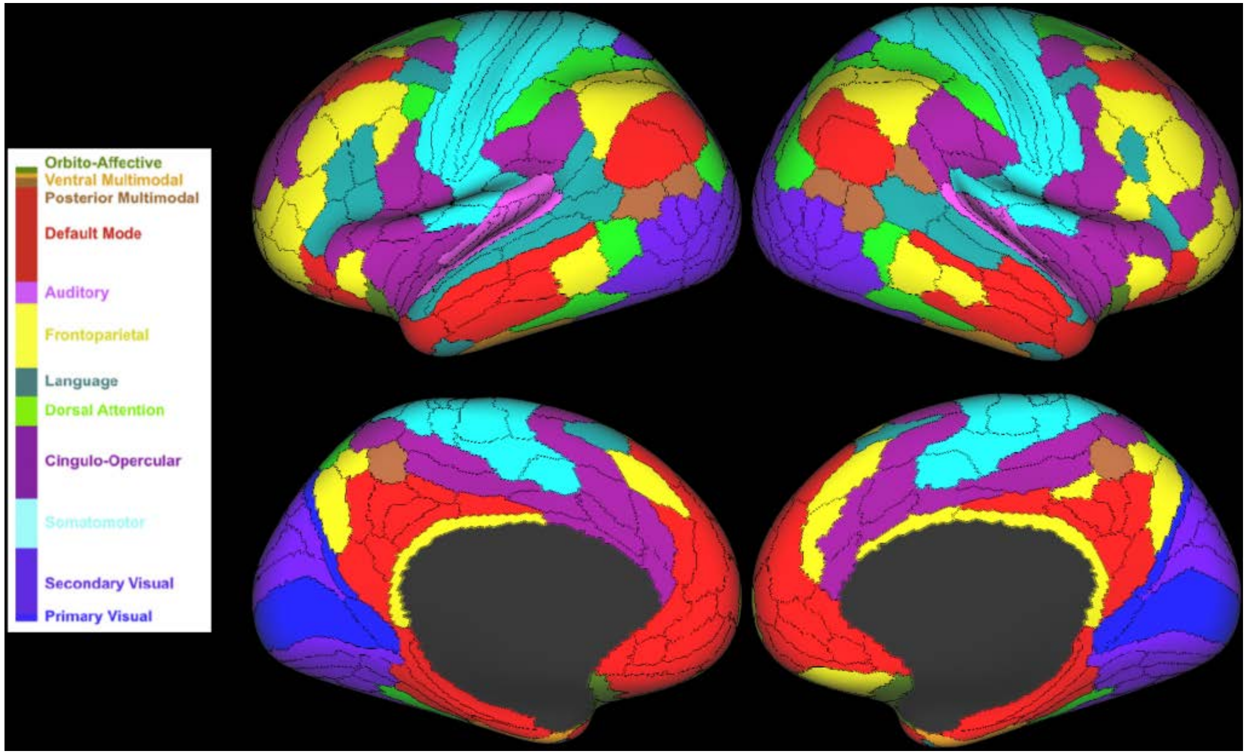
Glasser et al Nature 2016



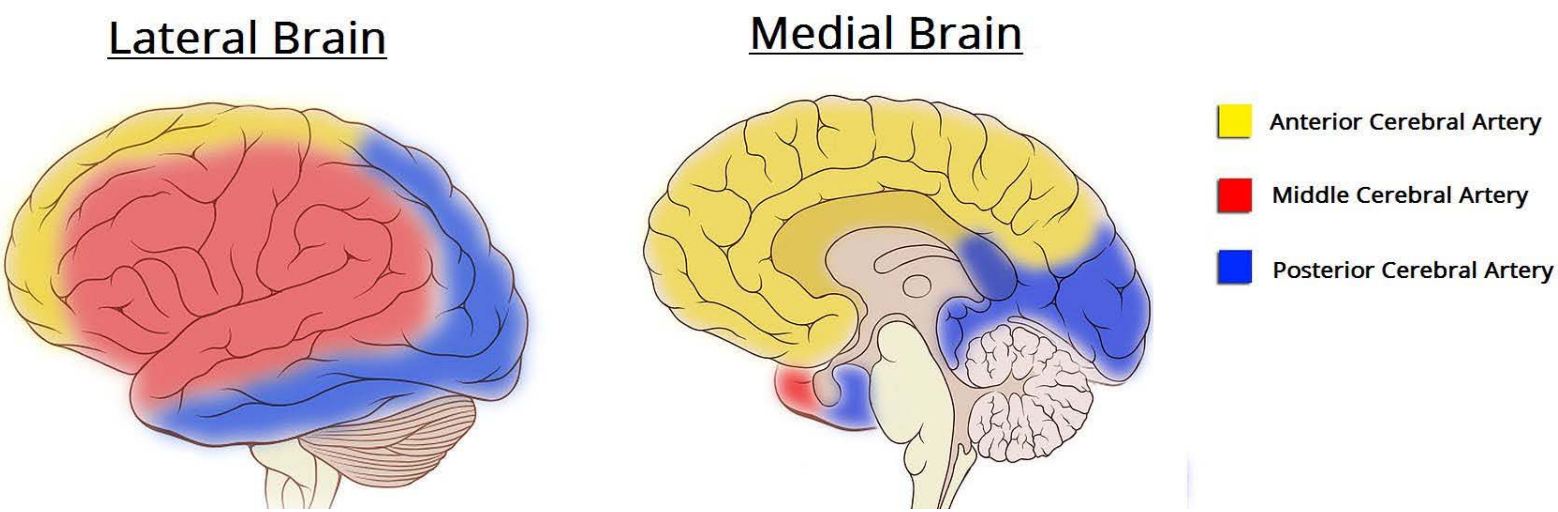
Glasser et al Nature 2016



Fox et al PNAS 2005



Ji et al NeuroImage *2019*

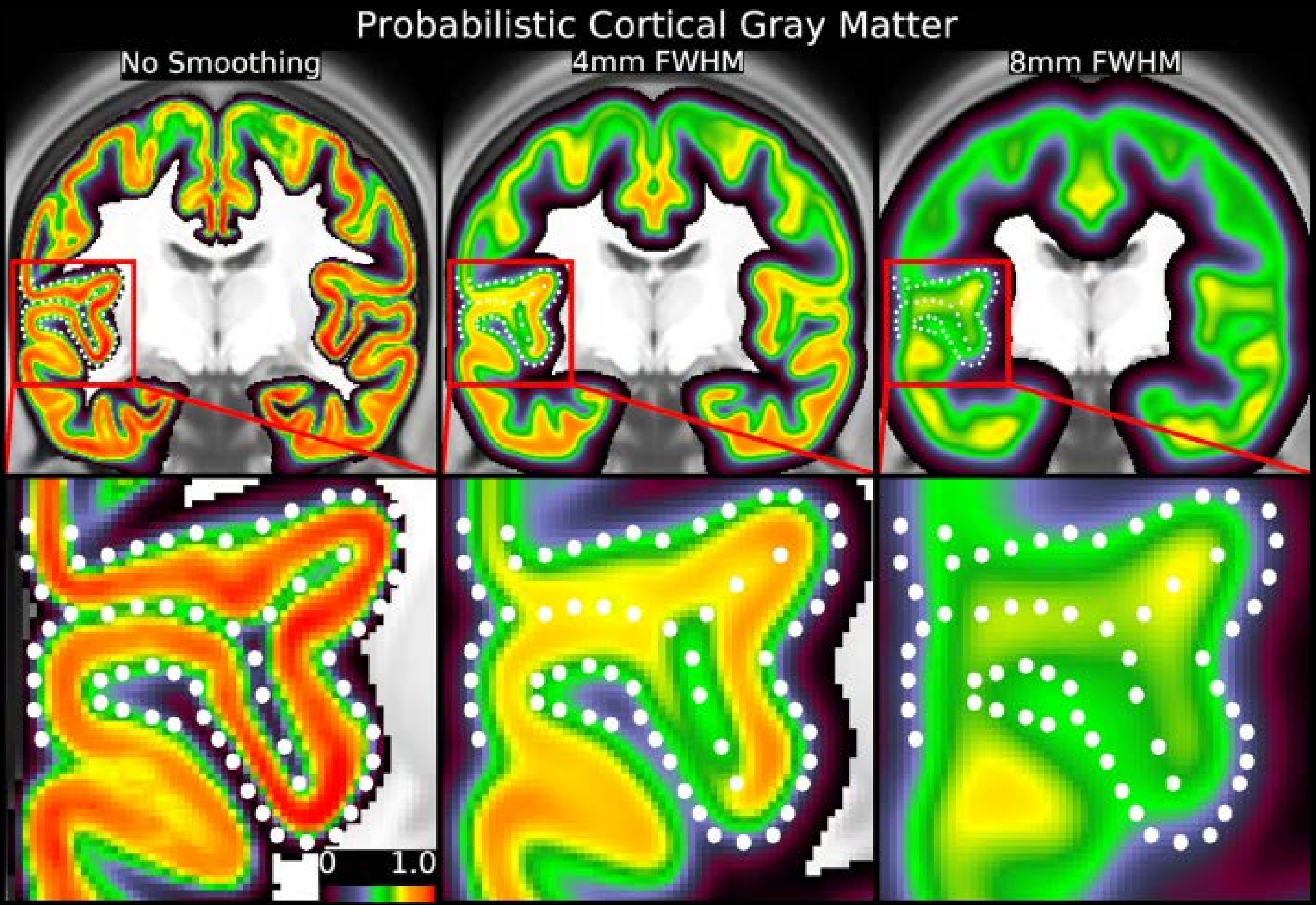


https://upload.wikimedia.org/wikipedia/commons/thumb/4/4a/Cerebral_vascular_territories.jpg/440px-Cerebral_vascular_territories.jpg

Cortex

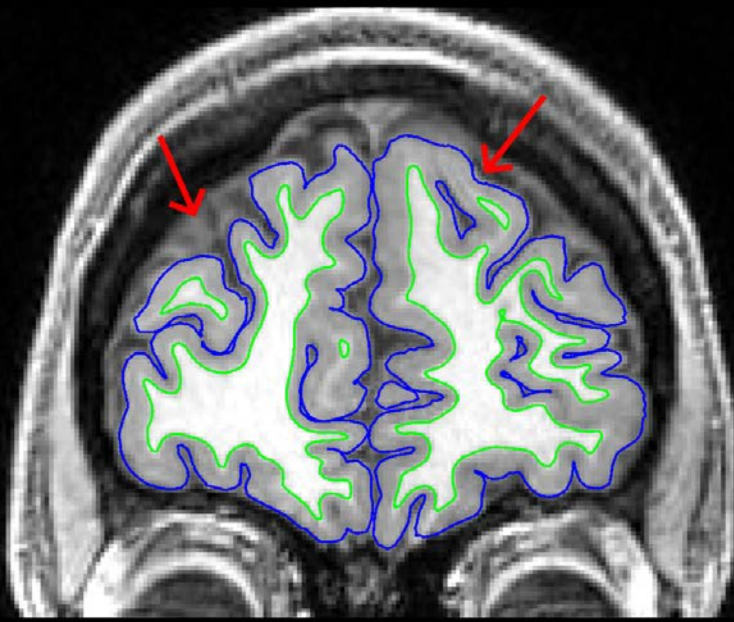
Surface vs volume analysis

Intersubject alignment

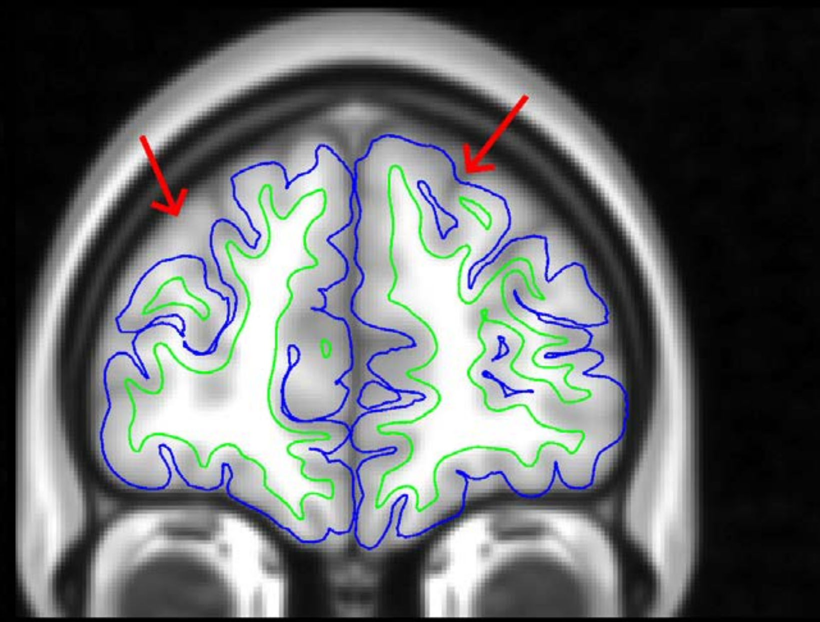


Supp figure from Coalson T. et al (2018) *PNAS*

Volumetric registration is suboptimal

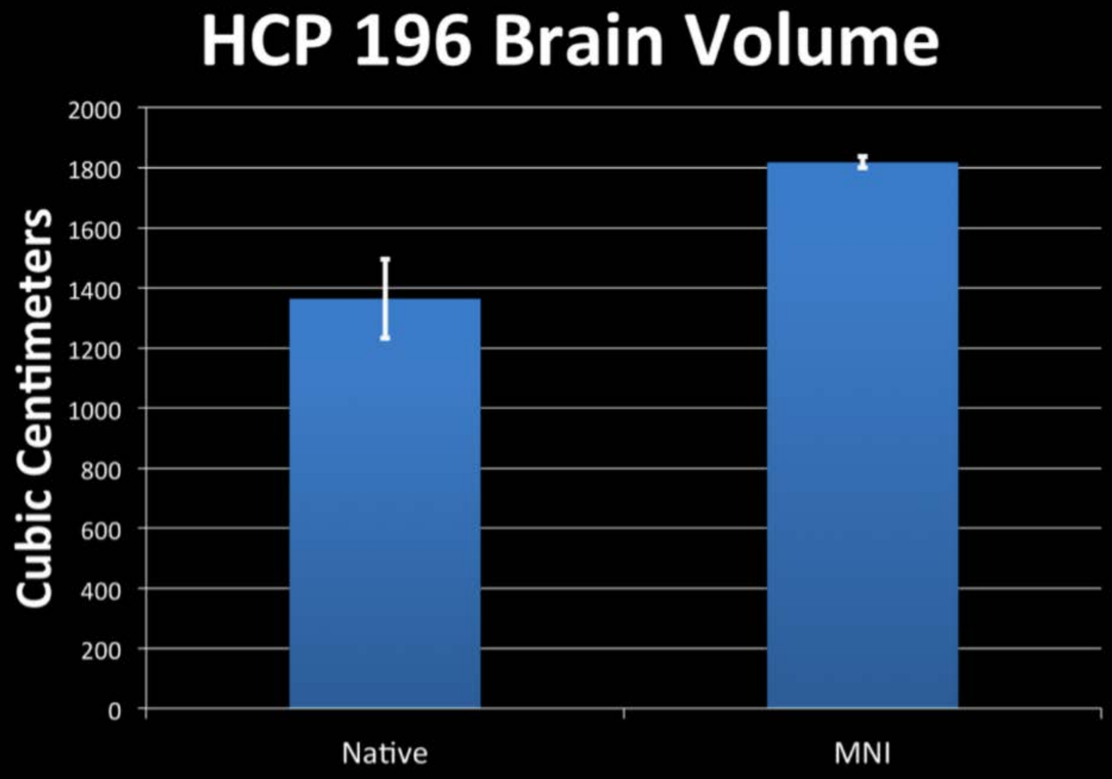


Overlay individual structural scan after non-linear MNI registration



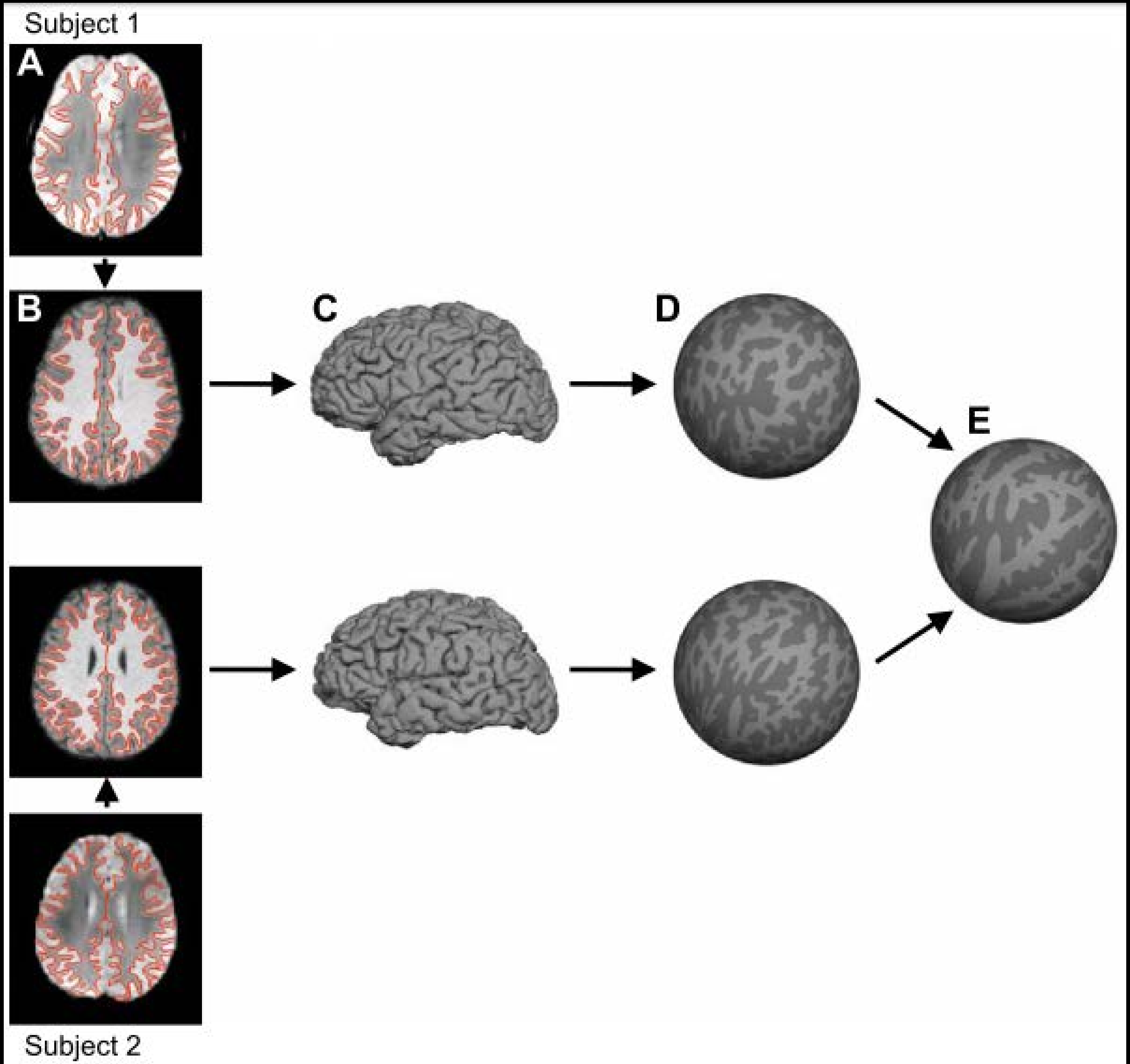
Overlay MNI template

MNI drift
Increase brain size by 37%



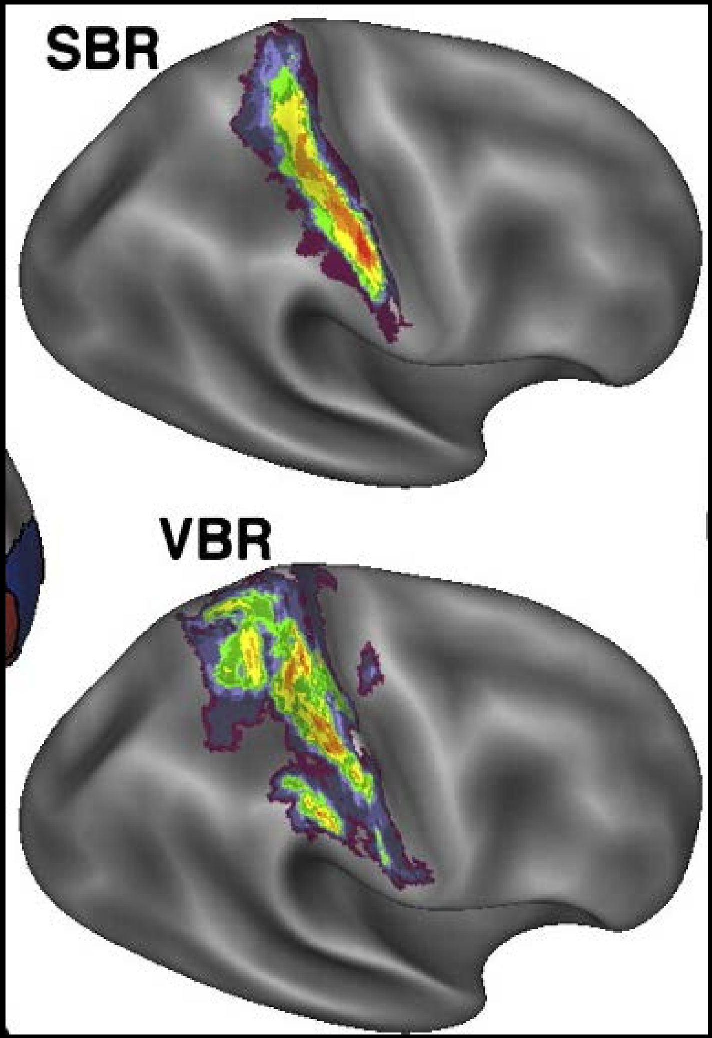
Glasser et al (2016) *Nature Neuroscience*

Surface-based approaches

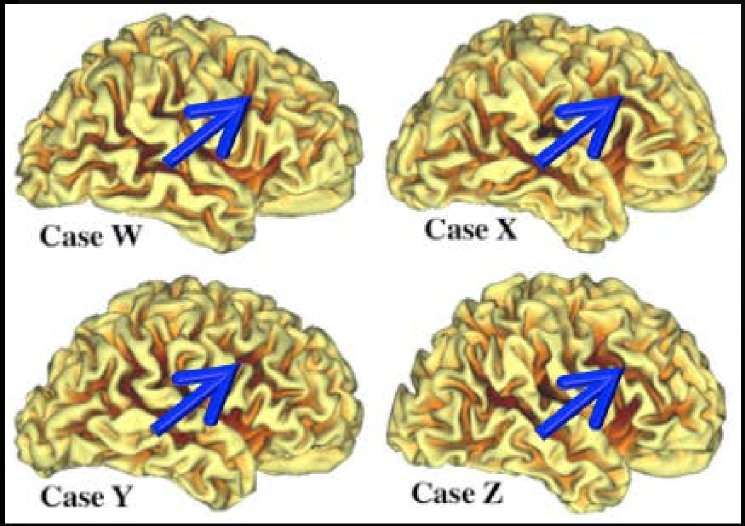


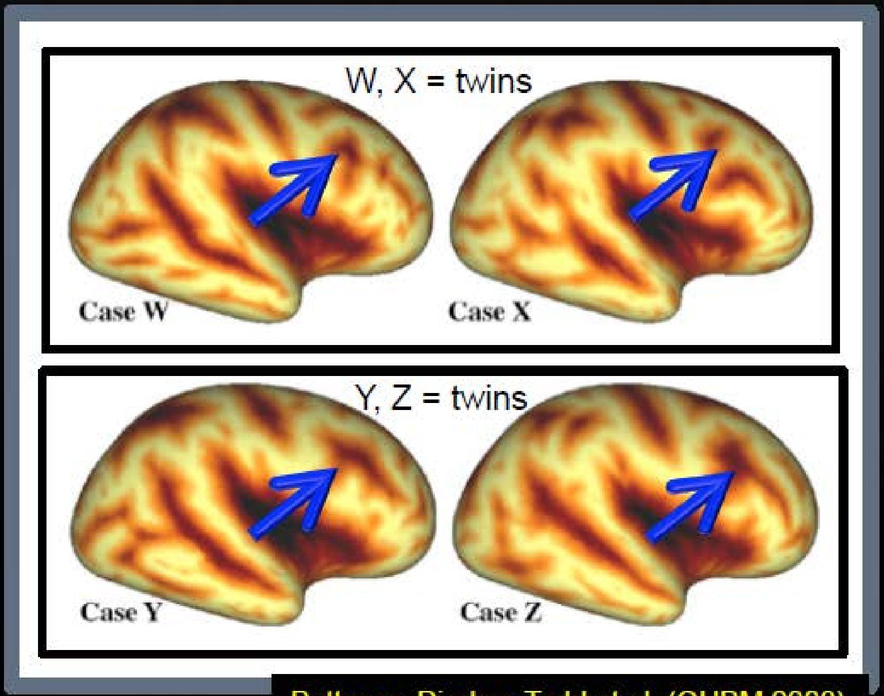
Thomas Yeo, BT. et al.
(2011) *J Neurophysiol*

Volume vs Surface



Van Essen D.C. (2012) *NeuroImage*





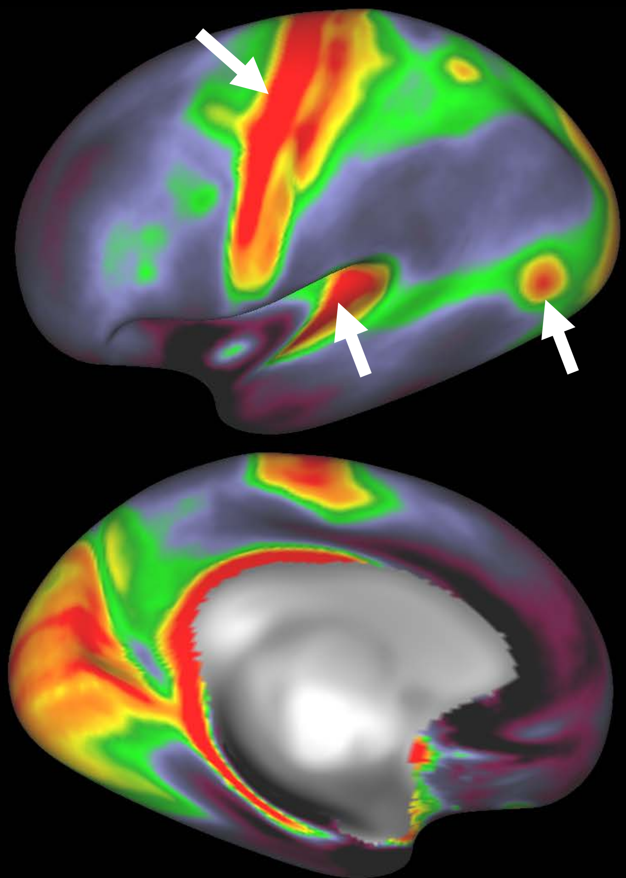
Botteron, Dierker, Todd et al. (OHBM 2008)

- Convolutions are complex!
- Highly variable across individuals
- More variable in 'higher cognitive' regions
- Variable even in identical twins, but some heritability

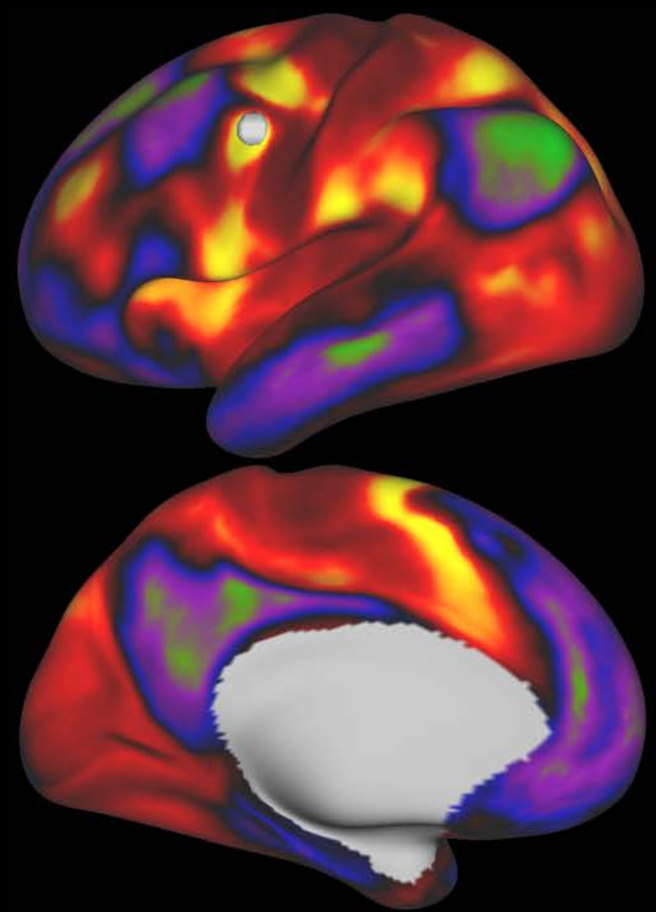
From HCP course slides

Areal feature-based surface registration

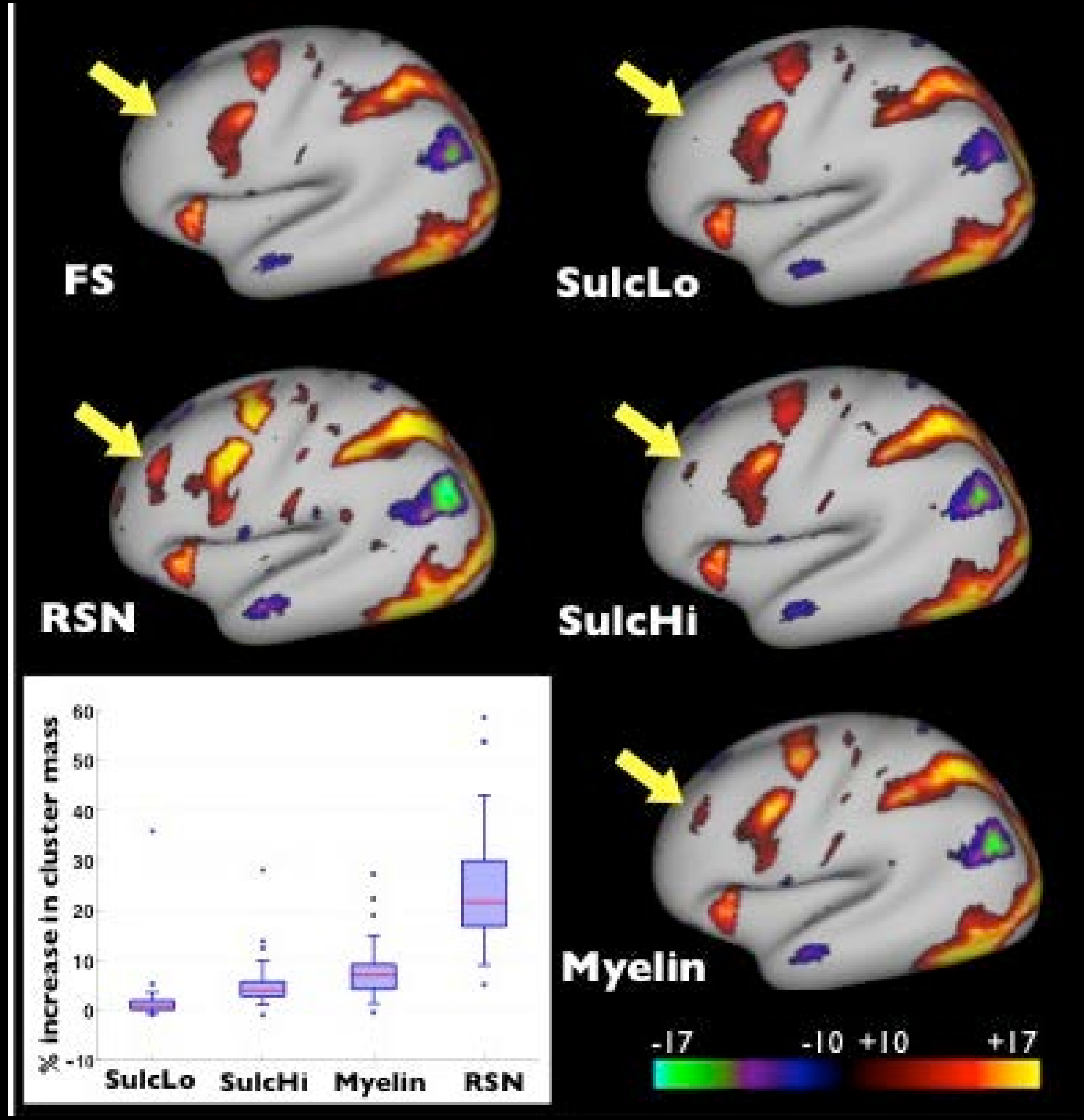
Myelin Map
T1w/T2w



rest fMRI
connectivity maps



Multimodal Surface Matching (MSM)

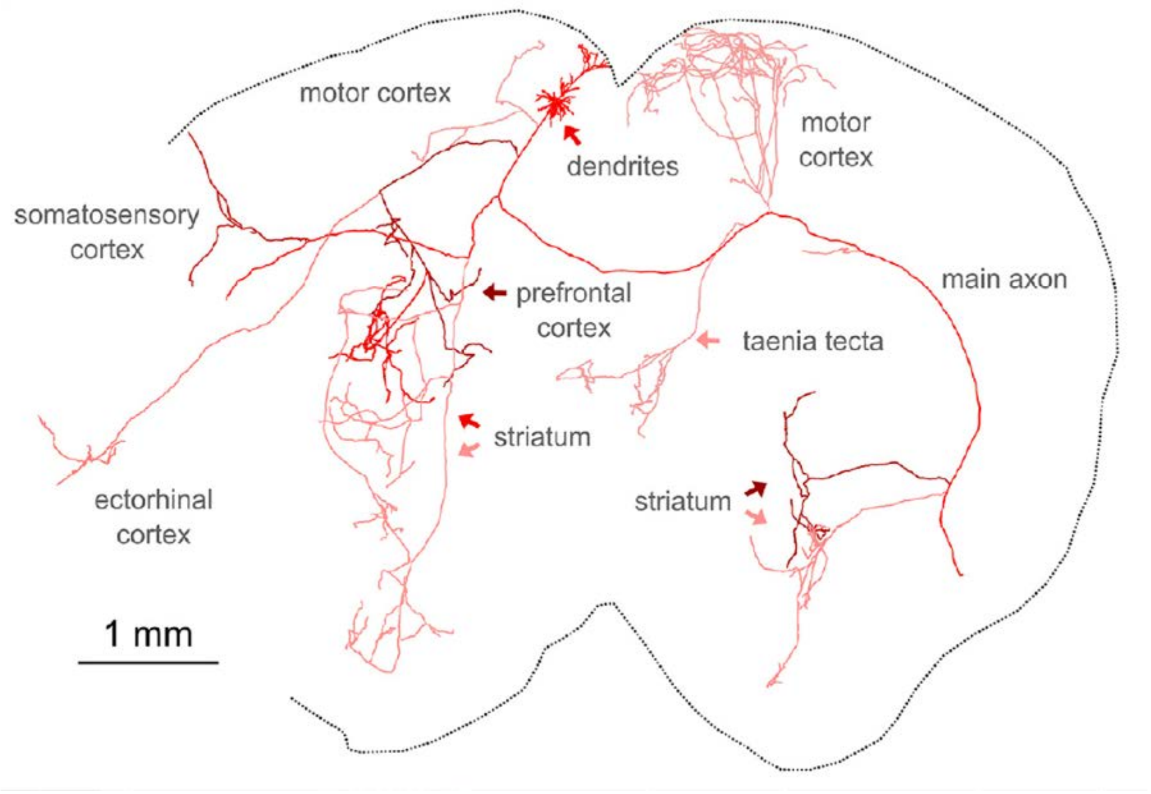


Robinson et al (2014)
NeuroImage

Cortex

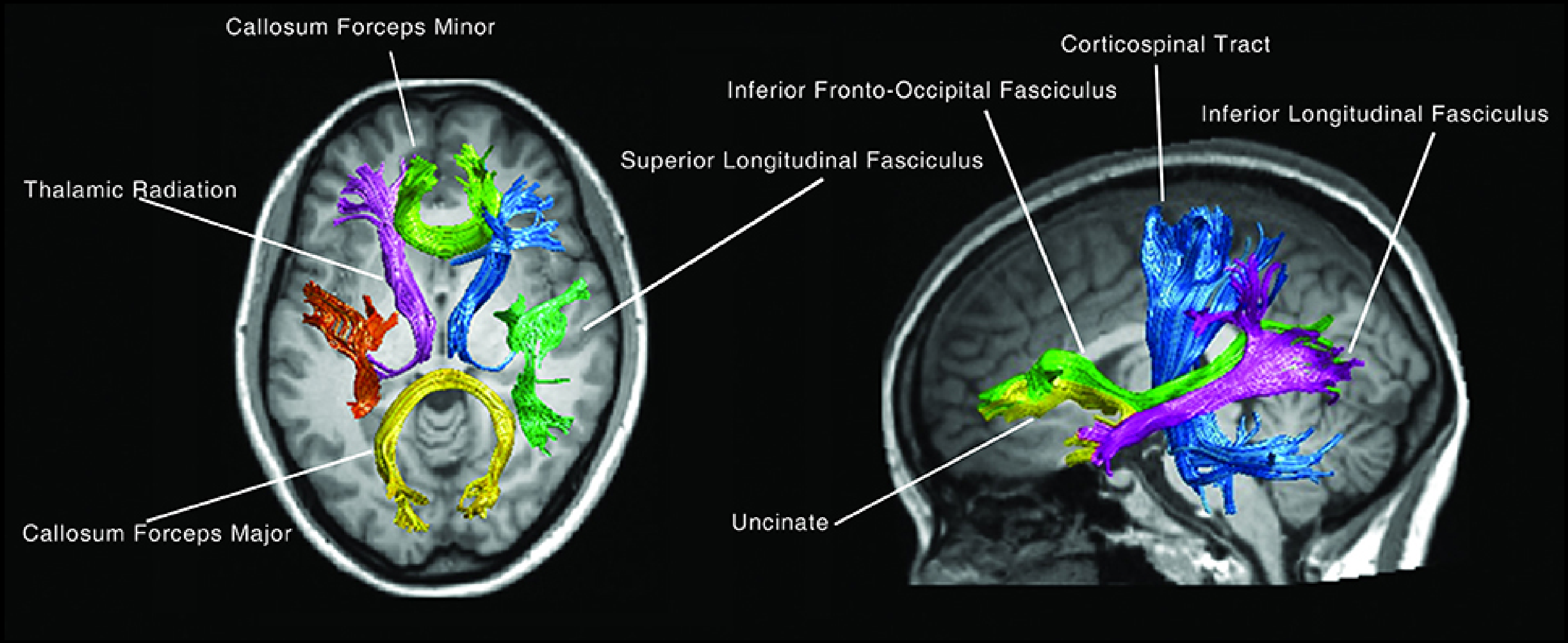
Anatomical connections

A single neuron connections

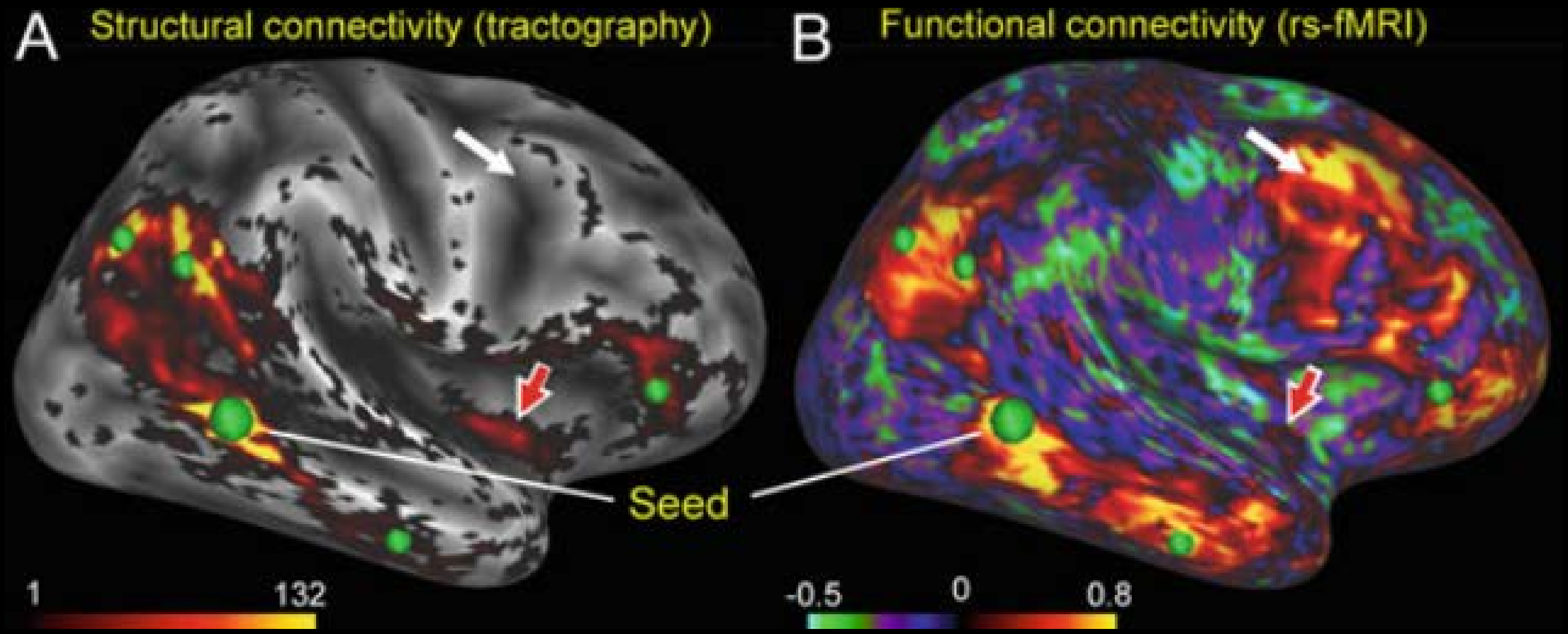


Economo et al. eLife 2016

White matter bundles

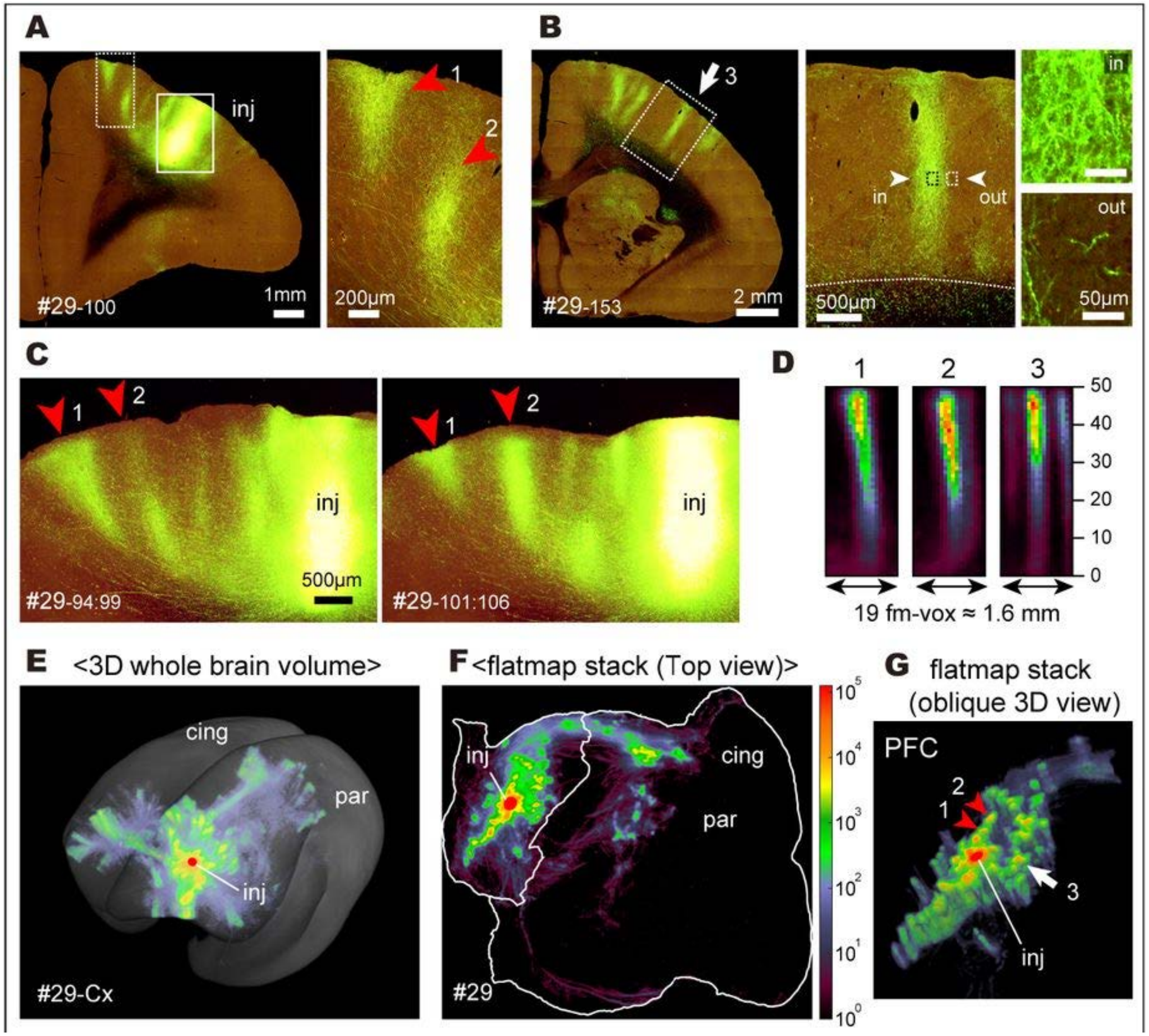


Shah et al Front Neuro 2018



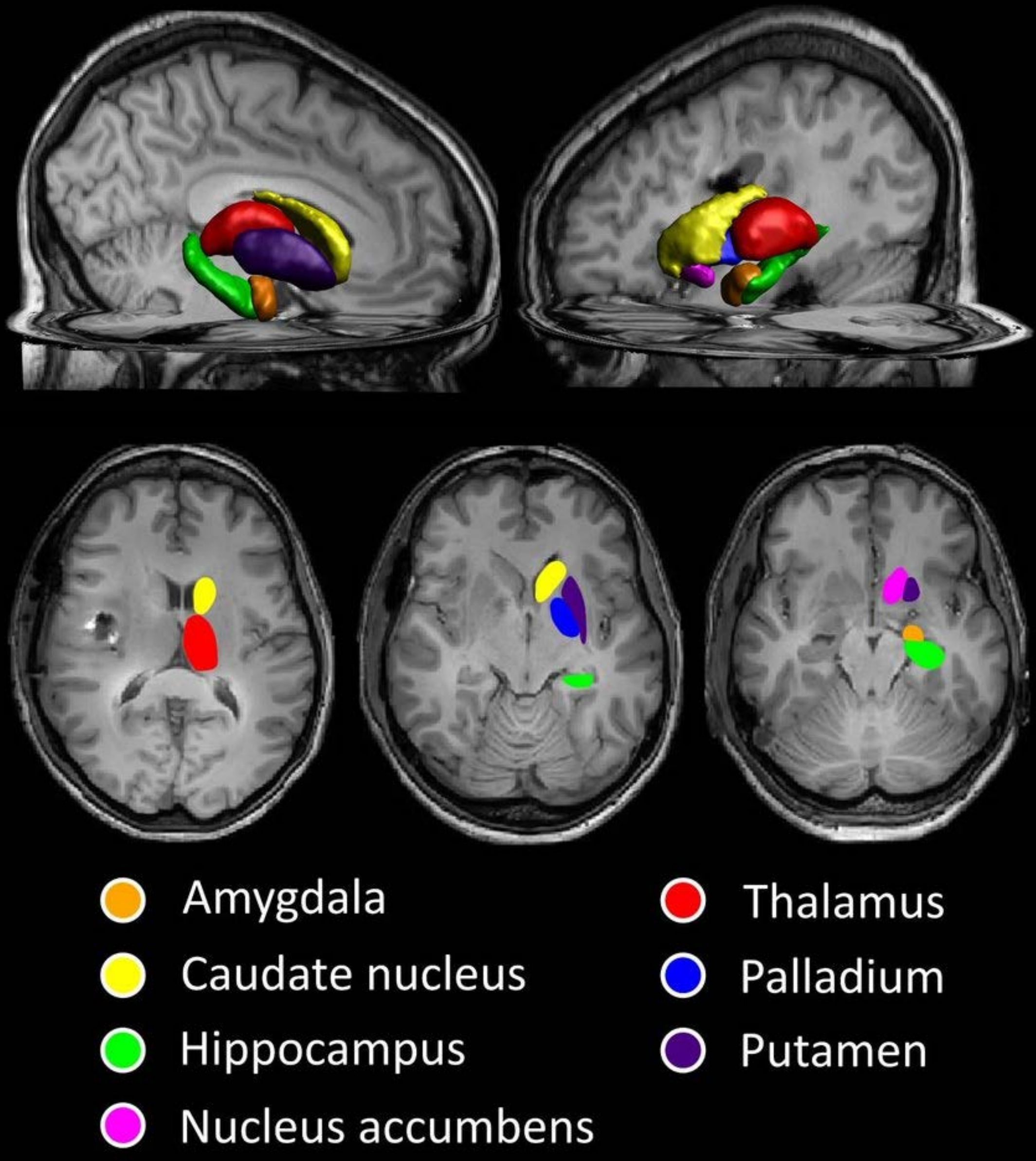
Van Essen et al. Micro-, Meso-, Macro-Connectomics of the Brain. 2016

Tract-tracing



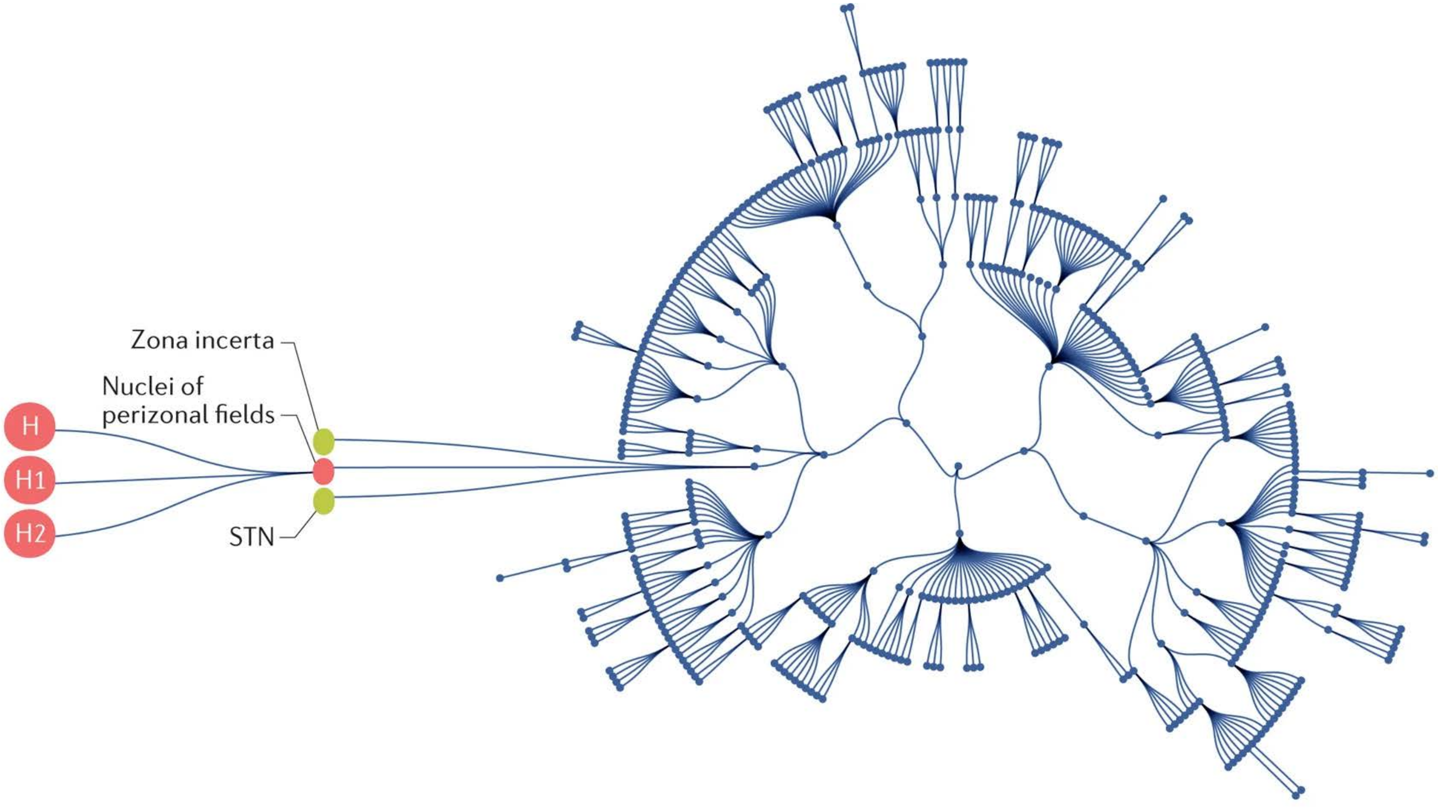
Watakabe et al
Neuron 2023

Deeper structures



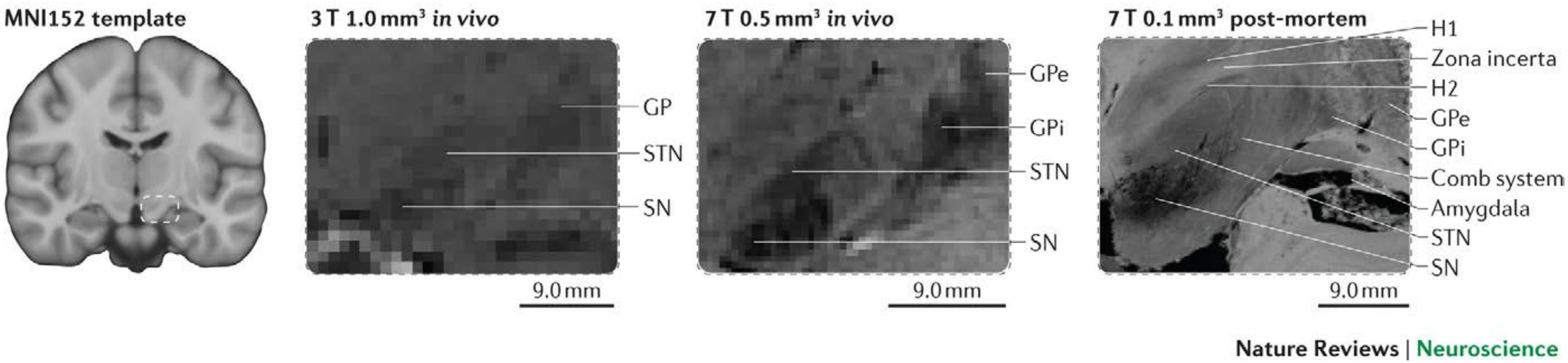
Nagtegaal et al *Clin & Trans Rad Onc* 2020

Subcortex: unchartered territory



Forstmann 2017
Nature Rev Neuro

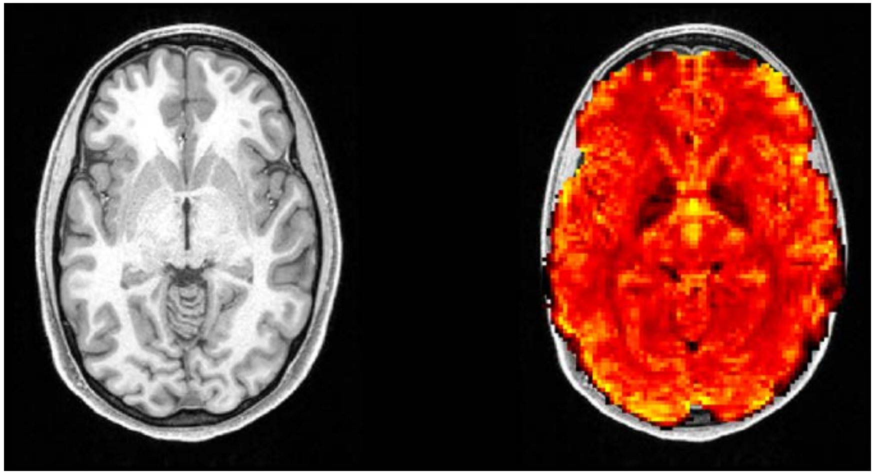
Subcortex: unchartered territory

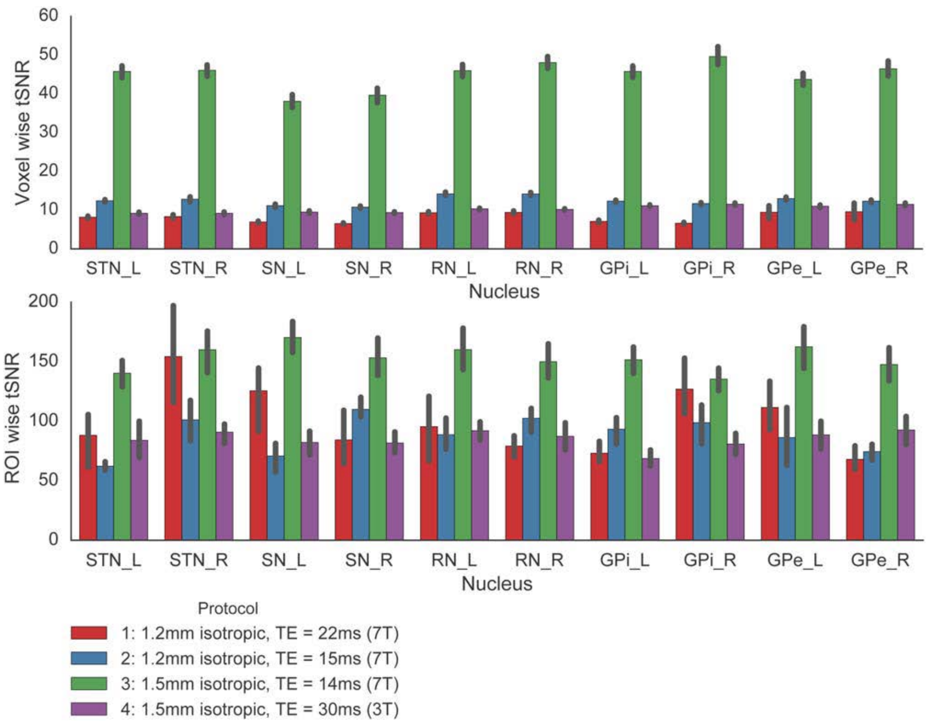


Forstmann 2017
Nature Rev Neuro

Special MRI sequences

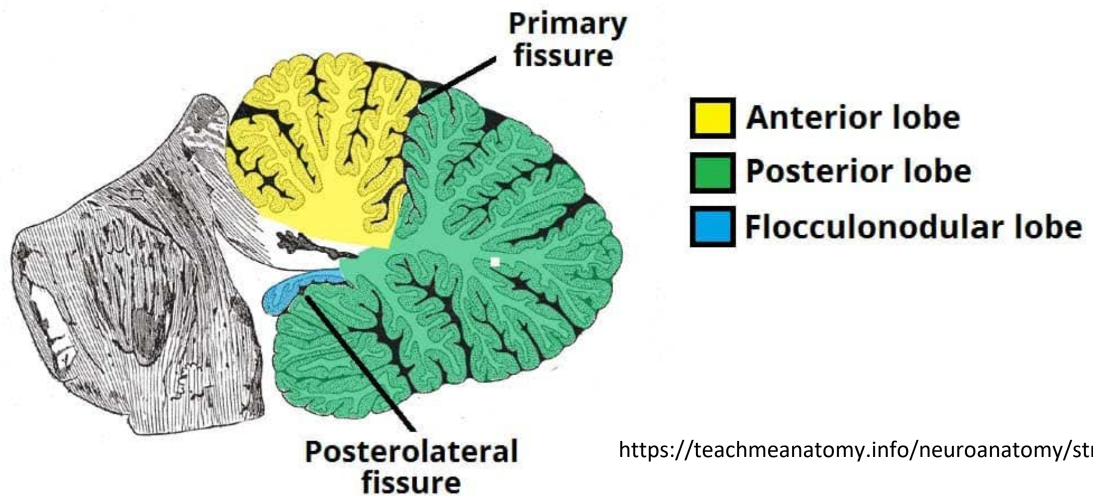
Typical sequences with echo time (TE) = ~30ms



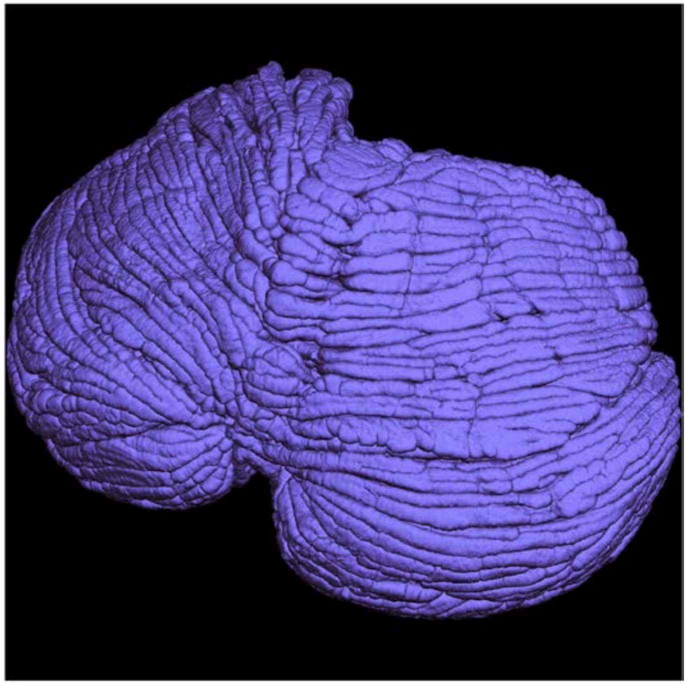


De Hollander et al HBM 2017

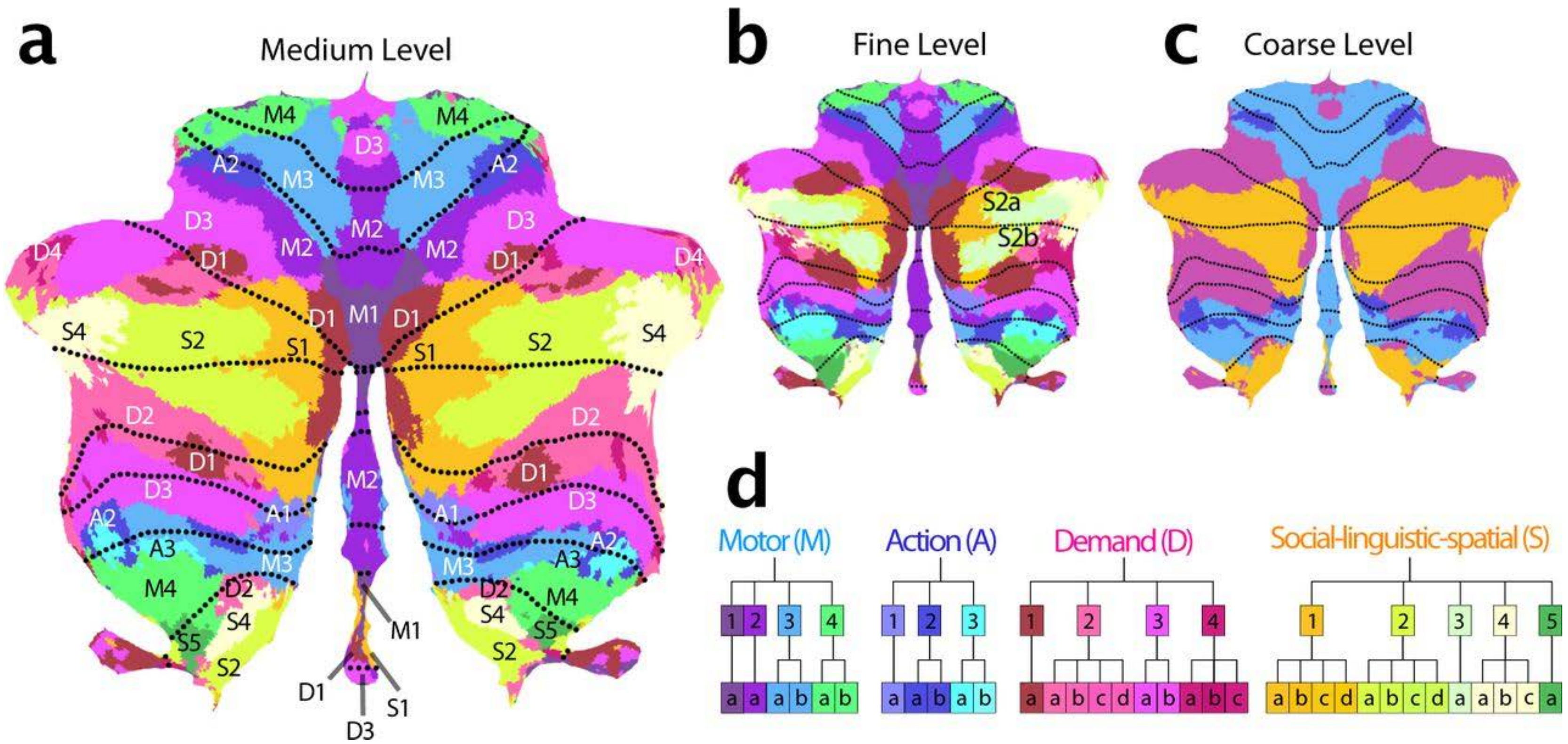
Cerebellum



https://teachmeanatomy.info/neuroanatomy/structures/cerebellum/



Sereno et al PNAS 2020



Nettekoven et al biorxiv 2023

Take home messages

- Understanding structure (anatomy) is key to understanding function
- Let your anatomical question guide your choice of imaging and analysis approaches