Introduction to Neuroanatomy for Cognitive Neuroscientists

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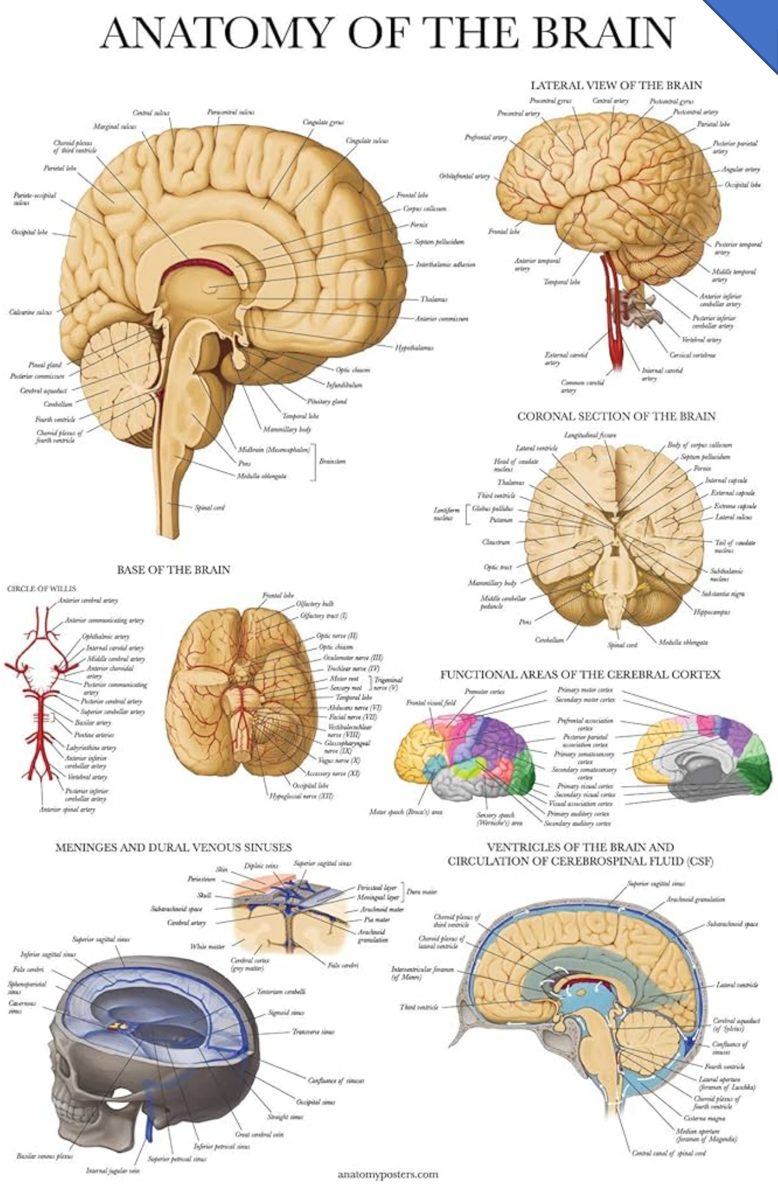
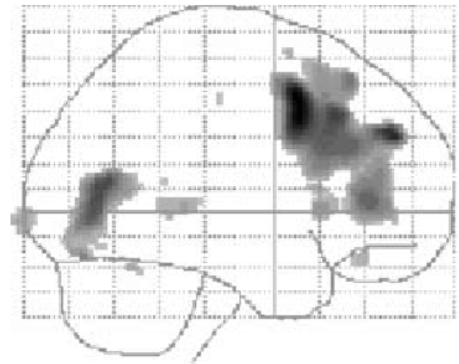
MRC Cognition and Brain Sciences Unit
University of Cambridge

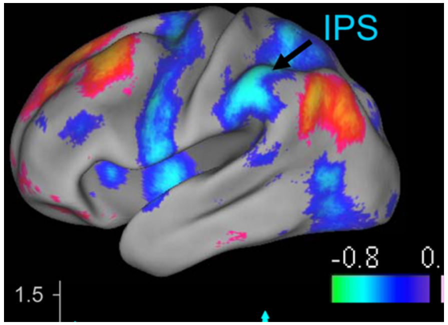
Textbook

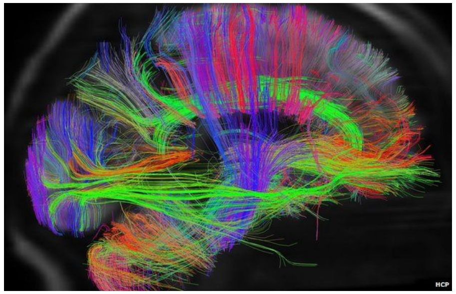
How to link them?

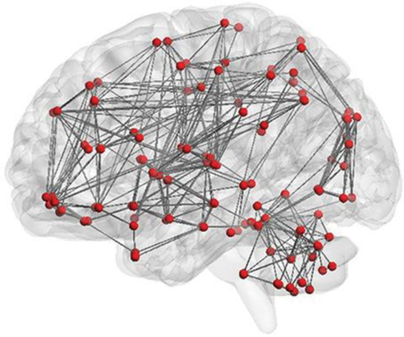
Modern Brain imaging

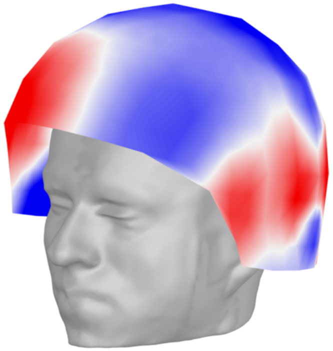


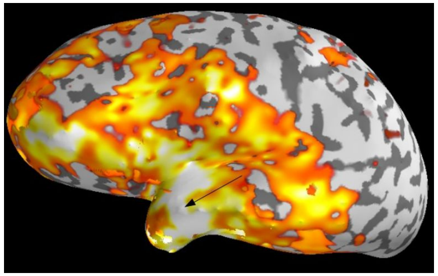




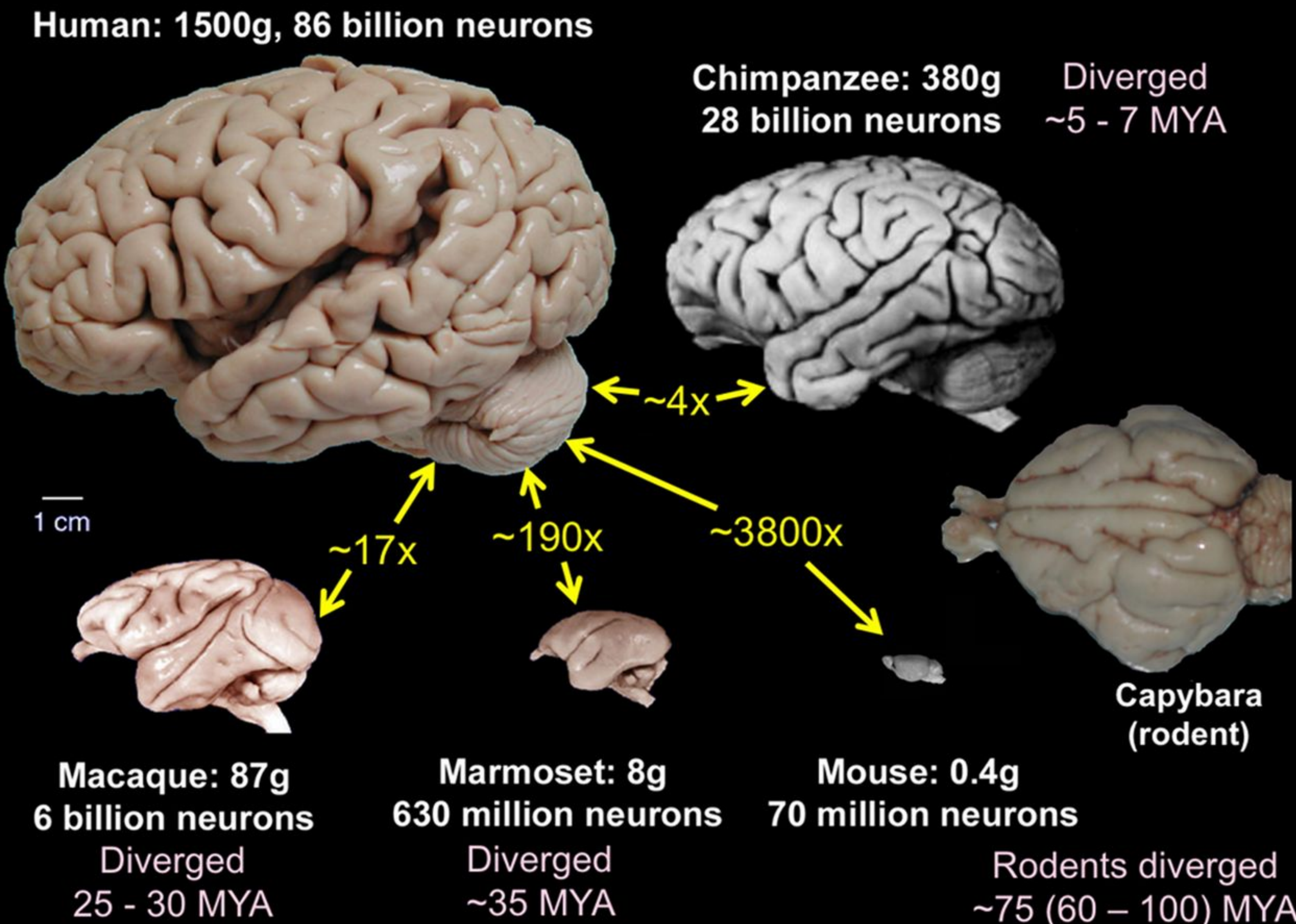






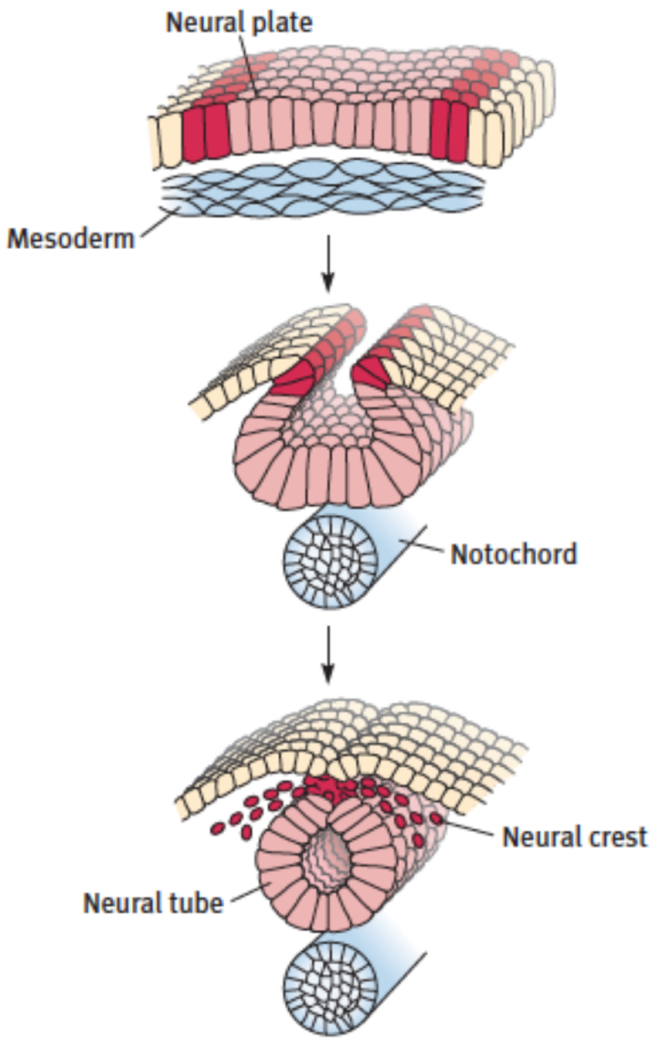


Evolutionary context

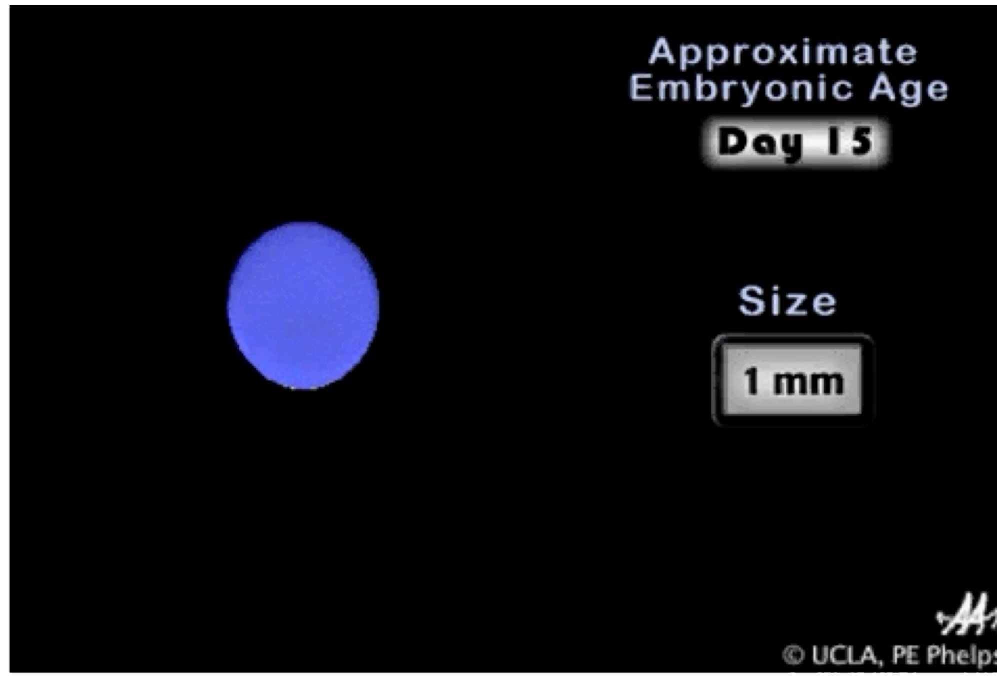


Van Essen et al PNAS 2019

Development

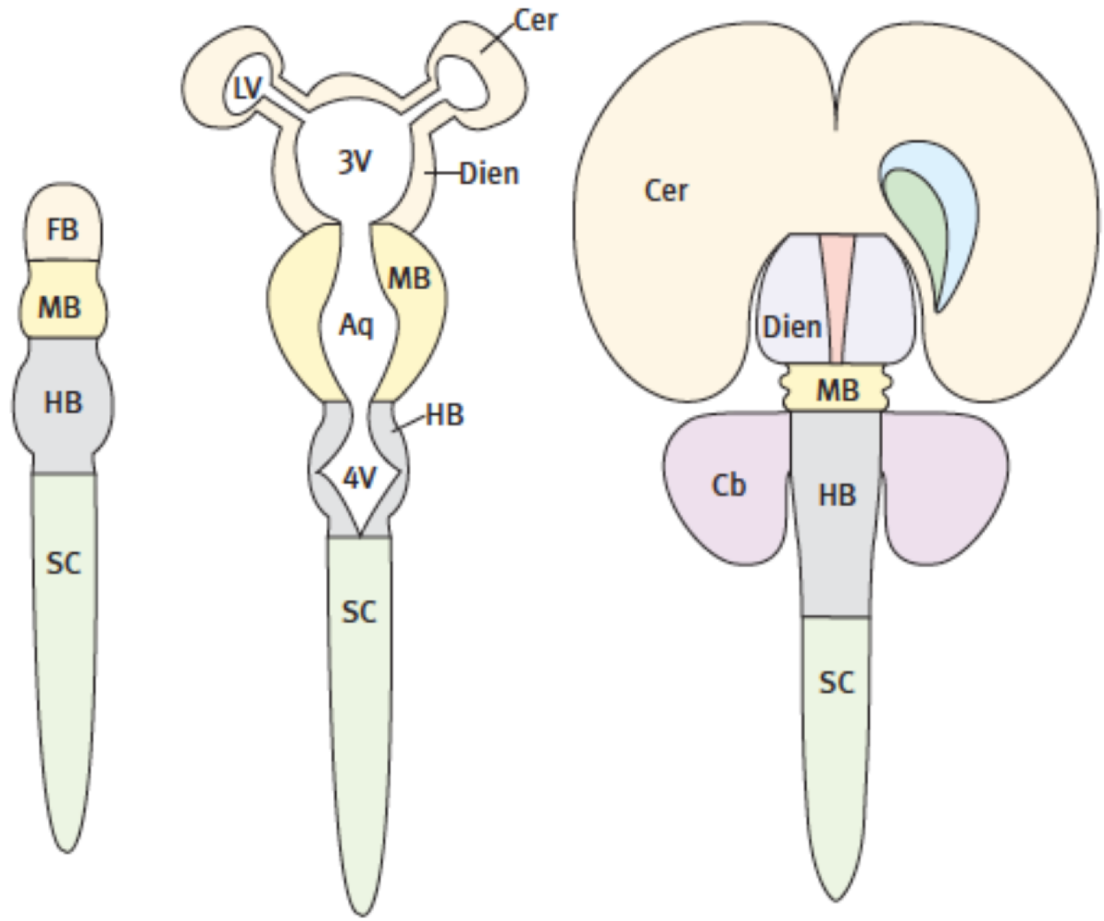


Charles Watson's IBB neuroanatomy supplement

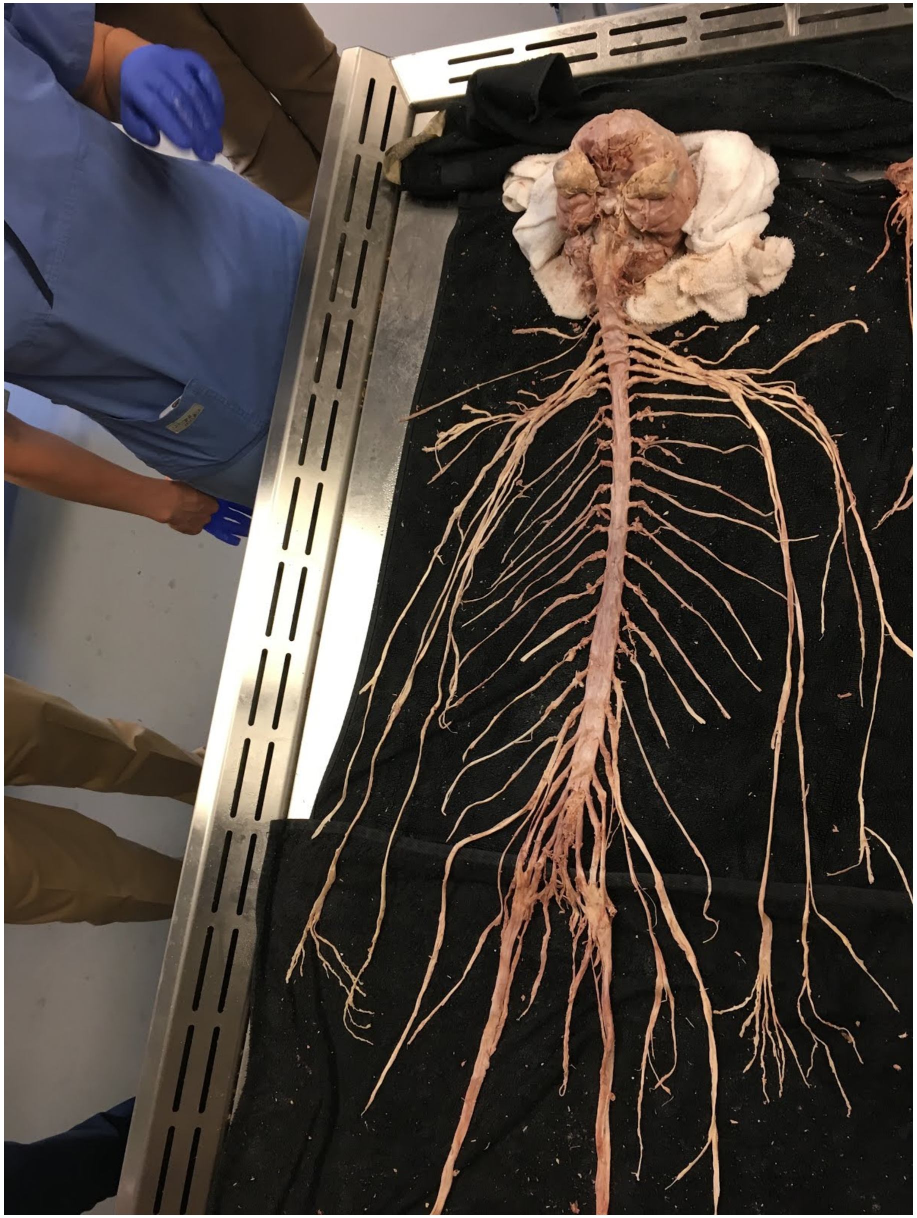


https://www.youtube.com/watch?v=wnnhMZtCvnQ

Segmentation in the brain

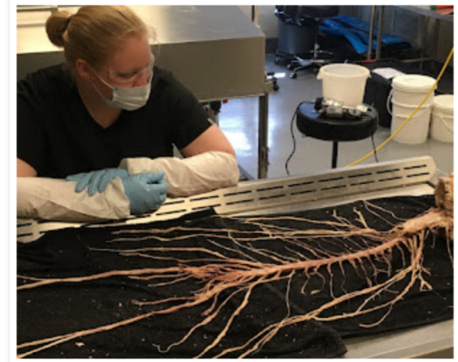


Charles Watson's IBB neuroanatomy supplement



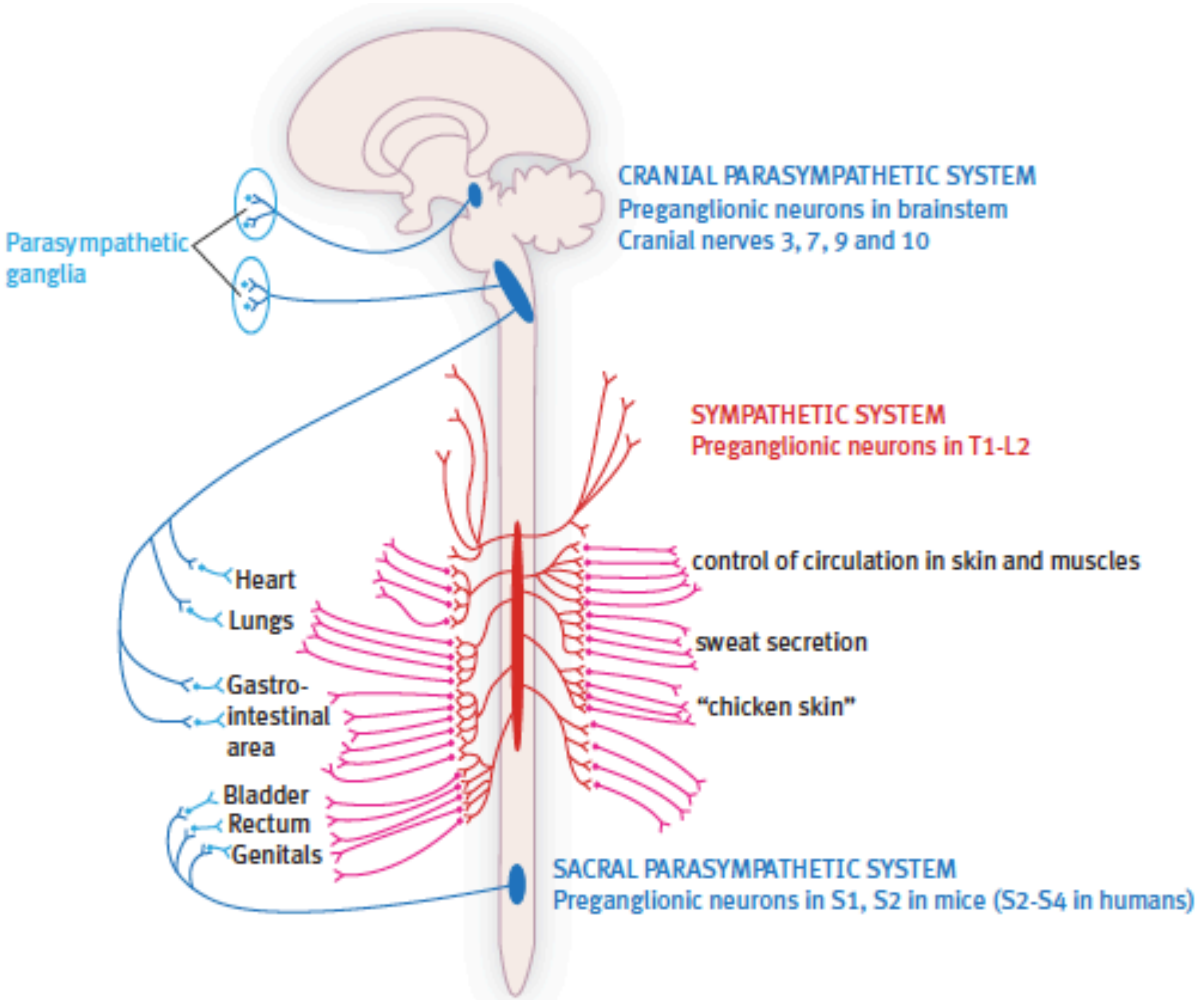
Remarkable en bloc dissection of human central and peripheral nervous system accomplished at University of Colorado

Shannon Curran, a graduate student in the Modern Human Anatomy Program at the University of Colorado Anschutz Medical Campus, recently completed an *en bloc* dissection of the central nervous system along with an extensive portion of the peripheral nervous system from a human cadaver donor. "It's pretty amazing," said Assistant Professor Maureen Stabio "There are only a handful of these prosections in the world ... We are so lucky to have such talented and ambitious students on our campus."



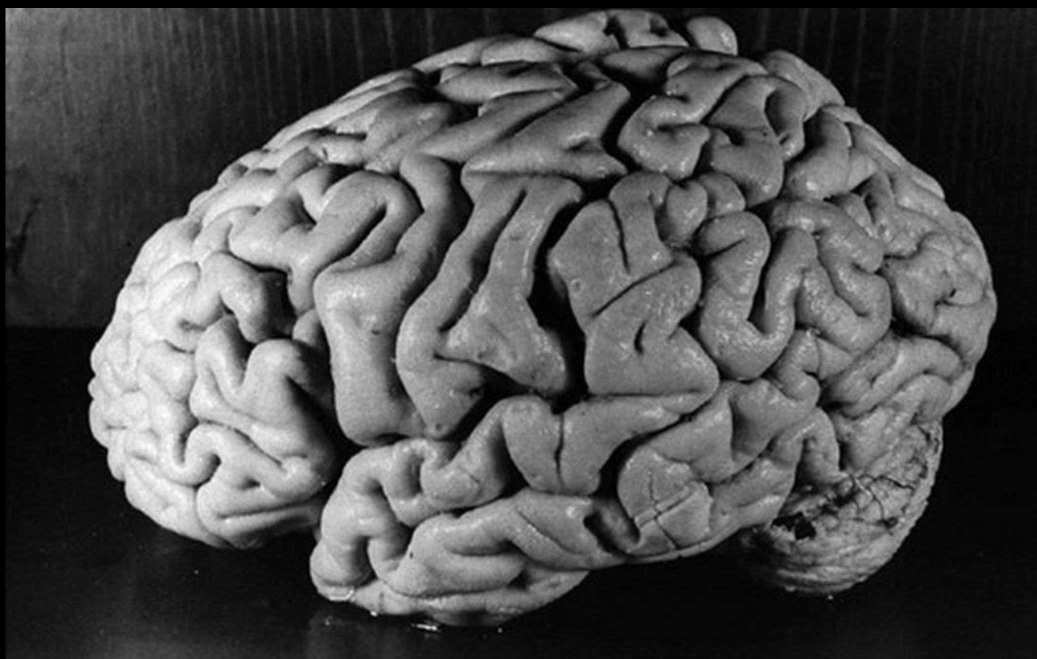
Shannon Curran, MS with her dissection

Autonomic nervous system

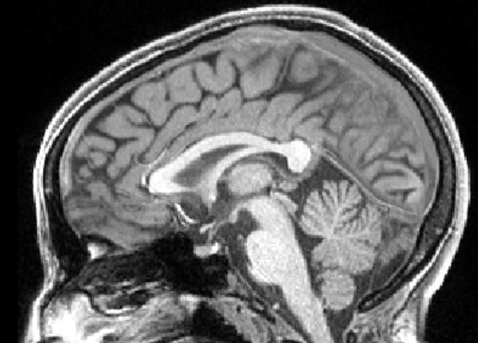


Cortex

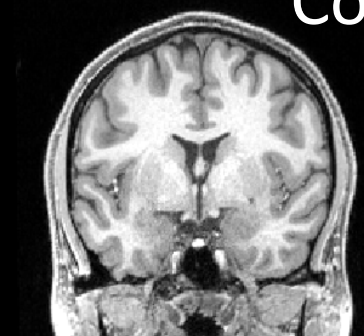
Basic MRI landmarks



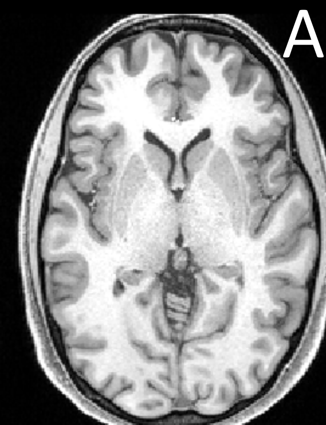
Sagittal

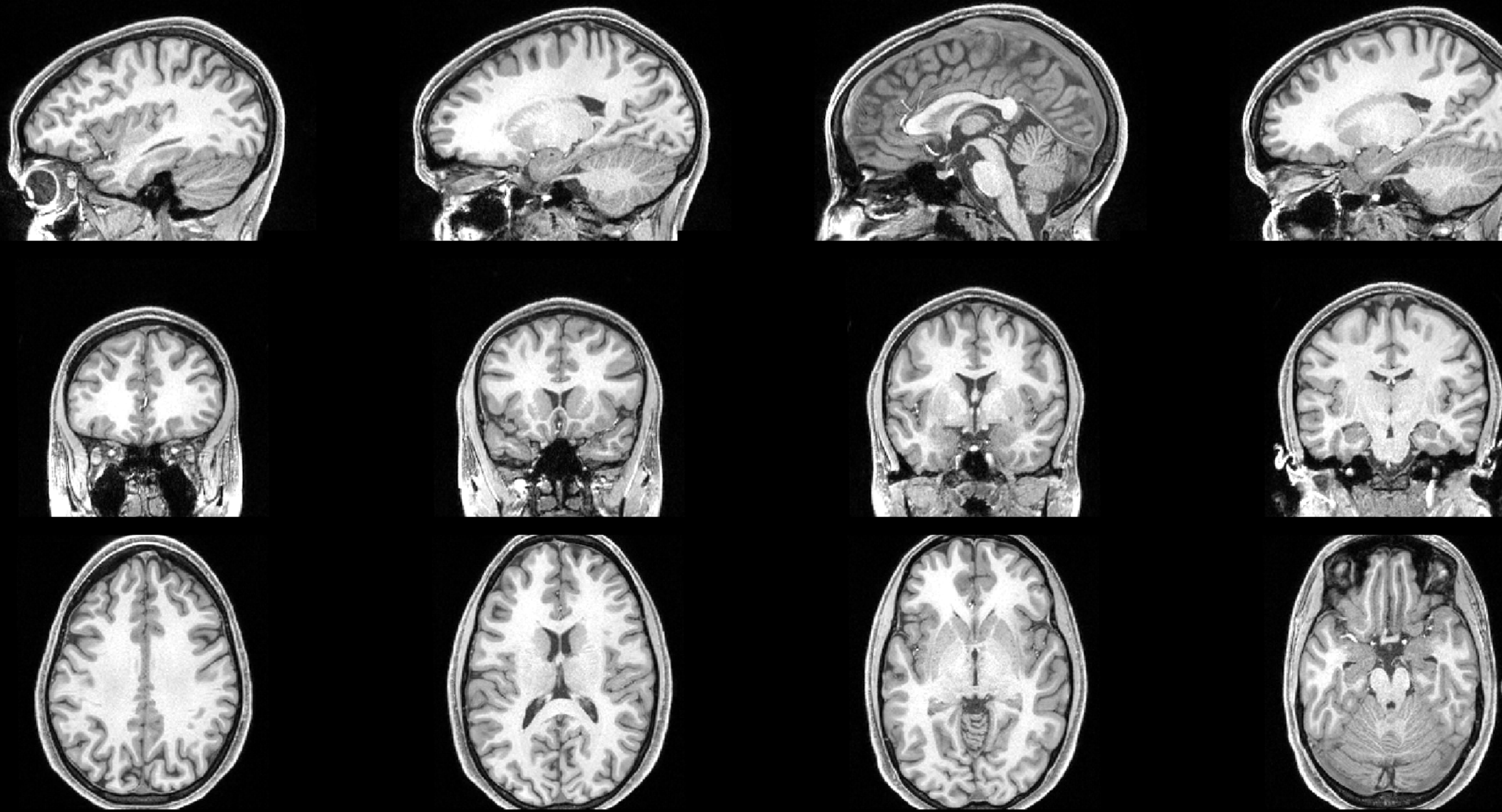


Coronal

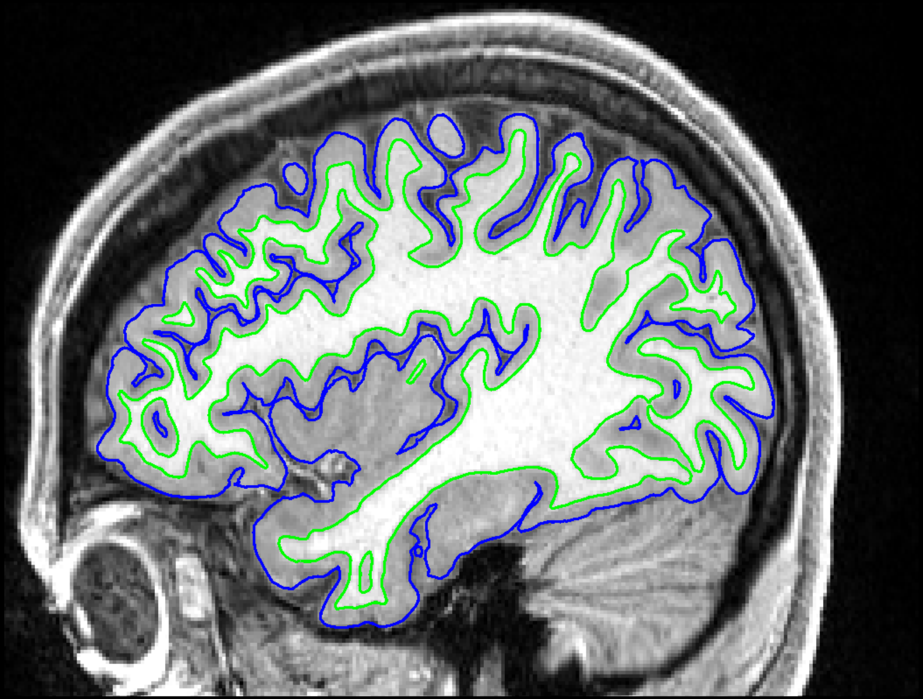


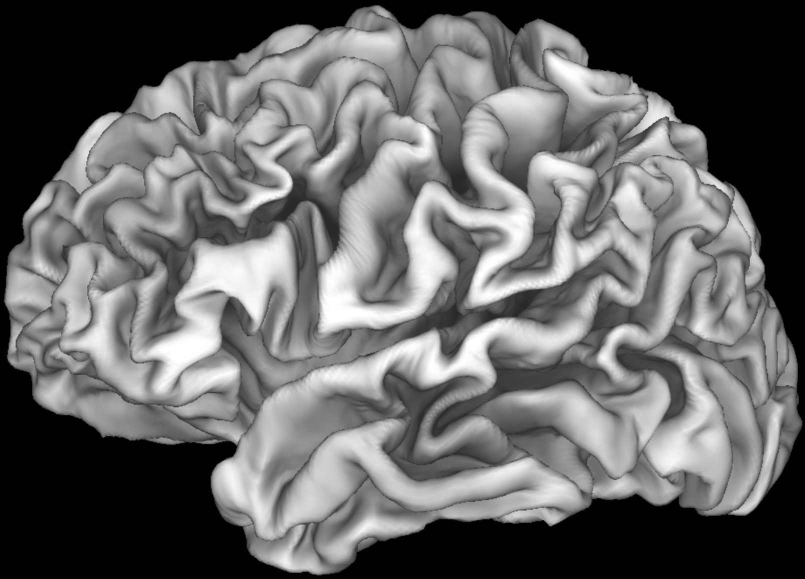
Axial





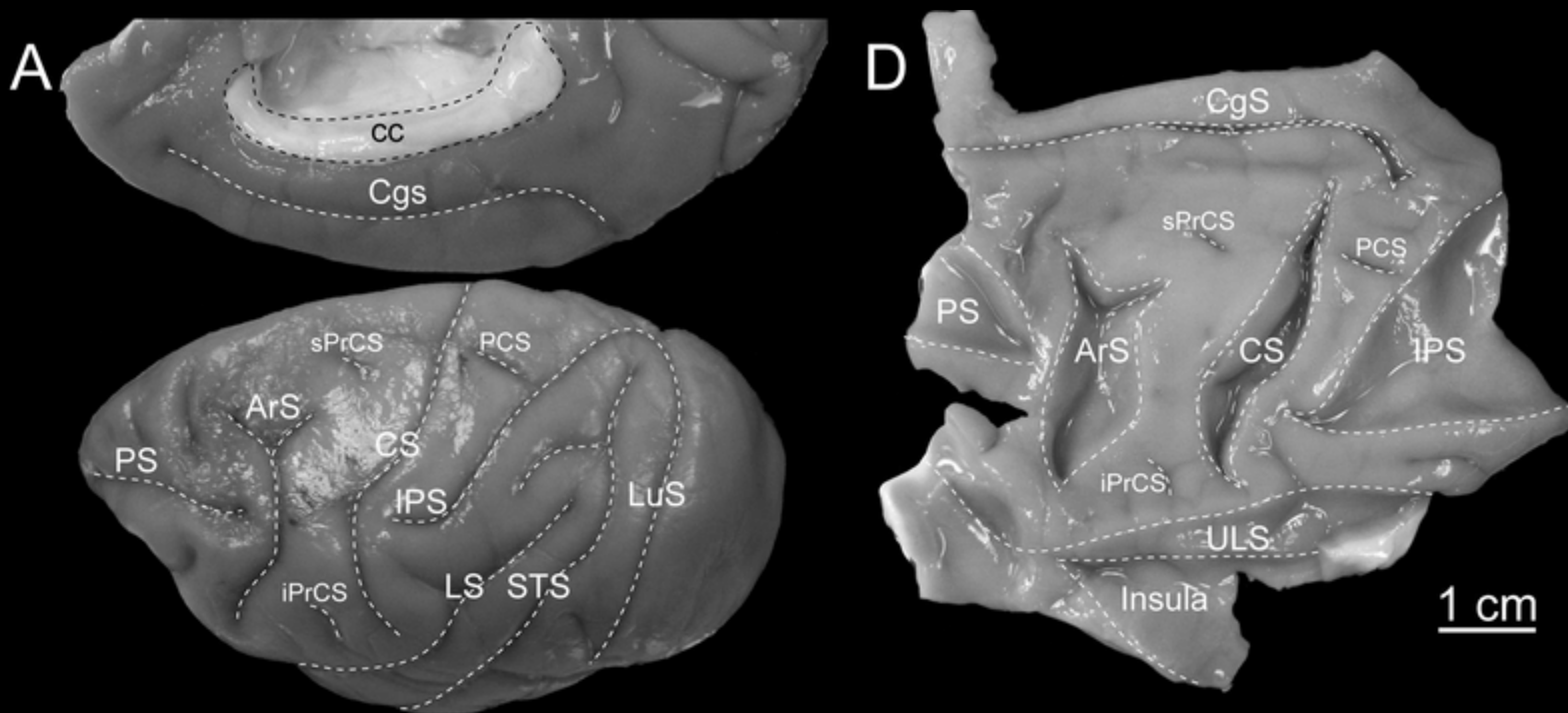
Cortical surface 3D reconstruction





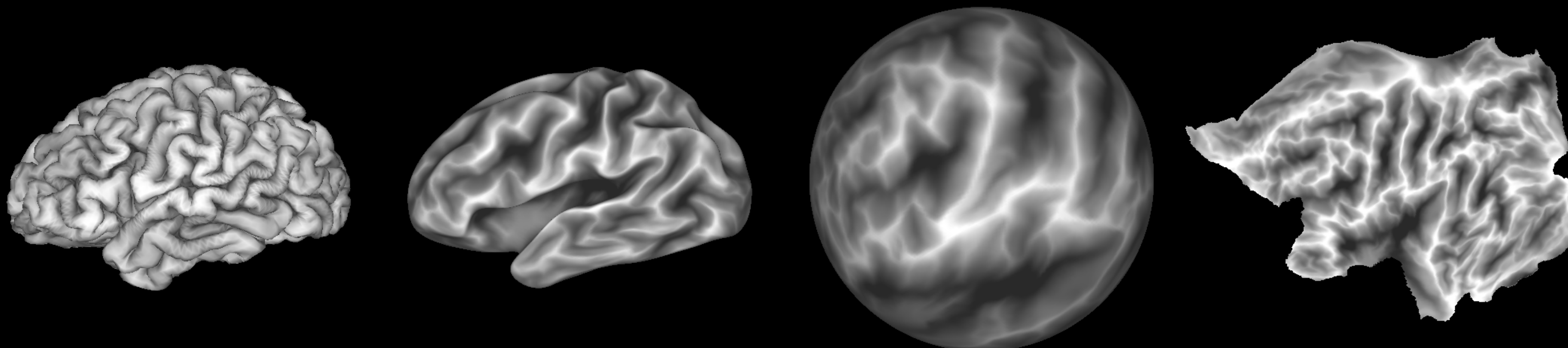
Example subject from HCP-style data scanned at CBU

Non-human primate flat cortical surface



Human example

pial | inflated | Spherical projection | Flat map



Cortical layers

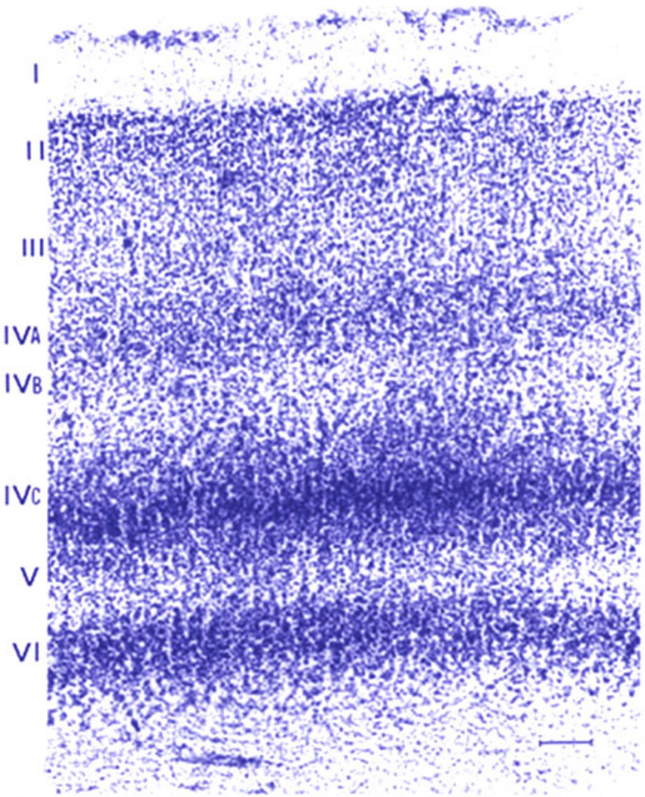
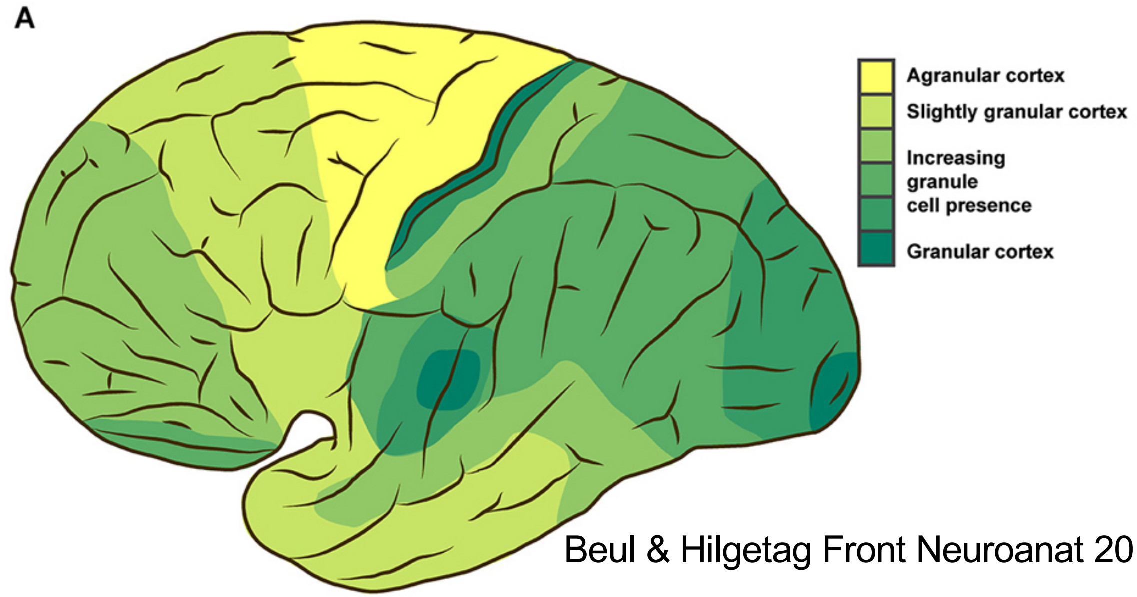


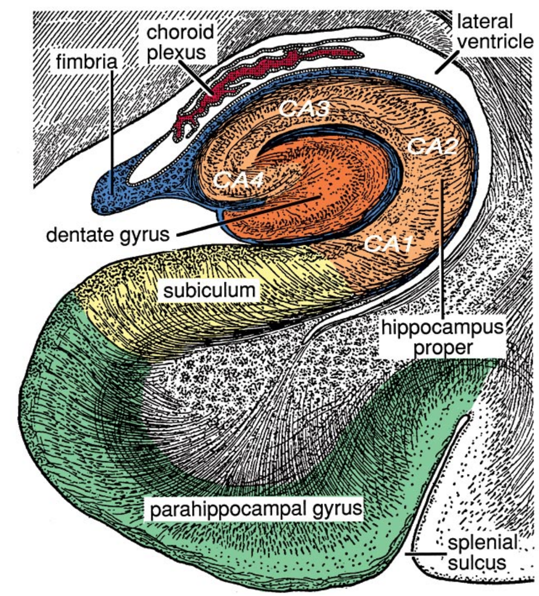
Figure 13. Nissl stain of the visual cortex reveals the different layers I through VI quite clearly.

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

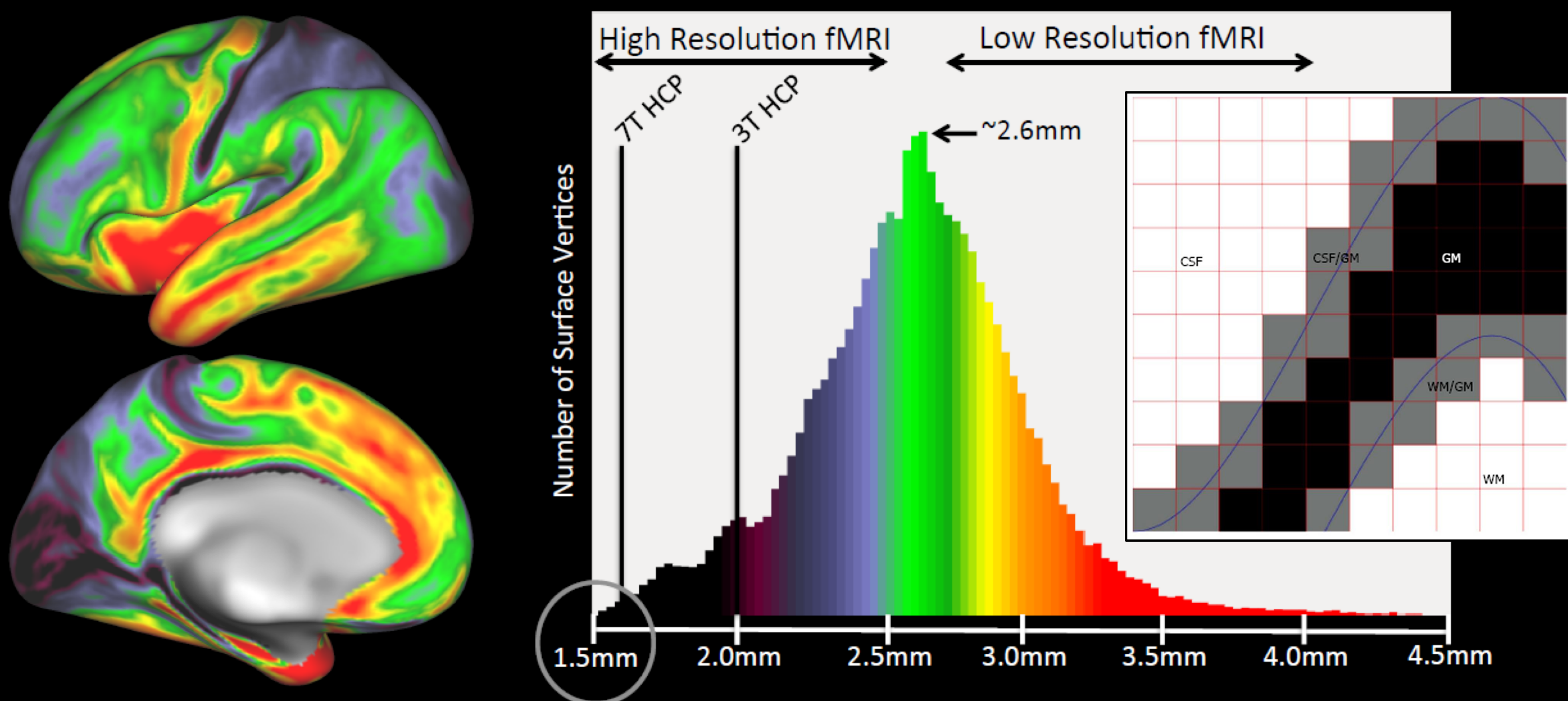


Beul & Hilgetag Front Neuroanat 2015

Hippocampus is a cortical structure with 3 layers



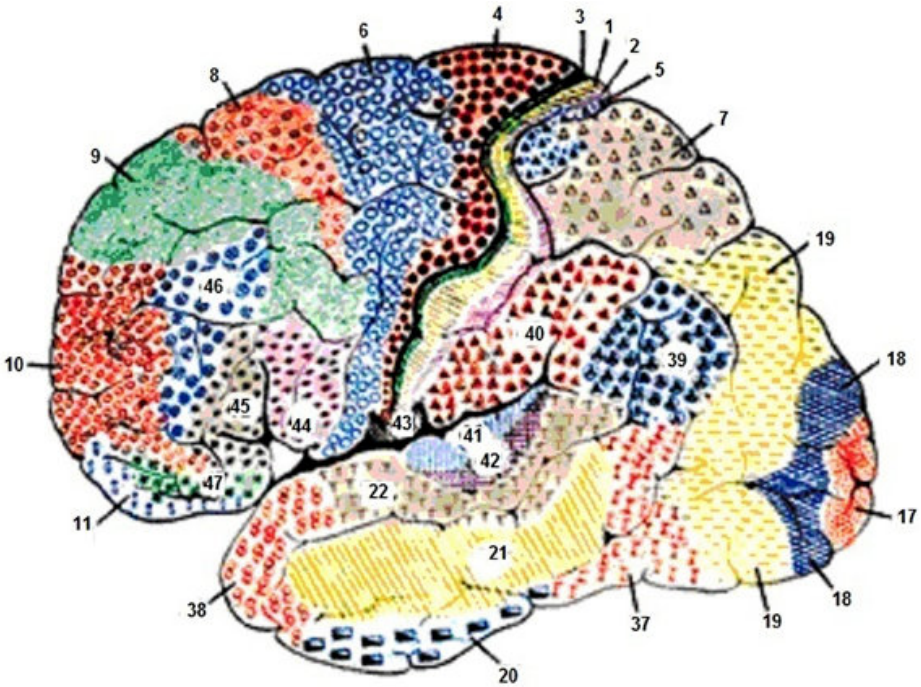
Cortical Neuroanatomy Drives Spatial Resolution Choices for Acquiring HCP-style MRI Data



- 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

Area V1 (17)



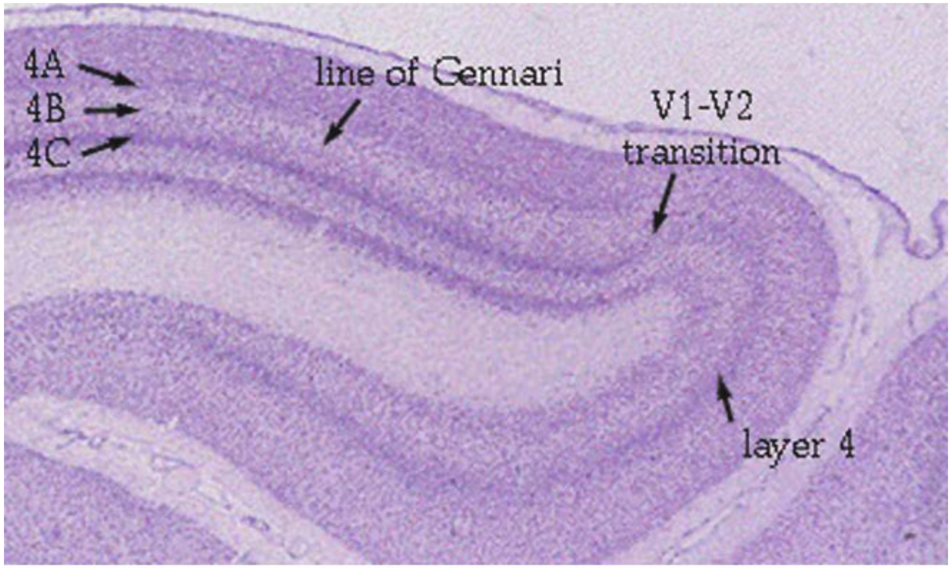
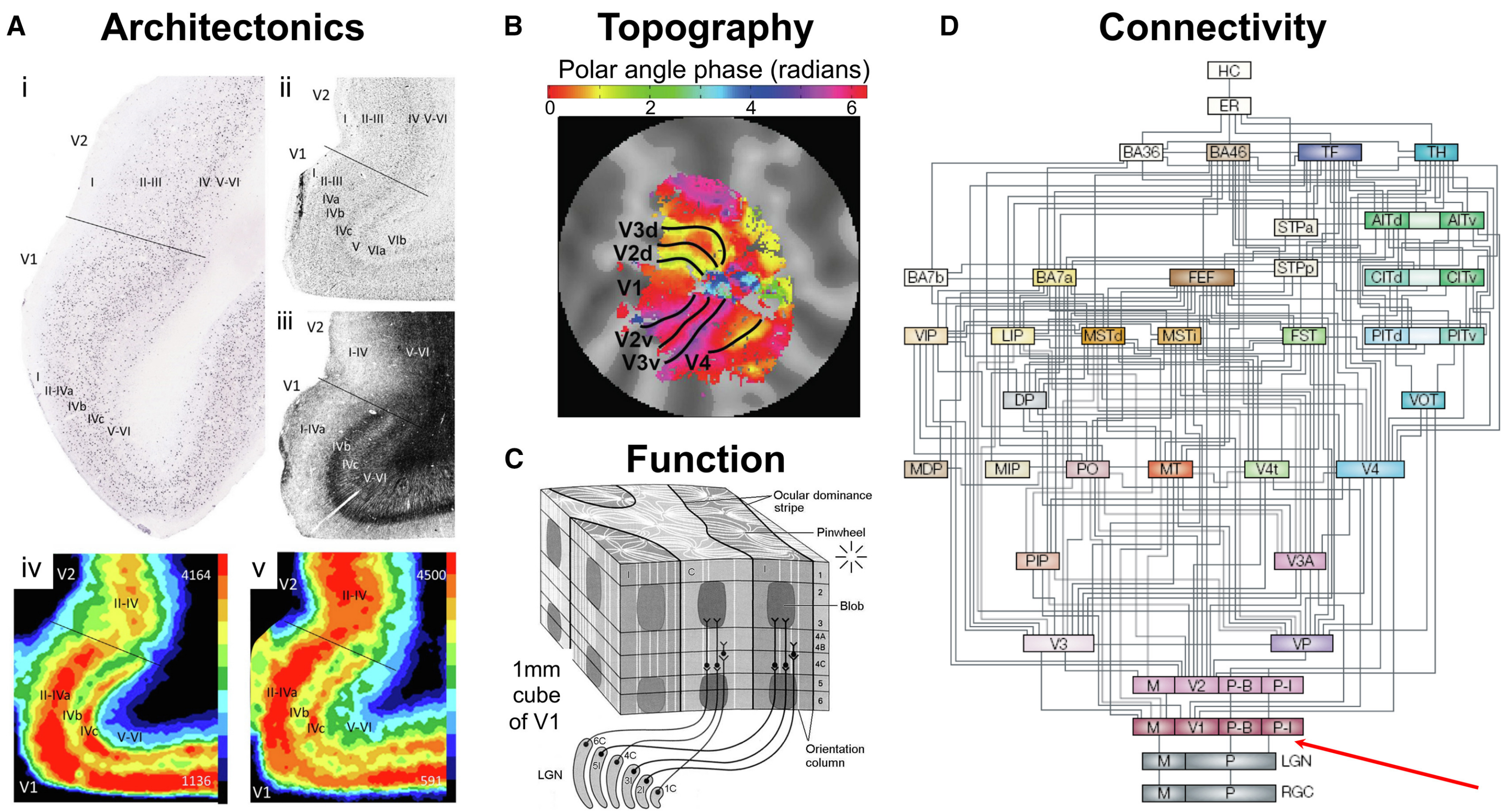


Figure 9. Nissl stained section of the visual cortex to show the border between area 17 (V1) and area 18 (V2).

Brodmann (1909)

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

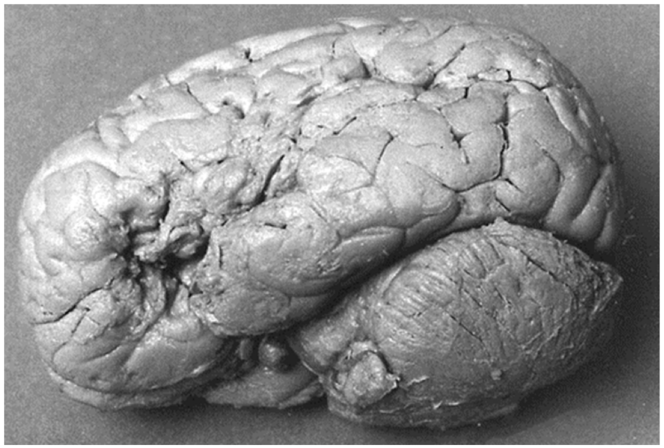
Defining a cortical area
Van Essen's **FACT**

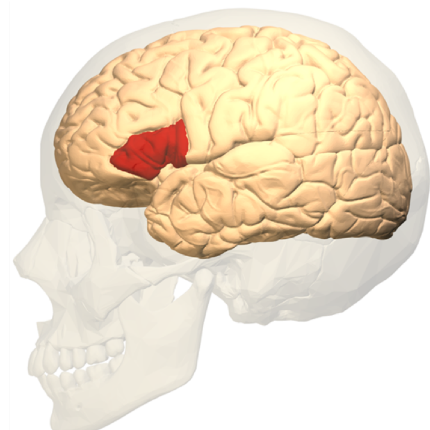


Example of defining V1

Petersen et al (2024) Neuron

Functional lesions: Broca's area



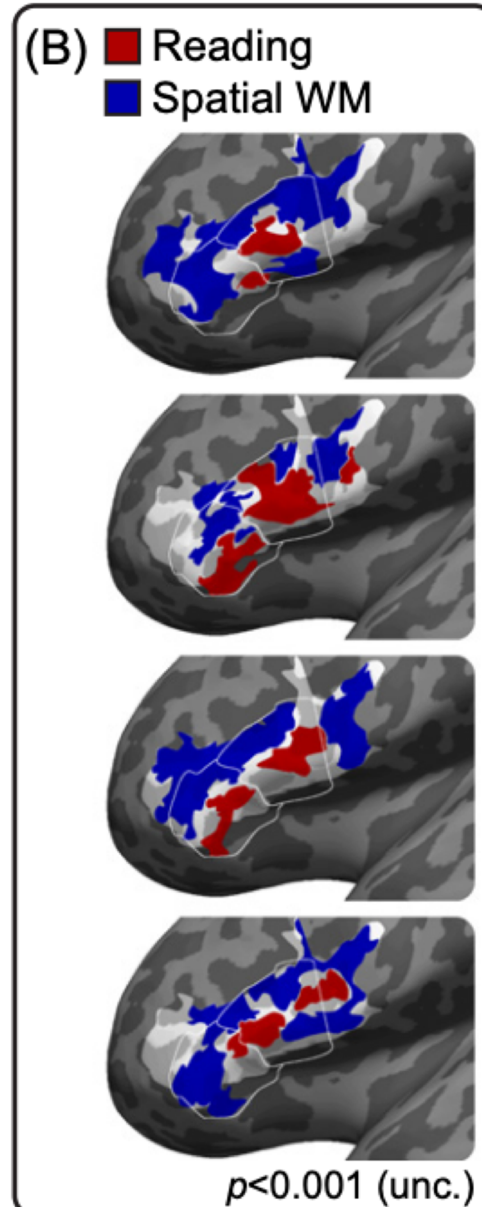


Trends in Cognitive Sciences

Opinion

Broca's Area Is Not a Natural Kind

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

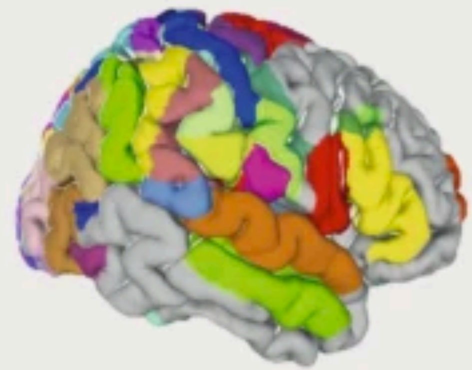


Local

Histology-based:
- Cytoarchitecture
- Receptors
- Myelin

MRI-based:
- Myelin
- Meta-analytic activation modelling

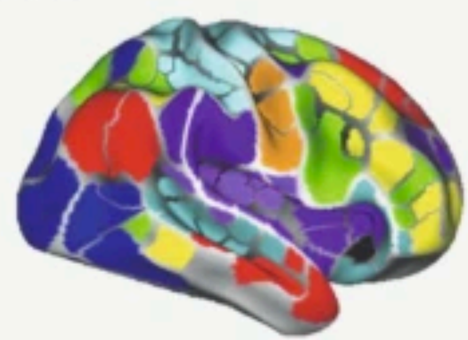
Border detection in cortex based on cytoarchitecture



Global

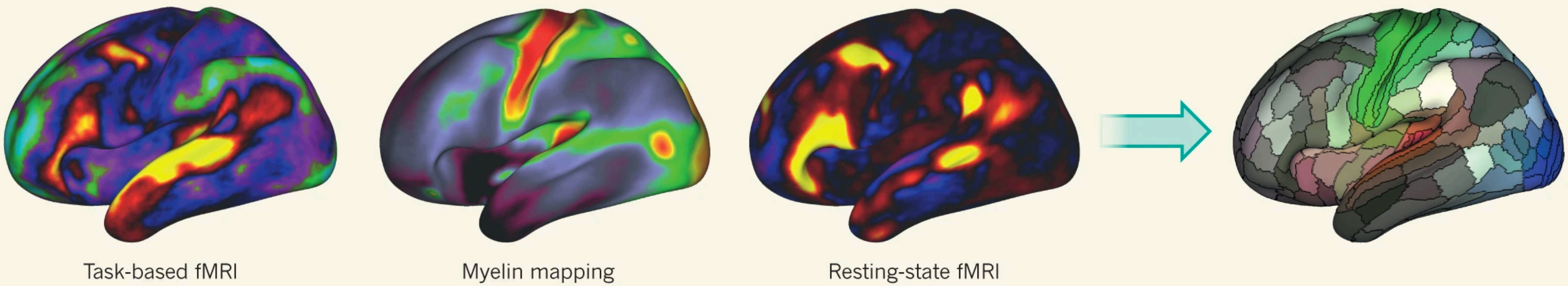
MRI-based:
- Resting-state functional connectivity
- Meta-analytic connectivity modelling
- Diffusion tractography
- Structural covariance

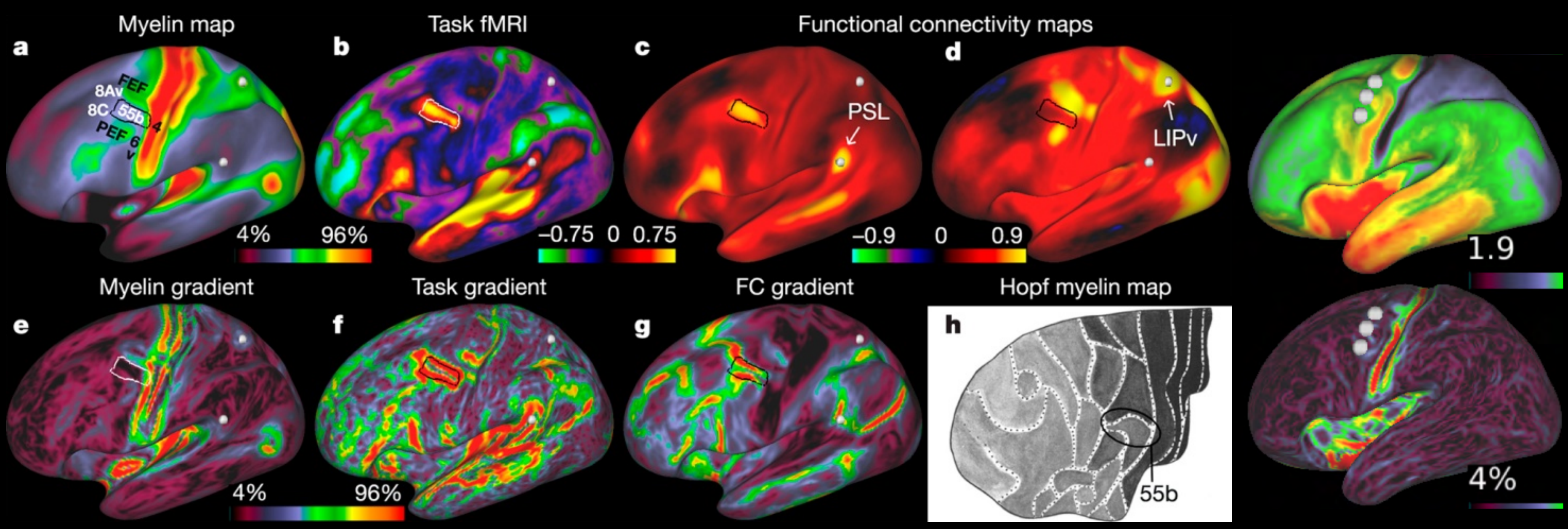
Boundary mapping of resting-state functional connectivity of cerebral cortex



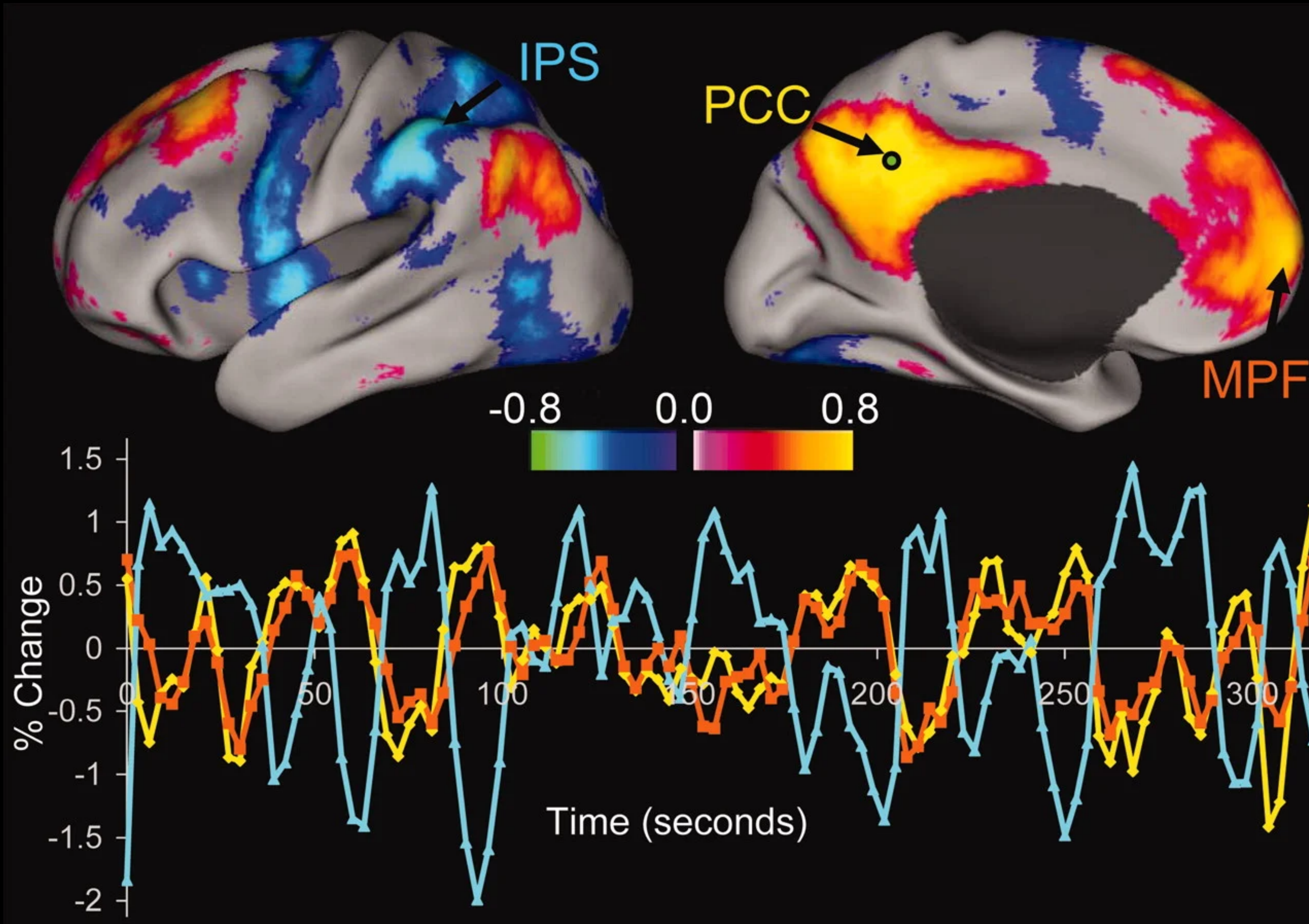
Eickhoff et al Nature Rev Neuro 2018

Multimodal atlases

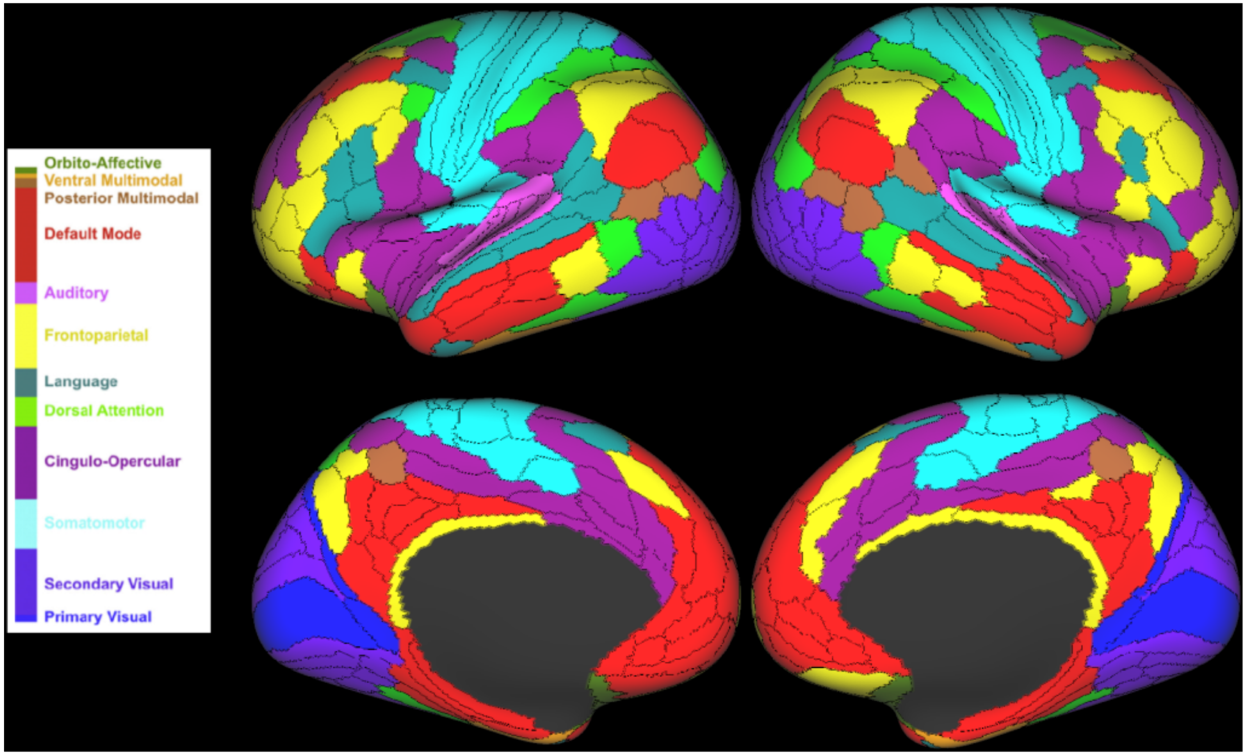




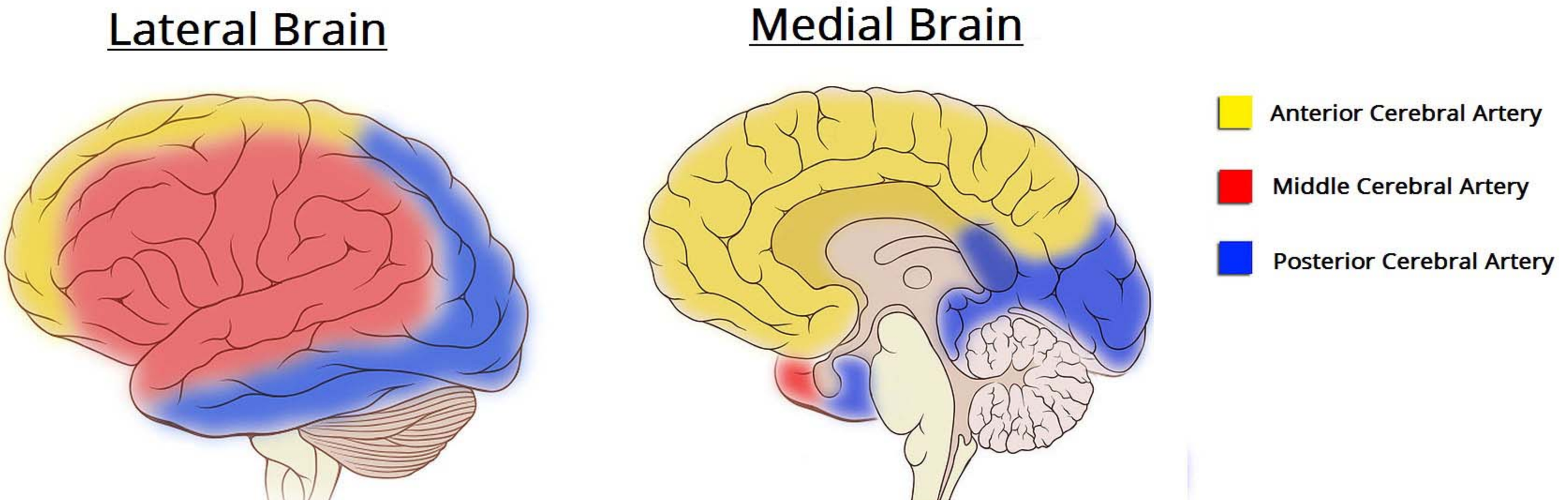
Glasser et al Nature 2016



Fox et al PNAS 2005



Ji et al NeuroImage *2019*

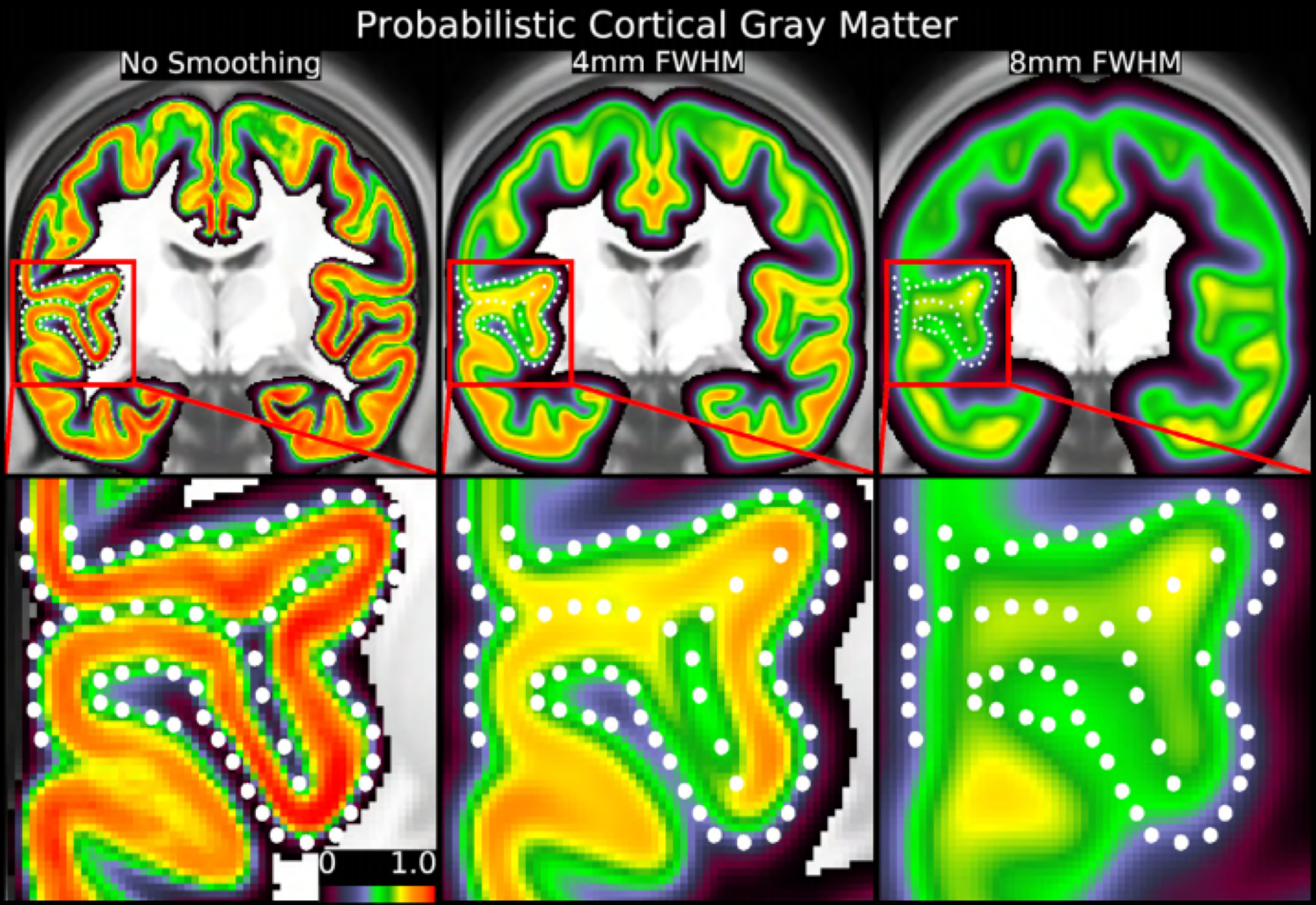


https://upload.wikimedia.org/wikipedia/commons/thumb/4/4a/Cerebral_vascular_territories.jpg/440px-Cerebral_vascular_territories.jpg

Cortex

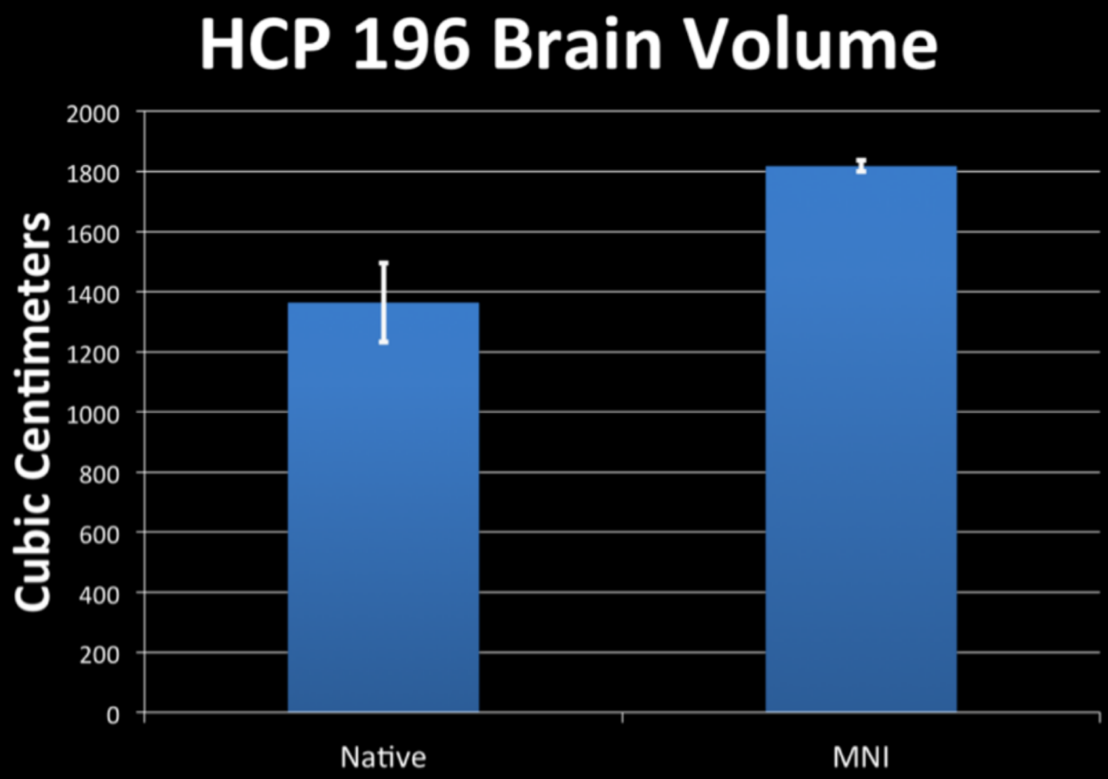
Surface vs volume analysis

Intersubject alignment

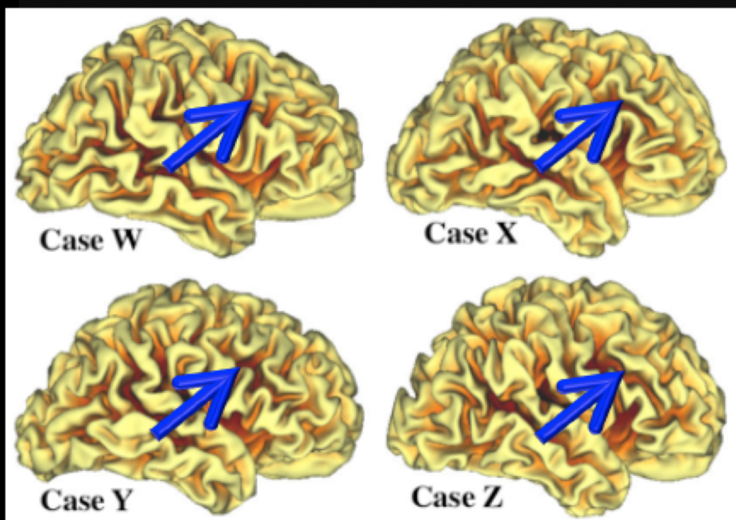


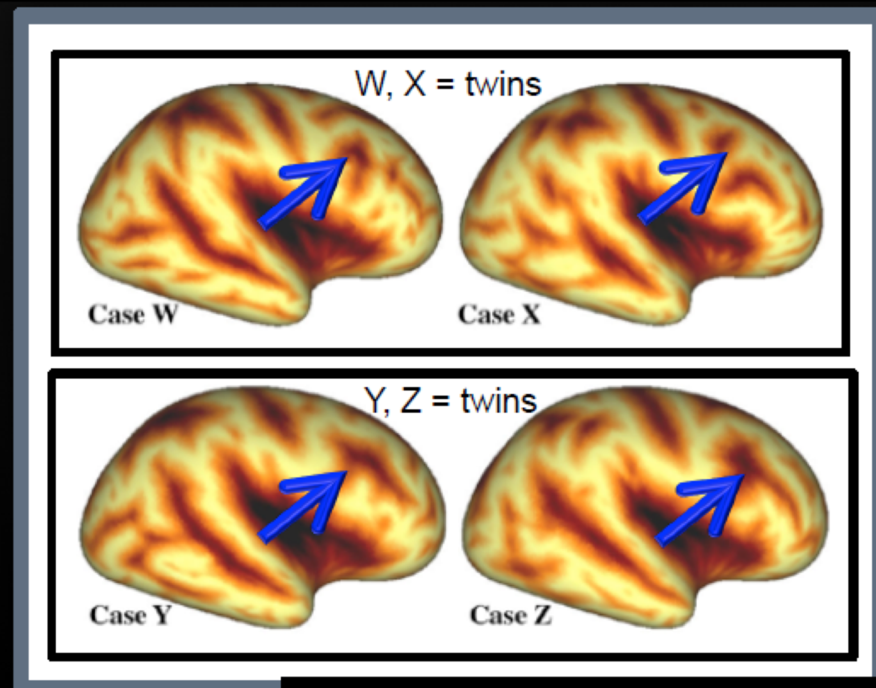
Supp figure from Coalson T. et al (2018) *PNAS*

MNI drift
Increase brain size by 37%



Glasser et al (2016) *Nature Neuroscience*





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

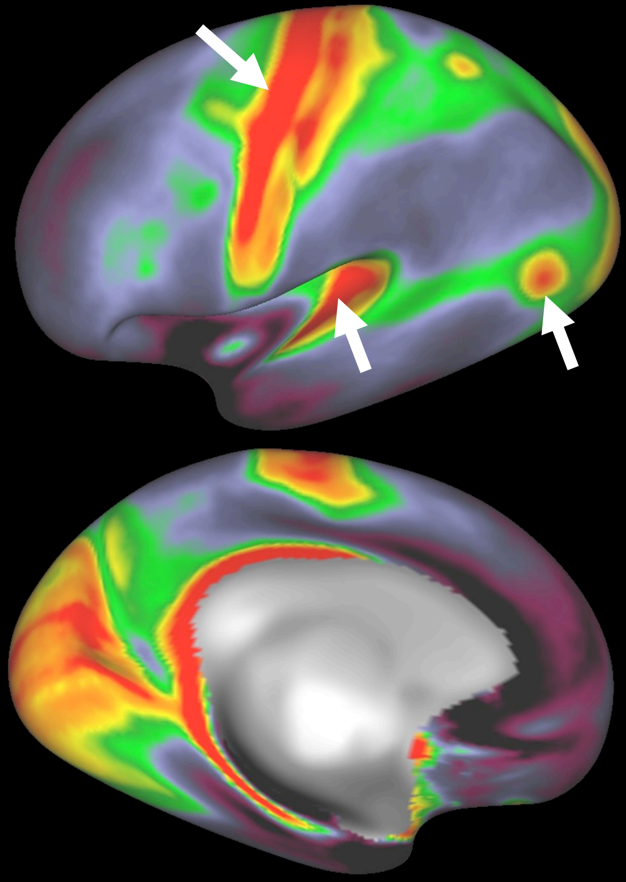
- Convolutions are complex!
- Highly variable across individuals
- More variable in ‘higher cognitive’ regions
- Variable even in identical twins, but some heritability

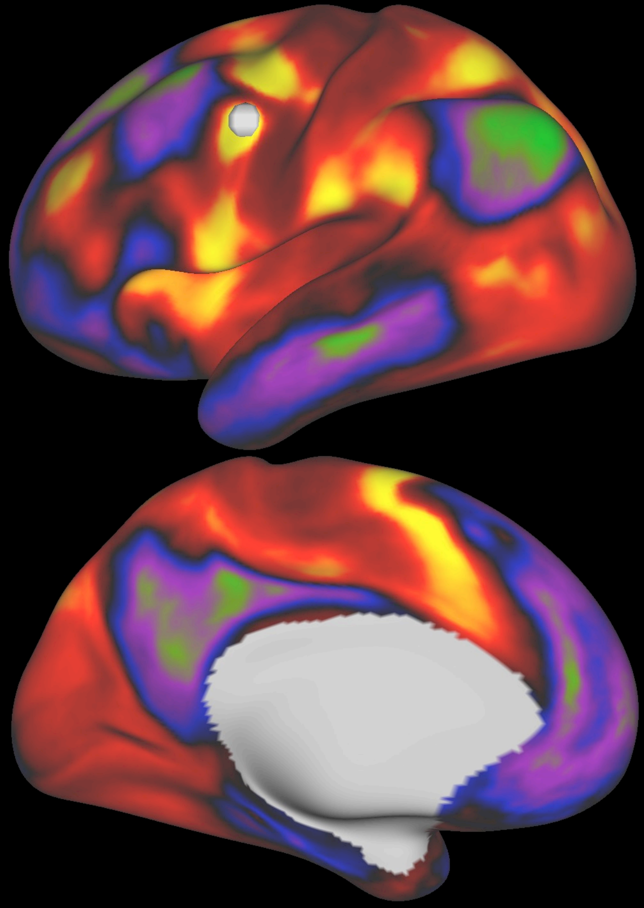
From HCP course slides

Areal feature-based surface registration

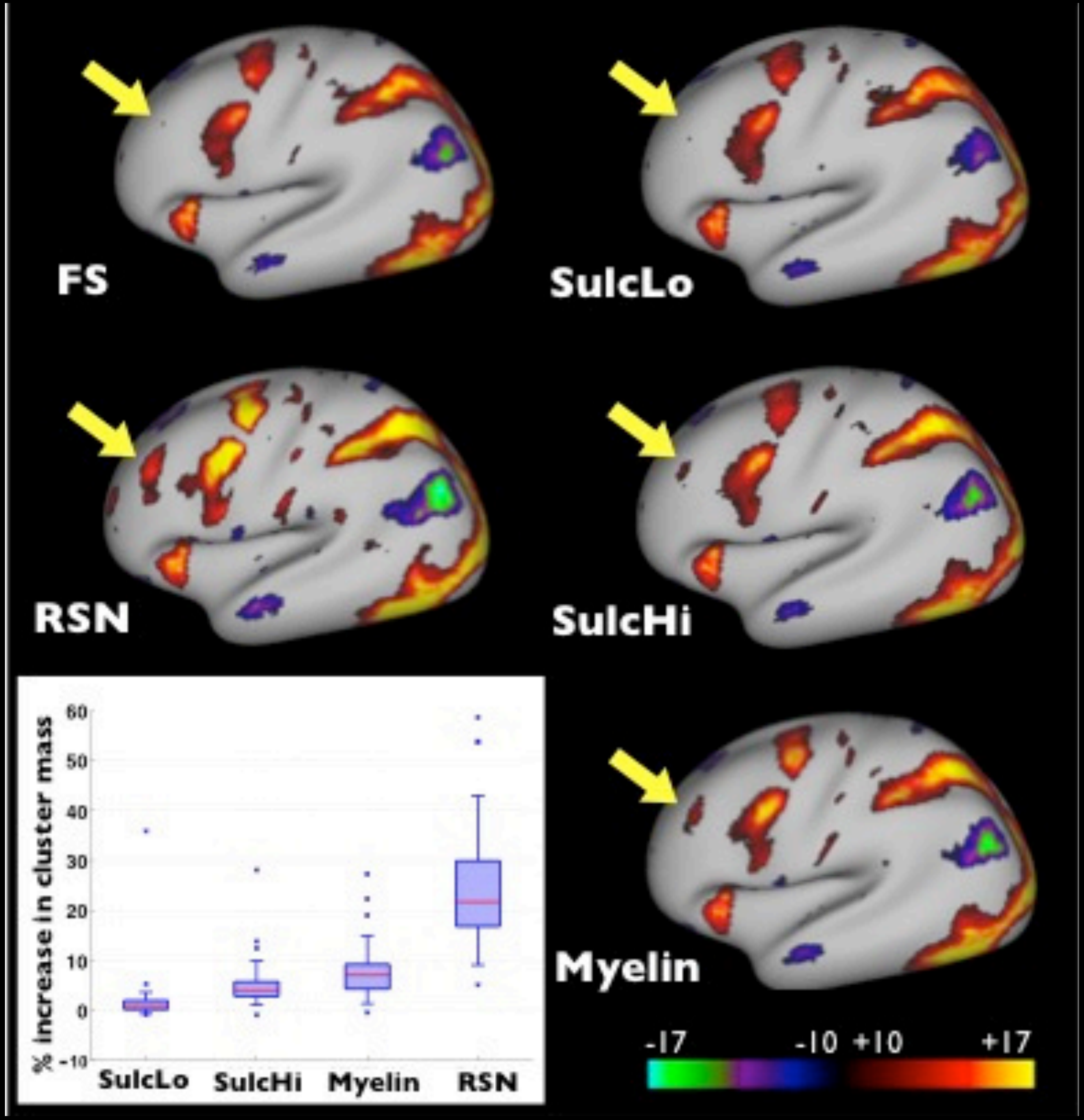
Myelin Map
T1w/T2w

rest fMRI
connectivity maps





Multimodal Surface Matching (MSM)

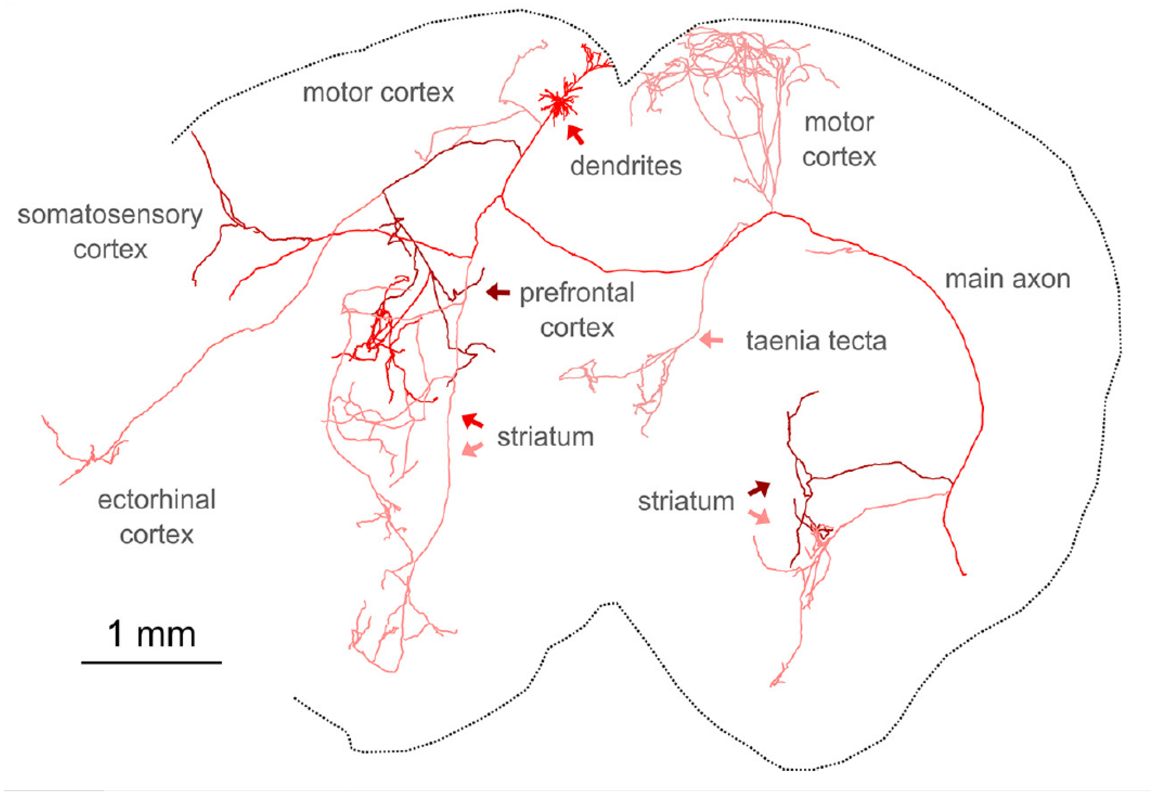


Robinson et al (2014)
NeuroImage

Cortex

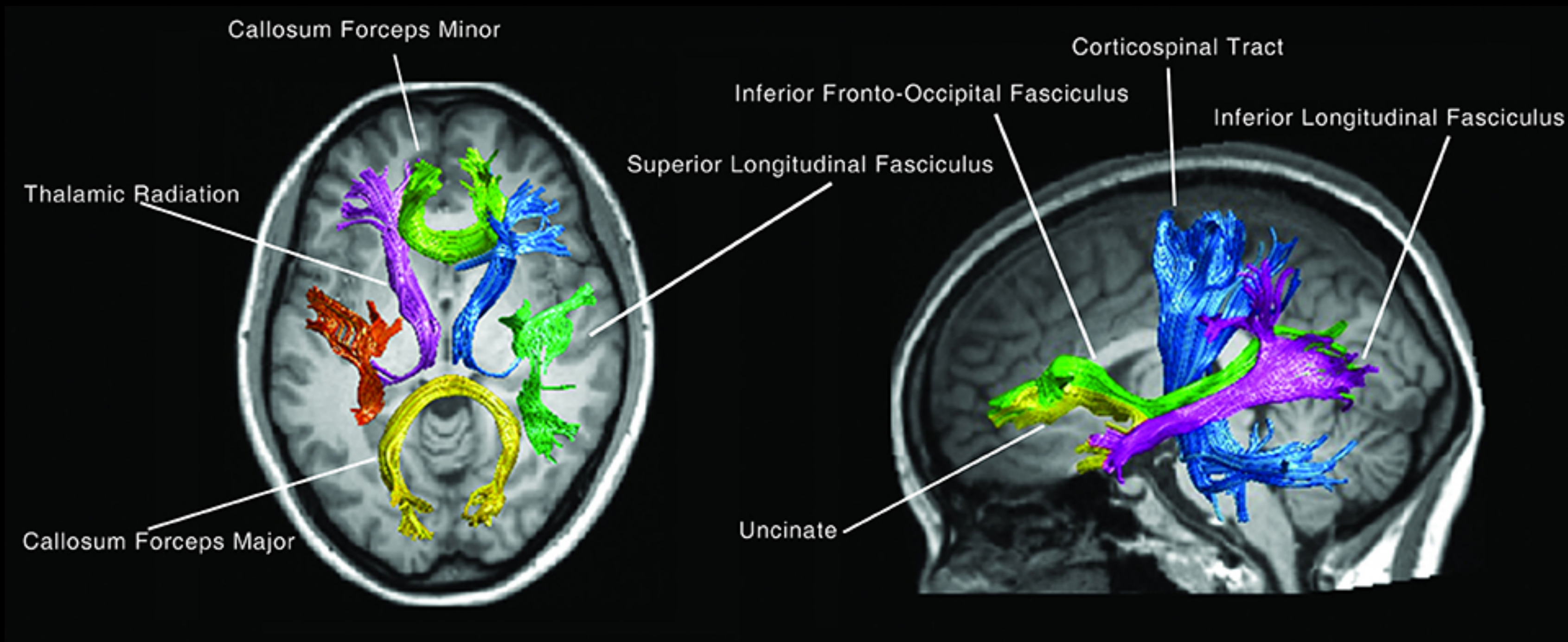
Anatomical connections

A single neuron connections



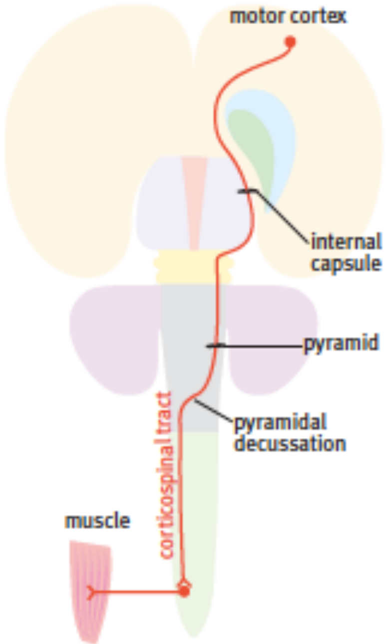
Economo et al. eLife 2016

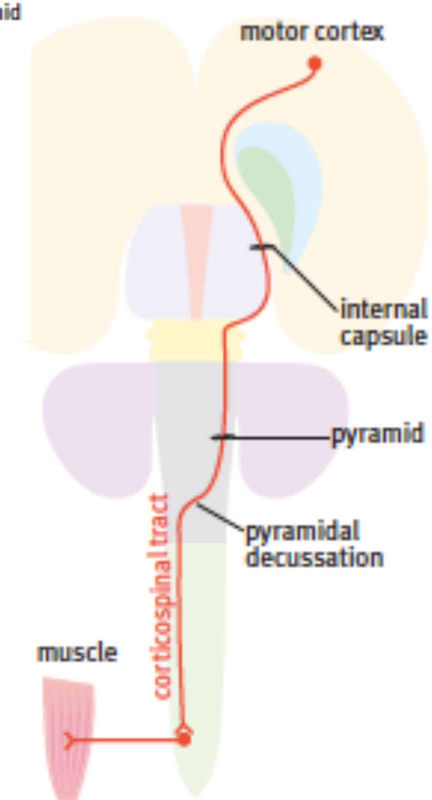
White matter bundles

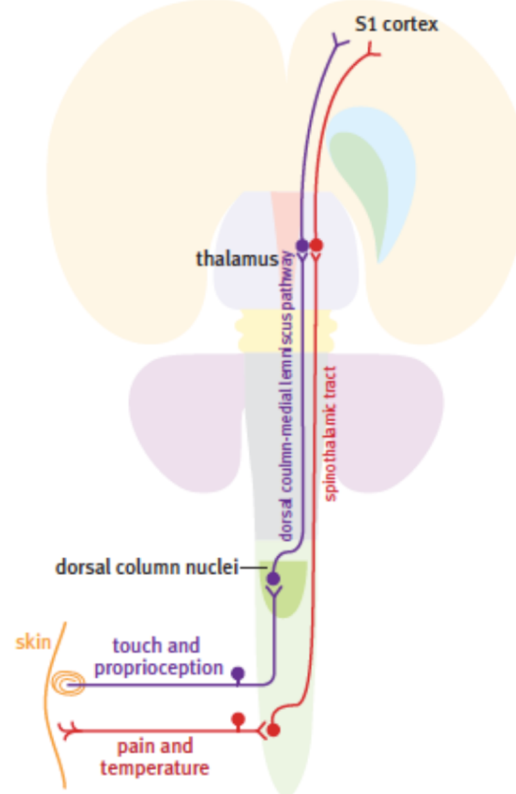


Shah et al Front Neuro 2018

Cortico-spinal tracts







Descending (motor) tracts

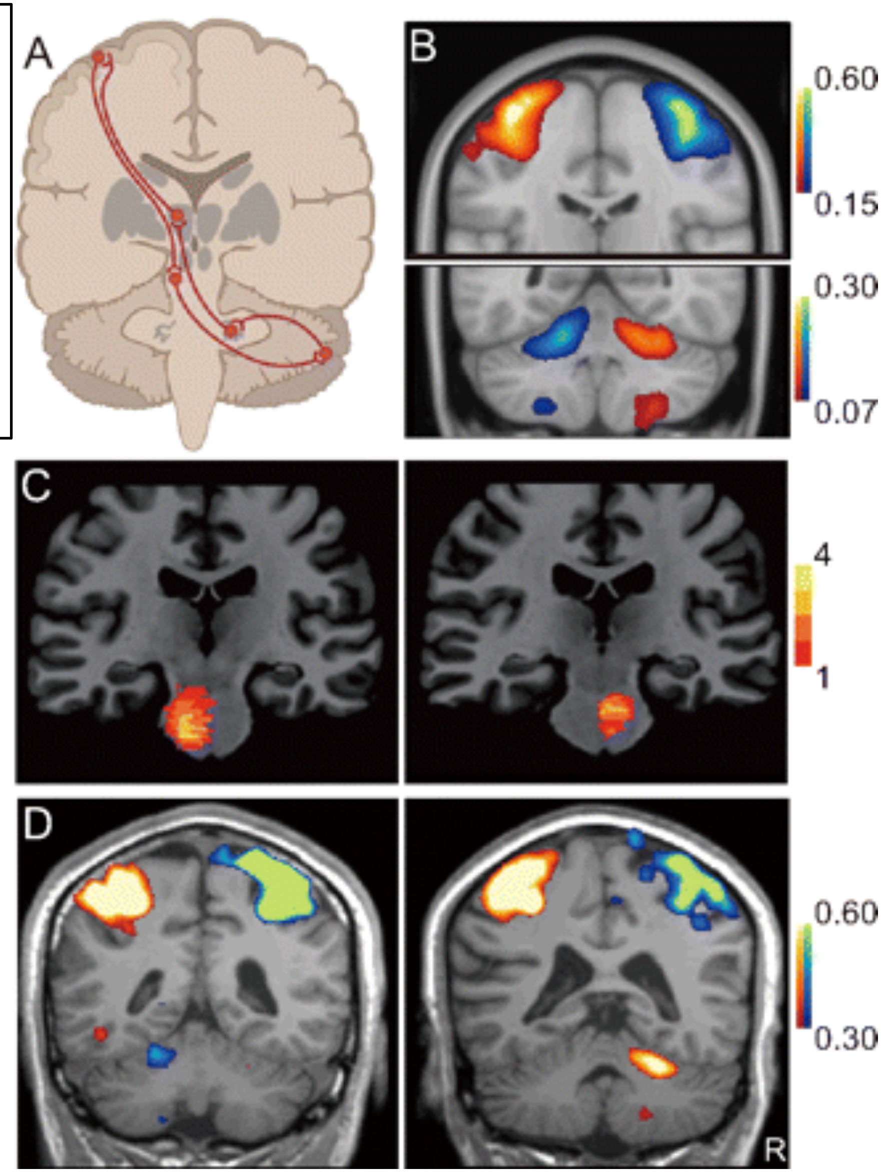
Ascending (sensory) tracts

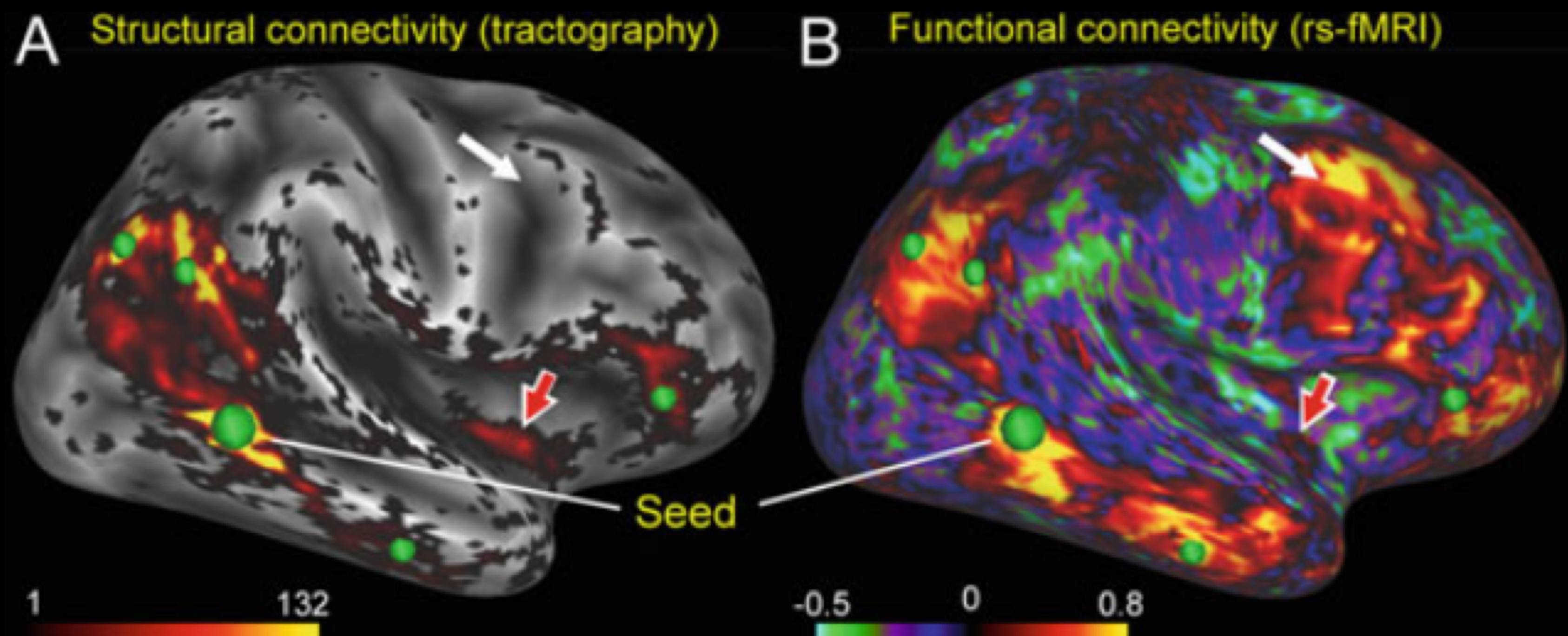
Behavioral/Systems/Cognitive

Focal Pontine Lesions Provide Evidence That Intrinsic Functional Connectivity Reflects Polysynaptic Anatomical Pathways

Jie Lu,[1]* Hesheng Liu,[3]* Miao Zhang,[1] Danhong Wang,[3] Yanxiang Cao,[1] Qingfeng Ma,[2] Dongdong Rong,[1] Xiaoyi Wang,[1] Randy L. Buckner,[3,4,5,6] and Kuncheng Li[1]

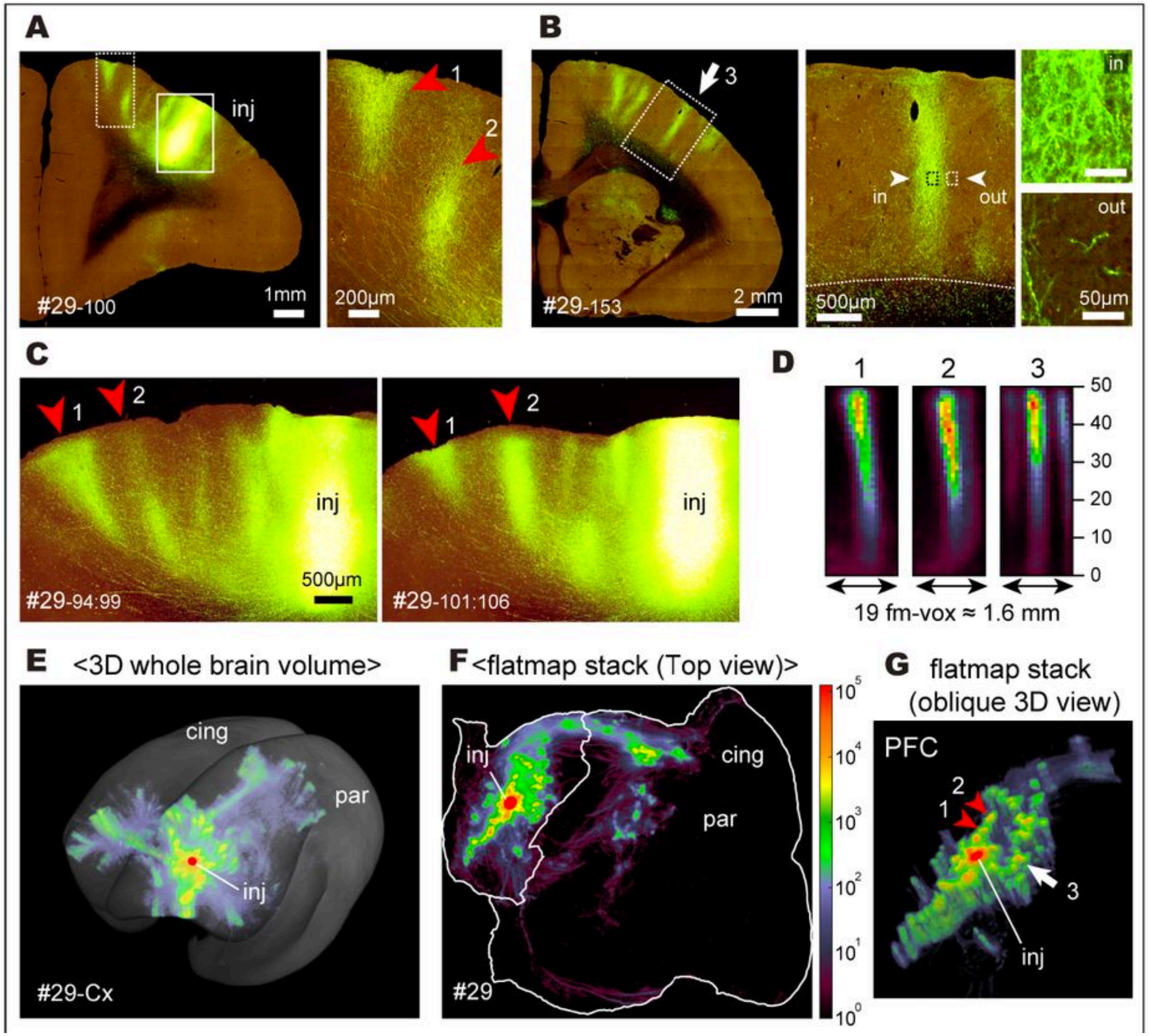
Departments of [1]Radiology and [2]Neurology, Xuanwu Hospital of Capital Medical University, Beijing 100053, China, [3]Athinoula A. Martinos Center for Biomedical Imaging, Department of Radiology and [4]Department of Psychiatry, Massachusetts General Hospital, Charlestown, Massachusetts 02129, [5]Psychology and Center for Brain Science, Harvard University, Cambridge, Massachusetts 02138, and [6]Howard Hughes Medical Institute, Cambridge, Massachusetts 02138





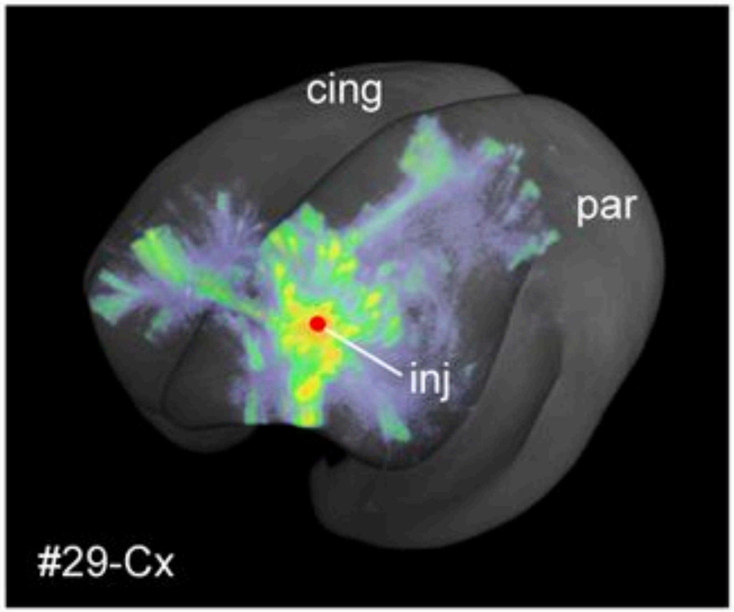
Van Essen et al. Micro-, Meso-, Macro-
Connectomics of the Brain. 2016

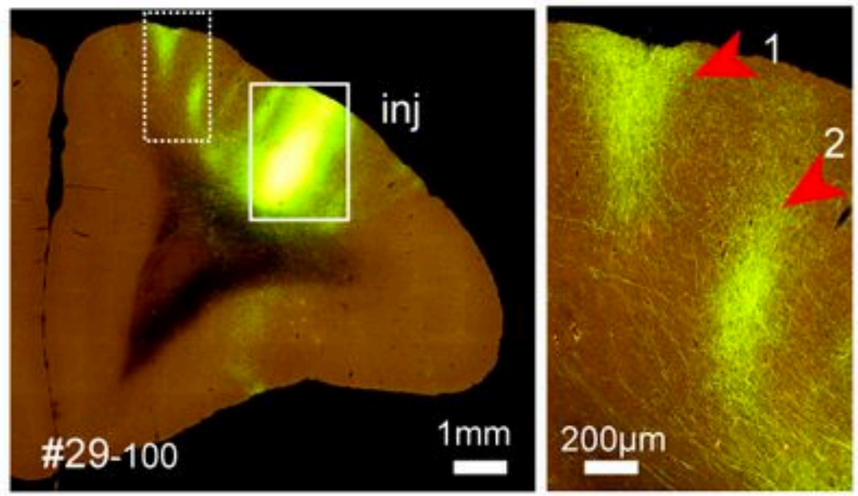
Tract-tracing



Watakabe et al
Neuron 2023

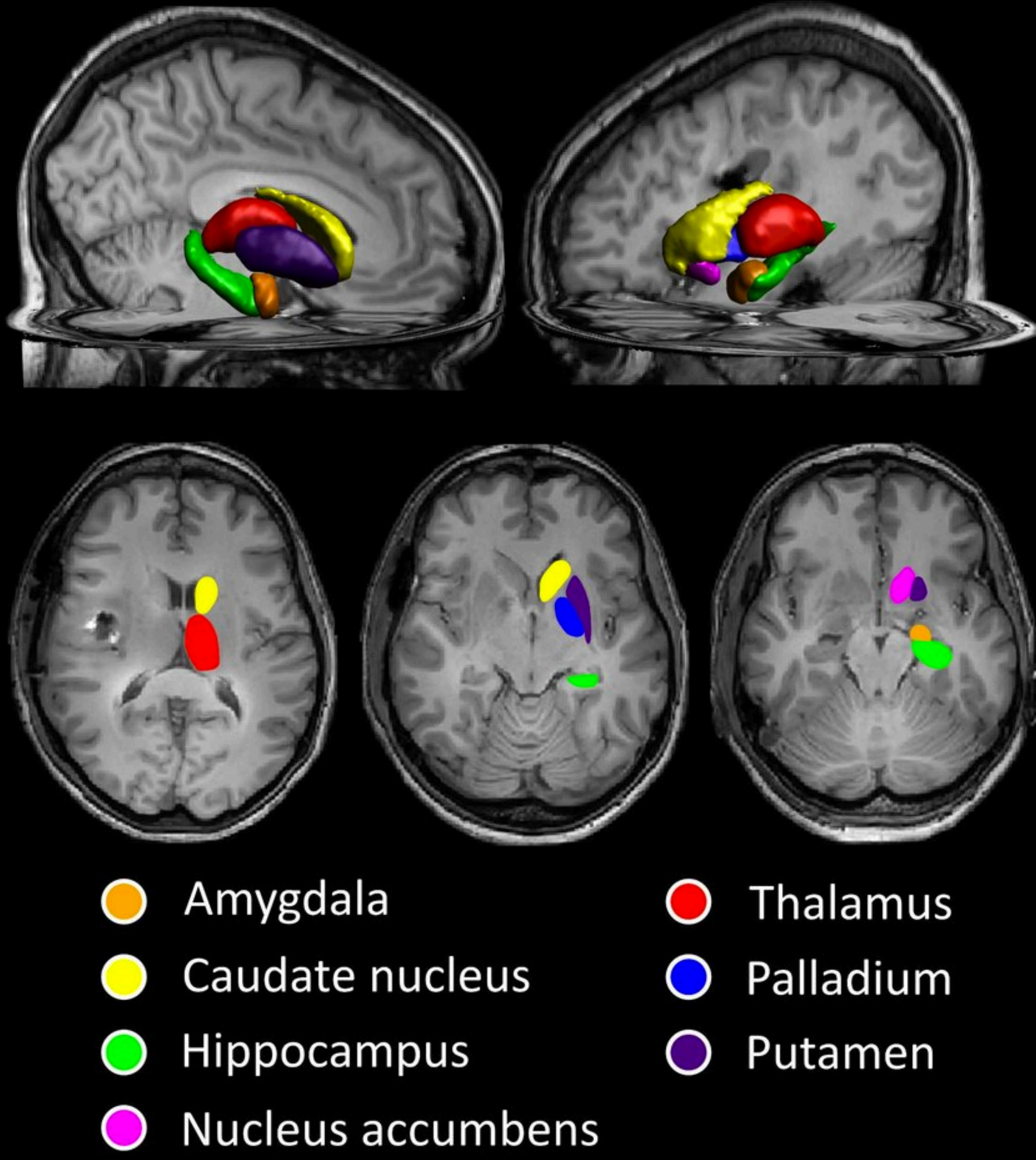
Gold standard: tract-tracing





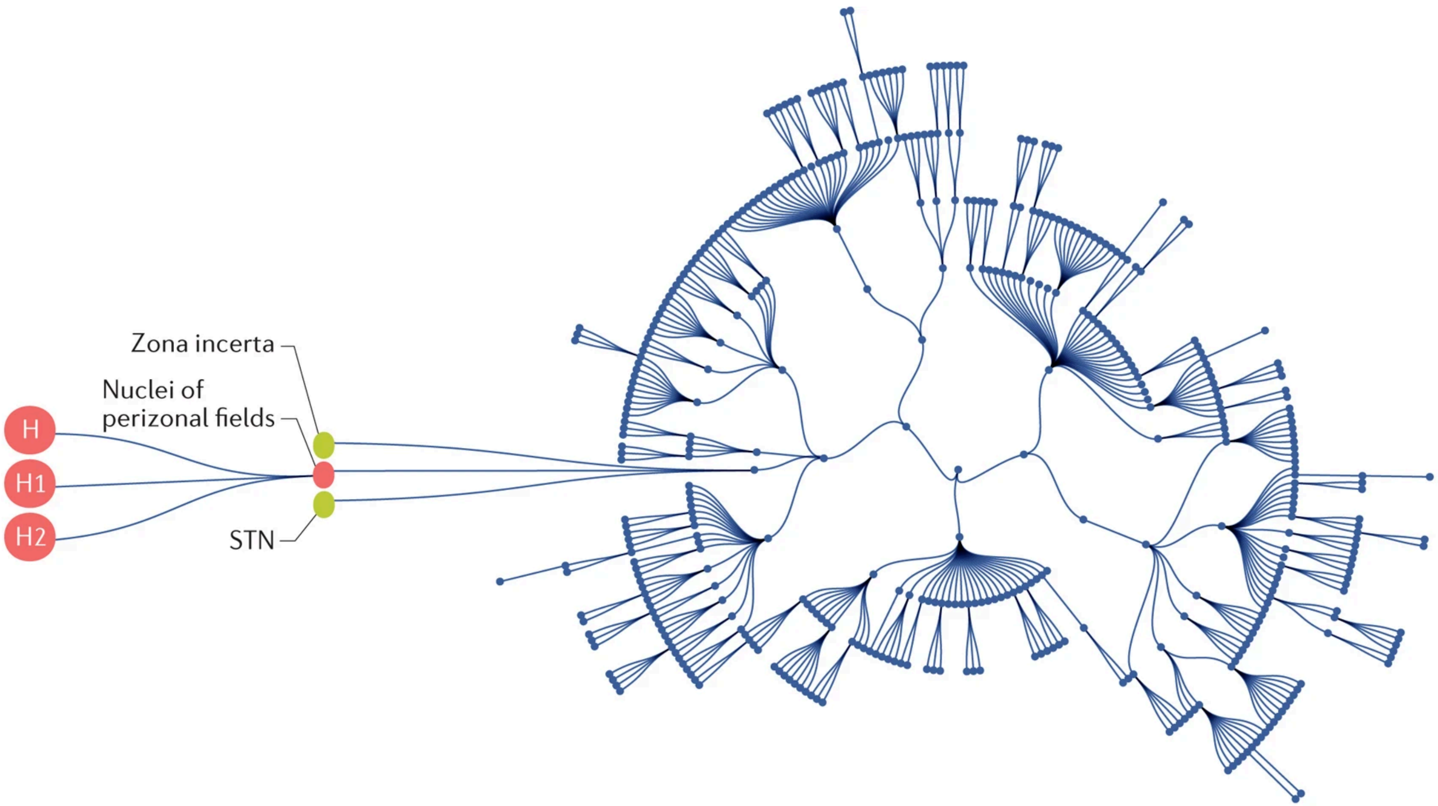
Watakabe et al
Neuron 2023

Deeper structures



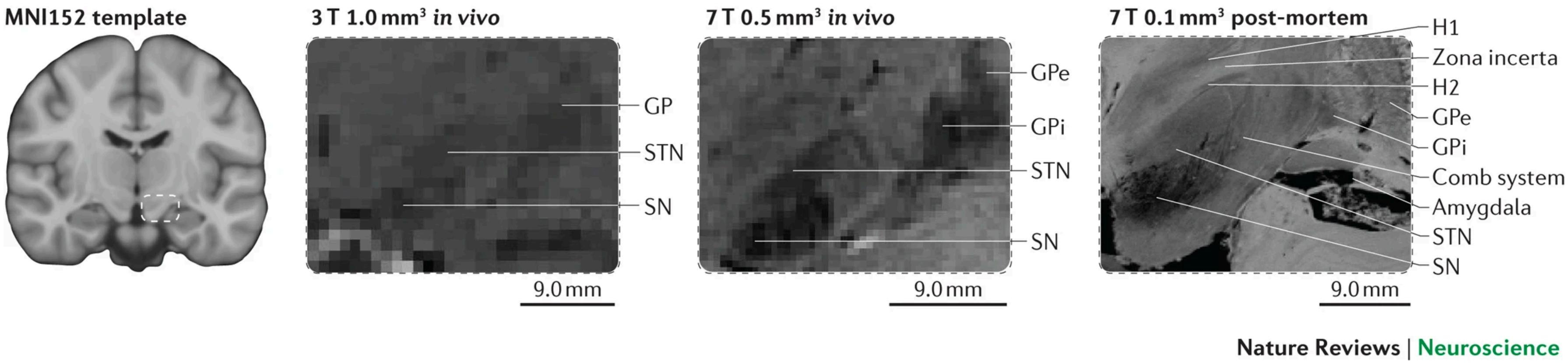
Nagtegaal et al *Clin & Trans Rad Onc* 2020

Subcortex: unchartered territory



Forstmann 2017
Nature Rev Neuro

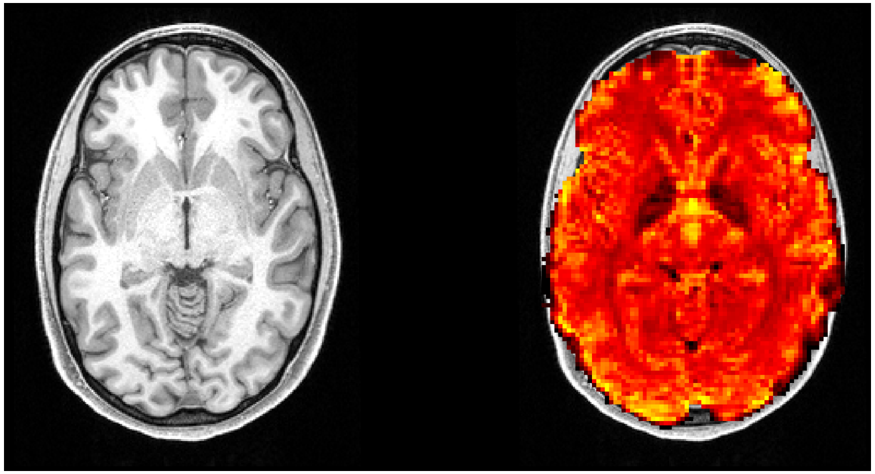
Subcortex: unchartered territory

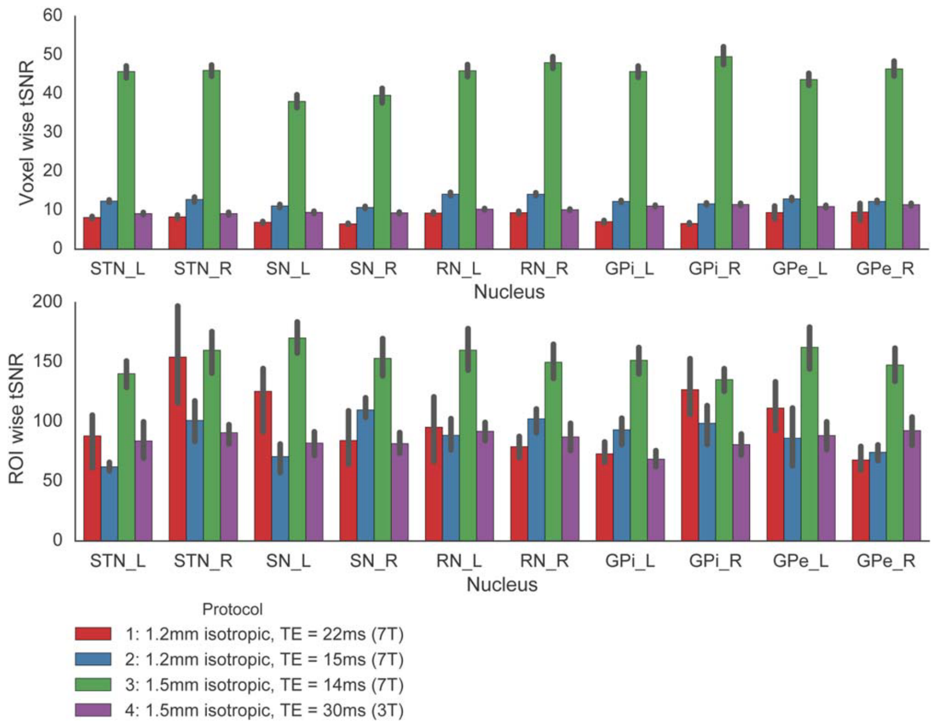


Forstmann 2017
Nature Rev Neuro

Special MRI sequences

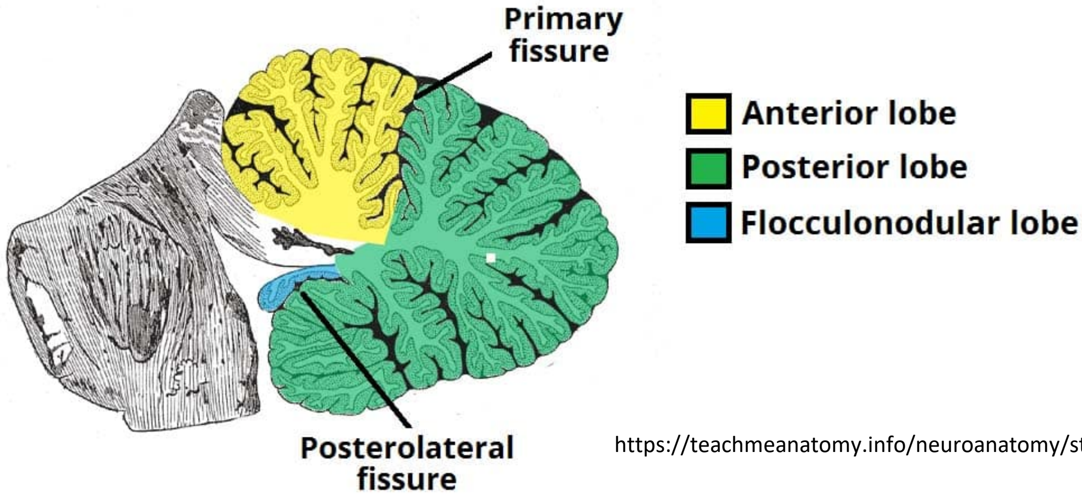
Typical sequences with echo time (TE) = ~30ms



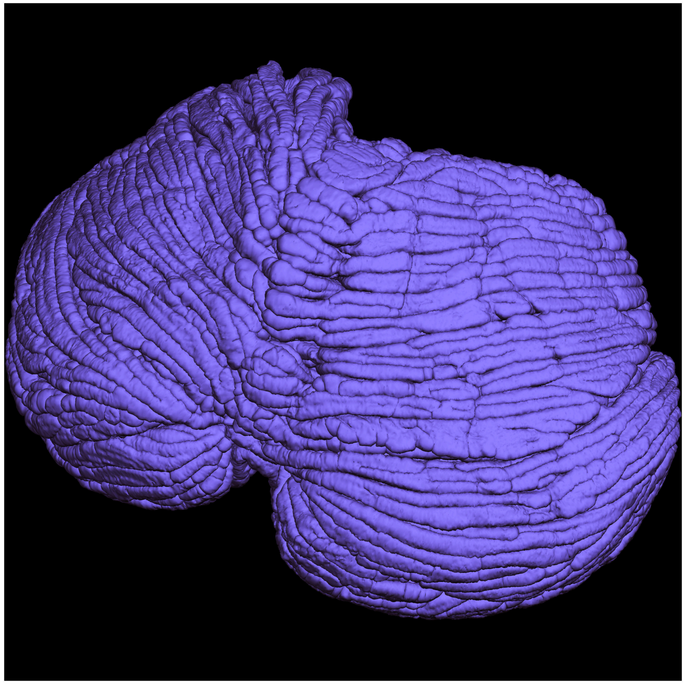


De Hollander et al HBM 2017

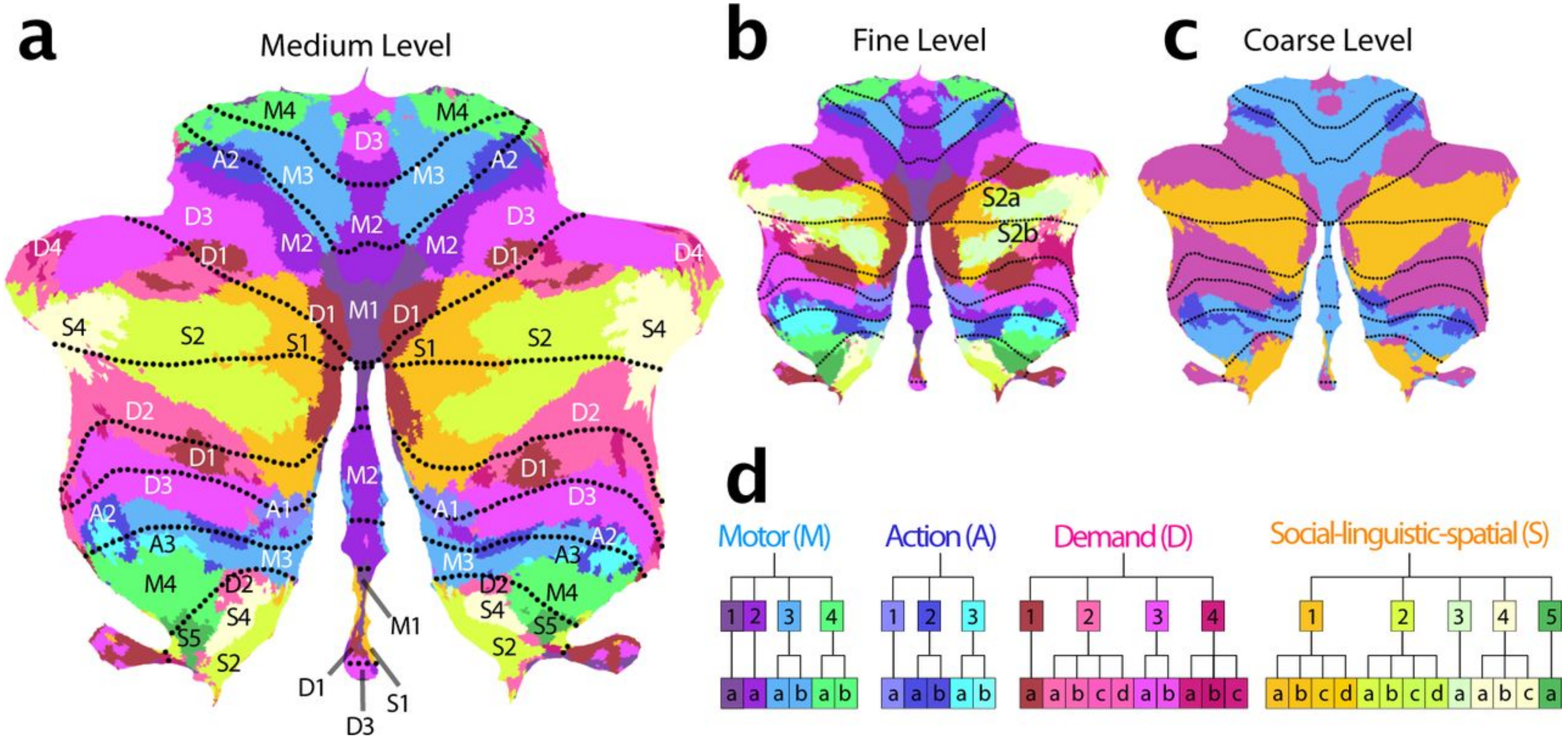
Cerebellum



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



Sereno et al PNAS 2020



Nettekoven C. et al., Nature Communications 2024

Take home messages

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