



MRC Cognition  
and Brain  
Sciences Unit



UNIVERSITY OF  
CAMBRIDGE

# (Modern) Brain anatomy for cognitive neuroscientists

Moataz Assem

Research Associate

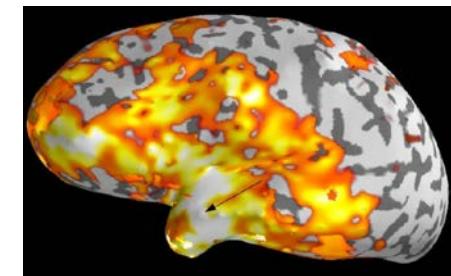
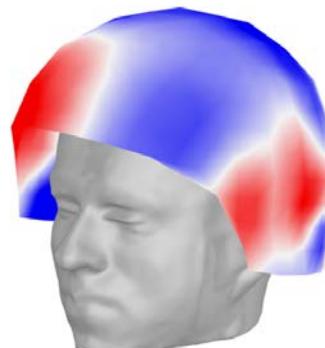
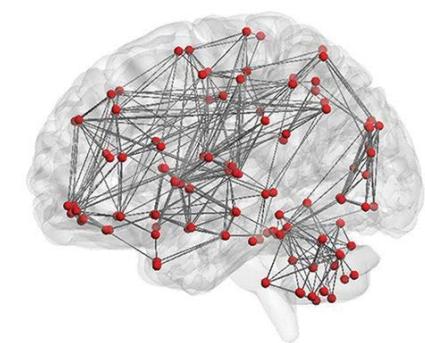
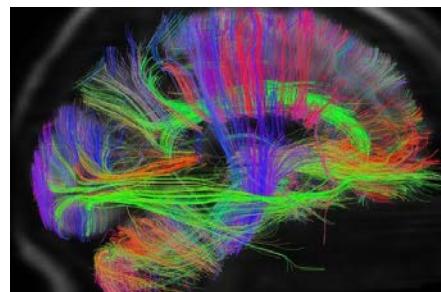
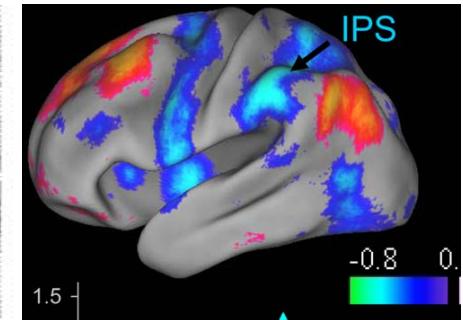
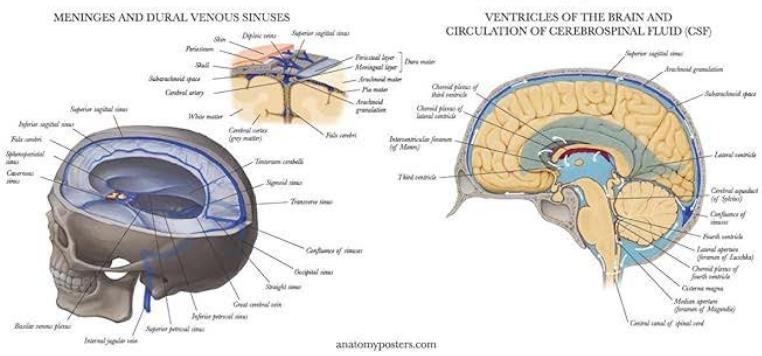
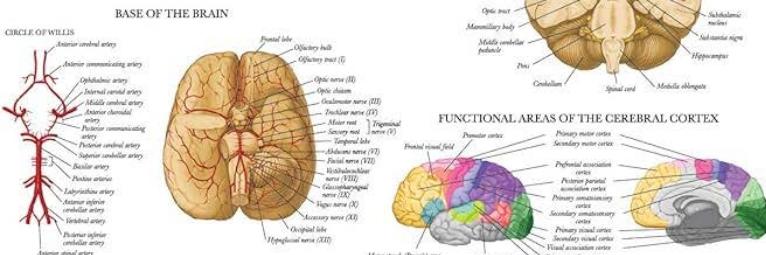
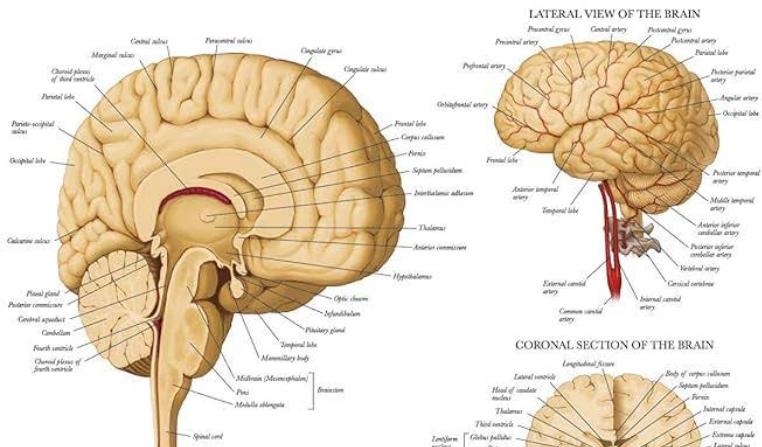
MRC Cognition and Brain Sciences Unit  
University of Cambridge

# Textbook

## ANATOMY OF THE BRAIN

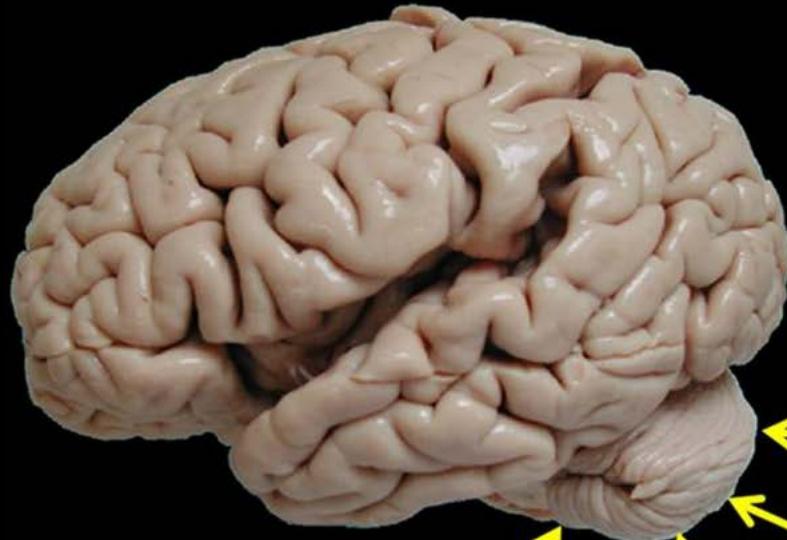
## How to link them?

# Modern Brain imaging



# Evolutionary context

**Human: 1500g, 86 billion neurons**



1 cm

**Chimpanzee: 380g  
28 billion neurons**

Diverged  
~5 - 7 MYA



**Macaque: 87g  
6 billion neurons**

Diverged  
25 - 30 MYA

~4x

~190x

~17x

~3800x



**Marmoset: 8g  
630 million neurons**

Diverged  
~35 MYA



**Capybara  
(rodent)**

**Mouse: 0.4g  
70 million neurons**

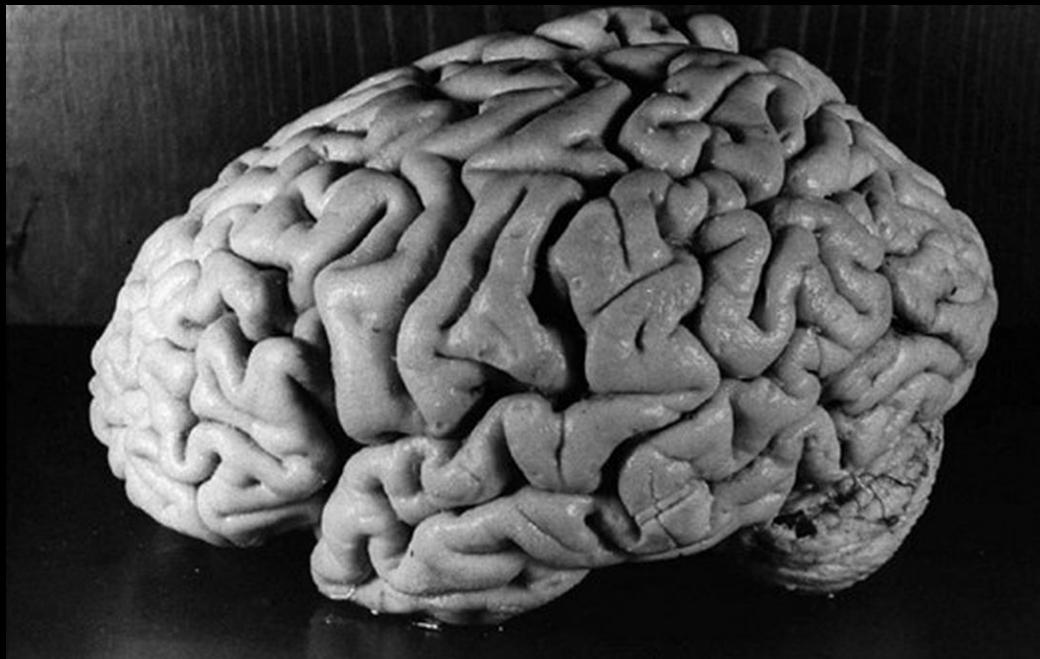
Rodents diverged  
~75 (60 – 100) MYA

Van Essen et al PNAS 2019

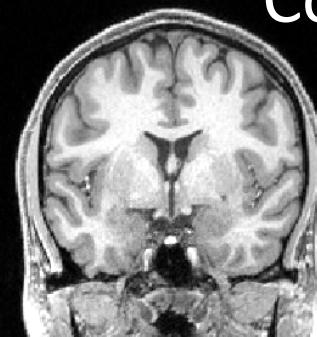
# Cortex

Basic MRI landmarks

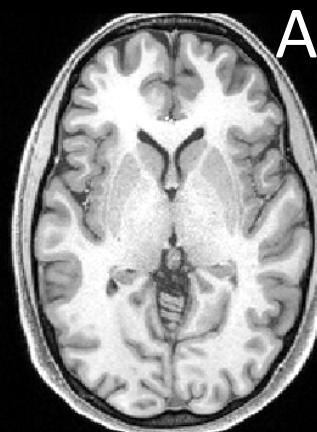
Sagittal

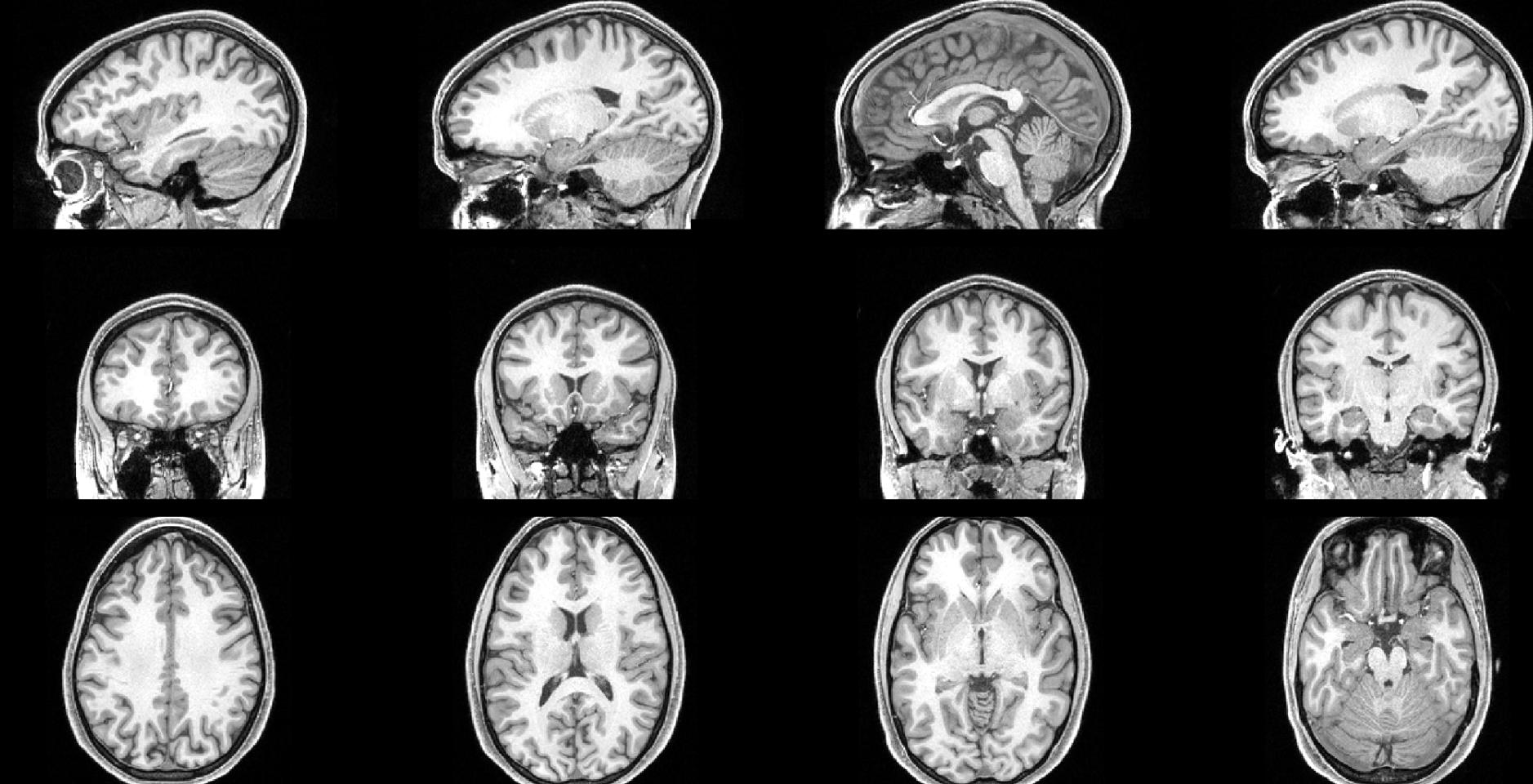


Coronal

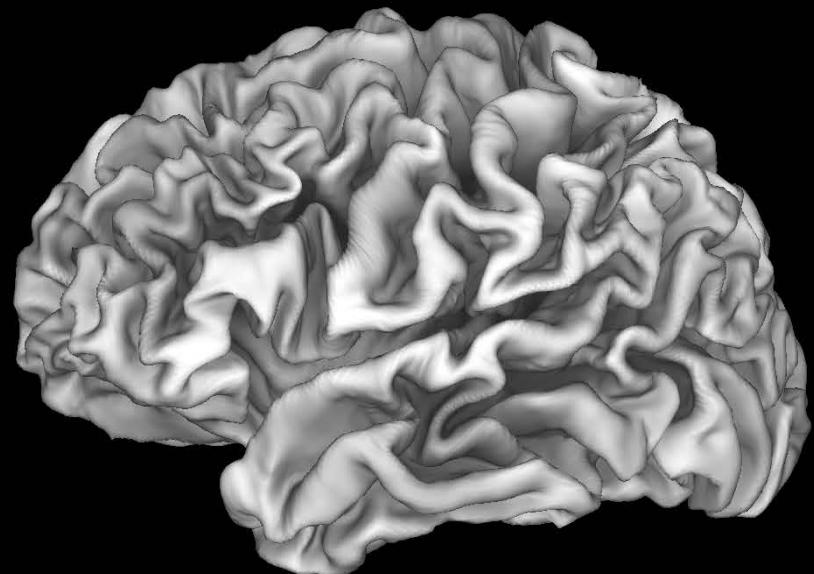
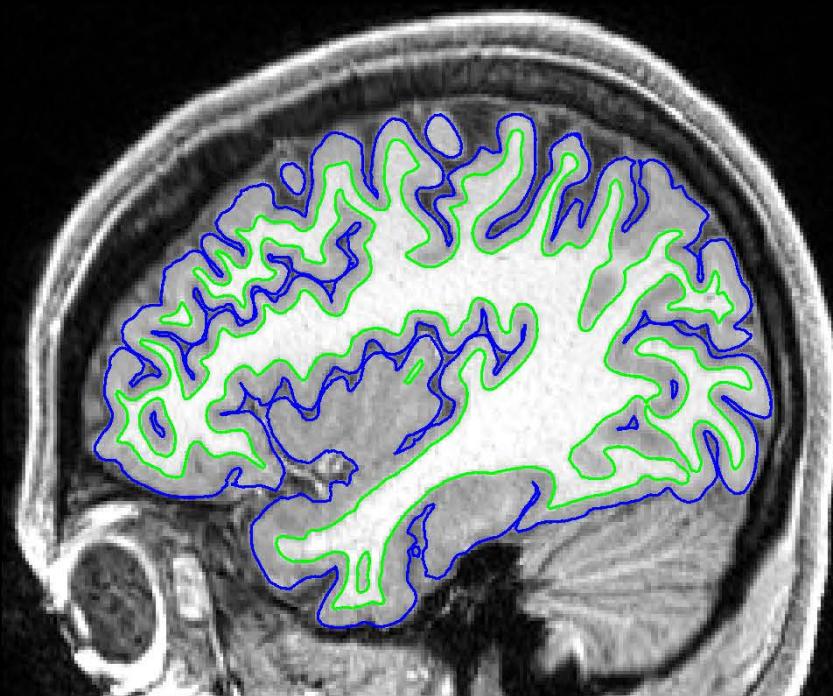


Axial



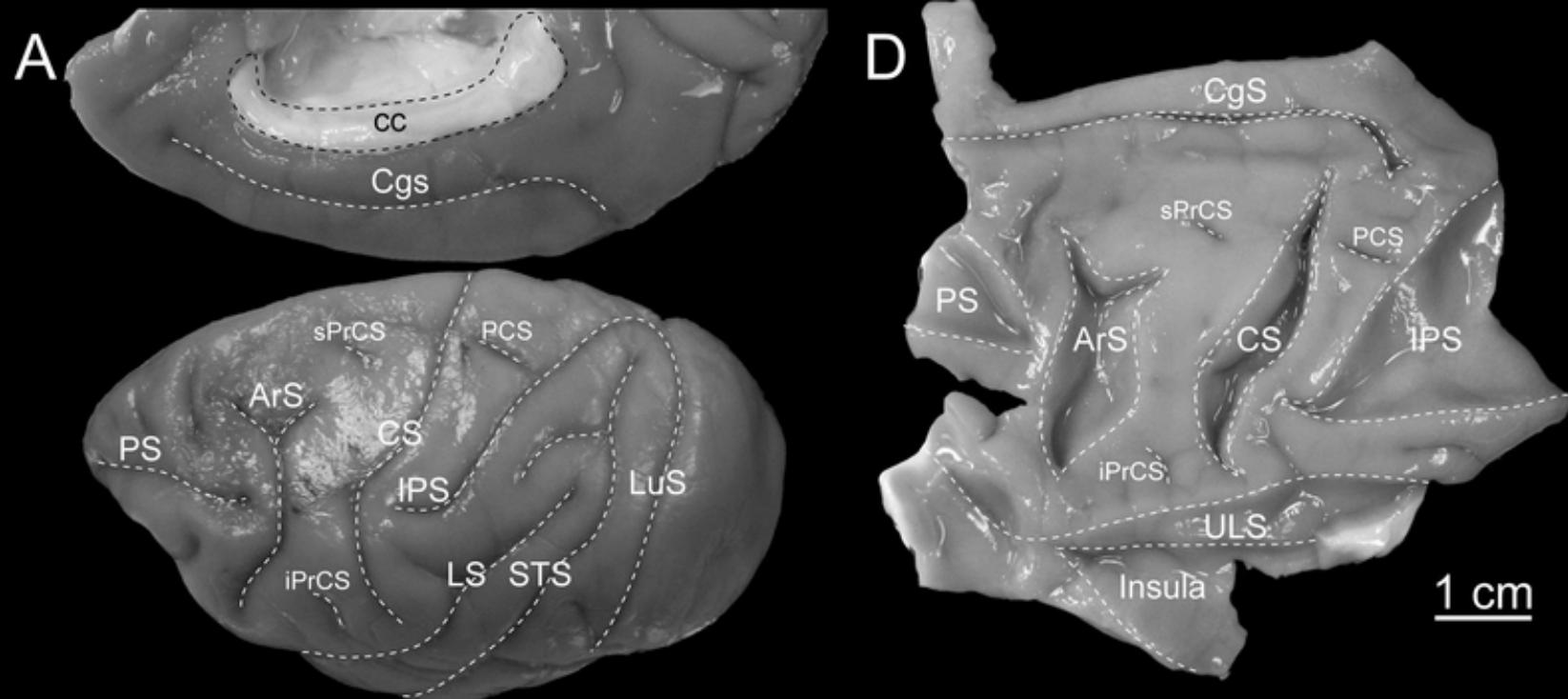


# Cortical surface 3D reconstruction



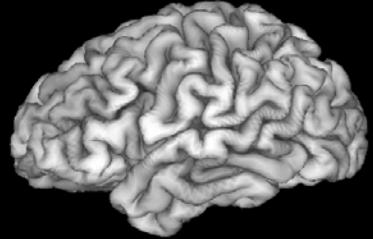
Example subject from HCP-style data scanned at CBU

# Non-human primate flat cortical surface

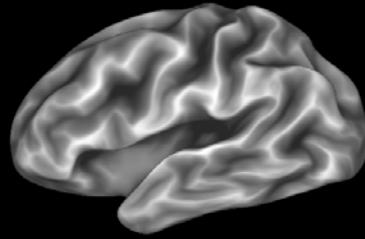


# Human example

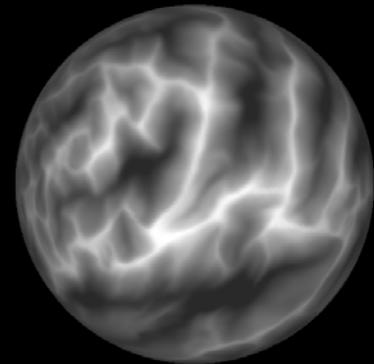
pial



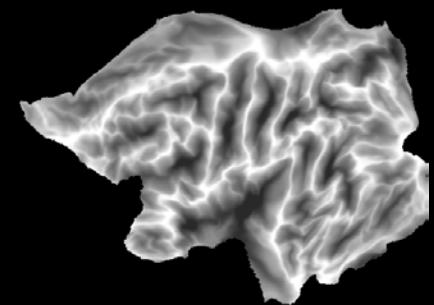
inflated



Spherical  
projection



Flat  
map



# Cortical layers

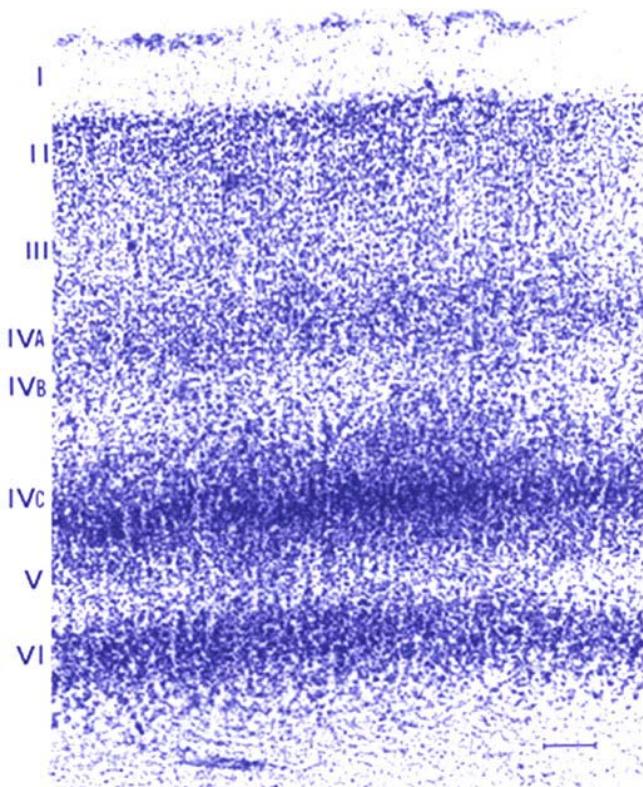
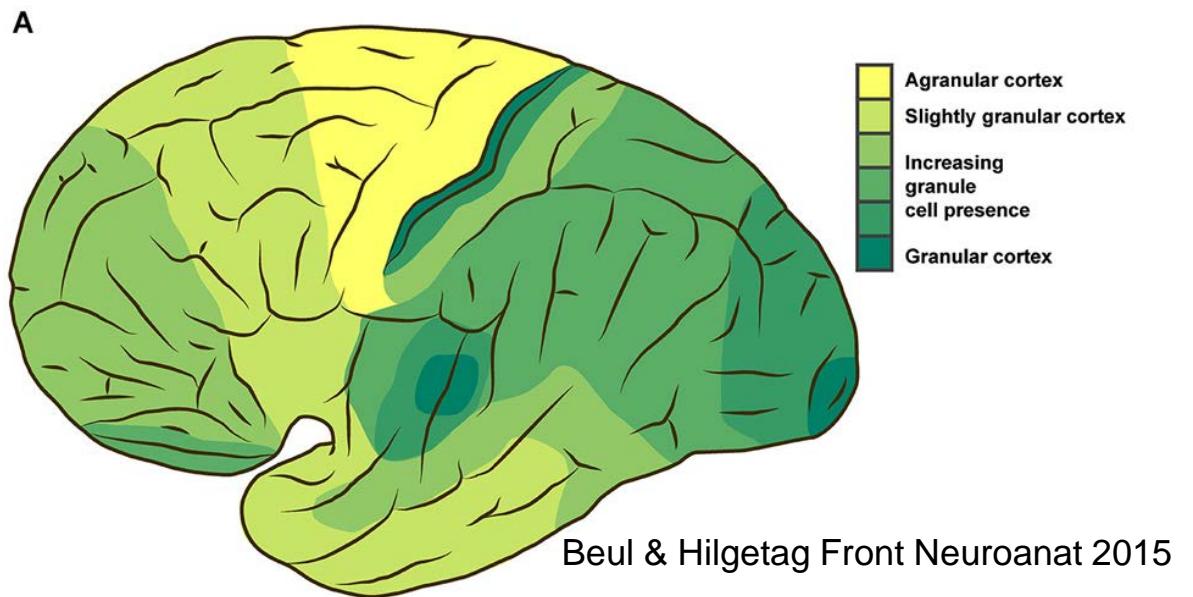
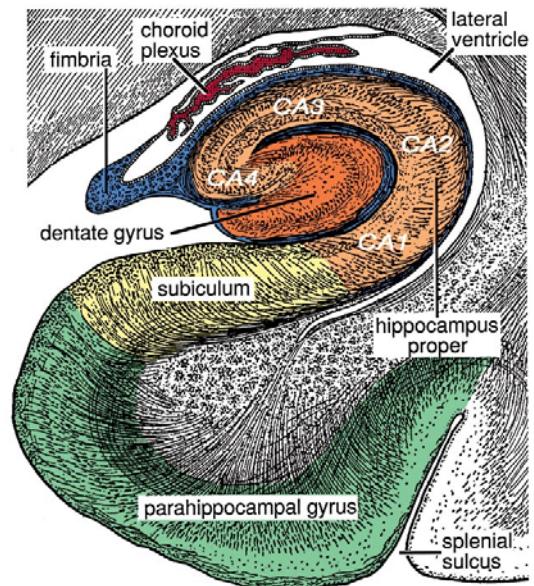


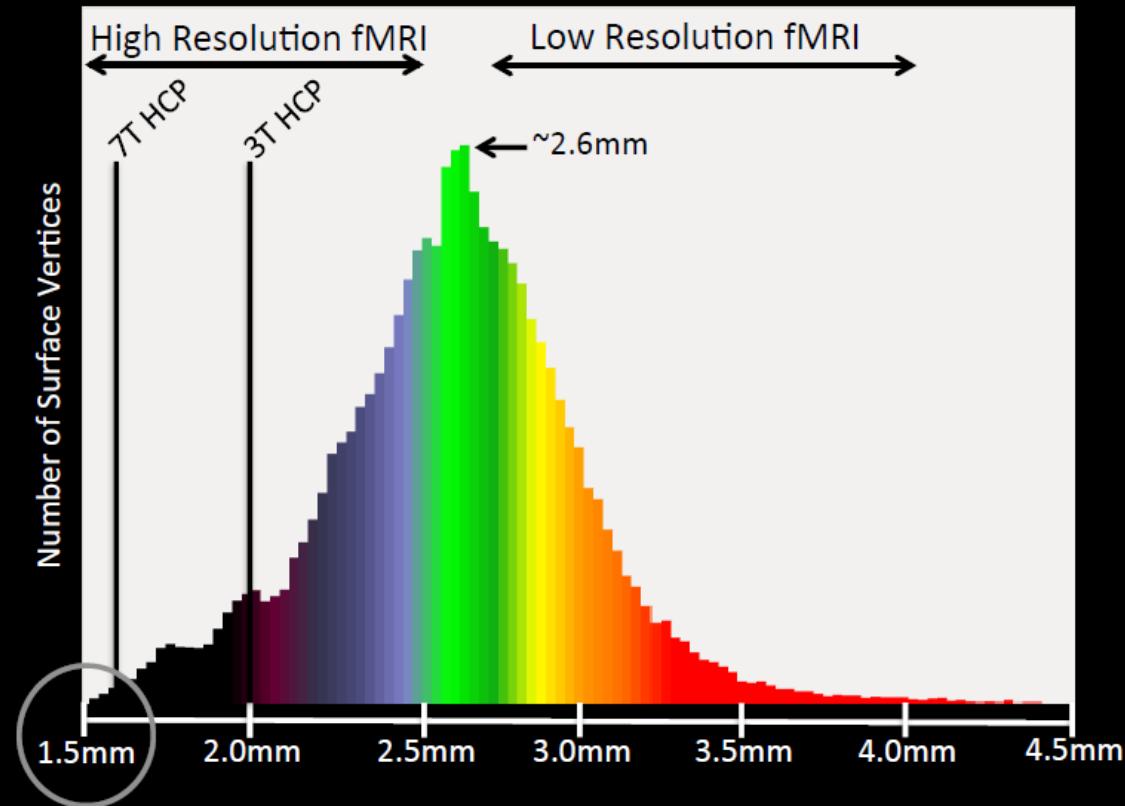
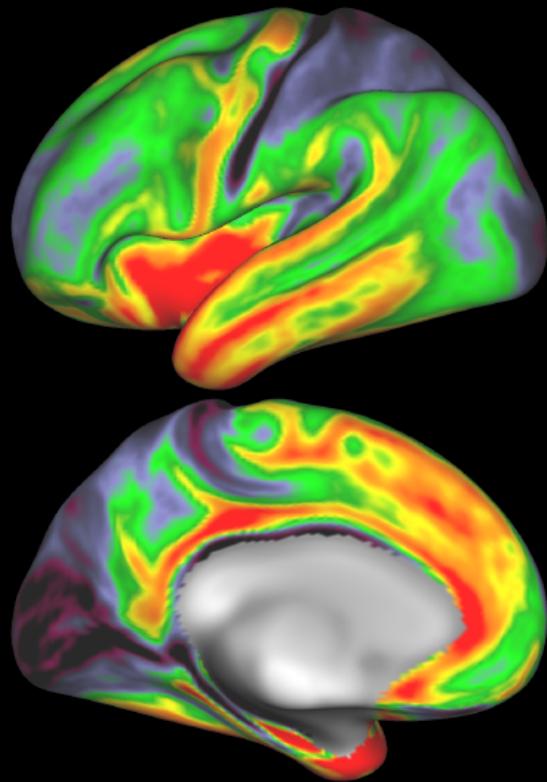
Figure 13. Nissl stain of the visual cortex reveals the different layers I through VI quite clearly.



Hippocampus is a cortical structure

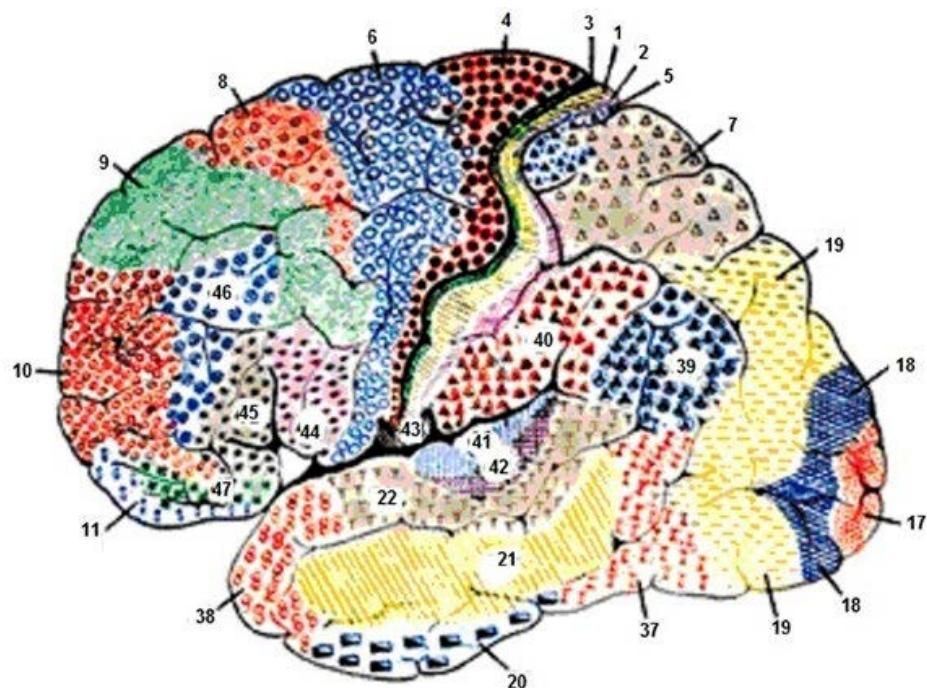


# Cortical Neuroanatomy Drives Spatial Resolution Choices for Acquiring HCP-style MRI Data



- 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



Area V1 (17)

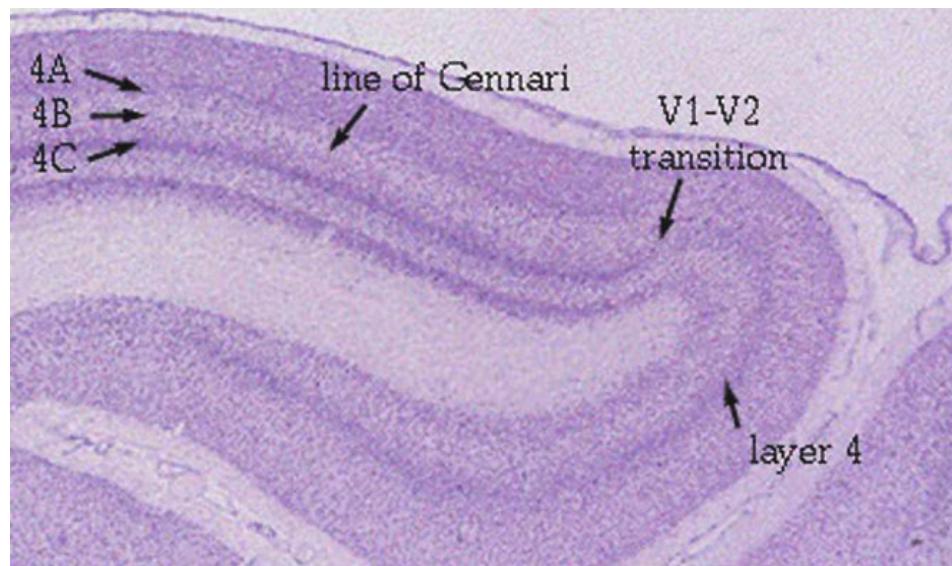
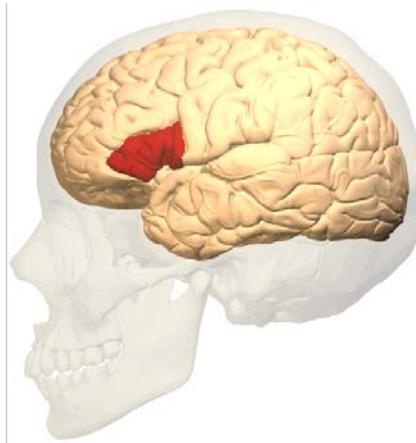
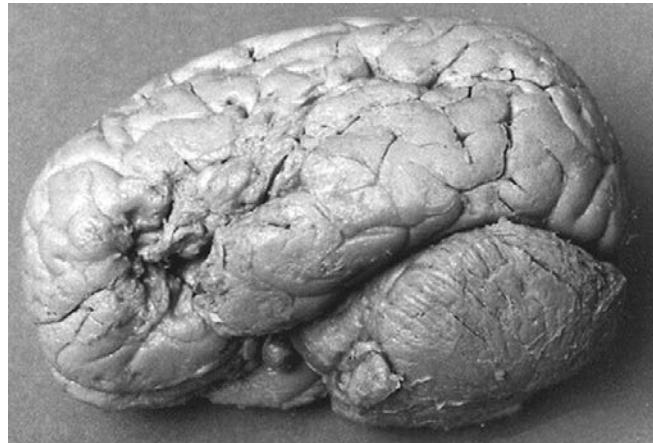


Figure 9. Nissl stained section of the visual cortex to show the border between area 17 (V1) and area 18 (V2).

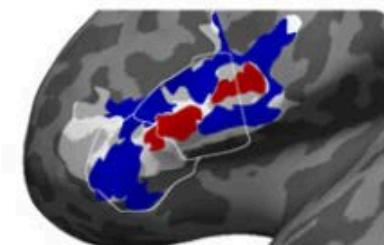
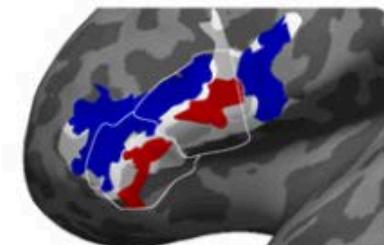
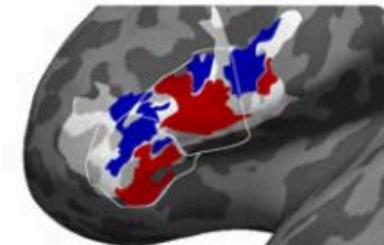
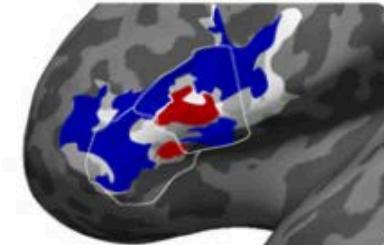
Brodmann (1909)

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

# Functional lesions: Broca's area



(B)   
■ Reading  
■ Spatial WM



$p < 0.001$  (unc.)

Trends in Cognitive Sciences

Opinion

Broca's Area Is Not a Natural Kind

Evelina Fedorenko<sup>1,\*</sup> and Idan A. Blank<sup>2,\*</sup>

## Local

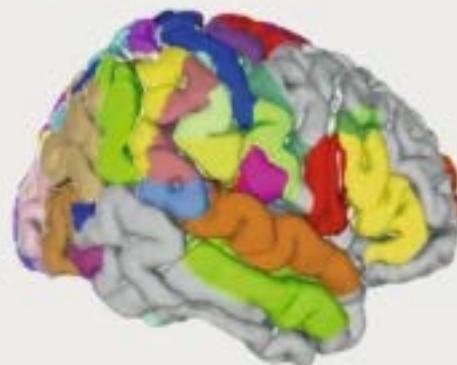
### Histology-based:

- Cytoarchitecture
- Receptors
- Myelin

### MRI-based:

- Myelin
- Meta-analytic activation modelling

Border detection in cortex based on cytoarchitecture

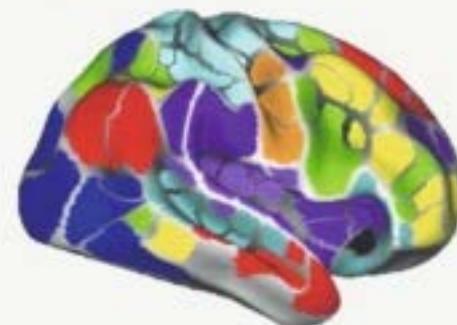


## Global

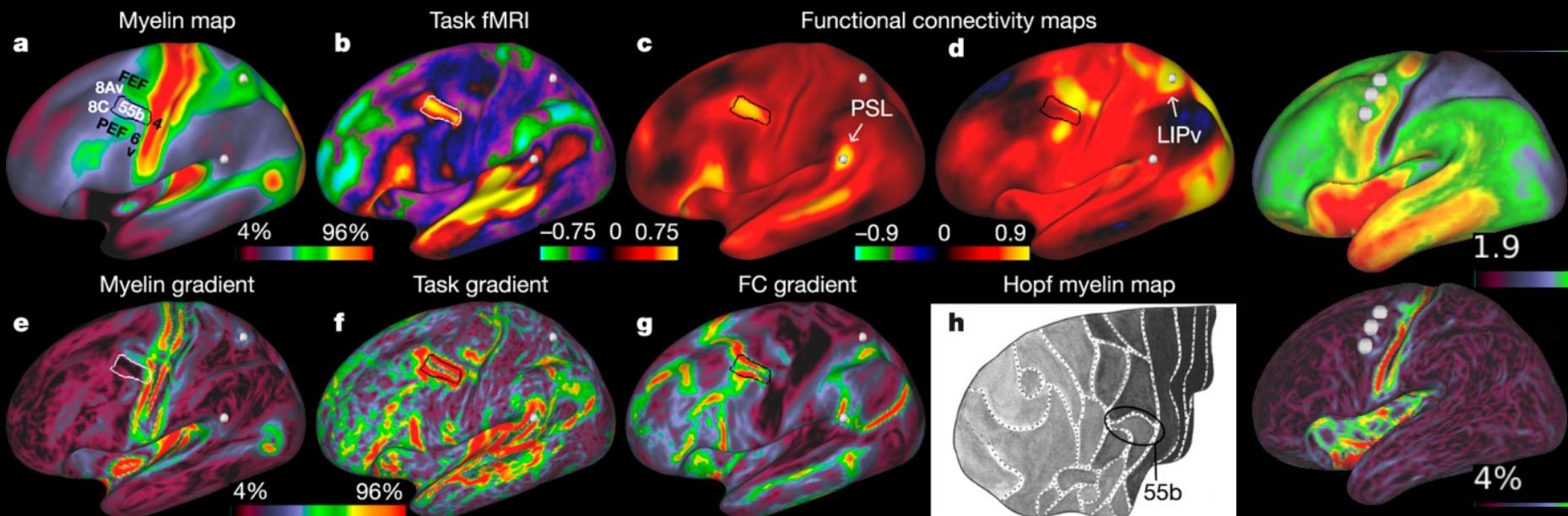
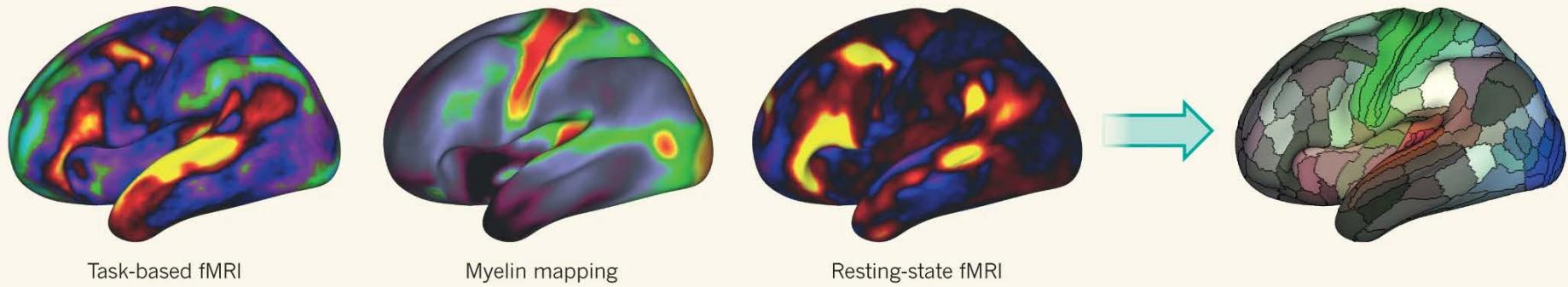
### MRI-based:

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

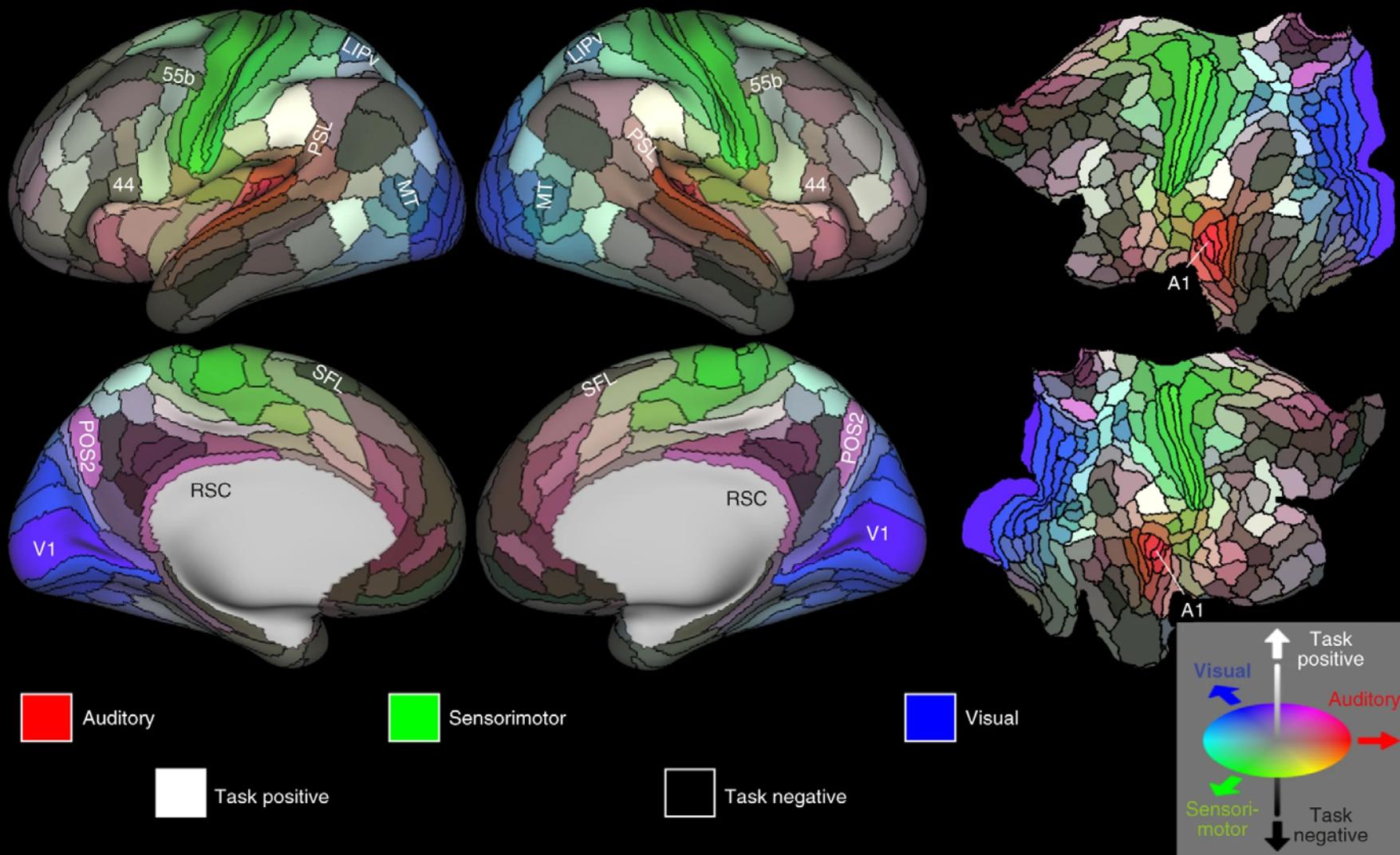
Boundary mapping of resting-state functional connectivity of cerebral cortex

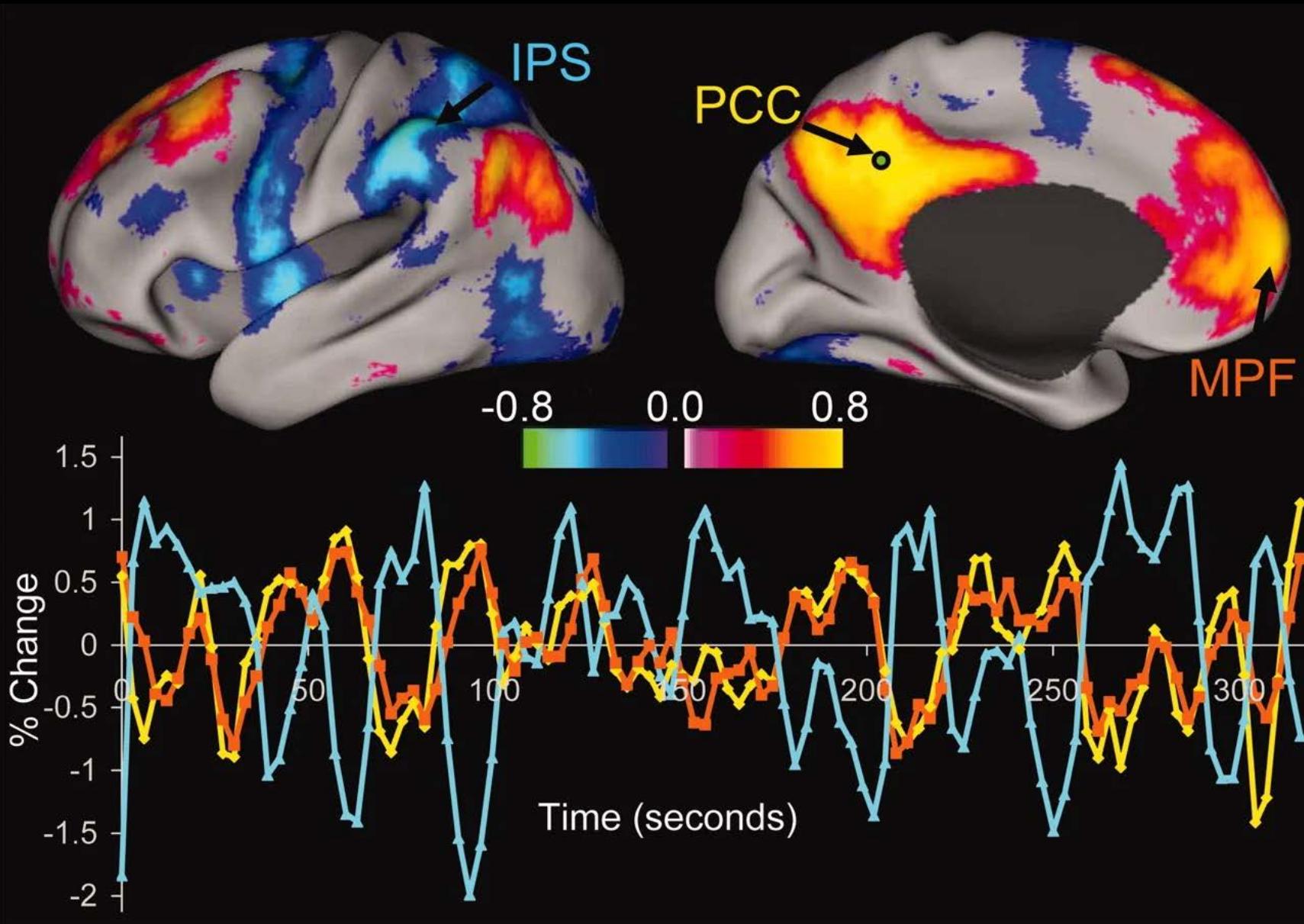


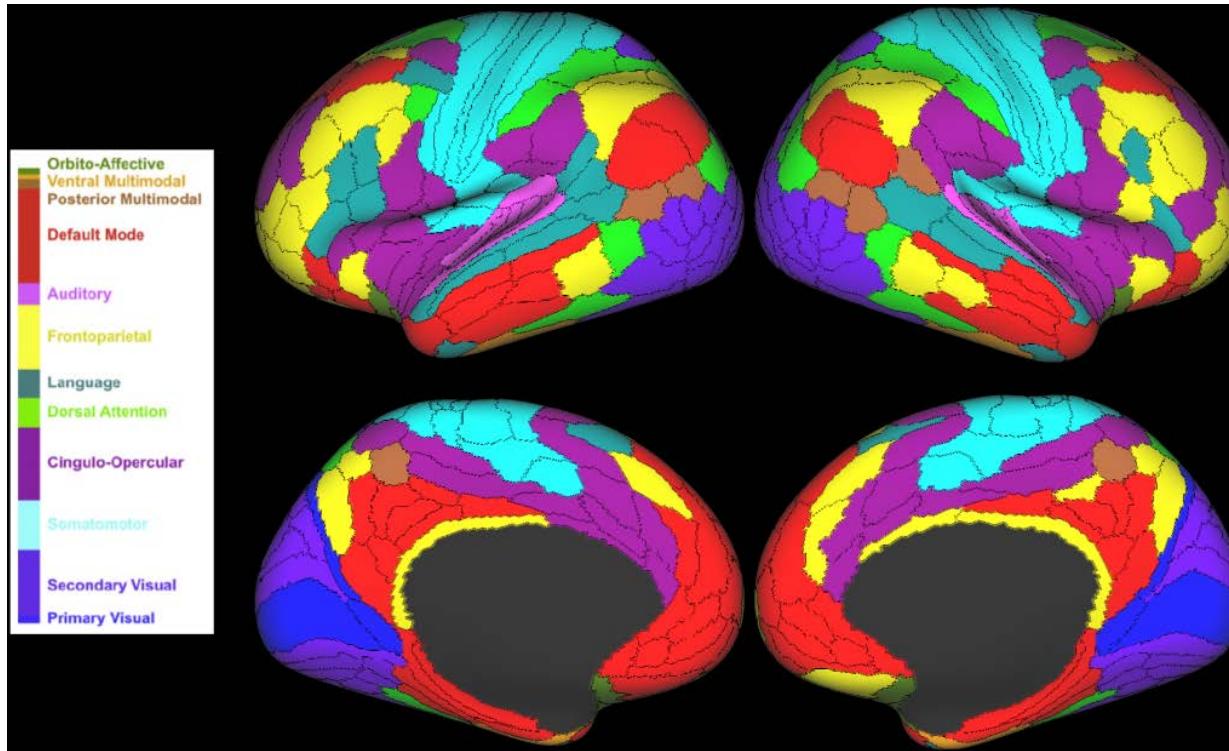
# Multimodal atlases



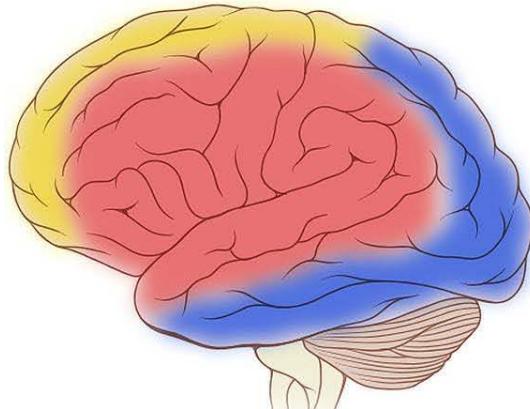
The HCP's multimodal cortical parcellation (HCP\_MMP1.0)



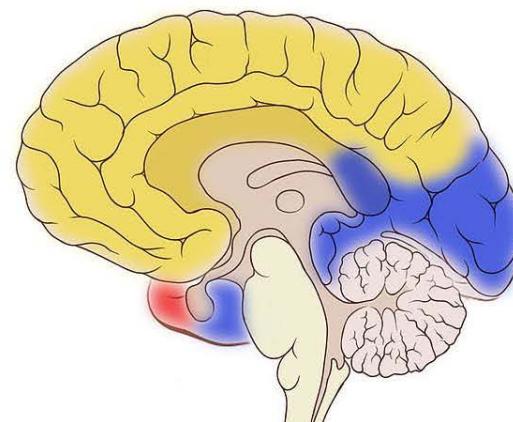




Lateral Brain



Medial Brain



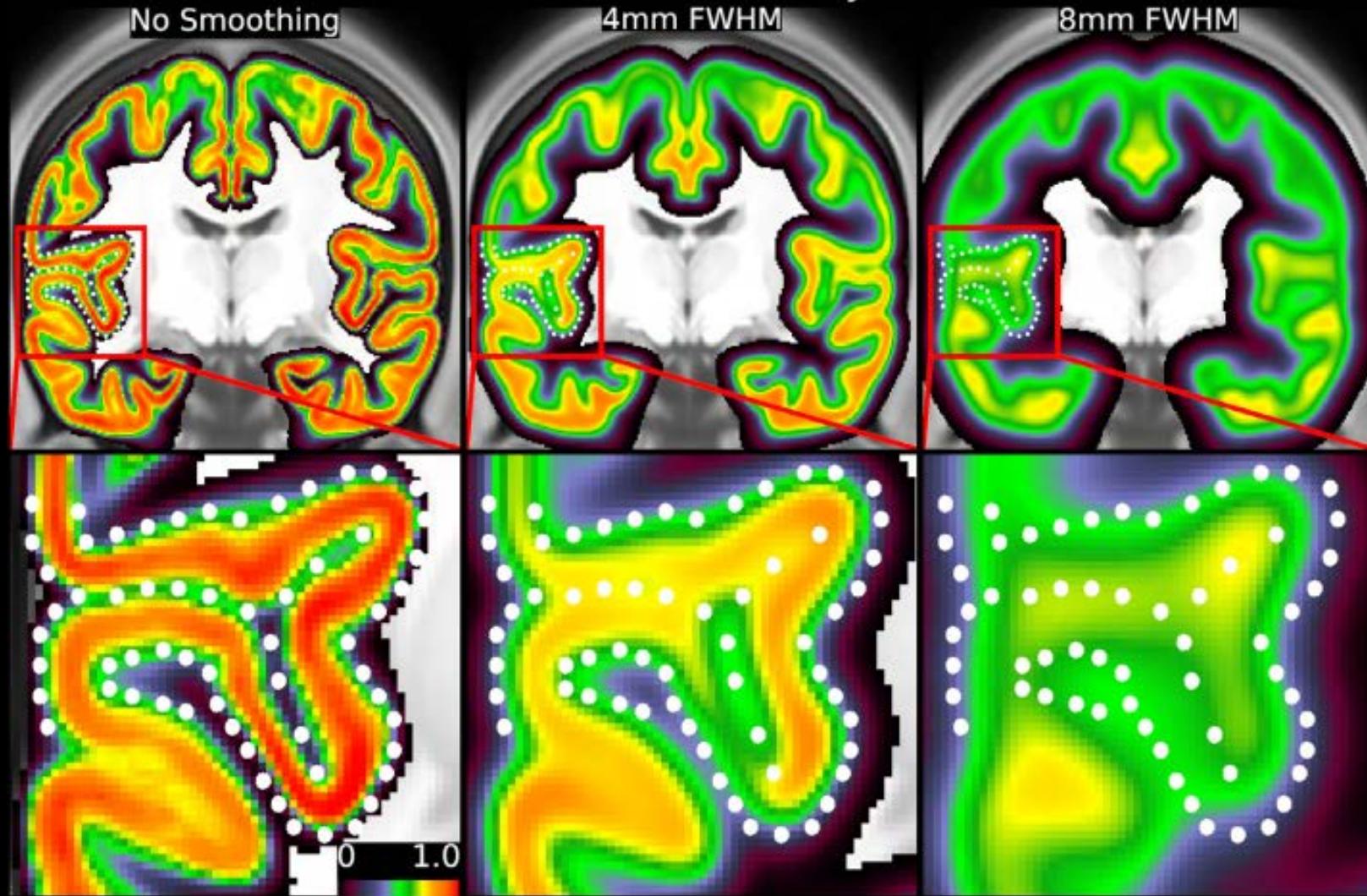
- Yellow: Anterior Cerebral Artery
- Red: Middle Cerebral Artery
- Blue: Posterior Cerebral Artery

# Cortex

Surface vs volume analysis

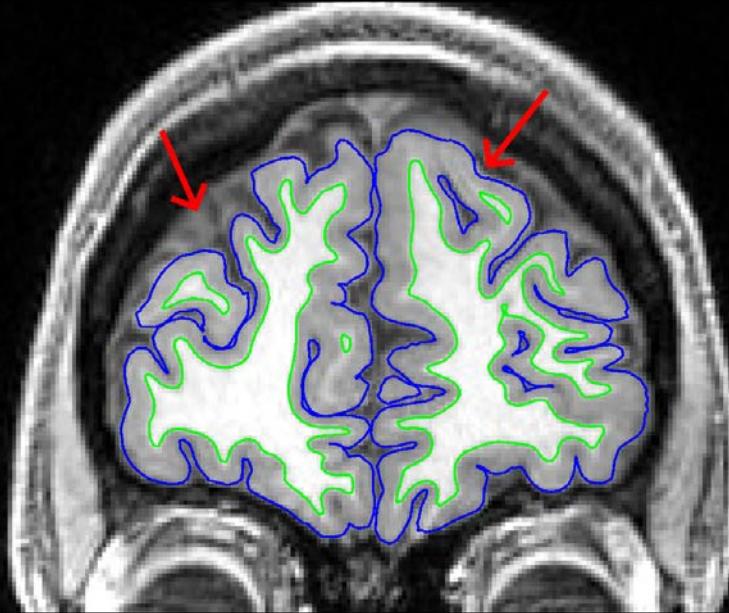
Intersubject alignment

## Probabilistic Cortical Gray Matter

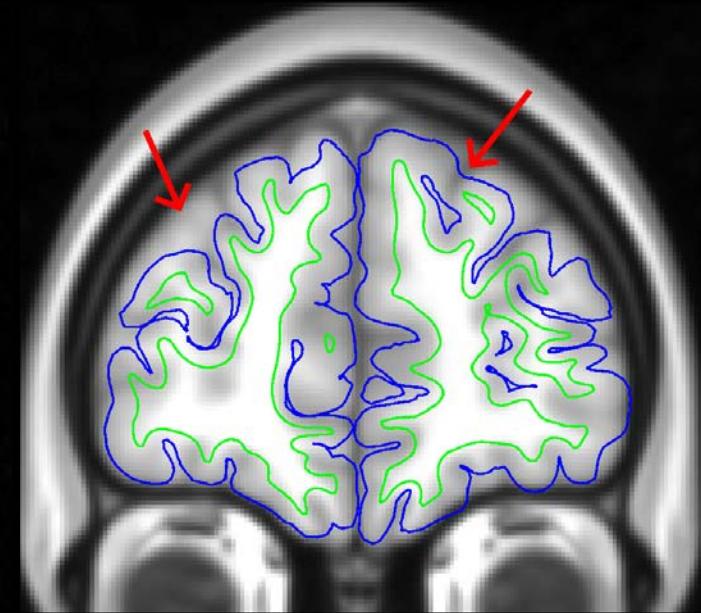


Supp figure from Coalson T. et al (2018) PNAS

# Volumetric registration is suboptimal

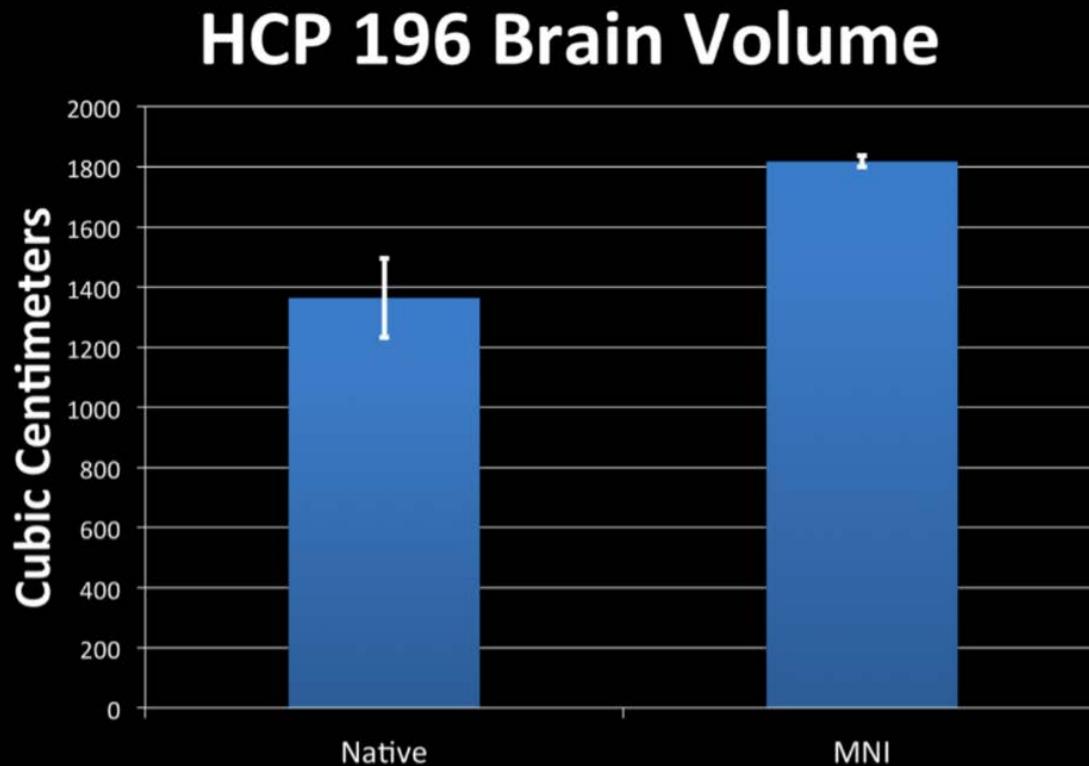


Overlay individual structural  
scan after non-linear MNI  
registration



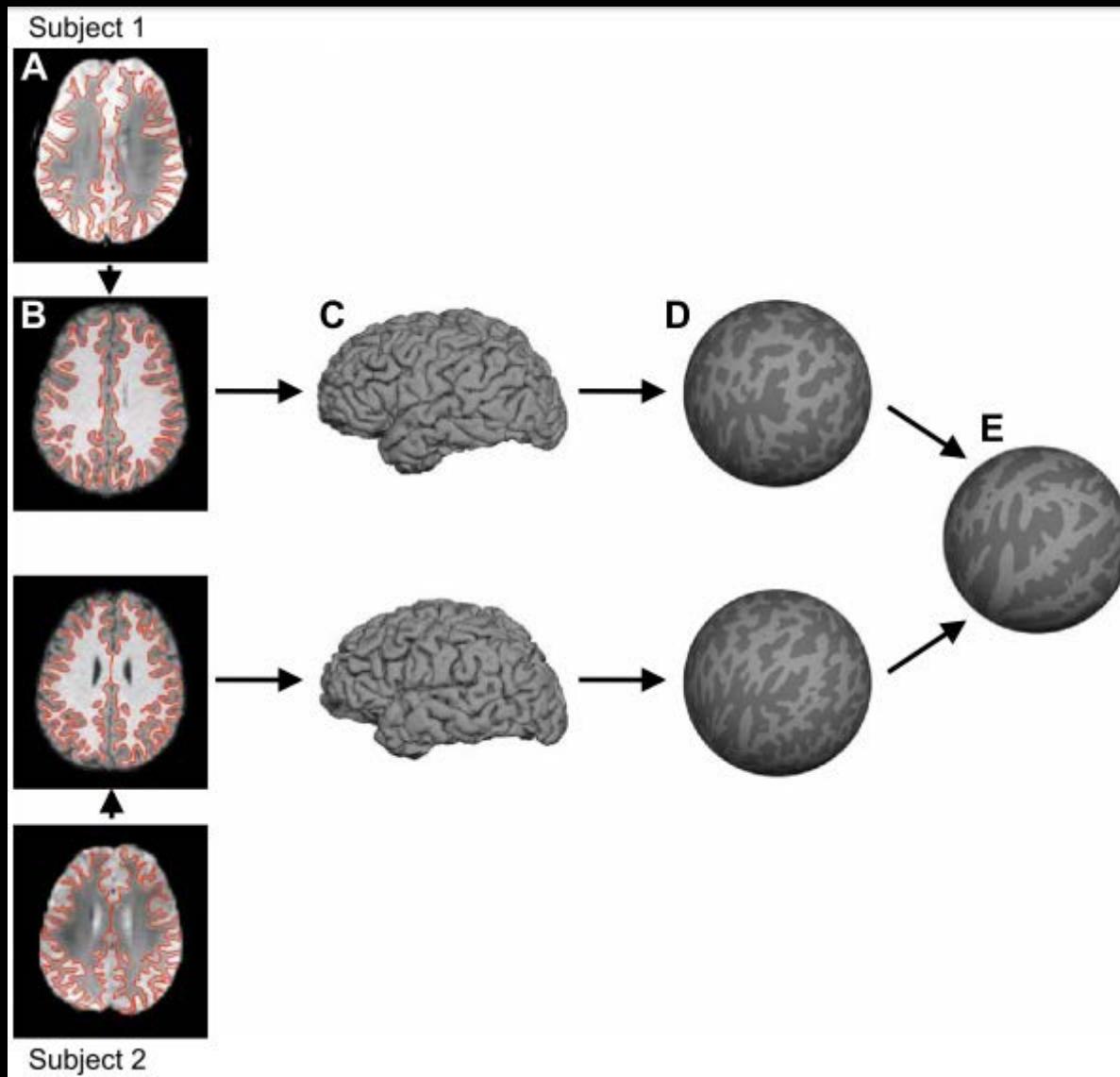
Overlay MNI template

MNI drift  
Increase brain size by 37%



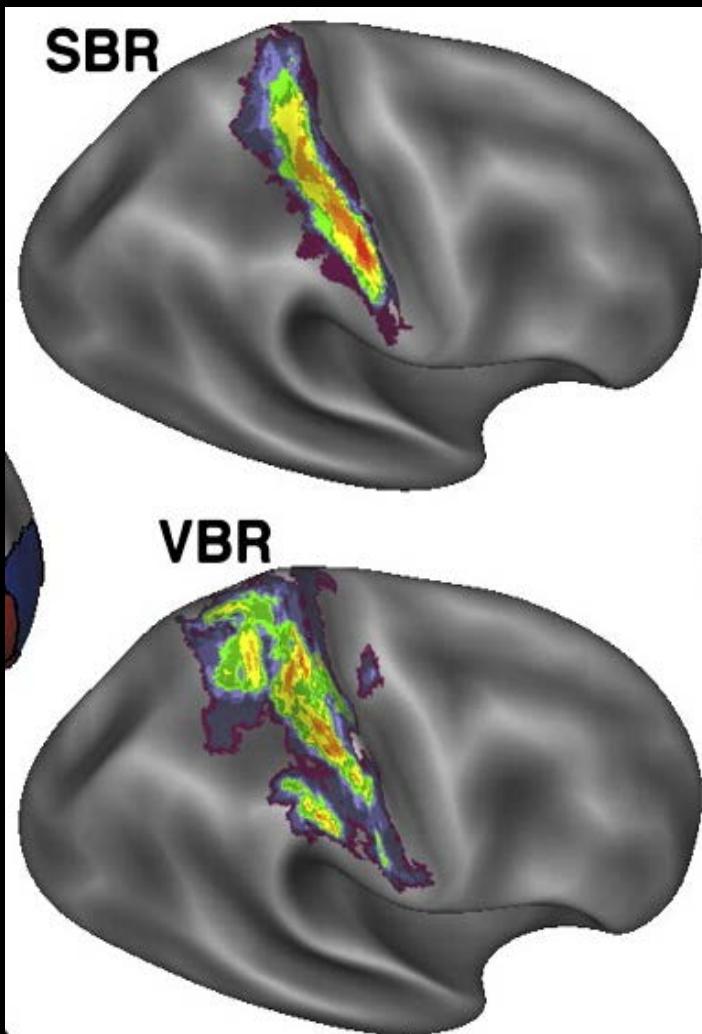
Glasser et al (2016) *Nature Neuroscience*

# Surface-based approaches

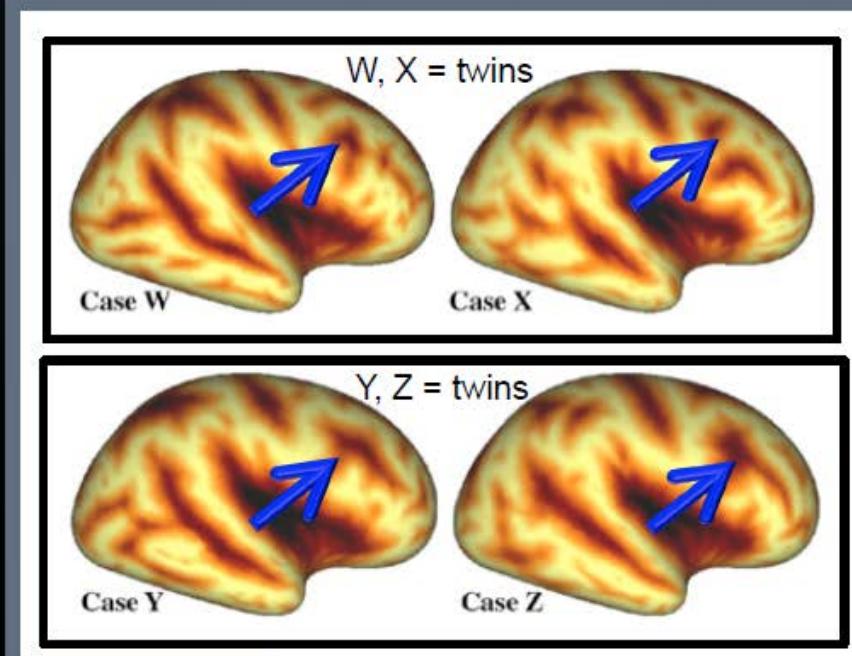
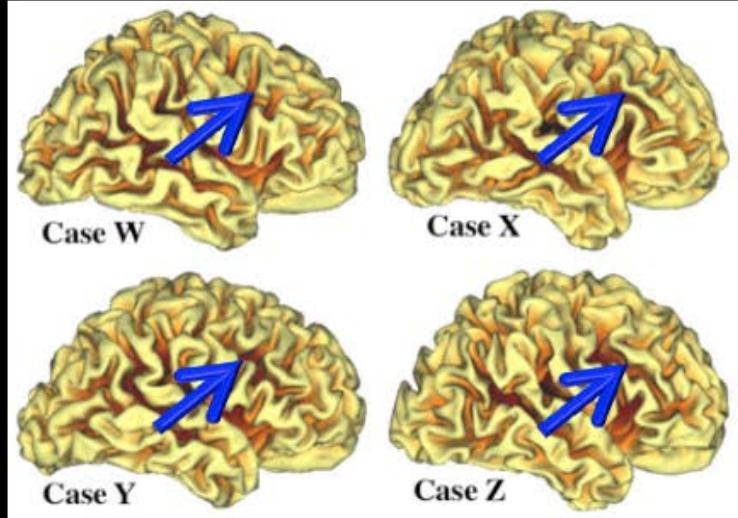


Thomas Yeo, BT. et al.  
(2011) *J Neurophysiol*

# Volume vs Surface



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



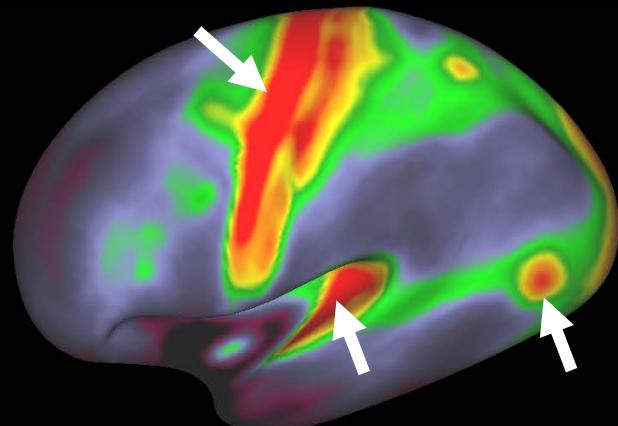
- Convolutions are complex!
- Highly variable across individuals
- More variable in ‘higher cognitive’ regions
- Variable even in identical twins, but some heritability

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

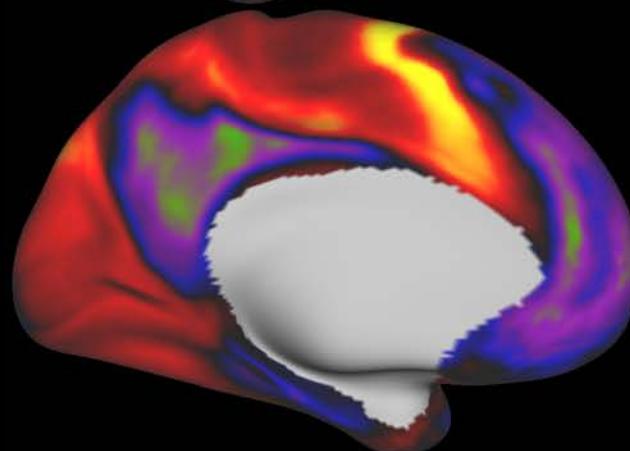
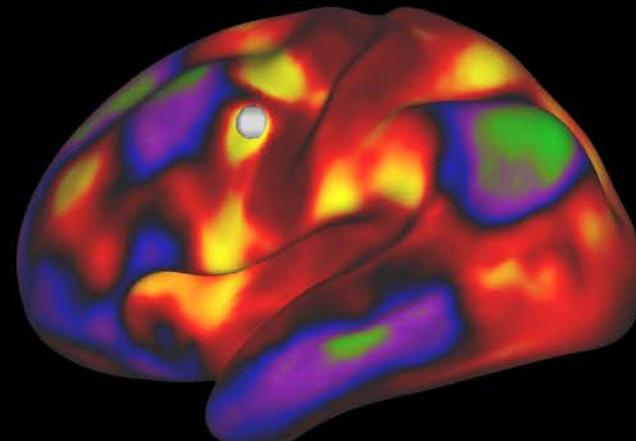
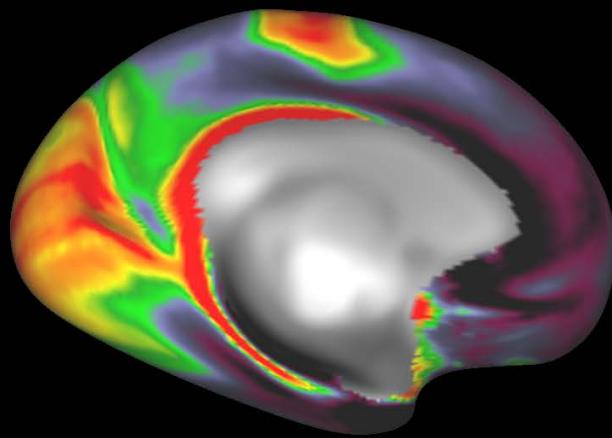
From HCP course slides

# Areal feature-based surface registration

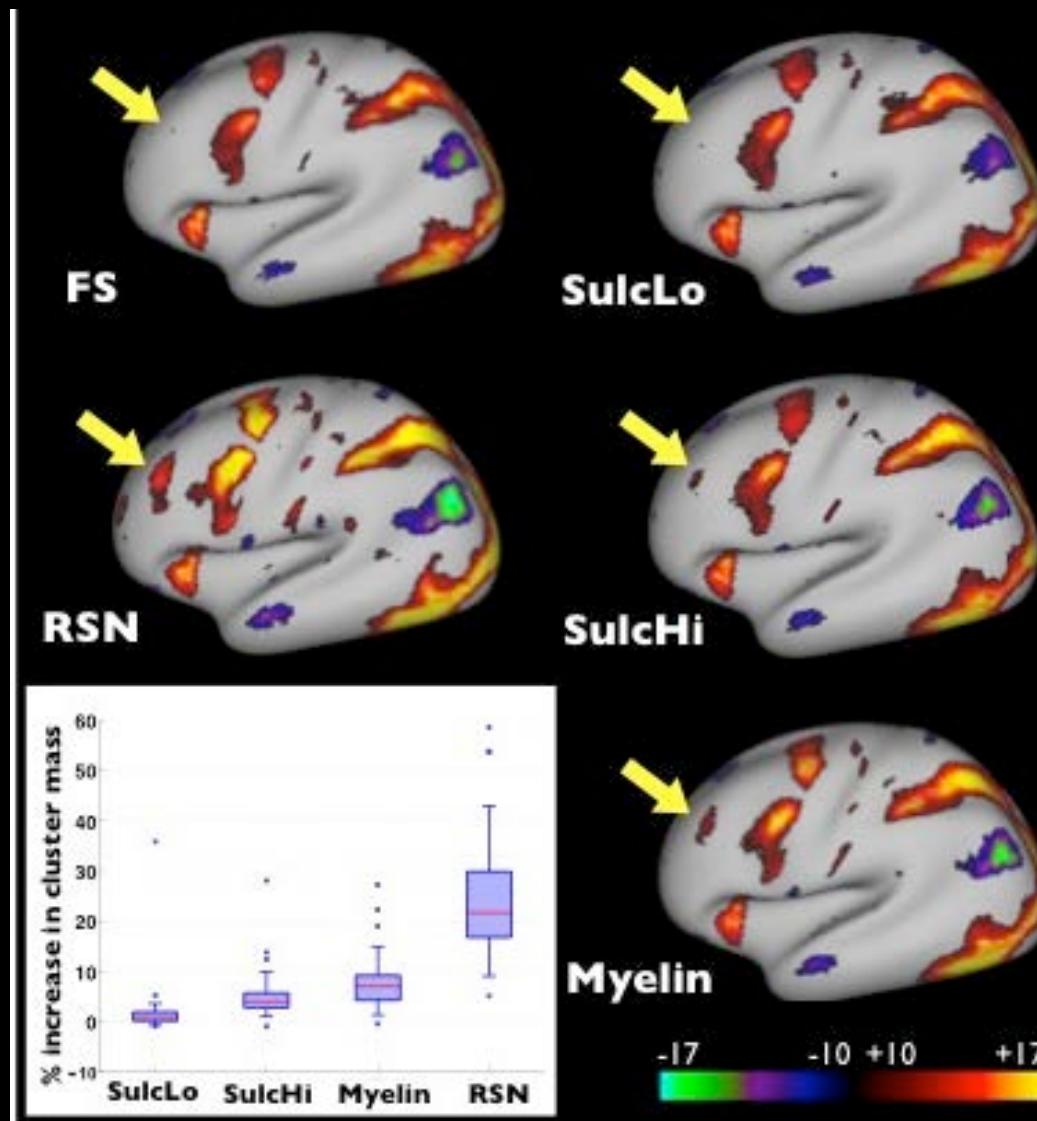
Myelin Map  
T1w/T2w



rest fMRI  
connectivity maps



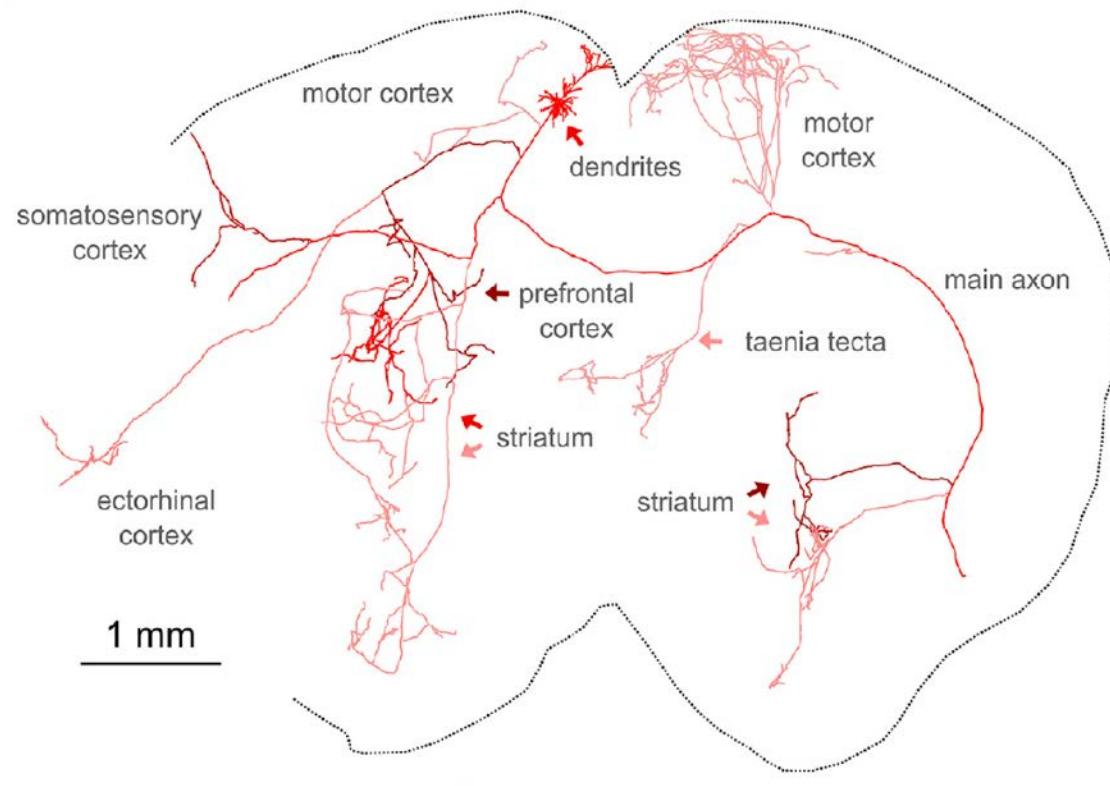
# Multimodal Surface Matching (MSM)



# Cortex

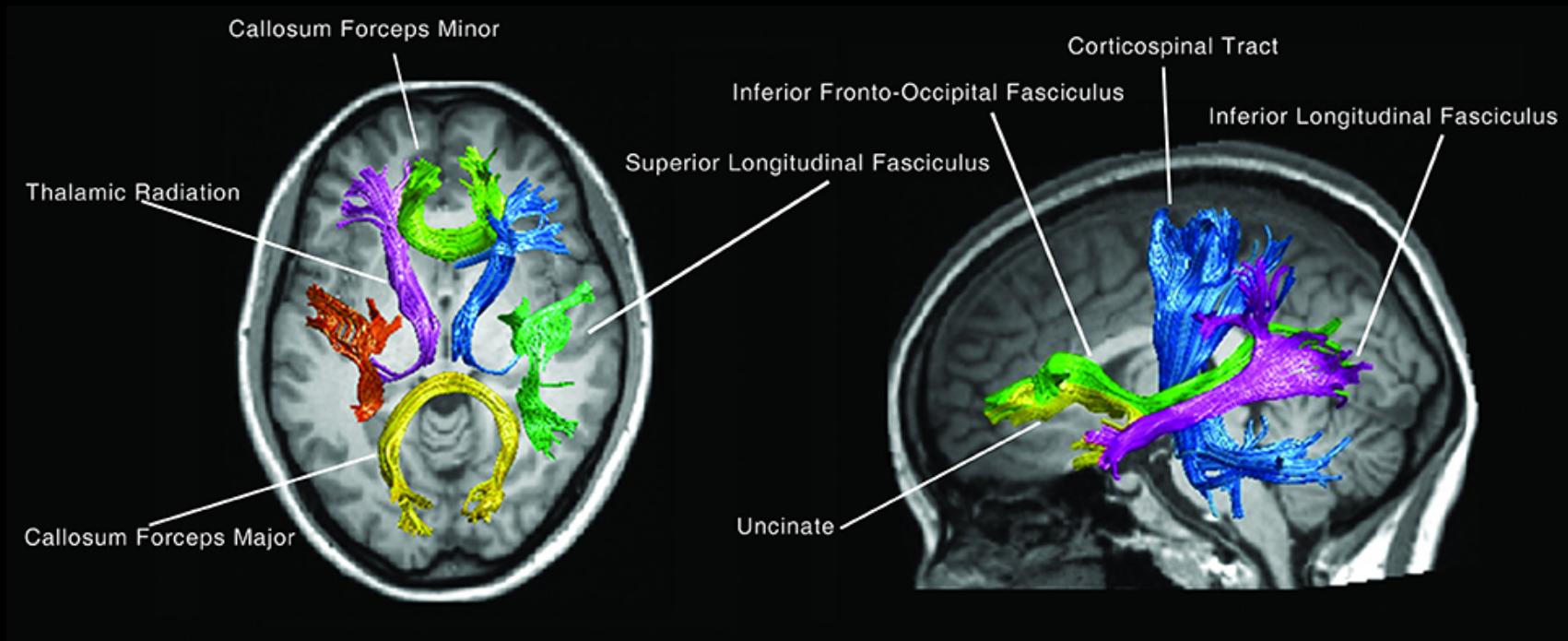
Anatomical connections

# A single neuron connections



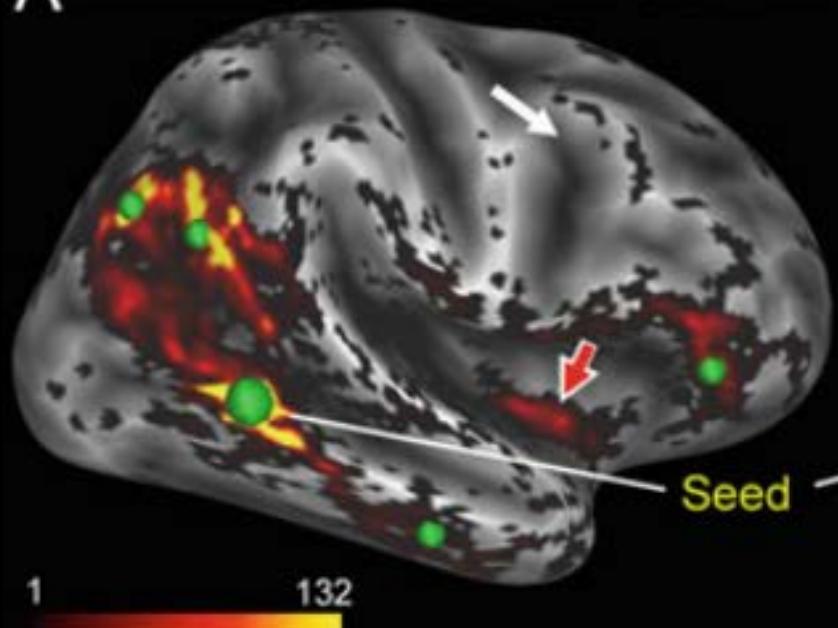
Economou et al. eLife 2016

# White matter bundles

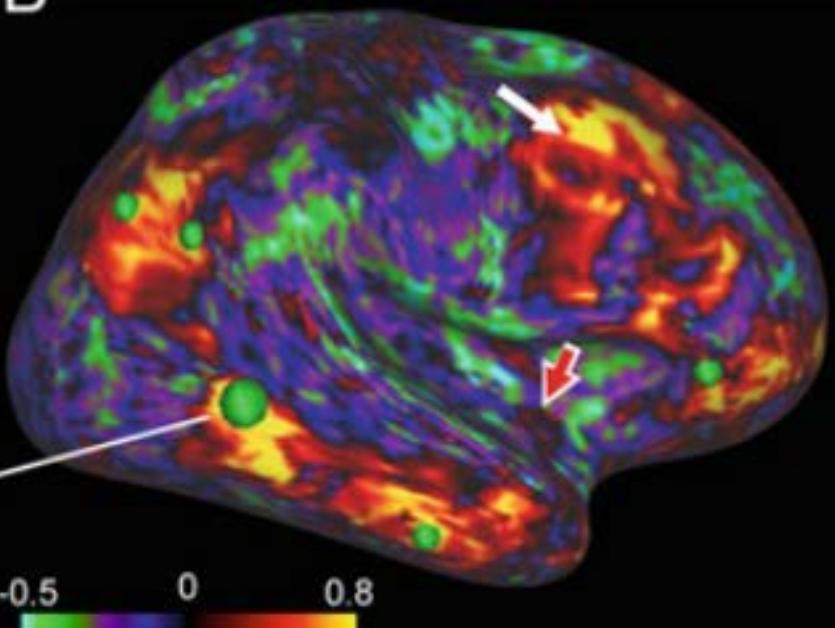


Shah et al Front Neuro 2018

**A** Structural connectivity (tractography)

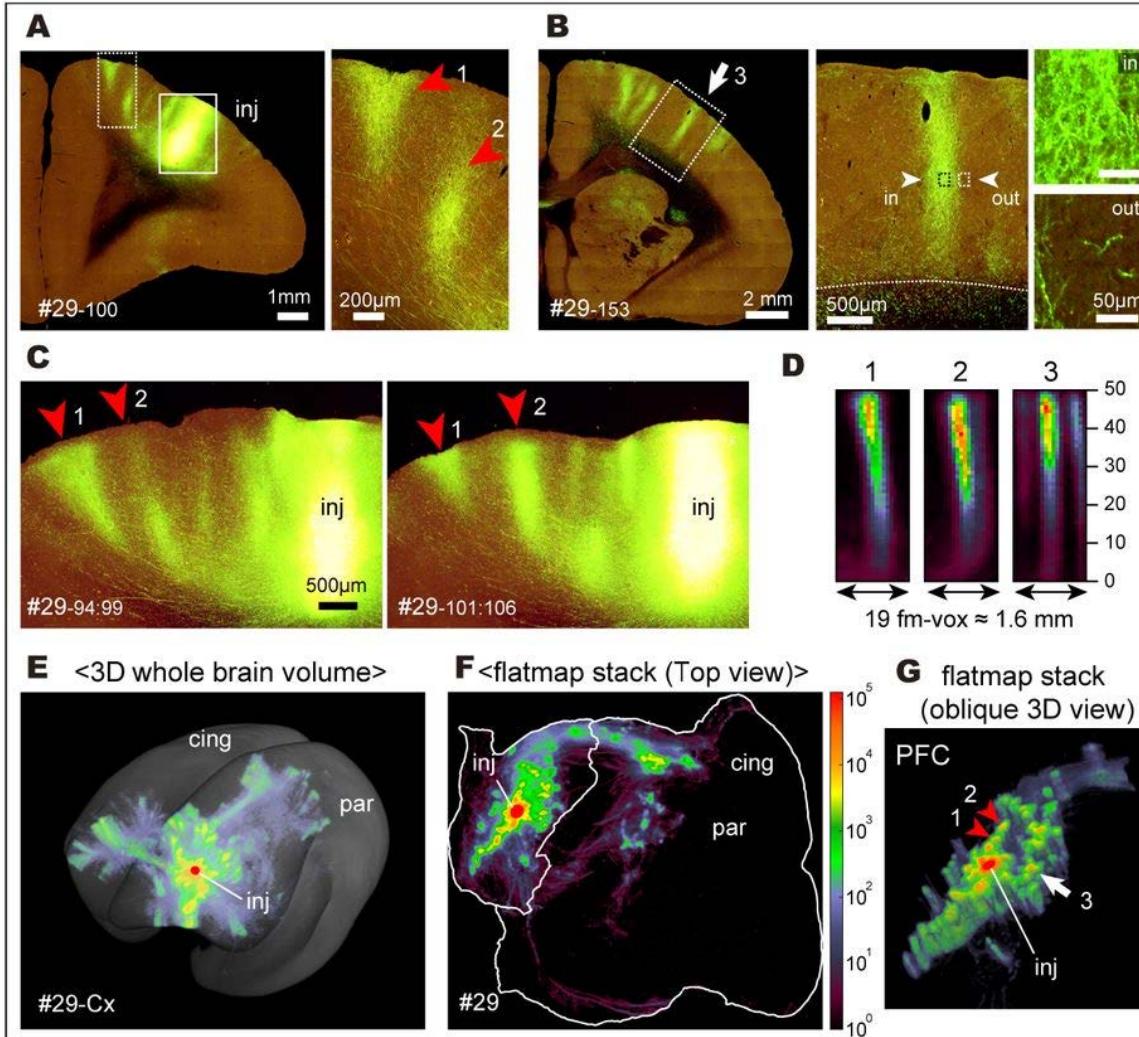


**B** Functional connectivity (rs-fMRI)



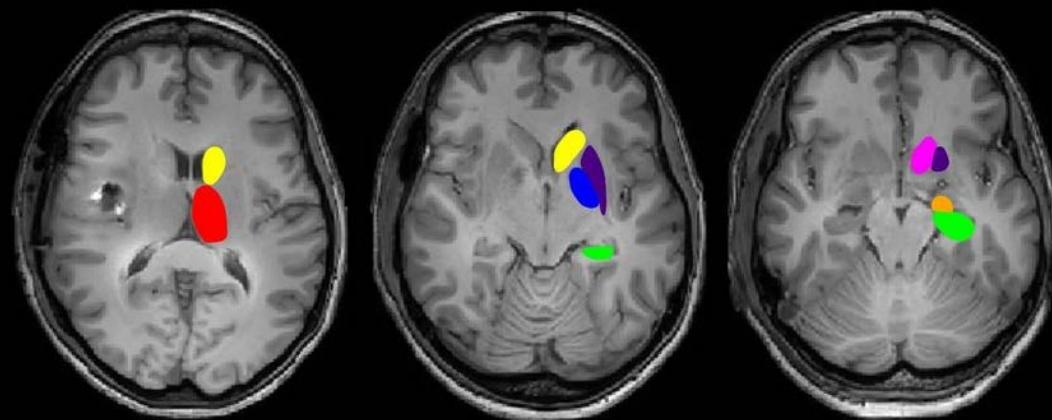
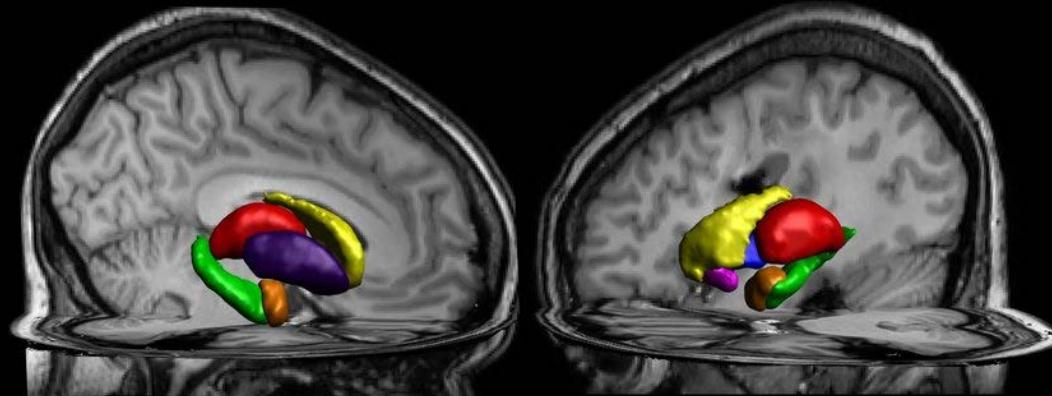
Van Essen et al. Micro-, Meso-, Macro-  
Connectomics of the Brain. 2016

# Tract-tracing



Watakabe et al  
Neuron 2023

# Deeper structures

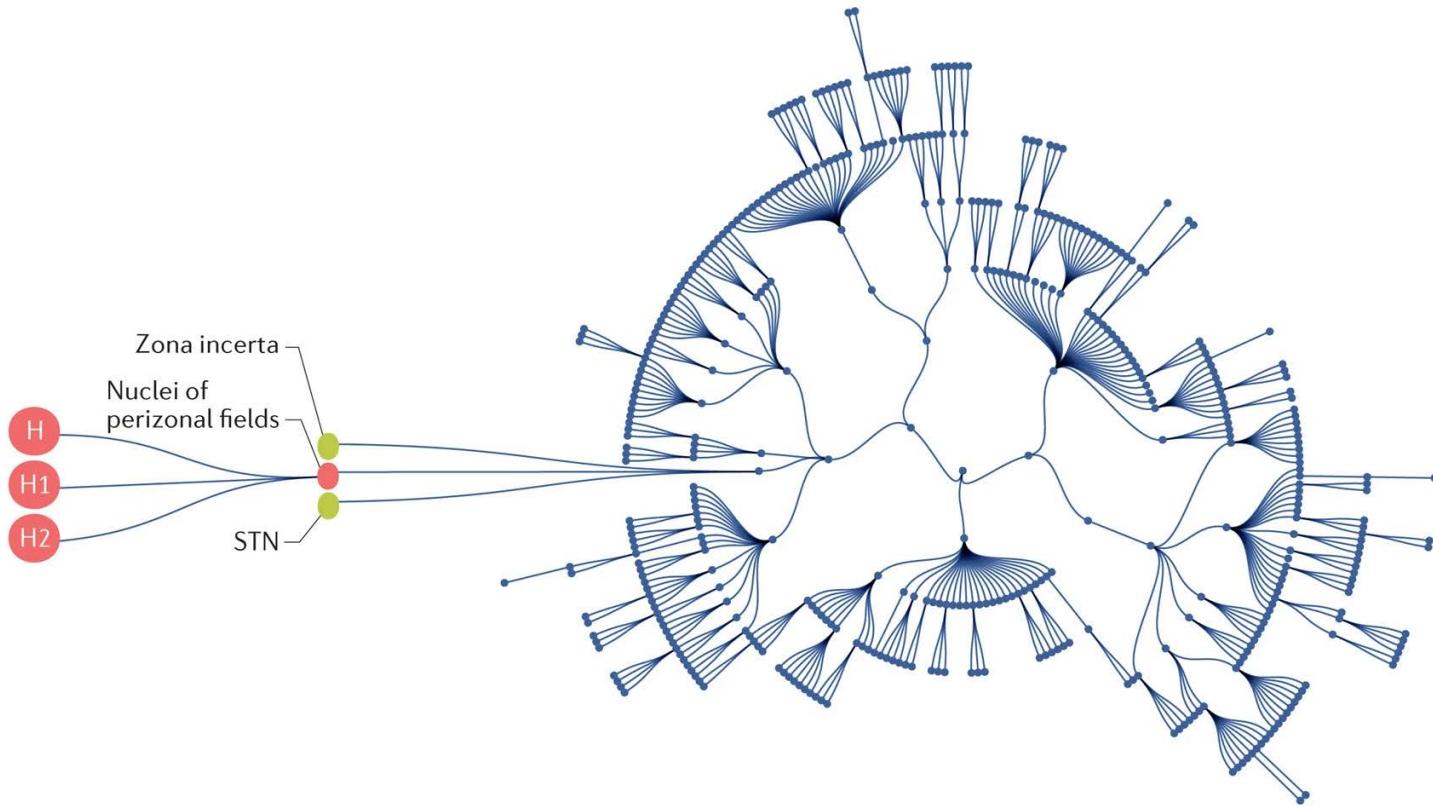


- Amygdala
- Caudate nucleus
- Hippocampus
- Nucleus accumbens

- Thalamus
- Palladium
- Putamen

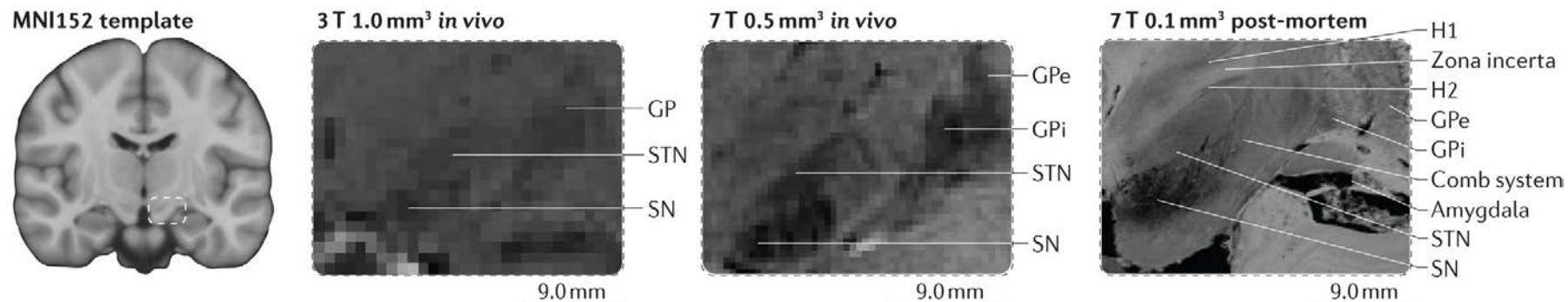
Nagtegaal et al *Clin & Trans Rad Onc* 2020

# Subcortex: uncharted territory



Forstmann 2017  
Nature Rev Neuro

# Subcortex: uncharted territory

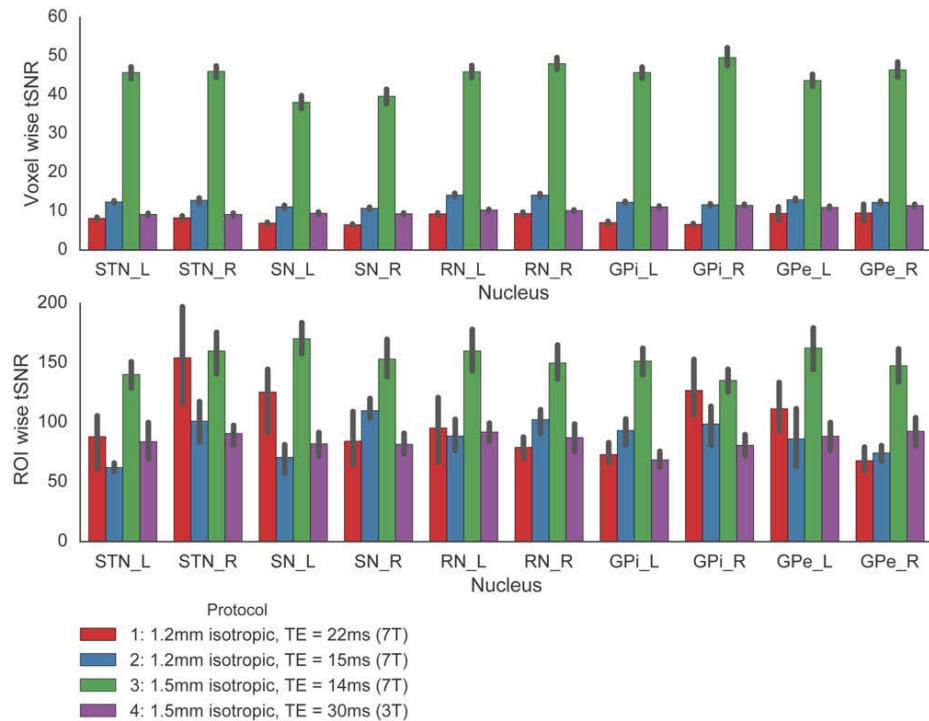
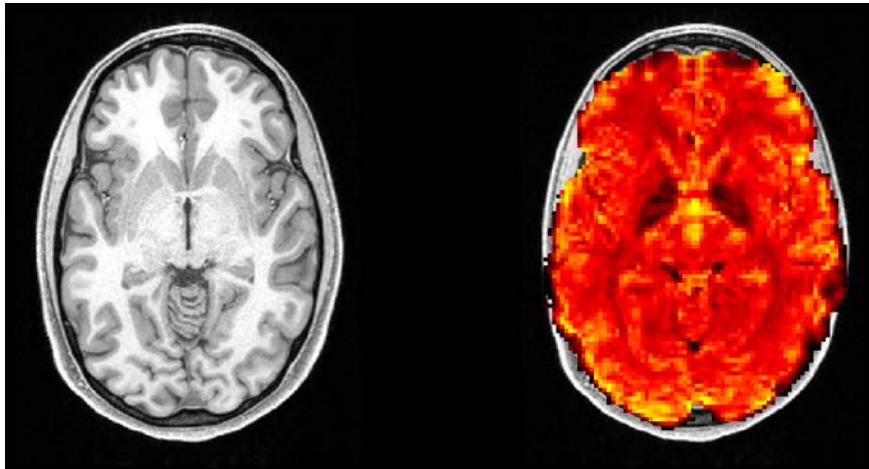


Nature Reviews | Neuroscience

Forstmann 2017  
Nature Rev Neuro

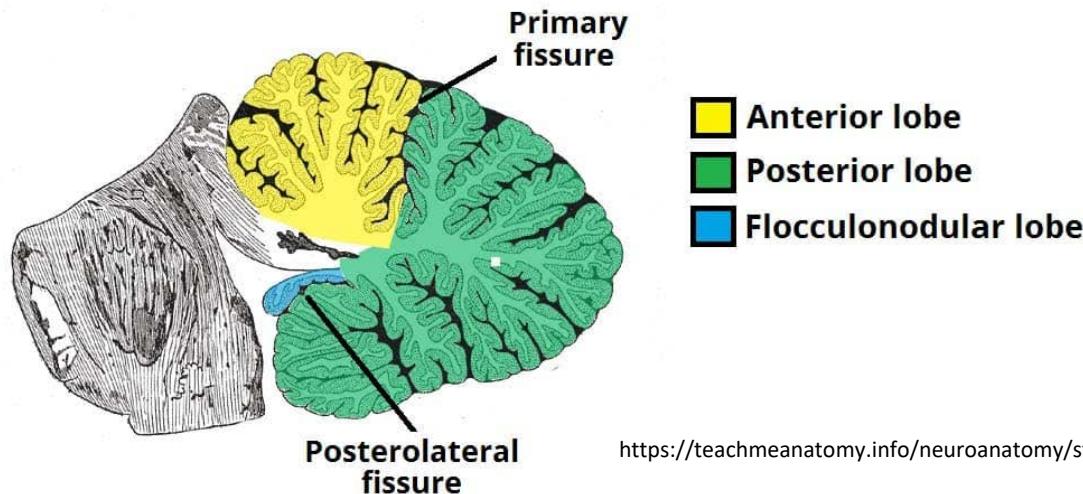
# Special MRI sequences

Typical sequences with echo time (TE) =  $\sim 30\text{ms}$

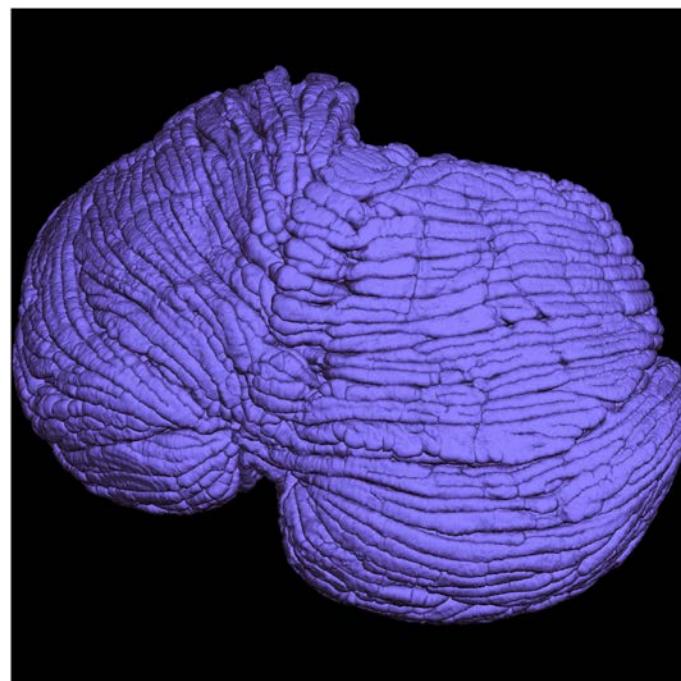


De Hollander et al HBM 2017

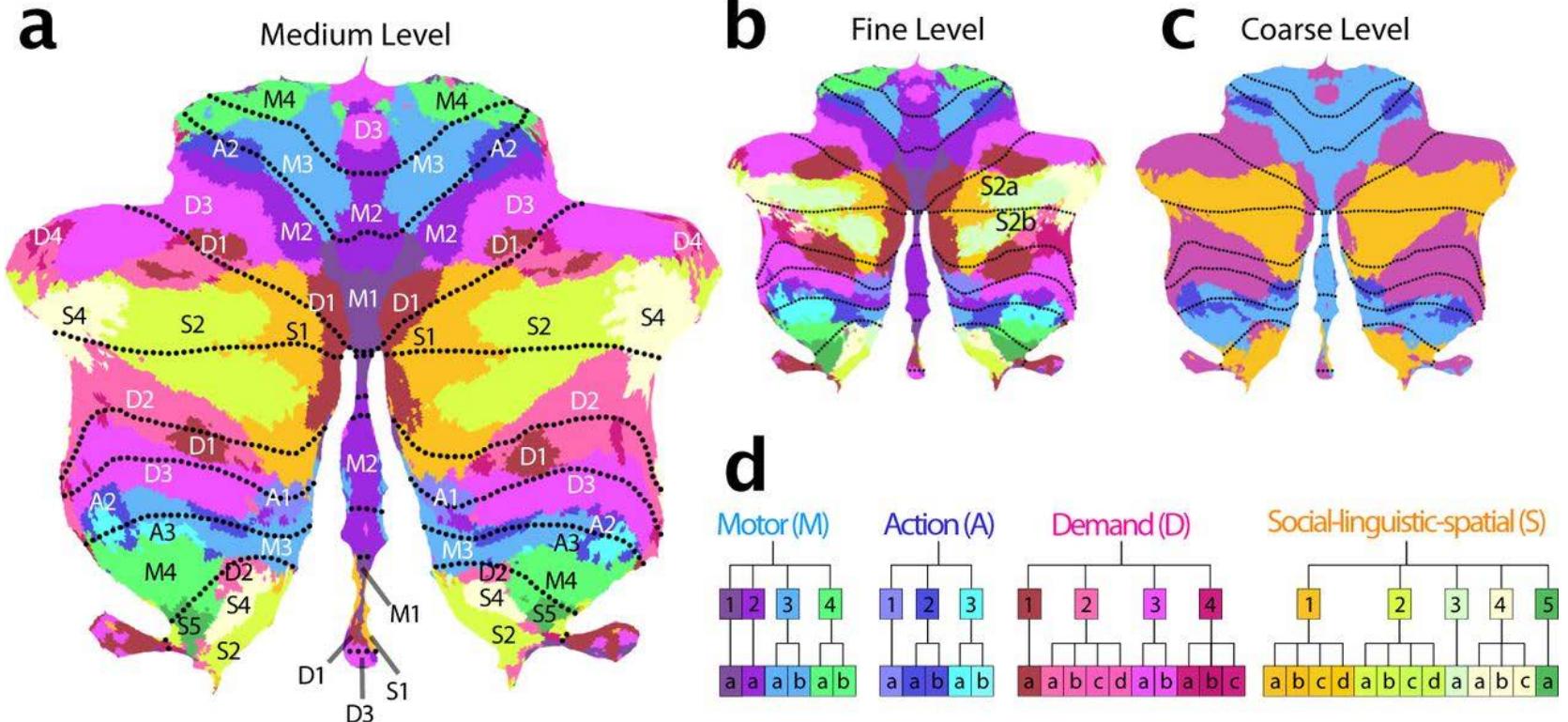
# Cerebellum



<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