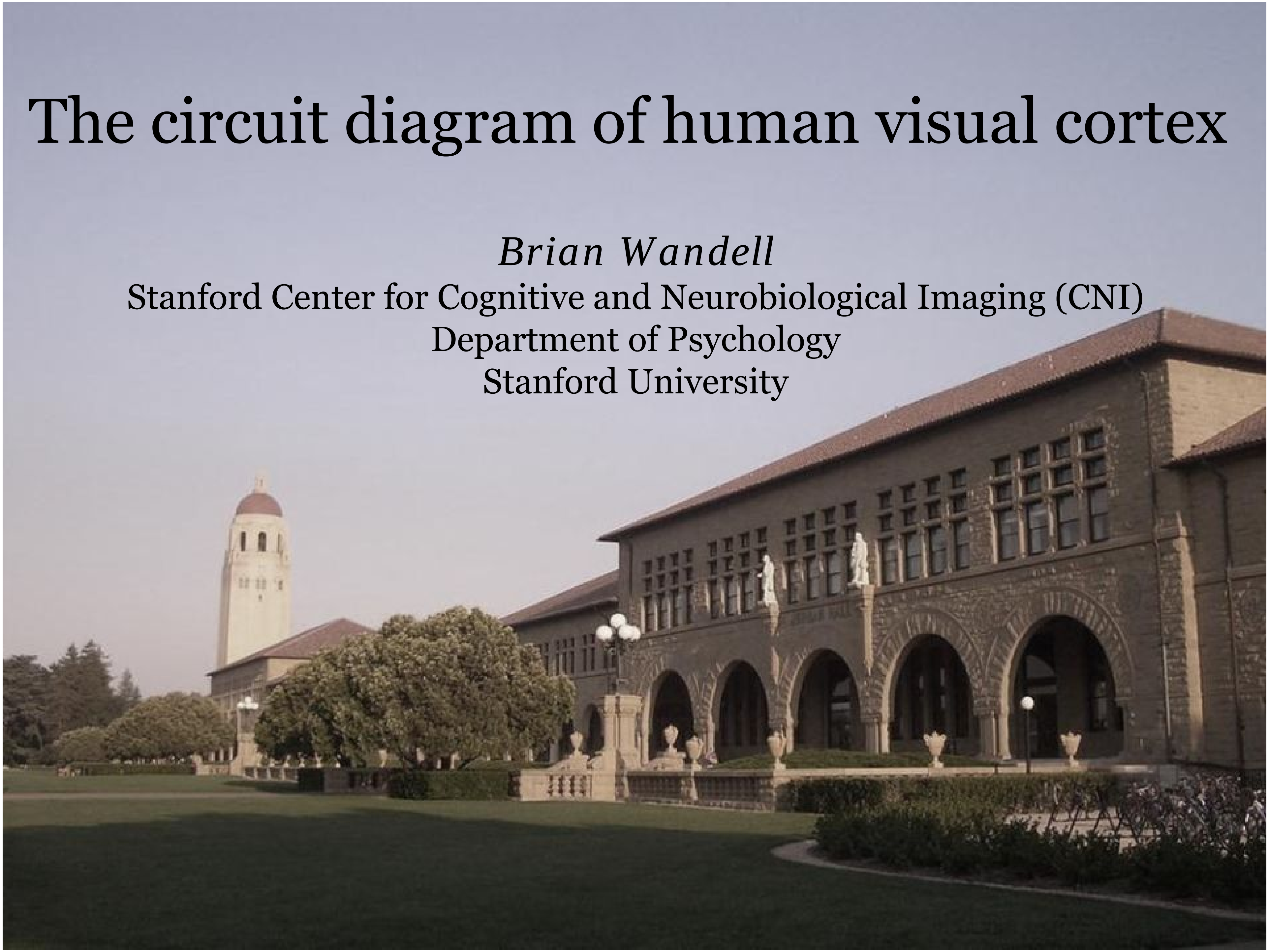
The circuit diagram of human visual cortex

Brian Wandell
Stanford Center for Cognitive and Neurobiological Imaging (CNI)
Department of Psychology
Stanford University



The circuit diagram of human visual cortex

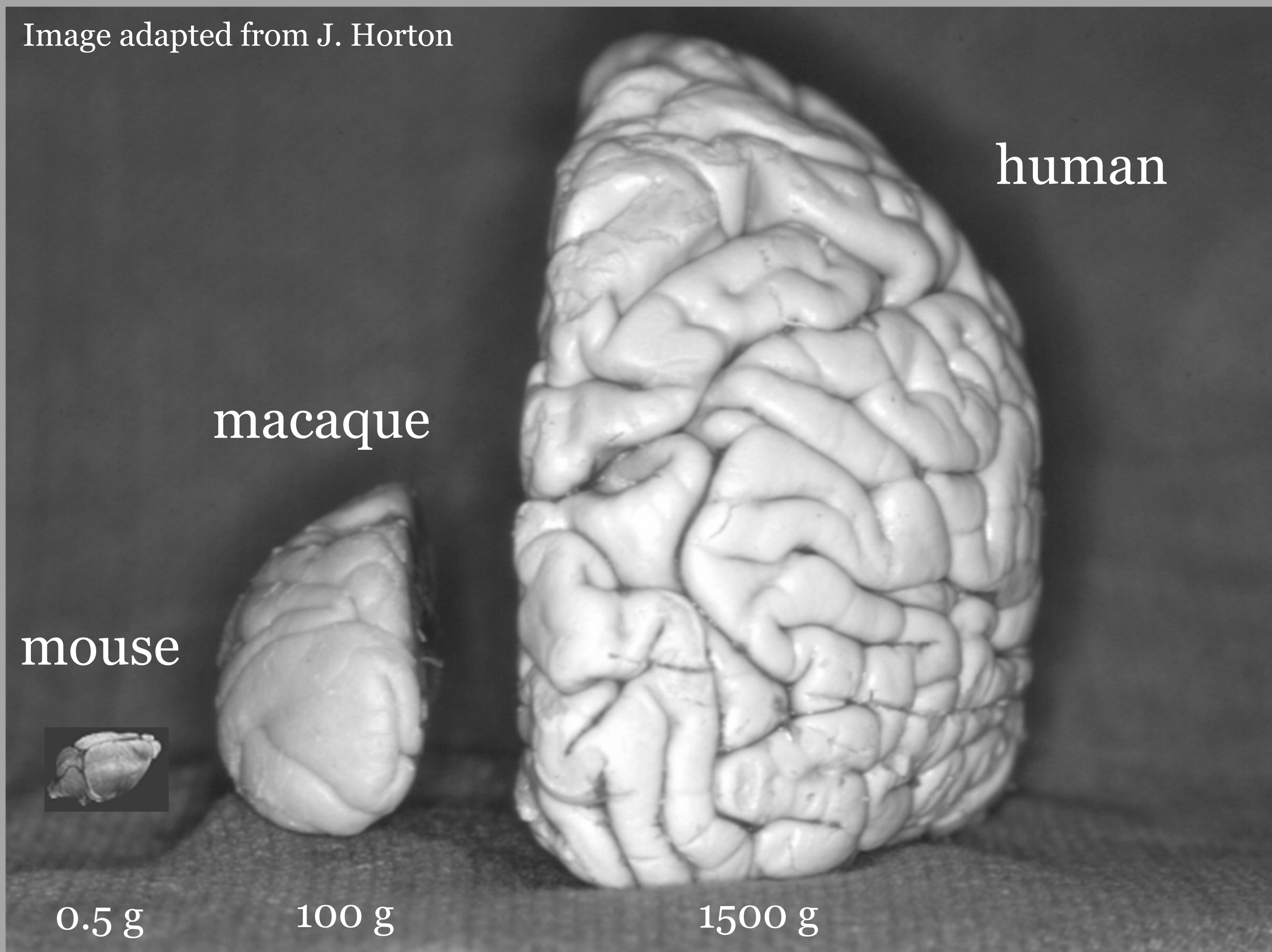
- Introduction to diffusion imaging
- Diffusion: Within the voxel
- Diffusion: Across voxels (tractography)
- Visual field maps and tractography

Ariel
Rokem

Franco
Pestilli

Hiromasa
Takemura

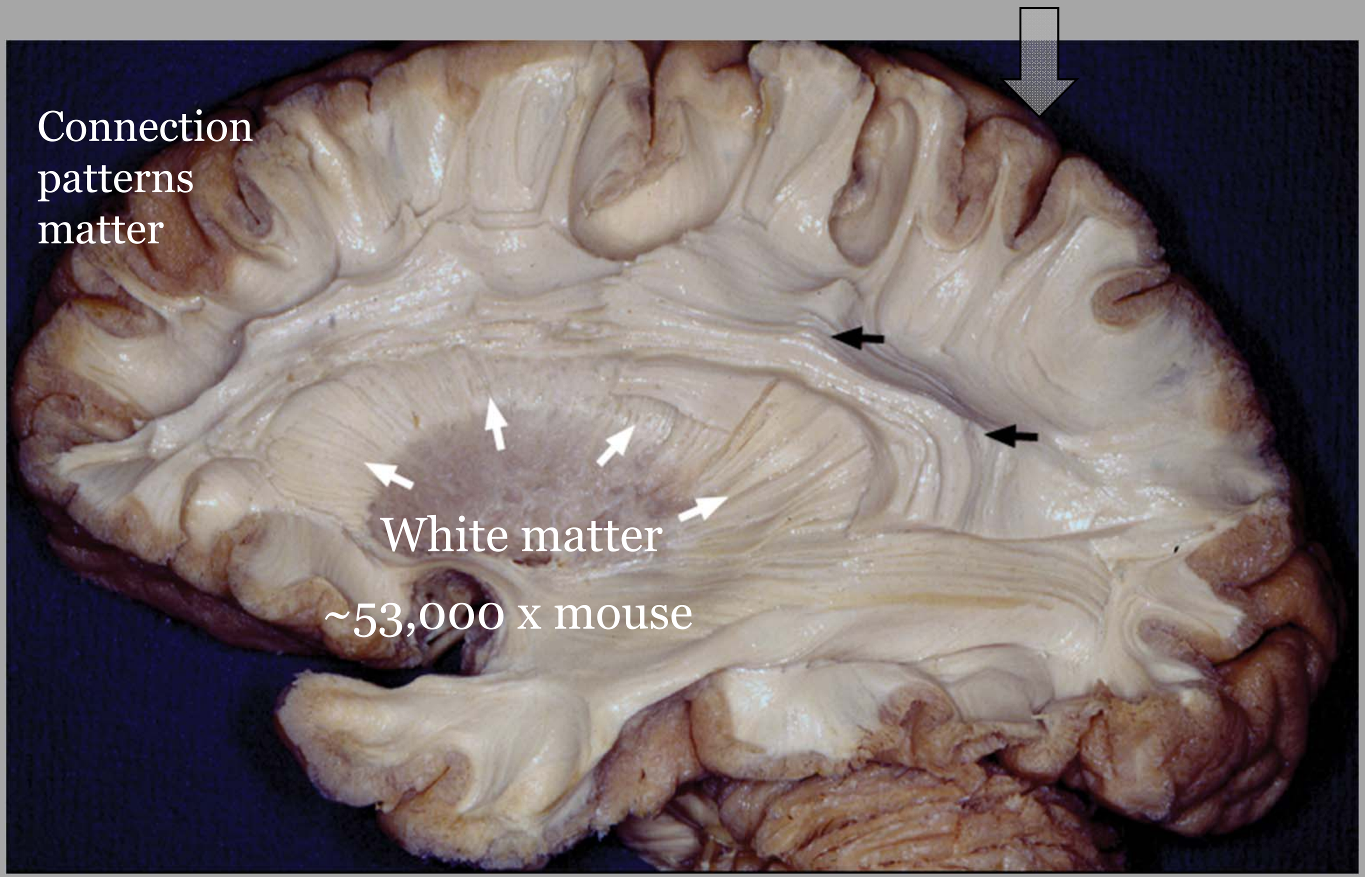
The human brain



Human brain characteristics

- Neuron cell bodies in cortex
- Long-range axons in white matter
- A system with active wires that develop and whose properties correlate with visual skills (e.g., sight word efficiency)

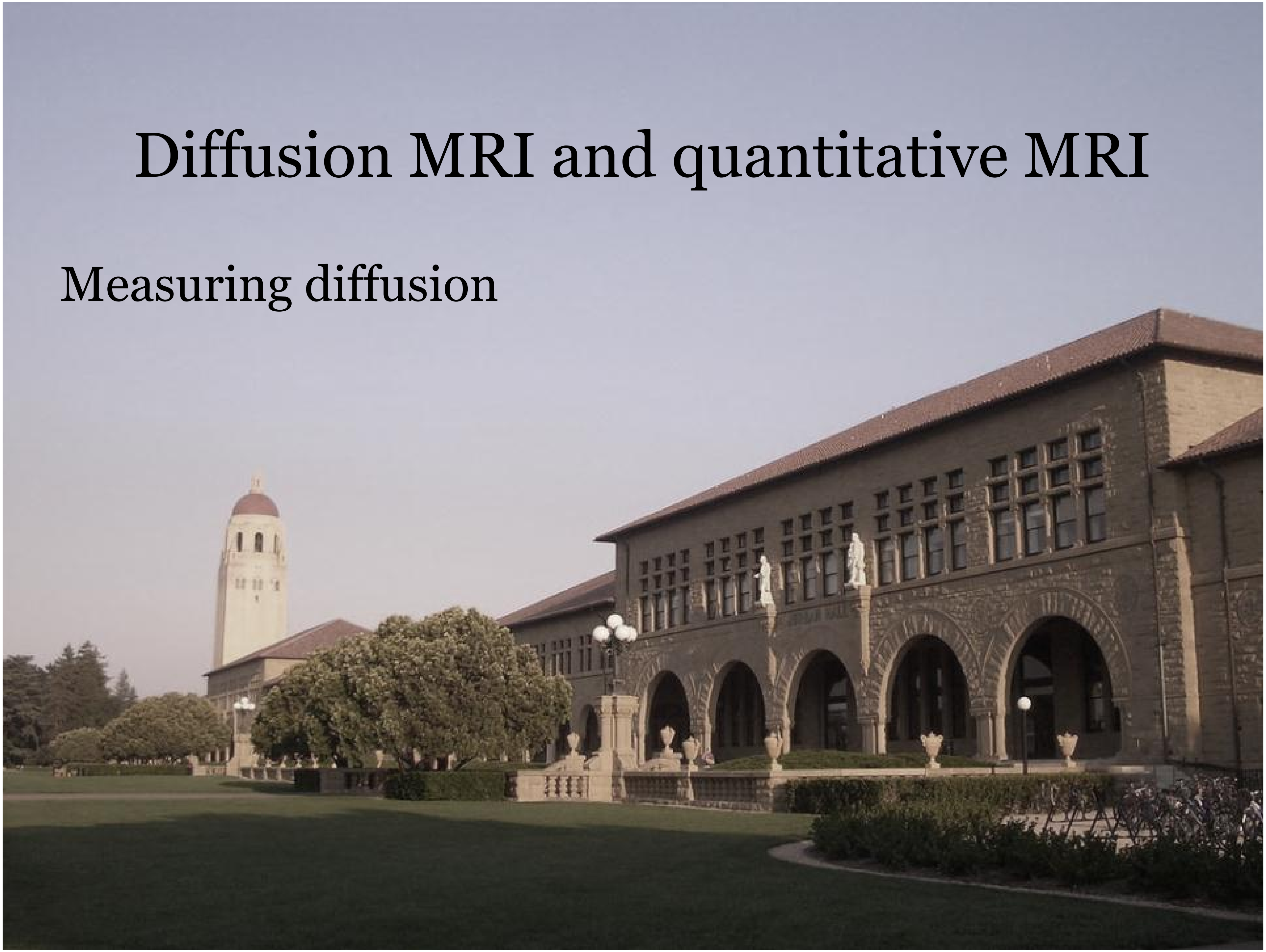
Cortex ~7500 x mouse



Courtesy Professor Ugur Ture

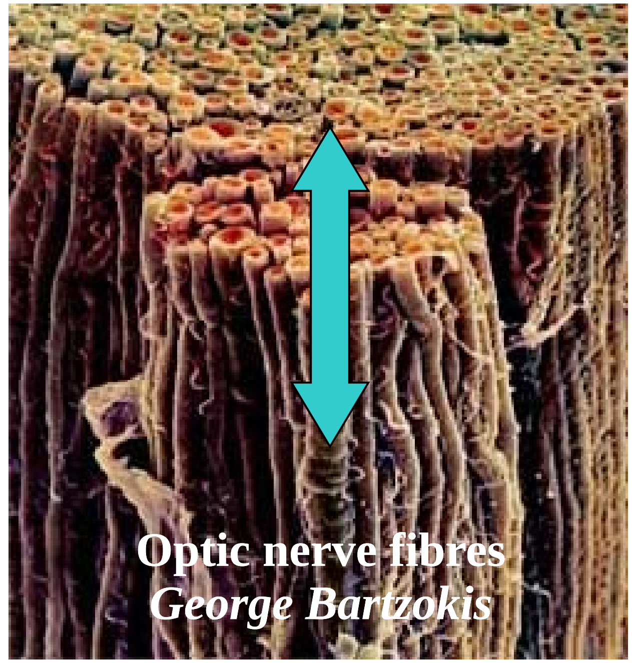
Diffusion MRI and quantitative MRI

Measuring diffusion

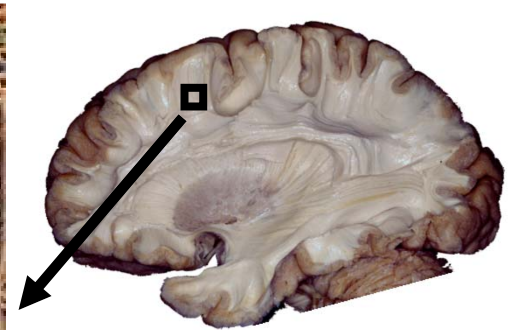


Diffusion probes brain microscopic structure

Along the axon, within the cytoskeleton, water diffuses easily; the **Apparent Diffusion Coefficient (ADC)** is relatively large

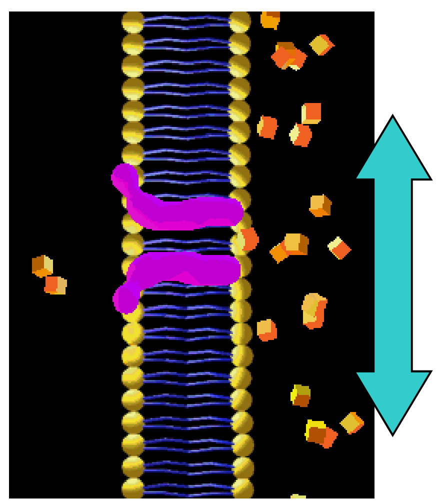


Optic nerve fibres
George Bartzokis



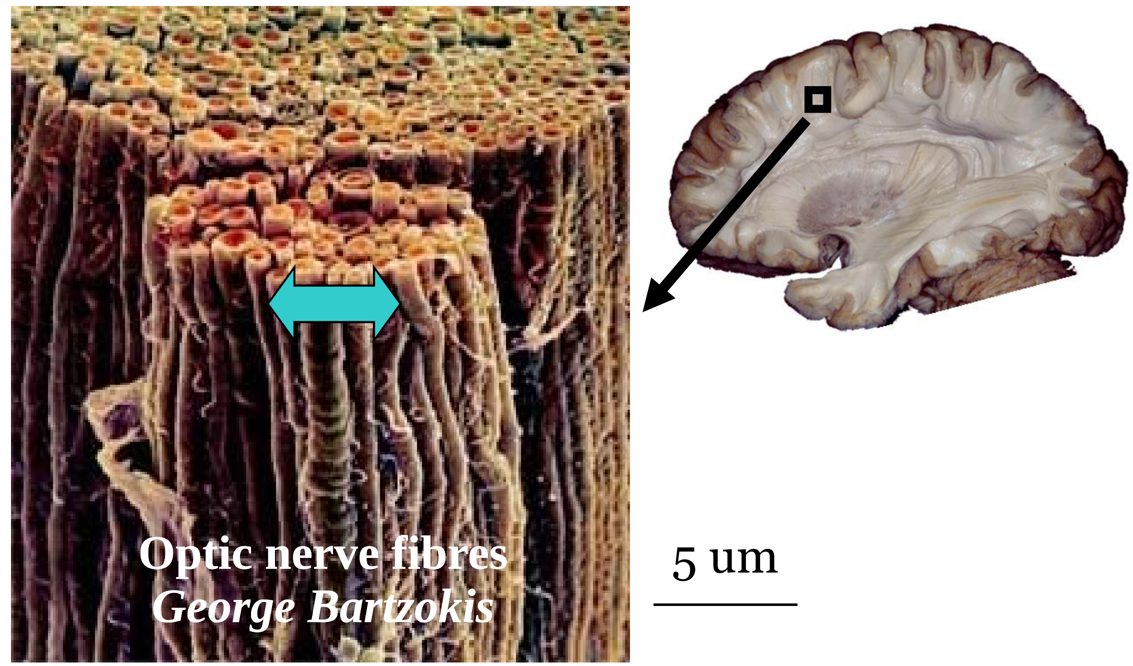
5 um

Longitudinal diffusivity ($\mu m^2/ms$)



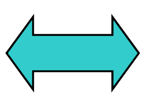
Diffusion probes brain microscopic structure

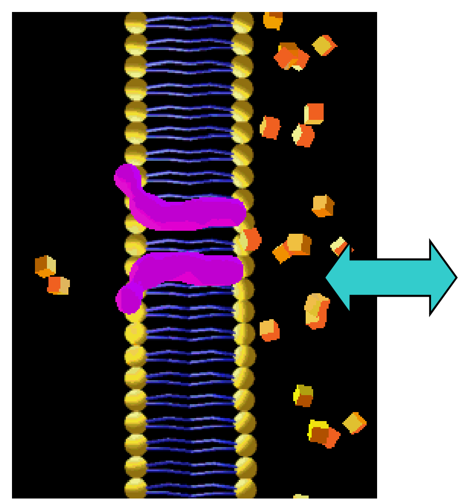
Bi-lipid cell membranes limit diffusion. Hence, perpendicular to axons the **ADC** is relatively small



5 um

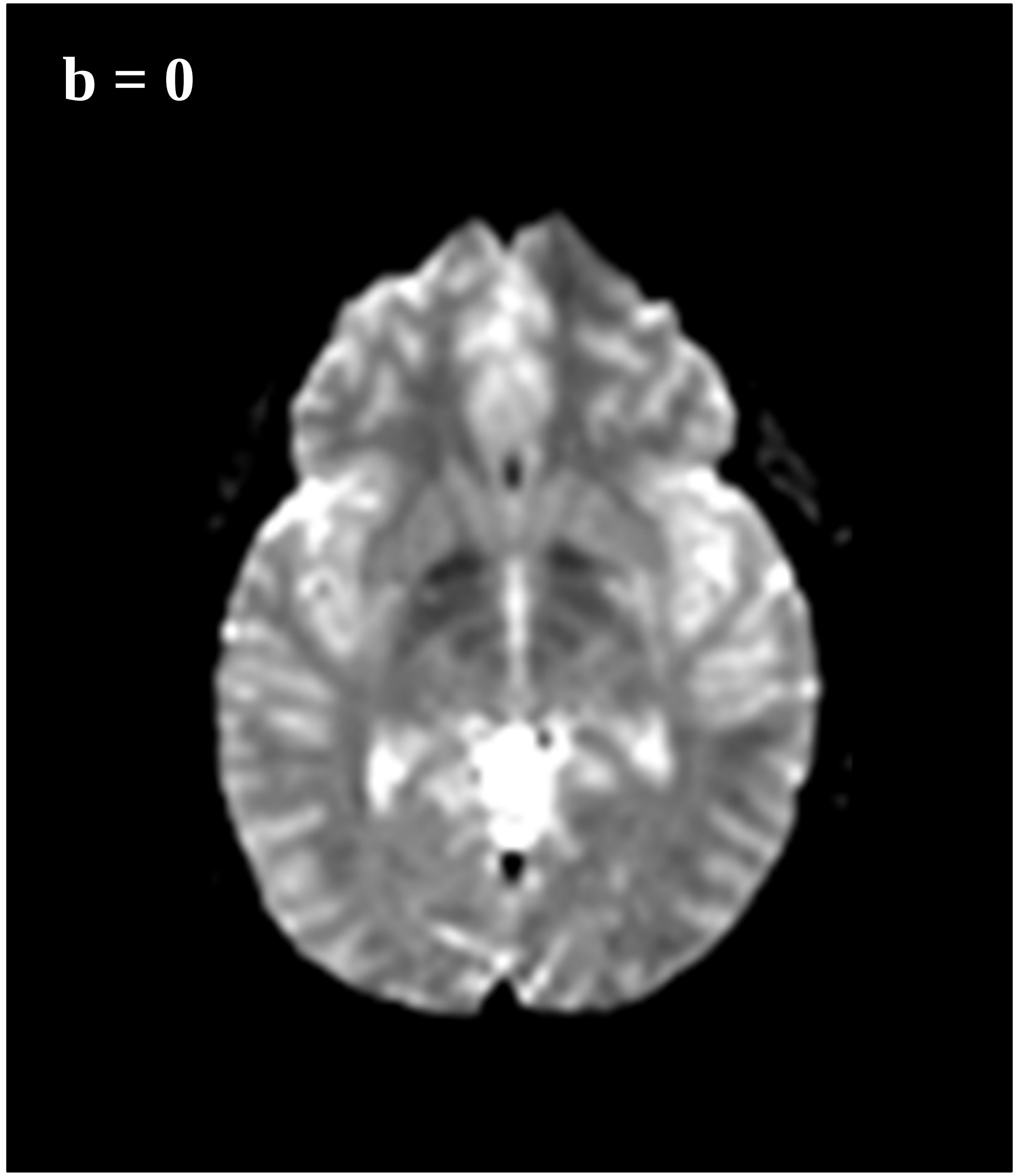
Radial Diffusivity (μm^2/ms)





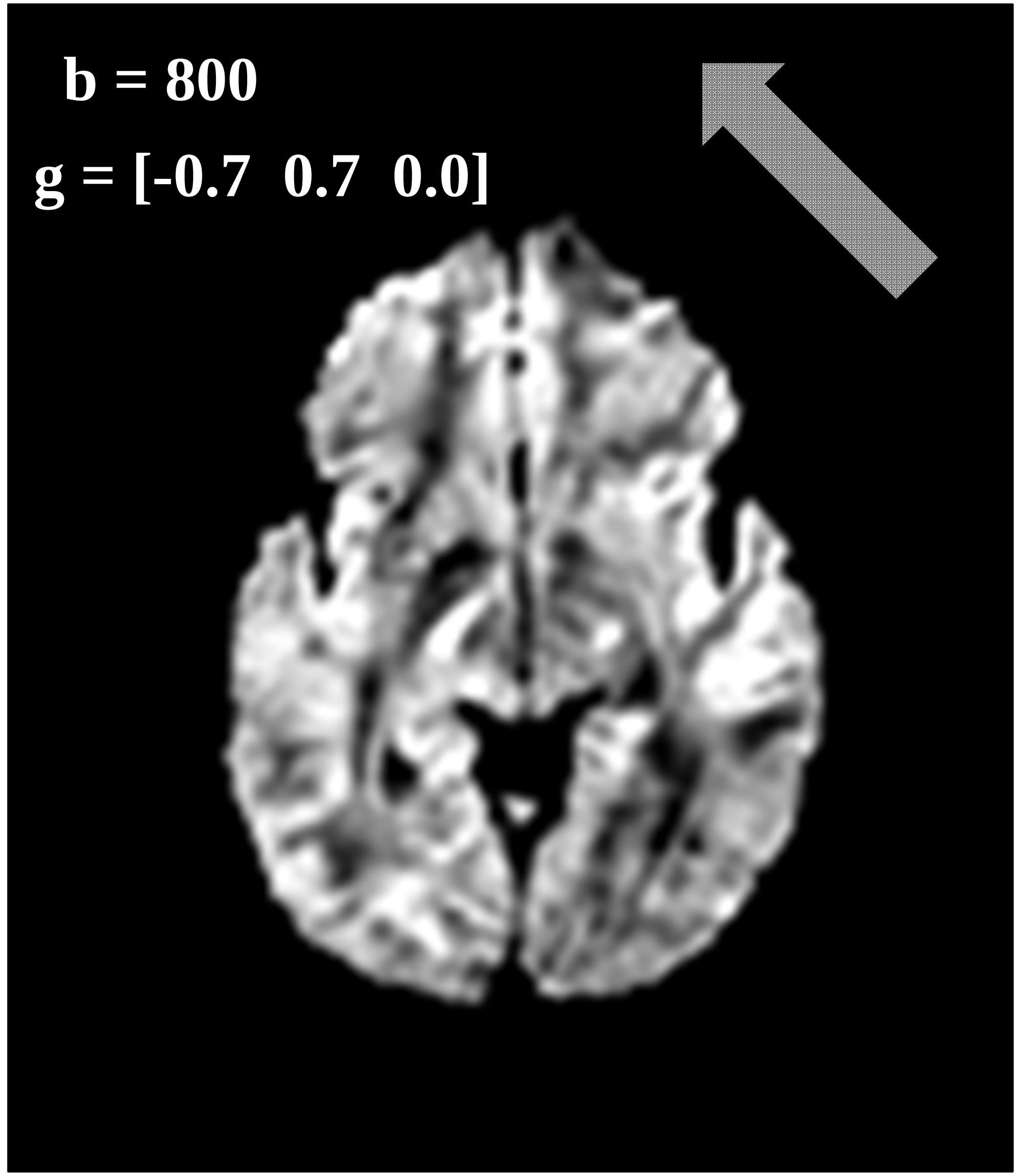
Non-diffusion MR image

Dark means large
signal attenuation
High ADC



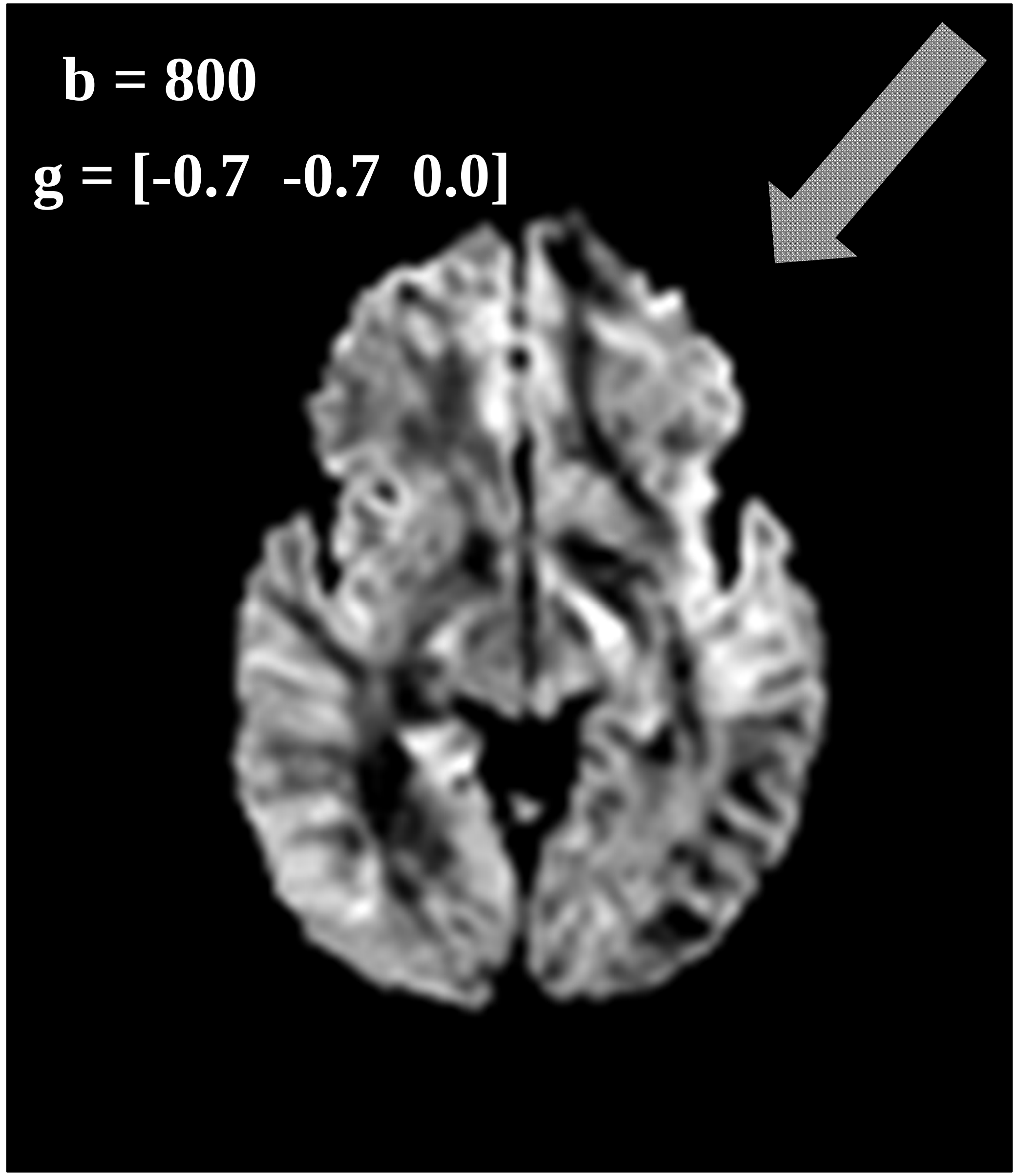
Diffusion weighted images

Dark means large
signal attenuation
High ADC



Diffusion weighted images

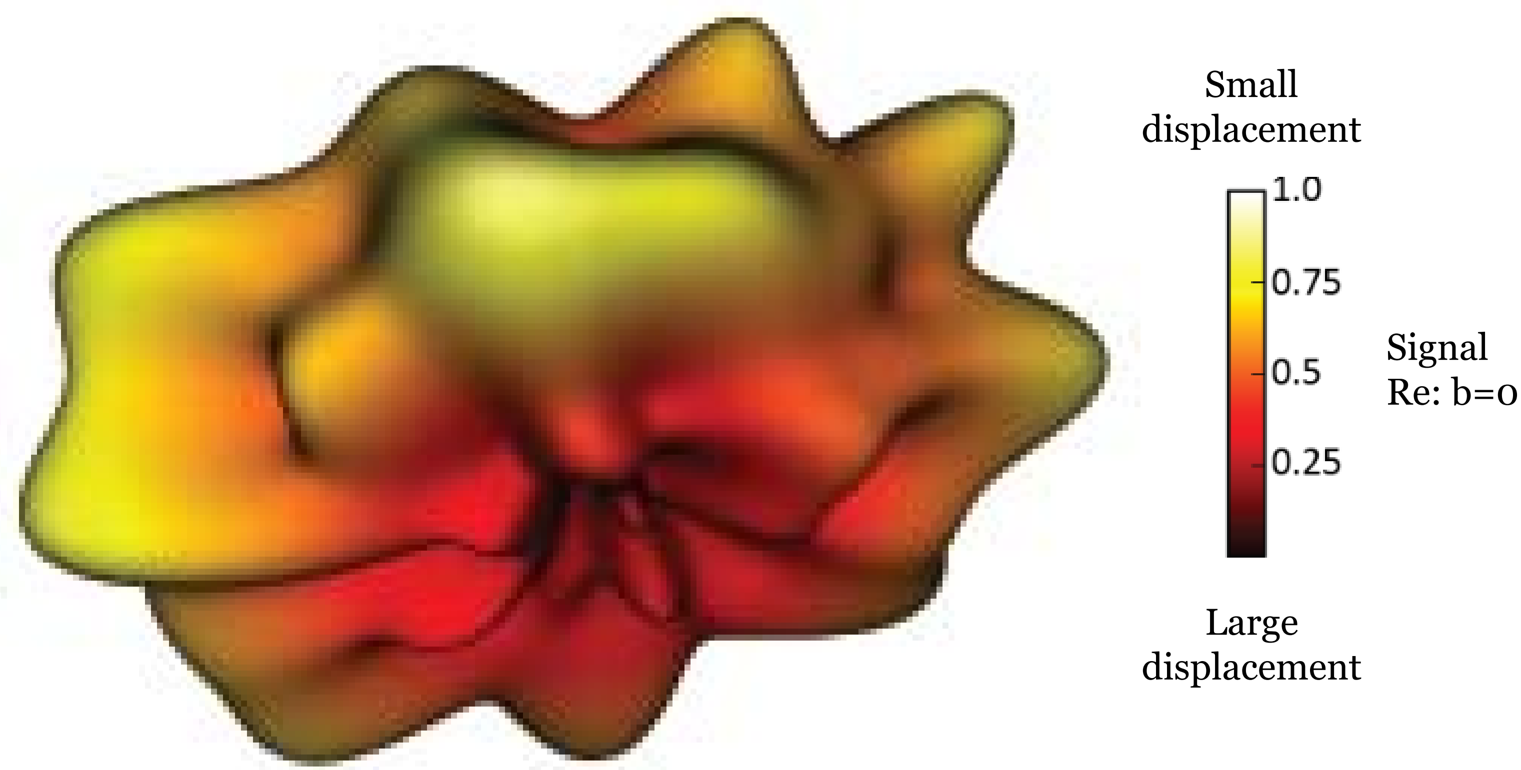
Dark means large
signal attenuation
High ADC



Diffusion data analysis

High angular resolution diffusion imaging (HARDI)

MRI diffusion signal for each voxel

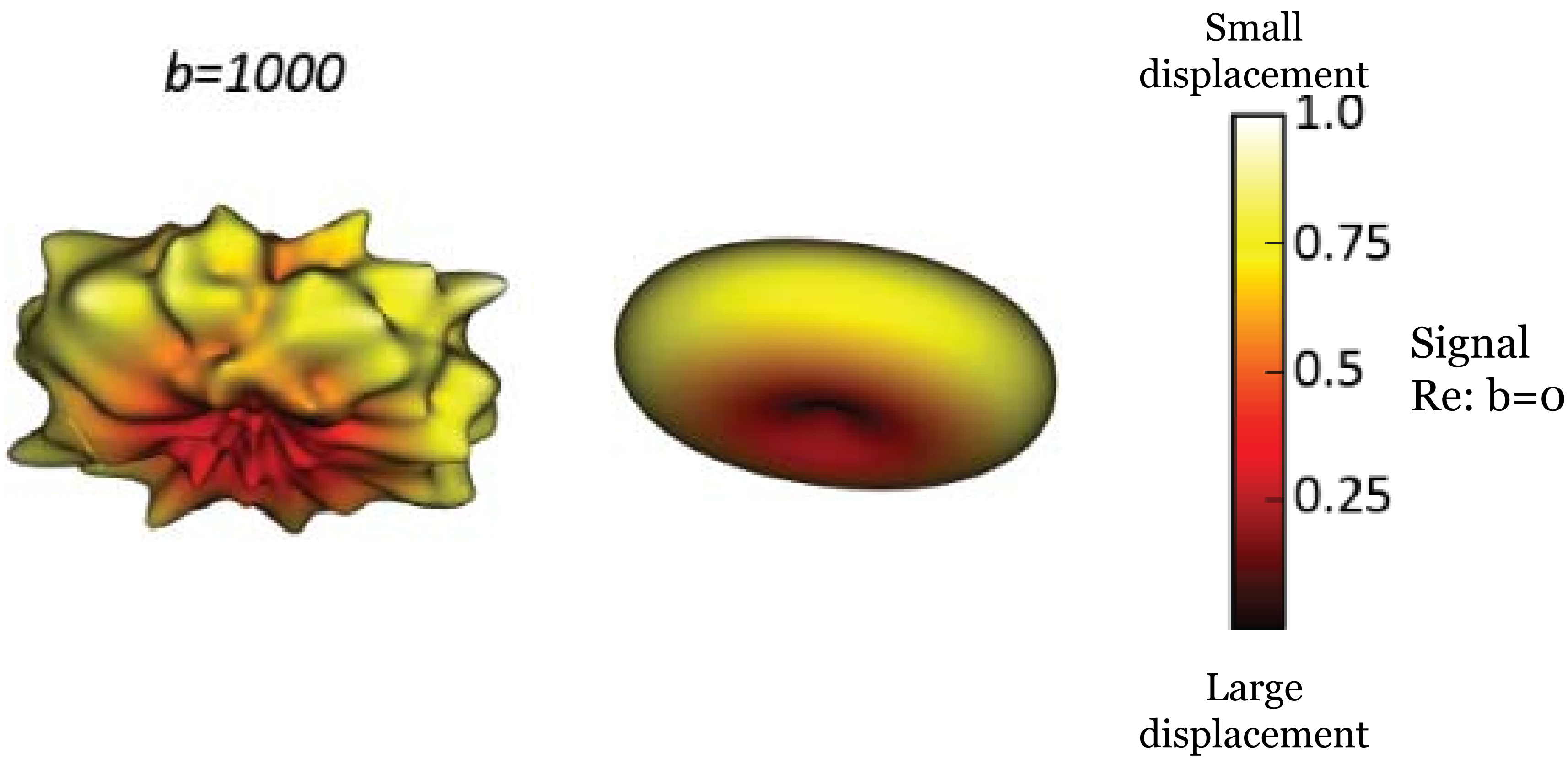


Evaluating diffusion models within the voxel

Ariel Rokem

Diffusion tensor model (DTM)

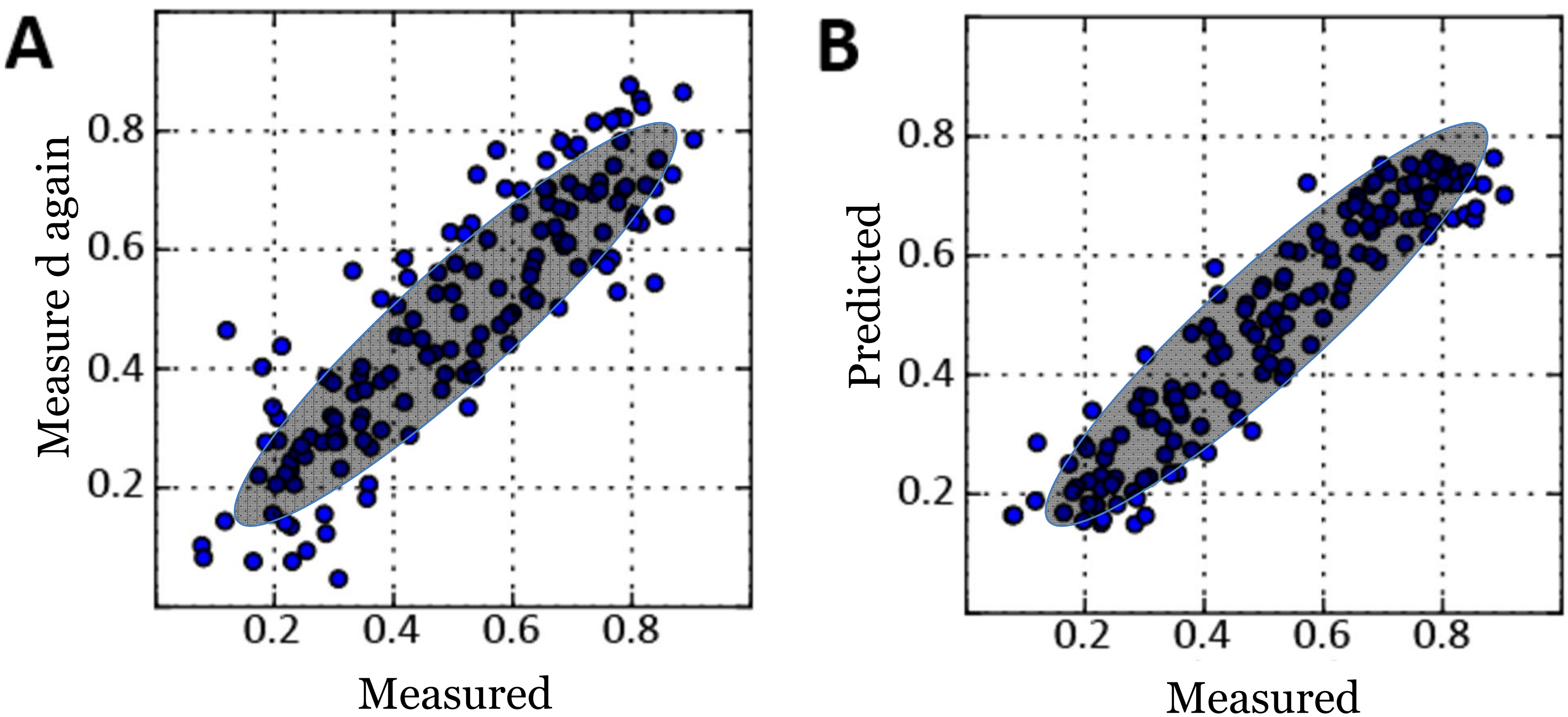
Predicts the **voxel diffusion signal** with a phenomenological equation, motivated by Gaussian diffusion.



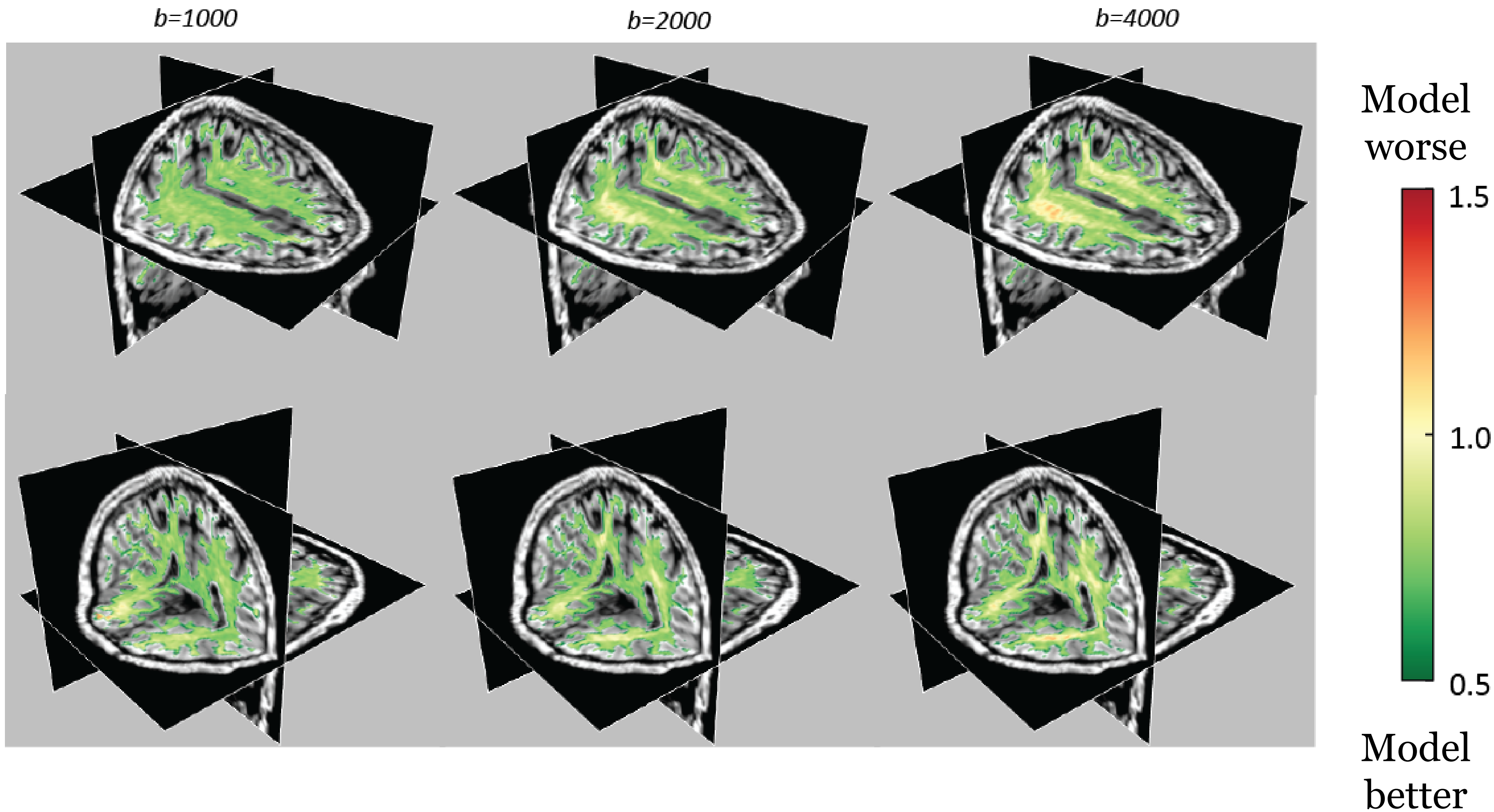
DTM predicts independent data (cross-validates) more accurately than replication

Replication

Prediction



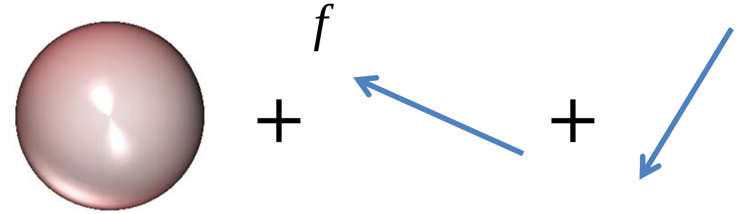
DTM misses in a few regions



Sparse fascicle model (SFM)

Predicts the **voxel diffusion signal** with a model of the sum of fascicles plus isotropic diffusion

$$S(\theta) = w_0 D_0 + \sum_f w_f D_f(\theta)$$



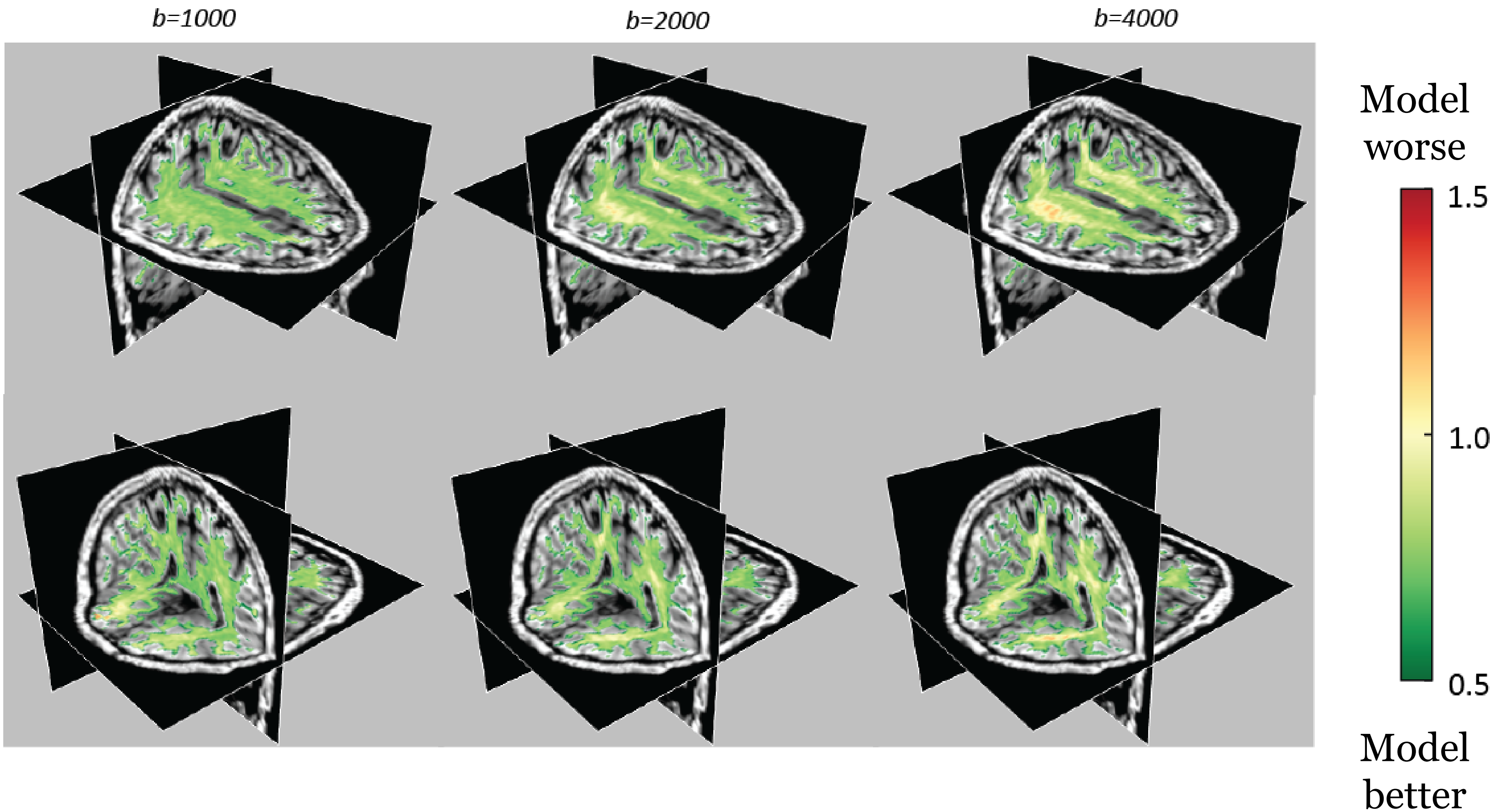
Ball

Sticks

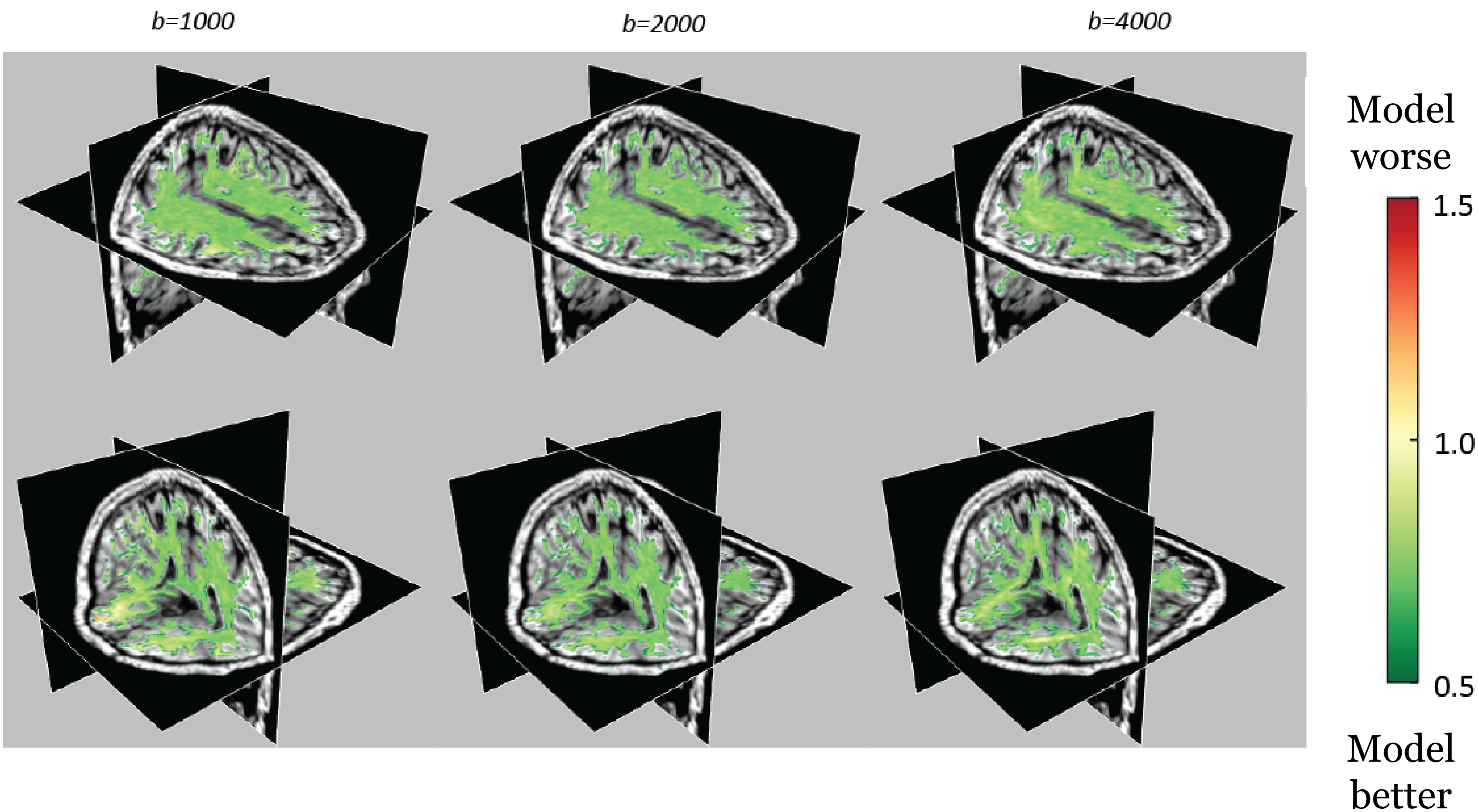
Measured

Modeled

SFM better (slightly) than DTM

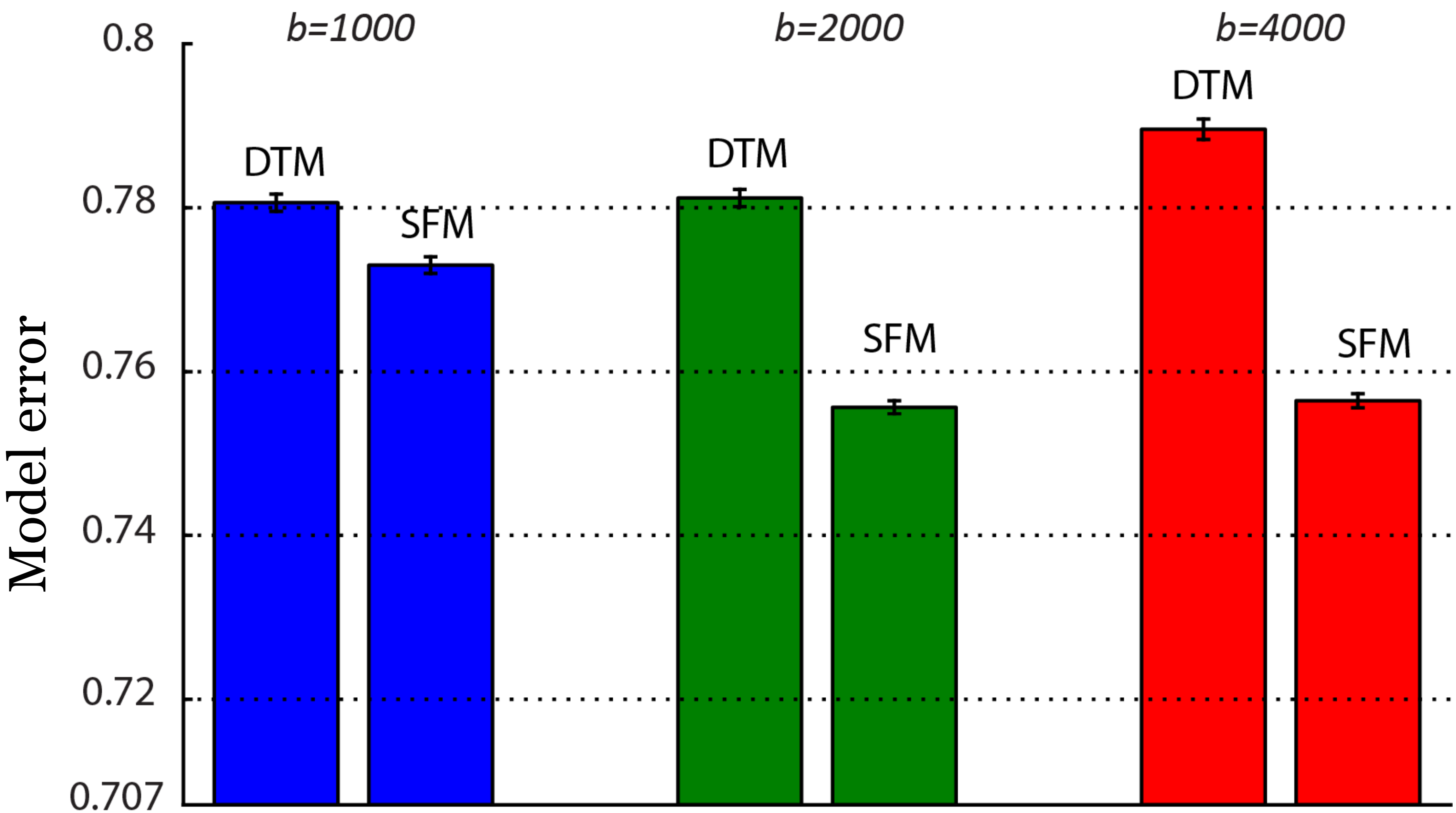


SFM better (slightly) than DTM



SFM slightly outperforms DTM

Both are very good, and just short of best possible performance

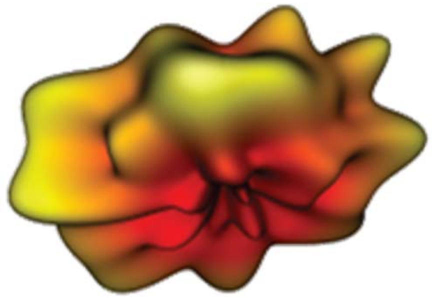


Best possible = $\frac{1}{\sqrt{2}}$

Model-based neuroanatomy: Validation and statistical inference in living connectomes

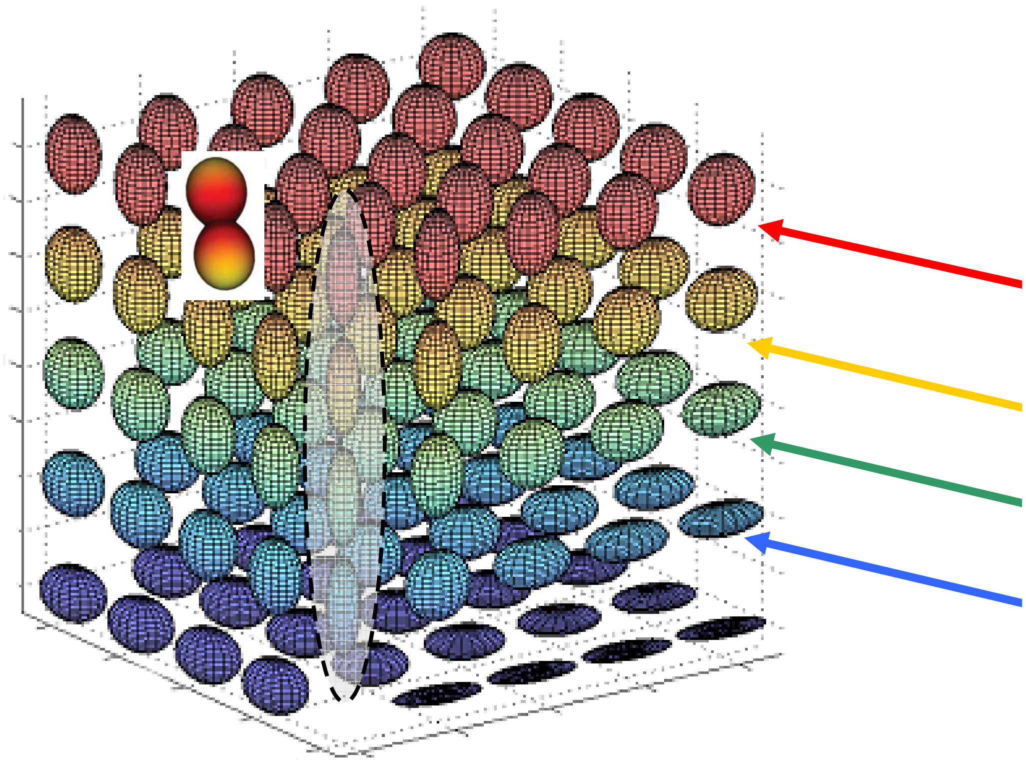
Franco Pestilli

Tractography

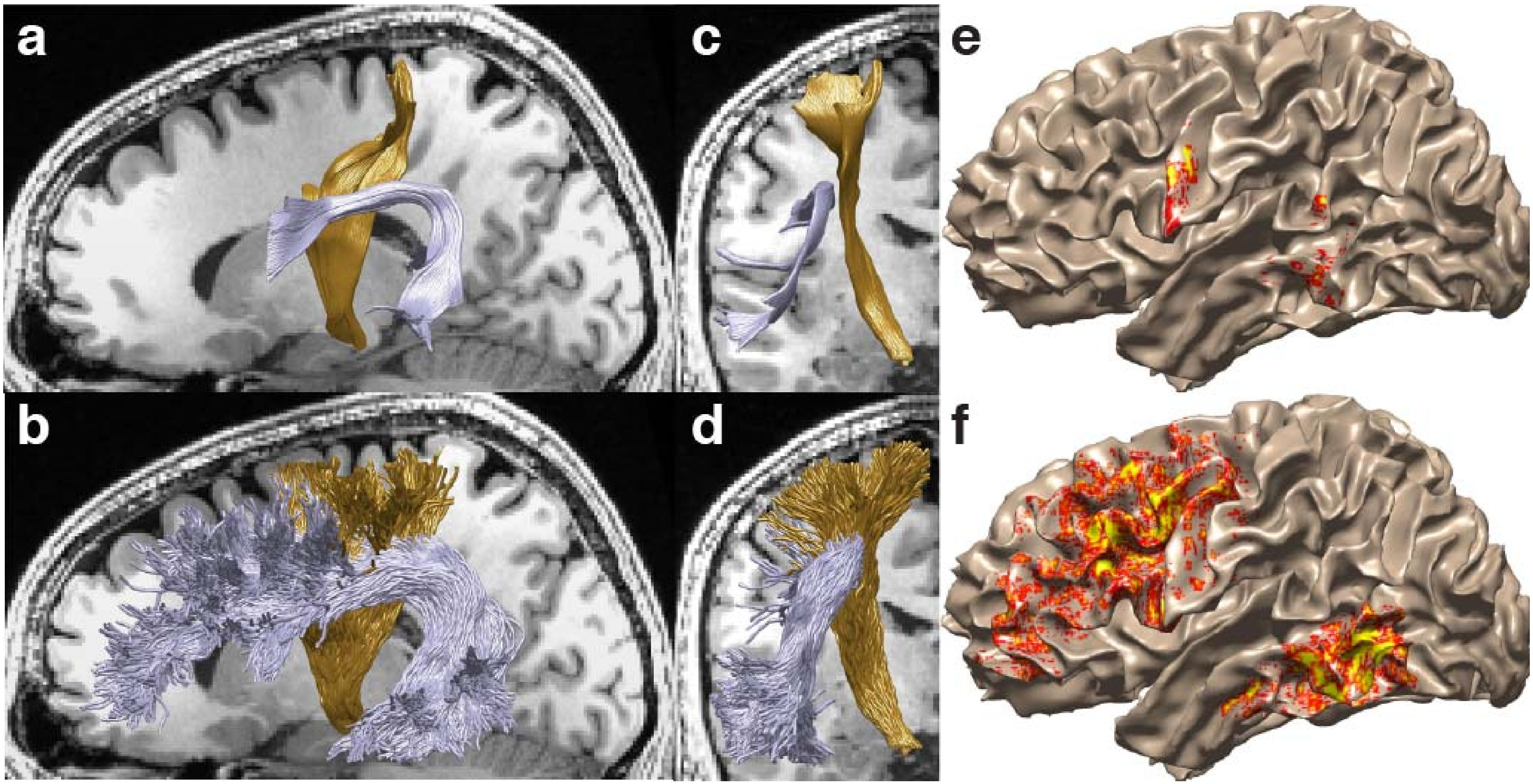


Diffusion data are surfaces

Use the local (voxel) diffusion measurements to estimate white matter tracts

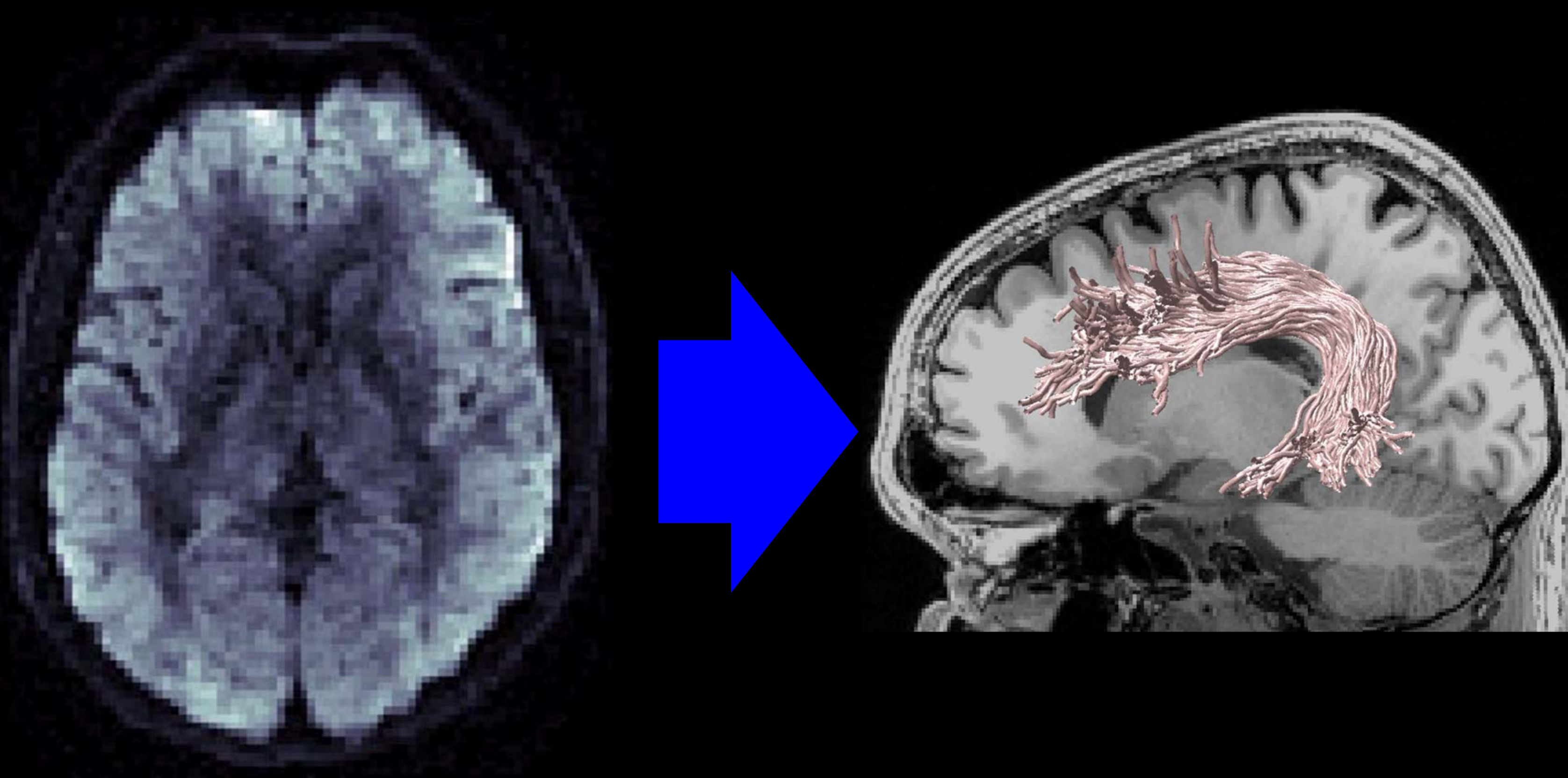


Tractography algorithms differ. A lot.



Standard tractography

Estimate fascicles from diffusion data



Linear iterative fascicle evaluation (LIFE)

Predict diffusion data from fascicles

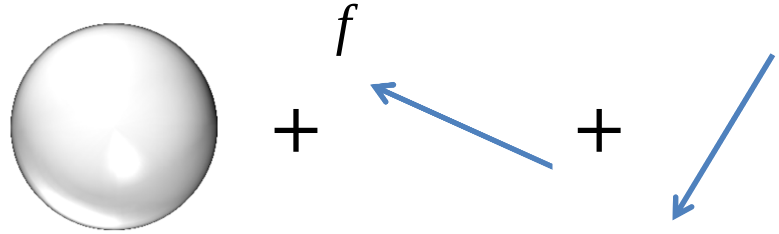
Compare how well different models and algorithms do

Fascicle contributions

- Each fascicle makes a contribution to the diffusion signal for each voxel it passes through
- The contribution depends on the fascicle orientation

In each voxel, use the tractography fascicles as the sticks

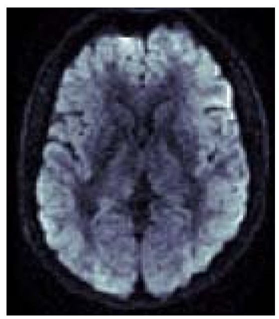
$$S(\theta) = w_0 D_0 + \sum_f w_f D_f(\theta)$$



Set up the non-negative LS equations

- Each fascicle makes a contribution to the diffusion signal for each voxel it passes through
- The contribution depends on the fascicle orientation
- The fascicles can contribute somewhat different amounts (weighted)

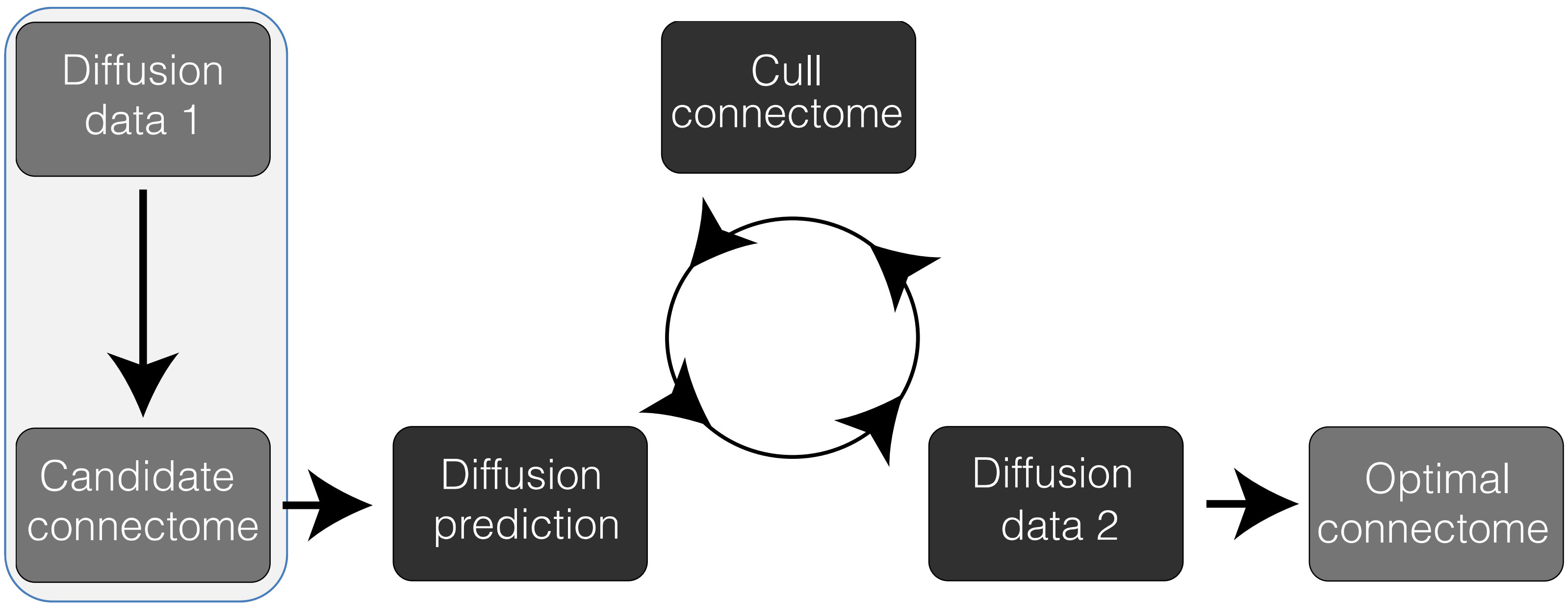
Diffusion signal, S(θ)



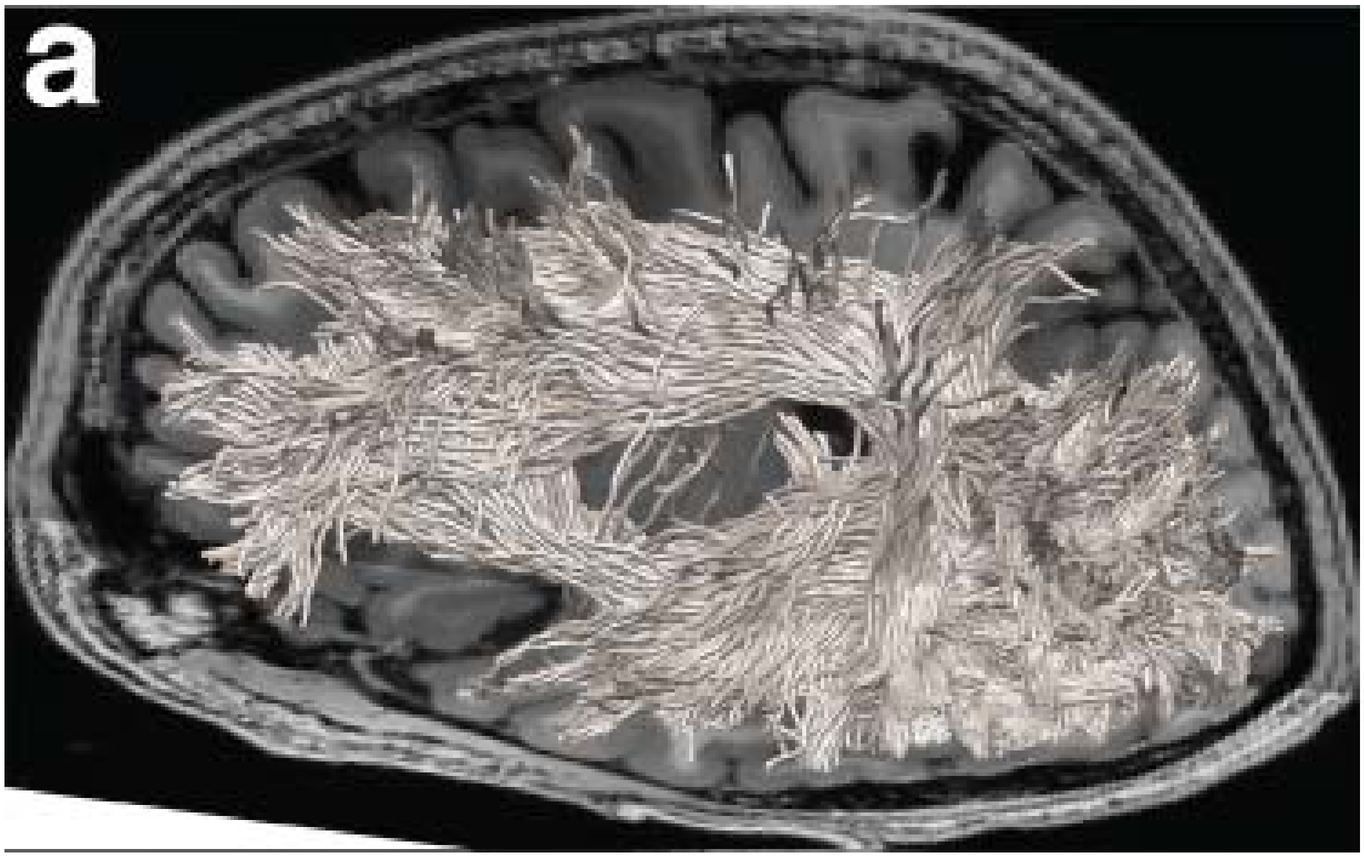
S(θ) [ ] = (Each column is the set of fascicle predictions for this voxel) [ ] Weight for each fascicle

Linear Iterative Fascicle Evaluation (LIFE)

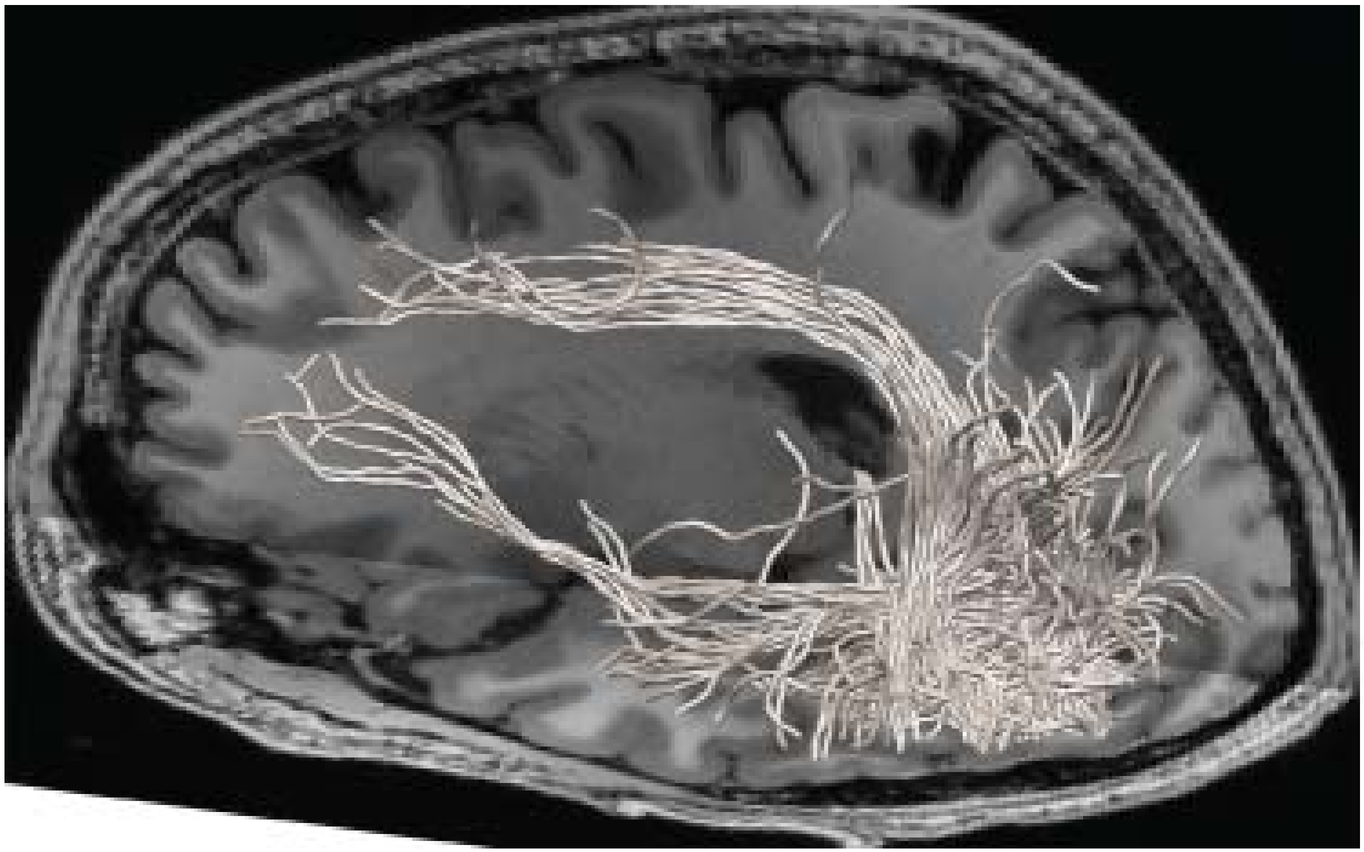
Cull fascicles with zero weights



Tractography solution for fascicles with hMT+ endpoints

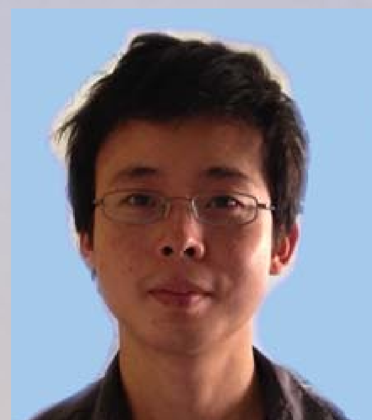


Culled solution explains the data just as well

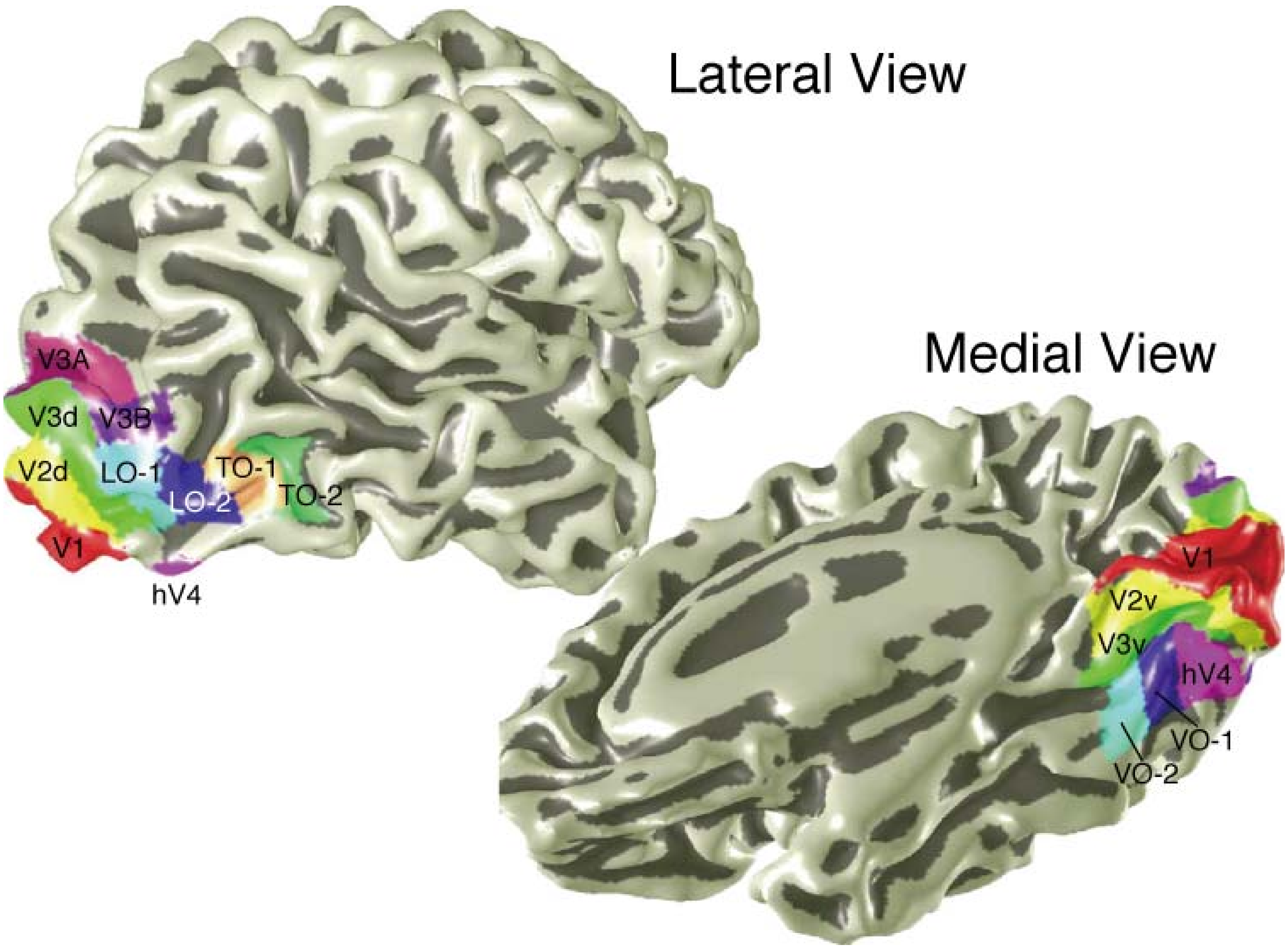


Map organization and white matter: Dorsal-ventral streams

Hiromasa Takemura



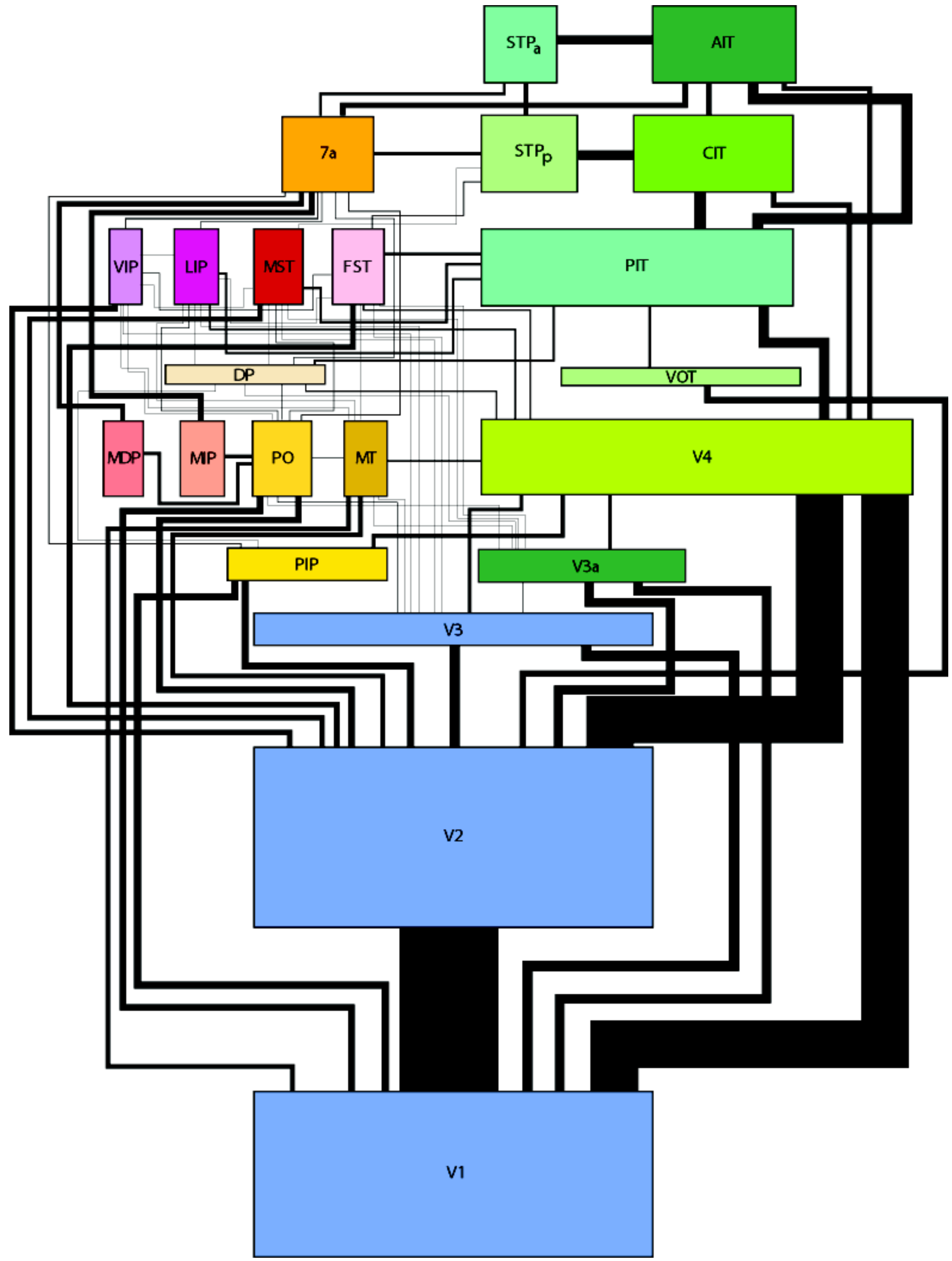
Visual field maps in humans



Wandell and Winawer (2011) *Vision Res*

Macaque field map organization

Felleman and Van Essen (1991),
Annotated by
Wallish and Movshon (2008)



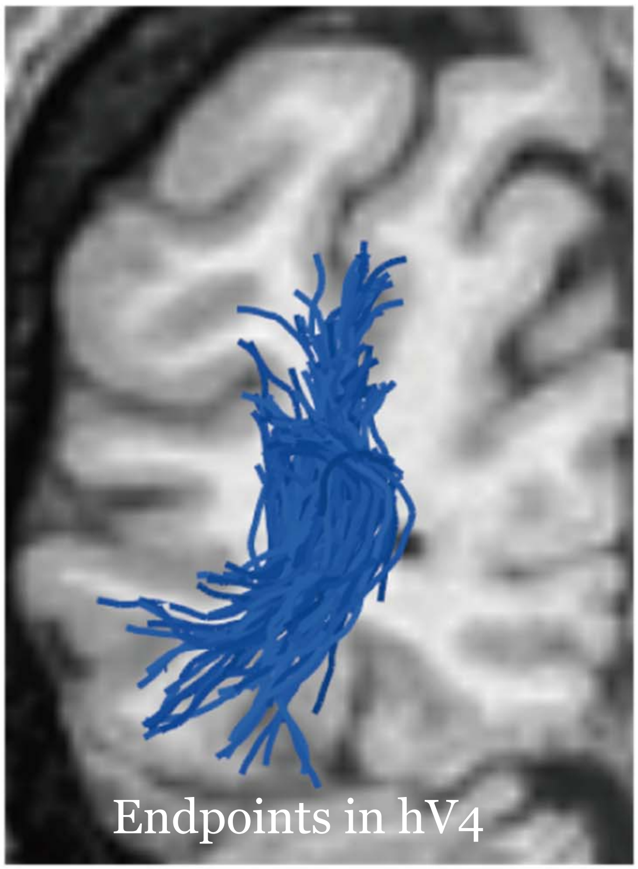
Human diagram

V3 is much bigger (75% of V2)
V3A is accompanied by V3B
hV4 position

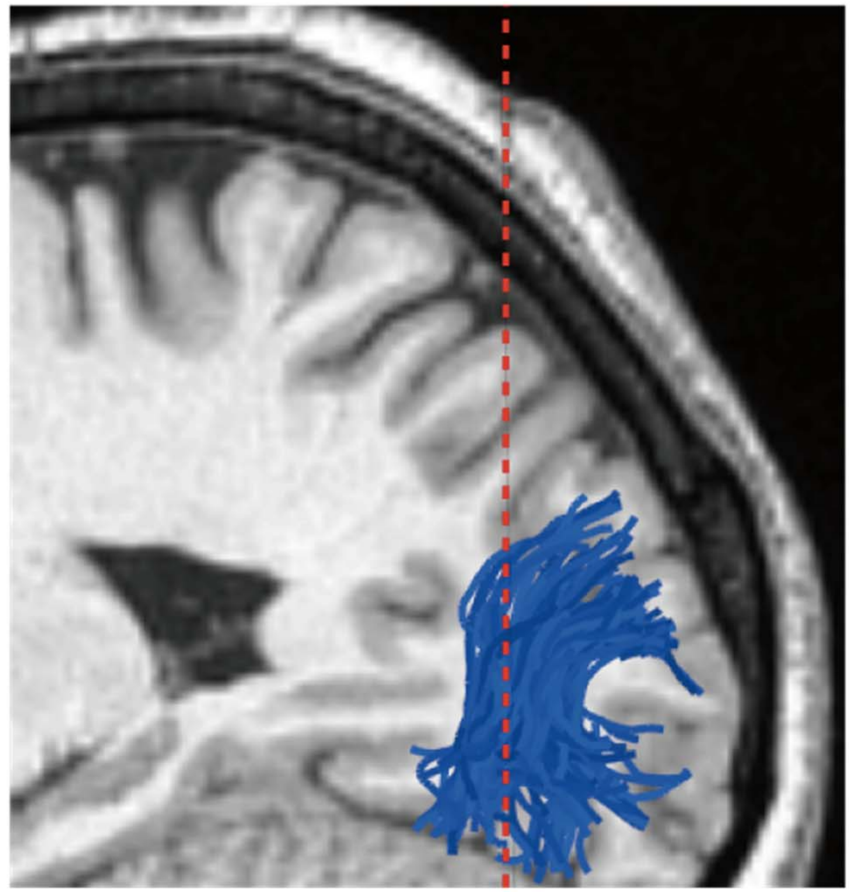
What about dorsal-ventral segregation

Posterior Vertical Occipital Fasciculus (VOF)

Coronal



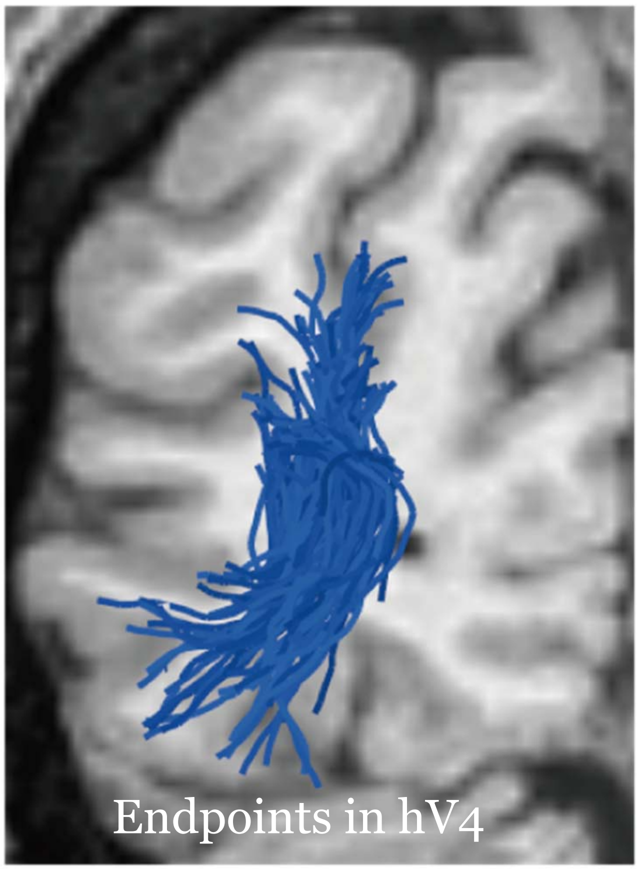
Sagittal

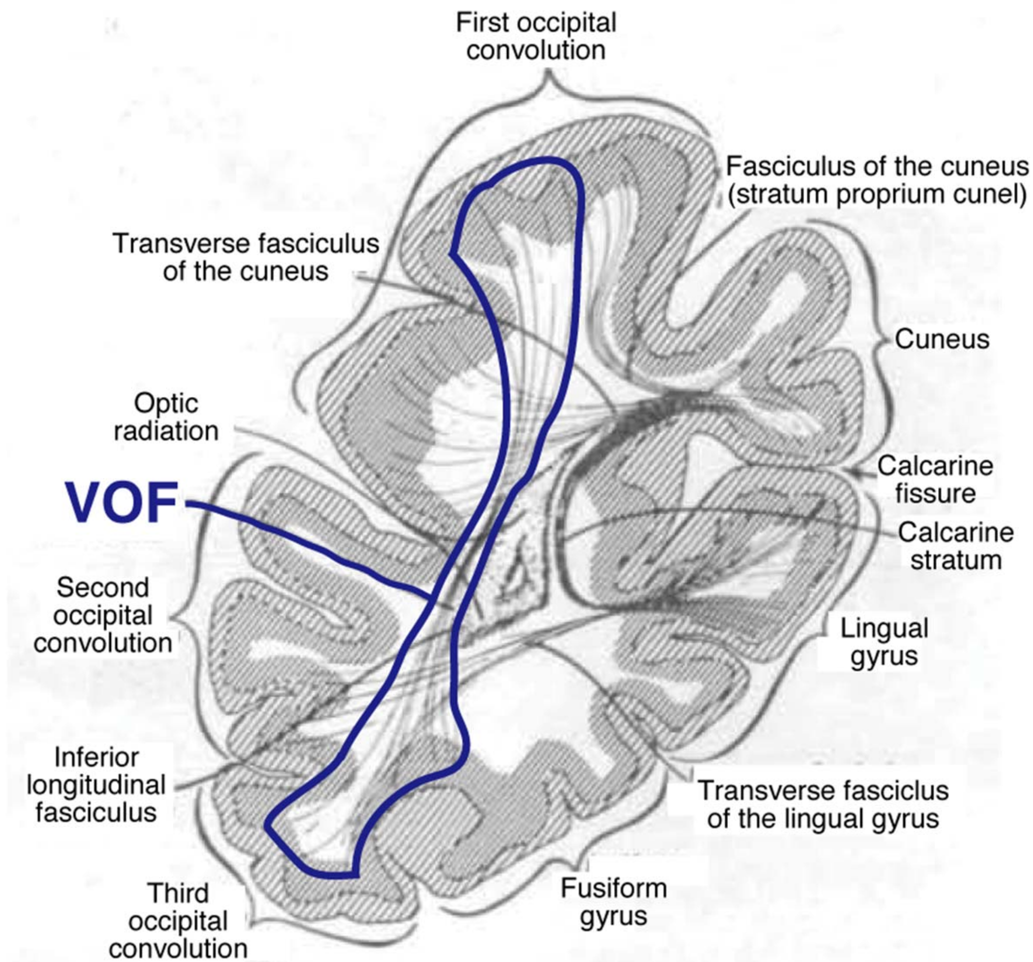


Posterior Vertical Occipital Fasciculus (VOF)

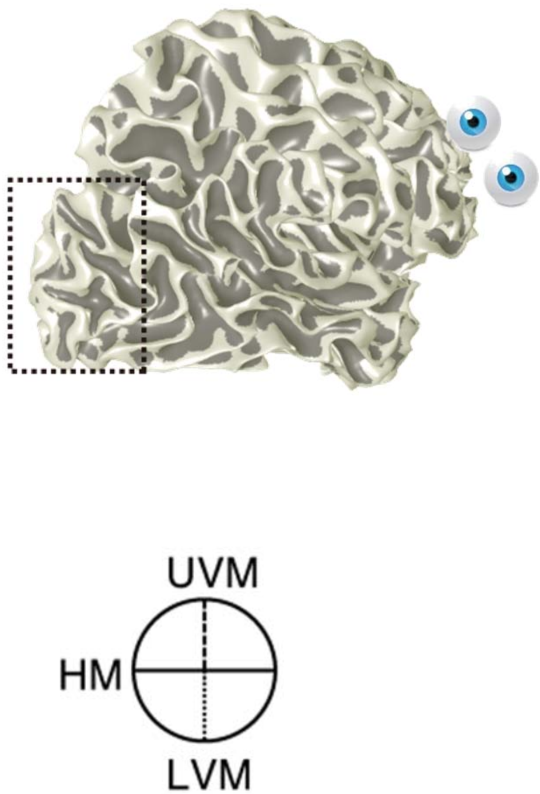
(Dejerine, 1895; Modified by Greenblatt, 1973)

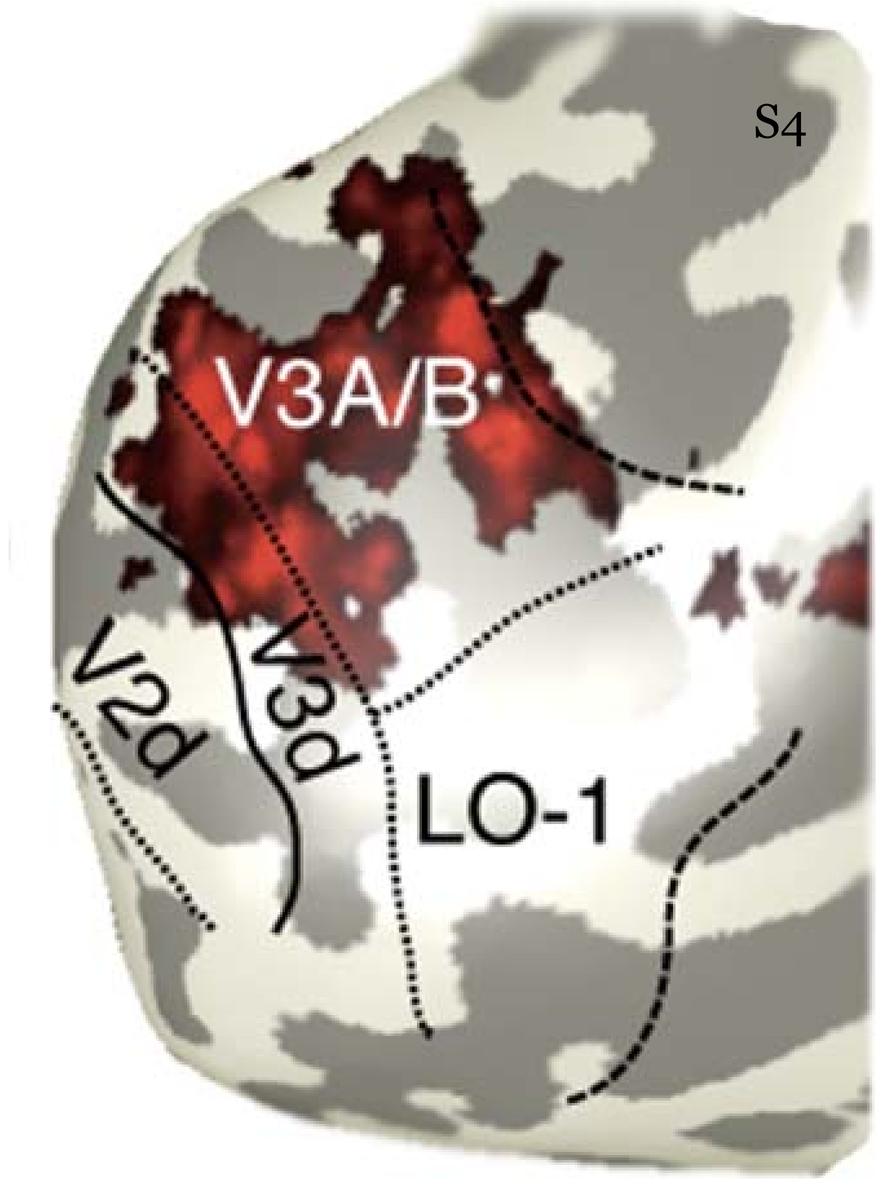
Coronal



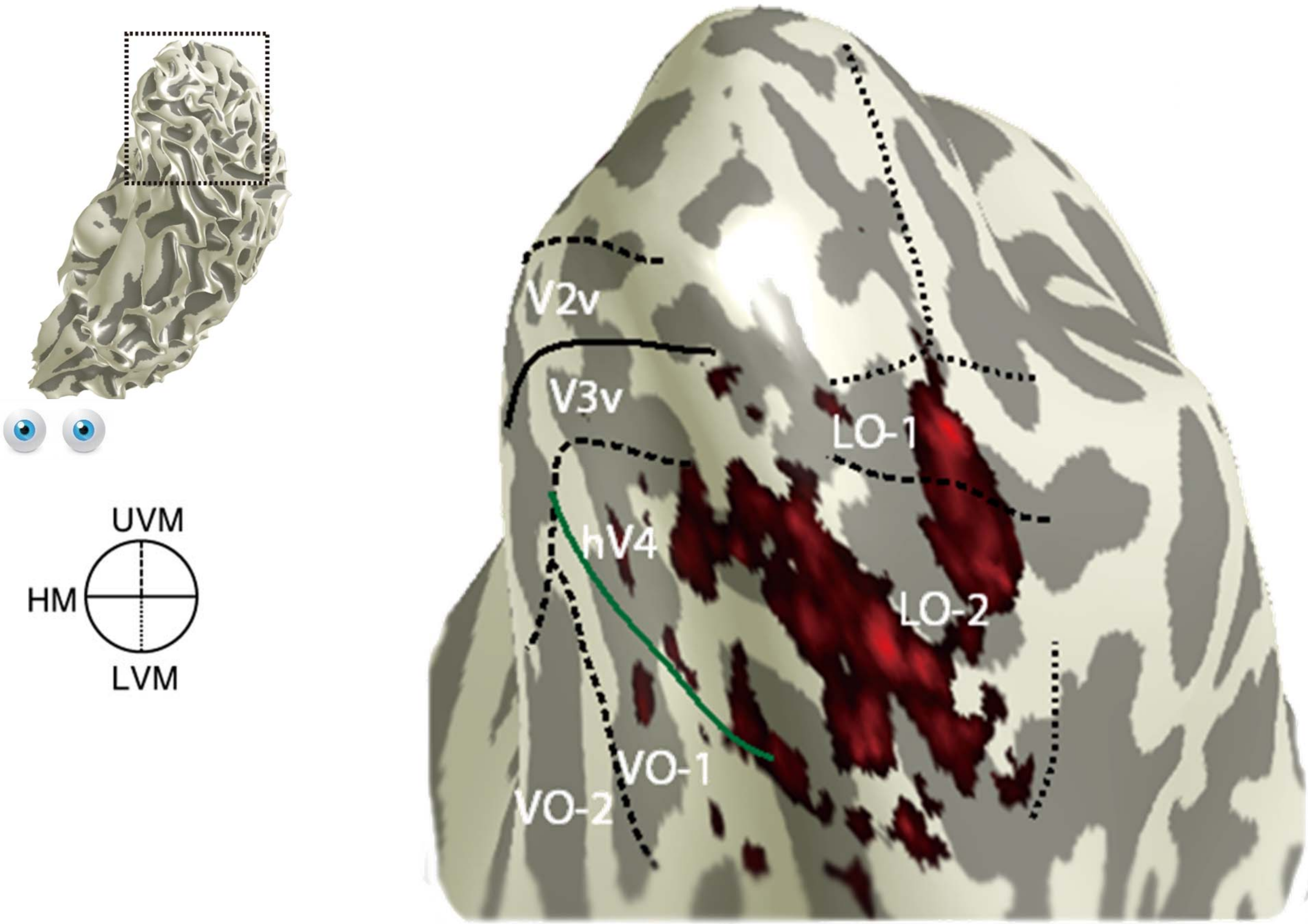


Dorsal VOF endpoints

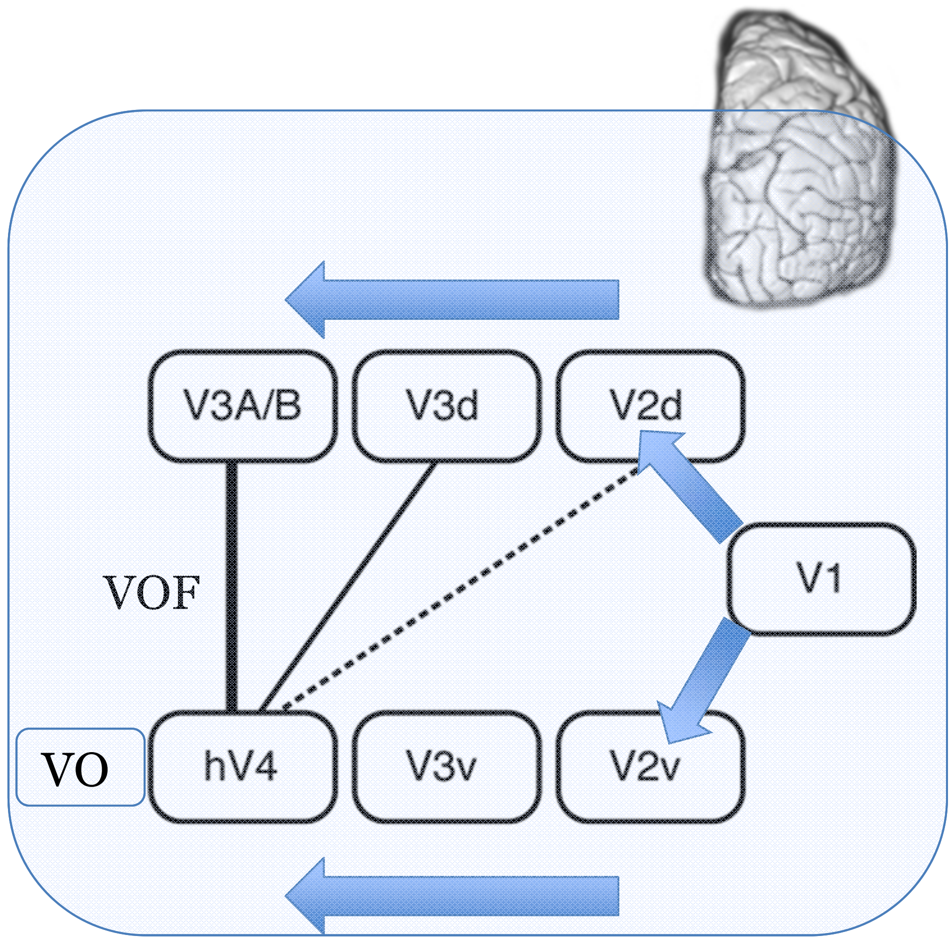




Ventral VOF endpoints

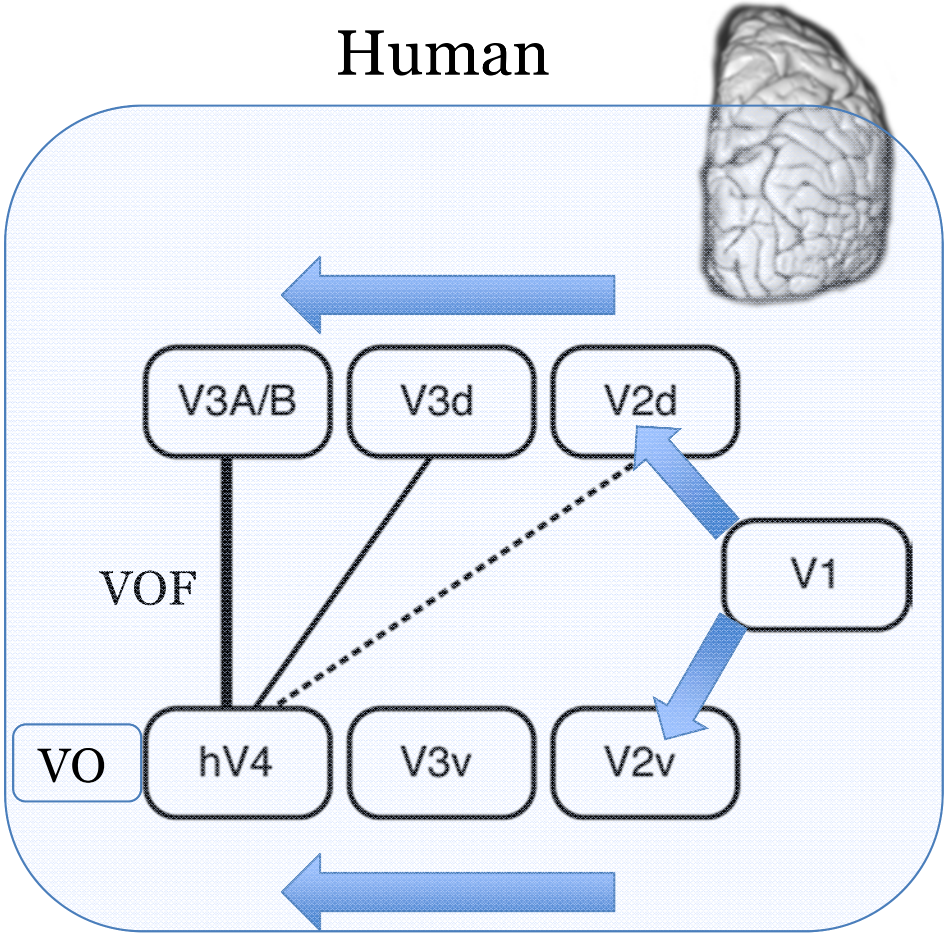


The human wiring diagram



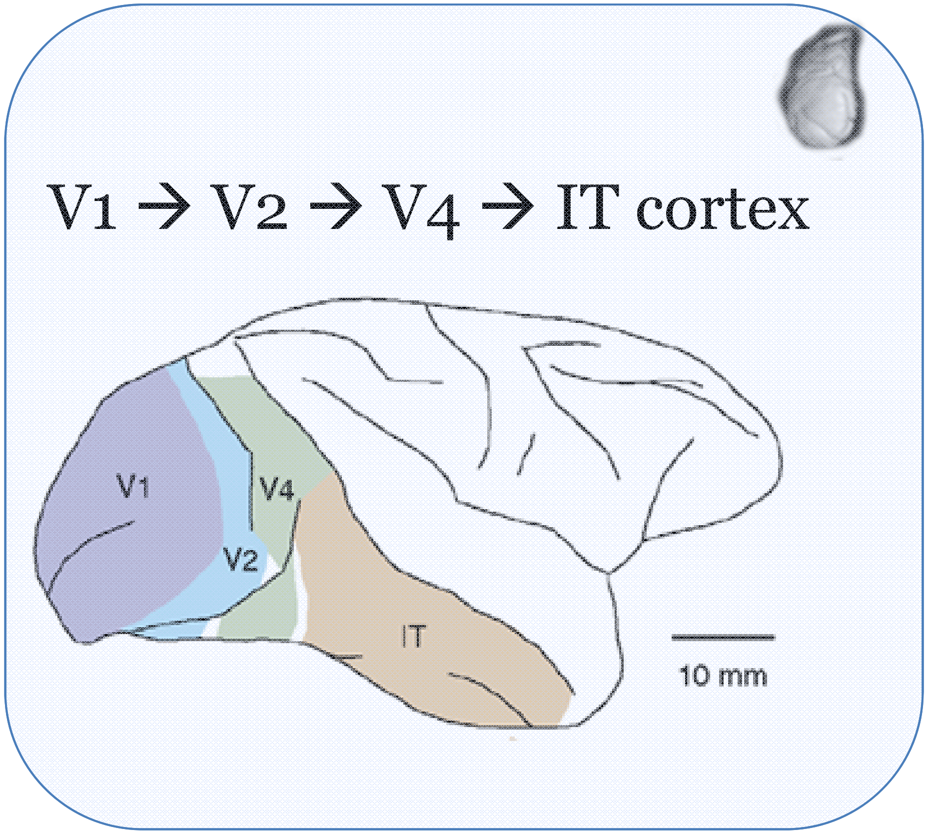
Rethinking the human wiring diagram

Human



Macaque electrophysiology

V1 → V2 → V4 → IT cortex



DiCarlo and Cox, 2007

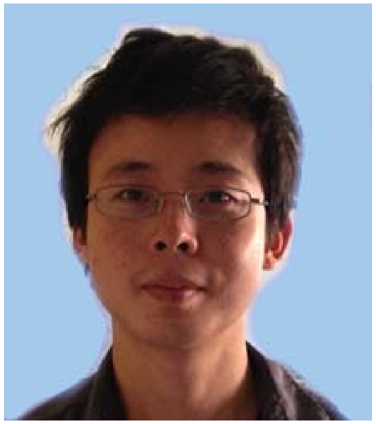
Thank you!

Stanford

J. Winawer
A. Mezer
M. Perry
K. Kay
J. Yeatman
B. Dougherty

Ariel
Rokem

Franco
Pestilli



Hiromasa
Takemura