

*Diffusion Spectrum Imaging:
a brief intro*

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DTI tractography - HBM Paris 1995

• Abstracts •

WHITE MATTER CONNECTIVITY EXPLORED BY MRI

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Introduction

Water diffusion assessed by MRI accurately portrays the local material anisotropy of living tissue. In the CNS, MRI of diffusion anisotropy can provide dramatic images of the orientation fields of cerebral white matter. In order to map neuroanatomic connectivity, we have investigated the feasibility of deducing from these orientation fields the large scale trajectories of cerebral white matter tracts.

were reconstructed as described below, and compared with known anatomy.

Putative white matter tracts were defined by numerical integration of the diffusion anisotropy tensor field. Two approaches were investigated. The first approach postulates fiber tracts parallel with the principal orientation of diffusivity at each location. Then fiber position $x^\alpha(\tau)$, $\alpha \in \{1,2,3\}$, will satisfy the first order differential equation:

$$dx^\alpha/d\tau \pm e_1(x) v_1^\alpha(x) = 0 \quad [1]$$

where e_1 denotes the maximal eigenvalue of the diffusion tensor and v_1^α is its respective eigenvector. The sign ambiguity of Eq. [1] is resolved by an arbitrary, but locally consistent, choice. The second approach considers the distance in tissue defined by the mean diffusion times between points. This distance defines a (non-Euclidean) geometry in which the role of a metric tensor is played by the negative of the diffusion tensor, and it is natural to postulate that fiber tracts are the minimal paths between points. Such paths satisfy the second order geodesic equation:

$$d^2x^\alpha/d\tau^2 + \Gamma^{\alpha}_{\mu\nu} (dx^\mu/d\tau)(dx^\nu/d\tau) = 0 \quad [2a]$$

with repeated indices summed, where Γ represents the connection coefficients of $\mathbf{D} = D_{\alpha\beta}$:

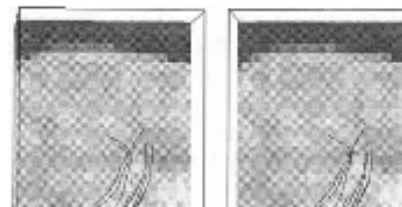
$$\Gamma^{\alpha}_{\mu\nu} = 1/2 (\mathbf{D}^{-1})^{\alpha\gamma} (\partial D_{\mu\beta}/\partial x^\gamma + \partial D_{\nu\beta}/\partial x^\mu + \partial D_{\mu\nu}/\partial x^\beta) \quad [2b]$$

Eq. [2] may be solved given an initial point x^α and an initial slope $dx^\alpha/d\tau$.

Results

Fiber tracts reconstructed via Eq. [1] were in good agreement with known anatomy. Fig 1 shows fibers of the left *corona radiata* tracked from diencephalon to cortical mantle; fiber data are superposed upon parasagittal magnitude MRI; right is rostral.

Solution of the geodesic Eq. [2a-2b] is less robust. In the



Wendell Krieg 1963 - human white matter by dissection

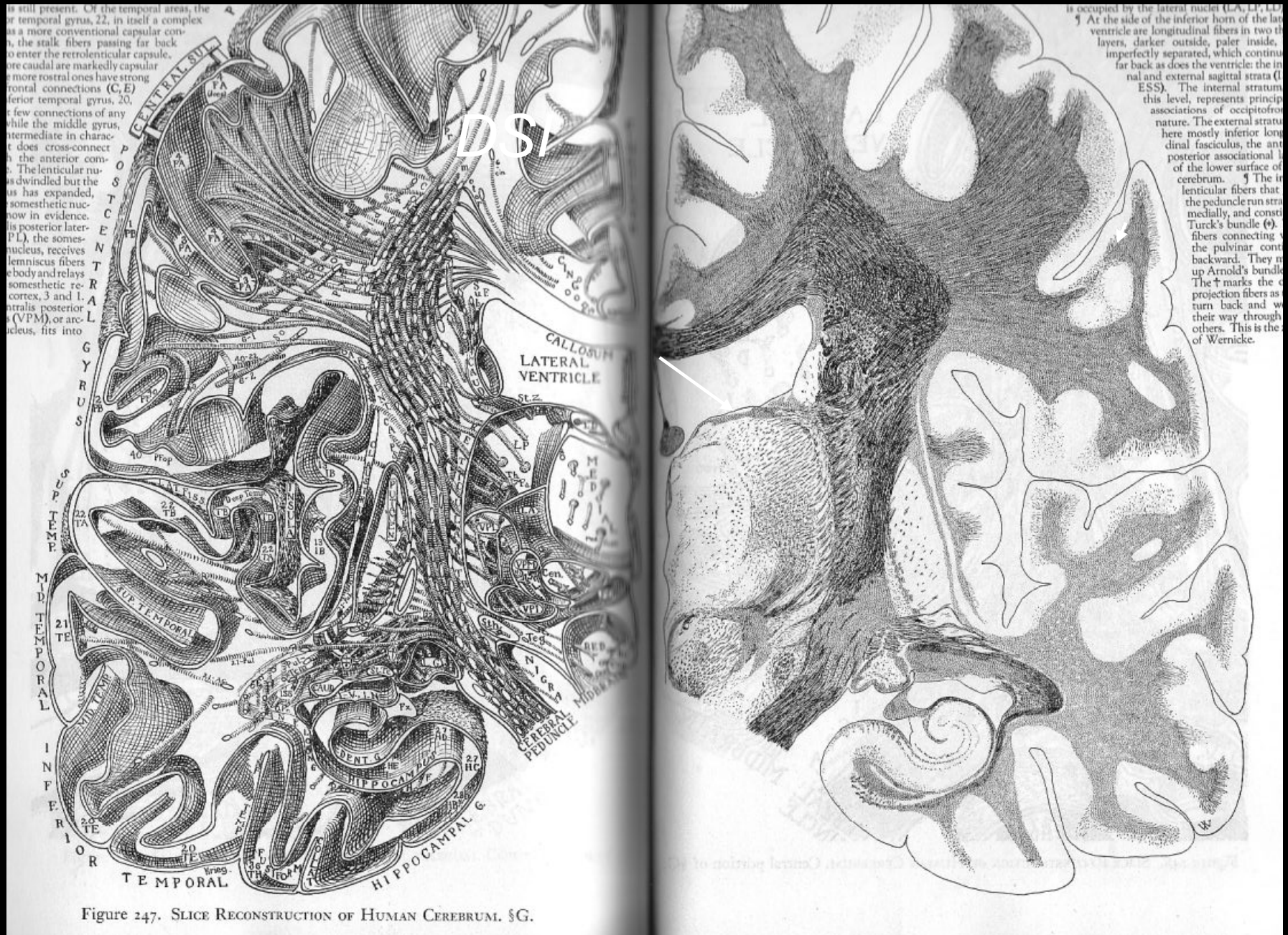
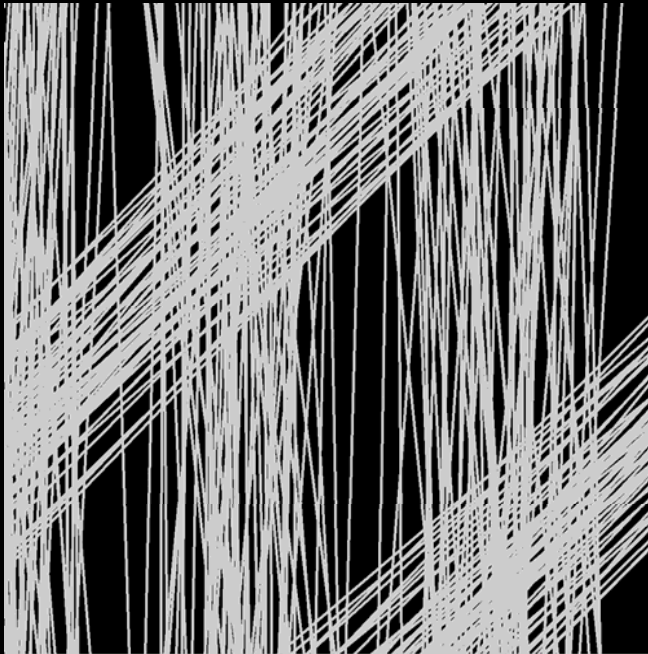


Figure 247. SLICE RECONSTRUCTION OF HUMAN CEREBRUM. S.G.

Diffusion MRI - tissue structure is traced by 3D patterns of water diffusion

1994: diffusion tensors show average fiber directions

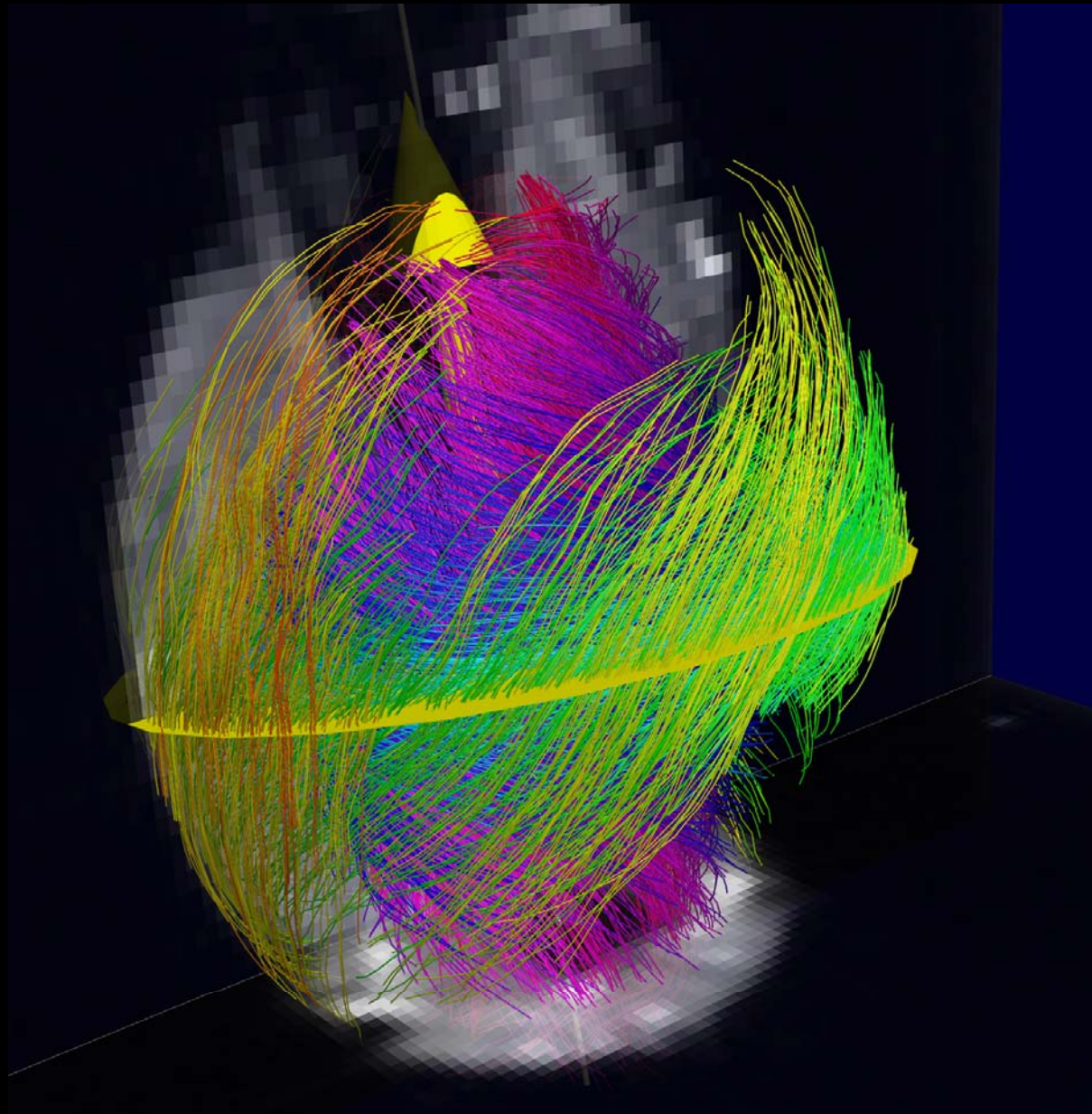
tissue



diffusion tensor



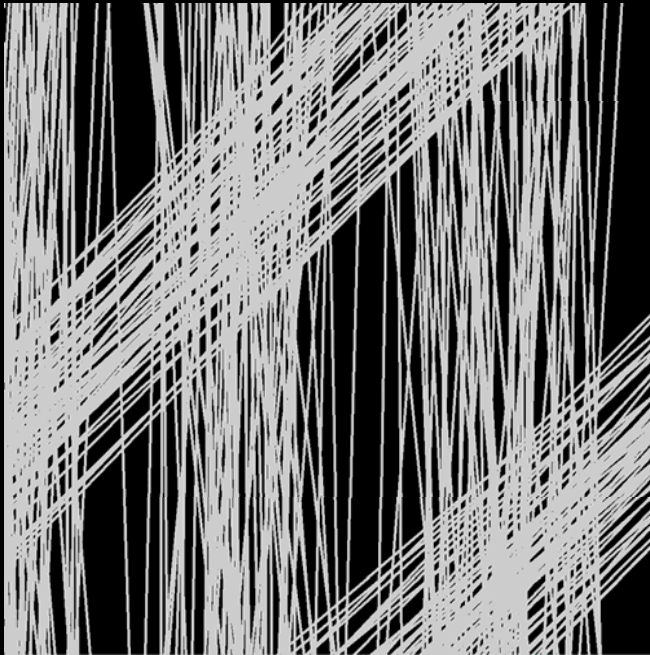
DTI tracography of the myocardium



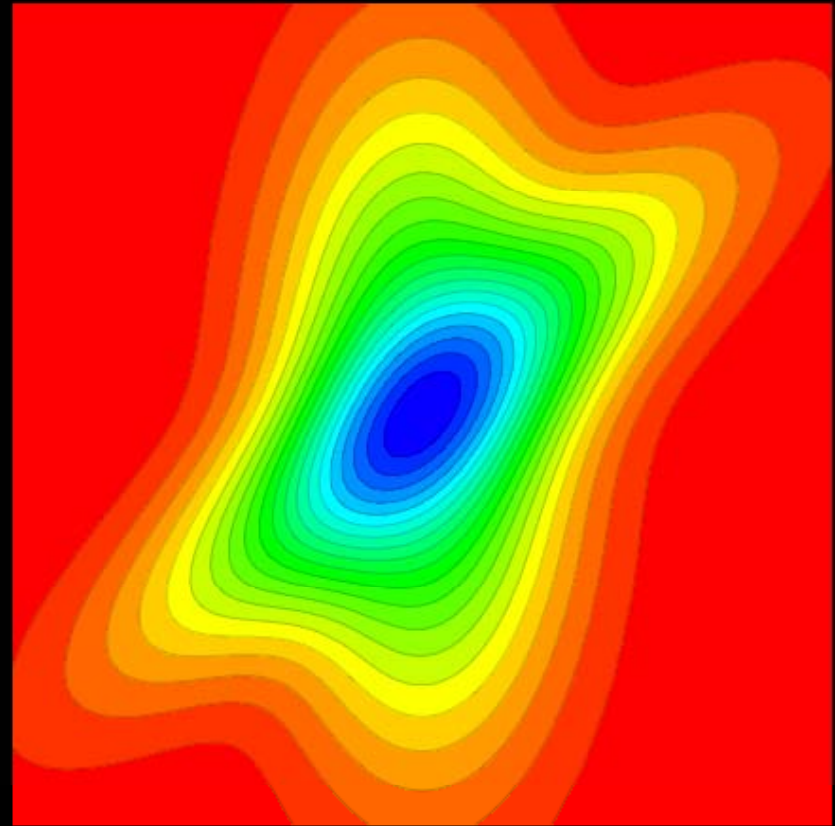
Water diffusion traces tissue fiber structure

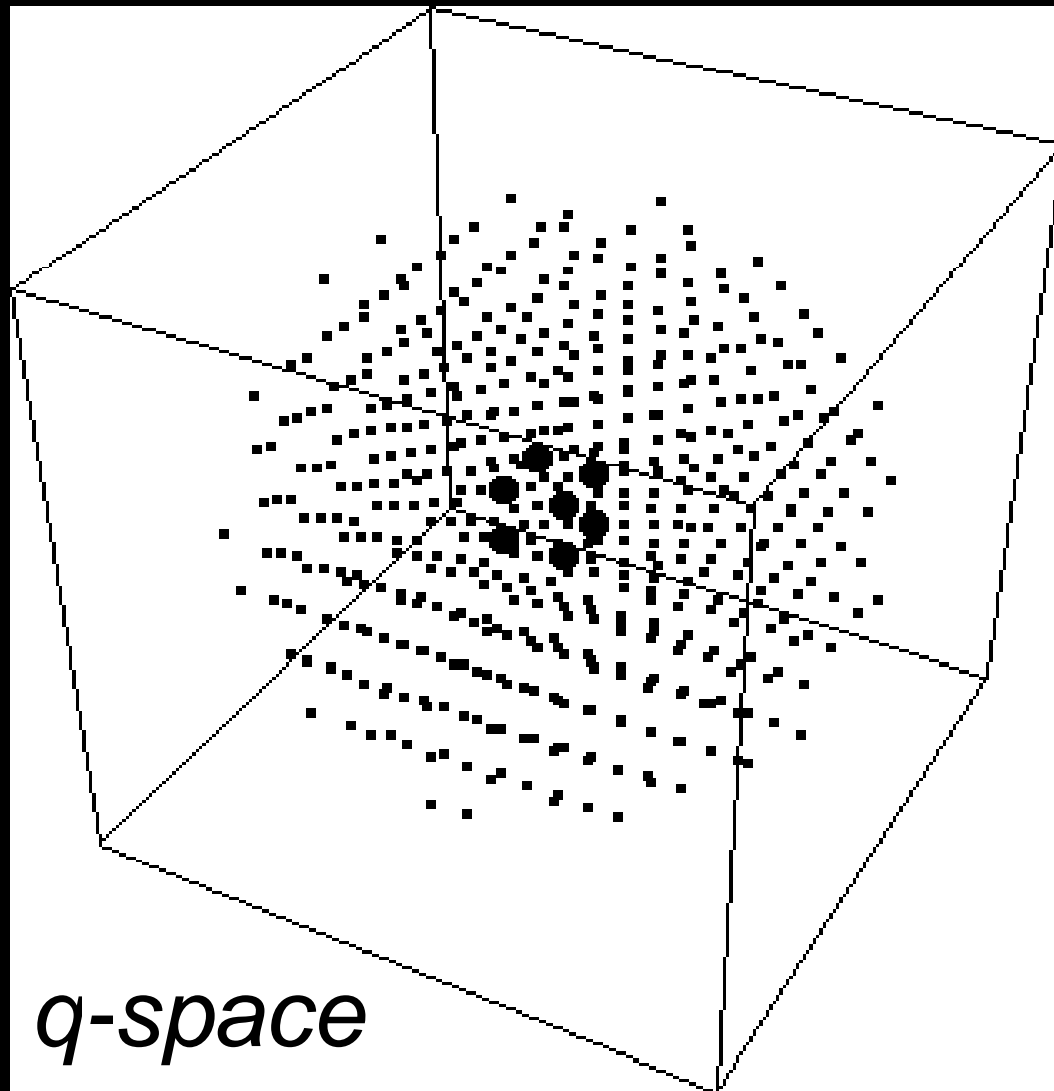
2000: diffusion spectrum MRI (DSI) resolves the crossings

brain tissue



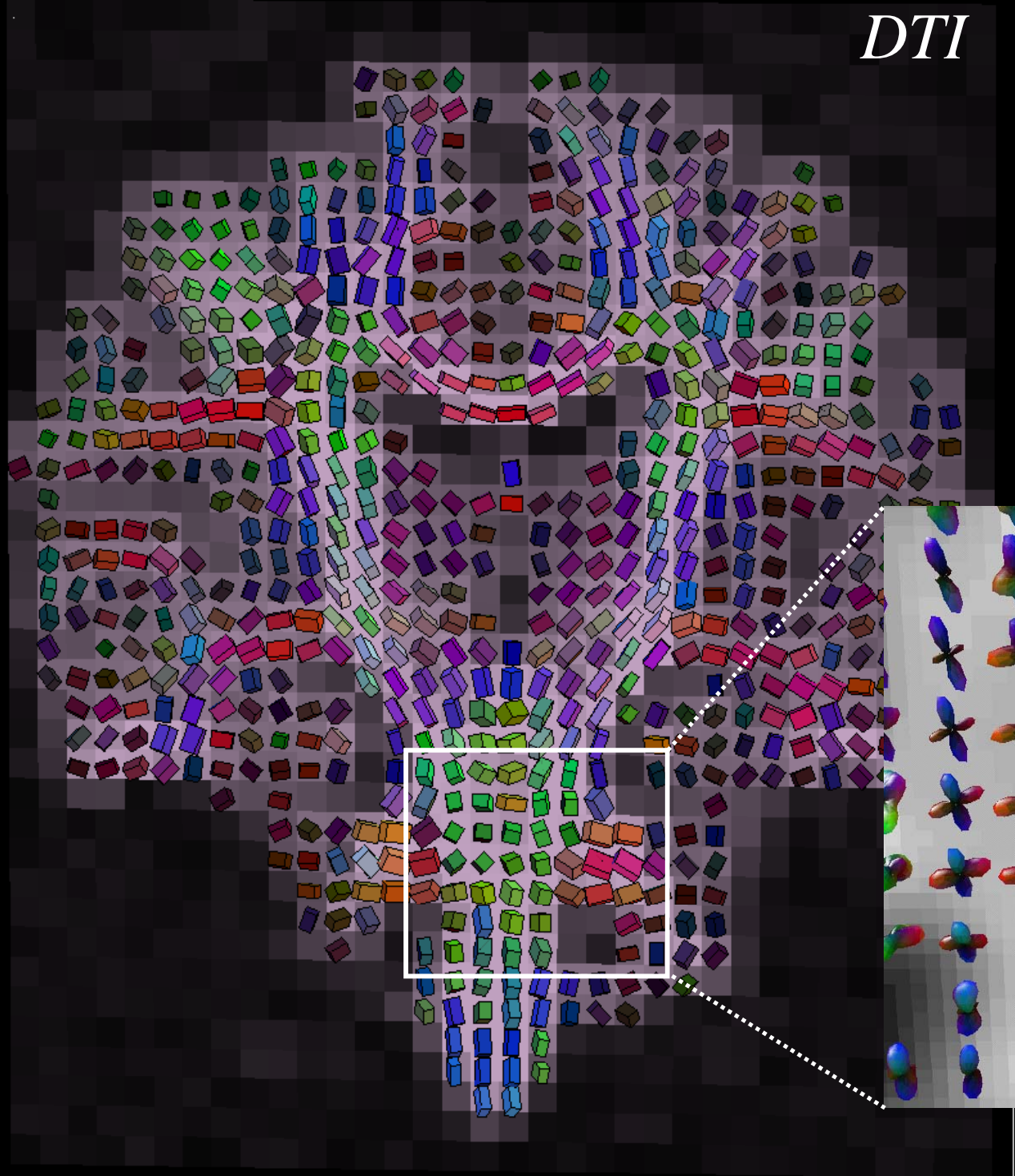
diffusion spectrum



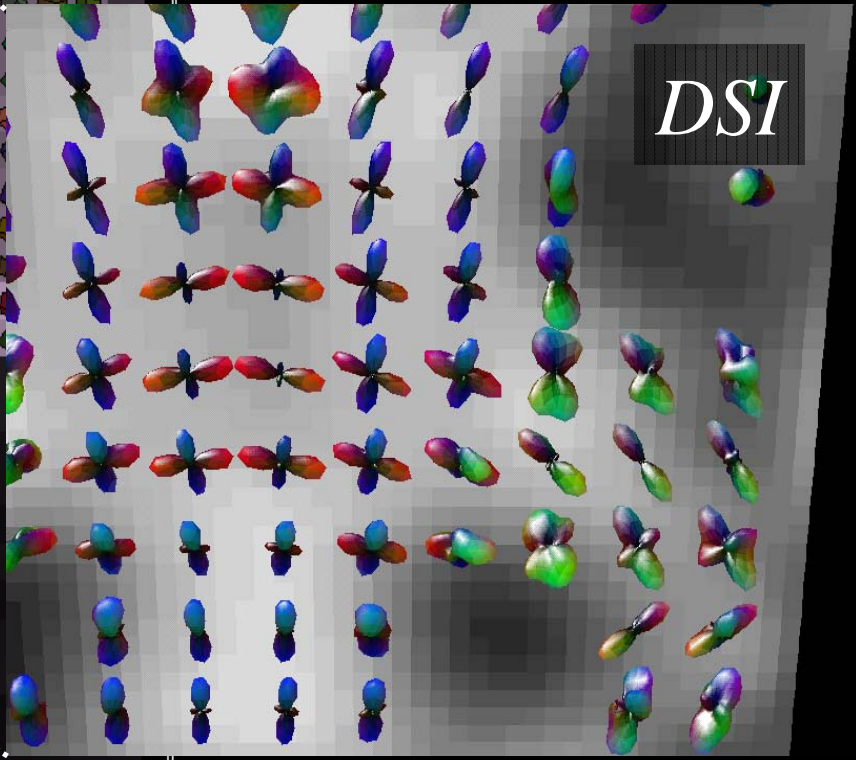


DTI: 7 q -samples, recon with tensor fit
DSI: 500 q -samples, recon with 3DFT

DTI

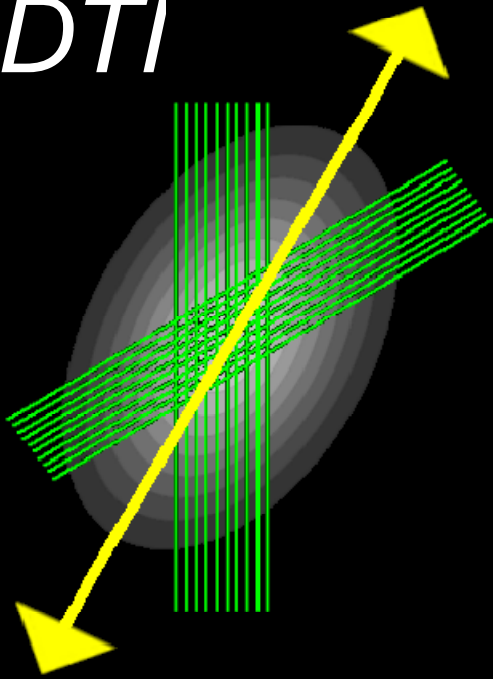


DSI



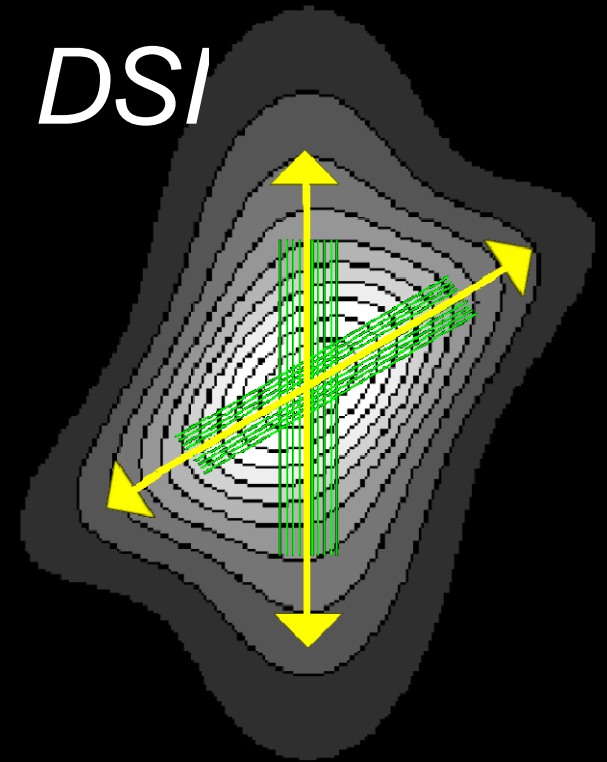
Why DSI not DTI?

DTI

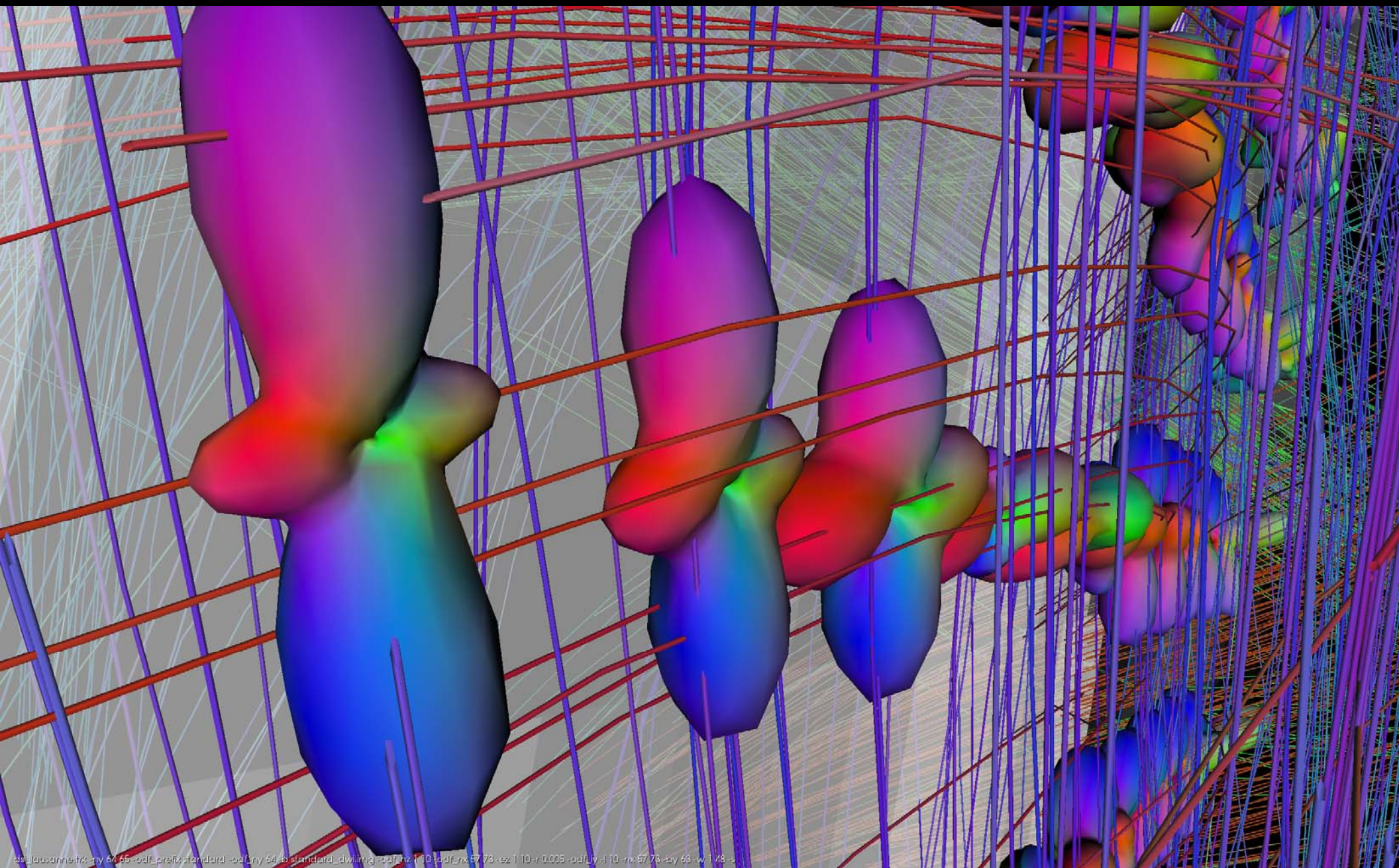


fibers
diffusion observed
tractography

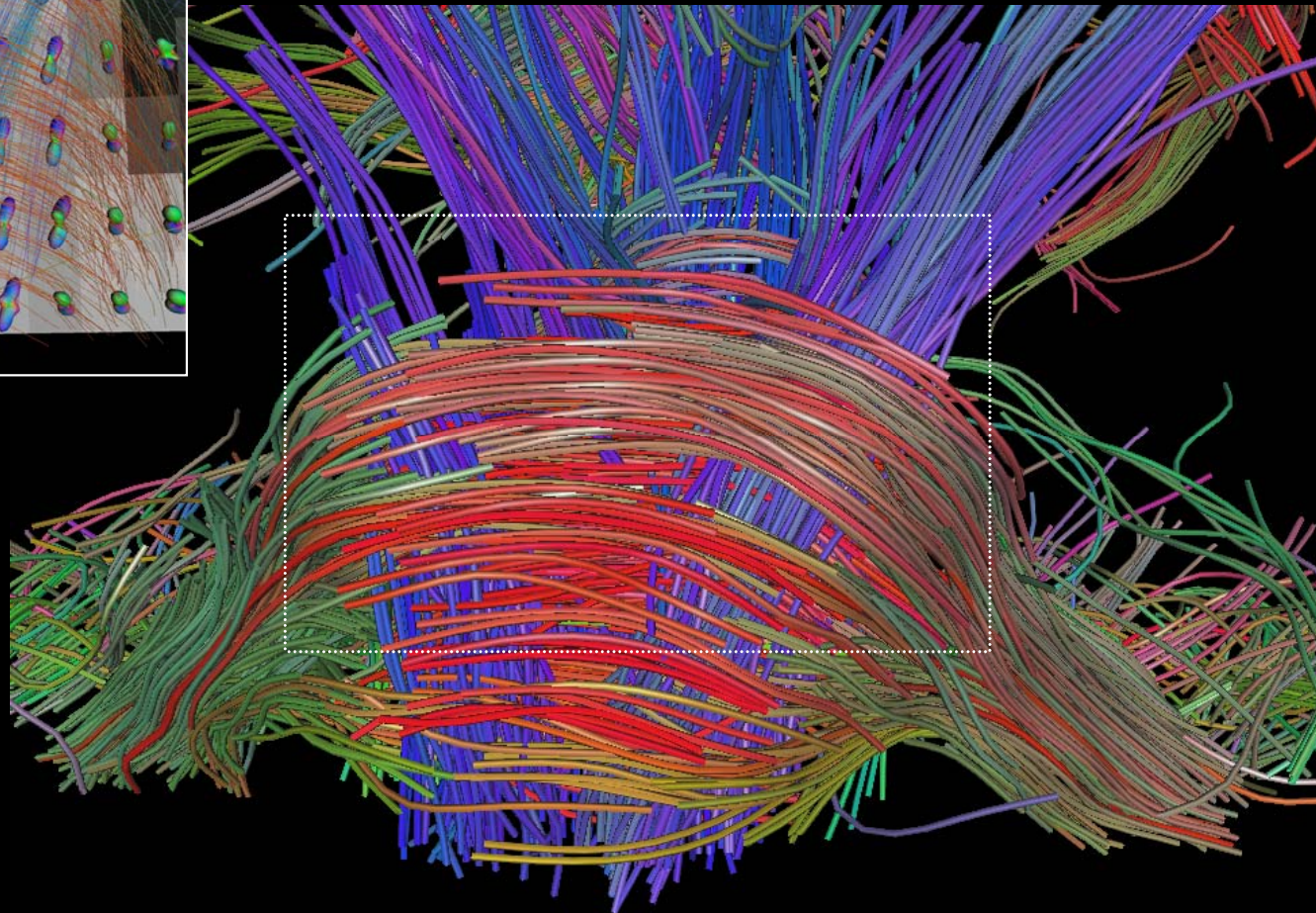
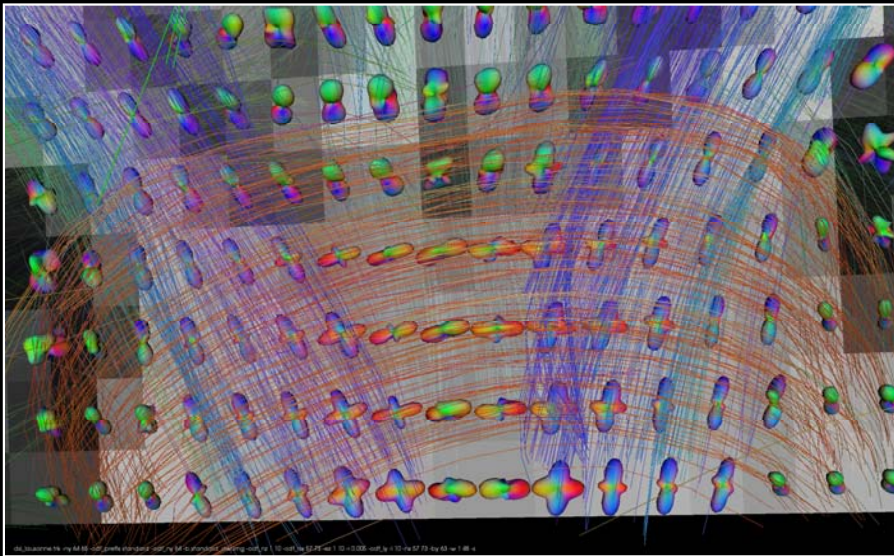
DSI



ODFs and tracks, human pons in vivo 3T

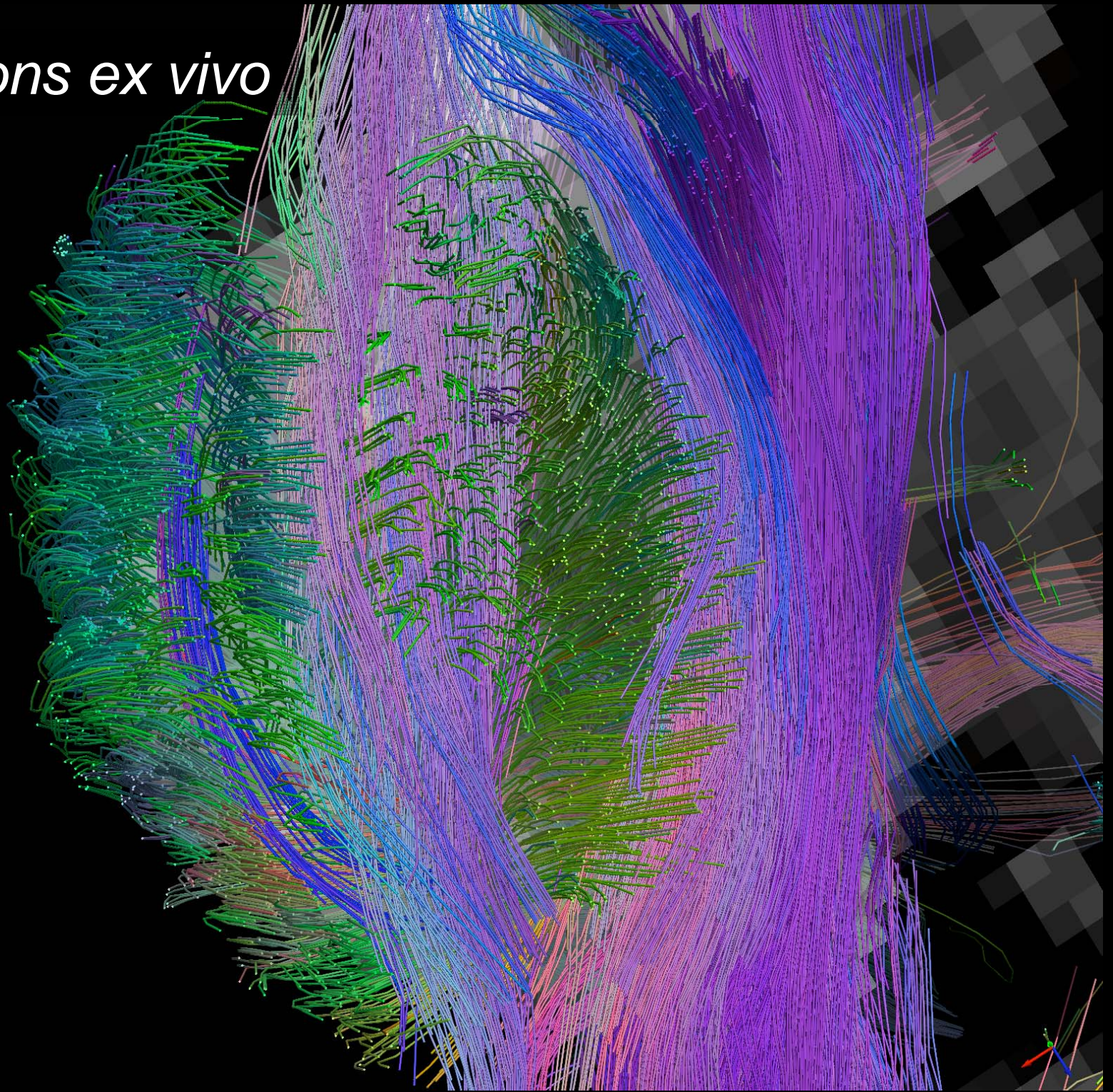


*DSI tractography - Pons normal human subject in vivo
middle cerebellar peduncle - red
corticospinal tract - blue*



3T DSI SE 3500/96
2.6mm b_{max} 8500 53min

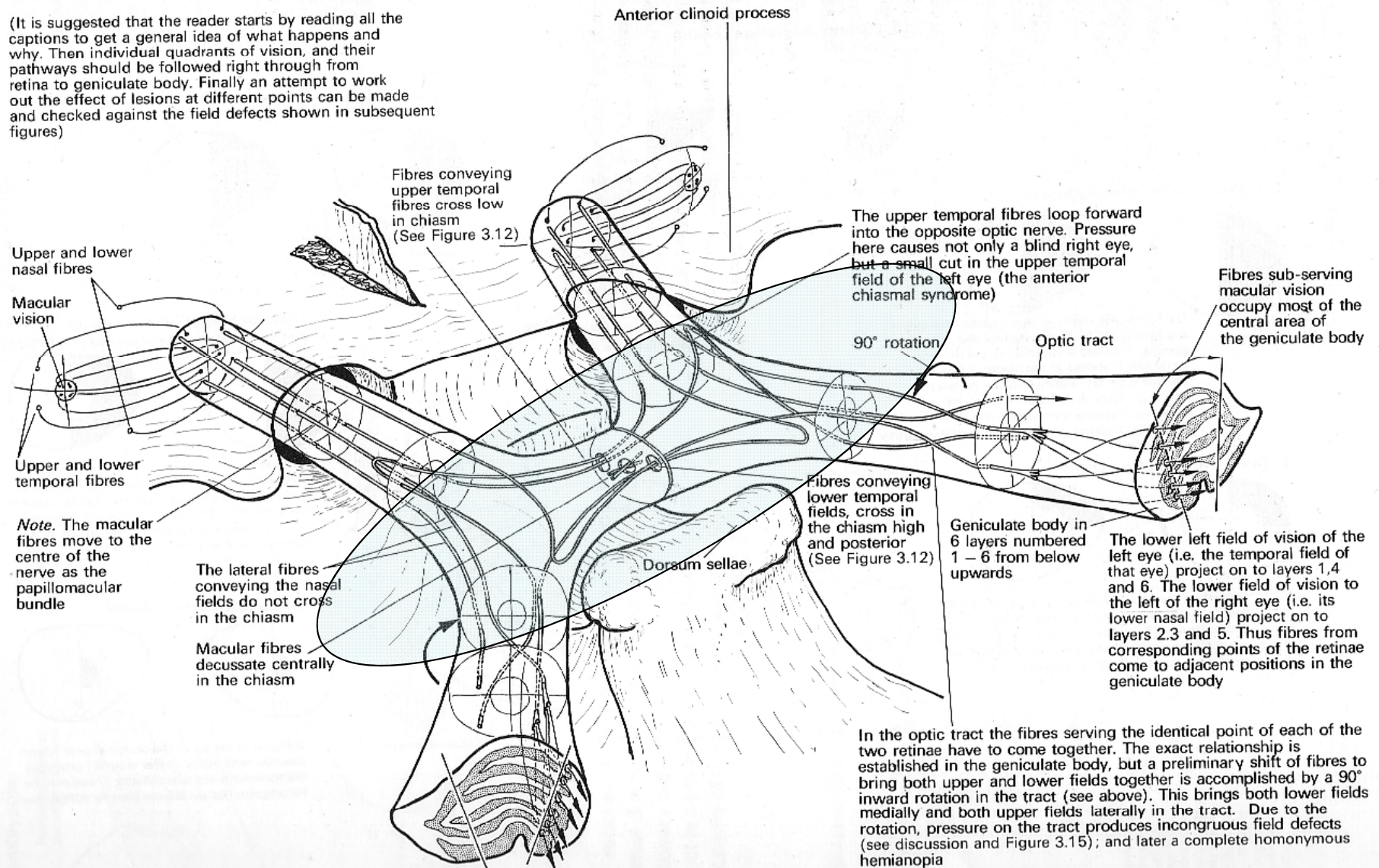
Human pons ex vivo



Optic chiasm

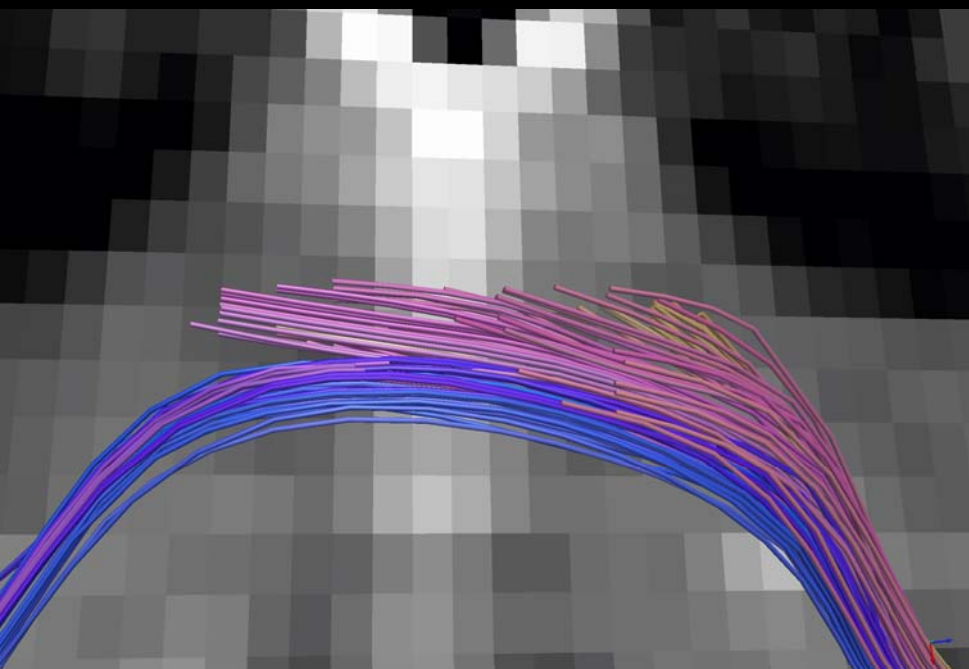
Figure 3.6. The Functional Anatomy of the Optic Nerves, Chiasm and Tracts to the Geniculate Body

(It is suggested that the reader starts by reading all the captions to get a general idea of what happens and why. Then individual quadrants of vision, and their pathways should be followed right through from retina to geniculate body. Finally an attempt to work out the effect of lesions at different points can be made and checked against the field defects shown in subsequent figures)

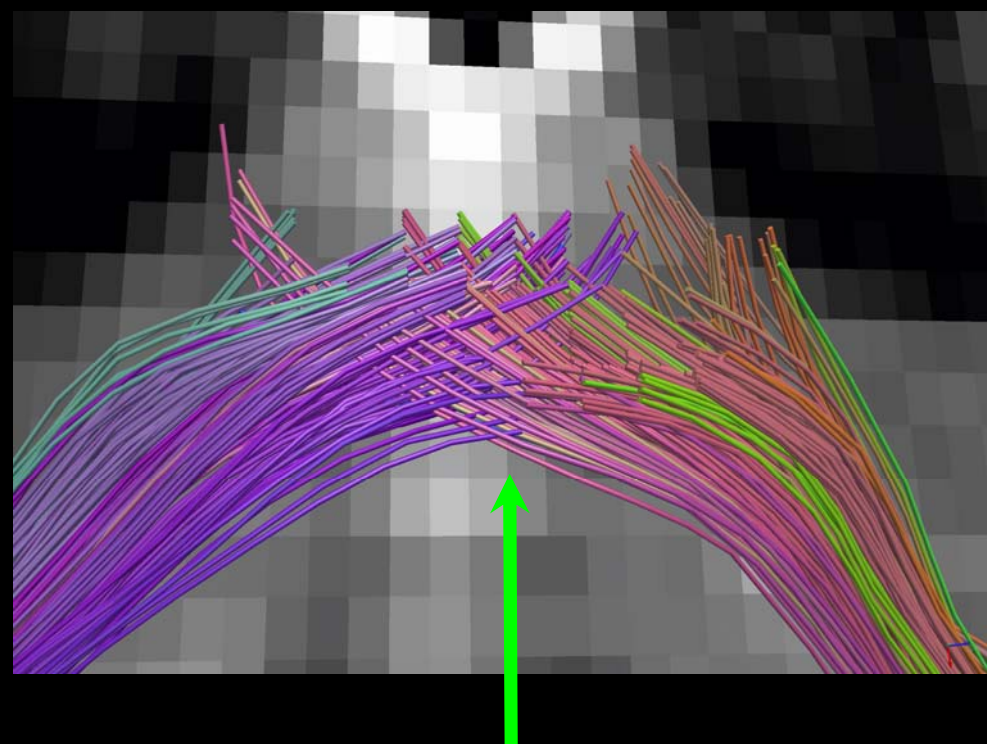


Optic chiasm

DTI



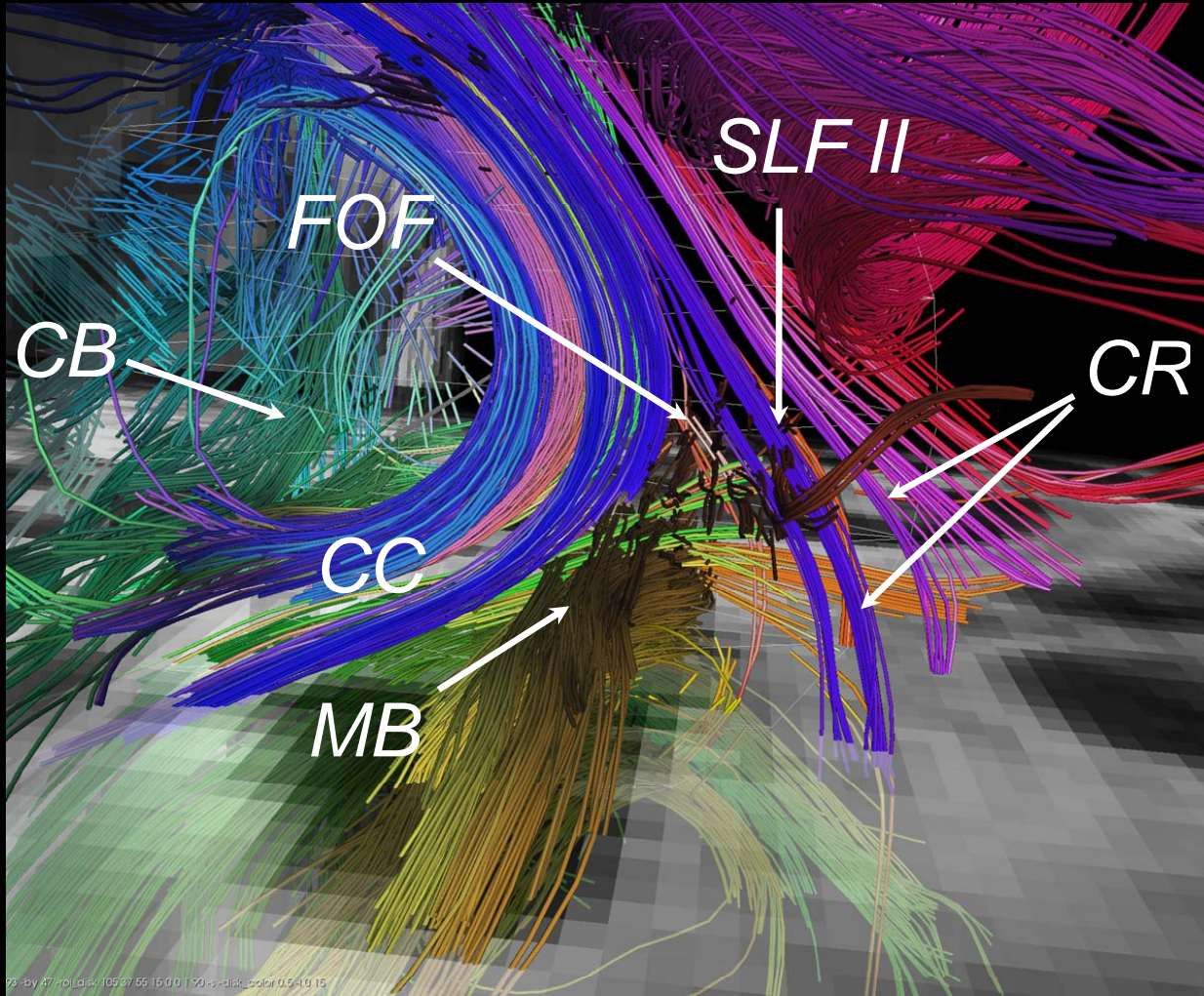
DSI



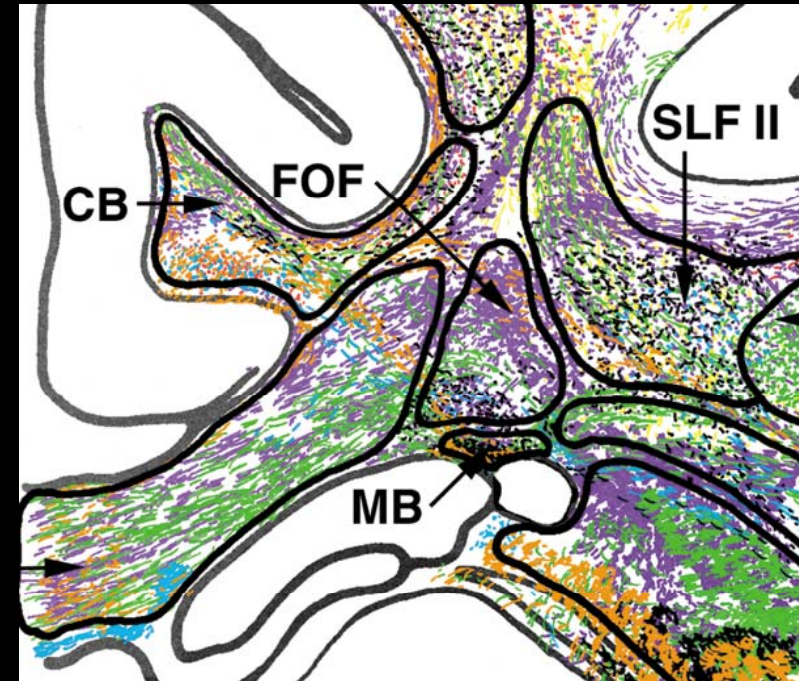
crossing

Macaque DSI and isotope gold standard

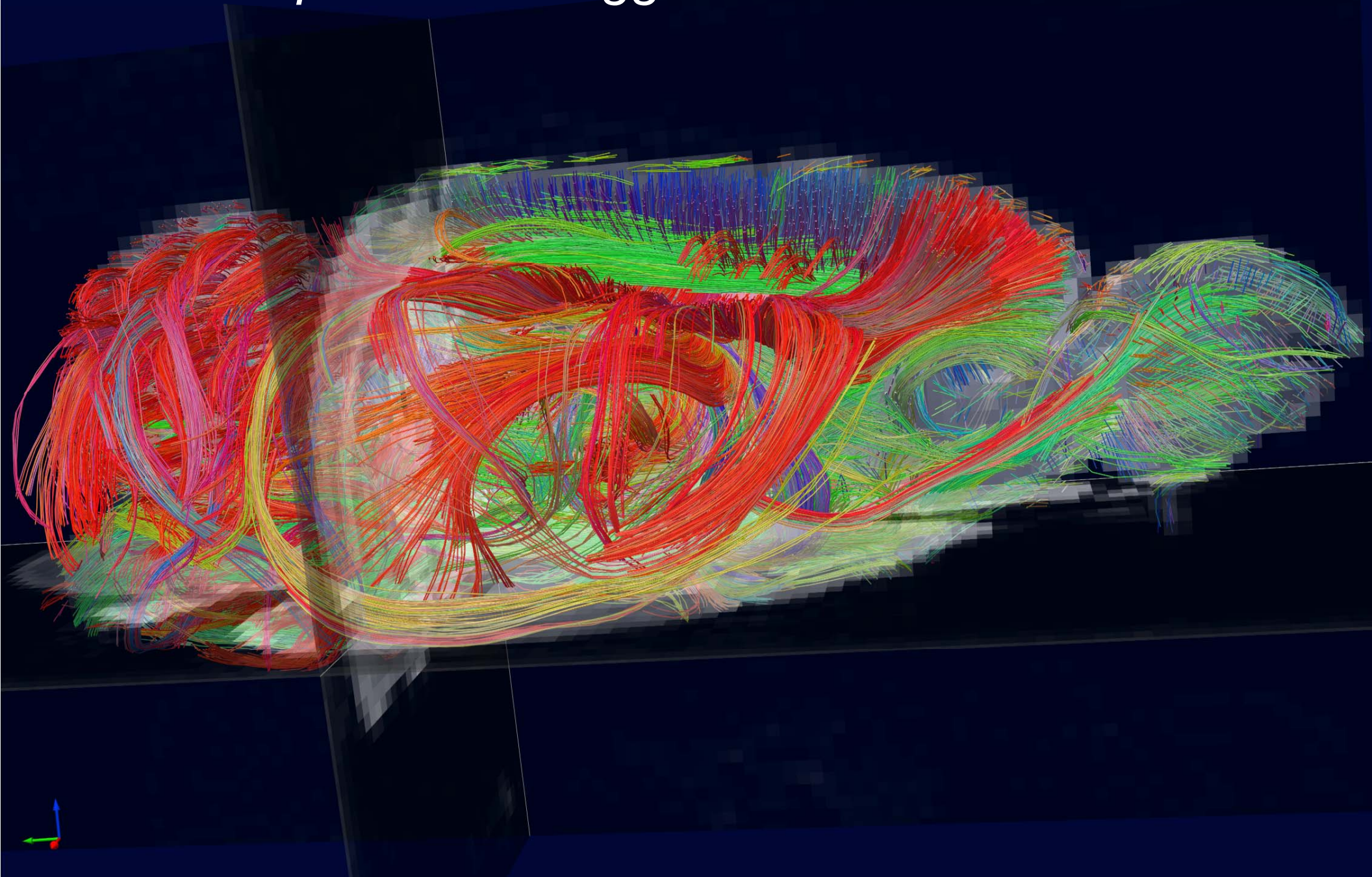
Muratoff bundle in context



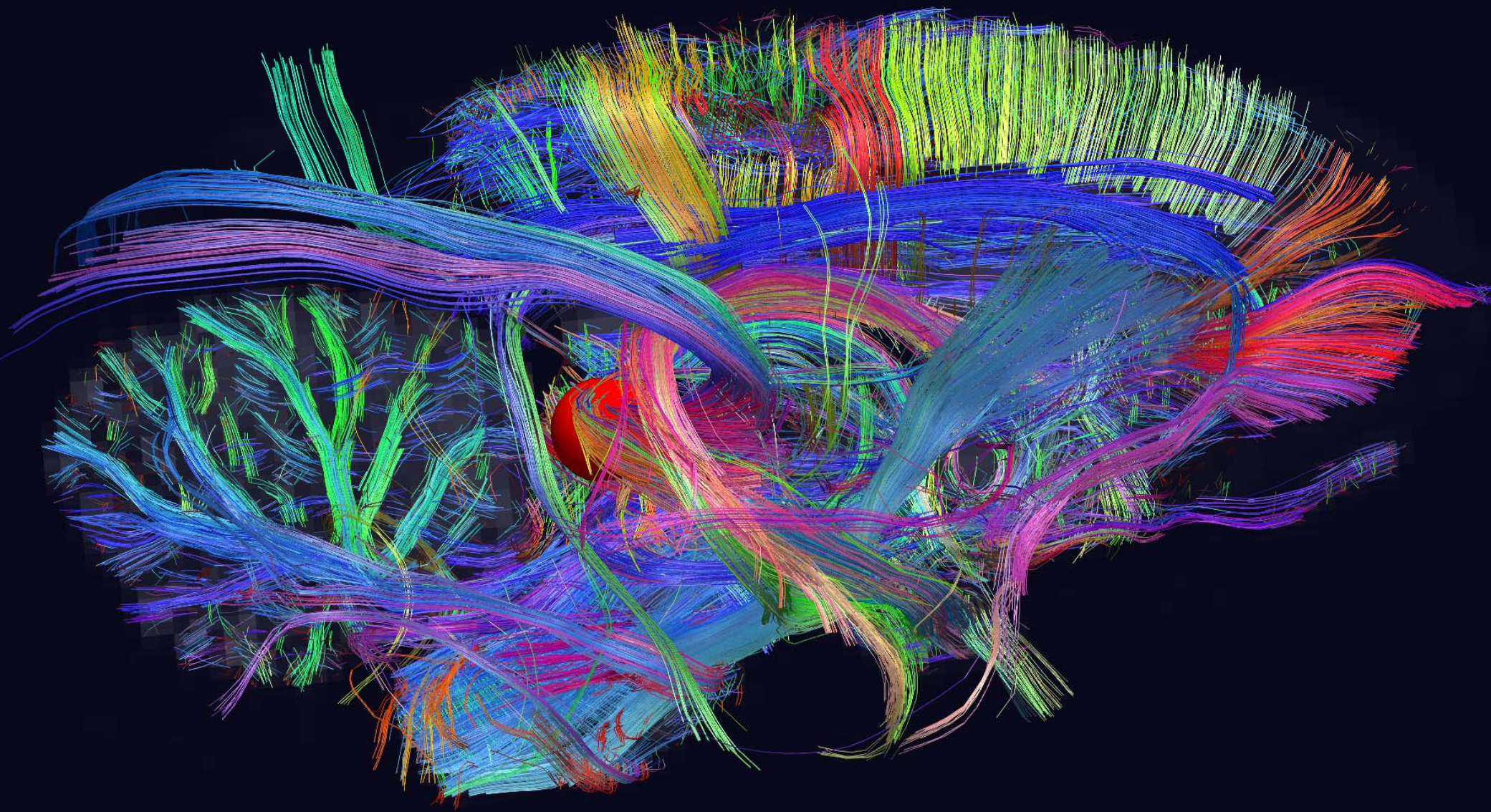
Pandya & Schmahmann



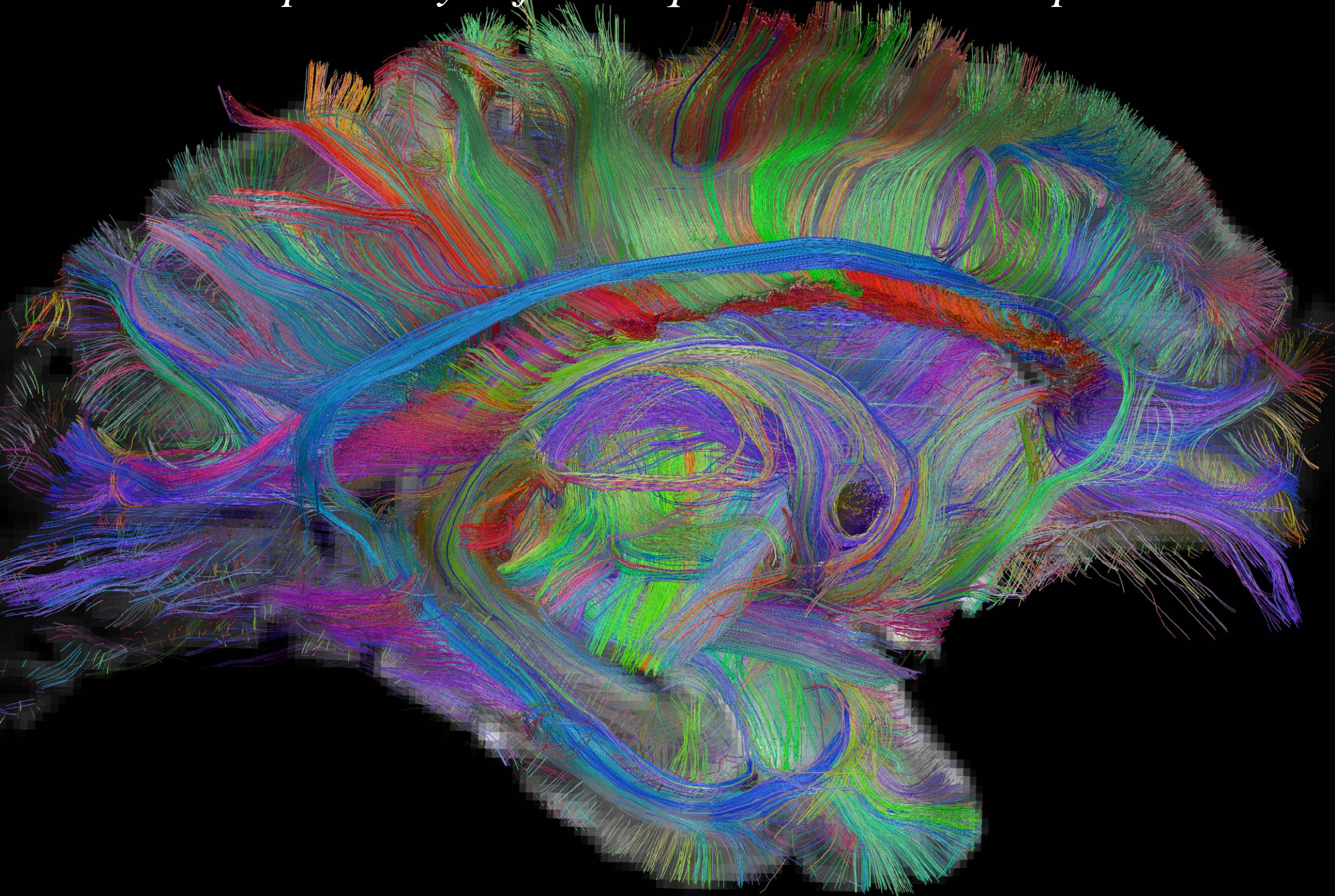
Rat DSI paths of a sagittal slice



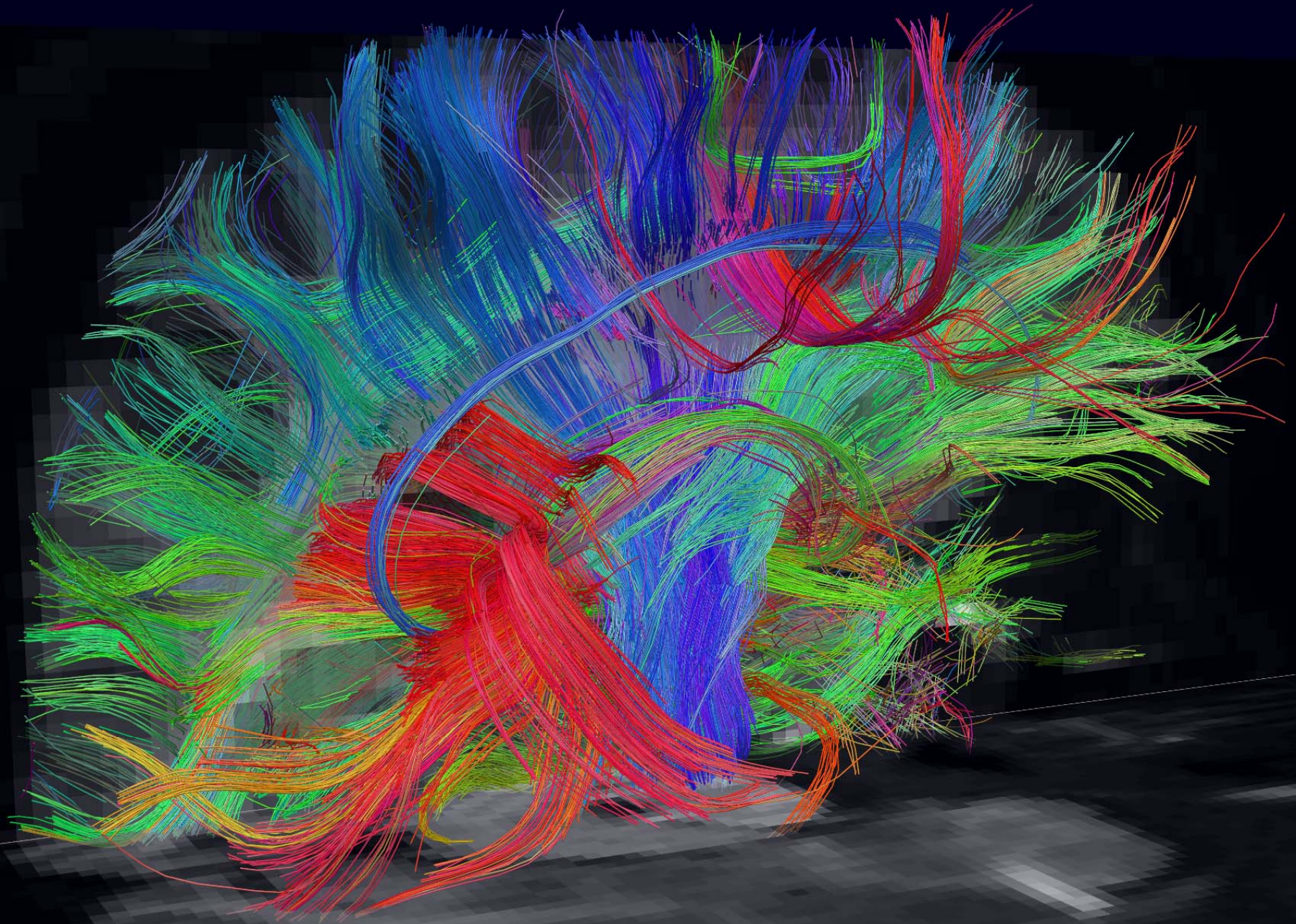
Owl monkey DSI - 3D paths of 1 slice



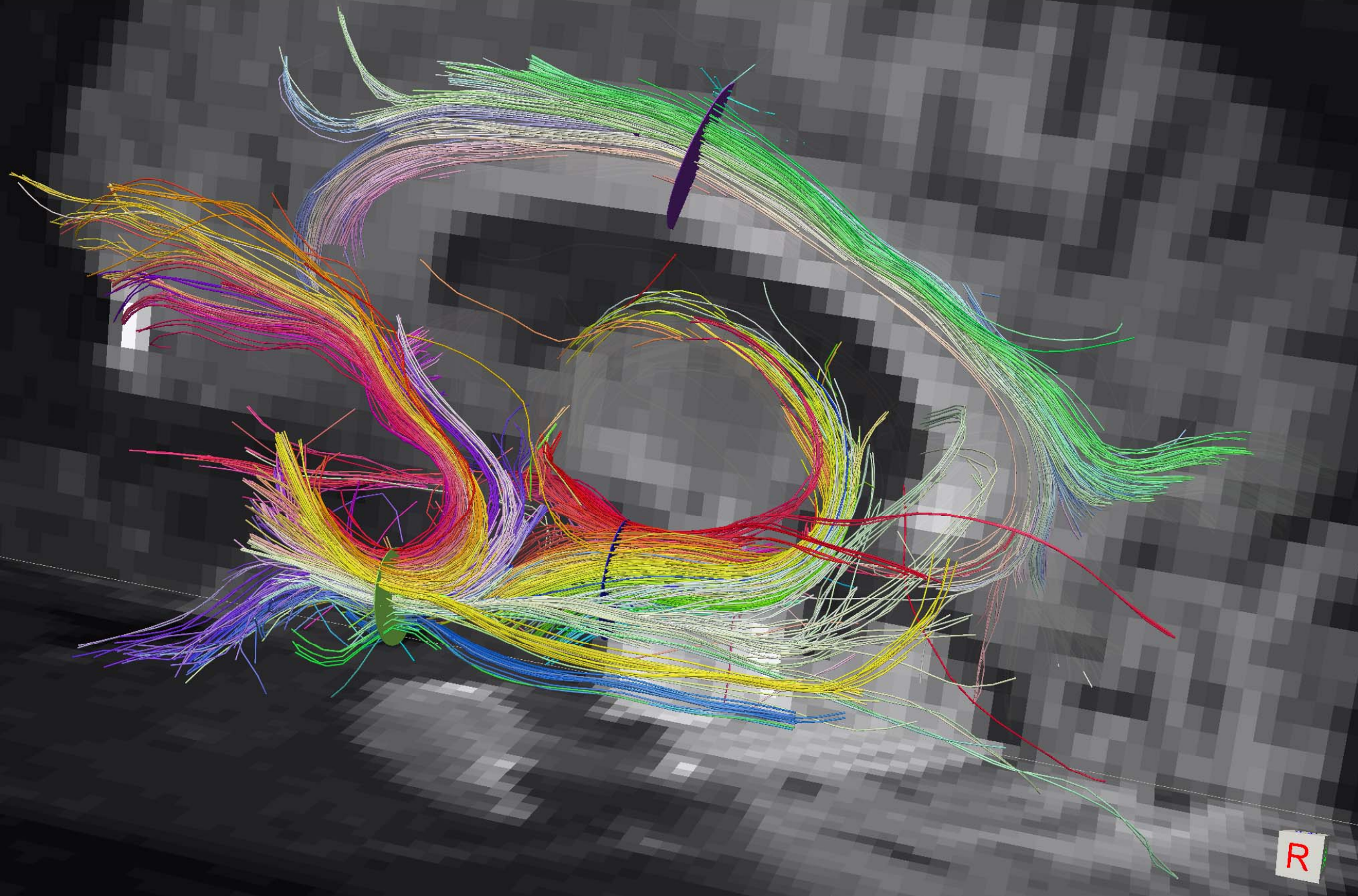
DSI pathways of macaque cerebral hemisphere



DSI human in vivo 3T

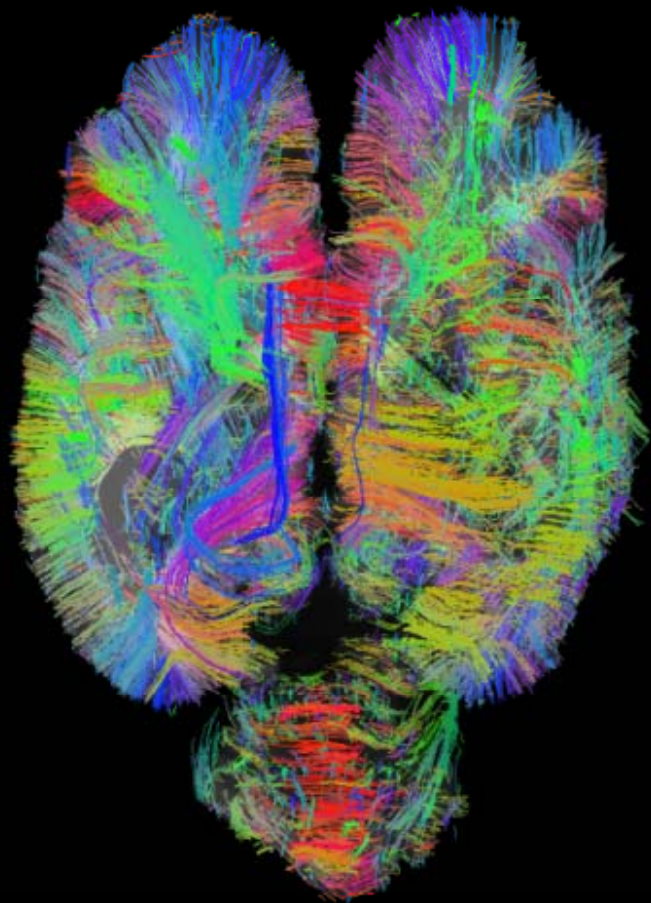


Human limbic circuit elements - CIND UCSF VA



Cat DSI

birth



day 100



Principles of organization common to all cortical areas

Association fibers

Local

Neighborhood

Long

Cord

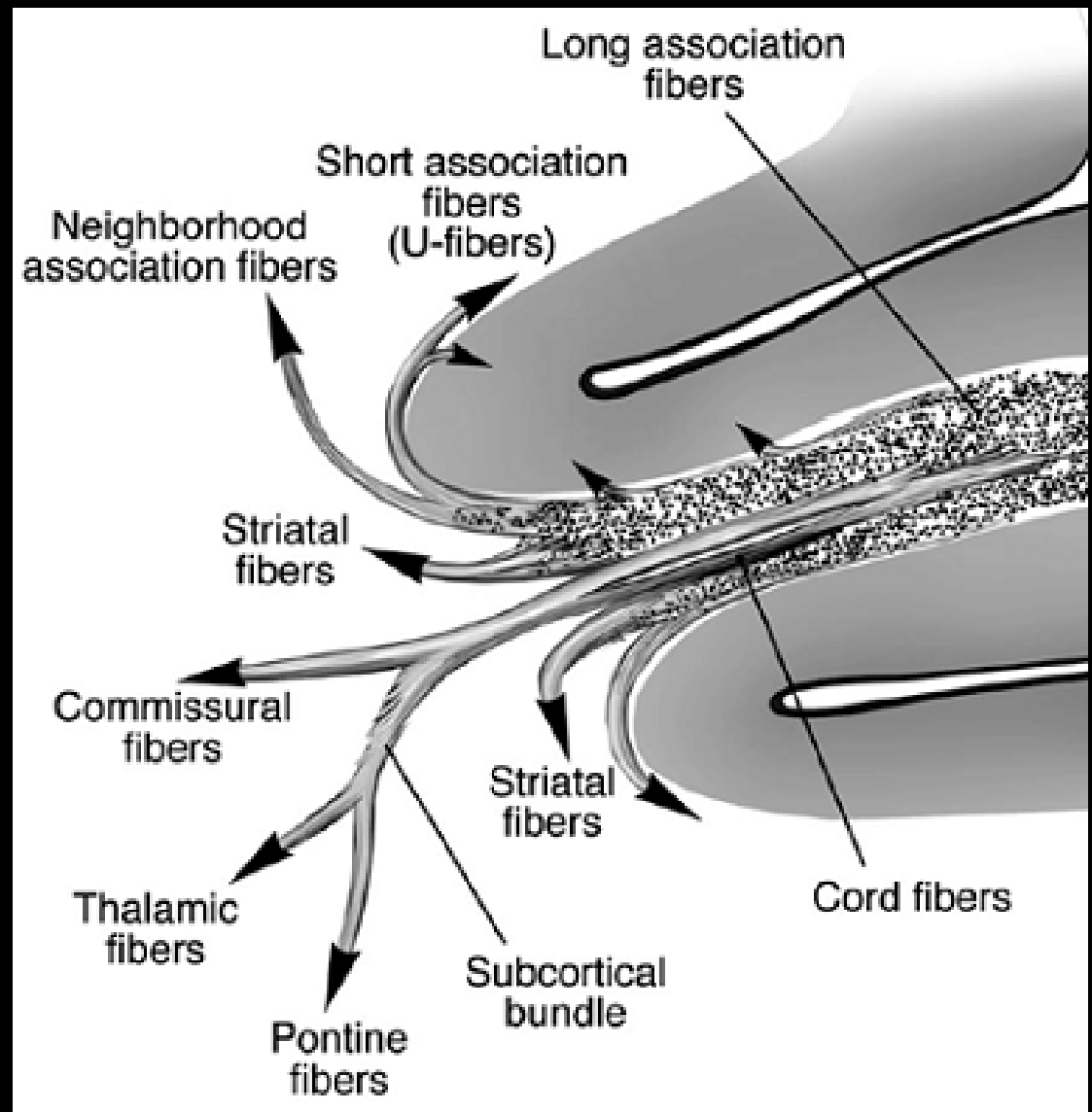
Commissural fibers

Subcortical bundle

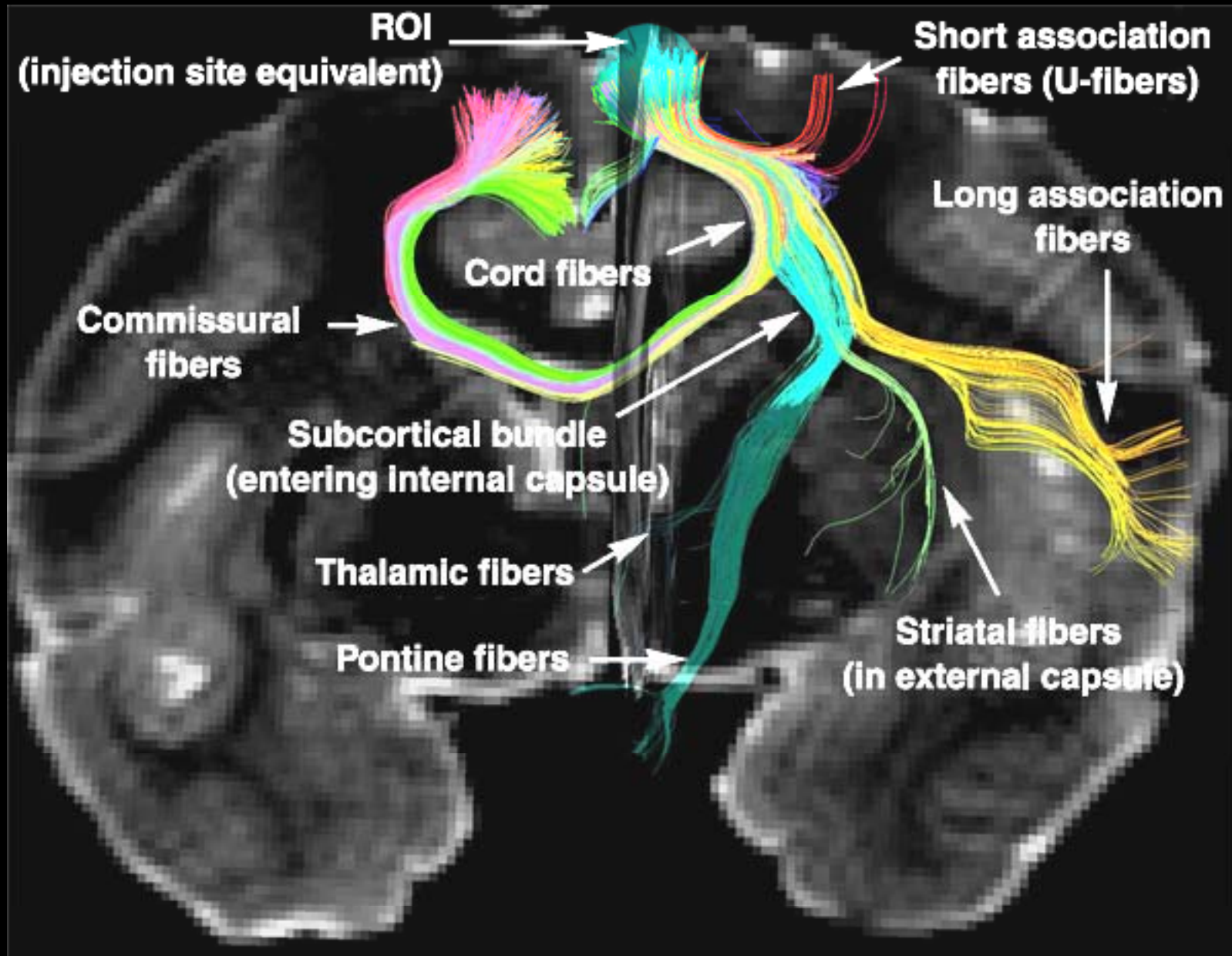
Striatal fibers

Muratoff bundle

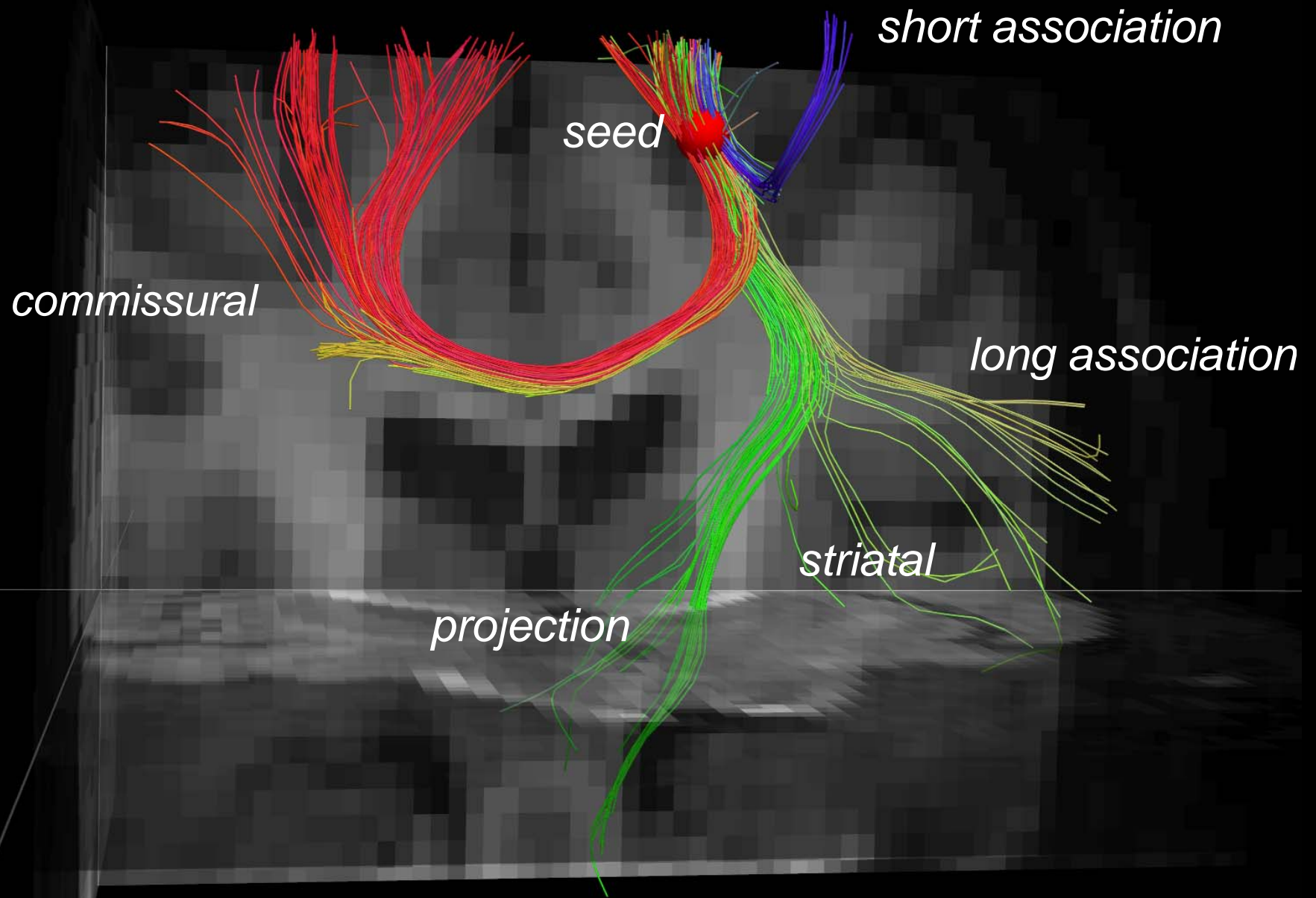
External capsule



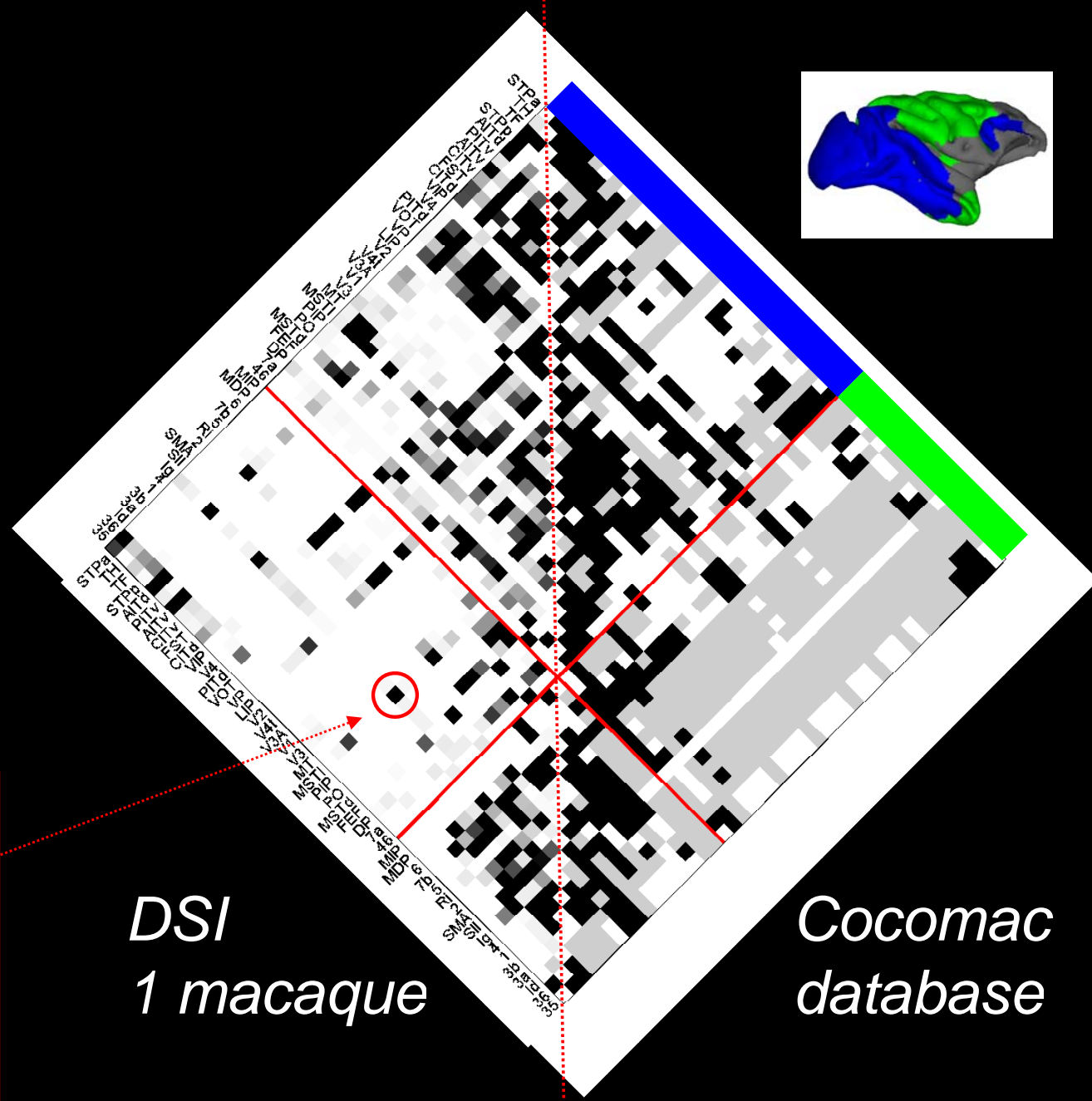
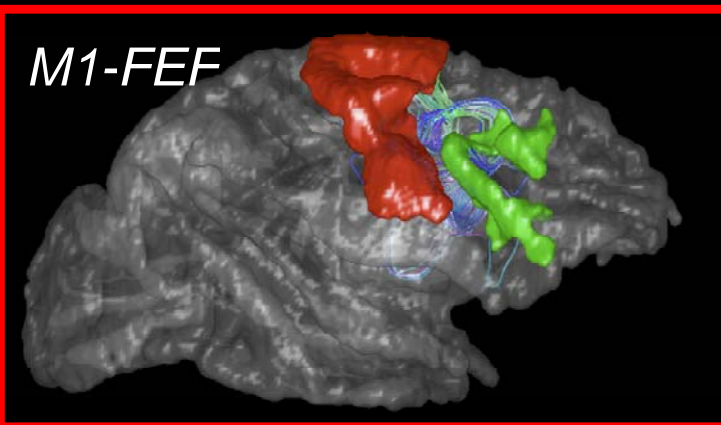
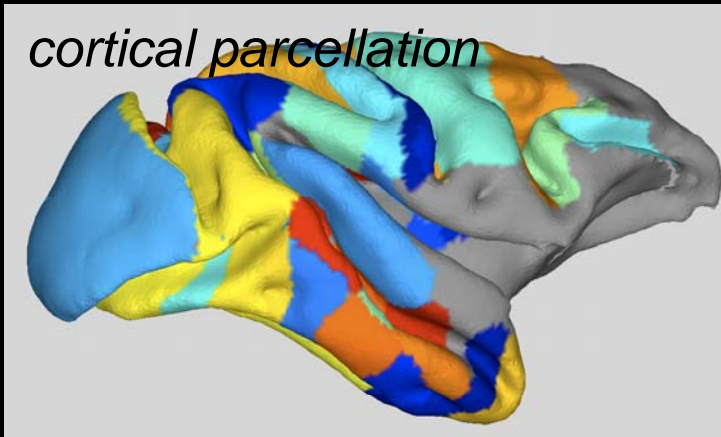
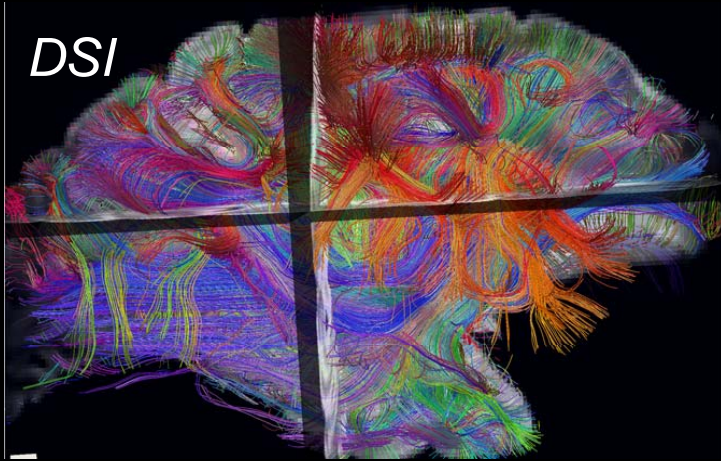
Connectional neuroanatomy with diffusion spectrum imaging



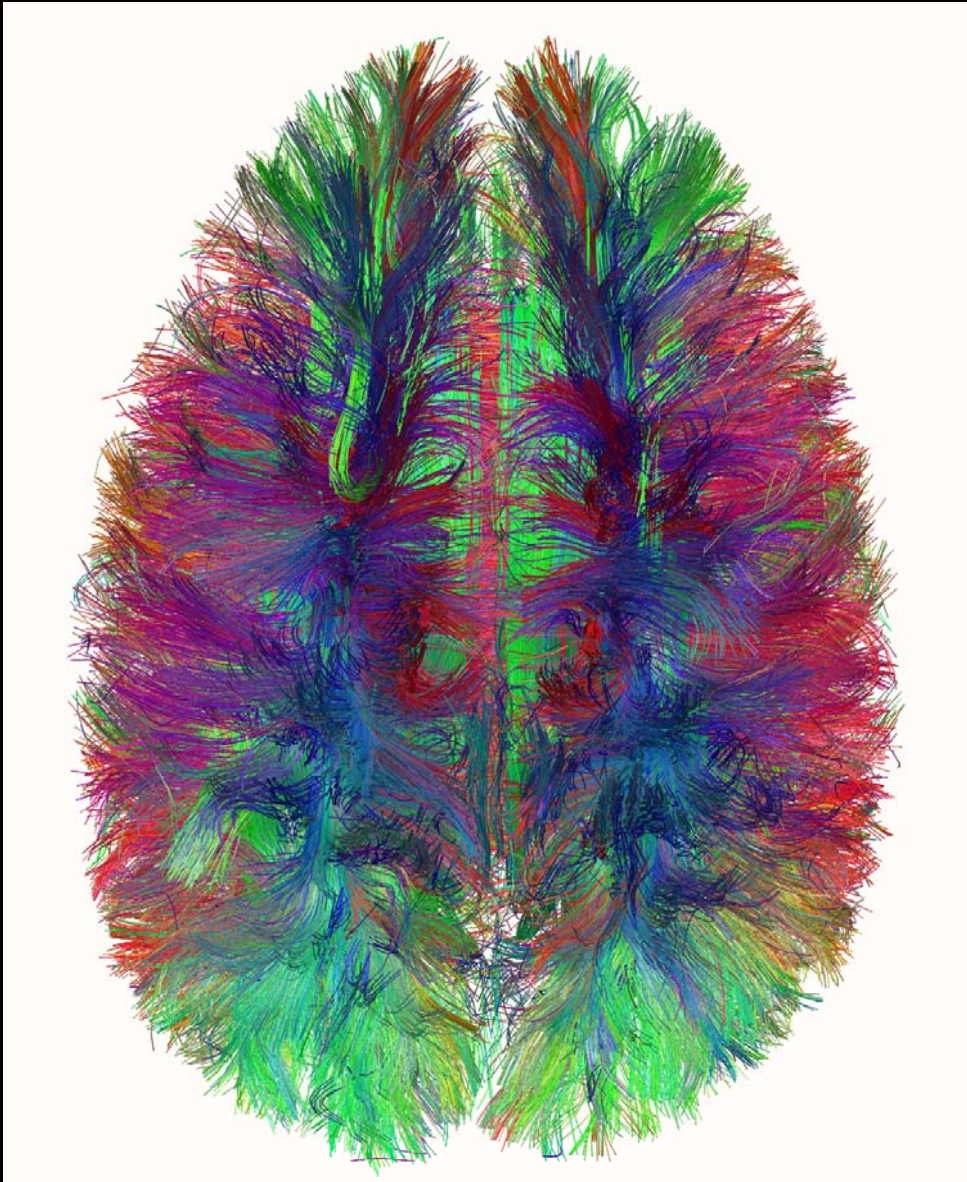
Connectivity of human superior frontal gyrus



Connectivity matrices



DSI in vivo human



human connectome

