



ヒトの脳の拡散MRI解析

# Diffusion MRI Analysis of the Human Brain

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Harvard Medical School

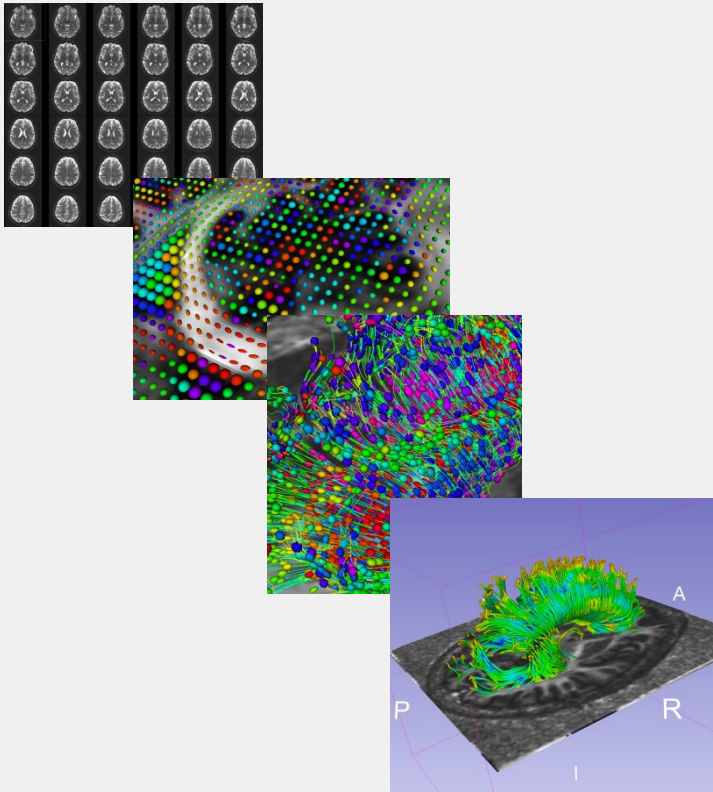
ハーバード大医学部

概要

# Tutorial Outline

This tutorial is an introduction to the fundamentals of Diffusion MRI analysis, from computation of DTI data to 3D visualization of fiber tracts.

fundamentals : 基礎  
computation : 計算  
visualization : 可視化  
fiber tracts : 腦白質線維束



# Tutorial Outline

- Part 1: Basics of Diffusion MRI mapping of white matter pathways  
mapping: 地図 (= 画像) の作成  
white matter pathways: 白質 (の線維神経) 路
- Part 2: Hands-on Diffusion MRI analysis using 3D Slicer  
3D Slicer : ソフトウェアの名前

# Learning Objectives

Following this tutorial, you will be able to

- 1) Compute a **diffusion tensor imaging (DTI)** volume from a diffusion weighted MRI scan
- 2) Understand the **shape of the diffusion tensor ellipsoid** in different regions of the brain
- 3) Reconstruct the **3D trajectory of white matter tracts** from DTI data

diffusion tensor : 拡散テンソル

ellipsoid : 楕円体

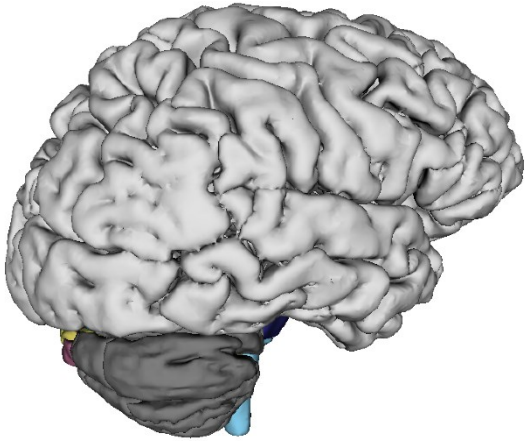
Trajectory : 軌跡

white matter tracts : (脳)白質神経束

# Tutorial Outline

- **Part 1: Basics of Diffusion MRI mapping of white matter pathways**
- Part 2: Hands-on Diffusion MRI analysis using 3D Slicer

# Human Brain



The human brain weighs between 1,300 and 1,400 g and contains **100, 000,000, 000 (100 billions)** neurons.

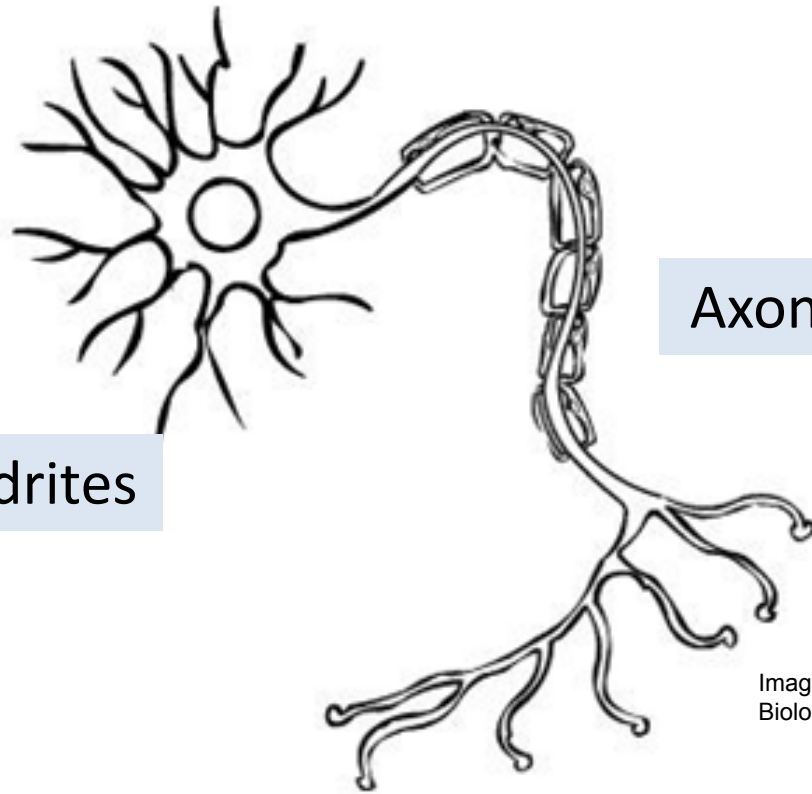
ニューロン: 神経細胞

神經細胞

# Neuron

細胞体

Cell  
Body



Dendrites

樹状突起

Axon

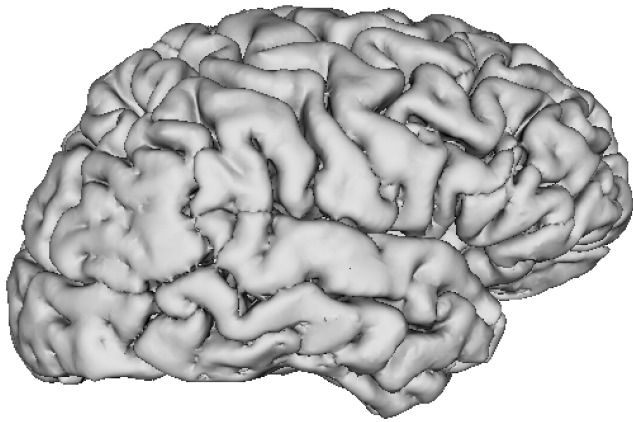
軸索

Axons terminals

軸索終端

Image source: BSC1007C Introductory  
Biology, State College of Florida

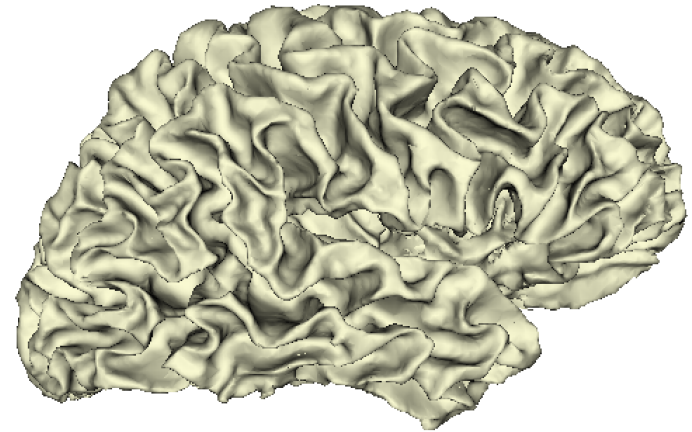
# Human Brain



灰白質

**Grey Matter**

**(neuron cell bodies)**



白質

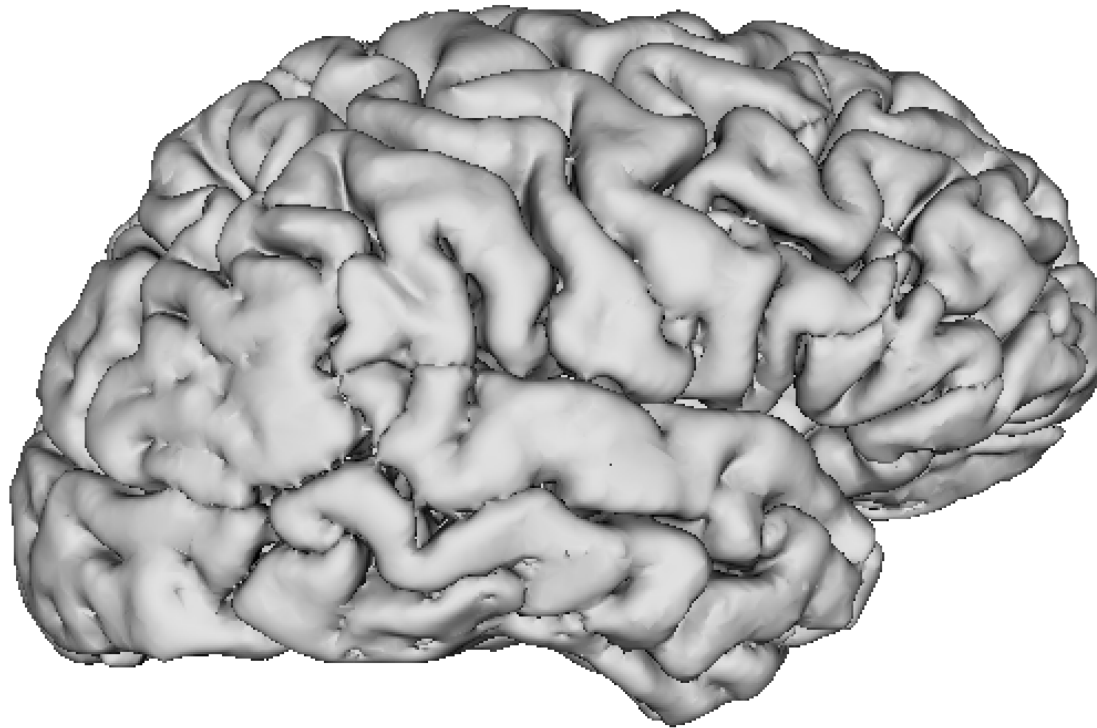
**White Matter**

**(neurons axons)**



大脳皮質

# Cerebral Cortex

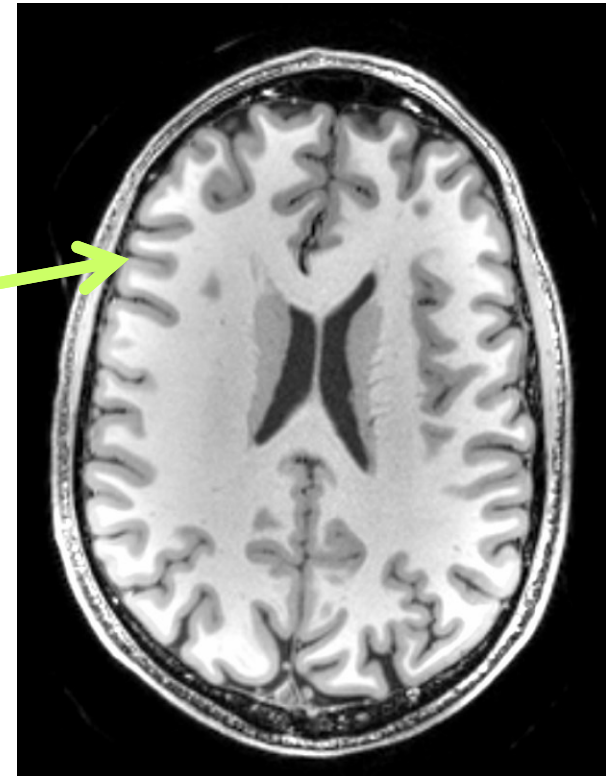
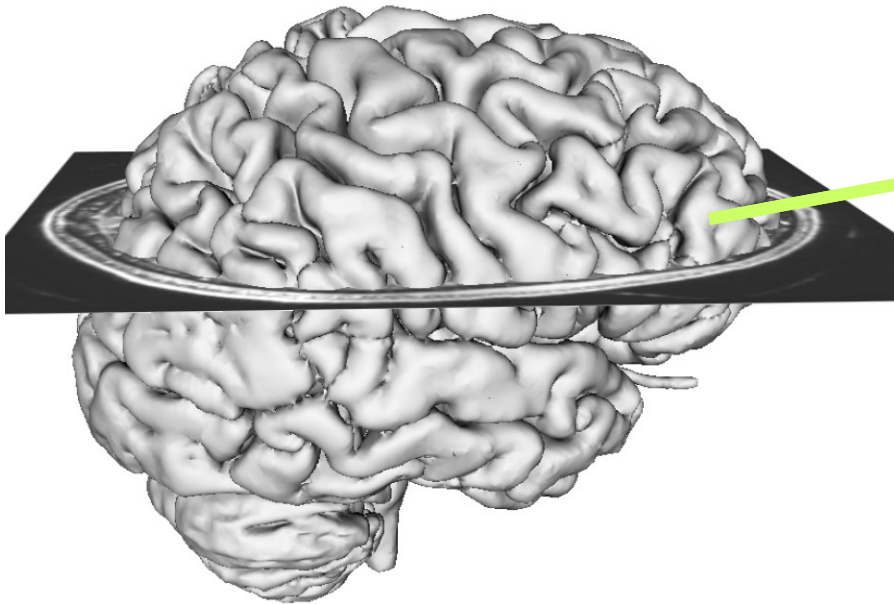


The cerebral cortex is composed of folded **grey matter**

折り畳まれた

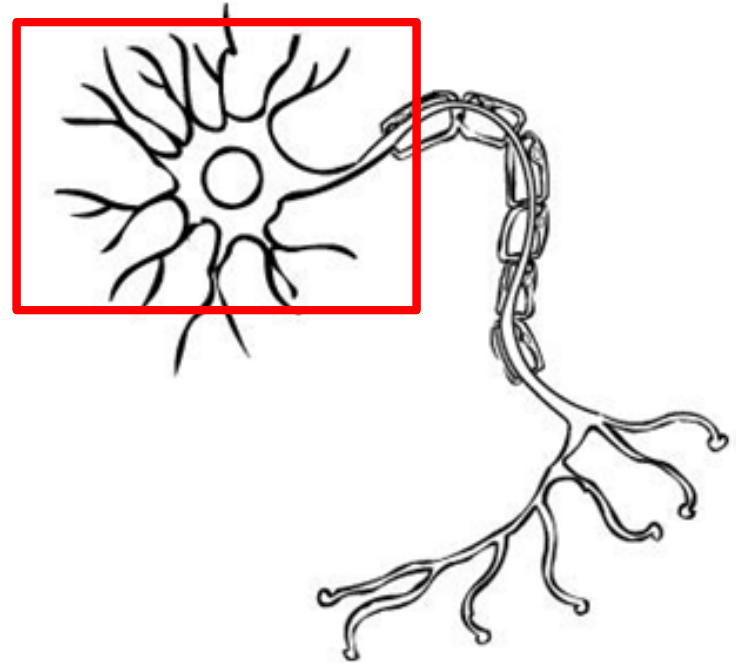
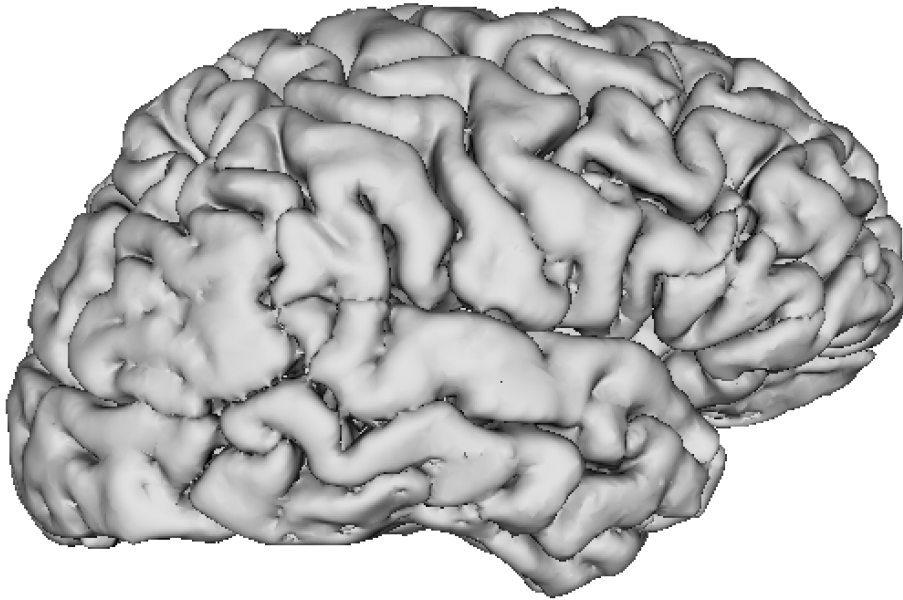
大腦皮質

# Cerebral Cortex



大腦皮質

# Cerebral Cortex



Grey Matter  
(neuron cell bodies)

大腦皮質

# Cerebral Cortex

前頭葉

## Frontal Lobe:

Decision making  
Problem solving  
Planning

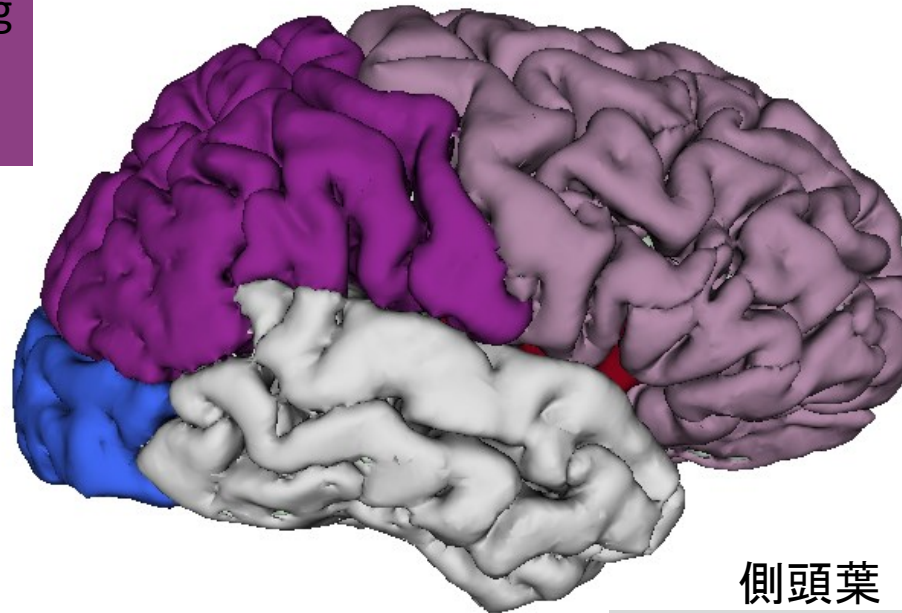
意思決定  
問題解決  
計画

側頭葉

## Temporal Lobe:

Memory  
Emotion  
Hearing  
Language

記憶  
感情  
聽覺  
言語



頭頂葉

## Parietal Lobe:

Reception and processing  
of sensory information  
from the body

sensory: 感覚の

後頭葉

## Occipital Lobe:

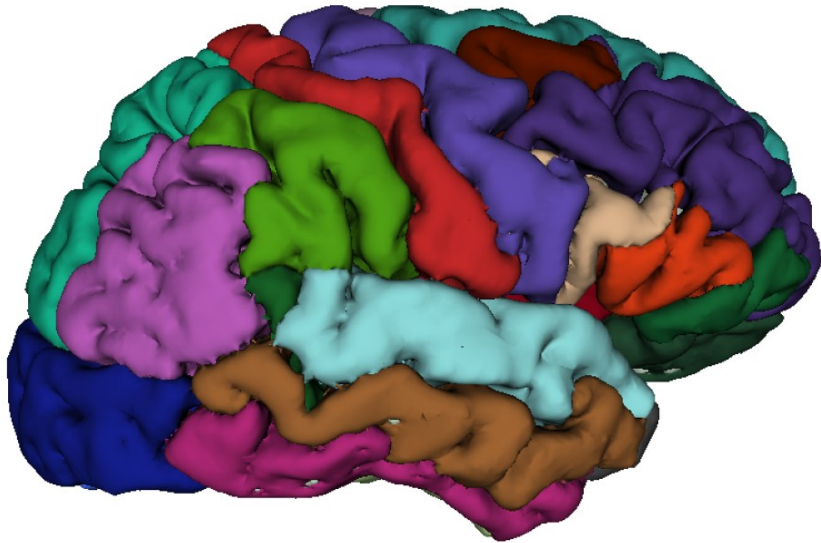
Vision

vision: 視覚

The cortex is divided into  
four sections called **lobes**.

葉

# Cerebral Cortex



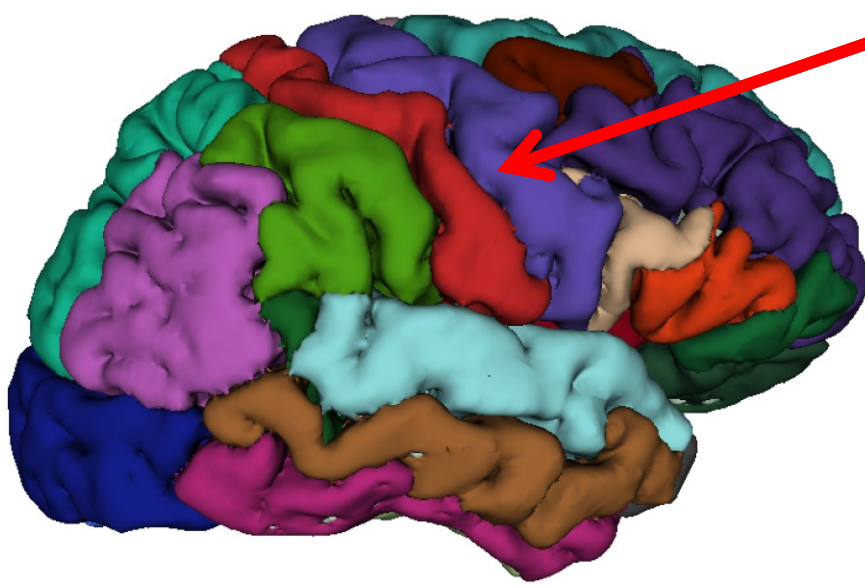
The lobes can be divided into functional areas involved in **movement, vision, hearing, touch, smell, thinking and reasoning.**

# 運動 Motor System

一次運動野

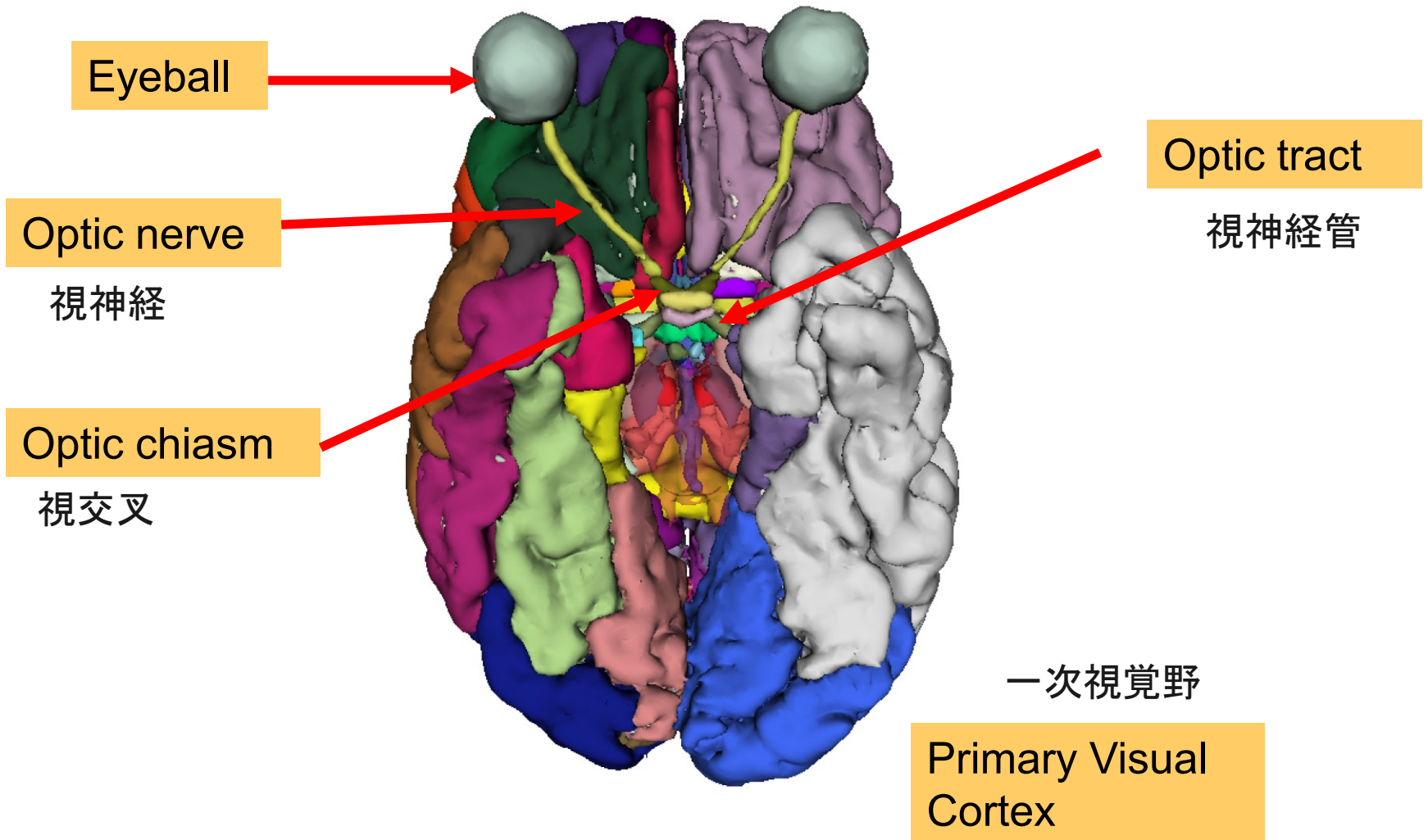
## Primary Motor Cortex:

- Located in pre-central gyrus of the frontal lobe
- Responsible for voluntary movement



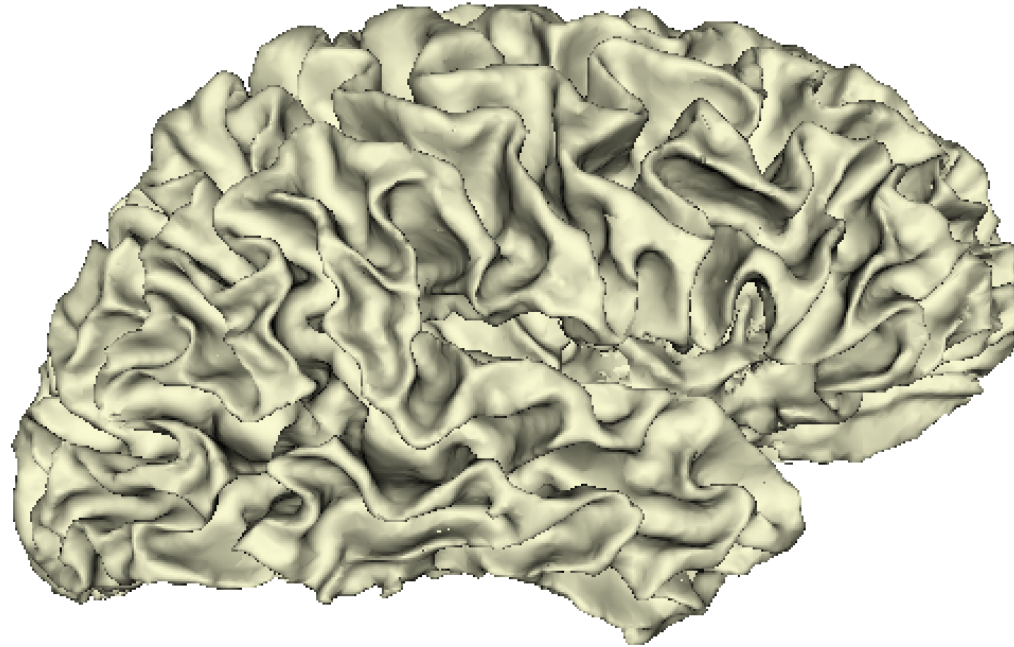
pre-central gyrus: 中心前回  
voluntary movement: 自發的運動

# 視覚の Visual System



腦白質

# Cerebral White Matter



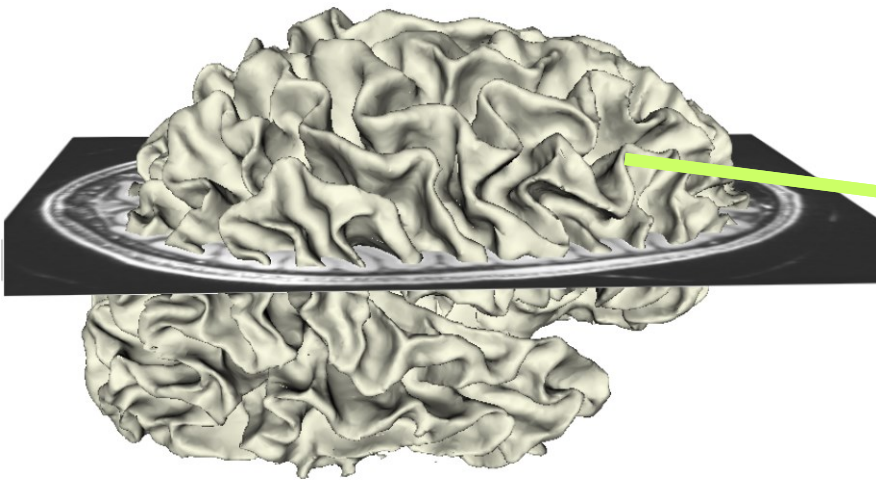
The human brain white matter is composed of myelinated axons.

有髓軸索



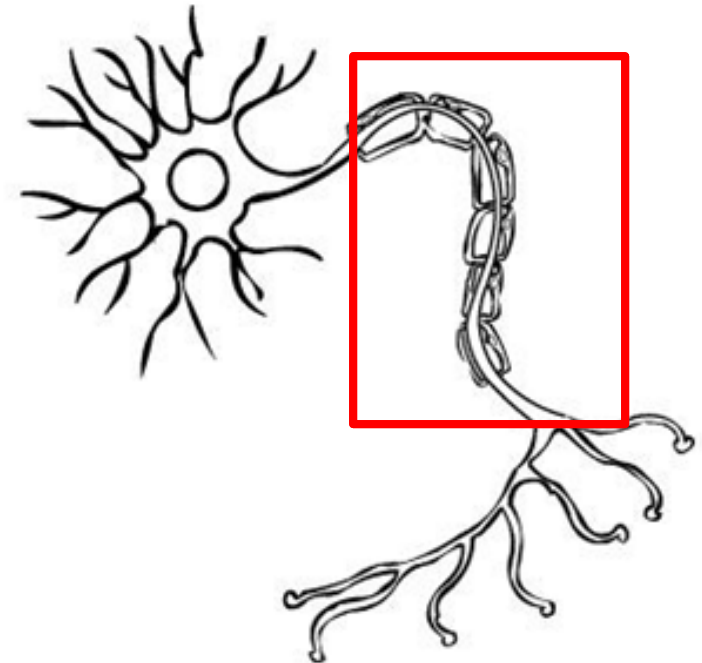
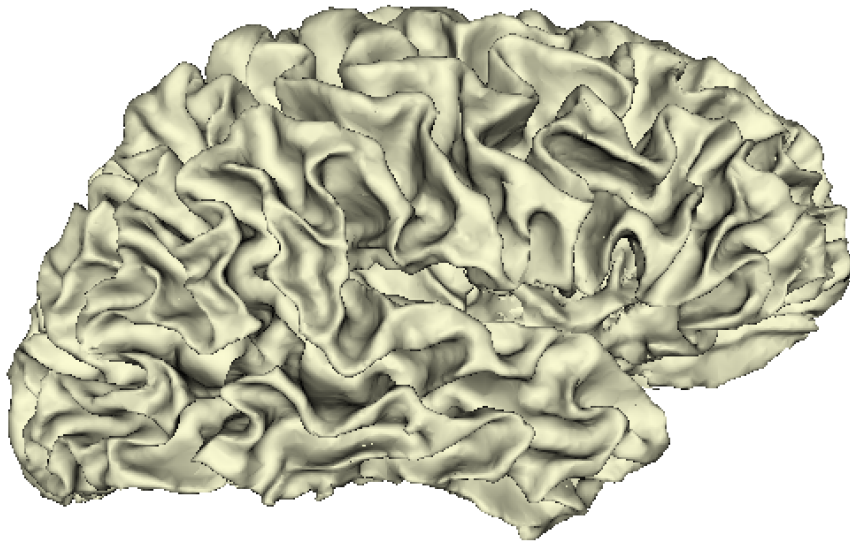
腦白質

# Cerebral White Matter



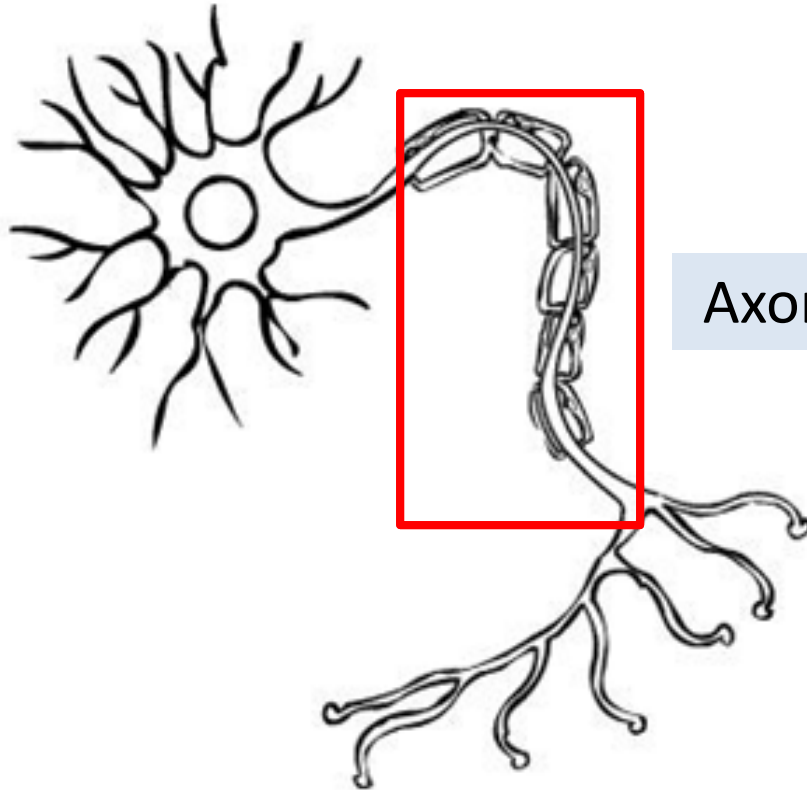
腦白質

# Cerebral White Matter



White Matter  
(neurons axons)

# 神経細胞 Neuron



Axon

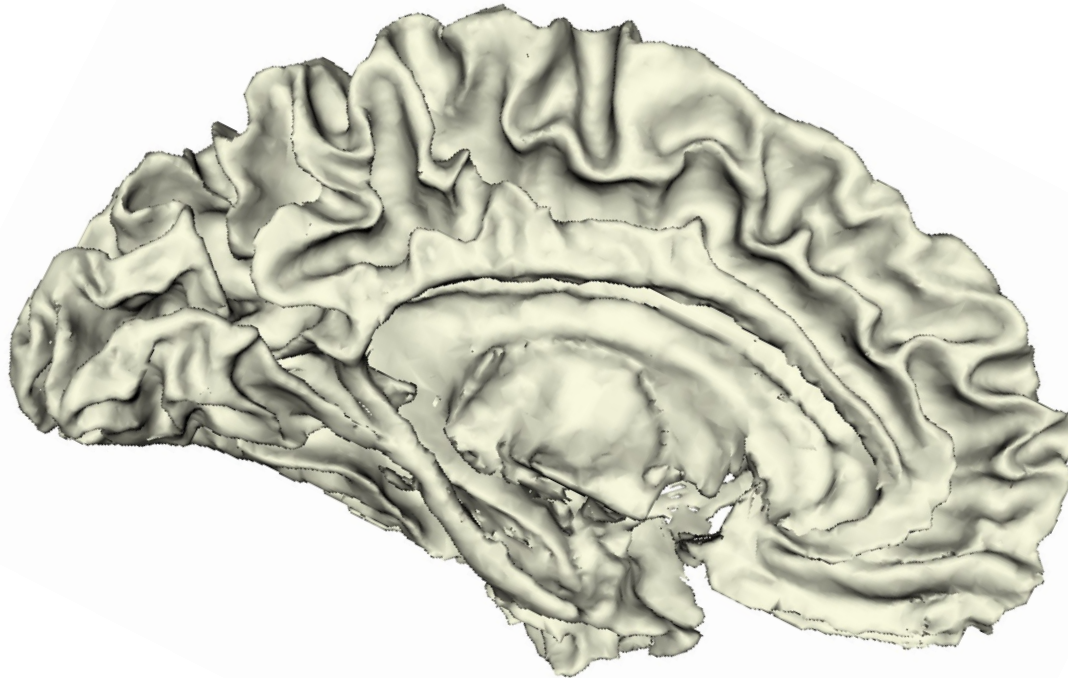
- Axons are coated with electrical insulation called **myelin** ミエリン
- Myelin increases the **speed of electrical communication** between neurons

Image source: BSC1007C Introductory  
Biology, State College of Florida

electrical insulation : (電気)絶縁体

白質の構造

# White Matter Structure



Diffusion MRI Analysis of the Human Brain,  
S.Pujol, ARR 2012-2017

白質の構造

# White Matter Structure



Diffusion MRI Analysis of the Human Brain,  
S.Pujol, ARR 2012-2017

ヒトの脳の白質

# Human White Matter Exploration

調査



Joseph Jules and Augusta  
Dejerine: Neuroanatomy atlas  
based on myelin-stained  
preparations

Neuroanatomy atlas : (脳)神経解剖学図譜  
myelin-stained preparations: ミエリン染色

*(Anatomie des centres nerveux,  
Paris, 1895-1901)*



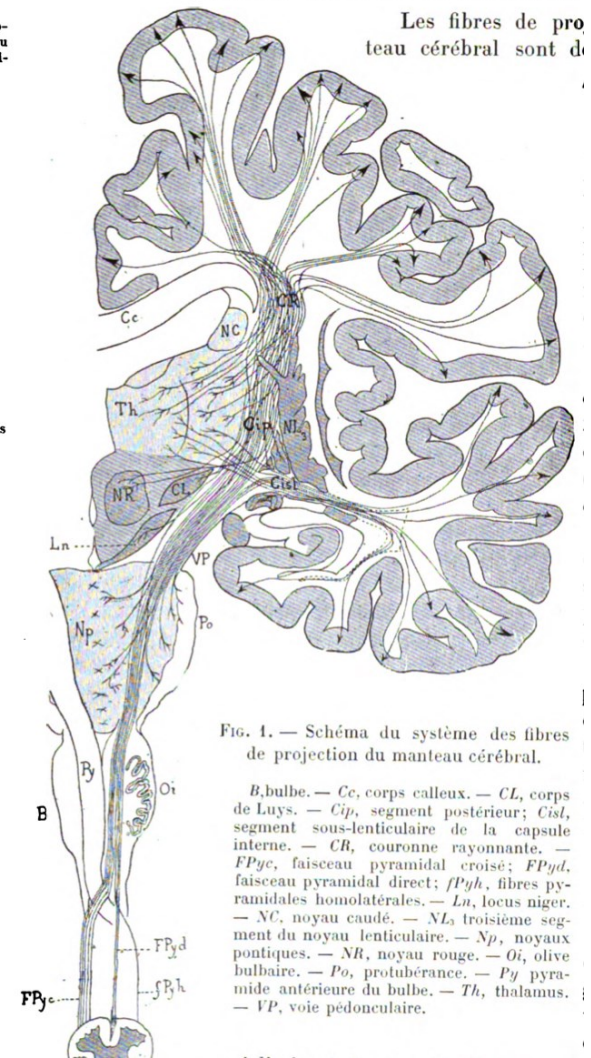
# (人名) Dejerine Atlas



Les fibres de projection du manteau cérébral sont des fibres corticifuges.

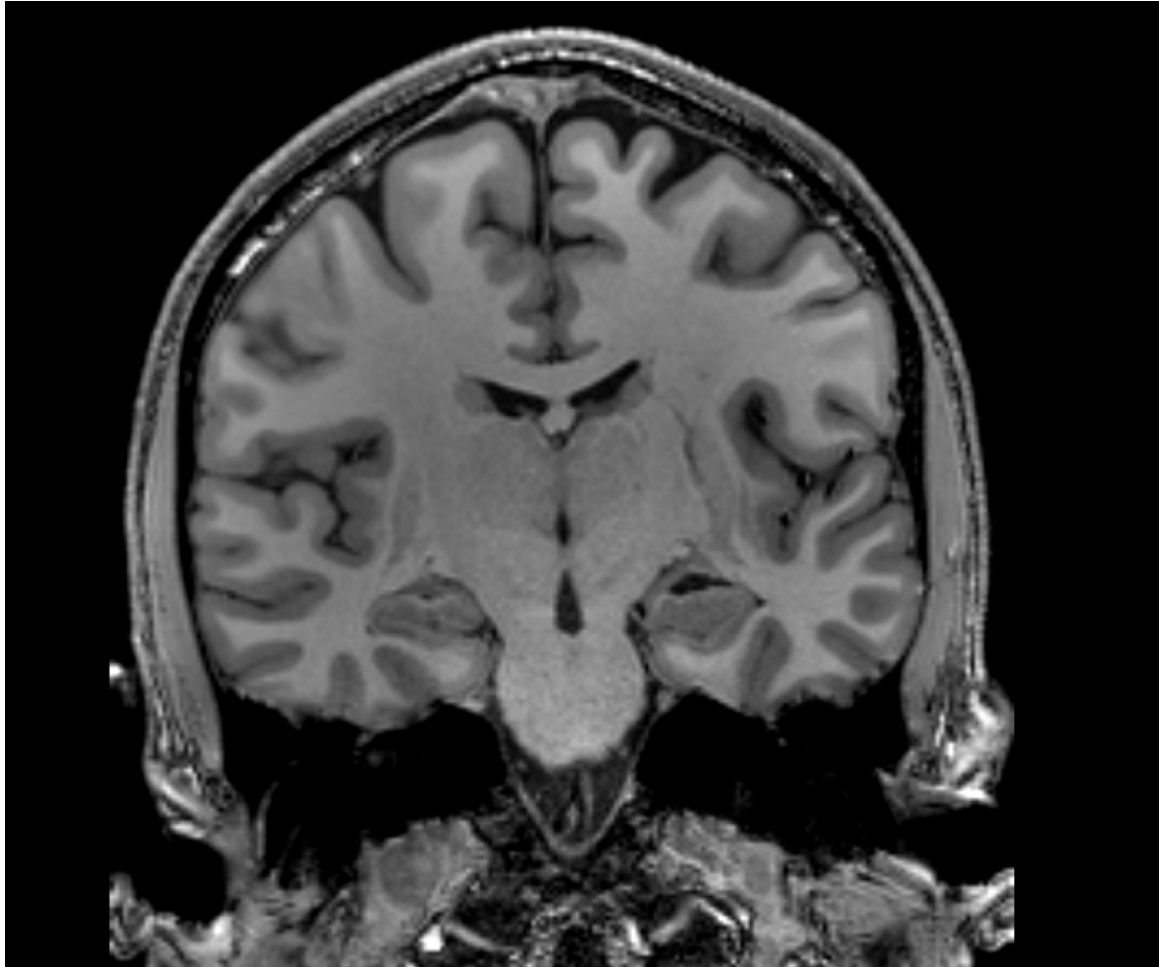
Leurs caractères communs.

Leur trajet.



構造の(形の) ⇔ 機能の(functional)

# Structural MRI



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S.Pujol, ARR 2012-2017



# 構造の(形の) Structural MRI

Les fibres de projection du manteau cérébral sont des fibres corticifuges.

Les fibres de projection du manteau cérébral sont des fibres corticifuges.

Leurs caractères communs.

Leur trajet.

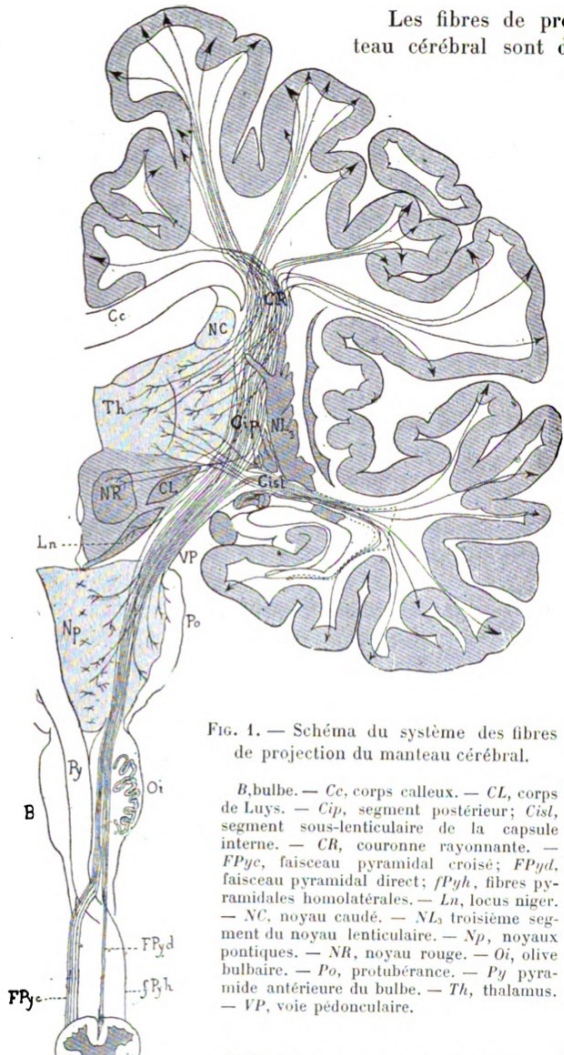
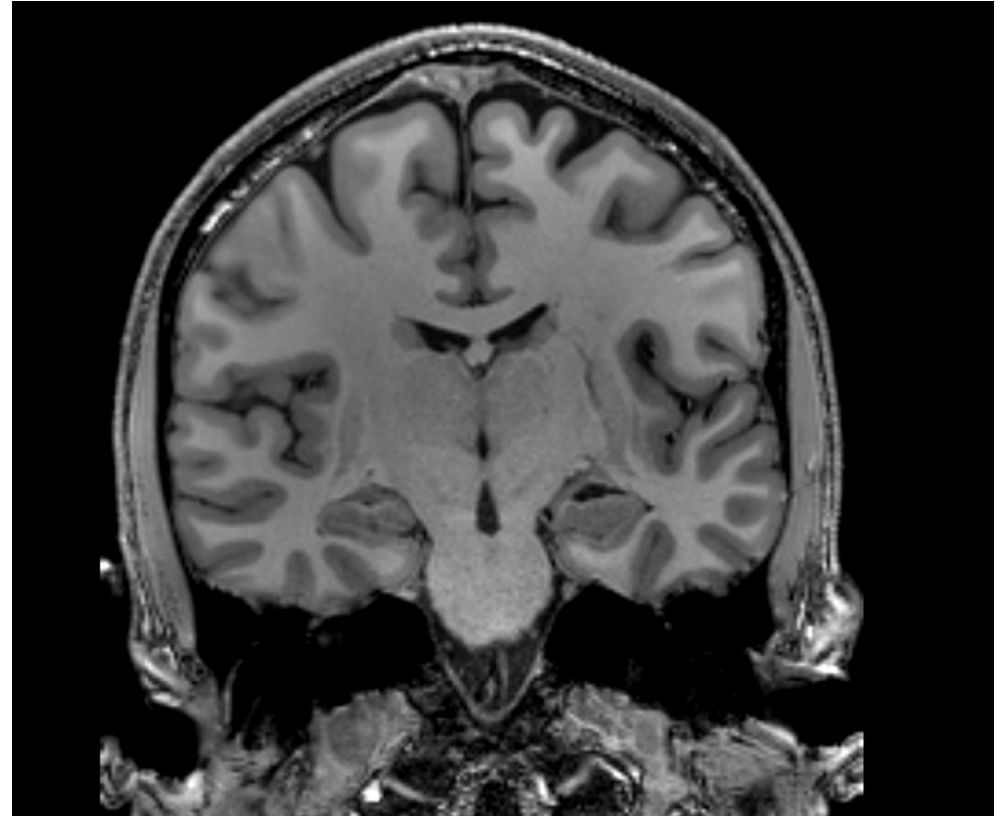


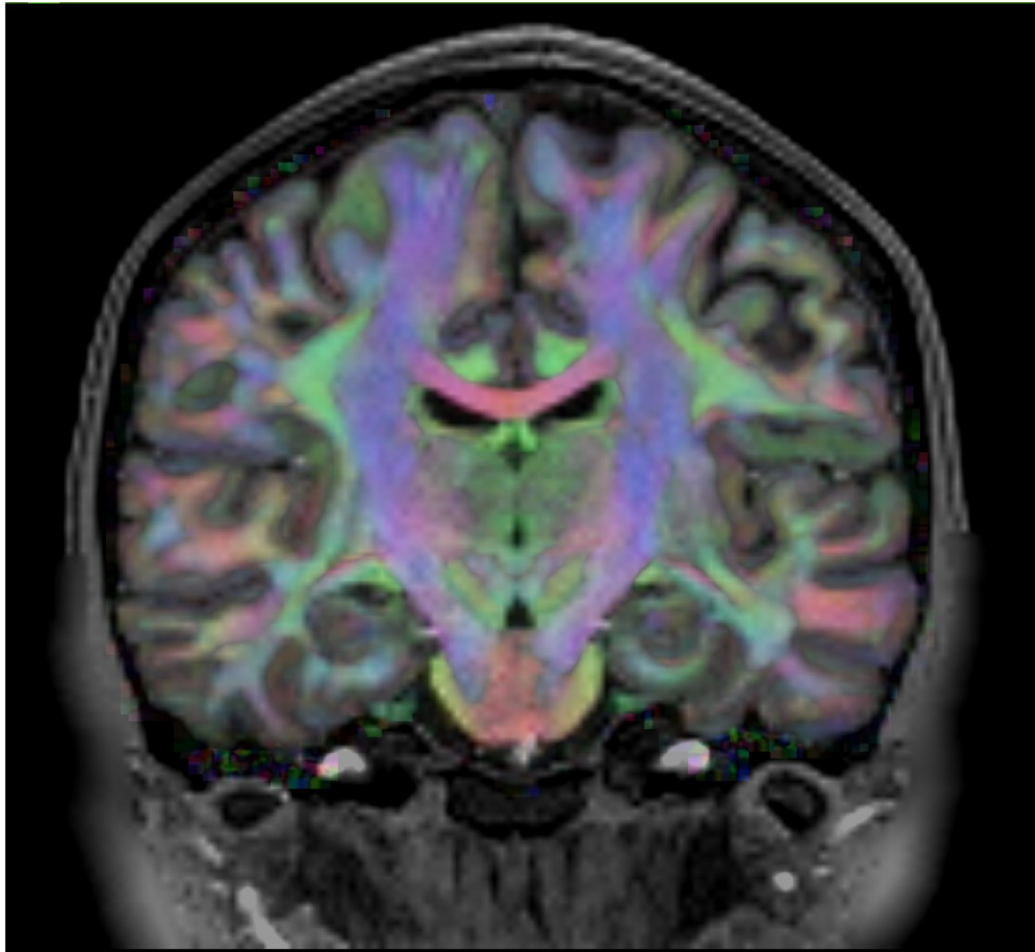
Fig. 1. — Schéma du système des fibres de projection du manteau cérébral.

B, bulbe. — Cc, corps calleux. — CL, corps de Luys. — C.p., segment postérieur; Cisl, segment sous-lenticulaire de la capsule interne. — CR, couronne rayonnante. — FPyc, faisceau pyramidal croisé; FPyd, faisceau pyramidal direct; FPyh, fibres pyramidales homolatérales. — Ln, locus niger. — NC, noyau caudé. — NL<sub>2</sub>, troisième segment du noyau lenticulaire. — Np, noyaux pontiques. — NR, noyau rouge. — Oi, olive bulbair. — Po, protubérance. — Py, pyramide antérieure du bulbe. — Th, thalamus. — VP, voie pedonculaire.



拡散強調MRI

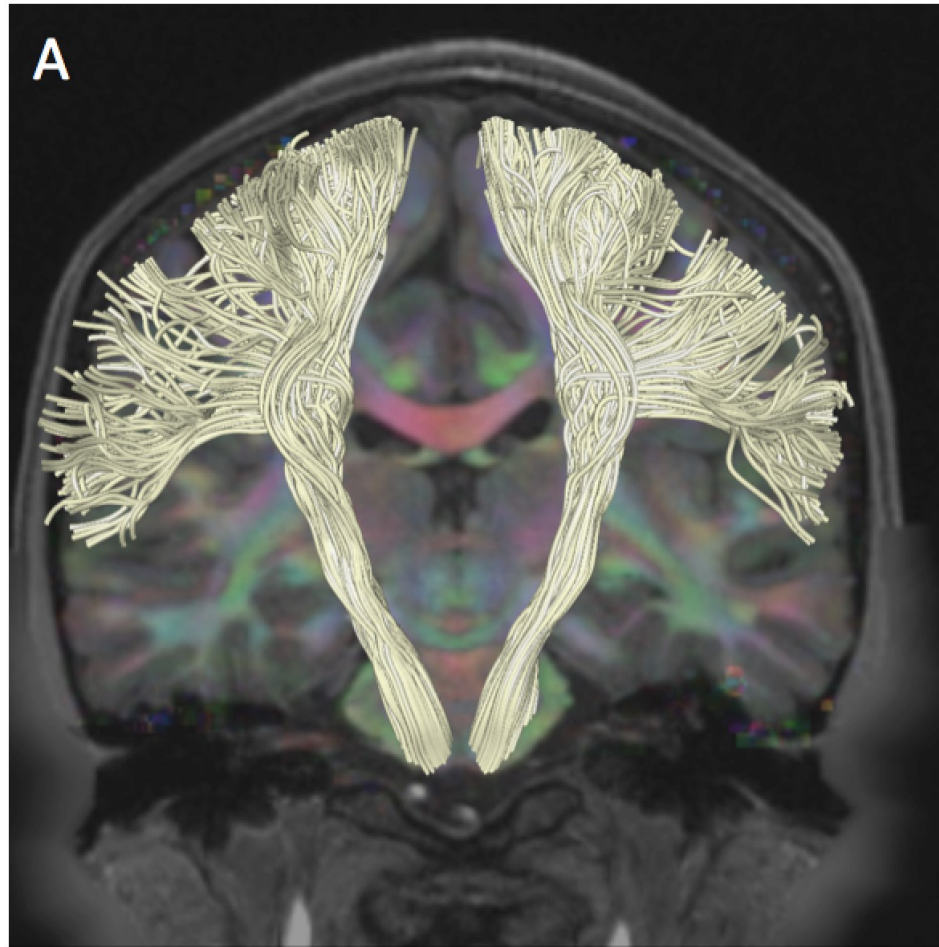
# Diffusion-weighted MRI



Diffusion MRI Analysis of the Human Brain,  
S.Pujol, ARR 2012-2017

トラクトグラフィ=神経束像

# Tractography



Diffusion MRI Analysis of the Human Brain,  
S.Pujol, ARR 2012-2017

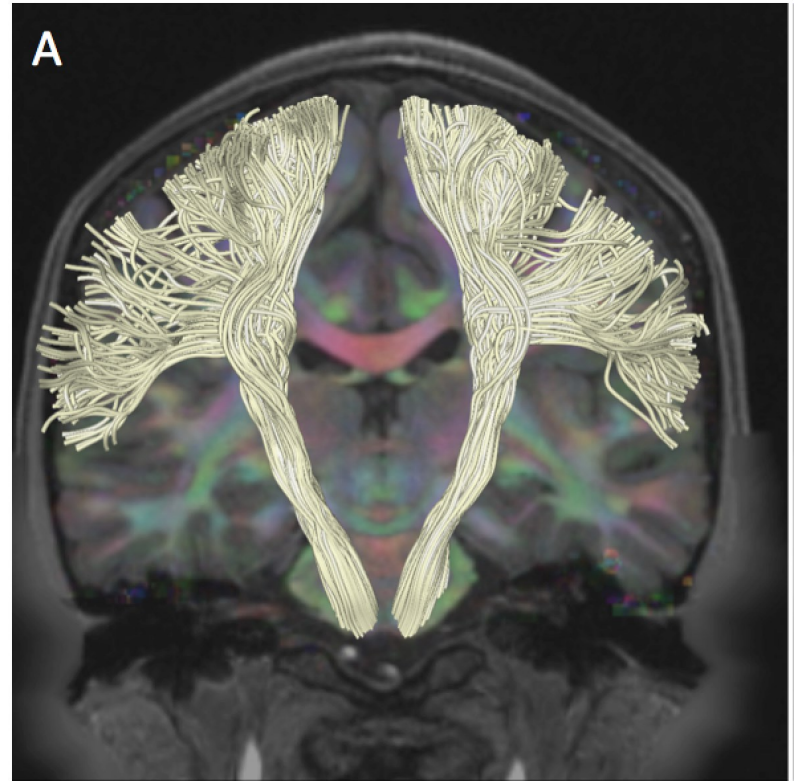
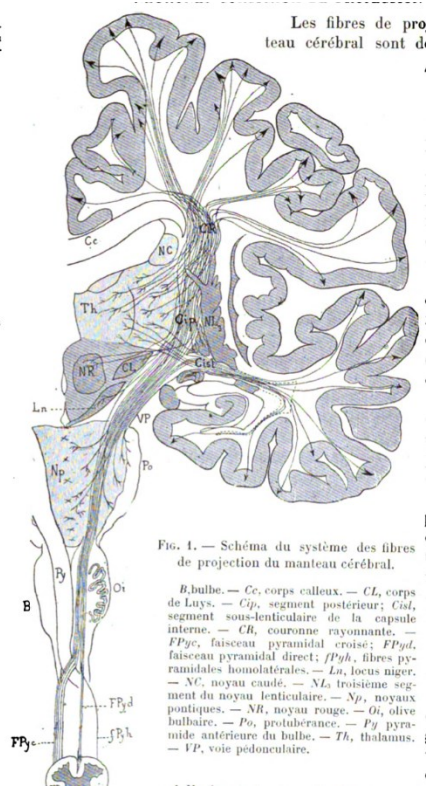
# 脳白質の調査

# White Matter Exploration

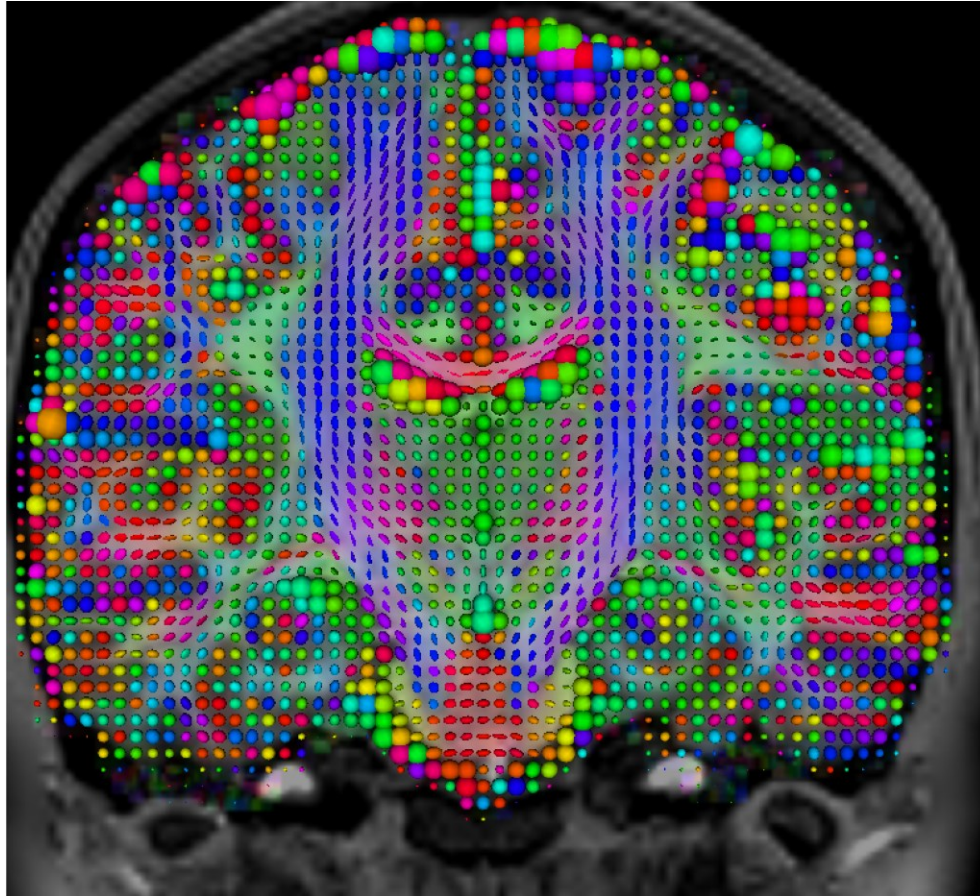


Les fibres de projection du manteau cérébral sont des fibres corticofuges.

Les caractères des fibres.



# Diffusion Weighted MRI

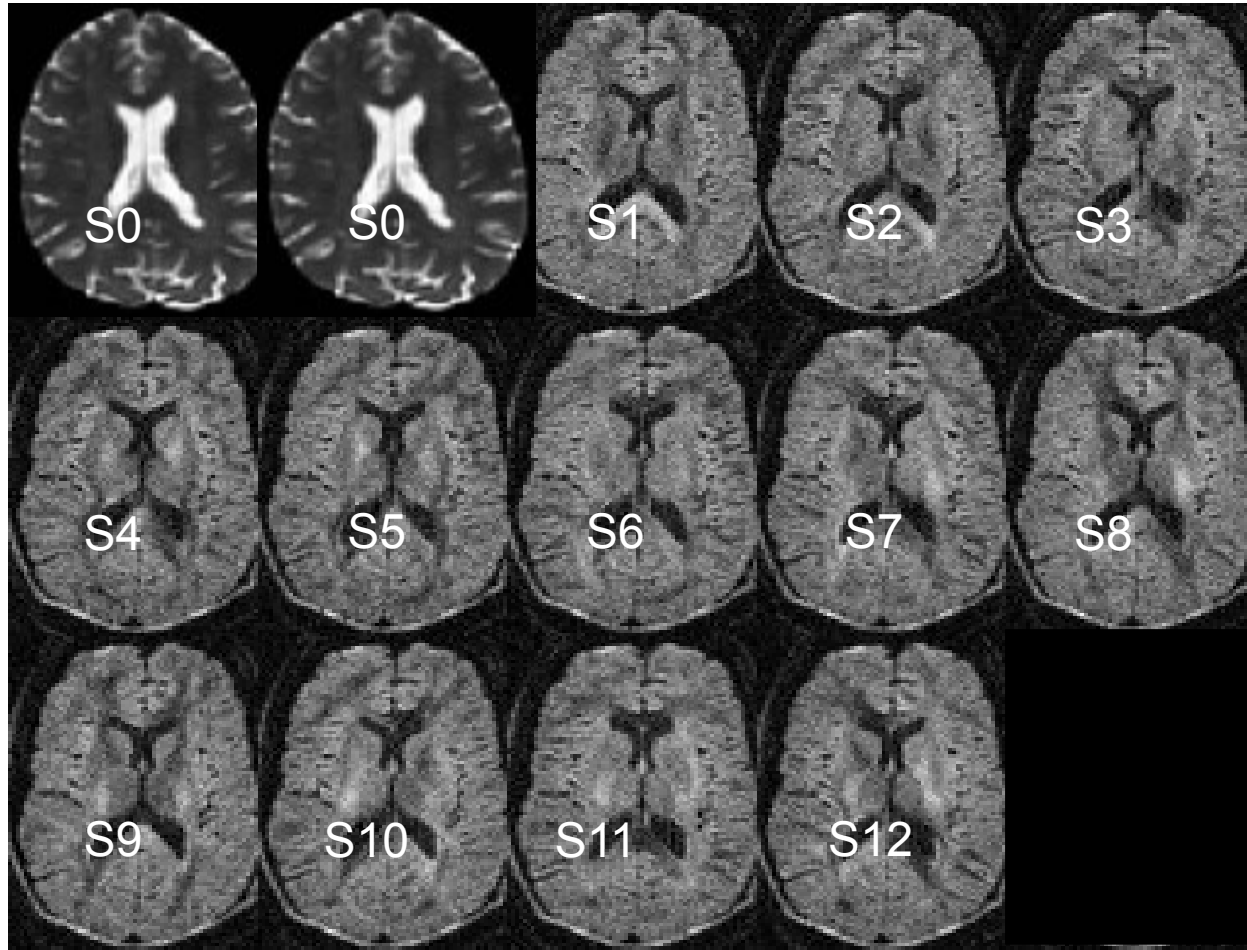


非侵襲 = 患者にダメージがない

- First **non-invasive** window on white matter anatomy
- Measurement of the diffusion of water molecules in the brain using diffusion sensitizing gradients

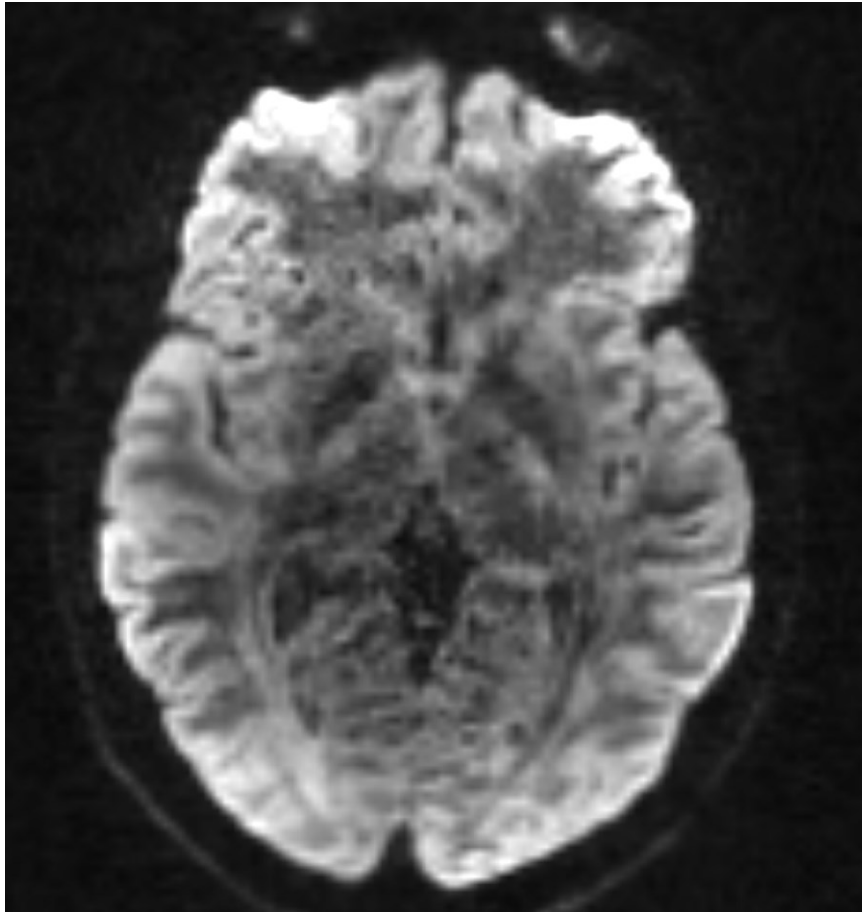
diffusion of water molecules: 水分子の拡散  
diffusion sensitizing gradients: 拡散検出傾斜(磁場)

# Diffusion Weighted MRI



In this example, the DWI scan was acquired with 12 diffusion sensitizing gradient directions (S1-S12) and 2 non-diffusion sensitizing gradients (S0)

# Diffusion Weighted MRI



- In **grey matter and cerebrospinal fluid**, the displacement of water molecules is identical in all directions: the diffusion is **isotropic**

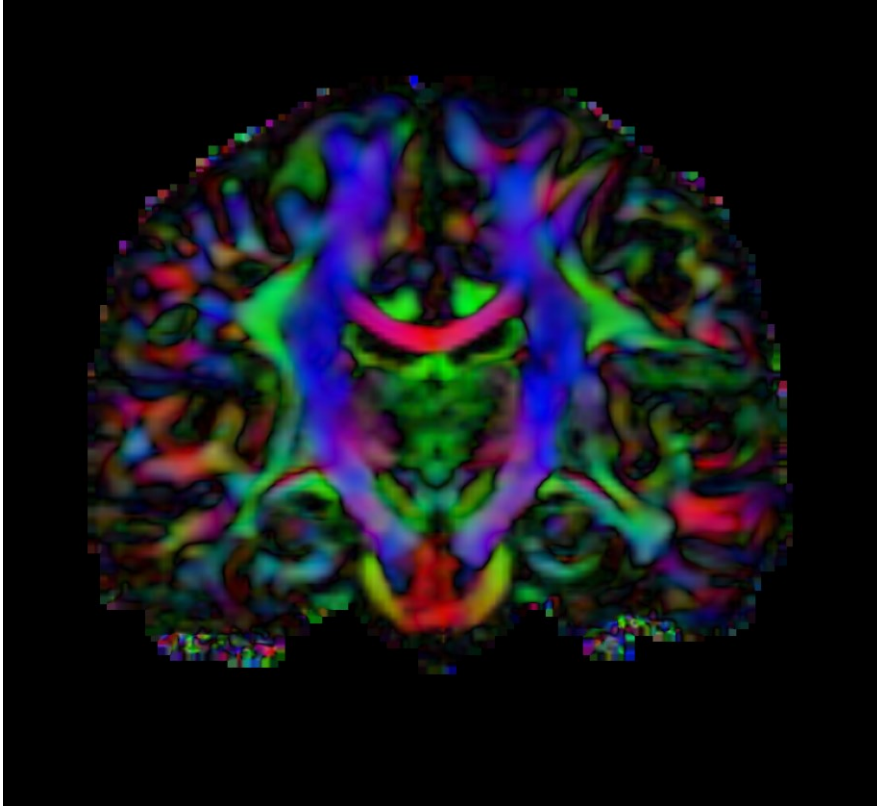
**cerebrospinal fluid (CSF): 腦脊髓液**  
**Isotropic: 等方的**

- In **white matter**, myelin sheets and axonal membranes act as barriers: the diffusion is **anisotropic**

**membrane : 膜**  
**Isotropic: 非等方的**

拡散テンソルイメージング

# Diffusion Tensor Imaging



Diffusion Tensor Imaging (DTI) is a **mathematical framework** that was developed to model the **anisotropic diffusion** of water molecules in the brain.

mathematical framework:

数学的フレームワーク(手法群)

anisotropic diffusion:

非等方な(方向によって異なる)拡散  
water molecule: 水分子



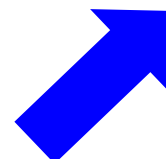
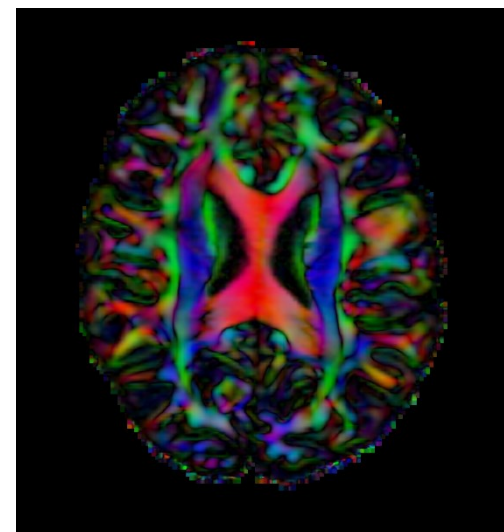
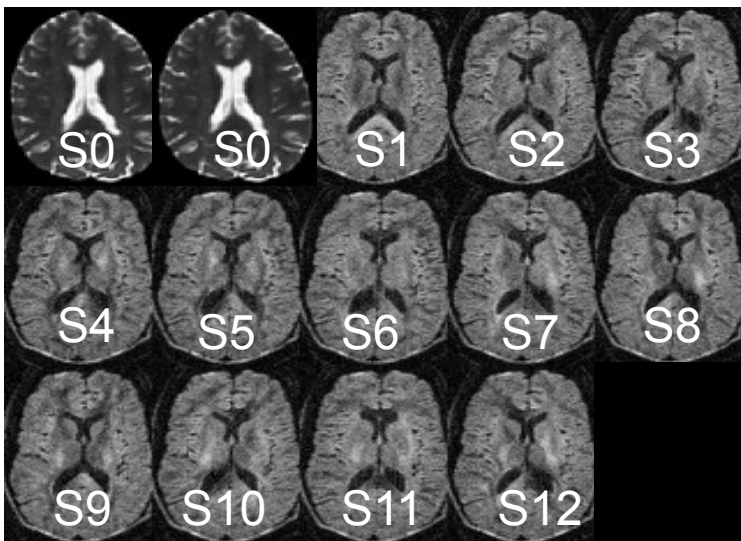
DWI(diffusion weighted image): 拡散強調像

拡散テンソル画像

# From DWI to DTI

DWI

DTI



Stejskal-Tanner (1965)

$$S_i = S_0 e^{-b \hat{g}_i^T \underline{D} \hat{g}_i}$$

gradient:  
拡散検出傾斜(磁場)

*S<sub>i</sub>*: DWI volume acquired with *i*th gradient

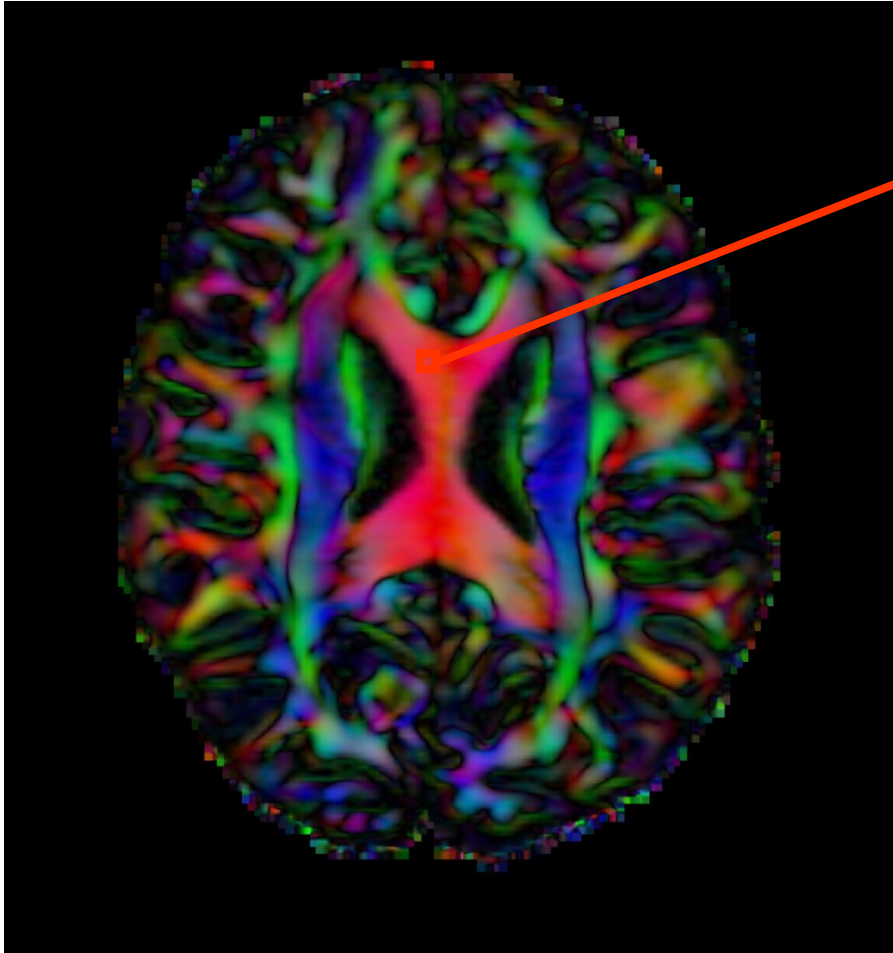
*S<sub>0</sub>*: Baseline volume

baseline : 基準

Volume : ボリュームデータ  
(3次元画像)

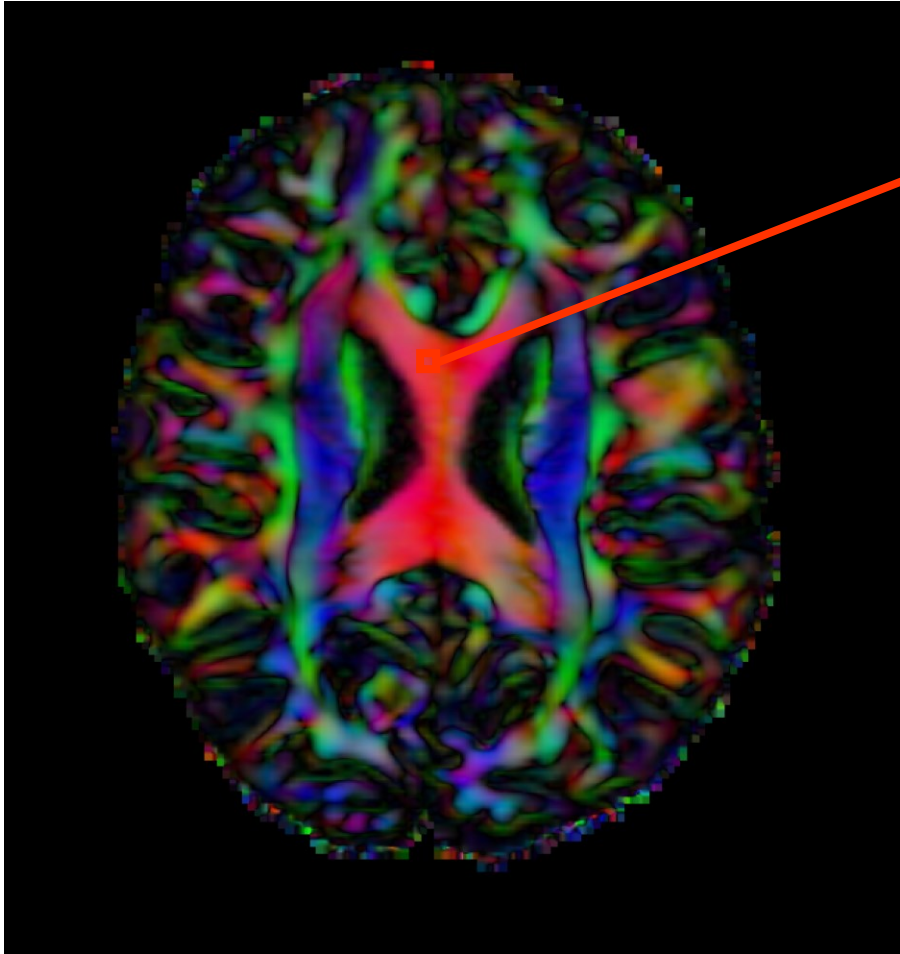
拡散テンソルイメージング

# Diffusion Tensor Imaging



$$S_i = S_0 e^{-b \hat{g}_i^T \underline{D} \hat{g}_i}$$

# Diffusion Tensor Imaging

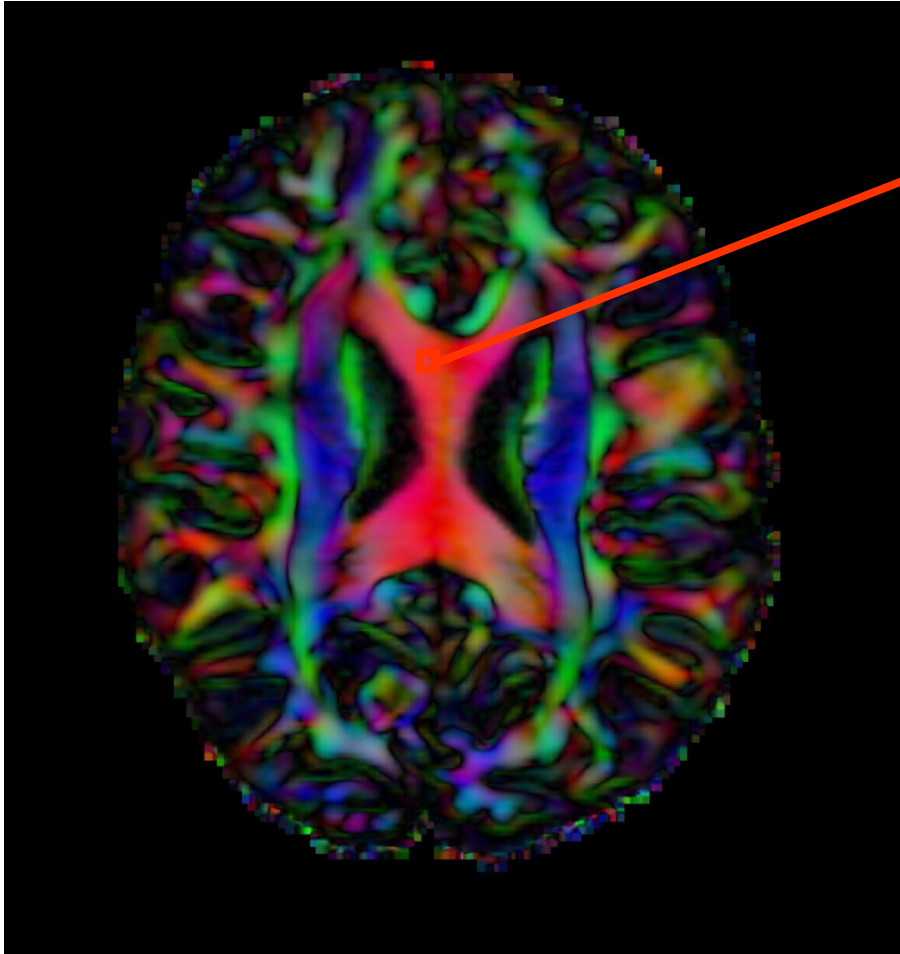


$$S_i = S_0 e^{-b\hat{g}_i^T \underline{D} \hat{g}_i}$$



$$\underline{D} = \begin{bmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{yx} & D_{yy} & D_{yz} \\ D_{zx} & D_{zy} & D_{zz} \end{bmatrix}$$

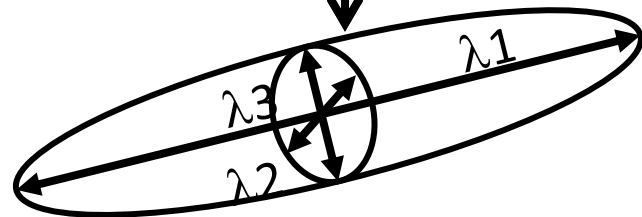
# Diffusion Tensor Imaging



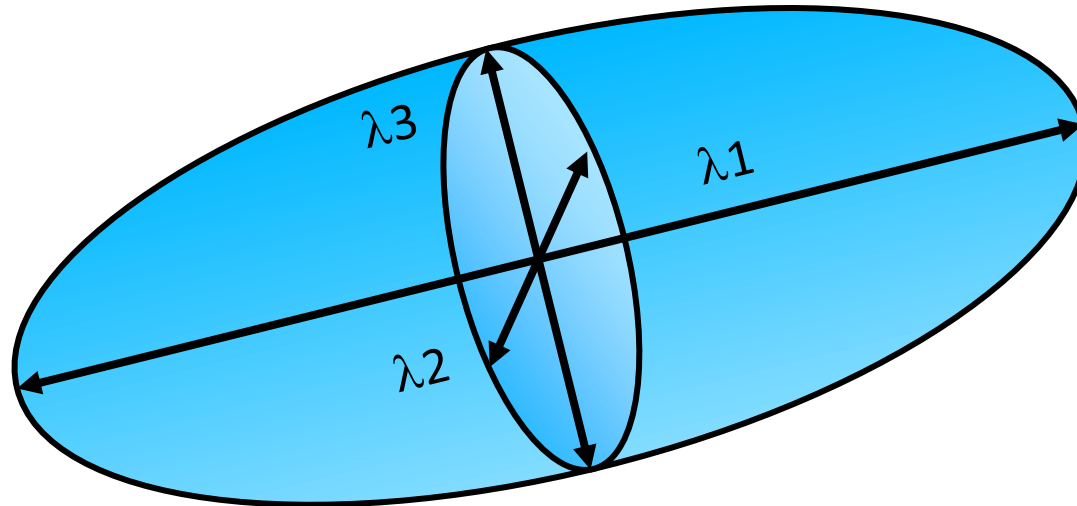
$$S_i = S_0 e^{-b\hat{g}_i^T \underline{D} \hat{g}_i}$$



$$\underline{D} = \begin{bmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{yx} & D_{yy} & D_{yz} \\ D_{zx} & D_{zy} & D_{zz} \end{bmatrix}$$



# 拡散テンソル Diffusion Tensor

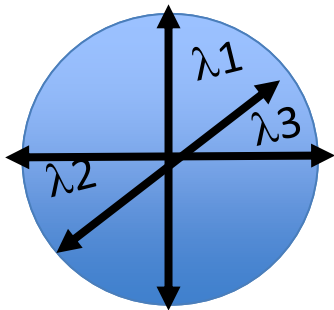


- The **diffusion tensor** in each voxel can be visualized as an ellipsoid.  
voxel: ボクセル = 画素

- The **principal directions of diffusion** of water molecules correspond to the axis of the ellipsoid.

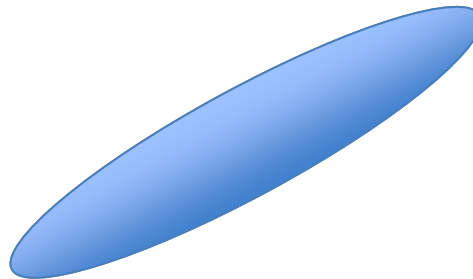
拡散テンソル

# Diffusion Tensor



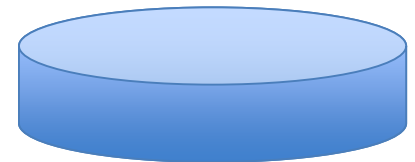
$$\lambda_1 = \lambda_2 = \lambda_3$$

Isotropic media  
(CSF, grey matter)



$$\lambda_1 \gg \lambda_2, \lambda_3$$

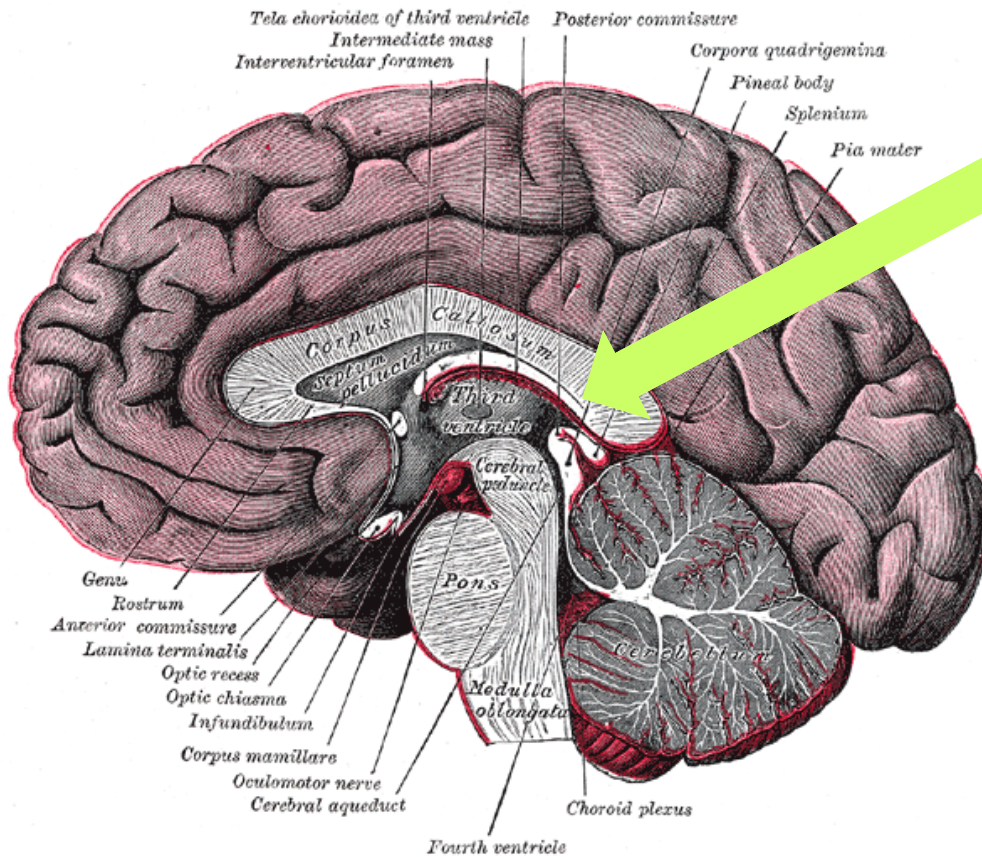
Anisotropic media  
(white matter)



$$\lambda_1 \sim \lambda_2 \gg \lambda_3$$

脳梁(のうりょう)

# Corpus Callosum



- The corpus callosum is a broad thick bundle of white matter fibers that connect the left and right hemisphere.

半球

- It is the largest white matter structure in the brain

Image from Grey's Anatomy

Diffusion MRI Analysis of the Human Brain,  
S.Pujol, ARR 2012-2017

脳梁(のうりょう)

# Corpus Callosum

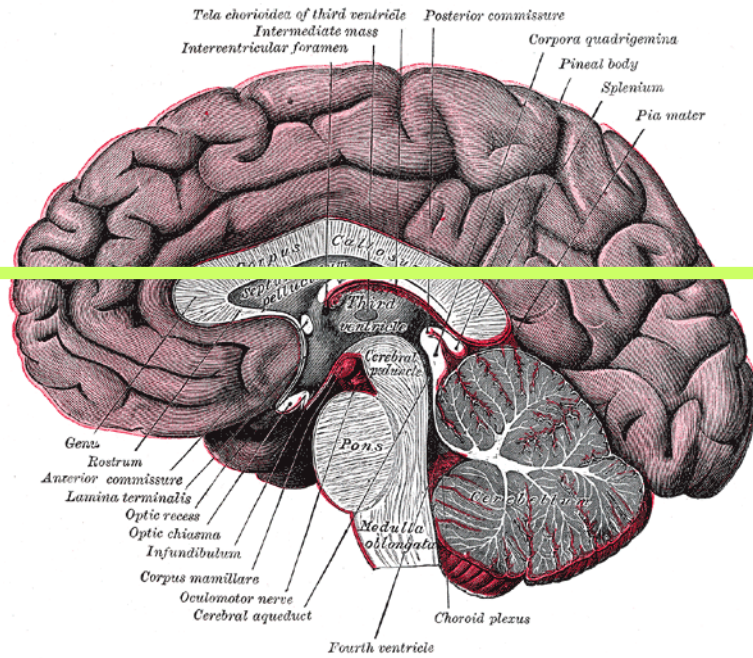
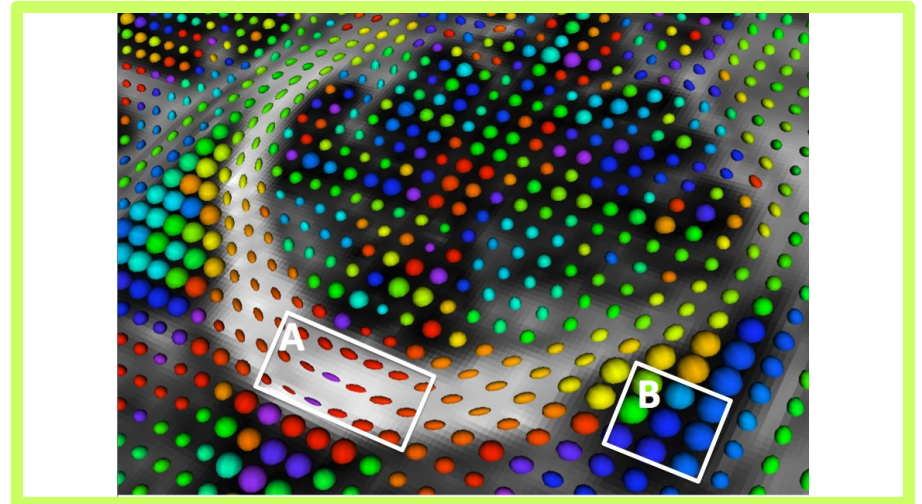
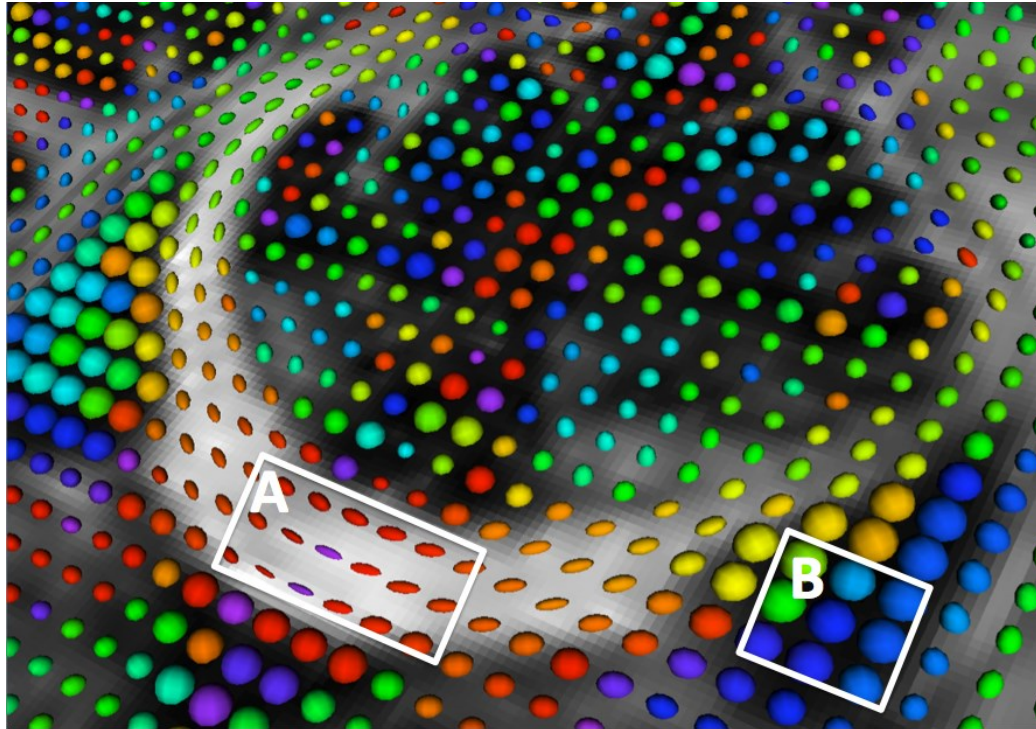


Image from Grey's Anatomy





# Diffusion Tensor Ellipsoid 楕円体



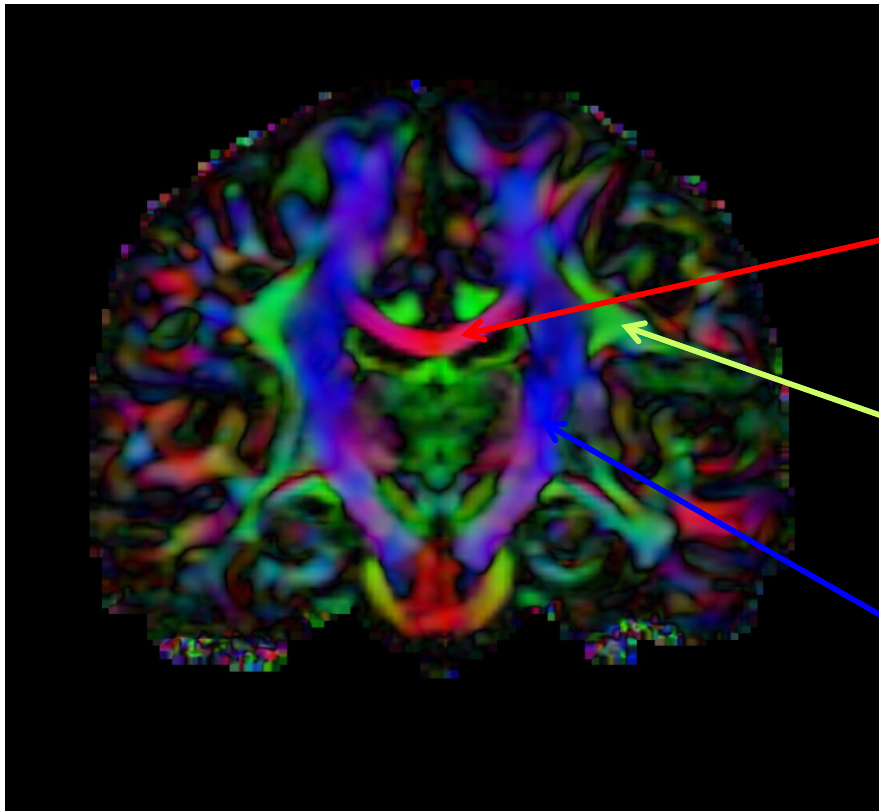
A: White Matter: Anisotropic Diffusion



B: CSF: Isotropic Diffusion



# DTI Color Map



Color coding:

Red: left-right  
(e.g. corpus callosum)

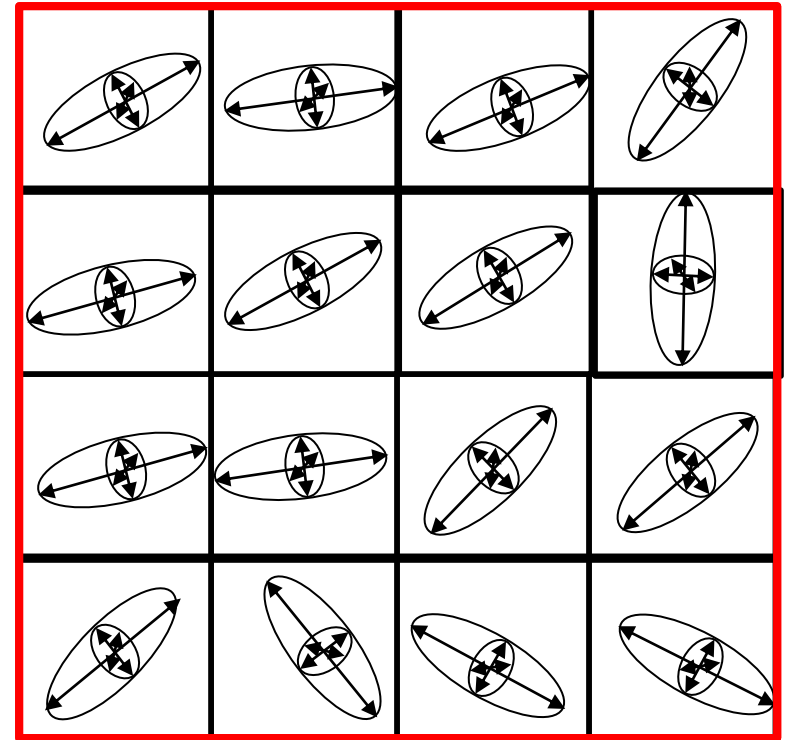
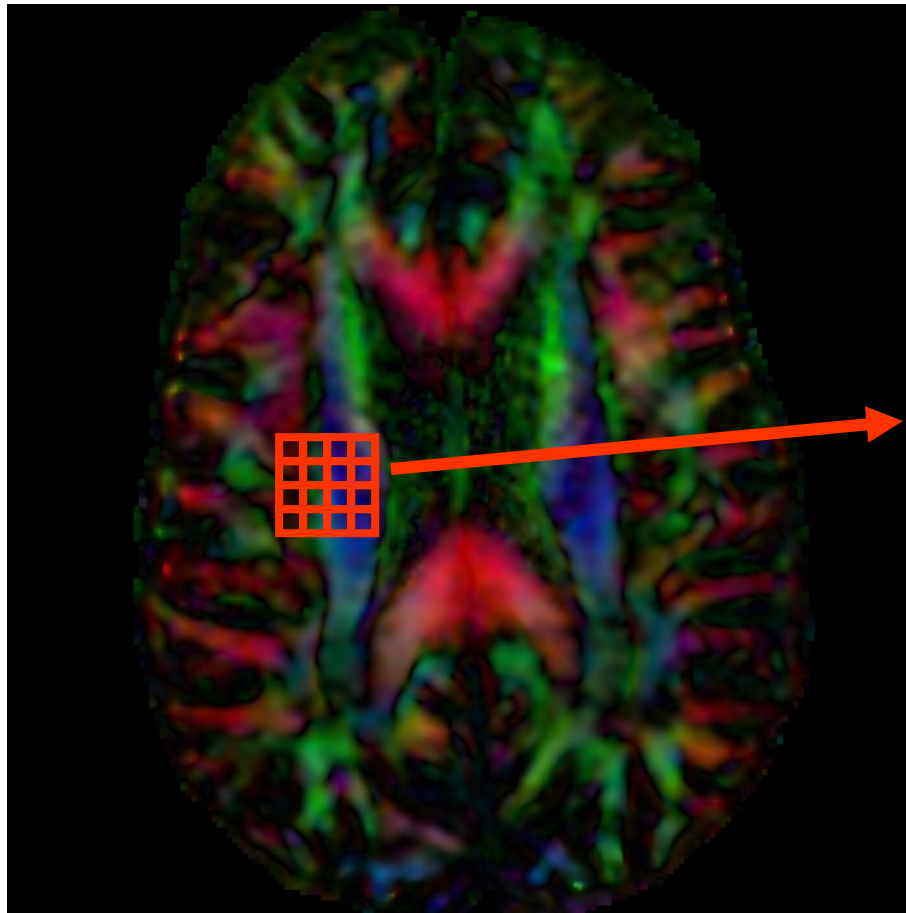
Green: anterior-posterior (e.g.  
superior portion of cingulum)  
上部带状回

Blue: inferior-superior (e.g.  
corticospinal tract)

皮質脊髓路

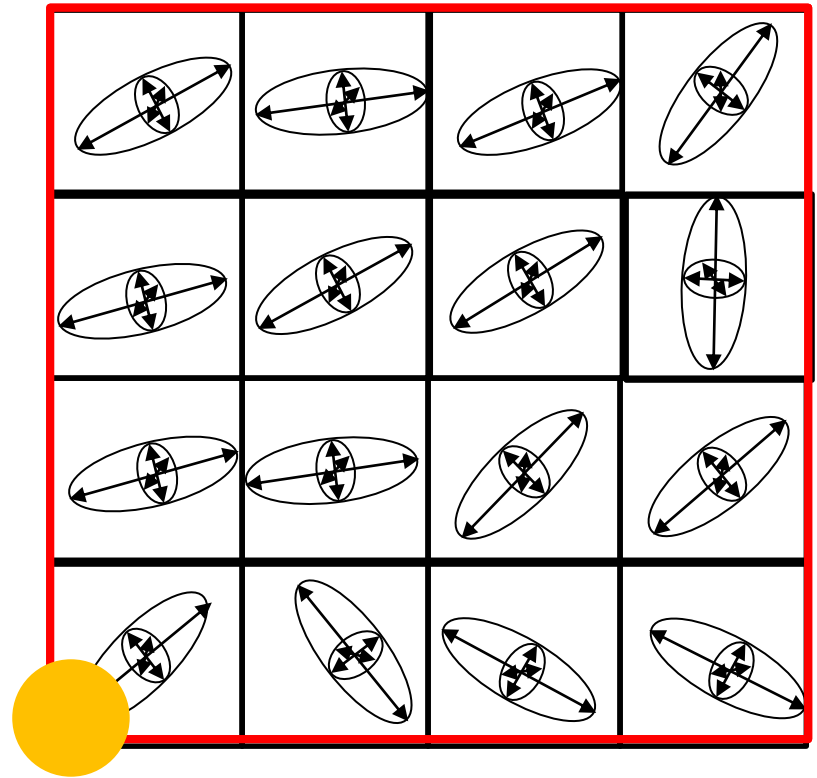
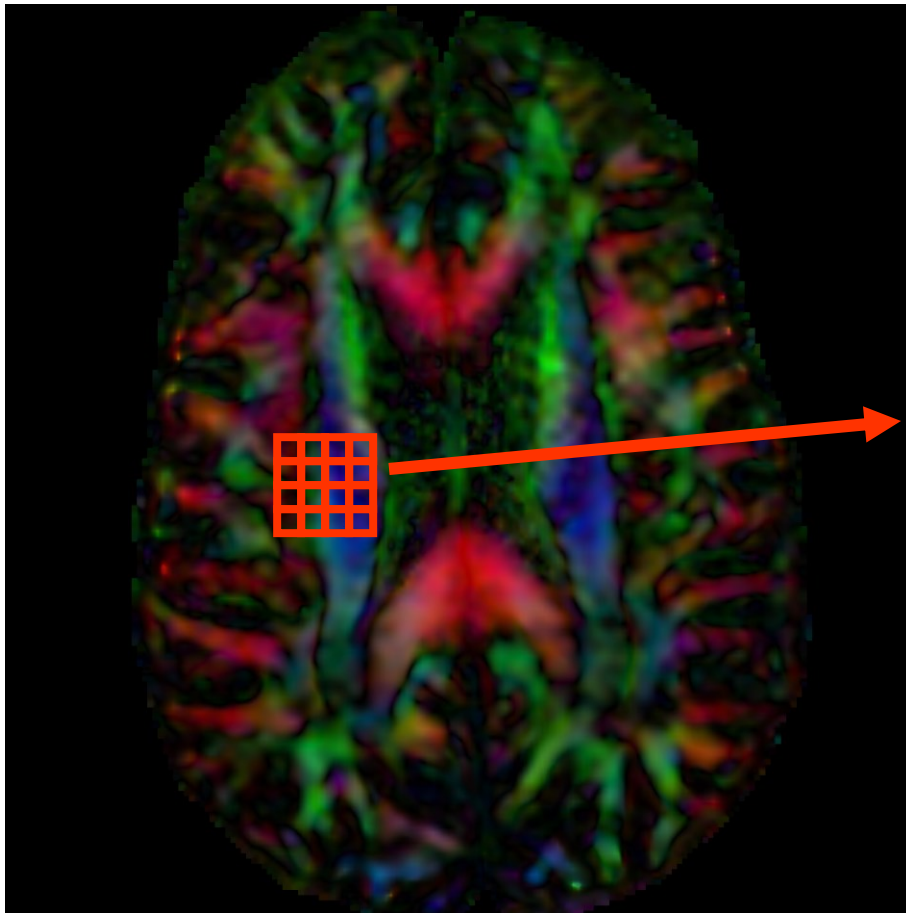
トラクトグラフィ=神経束像

# DTI Tractography



トラクトグラフィ=神経束像

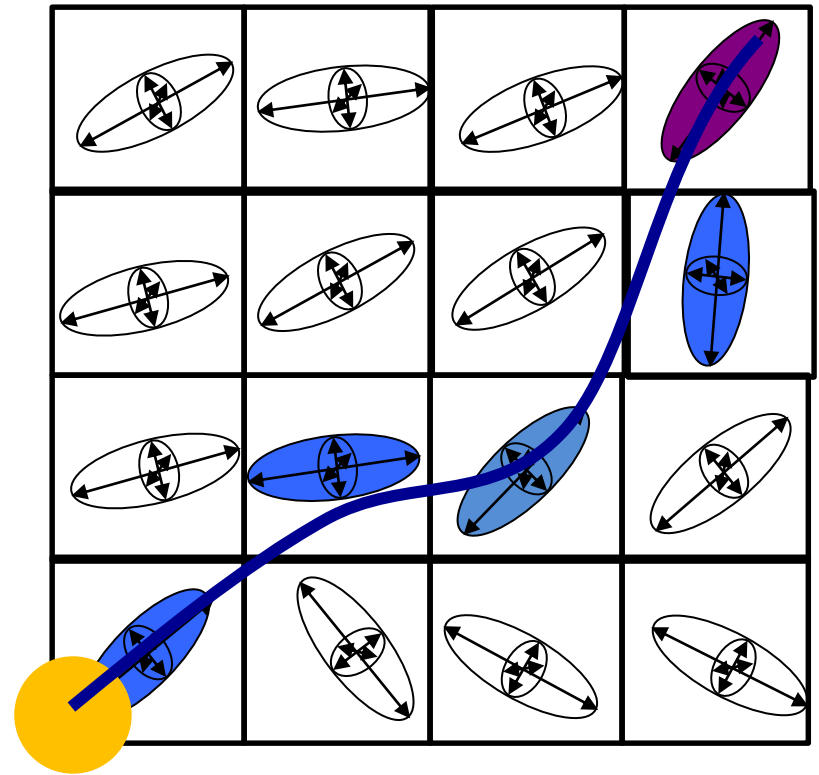
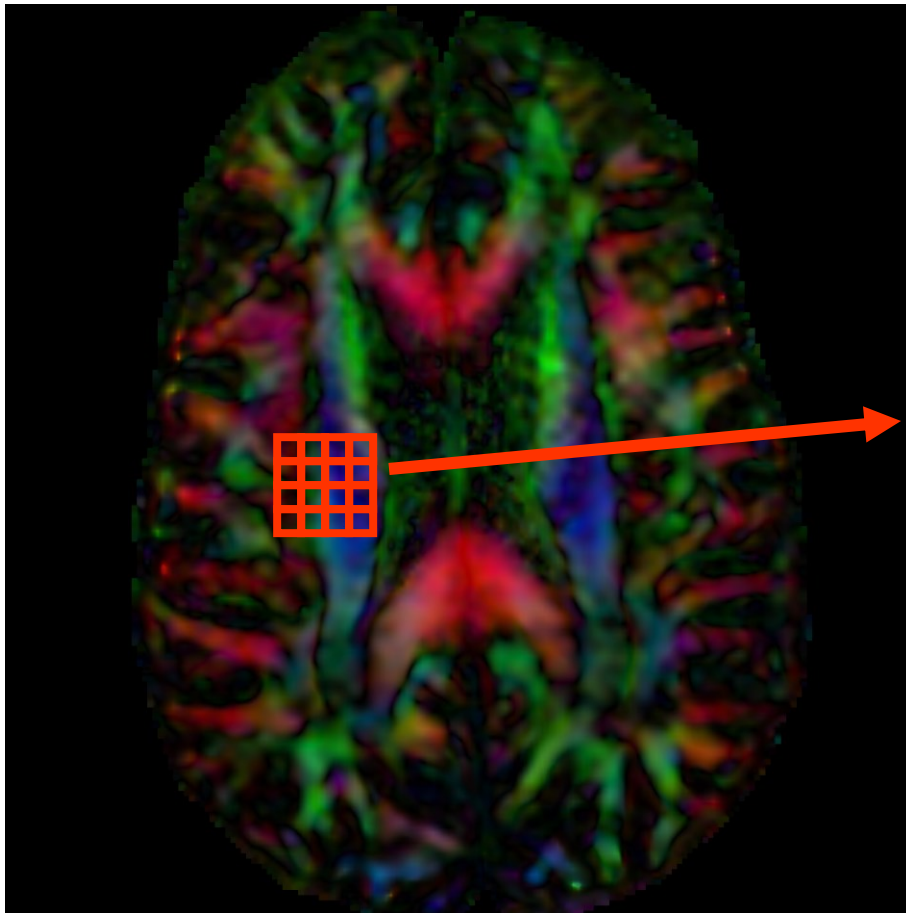
# DTI Tractography



Seed Point

トラクトグラフィ=神経束像

# DTI Tractography

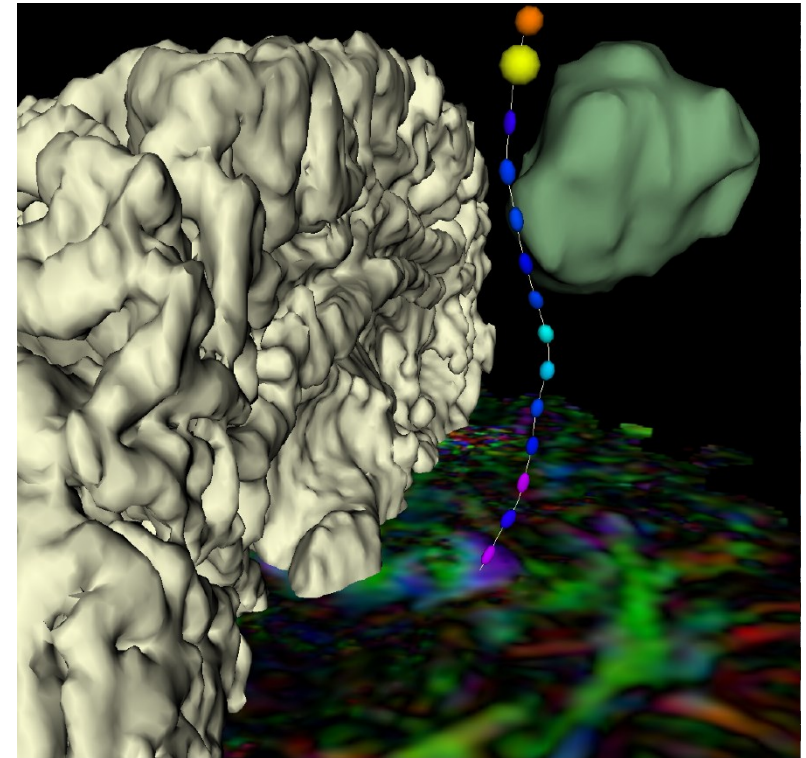
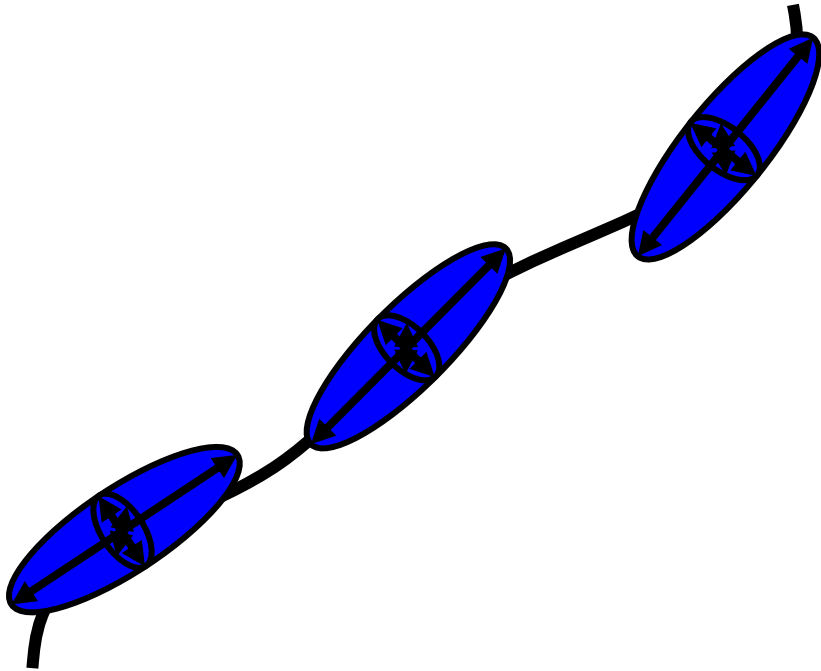


Seed Point

seed:種(たね) = 追跡開始点

トラクトグラフィ=神経束像

# DTI Tractography



再構成(像)

DTI tractography provides 3D reconstruction of the trajectory of white matter pathways

軌跡

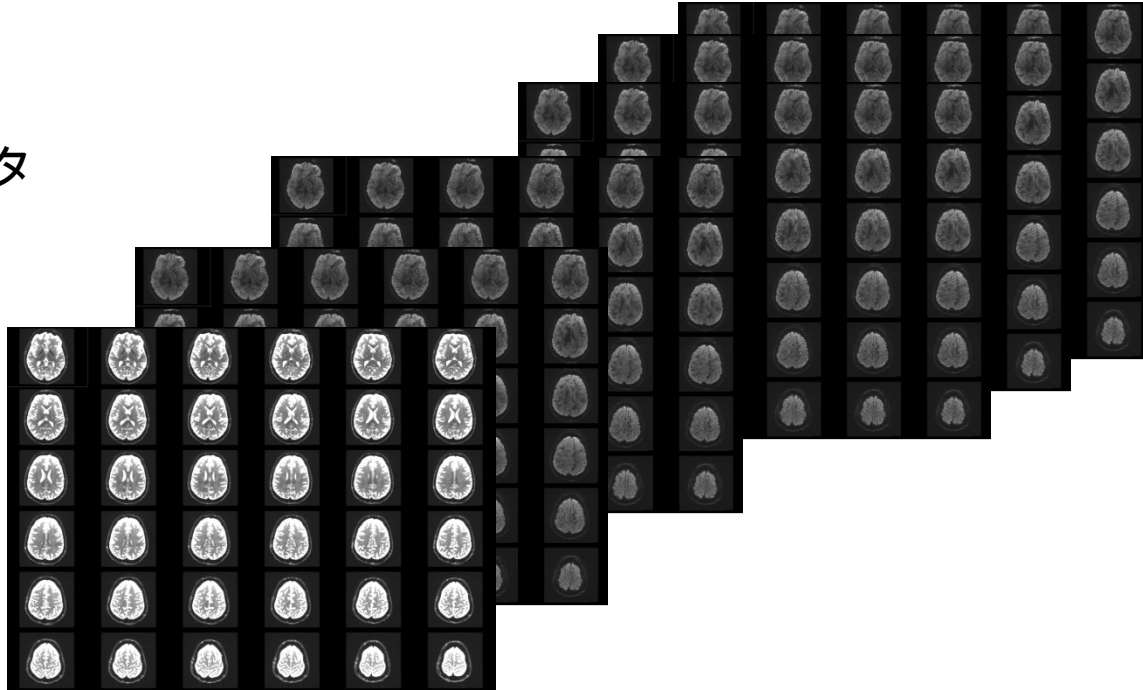
白質神経路

# Tutorial outline

- Part 1: Basics of Diffusion MRI mapping of white matter pathways
- **Part 2: Hands-on Diffusion MRI analysis using 3D Slicer**

# Tutorial DWI Dataset

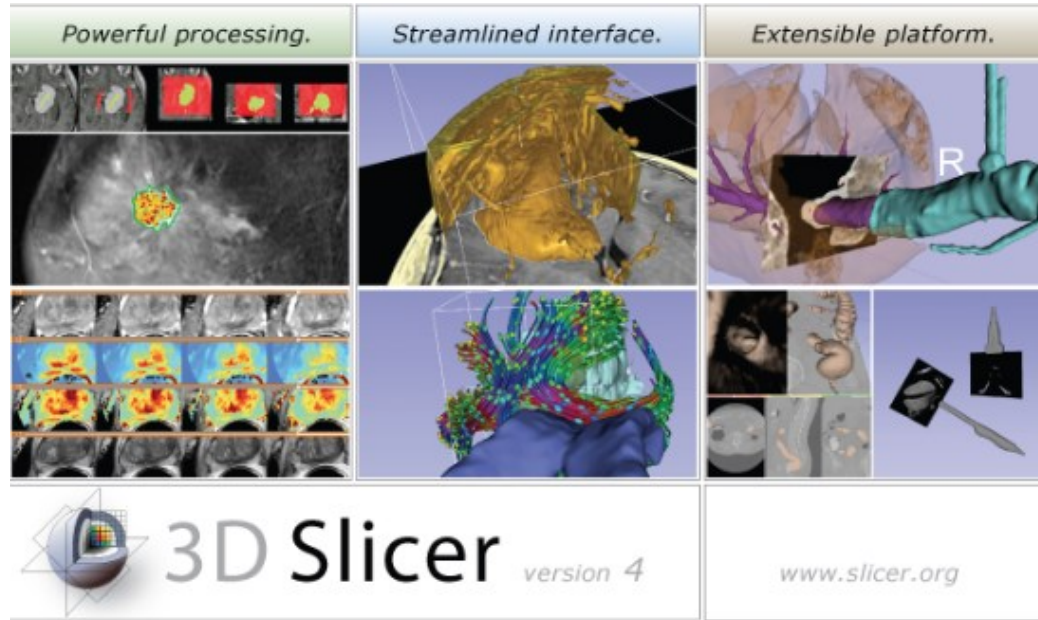
Volume :  
ボリュームデータ  
= 3次元画像



The Diffusion Weighted Imaging (DWI) dataset is composed of 1 volume acquired without diffusion-sensitizing gradient (baseline), and 41 volumes acquired with 41 different diffusion-sensitizing gradient directions.



# Tutorial Software



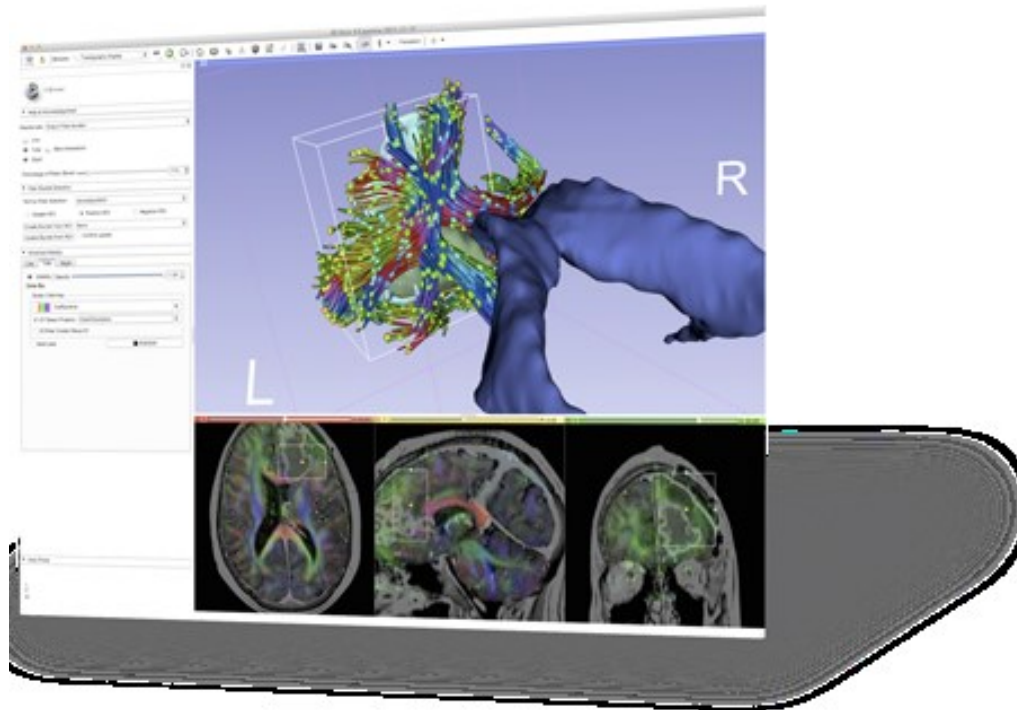
The tutorial uses the 3D Slicer software version 4.3

## *Disclaimer*

It is the responsibility of the user of 3DSlicer to comply with both the terms of the license and with the applicable laws, regulations and rules. Slicer is a tool for research, and is not FDA approved.

# 3D Slicer

オープンソース：  
プログラムのソースコードが公開されている

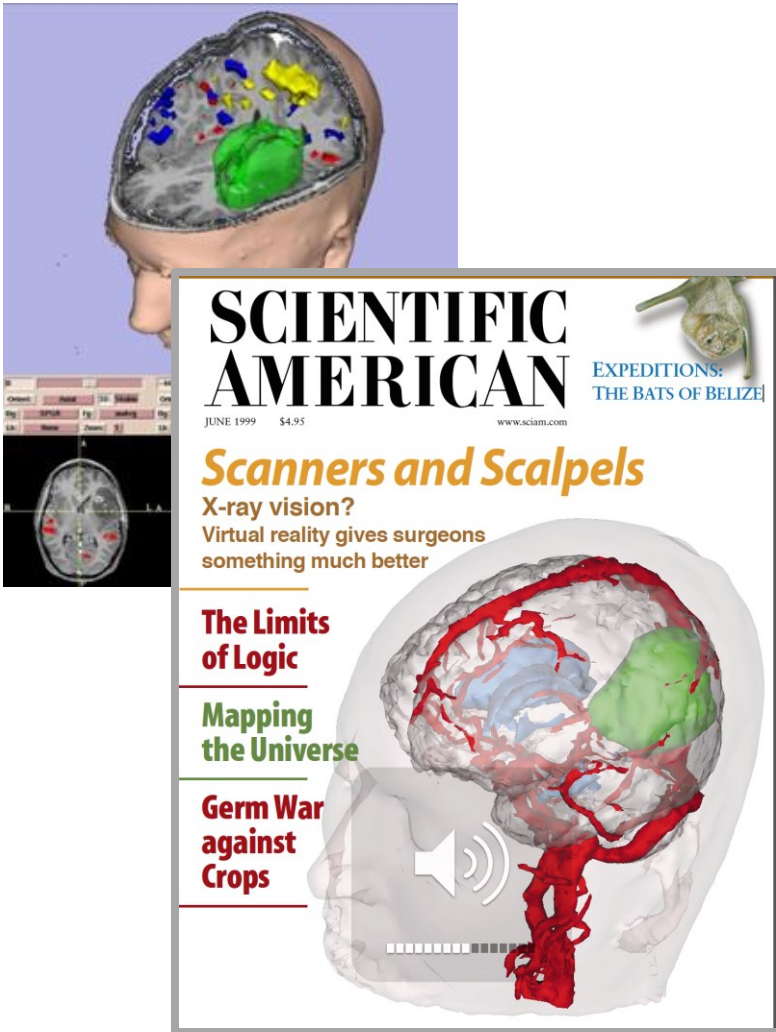


3D Slicer or 'Slicer' is an open-source platform for visualizing, analyzing and interacting with medical imaging data

# 3D Slicer History

- 1997: Slicer starts as a Master's thesis project between Harvard Medical School and the MIT in Boston, MA

Master's thesis: (大学院)修士の学位



# 3D Slicer History



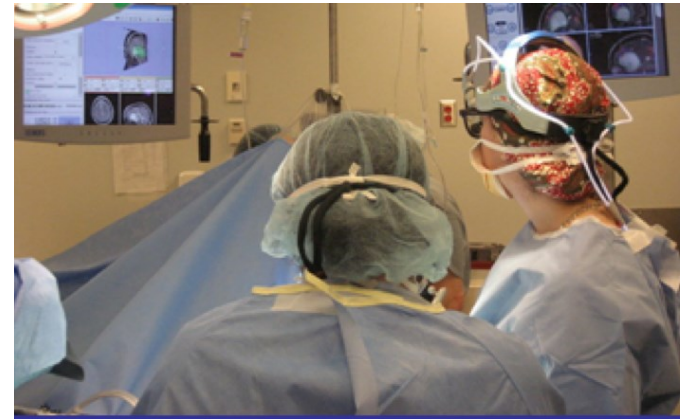
- 1997: Slicer starts as a Master's thesis project between Harvard Medical School and the MIT in Boston, MA
- 2017: Slicer is an open-source software platform for medical research used around the world

学際的な(=様々な専門の人が使える)プラットフォーム(ソフトウェア環境)

# A multi-disciplinary platform



An **open-source platform** for  
imaging scientists



An **end-user application** for  
clinicians

A software platform that is both  
**easy to extend** for scientists & **easy to use**  
for clinicians

# Bridging the gap to accelerate translational research

橋渡しのな研究



$$\frac{\partial}{\partial x_i} \frac{\partial}{\partial x_k} A$$
$$\frac{\partial}{\partial x_k} \sqrt{A} = \sqrt{A_k} + \frac{1}{c} \frac{\partial A_k}{\partial t} + \frac{1}{c^2} \frac{\partial^2 A_k}{\partial t^2} = \frac{1}{c} J_k$$
$$-\nabla^2 A_k + \frac{1}{c^2} \frac{\partial^2 A_k}{\partial t^2} + \frac{\partial}{\partial x_k} \left( \vec{\nabla} \cdot \vec{A} + \frac{1}{c} \frac{\partial \phi}{\partial t} \right) = \frac{4\pi}{c} J_k$$
$$-\nabla^2 \vec{A} + \frac{1}{c^2} \frac{\partial^2 \vec{A}}{\partial t^2} + \vec{\nabla} \left( \vec{\nabla} \cdot \vec{A} + \frac{1}{c} \frac{\partial \phi}{\partial t} \right) = \frac{4\pi}{c} \vec{J}$$

```
doms::log::Logger::write(
    "logger::settings::(doms::1)");
Application app(argc, argv);
app.setDescription("Example application");
app.setOrganizationName("Example");
app.setOrganizationDomain("example.com");
app.setApplicationName("Example");
QString settings;
QString databaseDirectory;
// set up the database
if (argc > 1)
{
    QString directory(QString::fromStdString(argv[1]));
    settings.setDatabaseDirectory(directory);
    settings.sync();
}
if (! settings.value("databaseDirectory", "").toString().isEmpty())
{
    databaseDirectory = settings.value("databaseDirectory").toString();
    QString currentDir = QDir::currentPath();
    QString currentDirRelative = QDir::currentPath().replace(currentDir, "");
    databaseDirectory = settings.value("databaseDirectory", "").toString().replace(currentDir, currentDirRelative);
}
databaseDirectory = settings.value("databaseDirectory", "").toString();
```



Image courtesy of Arya Nabavi, MD

Problem solving

問題解決

Algorithm Development

アルゴリズム開発

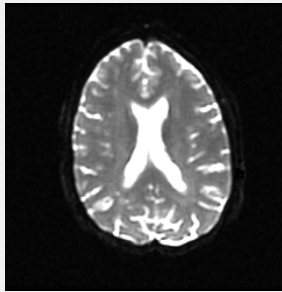
# 3D Slicer Community



- Clinicians 臨床医
- Clinical researchers 臨床研究者
- Engineers
- Postdoctoral fellows ポスドク
- Medical Students
- Engineering students
- Software developers
- Staff researchers 教員
- MR Technologists MRIの技術者

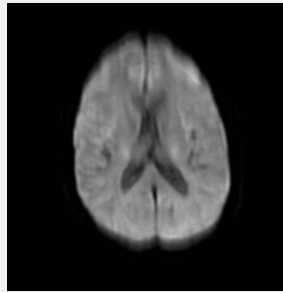
# MR Diffusion Analysis Pipeline

パイプライン=処理の手順



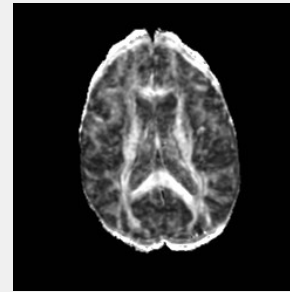
DWI  
Acquisition

拡散強調像取得



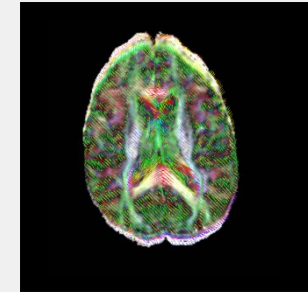
Tensor  
Calculation

拡散テンソル計算



Scalar  
Maps

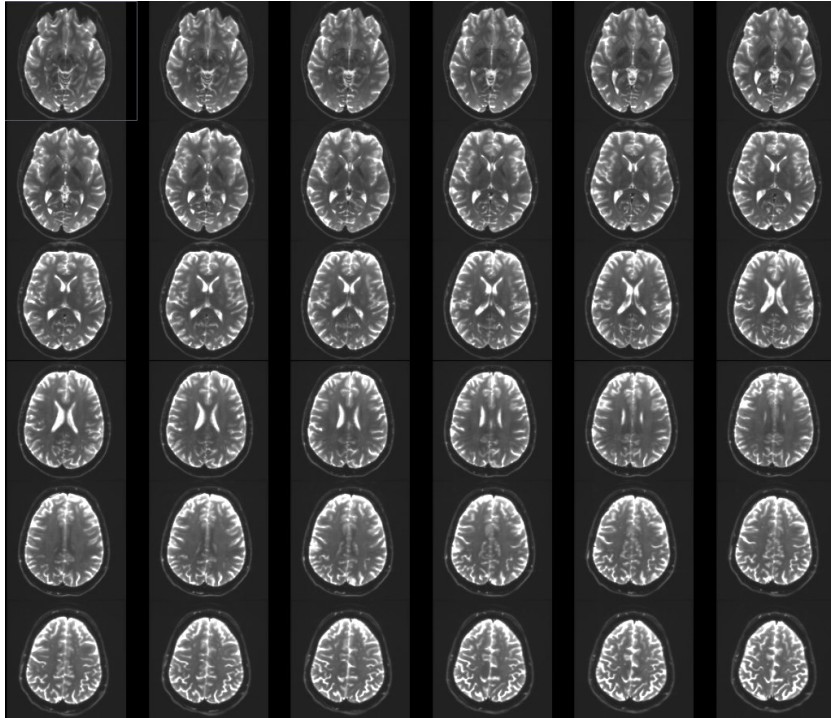
スカラ画像=  
拡散に関する  
画像特徴



3D  
Visualization

3次元可視化

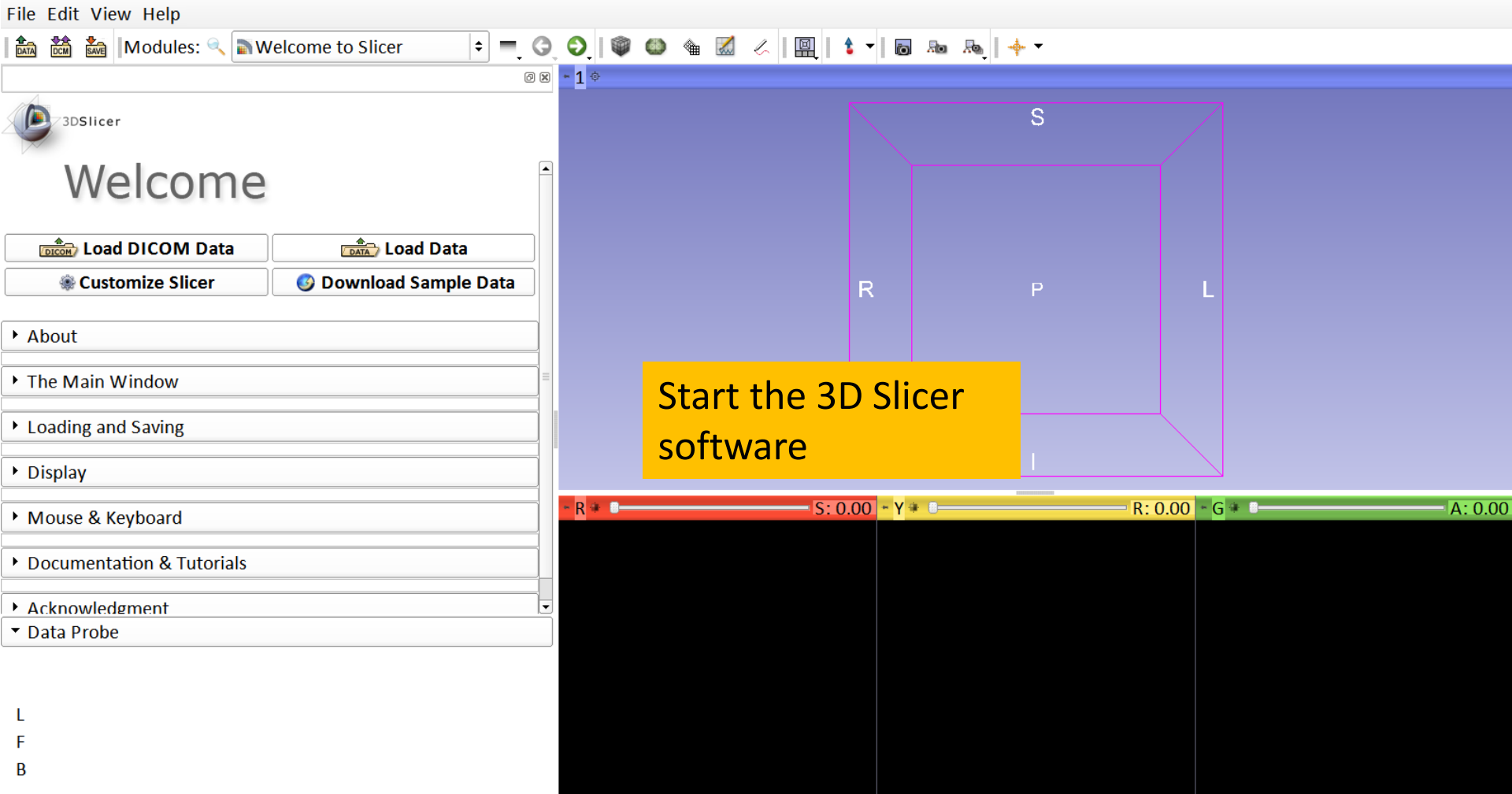




# Step 1: Loading the DWI dataset and mask

データの読み込みとマスキング

# Loading the DWI Dataset



# Loading the DWI Dataset

File Edit View Help

DATA DCM SAVE Modules: Welcome to Slicer

3DSlicer

## Welcome

Load DICOM Data

Customize Slicer

- About
- The Main Window
- Loading and Saving
- Display
- Mouse & Keyboard
- Documentation & Tutorials
- Acknowledgment
- Data Probe

DiffusionMRI\_tutorialData

Name	Date Modified	Size	Kind
dwi.raw.gz	30 Jan 2012 04:52 pm	67,7 MB	gzip c...a
dwi.nhdr	30 Jan 2012 04:52 pm	3 KB	TextEd...

Open the directory **DiffusionMRI\_tutorialData** and select the file **dwi.nhdr**

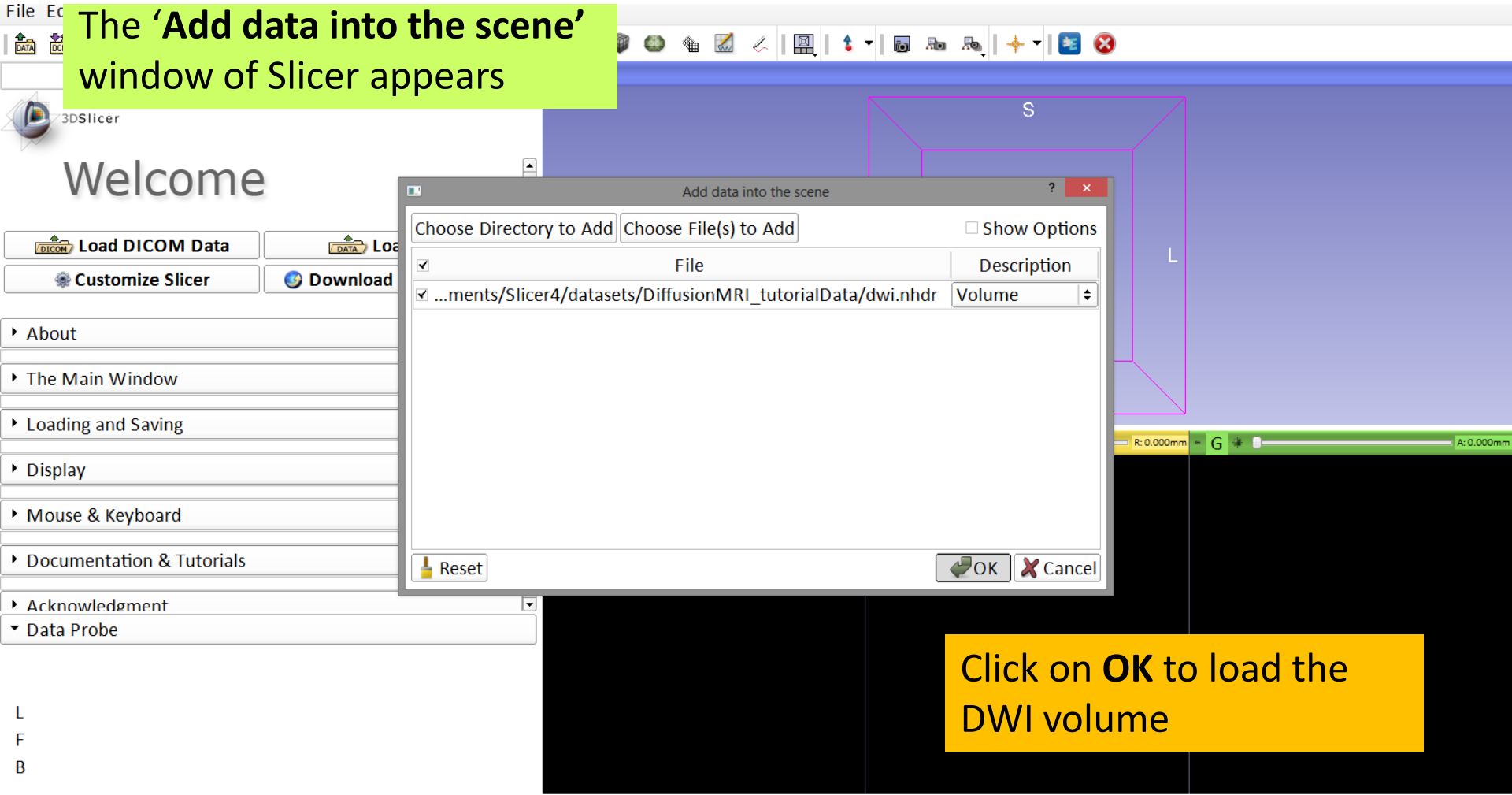
Drag and drop the file **dwi.nhdr** onto the viewer of Slicer

A: 0.000mm

L  
F  
B

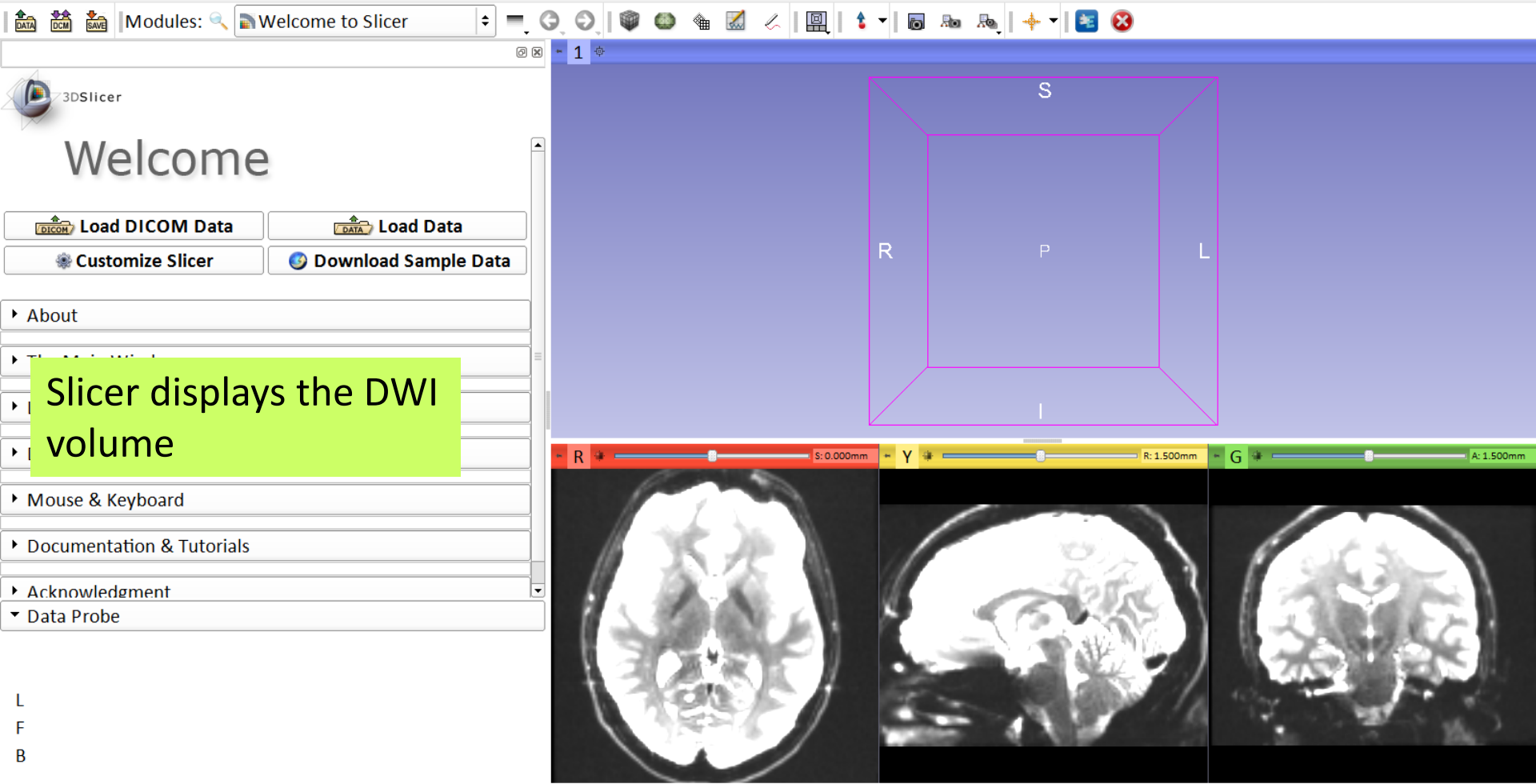
# Loading the DWI Dataset

The 'Add data into the scene' window of Slicer appears



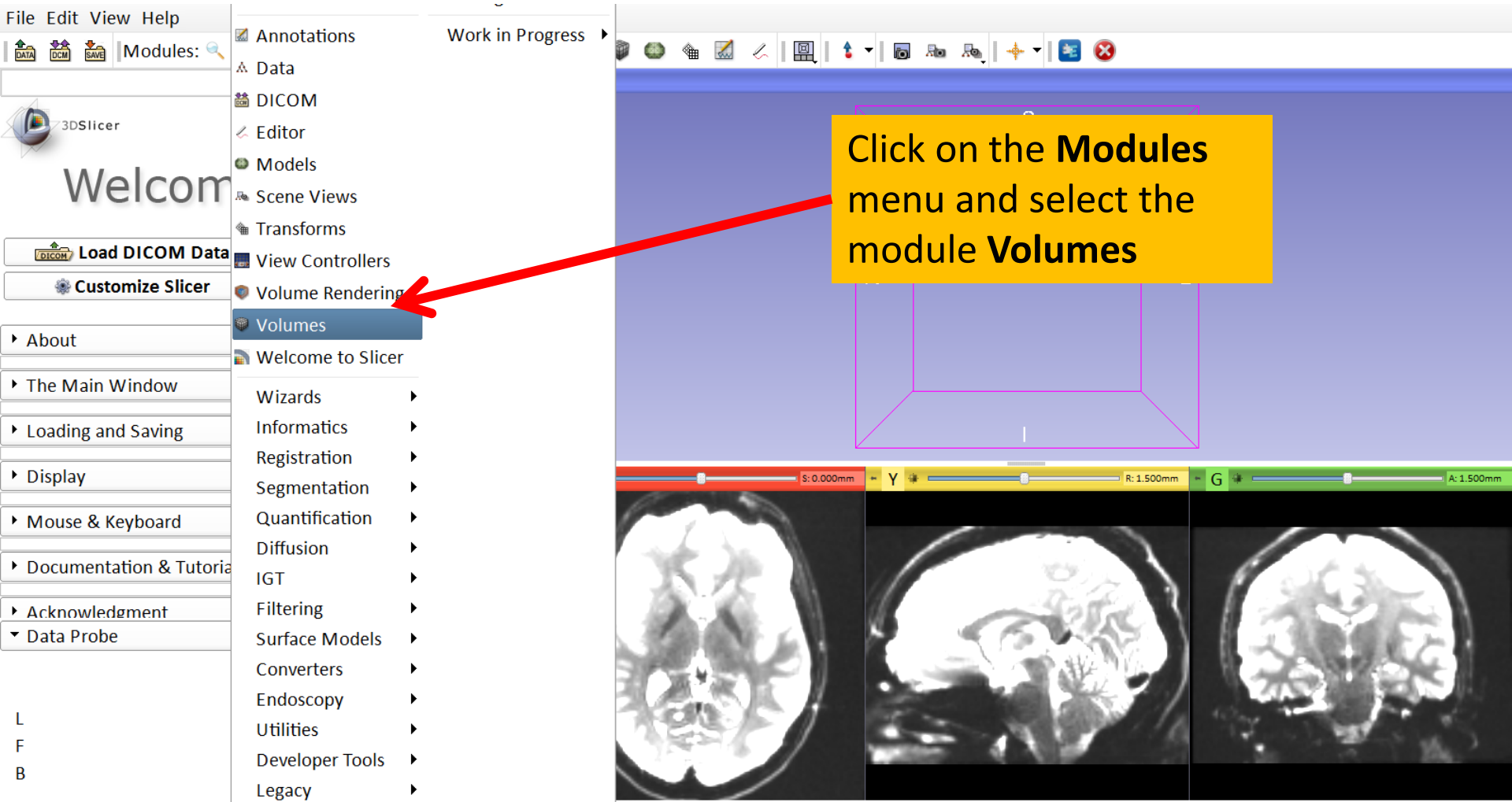
# Loading the DWI Dataset

File Edit View Help

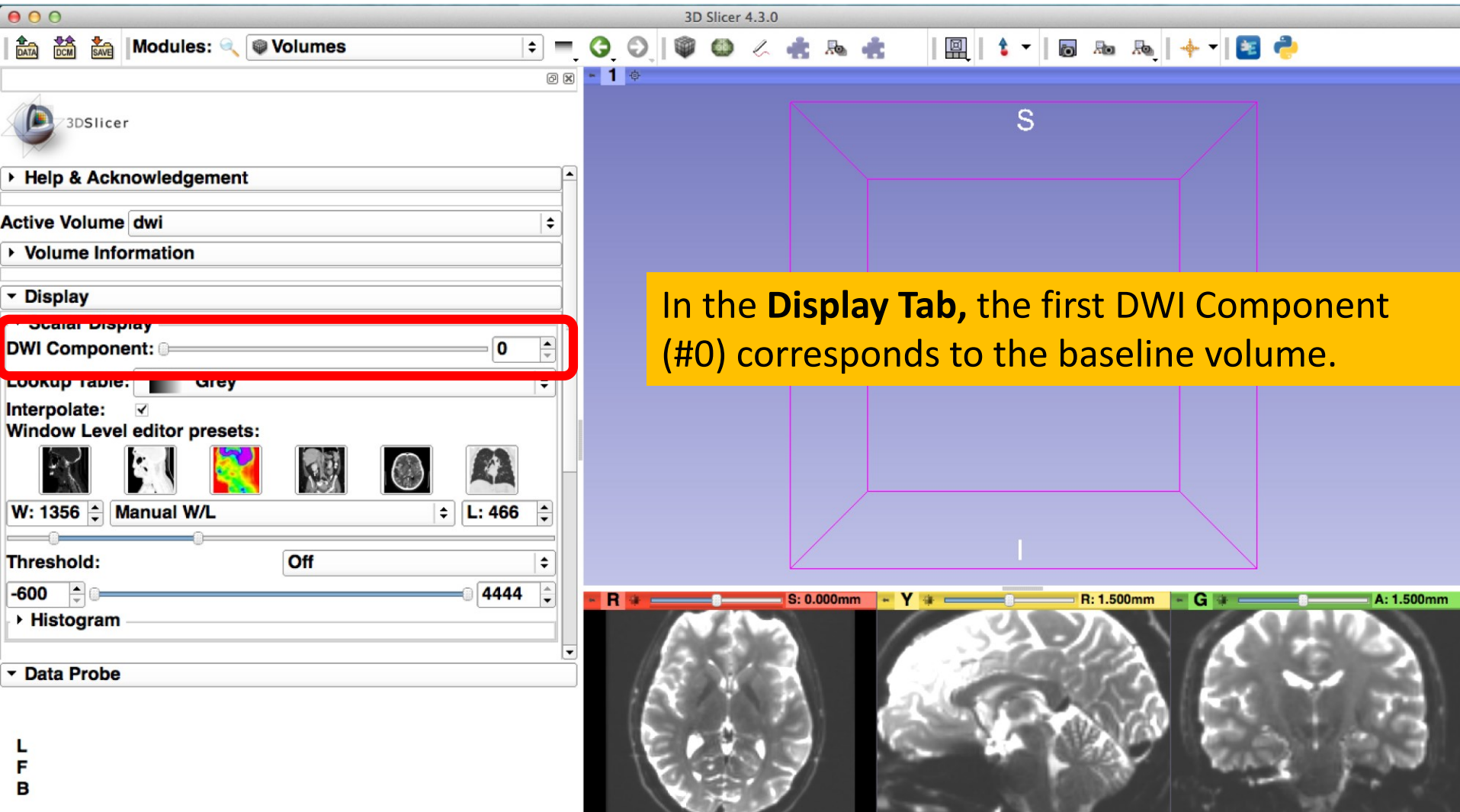


Slicer displays the DWI volume

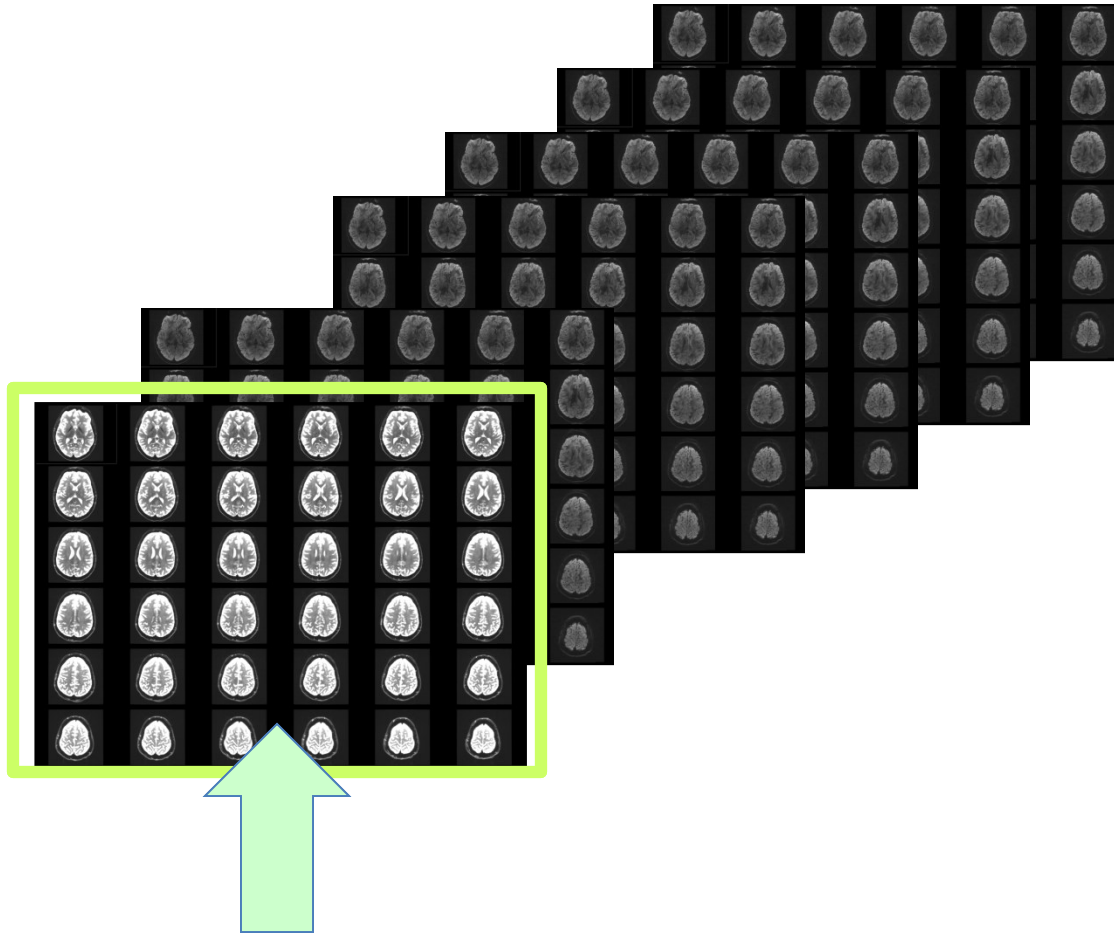
# Loading the DWI Dataset



# Loading the DWI dataset



# Tutorial DWI Dataset



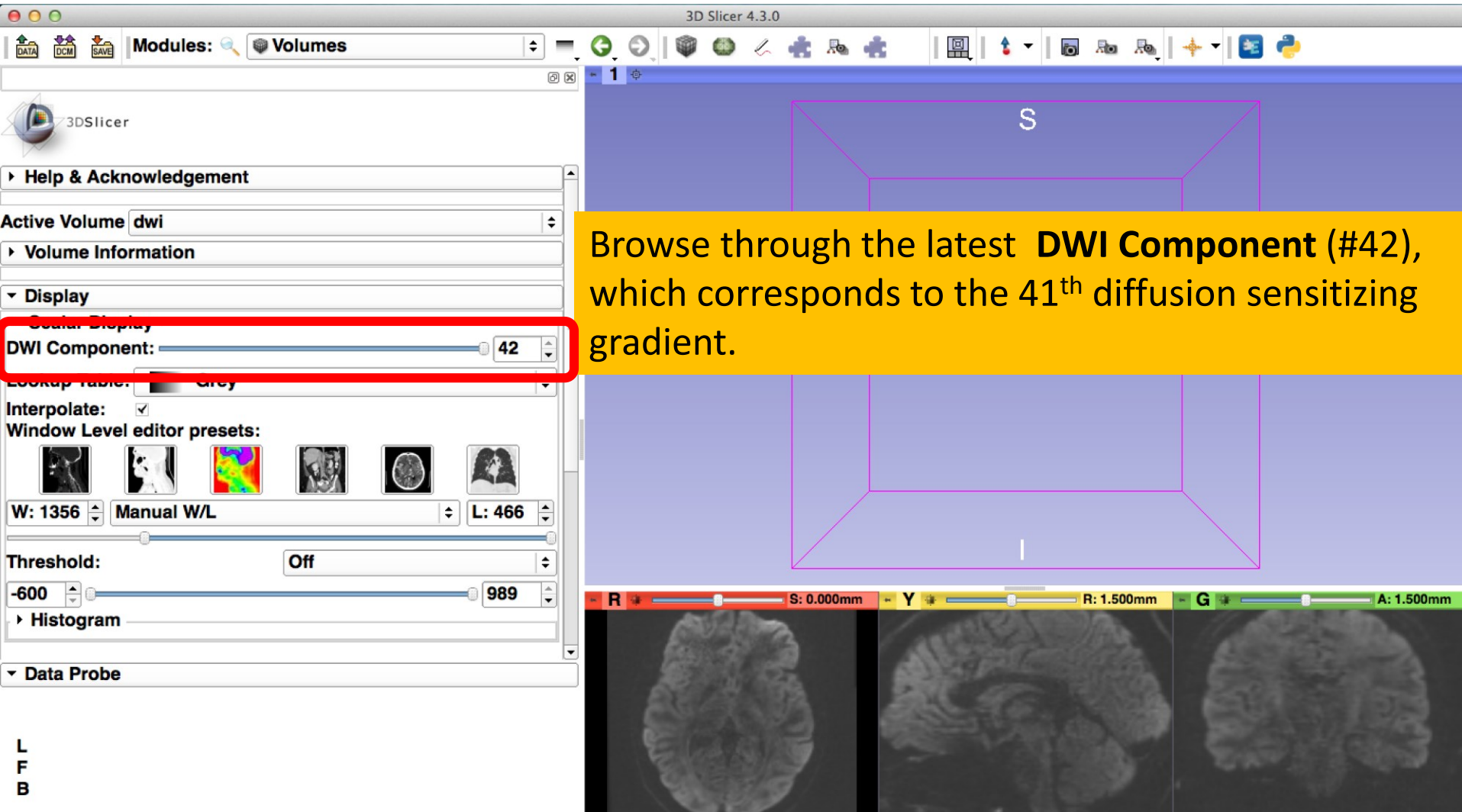
Baseline Volume

基準ボリューム

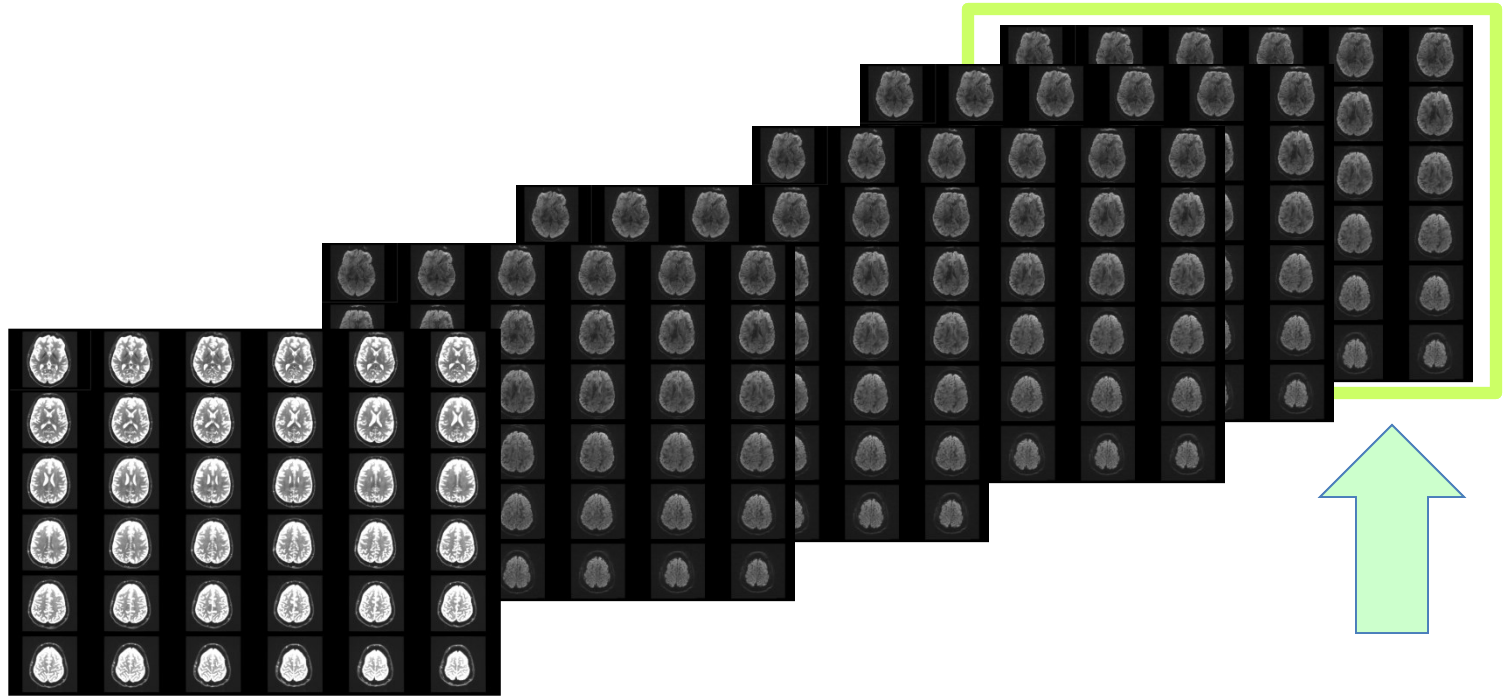
Diffusion MRI Analysis of the Human Brain,  
S.Pujol, ARR 2012-2017



# Loading the DWI dataset



# Tutorial DWI Dataset



42th diffusion  
sensitizing  
gradient

42番目の(方向の)拡散検出磁場

# Loading the DWI Dataset

File Edit View Help

DATA DCM SAVE Modules: Volumes

3DSlicer

Help & Acknowledgement

Active Volume: dwi

Volume Information

Display

Scalar Display

DWI Component: 10

Lookup Table: Grey

Interpolate:

Window Level editor presets:

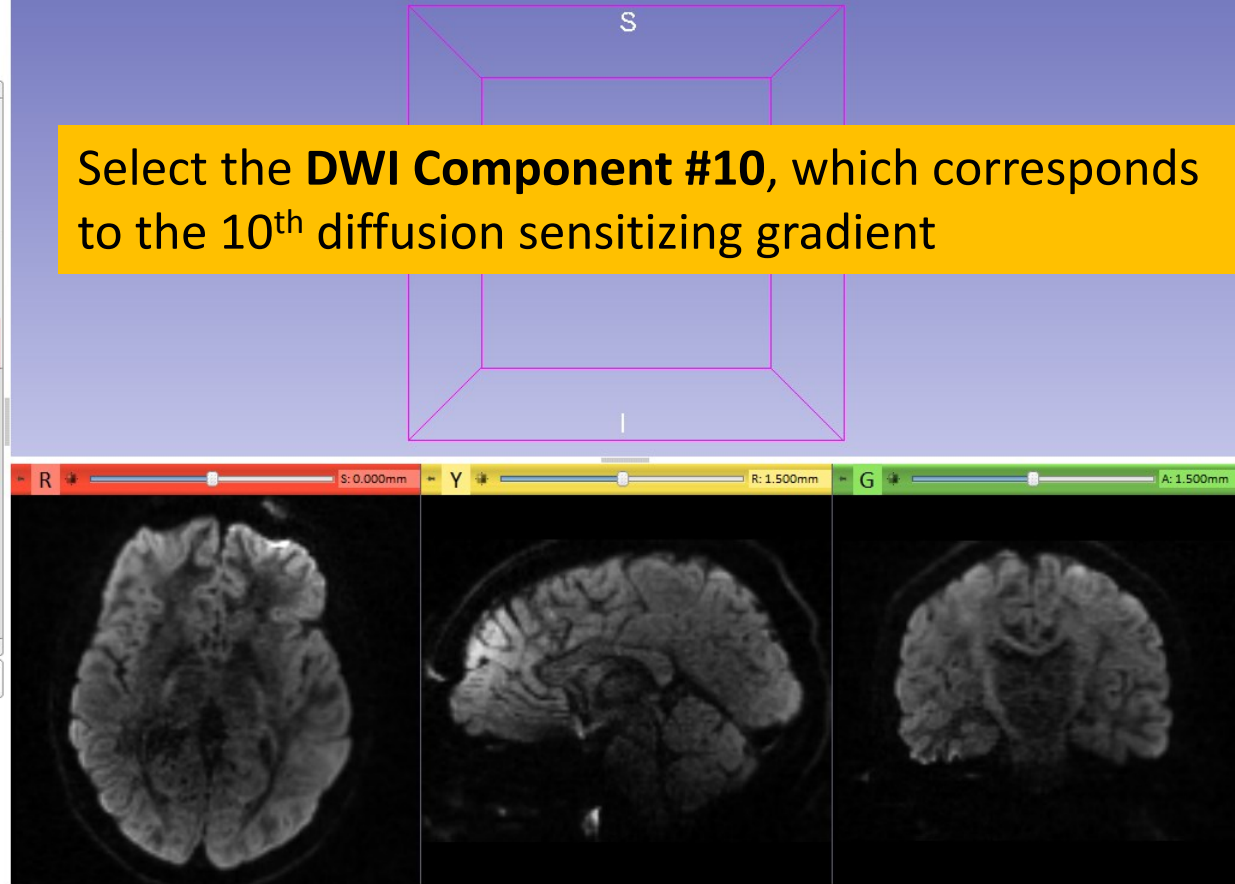


W: 771 Manual W/L L: 454

Threshold: Off

Data Probe

L  
F  
B



# Loading the DWI Dataset

File Edit View Help

3DSlicer

Active Volume: dwi

Volume Information

Display


Scalar Display

DWI Component: 10

Lookup Table: Grey

Interpolate:

Window Level editor presets:




W: 771 Manual W/L L: 454

Threshold: Off

Data Probe

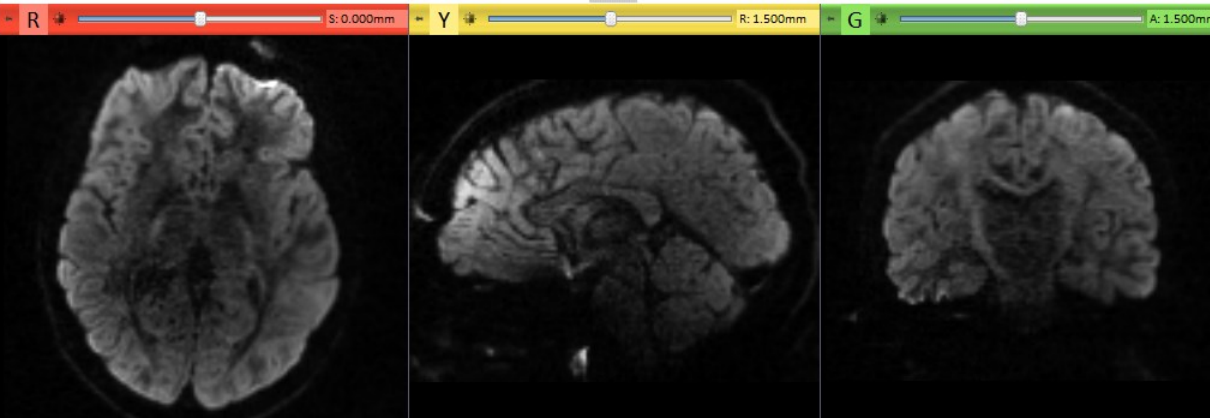
Adjust the **Window Level editor presets** with the **Volume** module menu

Window Level editor:  
明るさ・コントラスト調整エディタ



R S P L I

R: 0.000mm Y: 1.500mm G: 1.500mm A: 1.500mm



# Loading the DWI Dataset

File Edit View Help  
Modules: Volumes

3DSlicer

Help & Ackn

Active Volume

Volume Info

Display

Scalar Displa

DWI Compone

Lookup Table: Grey

Interpolate:

Window Level editor presets:

W: 771 Manual W/L L: 454

Threshold: Off

Data Probe

L  
F  
B

1. 2. 3.

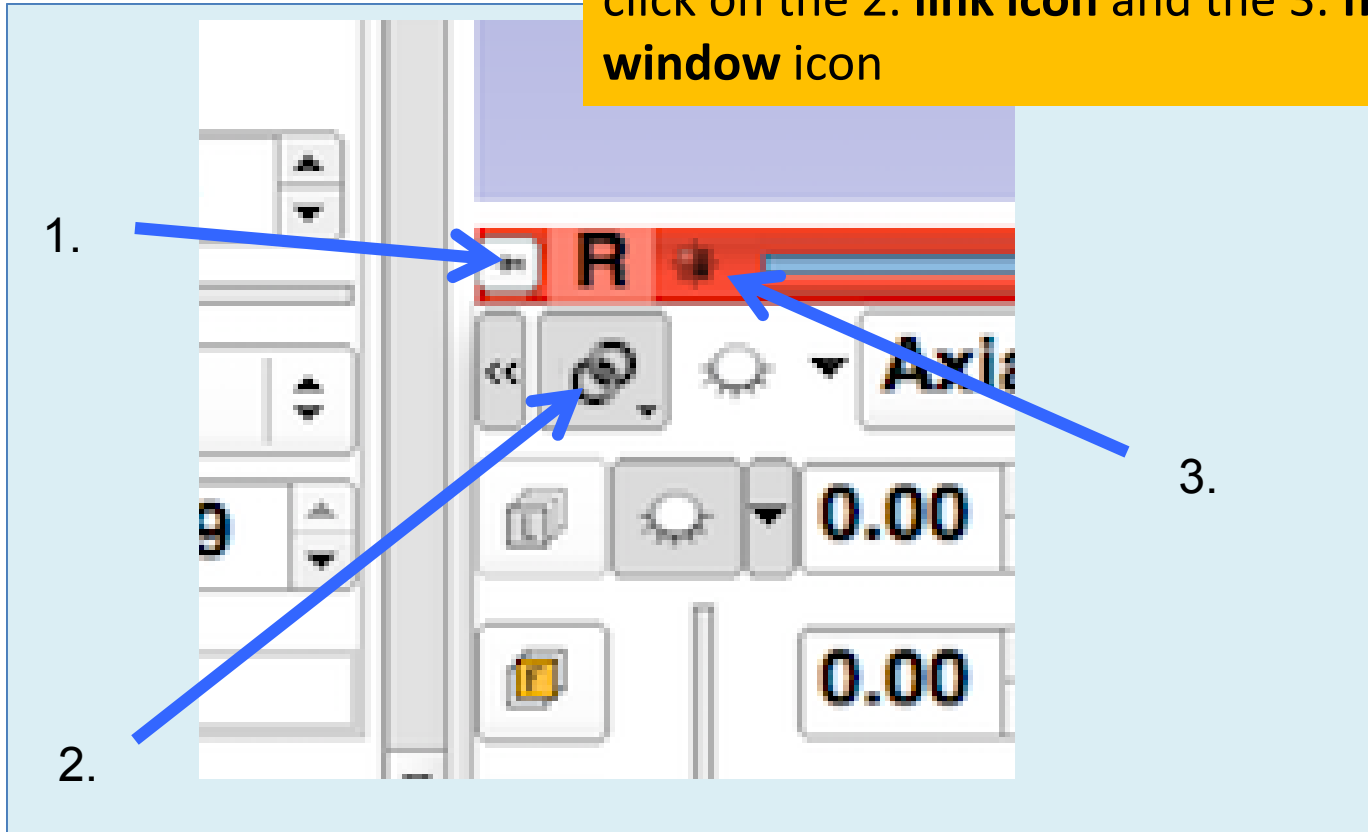
R P L

R: -0.750mm Y R: 0.750mm G A: 0.750mm

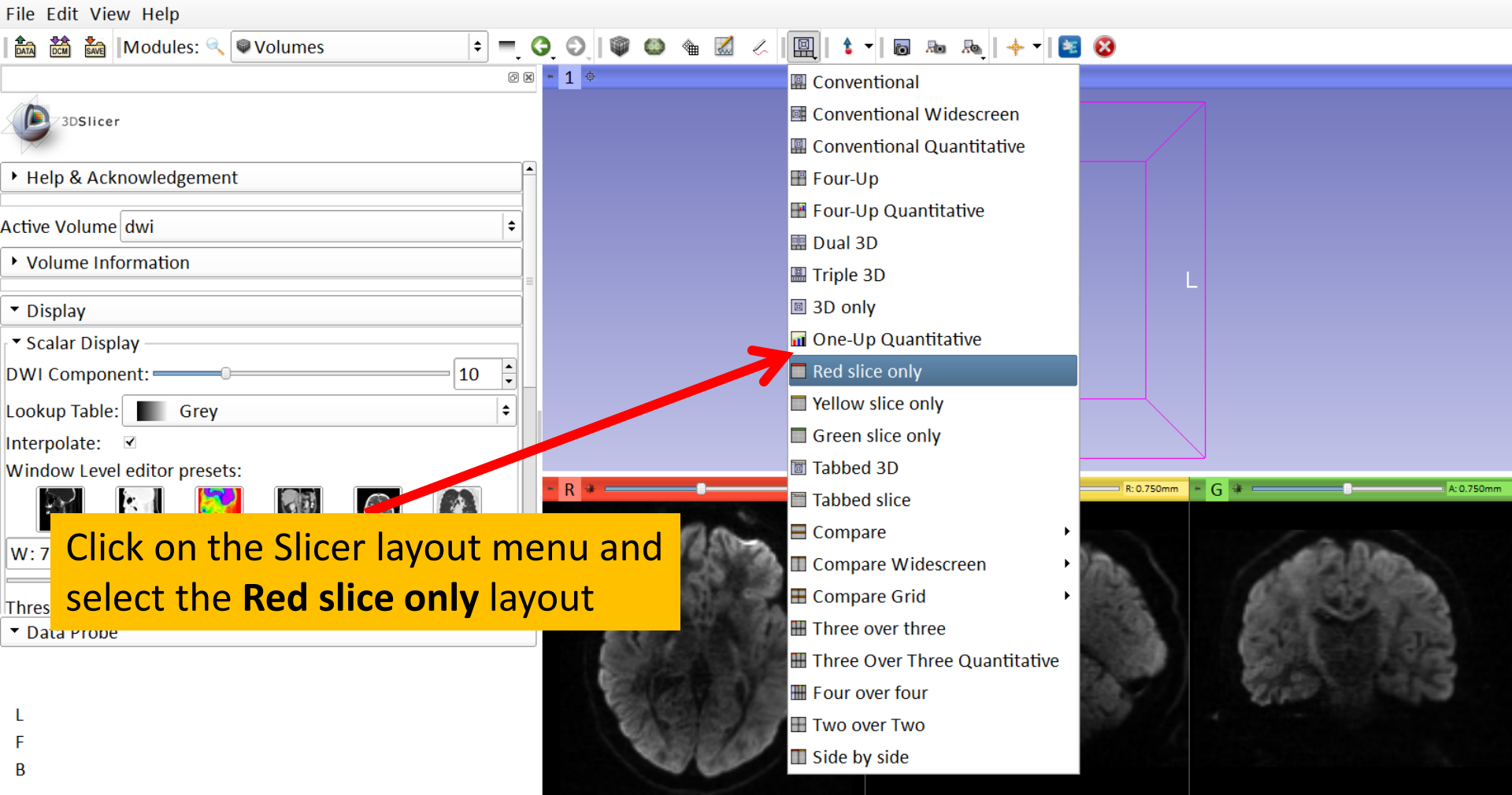
Axial dwi

# Loading the DWI Dataset

Position your mouse over the 1. **pin icon**, then click on the 2. **link icon** and the 3. **fit image to window icon**



# Loading the DWI Dataset



# Loading the DWI Dataset

File Edit View Help

DATA DCM SAVE Modules: Volumes

3DSlicer

Help & Acknowledgement

Active Volume dwi

Volume Information

Display

Slice through the volume to inspect the DWI data

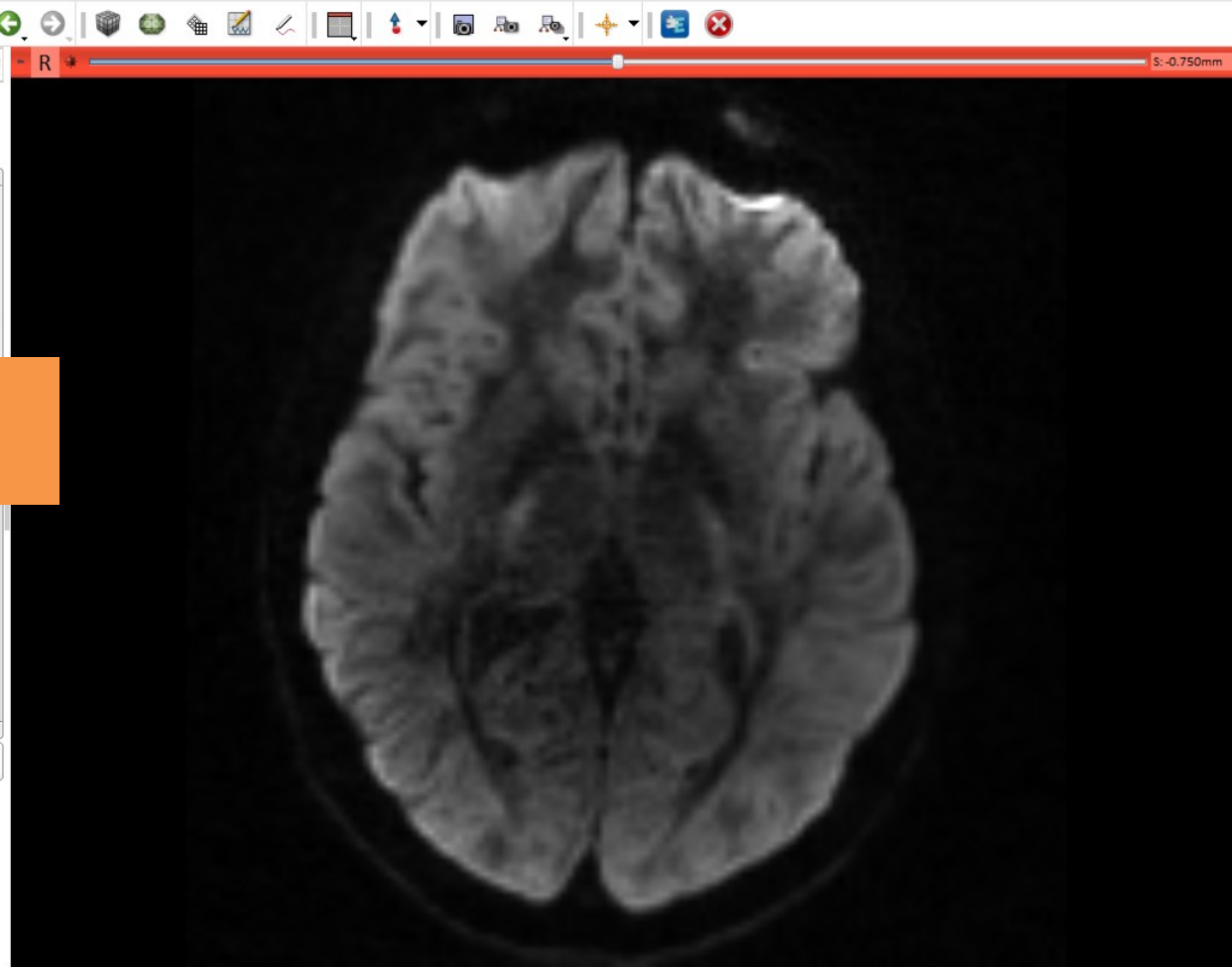
Interpolate:

Window Level editor presets:

W: 771 Manual W/L L: 454

Threshold: Off

Data Probe

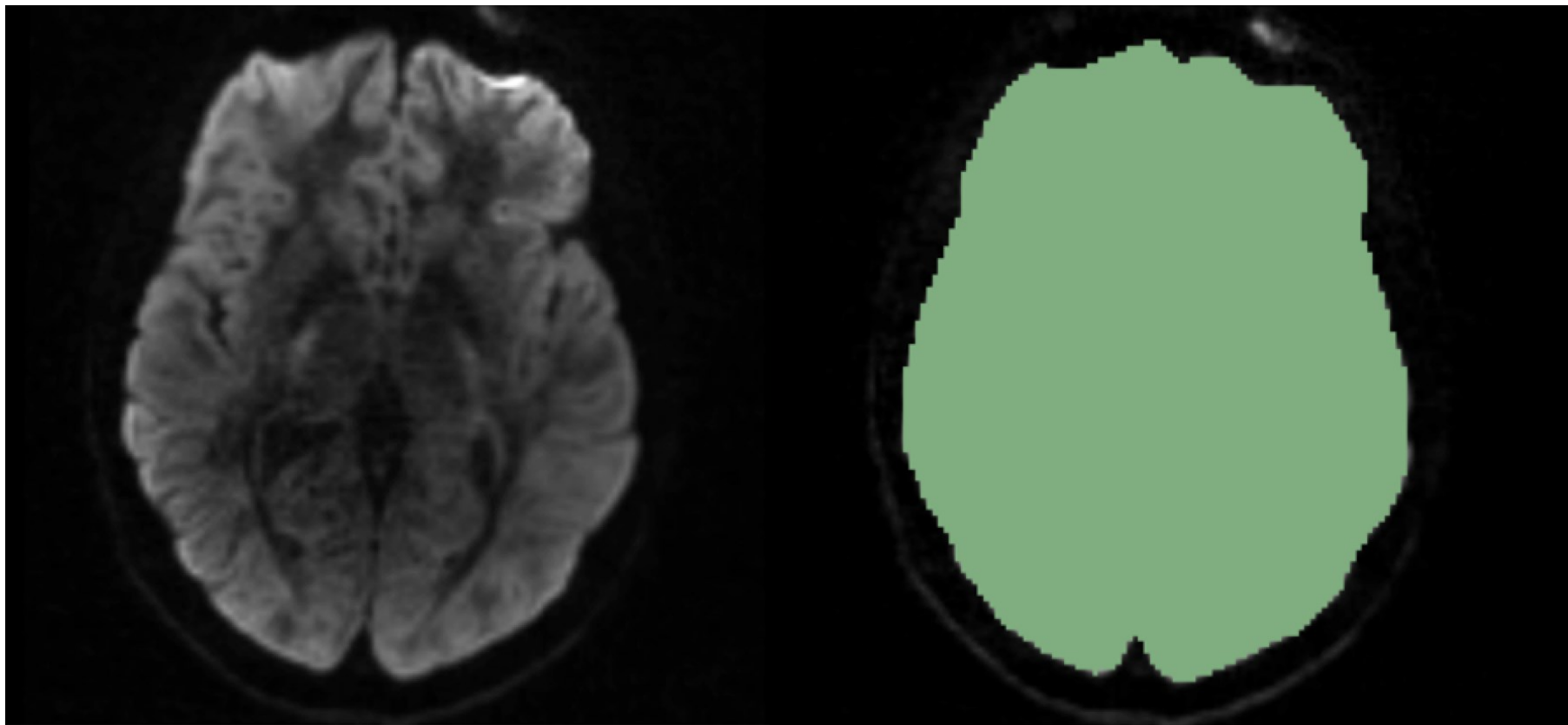


Inspect:  
しらべる

Diffusion MRI Analysis of the Human Brain,  
S.Pujol, ARR 2012-2017



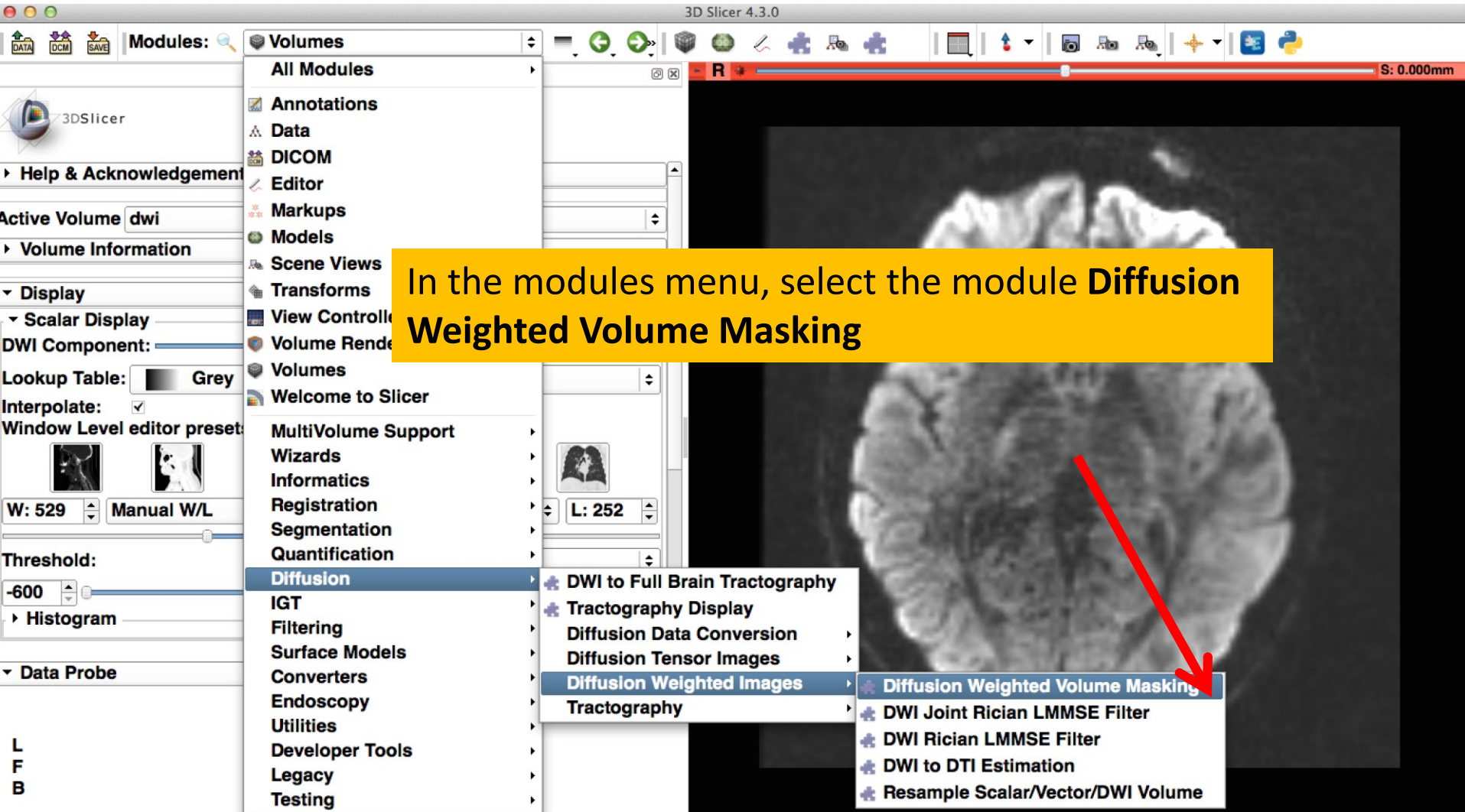
# DWI Dataset and DWI Mask



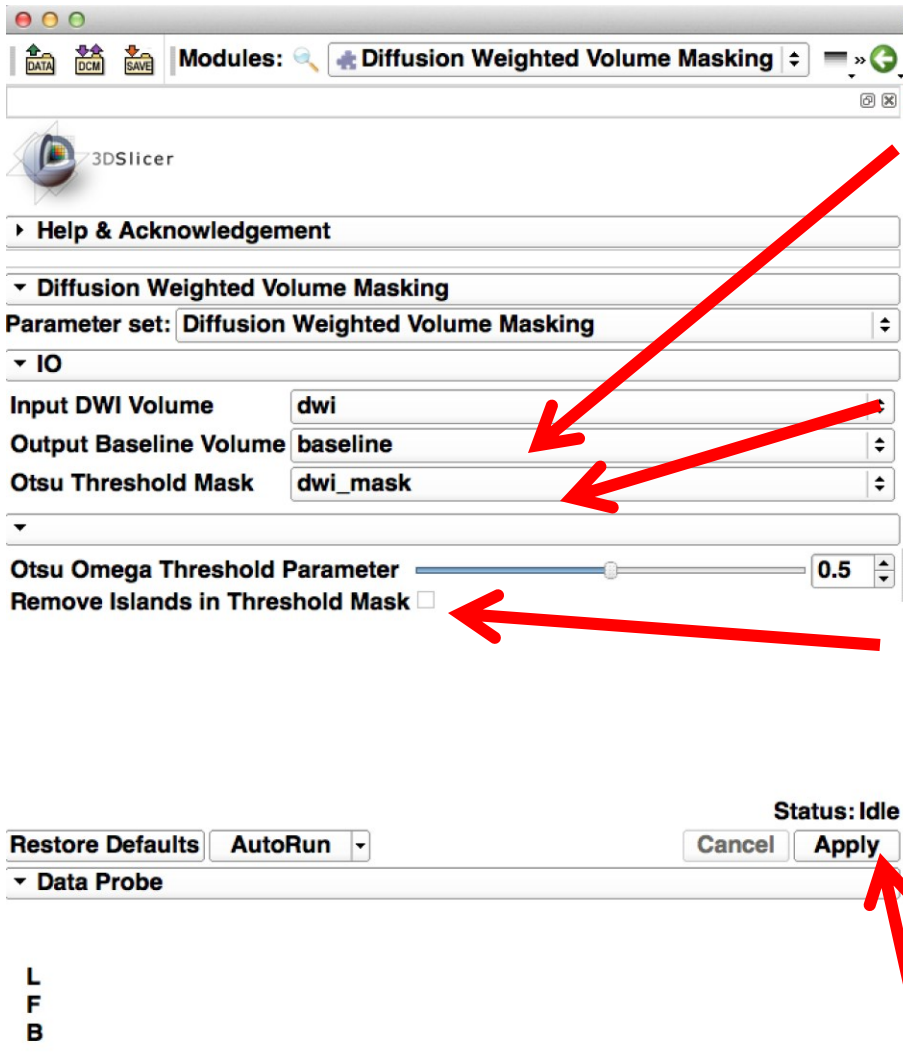
Diffusion MRI Analysis of the Human Brain,  
S.Pujol, ARR 2012-2017

マスク:  
処理の範囲を  
限定するエリア

# Creating the DWI Mask



# Creating the DWI Mask



The screenshot shows the 3D Slicer 4.3.0 interface with the Diffusion Weighted Volume Masking module active. The parameter set is 'Diffusion Weighted Volume Masking'. The 'IO' section is expanded, showing the following settings:

- Input DWI Volume: dwi
- Output Baseline Volume: baseline
- Otsu Threshold Mask: dwi\_mask
- Otsu Omega Threshold Parameter: 0.5
- Remove Islands in Threshold Mask:

At the bottom of the module, there are buttons for 'Restore Defaults', 'AutoRun', 'Cancel', and 'Apply'. The status is 'Idle'. Red arrows point from the text on the right to these specific settings in the interface.

1. Select **Output Baseline Volume** to **'Create and rename New Volume'**, and rename it **baseline**

2. Select Otsu Threshold Mask to **'Create and rename New Volume'**, and rename it **baseline** rename:  
名称変更

3. Uncheck **Remove Islands in Threshold Mask** uncheck:  
チェックを外す

4. Click on **Apply**



# Loading the DWI Mask

3D Slicer 4.3.0

Modules: Diffusion Weighted Volume Masking

3DSlicer

Help & Acknowledgement

Diffusion Weighted Volume Masking

Parameter set: Diffusion Weighted Volume Masking

IO

Input DWI Volume: **dwi**

Output Baseline Volume: baseline

Otsu Threshold Ma

Otsu Omega Thres

Remove Islands in

Status: Completed 100%

Restore Defaults AutoRun Cancel Apply

Data Probe

L  
F  
B

S: 0.000mm

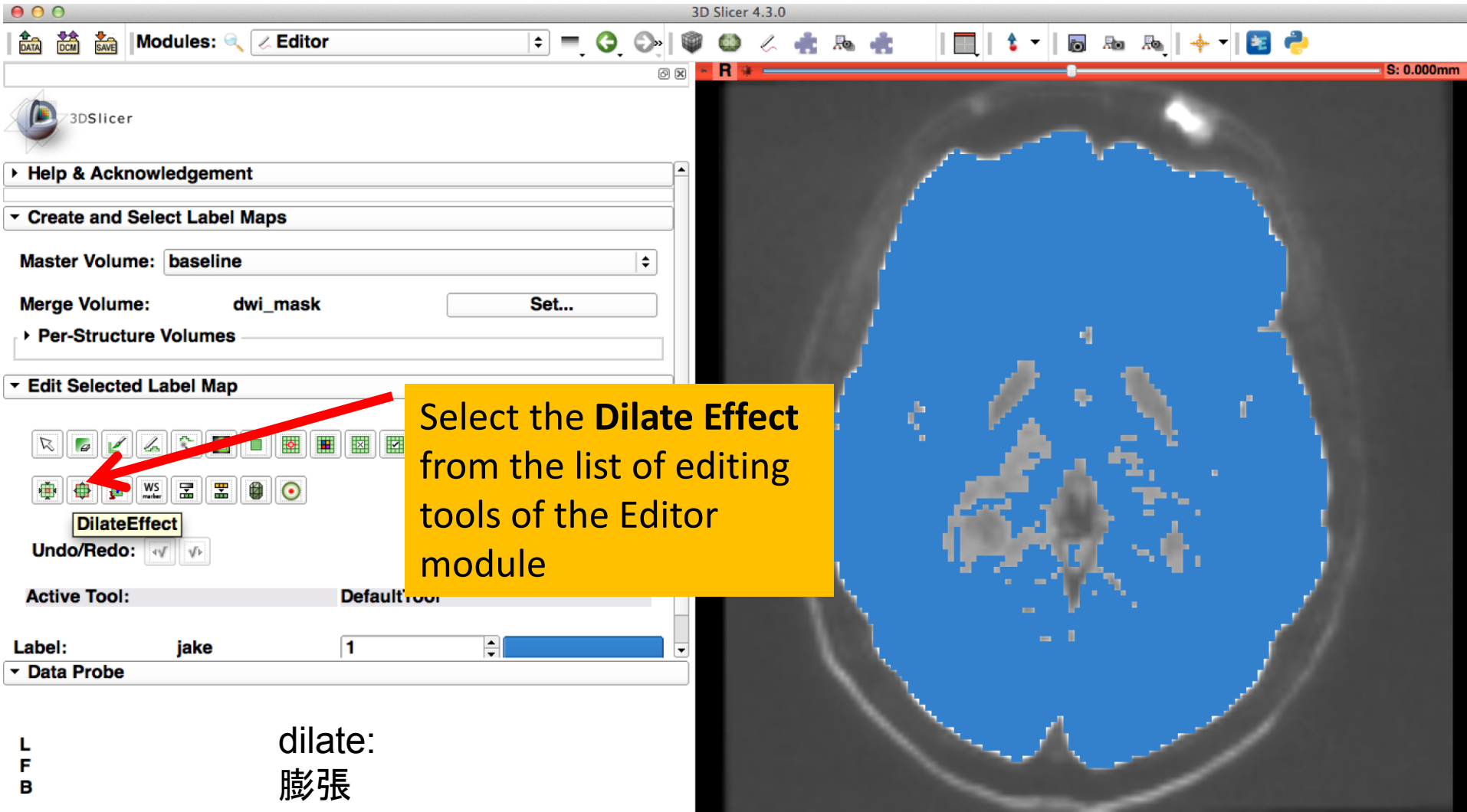
The **dwi\_mask** appears in the Red Slice viewer overlaid on the DWI image

# Loading the DWI Mask

The screenshot shows the 3D Slicer 4.3.0 interface. The 'Modules' dropdown menu is set to 'Editor', indicated by a red arrow. A yellow callout box says 'Select the Editor module from the main'. In the center, a 'Set' dialog box is open, containing the text: 'Create a merge label map for selected master volume baseline. New volume will be baseline-label. Select the color table node will be used for segmentation labels.' The 'GenericAnatomyColors' color table is selected in the dropdown. A red arrow points to the 'Apply' button, with a yellow callout box saying 'Click on Apply'. The background shows a brain slice with a blue mask. The interface includes a top toolbar, a left sidebar with 'Help & Acknowledgement', 'Create and Select Label Maps', and 'Edit Selected Label Map' sections, and a bottom status bar with 'L', 'F', and 'B' orientation indicators.



# Loading the DWI Mask



3D Slicer 4.3.0

Modules: Editor

3DSlicer

Help & Acknowledgement

Create and Select Label Maps

Master Volume: baseline

Merge Volume: dwi\_mask Set...

Per-Structure Volumes

Edit Selected Label Map

DilateEffect

Undo/Redo: [undo] [redo]

Active Tool: Default tool

Label: jake 1

Data Probe

L  
F  
B

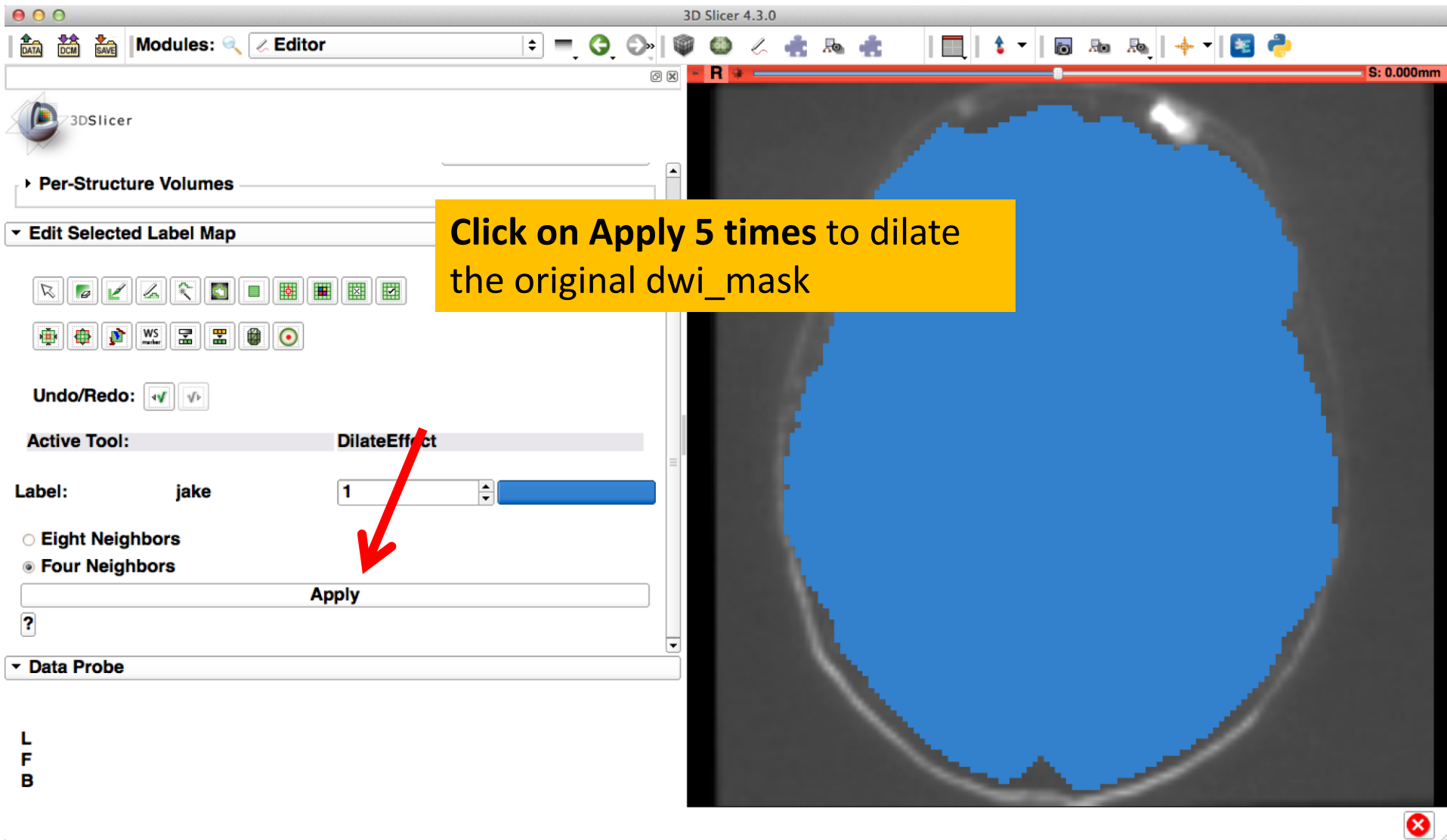
dilate:  
膨張

S: 0.000mm

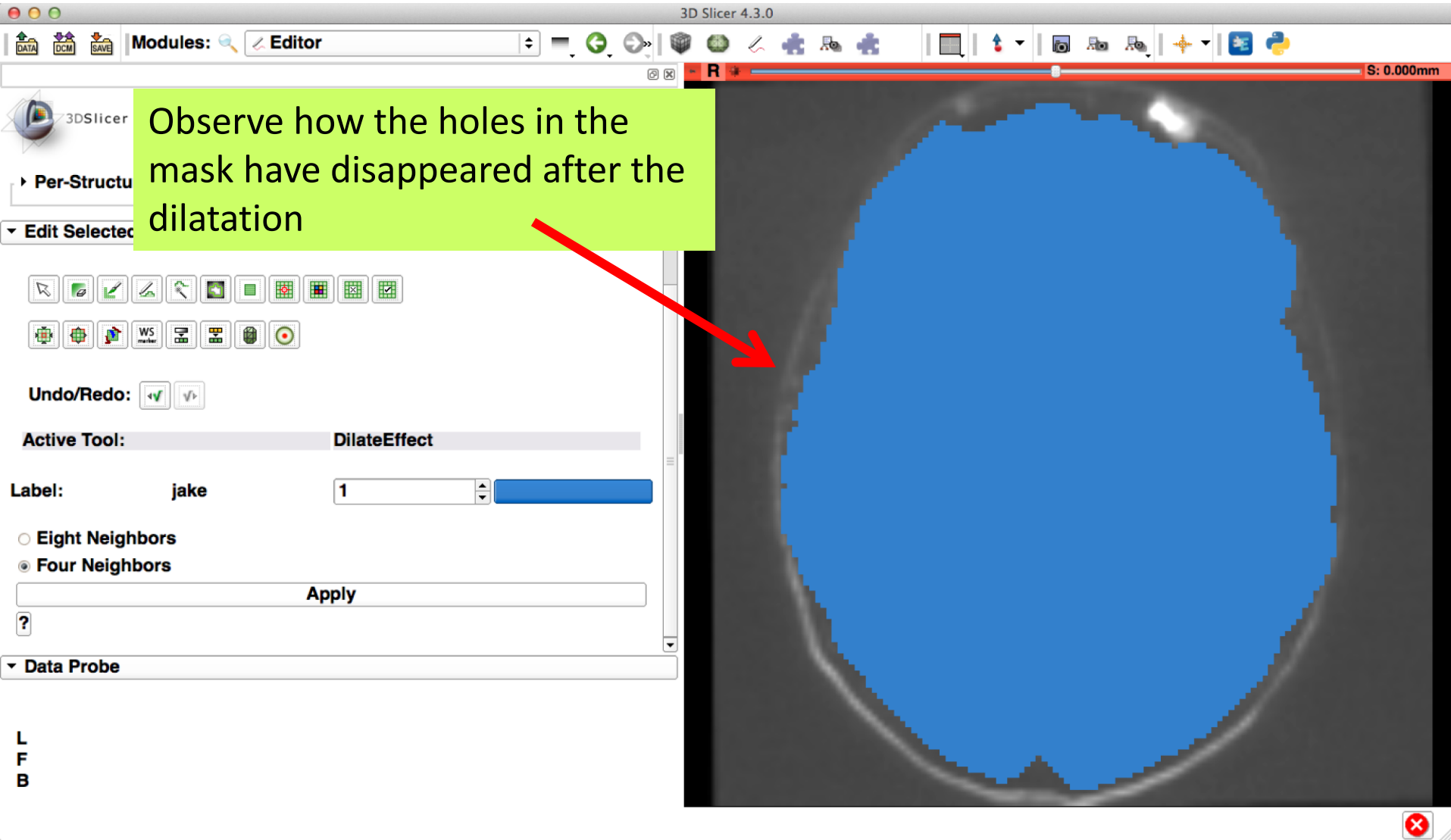
Select the **Dilate Effect** from the list of editing tools of the Editor module



# Loading the DWI Mask

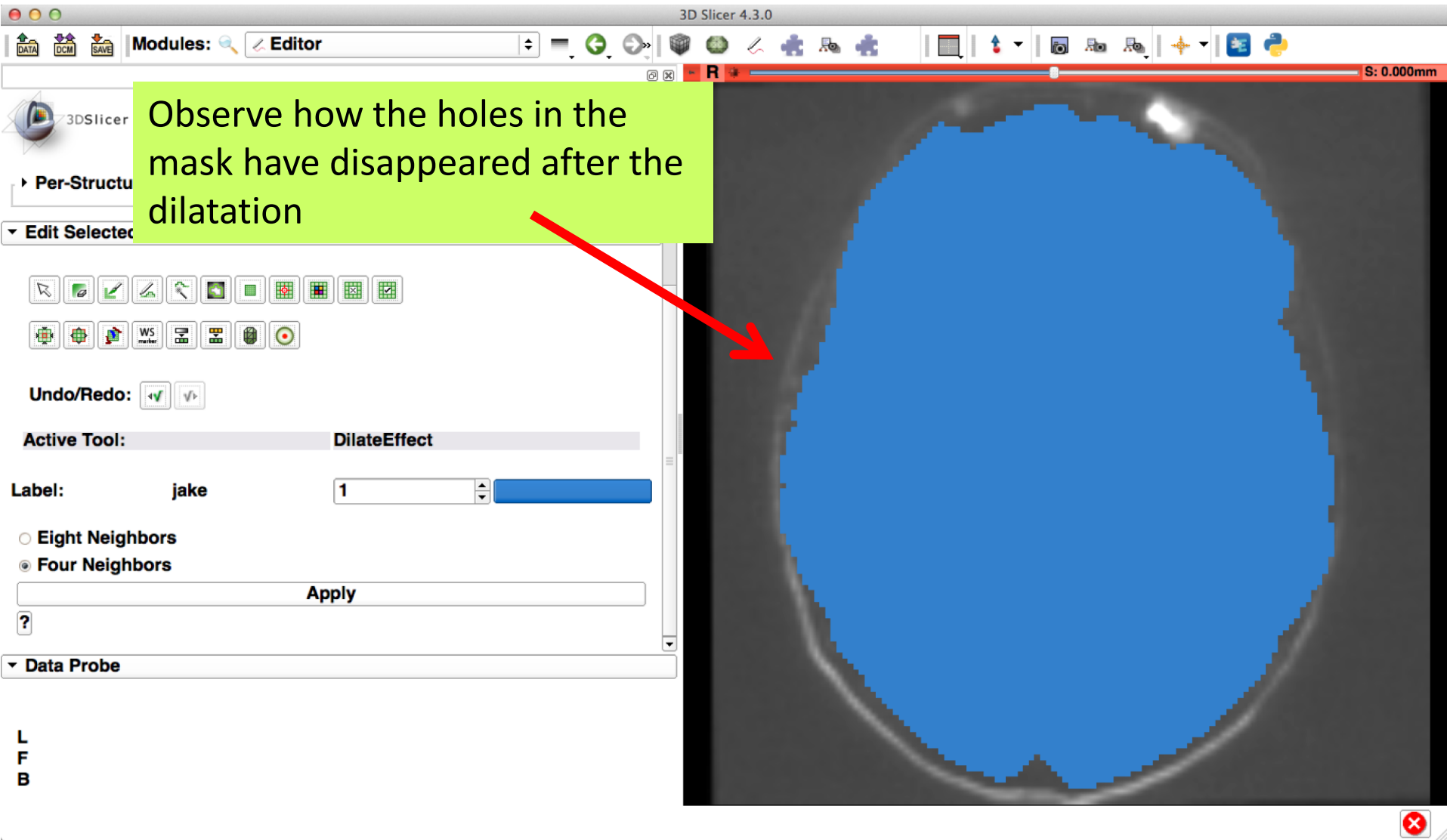


# Loading the DWI Mask

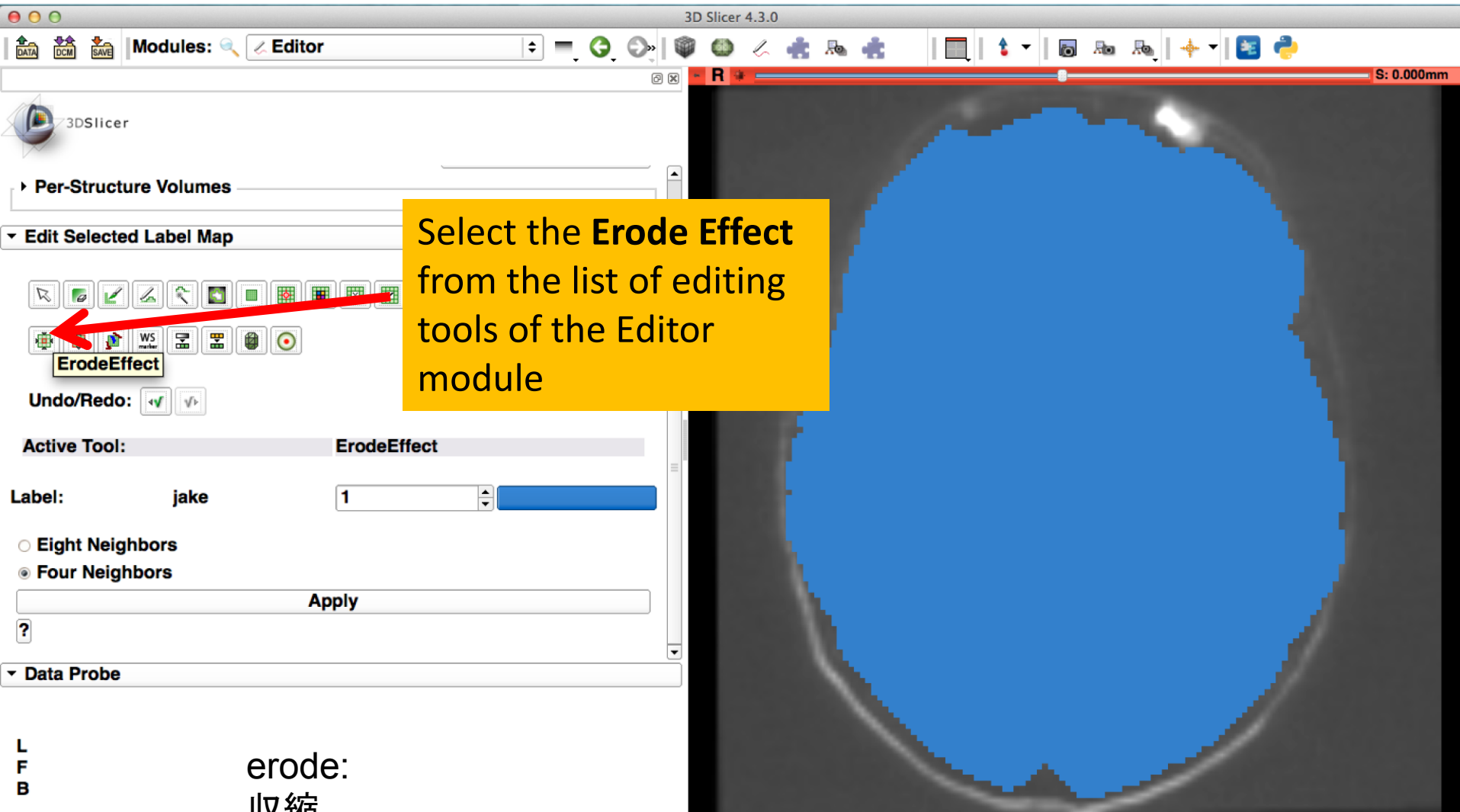




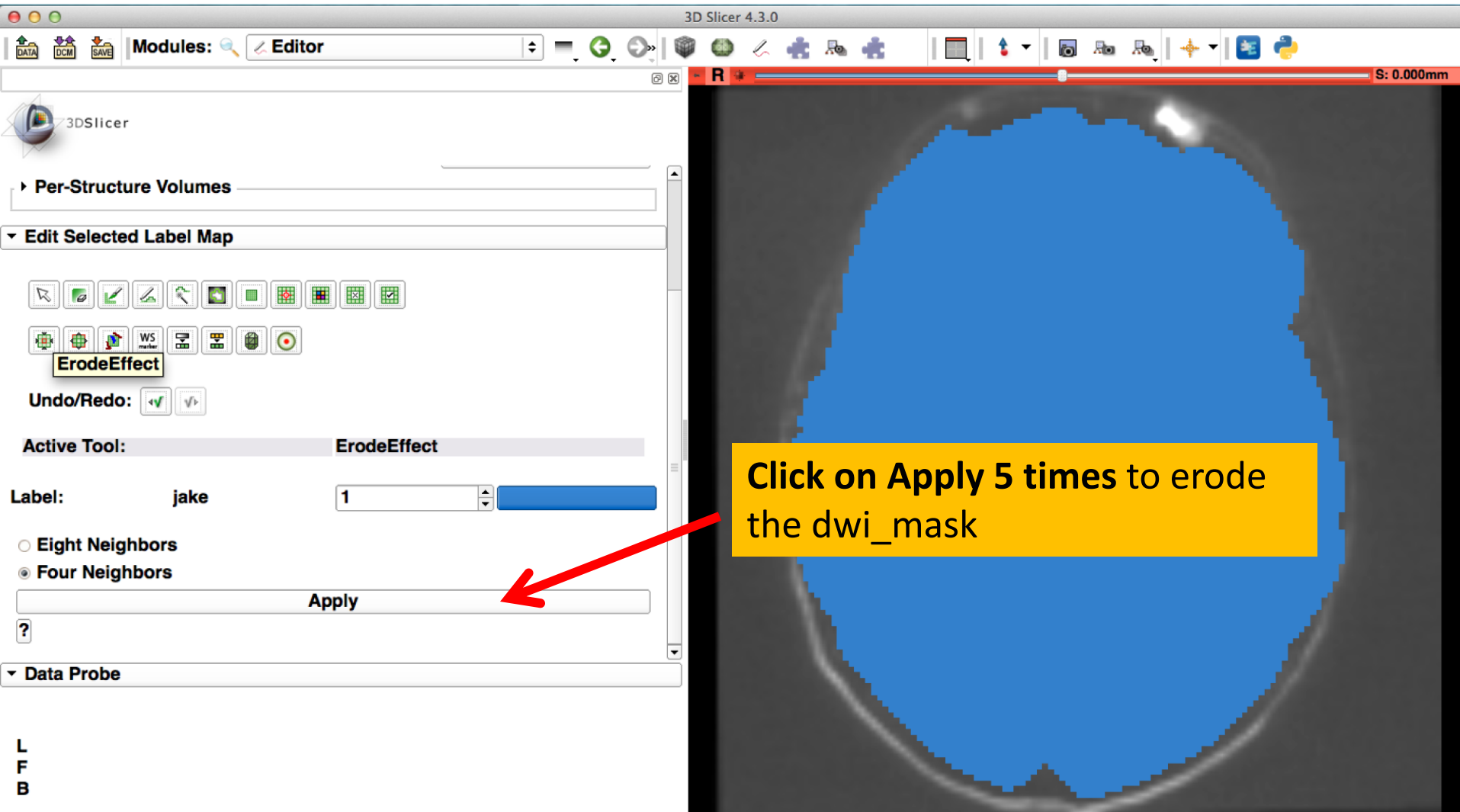
# Loading the DWI Mask



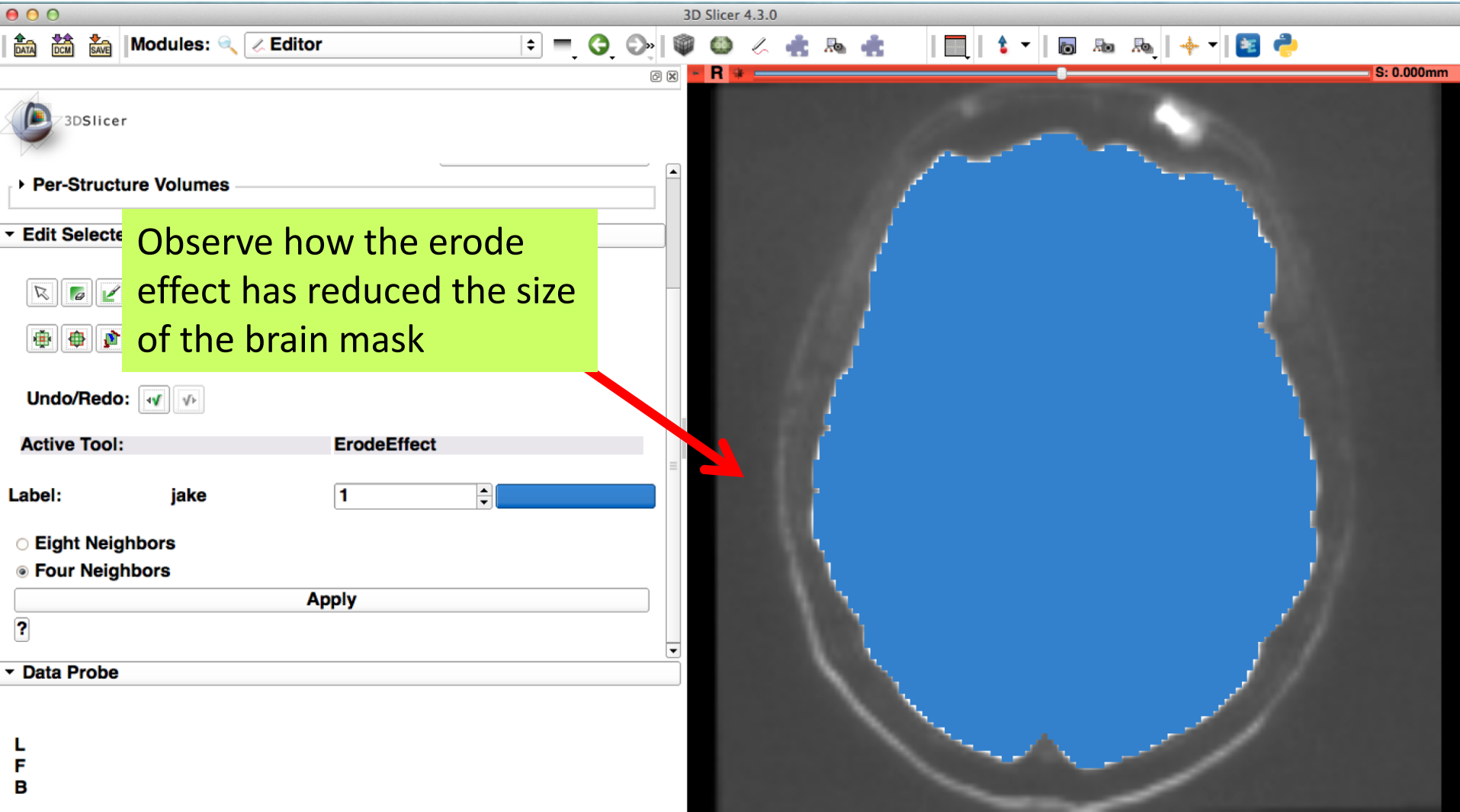
# Loading the DWI Mask

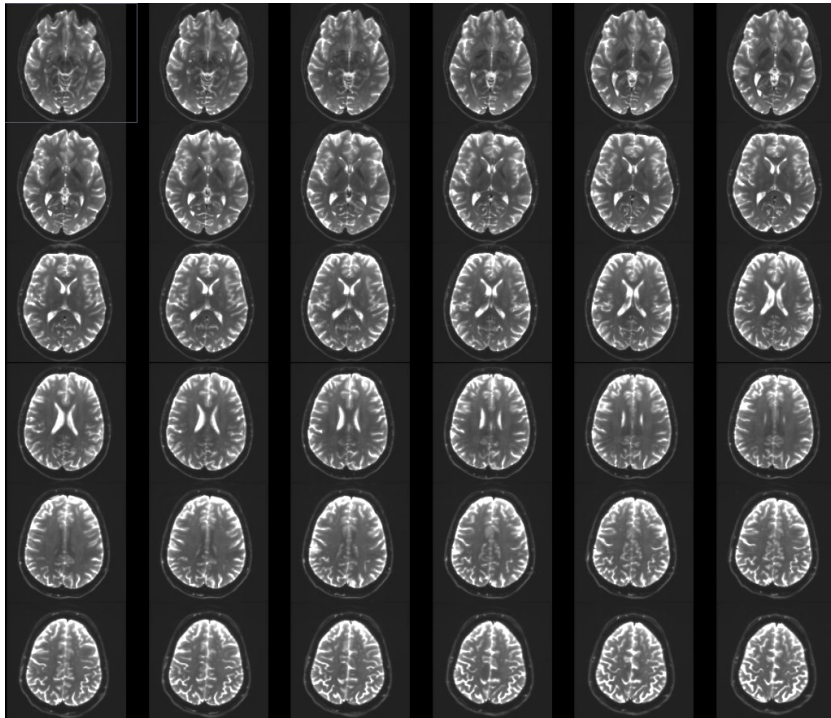


# Loading the DWI Mask



# Loading the DWI Mask

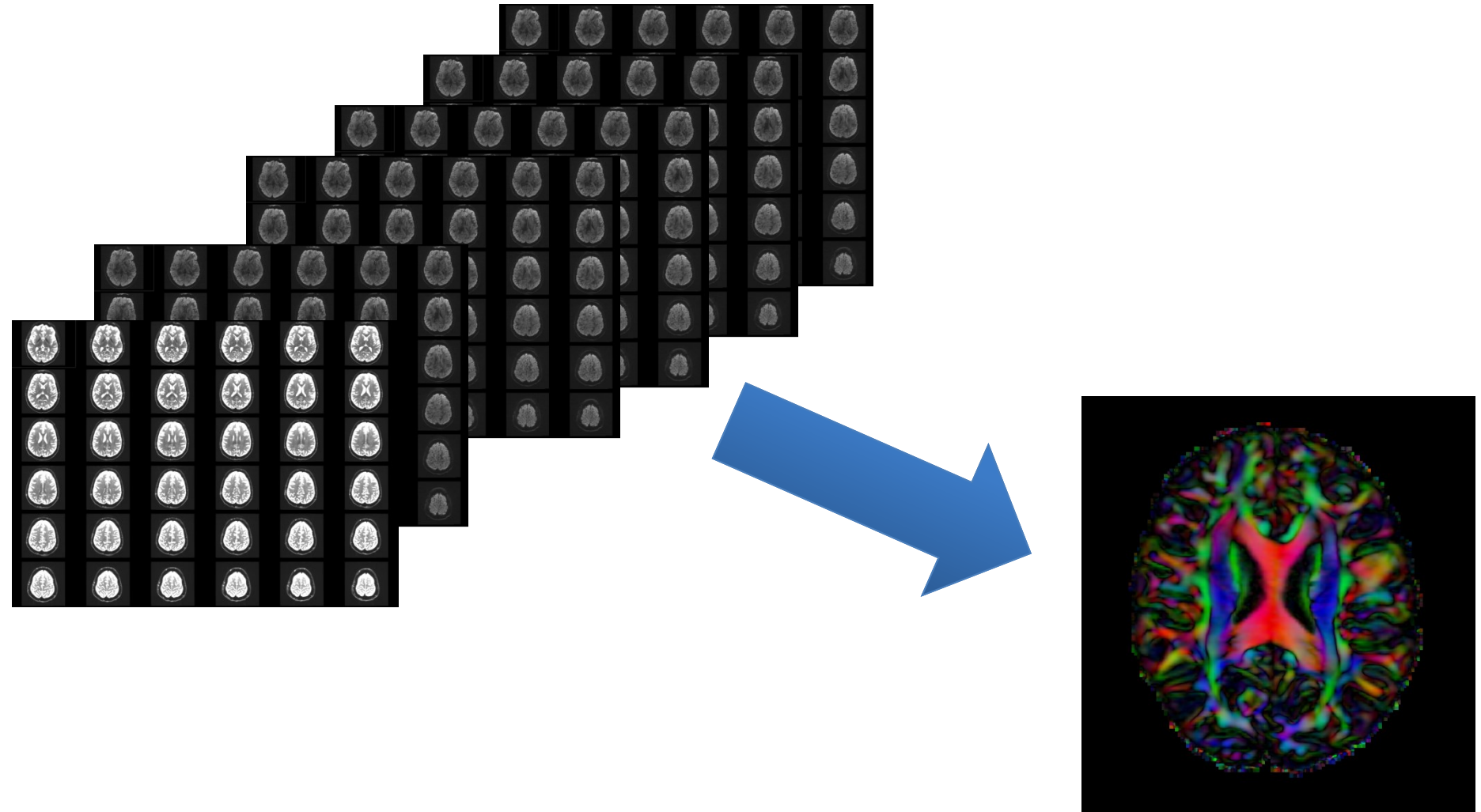




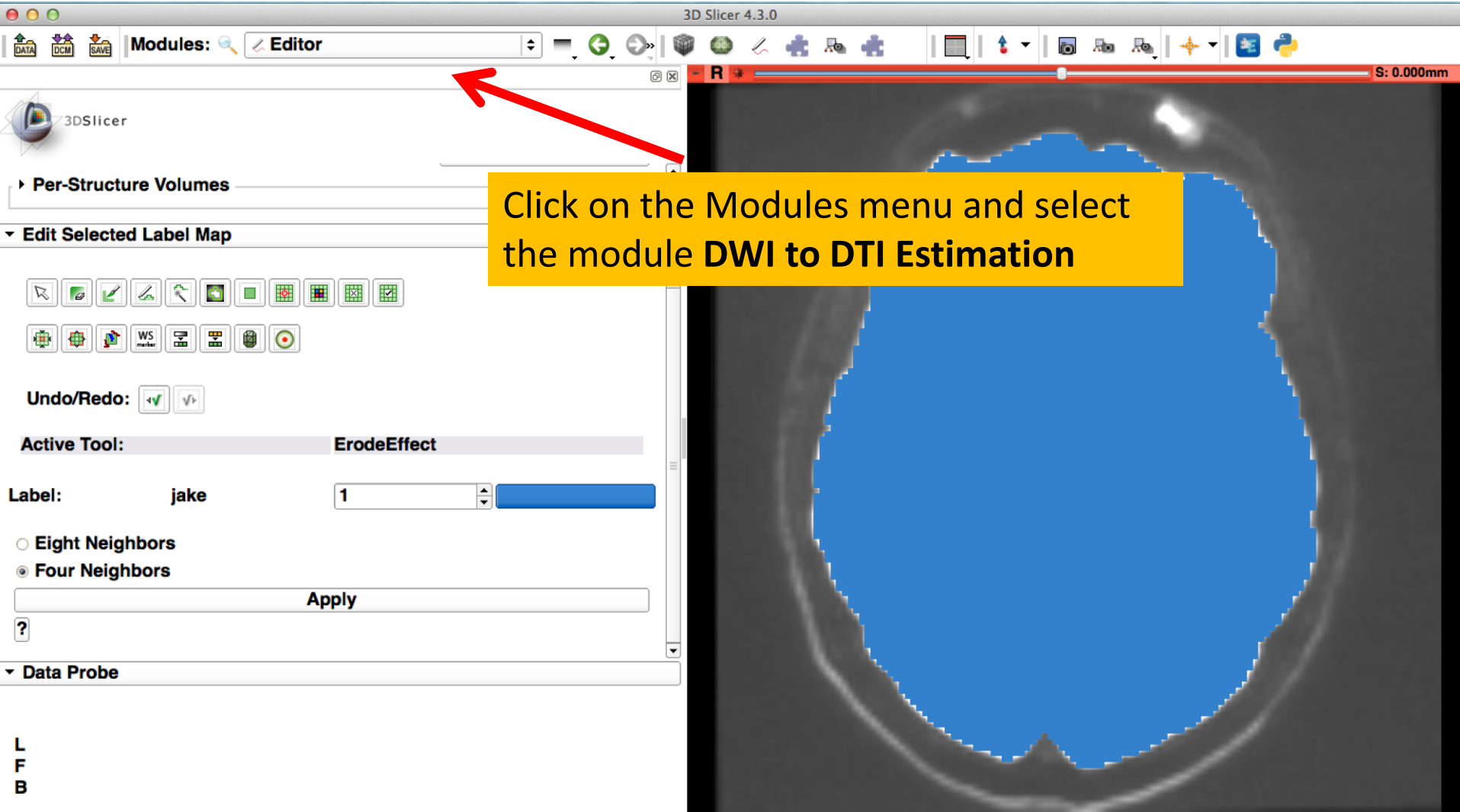
## Step 2: Computing the DTI dataset

拡散テンソル画像データの計算

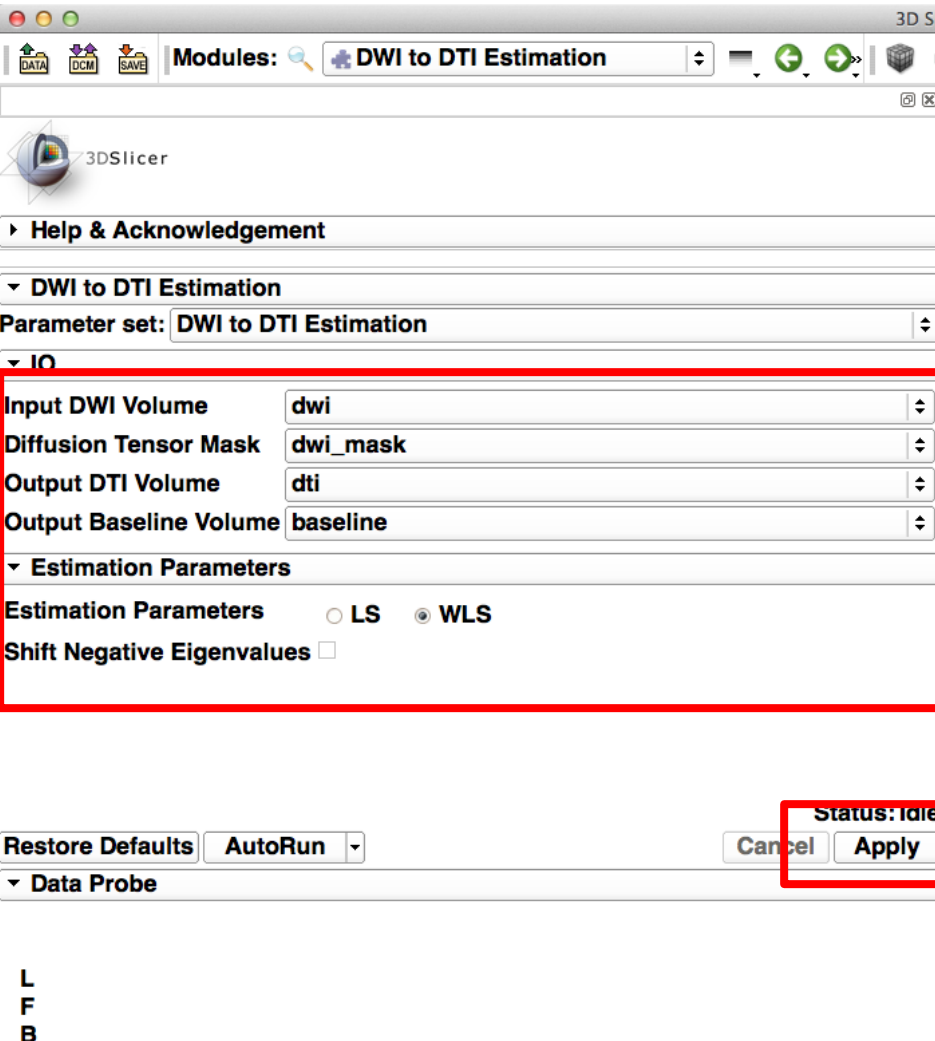
# From DWI to DTI



# From DWI to DTI



# From DWI to DTI



Select the module **DWI to DTI Estimation** in the modules menu:

-select the **Input DWI volume 'dwi'**

-select **Diffusion Tensor Mask 'dwi\_mask'**

-select **Output DTI Volume 'Create and Rename New Volume'**, and rename it **'dti'**

-set **Output Baseline Volume to baseline**

-select the **Estimation Parameter 'WLS'** (Weighted Least Squares)

- click on **Apply**



# From DWI to DTI

3D Slicer 4.3.0

Modules: DWI to DTI Estimation

Parameter set: DWI to DTI Estimation

Input DWI Volume  
Diffusion Tensor Mask  
Output DTI Volume  
Output Baseline Volume

Estimation Parameters

Status: Completed 100%

Restore Defaults AutoRun Cancel Apply

Data Probe

Click on the small **pin icon** to display the slice menu

Click on the **links icon** to link all three slices together

Click on the **eye icon** next to **dwi\_mask** to turn off the visibility of the mask

3D Slicer 4.3.0

Axial

dwi\_mask  
None  
baseline

0.00  
0.00  
1.00

3D Slicer 4.3.0

Axial

dwi\_mask  
None  
baseline

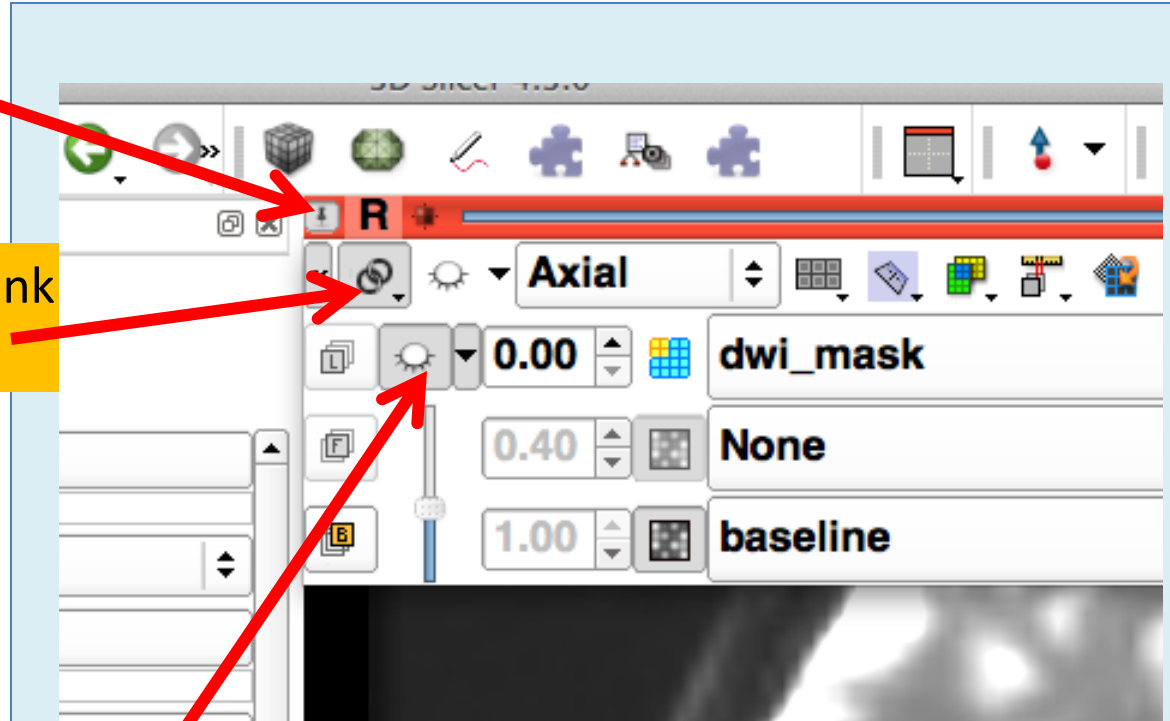
0.00  
0.40  
1.00

# From DWI to DTI

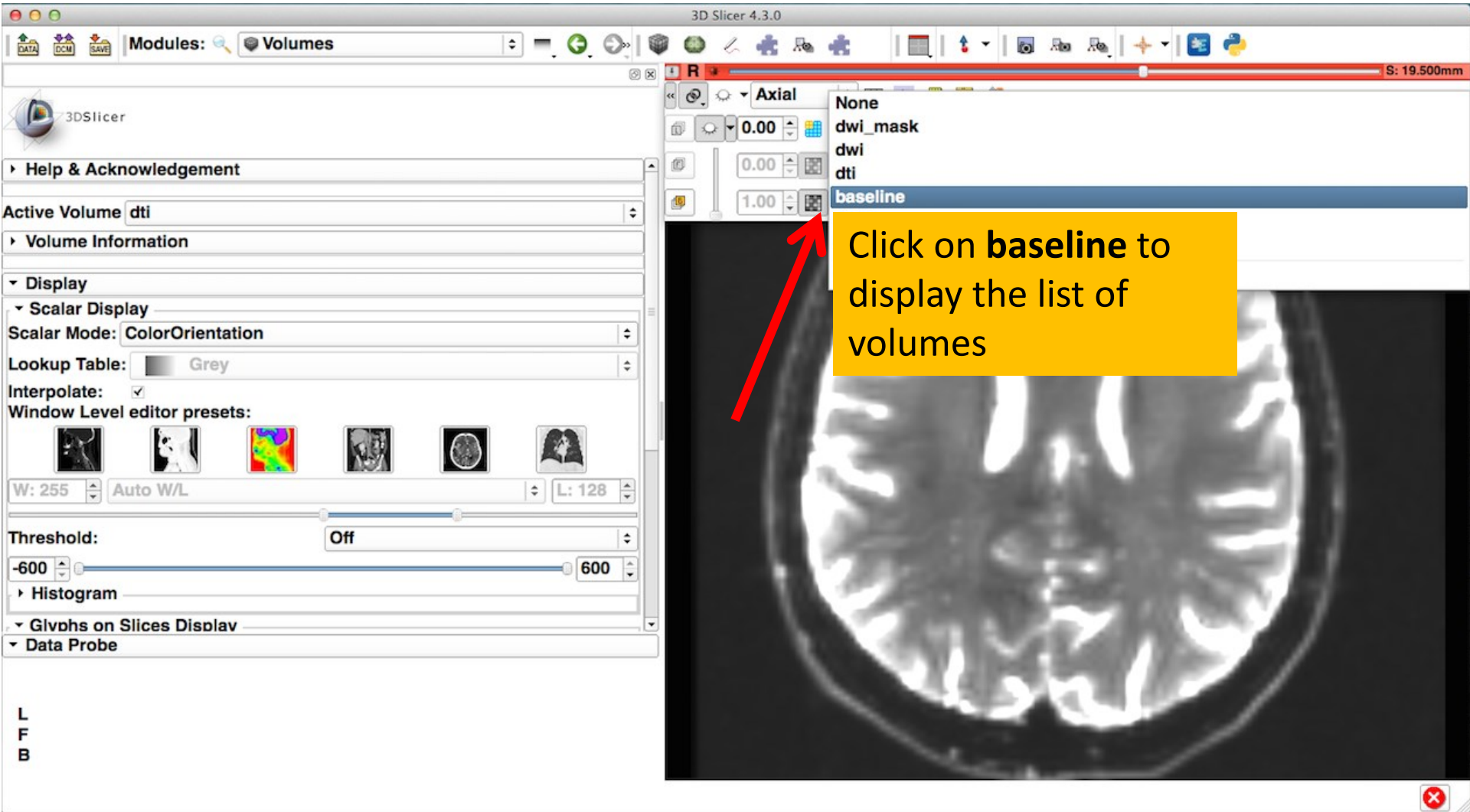
Click on the small **pin icon** to display the slice menu

Click on the **links icon** to link three slices together

Click on the **eye icon** next to **dwi\_mask** to turn off the visibility of the mask



# From DWI to DTI



# From DWI to DTI

3D Slicer 4.3.0

Modules: DWI to DTI Estimation

3DSlicer

Help & Acknowledgement

DWI to DTI Estimation

Parameter set: DWI to DTI Estimation

IO

Input DWI Volume: dwi

Diffusion Tensor Mask: dwi\_ma

Output DTI Volume: dti

Output Baseline Volume: baseline

Estimation Parameters

Estimation Parameters:  LS  WLS

Shift Negative Eigenvalues:

Status: Completed 100%

Restore Defaults AutoRun Cancel Apply

Data Probe

L  
F  
B

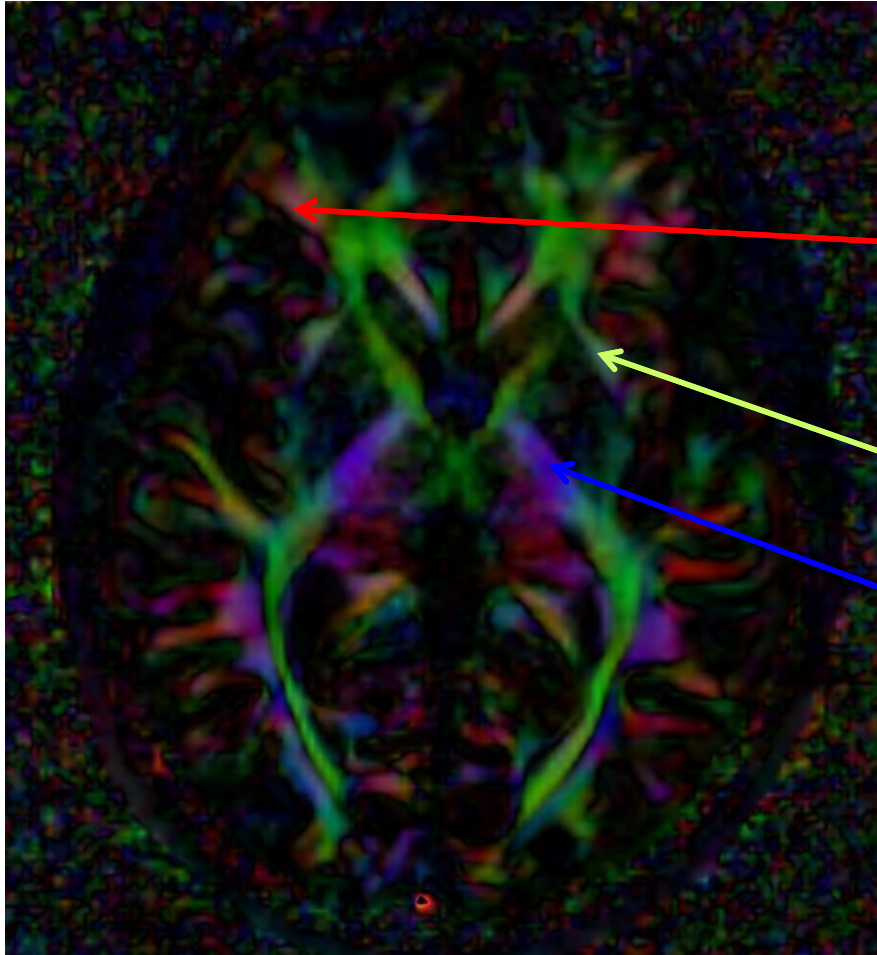
Axial 0.00 0.00 1.00

None  
dwi\_mask  
dwi  
dti  
baseline

Rename current Volume

Select the volume dti

# DTI Color Map



Color coding: カラーコーディング  
=色付け

Red: left-right

Green: anterior-posterior

Blue: inferior-superior

# Exploring the DWI Dataset

3D Slicer 4.3.0

Modules: DWI to DTI Estimation

Parameter set: DWI to DTI Estimation

Input DWI Volume: dwi

Diffusion Tensor Mask: dwi\_mask

Output DTI Volume: dti

Output Baseline Volume: baseline

Estimation Parameters

Estimation Parameters:  LS

Shift Negative Eigenvalues:

Status: Completed 100%

Restore Defaults AutoRun Cancel Apply

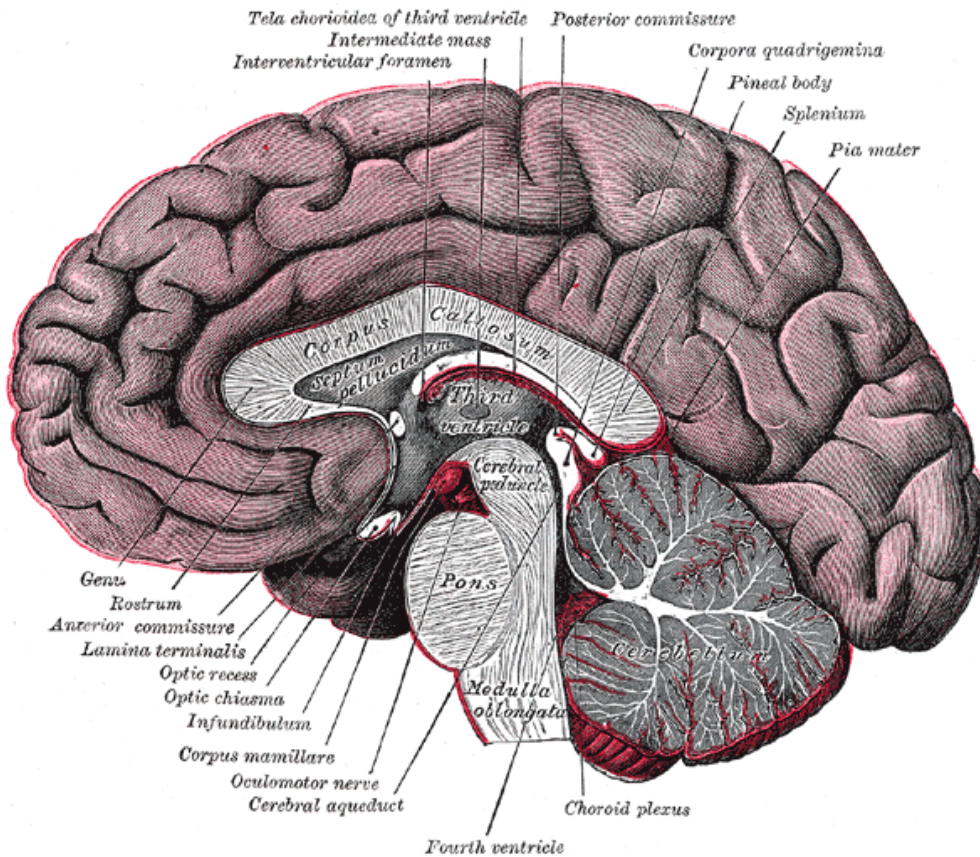
Data Probe

L  
F  
B

脑梁

Use the slider to browse through the dti volume and locate the **Corpus Callosum**

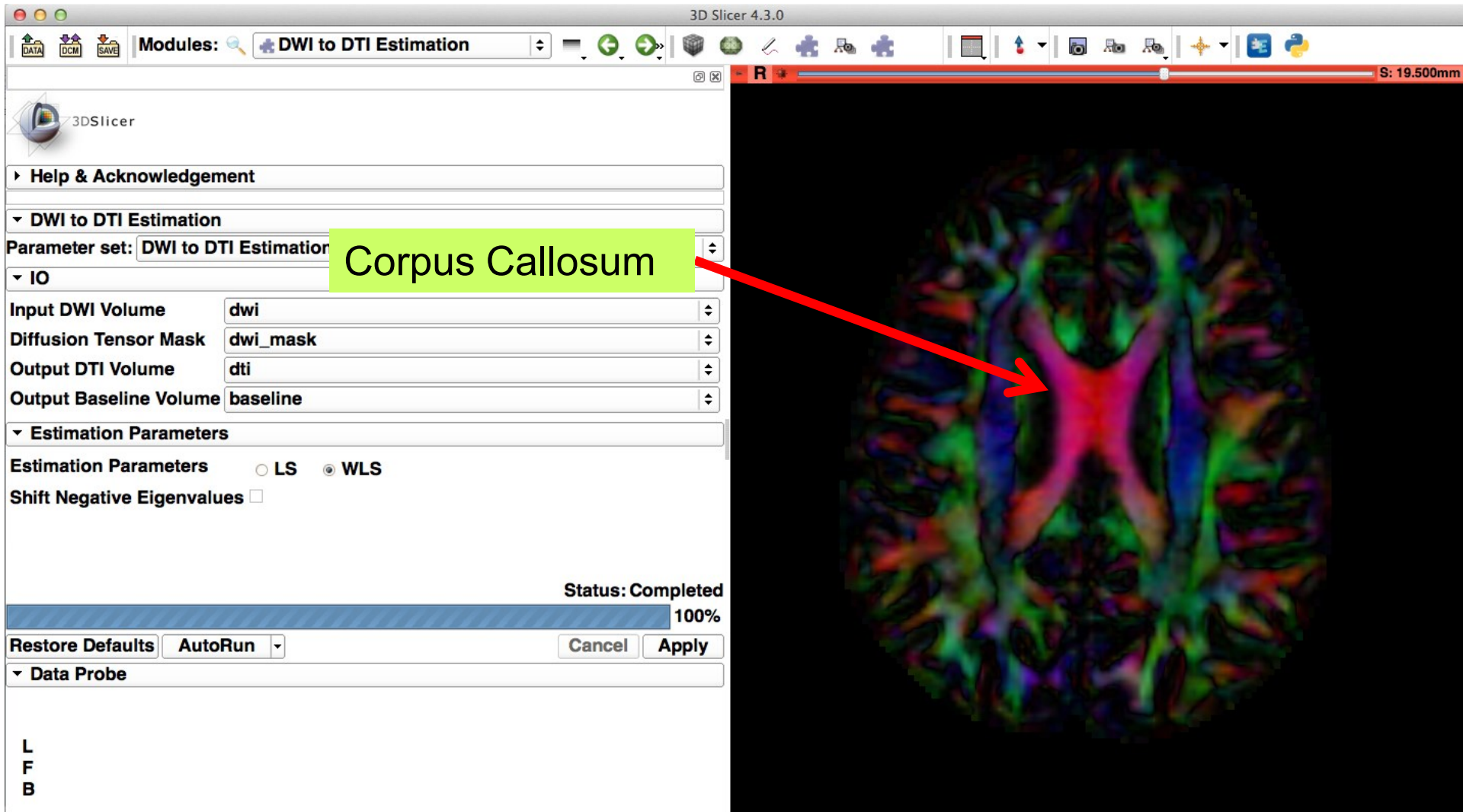
# Corpus Callosum



The corpus callosum is a broad thick bundle of dense myelinated fibers that connect the left and right hemisphere. It is the largest white matter structure in the brain

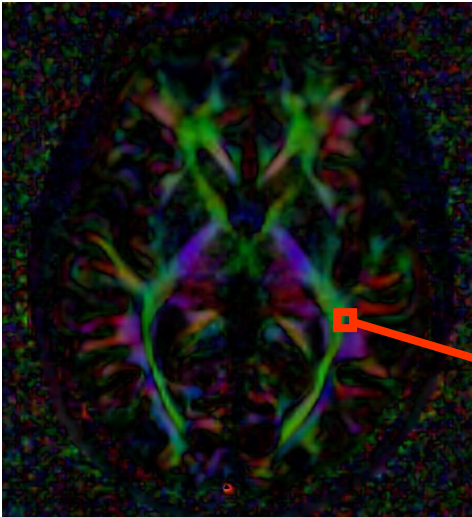
hemisphere : 半球

# Corpus Callosum





# Diffusion Tensor Data



$$S_i = S_0 e^{-b\hat{g}_i^T \underline{D} \hat{g}_i}$$

Stejskal-Tanner equation (1965)

$$\underline{\mathbf{D}} = \begin{bmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{yx} & D_{yy} & D_{yz} \\ D_{zx} & D_{zy} & D_{zz} \end{bmatrix}$$

The diffusion tensor  $\underline{\mathbf{D}}$  in the voxel (I,J,K) is a 3x3 symmetric matrix.

スカラー画像＝拡散の特徴を表す画像

# Scalar Maps: Fractional Anisotropy

Fractional Anisotropy(FA) : 比率による非等方性

- FA(D) is <sup>固有</sup>intrinsic to the tissue and is <sup>独立</sup>independent of the direction of the diffusion sensitizing gradients.

- FA(D) can be used to <sup>特徴づける</sup>characterize the shape (degree of 'out-of-roundness') of the diffusion ellipsoid

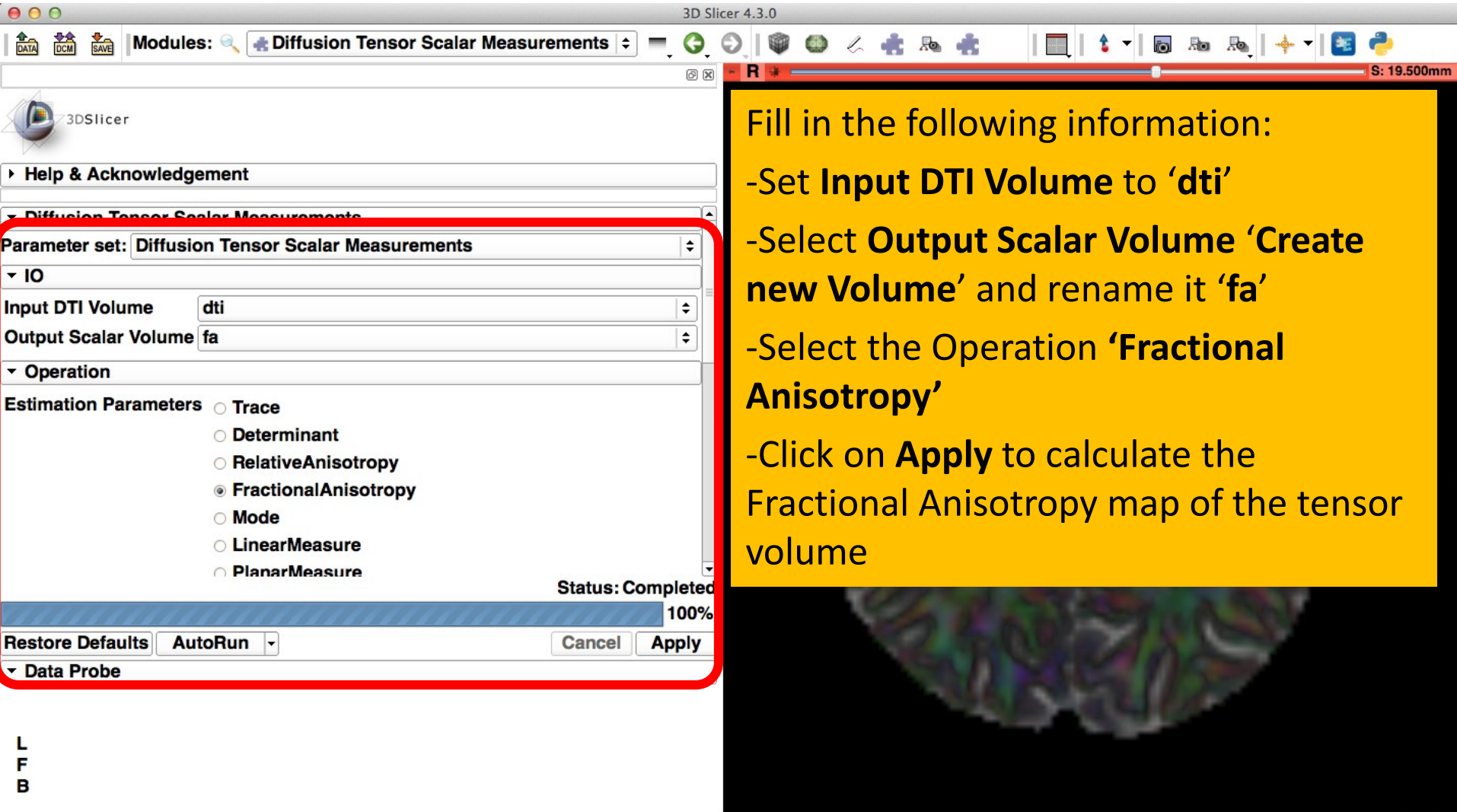
• Low FA:



High FA:



# Fractional Anisotropy



3D Slicer 4.3.0

Modules: Diffusion Tensor Scalar Measurements

Parameter set: Diffusion Tensor Scalar Measurements

IO

Input DTI Volume: dti

Output Scalar Volume: fa

Operation

Estimation Parameters

- Trace
- Determinant
- RelativeAnisotropy
- FractionalAnisotropy
- Mode
- LinearMeasure
- PlanarMeasure

Status: Completed 100%

Restore Defaults AutoRun Cancel Apply

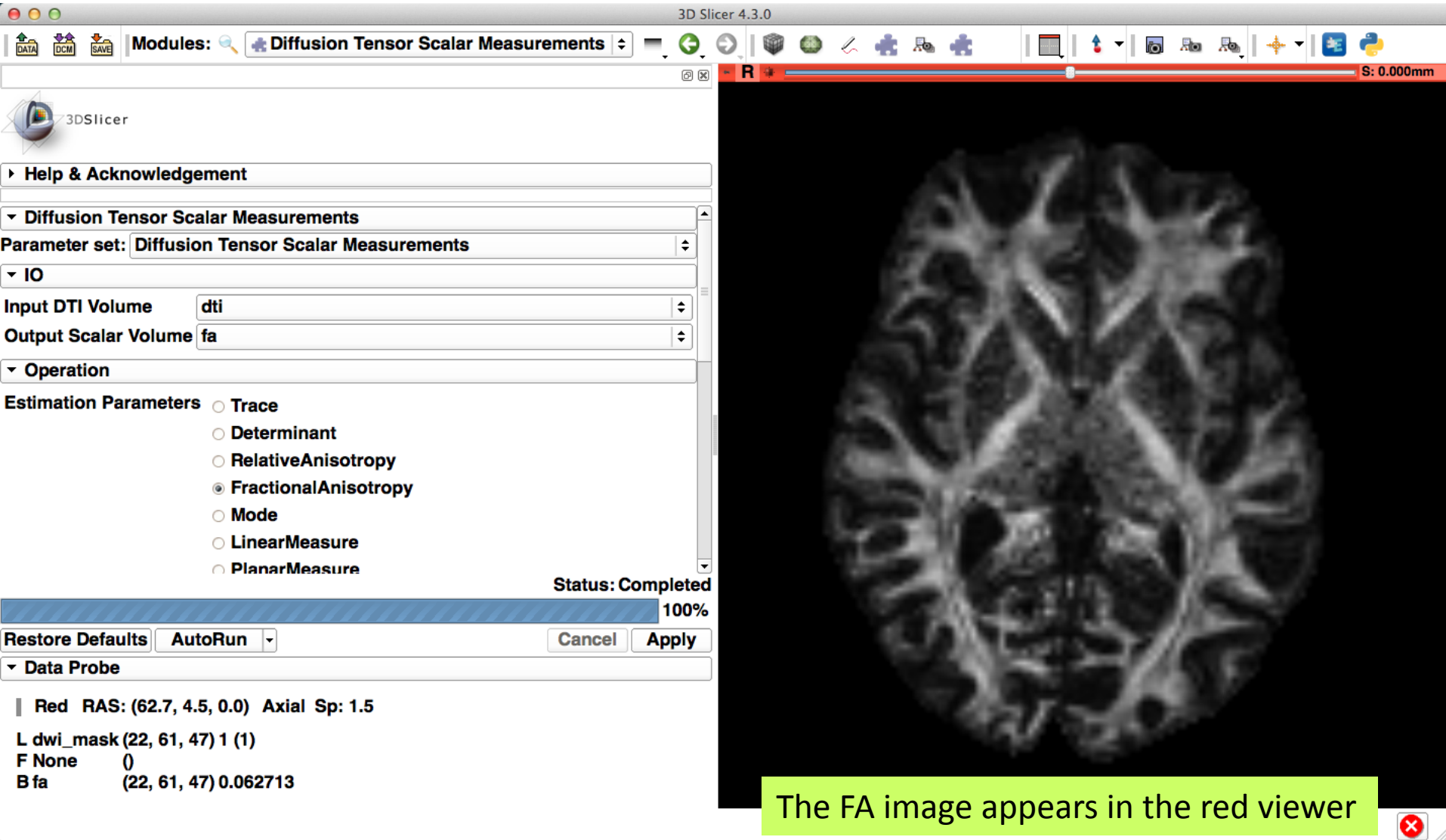
Data Probe

L  
F  
B

Fill in the following information:

- Set **Input DTI Volume** to 'dti'
- Select **Output Scalar Volume** 'Create new Volume' and rename it 'fa'
- Select the Operation '**Fractional Anisotropy**'
- Click on **Apply** to calculate the Fractional Anisotropy map of the tensor volume

# Fractional Anisotropy



3D Slicer 4.3.0

Modules: Diffusion Tensor Scalar Measurements

Parameter set: Diffusion Tensor Scalar Measurements

IO

Input DTI Volume: dti

Output Scalar Volume: fa

Operation

Estimation Parameters

- Trace
- Determinant
- RelativeAnisotropy
- FractionalAnisotropy
- Mode
- LinearMeasure
- PlanarMeasure

Status: Completed

100%

Restore Defaults AutoRun Cancel Apply

Data Probe

Red RAS: (62.7, 4.5, 0.0) Axial Sp: 1.5

L dwi\_mask (22, 61, 47) 1 (1)

F None 0

B fa (22, 61, 47) 0.062713

The FA image appears in the red viewer

# Fractional Anisotropy

The screenshot shows the 3D Slicer 4.3.0 interface. The 'Diffusion Tensor Scalar Measurements' module is active. The 'IO' section shows 'Input DTI Volume' set to 'dti' and 'Output Scalar Volume' set to 'fa'. A yellow text box provides instructions: 'Position your mouse over the pin icon and click the '>>' icon to display this table. Set the background volume to 'fa' and be sure the foreground volume is still set to 'dti' with Opacity at .40'. The 'Properties' panel on the right shows a table of volumes with their opacities: 'dwi\_mask' at 0.00, 'dti' at 0.40, and 'fa' at 1.00. The main view displays an axial brain slice with a color-coded DTI visualization.

3D Slicer 4.3.0

Modules: Diffusion Tensor Scalar Measurements

3DSlicer

Help & Acknowledgement

Diffusion Tensor Scalar Measurements

Parameter set: Diffusion Tensor Scalar Measurements

IO

Input DTI Volume dti

Output Scalar Volume fa

Position your mouse over the pin icon and click the '>>' icon to display this table. Set the background volume to 'fa' and be sure the foreground volume is still set to 'dti' with Opacity at .40

Volume	Opacity
dwi_mask	0.00
dti	0.40
fa	1.00

100% Completed

Cancel Apply

L  
F  
B



# Fractional Anisotropy

Explore the FA values in the Corpus Callosum and in adjacent gray matter areas. Note how the FA values are high in the white matter areas, and low in gray matter regions

Output Scalar volume: fa

Operation

Estimation Parameters

- Trace
- Determinant
- Relative Anisotropy
- Fractional Anisotropy
- Mode
- Linear Measure
- Planar Measure

Status: Completed 100%

Restore Defaults AutoRun Cancel Apply

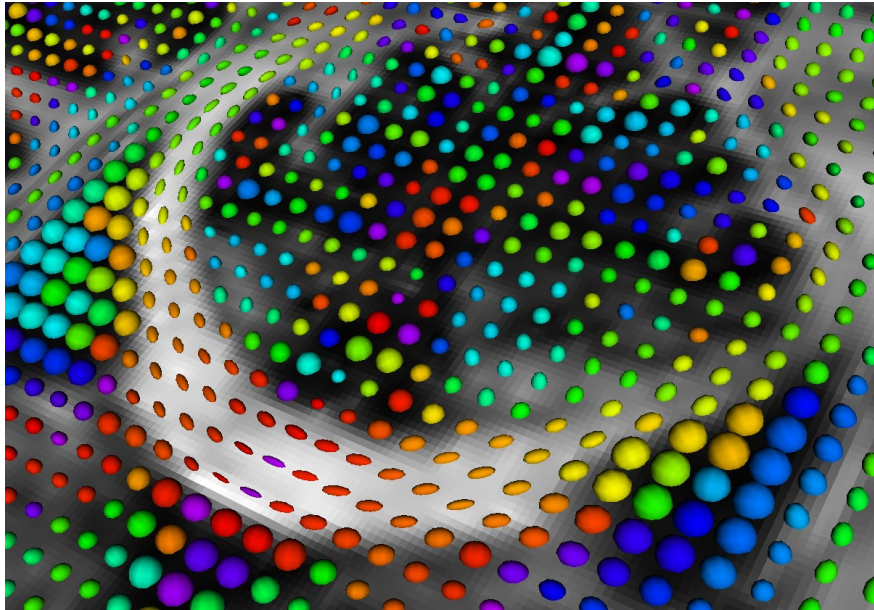
Data Probe

Red RAS: (73.9, 5.0, 19.7) Axial Sp: 1.5

L dwi\_mask (15, 61, 60) 0

F dti (15, 61, 60) ColorOrientation 0

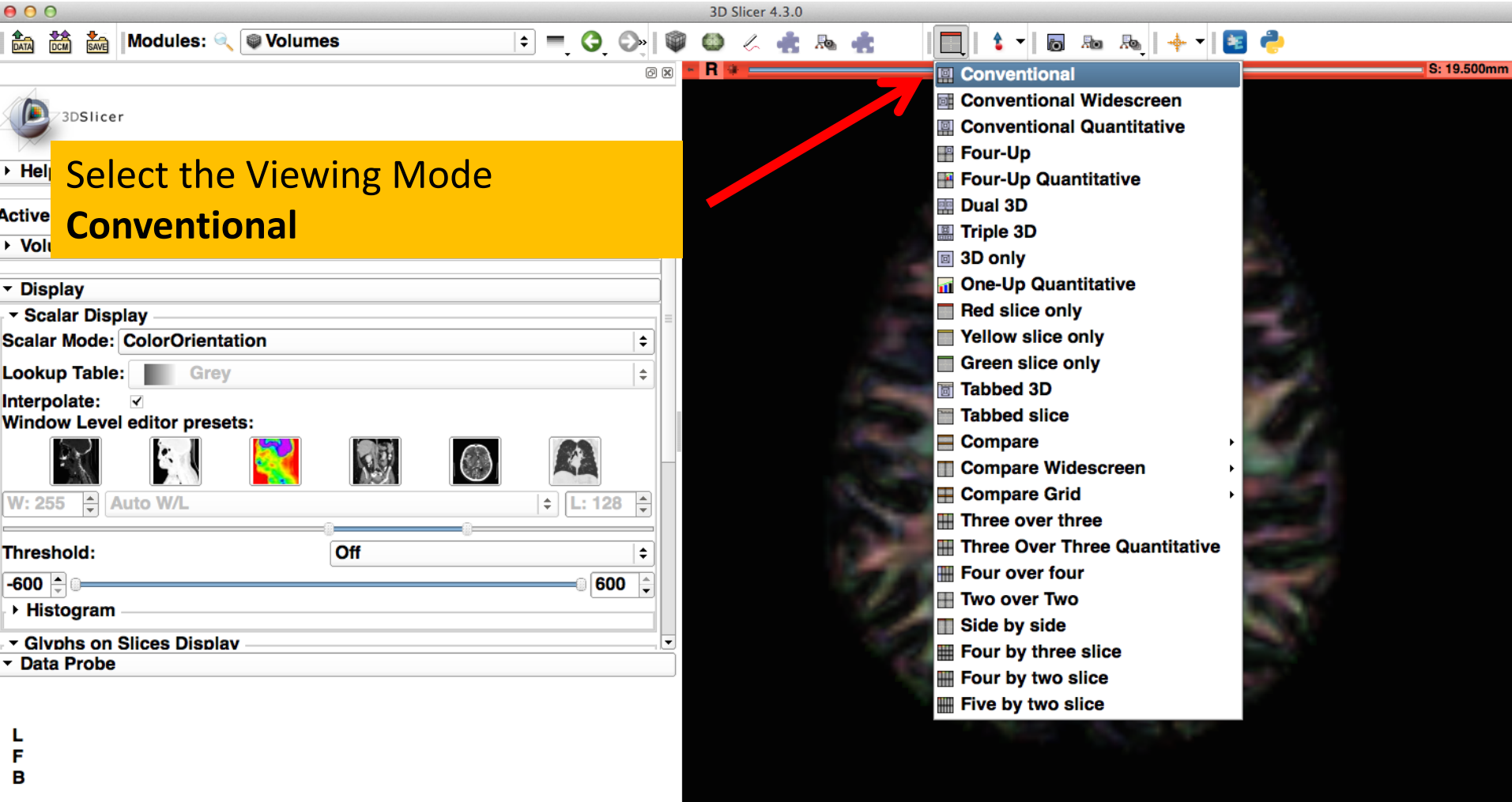
B fa (15, 61, 60) 0



## Step 3: Visualizing the diffusion tensor data

拡散テンソルデータの可視化

# 3D Visualization: Glyphs





# 3D Visualization: Glyphs

The screenshot shows the 3D Slicer 4.3.0 interface. The top toolbar contains a 'Modules' menu, which is highlighted with a red arrow. A yellow callout box points to this menu with the text: 'Click on the Modules menu and select the module **Volumes**'. The 'Volumes' module is selected in the 'Modules' dropdown. The left sidebar shows the 'Display' panel for the 'dti' volume, with 'Scalar Mode' set to 'ColorOrientation' and 'Lookup Table' set to 'Grey'. The 'Threshold' is set to 'Off' with a range from -600 to 600. The bottom left corner shows the 'L', 'F', and 'B' orientation buttons.

3D Slicer 4.3.0

Modules: Volumes

Conventional  
Conventional Widescreen  
Conventional Quantitative  
Four-Up

One-Up Quantitative  
Red slice only  
Yellow slice only  
Green slice only  
Tabbed 3D  
Tabbed slice  
Compare  
Compare Widescreen  
Compare Grid  
Three over three  
Three Over Three Quantitative  
Four over four  
Two over Two  
Side by side  
Four by three slice  
Four by two slice  
Five by two slice

Click on the Modules menu and select the module **Volumes**

Active Volume dti

Volume Information

Display

Scalar Display

Scalar Mode: ColorOrientation

Lookup Table: Grey

Interpolate:

Window Level editor presets:

W: 255 Auto W/L L: 128

Threshold: Off

-600 600

Histogram

Glyphs on Slices Display

Data Probe

L  
F  
B

# 3D Visualization: Glyphs

Position the mouse over the **pin icon** and select the '<<' icon to display the axial slice toolbar. Set the **Foreground** to 'fa' and the **Background** to 'dti', with the **Foreground opacity** set to **1.00**

W: 255 Auto W/L L: 128

Threshold: Off

-600 600

Histogram

Glvohs on Slices Displav

Data Probe

Red RAS: (-51.9, -54.5, 19.5) Axial Sp: 1.5

L dwi\_mask (99, 100, 60) 0 (0)  
F fa (99, 100, 60) 0  
B dti (99, 100, 60) ColorOrientation 0

# 3D Visualization: Glyphs

3D Slicer 4.3.0

Modules: Volumes

Active Volume: dti

Volume Information

Display

Scalar Display

Scalar Mode: ColorOrientation

Lookup Table: Grey

Interpolate:

Window Level editor presets:

W: 255 Auto W/L L: 128

Threshold: Off

-600 600

Histogram

Glyphs on Slices Display

Data Probe

L  
F  
B

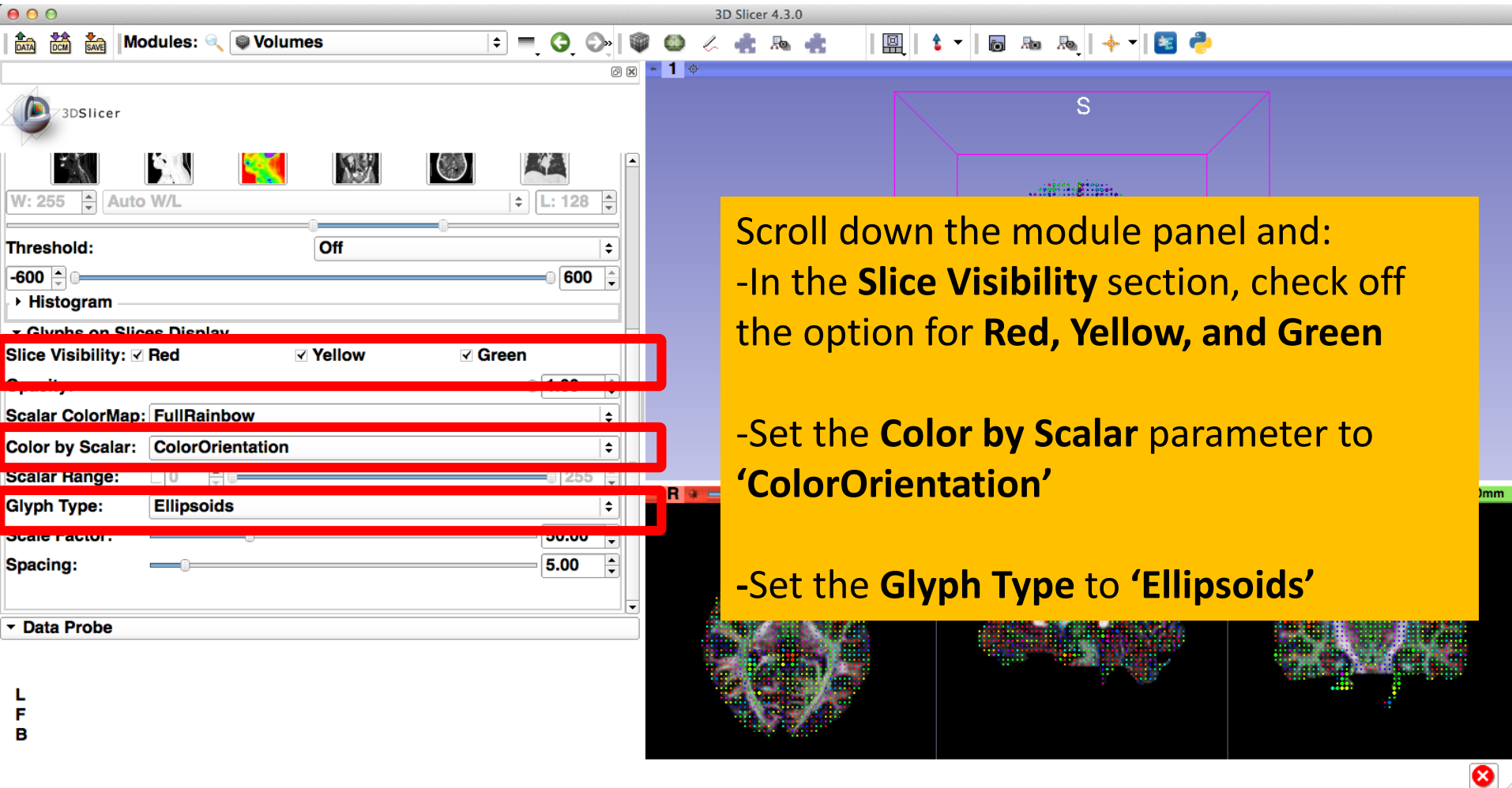
S

Set the **Active Volume** to 'dti' and the **Scalar Mode** to 'ColorOrientation'

R S: 19.500mm Y R: 1.500mm G A: 1.500mm

# 3D Visualization: Glyphs

Scroll down: スクロールバーで画面を下に移動



3D Slicer 4.3.0

Modules: Volumes

3DSlicer

W: 255 Auto W/L L: 128

Threshold: Off

-600 600

Histogram

↳ Glyphs on Slices Display

Slice Visibility:  Red  Yellow  Green

Quality: 1.00

Scalar ColorMap: FullRainbow

Color by Scalar: ColorOrientation

Scalar Range: 0 255

Glyph Type: Ellipsoids

Scale Factor: 50.00

Spacing: 5.00

Data Probe

L  
F  
B

S

R

0mm

Scroll down the module panel and:

- In the **Slice Visibility** section, check off the option for **Red, Yellow, and Green**
- Set the **Color by Scalar** parameter to **'ColorOrientation'**
- Set the **Glyph Type** to **'Ellipsoids'**

# 3D Visualization: Glyphs

The glyphs appear in all 3 slice viewers

3D Slicer 4.3.0

Modules: Volumes

W: 255 Auto W/L L: 128

Threshold: Off

-600 600

Histogram

Glyphs on Slices Display

Slice Visibility:  Red  Yellow  Green

Opacity: 1.00

Scalar ColorMap: FullRainbow

Color by Scalar: ColorOrientation

Scalar Range: 0 255

Glyph Type: Ellipsoids

Scale Factor: 50.00

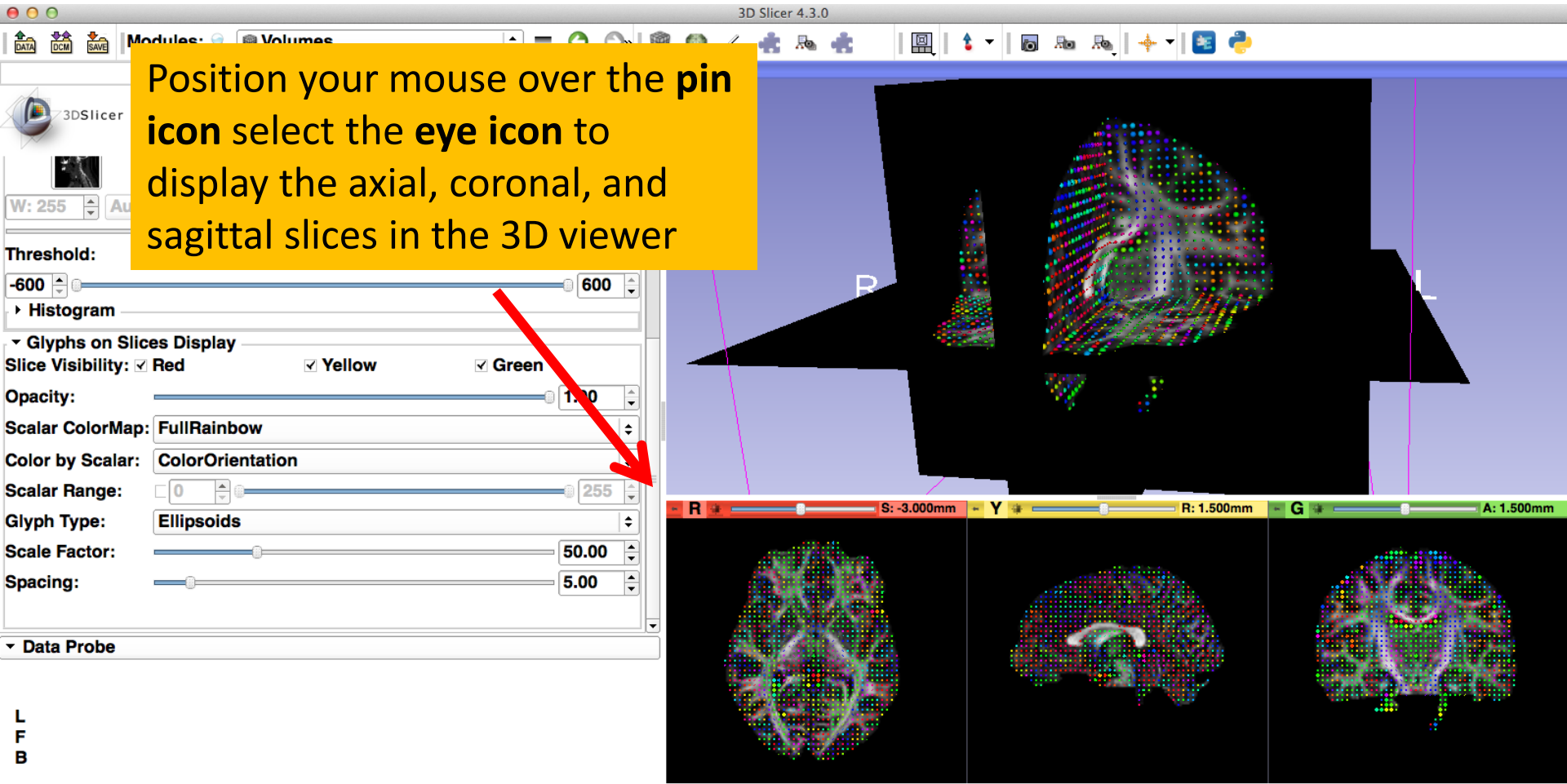
Spacing: 5.00

Data Probe

L  
F  
B

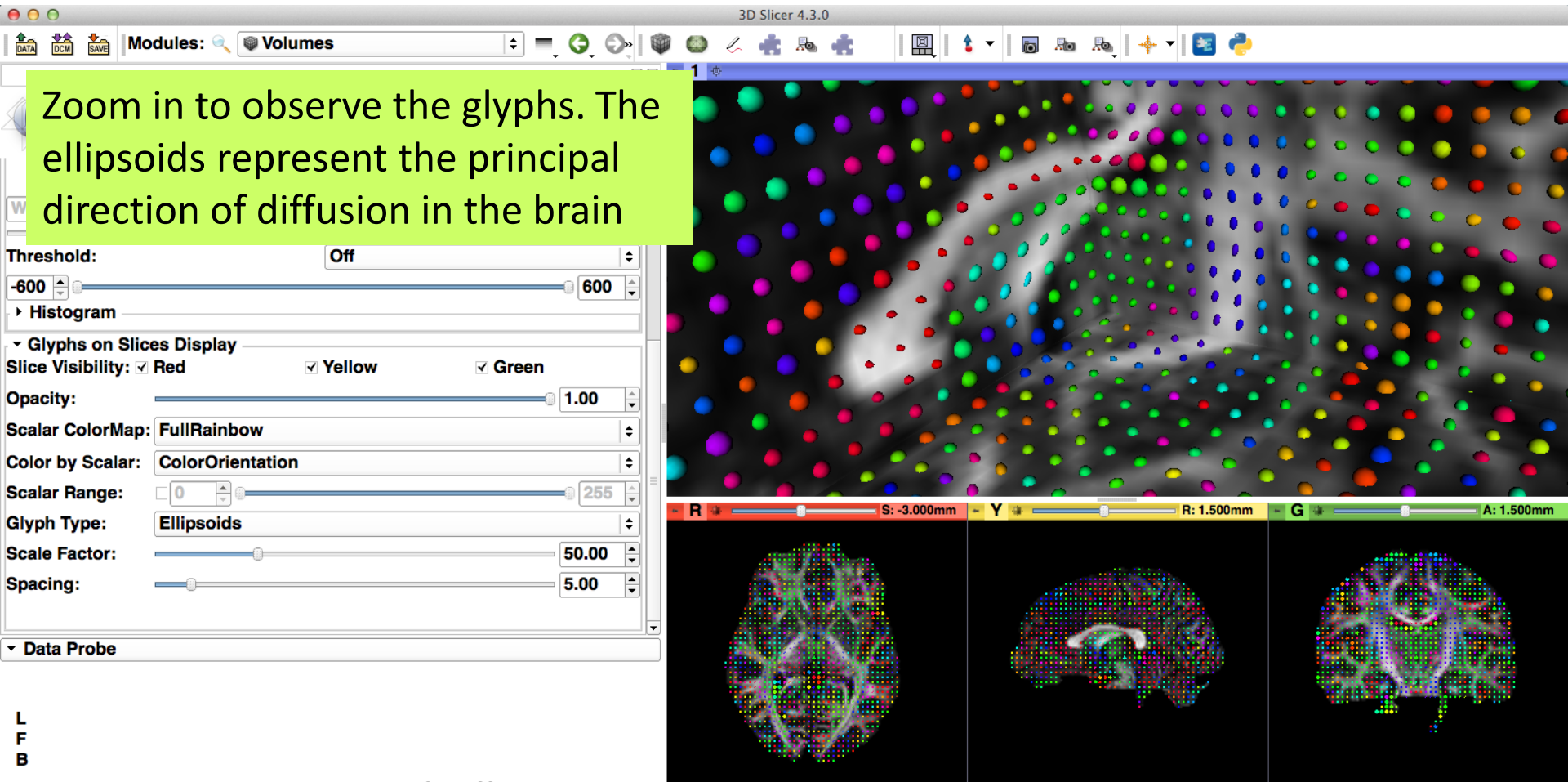
R S: -3.000mm Y R: 1.500mm G A: 1.500mm

# 3D Visualization: Glyphs

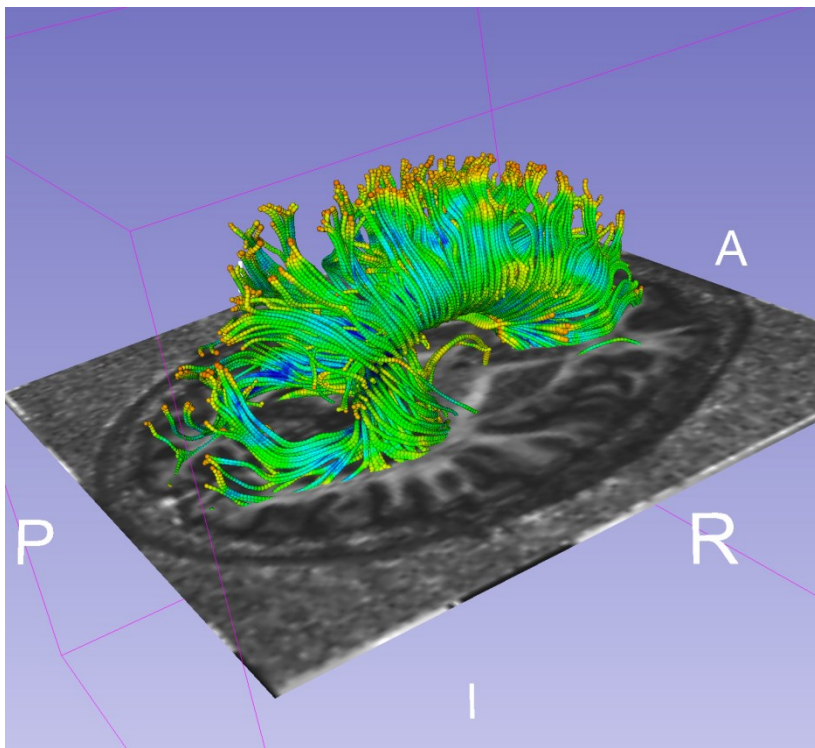


# 3D Visualization: Glyphs

Zoom in to observe the glyphs. The ellipsoids represent the principal direction of diffusion in the brain



principal direction of diffusion:  
拡散の手方向



## Step 4: Generating fiber tracts

線維束の生成

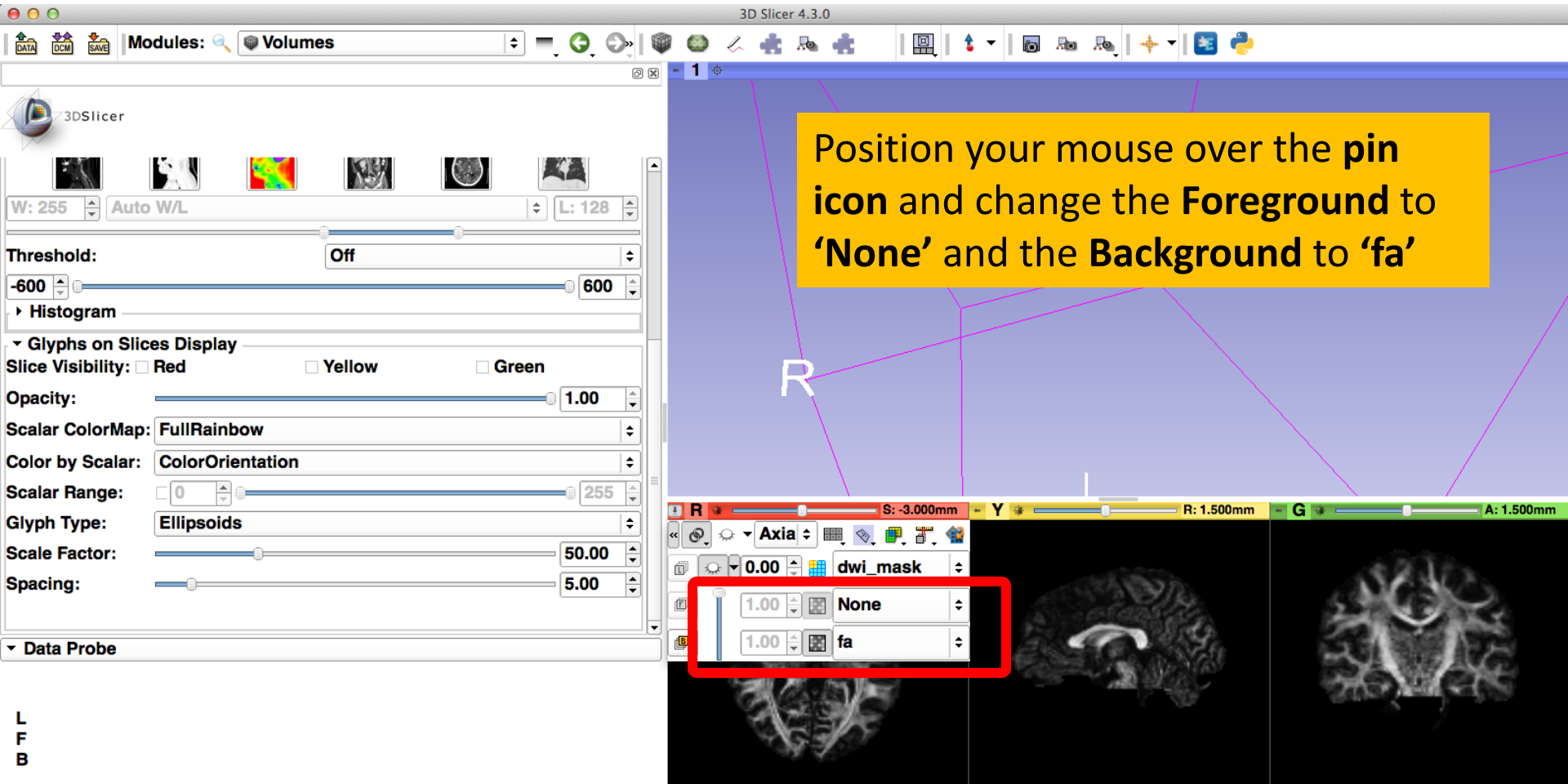


# Diffusion MRI tractography

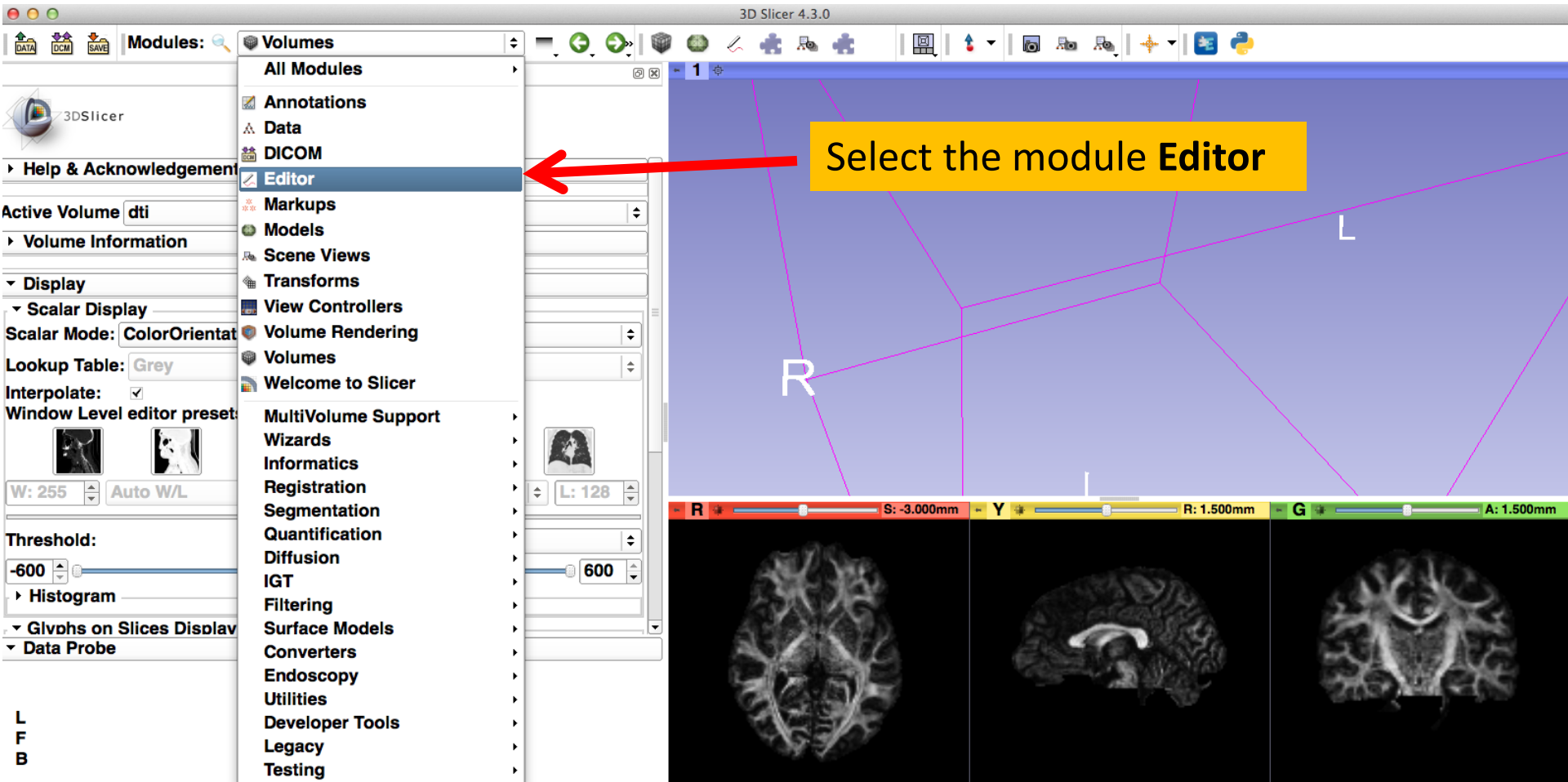
deselect: 選択を外す

The screenshot displays the 3D Slicer 4.3.0 interface. On the left, the 'Volumes' panel is open, showing the 'Glyphs on Slices Display' section. A red box highlights the 'Slice Visibility' options:  Red,  Yellow, and  Green. Below this, the 'Opacity' is set to 1.00, 'Scalar ColorMap' is 'FullRainbow', 'Color by Scalar' is 'ColorOrientation', 'Scalar Range' is 0 to 255, 'Glyph Type' is 'Ellipsoids', 'Scale Factor' is 50.00, and 'Spacing' is 5.00. The main 3D view shows a brain model with three orthogonal slices: Axial (R: -3.000mm), Coronal (R: 1.500mm), and Sagittal (A: 1.500mm). A yellow text box with a red arrow pointing to the 'Slice Visibility' section contains the instruction: 'Deselect the option for Red, Yellow, and Green Slice Visibility, and deselect the eye icon'. Another red arrow points to the 'eye' icon in the slice control bar. The bottom right corner features a red 'X' icon.

# Diffusion MRI tractography



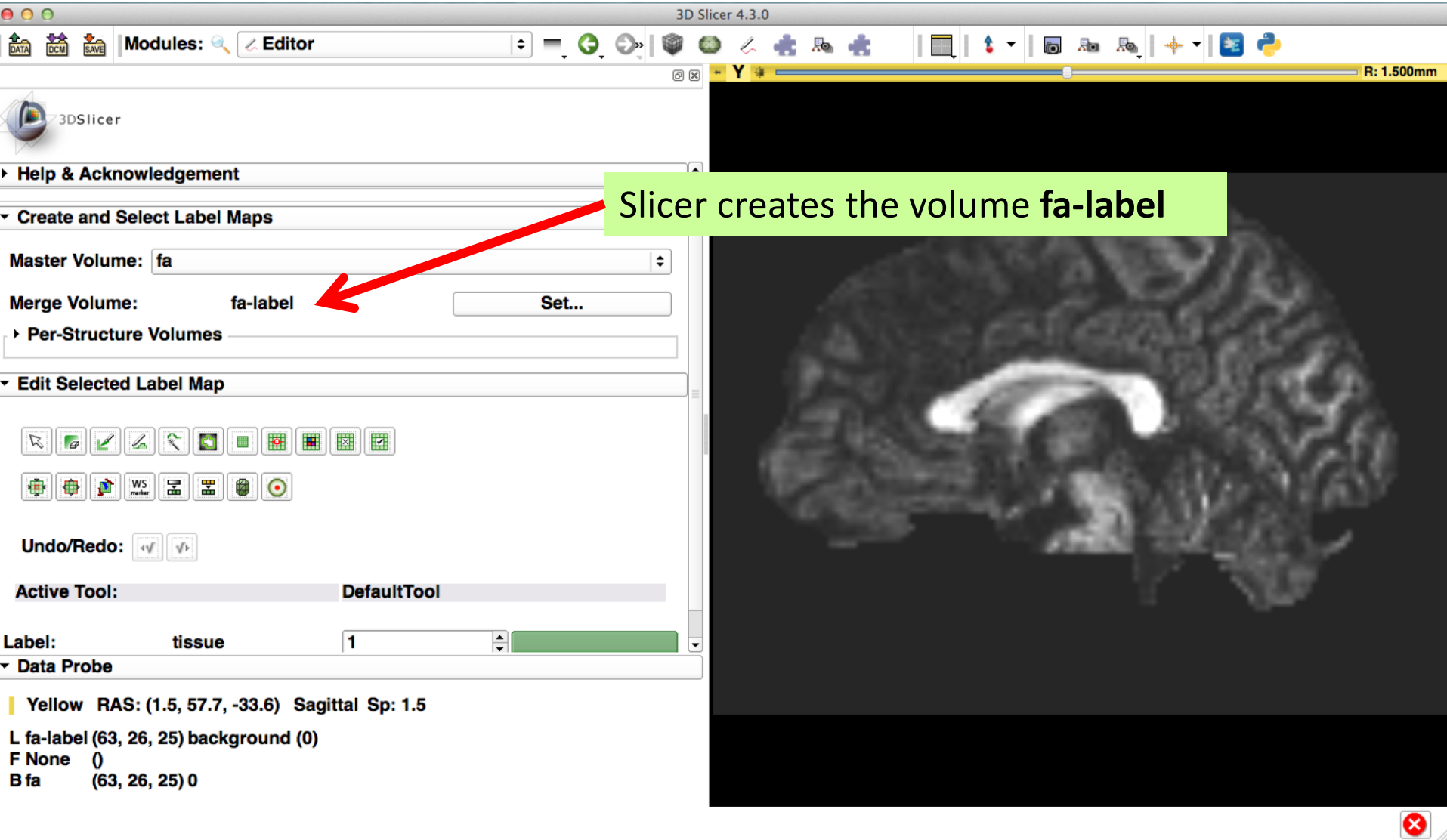
# Diffusion MRI tractography



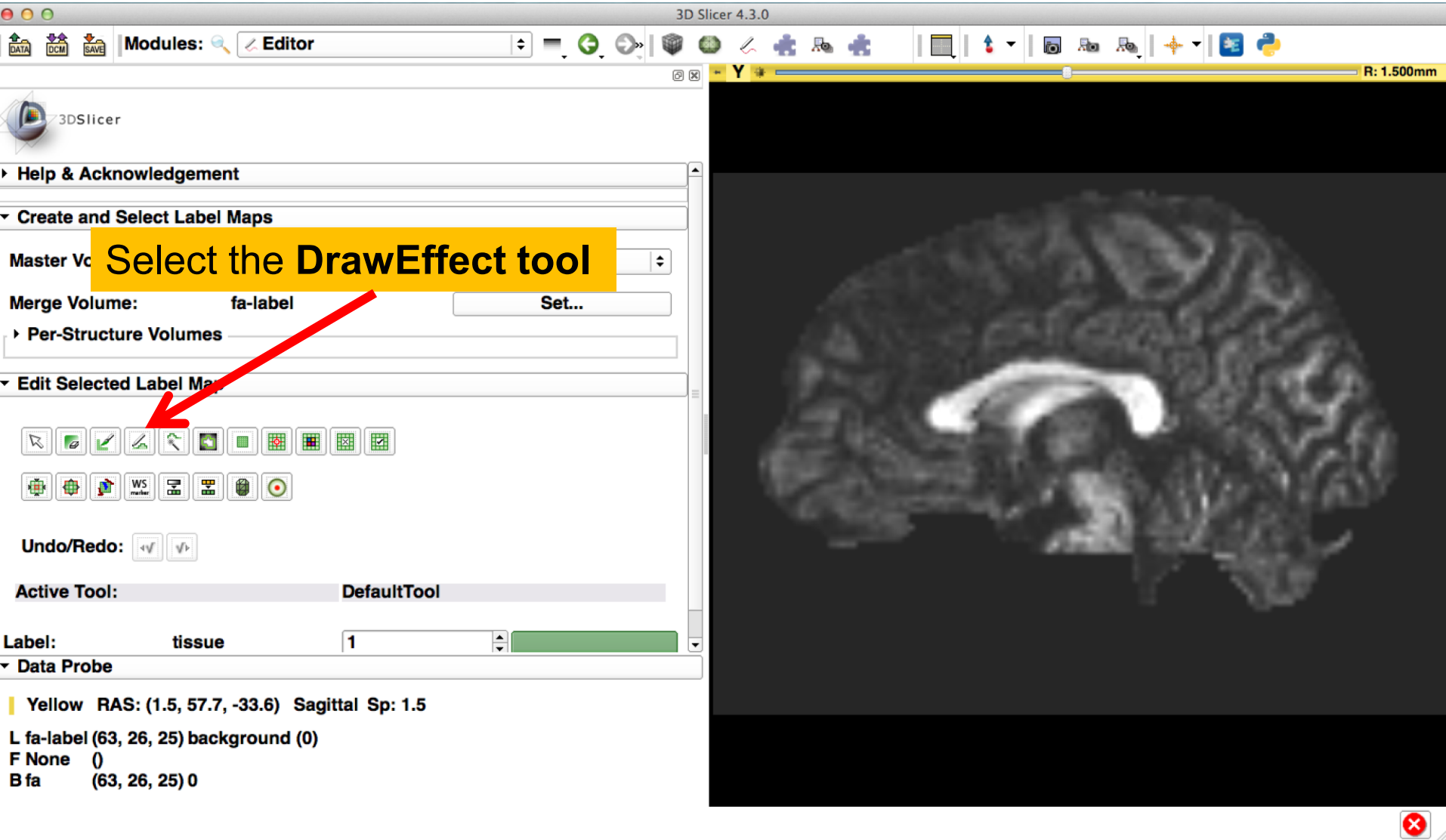
# Diffusion MRI tractography

The image shows the 3D Slicer 4.3.0 software interface. The 'Create and Select Label Maps' panel is visible on the left, with the 'Master Volume' dropdown menu set to 'fa'. A yellow callout box with the text 'Set the Master Volume to fa' has a red arrow pointing to this dropdown. In the center, a dialog box titled 'Set' is open, containing the text: 'Create a merge label map for selected master volume fa. New volume will be fa-label. Select the color table node will be used for segmentation labels.' Below this text is a dropdown menu showing 'GenericAnatomyColor' and two buttons: 'Apply' and 'Cancel'. A red arrow points from the 'Apply' button to a yellow callout box on the right that says 'Click on Apply to create an empty labelmap'. The background shows a sagittal view of a brain MRI slice.

# Diffusion MRI tractography



# Diffusion MRI tractography



3D Slicer 4.3.0

Modules: Editor

Help & Acknowledgement

Create and Select Label Maps

Master Volume: **Select the DrawEffect tool**

Merge Volume: fa-label Set...

Per-Structure Volumes

Edit Selected Label Map

Undo/Redo: [Undo] [Redo]

Active Tool: DefaultTool

Label: tissue 1

Data Probe

Yellow RAS: (1.5, 57.7, -33.6) Sagittal Sp: 1.5

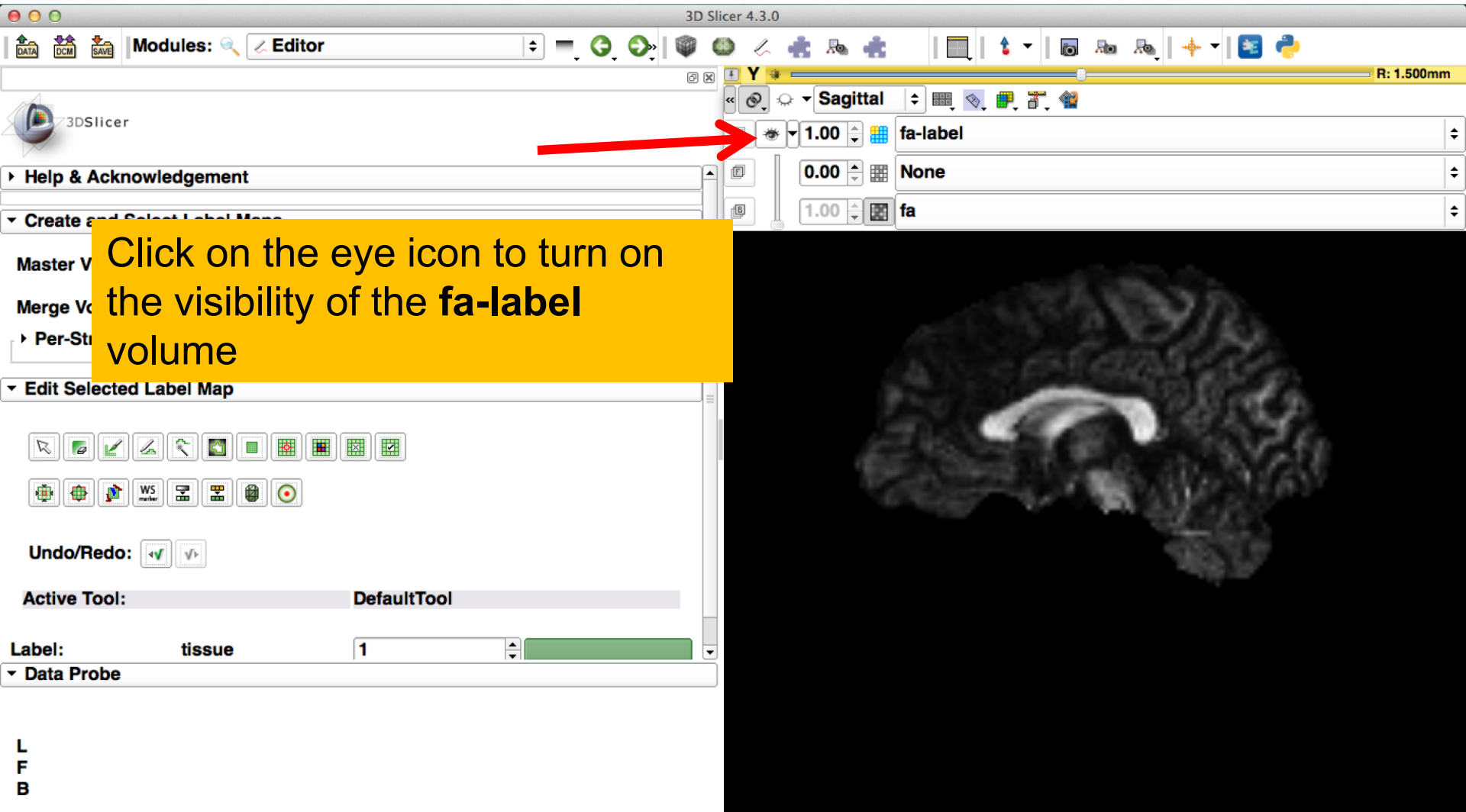
L fa-label (63, 26, 25) background (0)

F None (0)

B fa (63, 26, 25) 0

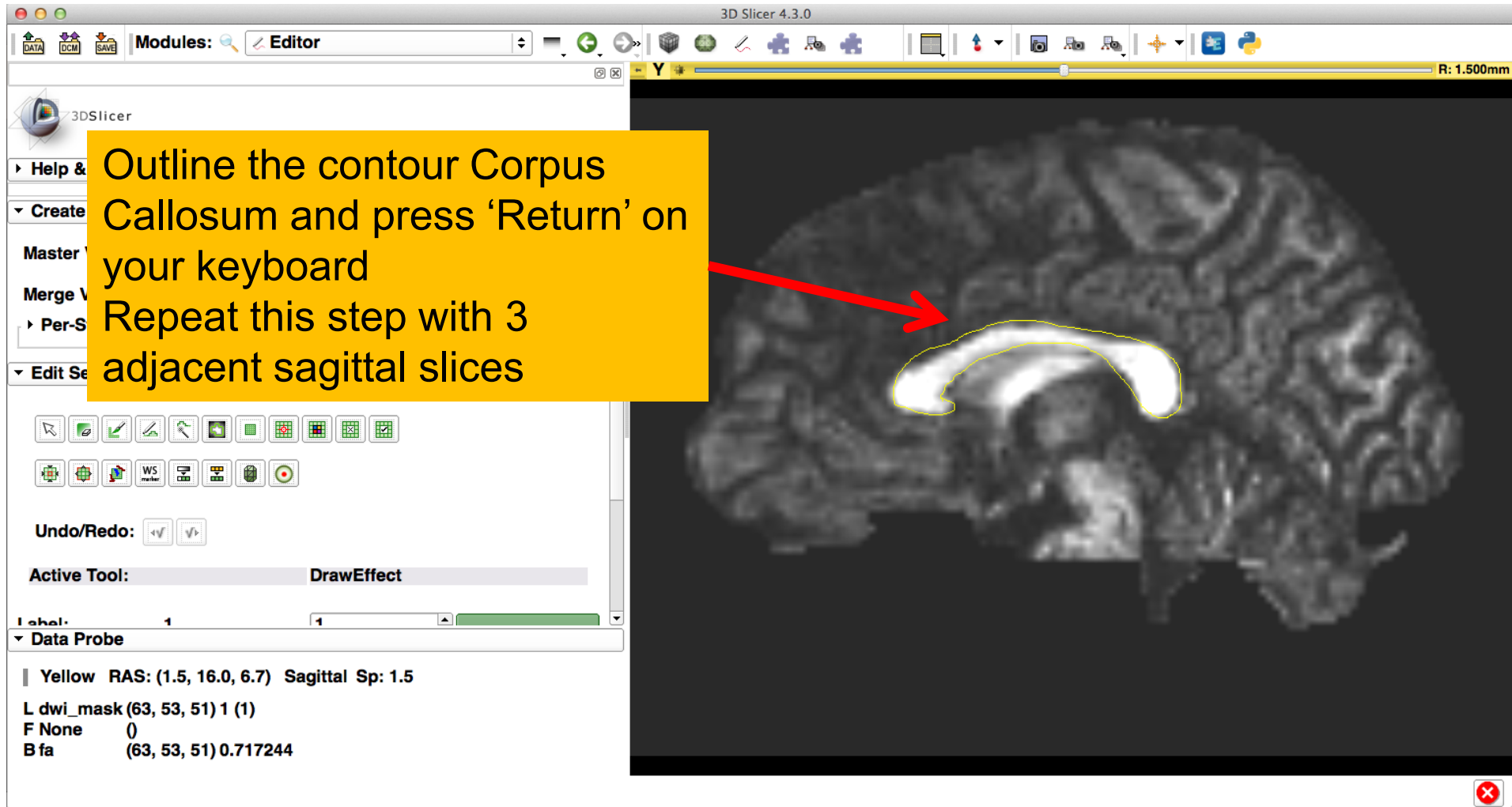
R: 1.500mm

# Diffusion MRI tractography



# Diffusion MRI tractography

outline: 輪郭を描く    adjacent: 隣接した    sagittal: サジタル(脳を左右に分割するような)



3D Slicer 4.3.0

Modules: Editor

R: 1.500mm

3DSlicer

Help & Create Master Merge V Per-S Edit Se

Outline the contour Corpus Callosum and press 'Return' on your keyboard  
Repeat this step with 3 adjacent sagittal slices

Undo/Redo: [Undo] [Redo]

Active Tool: DrawEffect

Label: 1

Data Probe

Yellow RAS: (1.5, 16.0, 6.7) Sagittal Sp: 1.5

L dwi\_mask (63, 53, 51) 1 (1)

F None 0

B fa (63, 53, 51) 0.717244



# Diffusion MRI tractography

seeded: 追跡が開始される

region of interest : 関心領域 = 設定領域

File Edit View Help

DATA DCM SAVE Modules: Editor

3DSlicer

Help & Acknowledgement

Create and Select Label Maps

Master

Merge

Per

Edit

The tracts will be seeded from the region of interest defined in the Corpus Callosum area.



Undo/Redo: [undo] [redo]

Active Tool: DrawEffect

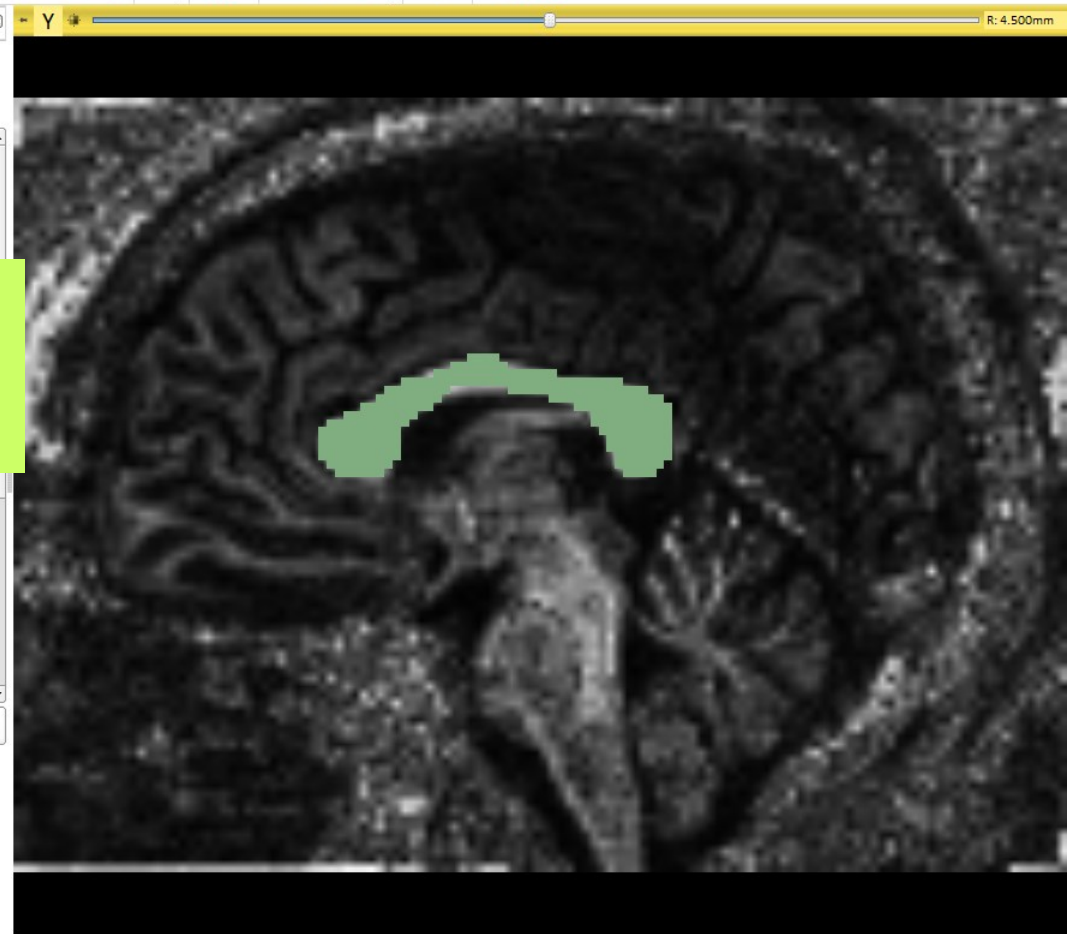
Data Probe

Yellow RAS: (3.0, 38.4, -9.3) Sagittal Sp: 1.5

L fa-label (62, 38, 41) background (0)

F None ()

B fa (62, 38, 41) 0.22537



# Diffusion MRI tractography

The image shows the 3D Slicer software interface. On the left, the 'Modules' panel is open, displaying a list of modules. The 'Diffusion' module is selected, and its sub-menu is open, showing 'Tractography Label Map Seeding' as the selected option. A yellow text box with the instruction 'Select the module Tractography Label Map Seeding' is overlaid on the main window, with a red arrow pointing to the selected menu item. The main window displays a grayscale MRI scan of a brain slice with a green seed region.

File Edit View Help

Annotations Work in Progress

Data

DICOM

Editor

Models

Scene Views

Transforms

View Controllers

Volume Rendering

Volumes

Welcome to Slicer

Wizards

Informatics

Registration

Segmentation

Quantification

**Diffusion**

- DWI to Full Brain Tractography
- Tractography Display
- Diffusion Data Conversion
- Diffusion Tensor Images**
- Diffusion Weighted Images
- Tractography

- Diffusion Tensor Scalar Measurements
- Resample DTI Volume
- Tractography Interactive Seeding
- Tractography Label Map Seeding**

Select the module  
**Tractography Label Map Seeding**

L  
F  
B

# Diffusion MRI tractography

File Edit View Help

Modules: Tractography Label Map Seeding

3DSlicer

Help & Acknowledgement

Tractography Label Map Seeding

Parameter set: Tractography Label Map Seeding

IO

Input DTI Volume dti

Input Label Map fa-label

Output Fiber Bundle corpusCallosum

Seed Placement Options

Use Index Space

Seed Spacing 2.00

Random Grid

Status: Idle

Restore Defaults AutoRun Cancel Apply

Data Probe

L  
F  
B

R: 4.500mm

**-Set the Input DTI Volume to 'dti'**  
**-Set the Input Label Map to 'fa-label'**  
**-Set Output Fiber Bundle to 'Create and Rename New Fiber Bundle' and rename it 'corpusCallosum'**

ROI (region of interest) : 関心領域 = 設定領域

# ROI Drawing

File Edit View Help

Modules: Tractography Label Map Seeding

3DSlicer

▶ Help & Acknowledgement

▼ Tractography Label Map Seeding

Parameter set: Tractography Label Map Seeding

▼ IO

Input DTI Volume dti

Input Label Map fa-label

Output Fiber Bundle corpusCallosum

▼ Seed Placement Options

Use Index Space

Seed Spacing 2.00

Random Grid

Status: Idle

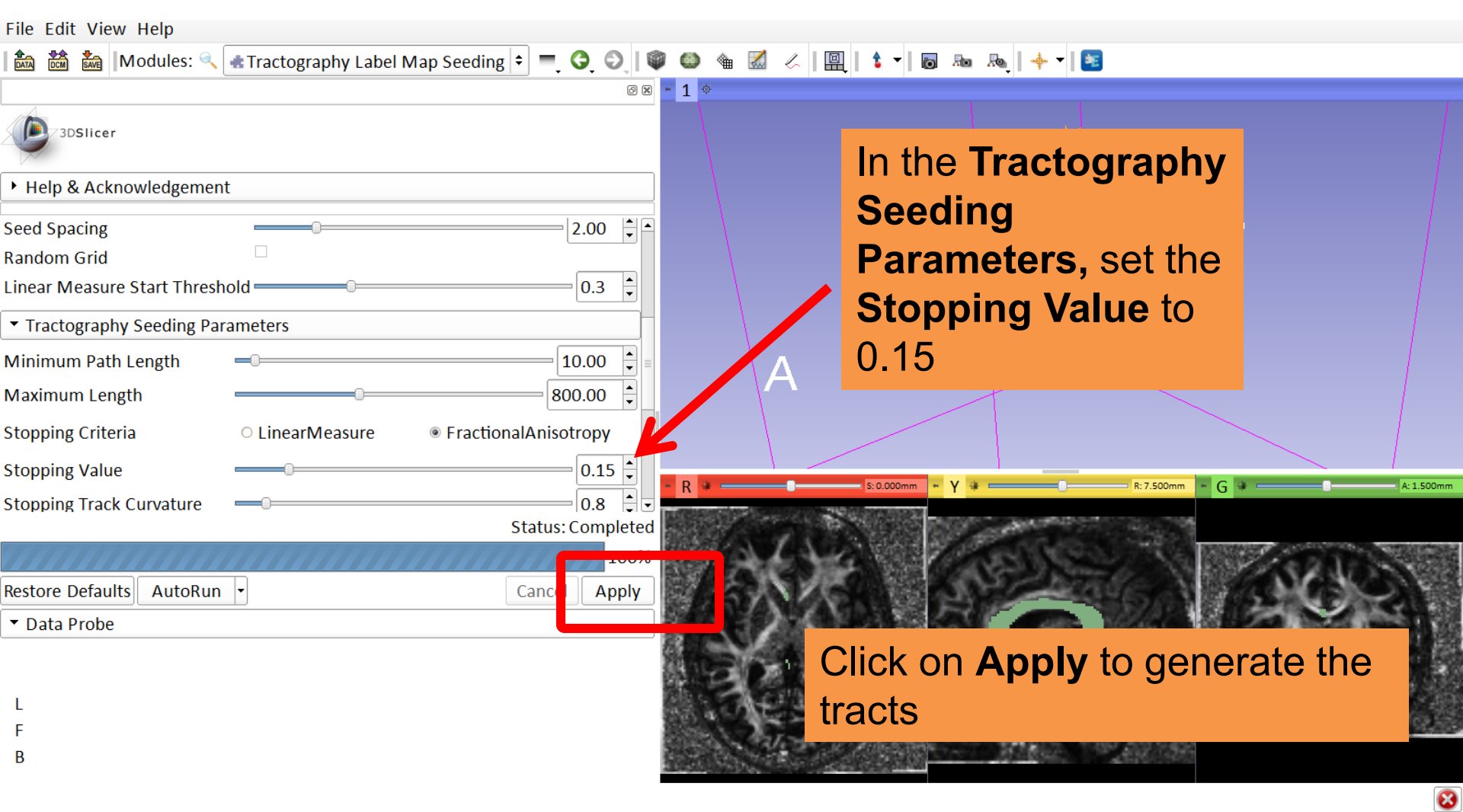
Restore Defaults AutoRun Cancel Apply

▼ Data Probe

L  
F  
B

**Under Seed Placement Options, check off the option for 'Use Index Space'**

# Labelmap Seeding: Tracts



# Labelmap Seeding: Tracts

File Edit View Help

Modules: Tractography Label Map Seeding

3DSlicer

Help & Acknowledgement

Seed Spacing: 2.00

Random Grid:

Linear Measure Start Threshold: 0.3

Tractography Seeding Parameters

Minimum Path Length: 10.00

Maximum Length: 800.00

Stopping Criteria:  LinearMeasure  FractionalAnisotropy

Stopping Value: 0.15

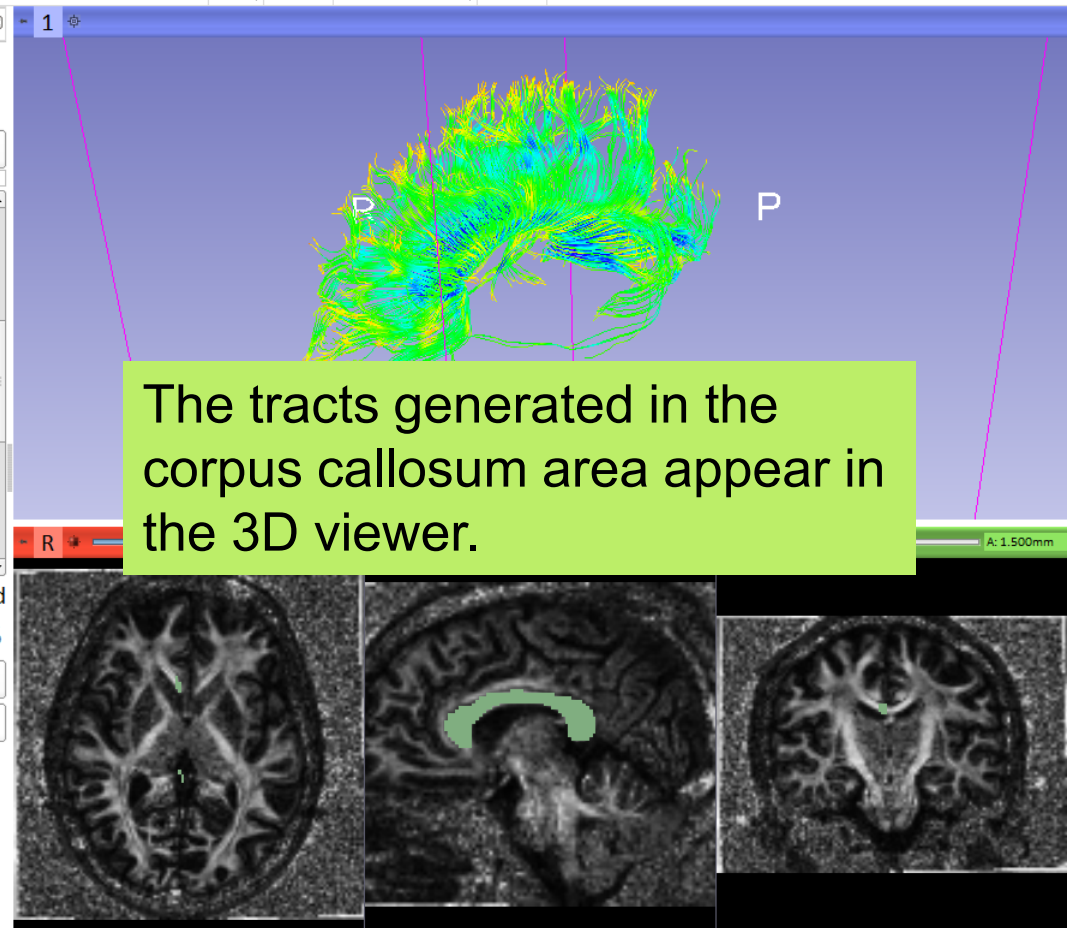
Stopping Track Curvature: 0.8

Status: Completed

100%

Restore Defaults AutoRun Cancel Apply

Data Probe



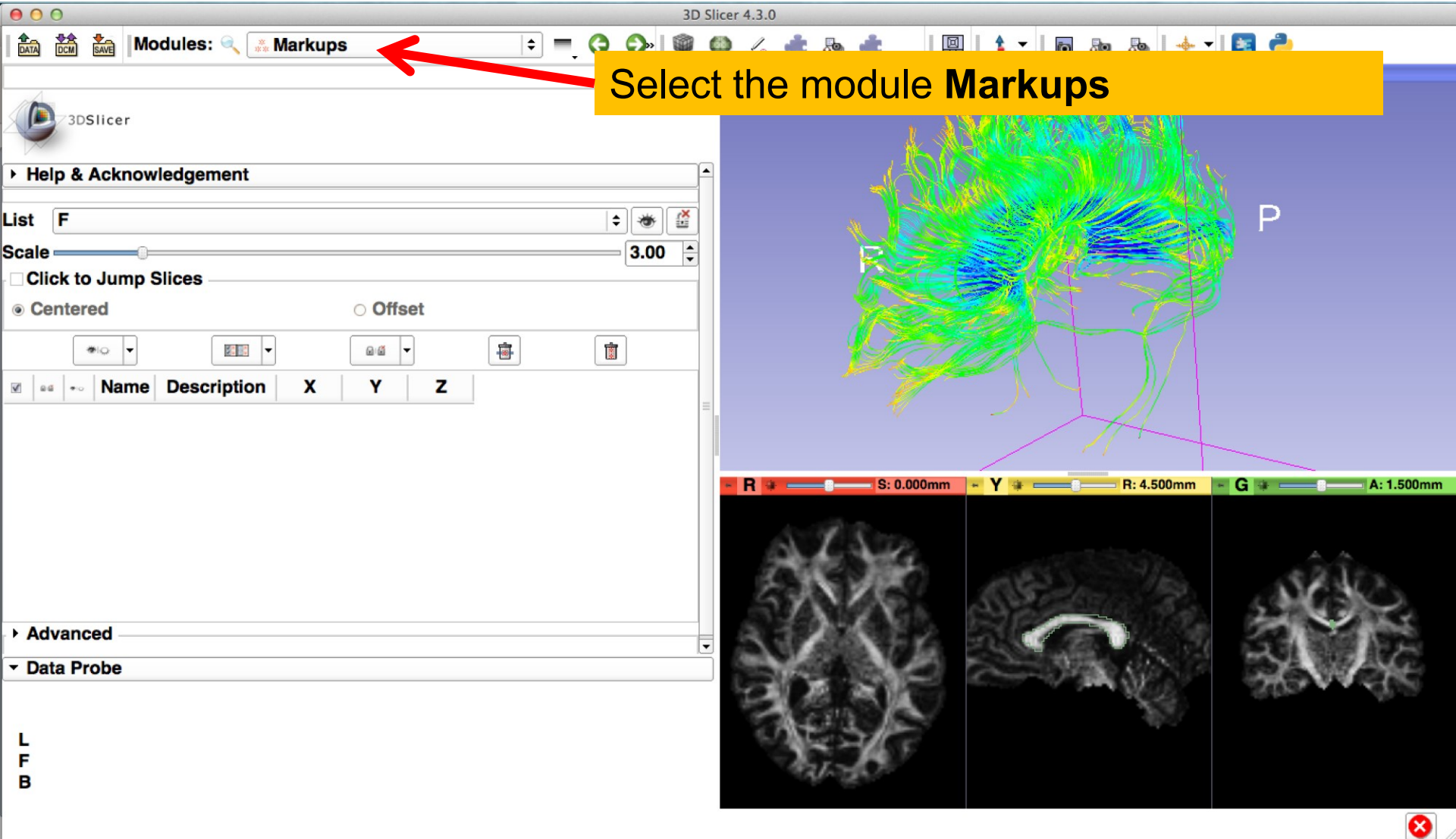
tracts: 追跡軌跡  
generated: 生成される

L  
F  
B

基準点による追跡開始点設定

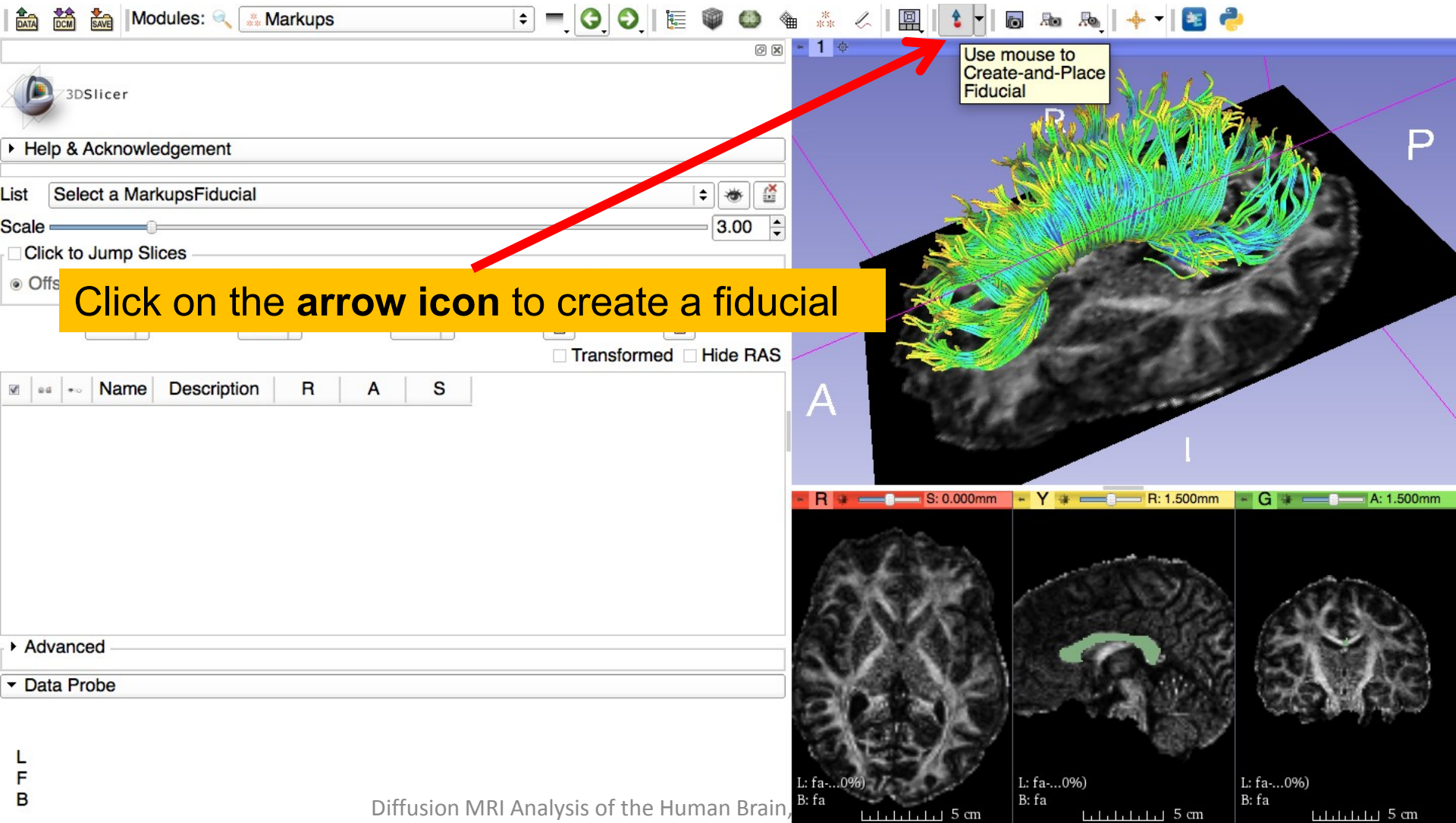
# Fiducial Seeding

fiducial: 基準(点)



基準点による追跡開始点設定

# Fiducial Seeding





# Fiducial Seeding

3DSlicer

Modules: Markups

Help & Acknowledgement

List F

Sc

Position the fiducial near the corpus callosum fibers in the 3D scene

Transformed Hide RAS

	Name	Description	R	A	S
1	F-1		-3.137	1.500	23.736

position:  
~の位置に設定する

Advanced

Data Probe

L  
F  
B

R S: 22.500mm Y: 1.500mm G A: 1.500mm

L: fa-...0%)  
B: fa

L: fa-...0%)  
B: fa

L: fa-...0%)  
B: fa

5 cm 5 cm 5 cm



# Fiducial Seeding

3D Slicer 4.3.0

Modules: **Tractography Interactive Seeding**

Help & Acknowledgement

IO

Parameters: **FiducialSeedingParameters**

Presets: **Slicer4 Interactive Seeding Defaults**

IO

**Input DTI Volume**: dti

**Input Fiducials, Model or Label Map**: F

**Output Fiber Bundle**: fiber

**Enable Seeding Tracts**:

Seed Placement Options

Fiducial Region Size: 2.50mm

Fiducial Seeding Step Size: 1.00mm

Seed Selected Fiducials:

Max Number of Seeds: 100

Data Probe

L  
F  
B

S: 0.000mm Y R: 4.500mm G A: 1.500mm

**Select the module Tractography Interactive Seeding**

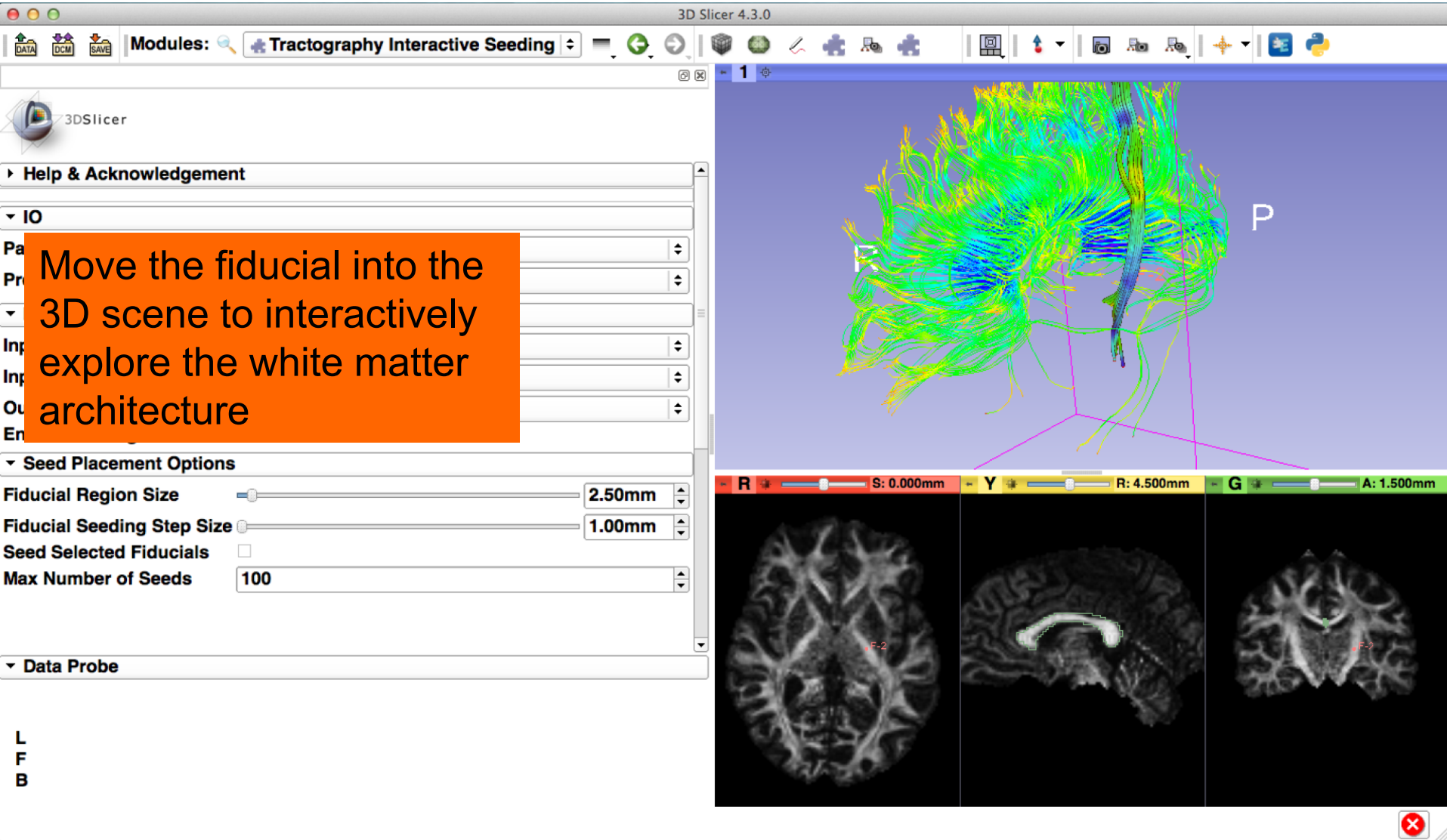
**Set the Input DTI volume to 'dti'**

**Set the Input Fiducials, Model or Label Map to 'F'**

**Select the Output Fiber Bundle 'Create New Fiber Bundle' and rename it 'fiber'**

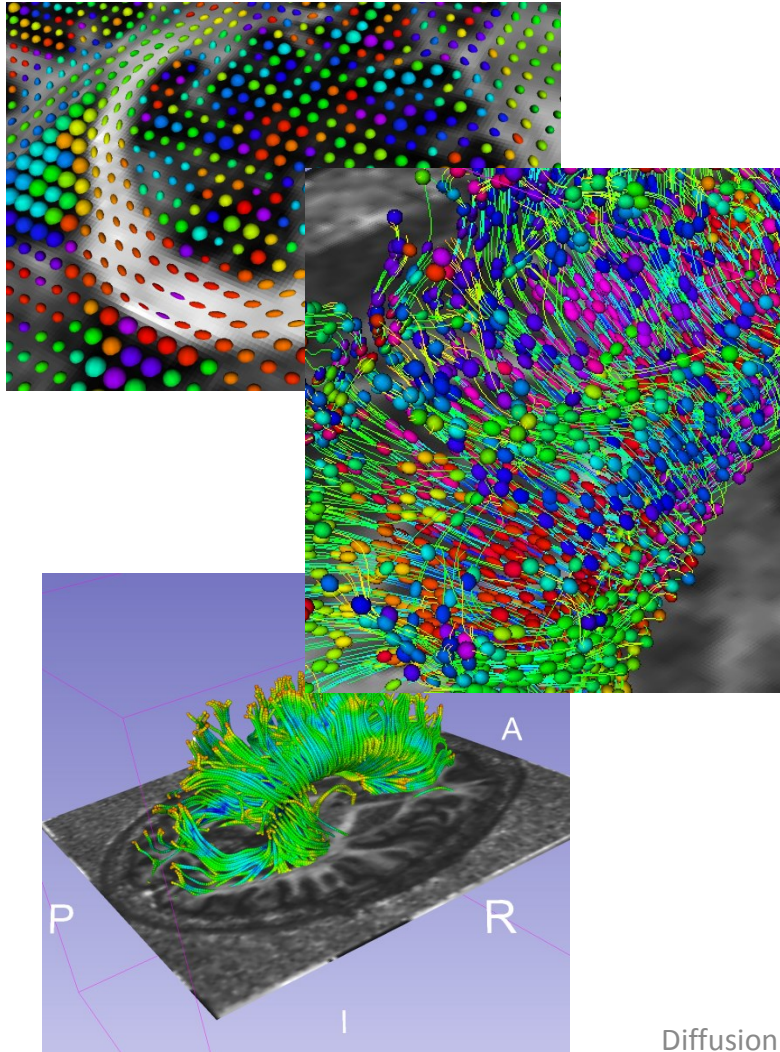
**Check Enable Seeding Tracts** enable: 可能にする

# Fiducial Seeding



結論

# Conclusion



This tutorial guided you through the different steps of a Diffusion MR analysis pipeline, from tensor estimation to 3D tracts visualization, for exploring and studying the 3D architecture of the brain white matter.

pipeline : 処理のパイプライン(手順)  
Architecture : 構造

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