



# UKF Tractography Tutorial

Pegah Kahali, M.D.

Surgical Planning Laboratory  
Harvard Medical School





# 3DSlicer

- The tutorial uses the 3DSlicer software ([www.slicer.org](http://www.slicer.org))

**3DSlicer** A multi-platform, **free and open source** software package for **visualization** and **medical image computing**

[Download](#) [Slicer Training](#) [Feedback](#)

### About Slicer

- ▶ Introduction
- ▶ Acknowledgments
- ▶ News
- ▶ Contact Us
- ▶ Licensing
- ▶ Commercial Use

### Publication

- ▶ Publication DB
- ▶ Image Gallery
- ▶ Slicer Community
- ▶ Citing Slicer

### Documentation

- ▶ Slicer Training
- ▶ User Manual
- ▶ Developer Manual

### Help

- ▶ Help
- ▶ User FAQ
- ▶ Developer FAQ
- ▶ Mailing Lists

### Links

- ▶ [download.slicer.org](http://download.slicer.org)
- ▶ [wiki.slicer.org](http://wiki.slicer.org)

### The community of Slicer developers is proud to announce the release of Slicer 4.5


Slicer 4.5 introduces:

- An improved App Store, known as the Extension Manager, for adding plug-ins to Slicer. More than 80 plug-ins and packages of plug-ins are currently available.
- Close to 150 feature improvements and bug fixes have resulted in improved performance and stability.
- Improvements to many modules.

Read the Announcements for more details and click here to download Slicer 4.5.

Slicer is made possible through contributions from an international community of scientists from a multitude of fields, including engineering and biomedicine.

Powerful processing.	Streamlined interface.	Extensible platform.

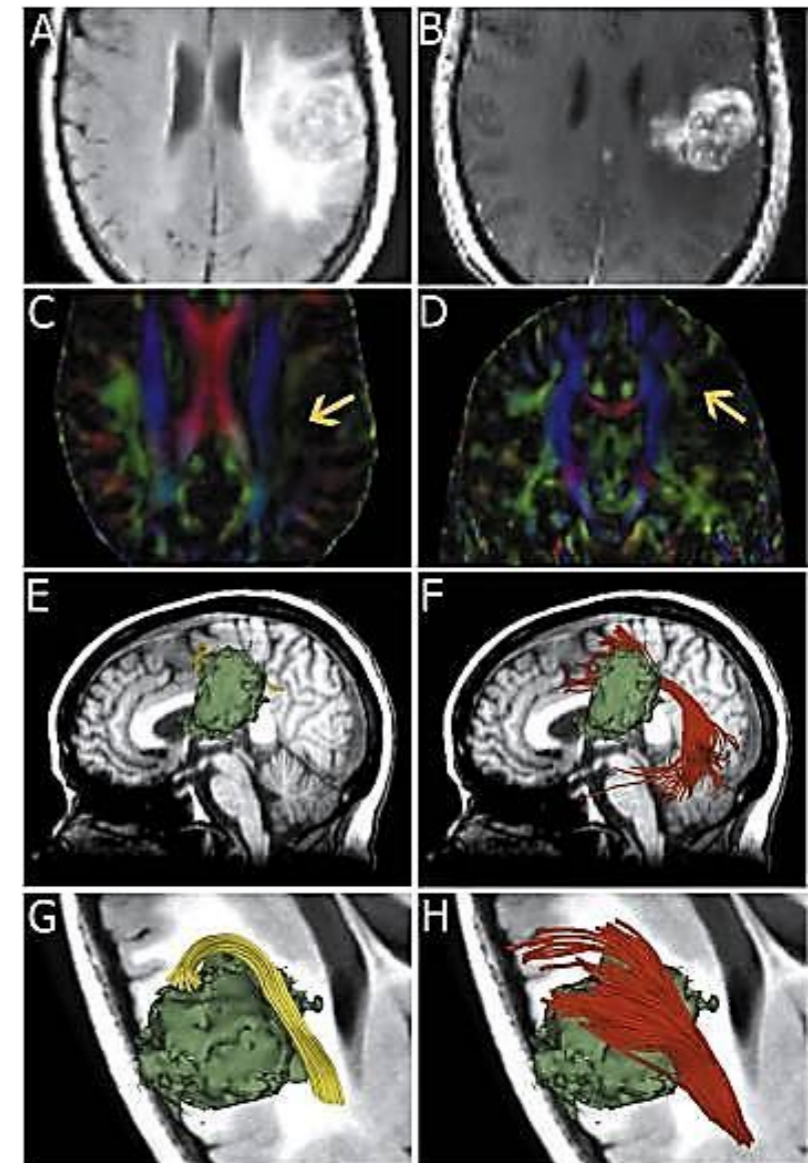
 **3D Slicer** version 4 [www.slicer.org](http://www.slicer.org)

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.



# 3DSlicer

- An **end-user** application for image analysis
- An **open-source** environment for software development
- A software platform that is both **easy to use** for clinical researchers and **easy to extend** for programmers



[Chen et al, 2015]

# UKF Installation

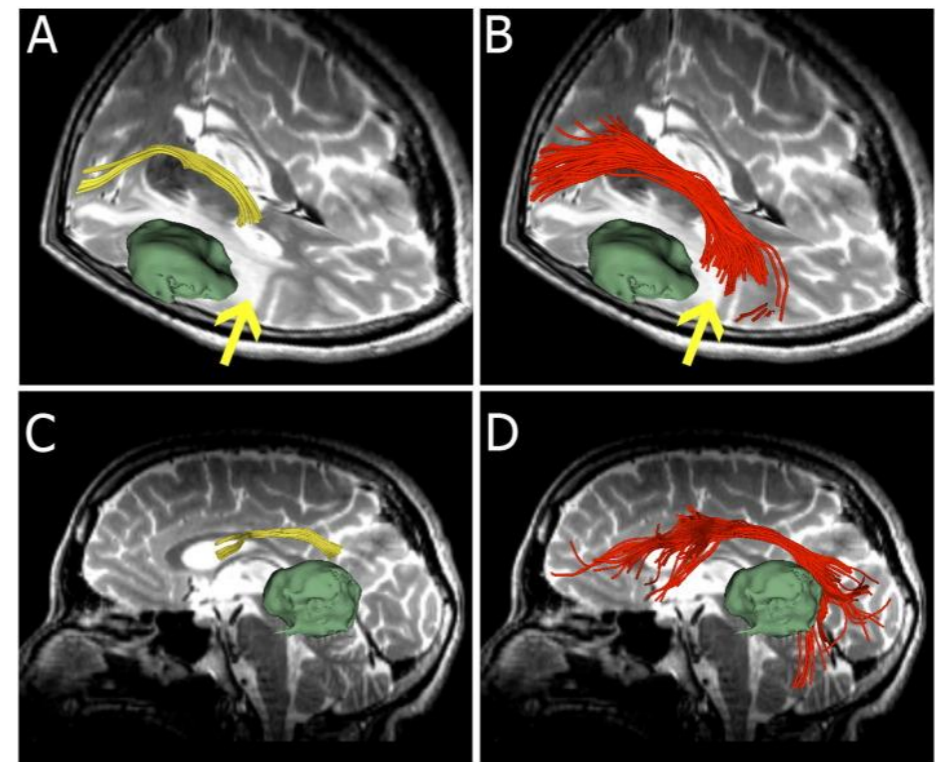
- 3D Slicer now supports plug-ins/extensions that are available for download from an extension server. Extensions allow end-users to selectively install features that are useful for them.
- UKF tractography can be installed on Slicer using “Extension Manager”.
- Instructions: [Extension Manager Wiki](#)

# UKF Tractography

- Unscented Kalman Filter tractography method:
  - Simultaneous model estimation and tractography
  - The diffusion model is fit to the data during tractography not before.

# Why UKF

- UKF tractography may detect more fibers comparing to single-tensor streamline tractography (Slicer default method), especially in edematous areas.
- For example: The UKF two-tensor model traces a larger volume arcuate fasciculus in the setting of edema.



[Chen et al, 2015]

# Unscented Kalman Filter Tractography

[Inf Process Med Imaging. 2009;21:126-38.](#)

## **Neural tractography using an unscented Kalman filter.**

[Malcolm JG](#)<sup>1</sup>, [Shenton ME](#), [Rathi Y](#).

### **⊖ Author information**

<sup>1</sup>Psychiatry Neuroimaging Laboratory, Harvard Medical School, Boston, MA, USA. [malcolm@bwh.harvard.edu](mailto:malcolm@bwh.harvard.edu)

### **Abstract**

We describe a technique to simultaneously estimate a local neural fiber model and trace out its path. Existing techniques estimate the local fiber orientation at each voxel independently so there is no running knowledge of confidence in the estimated fiber model. We formulate fiber tracking as recursive estimation: at each step of tracing the fiber, the current estimate is guided by the previous. To do this we model the signal as a mixture of Gaussian tensors and perform tractography within a filter framework. Starting from a seed point, each fiber is traced to its termination using an unscented Kalman filter to simultaneously fit the local model and propagate in the most consistent direction. Despite the presence of noise and uncertainty, this provides a causal estimate of the local structure at each point along the fiber. Synthetic experiments demonstrate that this approach reduces signal reconstruction error and significantly improves the angular resolution at crossings and branchings. In vivo experiments confirm the ability to trace out fibers in areas known to contain such crossing and branching while providing inherent path regularization.

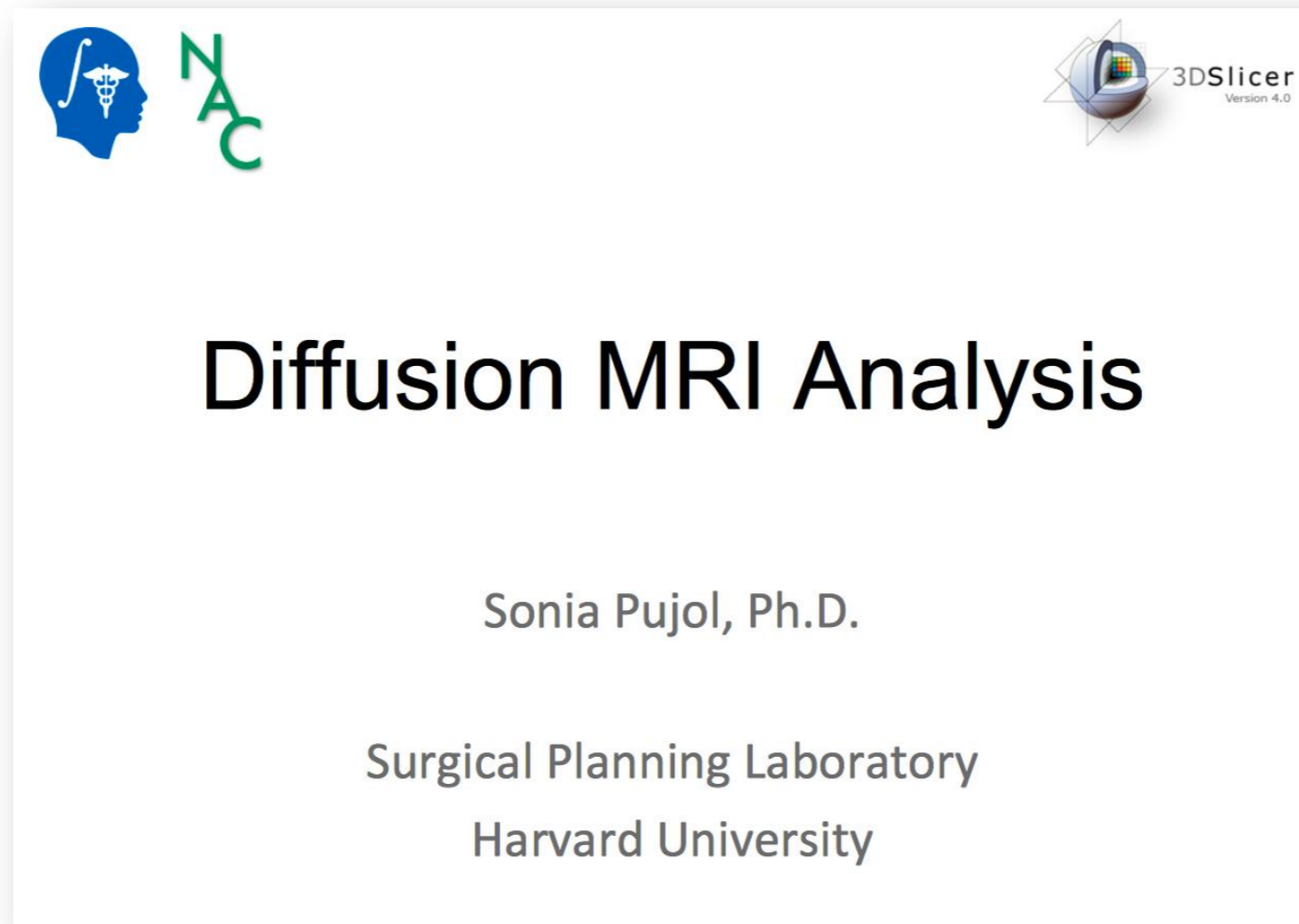
PMID: 19694258 [PubMed - indexed for MEDLINE] PMCID: PMC2768602 **Free PMC Article**

[Neural Tractography Using an Unscented Kalman Filter](#)

[Malcom et al., 2009]

# Before getting started...

- take a look at: [Diffusion Tensor Imaging Tutorial](#)

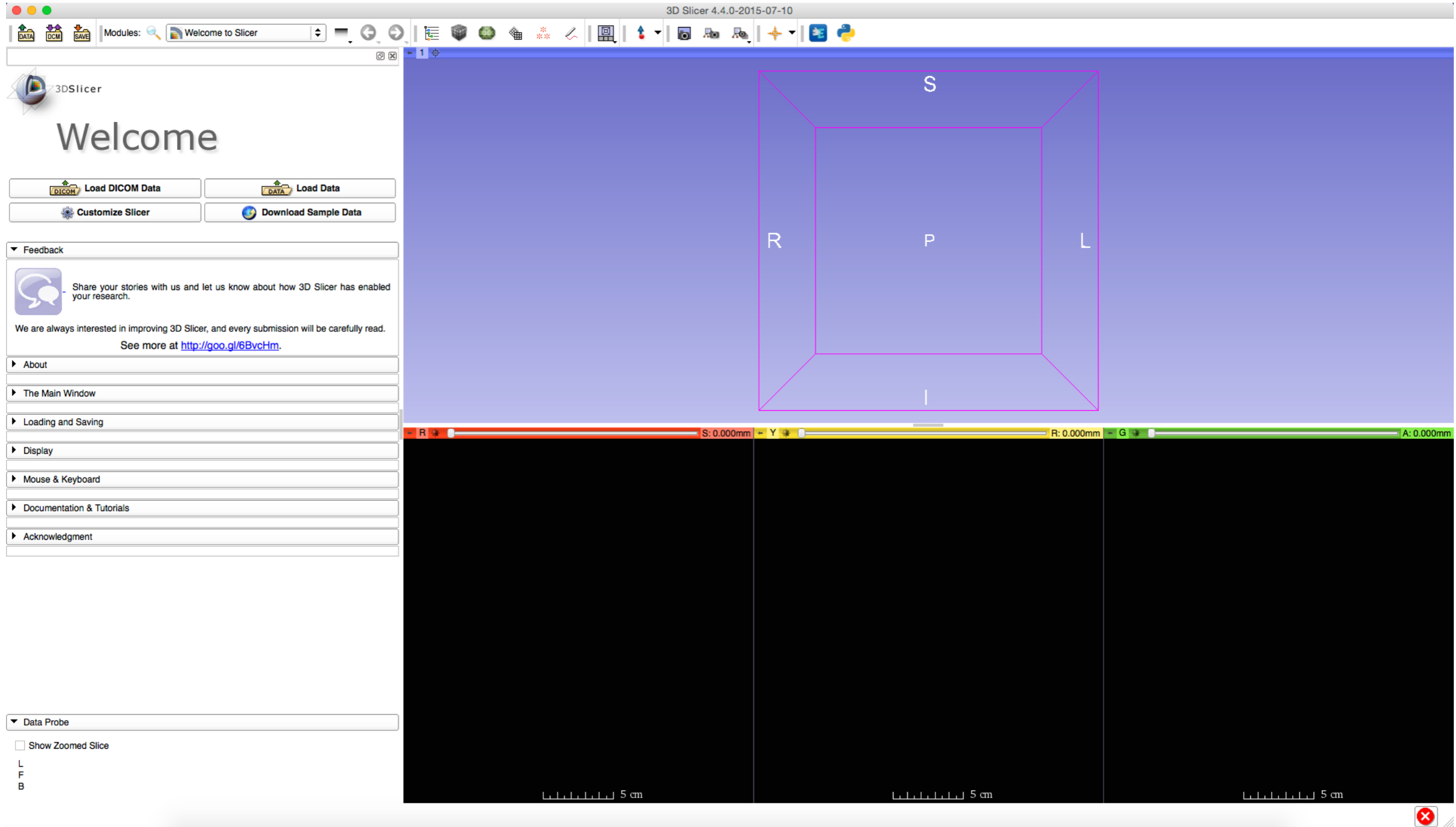




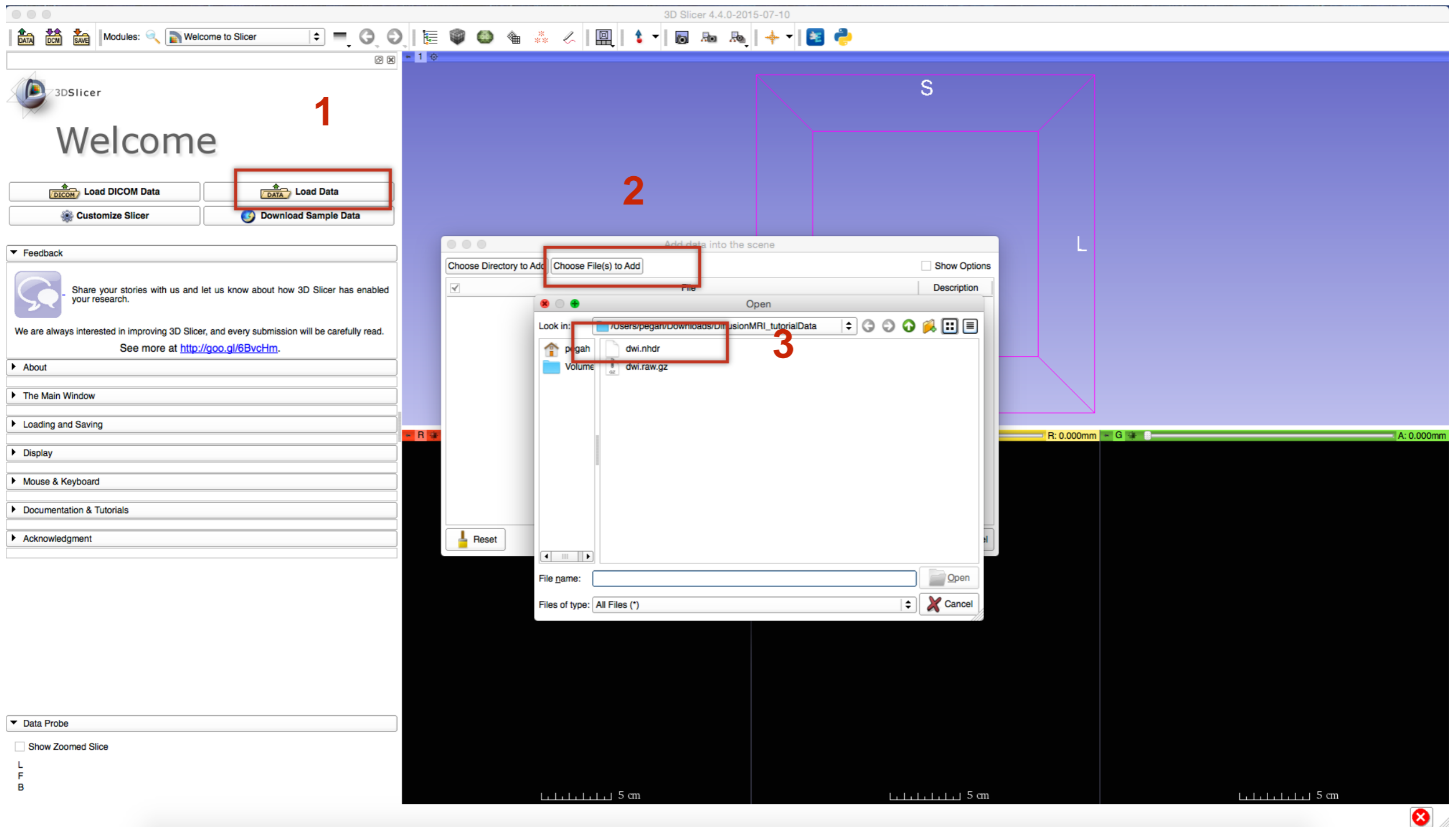
# DWI Dataset

- Download the data at: [DWI Dataset](#)
- The Diffusion Weighted Imaging (DWI) dataset is composed of :
  - 1 volume acquired without diffusion-sensitizing gradient
  - 41 volumes acquired with 41 different diffusion-sensitizing gradient directions

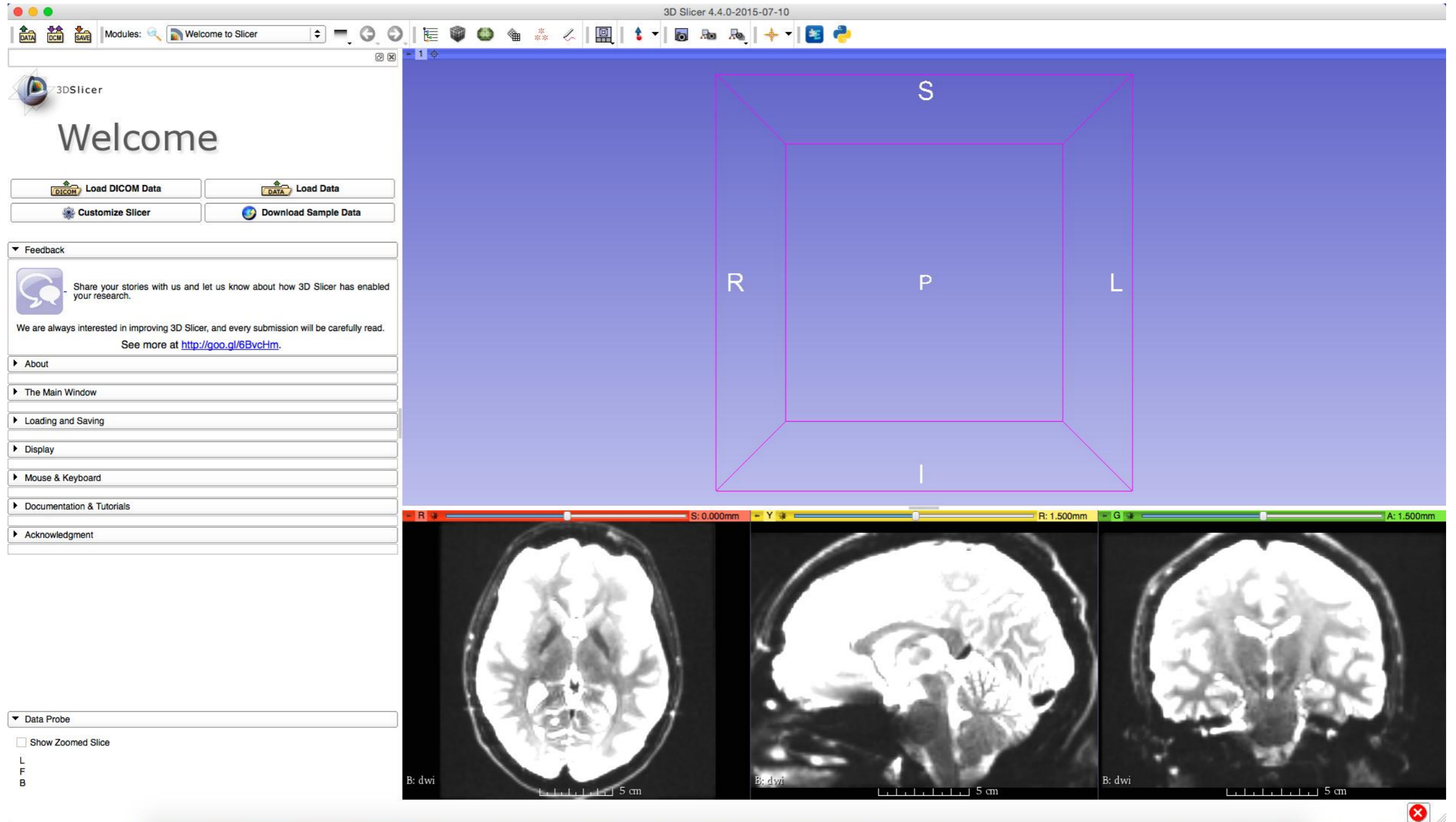
# Start Slicer



# Load the data



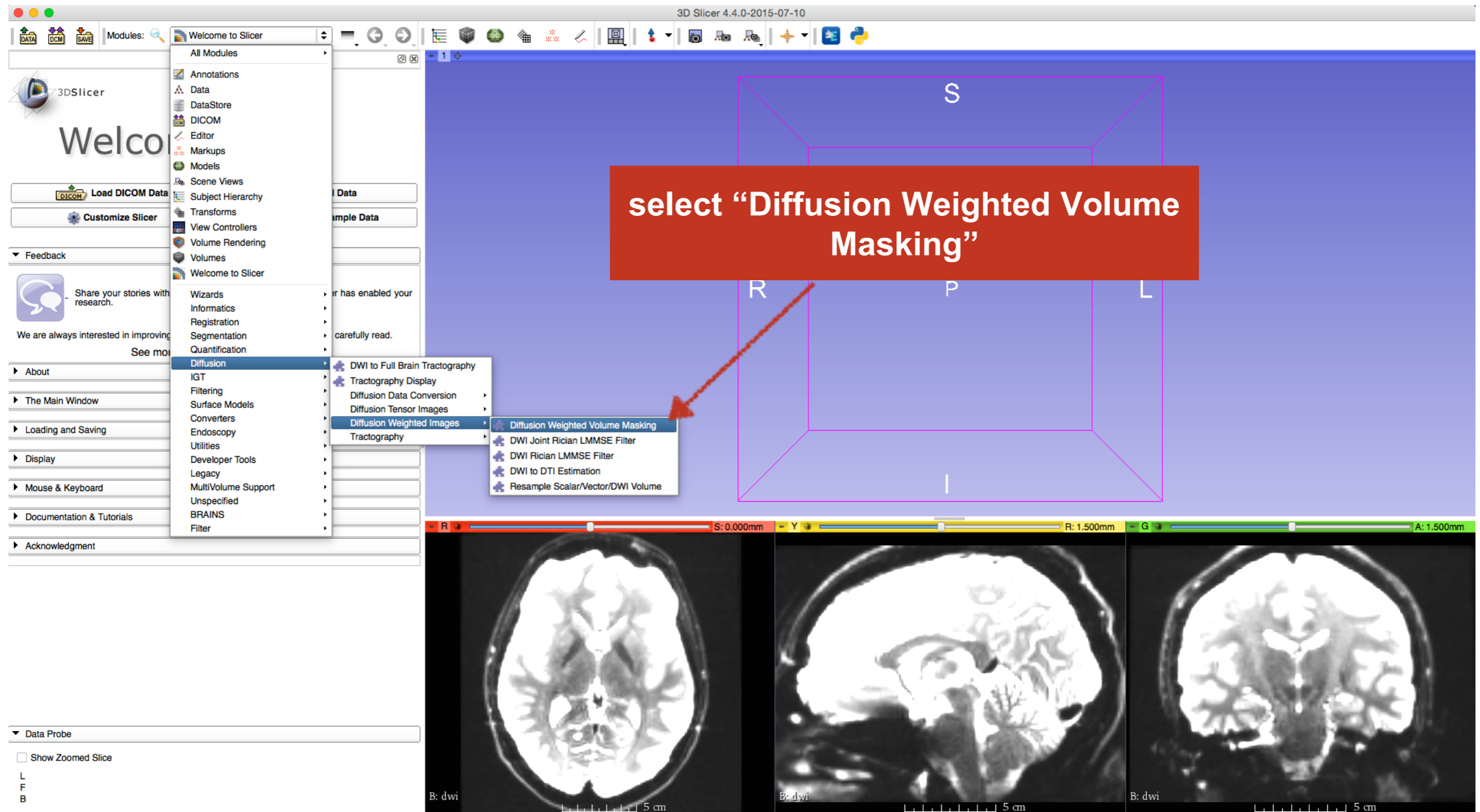
# There you go...!



# Main Steps

- Creating a brain mask
- Creating FA map
- Creating region of interest for tract seeding
- UKF tractography

# Brain Mask Creation



**the input is the DWI volume you loaded**

3D Slicer 4.4.0-2015-07-10

Modules: Diffusion Weighted Volume Masking

Parameter set: Diffusion Weighted Volume Masking

Input DWI Volume: dwi

Output Baseline Volume: Output Baseline Volume

Otsu Threshold Mask: Otsu Threshold Mask

Otsu Omega Threshold Parameter: 0.5

Remove Islands in Threshold Mask

create new volumes as the Baseline and Mask

set best parameters here

Status: Idle

Apply

Restore Defaults AutoRun

Cancel

Show Zoomed Slice

L F B

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

B: dwi 5 cm



# the Otsu segmentation algorithm produces a mask

3D Slicer 4.4.0-2015-07-10

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: Output Baseline Volume

Otsu Threshold Mask: Otsu Threshold Mask

Otsu Omega Threshold Parameter: 0.0

Remove Islands in Threshold Mask:

Status: Completed 100%

Restore Defaults AutoRun Cancel Apply

Data Probe

Show Zoomed Slice

L F B

S

this mask can then be used when estimating the diffusion tensor image, in order not to estimate tensors all over the volume

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

L: Otsu Threshold Mask (100%) B: Output Baseline Volume 5 cm

L: Otsu Threshold Mask (100%) B: Output Baseline Volume 5 cm

L: Otsu Threshold Mask (100%) B: Output Baseline Volume 5 cm





# Tract Seeding

- For whole brain tractography with UKF, the Otsu threshold mask is used as the brain mask.
- To seed a specific tract of interest, label maps can be drawn on either:
  - DWI (output baseline volume)
  - FA map

# Tract Selection

- Note that FA maps can be more informative for selecting ROIs.
- For that purpose you should first estimate DTI and calculate FA map
- Although these maps are only used here for ROI selection and the model is again estimated from DWI for UKF tractography.

# DWI to DTI Estimation

3D Slicer 4.4.0-2015-07-10

Diffusion Weighted Volume Masking

Parameter set: Diffusion Weighted Volume Masking

Input DWI Volume: dwi

Output Baseline Volume: Output Baseline Volume

Otsu Threshold Mask: Otsu Threshold Mask

Otsu Omega Threshold Parameter: 0.0

Remove Islands in Threshold Mask:

Diffusion

- DWI to Full Brain Tractography
- Tractography Display
- Diffusion Data Conversion
- Diffusion Tensor Images
- Diffusion Weighted Images
  - Diffusion Weighted Volume Masking
  - DWI Joint Rician LMMSE Filter
  - DWI Rician LMMSE Filter
  - DWI to DTI Estimation**
  - Resample Scalar/Vector/DWI Volume
- Tractography

select this module

S

R

L

P

R: 0.000mm

Y

R: 1.500mm

G

A: 1.500mm

Status: Completed

100%

Restore Defaults

AutoRun

Cancel

Apply

Data Probe

Show Zoomed Slice

L

F

B

L: Otsu Threshold Mask (100%)  
B: Output Baseline Volume

5 cm

L: Otsu Threshold Mask (100%)  
B: Output Baseline Volume

5 cm

L: Otsu Threshold Mask (100%)  
B: Output Baseline Volume

5 cm

# Set the Parameters

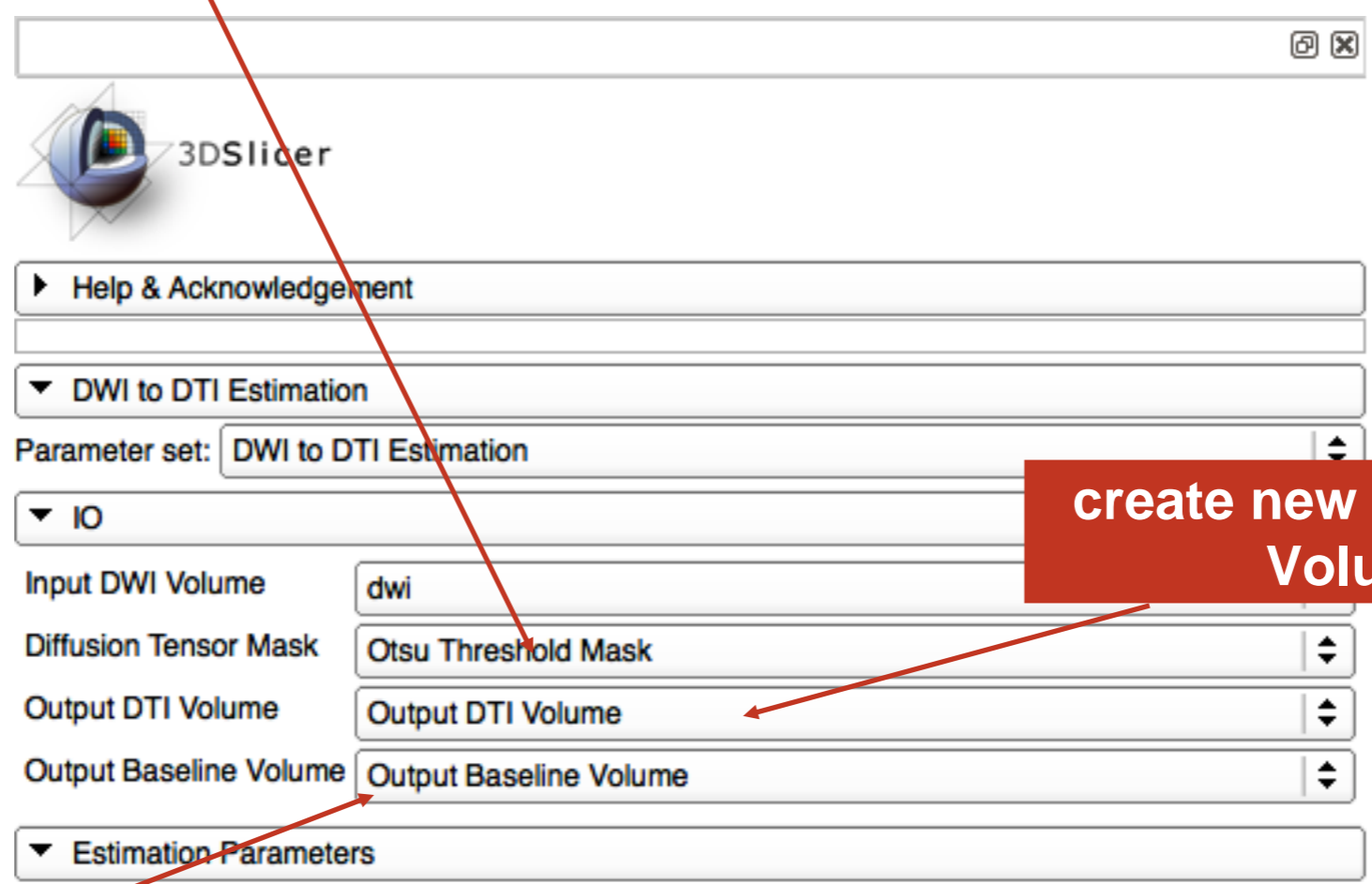
The screenshot displays the 3D Slicer 4.4.0-2015-07-10 interface. The main window shows a 3D brain model with a purple bounding box labeled with 'S' (Superior), 'R' (Right), 'P' (Posterior), 'L' (Left), and 'I' (Inferior). The left sidebar contains the 'DWI to DTI Estimation' module parameters, which are highlighted with a red border. The parameters are as follows:

- Parameter set: DWI to DTI Estimation
- IO
  - Input DWI Volume: dwi
  - Diffusion Tensor Mask: Otsu Threshold Mask
  - Output DTI Volume: Output DTI Volume
  - Output Baseline Volume: Output Baseline Volume
- Estimation Parameters
  - Estimation Parameters:  LS  WLS
  - Shift Negative Eigenvalues:

At the bottom, three 2D slices are shown, each with a 5 cm scale bar. The slices are labeled 'L: Otsu Threshold Mask (100%)' and 'B: Output Baseline Volume'. The status bar at the bottom indicates 'Status: Idle' and 'AutoRun' is selected.



**select Otsu Threshold Mask you already created**



**create new Output DTI Volume**

**select the "Output Baseline Volume" you already created**

**select WLS (Weighted Least Square)**

***Click Apply***

# Status: Completed! 100%

The screenshot displays the 3D Slicer 4.4.0-2015-07-10 interface. The main window shows a 3D brain volume with a red callout box containing the text: "select 'Output DTI Volume' as the background and 'None' for foreground and label map". The callout box has an arrow pointing to the volume. The interface includes a top toolbar, a left sidebar with the "DWI to DTI Estimation" module selected, and a bottom panel with three viewports: "Output DTI Volume", "Otsu Threshold Mask (100%)", and "Output Baseline Volume".

**Module Parameters:**

- Parameter set: DWI to DTI Estimation
- IO
  - Input DWI Volume: dwi
  - Diffusion Tensor Mask: Otsu Threshold Mask
  - Output DTI Volume: Output DTI Volume
  - Output Baseline Volume: Output Baseline Volume
- Estimation Parameters
  - Estimation Parameters:  LS  WLS
  - Shift Negative Eigenvalues:

**Status: Completed 100%**

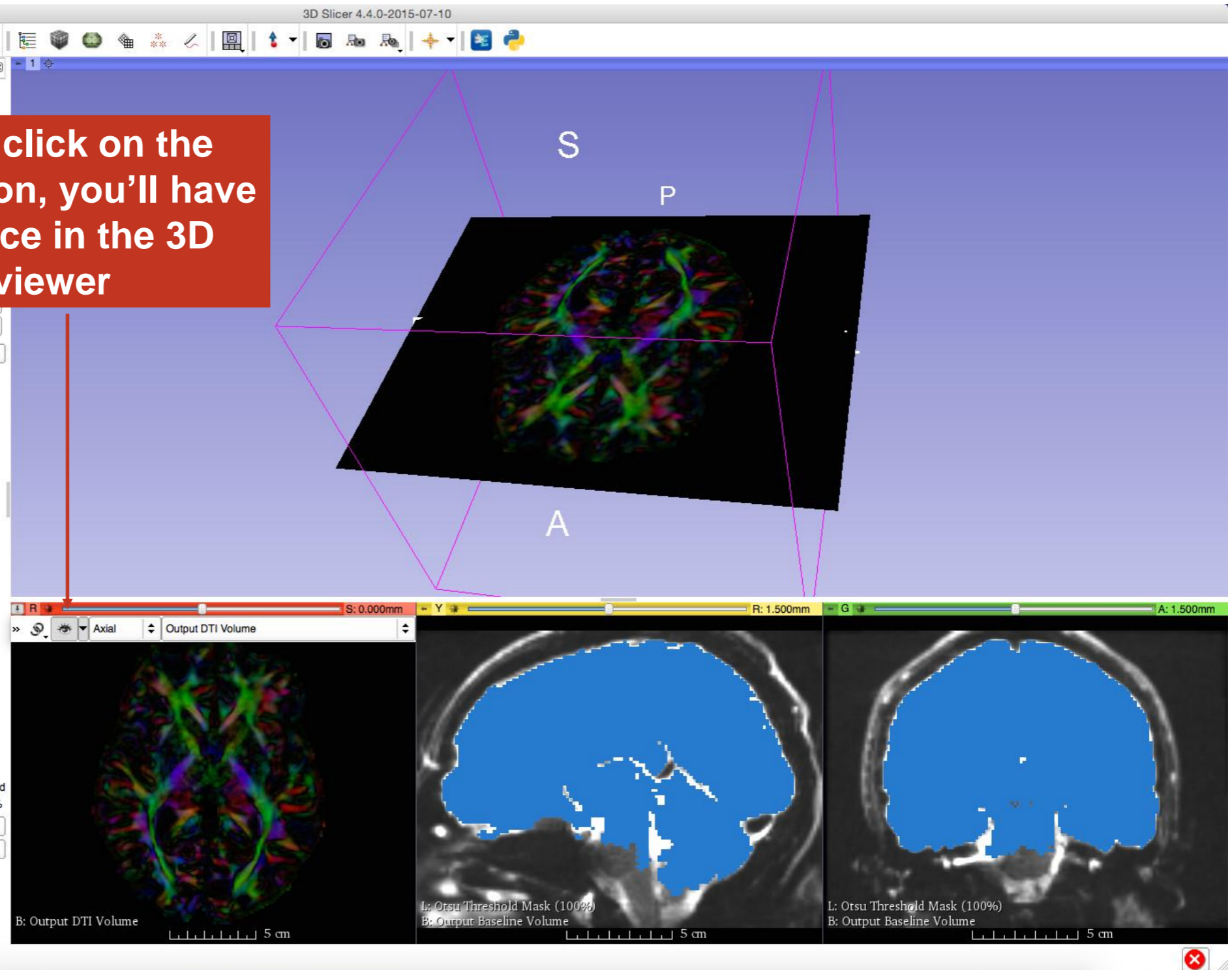
**Data Probe:**

- Yellow RAS: ( 1.5, 80.4, 15.8) Sagittal Sp: 1.5
- L Otsu Threshold Mask ( 63, 10, 58) Black (0)
- F None
- B Output Baseline Volume ( 63, 10, 58) 135

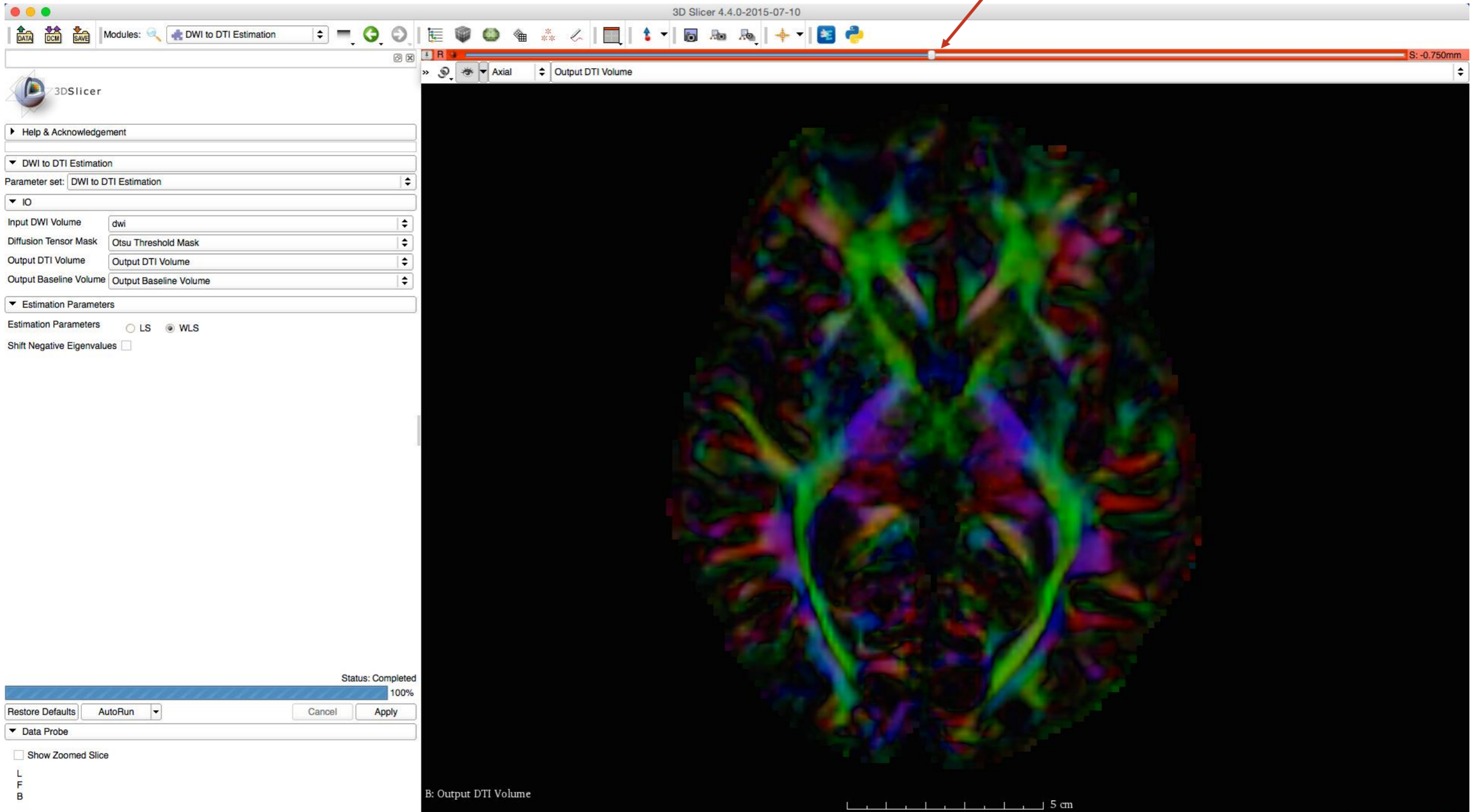


# color-coded DTI volume

if you click on the  
“eye” icon, you’ll have  
the slice in the 3D  
viewer



browse through the DTI volume here





# Diffusion Tensor Scalar Measurements; FA

The image shows the 3D Slicer software interface. The main window displays a brain slice with a color-coded Diffusion Tensor Imaging (DTI) volume. The left sidebar contains a 'Modules' panel with a search bar and a list of modules. The 'Diffusion' module is selected, and its sub-menu is open, showing 'Diffusion Tensor Scalar Measurements' as the active option. A red callout box with the text 'select the module' and an arrow points to this option. The top toolbar includes icons for file operations, navigation, and visualization. The bottom status bar shows 'Status: Completed' and '100%' progress. The bottom right corner of the main window displays 'B: Output DTI Volume' and a 5 cm scale bar.

3D Slicer 4.4.0-2015-07-10

Modules: DWI to DTI Estimation

Parameter set: DWI to DTI Estimation

IO

Input DWI Volume: dwi

Diffusion Tensor Mask: Otsu Threshold

Output DTI Volume: Output DTI Volume

Output Baseline Volume: Output Baseline Volume

Estimation Parameters

Estimation Parameters:  LS

Shift Negative Eigenvalues:

Status: Completed 100%

Restore Defaults AutoRun Cancel Apply

Data Probe

Show Zoomed Slice

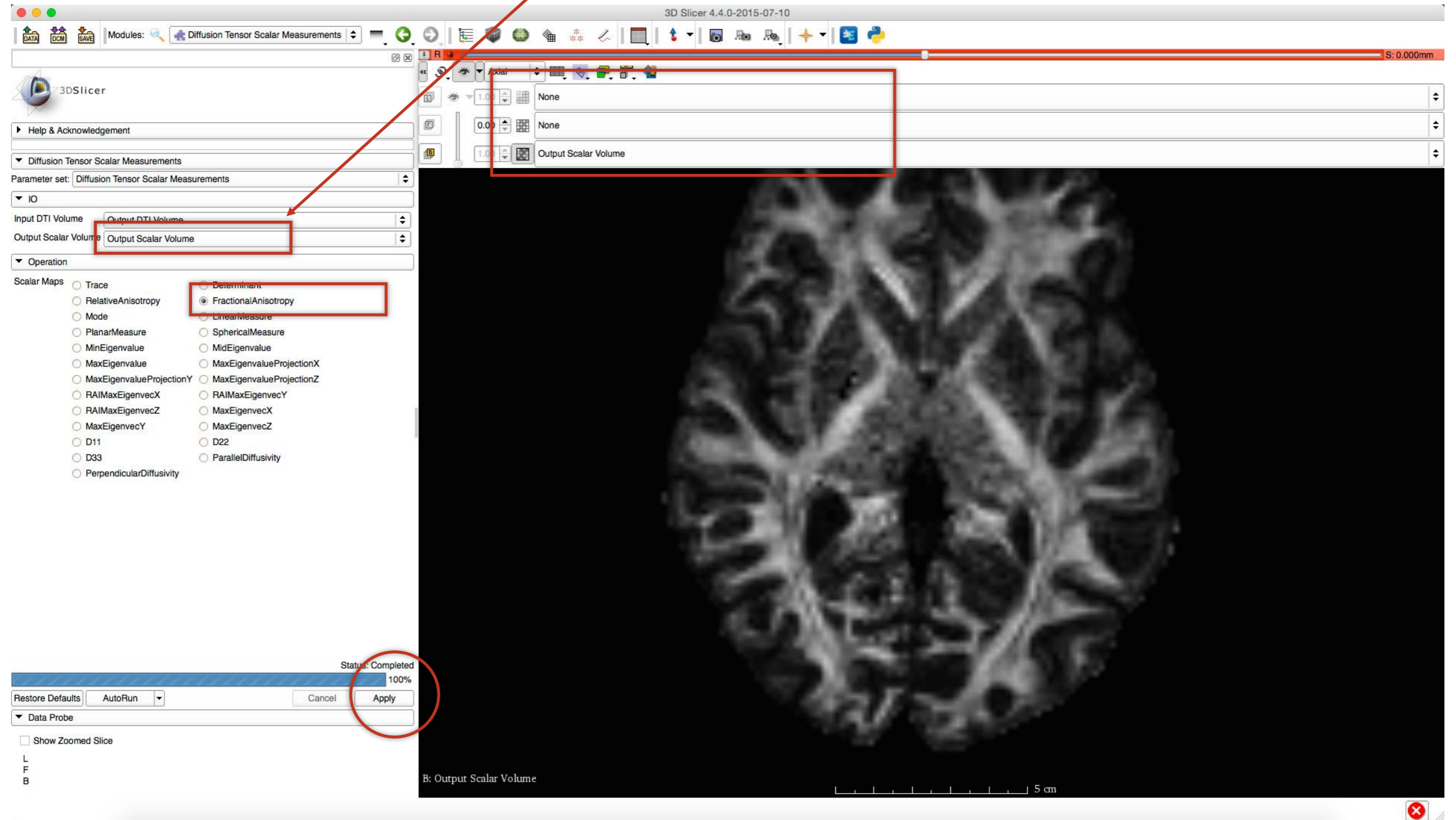
L  
F  
B

select the module

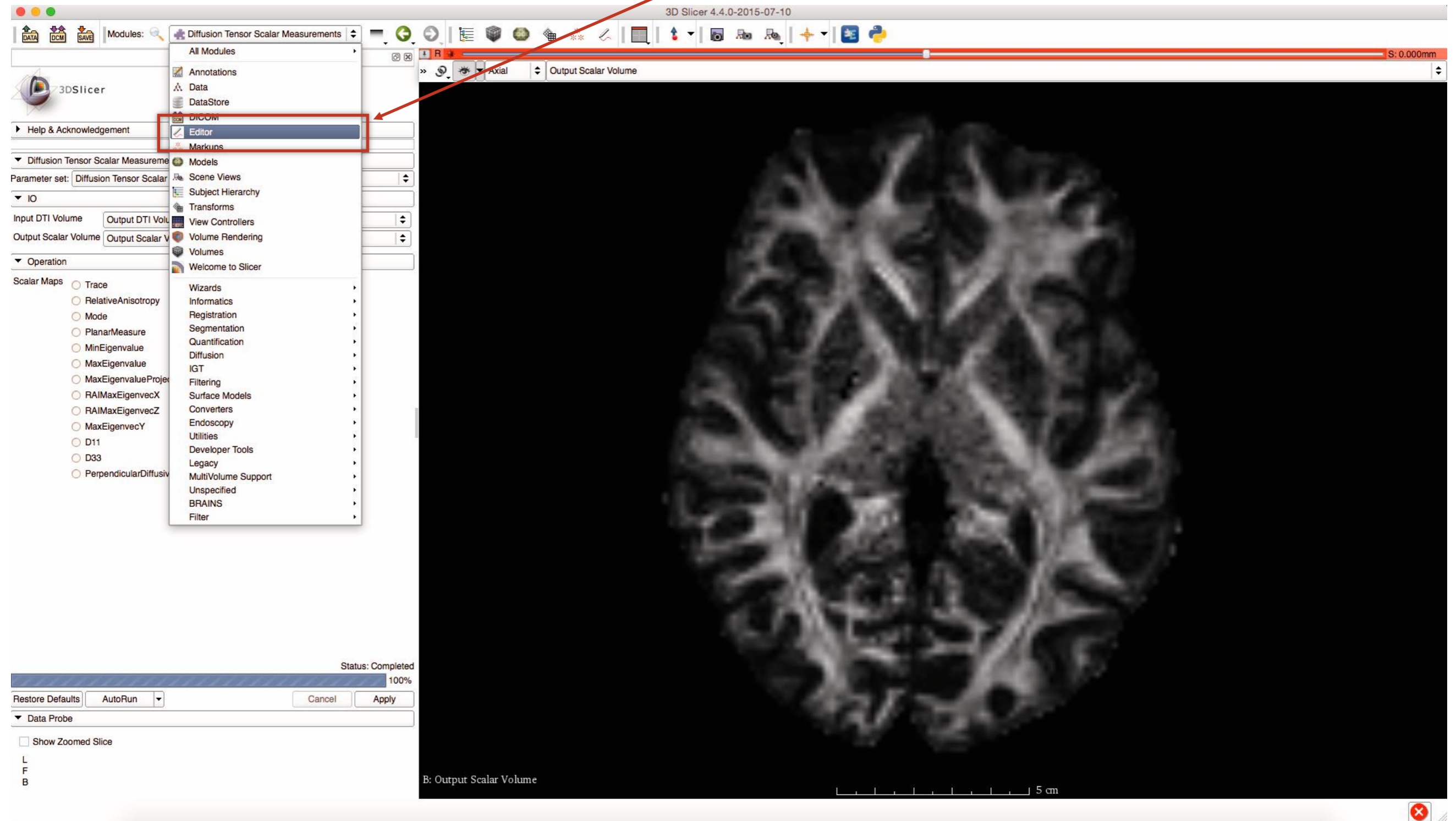
B: Output DTI Volume

5 cm

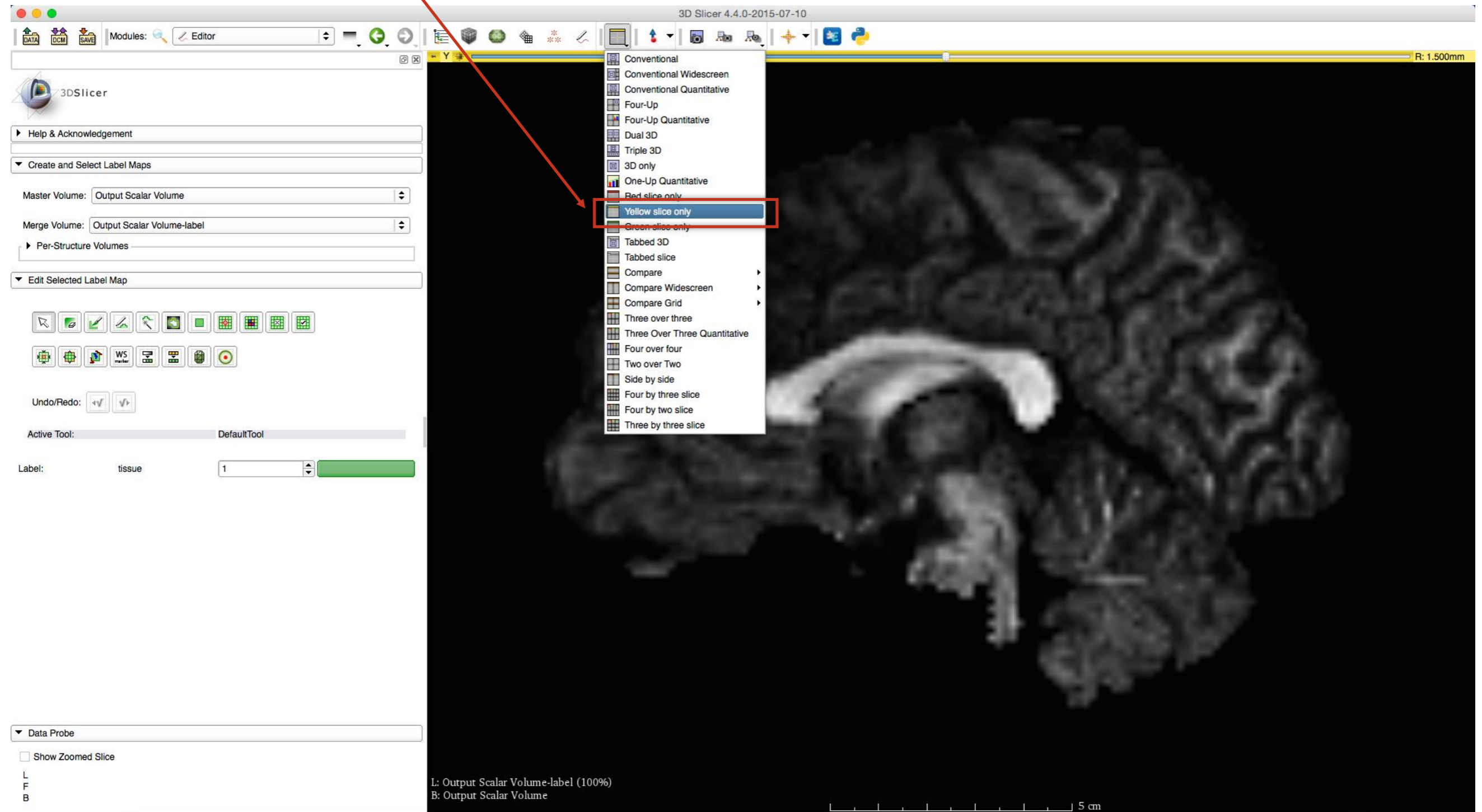
# create new Output Scalar Volume (FA)



# Select the Editor Module



to be able to select ROI for CC as an example,  
select sagittal view (yellow slice only)



# ROI Definiton

3D Slicer 4.4.0-2015-07-10

Modules: Editor

3DSlicer

Help & Acknowledgement

Create and Select Label Maps

Master Volume: Output Scalar Volume

Merge Volume: Output Scalar Volume-label

Per-Structure Volumes

Edit Selected Label Map

Active Tool: DrawEffect

Label: tissue 1

Paint Over

Threshold Paint

Apply

Data Probe

Show Zoomed Slice

L  
F  
B

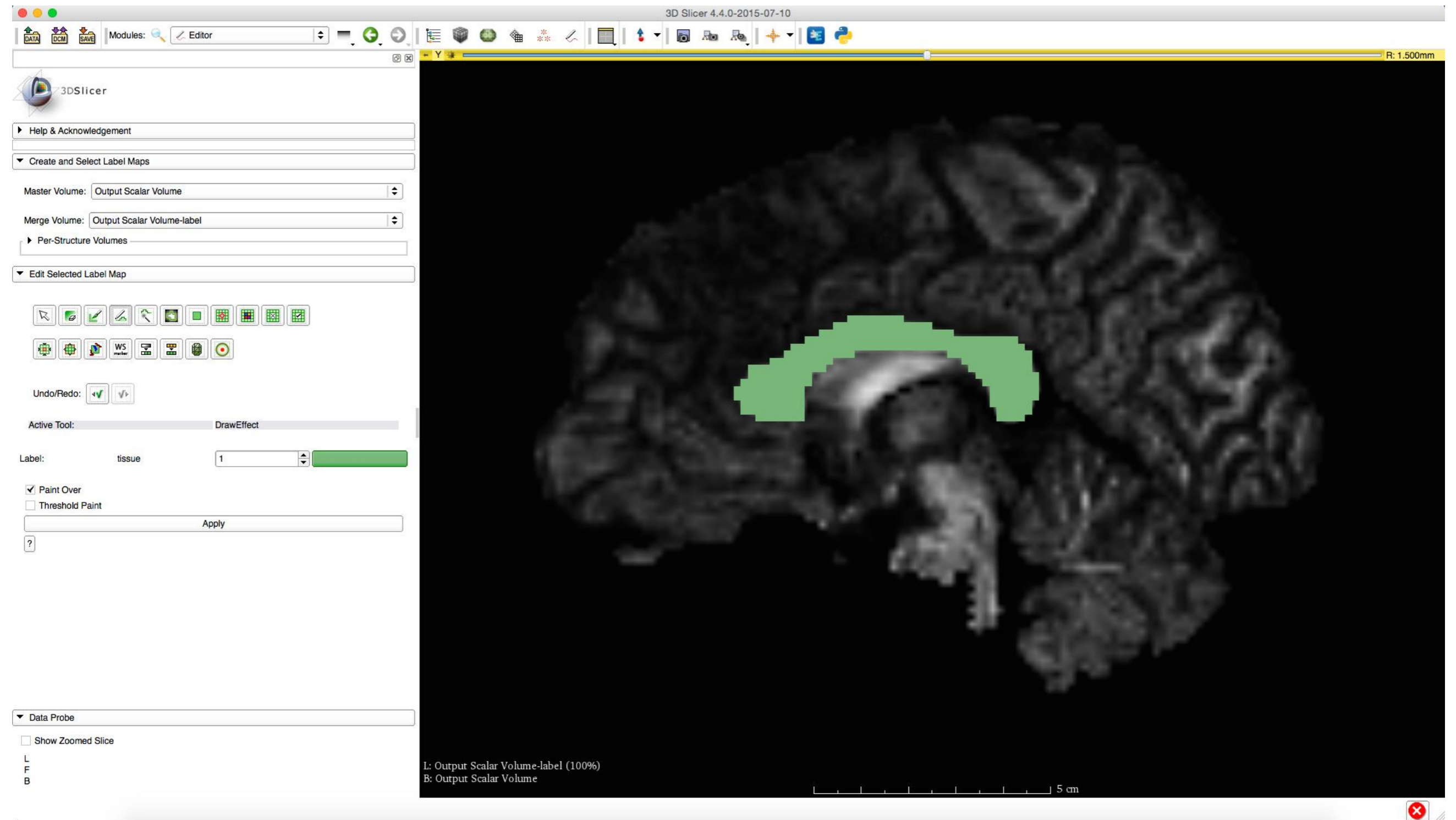
L: Output Scalar Volume-label (100%)  
B: Output Scalar Volume

5 cm

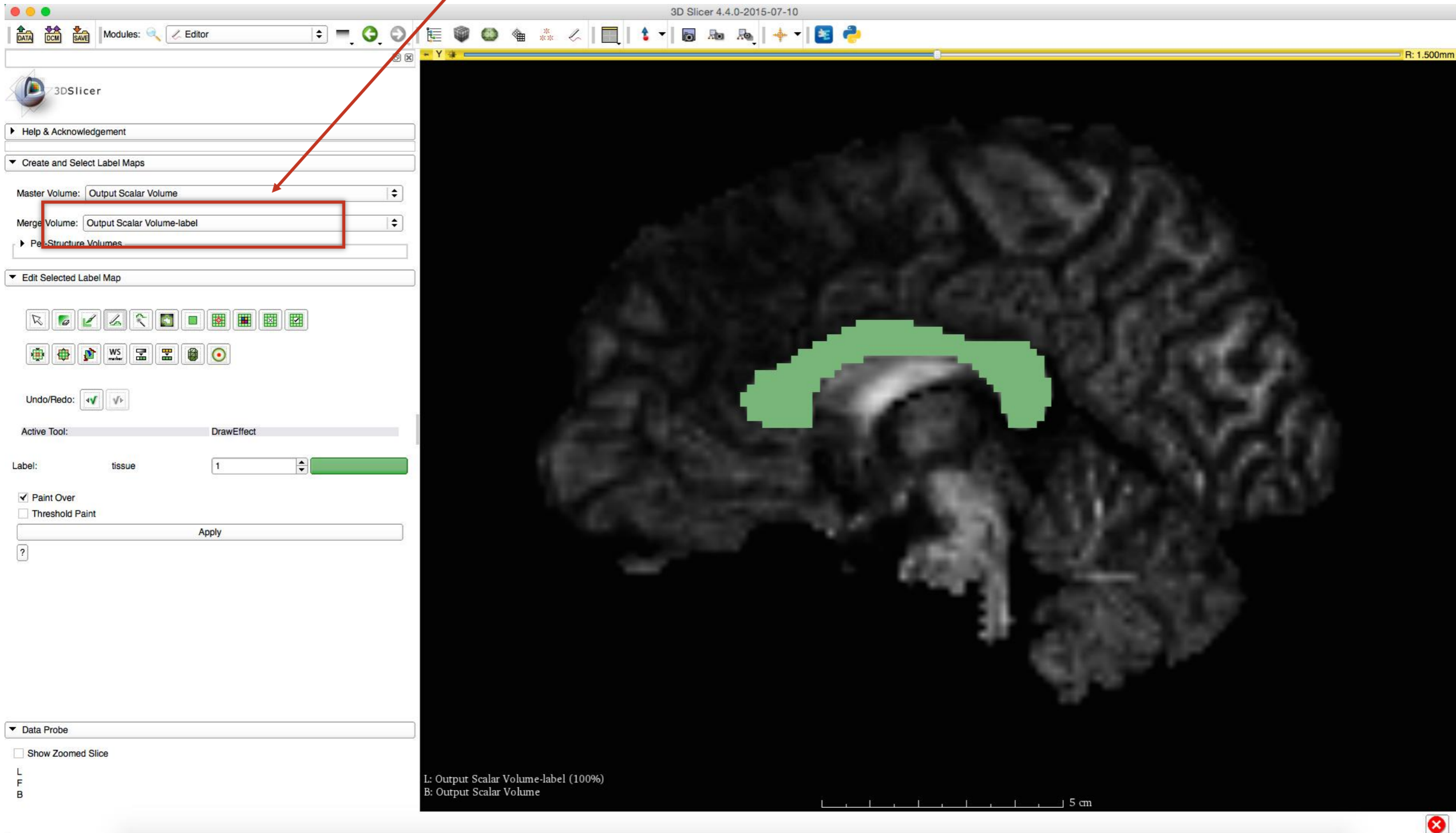
R: 1.500mm

select the "DrawEffect" tool and mark the contour of CC

press enter  
repeat this for 3 adjacent slices



label map containing the corpus callosum is created

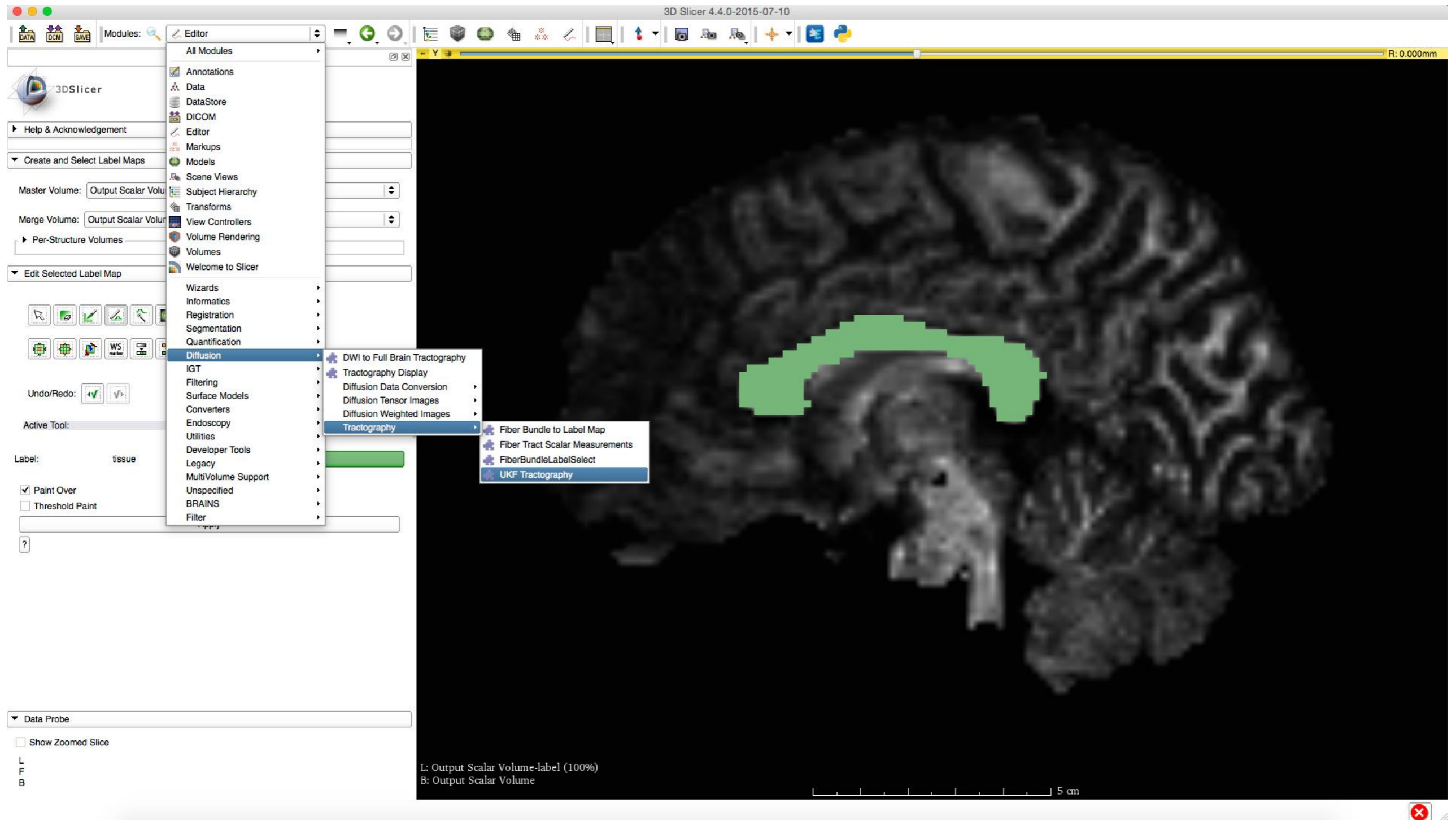


# UKF Tractography

- The module can use different methods:
  - 1-Tensor tractography (single fiber model)
  - 2-Tensor tractography (crossing fiber model)
  - NODDI (estimates microstructural complexity of dendrites and axons)
- ❖ The module can add a term for the free water model. This model tries to separate the signal from partial voluming with cerebrospinal fluid.



# UKF Tractography Module



**select the label map as seeds for tractography**

**select the number of the label map**

▼ UKF Tractography

Parameter set: UKF Tractography

▼ IO

Input DWI volume: dwi

Input Label Map: Output Scalar Volume-label

ROI label to use for seeding: 1

Brain mask: Otsu Threshold Mask

Output Fibers: Output Fibers





**select the Otsu Mask to confine the tractography**

**create new FiberBundle**

for bigger voxels, use higher number of seeds per voxel

To increase seeding sensitivity, lower seed FA (0.15)

▼ Tractography Options

Seeding: Number of seeds per voxel		1	▲ ▼
Seeding: Minimum seed FA		0.18	▲ ▼
Stopping Criterion: Terminating FA		0.15	▲ ▼
Stopping Criterion: Terminating GA		0.10	▲ ▼

To track further, lower terminating FA (0.1) and GA (0.075)

**Set other parameters here:**

▼ Tractography Options

Seeding: Number of seeds per voxel

Seeding: Minimum seed FA

Stopping Criterion: Terminating FA

Stopping Criterion: Terminating GA

Tracking: Number of threads

Tracking: Number of tensors/orientations in model  1  2

Tracking: Step length of tractography (in mm)

Tracking: Rate of change of tensor direction/orientation

Output: Step length of output tractography (in mm)

Output: Maximum tract length (in mm)

Output: Save Normalized Mean Square Error

▼ Tensor Model

Tensor Model: Estimate term for free water

Output: Save tensor FA

Output: Save tensor trace

Output: Save free water fraction

Output: Save tensors

UKF Parameter (Advanced): Rate of change of eigenvalues

UKF Parameter (Advanced): Rate of change of freewater weight

► NODDI Model

► Signal Parameters (Expert Only)

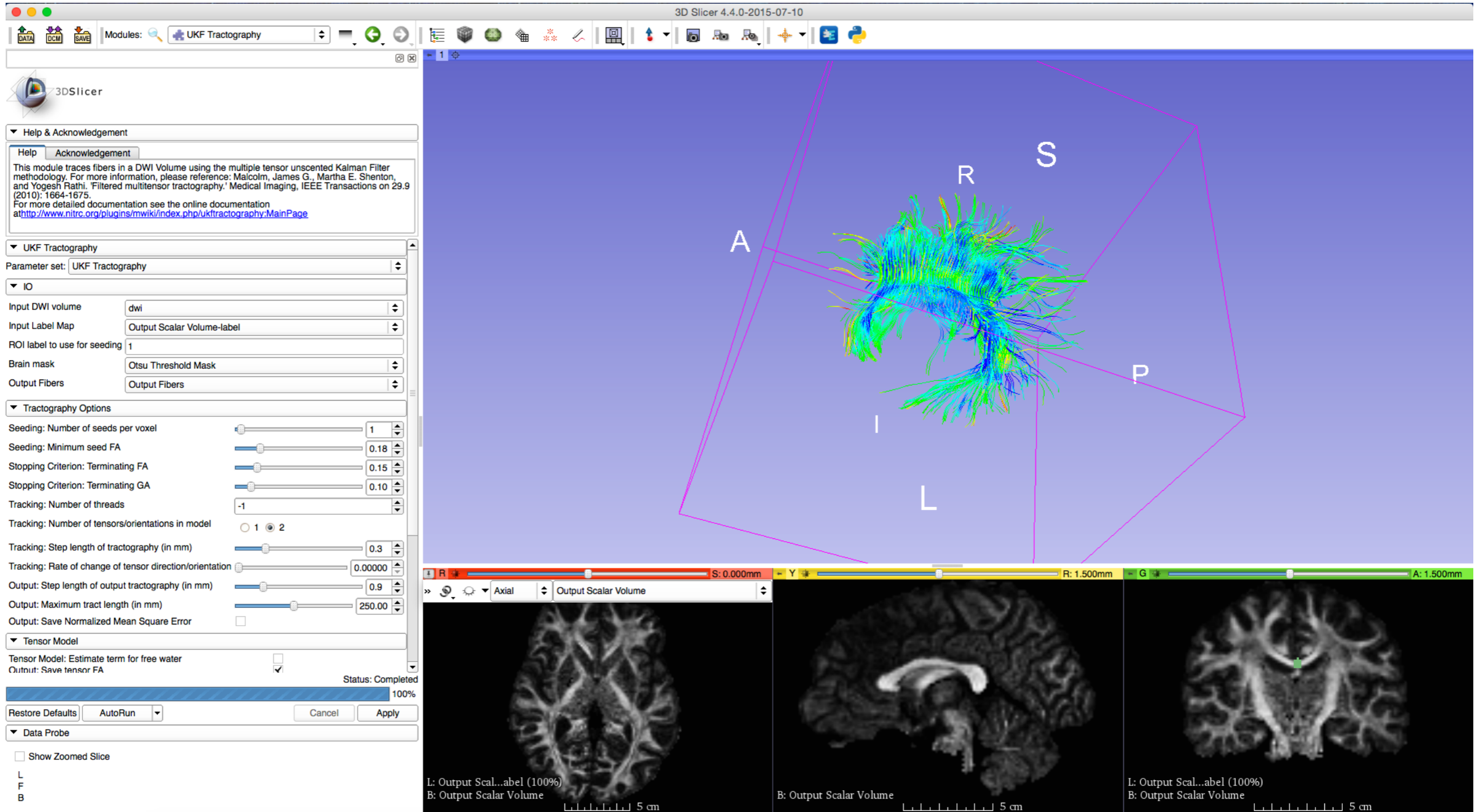
► Not Used: Debug/Develop Only

***Click Apply***

find out more details at:

[Documentation/Nightly/Modules/UKFTractography](https://www.fsl.fmrib.ox.ac.uk/fsl/docs/fsl4.1.0/Documentation/Nightly/Modules/UKFTractography)

# Corpus Callosum



# Conclusion

- This tutorial, helps you to load diffusion data, run the tensor estimation, calculate scalar measurements, and define ROIs to finally be able to run UKF tractography.
- contact: [yogesh@bwh.harvard.edu](mailto:yogesh@bwh.harvard.edu)

# Acknowledgments

- **U01CA199459**, Open Source Diffusion MRI Technology For Brain Cancer Research
- **P41EB015898**, National Center for Image Guided Therapy (NCIGT)
- **P41EB015902**, Neuroimage Analysis Center (NAC)