



NA-MIC

National Alliance for Medical Image Computing

<http://na-mic.org>

Diffusion Tensor Imaging tutorial



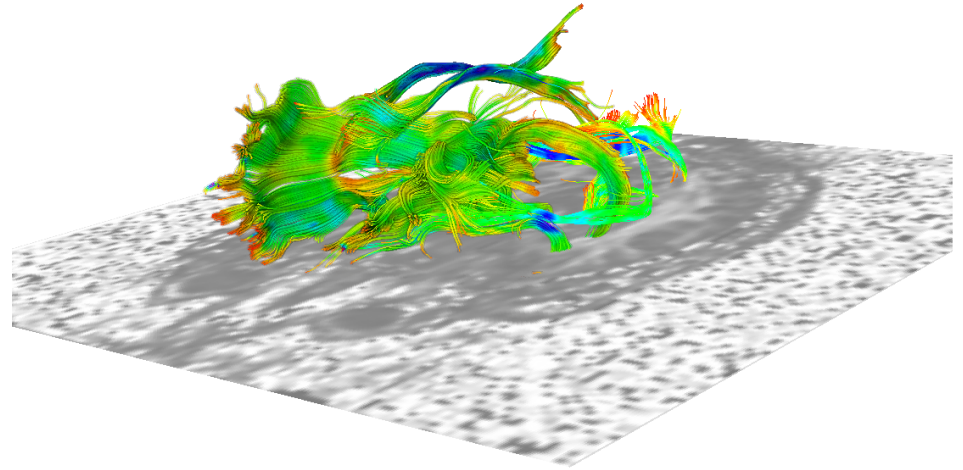
Sonia Pujol, PhD

Surgical Planning Laboratory
Harvard University



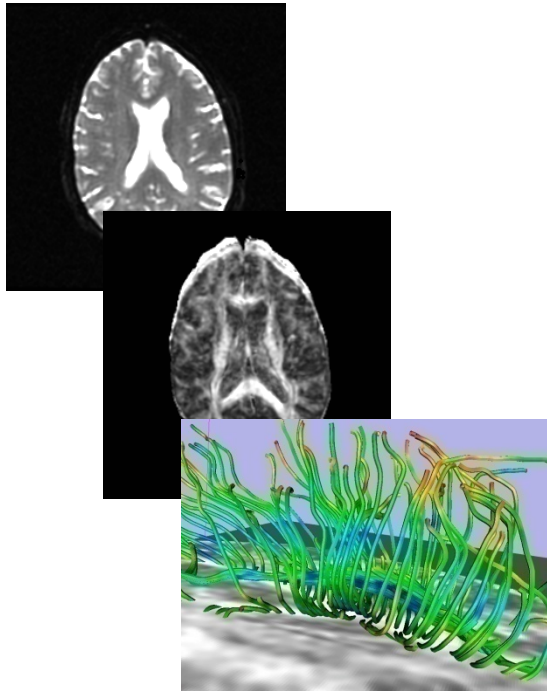
DTI tutorial

This tutorial is an introduction to the advanced **Diffusion MR** capabilities of the **Slicer3** software for medical image analysis.





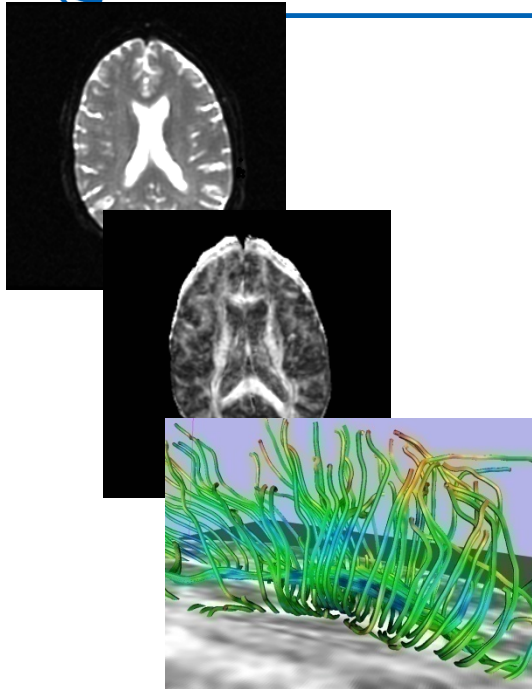
Outline



This tutorial guides you through the process of **loading diffusion MR data**, **estimating diffusion tensors**, and **performing tractography** of white matter bundles.



Outline



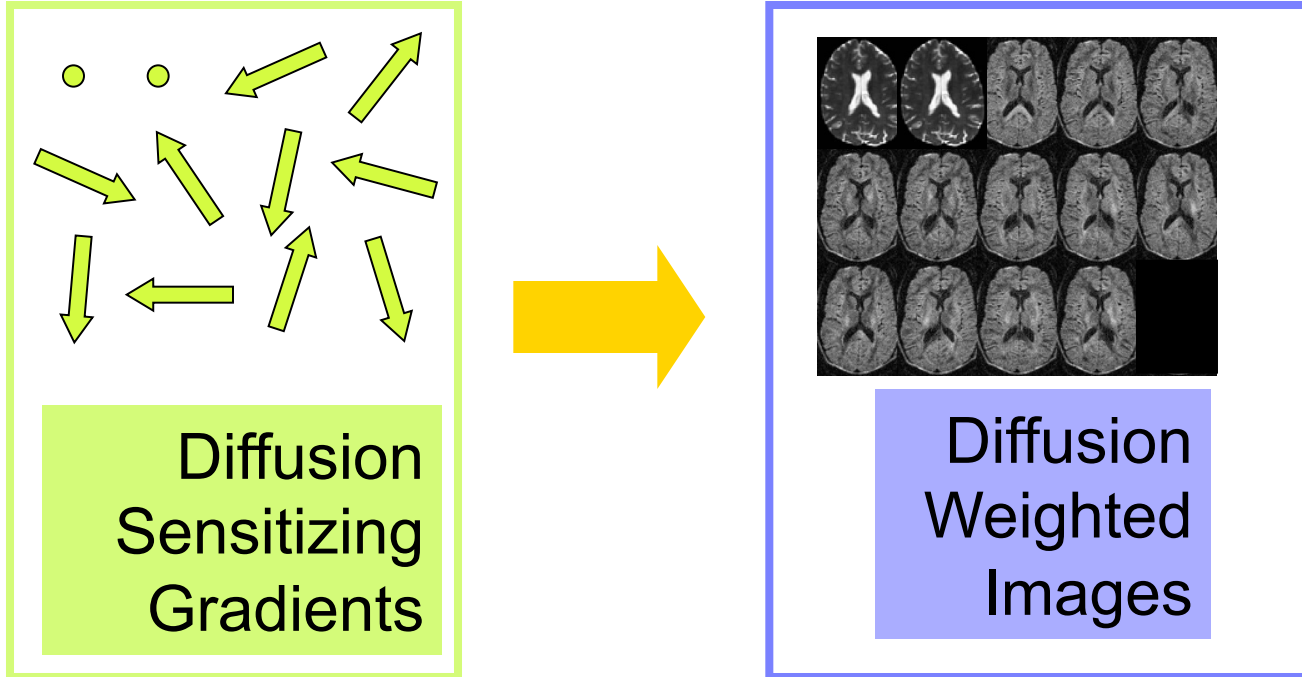
The processing pipeline uses **9 image analysis modules** of Slicer3.6

1. Data
2. Volumes
3. Diffusion Tensor Estimation
4. Diffusion Tensor Scalar Measurements
5. Editor
6. LabelMap Seeding
7. Fiber Bundles
8. Fiducials
9. Fiducial Seeding



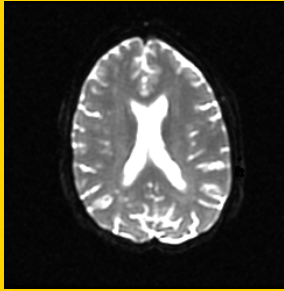
Tutorial Dataset

The Diffusion MR tutorial dataset is composed of a **Diffusion Weighted MR scan** of the brain acquired with 12 gradient directions and 2 baseline.

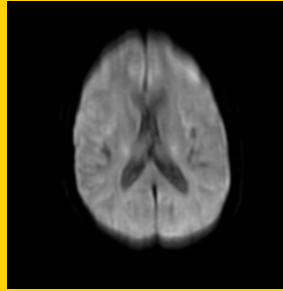




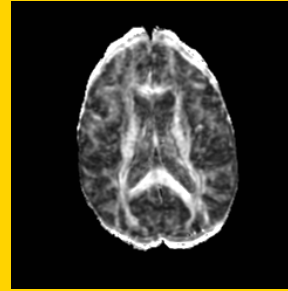
DTI Processing Pipeline



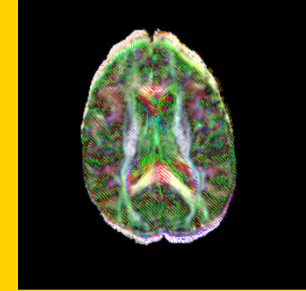
DWI
Acquisition



Tensor
Calculation



Scalar
Maps



3D
Visualization



Start Slicer3

Linux/Mac users

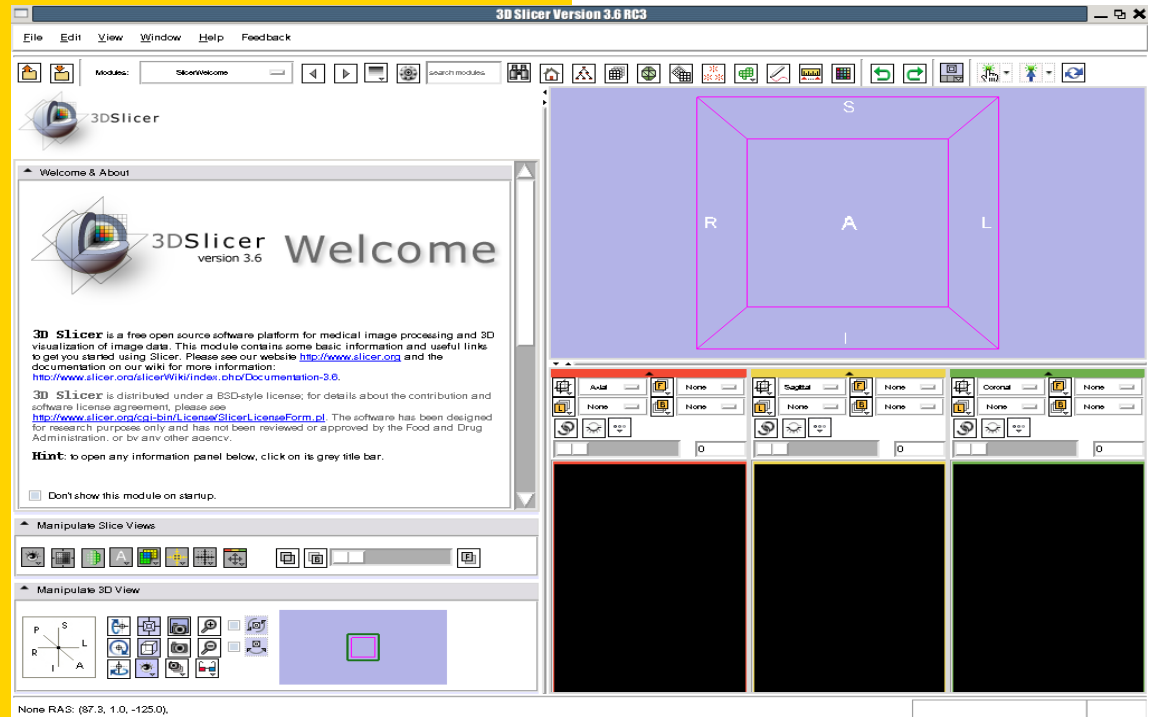
Launch the Slicer3 executable located in the Slicer3.6 directory

Windows users

Select

Start → All Programs

→ Slicer3-3.6-2011-03-04 → Slicer3





Slicer Welcome

3D Slicer Version 3.6 RC3

File Edit View Window Help Feedback

Modules: SlicerWelcome

3DSlicer

Welcome & About

3DSlicer version 3.6

3D Slicer is a free open source software platform for visualization of image data. This module contains some information to get you started using Slicer. Please see our website for more information: <http://www.slicer.org/slicerWiki/index.php/Documentation>

3D Slicer is distributed under a BSD-style license; please see <http://www.slicer.org/cgi-bin/License/SlicerLicenseForm.pl>. The software has been designed for research purpose only and has not been reviewed or approved by the Food and Drug Administration, or by any other agency.

Hint: to open any information panel below, click on its grey title bar.

Don't show this module on startup.

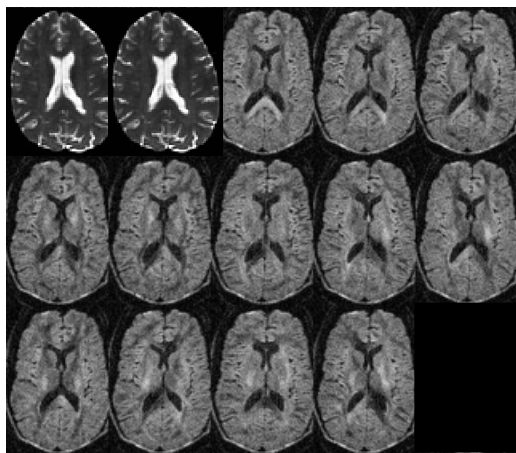
Manipulate Slice Views

Manipulate 3D View

None RAS: (87.3, 1.0, -125.0)

The **SlicerWelcome** module is the module displayed by default.

This module gives an overview of the GUI of Slicer3, and data loading & saving functionalities.

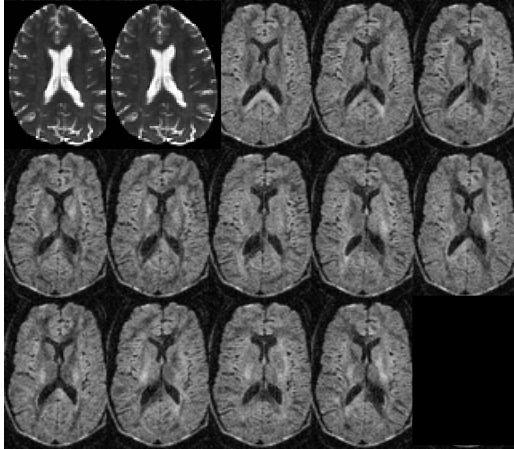


Part 1:

Diffusion data loading and tensor estimation

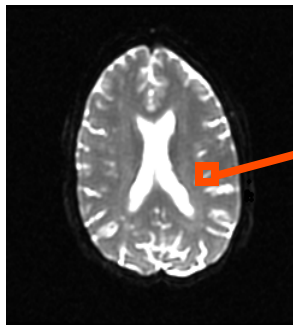


Diffusion Tensor Imaging



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

(Stejskal and Tanner 1965, Basser 1994)

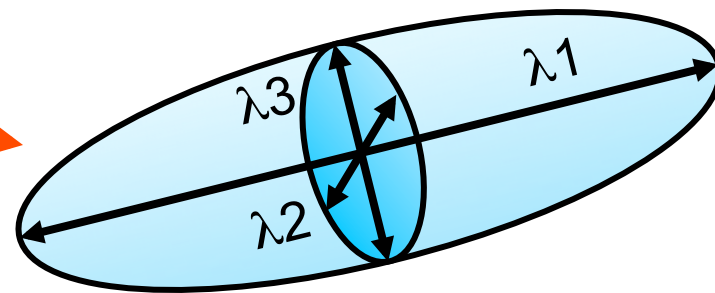
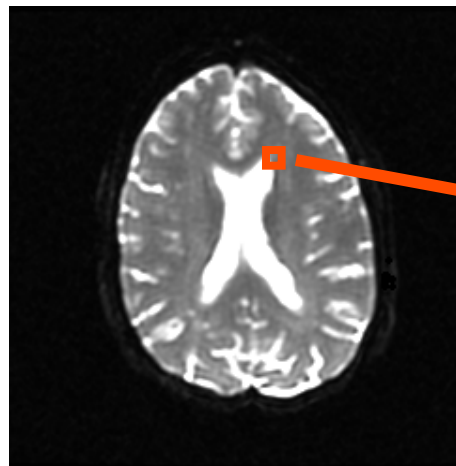


$$\underline{D} = \begin{bmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{yx} & D_{yy} & D_{yz} \\ D_{zx} & D_{zy} & D_{zz} \end{bmatrix}$$



Physical Interpretation

The diffusion tensor \underline{D} in the voxel (I,J,K) can be visualized as an ellipsoidal isoprobability surface in which the principal axes correspond to the eigenvectors.





Loading the DWI volume

Select File → Add Volume from the File menu

3D Slicer Version 3.6 RC3

File Edit View Window Help Feedback

3DSlicer

Welcome & About

3DSlicer version 3.6

3D Slicer is a free open source software platform for medical image processing and 3D visualization of image data. This module contains some basic information and useful links to get you started using Slicer. Please see our website <http://www.slicer.org> and the documentation on our wiki for more information: <http://www.slicer.org/slicerWiki/index.php/Documentation-3.6>.

3D Slicer is distributed under a BSD-style license; for details about the contribution and software license agreement, please see <http://www.slicer.org/cgi-bin/License/SlicerLicenseForm.pl>. The software has been designed for research purpose only and has not been reviewed or approved by the Food and Drug Administration, or by any other agency.

Hint: to open any information panel below, click on its grey title bar.

Don't show this module on startup.

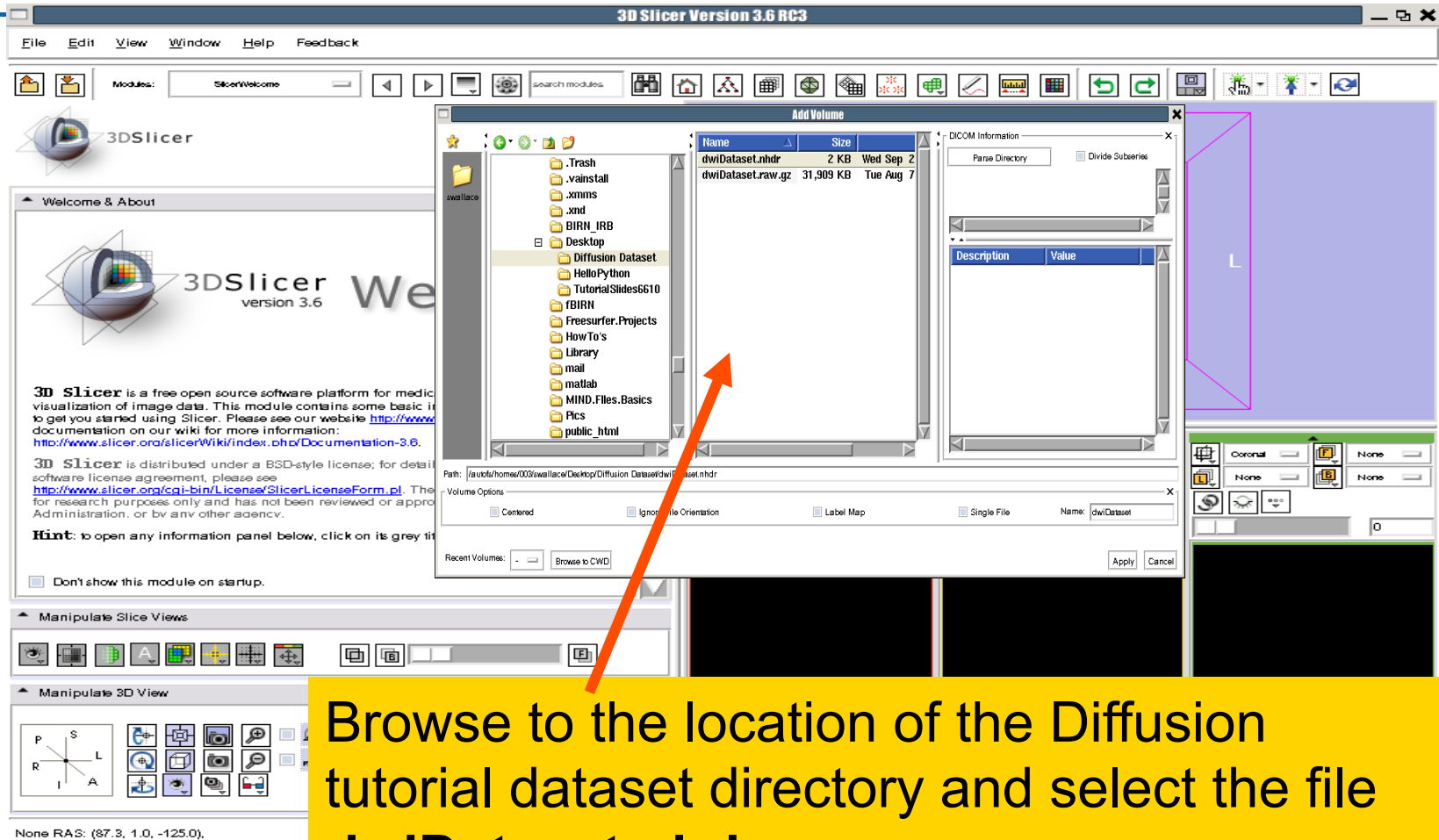
Manipulate Slice Views

Manipulate 3D View

None RAS: (87.3, 1.0, -125.0).



Loading the DWI volume

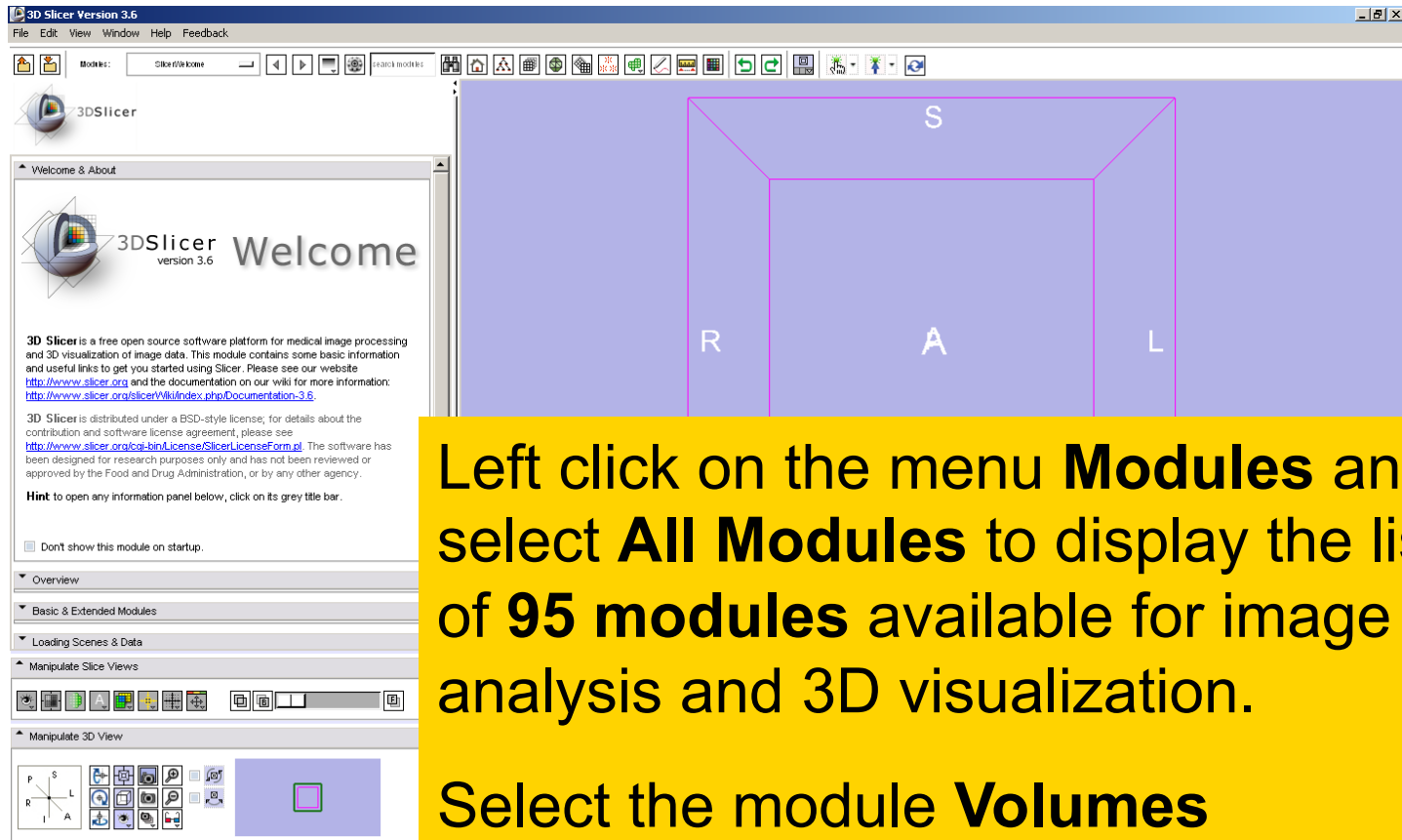


Browse to the location of the Diffusion tutorial dataset directory and select the file **dwiDataset.nhdr**

Click on **Apply** to load the volume



Loading the DWI volume

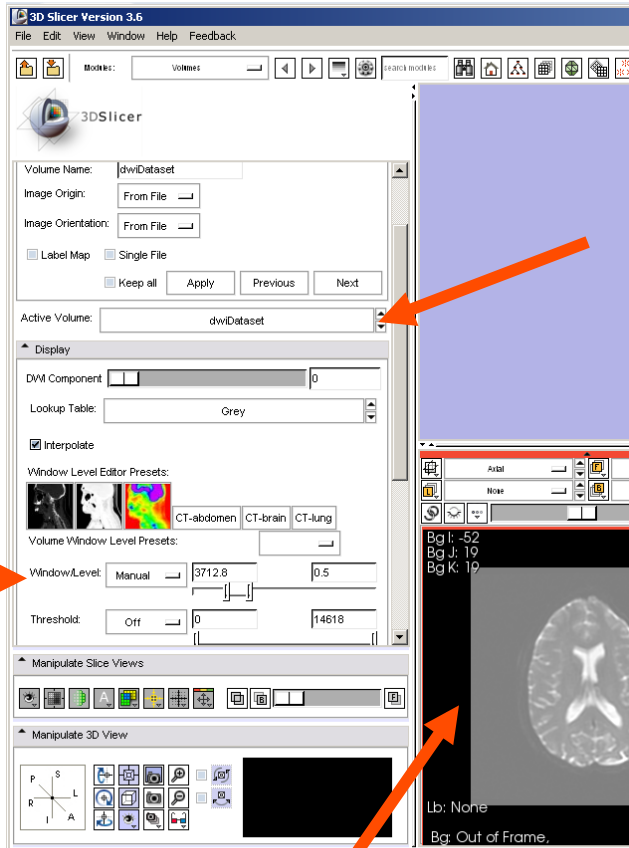


Left click on the menu **Modules** and select **All Modules** to display the list of **95 modules** available for image analysis and 3D visualization.

Select the module **Volumes**



Loading the DWI volume

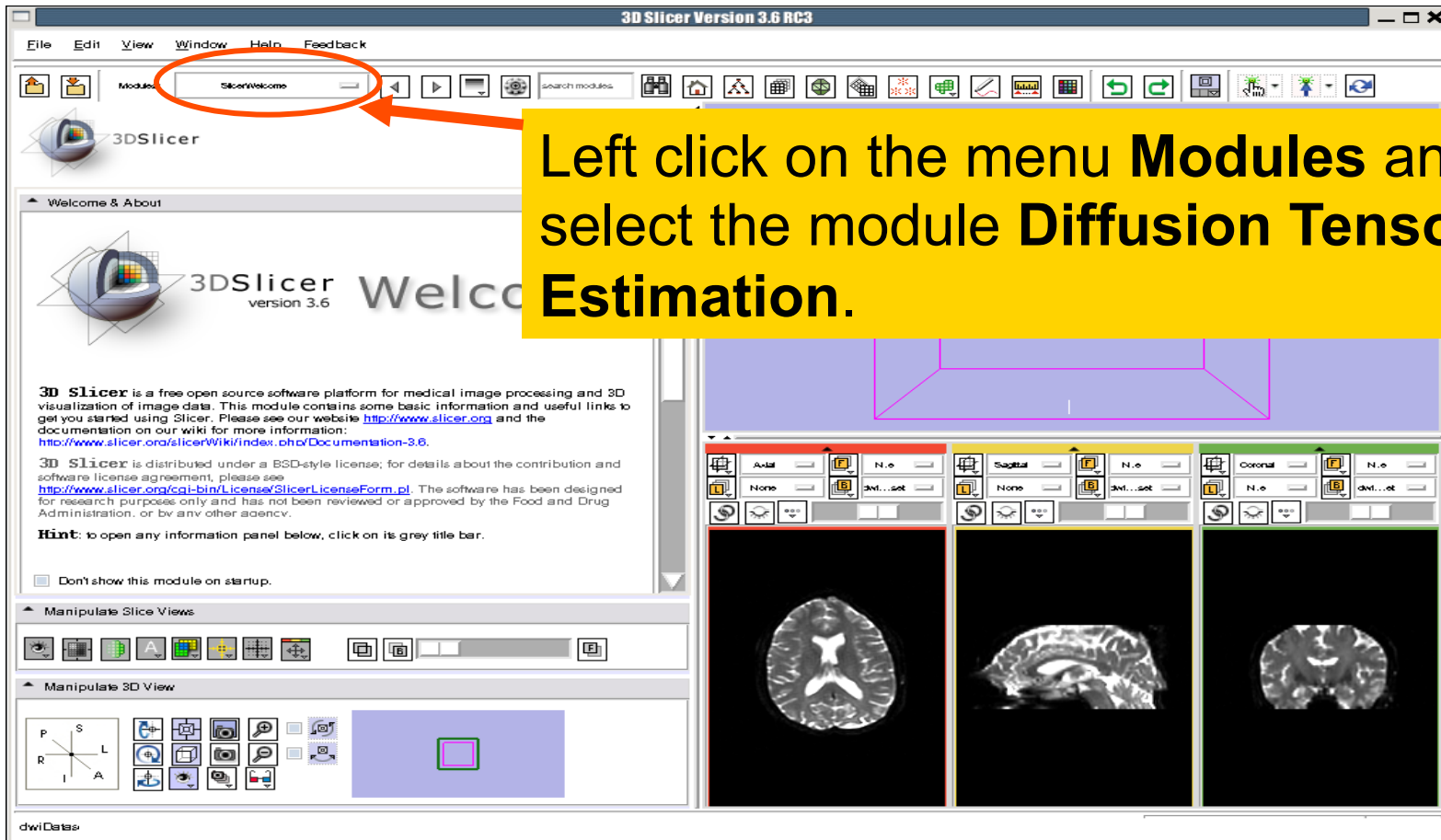


Select the Active Volume **dwiDataset** and adjust the Window/Level Parameters

Slicer displays the anatomical views of the baseline volume of the diffusion dataset in the 2D Slice Viewer.



Tensor Estimation



Left click on the menu **Modules** and select the module **Diffusion Tensor Estimation**.



Tensor Estimation

**Select the Input DWI Volume
dwiDataset**

Left click on **OutputDTIVolume and
select ‘**Create New Diffusion
Tensor Volume**’**

**Left click on **Output Baseline
Volume** and select ‘**Create New
Volume**’**

Left click on **Otsu Threshold Mask
and select ‘**Create New Volume**’**

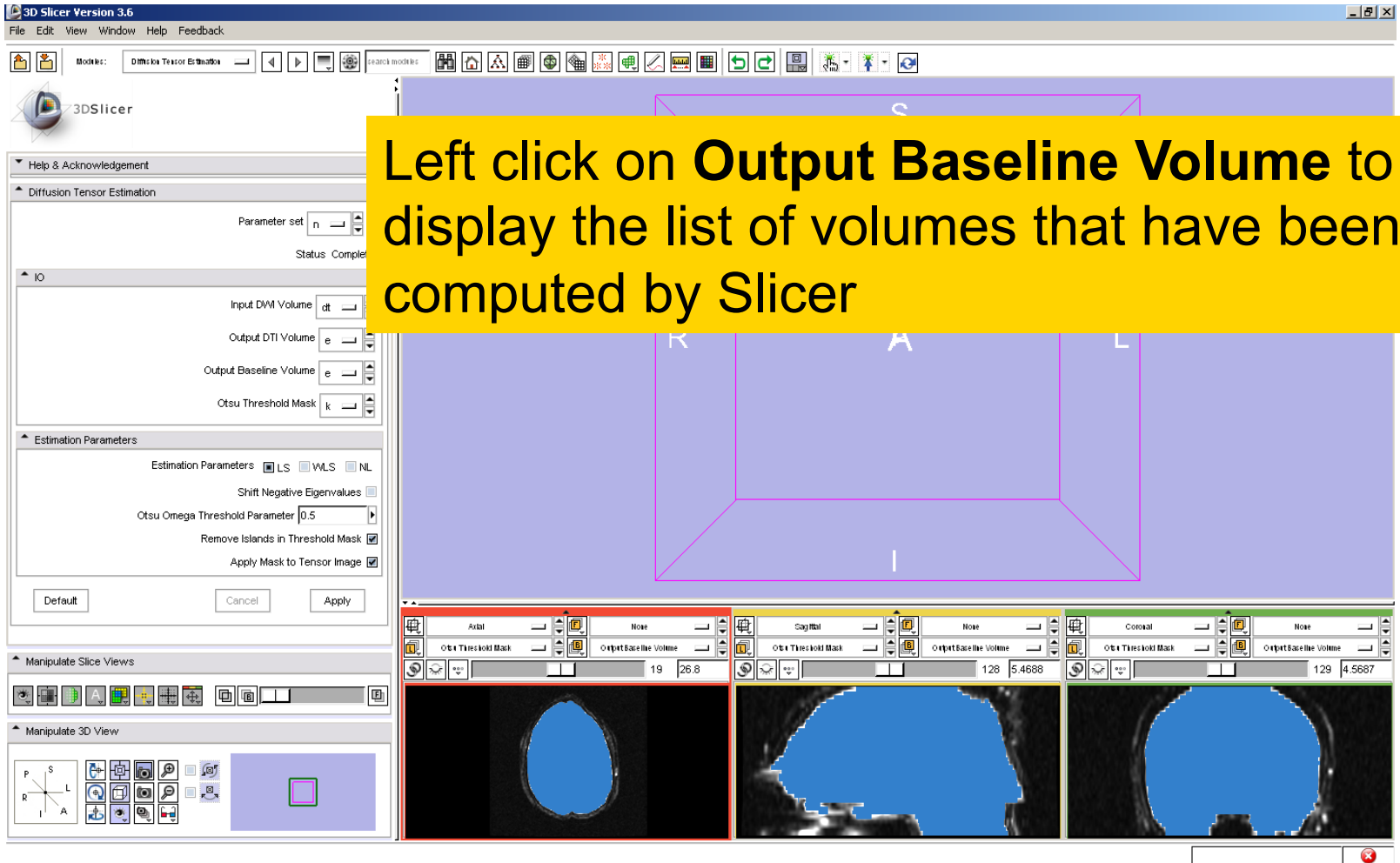


Tensor Estimation

Select the Tensor Estimation Algorithm **LS** (Least Squares), and click on **Apply** to estimate the tensors.



Tensor Estimation





Tensor Estimation

Output DTI Volume is the volume of estimated tensors

Output Baseline Volume is the Baseline volume

Output Threshold Mask is the tensor mask (blue)

The screenshot displays a software interface for tensor estimation. On the left, there is a control panel with the following sections:

- Input/Output Volumes:** Input DTI Volume (dt), Output DTI Volume (e), Output Baseline Volume (e), and Otsu Threshold Mask (k).
- Estimation Parameters:** Estimation Parameters (LS, WLS, NL), Shift Negative Eigenvalues, Otsu Omega Threshold Parameter (0.5), Remove Islands in Threshold Mask (checked), and Apply Mask to Tensor Image (checked).
- Manipulate Slice Views:** A toolbar with icons for slice manipulation.
- Manipulate 3D View:** A toolbar with icons for 3D view manipulation.

The main area shows a 3D view of a brain slice with a purple bounding box. An orange arrow points to a context menu that lists the following options:

- None
- dwi/Dataset
- Output DTI Volume
- Output Baseline Volume
- Otsu Threshold Mask
- Rename...
- Edit Properties...
- Delete...

The bottom of the interface shows three slice views: Axial, Sagittal, and Coronal. Each slice view displays a brain slice with a blue threshold mask overlaid on the white matter regions.



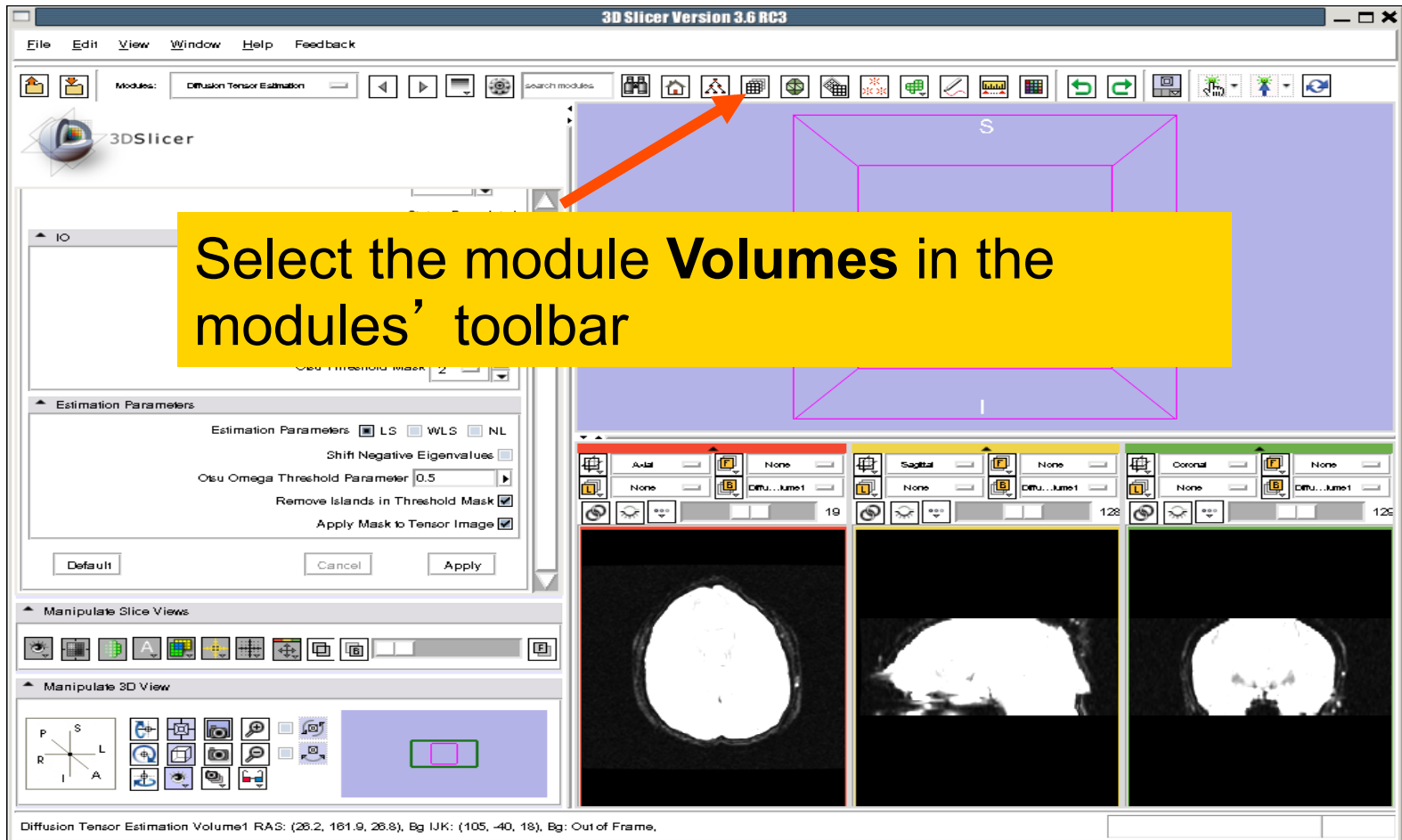
Tensor Estimation

Click on the link icon, left click on **Output Threshold Mask and select **None****

The screenshot shows the 3D Slicer Version 3.6 interface. The 'Diffusion Tensor Estimation' module is active. The 'IO' section shows 'Output Threshold Mask' set to 'None'. The 'Estimation Parameters' section shows 'LS' selected. The 'Manipulate 3D View' section shows a 3D view of a brain slice with a purple bounding box. The 'Manipulate Slice Views' section shows three slice views: Axial, Sagittal, and Coronal. The 'Output Threshold Mask' dropdown menu is highlighted with a red box and a red arrow pointing to the 'None' option.



Tensor Estimation





Tensor Estimation

Select the **Active Volume** 'Output Baseline Volume' and click on the tab **Display**

3D Slicer Version 3.6

File Edit View Window Help Feedback

Volume Name: Output Baseline Volume

Image Origin: From File

Image Orientation: From File

Label Map Single File

Keep all Apply Previous Next

Active Volume: Output Baseline Volume

Display

Diffusion Editor

Info

Manipulate Slice Views

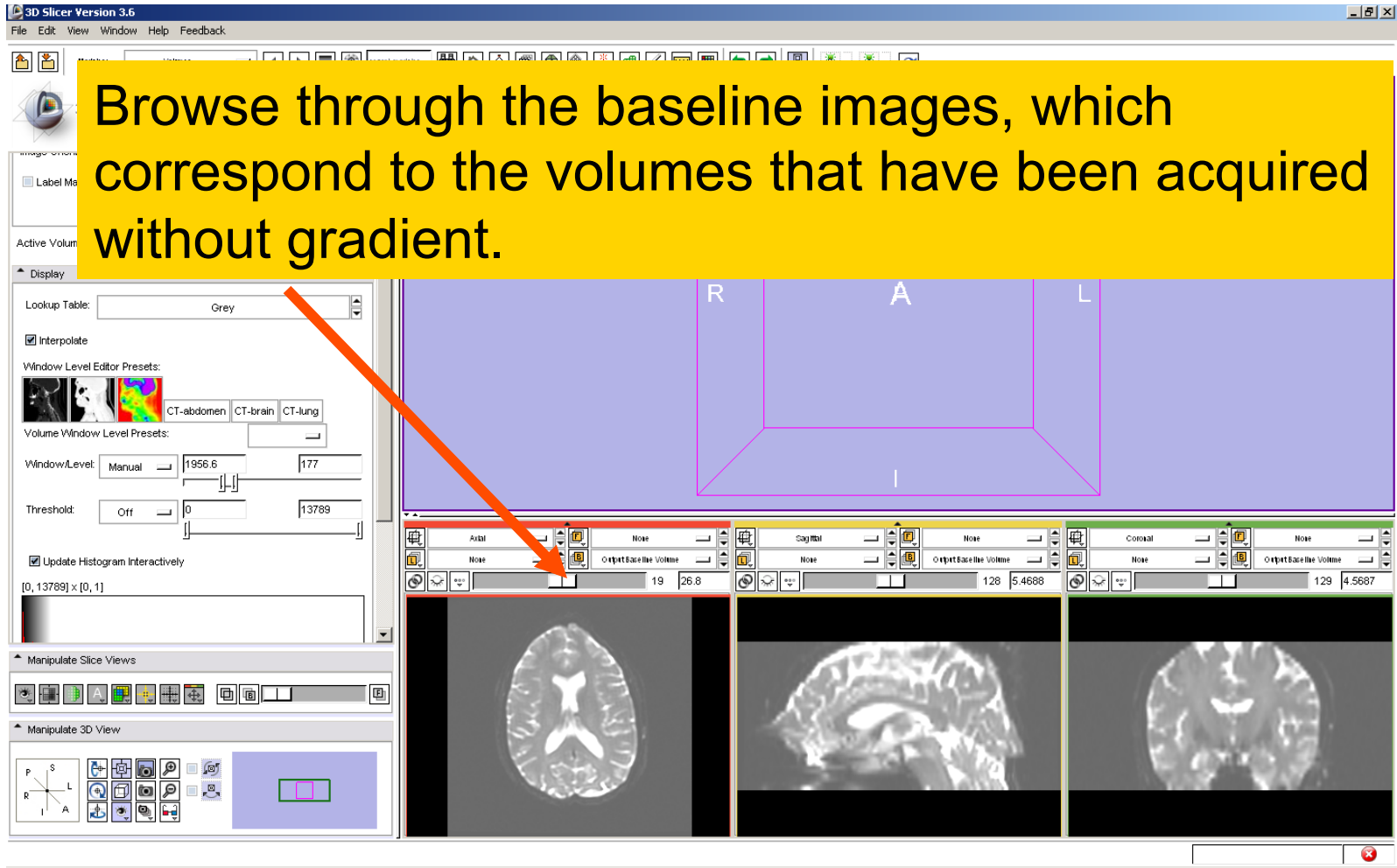
Manipulate 3D View

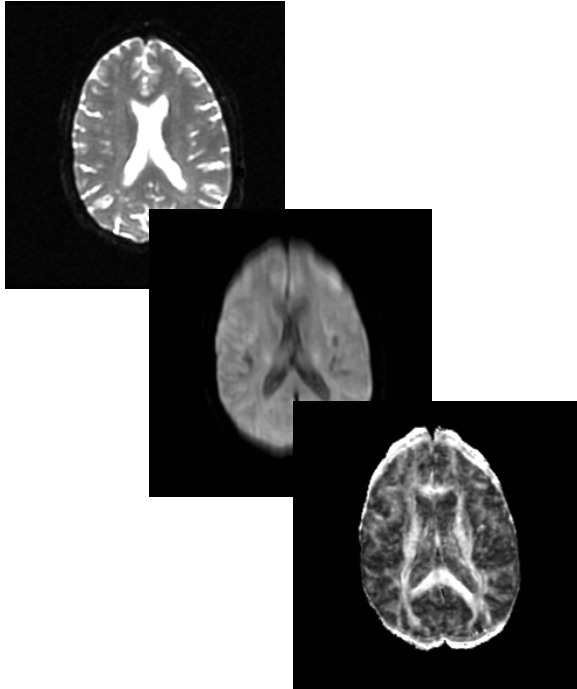
Output Baseline Volume RAS: (-156.1, -115.0, 32.8), Bg: Slice not shown



Tensor Estimation

Browse through the baseline images, which correspond to the volumes that have been acquired without gradient.





Part2:

Scalar Measurements



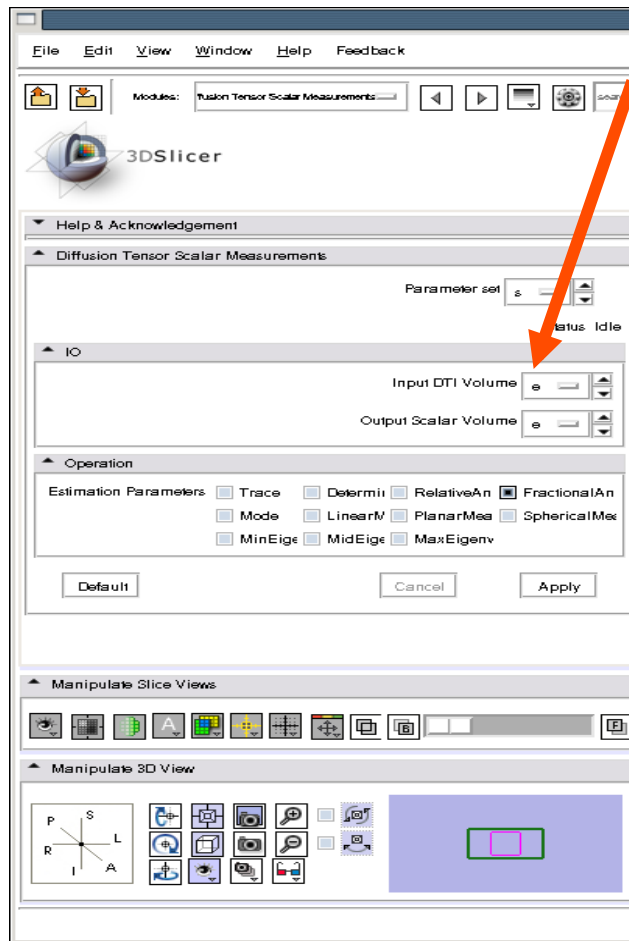
Scalar Measurements

Select the category **Diffusion**--> **Utilities** from the list of modules, and left click on the **Diffusion Tensor Scalar Measurements** module.

The screenshot shows the 3D Slicer 3.6 interface. The 'Volumes' menu is circled in red. The main window displays a 3D view of a brain slice with a purple bounding box. Below the 3D view are three 2D slice views: Axial, Sagittal, and Coronal. The interface includes various toolbars and panels for image manipulation and display settings.



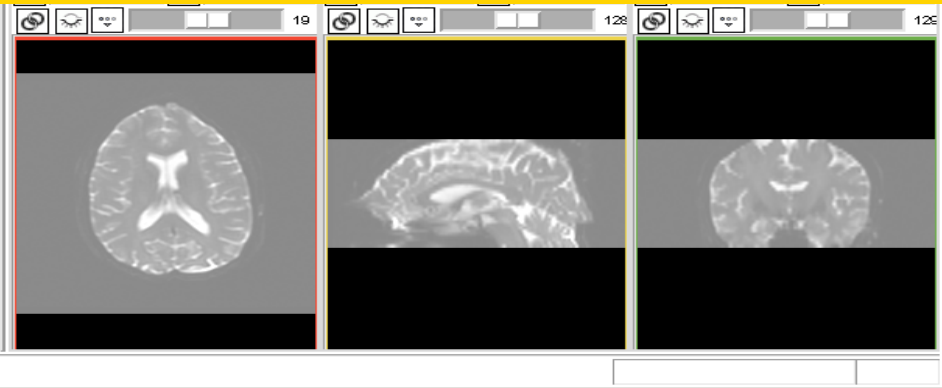
Scalar Measurements



Select the Input DTI Volume **Output DTI Volume**

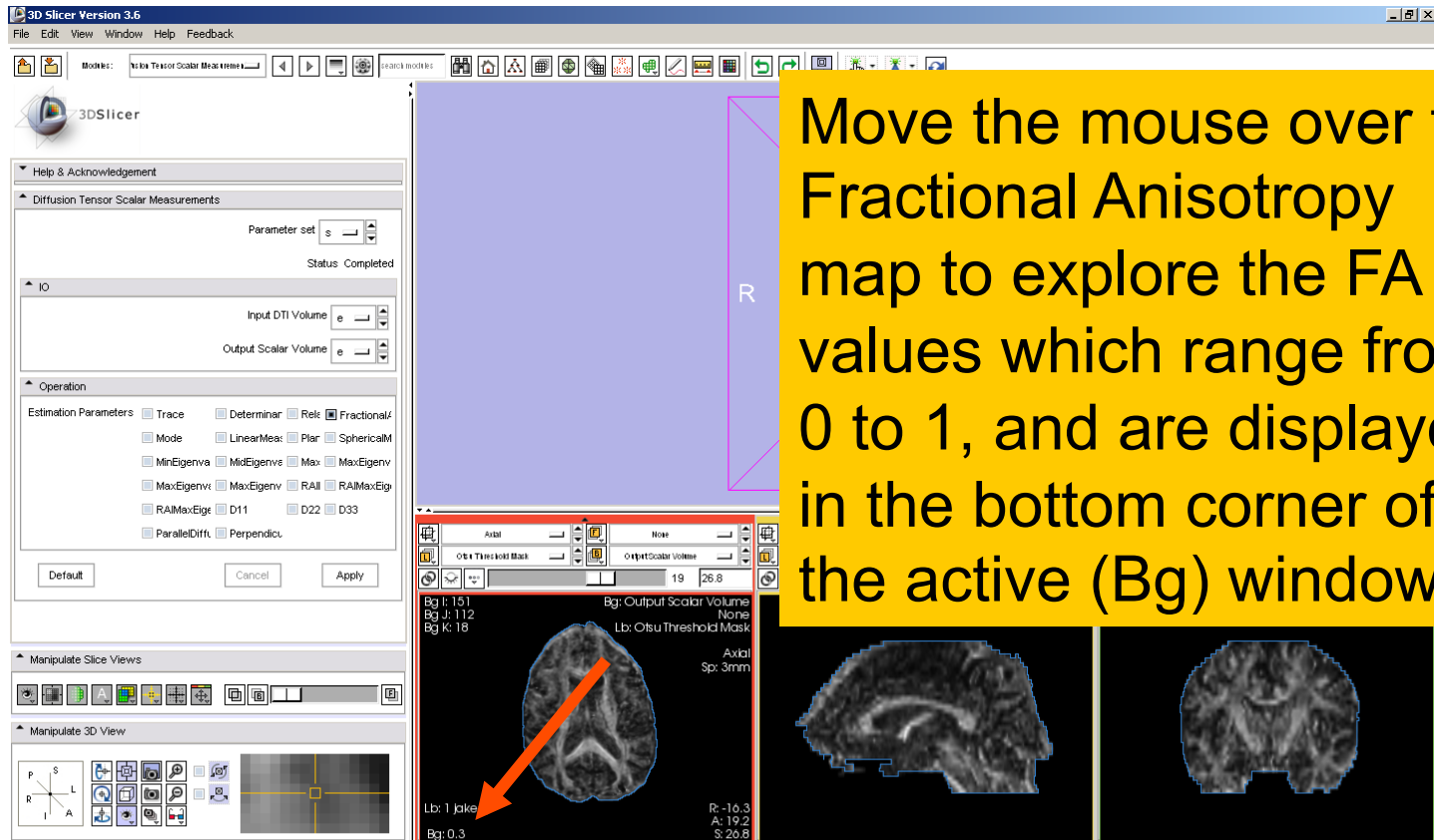
Select the Output Scalar Volume **'Create New Volume'**

Select the Operation **Fractional Anisotropy**, and click on **Apply**





Fractional Anisotropy Volume





Part 3:

Region of Interest based Tractography



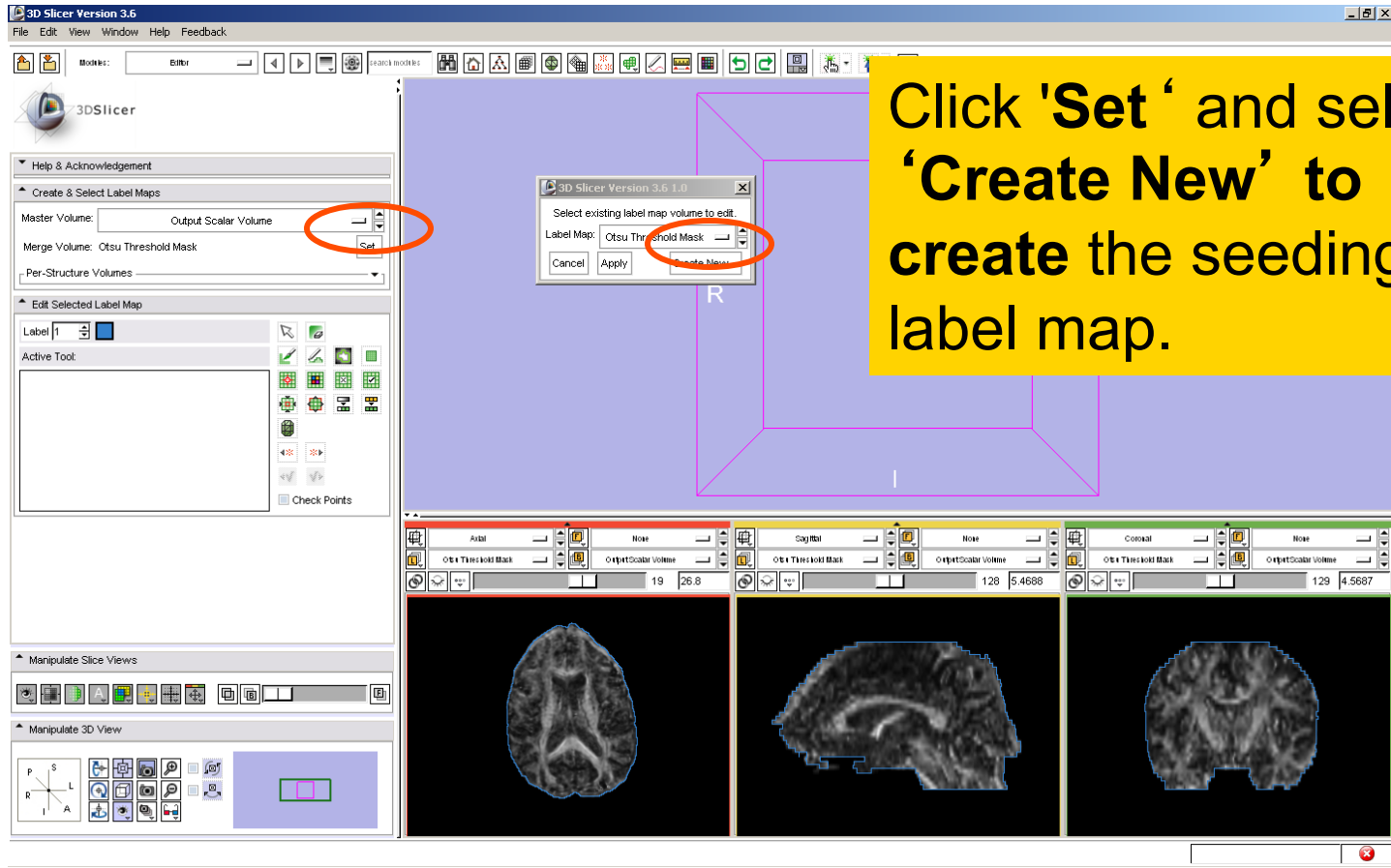
LabelMap Generation

Select the module **Editor** in the modules menu.

The screenshot shows the 3D Slicer software interface. The 'Editor' module is selected in the modules menu, indicated by a red circle and an arrow. The 'Master Volume' is set to 'Output Scalar Volume', also indicated by a red circle and an arrow. A yellow callout box with an arrow pointing to the 'Output Scalar Volume' dropdown contains the text: 'Select the Master Volume as 'Output Scalar Volume''. The main 3D view shows a brain slice with a purple bounding box labeled 'R'. The bottom panel shows three slice views: Axial, Sagittal, and Coronal. The status bar at the bottom indicates the coordinates for the 'Output Scalar Volume' in RAS and LJK spaces.

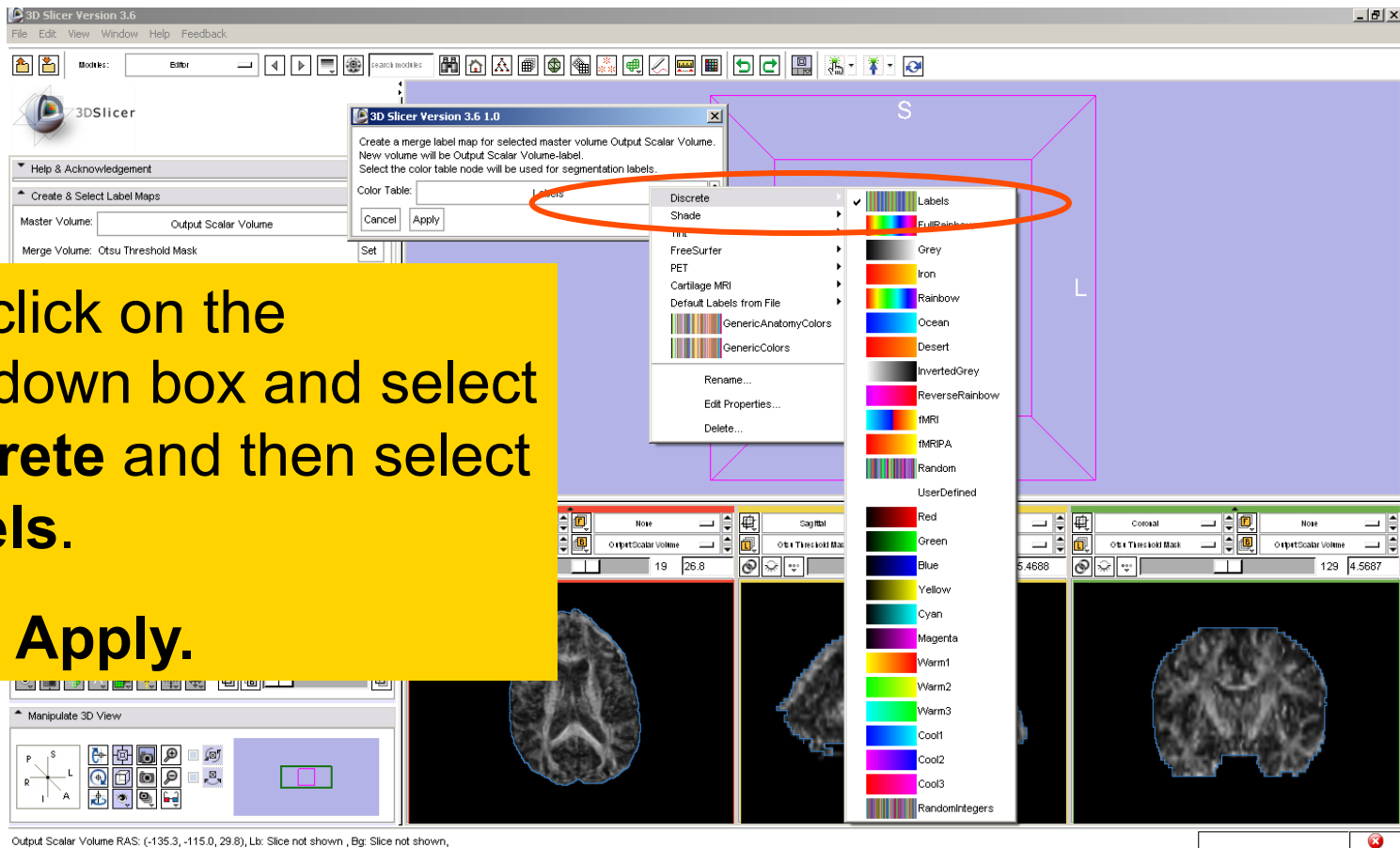


Label Map Generation





LabelMap Generation



Left click on the dropdown box and select **Discrete** and then select **Labels**.
Click **Apply**.



LabelMap Generation

Left click on the Slicer Viewer Menu icon, and select the label map **Output Scalar Volume-label**

Output Scalar Volume RAS: (96.2, 126.0, 23.8), Bg LfK: (31, -2, 19), Lb: Out of Frame, Bg: Out of Frame.



LabelMap Generation

3D Slicer Version 3.6
File Edit View Window Help Feedback

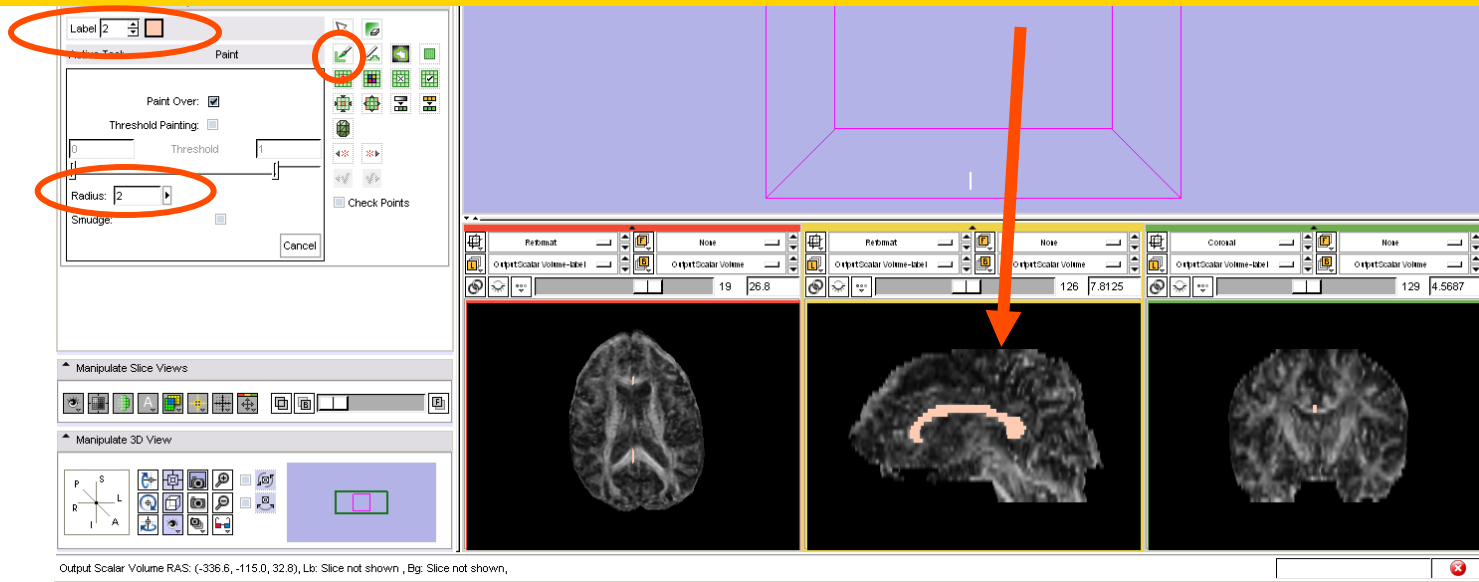
Left click on the Slicer Viewer Menu icon, and select **Don't Show label volume outlines**

The screenshot displays the 3D Slicer interface. A yellow banner at the top contains the instruction: "Left click on the Slicer Viewer Menu icon, and select **Don't Show label volume outlines**". An orange arrow points from this text to the Slicer Viewer menu icon in the bottom-left corner of the 3D view. The menu is open, showing the option "Don't show label volume outlines" selected. The 3D view shows a brain slice with a purple label volume and its outlines. The left sidebar contains various tool panels, and the bottom shows slice views and a control panel.



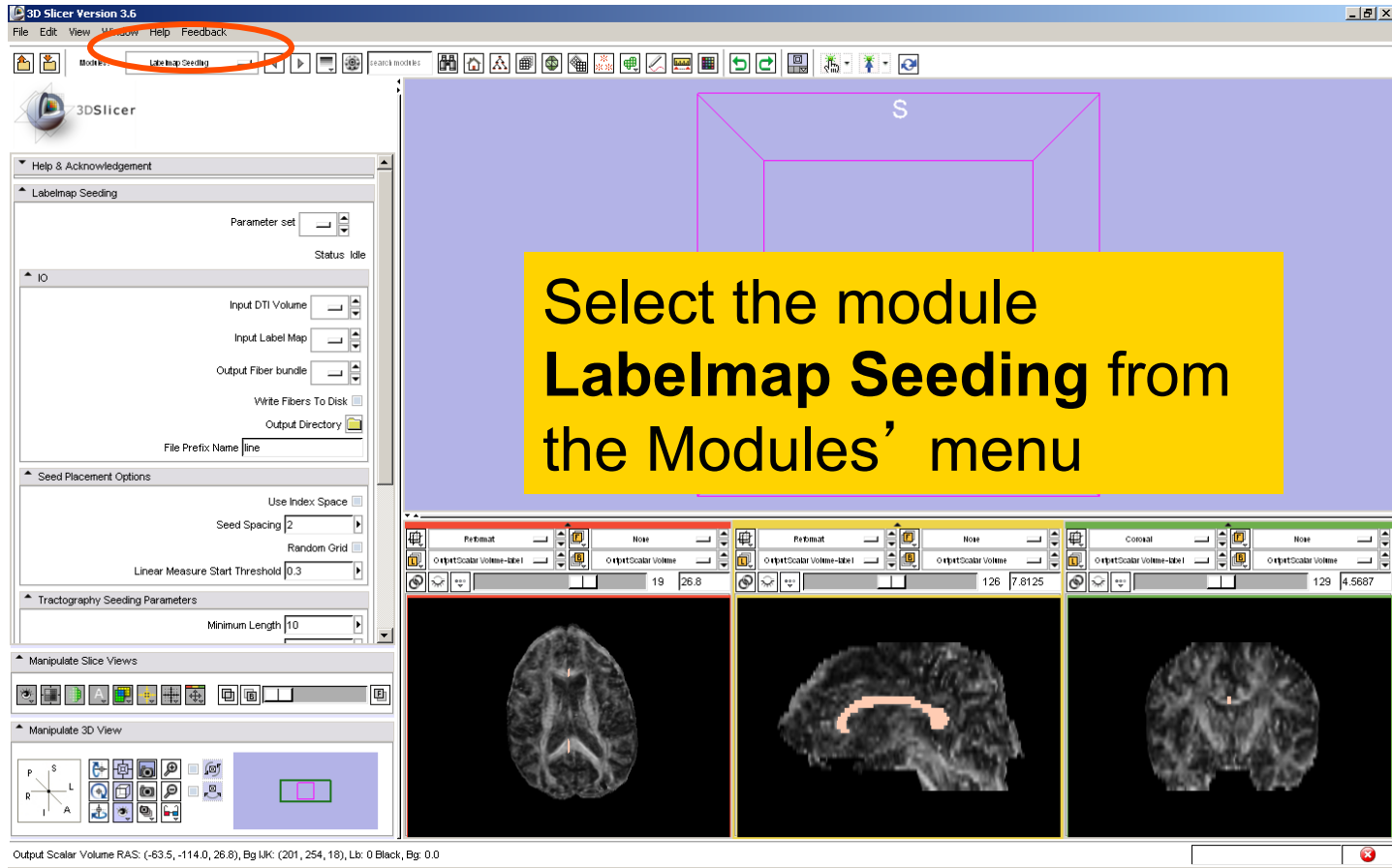
LabelMap Generation

Select the label 2 (pink), click on the icon **Paint** , set the radius to **2** and draw a region of interest within the corpus callosum in the sagittal view on a set of 2 or 3 slices





LabelMap Seeding





LabelMap Seeding

**Select the Input DTI volume
‘Output DTI Volume’**

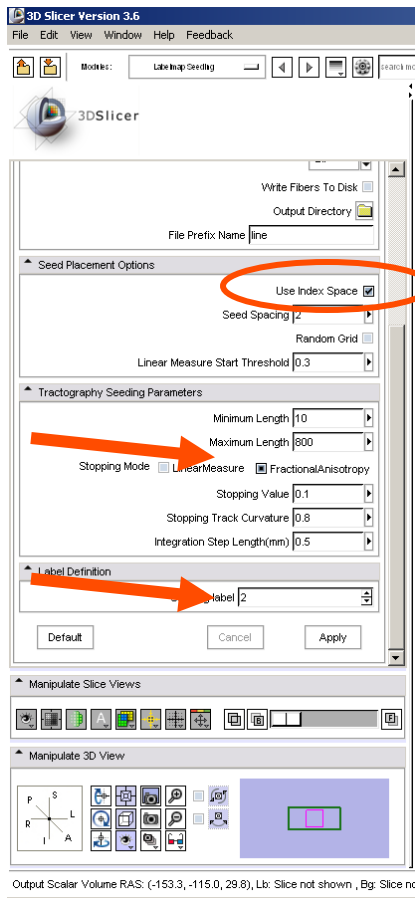
**Select the Input Label Map
‘Output Scalar Volume -
label’**

**Select Output Fiber Bundle
‘Create New Fiber
Bundle’**

3D Slicer Version 3.6
File Edit View Window Help Feedback
3DSlicer
Help & Acknowledgement
Labelmap Seeding
Parameter set: g
Status: Idle
IO
Input DTI Volume: e
Input Label Map: OI
Output Fiber bundle: L1
Write Fibers To Disk
Output Directory
Seed Placement Options
Use Index Space
Seed Spacing: 2
Random Grid
Linear Measure Start Threshold: 0.3
Tractography Seeding Parameters
Minimum Length: 10
Manipulate Slice Views
Manipulate 3D View
Output Scalar Volume RAS: (165.2, 223.3, 20.8), Lr: Slice not shown, Bg: Slice not shown



LabelMap Seeding



In the Seed Placement Options tab, select Use Index Space.

In the Tractography Seeding Parameters tab, select the 'Stopping Mode' **Fractional Anisotropy**, and use the default parameters for the minimum and maximum tract length, stopping value, stopping track curvature and integration step length.

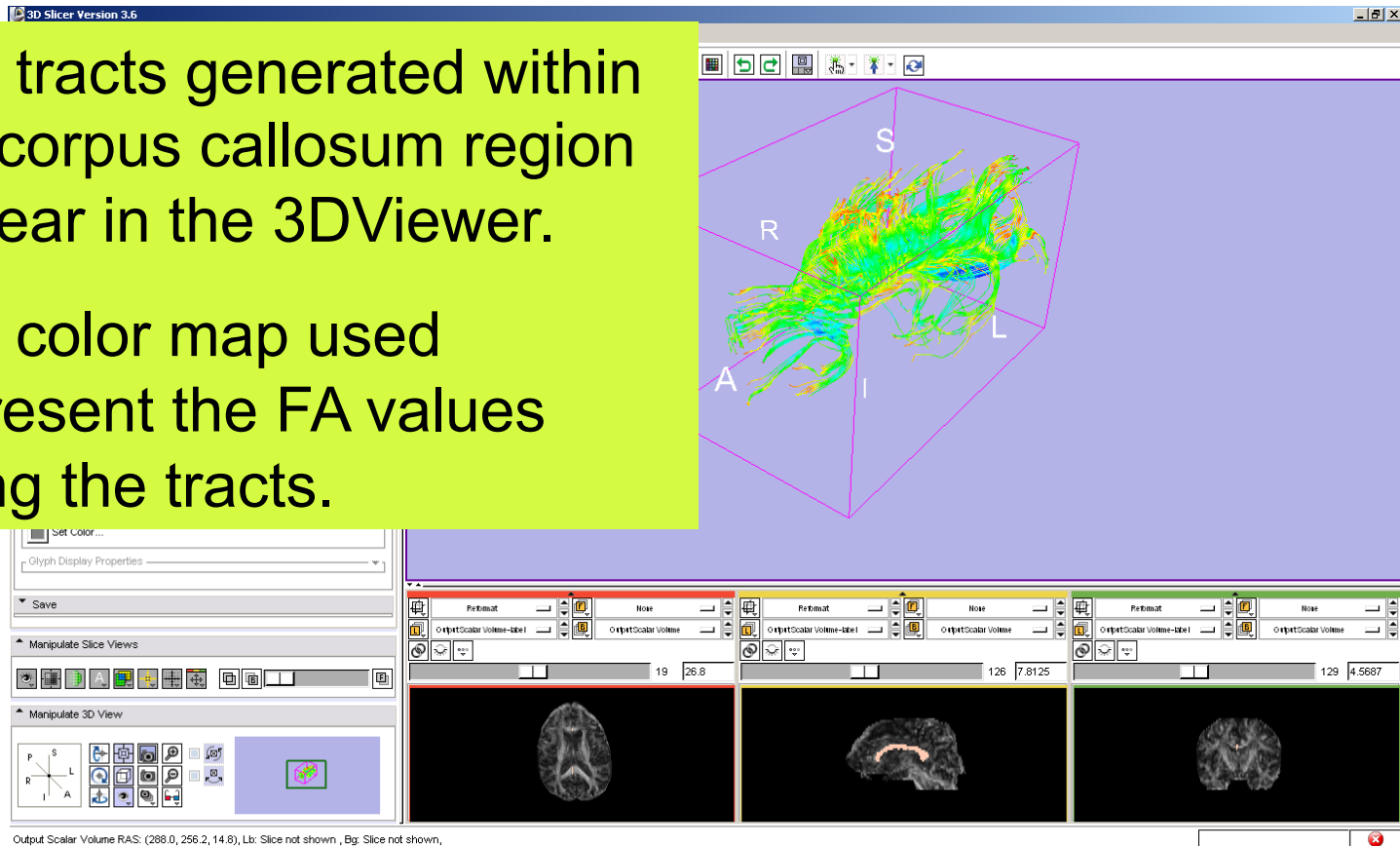
In the Label Definition tab, set 'Seeding label' to label 2, and click on **Apply**



LabelMap Seeding

The tracts generated within the corpus callosum region appear in the 3DViewer.

The color map used represent the FA values along the tracts.





LabelMap Seeding

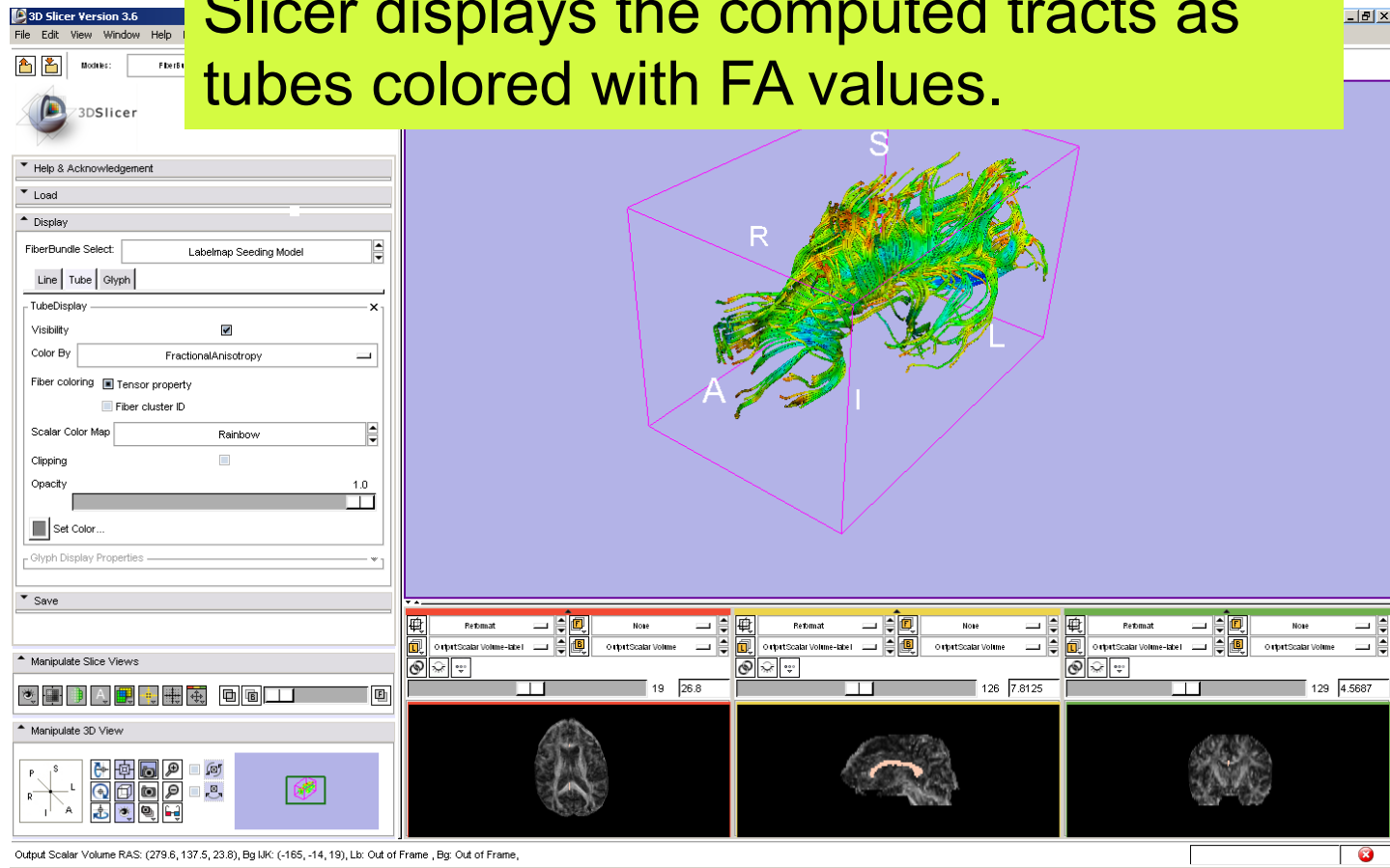
Select the module **FiberBundles**, and click on the tab **Tube** in the Display panel

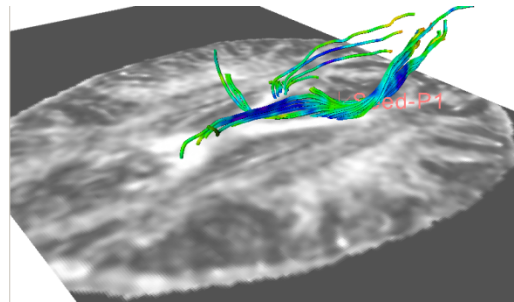
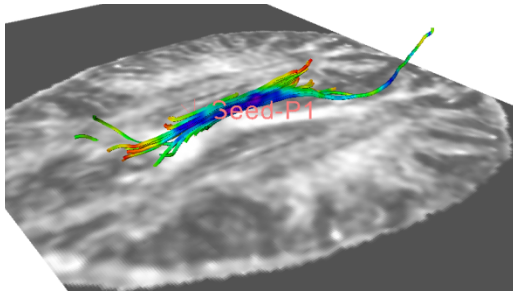
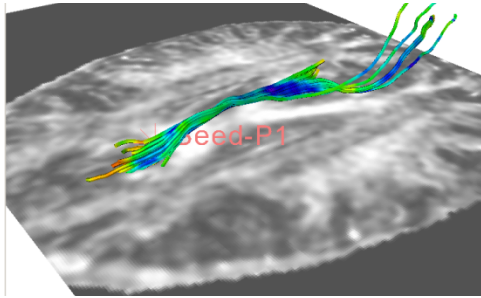
Check the visibility box to display the tubes.



LabelMap Seeding

Slicer displays the computed tracts as tubes colored with FA values.





Part 4:

**Tractography
on-the-fly**



Fiducial Seeding

Set Fiducial List to Create New FiducialList

The screenshot displays the 3D Slicer 3.6.4-beta interface. A yellow banner at the top of the software window reads "Set Fiducial List to Create New FiducialList". An orange arrow points to the "Fiducial List" dropdown menu in the "Modify A Selected Fiducial List & Its Fiducials" panel on the left. The main 3D view shows a brain with a purple wireframe box and a green and blue fiber bundle. The bottom of the interface shows three orthogonal slice views (Axial, Sagittal, Coronal) of the brain.




Fiducial Seeding

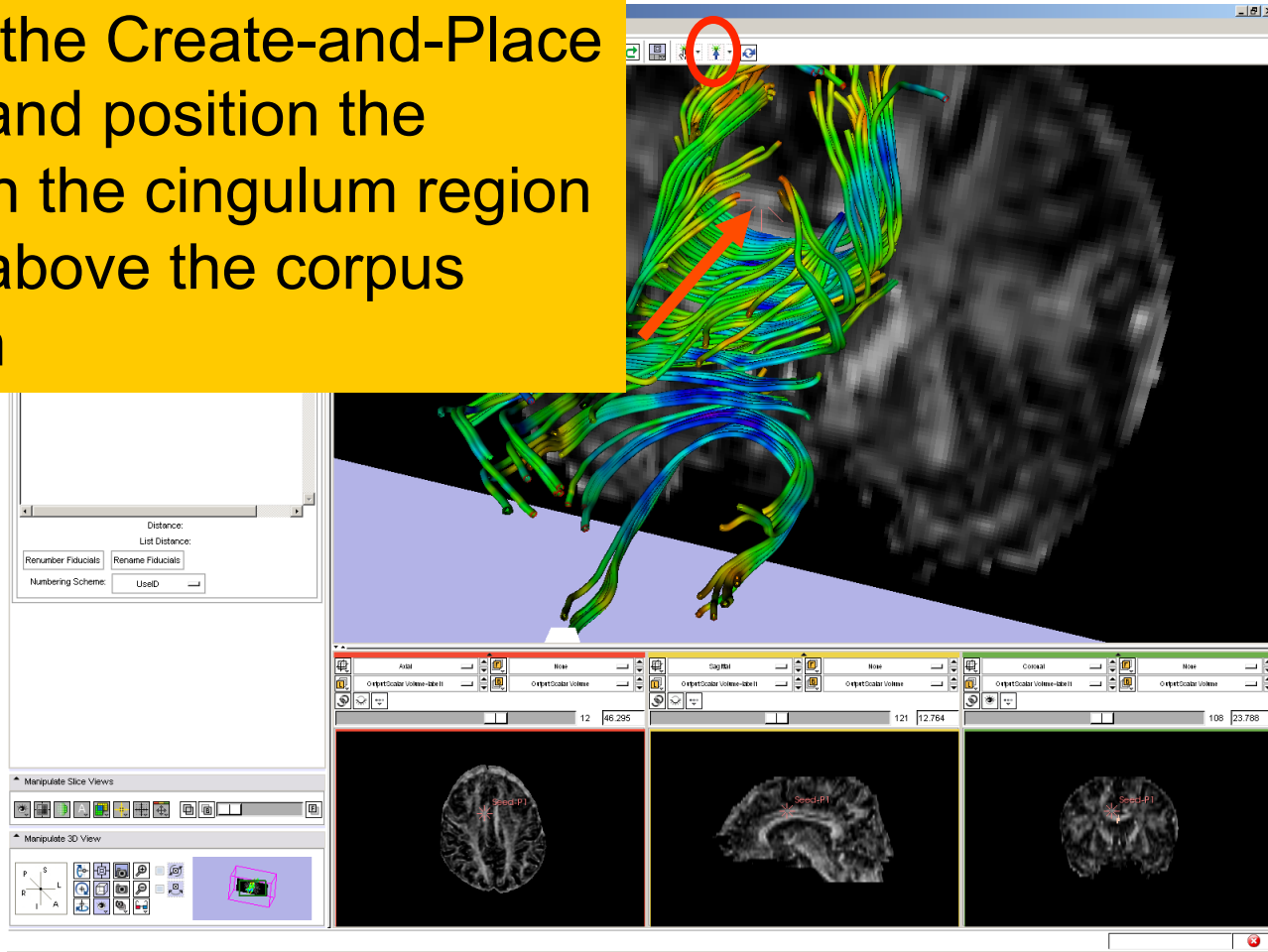
Left click on **FiducialList** and select **Rename**

The screenshot displays the 3D Slicer software interface. The main 3D view shows a brain with a purple wireframe box. The wireframe box is labeled with 'R' (Right), 'L' (Left), 'A' (Anterior), and 'I' (Inferior). A yellow text box is overlaid on the 3D view, containing the instruction: 'Left click on **FiducialList** and select **Rename**'. The software interface includes a 'Modify All Fiducial Lists' panel on the left, which has a 'FiducialList' dropdown menu. Below the dropdown are buttons for 'Renumeral Fiducials' and 'Rename Fiducials'. The bottom of the interface shows three slice views: Axial, Sagittal, and Coronal.



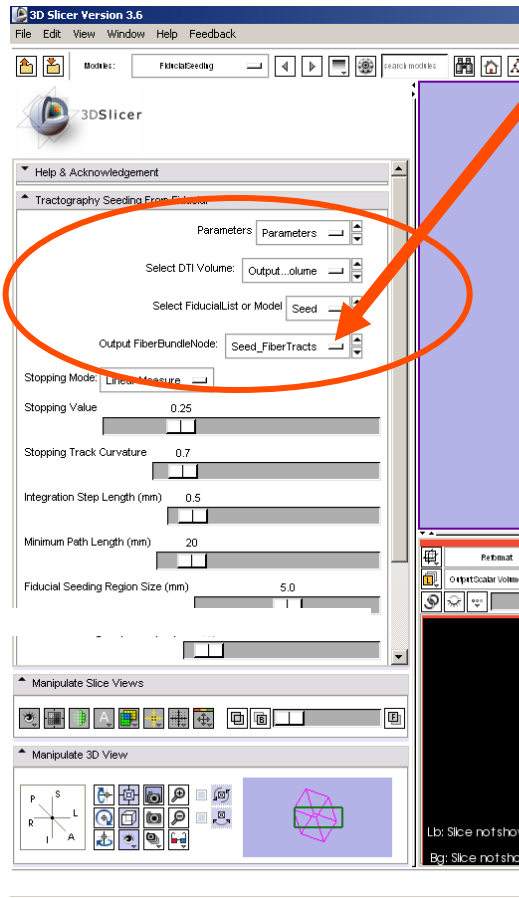
Fiducial Seeding

Click on the Create-and-Place icon  and position the fiducial in the cingulum region located above the corpus callosum





Fiducial Seeding



Select the module **Fiducial Seeding**

Set the Output FiberBundleNode to **Create New FiberBundle**

Important: this step must be done first



Fiducial Seeding

Set the DTI Volume to Output DTI Volume

Select the Fiducial List Seed

3D Slicer Version 3.6
File Edit View Window Help Feedback

Books: FiducialSeeding

3DSlicer

Help & Acknowledgement

Tractography Seeding From Fiducials

Parameters Parameters

Select DTI Volume: Output...volume

Select FiducialList or Model: Seed

Output FiberBundleNode: Seed_FiberTracts

Stopping Mode: Lines Measure

Stopping Value: 0.25

Stopping Track Curvature: 0.7

Integration Step Length (mm): 0.5

Minimum Path Length (mm): 20

Fiducial Seeding Region Size (mm): 5.0

Manipulate Slice Views

Manipulate 3D View

Reformat None Output Scalar Volume

Reformat None Output Scalar Volume

Reformat None Output Scalar Volume

Bg: Output Scalar Volume
Lb: Output Scalar Volume-label

Reformat Sp: 3mm

Bg: 0
Bg J: 150
Bg K: 24

Bg: Output Scalar Volume
Lb: Output Scalar Volume-label

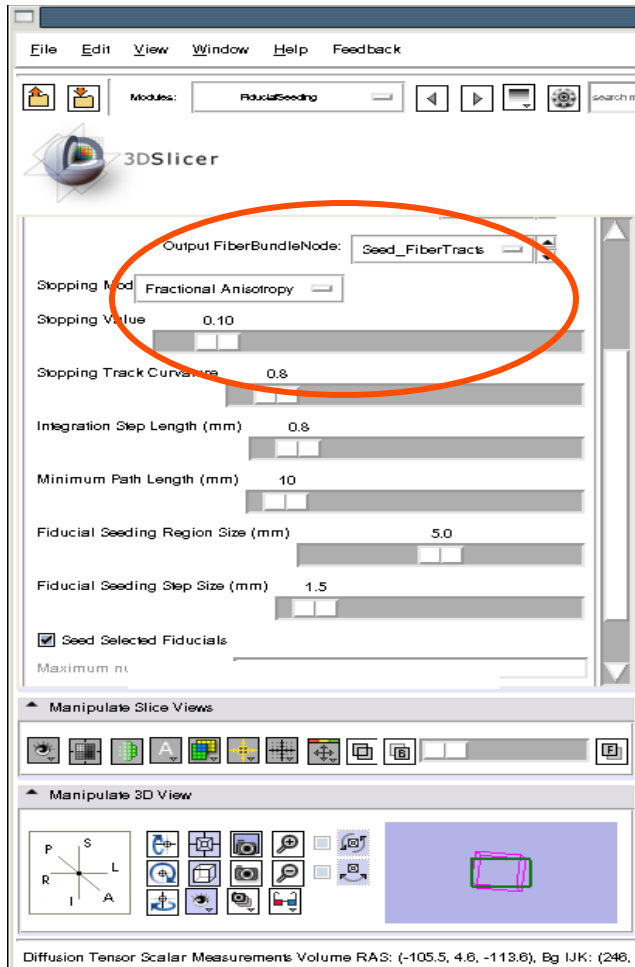
Reformat Sp: 0.938mm

Lb: Slice not shown
R: 105.0
A: -115.0
S: 40.0

Lb: 0 Black
R: 125.0
A: -22.2
S: 0.0



Fiducial Seeding



Set the Stopping Mode to **Fractional Anisotropy** and set the tractography parameters to the values that we used for the corpus callosum:

Stopping Value: 0.1

Stopping Track Curvature: 0.8

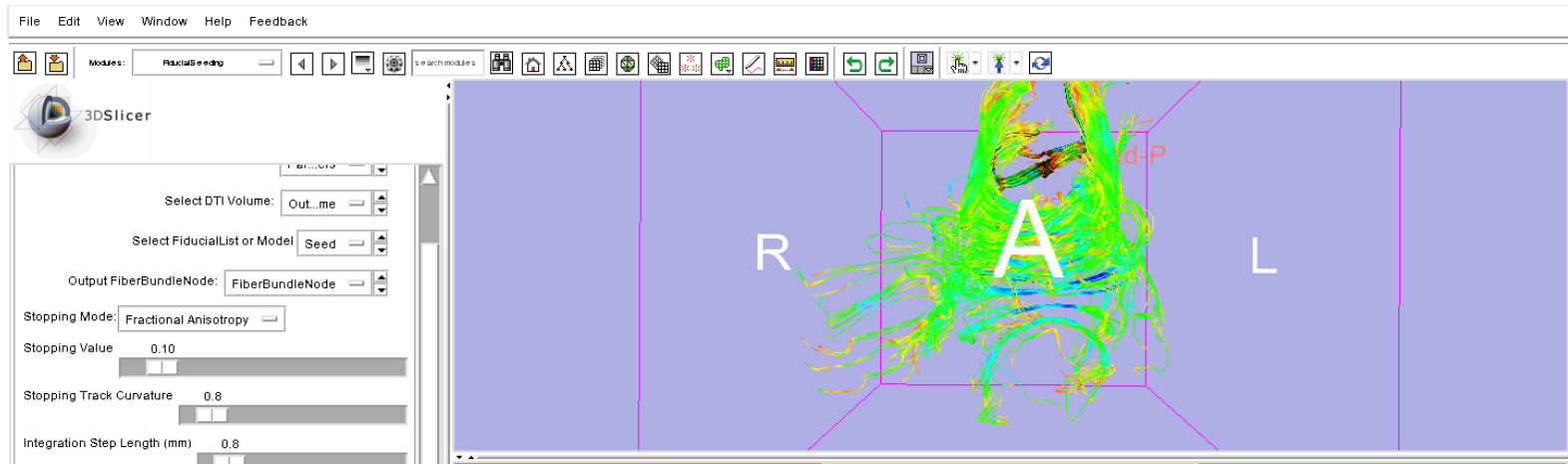
Step Length: 0.8 mm

Minimum Path Length: 10 mm

Fiducial Stepping Size: 1.5 mm



Fiducial Seeding



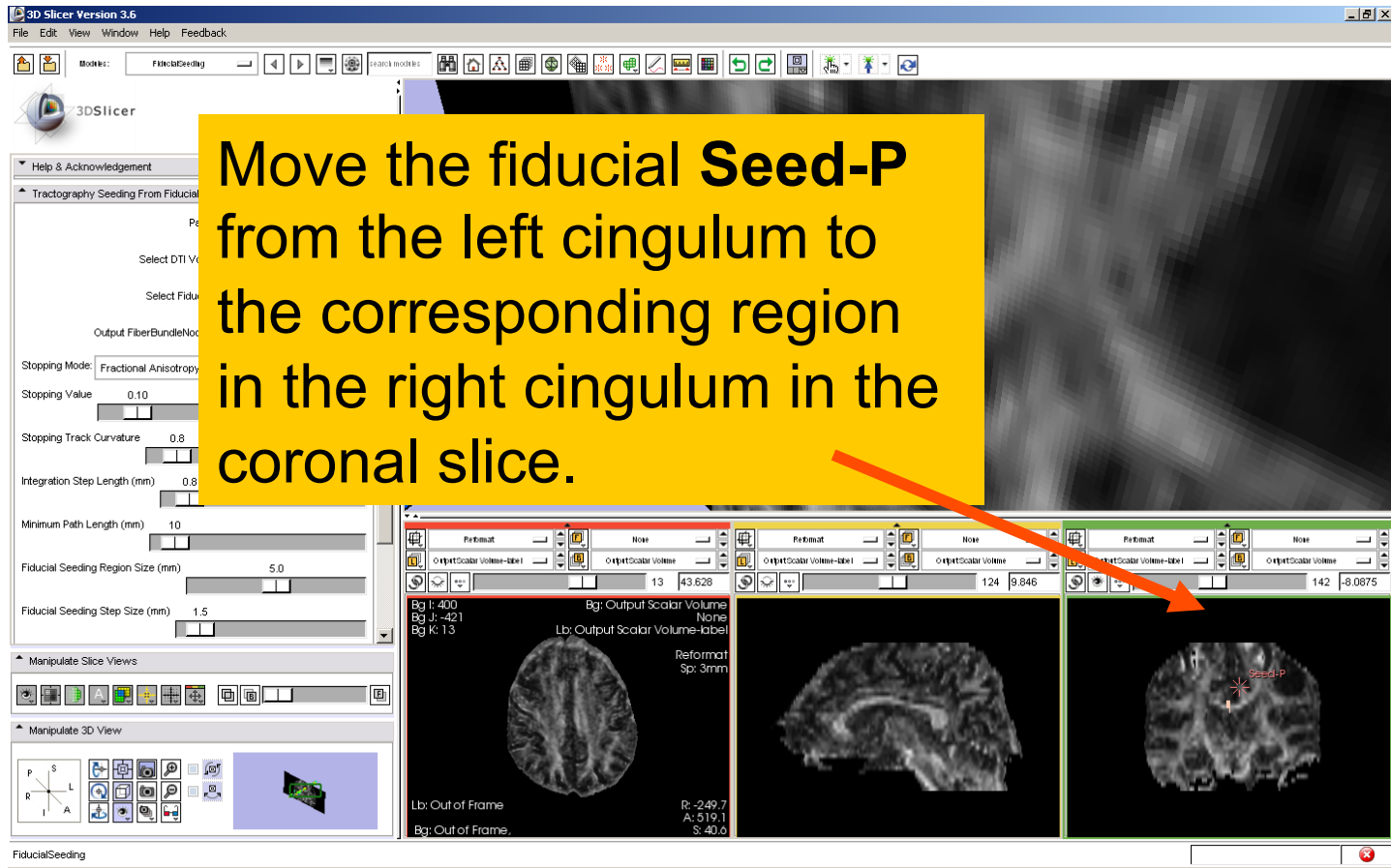
Slicer displays the tracts seeded from the Fiducial Seed-P.

The tracts correspond to the region of the cingulum located above the corpus callosum.

For better visualization, uncheck the visibility box under **Tubes** in the **Fiber Bundles** module (Slide 42).

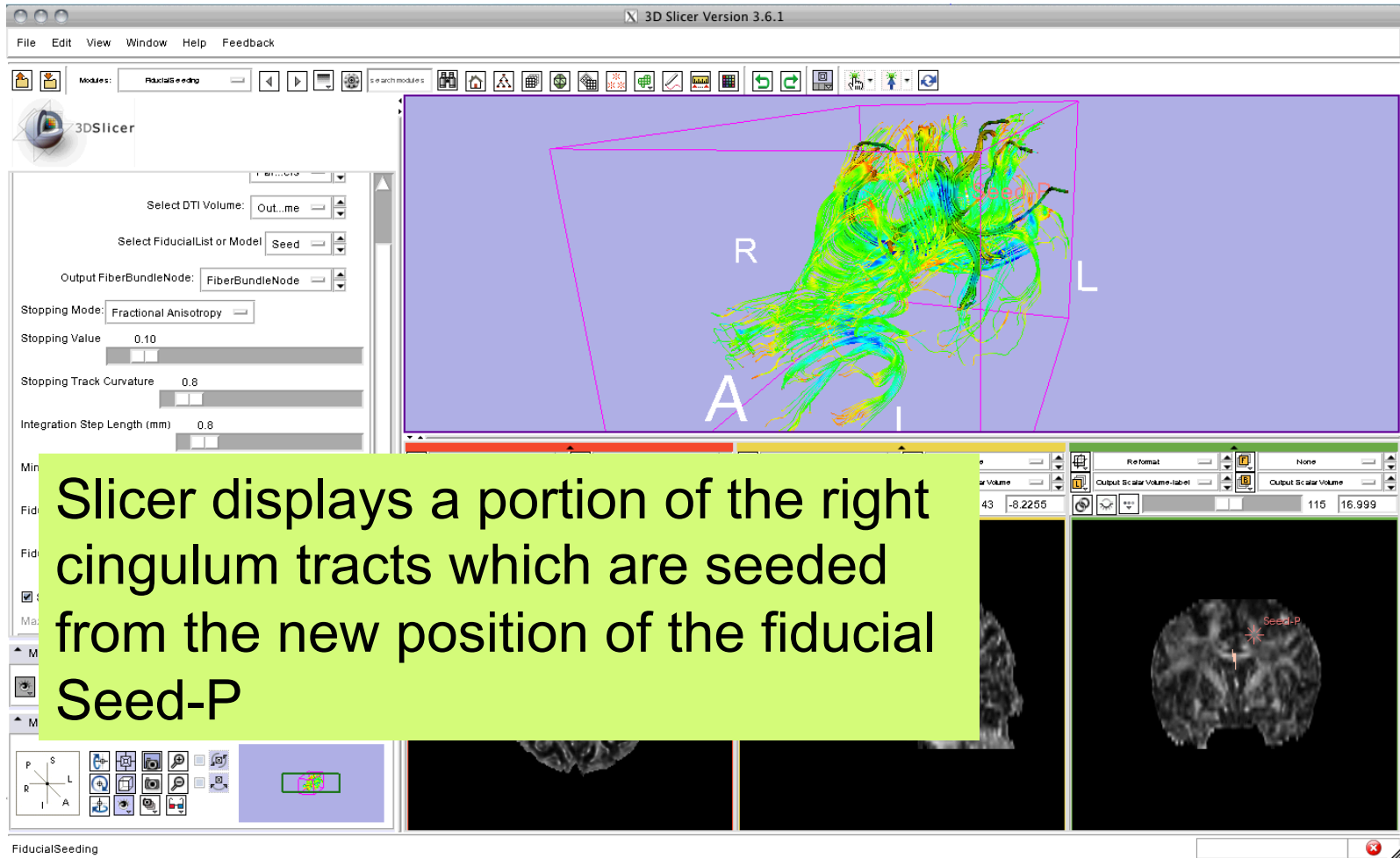


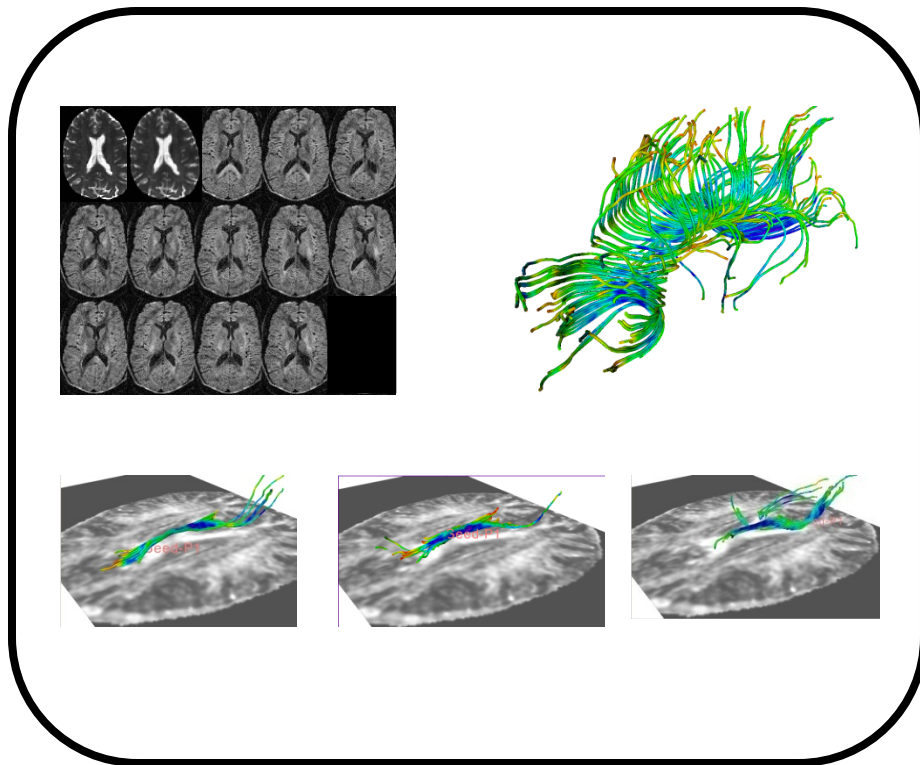
Fiducial Seeding





Fiducial Seeding





Part 5:

Saving a DTI Scene



DTI Scene

Select the module Data

Slicer displays the list of volumes and models generated in this tutorial

3D Slicer Version 3.6.1

File Edit View Window Help Feedback

Modules: Data

MRML Tree

- Scene
 - View
 - Default Scene Camera
 - dwiDataset
 - Output DTI Volume
 - Output Baseline Volume
 - Otsu Threshold Mask
 - Output Scalar Volume
 - Output Scalar Volume-label
 - Labelmap Seeding Model
 - Seed
 - FiberBundleNode

MRML Node Inspector

Load & Add Scenes Or Individual Datasets

- Load new scene (close current)
- Add a scene (to current)
- Add data or a data directory

Manipulate Slice Views

Manipulate 3D View

Reformat None Reformat None Reformat None

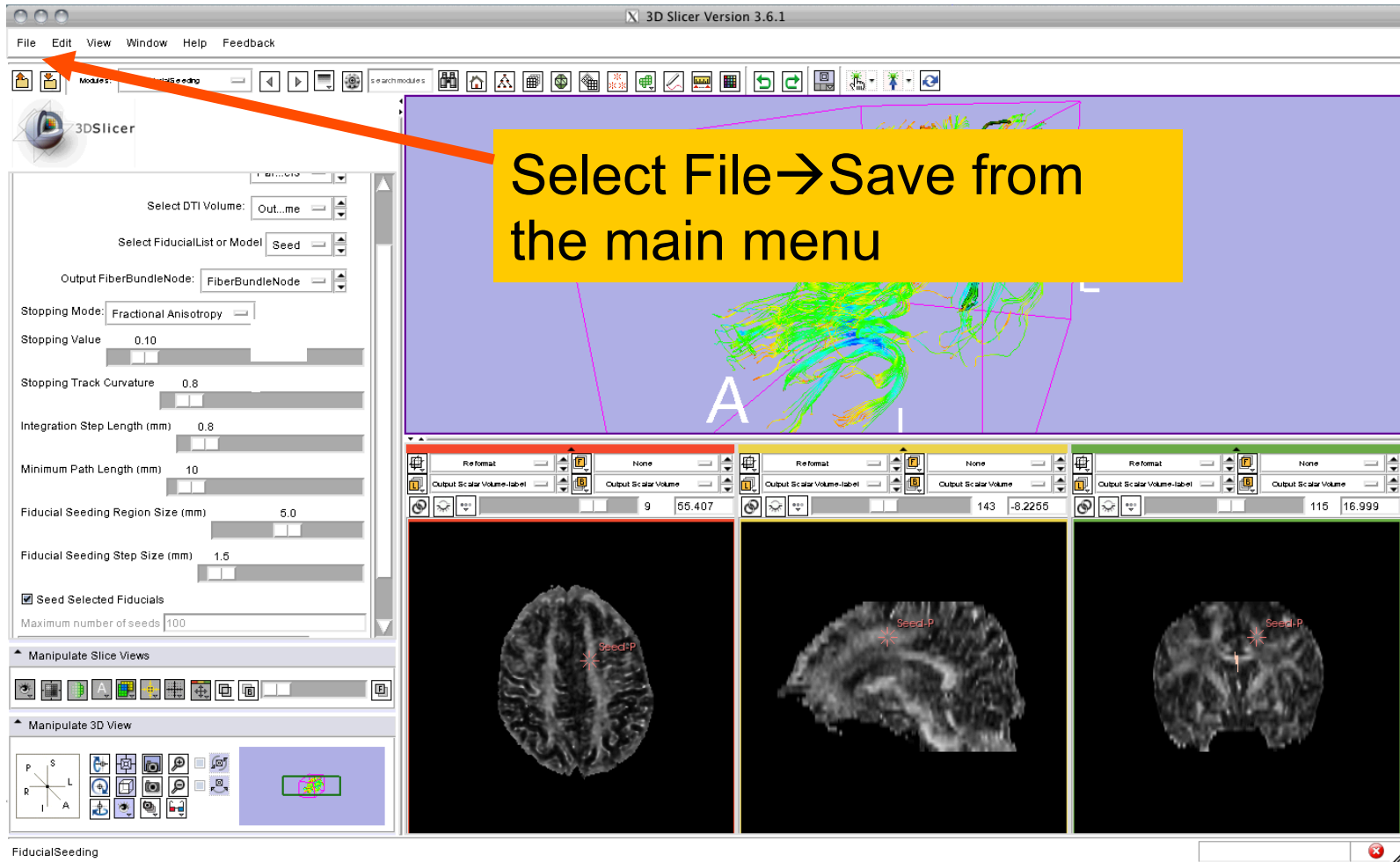
Output Scalar Volume-label Output Scalar Volume Output Scalar Volume-label Output Scalar Volume Output Scalar Volume-label Output Scalar Volume

19 26.8 128 5.4688 129 4.5687

Data



Saving a DTI Scene





Saving a DTI Scene

Browse to a directory where you would like to save the data. Once you have selected a directory, select all the files that have been created during this tutorial and click on **Save Selected**

Save Scene & Data Options

Change Destination for All Selected: D:/SlicerData/DiffusionDataset/

Select	Node Name	Node Type	Node Status	File Format	File Name	Data Directory
<input checked="" type="checkbox"/>	[Scene Description]	[SCENE]	Modified	MRML (.mrmli)	SlicerScene1	D:/SlicerData/DiffusionDataset/
<input type="checkbox"/>	dwiDataset	DiffusionWei...	Not Modified	NRRD (.nhdr)	dwiDataset.nhdr	D:/SlicerData/DiffusionDataset/
<input checked="" type="checkbox"/>	Output DTI Volume	DiffusionTen...	Not Modified	NRRD (.nhdr)	Output DTI Volume.nhdr	D:/SlicerData/DiffusionDataset/
<input checked="" type="checkbox"/>	Output Baseline Volume	Volume	Modified	NRRD (.nrrd)	Output Baseline Volum...	D:/SlicerData/DiffusionDataset/
<input checked="" type="checkbox"/>	Otsu Threshold Mask	Volume	Modified	NRRD (.nrrd)	Otsu Threshold Mask.n...	D:/SlicerData/DiffusionDataset/
<input checked="" type="checkbox"/>	Output Scalar Volume	Volume	Modified	NRRD (.nrrd)	Output Scalar Volume...	D:/SlicerData/DiffusionDataset/
<input checked="" type="checkbox"/>	Output Scalar Volume-label	Volume	Modified	NRRD (.nrrd)	Output Scalar Volume-l...	D:/SlicerData/DiffusionDataset/
<input checked="" type="checkbox"/>	Labelmap Seeding Model	FiberBundle	Modified	Poly Data (.vtk)	Labelmap Seeding Mo...	D:/SlicerData/DiffusionDataset/
<input checked="" type="checkbox"/>	Seed	FiducialList	Modified	Fiducial List CSV (.fcsv)	Seed.fcsv	D:/SlicerData/DiffusionDataset/
<input checked="" type="checkbox"/>	Seed_FiberTracts	FiberBundle	Modified	Poly Data (.vtk)	Seed_FiberTracts.vtk	D:/SlicerData/DiffusionDataset/

Save Selected Cancel



Saving a DTI Scene

Select File → Close Scene to close the current DTI Scene

3D Slicer Version 3.6 RC3

File Edit View Window Help

Modules: SlicerWelcome

3DSlicer

Welcome & About

3DSlicer version 3.6 **Welcome**

3D Slicer is a free open source software platform for medical image processing and 3D visualization of image data. This module contains some basic information and useful links to get you started using Slicer. Please see our website <http://www.slicer.org> and the documentation on our wiki for more information: <http://www.slicer.org/slicerWiki/index.php/Documentation-3.6>.

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Hint: to open any information panel below, click on its grey title bar.

Don't show this module on startup.

Manipulate Slice Views

Manipulate 3D View

None RAS: (87.3, 1.0, -125.0)



Loading a DTI Scene

Select File → Load Scene and browse to the location where you saved the scene **SlicerScene1.mrml**

3D Slicer Version 3.6 RC3

File Edit View Window Help

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3DSlicer

Welcome & About

3DSlicer version 3.6 Welcome

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3D Slicer is distributed under a BSD-style license; for details about the contribution and software license agreement, please see <http://www.slicer.org/cgi-bin/License/SlicerLicenseForm.pl>. The software has been designed for research purposes only and has not been reviewed or approved by the Food and Drug Administration, or by any other agency.

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Don't show this module on startup.

Manipulate Slice Views

Manipulate 3D View

None RAS: (87.3, 1.0, -125.0)



Loading a DTI Scene

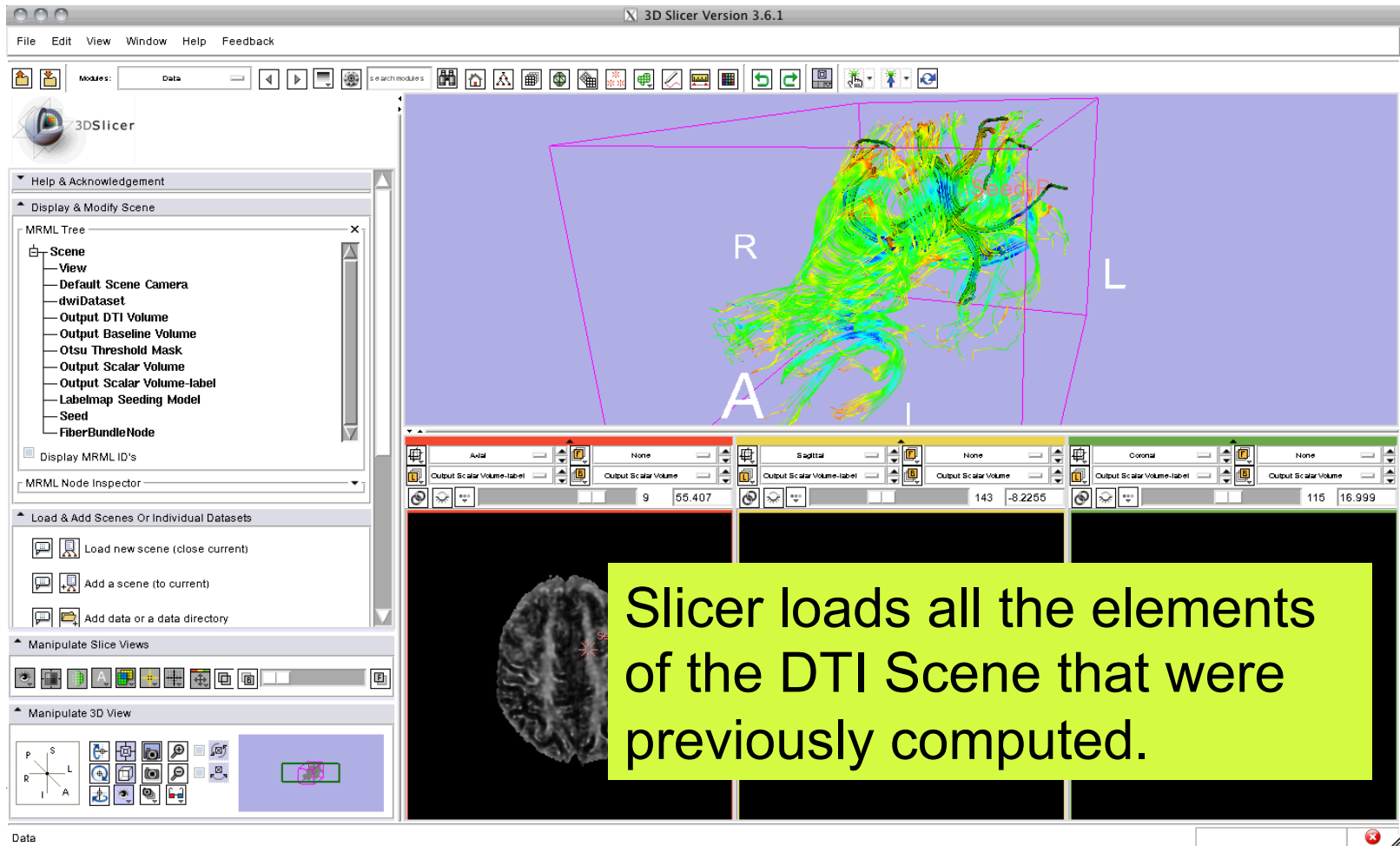
Select the scene **SlicerScene1.mrml and click on **Open****

The screenshot shows the 3D Slicer interface with a 'Select File' dialog box open. The dialog box displays a list of files and folders. The file 'SlicerScene1.mrml' is selected. The 'Open' button is circled in red. The background shows the 3D Slicer interface with a 3D view of a brain slice and various toolbars.

Name	Size	Modified time
SlicerScene1.mrml	28 KB	07/31/10 16:13:36

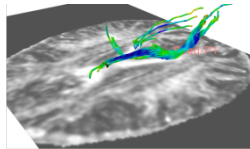
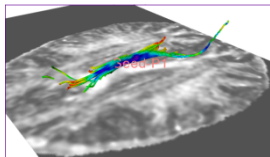
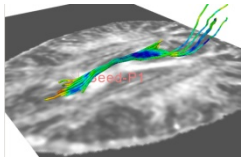
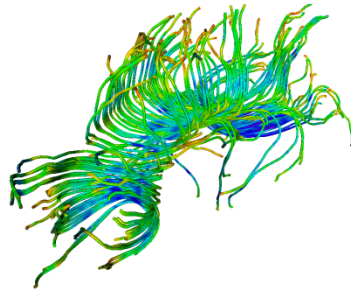
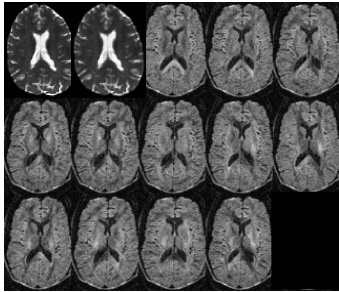


Loading a DTI Scene





Conclusion



This tutorial guided you through some of the **Diffusion MR** capabilities of the **Slicer3** software for studying the brain white matter pathways.

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Slicer Community

www.slicer.org

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Acknowledgments



National Alliance for Medical Image Computing

NIH U54EB005149



Neuroimage Analysis Center

NIH P41RR013218