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# **Diffusion Tensor Imaging tutorial**



**Sonia Pujol, PhD**  
**Surgical Planning Laboratory**  
**Harvard University**

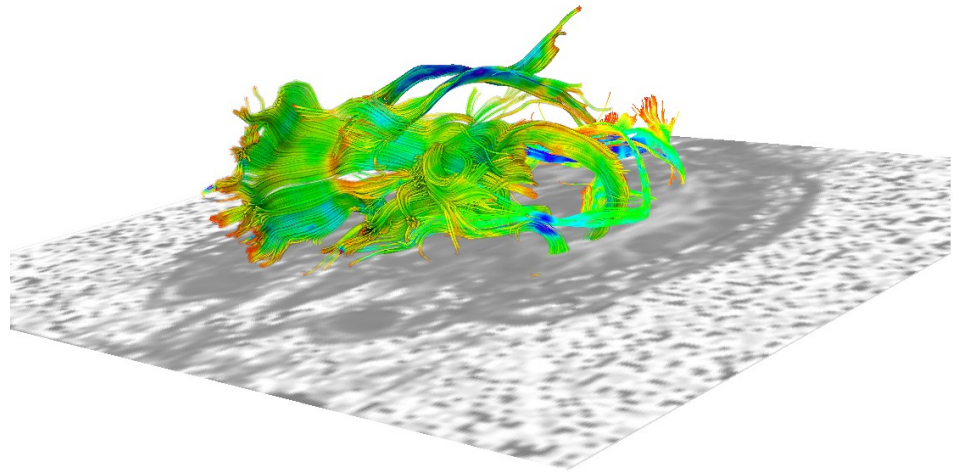
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# DTI tutorial

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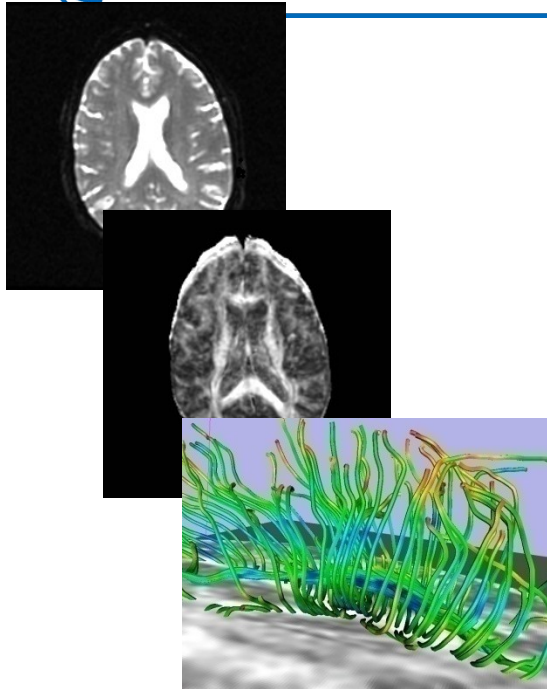
This tutorial is an introduction to the advanced **Diffusion MR** capabilities of the **Slicer3** software for medical image analysis.





# Outline

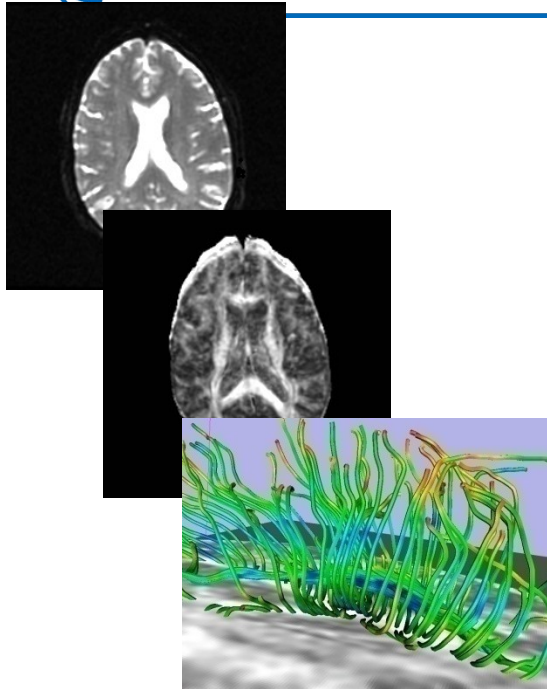
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This tutorial guides you through the process of **loading diffusion MR data**, **estimating diffusion tensors**, and **performing tractography** of white matter bundles.



# Outline



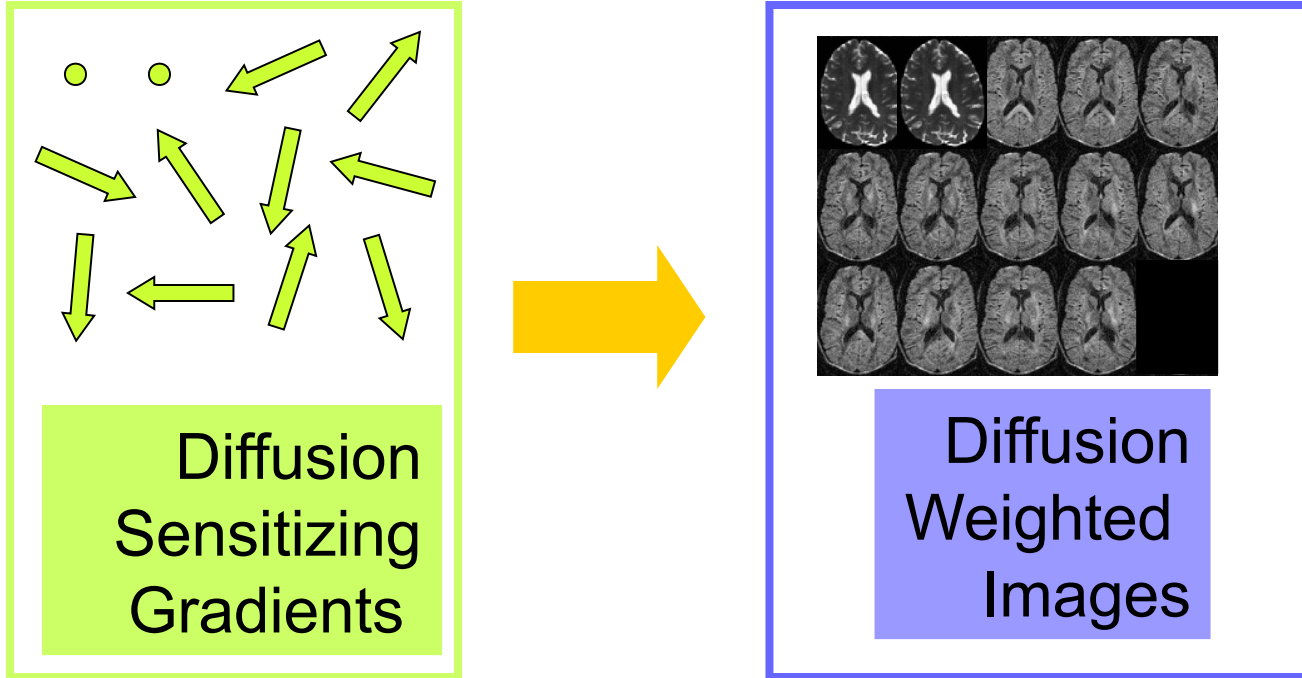
The processing pipeline uses **9 image analysis modules** of Slicer3.6

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



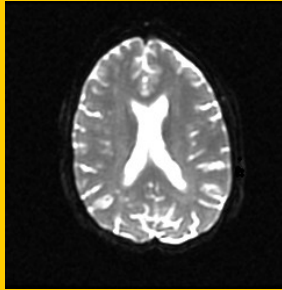
# Tutorial Dataset

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

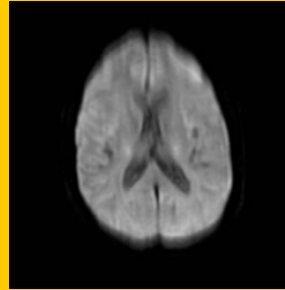




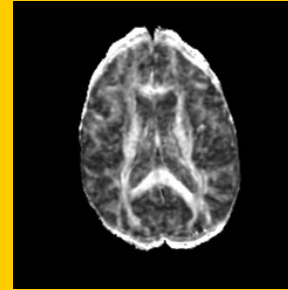
# DTI Processing Pipeline



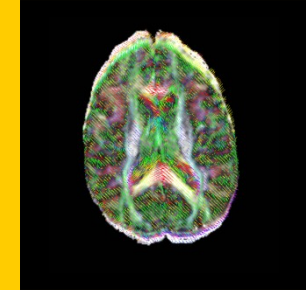
DWI  
Acquisition



Tensor  
Calculation



Scalar  
Maps



3D  
Visualization



# Start Slicer3

**Linux/Mac users**

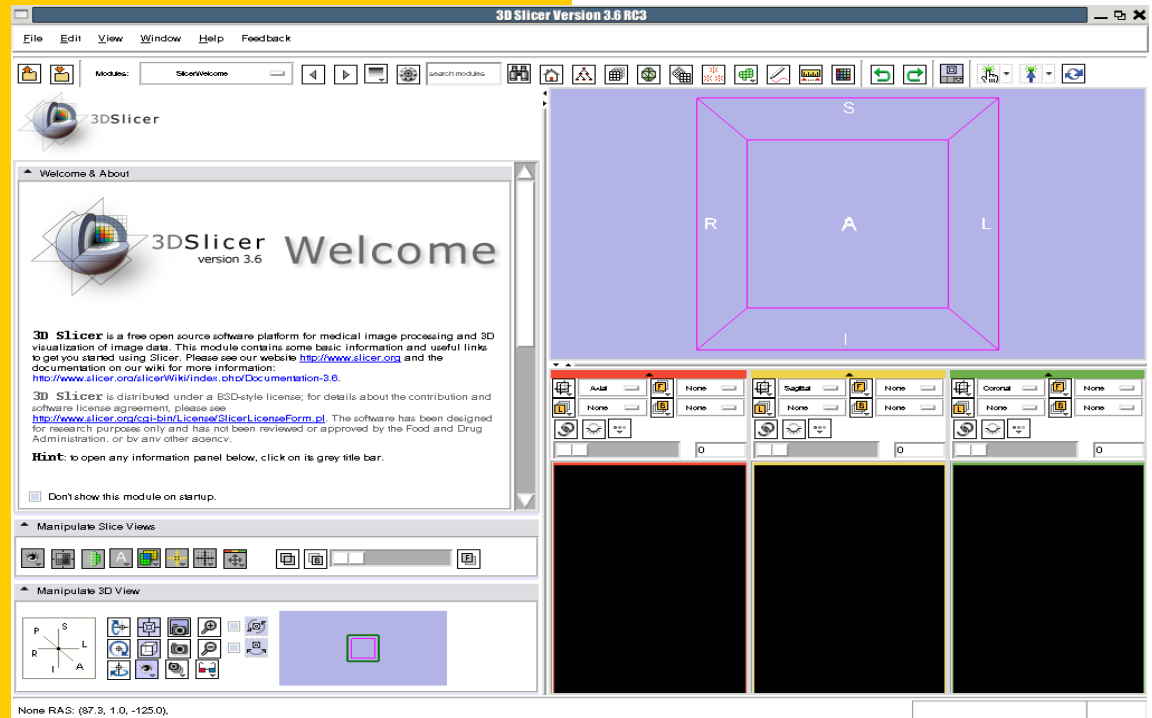
Launch the Slicer3 executable located in the Slicer3.6 directory

**Windows users**

Select

Start → All Programs

→ Slicer3-3.6-2010-06-10 → 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

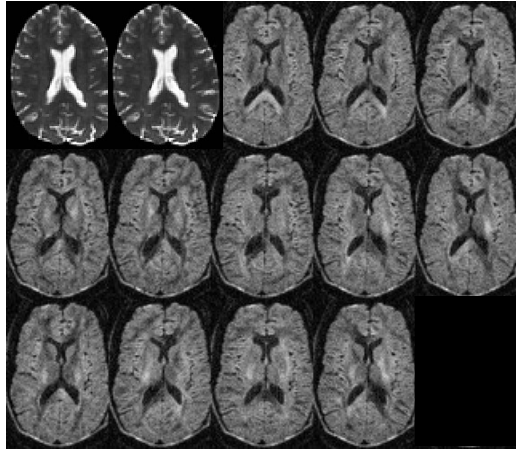
Manipulate 3D View

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.





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

# Part 1:

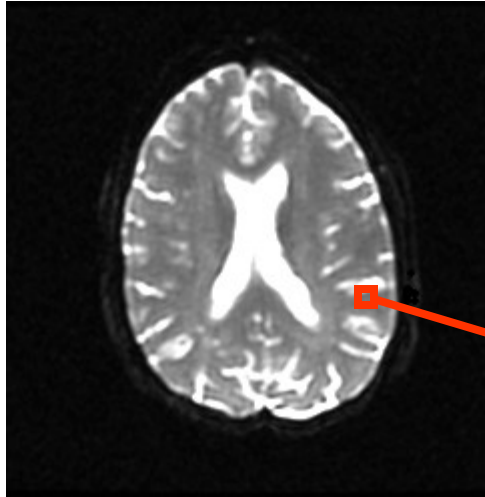
# Diffusion data loading and tensor estimation



# Diffusion Tensor

Stejskal-Tanner

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



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



# Loading the DWI volume

**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

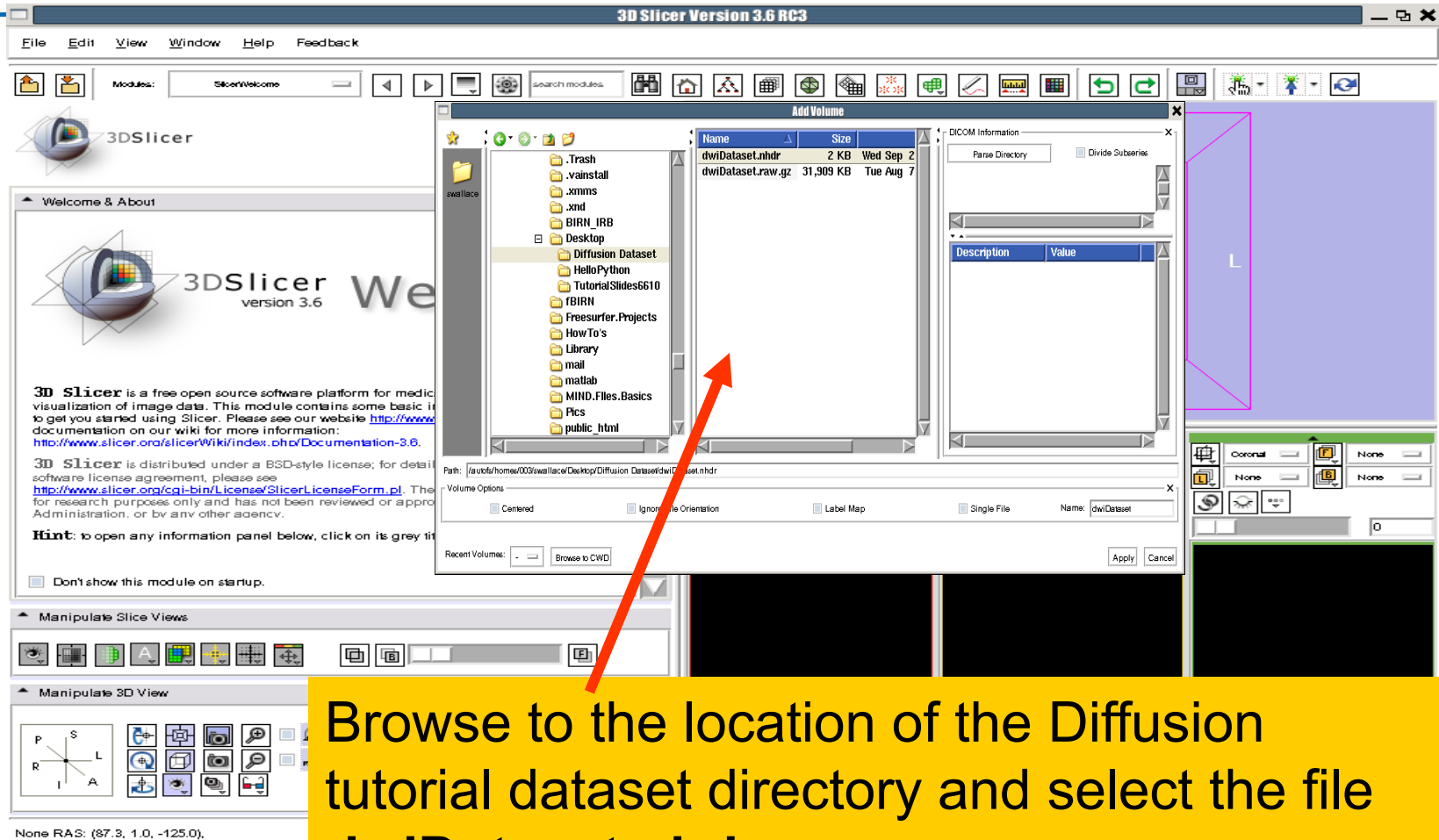
Manipulate 3D View

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

**Select File → Add Volume from the File menu**



# Loading the DWI volume



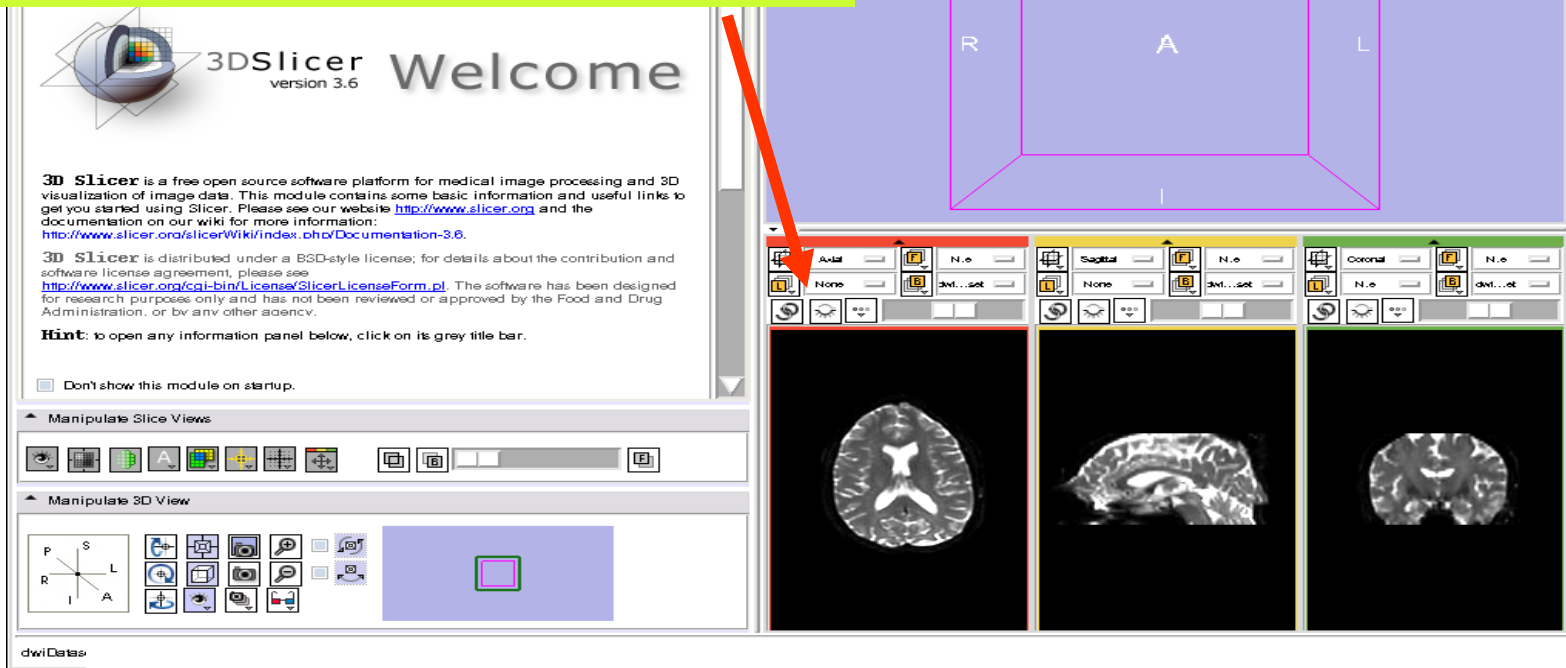
Browse to the location of the Diffusion tutorial dataset directory and select the file **dwiDataset.nhdr**

Click on **Apply** to load the volume



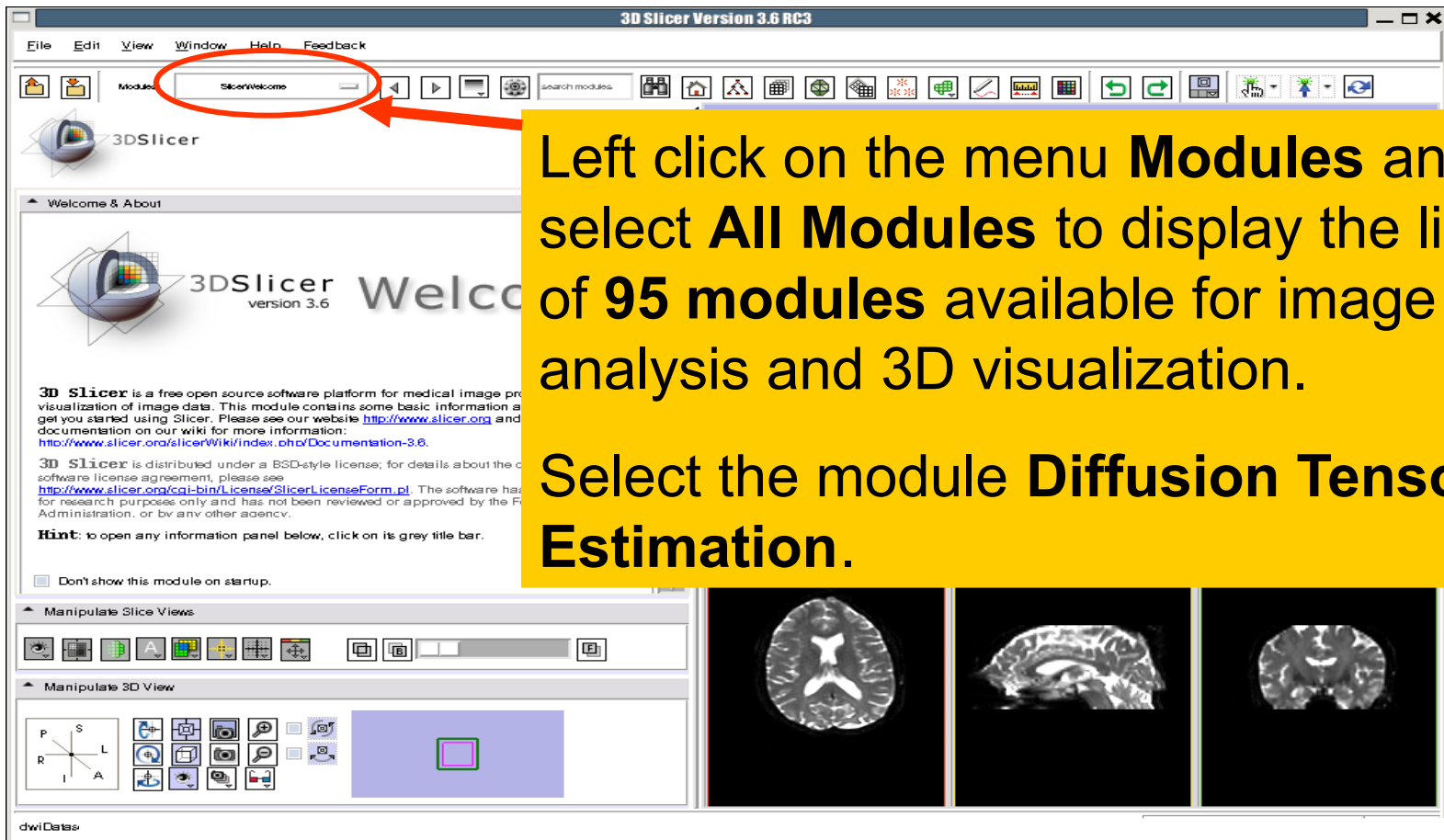
# Loading the DWI volume

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





# Tensor Estimation

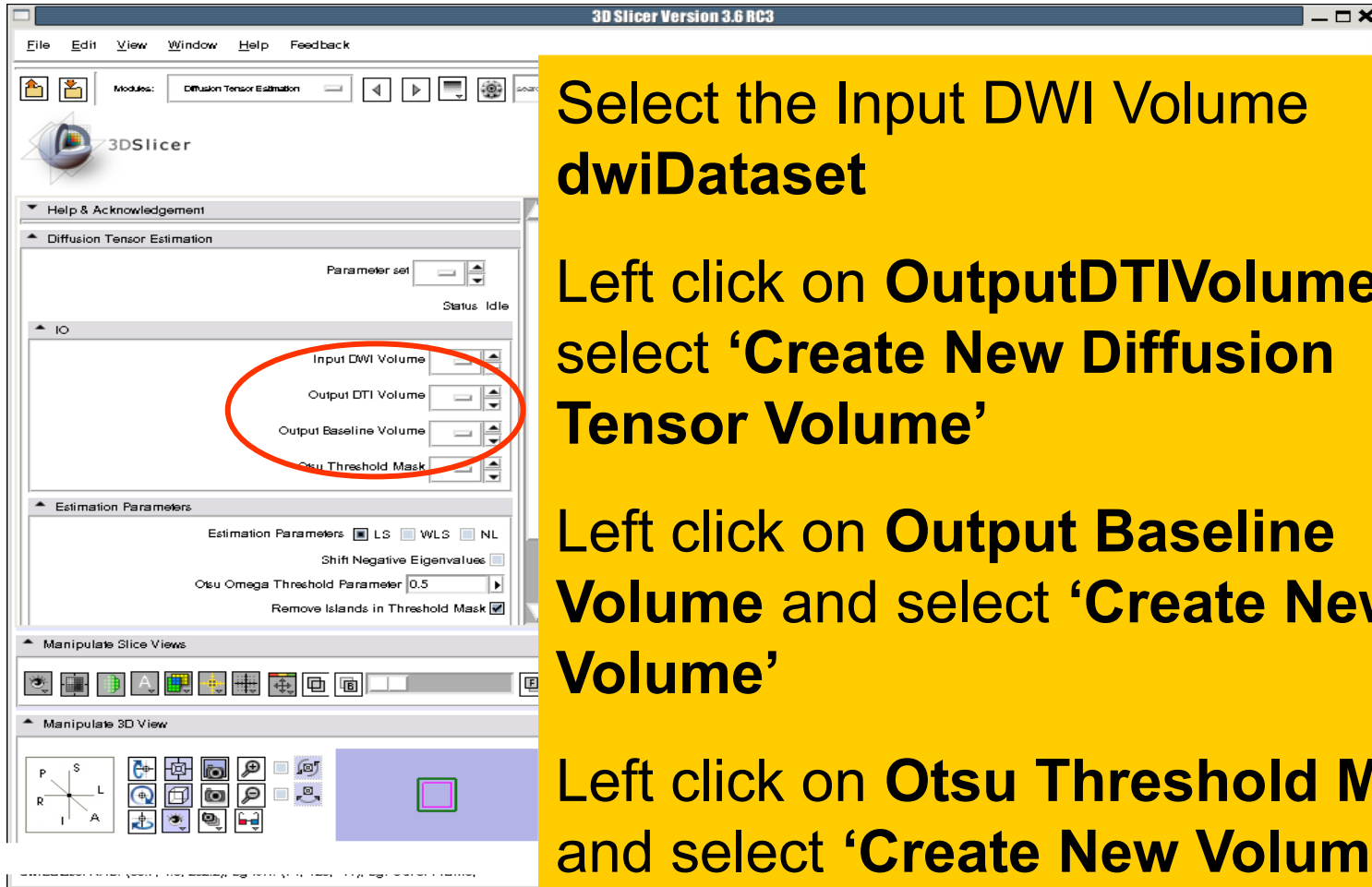


Left click on the menu **Modules** and select **All Modules** to display the list of **95 modules** available for image analysis and 3D visualization.

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

**Left click on Output Baseline Volume to display the list of volumes that have been computed by Slicer**

3D Slicer Version 3.6 RC3

File Edit View Window Help Feedback

Modules: Diffusion Tensor Estimation

IO

Input

Output

Output Baseline Volume

Otsu Threshold Mask 2

Estimation Parameters

Estimation Parameters  LS  WLS  NL

Shift Negative Eigenvalues

Otsu Omega Threshold Parameter 0.5

Remove Islands in Threshold Mask

Apply Mask to Tensor Image

Default Cancel Apply

Manipulate Slice Views

Manipulate 3D View

Diffusion Tensor Estimation Volume1 RAS: (79.9, 166.8, 23.8), Bg IJK: (48, -46, 19), Lb: Out of Frame, Bg: Out of Frame.

Diffusion Tensor Estimation Volumes 1  
None  
Lb: Diffusion Tensor Estimation Volumes 2  
Coronal  
Sp: 0.938mm  
R: 41.6  
A: 5.5  
S: -131.3

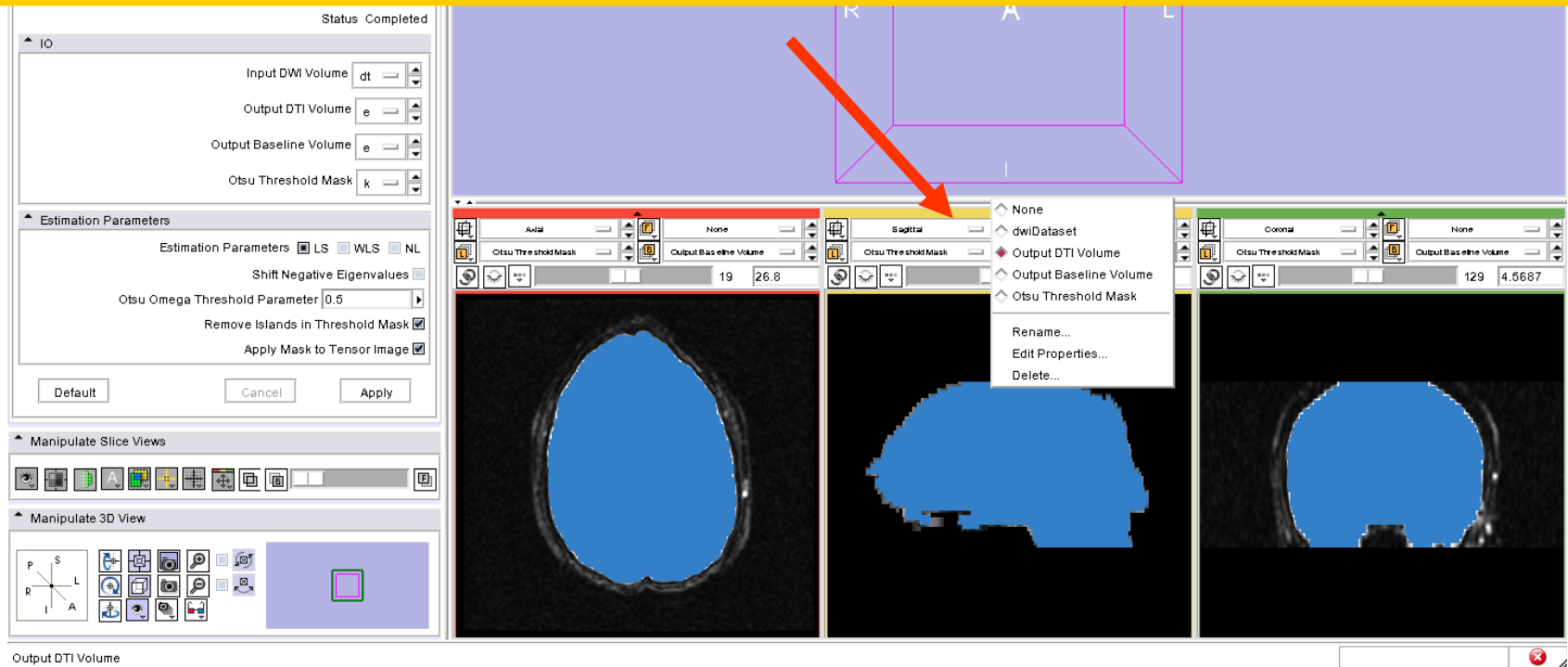


# Tensor Estimation

**Output DTI Volume** is the volume of estimated tensors

**Output Baseline Volume** is the Baseline volume

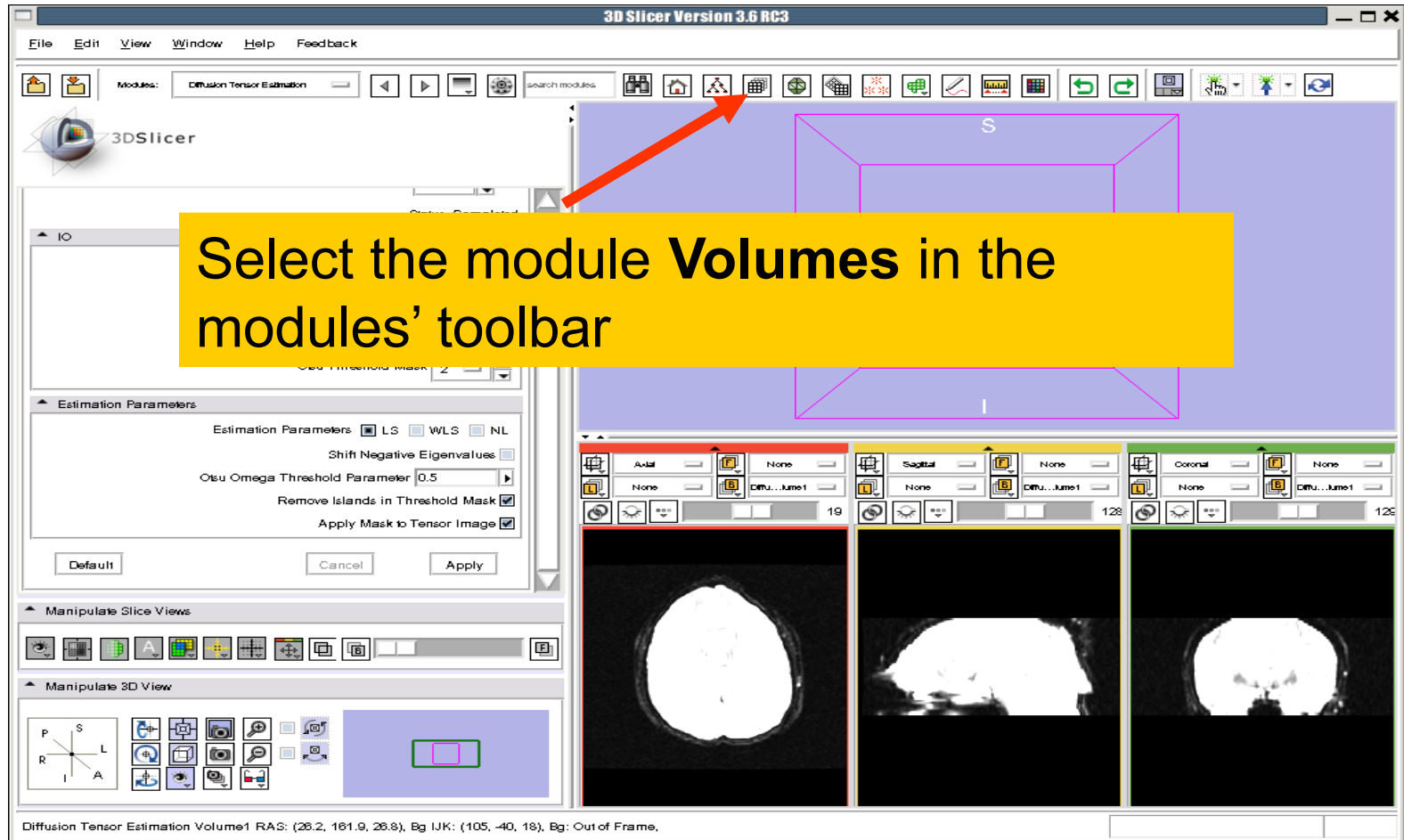
**Otsu Threshold Mask** is the tensor mask (blue)







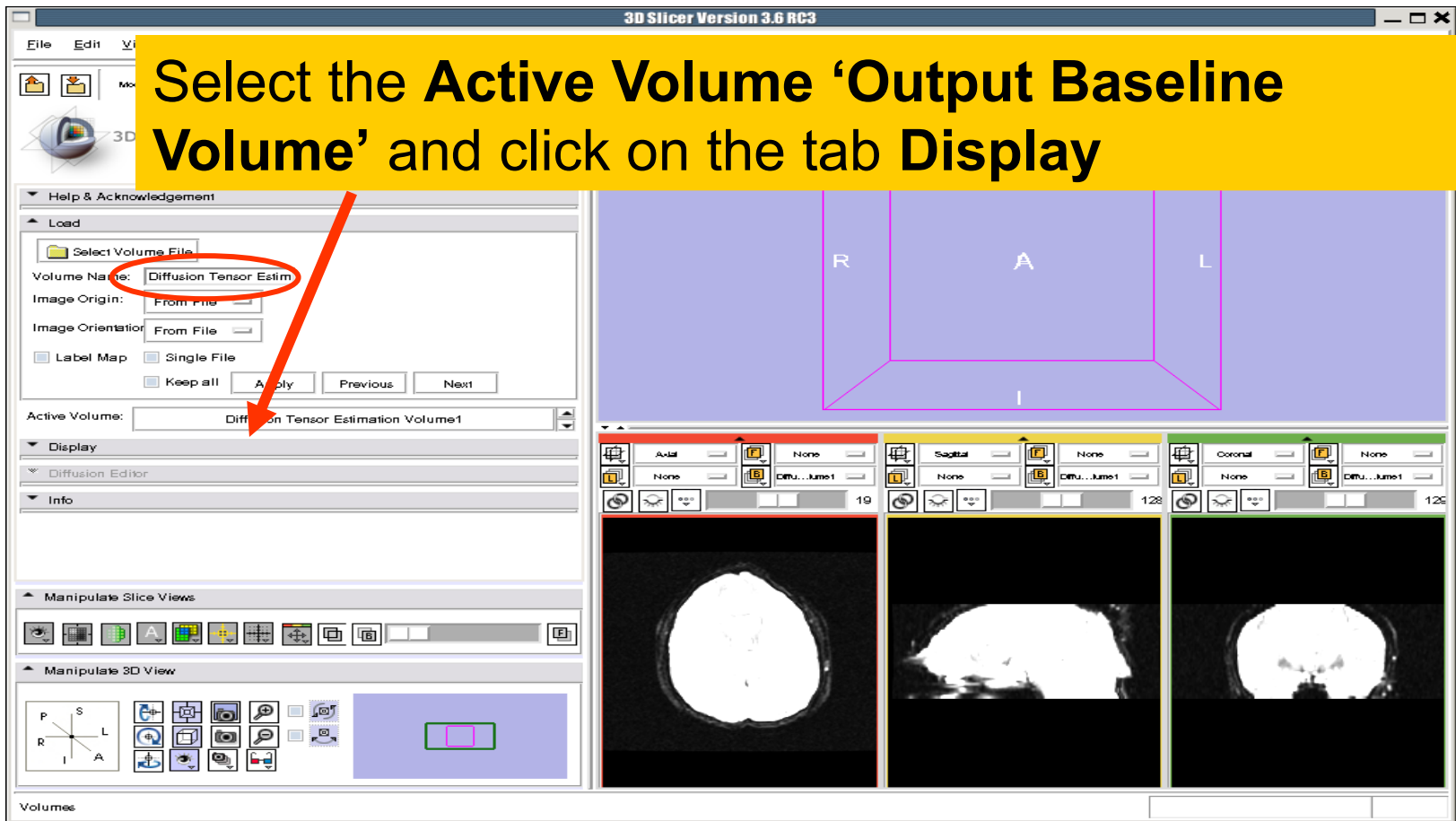
# Tensor Estimation





# Tensor Estimation

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





# Tensor Estimation

3D Slicer Version 3.6 RC3

File Edit View Window Help Feedback

Adjust the Window/Level parameters of the baseline volume using the slider

Active Volume:

Display

Lookup Table: Grey

Interpolate

Window Level Editor Presets:

Volume Window Level Preset: CT-abdomen CT-brain CT-lung

Window/Level: Manual 8701.8 -147.45

Threshold: Off 0 13789

Update Histogram Interactively

[0, 13789] x [0, 1]

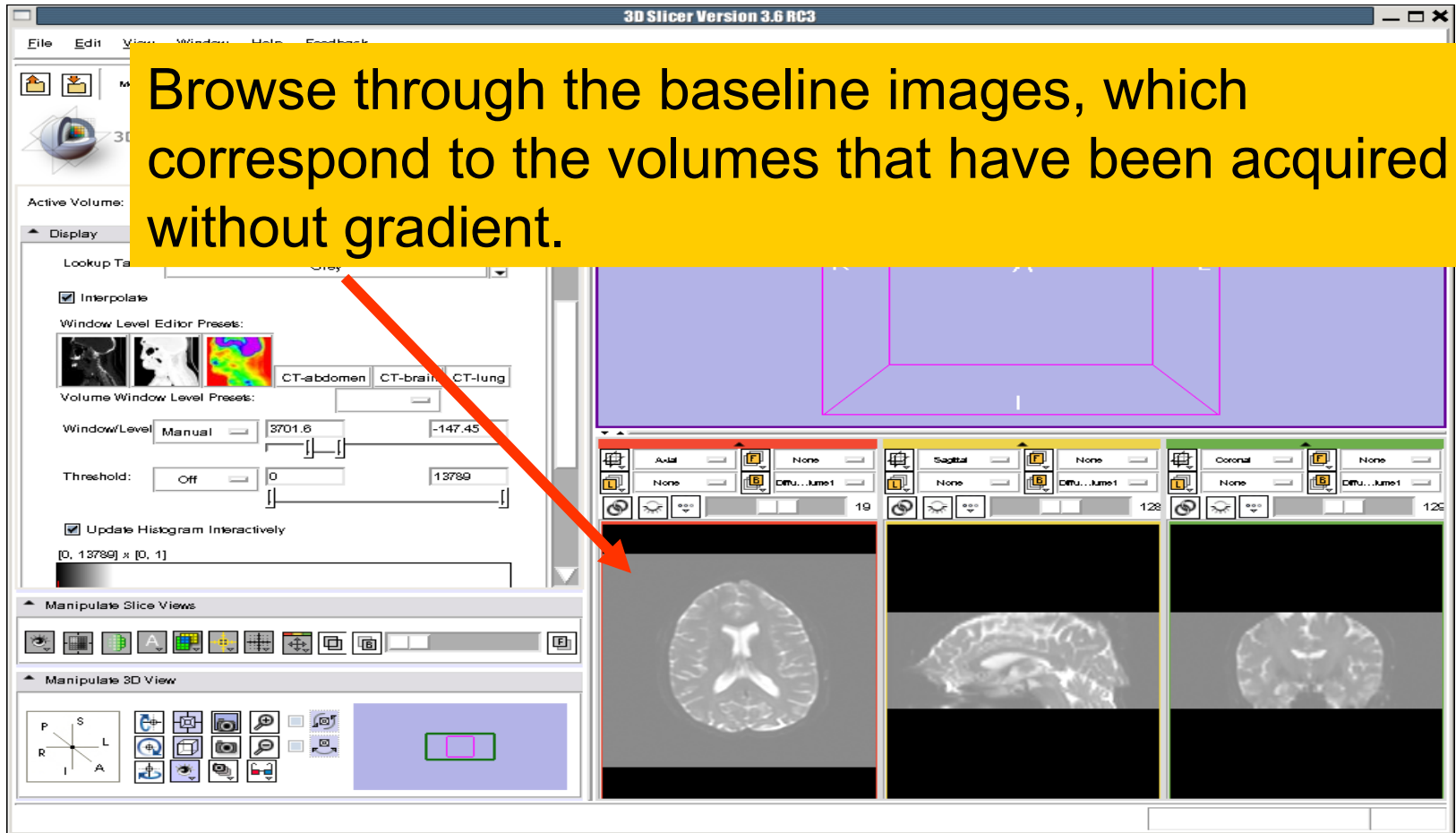
Manipulate Slice Views

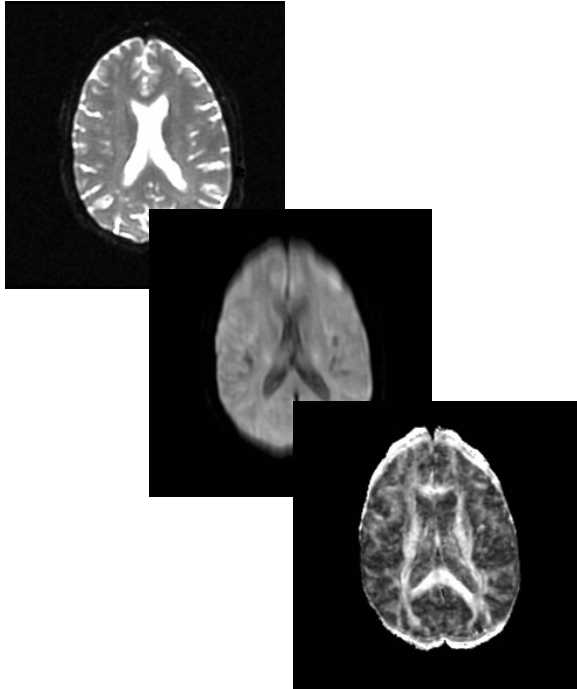
Manipulate 3D View



# Tensor Estimation

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





# Part2:

# Scalar Measurements



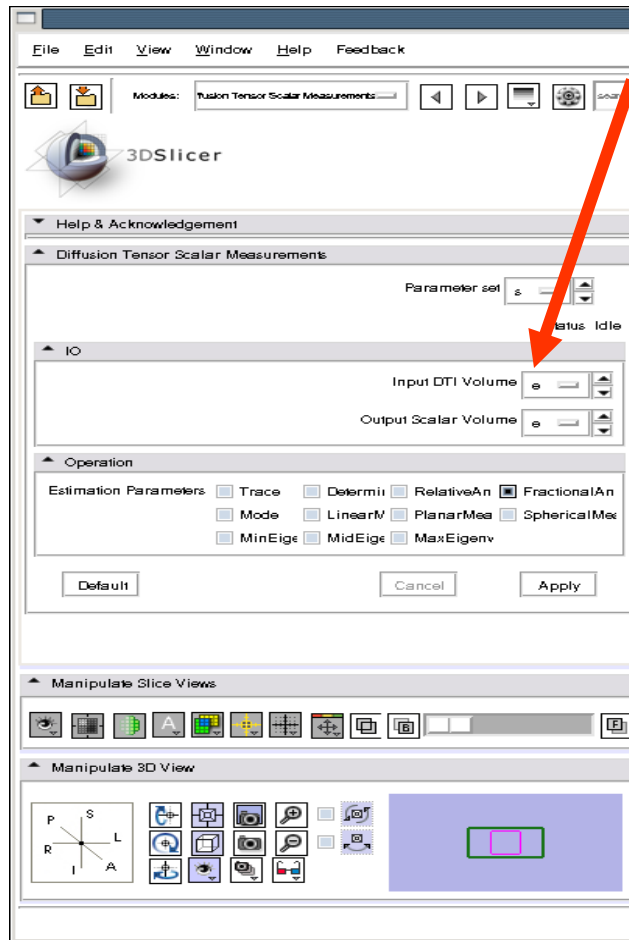


# Scalar Measurements

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



# Scalar Measurements



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

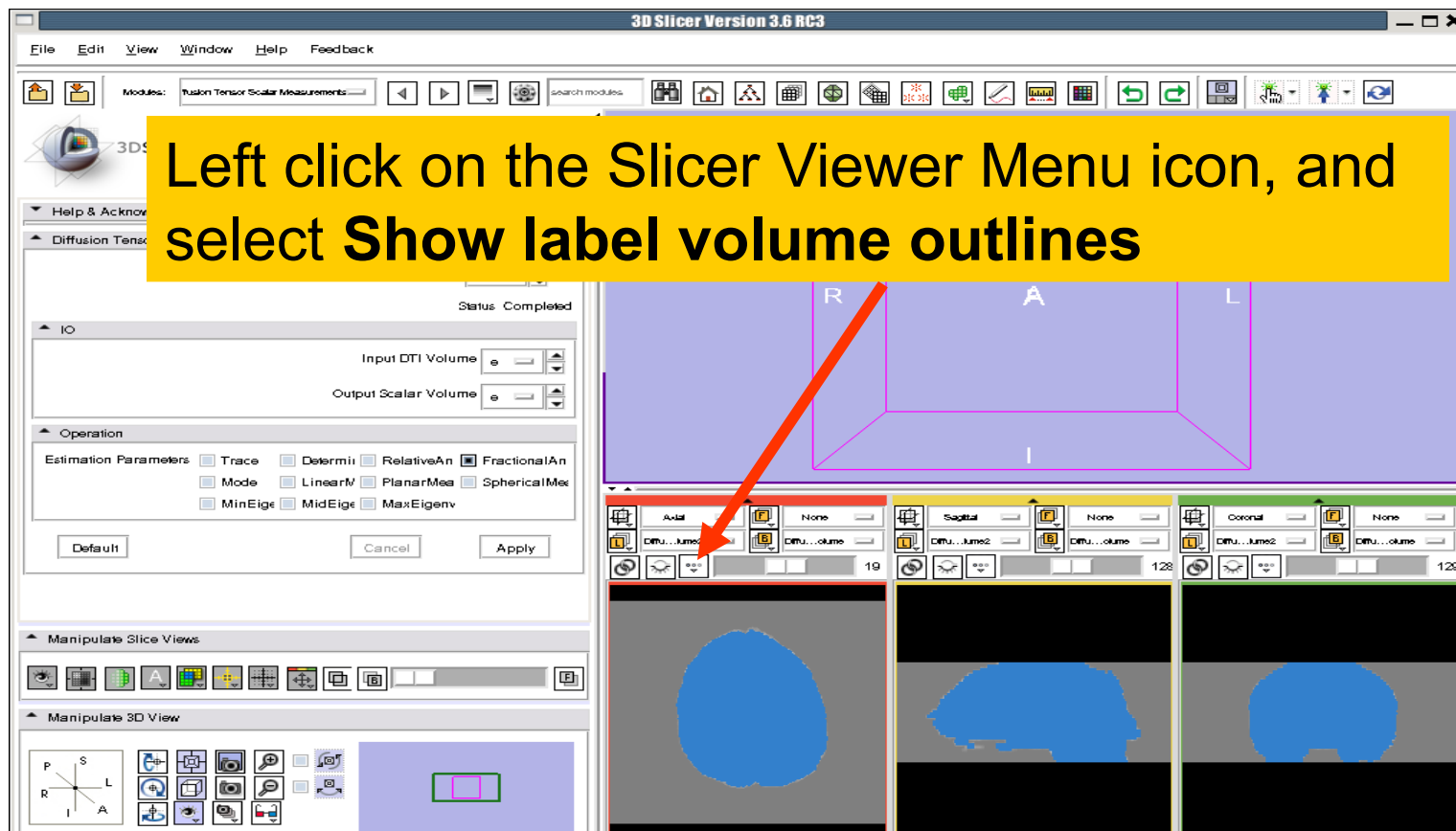
Select the Output Scalar Volume **'Create New Volume'**

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



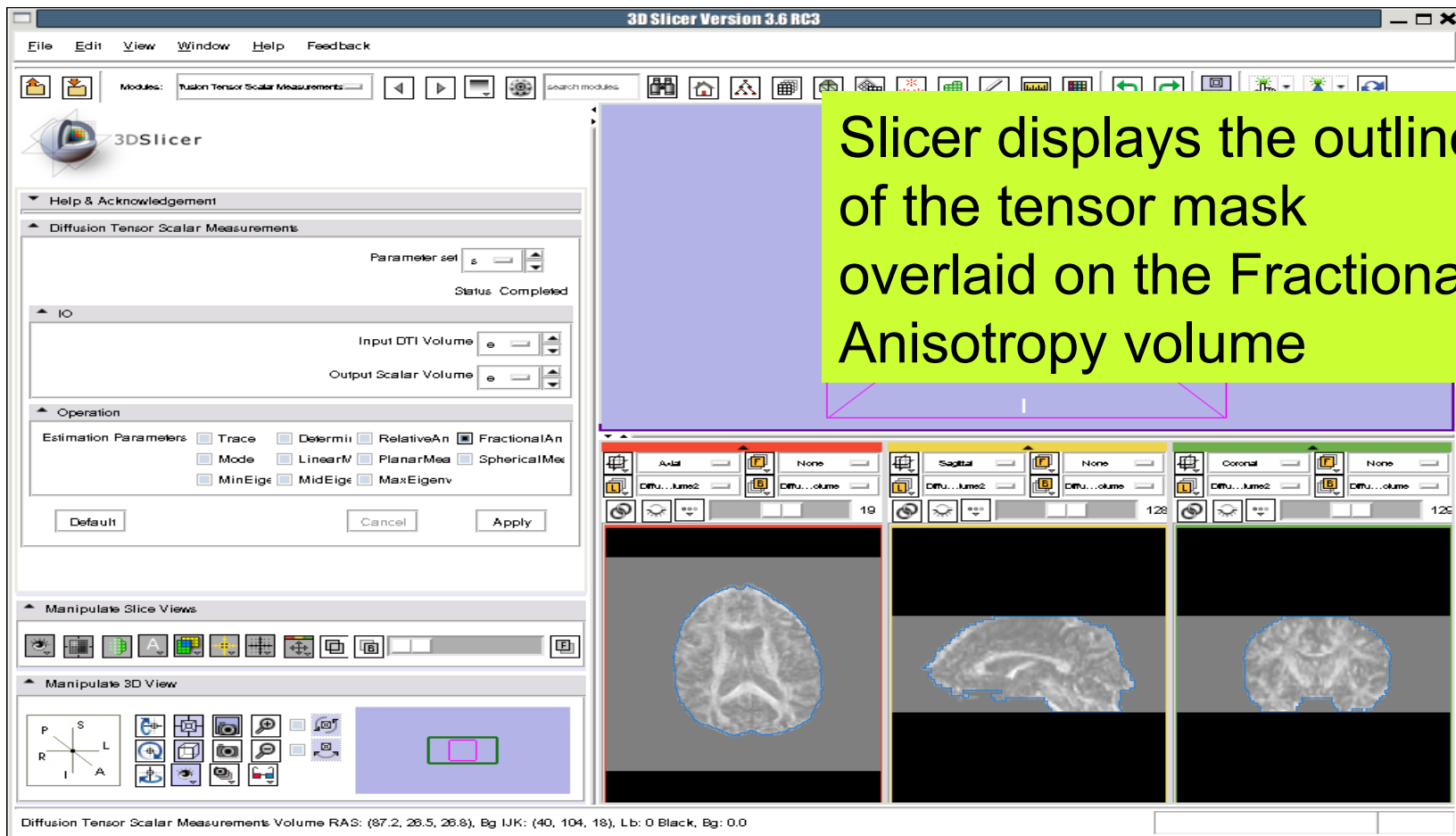


# Fractional Anisotropy Volume





# Fractional Anisotropy Volume





# Fractional Anisotropy Volume

3D Slicer Version 3.6 RC3

File Edit View Window Help Feedback

Modules: Diffusion Tensor Scalar Measurements

3DSlicer

Help & Acknowledgement

Diffusion Tensor Scalar Measurements

Parameter set: s

Status: Completed

IO

Input DTI Volume

Output Scalar Volume

Operation

Estimation Parameters

Trace  Determin  RelativeAn  FractionalAn

Mode  LinearM  PlanarMea  SphericalMex

MinEige  MidEige  MaxEigenv

Default Cancel Apply

Manipulate Slice Views

Manipulate 3D View

Diffusion Tensor Scalar Measurements Volume RAS: (-1.8, -25.9, 28.8), Bg IJK: (135, 180, 18), Lb: 1 jake, Bg: 0.6

Diffusion Tensor Scalar Measurement Bg J: 150 Bg IJK: Diffusion Tensor Estimation

Lb: 1 jake R: -1.8 A: -25.9 S: 28.8

Lb: Out of frame R: -35.6 A: 4.6 S: -101.9

Lb: Out of frame R: -35.6 A: 4.6 S: -101.9

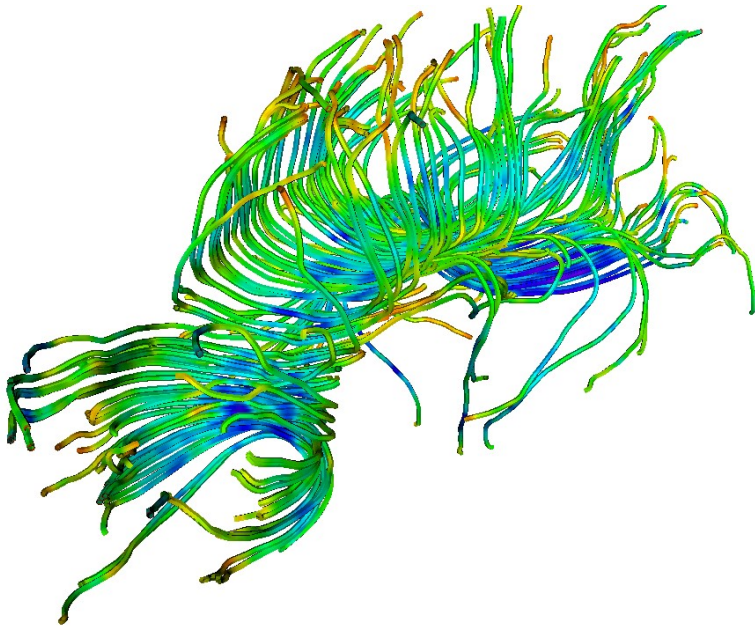
Move the mouse over the Fractional Anisotropy map to explore the FA values which range from 0 to 1, and are displayed in the bottom corner of the active (Bg) window.



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## Part 3:

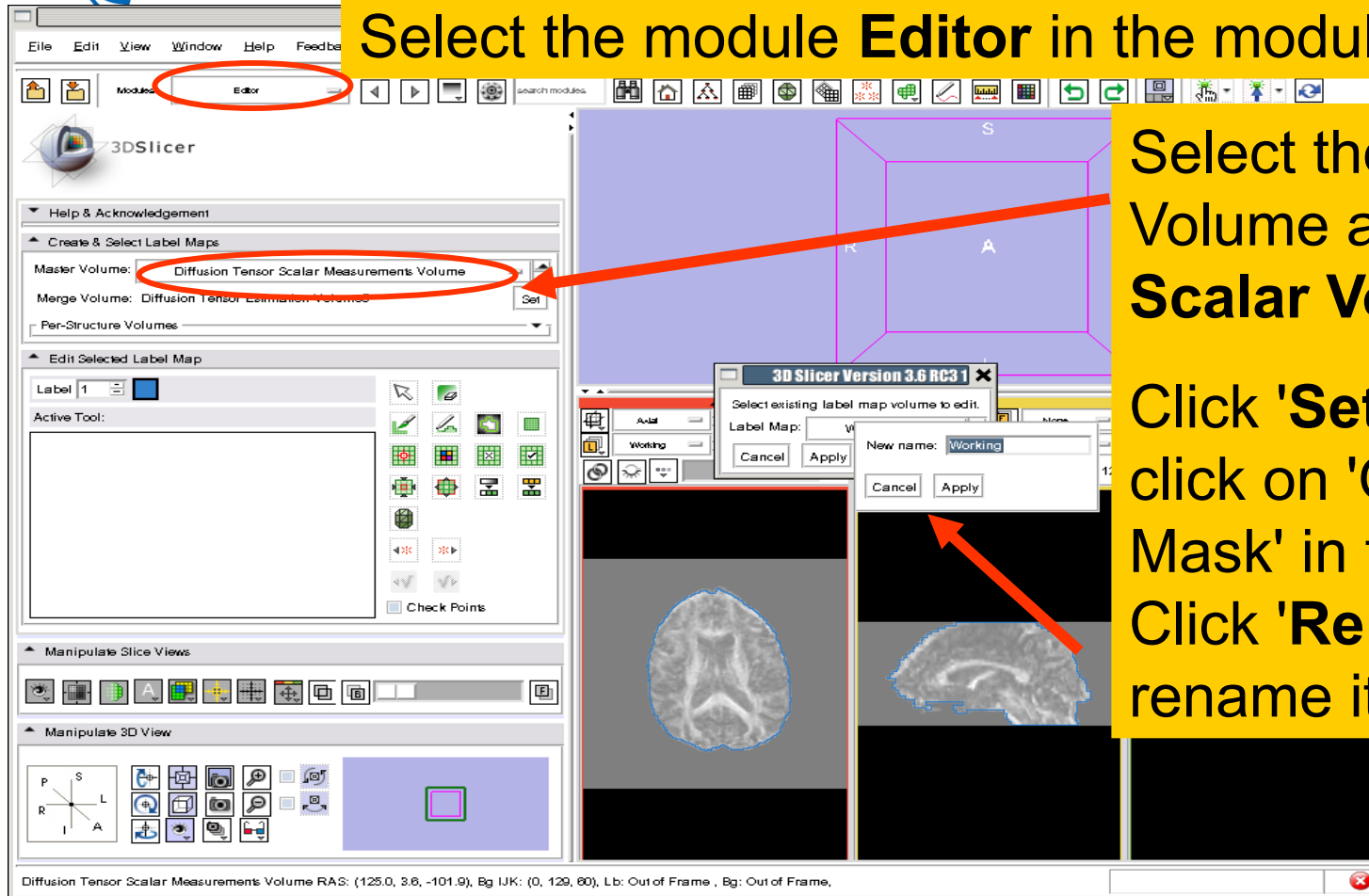
# Region of Interest based Tractography





# LabelMap Generation

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



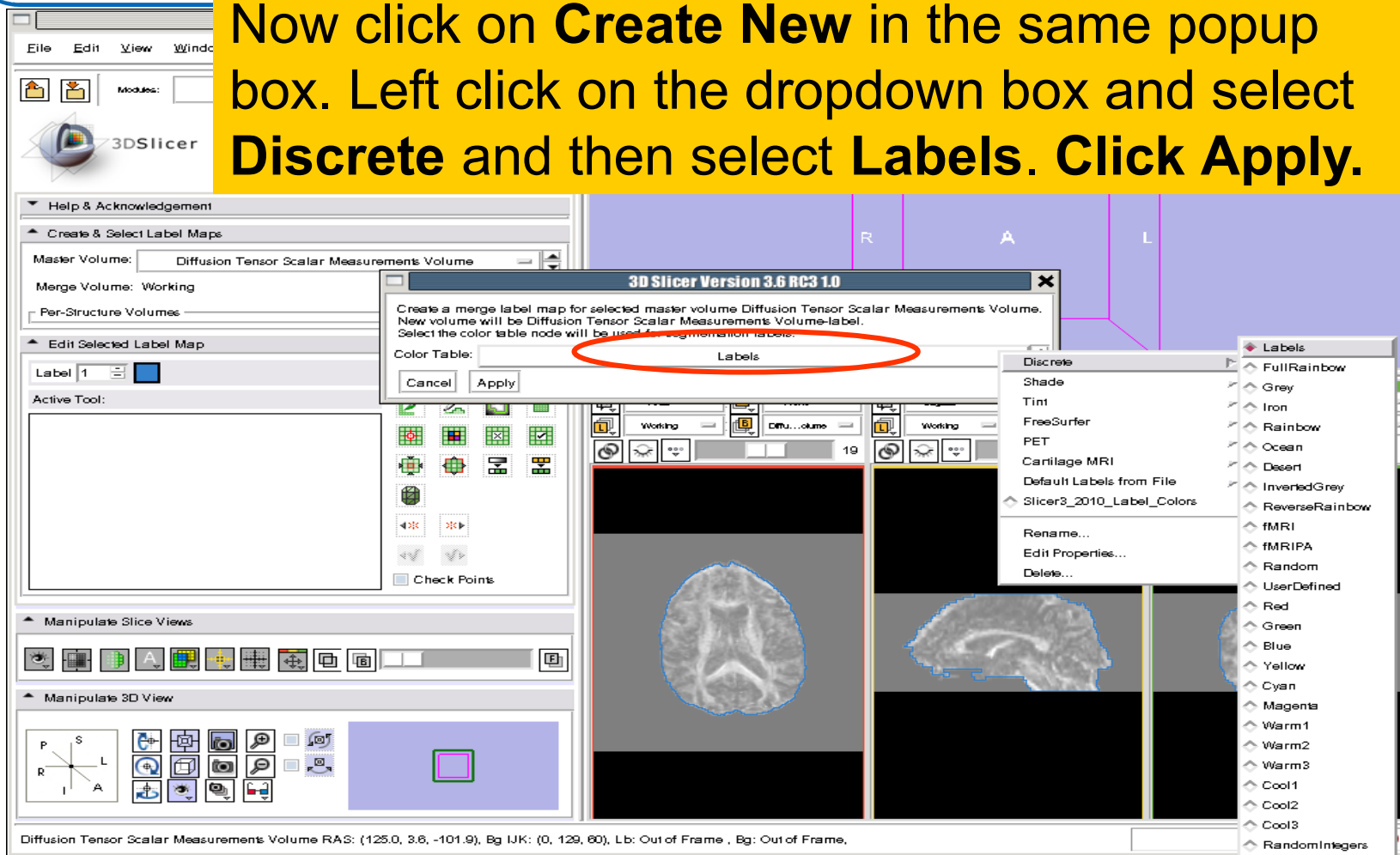
Select the Master Volume as **Output Scalar Volume**

Click '**Set**', then left click on 'Otsu Threshold Mask' in the popup box. Click '**Rename**' and rename it as '**Working**'



# LabelMap Generation

Now click on **Create New** in the same popup box. Left click on the dropdown box and select **Discrete** and then select **Labels**. Click **Apply**.



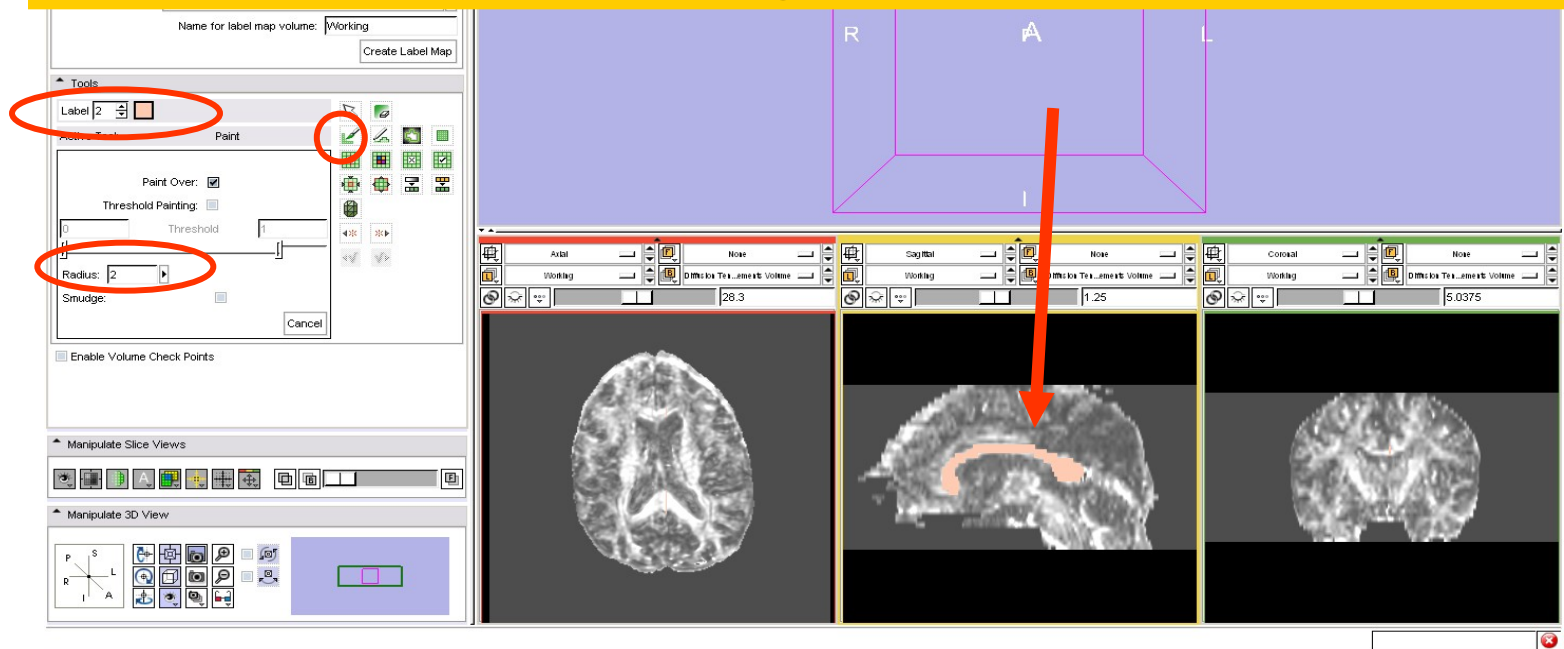






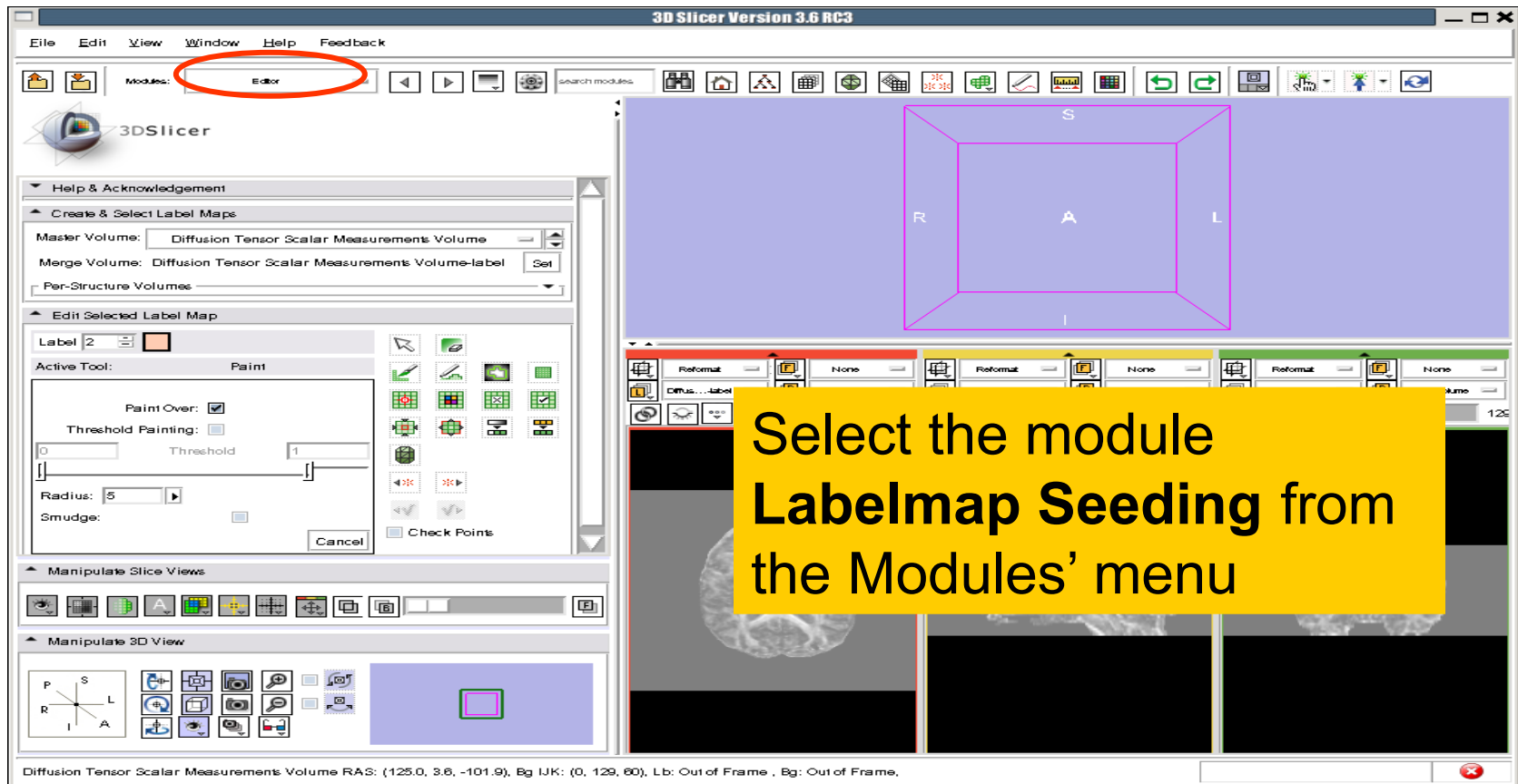
# LabelMap Generation

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 few slices



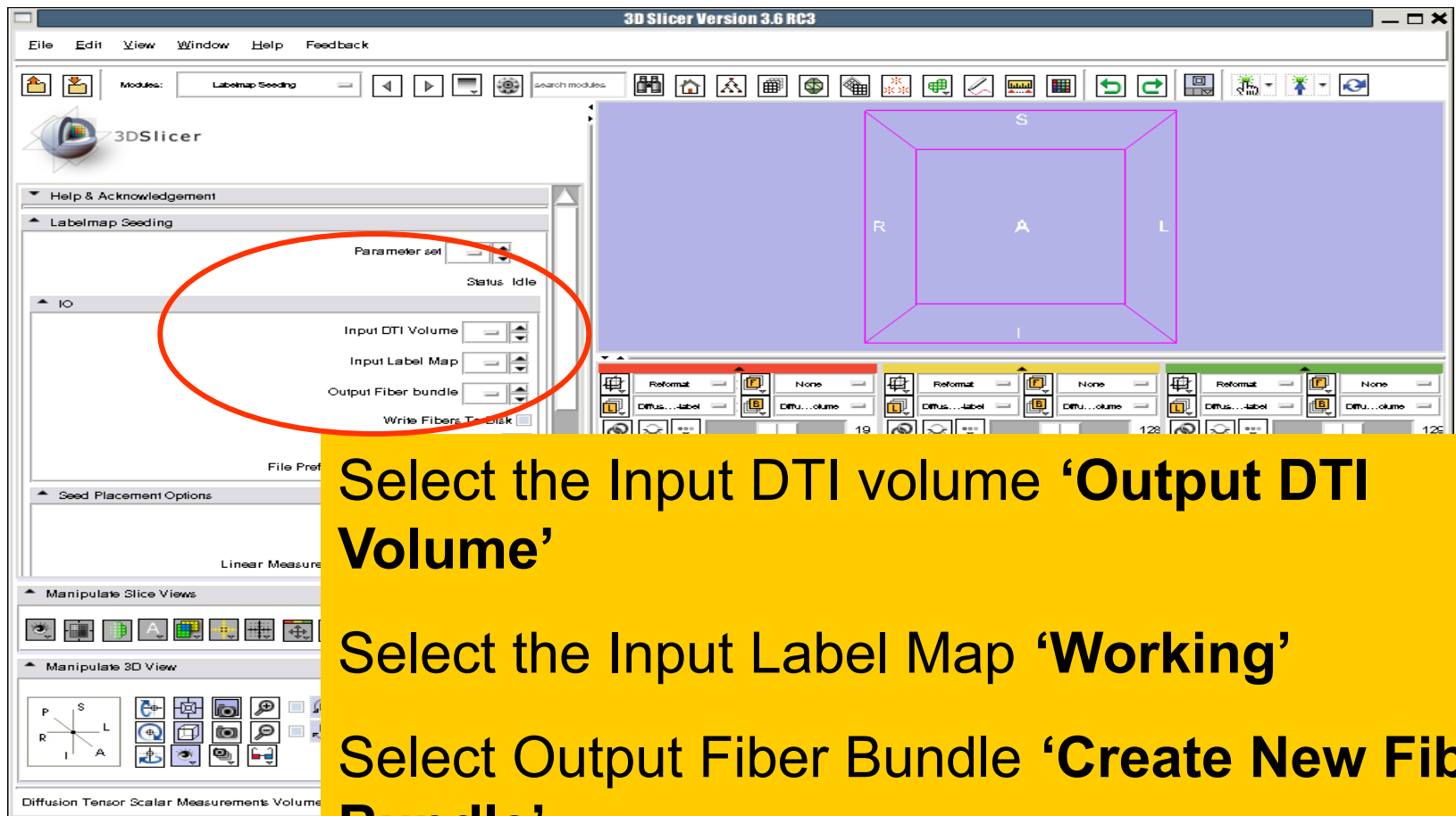


# LabelMap Seeding





# LabelMap Seeding



Select the Input DTI volume **'Output DTI Volume'**

Select the Input Label Map **'Working'**

Select Output Fiber Bundle **'Create New Fiber Bundle'**



# LabelMap Seeding

3D Slicer Version 3.6 RC3

File Edit View Window Help Feedback

Modules: Labelmap Seeding

3DSlicer

Output Directory

File Prefix Name line

Seed Placement Options

Seed Spacing 2

Random Grid

Linear Measure Start Threshold 0.3

Tractography Seeding Parameters

Minimum Length 10

Maximum Length 800

Stopping Mode  LinearMeasure  FractionalAnisotropy

Stopping Value 0.1

Stopping Track Curvature 0.8

Integration Step Length(mm) 0.5

Label Definition

Seeding label 2

Default Cancel Apply

Manipulate Slice Views

Manipulate 3D View

Diffusion Tensor Scalar Measurements Volume RAS: (125.0, 3.8, -101.9), Bg IJK: (0, 129, 60), Lb: Out of Frame, Bg: Out of Frame.

Set the Seed Spacing to **2 mm** and select the Stopping Mode **Fractional Anisotropy**

Use the default parameters for the minimum and maximum tract length, stopping value and stopping track curvature.

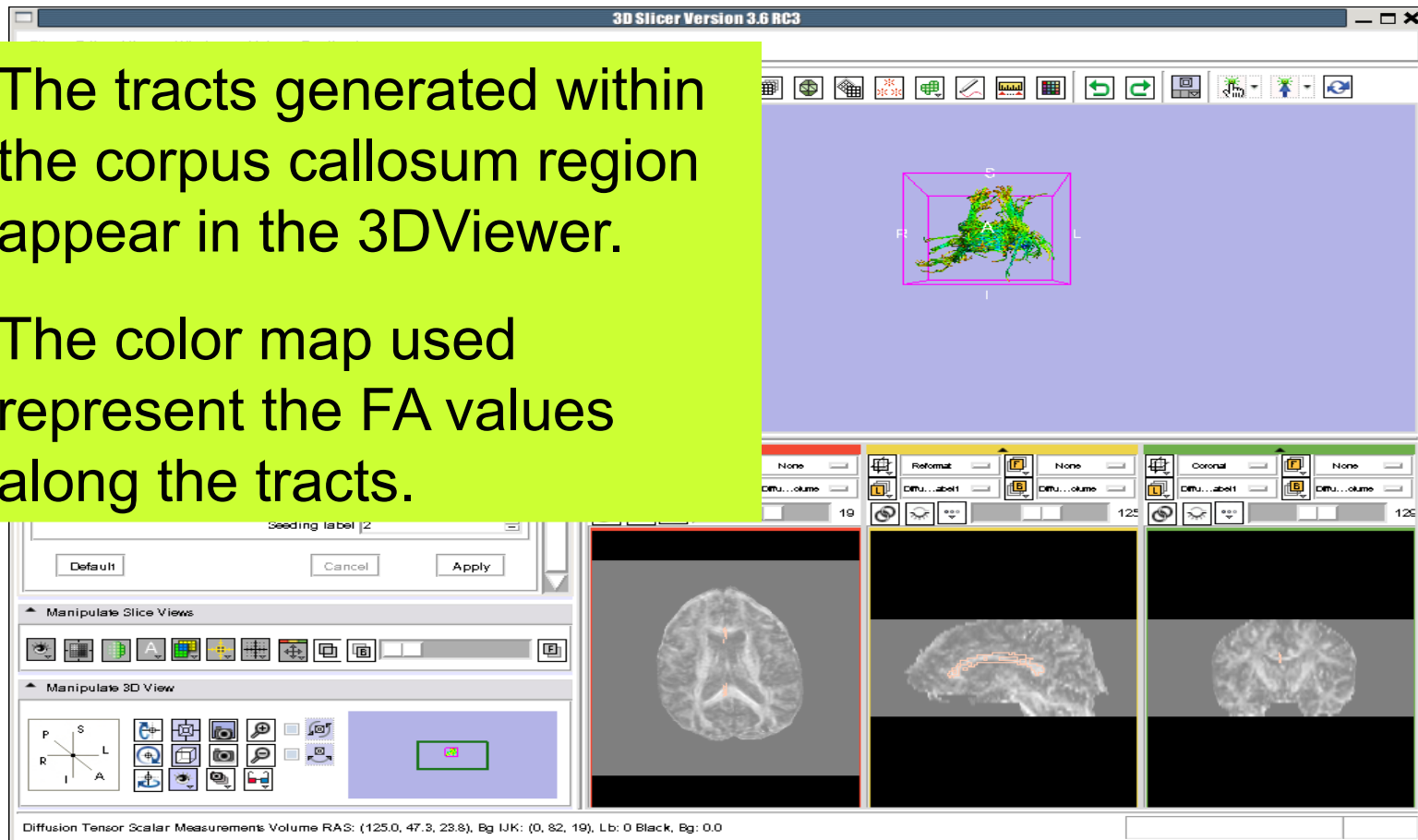
Set Seeding label to label 2, and click on **Apply**



# LabelMap Seeding

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

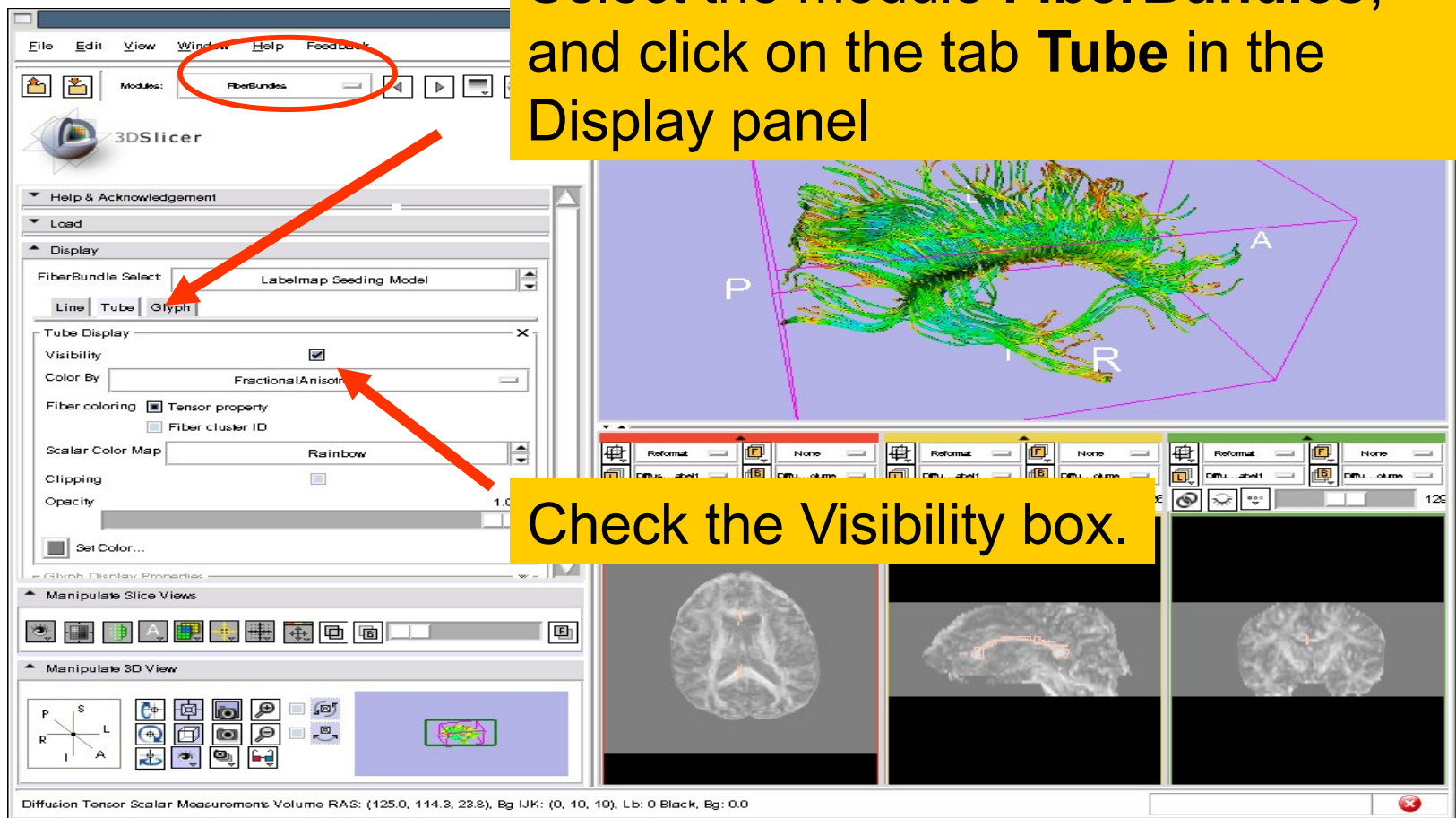
The color map used represent the FA values along the tracts.





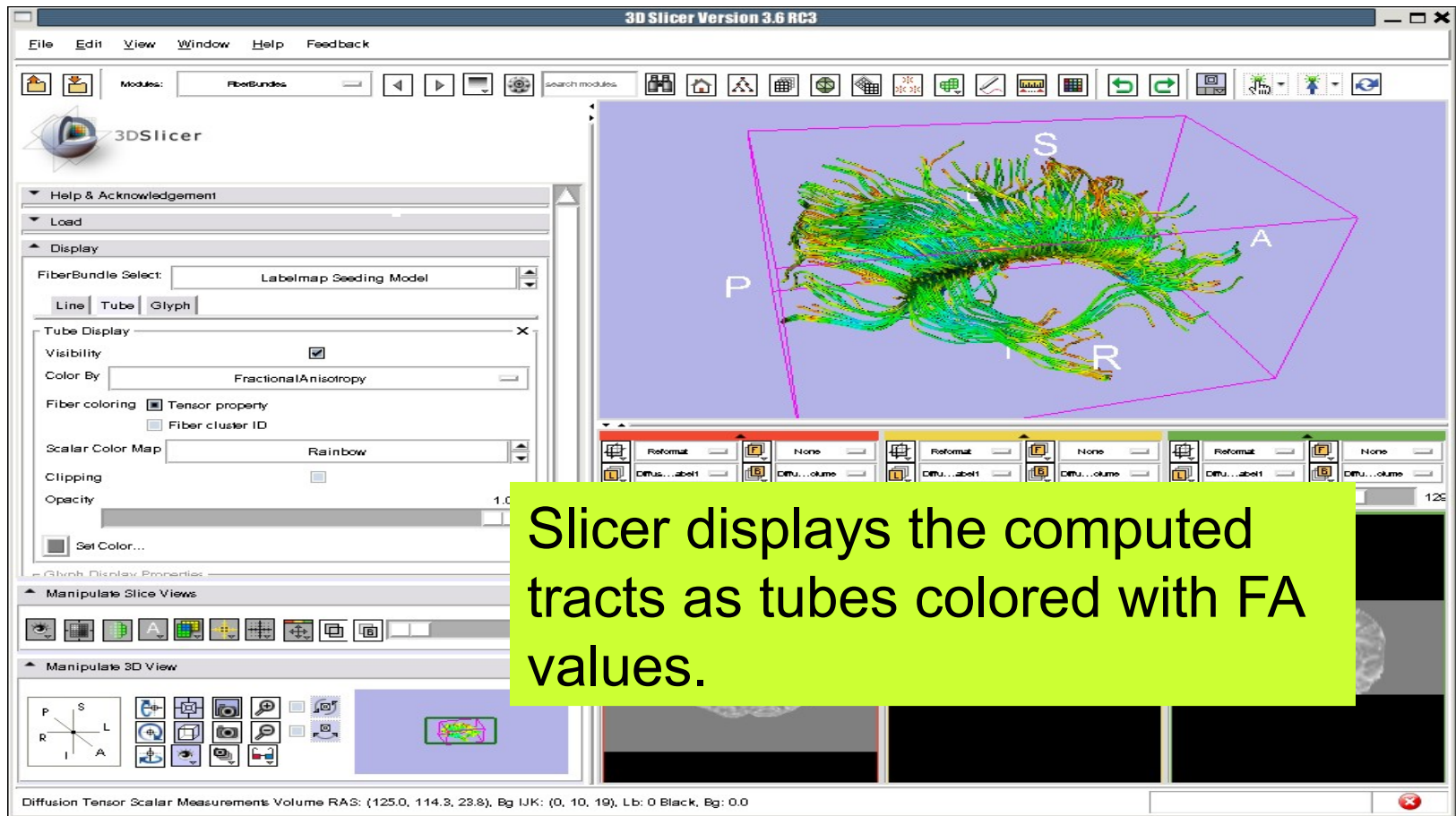
# LabelMap Seeding

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

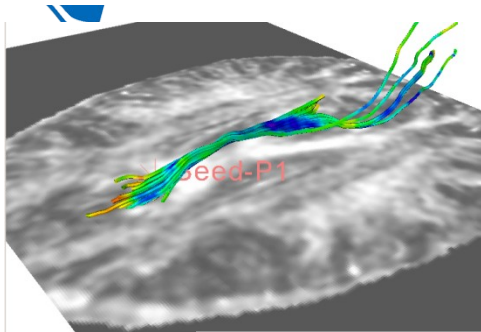




# LabelMap Seeding



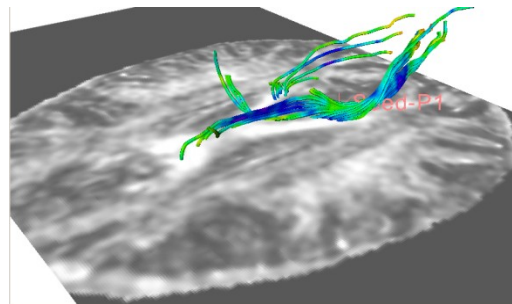
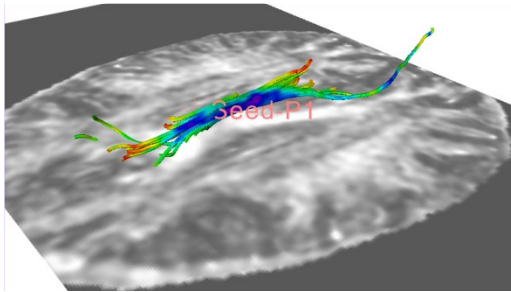




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## Part 4:

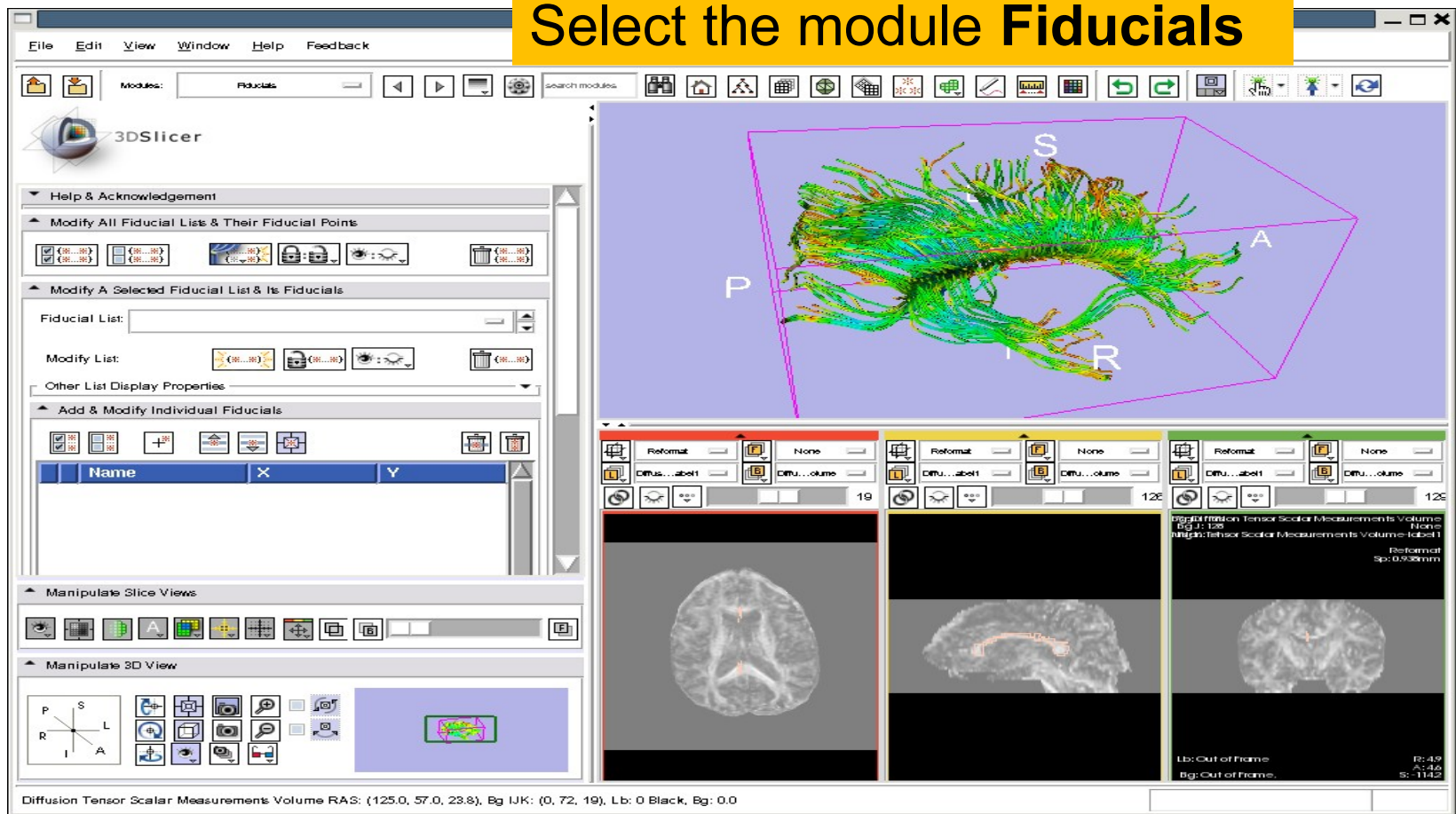
# Tractography on-the-fly





# Fiducial Seeding

Select the module **Fiducials**





# Fiducial Seeding

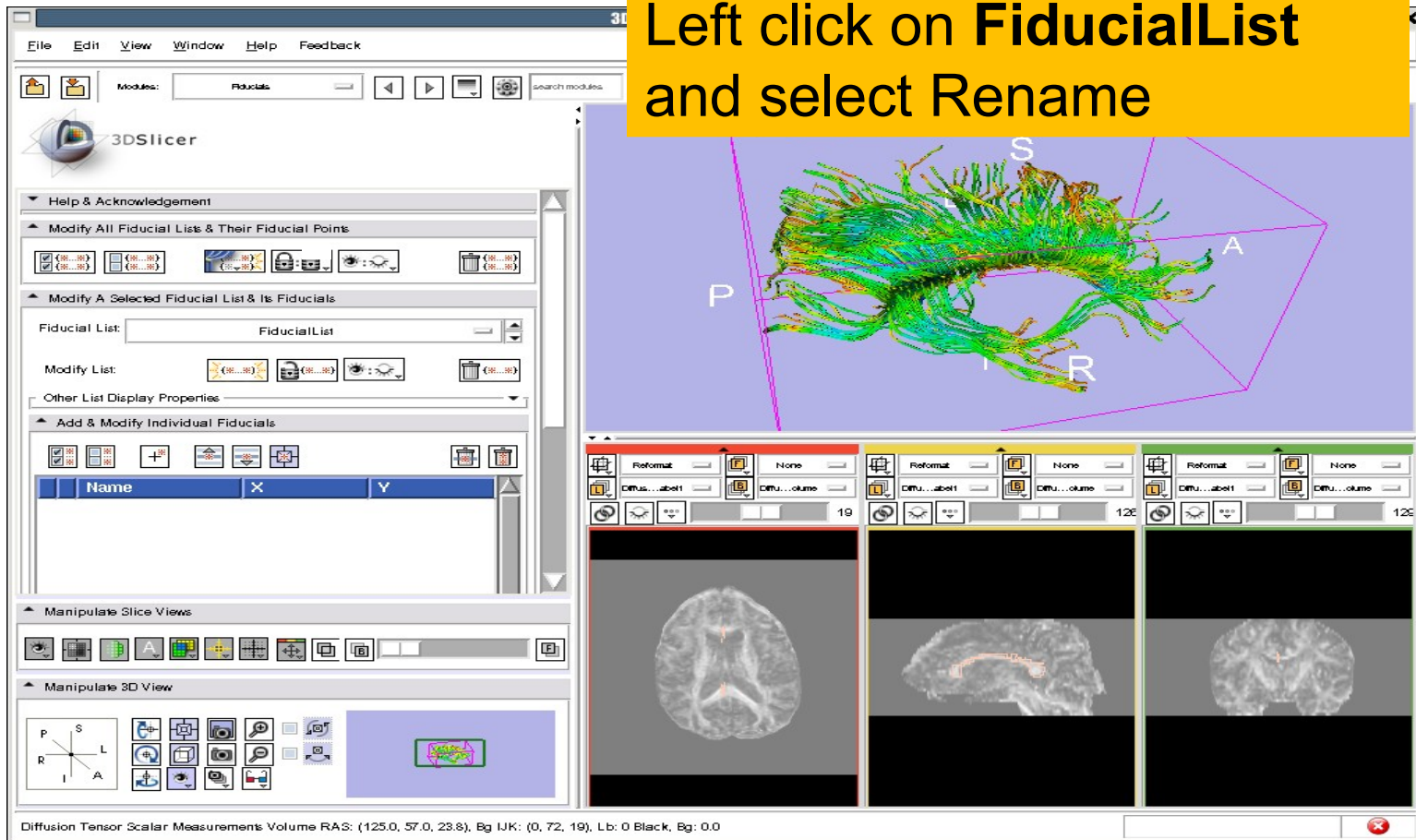
Set Fiducial List to Create New FiducialList

The screenshot displays the 3DSlicer software interface. On the left, the 'Fiducial List' panel is open, showing options to 'Modify All Fiducial Lists & Their Fiducial Points' and 'Modify A Selected Fiducial List & Its Fiducial'. A red arrow points from the 'Set Fiducial List to Create New FiducialList' text to the 'Fiducial List' input field. The main 3D view shows a brain model with a purple bounding box and axes labeled P, S, I, R, A. Below the 3D view are three slice views (axial, sagittal, and coronal) showing the brain model in different orientations. The status bar at the bottom indicates the current volume and its properties: 'Diffusion Tensor Scalar Measurements Volume RAS: (125.0, 57.0, 23.8), Bg IJK: (0, 72, 19), Lb: 0 Black, Bg: 0.0'.



# Fiducial Seeding

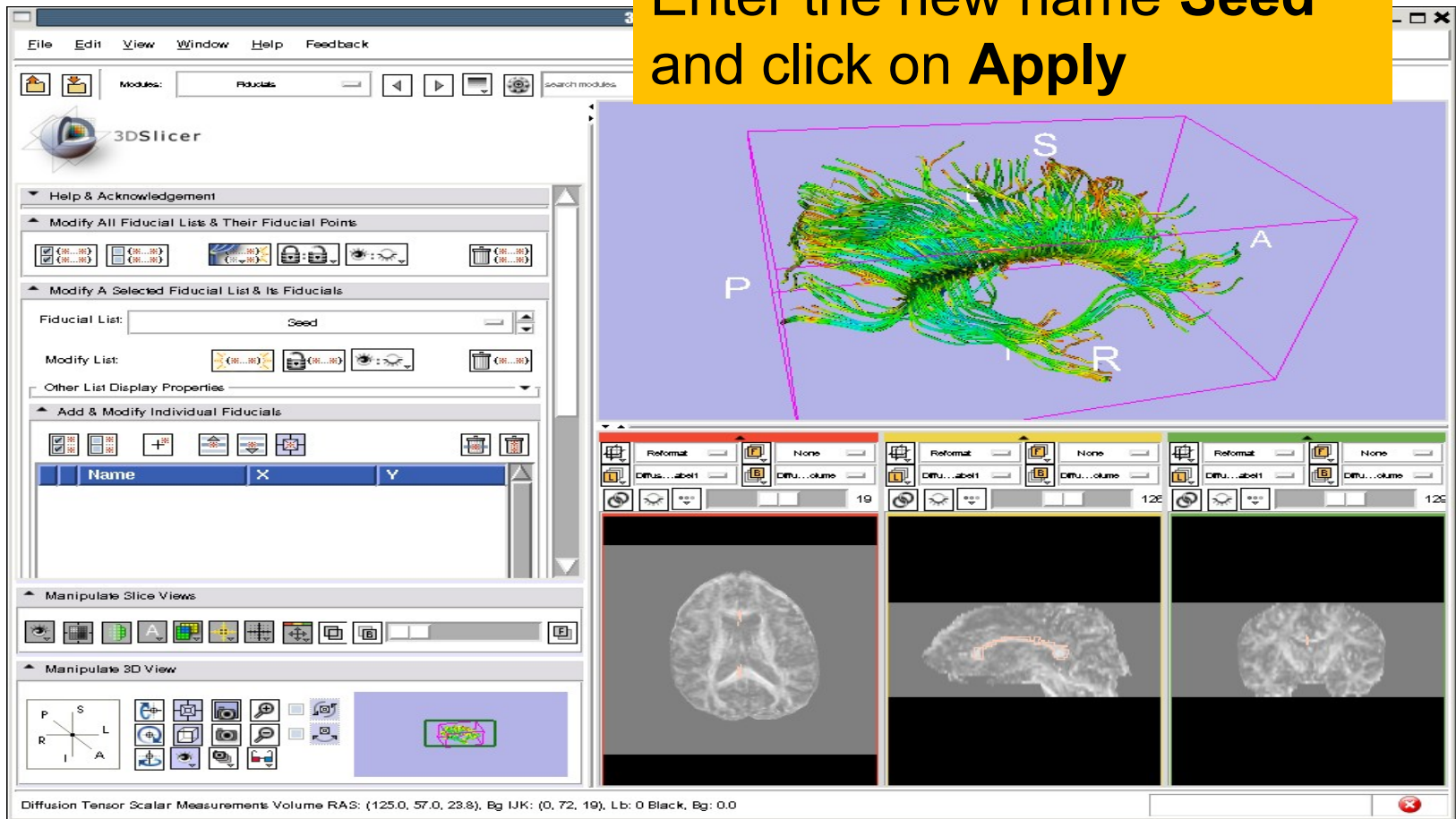
Left click on **FiducialList**  
and select **Rename**





# Fiducial Seeding

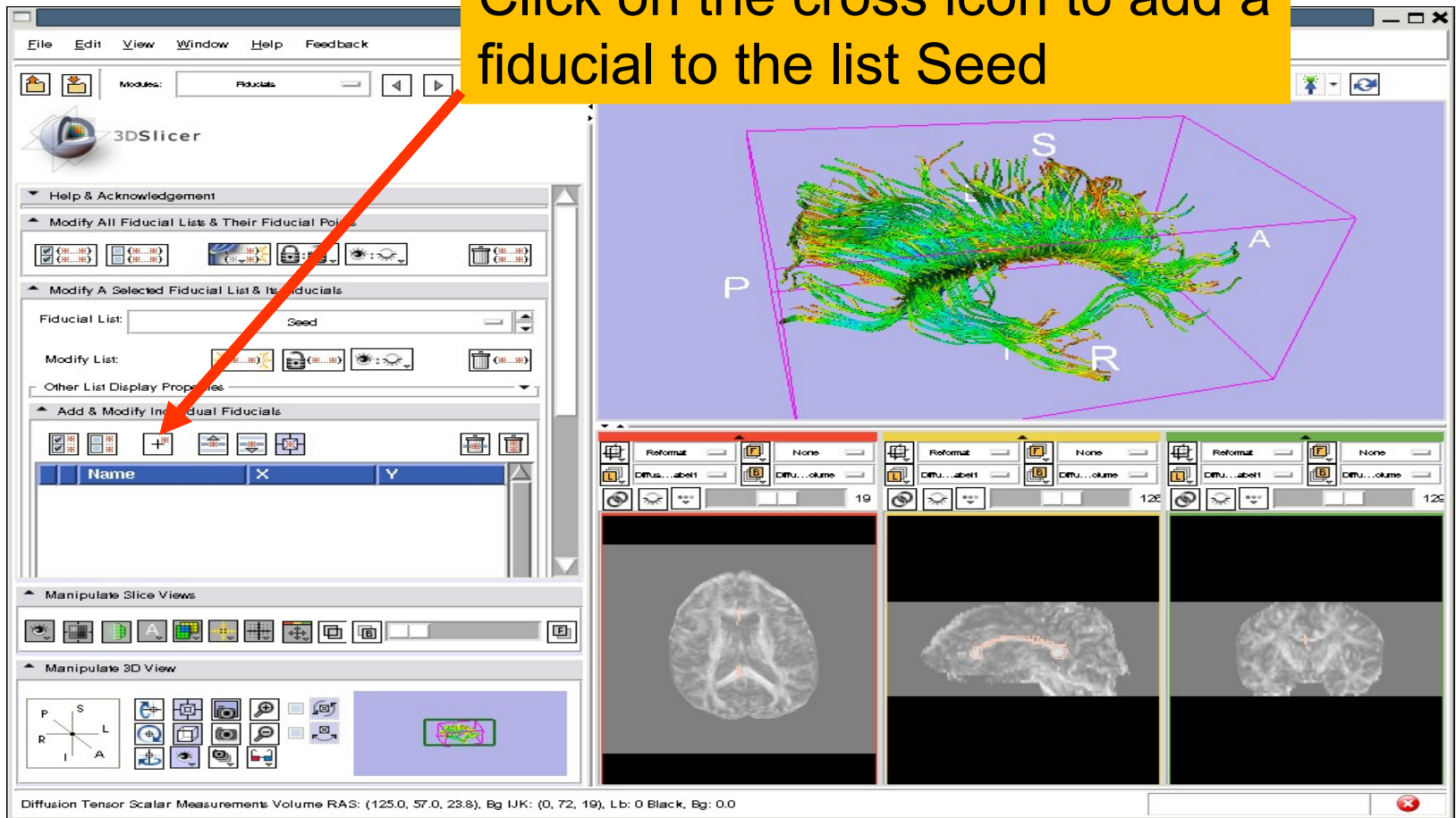
Enter the new name **Seed** and click on **Apply**





# Fiducial Seeding

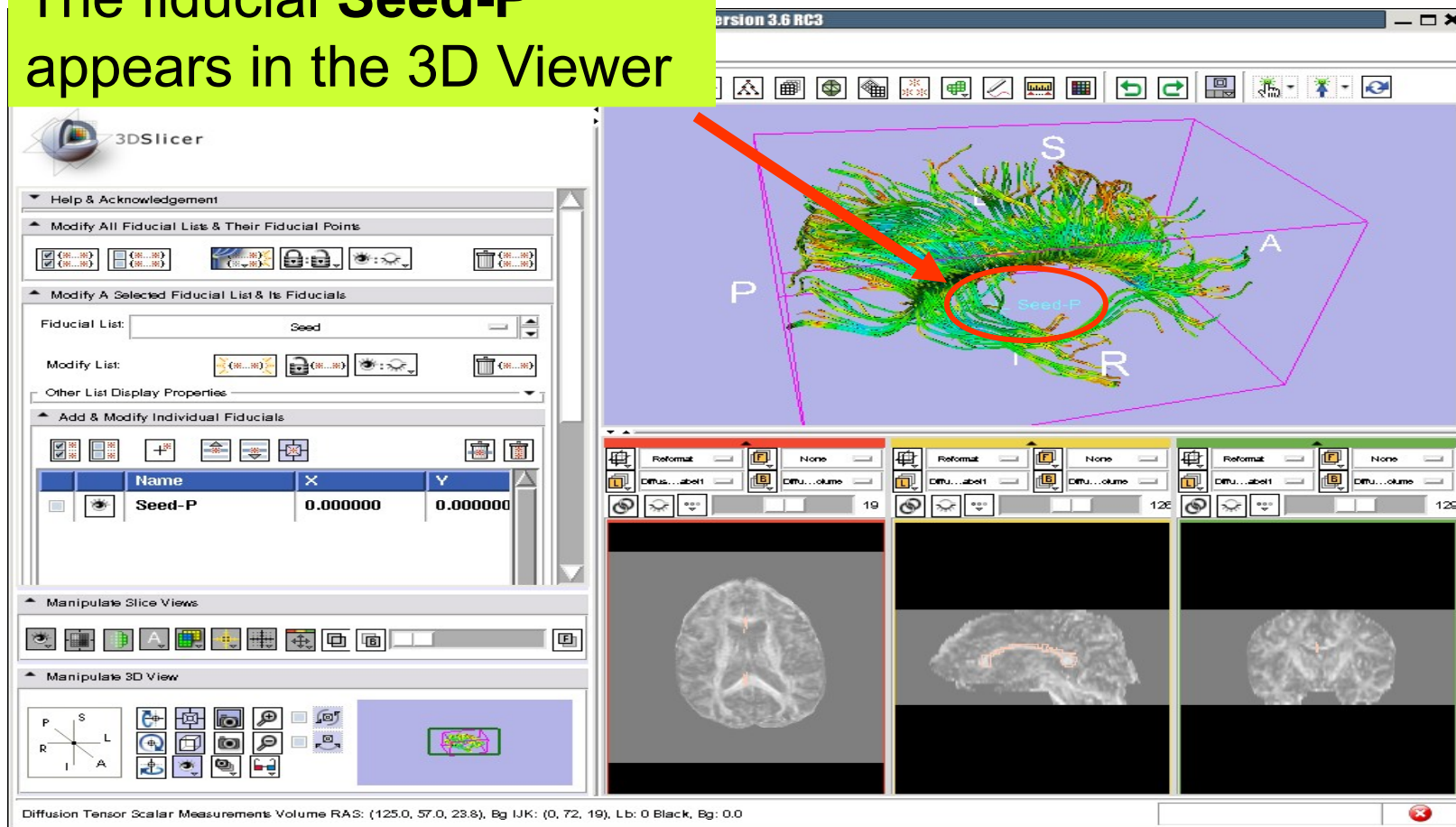
Click on the cross icon to add a fiducial to the list Seed





# Fiducial Seeding

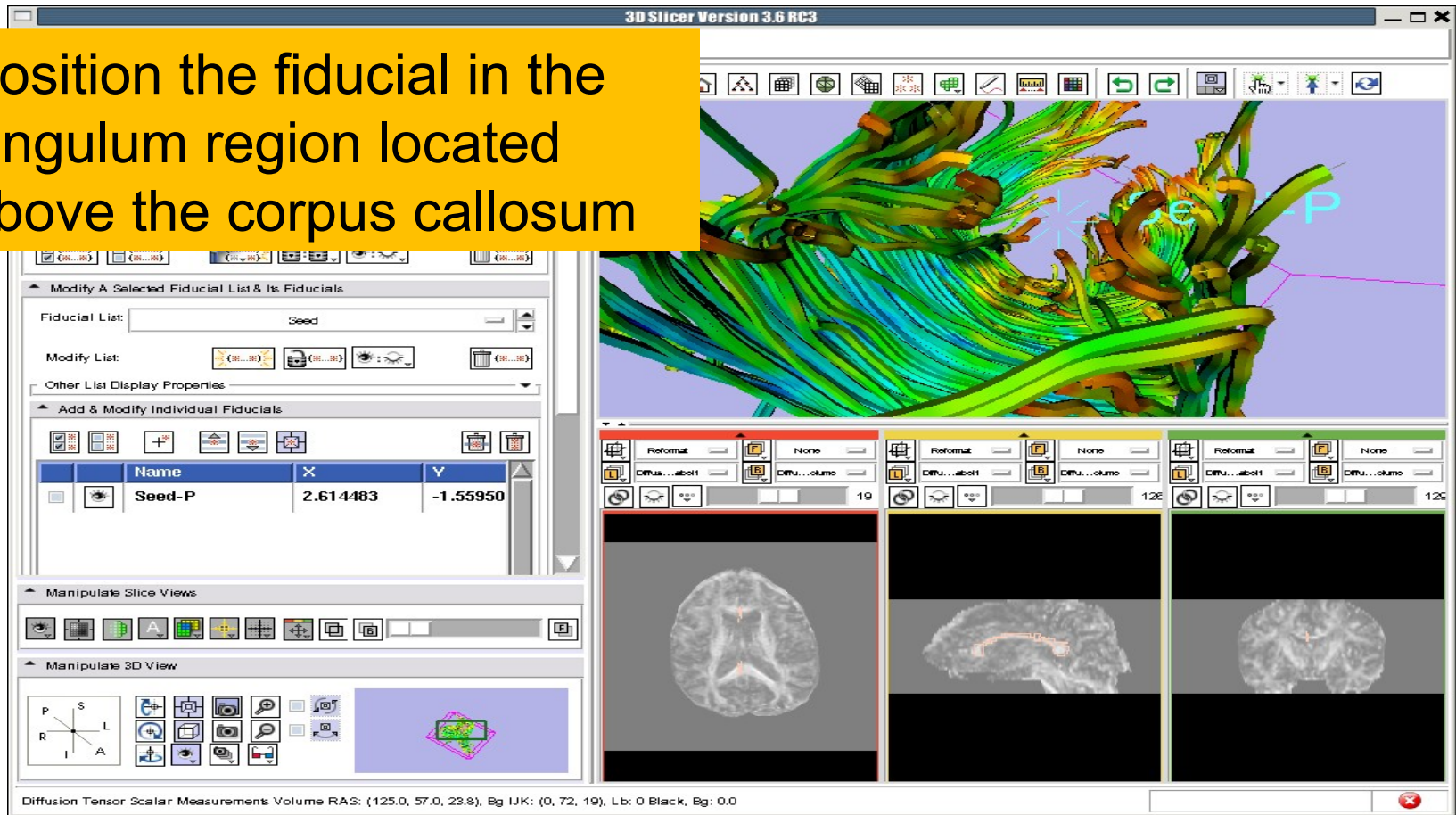
The fiducial **Seed-P** appears in the 3D Viewer





# Fiducial Seeding

Position the fiducial in the cingulum region located above the corpus callosum







# Fiducial Seeding

Select the **Seed-P** fiducial:  
we will use this fiducial to  
drive the tractography

The screenshot shows the rsion 3.6 RC3 software interface. The main window displays a 3D tractography visualization of white matter fibers in a brain, with a red 'Seed-P' fiducial point marked. The control panel on the left includes sections for 'Modify All Fiducial Lists & Their Fiducial Points', 'Modify A Selected Fiducial List & Its Fiducials', 'Add & Modify Individual Fiducials', 'Manipulate Slice Views', and 'Manipulate 3D View'. A red arrow points to the 'Seed-P' fiducial in the 'Add & Modify Individual Fiducials' table.

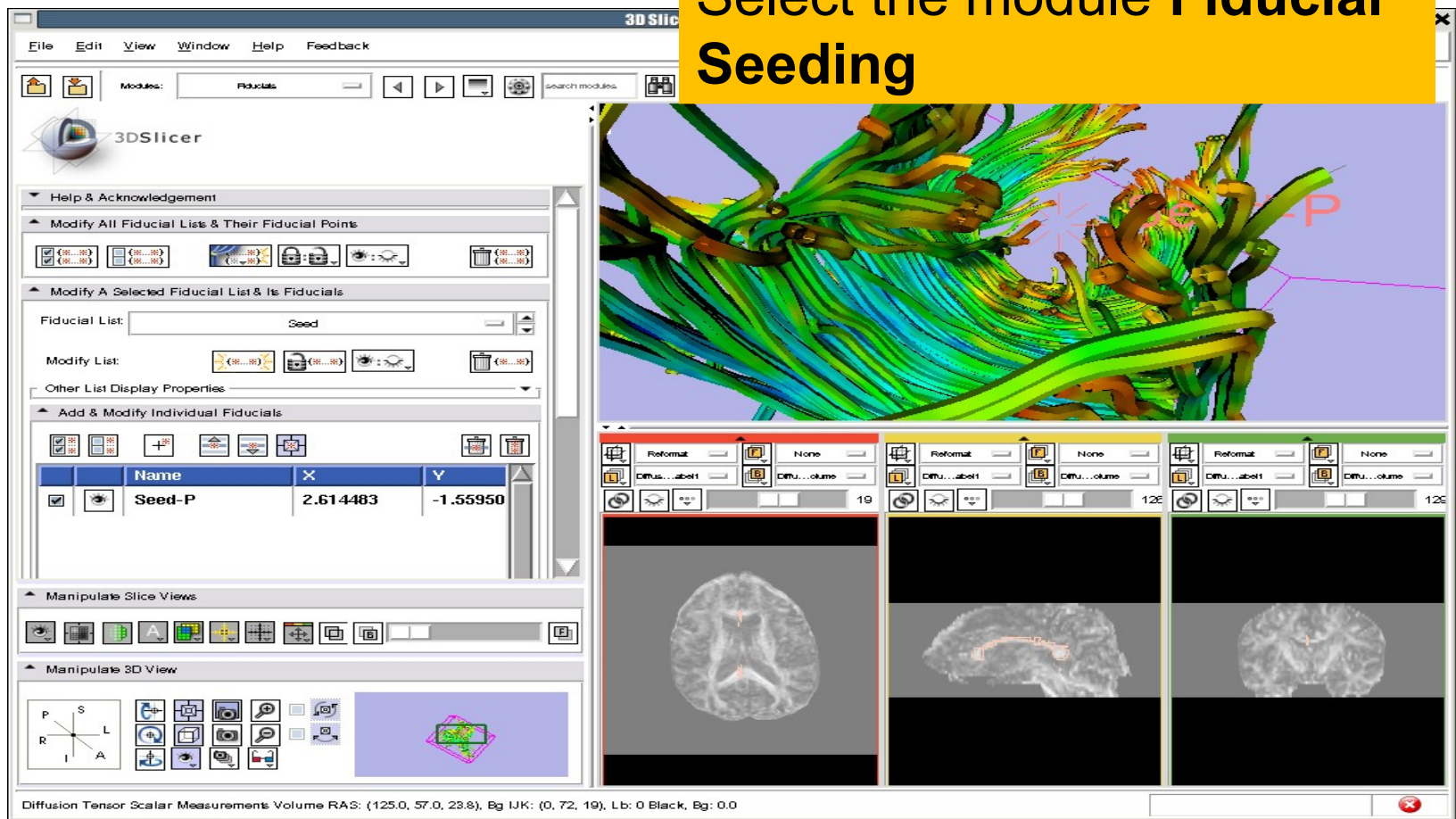
	Name	X	Y
<input checked="" type="checkbox"/>	Seed-P	2.614483	-1.55950

Diffusion Tensor Scalar Measurements Volume RAS: (125.0, 57.0, 23.8), Bg IJK: (0, 72, 19), Lb: 0 Black, Bg: 0.0



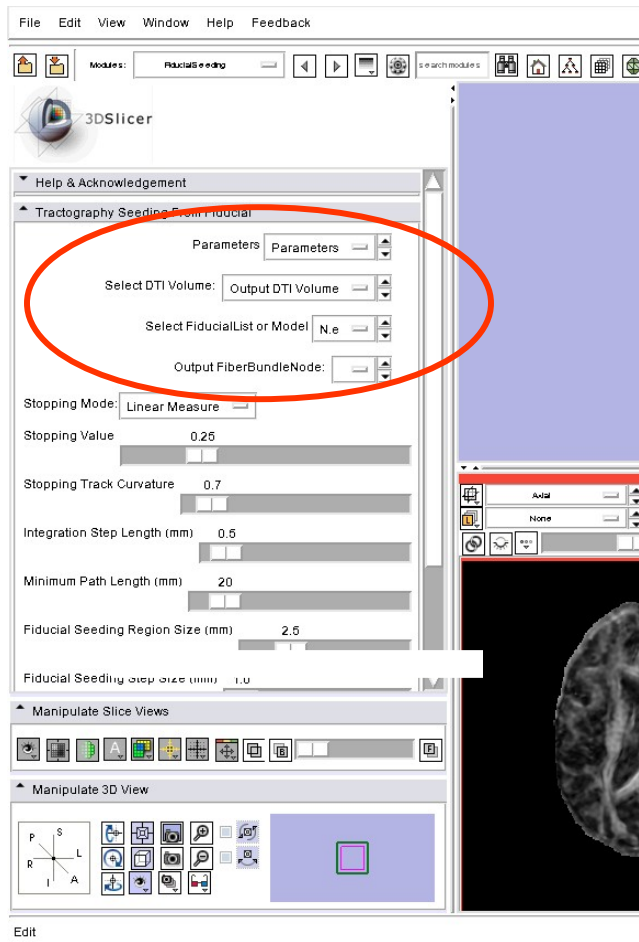
# Fiducial Seeding

Select the module **Fiducial Seeding**





# Fiducial Seeding



File Edit View Window Help Feedback

3DSlicer

Tractography Seeding From Fiducial

Parameters Parameters

Select DTI Volume: Output DTI Volume

Select FiducialList or Model: Ne

Output FiberBundleNode:

Stopping Mode: Linear 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): 2.5

Fiducial Seeding Step Size (mm): 1.0

Manipulate Slice Views

Manipulate 3D View

Edit

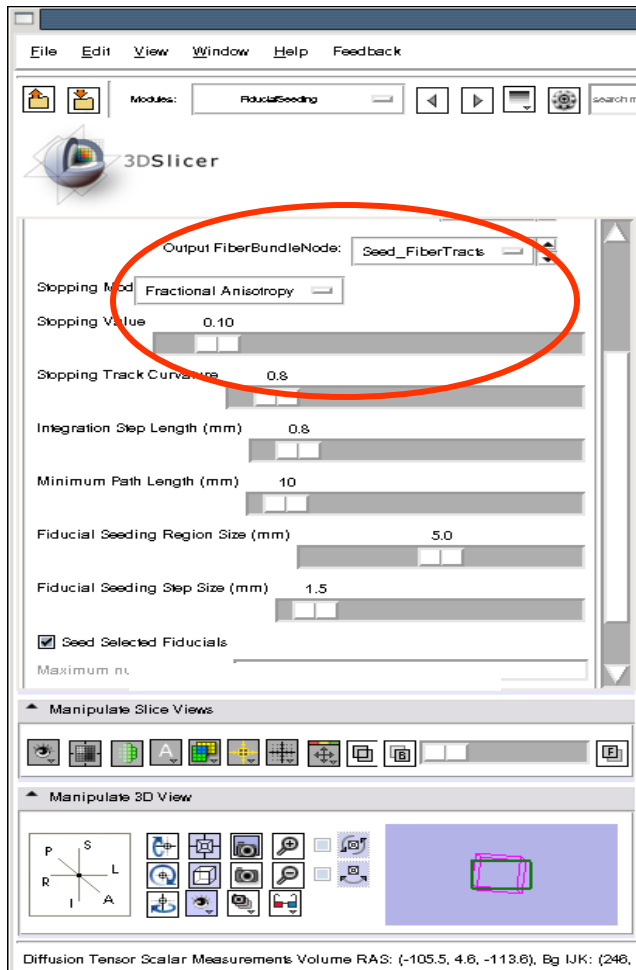
Set the DTI Volume to **Output DTI Volume**

Select the Fiducial List **Seed**

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



# 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**

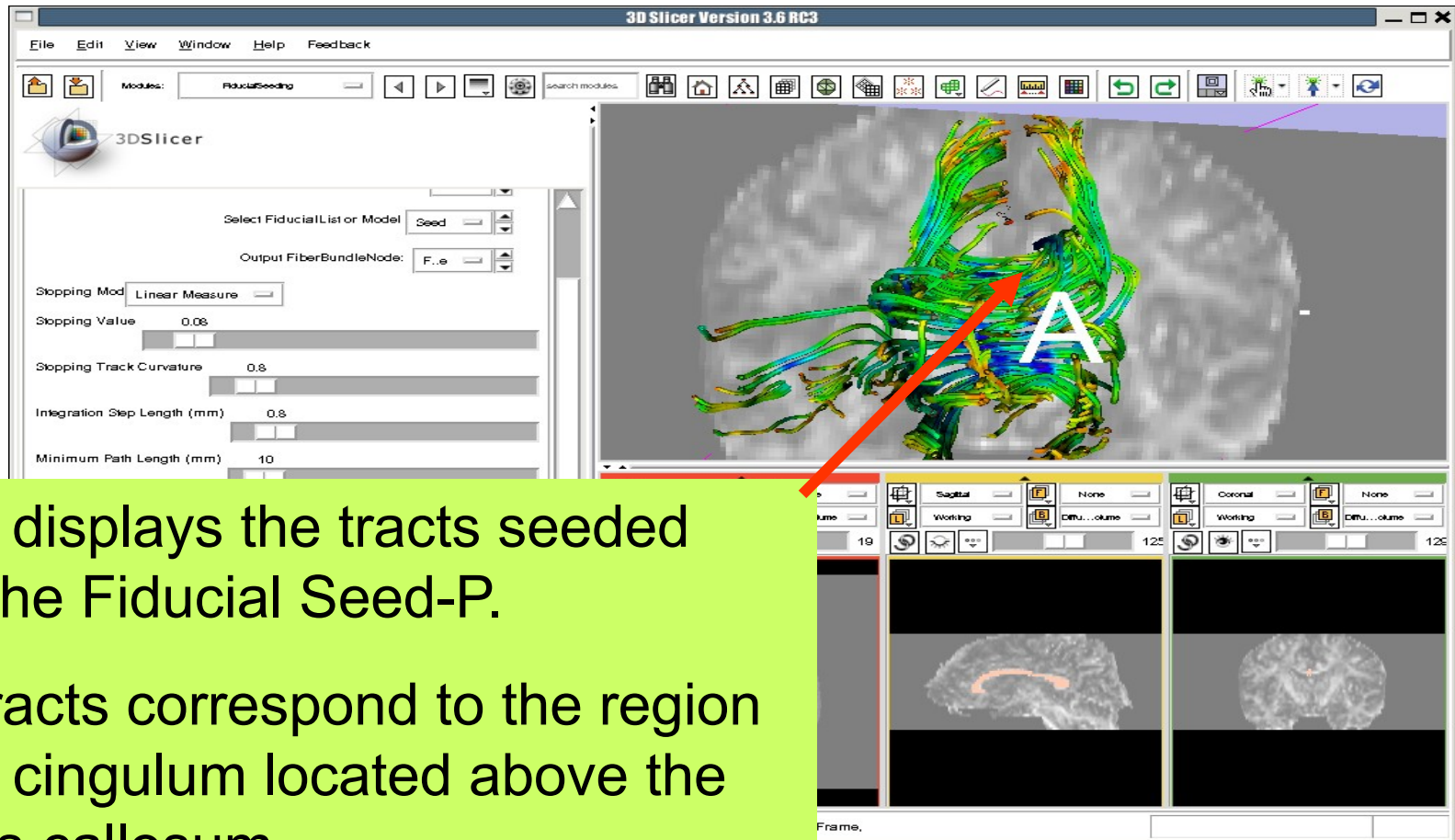
**Step Length: 0.8 mm**

**Minimum Path Length: 10 mm**

**Fiducial Stepping Size: 1.5 mm**



# Fiducial Seeding



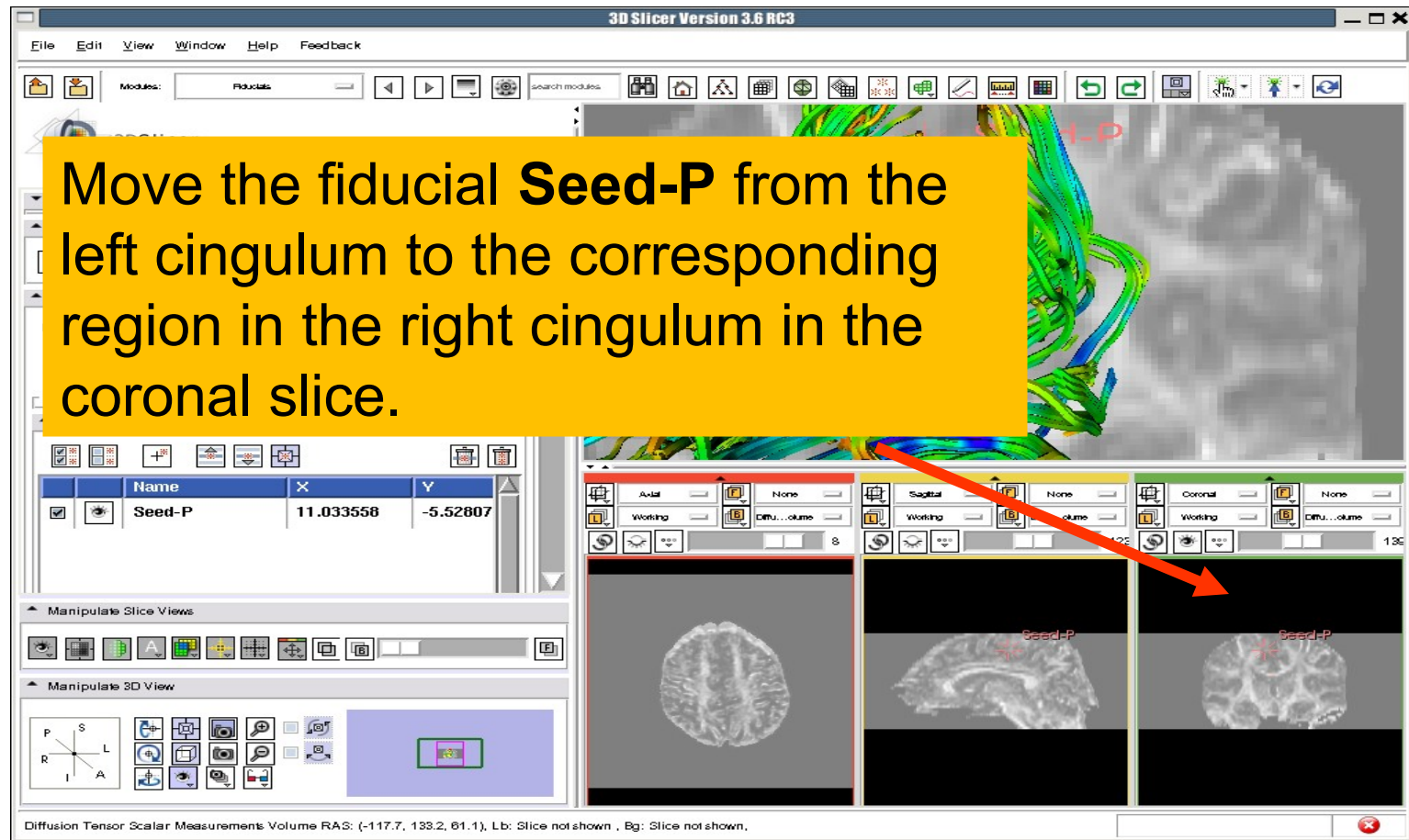
Slicer displays the tracts seeded from the Fiducial Seed-P.

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



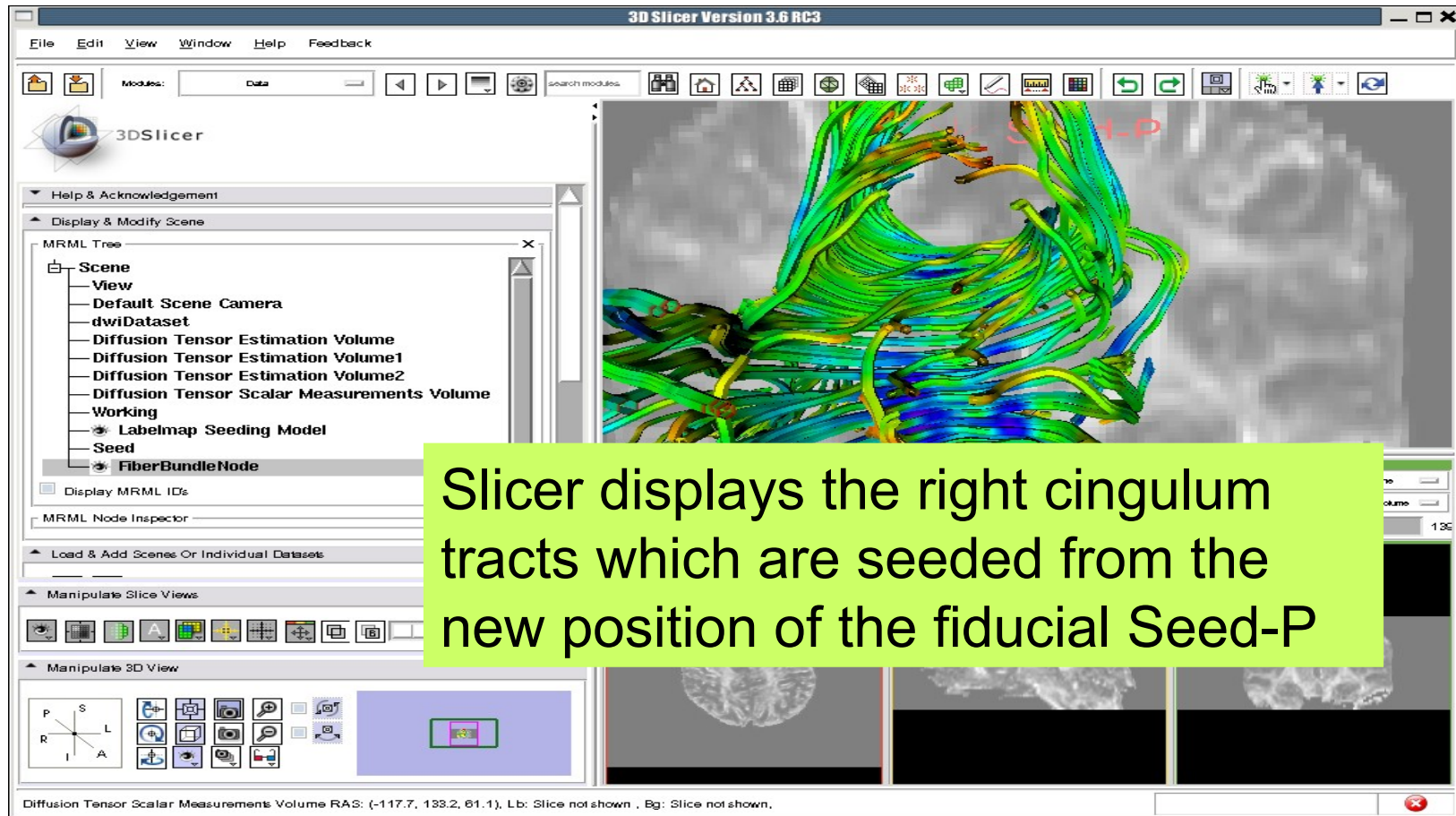
# Fiducial Seeding

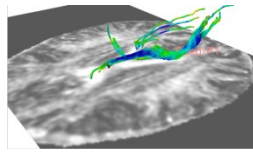
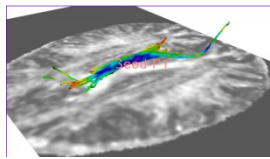
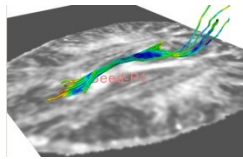
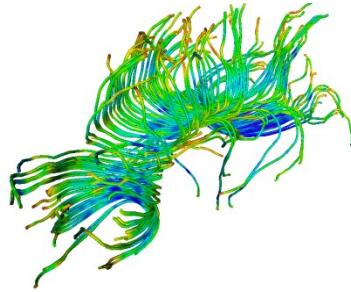
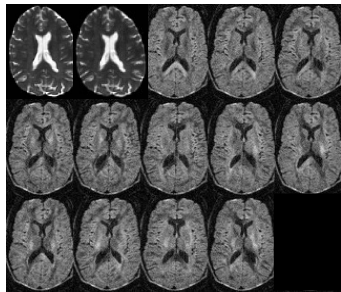
Move the fiducial **Seed-P** from the left cingulum to the corresponding region in the right cingulum in the coronal slice.





# 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

MRML Tree

- Scene
  - View
  - Default Scene Camera
  - dwidataset
  - Diffusion Tensor E on Volume
  - Diffusion Tensor E on Volume1
  - Diffusion Tensor Estimation Volume2
  - Diffusion Tensor S alar Measurements Volume
  - Working
  - Labelmap Seeding Model
  - Seed
  - FiberBundleNode

Diffusion Tensor Scalar Measurements Volume RAS: (-117.7, 133.2, 61.1), Lb: Slice not shown , Bg: Slice not shown.



# Saving a DTI Scene

3D Slicer Version 3.6 RC3

File Edit View Window Help Feedback

3DSlicer

Help & Acknowledgement

Display & Modify Scene

MRML Tree

- Scene
  - View
  - Default Scene Camera
  - dwiDataset
  - Diffusion Tensor Es in Volume
  - Diffusion Tensor Estimation Volume1
  - Diffusion Tensor Es imation Volume2
  - Diffusion Tensor Scalar Measurements Volume
  - Working
  - Labelmap Seeding Model
  - Seed
  - FiberBundleNode

Display MRML IDs

MRML Node Inspector

Load & Add Scenes Or Individual Datasets

Manipulate Slice Views

Manipulate 3D View

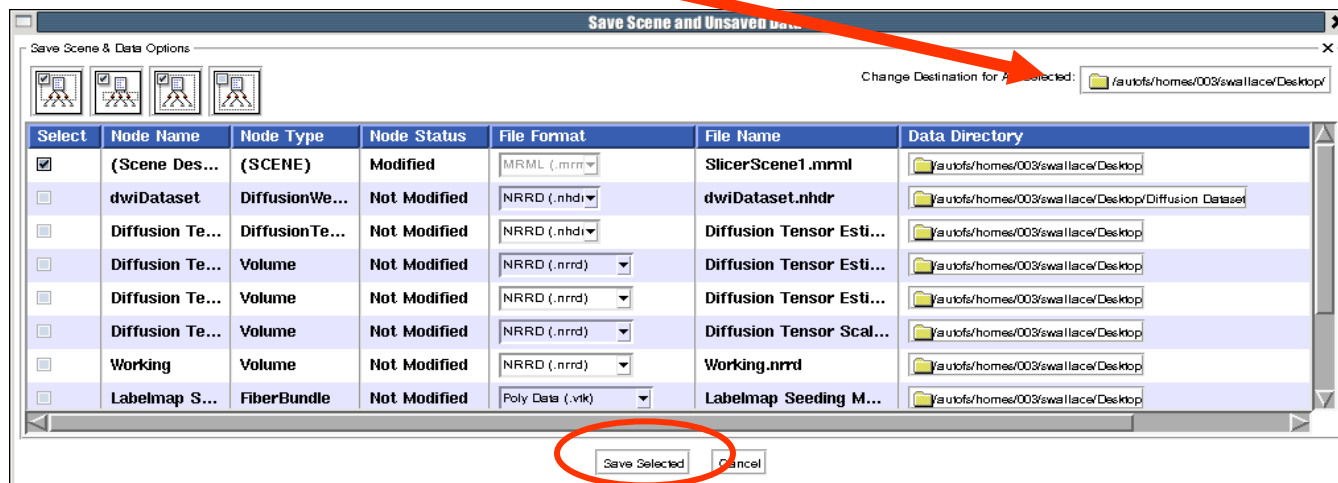
Diffusion Tensor Scalar Measurements Volume RAS: (-117.7, 139.2, 81.1), Lb: Slice not shown , Bg: Slice not shown.

Select File → Save from the main menu



# Saving a DTI Scene

Browse to a directory where you would like to save the data. Once you have selected a directory, click on **Save Selected**





# 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>.

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.

**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

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>.

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.

**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)

R A L

0 0 0



# Loading a DTI Scene

3D Slicer Version 3.6 RC3

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, and the 'Open' button is circled in red. The background shows the 3D Slicer interface with a 'Welcome & About' panel and a 'Manipulate Slice Views' panel.

Name	Size	Modified
Diffusion Dataset		Mon Jun 7 19:06:04 2
HelloPython		Sun Jun 6 15:40:26 2
TutorialSlides6610		Sun Jun 6 17:08:39 2
SlicerScene1.mrml	34 KB	Mon Jun 7 19:43:50 2

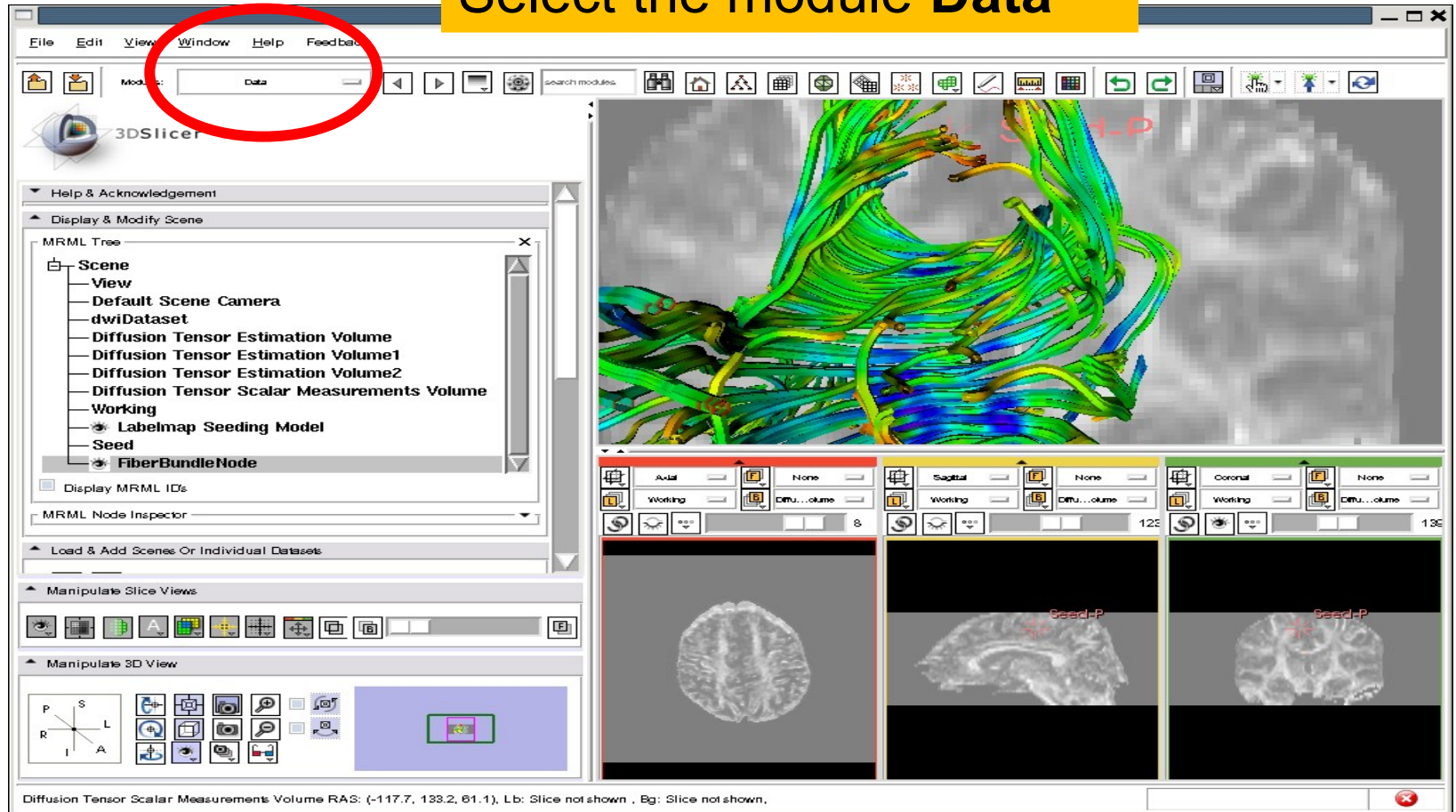
File name: SlicerScene1.mrml  
Files of type: Scenes (\*.mrml \*.mri \*.cat)

None RAS: (87.3, 1.0, -125.0)



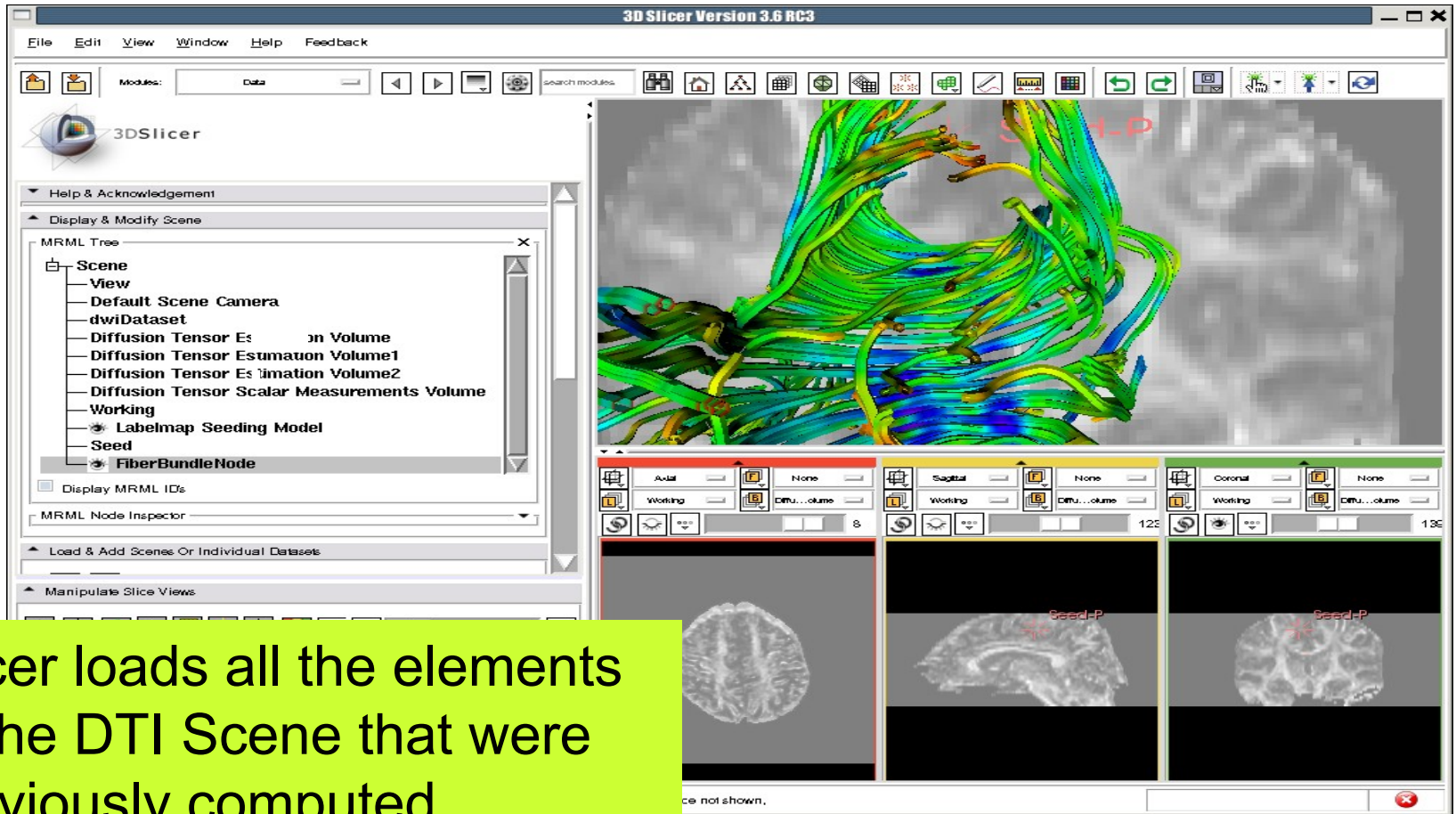
# Loading a DTI Scene

Select the module **Data**





# Loading a DTI Scene

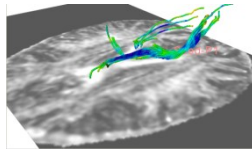
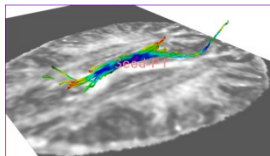
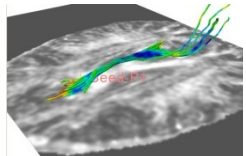
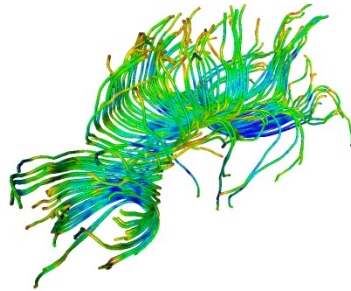
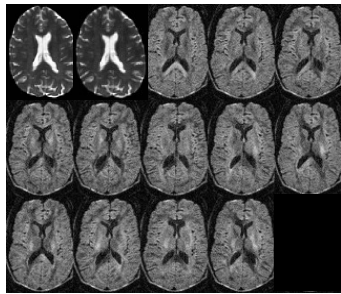


Slicer loads all the elements of the DTI Scene that were previously computed.





# Conclusion



This tutorial guided you through some of the **Diffusion MR** capabilities of the **Slicer3** software.

spujol@bwh.harvard.edu



# Acknowledgments

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