



NA-MIC

National Alliance for Medical Image Computing

<http://na-mic.org>

Diffusion Tensor Imaging tutorial



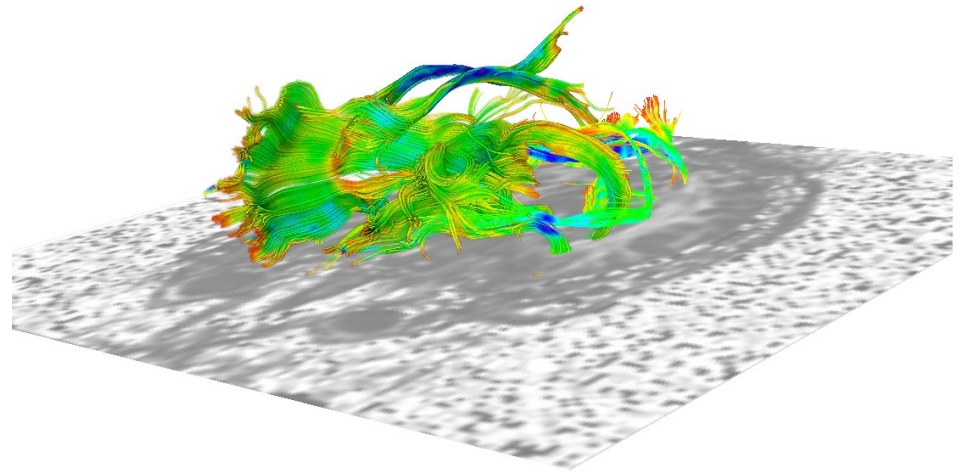
Sonia Pujol, PhD

Surgical Planning Laboratory
Harvard University



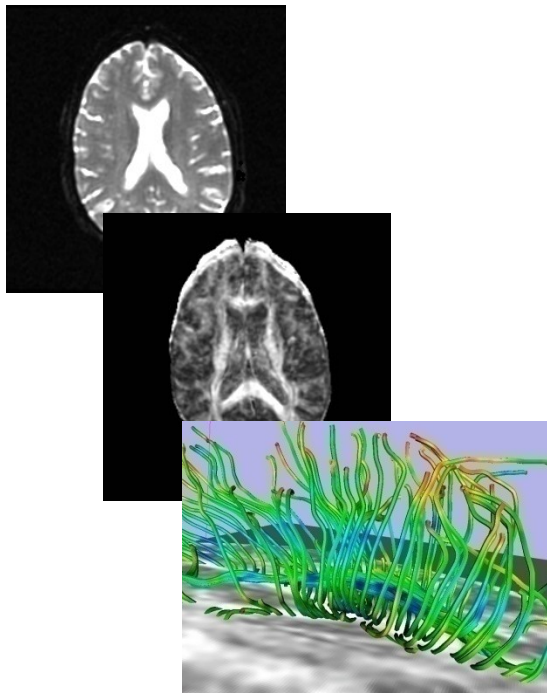
DTI tutorial

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





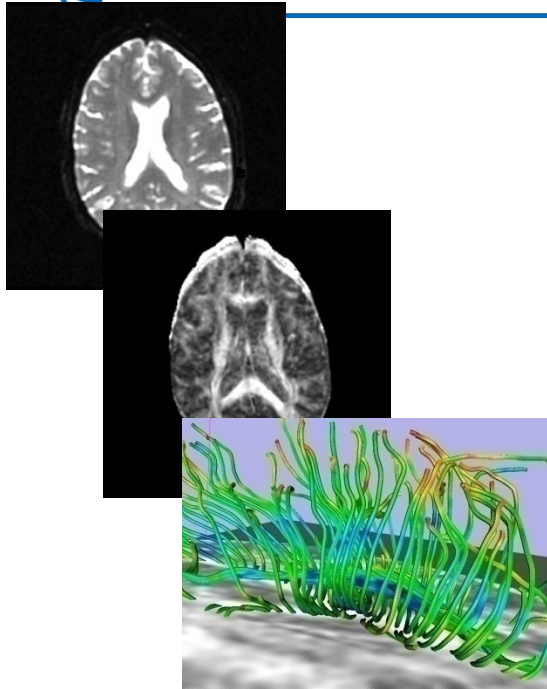
Outline



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



Outline



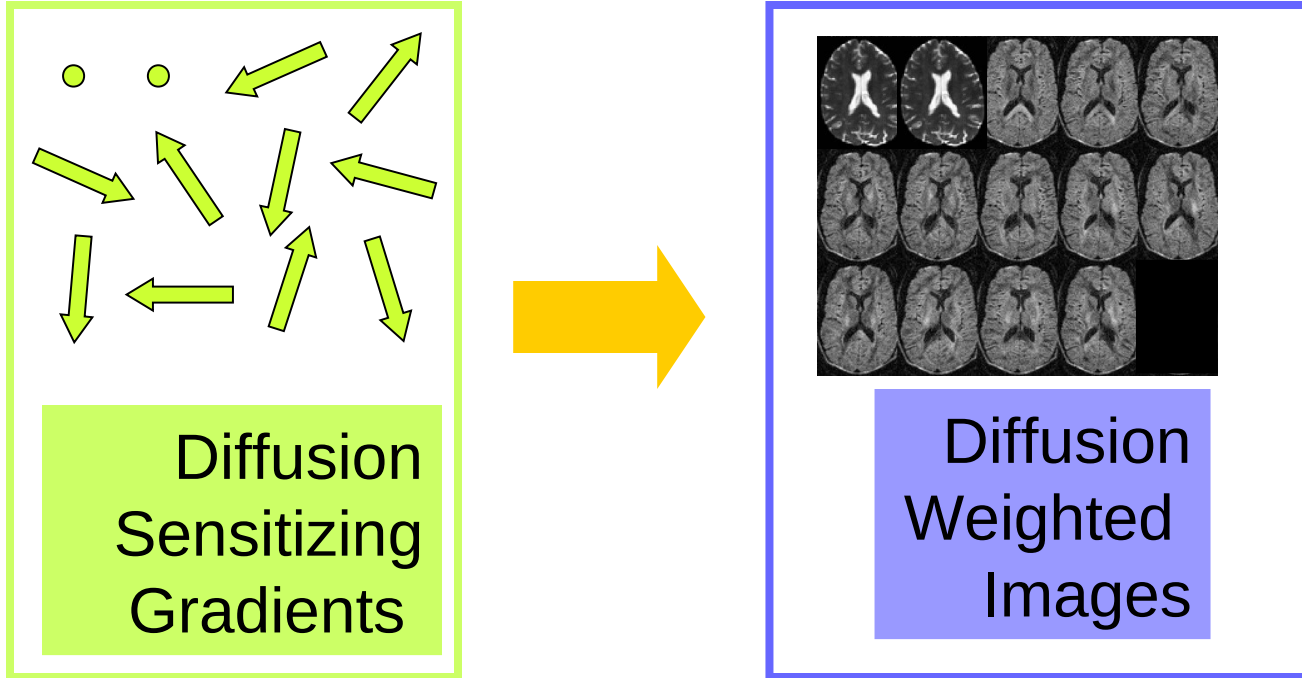
The processing pipeline uses **9 image analysis modules** of Slicer3.6

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



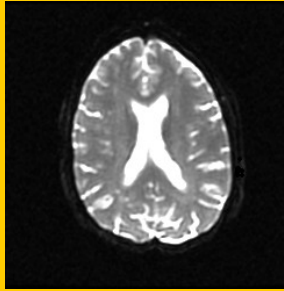
Tutorial Dataset

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

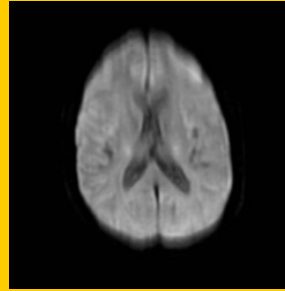




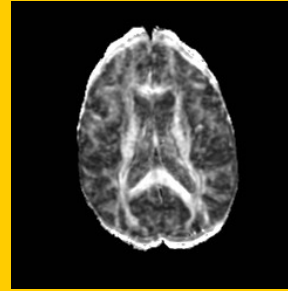
DTI Processing Pipeline



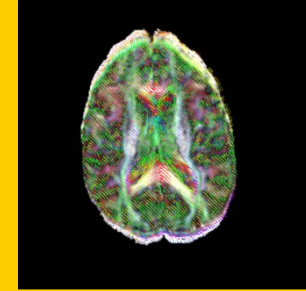
DWI
Acquisition



Tensor
Calculation



Scalar
Maps



3D
Visualization



Start Slicer3

Linux/Mac users

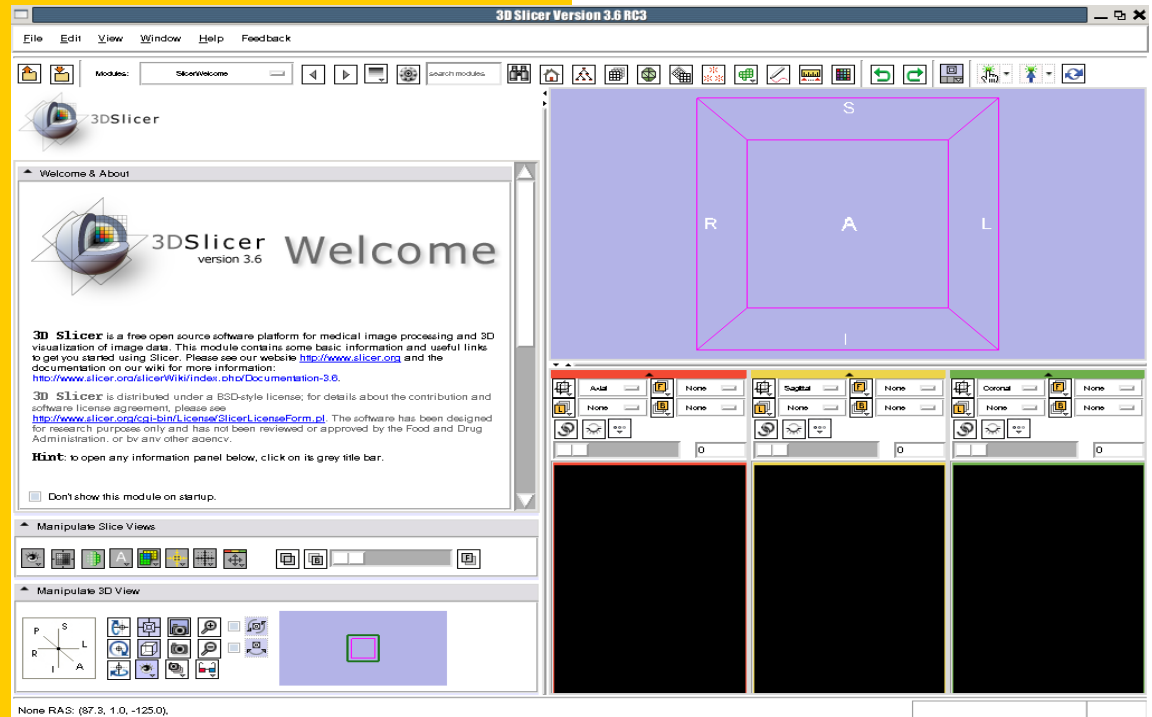
Launch the Slicer3 executable located in the Slicer3.6 directory

Windows users

Select

Start → All Programs

→ Slicer3-3.6-RC3-2010-06-04 → Slicer3

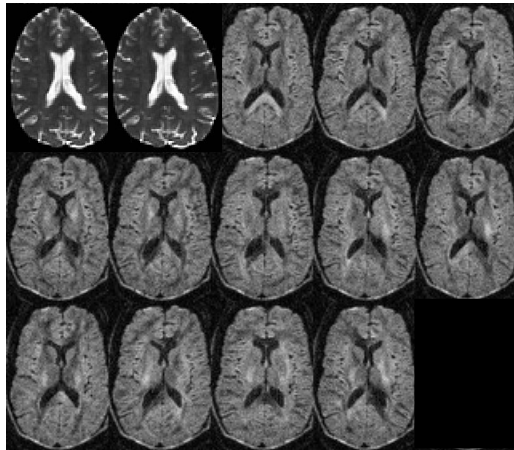




Slicer Welcome

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:

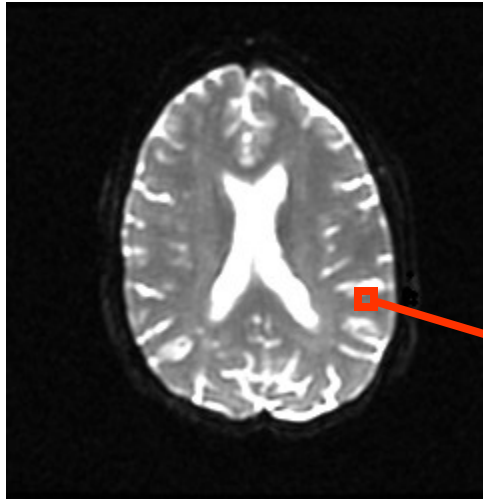
Diffusion data loading and tensor estimation



Diffusion Tensor

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

Select File → Add Volume from the File menu

3D Slicer 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.

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



Loading the DWI volume

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 medical visualization of image data. This module contains some basic information to get you started using Slicer. Please see our website <http://www.slicer.org> for more information: <http://www.slicer.org/slicerWiki/index.php/Documentation-3.6>.

3D Slicer is distributed under a BSD-style license; for detailed software license agreement, please see <http://www.slicer.org/cgi-bin/License/SlicerLicenseForm.pl>. This software is for research purposes only and has not been reviewed or approved 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).

Add Volume

Name	Size	Date
dwiDataset.nhdr	2 KB	Wed Sep 2
dwiDataset.raw.gz	31,309 KB	Tue Aug 7

DICOM Information

Parse Directory Divide Subseries

Description	Value
-------------	-------

Path: /a/ufdz/home/003swallace/Desktop/Diffusion Dataset/dwiDataset.nhdr

Volume Options

Centered Ignore Orientation Label Map Single File Name: dwiDataset

Recent Volumes:

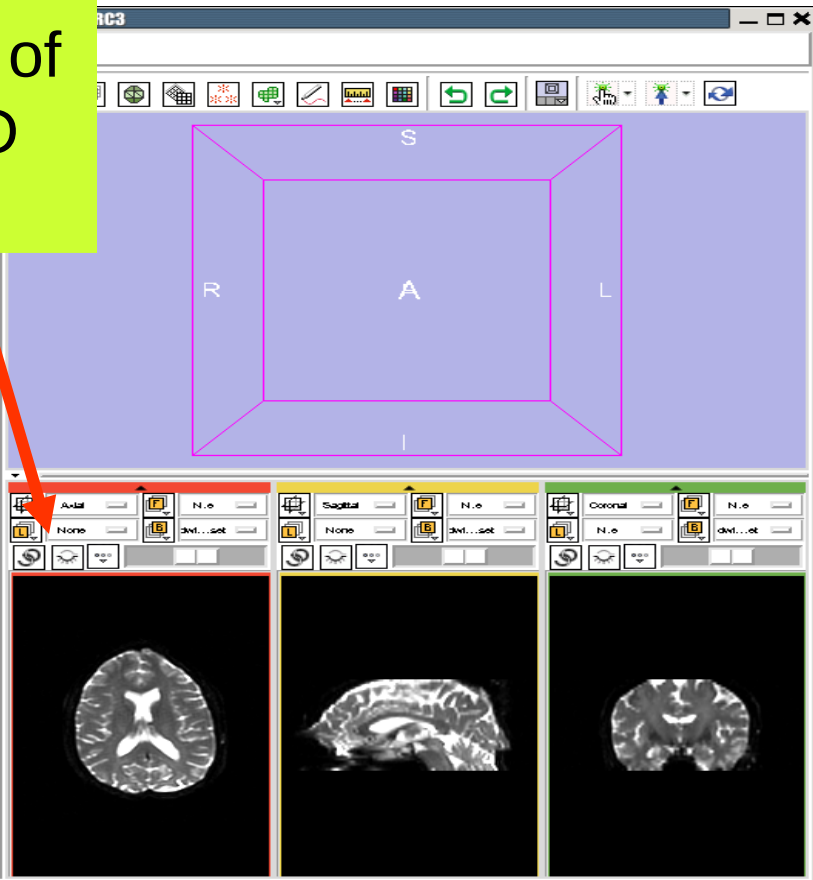
Browse to the location of the Diffusion tutorial dataset directory and select the file **dwiDataset.nhdr**

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

3D Slicer Version 3.6 RC3

File Edit View Window Help Feedback

Modules SlicerWelcome

3DSlicer

Welcome & About

3DSlicer version 3.6 Welco

3D Slicer is a free open source software platform for medical image pre-visualization of image data. This module contains some basic information to get you started using Slicer. Please see our website <http://www.slicer.org> and 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 software license agreement, please see <http://www.slicer.org/cgi-bin/license/SlicerLicenseForm.pl>. The software has 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

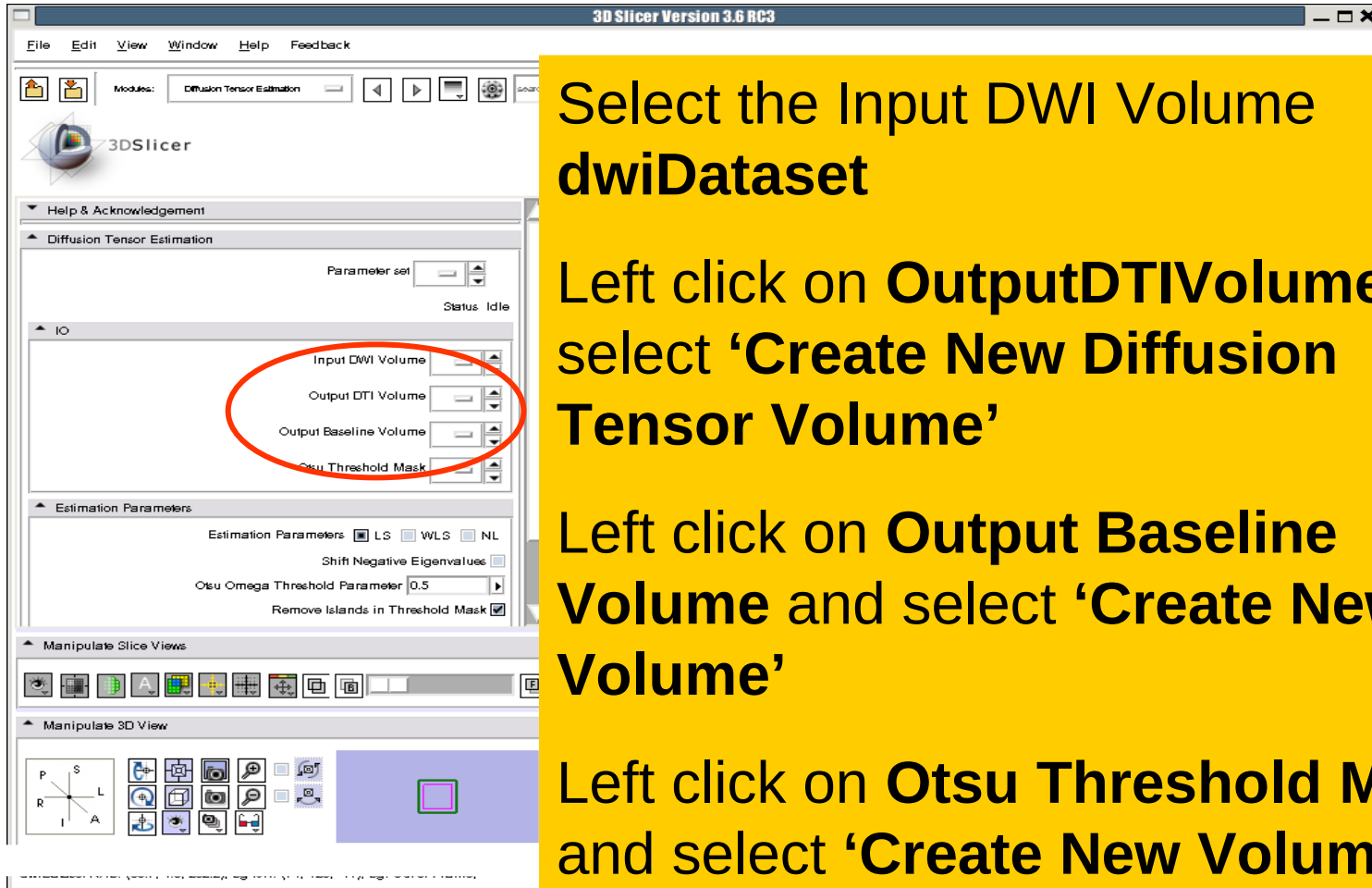
dwiData5

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

3D Slicer Version 3.6 RC3

File Edit View Window Help Feedback

Modules: Diffusion Tensor Estimation

IO

Input

Output

Output Base

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.

Diffu...ume2 Diffu...ume1

Diffu...ume2 Diffu...ume1

Diffu...ume2 Diffu...ume1

Bg: Diffusion Tensor Estimation Volumes 1
None
Lb: Diffusion Tensor Estimation Volumes 2
Coronal
Sp: 0.938mm

Lb: Slice not shown R: 41.6
A: 5.5
Bg: Slice not shown, S: -131.3

Left click on **Diffusion Tensor Volume 1** to display the list of volumes that have been computed by Slicer

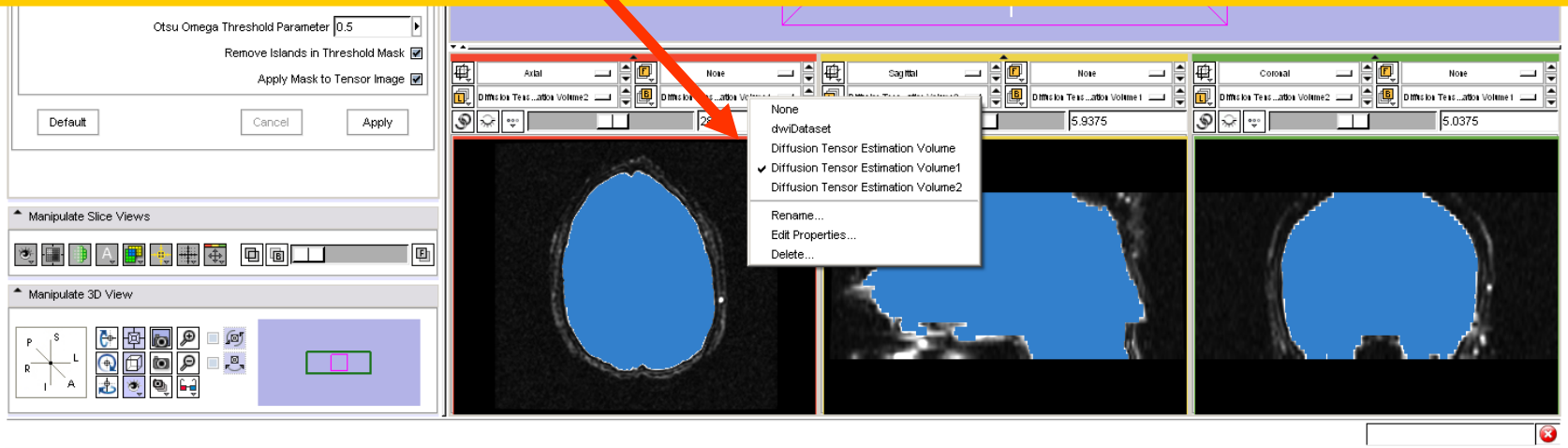


Tensor Estimation

Diffusion Tensor Estimation Volume is the volume of estimated tensors

Diffusion Tensor Estimation Volume 1 is the Baseline volume

Diffusion Tensor Estimation Volume 2 is the tensor mask (blue)





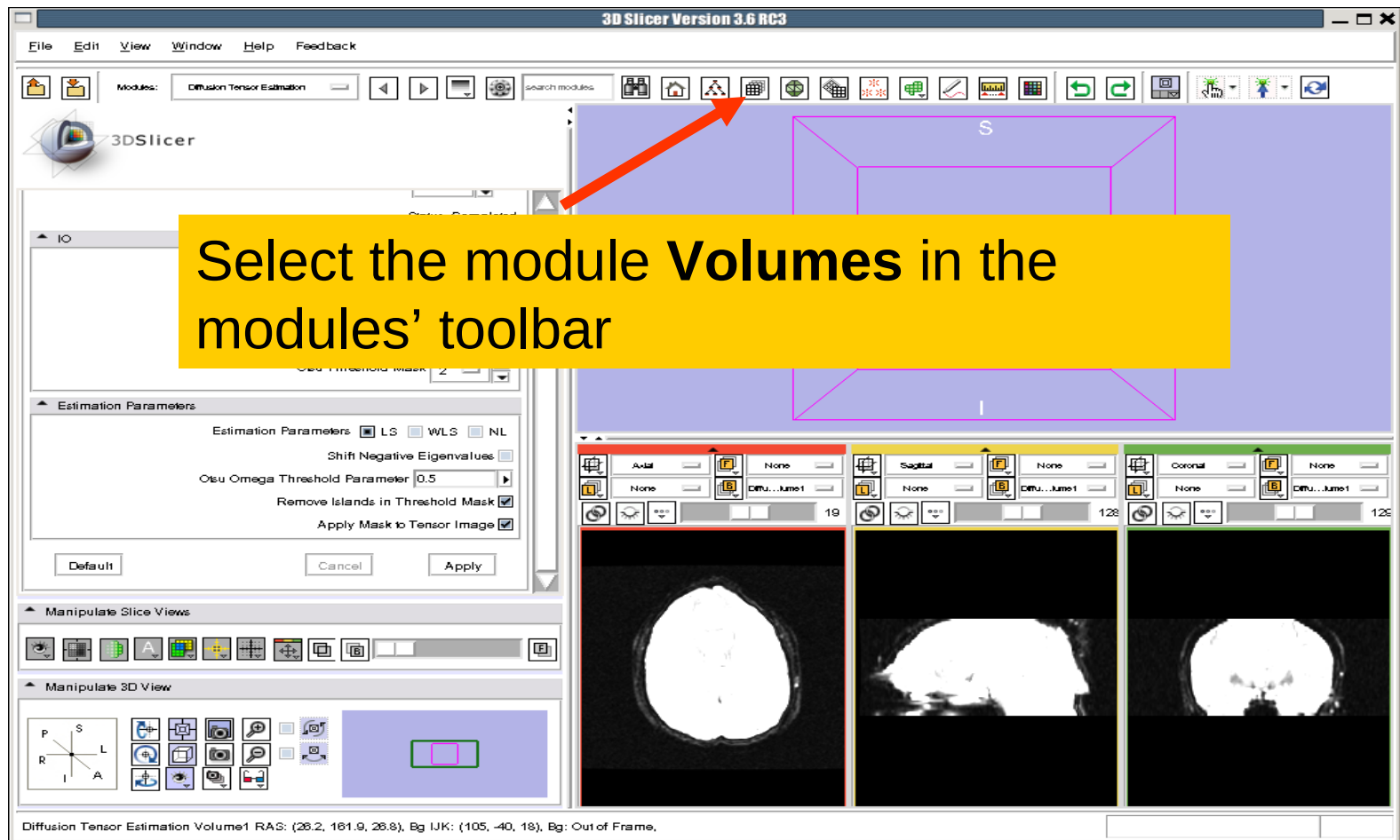
Tensor Estimation

Click on the link icon, left click on **Diffusion Tensor Volume 2** and select **None**

The screenshot shows the 3D Slicer software interface. The main window displays a 3D view of a brain slice with a purple bounding box. Below the 3D view are three slice views: Axial, Sagittal, and Coronal. The Diffusion Tensor Estimation module is active, and the 'Diffusion Tensor Volume 2' dropdown menu is open, showing 'None' as the selected option. A red arrow points to the 'None' option. The interface also shows various toolbars and panels, including 'IO', 'Estimation Parameters', and 'Manipulate Slice Views'.



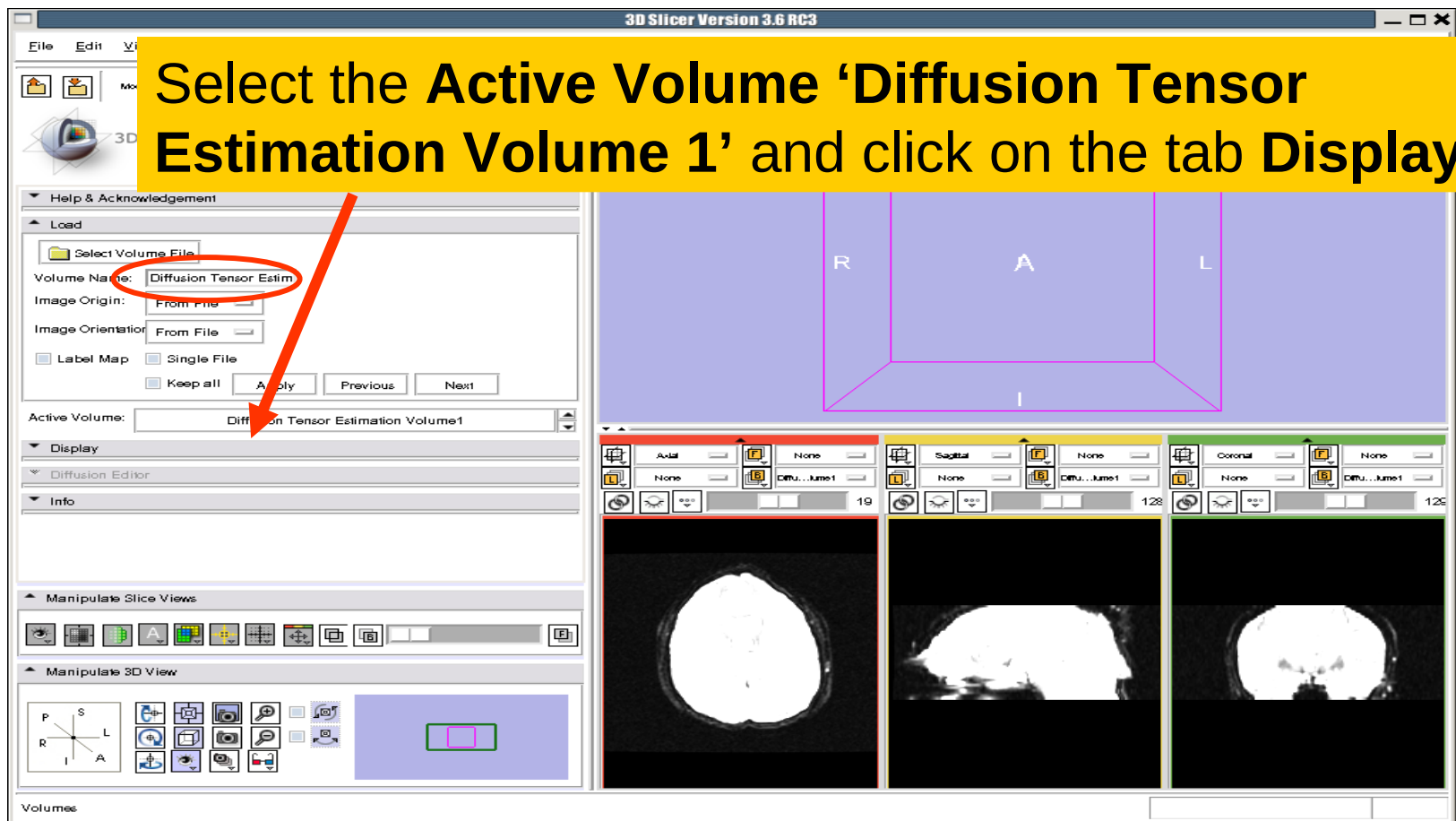
Tensor Estimation





Tensor Estimation

Select the Active Volume 'Diffusion Tensor Estimation Volume 1' and click on the tab Display





Tensor Estimation

3D Slicer Version 3.6 RC3

File Edit View Window Help Feedback

Active Volume:

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

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]

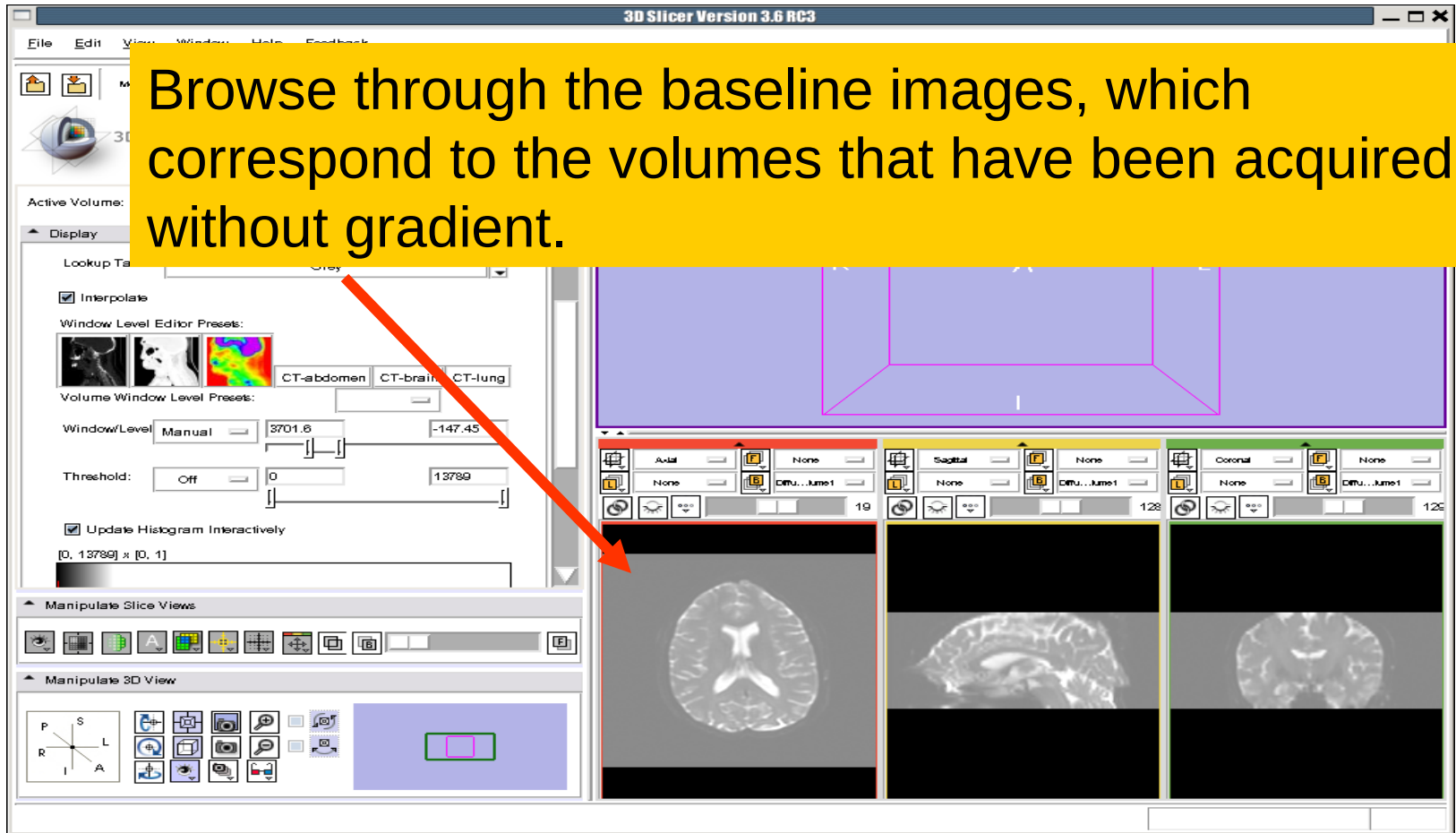
Manipulate Slice Views

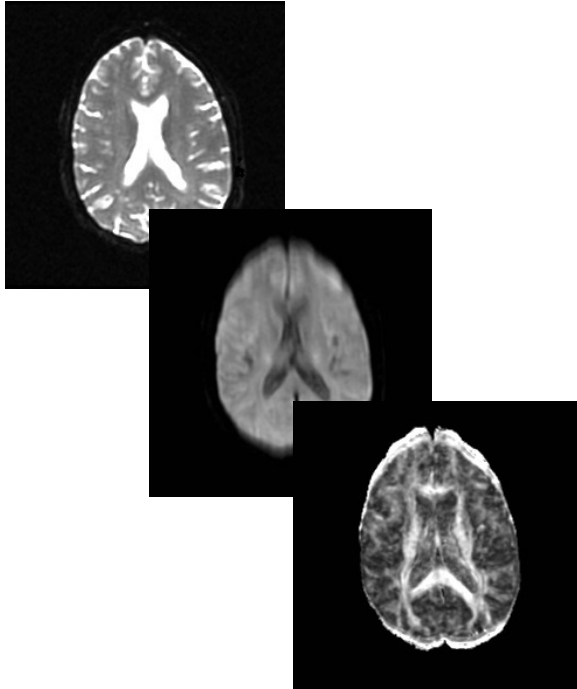
Manipulate 3D View



Tensor Estimation

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





Part2:

Scalar Measurements

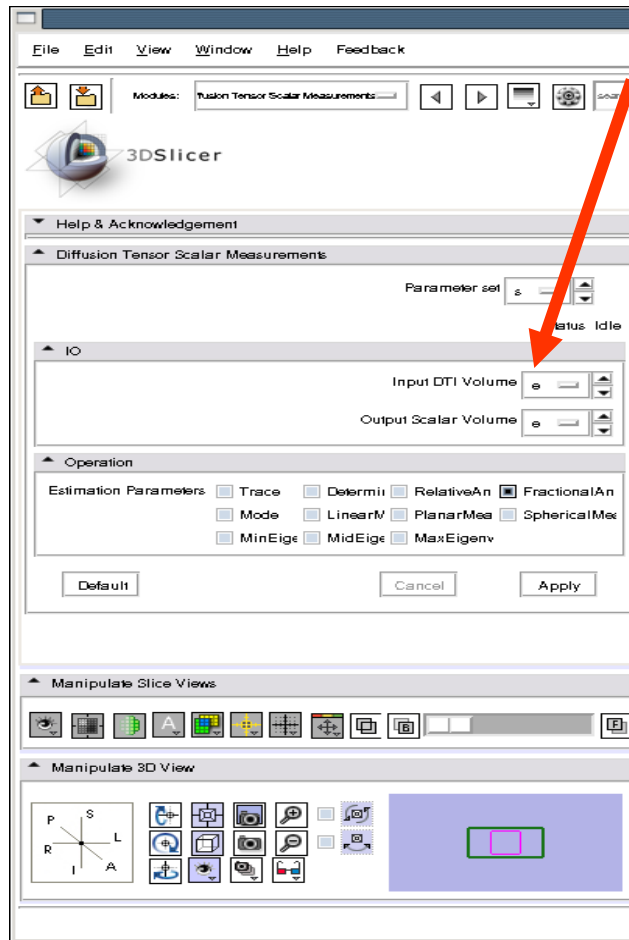


Scalar Measurements

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 **Diffusion Tensor Estimation Volume**

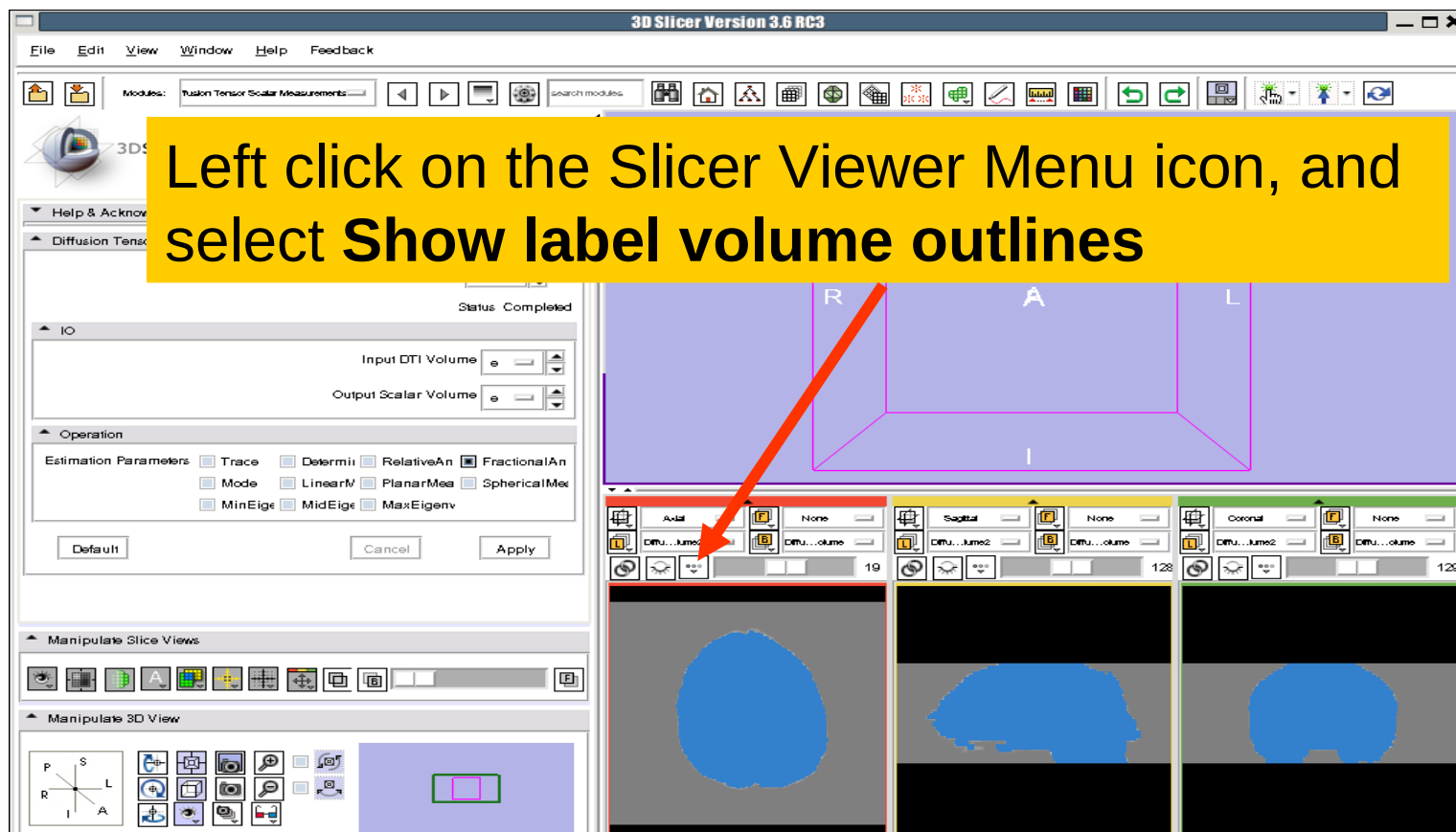
Select the Output Scalar Volume **'Create New Volume'**

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





Fractional Anisotropy Volume





Fractional Anisotropy Volume

3D Slicer displays the outline of the tensor mask overlaid on the Fractional Anisotropy volume

Diffusion Tensor Scalar Measurements Volume RAS: (87.2, 26.5, 26.8), Bg IJK: (40, 104, 18), Lb: 0 Black, Bg: 0.0



Fractional Anisotropy Volume

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.



Part 3:

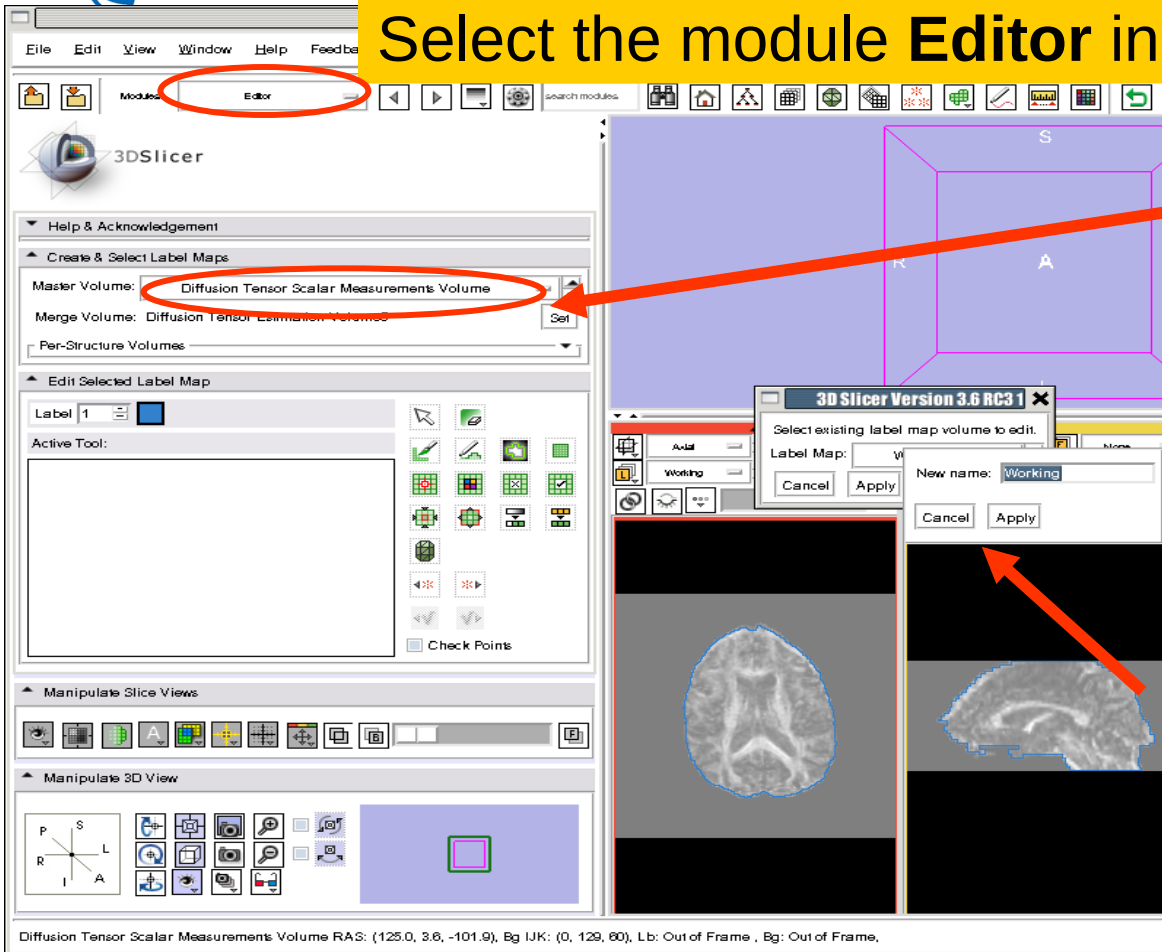
Region of Interest based Tractography





LabelMap Generation

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



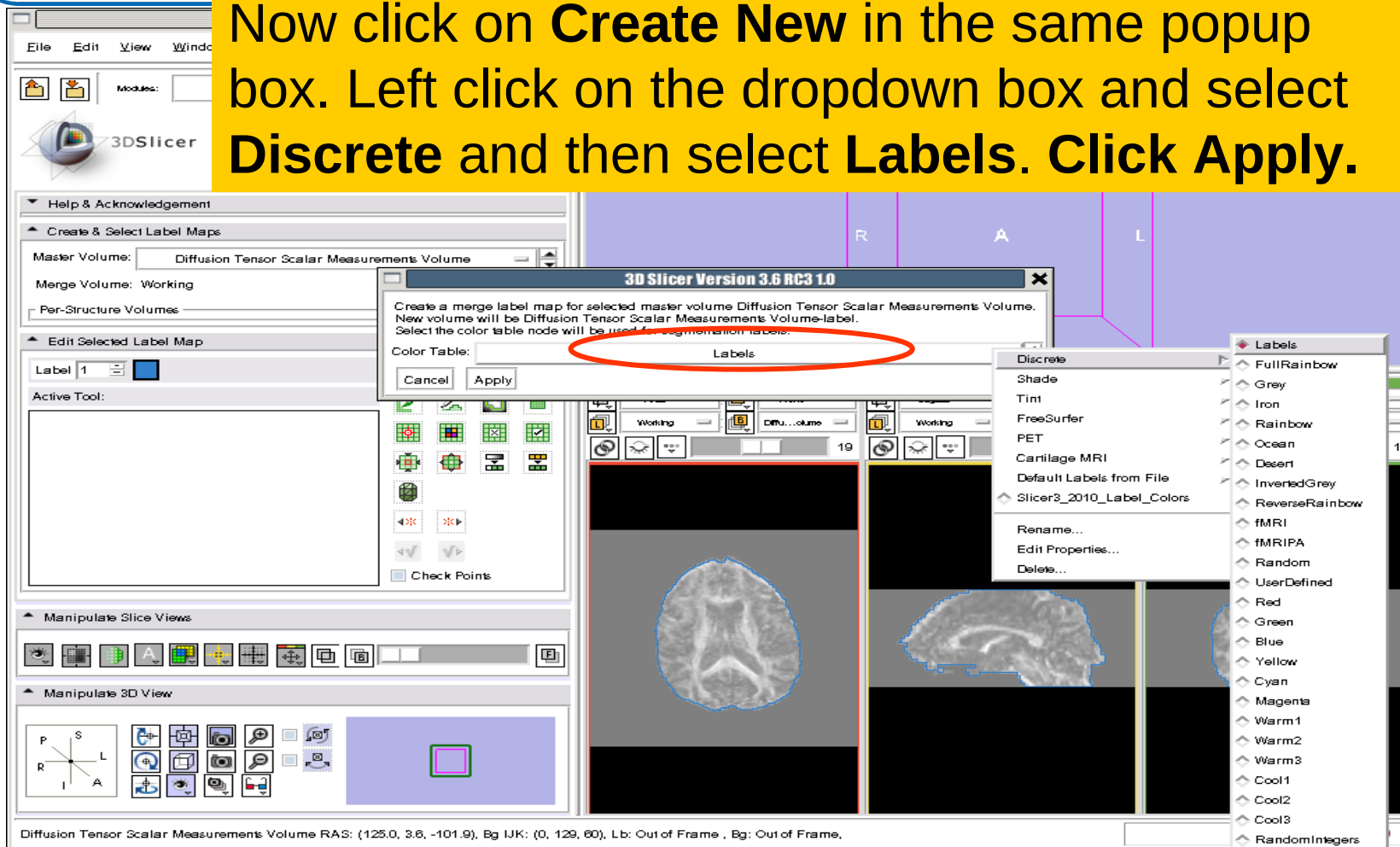
Select the Master Volume as **Diffusion Tensor Scalar Measurements Volume**

Click '**Set**', then left click on 'Diffusion Tensor Estimation Volume 2' in the popup box. Click '**Rename**' and rename it as '**Working**'



LabelMap Generation

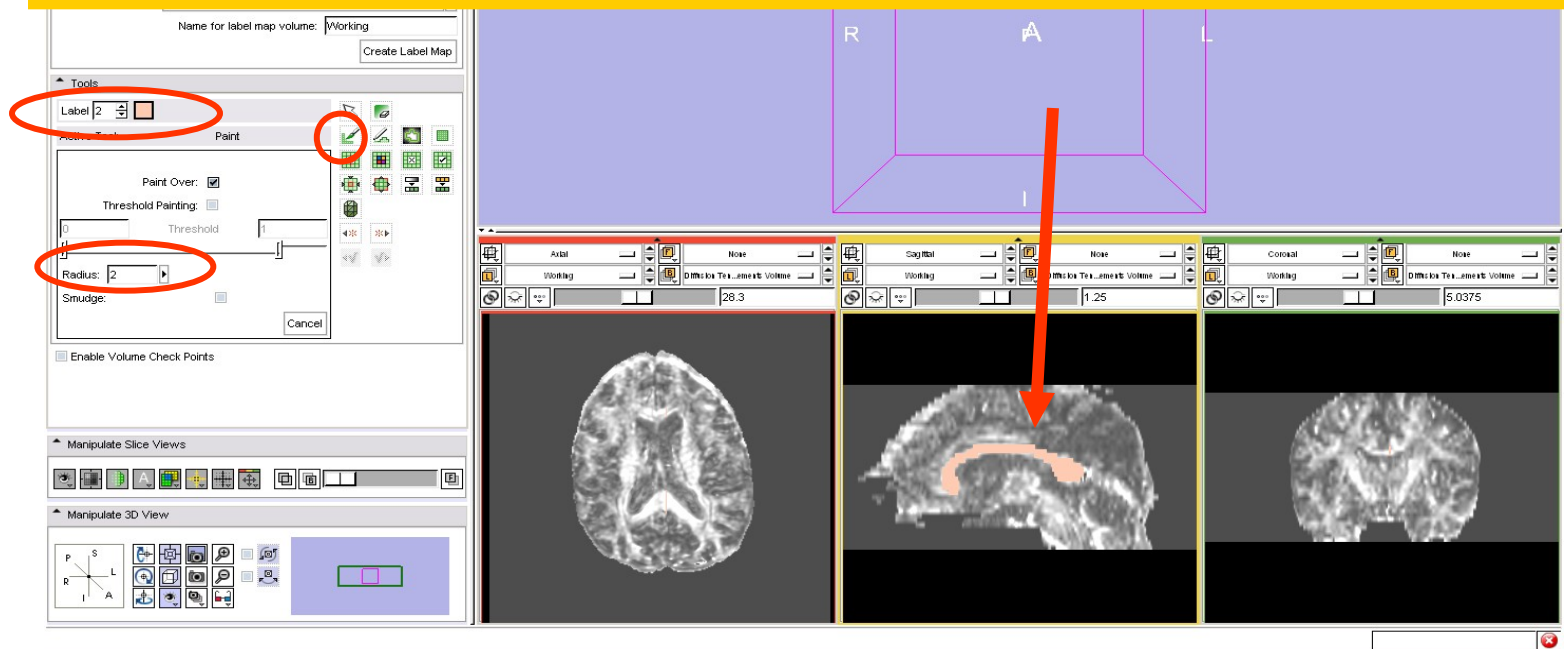
Now click on **Create New** in the same popup box. Left click on the dropdown box and select **Discrete** and then select **Labels**. Click **Apply**.





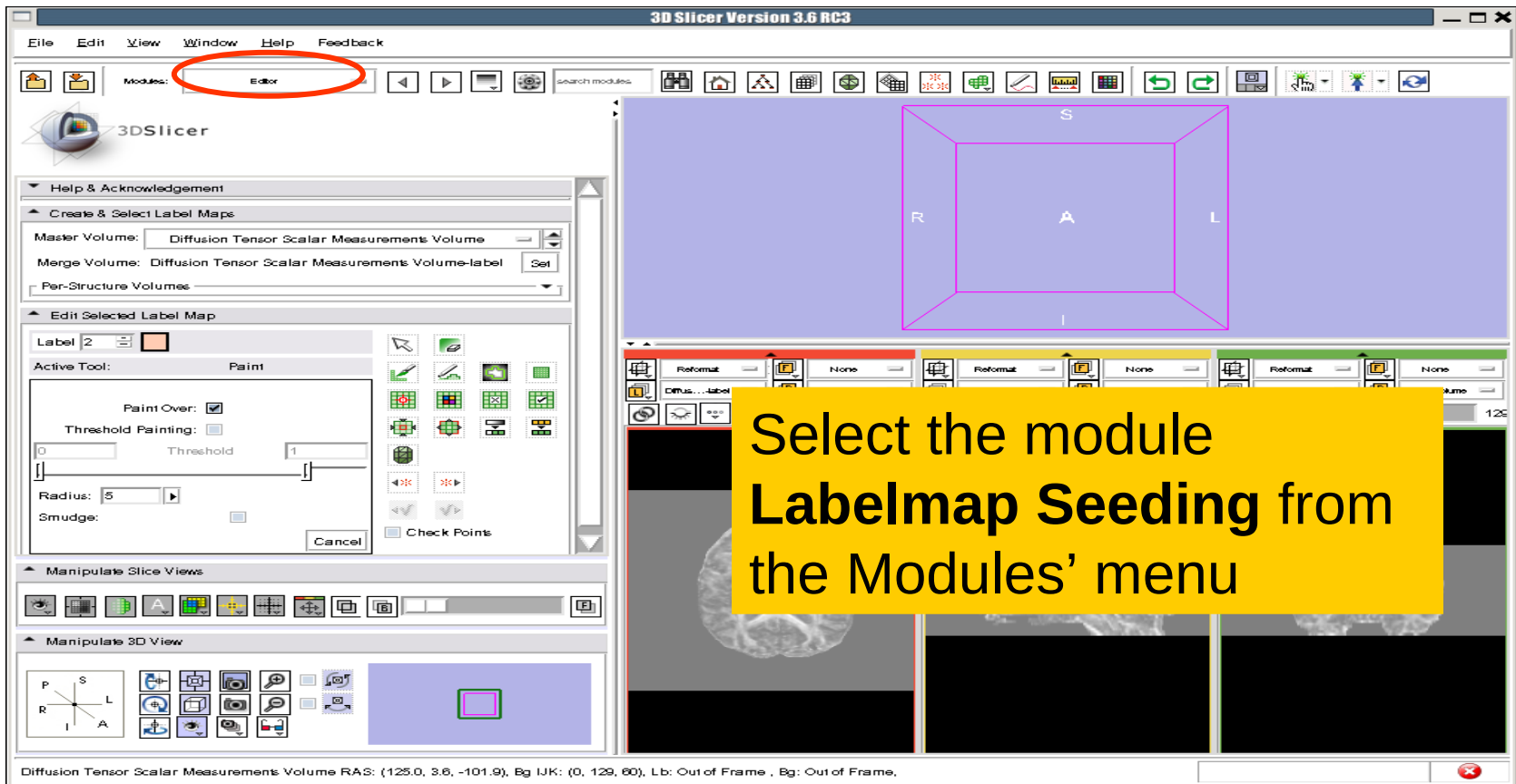
LabelMap Generation

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



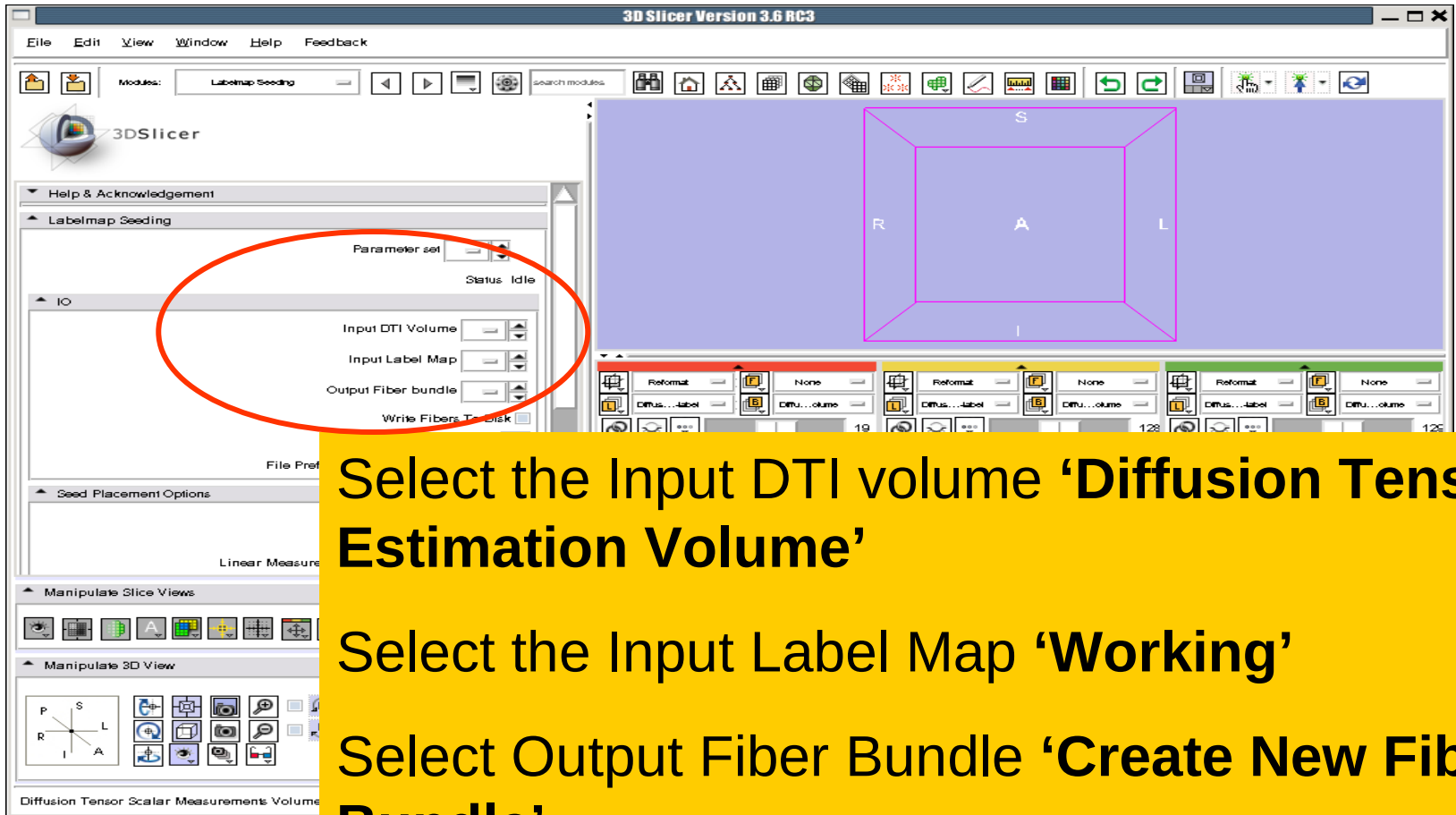


LabelMap Seeding





LabelMap Seeding





LabelMap Seeding

3D Slicer Version 3.6 RC3

File Edit View Window Help Feedback

Modules: Labelmap Seeding

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, 3.6, -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.

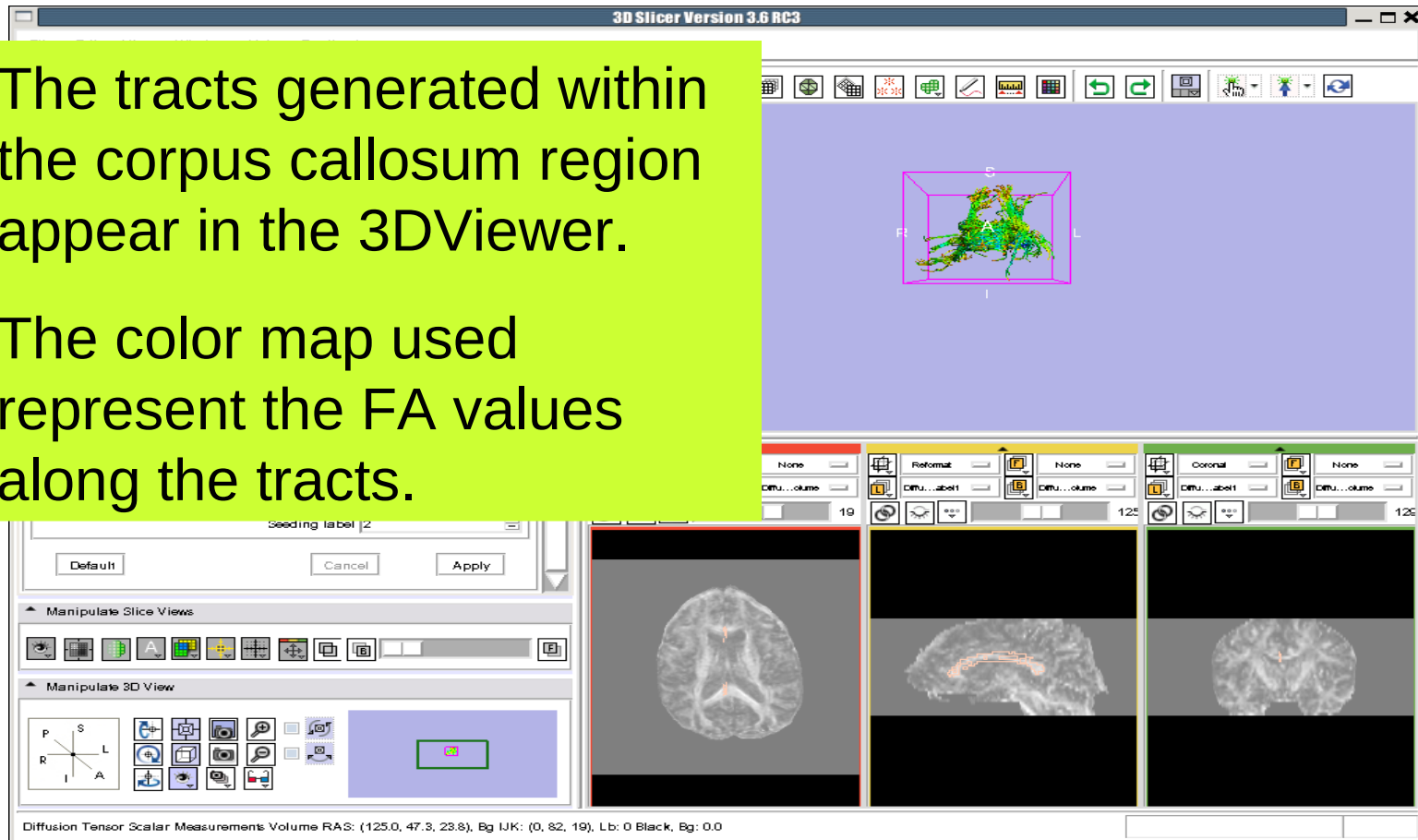
Set Seeding label to label 2, and click on **Apply**



LabelMap Seeding

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

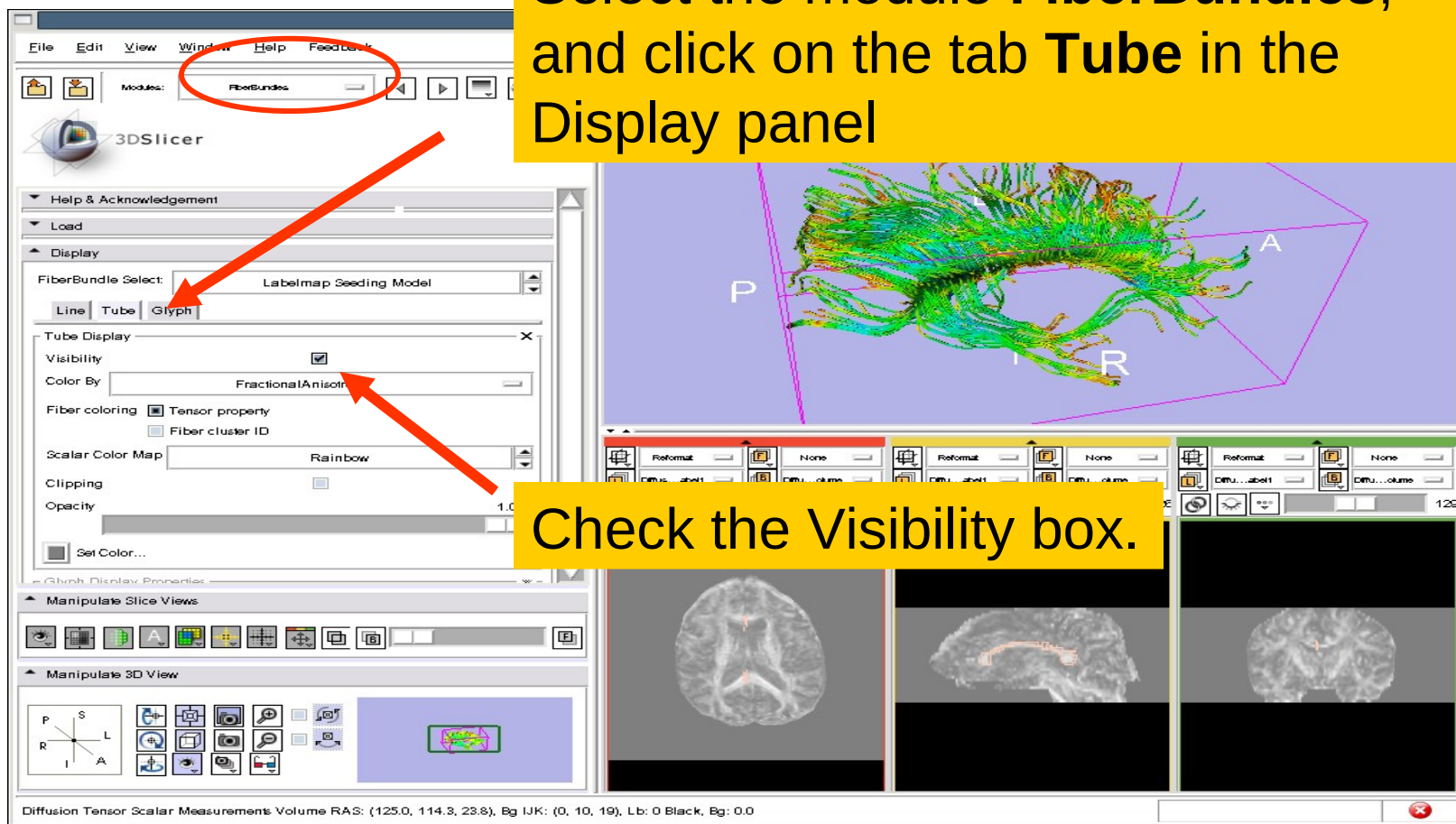
The color map used represent the FA values along the tracts.





LabelMap Seeding

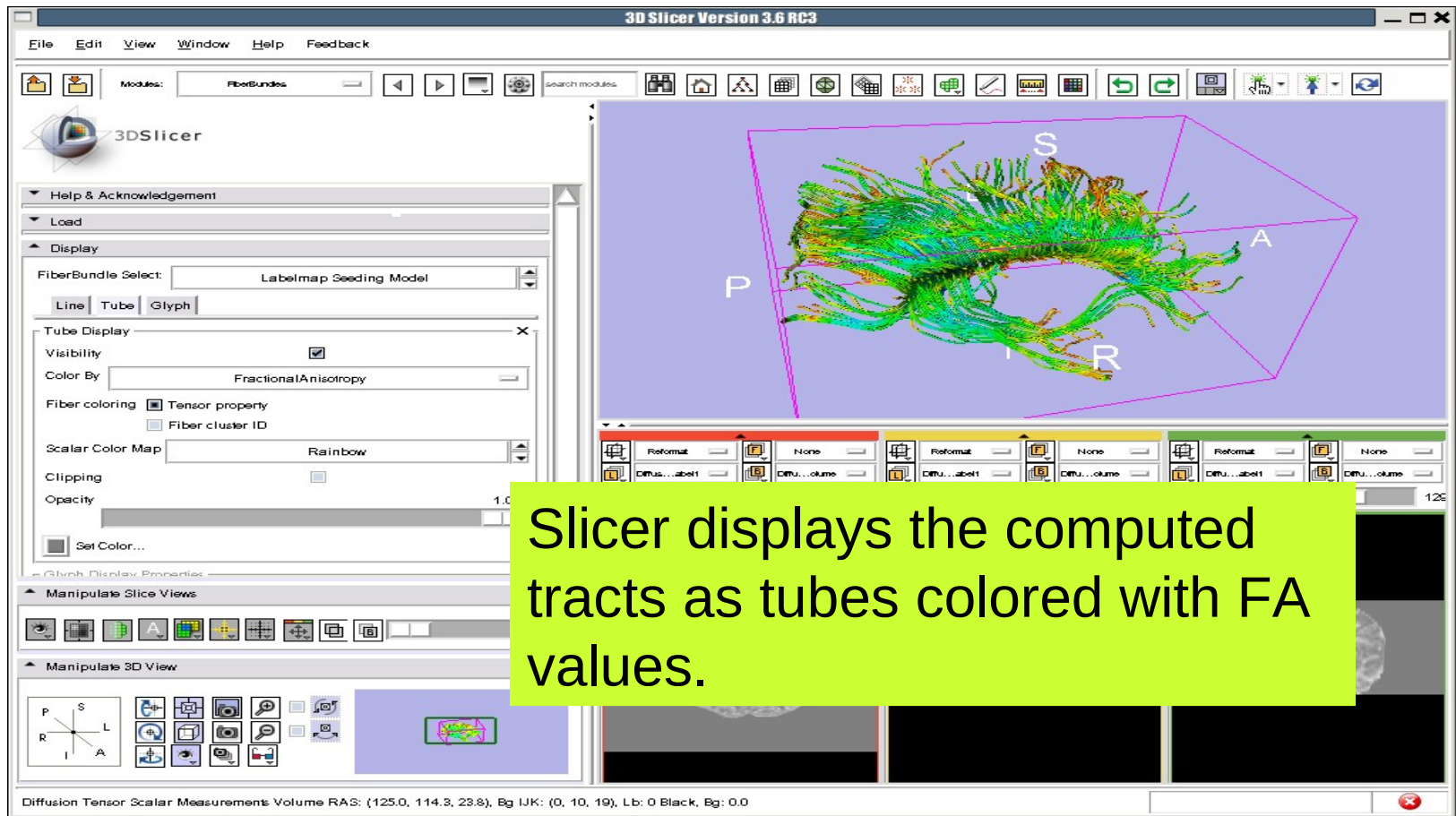
Select the module **FiberBundles**, and click on the tab **Tube** in the Display panel

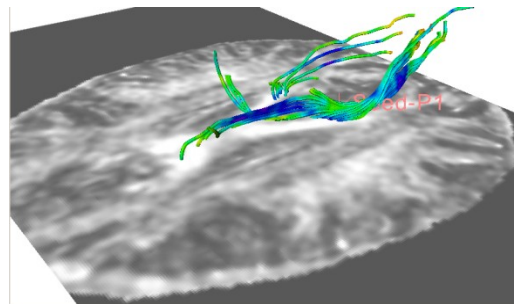
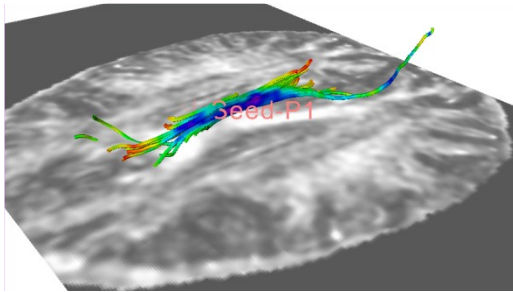
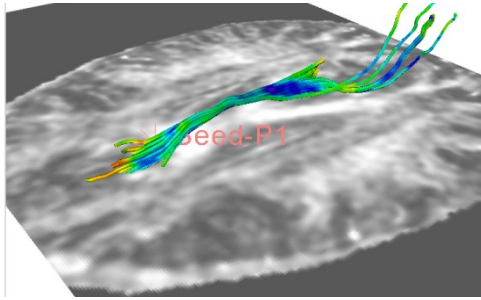


Check the Visibility box.



LabelMap Seeding





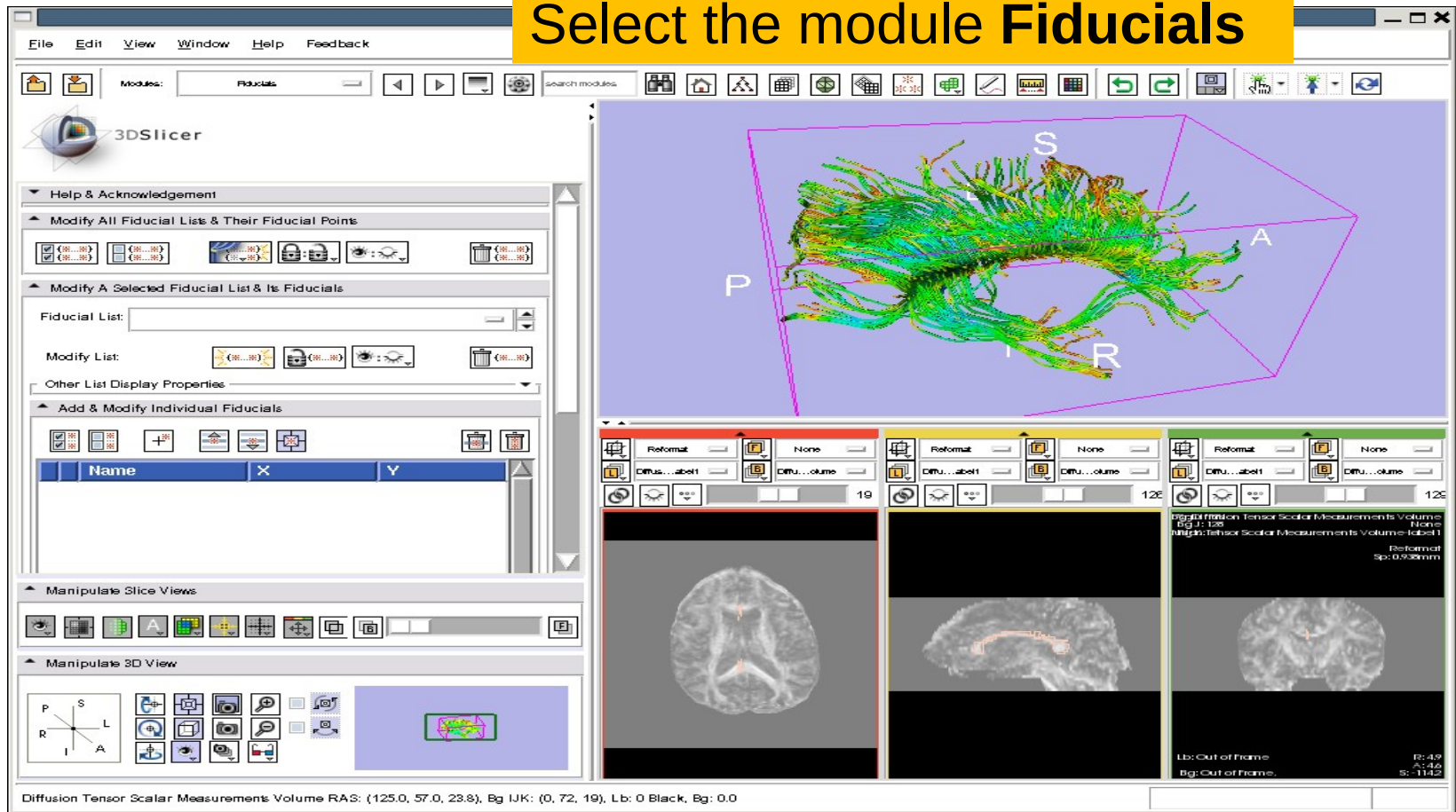
Part 4:

**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 Points'. 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

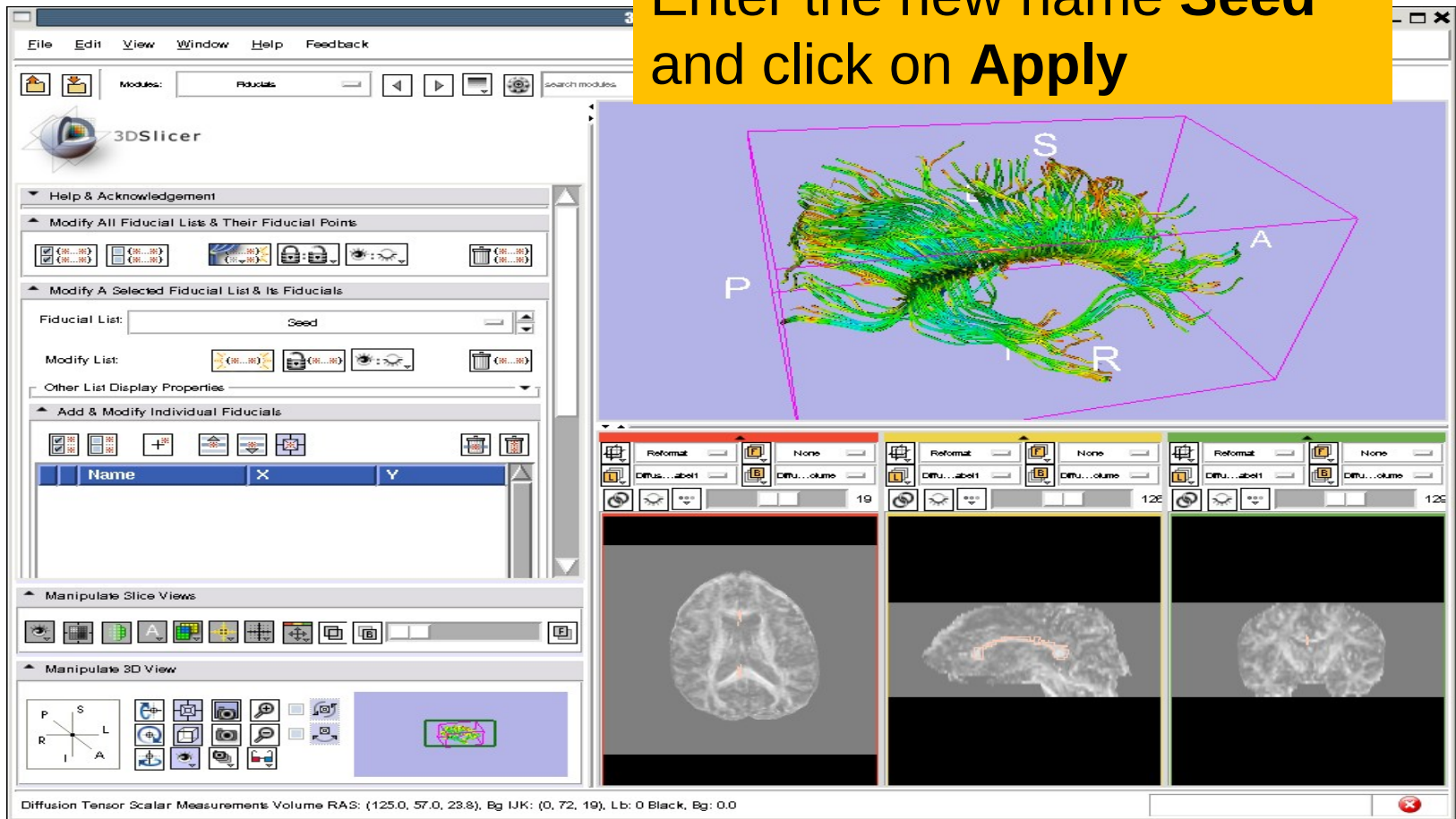
Left click on **FiducialList** and select **Rename**

The screenshot displays the 3DSlicer software interface. On the left, the 'FiducialList' panel is visible, showing a table with columns for 'Name', 'X', and 'Y'. The 'FiducialList' dropdown menu is open, and the 'Rename' option is highlighted. The main 3D view shows a brain model with several green fiducial points and a purple wireframe box. The points are labeled with letters: P (Posterior), S (Superior), I (Inferior), R (Right), and A (Anterior). The bottom of the interface shows three slice views (axial, sagittal, and coronal) and a status bar with coordinates: '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

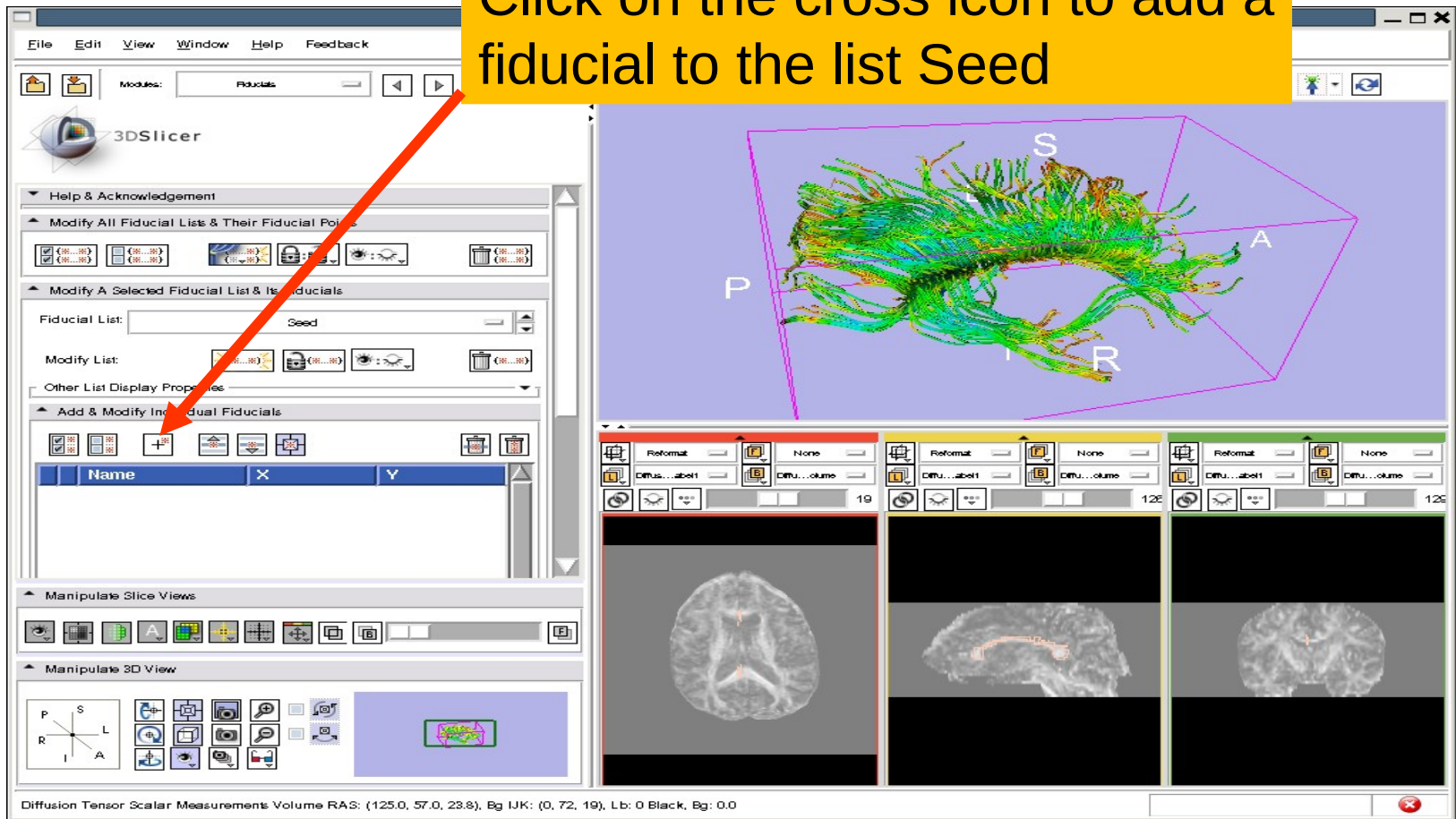
Enter the new name **Seed** and click on **Apply**





Fiducial Seeding

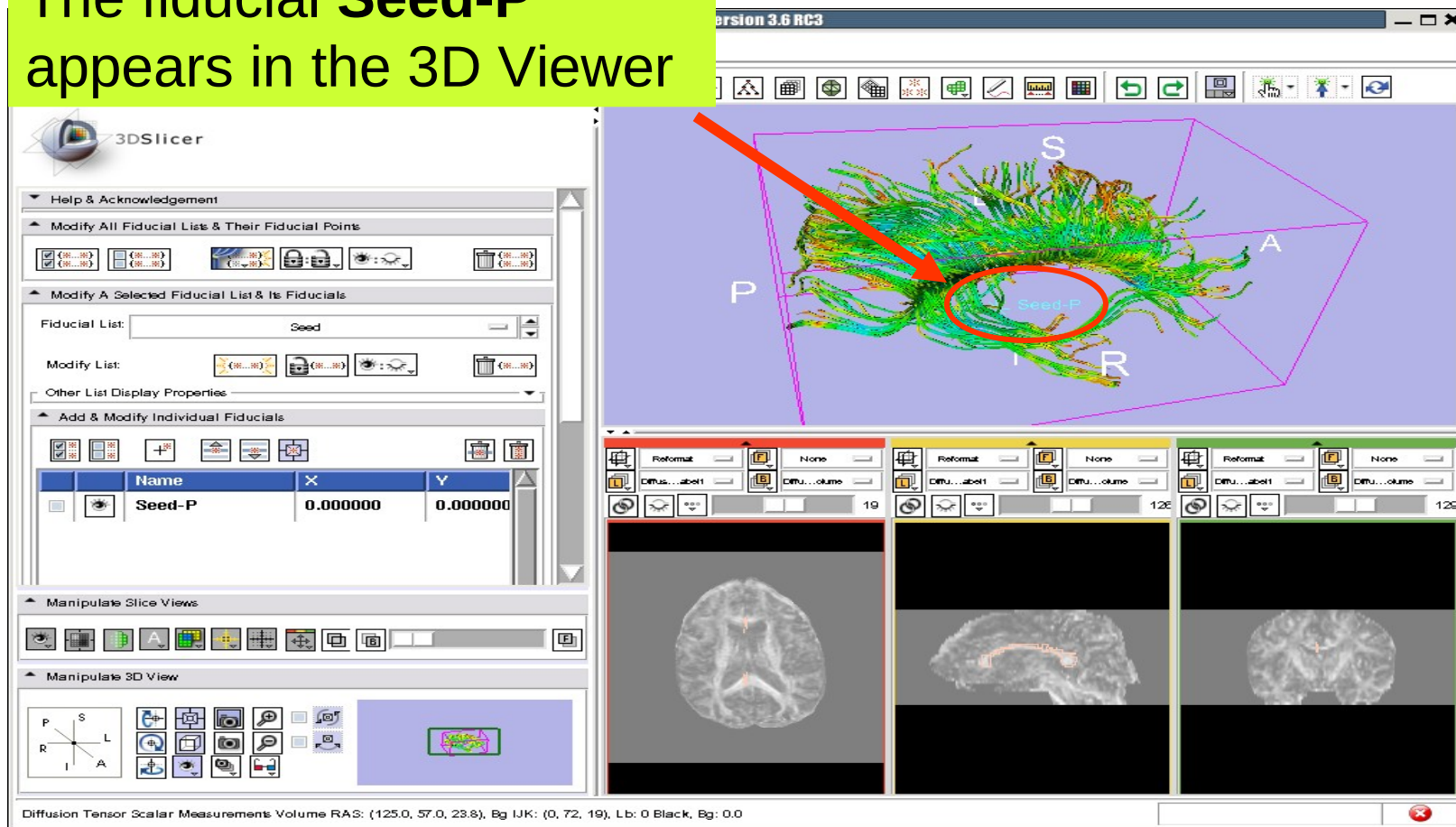
Click on the cross icon to add a fiducial to the list Seed





Fiducial Seeding

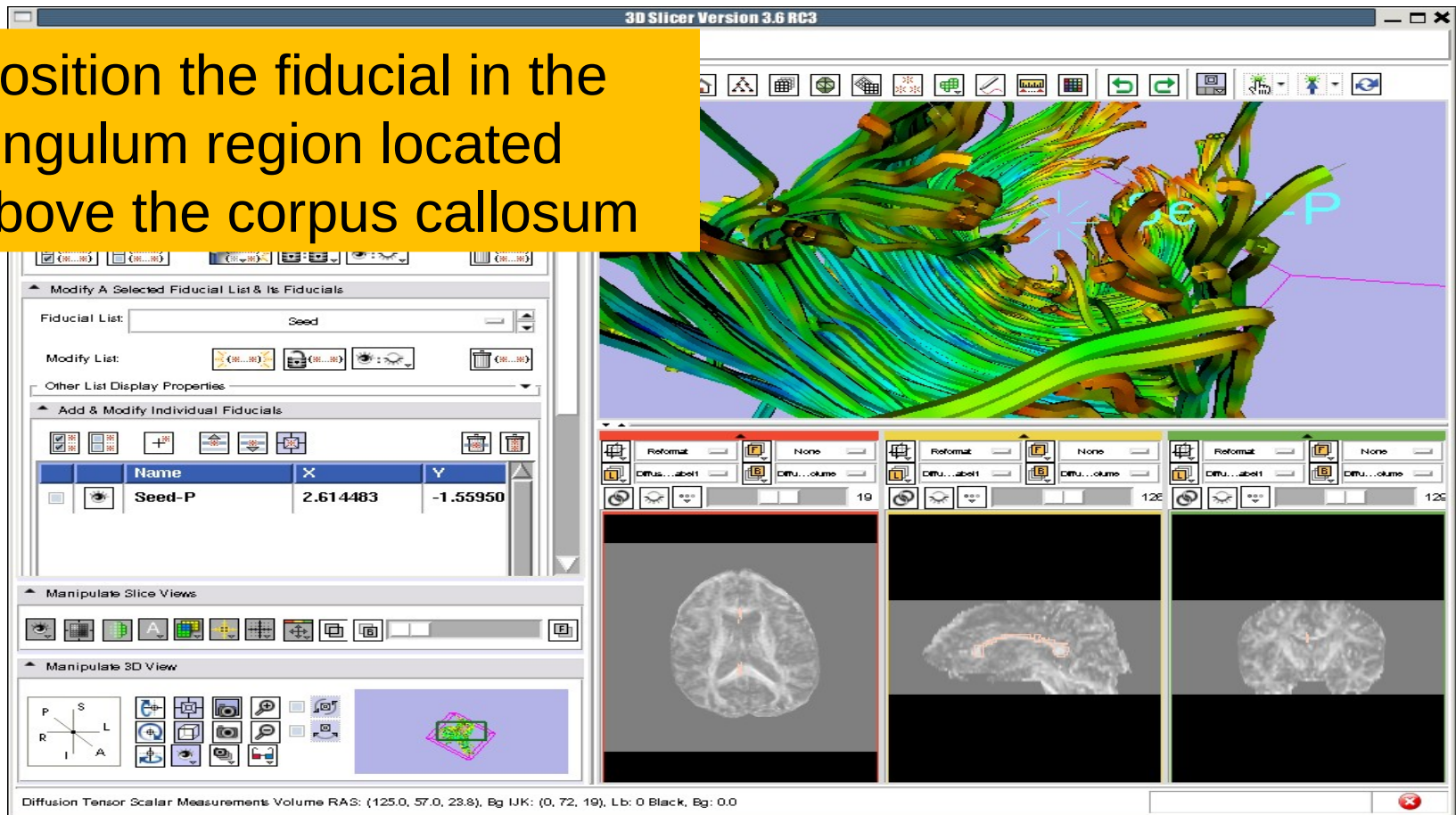
The fiducial **Seed-P** appears in the 3D Viewer





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 tracts in a brain, with a red 'P' label indicating the seed point. The control panel on the left is divided into several sections:

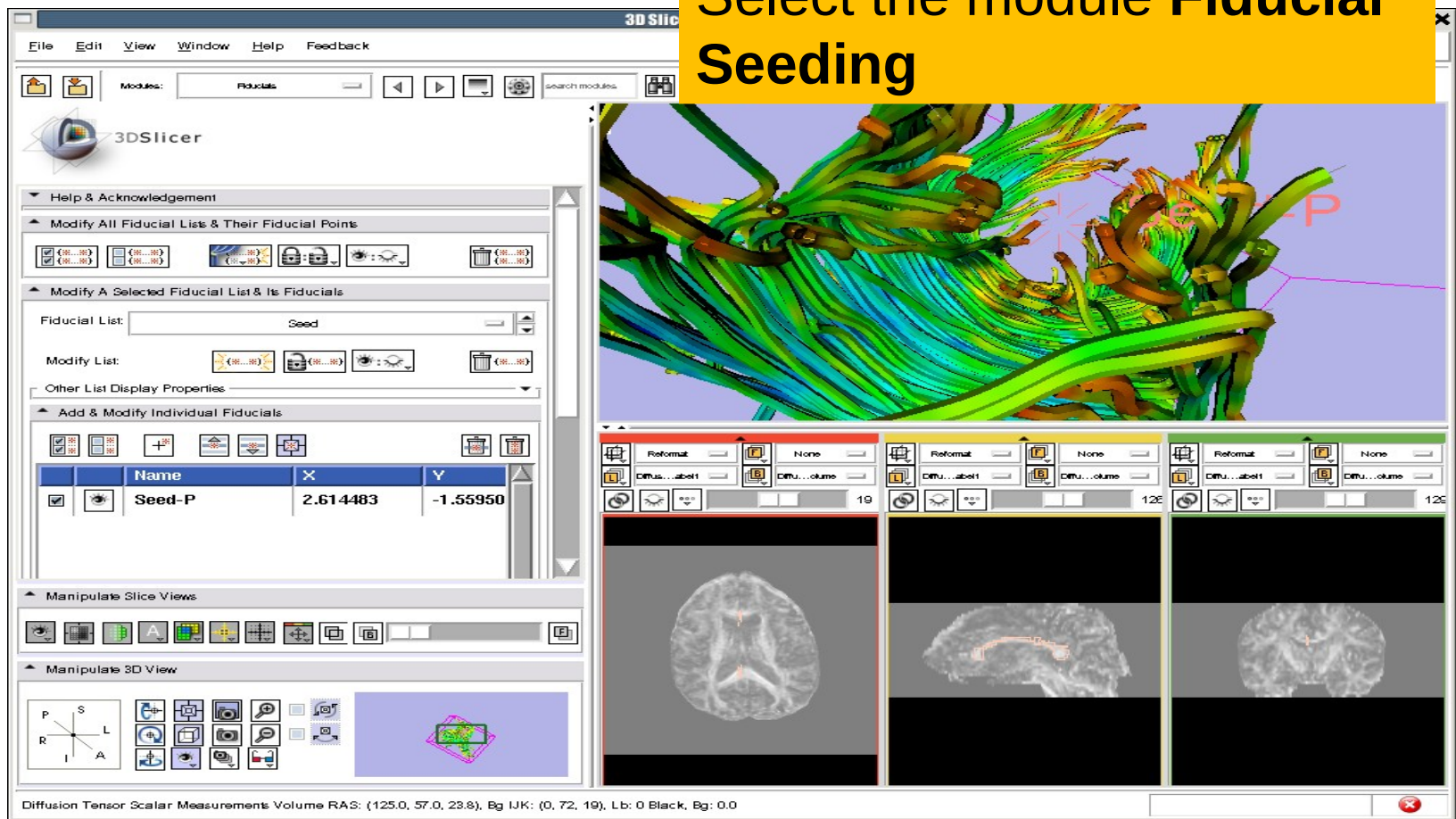
- Modify All Fiducial Lists & Their Fiducial Points**: Contains various icons for list management.
- Modify A Selected Fiducial List & Its Fiducials**: Shows the selected list 'Seed' and options to modify it.
- Add & Modify Individual Fiducials**: A table with columns for Name, X, and Y coordinates. The 'Seed-P' fiducial is selected, with X=2.614483 and Y=-1.55950.
- Manipulate Slice Views**: Contains icons for viewing and manipulating slice views.
- Manipulate 3D View**: Contains icons for manipulating the 3D view and a small 3D preview window.

The bottom status bar displays: 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

Modules: FiducialSeeding

3DSlicer

Help & Acknowledgement

Tractography Seeding From Fiducial

Parameters Parameters

Select DTI Volume: Diffusion Tensor Estimation Volume

Select Fiducial List or Model: None

Output FiberBundleNode: Labelmap Seeding Model

Stopping Mod: Linear Measure

Stopping Value: 0.25

Stopping Track Curvature: 0.7

Integration Step Length (mm): 0.5

Minimum Path Length (mm): ∞

Manipulate Slice Views

Manipulate 3D View

Diffusion Tensor Scalar Measurements Volume RAS: (-93.2, 5.5, -114.8), Lb: Slice not shown , Bg: Slice not shown.

Lb: 0 Back Bg: 0.8	R: -21.4 A: -40.0 S: 20.8	Lb: Out of frame Bg: Out of frame	R: 7.8 A: 124.1 S: -30.2	Lb: Slice not shown Bg: Slice not shown	R: -93.2 A: 5.5 S: -114.8
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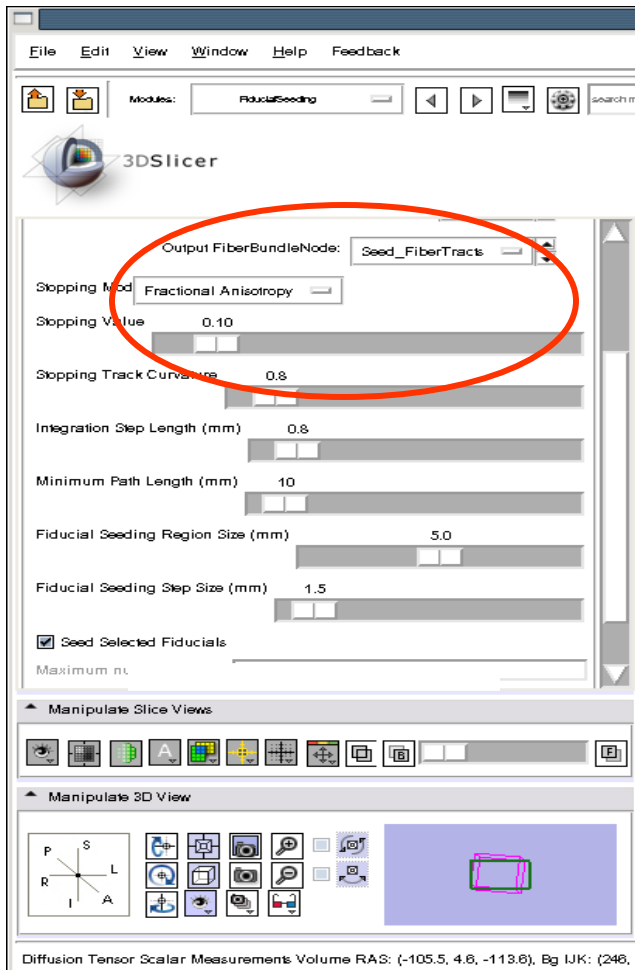
Set the DTI Volume to **Diffusion Tensor Estimation Volume**

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

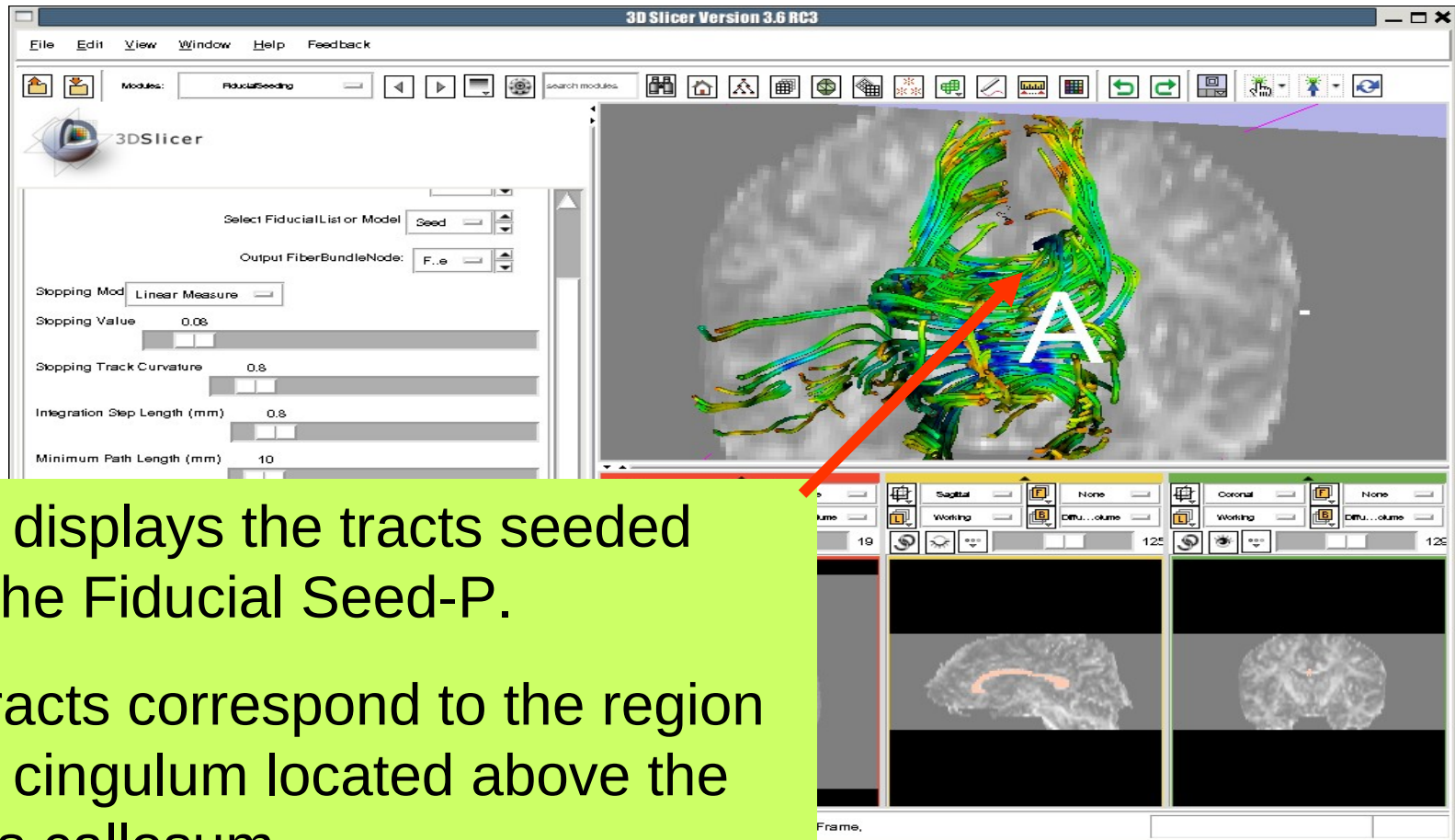
Step Length: 0.8 mm

Minimum Path Length: 10 mm

Fiducial Stepping Size: 1.5 mm



Fiducial Seeding



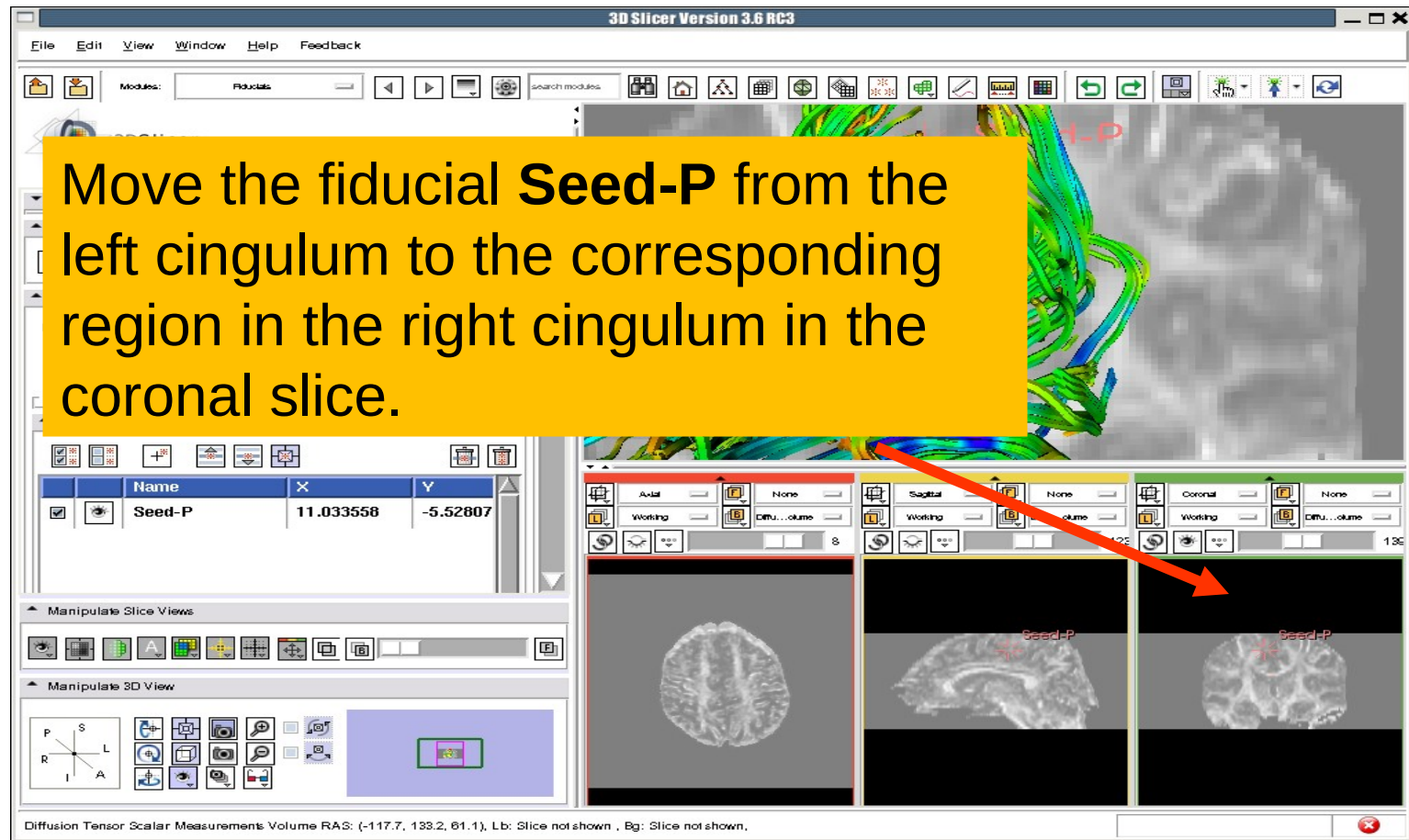
Slicer displays the tracts seeded from the Fiducial Seed-P.

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



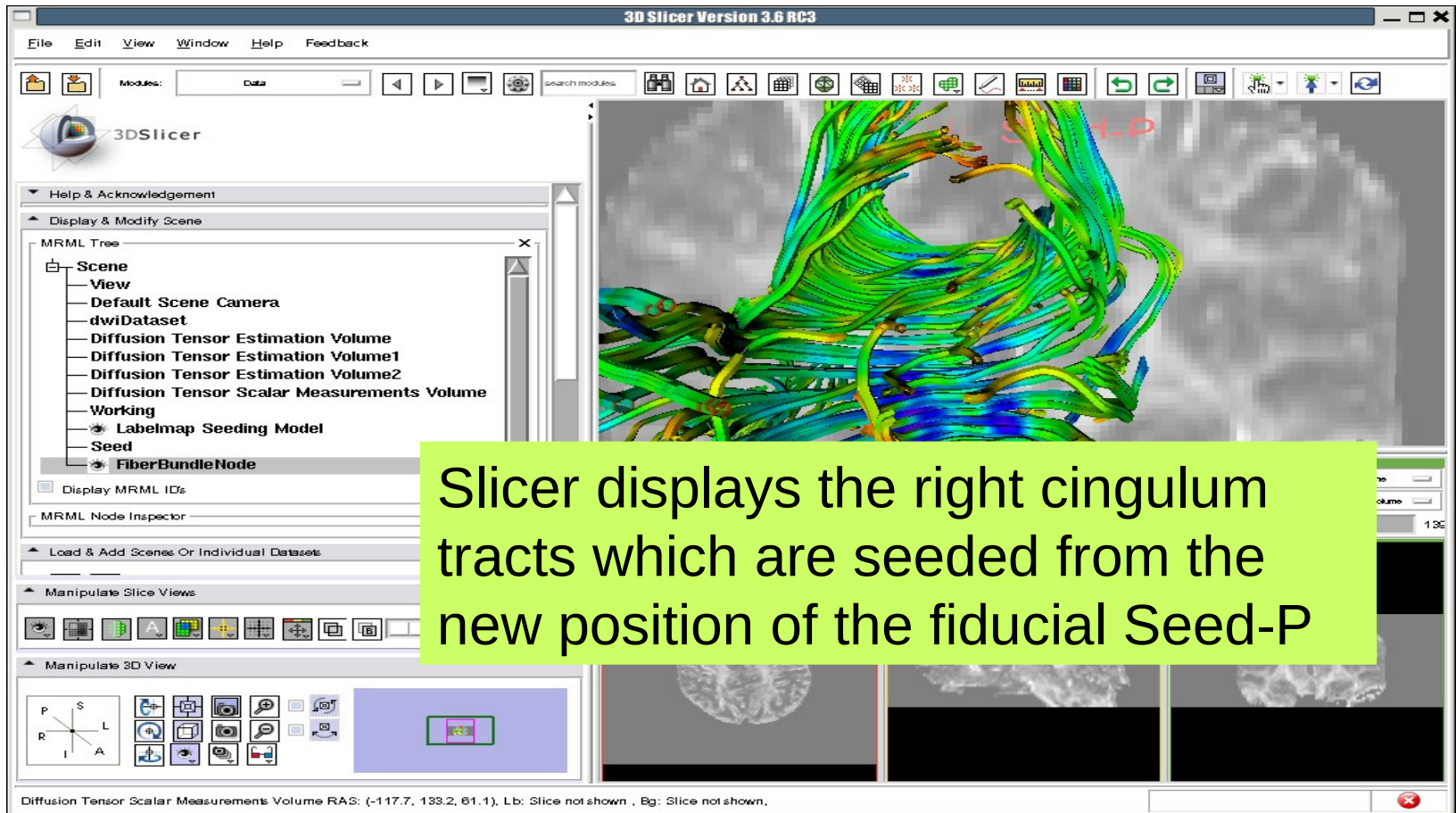
Fiducial Seeding

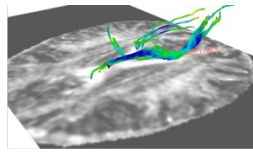
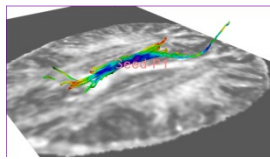
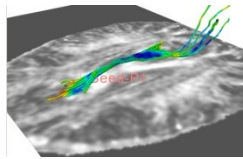
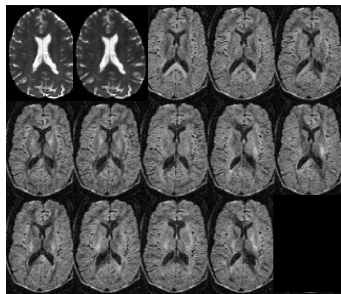
Move the fiducial **Seed-P** from the left cingulum to the corresponding region in the right cingulum in the coronal slice.





Fiducial Seeding





Part 5:

Saving a DTI Scene



DTI Scene

The screenshot shows the 3D Slicer Version 3.6 RC3 interface. The 'Data' module is selected in the top toolbar, highlighted by a red circle. A yellow callout box points to this selection with the text 'Select the module Data'. The MRML Tree on the left lists the following items: 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, and FiberBundleNode. A green callout box points to this list with the text 'Slicer displays the list of volumes and models generated in this tutorial'. The main 3D view shows a bundle of green and blue fiber-like structures. Below the 3D view are three slice views: an axial slice, a sagittal slice, and a coronal slice, both showing red 'Seed-P' markers. The status bar at the bottom indicates 'Diffusion Tensor Scalar Measurements Volume RAS: (-117.7, 133.2, 61.1), Lb: Slice not shown, Bg: Slice not shown.'



Saving a DTI Scene

Select File → Save from the main menu

3D Slicer Version 3.6 RC3

File Edit View Window Help Feedback

MRML Tree

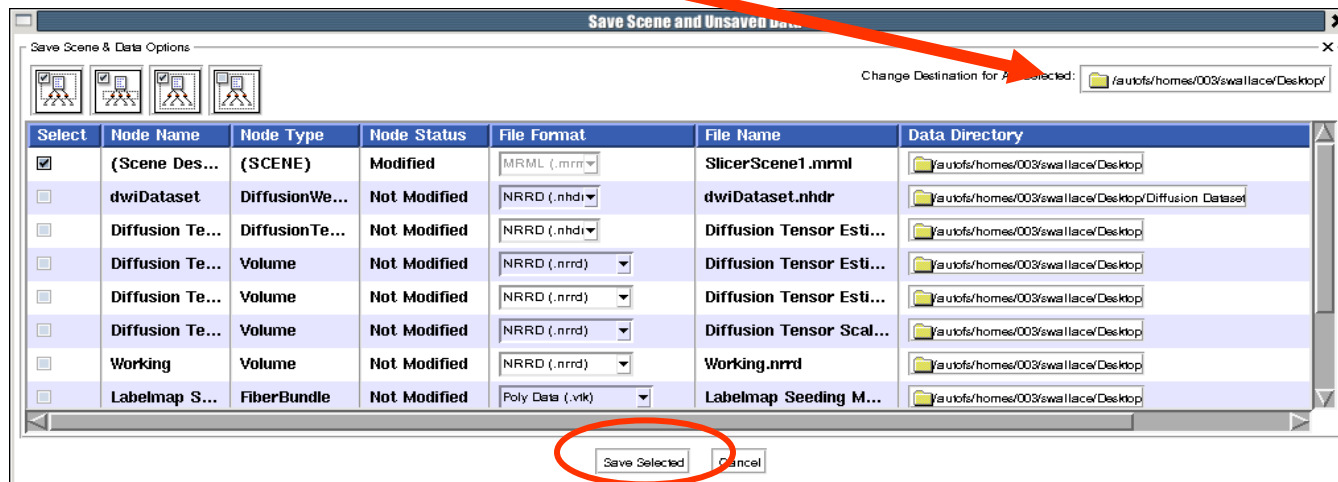
- Scene
 - View
 - Default Scene Camera
 - dwiDataset
 - Diffusion Tensor Es in Volume
 - Diffusion Tensor Estimation Volume1
 - Diffusion Tensor Es imation Volume2
 - Diffusion Tensor Scalar Measurements Volume Working
 - Labelmap Seeding Model
 - Seed
 - FiberBundleNode

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



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

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

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

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

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

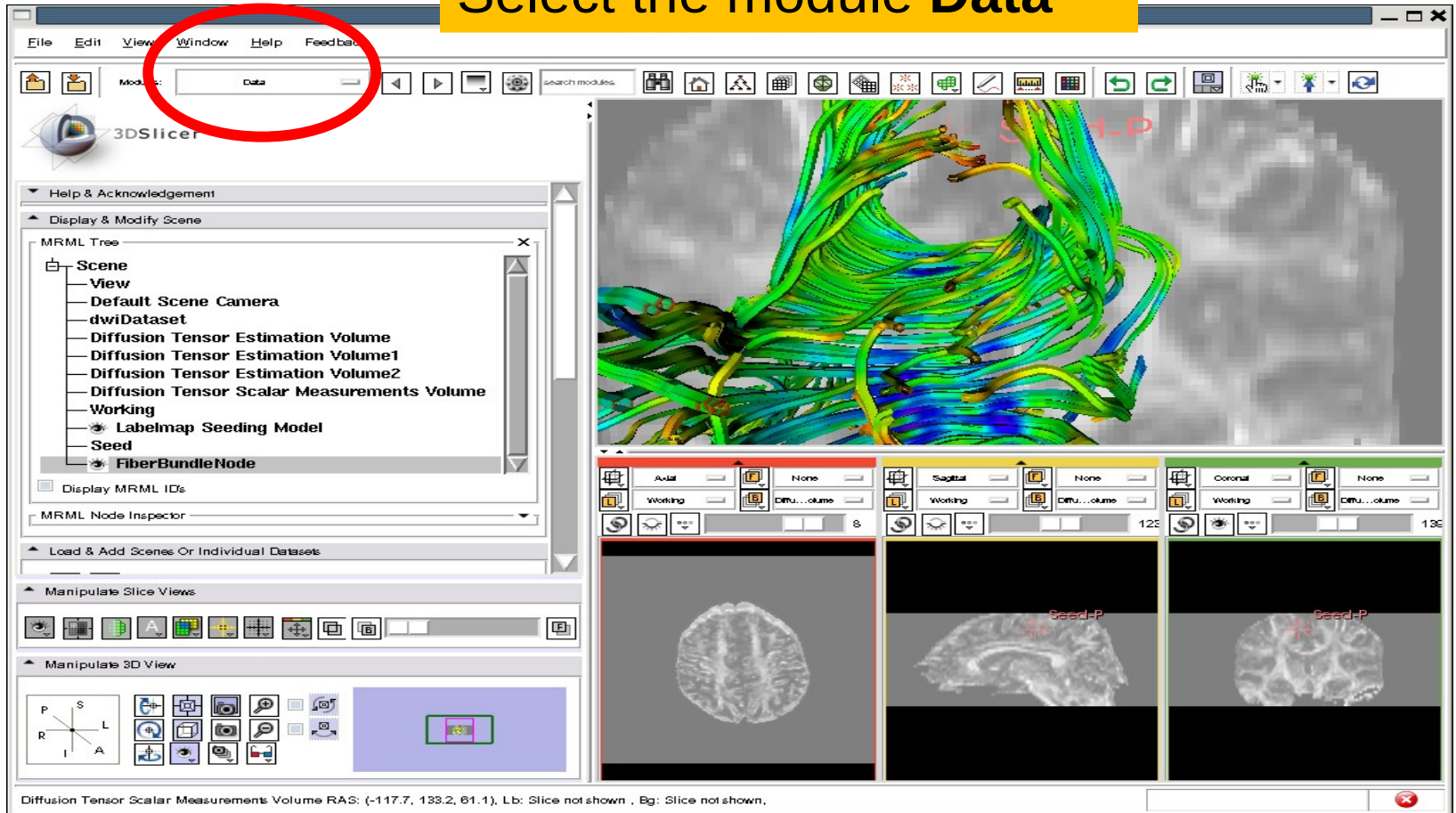
File name: SlicerScene1.mrml
Files of type: Scenes (.mrml;.mrml;.mri;.mib)

None RAS: (87.3, 1.0, -125.0)



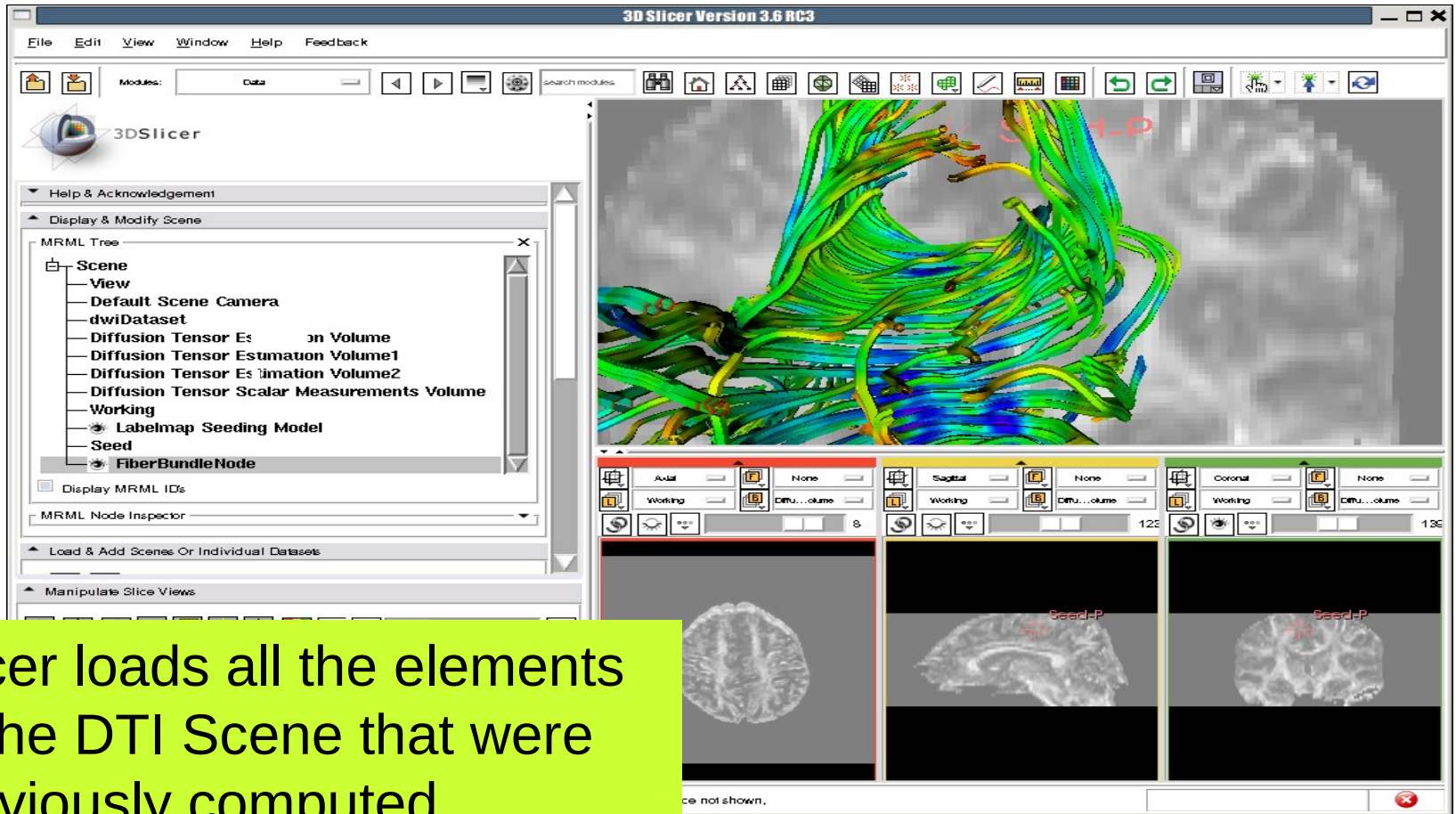
Loading a DTI Scene

Select the module **Data**





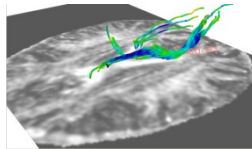
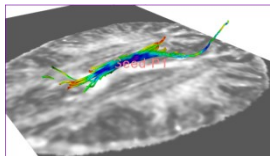
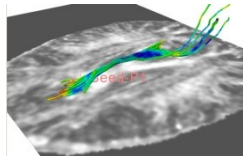
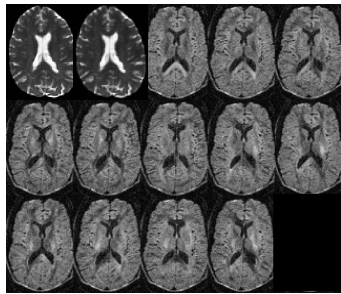
Loading a DTI Scene



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



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