



Exploring Peritumoral White Matter Fibers for Neurosurgical Planning

Sonia Pujol, Ph.D.

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Harvard University

Clinical Goal

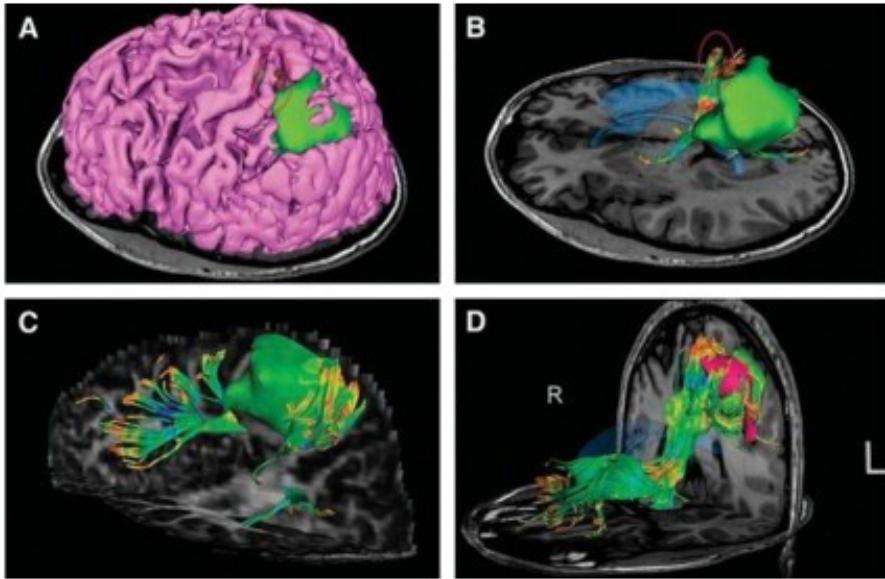
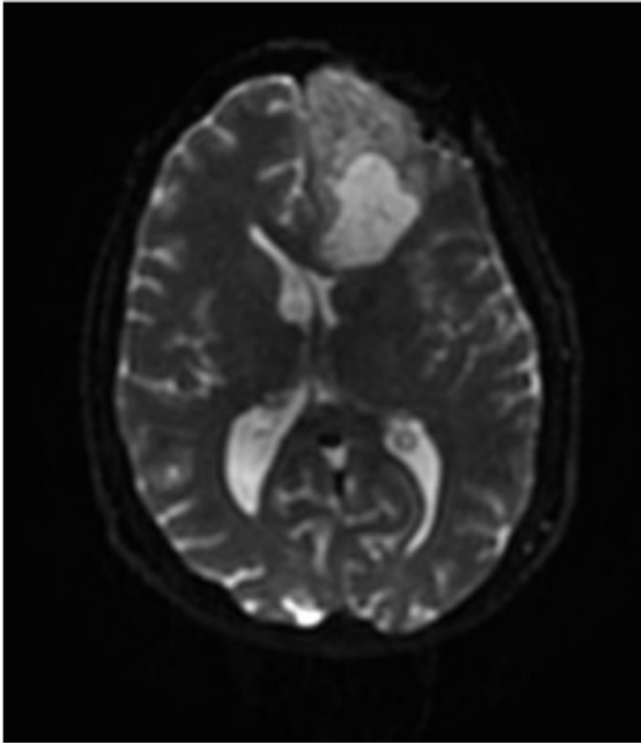


Image Courtesy of Dr. Alexandra Golby, Brigham and Women's Hospital, Boston, MA..

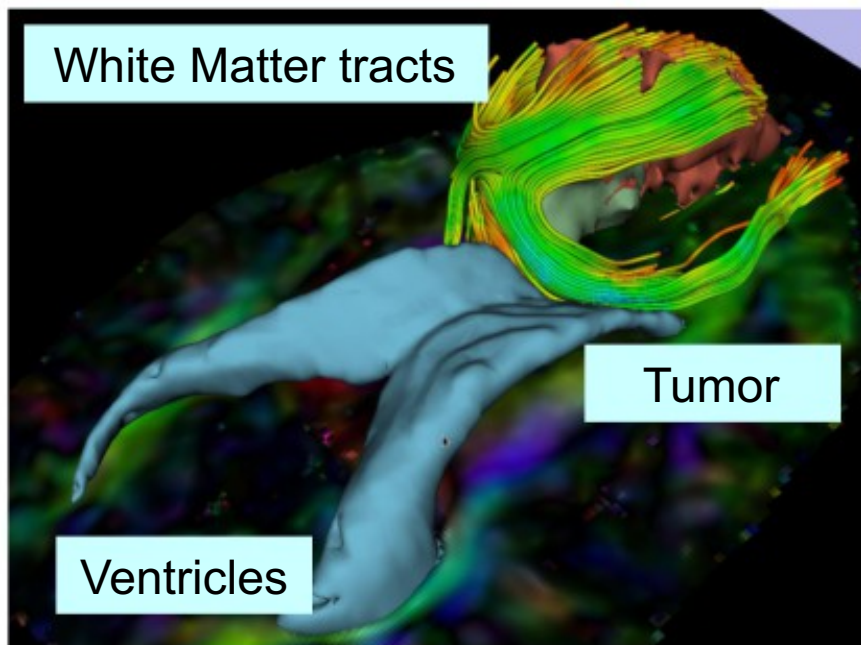
Diffusion Tensor Imaging (DTI) Tractography has the potential to bring valuable spatial information on tumor infiltration and tract displacement for neurosurgical planning of tumor resection.

Clinical Case

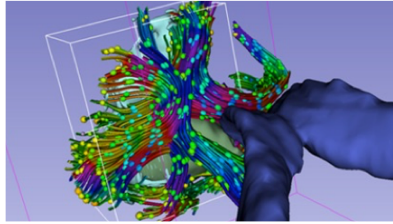


- 35 year-old male diagnosed with Glioblastoma multiform (GBM)
- Diffusion Weighted Imaging (DWI) acquisition for neurosurgical planning

Clinical Goal



The goal of this tutorial is to explore white matter fibers surrounding a tumor using Diffusion Tensor Imaging (DTI) Tractography.



Slicer DMRI

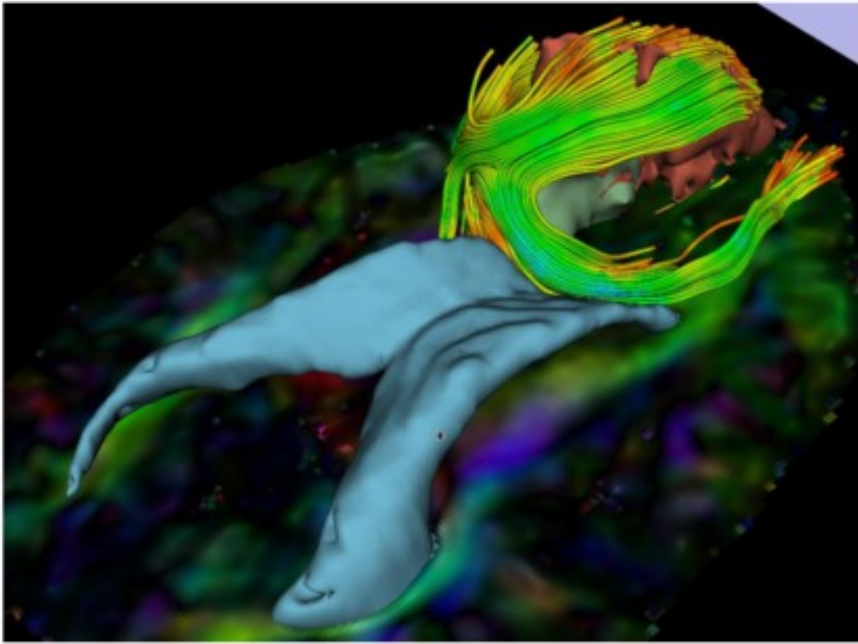
An open-source project to improve and extend diffusion magnetic resonance imaging software in 3D Slicer:

<http://dmri.slicer.org>

Please read the **Diffusion MRI Analysis** tutorial to install SlicerDMRI:

http://dmri.slicer.org/docs/diffusion_mri_analysis

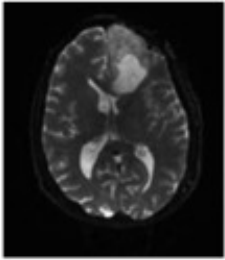
Image Analysis Pipeline



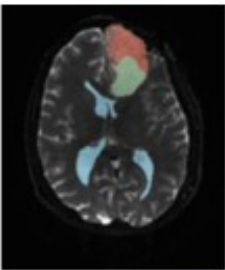
The image analysis pipeline described in this tutorial uses three different algorithms:

- 1) Grow Cut algorithm for segmentation of the tumor parts
- 2) Marching Cube algorithm for surface modeling
- 3) Single tensor streamline tractography algorithm for tract generation.

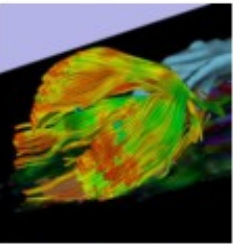
Overview of the analysis pipeline



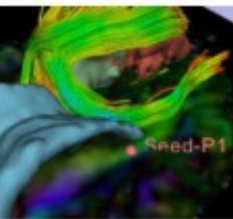
Part 1: Loading & Visualization of Diffusion Data



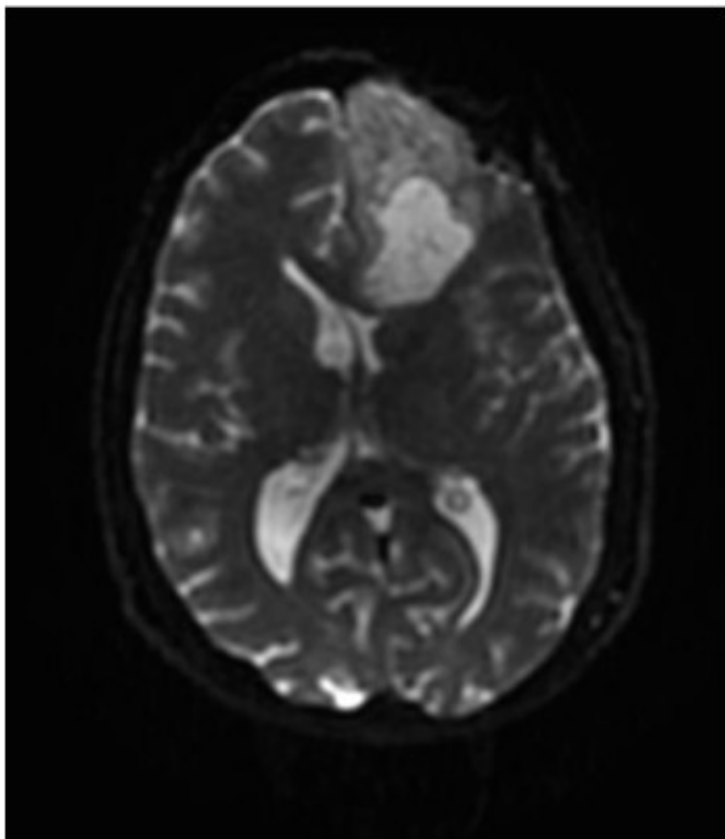
Part 2: Segmentation of lat. ventricles, and solid and cystic parts of the tumor



Part 3: Tractography reconstruction of white matter fibers in the peri-tumoral volume

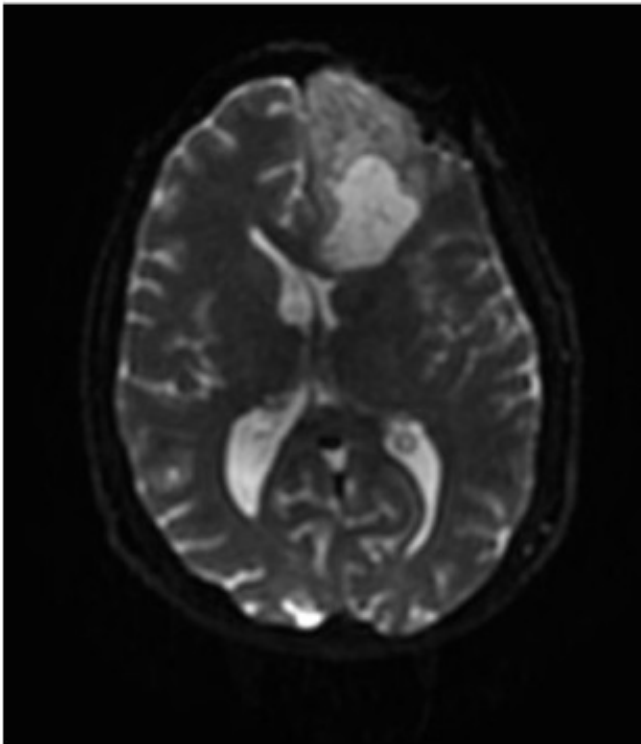


Part 4: Tractography exploration of the ipsilateral and contralateral side



Part 1: Loading and Visualization of Diffusion Data

Diffusion Tensor Imaging



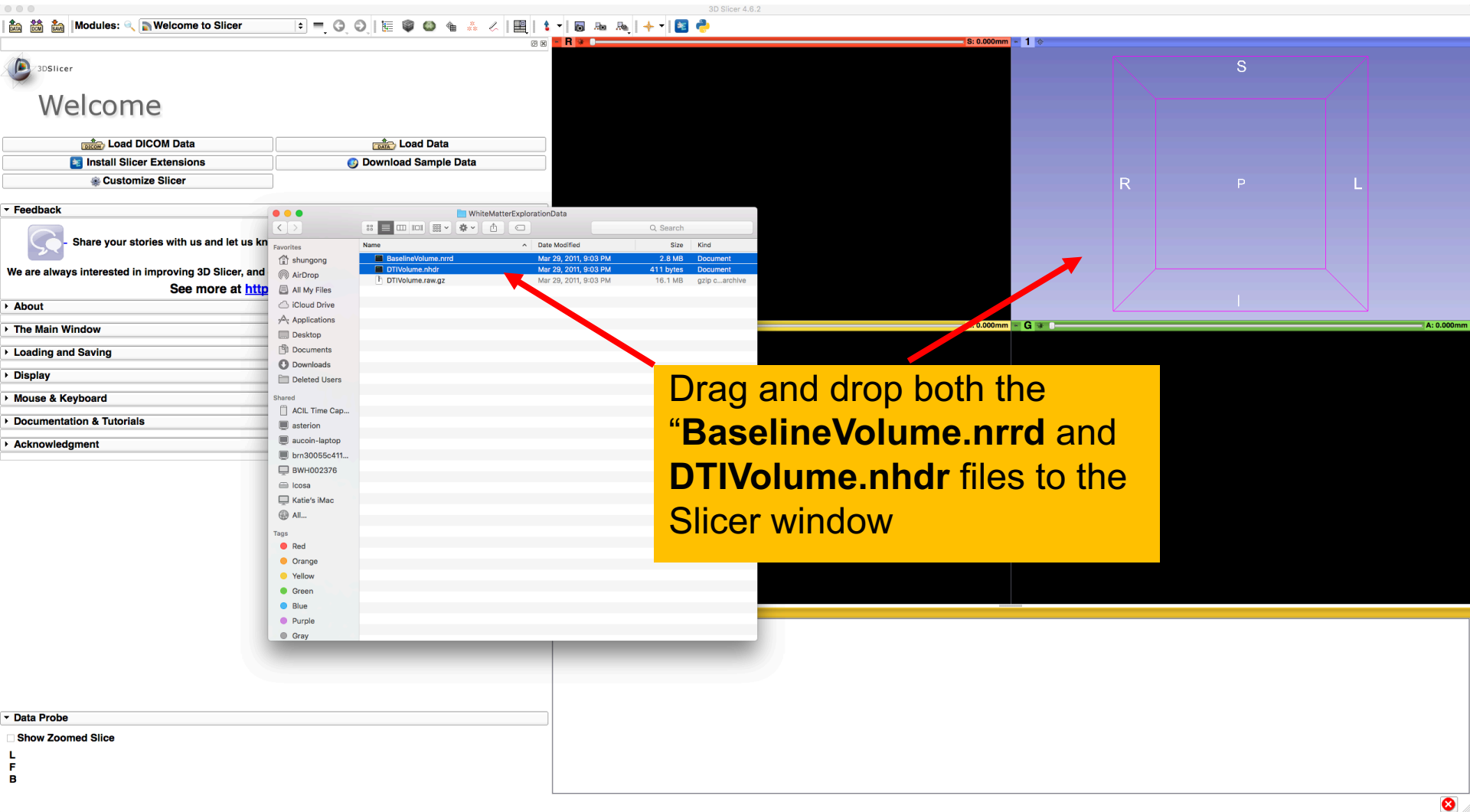
$$S_i = S_0 e^{-b \hat{g}_i^T D \hat{g}_i}$$

(Stejskal and Tanner 1965, Basser 1994)

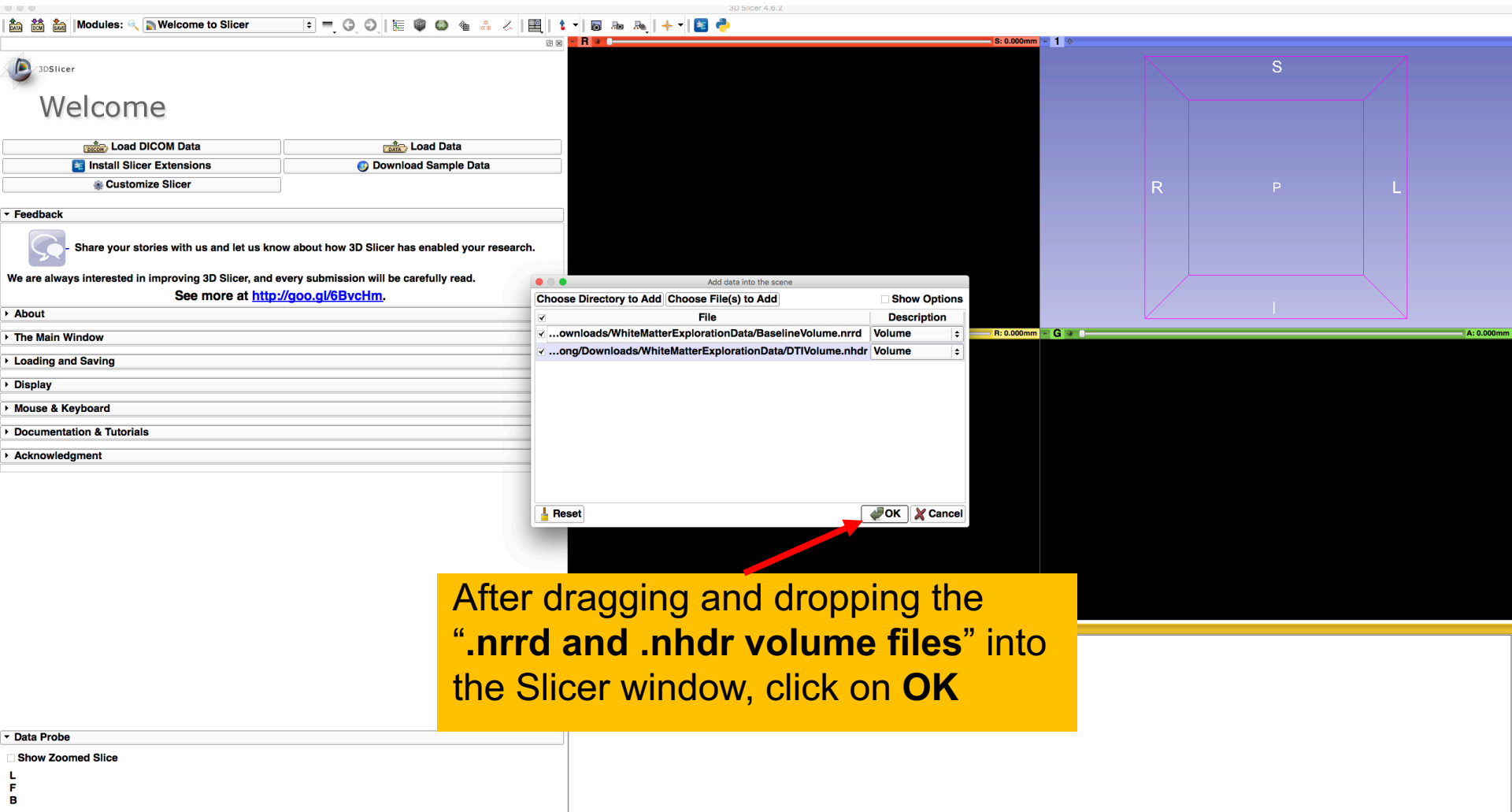
$$\underline{\mathbf{D}} = \begin{bmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{yx} & D_{yy} & D_{yz} \\ D_{zx} & D_{zy} & D_{zz} \end{bmatrix}$$



Loading DTI and Baseline Data

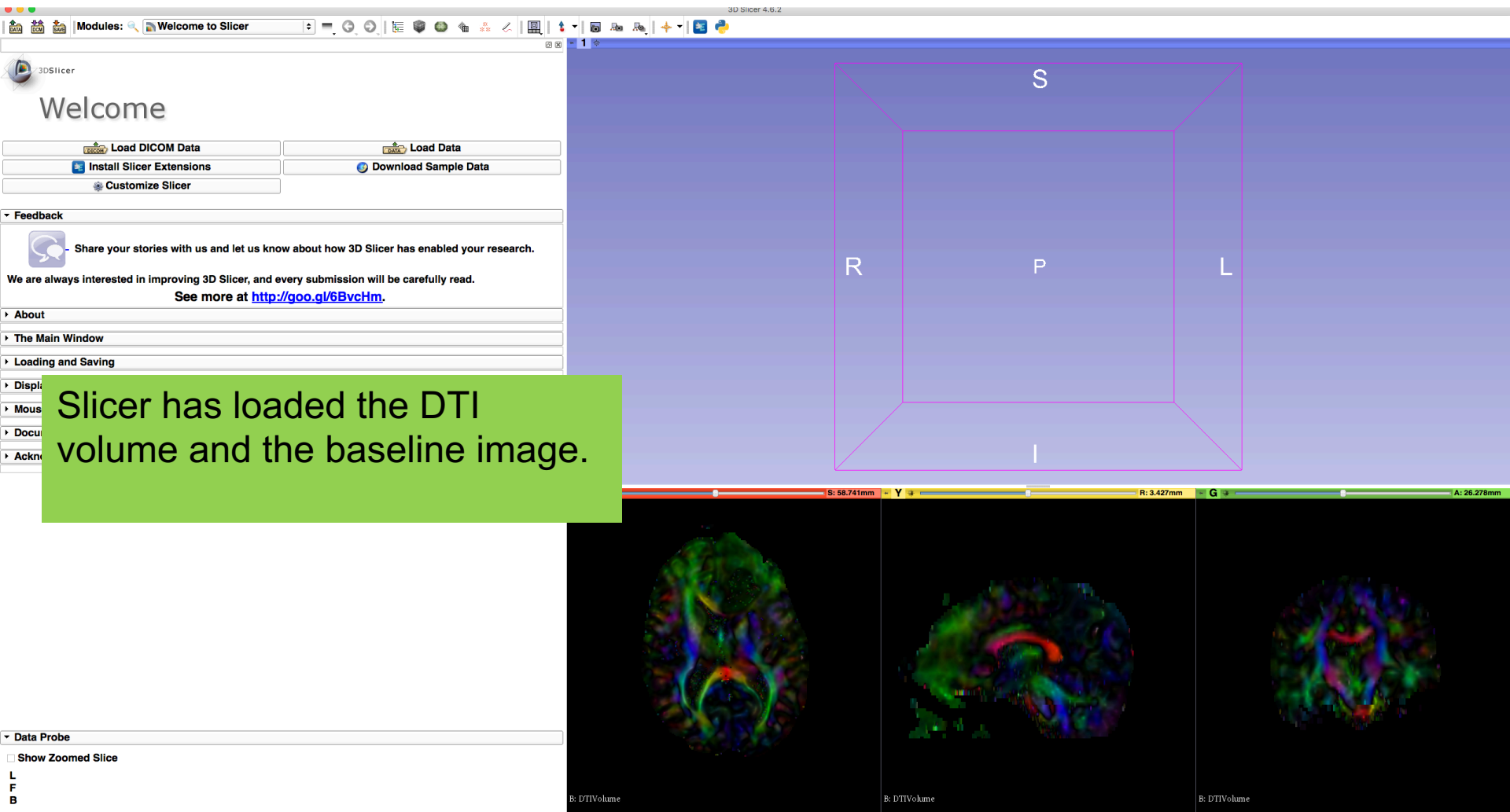


Loading DTI and Baseline Data



After dragging and dropping the
“.nrrd and .nhdr volume files” into
the Slicer window, click on **OK**

Loading DTI and Baseline Data



Loading DTI and Baseline Data

Click on the **pin icon** to display the slice menu, then click on the **link icon** to link the 3 anatomical viewers. Then change the background so it is set to **BaselineVolume**

3DSlicer

We are always

Feedback

About

The Main Window

Loading and

Display

Mouse & Keyboard

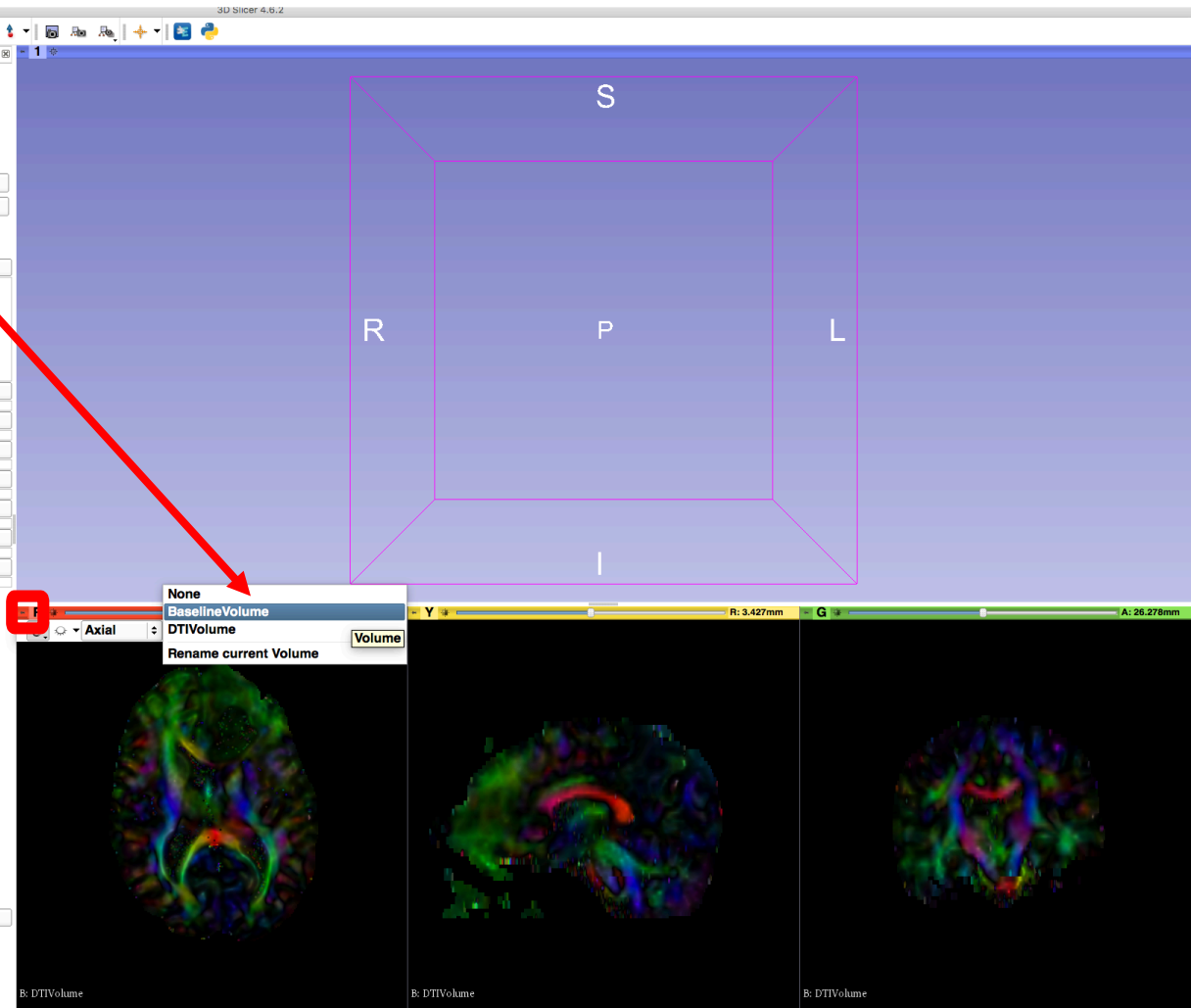
Documentation & Tutorials

Acknowledgment

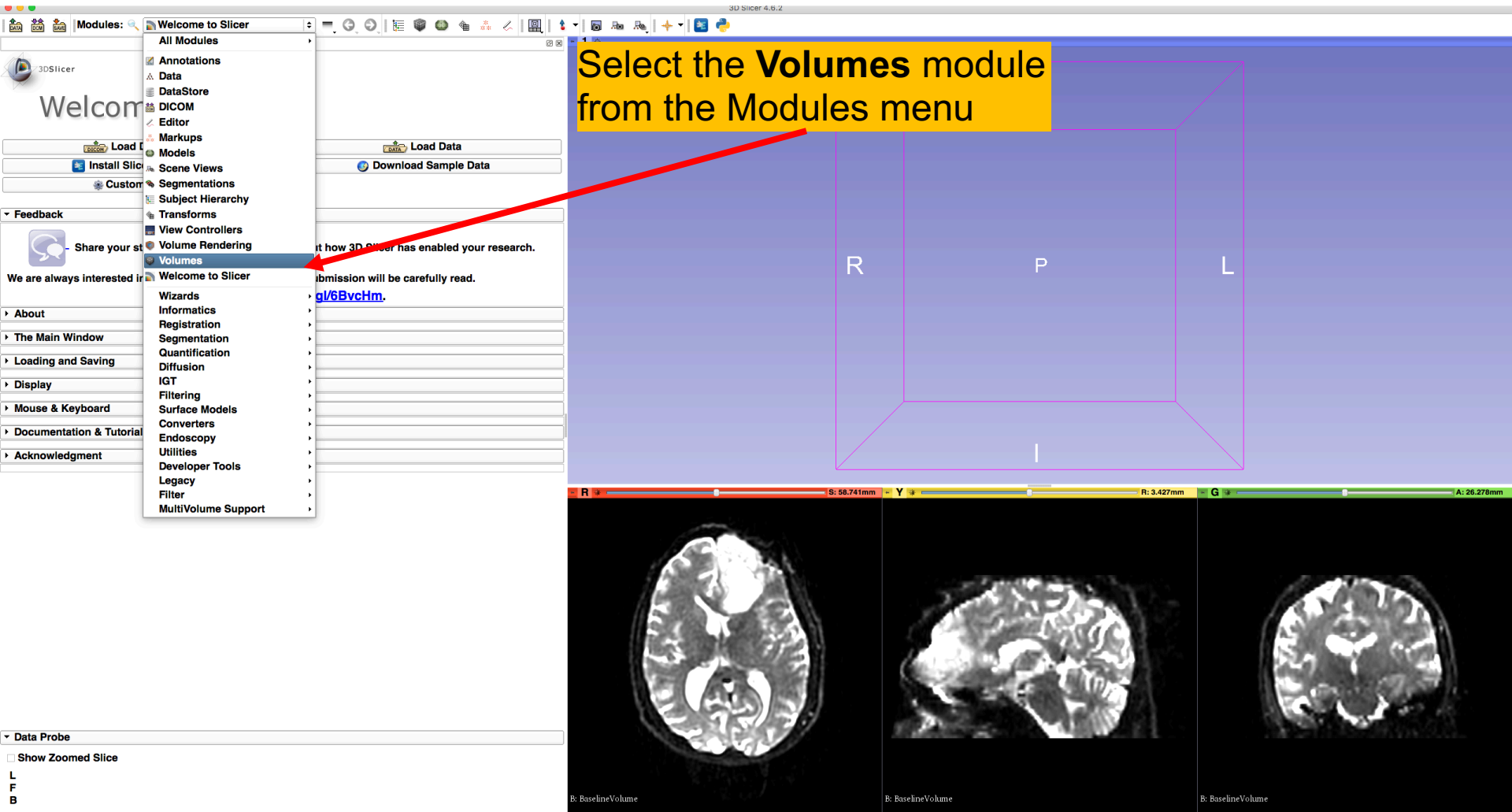
Data Probe

Show Zoomed Slice

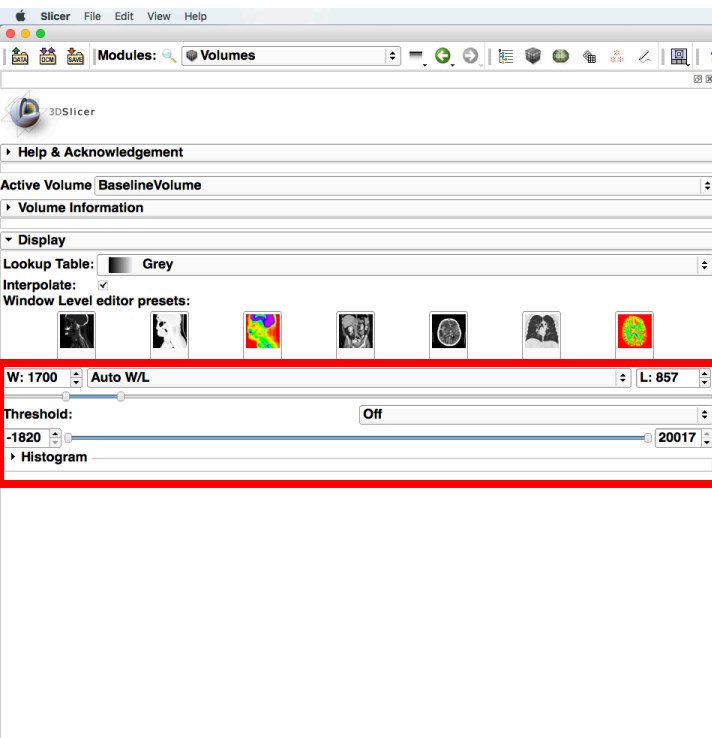
L
F
B



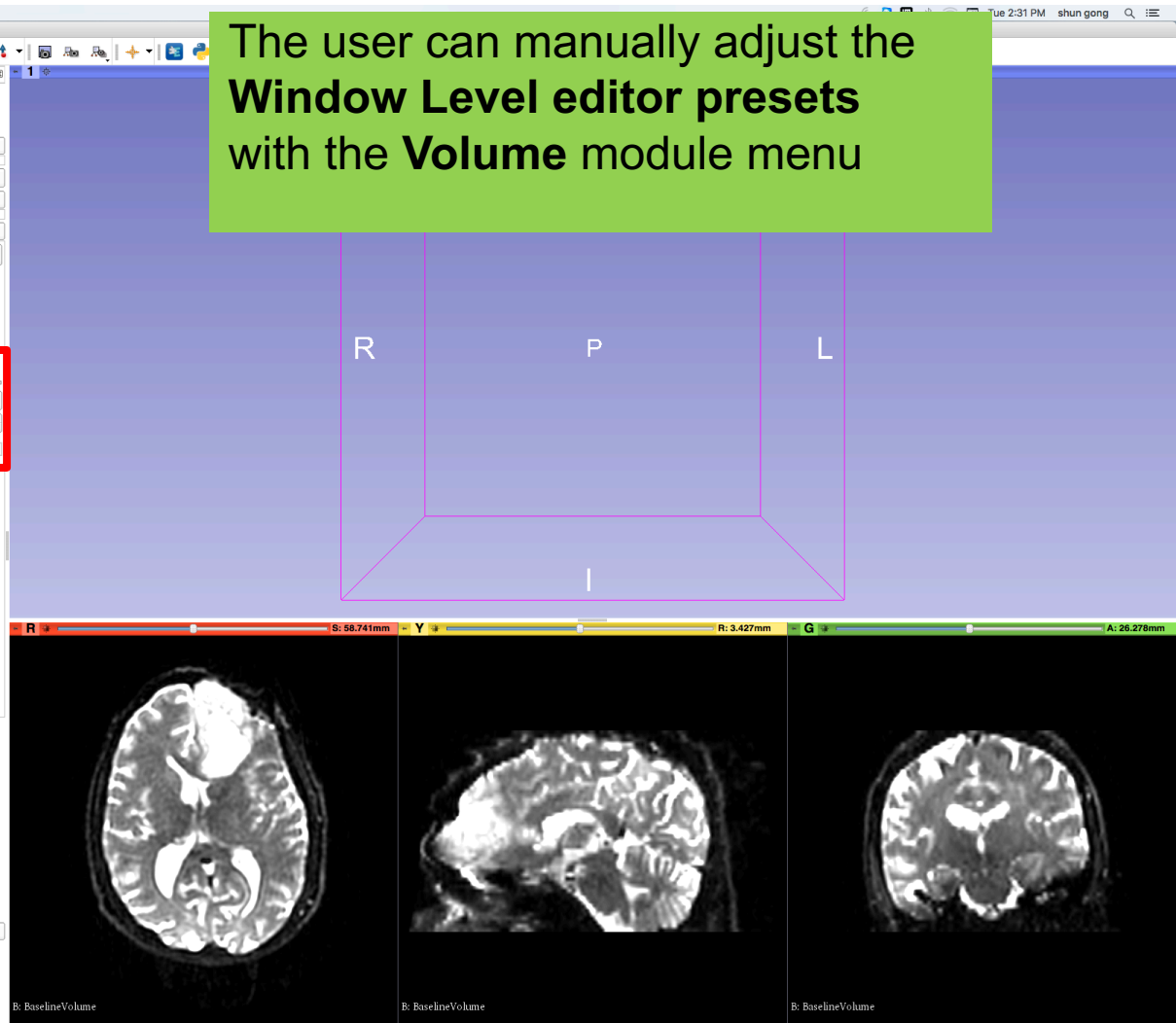
Loading DTI and Baseline Data



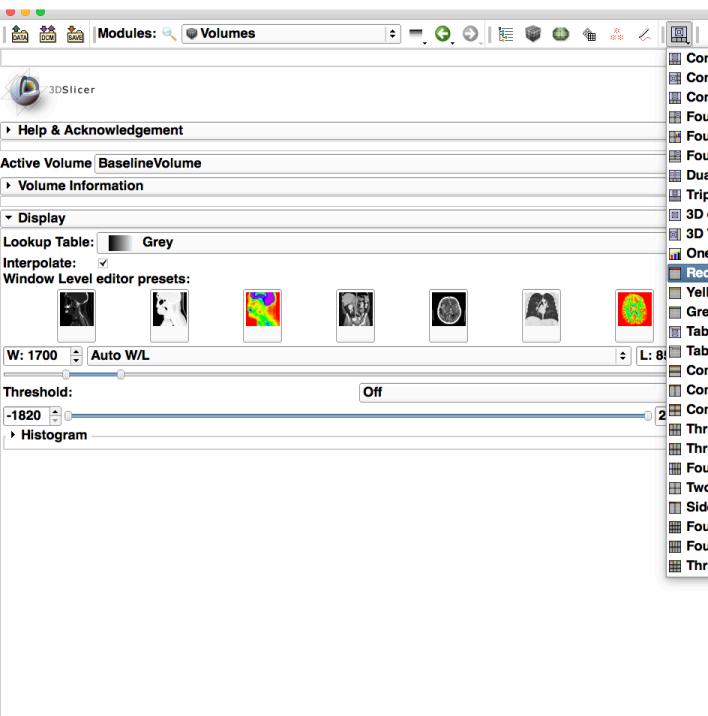
Loading DTI and Baseline Data



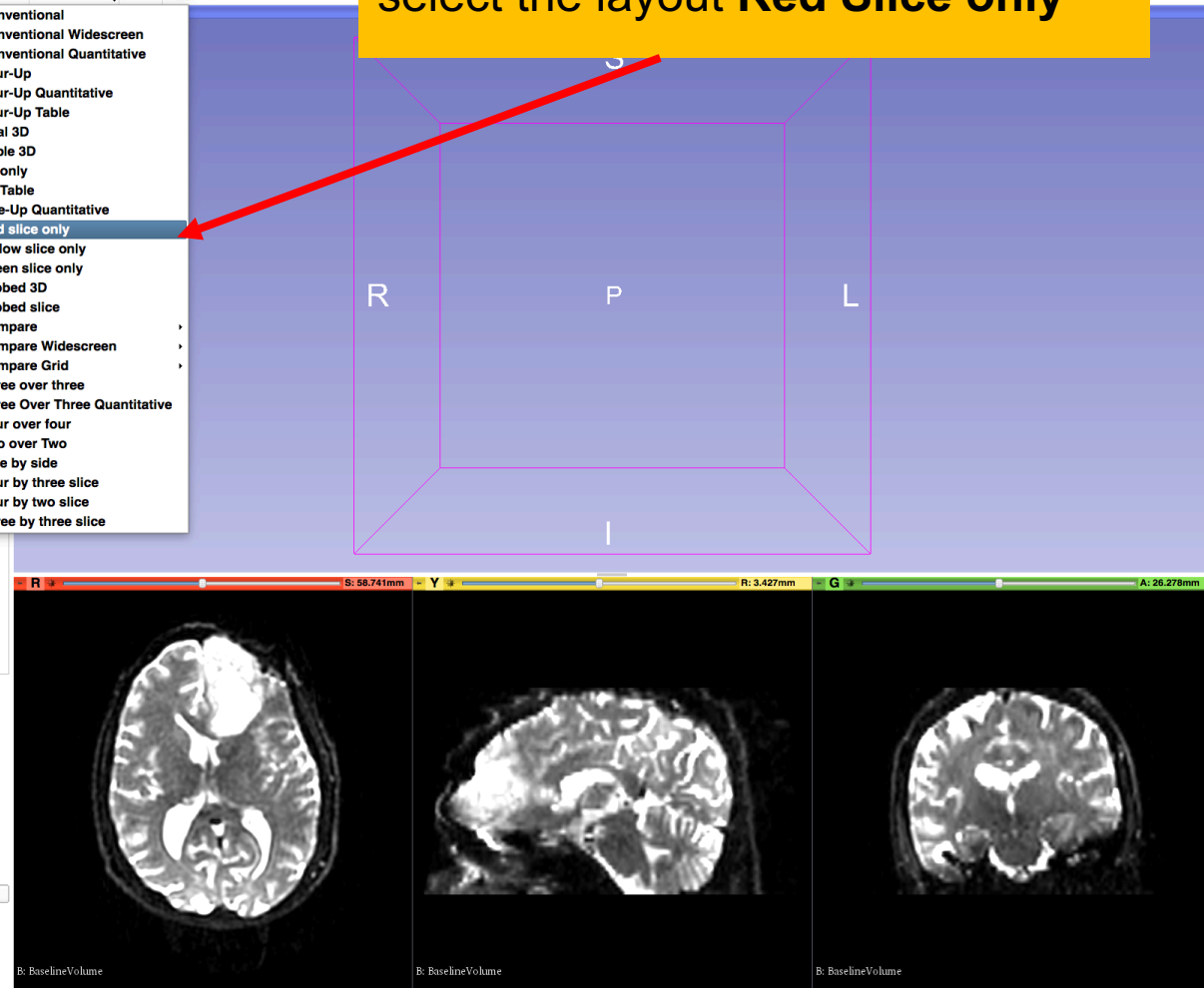
The user can manually adjust the **Window Level editor presets** with the **Volume** module menu

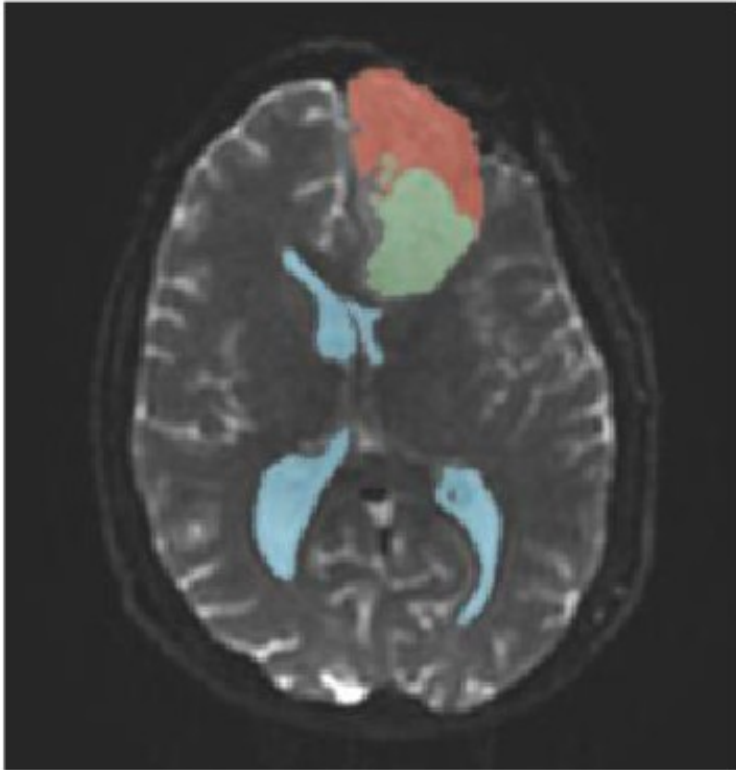


Loading DTI and Baseline Data



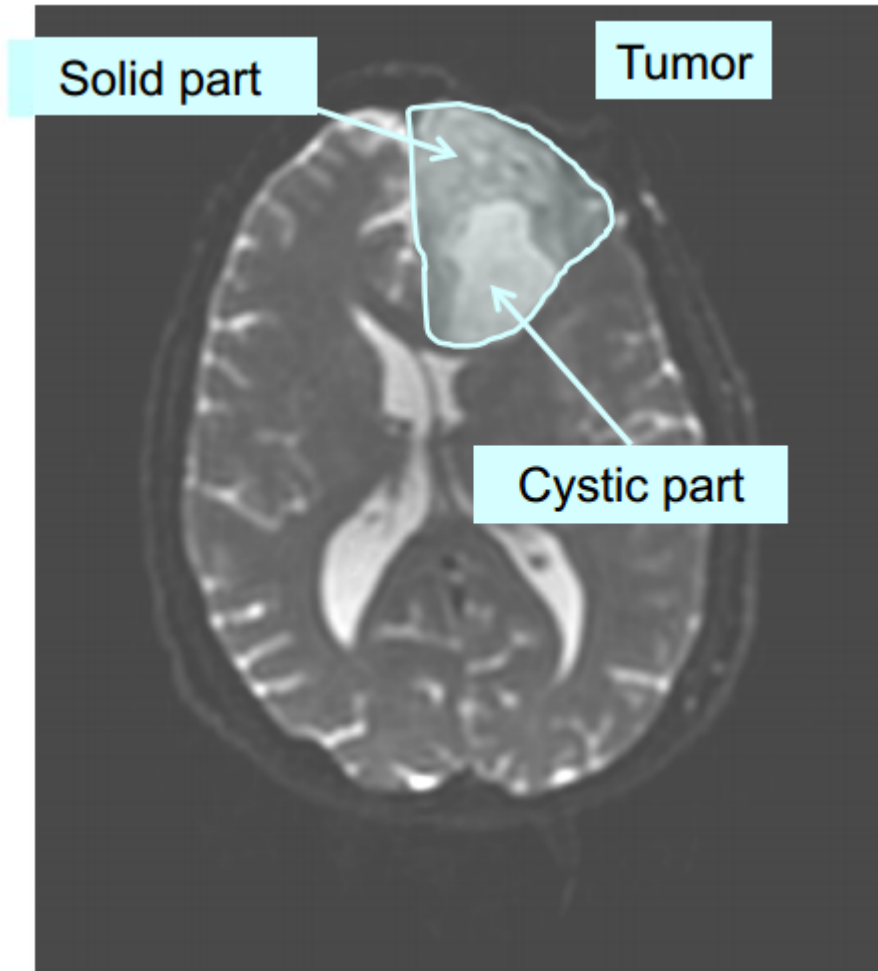
Click on the **Layout** menu and select the layout **Red Slice only**





Part 1:
Segmenting the
tumor and ventricles

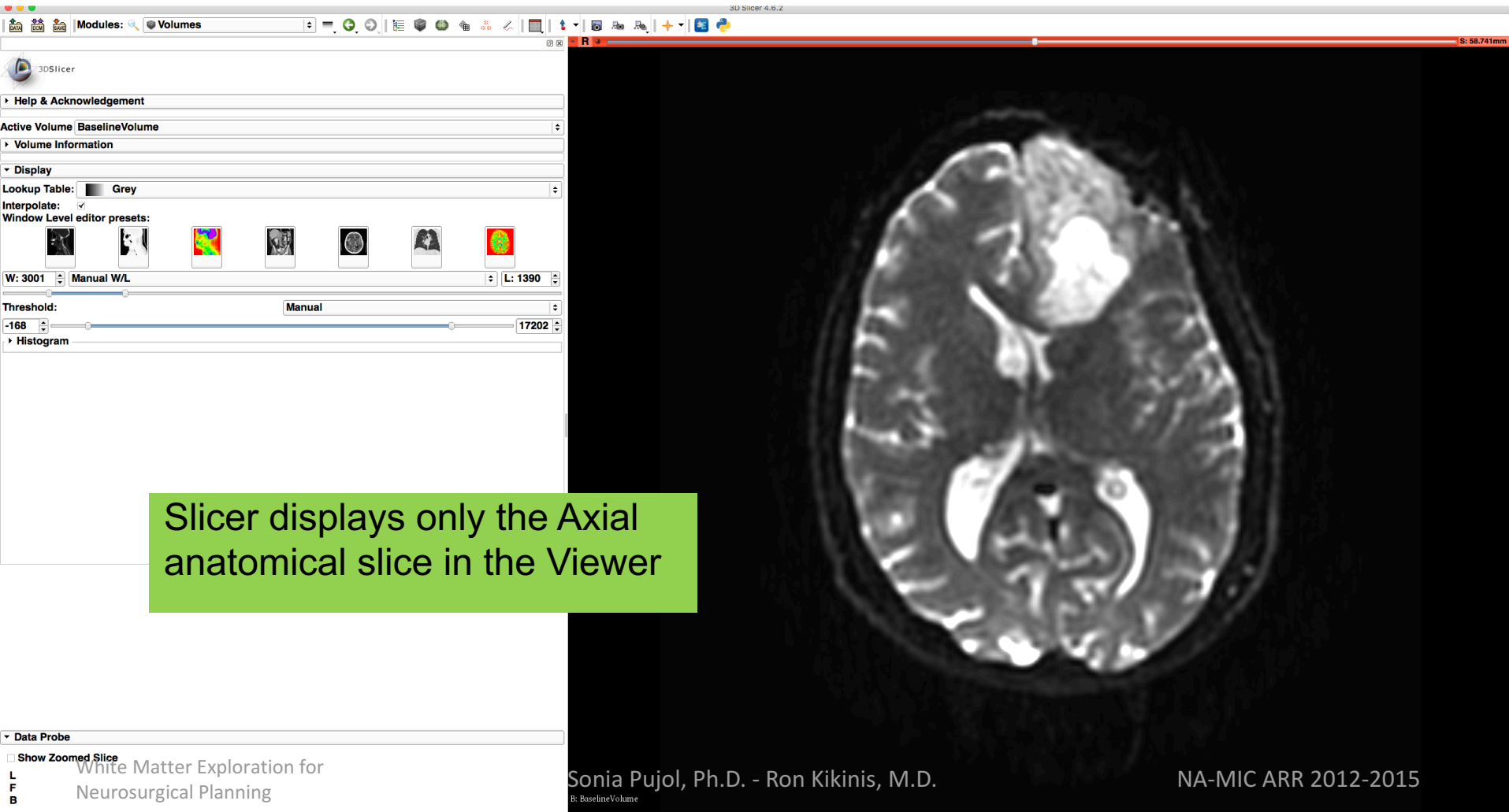
Tumor Segmentation



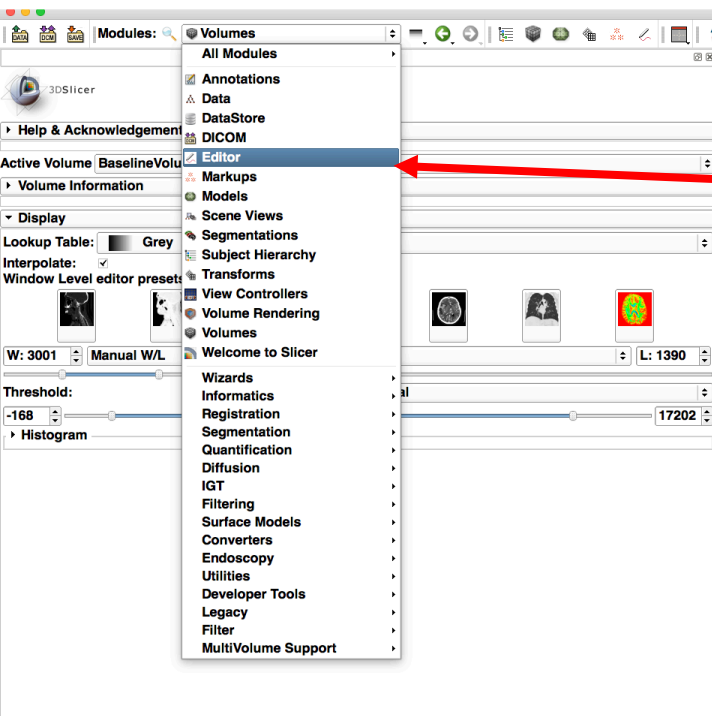
The tumor in this clinical case is composed of two parts: a solid part, and a cystic part.

In this section, we will segment the different parts of the tumor using a Grow Cut Segmentation algorithm.

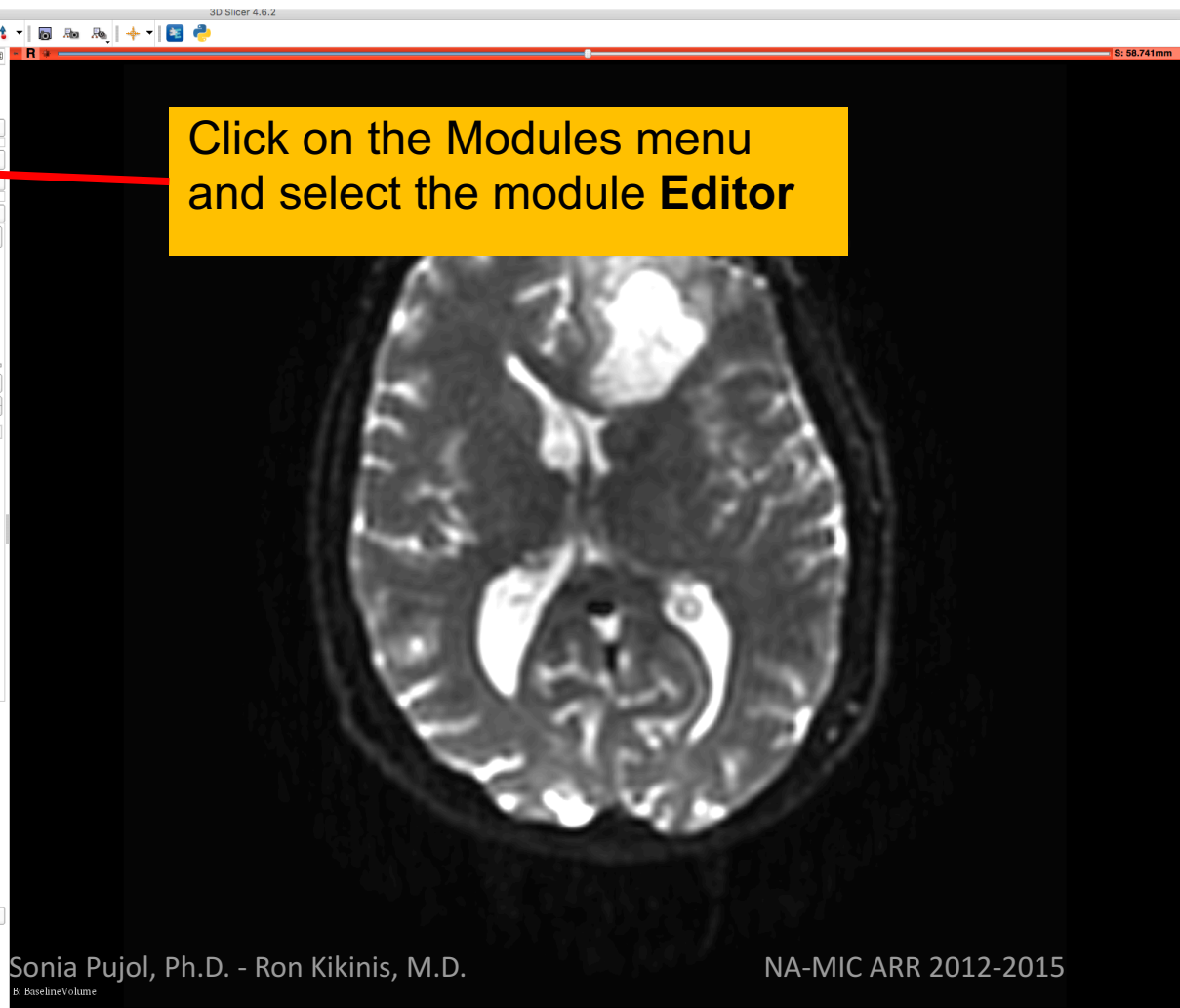
Tumor Segmentation



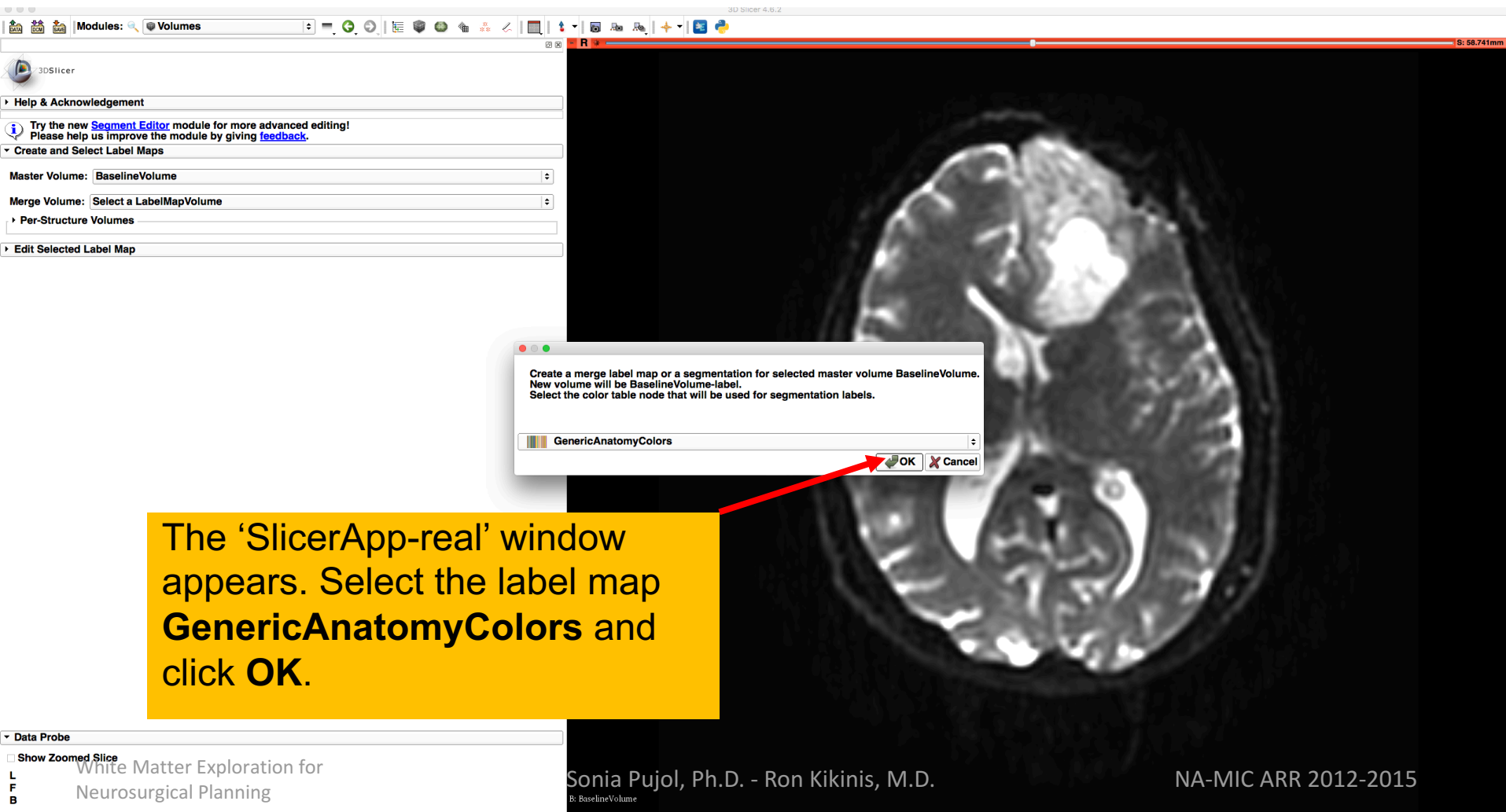
Tumor Segmentation



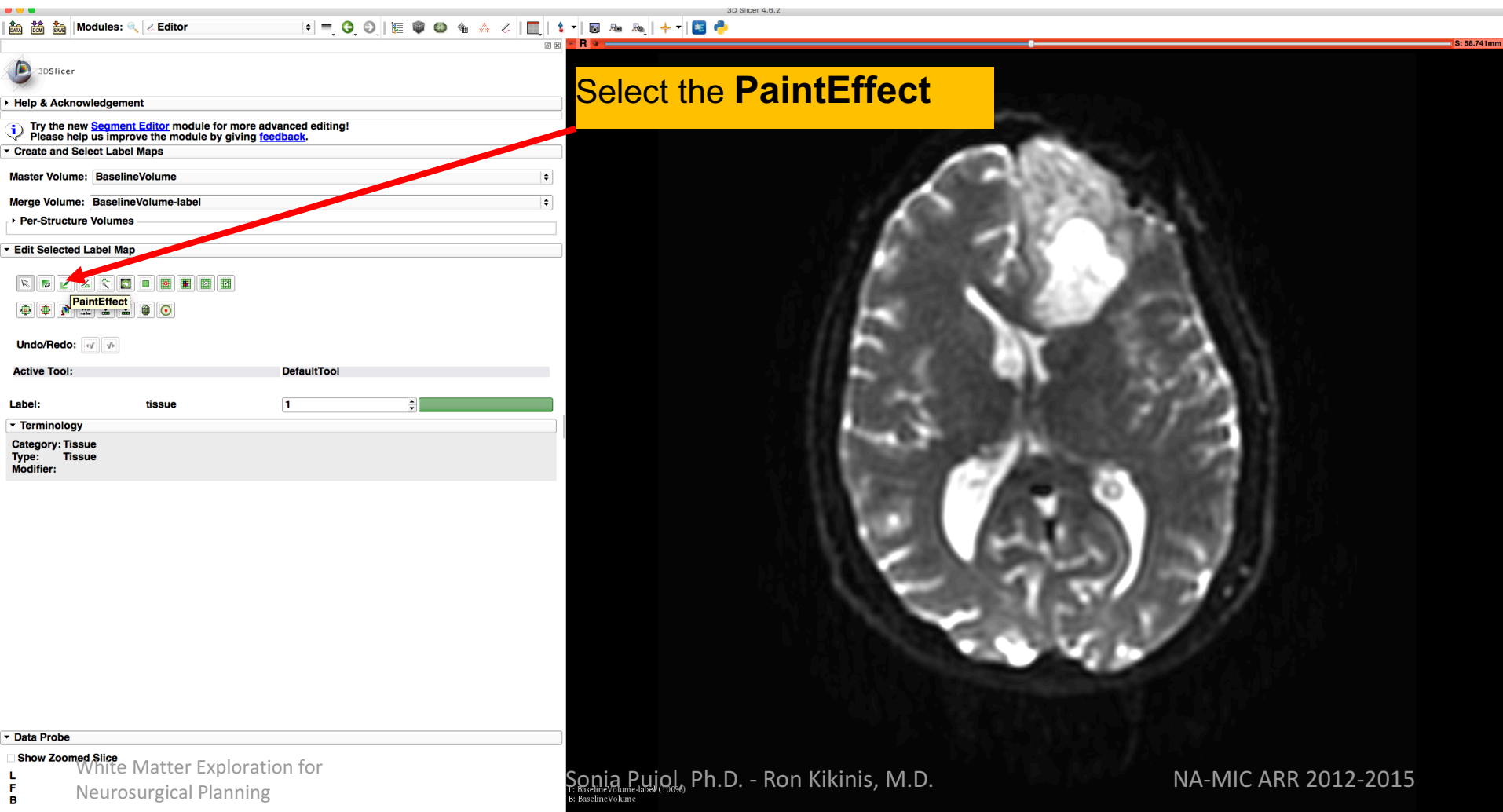
Click on the Modules menu
and select the module **Editor**



Tumor Segmentation



Tumor Segmentation



The screenshot displays the 3D Slicer 4.6.2 interface. On the left, the 'Modules' panel shows the 'Editor' module selected. Below it, the 'Edit Selected Label Map' section contains a toolbar with various tools. A red arrow points from a yellow text box to the 'PaintEffect' tool in this toolbar. The 'PaintEffect' tool is currently selected, and the 'Active Tool' dropdown is set to 'DefaultTool'. The 'Label' dropdown is set to 'tissue', and the 'Value' is set to '1'. The 'Terminology' section shows 'Category: Tissue', 'Type: Tissue', and 'Modifier:'. The 'Data Probe' section at the bottom has 'Show Zoomed Slice' checked. The main 3D view on the right shows an axial MRI slice of a brain with a white tumor region. A yellow text box with the text 'Select the PaintEffect' is overlaid on the 3D view. The status bar at the bottom indicates 'L: BaselineVolume-label (100%)' and 'B: BaselineVolume'.

3D Slicer 4.6.2

Modules: Editor

3D Slicer

Help & Acknowledgement

Try the new [Segment Editor](#) module for more advanced editing!
Please help us improve the module by giving [feedback](#).

Create and Select Label Maps

Master Volume: BaselineVolume

Merge Volume: BaselineVolume-label

Per-Structure Volumes

Edit Selected Label Map

PaintEffect

Undo/Redo: [Undo] [Redo]

Active Tool: DefaultTool

Label: tissue 1

Terminology

Category: Tissue

Type: Tissue

Modifier:

Data Probe

Show Zoomed Slice

White Matter Exploration for
Neurosurgical Planning

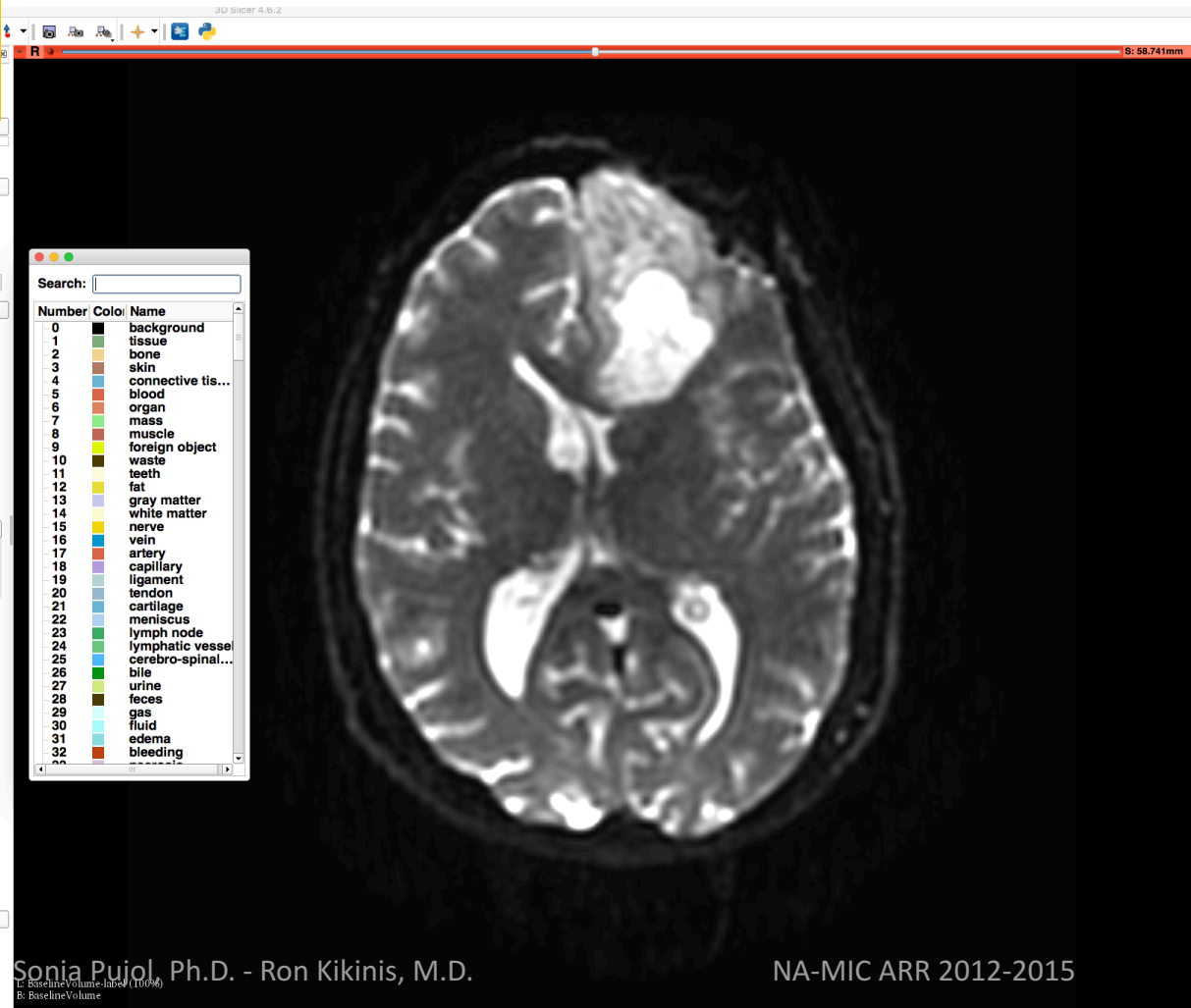
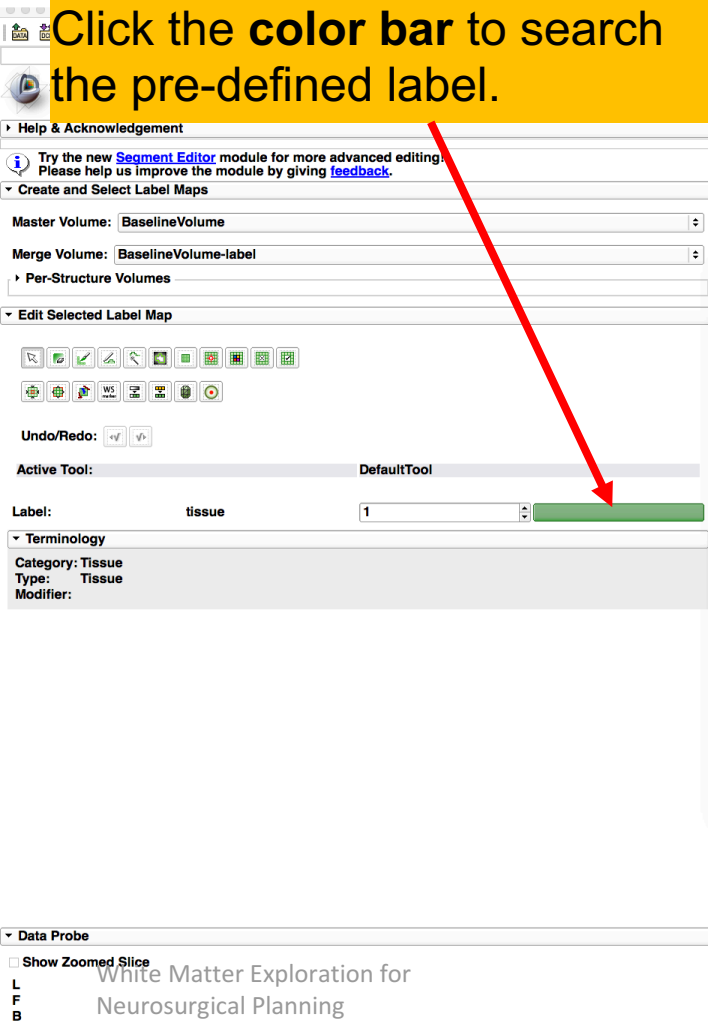
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L: BaselineVolume-label (100%)
B: BaselineVolume

Tumor Segmentation

Scroll down the **Editor** module.
Click the **color bar** to search
the pre-defined label.



Tumor Segmentation

Input **cyst** and select number **309** for cystic part of the tumor.

3D Slicer 4.6.2

Master volume: BaselineVolume

Merge Volume: BaselineVolume-label

Per-Structure Volumes

Edit Selected Label Map

Undo/Redo: [Undo] [Redo]

Active Tool: DefaultTool

Label: tissue 1

Terminology

Category: Tissue

Type: Tissue

Modifier:

Data Probe

Red (R 63.3, P 49.6, S 58.7) Axial Sp: 2.6

L BaselineVolume-label (67, 203, 25) background (0)

F None

B BaselineVolume (67, 203, 25) 34

Number Color Name

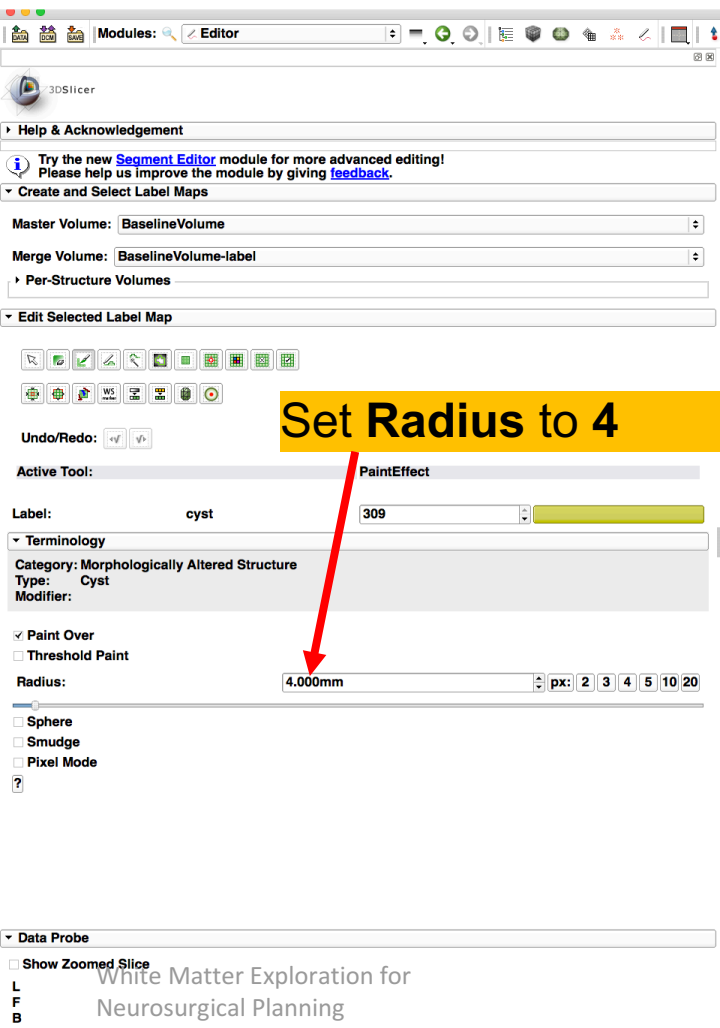
309 [Yellow] cyst

White Matter Exploration for Neurosurgical Planning

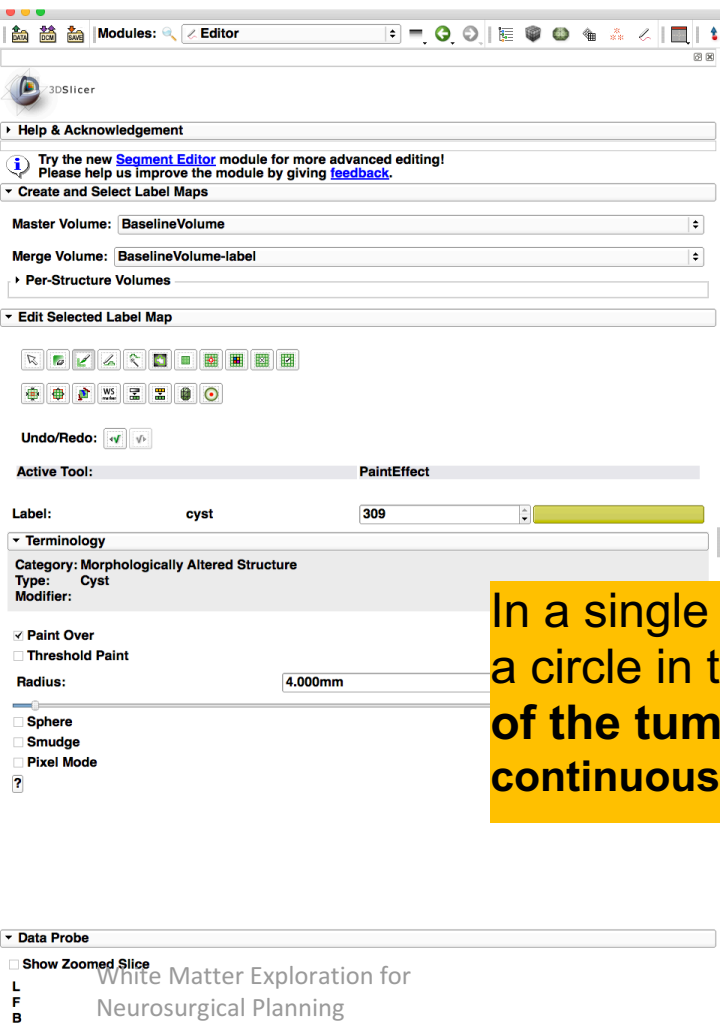
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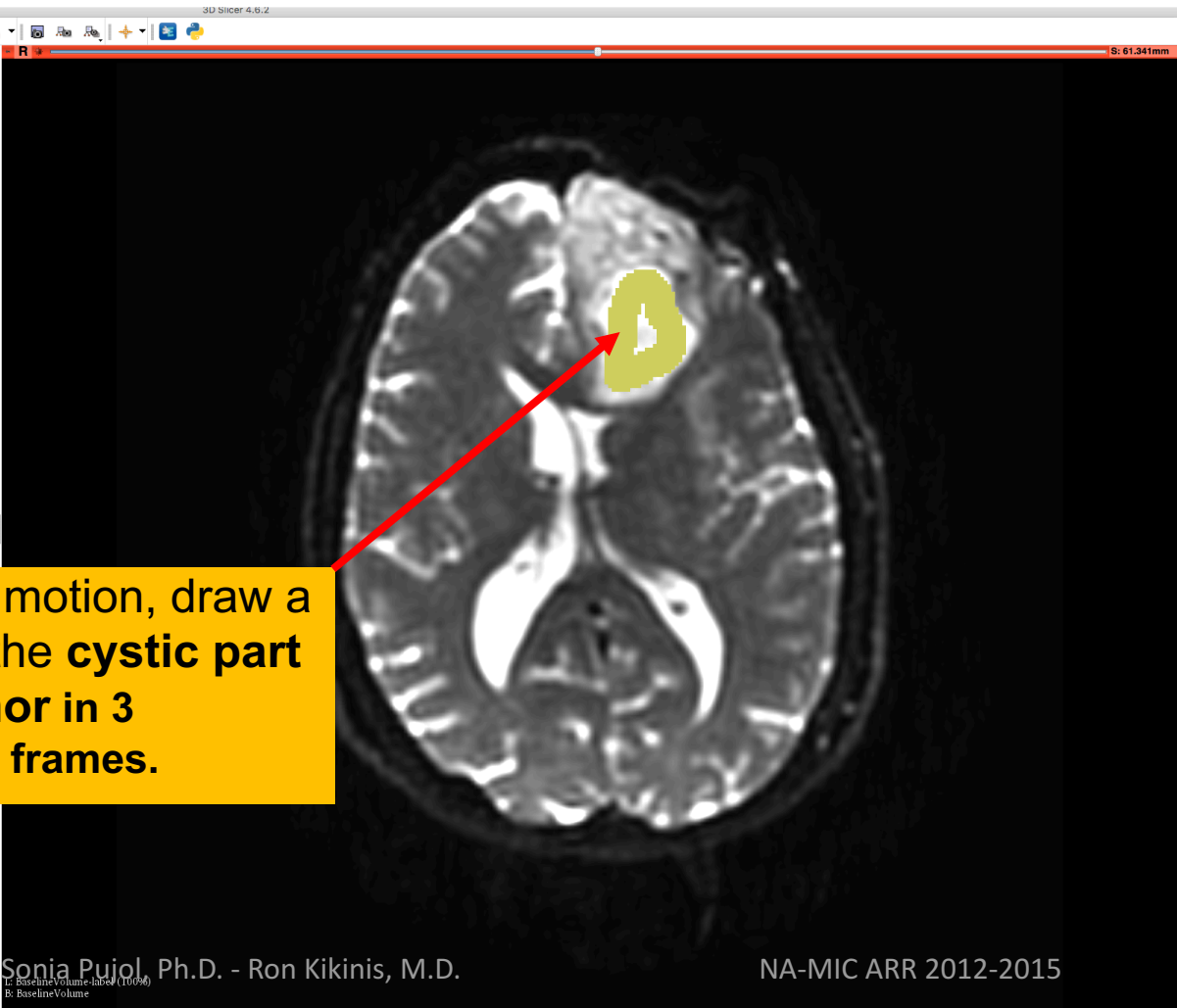
Tumor Segmentation



Tumor Segmentation



In a single motion, draw a circle in the **cystic part** of the tumor in 3 continuous frames.



Tumor Segmentation

Input **mass** and select number 7 for solid part of the tumor.

Merge Volume: BaselineVolume-label

Per-Structure Volumes

Edit Selected Label Map

Undo/Redo: [undo] [redo]

Active Tool: PaintEffect

Label: cyst 309

Terminology

Category: Morphologically Altered Structure

Type: Cyst

Modifier:

Paint Over

Threshold Paint

Radius: 4.000mm px: 2 3 4 5 10 20

Sphere

Smudge

Pixel Mode

Data Probe

Show Zoomed Slice

White Matter Exploration for Neurosurgical Planning

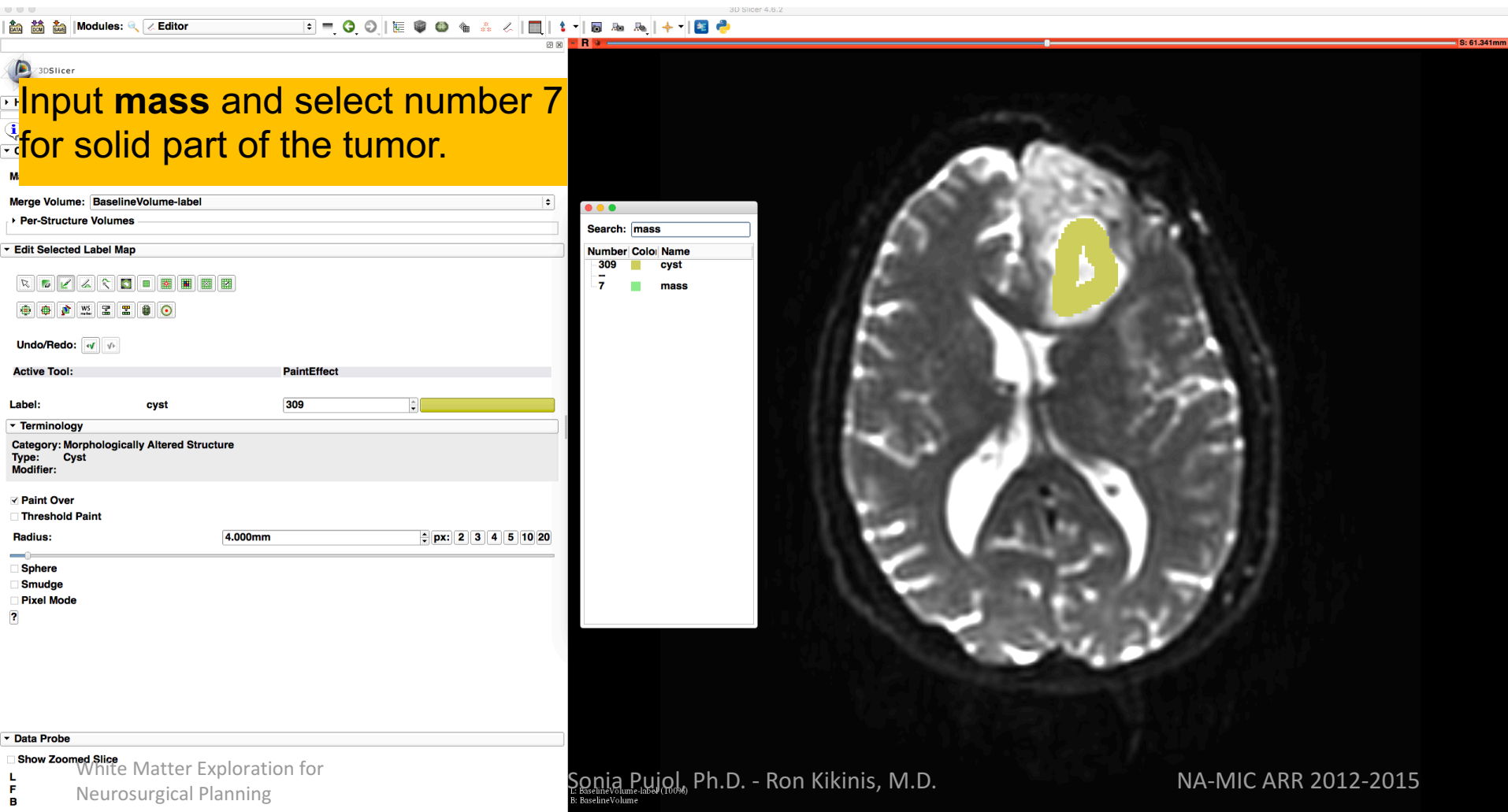
Search: mass

| Number | Color | Name |
|--------|--------|------|
| 309 | yellow | cyst |
| 7 | green | mass |

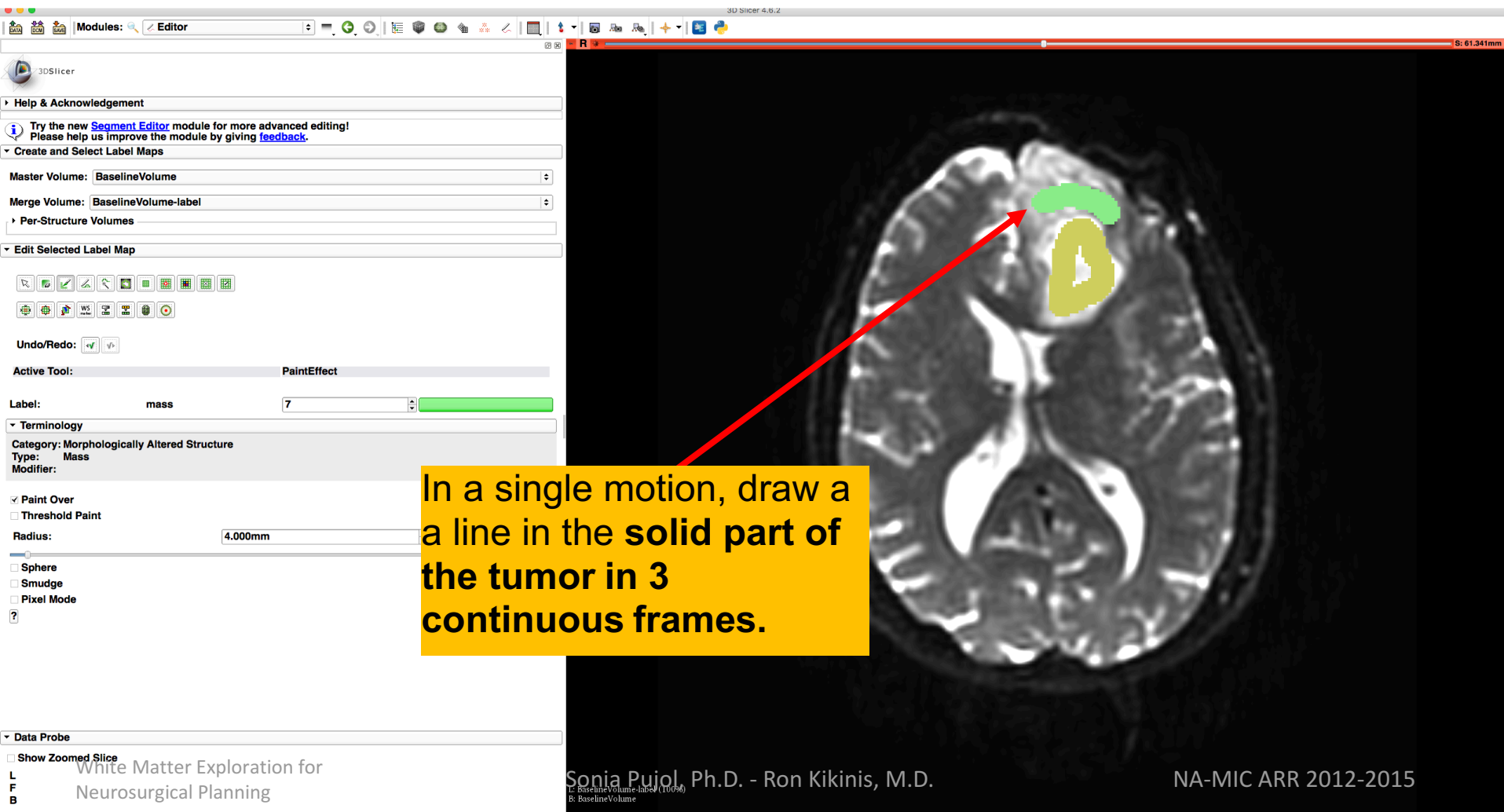
S: 61.341mm

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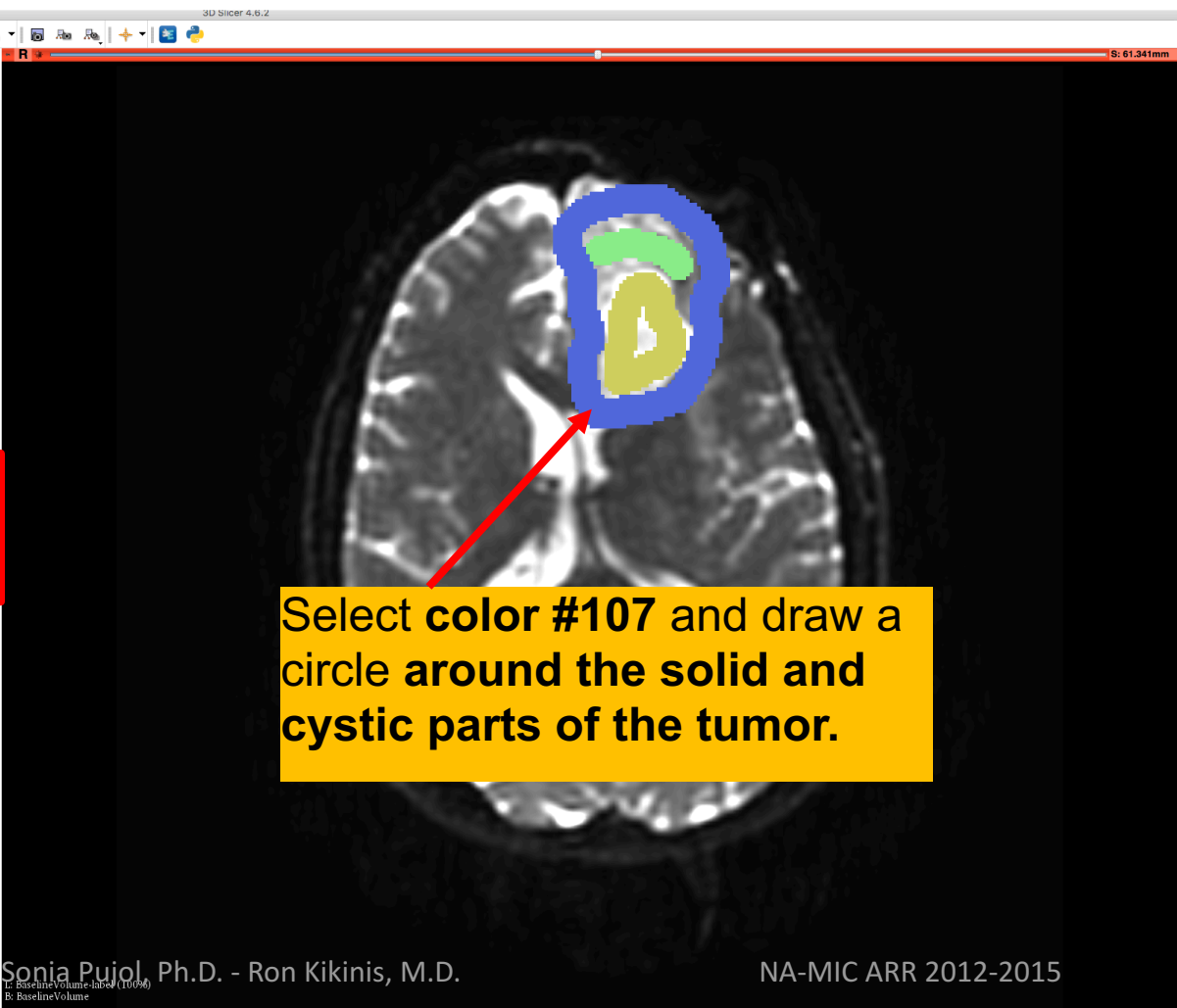
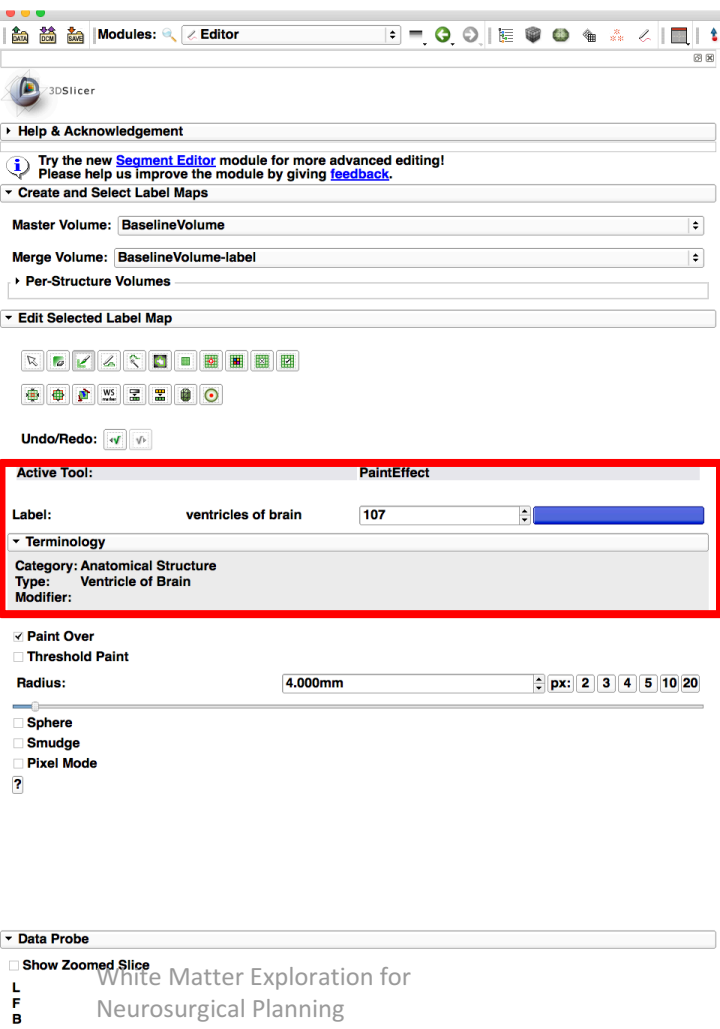
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Tumor Segmentation

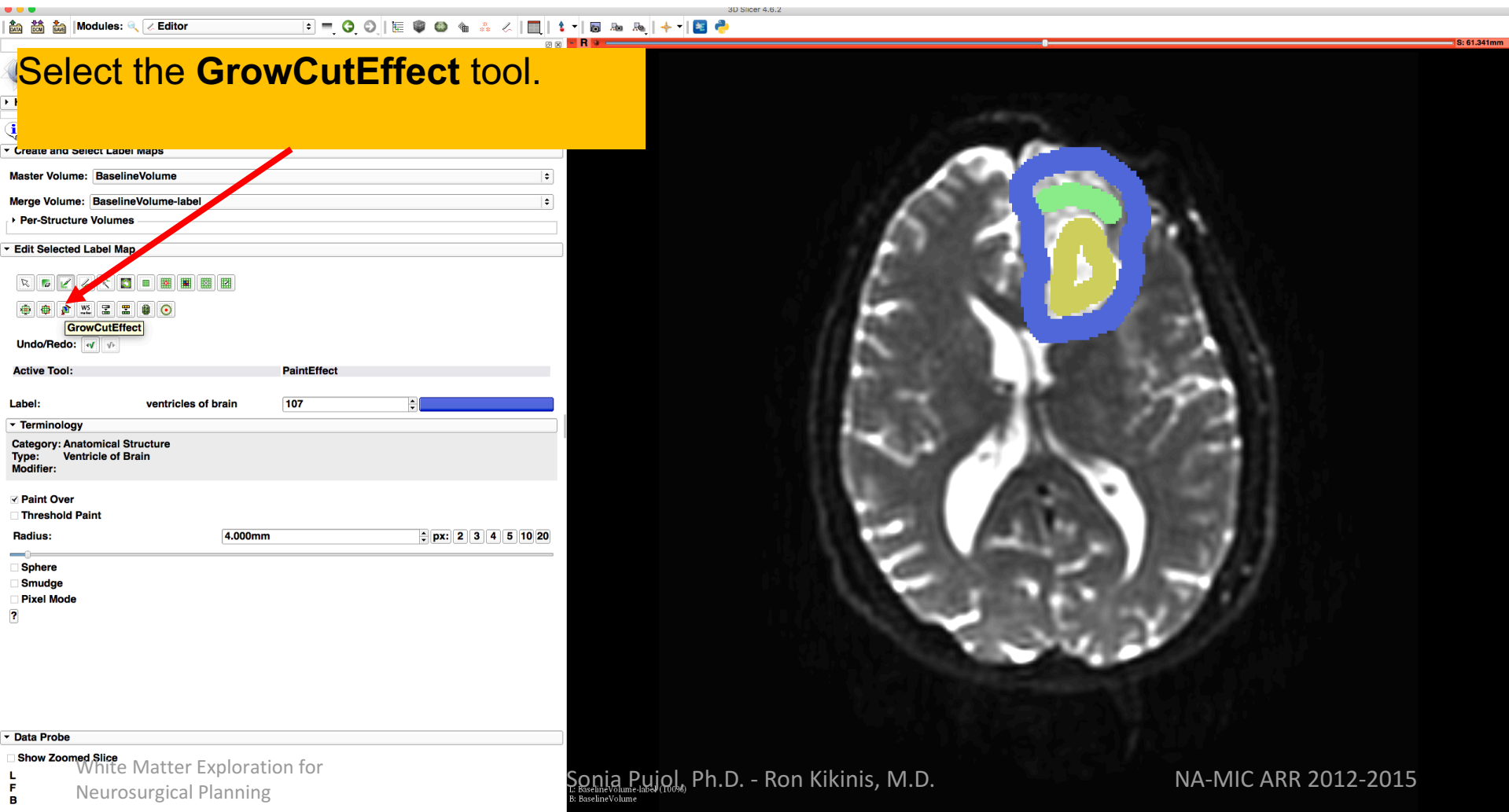


Tumor Segmentation



Tumor Segmentation

Select the **GrowCutEffect** tool.



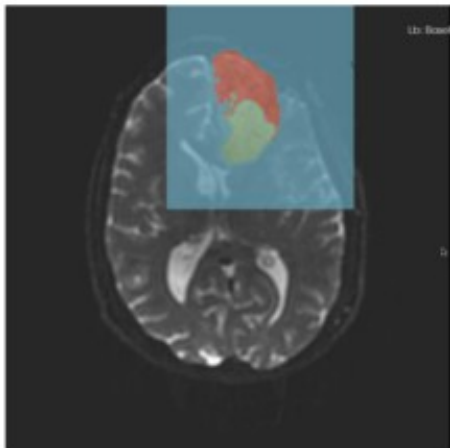
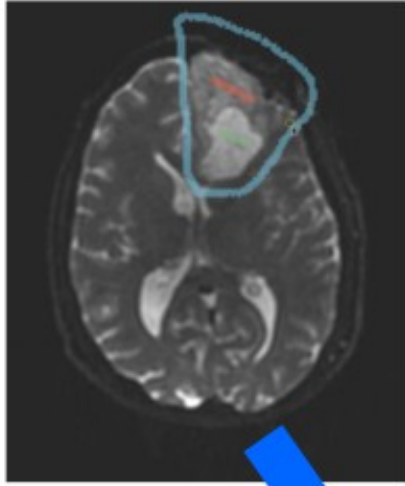
The screenshot shows the 3D Slicer 4.6.2 interface. The 'Modules' panel on the left has 'Editor' selected. The 'Create and Select Label Maps' panel shows 'Master Volume: BaselineVolume' and 'Merge Volume: BaselineVolume-label'. The 'Edit Selected Label Map' panel is active, showing a toolbar with the 'GrowCutEffect' tool selected (indicated by a red arrow). The 'Active Tool' is 'PaintEffect'. The 'Label' is 'ventricles of brain' with a value of '107'. The 'Terminology' panel shows 'Category: Anatomical Structure', 'Type: Ventricle of Brain', and 'Modifier:'. The 'Paint Over' checkbox is checked, and the 'Radius' is set to '4.000mm'. The 'Data Probe' panel shows 'Show Zoomed Slice' checked. The main window displays an axial brain MRI slice with a segmented tumor region highlighted in blue, green, and yellow.

White Matter Exploration for
Neurosurgical Planning

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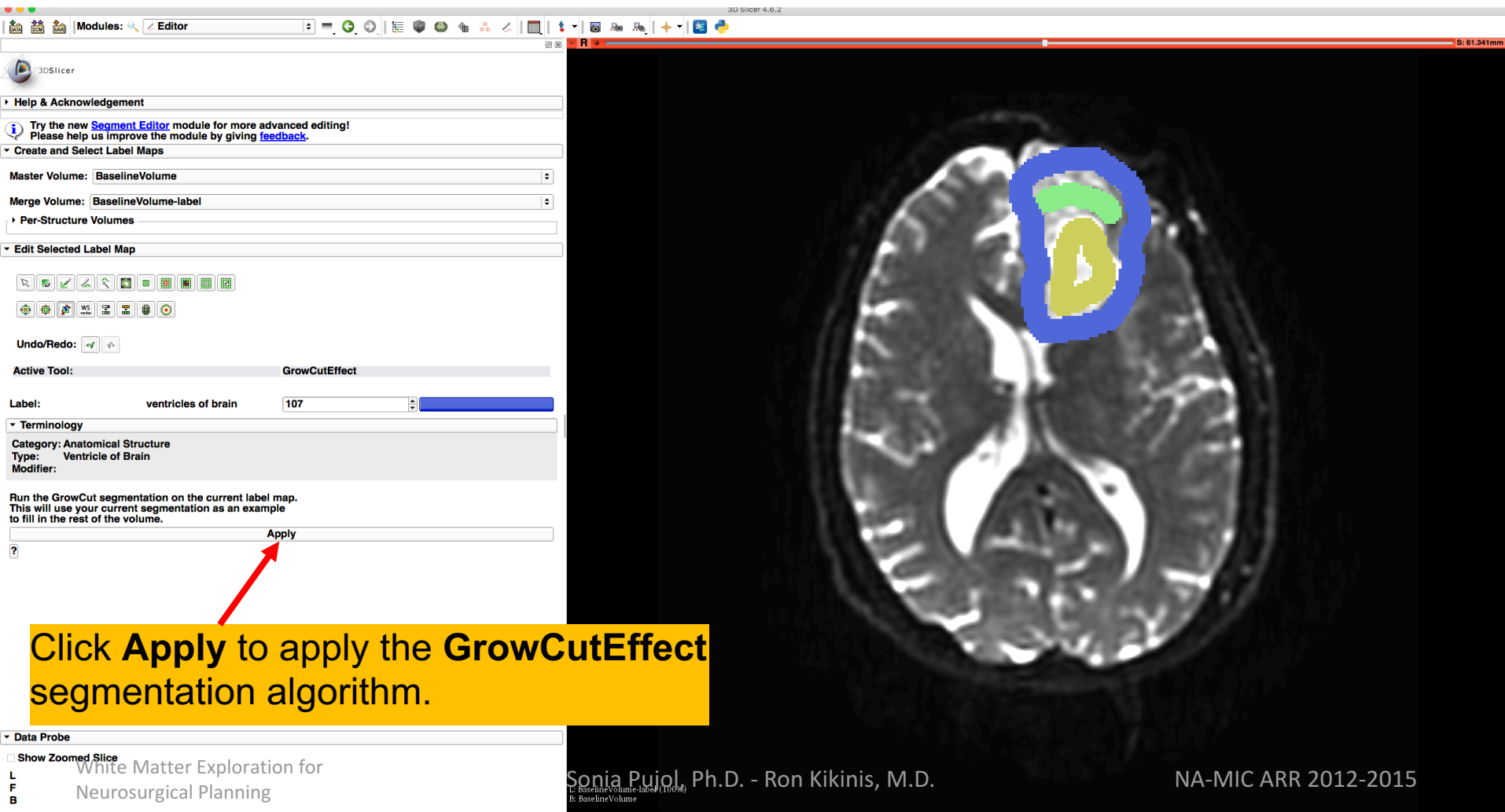
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Grow Cut Segmentation



- The Grow Cut Segmentation method is a competitive region growing algorithm using Cellular Automata.
- The algorithm performs multi-label image segmentation using a set of user input scribbles.
- V. Vezhnevets, V. Konouchine. "Grow-Cut" - Interactive Multi-Label N-D Image Segmentation". Proc. Graphicon. 2005 . pp. 150-156.

Tumor Segmentation



The screenshot displays the 3D Slicer 4.6.2 interface. On the left, the 'Modules' panel shows the 'Editor' module active. Below it, the 'Create and Select Label Maps' section is expanded, showing 'Master Volume: BaselineVolume' and 'Merge Volume: BaselineVolume-label'. The 'Edit Selected Label Map' section is also expanded, showing a toolbar with various segmentation tools. The 'Active Tool' is set to 'GrowCutEffect'. The 'Label' dropdown is set to 'ventricles of brain' with a value of '107'. The 'Terminology' section shows 'Category: Anatomical Structure', 'Type: Ventricle of Brain', and 'Modifier:'. Below this, a text box explains: 'Run the GrowCut segmentation on the current label map. This will use your current segmentation as an example to fill in the rest of the volume.' An 'Apply' button is visible, with a red arrow pointing to it from a yellow callout box. The main 3D view on the right shows an axial brain MRI slice with a segmented tumor region highlighted in blue, green, and yellow. The bottom of the interface shows the 'Data Probe' panel with 'Show Zoomed Slice' checked, and the 'White Matter Exploration for Neurosurgical Planning' module. The bottom right corner displays the text 'Sonia Pujol, Ph.D. - Ron Kikinis, M.D.' and 'NA-MIC ARR 2012-2015'.

Click **Apply** to apply the **GrowCutEffect** segmentation algorithm.

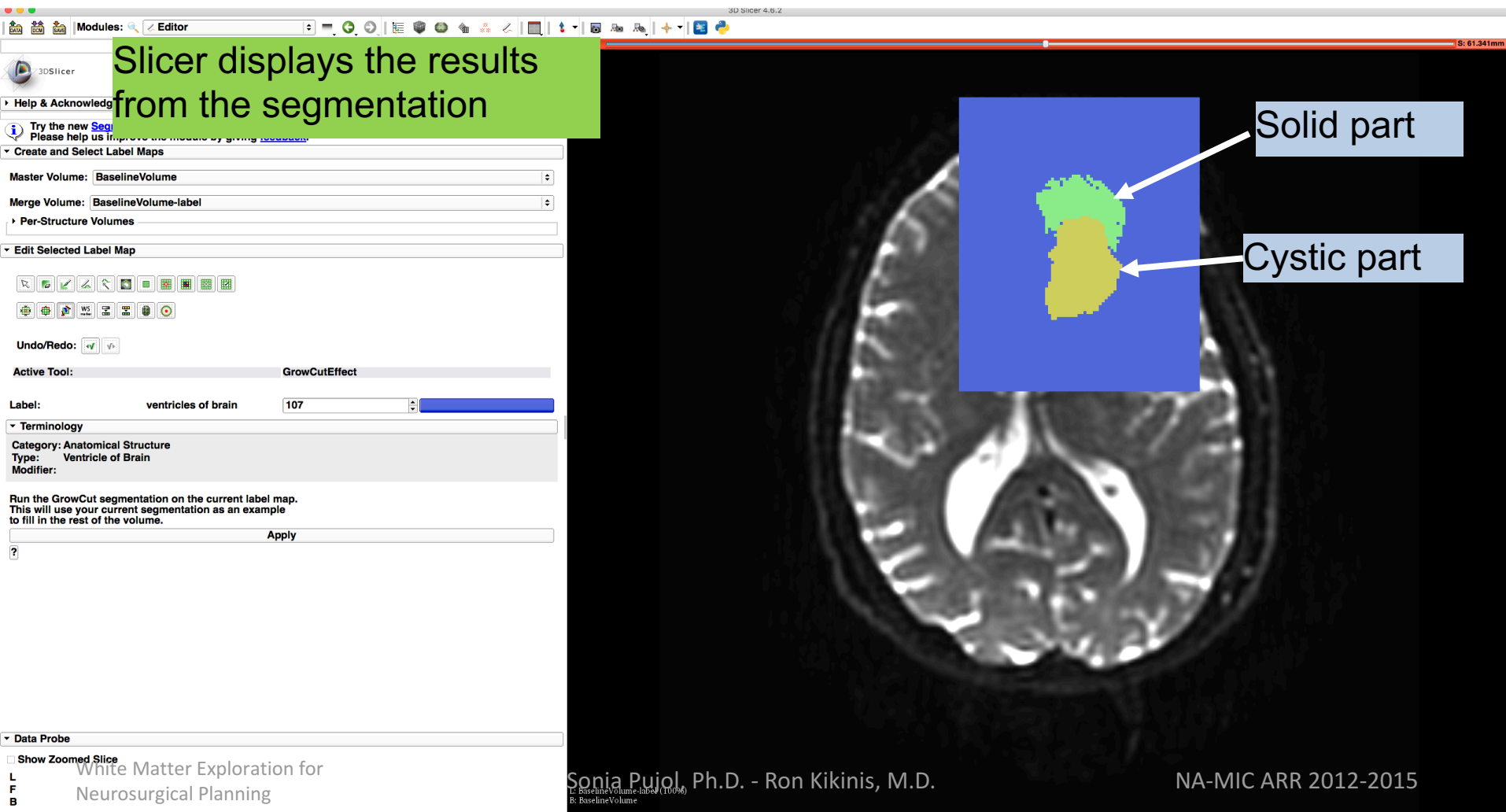
White Matter Exploration for
Neurosurgical Planning

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Tumor Segmentation

Slicer displays the results from the segmentation



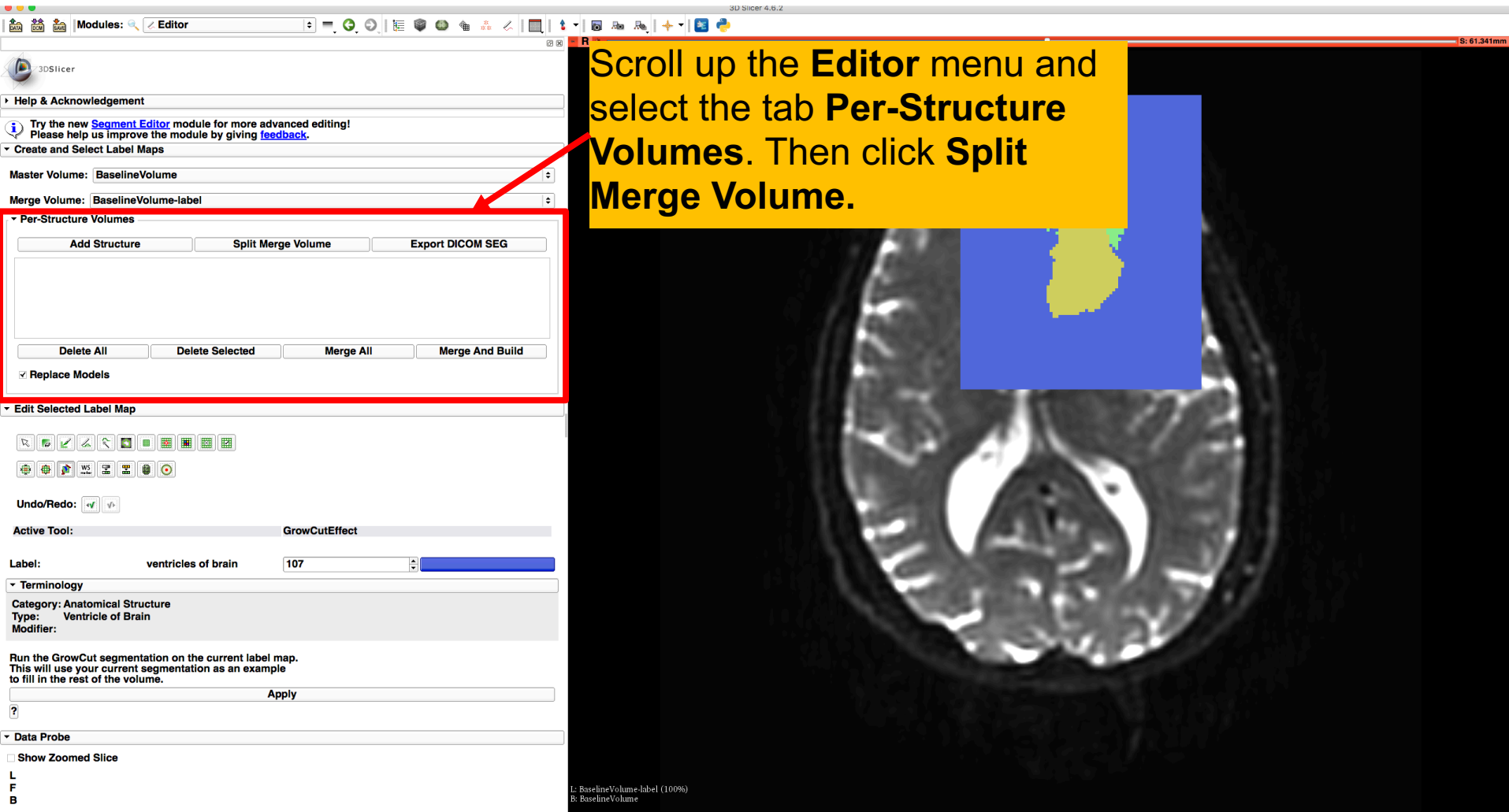
The screenshot shows the 3D Slicer software interface. The main window displays a brain MRI scan with a tumor segmentation. The tumor is highlighted in green and yellow, with labels 'Solid part' and 'Cystic part' pointing to the respective regions. The software interface includes a menu bar, a toolbar, and a panel on the left with various tool options.

White Matter Exploration for Neurosurgical Planning

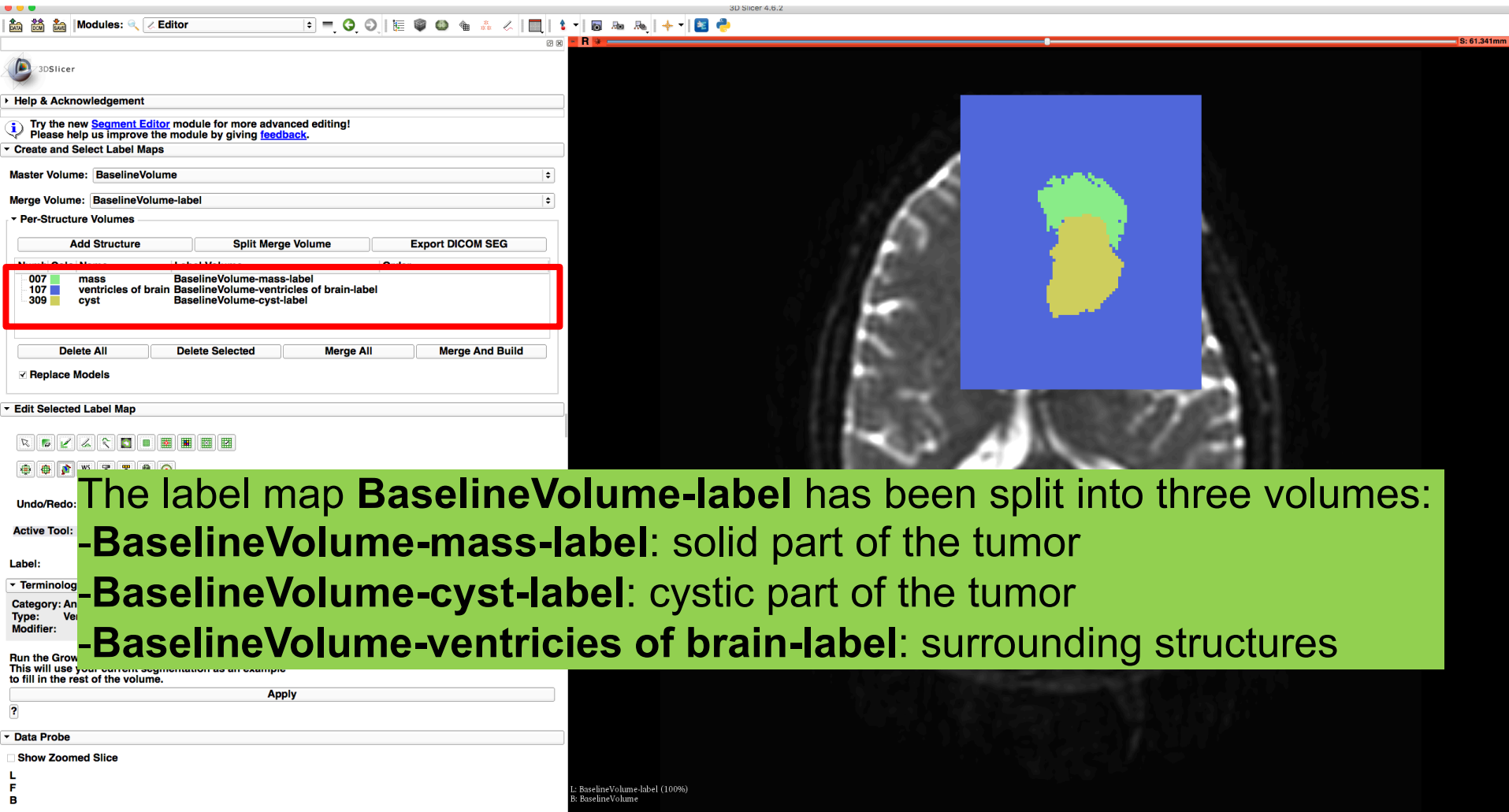
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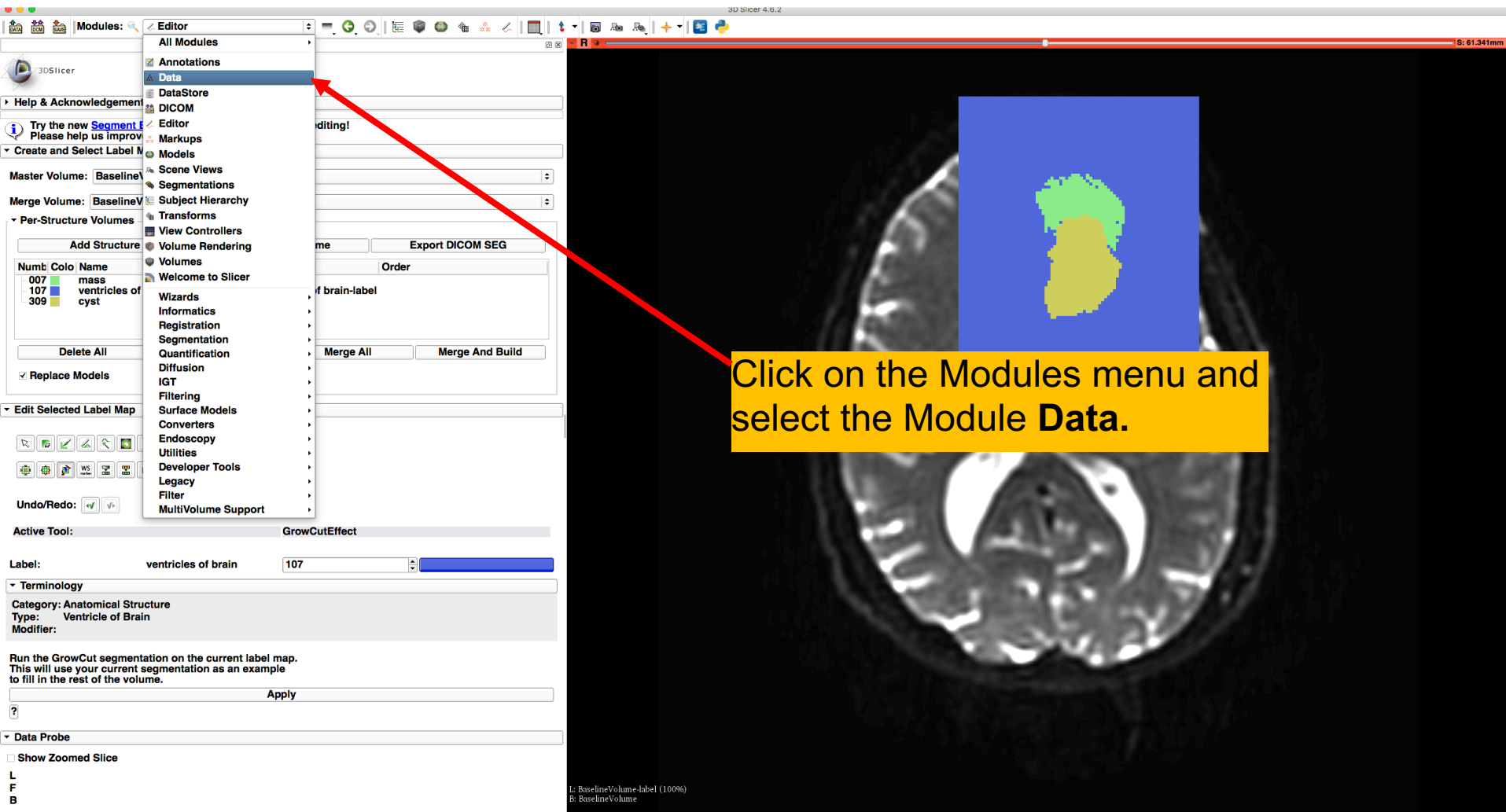
Tumor Segmentation



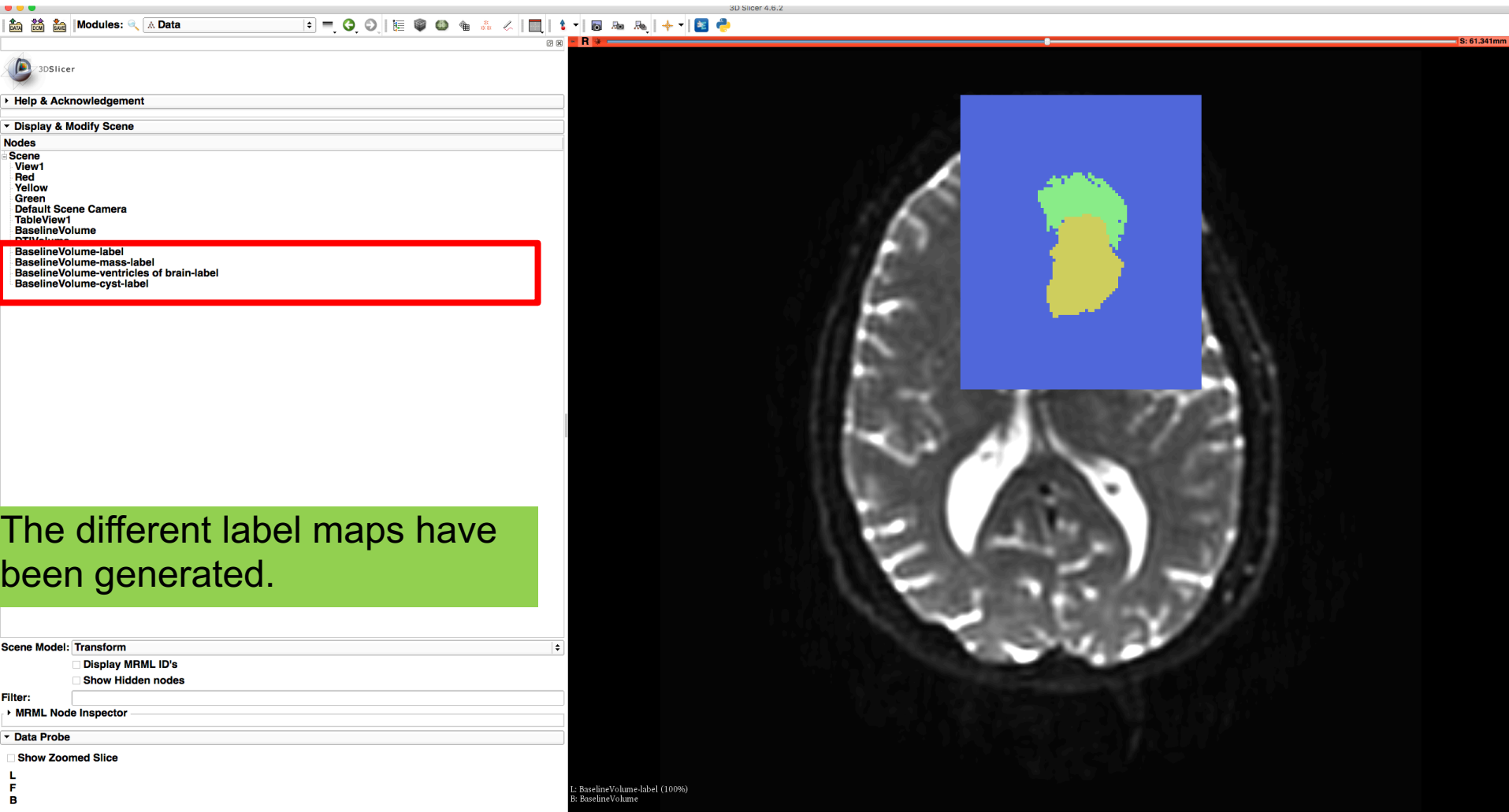
Tumor Segmentation



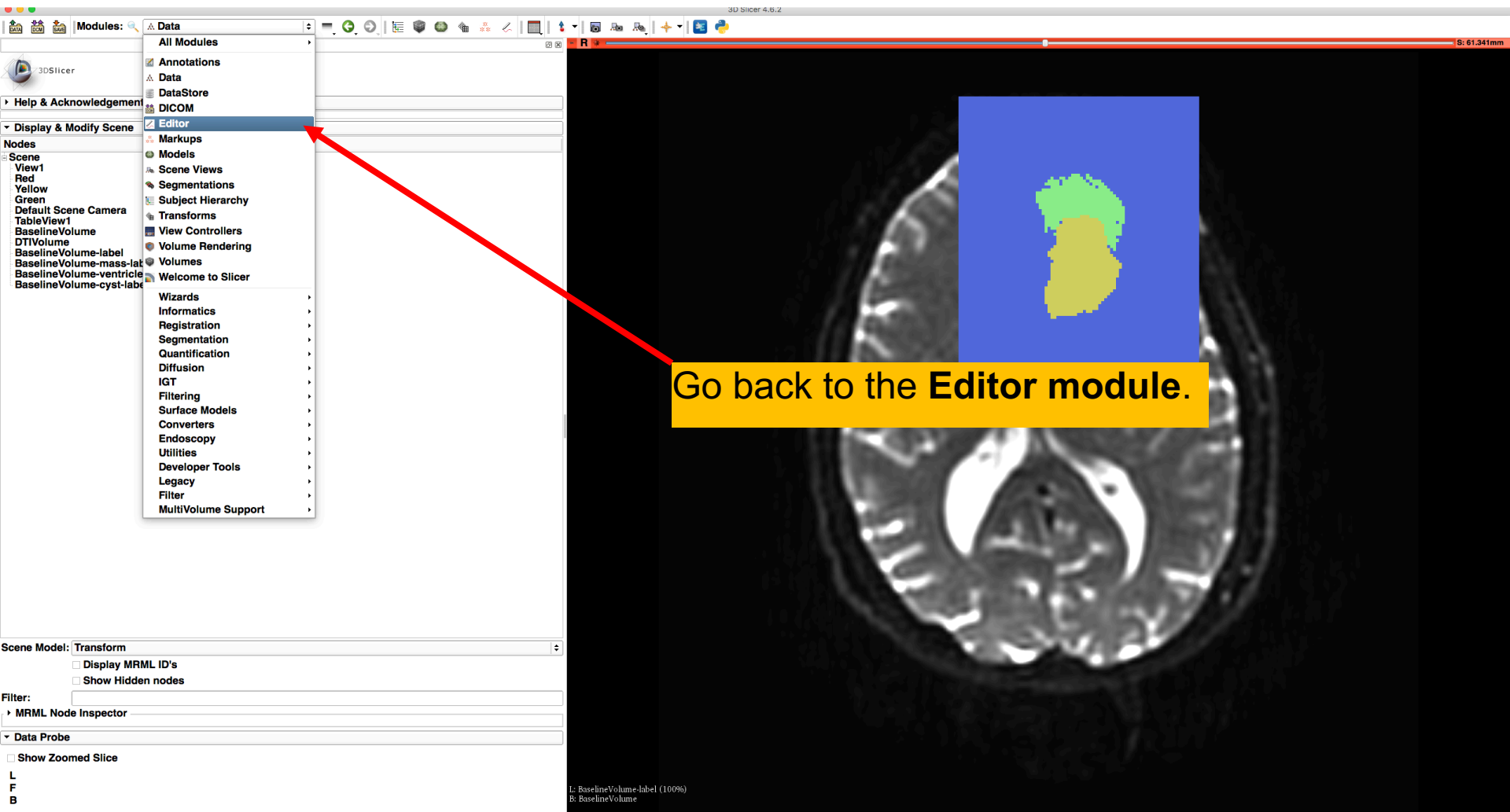
Tumor Segmentation



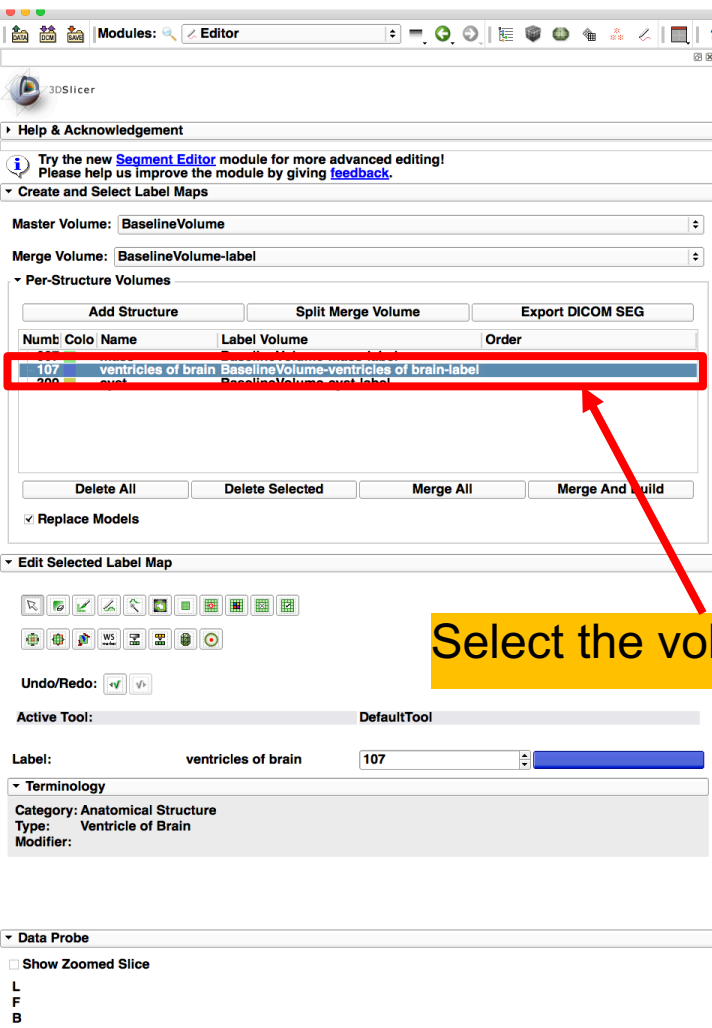
Tumor Segmentation



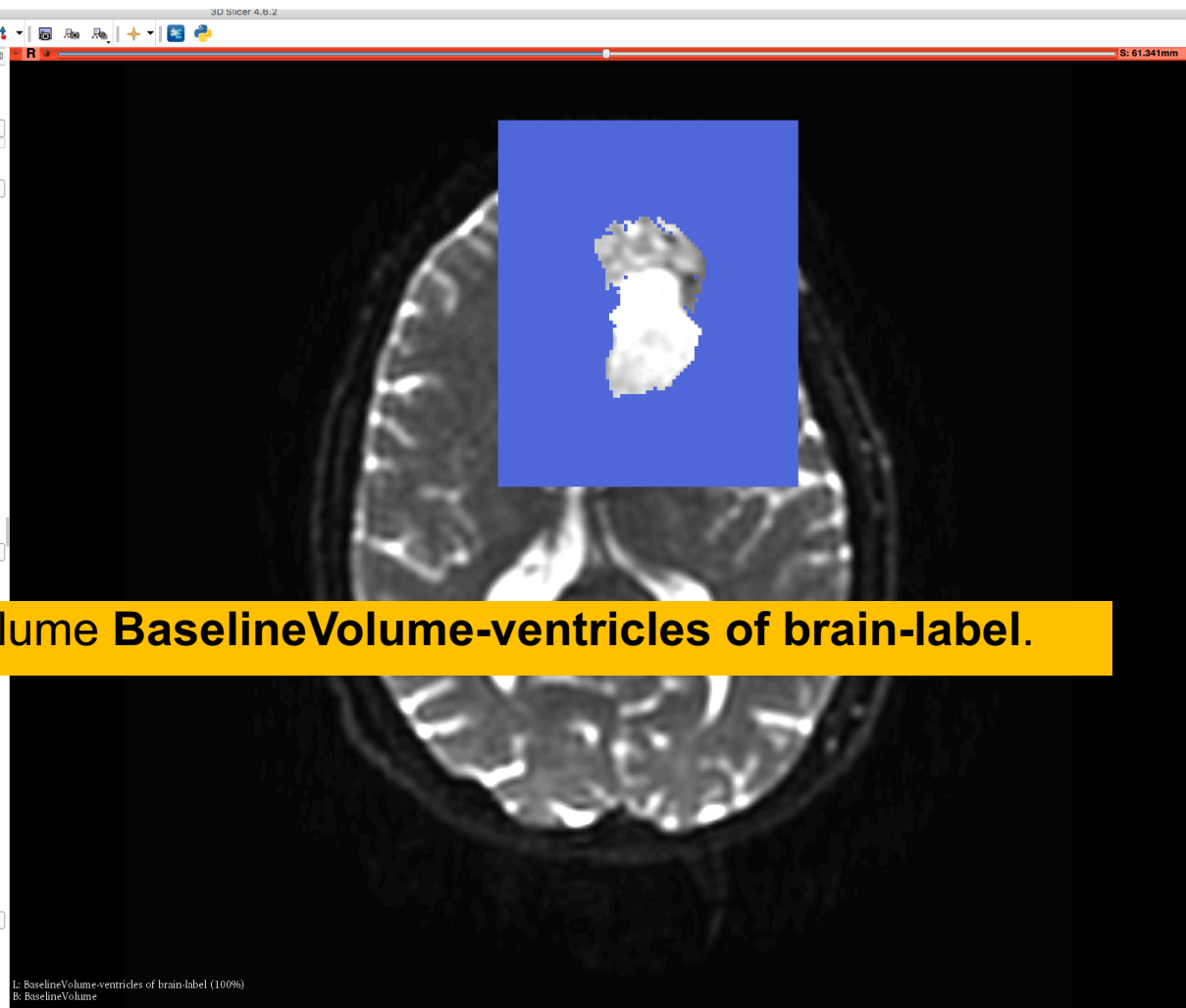
Ventricles Segmentation



Ventricles Segmentation



Select the volume **BaselineVolume-ventricles of brain-label**.



Ventricles Segmentation

The screenshot displays the 3D Slicer 4.6.2 interface. On the left, the 'Modules' panel shows the 'Editor' module selected. Below it, the 'Create and Select Label Maps' section is active, showing a table of label maps. The 'ventricles of brain' label map (ID 107) is selected. A red arrow points from a yellow text box to the 'ThresholdEffect' tool icon in the 'Edit Selected Label Map' panel. The 'ThresholdEffect' tool is active, with the 'Label' set to 'ventricles of brain' and the 'Threshold Range' set from 4549.25 to 18197.00. The main 3D view shows an axial MRI slice of a brain. A blue rectangular region of interest is drawn over a portion of the brain, and a yellow box highlights the 'ThresholdEffect' tool's settings panel. The bottom status bar indicates the current label map is 'BaselineVolume-ventricles of brain-label (100%)'.

3D Slicer 4.6.2

Modules: Editor

Help & Acknowledgement

Try the new [Segment Editor](#) module for more advanced editing!
Please help us improve the module by giving [feedback](#).

Create and Select Label Maps

Master Volume: BaselineVolume

Merge Volume: BaselineVolume-label

Per-Structure Volumes

Add Structure Split Merge Volume Export DICOM SEG

| Num | Color | Name | Label Volume | Order |
|-----|--------|---------------------|--|-------|
| 007 | green | mass | BaselineVolume-mass-label | |
| 107 | blue | ventricles of brain | BaselineVolume-ventricles of brain-label | |
| 309 | yellow | cyst | BaselineVolume-cyst-label | |

Delete All Delete Selected Merge All Merge And Build

Replace Models

Edit Selected Label Map

ThresholdEffect

Active Tool: ThresholdEffect

Label: ventricles of brain 107

Terminology

Category: Anatomical Structure
Type: Ventricle of Brain
Modifier:

Threshold Range: 4549.25 18197.00

Use For Paint

Apply

Data Probe

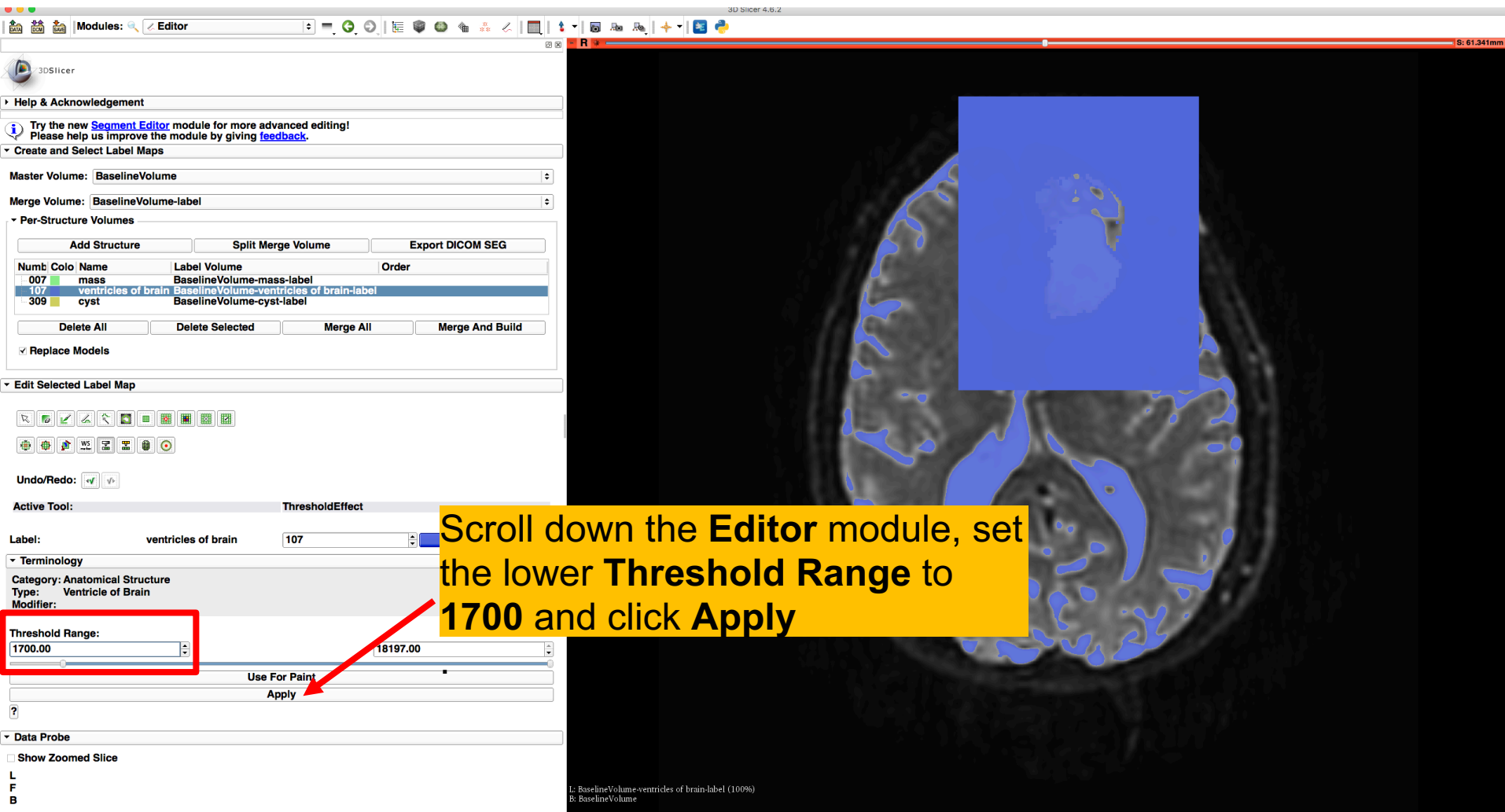
Show Zoomed Slice

L
F
B

L: BaselineVolume-ventricles of brain-label (100%)
B: BaselineVolume

Select the **ThresholdEffect** tool.

Ventricles Segmentation



3D Slicer 4.6.2

Modules: Editor

Help & Acknowledgement

Try the new [Segment Editor](#) module for more advanced editing!
Please help us improve the module by giving [feedback](#).

Create and Select Label Maps

Master Volume: BaselineVolume

Merge Volume: BaselineVolume-label

Per-Structure Volumes

Add Structure Split Merge Volume Export DICOM SEG

| Num | Color | Name | Label Volume | Order |
|-----|-------|---------------------|--|-------|
| 007 | | mass | BaselineVolume-mass-label | |
| 107 | | ventricles of brain | BaselineVolume-ventricles of brain-label | |
| 309 | | cyst | BaselineVolume-cyst-label | |

Delete All Delete Selected Merge All Merge And Build

Replace Models

Edit Selected Label Map

Active Tool: ThresholdEffect

Label: ventricles of brain 107

Terminology

Category: Anatomical Structure
Type: Ventricle of Brain
Modifier:

Threshold Range: 1700.00 18197.00

Use For Paint

Apply

Data Probe

Show Zoomed Slice

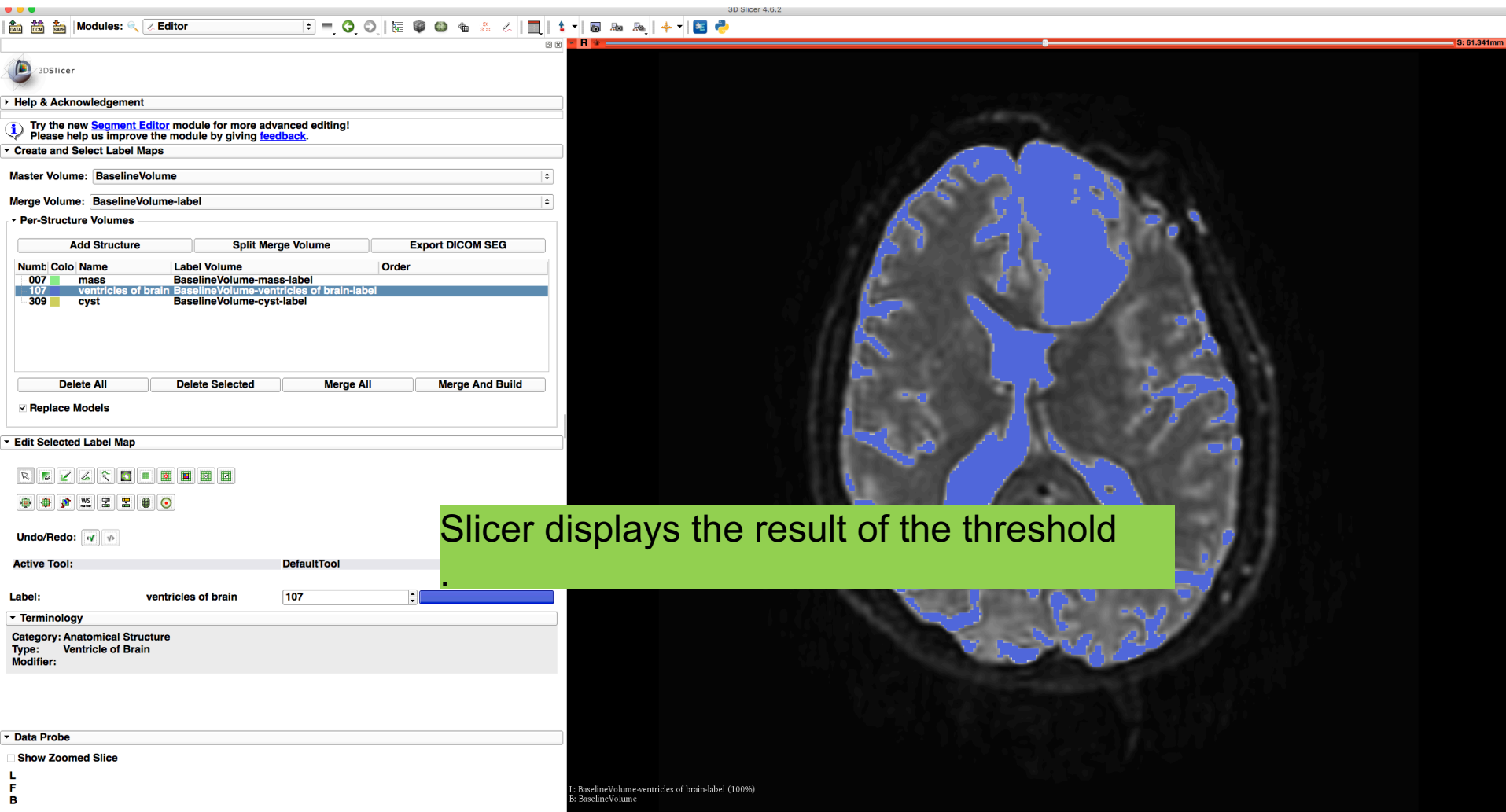
L
F
B

L: BaselineVolume-ventricles of brain-label (100%)
B: BaselineVolume

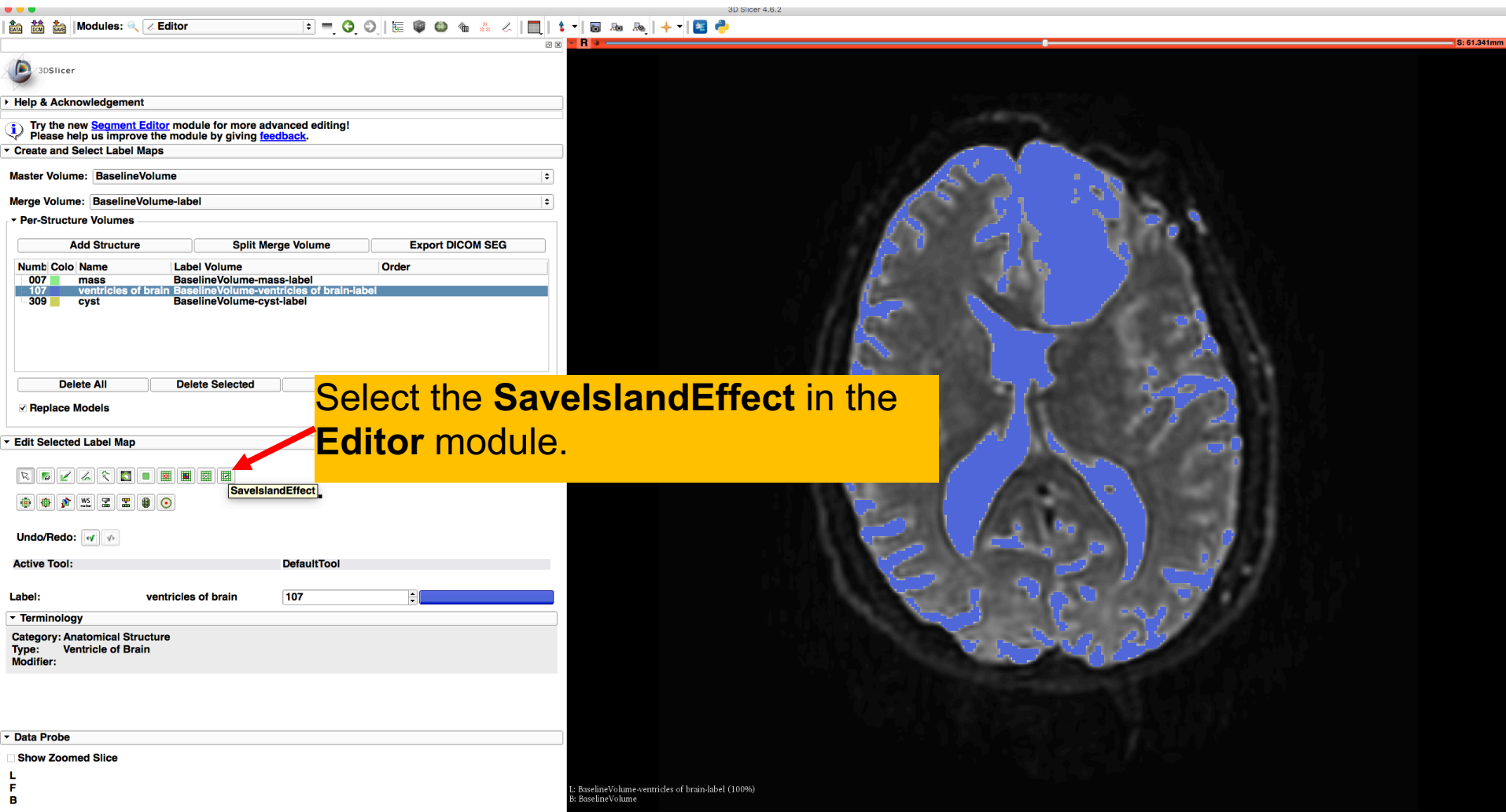
5: 61.341mm

Scroll down the **Editor** module, set the lower **Threshold Range** to **1700** and click **Apply**

Ventricles Segmentation



Ventricles Segmentation



Ventricles Segmentation

3DSlicer

Modules: Editor

Help & Acknowledgement

Try the new [Segment Editor](#) module for more advanced editing!
Please help us improve the module by giving [feedback](#).

Create and Select Label Maps

Master Volume: BaselineVolume

Merge Volume: BaselineVolume-label

Per-Structure Volumes

| Num | Color | Name | Label Volume | Order |
|-----|--------|---------------------|--|-------|
| 007 | green | mass | BaselineVolume-mass-label | |
| 107 | blue | ventricles of brain | BaselineVolume-ventricles of brain-label | |
| 309 | yellow | cyst | BaselineVolume-cyst-label | |

Delete All Delete Selected Merge All Merge And Build

Replace Models

Edit Selected Label Map

Undo/Redo

Active Tool

Label: ventricles of brain

Terminology

Category: Anatomical Structure
Type: Ventricle of Brain
Modifier:

Click on segmented region to remove all segmentation not directly connected to it.

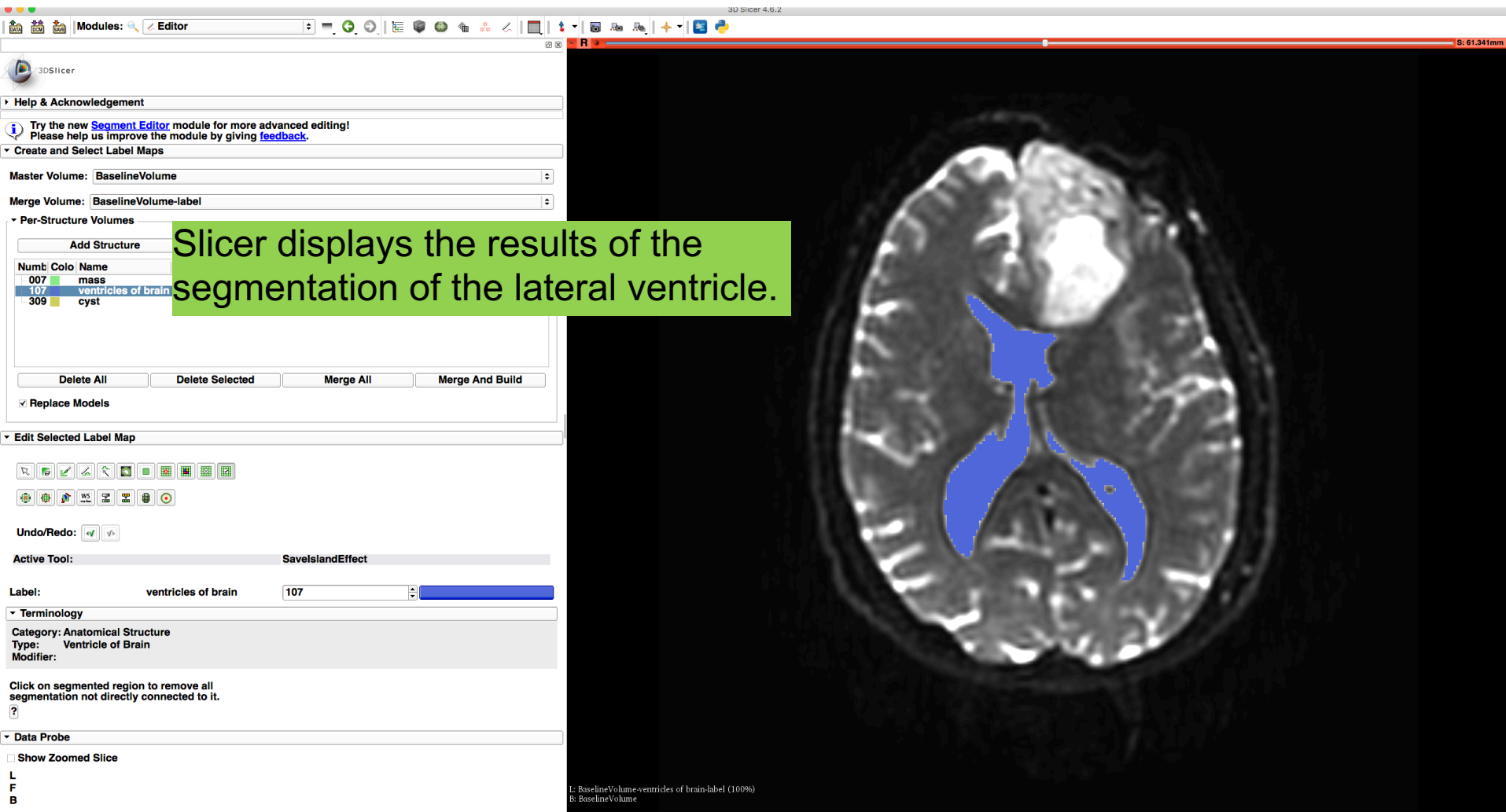
Data Probe

Red (R 108.4, P 55.5, S 61.3) Axial Sp: 2.6
L BaselineVolume...ain-label (22, 209, 26) background (0)
F None
B BaselineVolume (22, 209, 26) 1

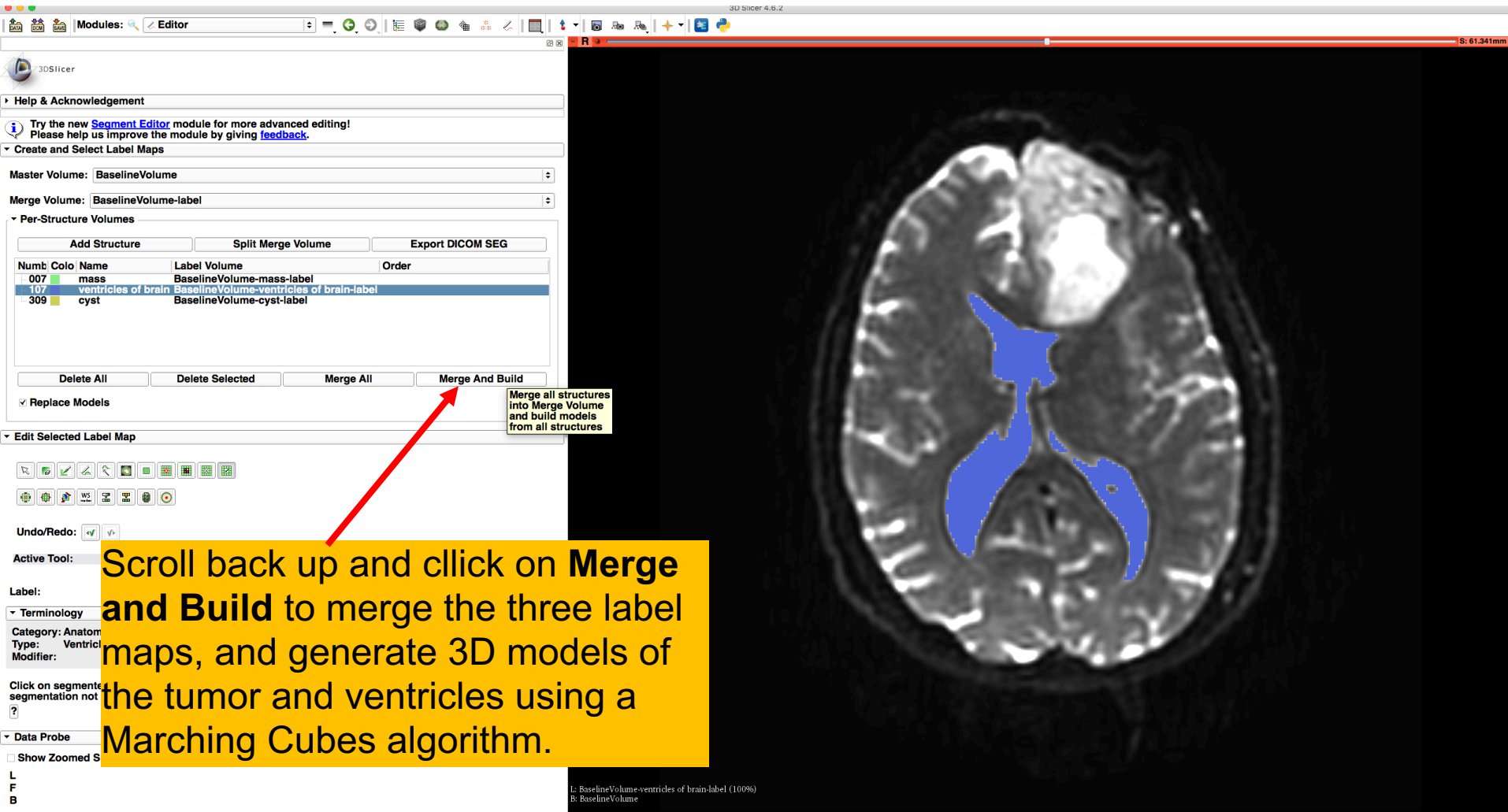


Click in the occipital horn of the ventricle .

Ventricles Segmentation



Ventricles Segmentation



3D Slicer 4.6.2

Modules: Editor

3D Slicer

Help & Acknowledgement

Try the new [Segment Editor](#) module for more advanced editing!
Please help us improve the module by giving [feedback](#).

Create and Select Label Maps

Master Volume: BaselineVolume

Merge Volume: BaselineVolume-label

Per-Structure Volumes

| Num | Color | Name | Label Volume | Order |
|-----|--------|---------------------|--|-------|
| 007 | green | mass | BaselineVolume-mass-label | |
| 107 | blue | ventricles of brain | BaselineVolume-ventricles of brain-label | |
| 309 | yellow | cyst | BaselineVolume-cyst-label | |

Delete All Delete Selected Merge All Merge And Build

Replace Models

Edit Selected Label Map

Undo/Redo: [undo] [redo]

Active Tool:

Label:

Terminology

Category: Anatom

Type: Ventricl

Modifier:

Click on segments segmentation not

Data Probe

Show Zoomed S

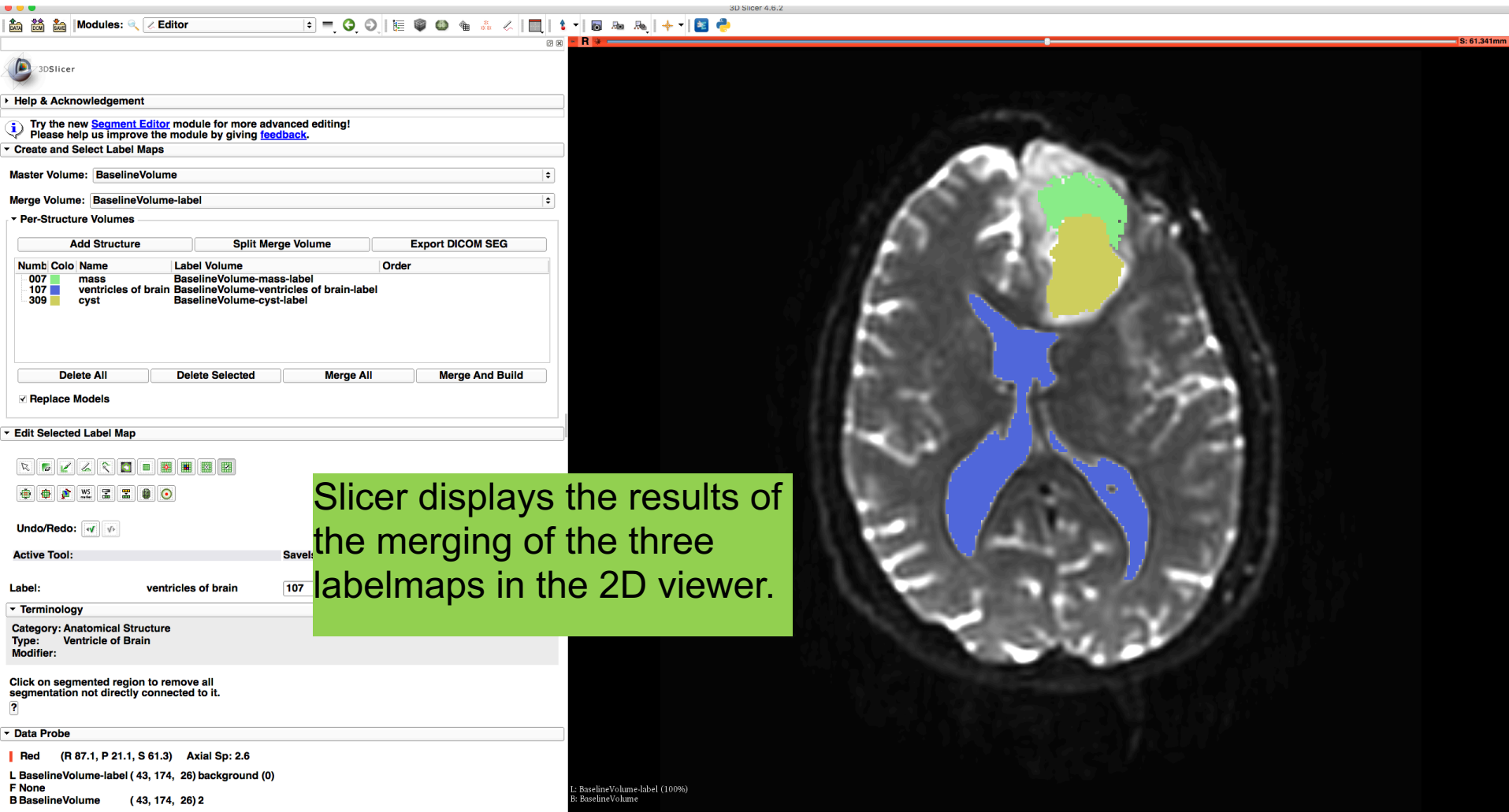
L
F
B

Merge all structures into Merge Volume and build models from all structures

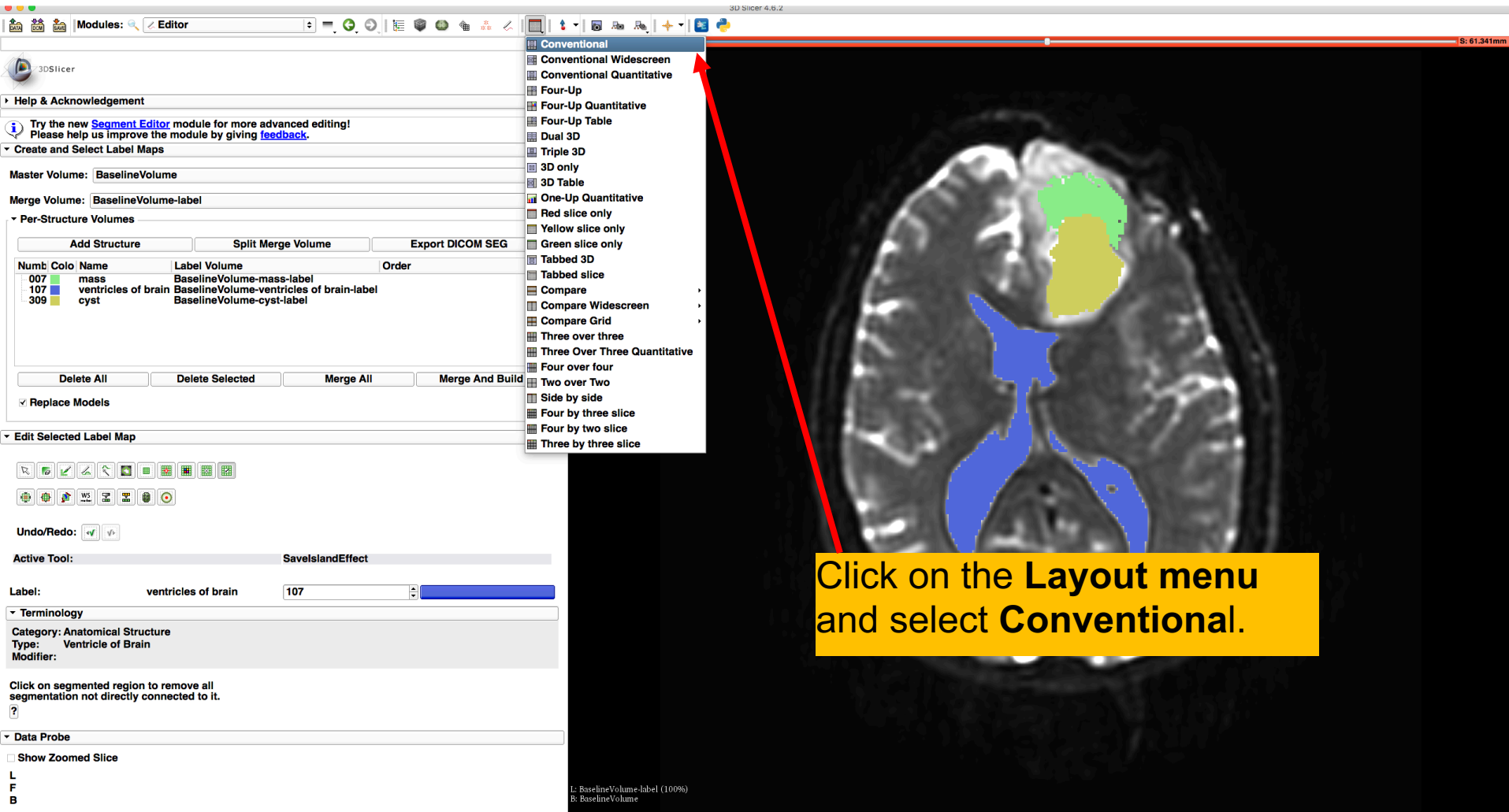
Scroll back up and click on **Merge and Build** to merge the three label maps, and generate 3D models of the tumor and ventricles using a Marching Cubes algorithm.

L: BaselineVolume-ventricles of brain-label (100%)
B: BaselineVolume

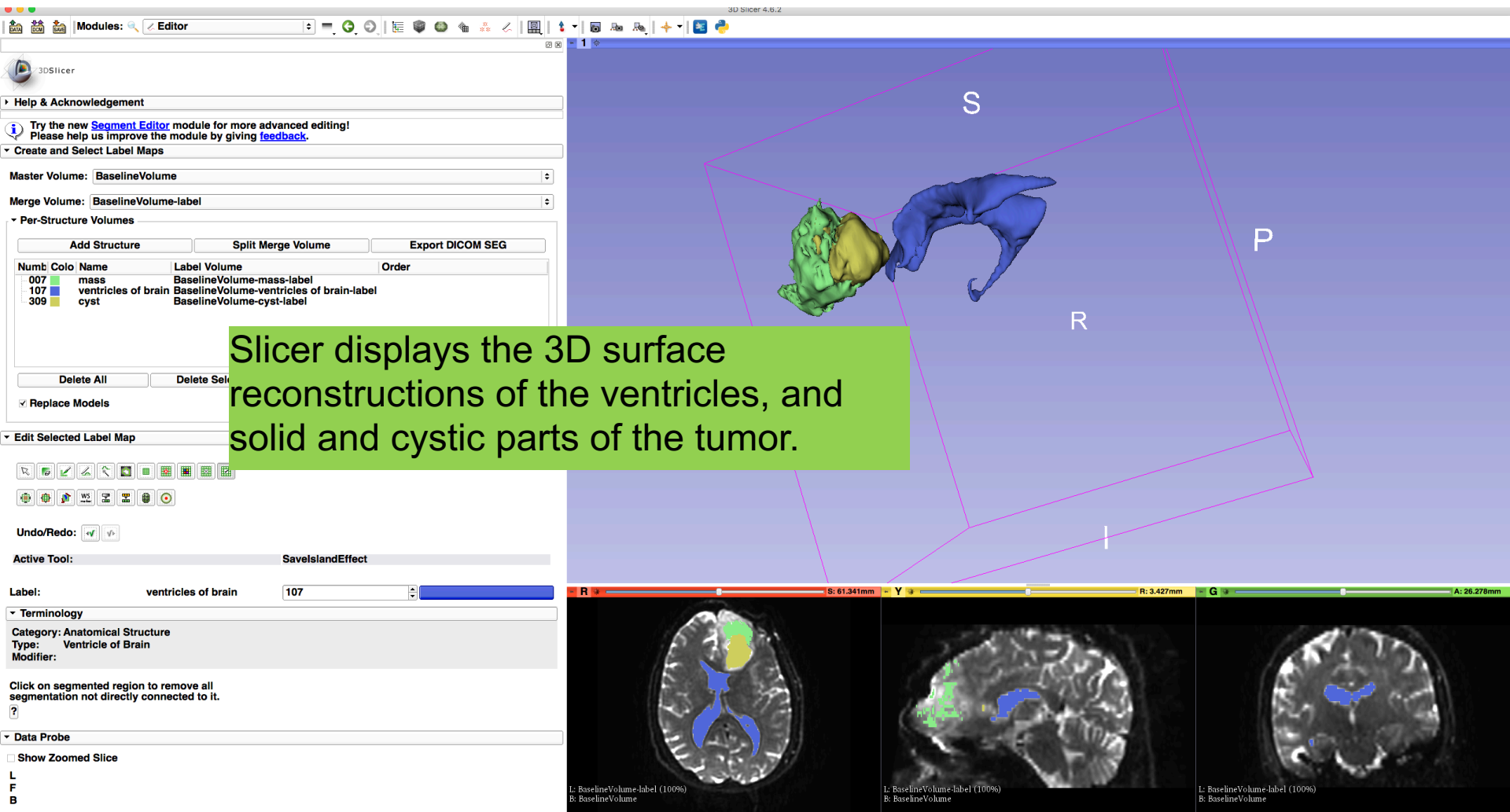
Final Result of Segmentation



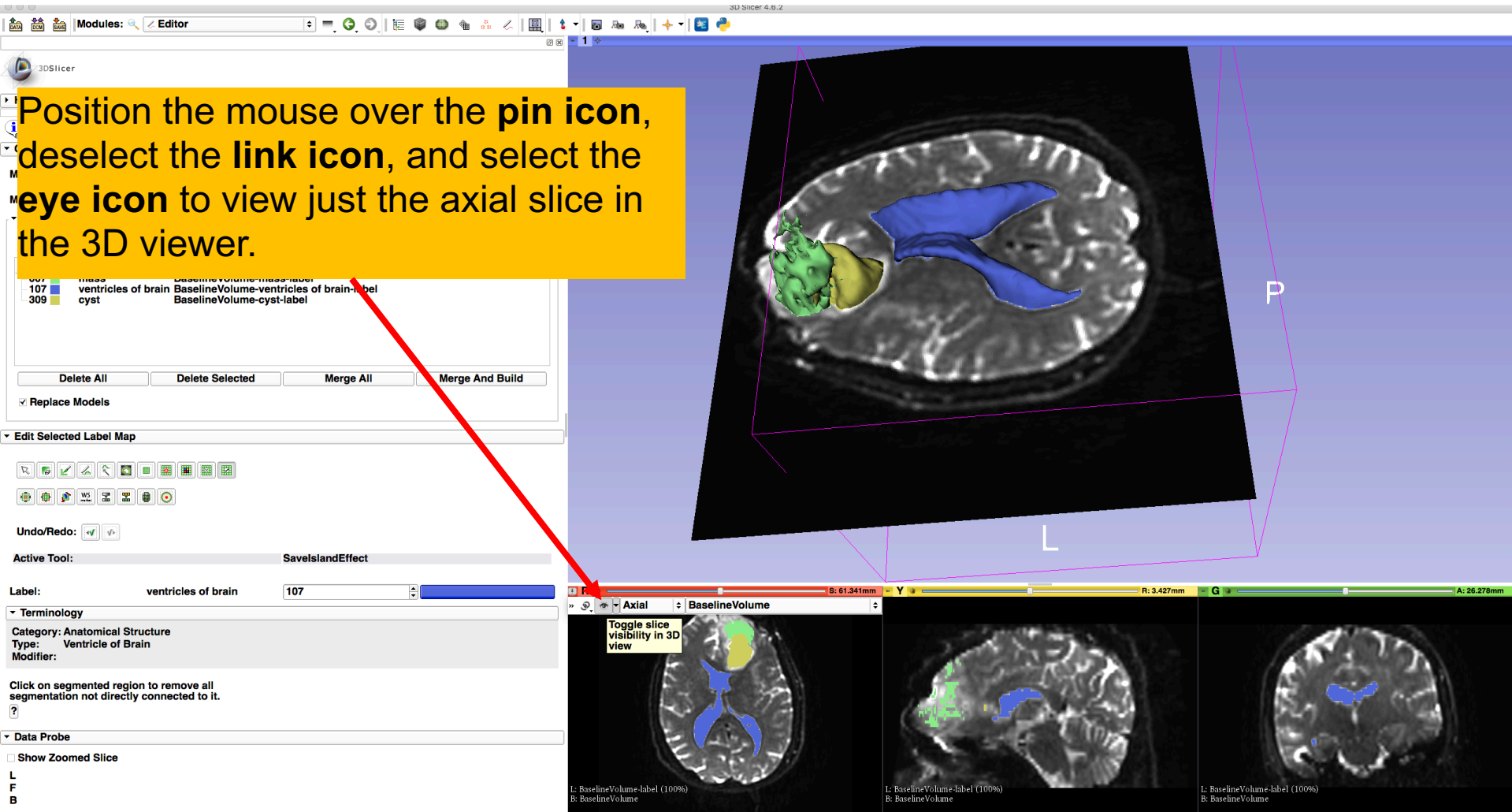
Final Result of Segmentation



Final Result of Segmentation



Definition of peri-tumoral volume



Definition of peri-tumoral volume

3D Slicer 4.6.2

Modules: Editor

Help & Acknowledgement

Try the new [Segment Editor](#) module for more advanced editing!
Please help us improve the module by giving [feedback](#).

Create and Select Label Maps

Master Volume: BaselineVolume

Merge Volume: BaselineVolume-label

Per-Structure Volumes

| Num | Color | Name | Label Volume | Order |
|-----|--------|------|---------------------------|-------|
| 007 | green | mass | BaselineVolume-mass-label | |
| 309 | yellow | cyst | BaselineVolume-cyst-label | |

Delete All Delete Selected Merge All Merge And Build

Replace Models

Edit Selected Label Map

DilateEffect

Undo/Redo: [undo] [redo]

Active Tool: SavelandEffect

Label: cyst 309

Terminology

Category: Morphologically Altered Structure

Type: Cyst

Modifier:

Click on segmented region to remove all segmentation not directly connected to it.

Data Probe

Show Zoomed Slice

L F B

Select the label map **BaselineVolume-cyst-label** (yellow) and select the **DilateEffect** tool.

R 61.341mm Y 3.427mm G 26.278mm

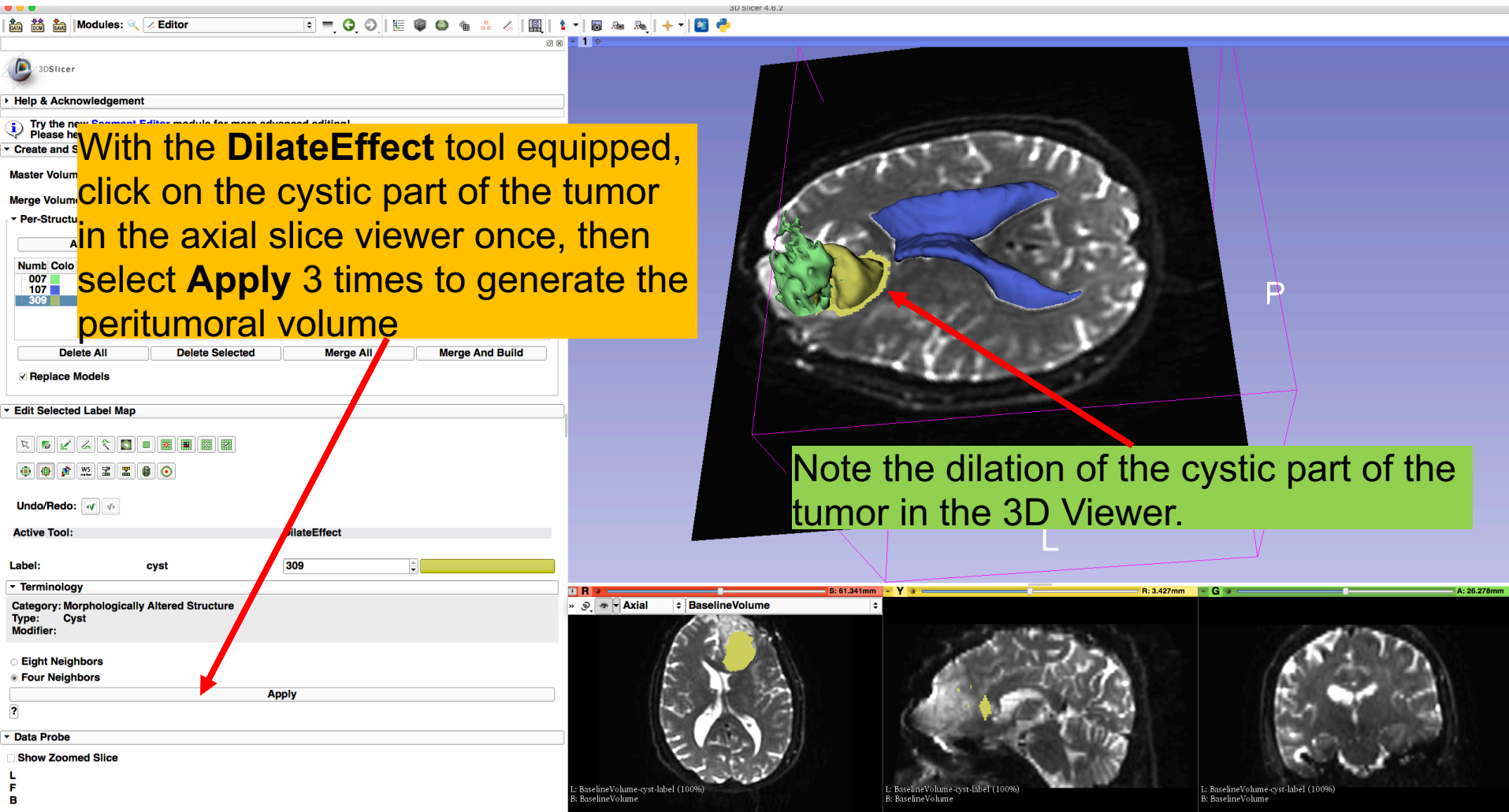
Axial BaselineVolume

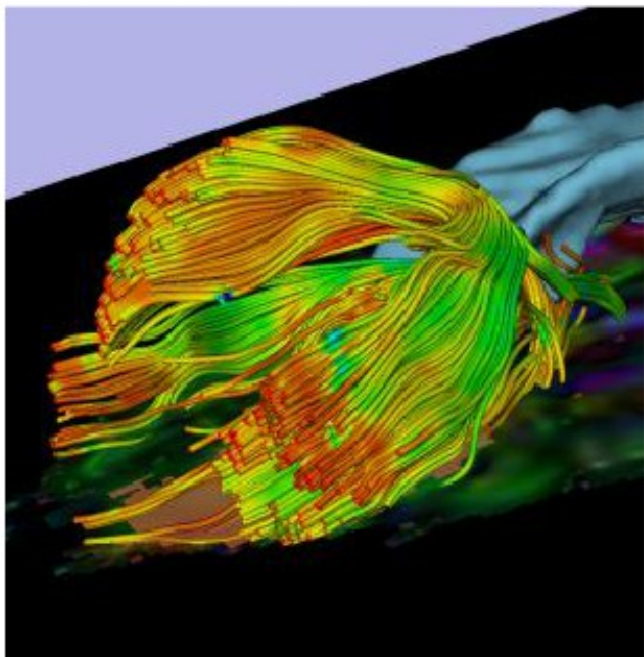
L: BaselineVolume-cyst-label (100%)
B: BaselineVolume

L: BaselineVolume-cyst-label (100%)
B: BaselineVolume

L: BaselineVolume-cyst-label (100%)
B: BaselineVolume

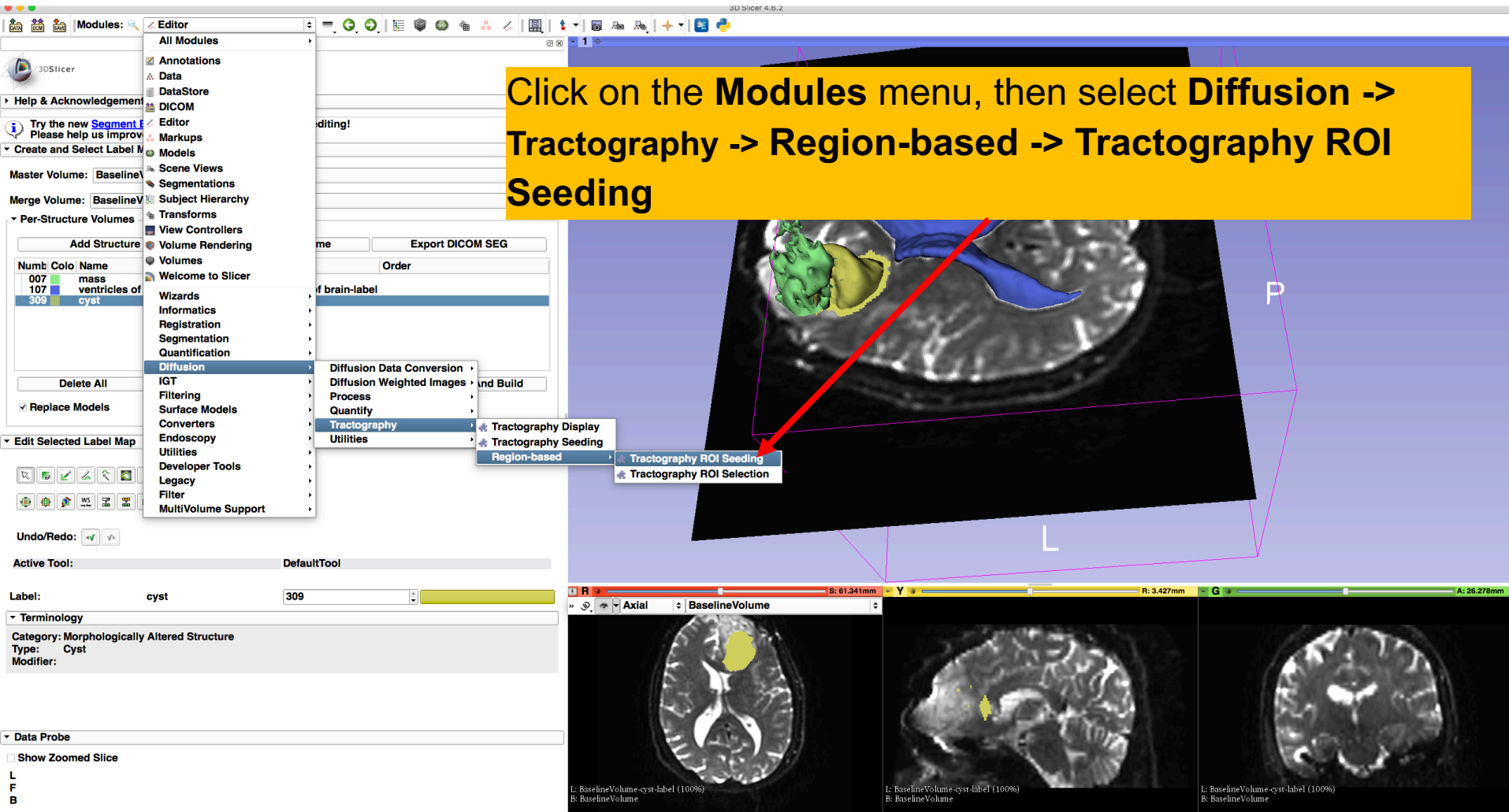
Definition of peri-tumoral volume





Part 2: Tractography exploration of peri- tumoral white matter fibers

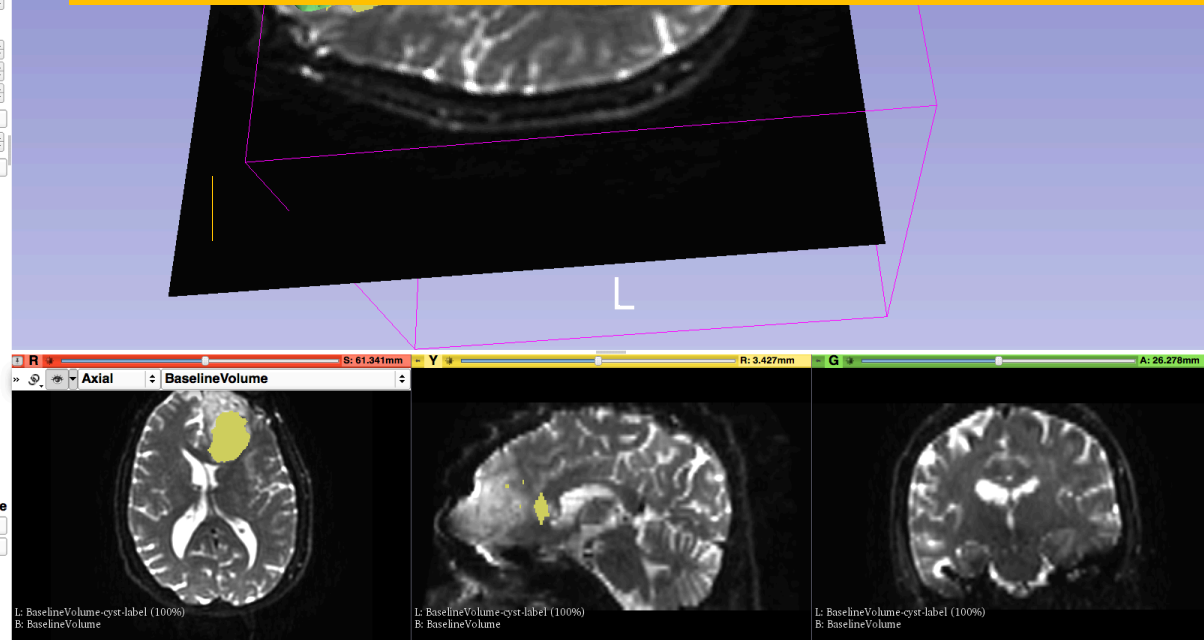
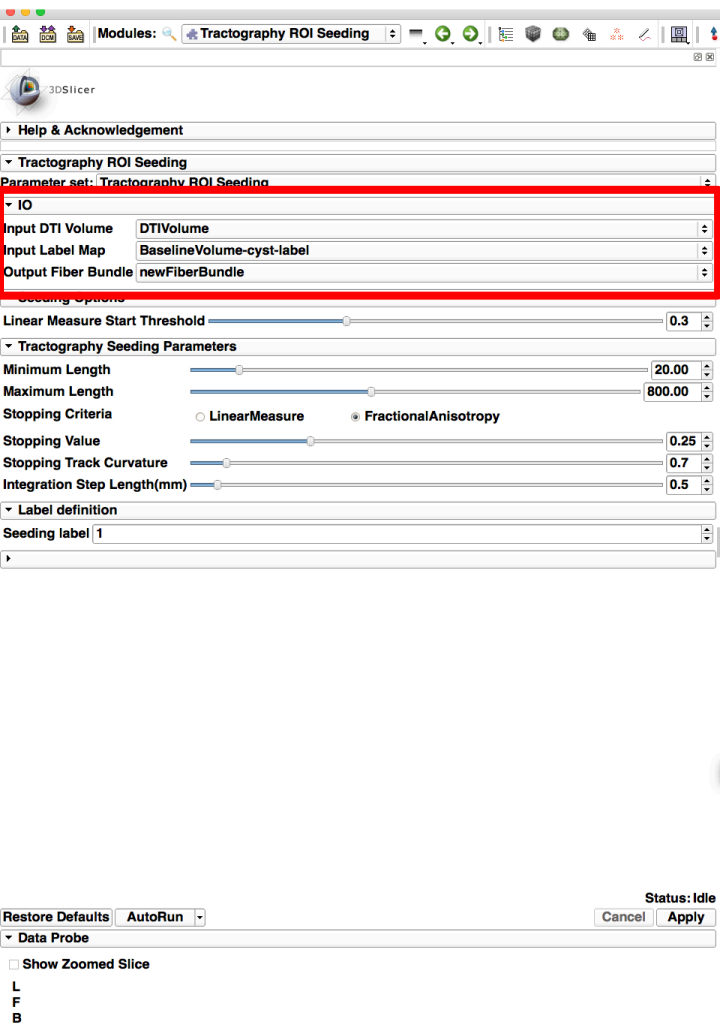
Tractography LabelMap Seeding



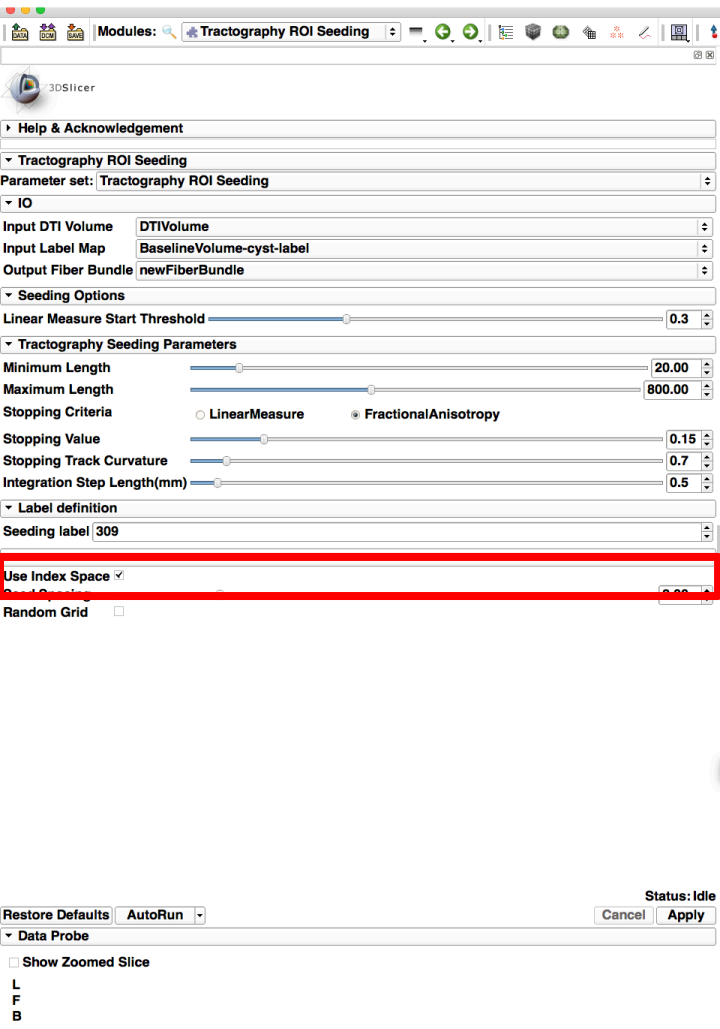
Tractography LabelMap Seeding

Go to I/O and set the following values:

- **Input DTI Volume:** DTIVolume
- **Input Label Map:** BaselineVolume-cyst-label
- **Output Fiber Bundle:** Create and rename newFiberBundle

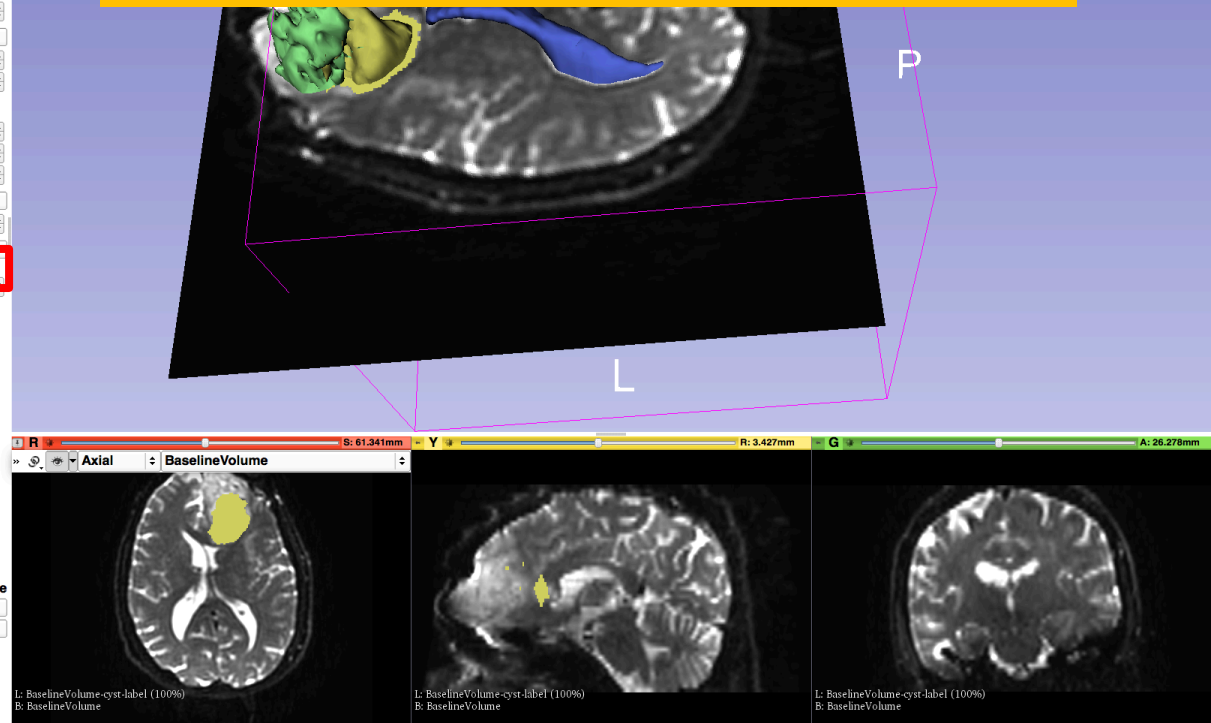


Tractography LabelMap Seeding

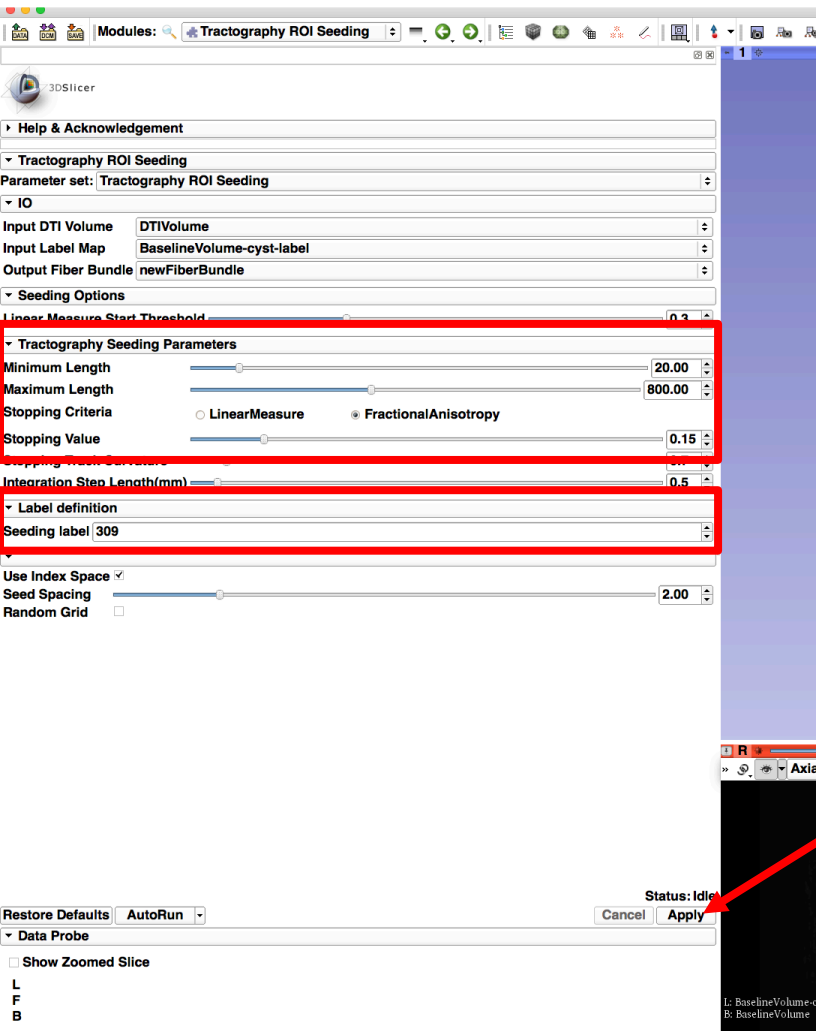


Scroll down and set the following values:

- Check **Use Index Space**



Tractography LabelMap Seeding



Scroll down to **Tractography Seeding Parameters** and set the following values:

- Set **Stopping Criteria** to **FractionalAnisotropy**
- Set **Stopping Value** to **0.15**

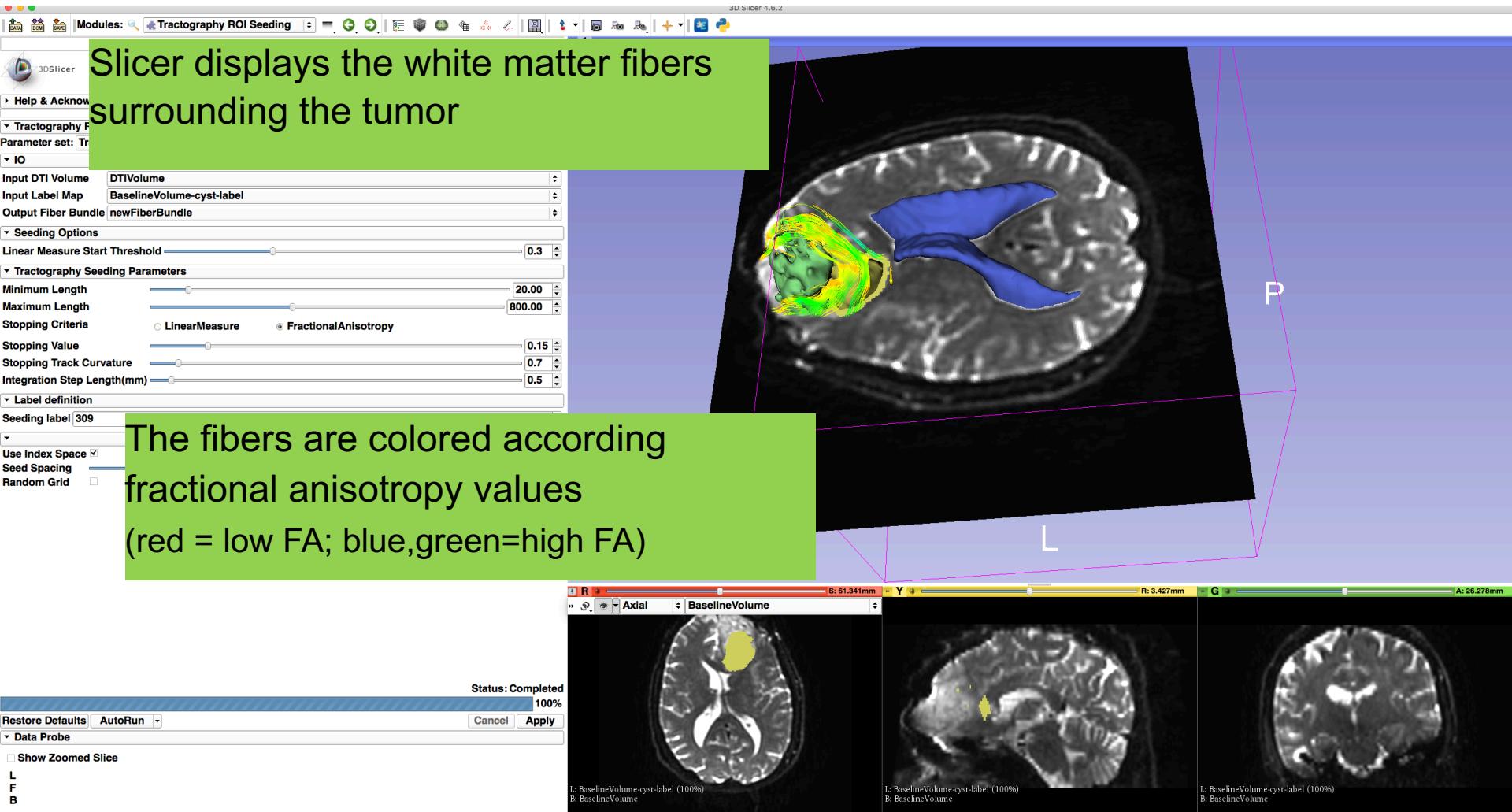
Scroll down to **Label Definition** and set the following values:

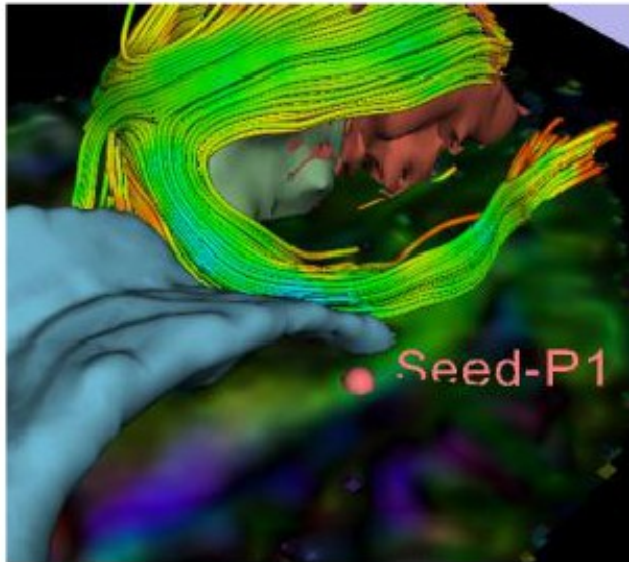
- Set **Seeding Label** to **309 (cyst)**

Click on **Apply**



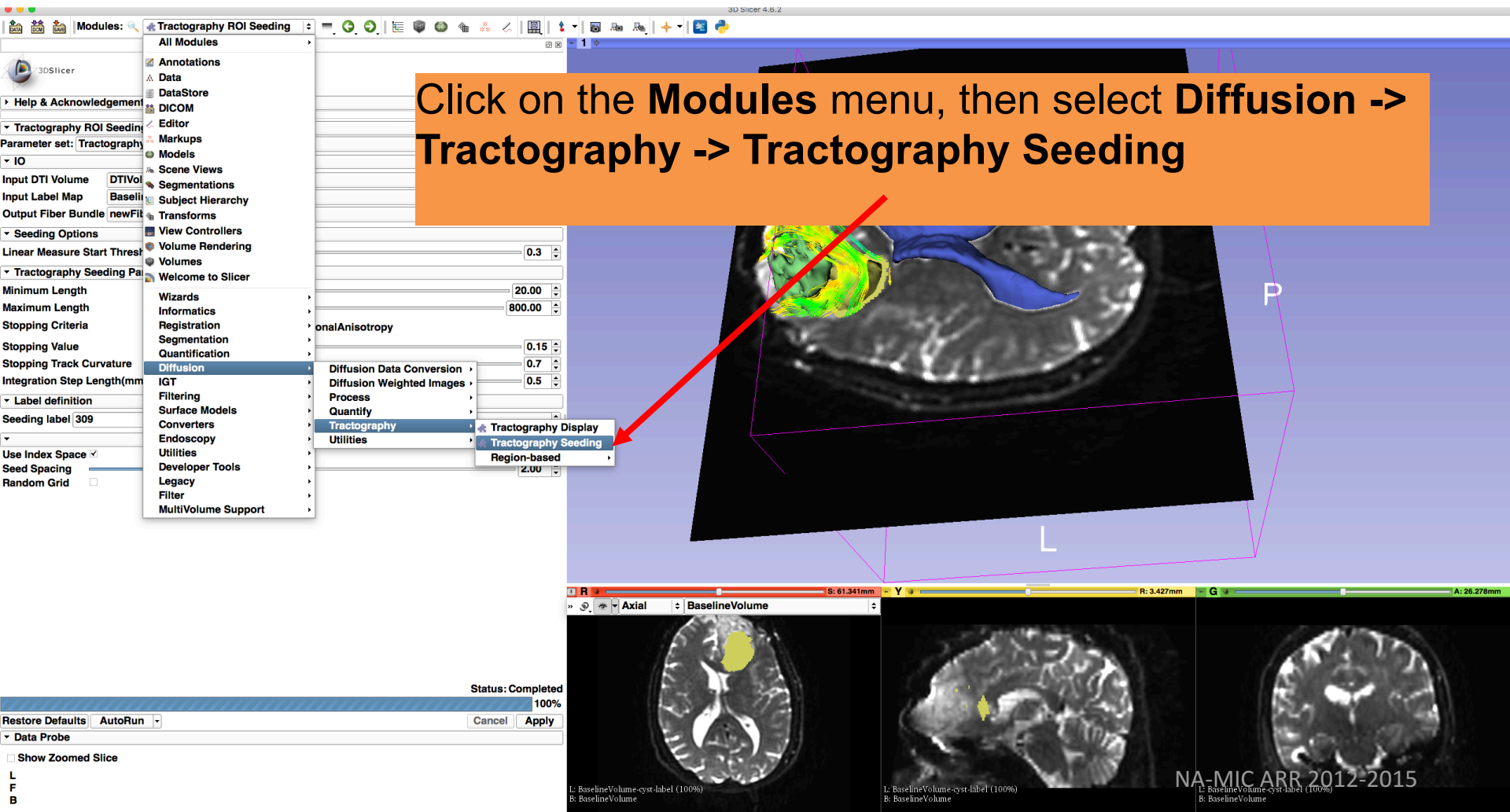
Tractography LabelMap Seeding



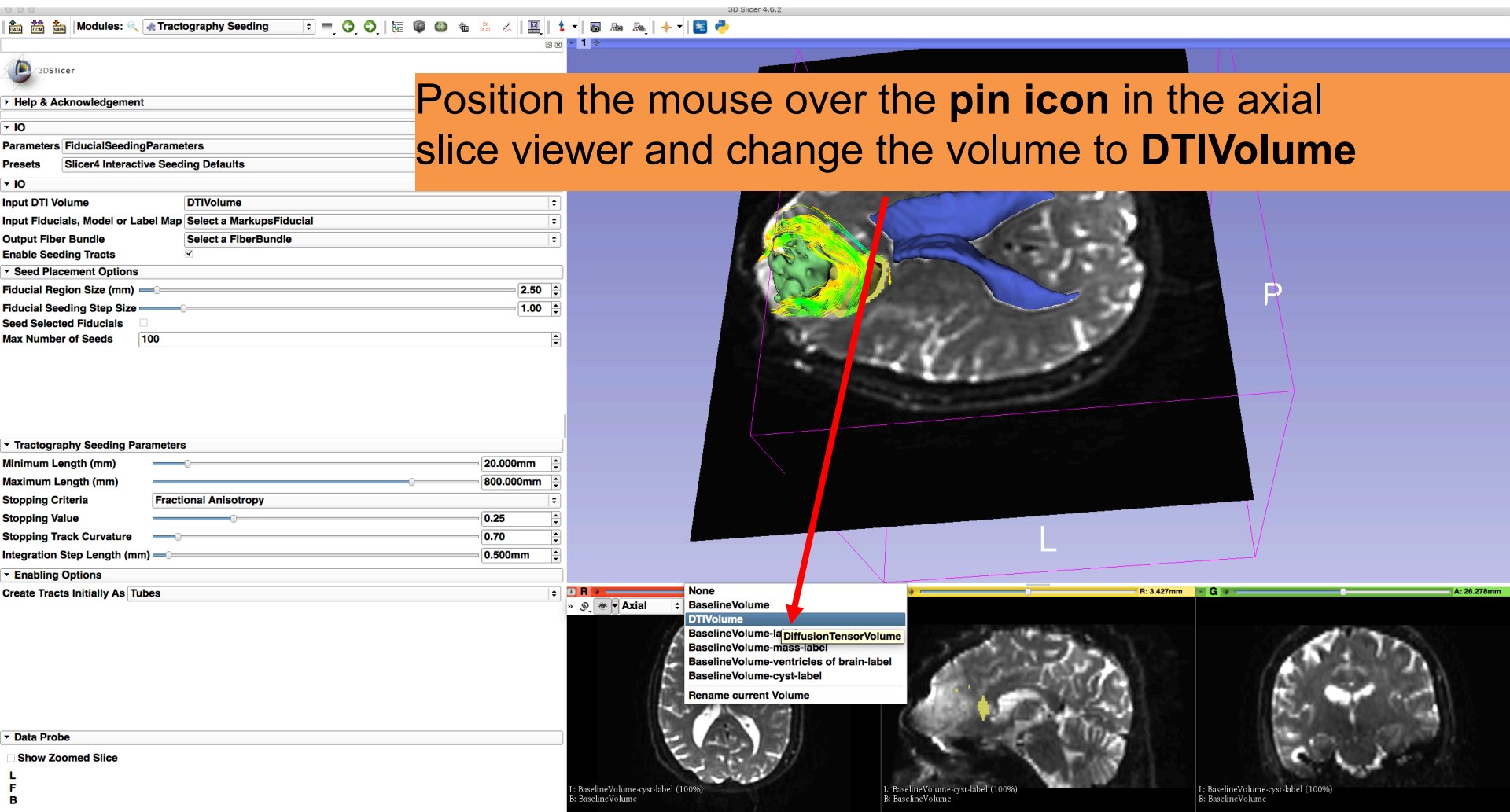


Part 4: Tractography exploration of the ipsilateral and contralateral side

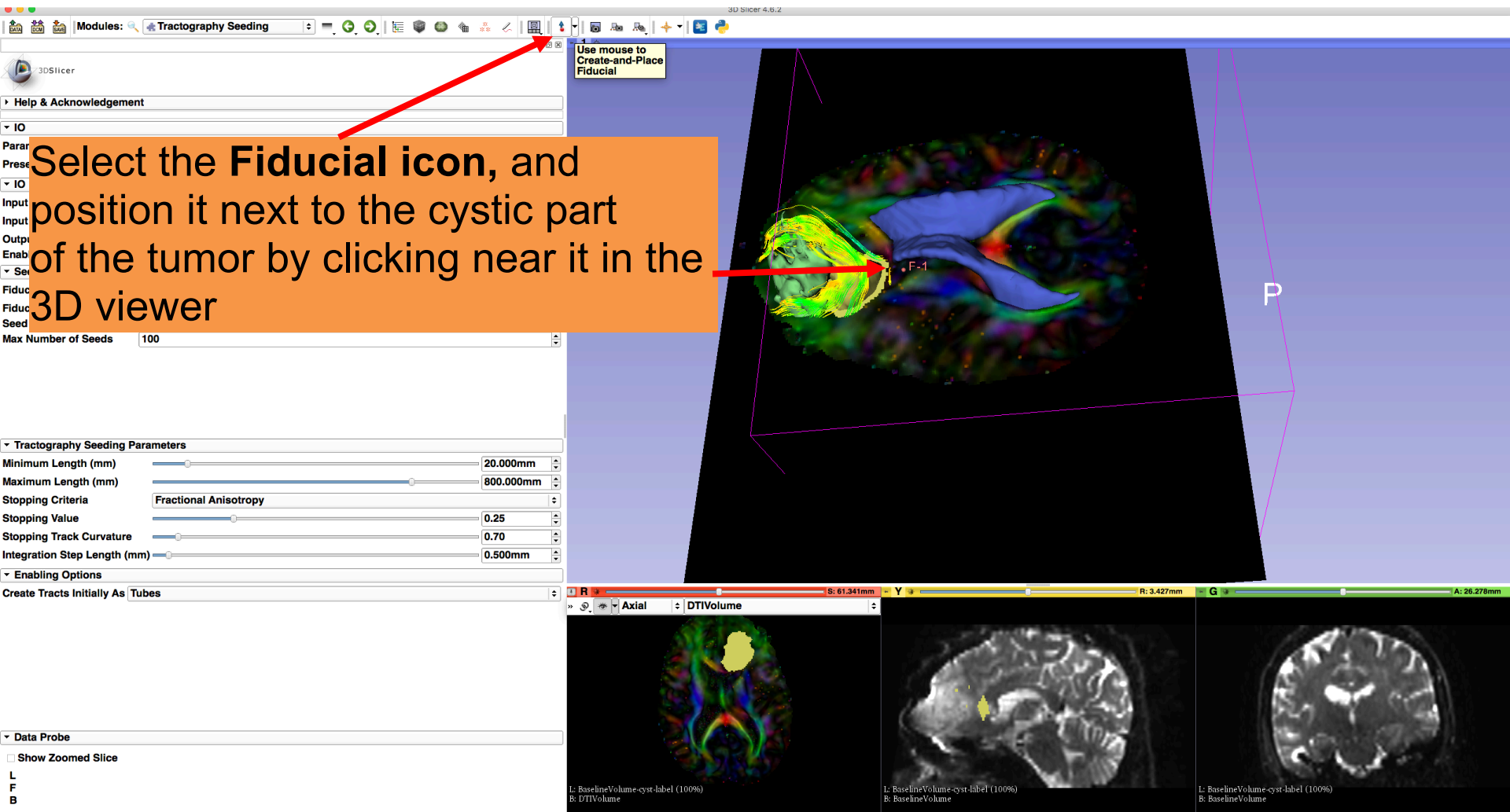
Tractography on-the-fly



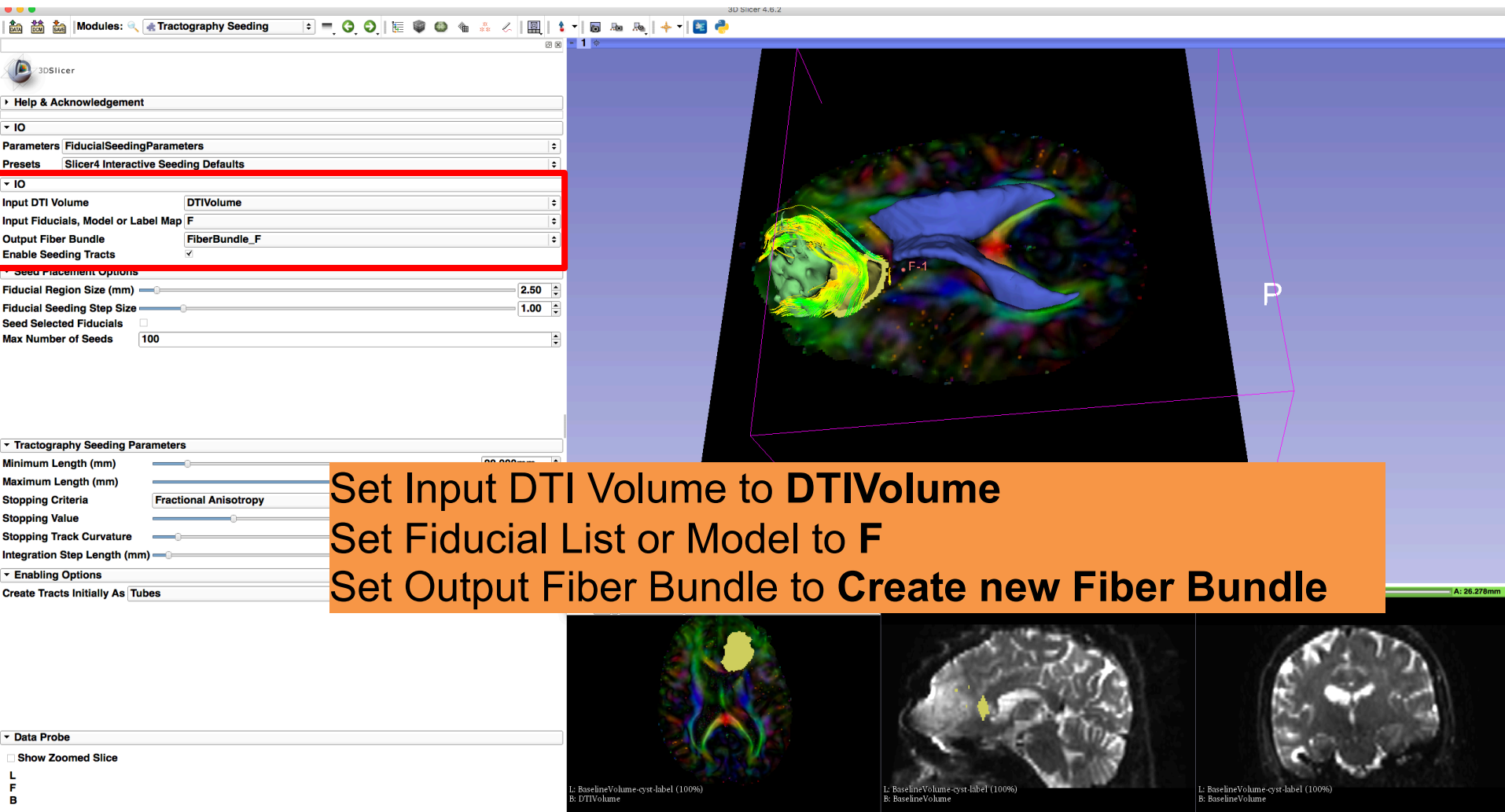
Tractography on-the-fly



Tractography on-the-fly



Tractography on-the-fly



3D Slicer 4.6.2

Modules: Tractography Seeding

Help & Acknowledgement

IO

Parameters: FiducialSeedingParameters

Presets: Slicer4 Interactive Seeding Defaults

IO

Input DTI Volume: DTIVolume

Input Fiducials, Model or Label Map: F

Output Fiber Bundle: FiberBundle_F

Enable Seeding Tracts: ☒

Seed Placement Options

Fiducial Region Size (mm): 2.50

Fiducial Seeding Step Size: 1.00

Seed Selected Fiducials: ☐

Max Number of Seeds: 100

Tractography Seeding Parameters

Minimum Length (mm): 0.000

Maximum Length (mm): 0.000

Stopping Criteria: Fractional Anisotropy

Stopping Value: 0.000

Stopping Track Curvature: 0.000

Integration Step Length (mm): 0.000

Enabling Options

Create Tracts Initially As: Tubes

Data Probe

Show Zoomed Slice: ☐

L: BaselineVolume-cyst-label (100%)
F: DTIVolume
B: BaselineVolume

L: BaselineVolume-cyst-label (100%)
B: BaselineVolume

L: BaselineVolume-cyst-label (100%)
B: BaselineVolume

Set Input DTI Volume to **DTIVolume**
Set Fiducial List or Model to **F**
Set Output Fiber Bundle to **Create new Fiber Bundle**

Tractography on-the-fly

3D Slicer 4.6.2

Modules: Tractography Seeding

Help & Acknowledgement

IO

Parameters: FiducialSeedingParameters

Presets: Slicer4 Interactive Seeding Defaults

IO

Input DTI Volume: DTIVolume

Input Fiducials, Model or Label Map: F

Output Fiber Bundle: FiberBundle_F

Enable Seeding Tracts: ☒

Seed Placement Options

Fiducial Region Size (mm): 2.50

Fiducial Seeding Step Size: 1.00

Seed Selected Fiducials: ☐

Max Number of Seeds: 100

Tractography Seeding Parameters

Minimum Length (mm): 10.000mm

Maximum Length (mm): 800.000mm

Stopping Criteria: Fractional Anisotropy

Stopping Value: 0.15

Stopping Track Curvature: 0.70

Integration Step Length (mm): 0.500mm

Enabling Options

Create Tracts Initially As: Tubes

Data Probe

Show Zoomed Slice

L: BaselineVolume-cyst-label (100%)
B: DTIVolume

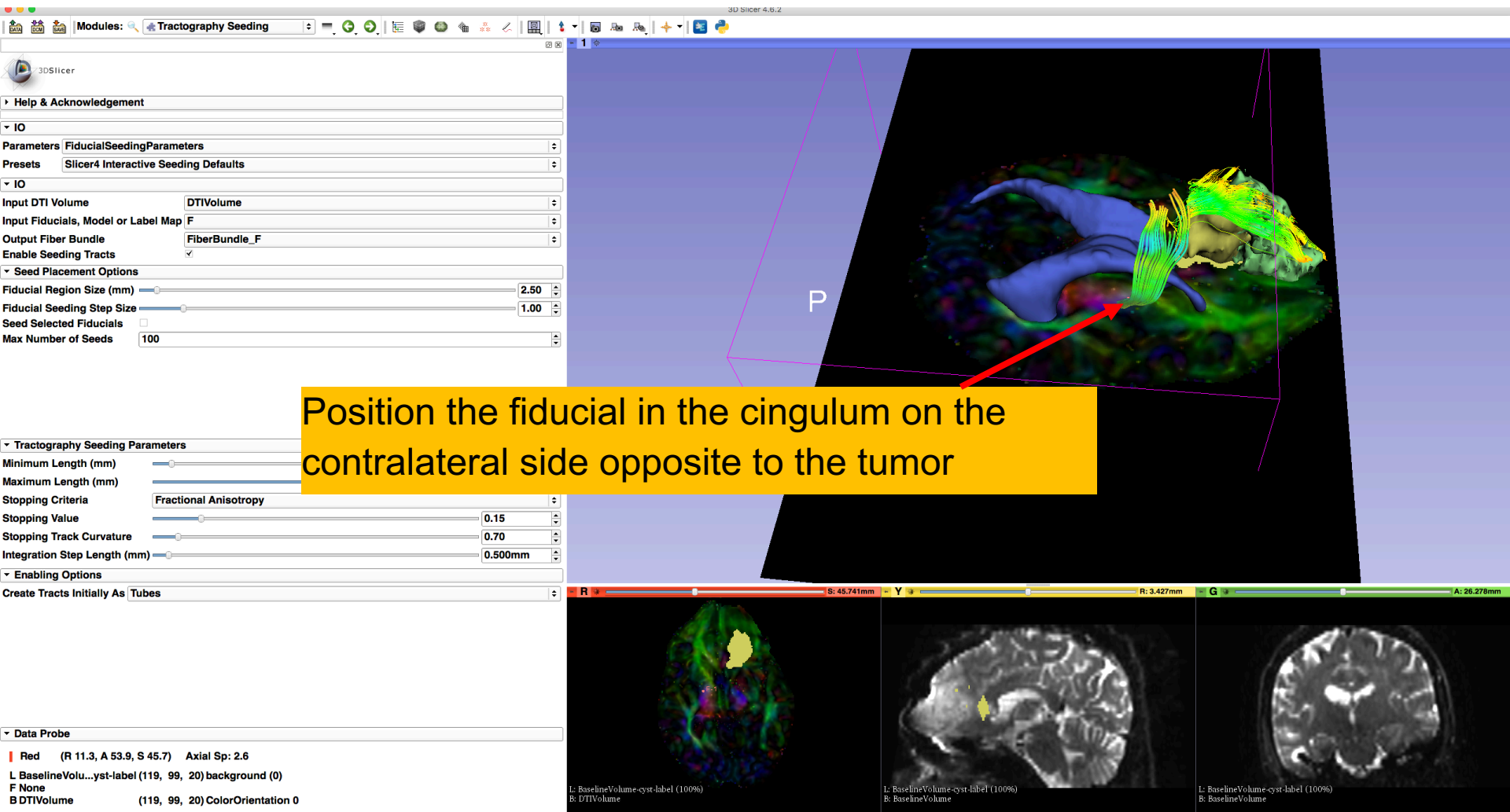
R: 61.341mm
Y: 3.427mm
G: 26.278mm

L: BaselineVolume-cyst-label (100%)
B: BaselineVolume

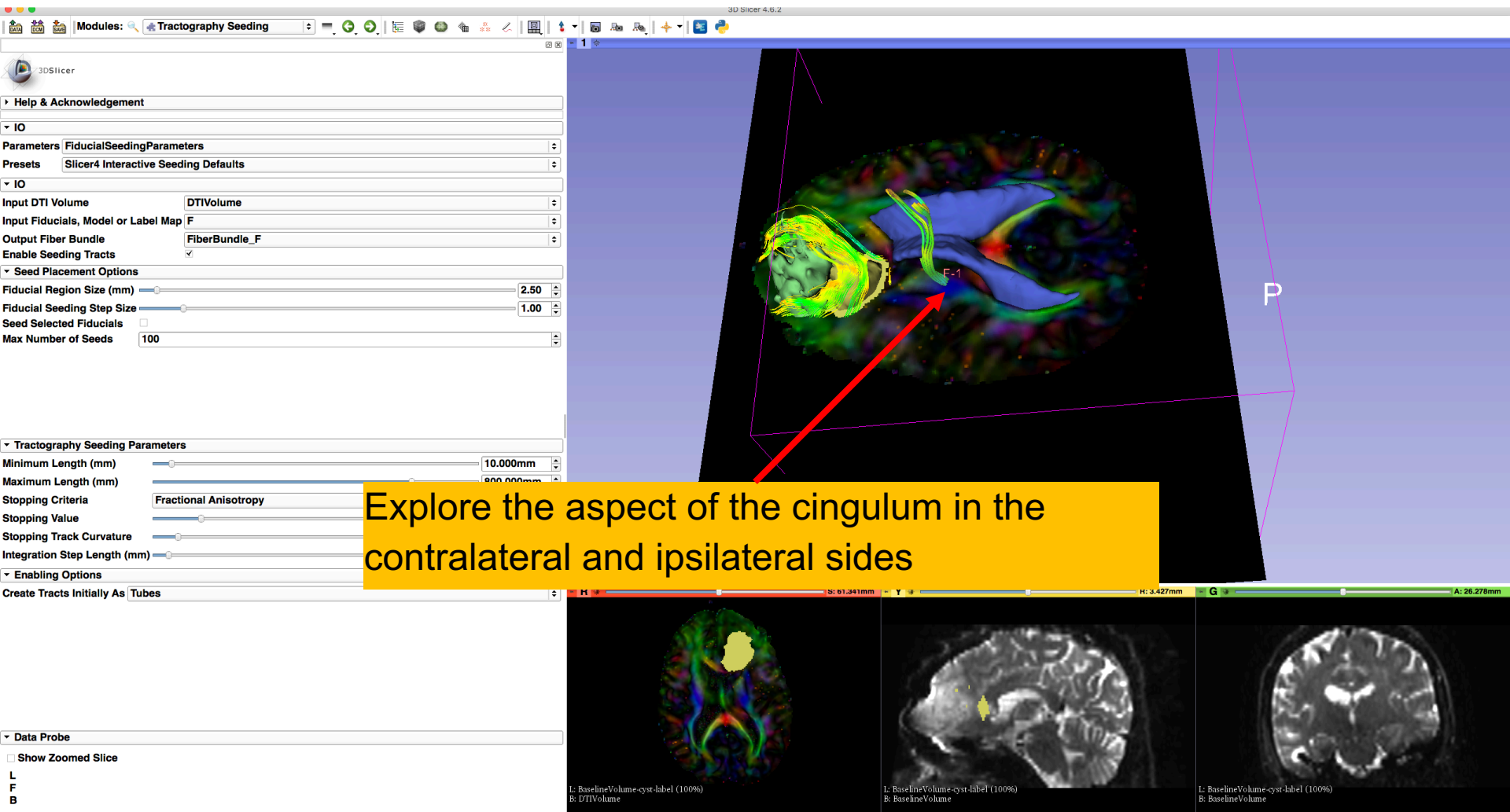
L: BaselineVolume-cyst-label (100%)
B: BaselineVolume

Scroll down the module and set the **Minimum Path Length** to 10.0 mm and the **FA Stopping Value** at 0.15

Tractography on-the-fly



Tractography on-the-fly



Conclusion

- Fully integrated pipeline for semi-automated tumor segmentation and white matter tract reconstruction
- 3D interactive exploration of the white matter tracts surrounding a tumor (peritumoral tracts) for neurosurgical planning

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