



Diffusion MRI Analysis

Sonia Pujol, Ph.D.

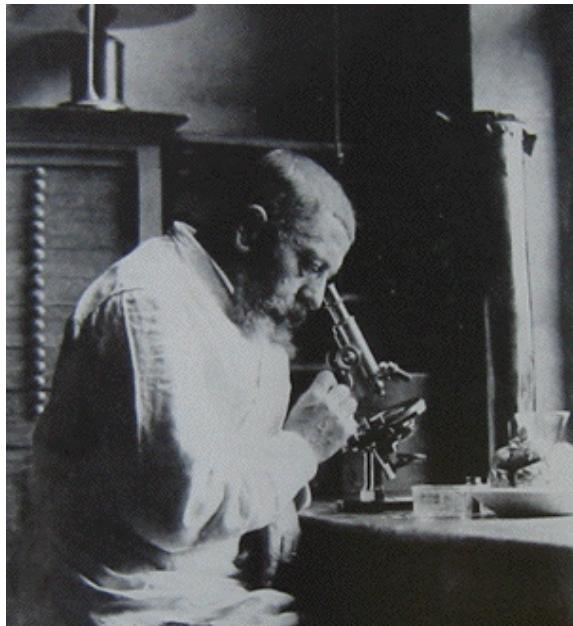
Surgical Planning Laboratory
Brigham and Women's Hospital
Harvard Medical School

Brain Anatomy



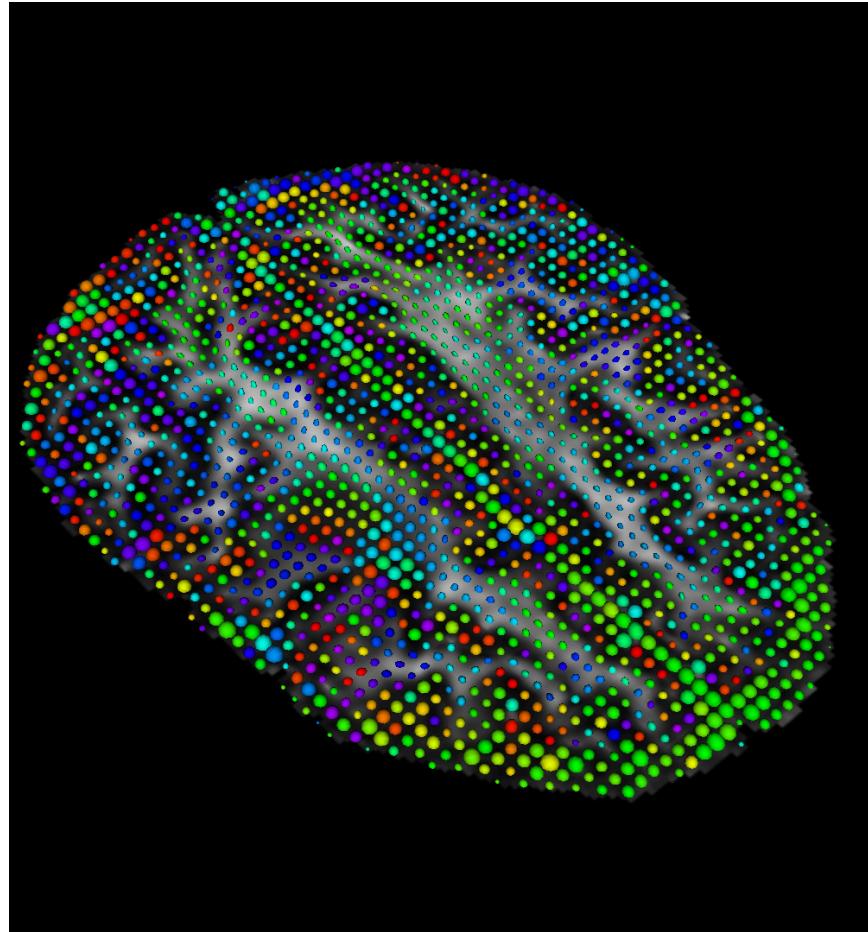
- White matter ~45% of the brain
- Myelinated nerve fibers (~ 10 μm axon diameter)

White Matter Exploration



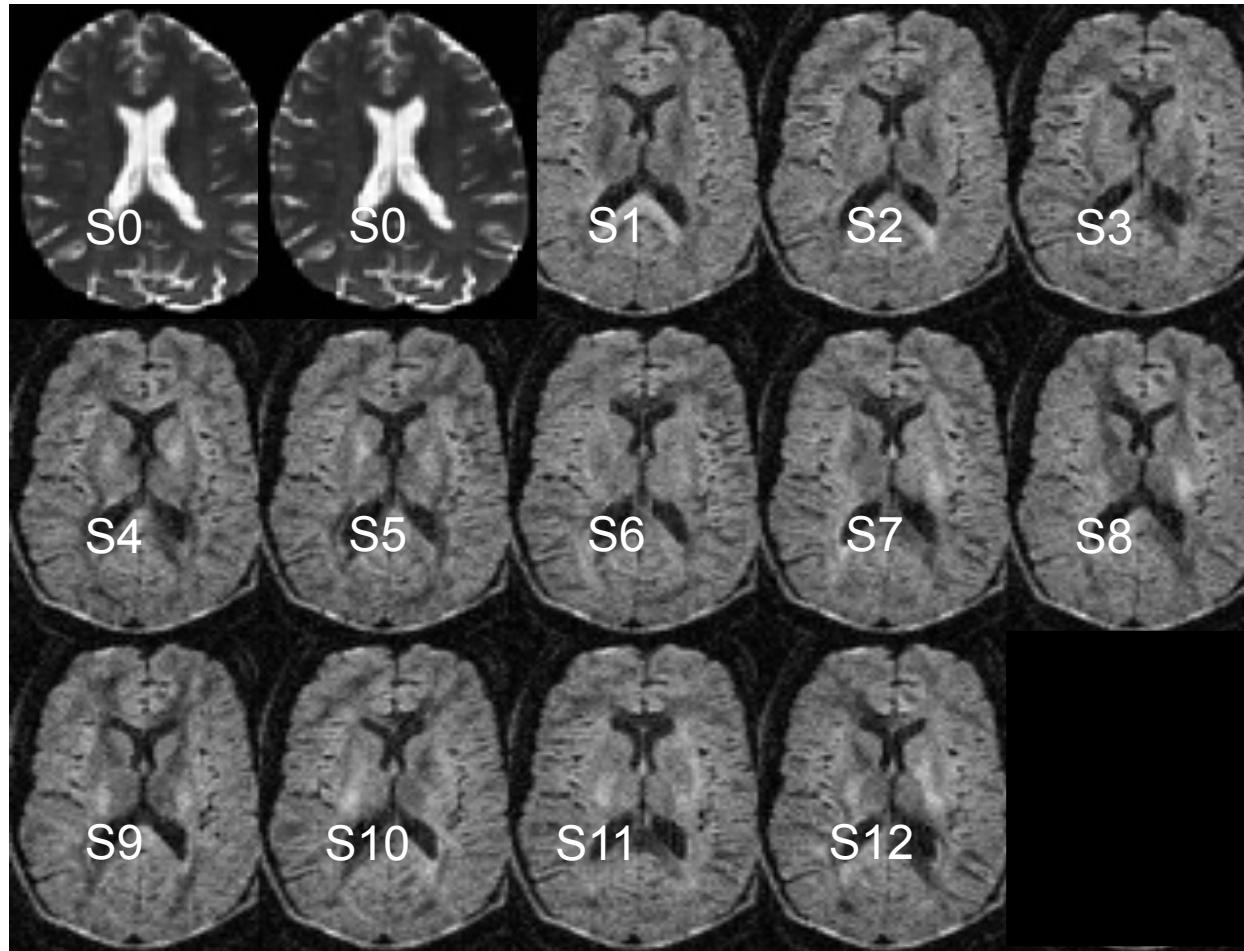
Jules Joseph and Augusta Dejerine (*Anatomie des centres nerveux* (Paris, 1890-1901)): Neuroanatomy atlas based on myelin stained preparation

Diffusion Tensor Imaging (DTI)



- First non-invasive window on white matter anatomy
- Measurement of the motion of water molecules using MRI techniques.
- Three-dimensional reconstruction of the trajectory of white matter bundles

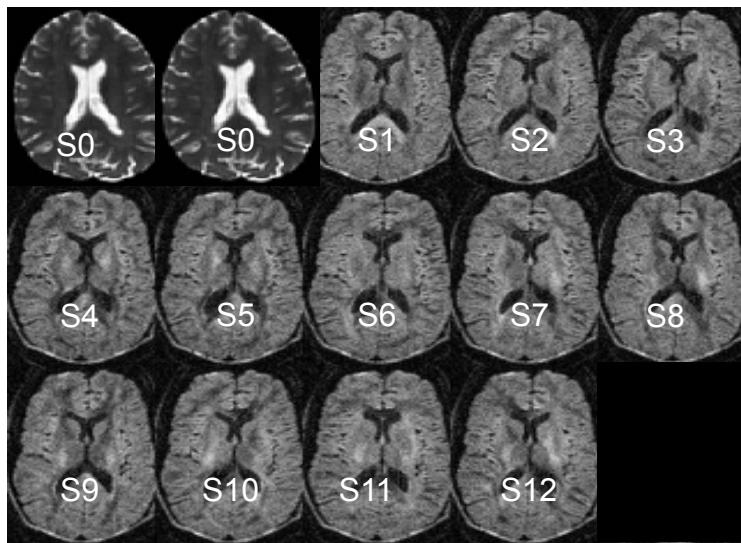
Diffusion Weighted Imaging (DWI)



In this example, the DWI scan was acquired with 12 diffusion sensitizing gradient directions (S1-S12) and 2 non-diffusion sensitizing gradients (S0)

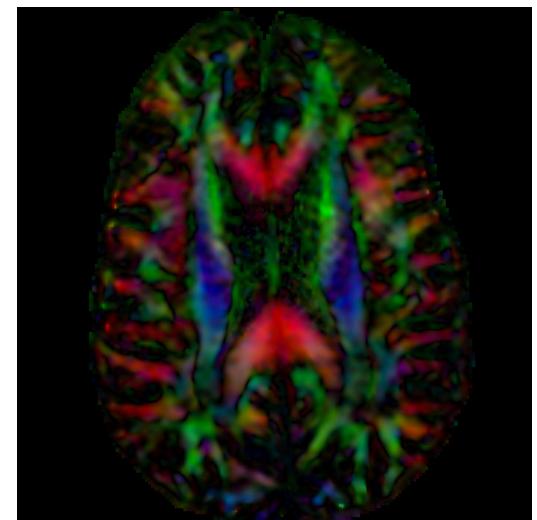
From DWI to DTI

DWI



DWI dataset

DTI



DTI dataset

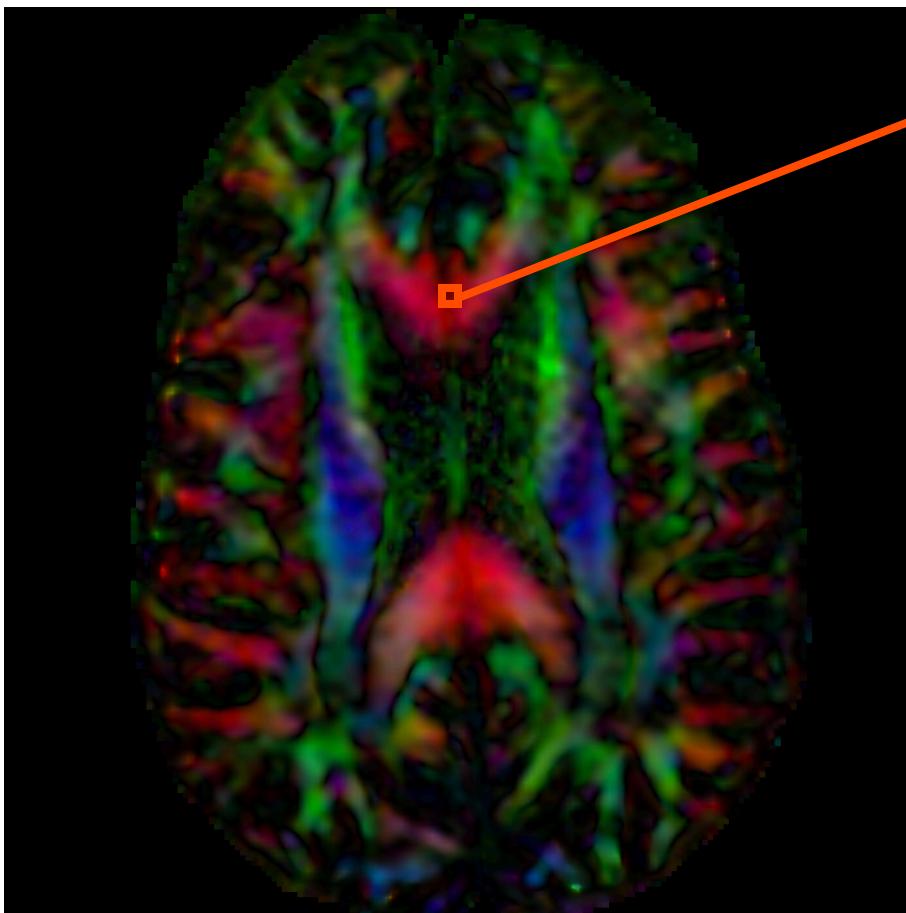


$$S_i = S_0 e^{-b \hat{g}^T D \hat{g}_i}$$

Stejskal-Tanner (1965)

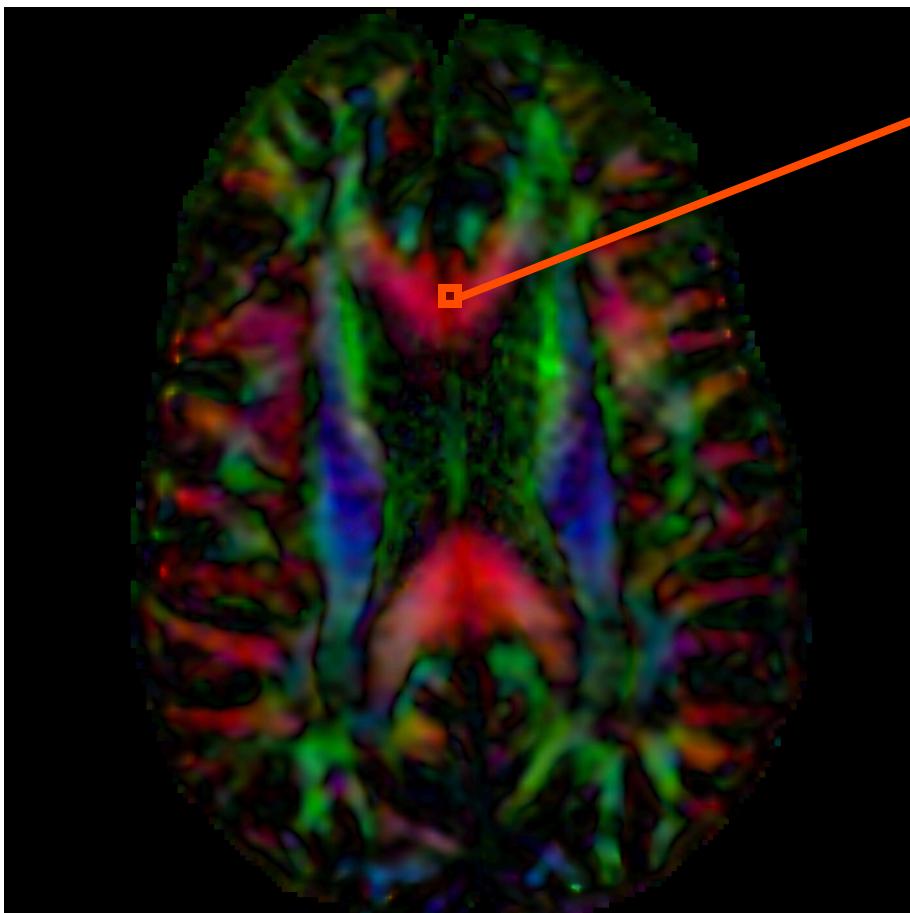
*S_i: DWI volume acquired with
ith gradient
S₀: Baseline volume*

Diffusion Tensor Imaging



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

Diffusion Tensor Imaging

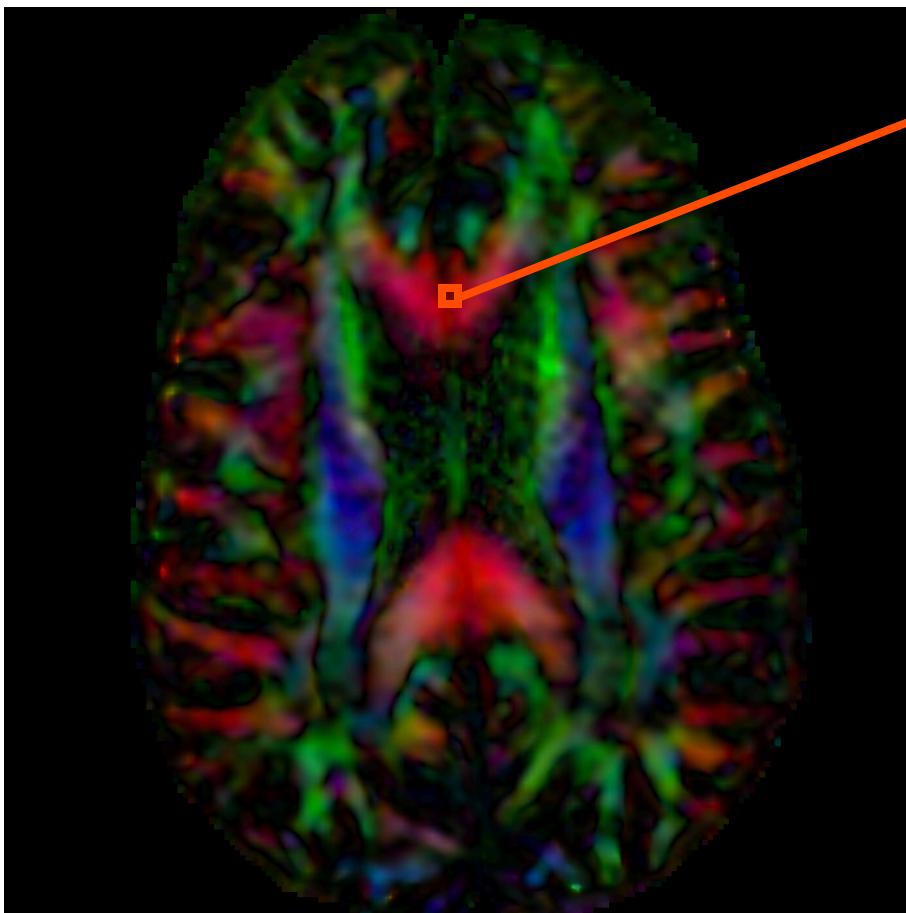


$$S_i = S_0 e^{-b \hat{g}_i^T \underline{D} \hat{g}_i}$$

↓

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

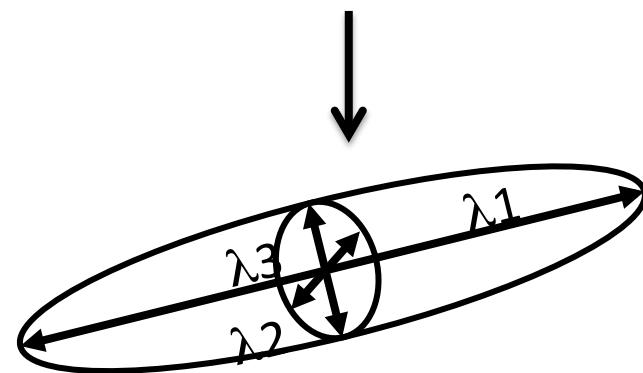
Diffusion Tensor Imaging



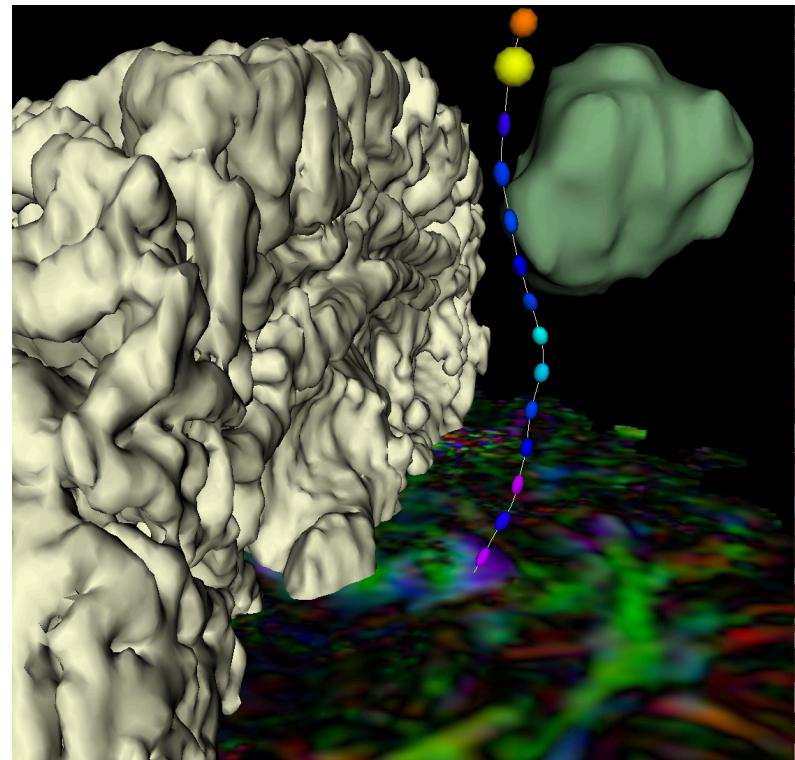
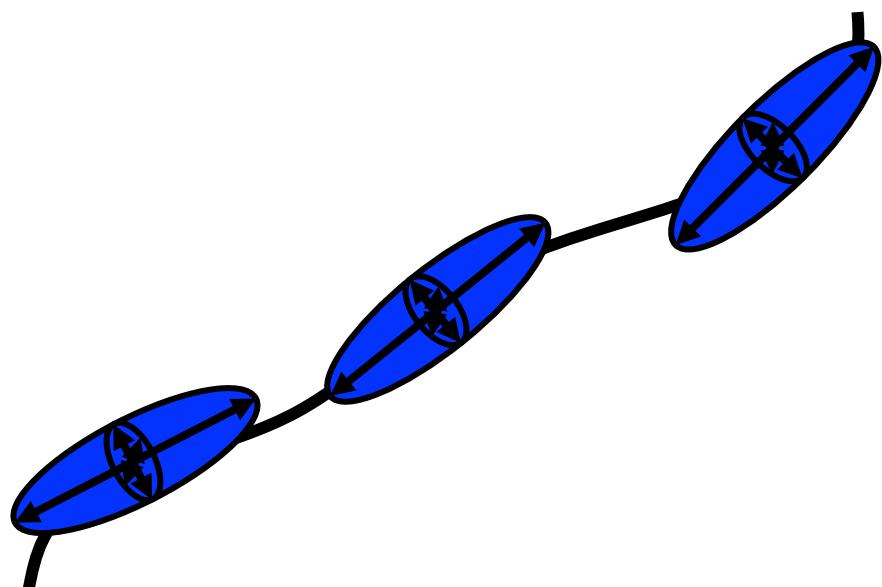
$$S_i = S_0 e^{-b \hat{g}^T \underline{D} \hat{g}_i}$$

↓

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

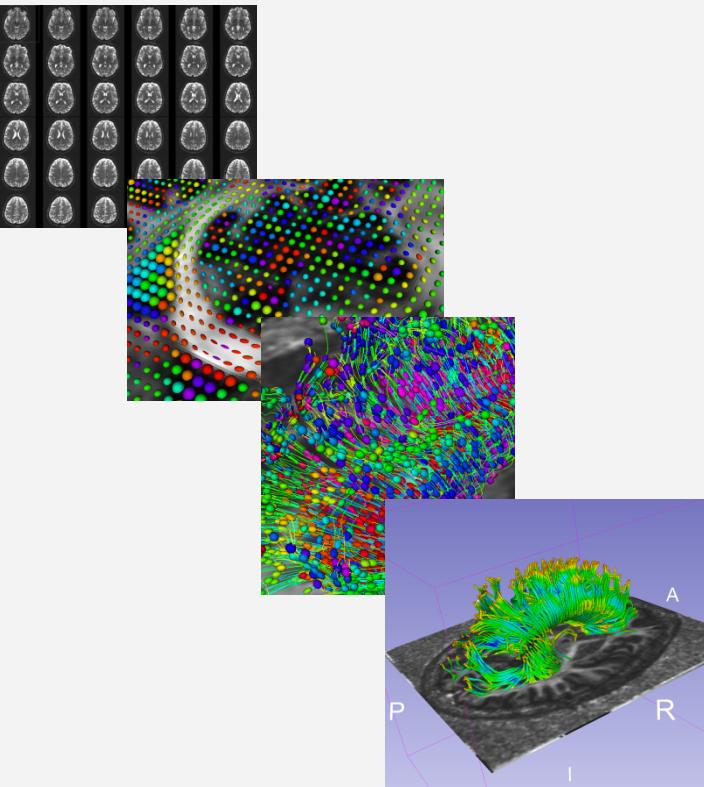


Tractography



DTI tractography provides 3D reconstruction of the trajectory of white matter pathways

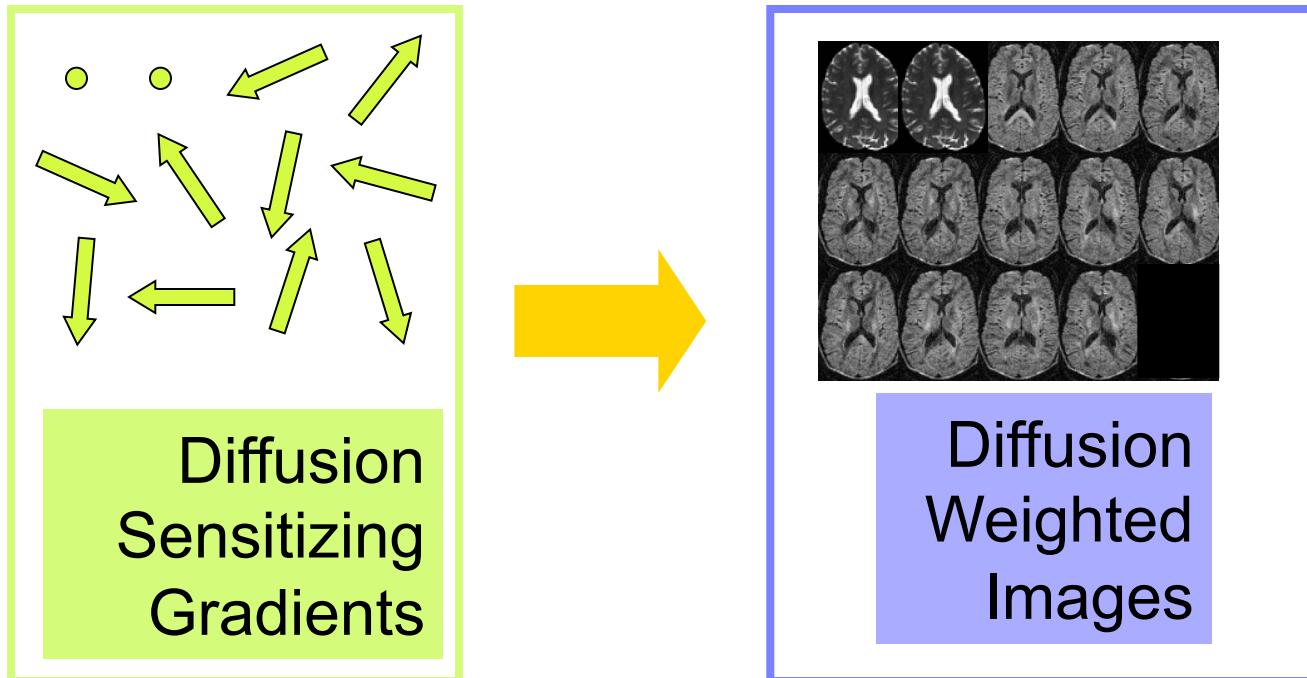
Tutorial Outline



This tutorial is an introduction to the fundamentals of Diffusion MRI analysis, from the estimation of diffusion tensors to the interactive 3D visualization of tracts.

Tutorial Dataset

The tutorial dataset is a Diffusion Weighted MR scan of the brain acquired with 41 diffusion sensitizing gradient directions and 7 baseline.



Tutorial Software

The tutorial uses the 3DSlicer (Version 4.5.0-1 Stable Release) software available at

<http://download.slicer.org>

Disclaimer

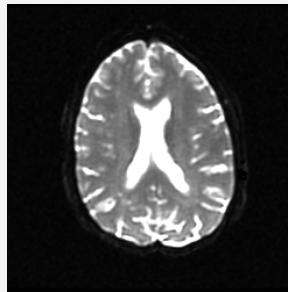
It is the responsibility of the user of 3DSlicer to comply with both the terms of the license and with the applicable laws, regulations and rules. Slicer is a tool for research, and is not FDA approved.

Learning Objectives

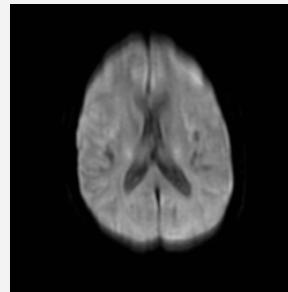
Following this tutorial, you'll be able to

- 1) Estimate a tensor volume from a set of Diffusion Weighted Images
- 2) Understand the shape and size of the diffusion ellipsoid
- 3) Reconstruct DTI tracts from a pre-defined region of interest
- 4) Interactively visualize DTI tracts seeded from a fiducial

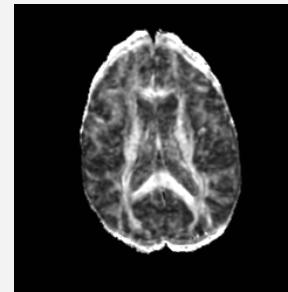
MR Diffusion Analysis Pipeline



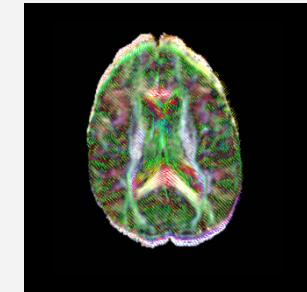
DWI
Acquisition



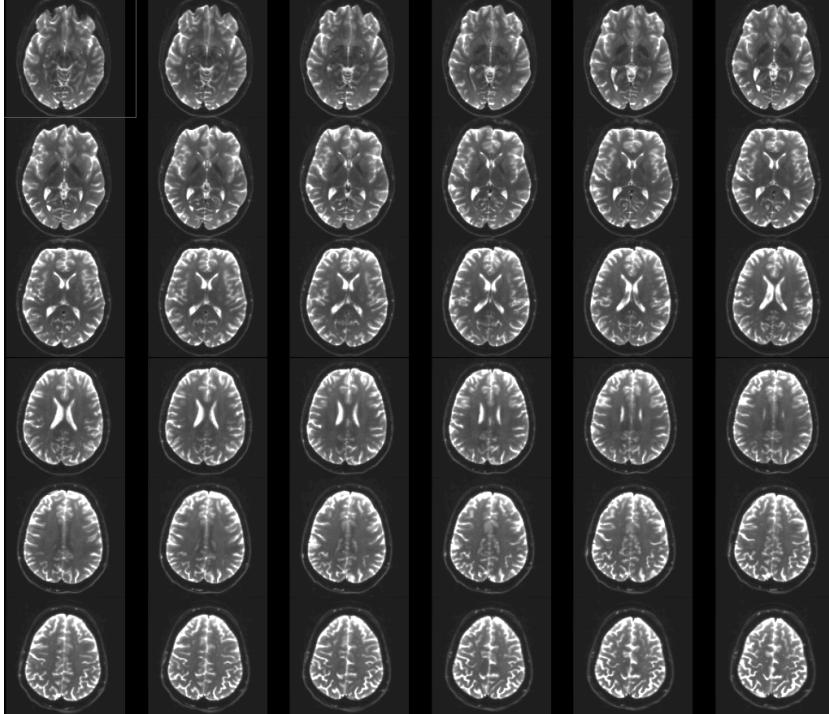
Tensor
Calculation



Scalar
Maps

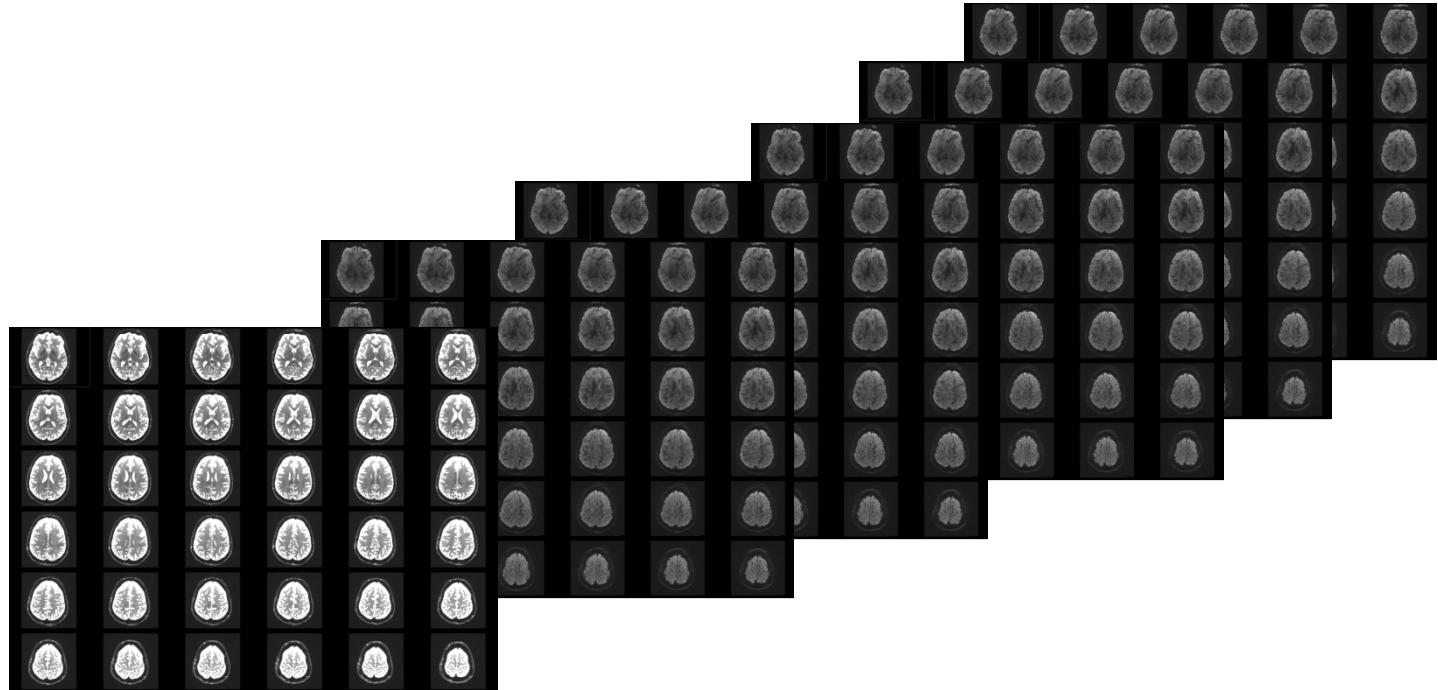


3D
Visualization



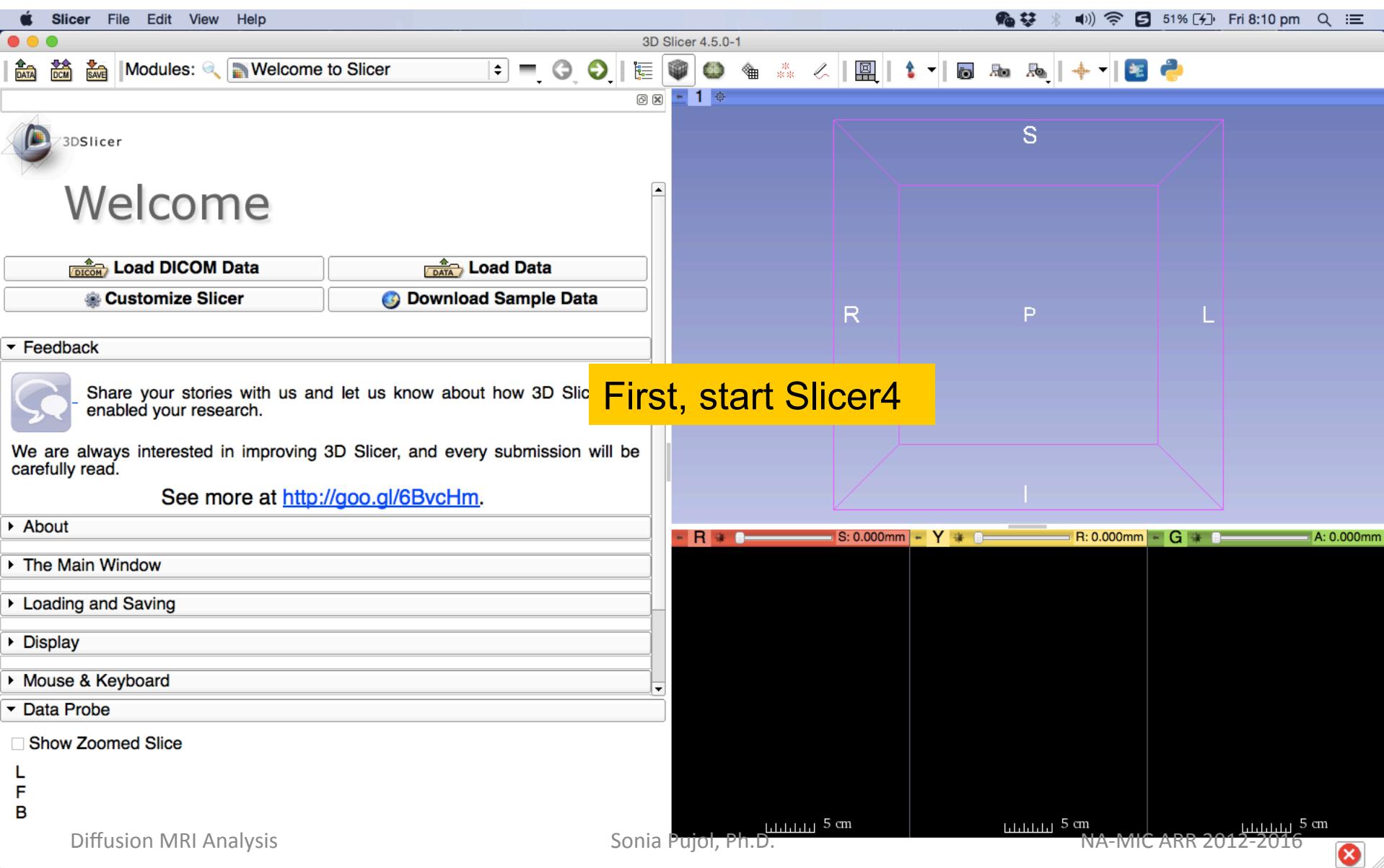
Part 1: From DWI images to Tensors

Understanding the DWI Dataset

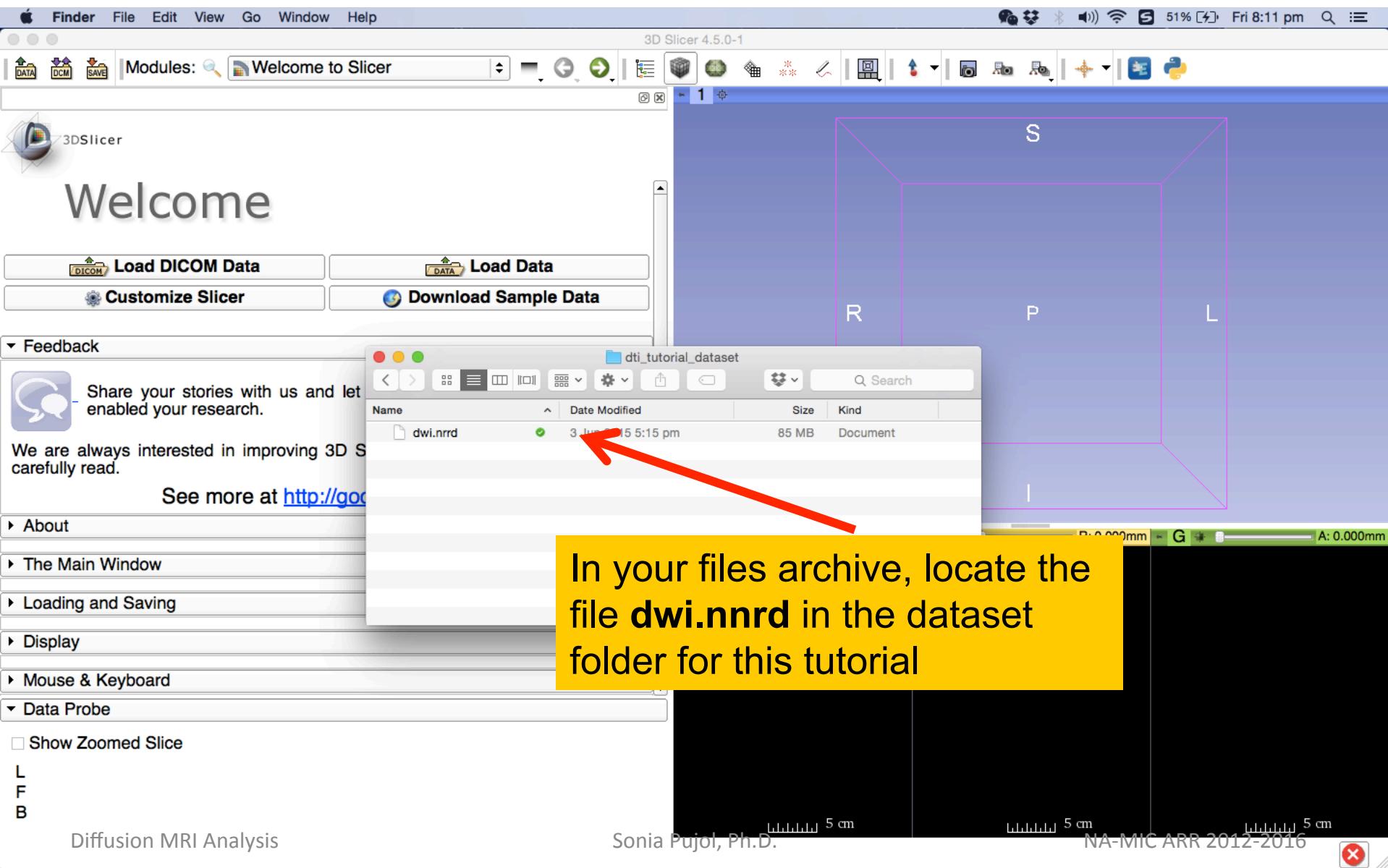


The Diffusion Weighted Imaging (DWI) dataset is composed of 48 volumes acquired with 41 different diffusion-sensitizing gradient directions, and 7 baseline image acquired without diffusion weighting.

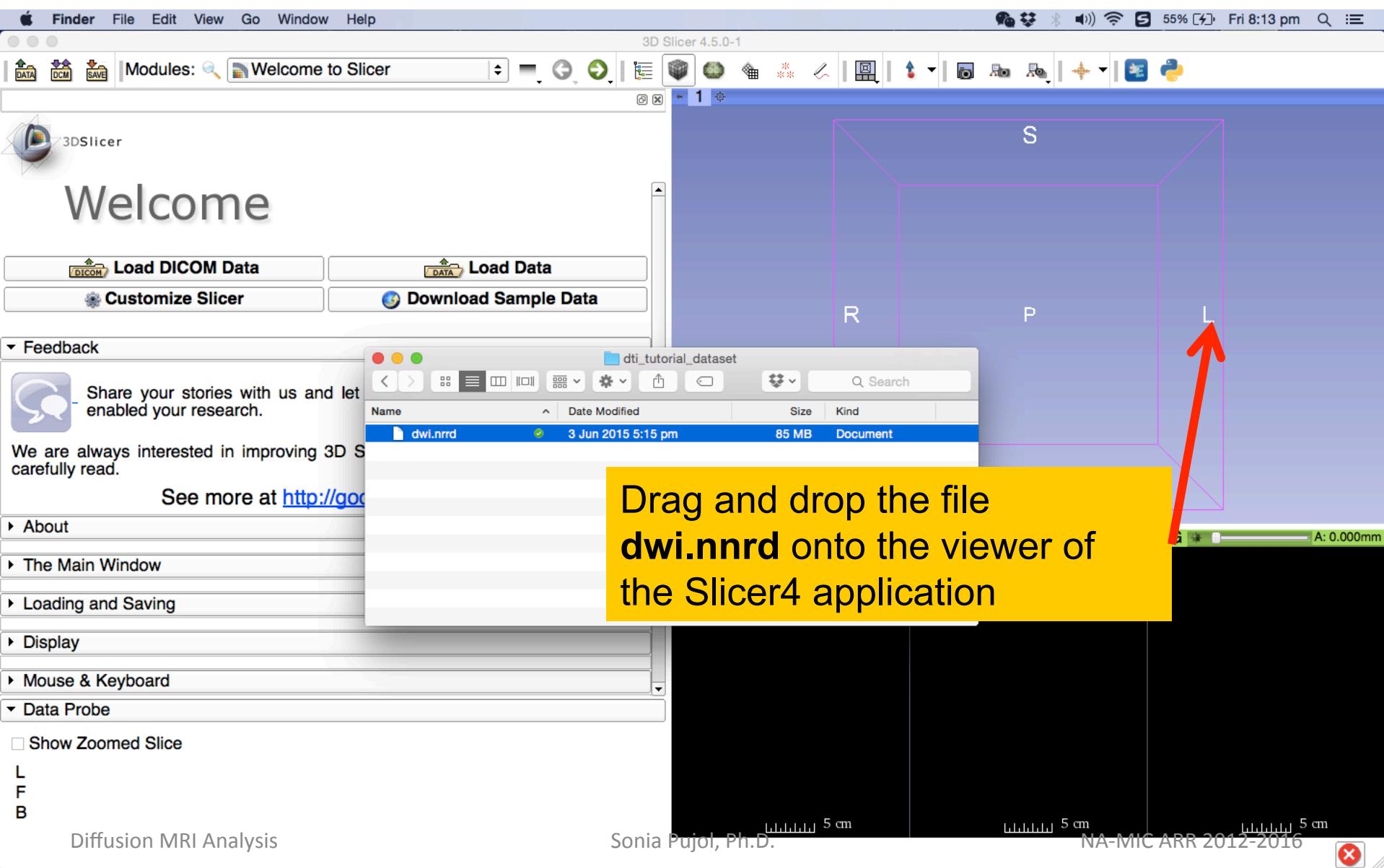
Loading the DWI Dataset



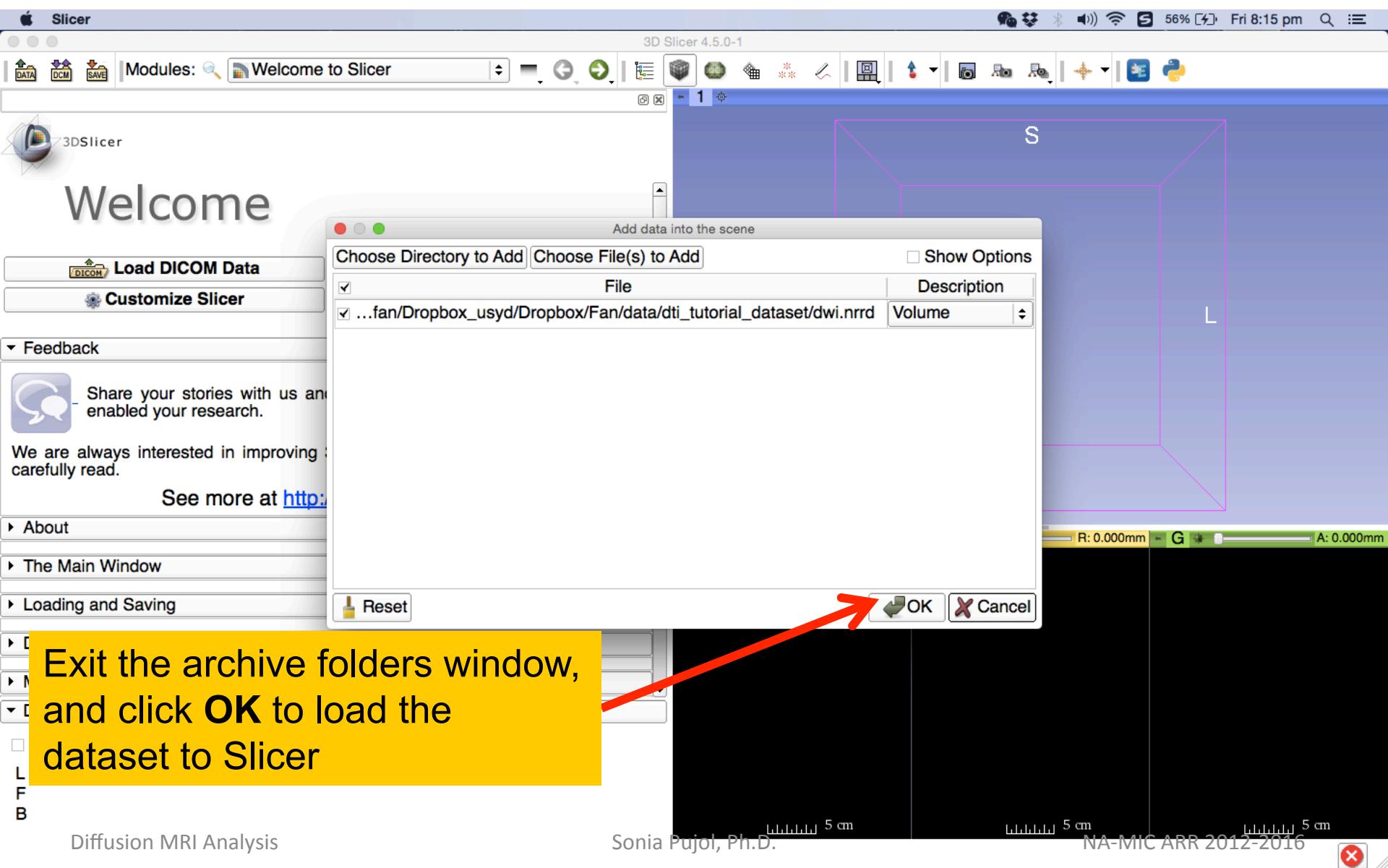
Loading the DWI Dataset



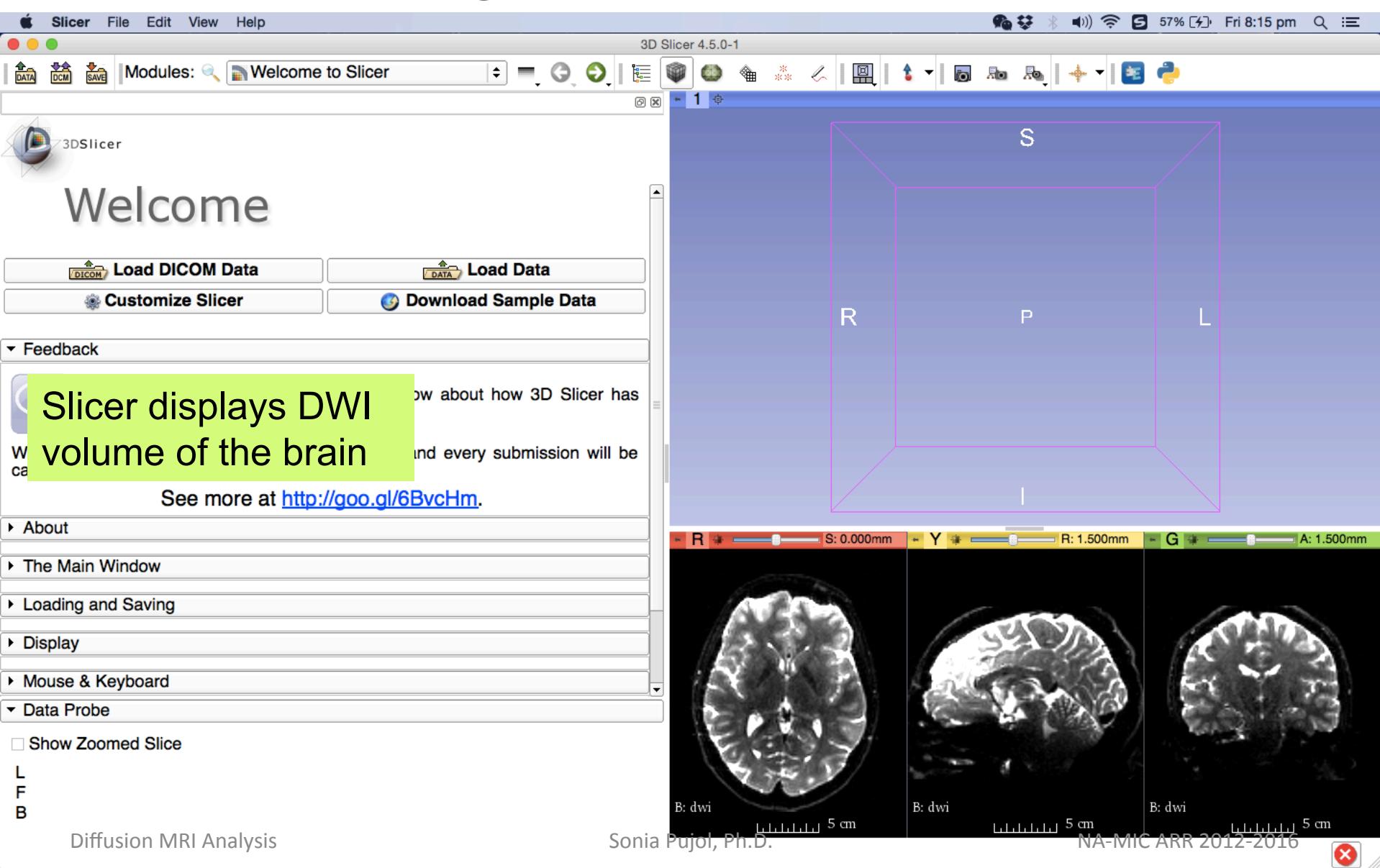
Loading the DWI Dataset



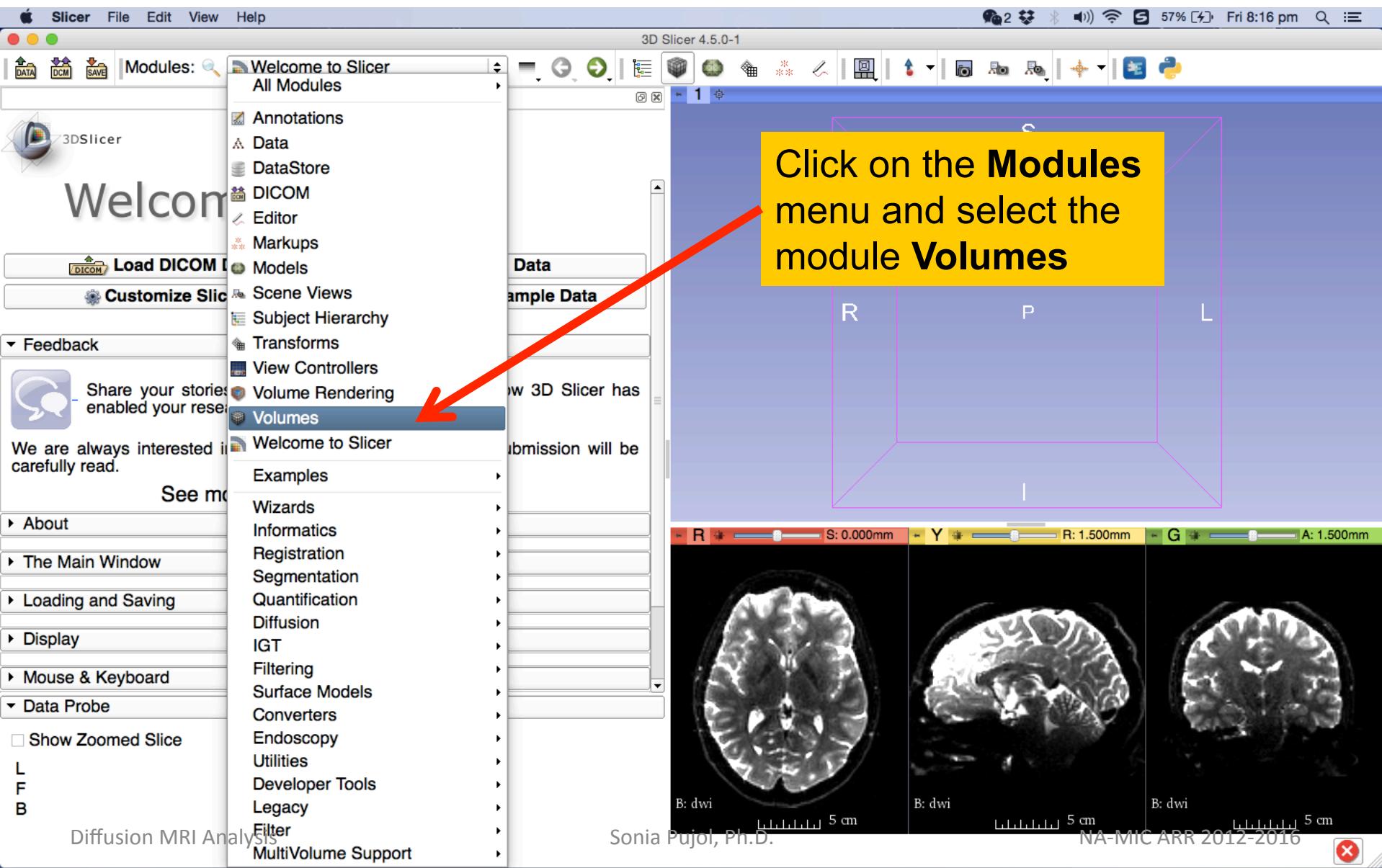
Loading the DWI Dataset



Loading the DWI Dataset



Loading the DWI Dataset



Loading the DWI Dataset

Slicer File Edit View Help

3D Slicer 4.5.0-1

DATA DCM SAVE Modules: Volumes

3DSlicer

Help & Acknowledgement

Active Volume dwi

Volume Information

Display

Scalar Display

DWI Component: 10

Lookup Table: Grey

Interpolate:

Window Level editor presets:

W: 400 Auto W/L L: 283

Threshold: Off

-600 1390

Histogram

Data Probe

Show Zoomed Slice

L F B

Diffusion MRI Analysis

The baseline image corresponds to the DWI Component #0.

Select the DWI Component #10, which corresponds to the 10th diffusion sensitizing gradient

S L

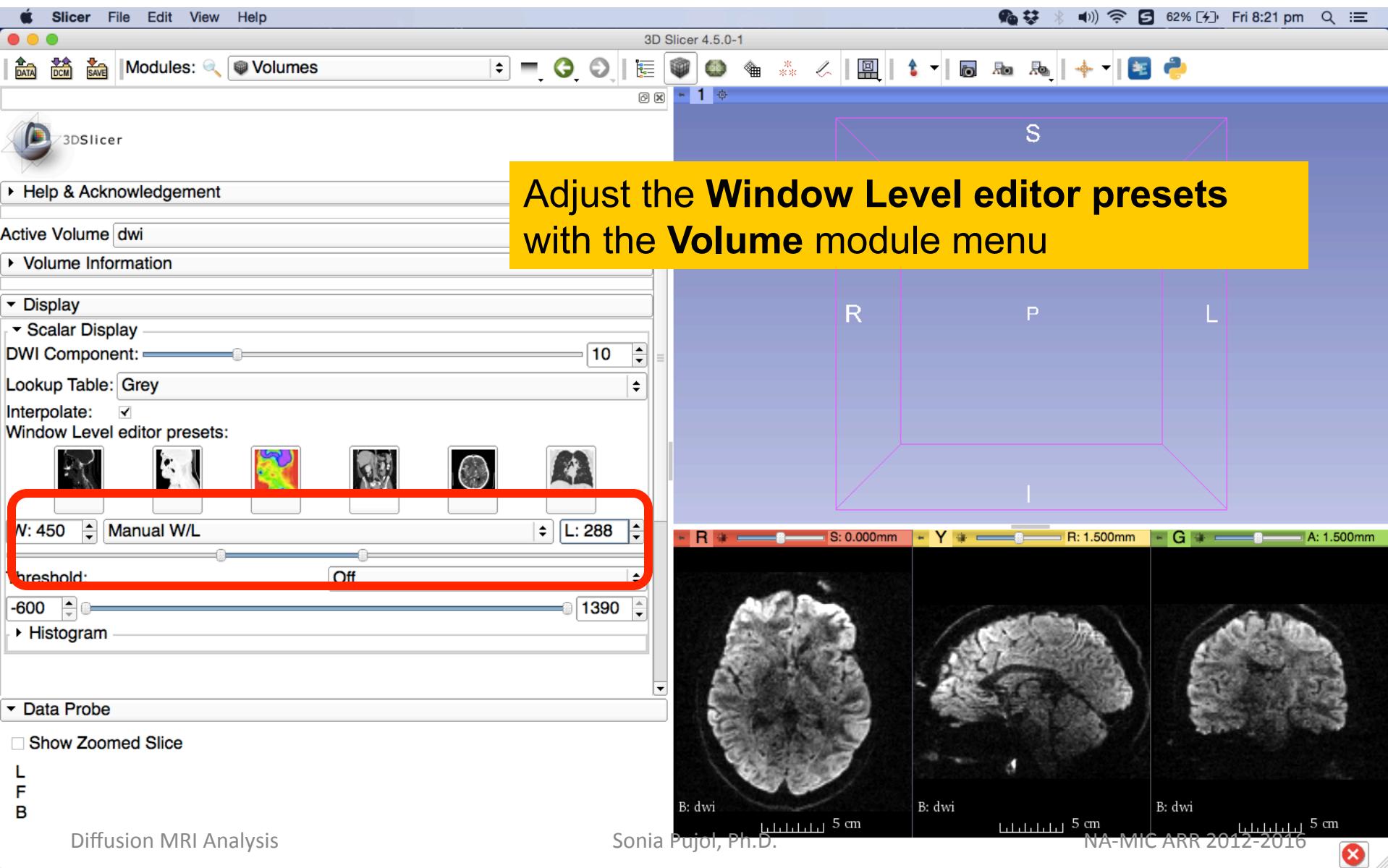
A: 1.500mm

B: dwi B: dwi B: dwi

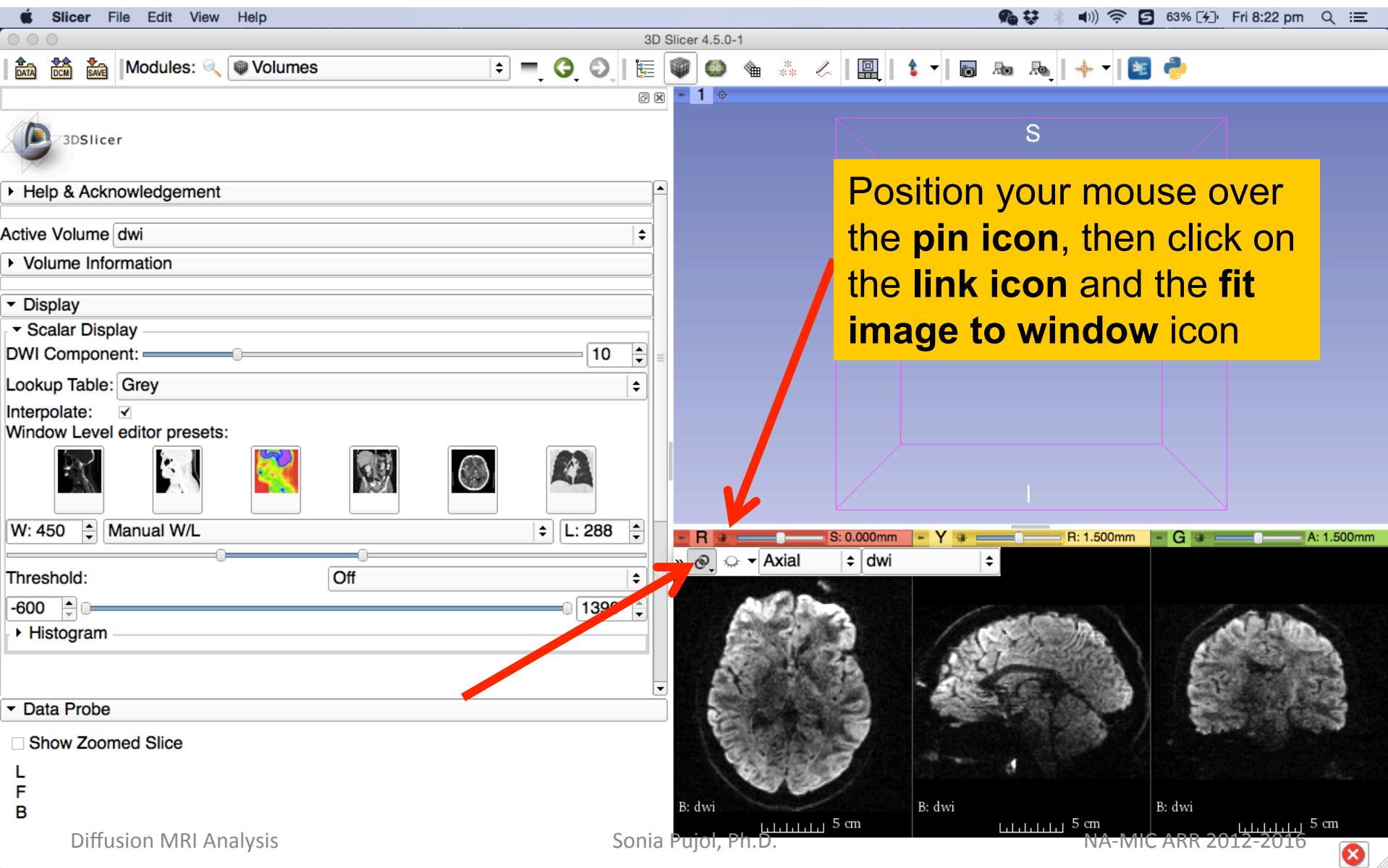
5 cm 5 cm 5 cm

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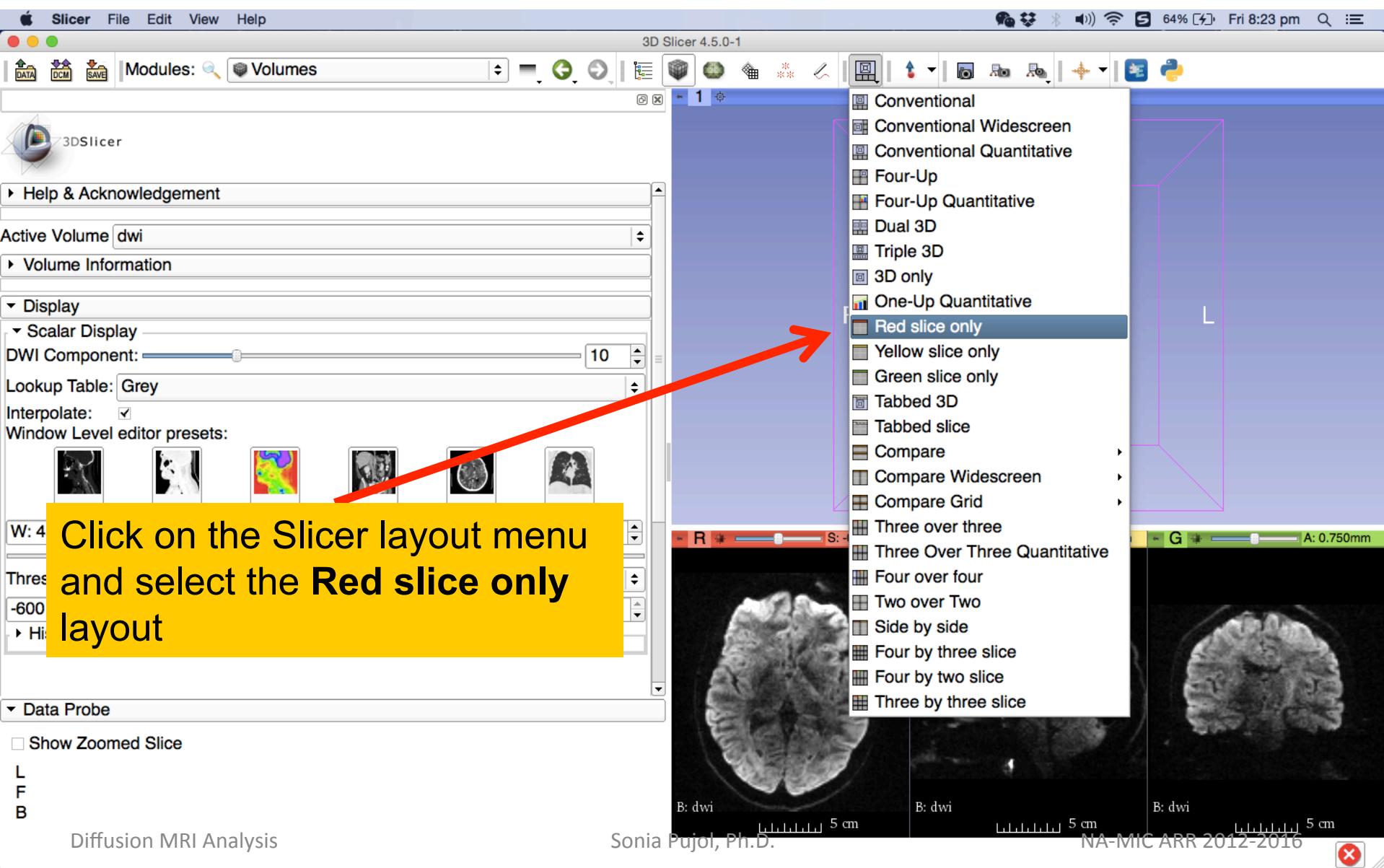
Loading the DWI Dataset



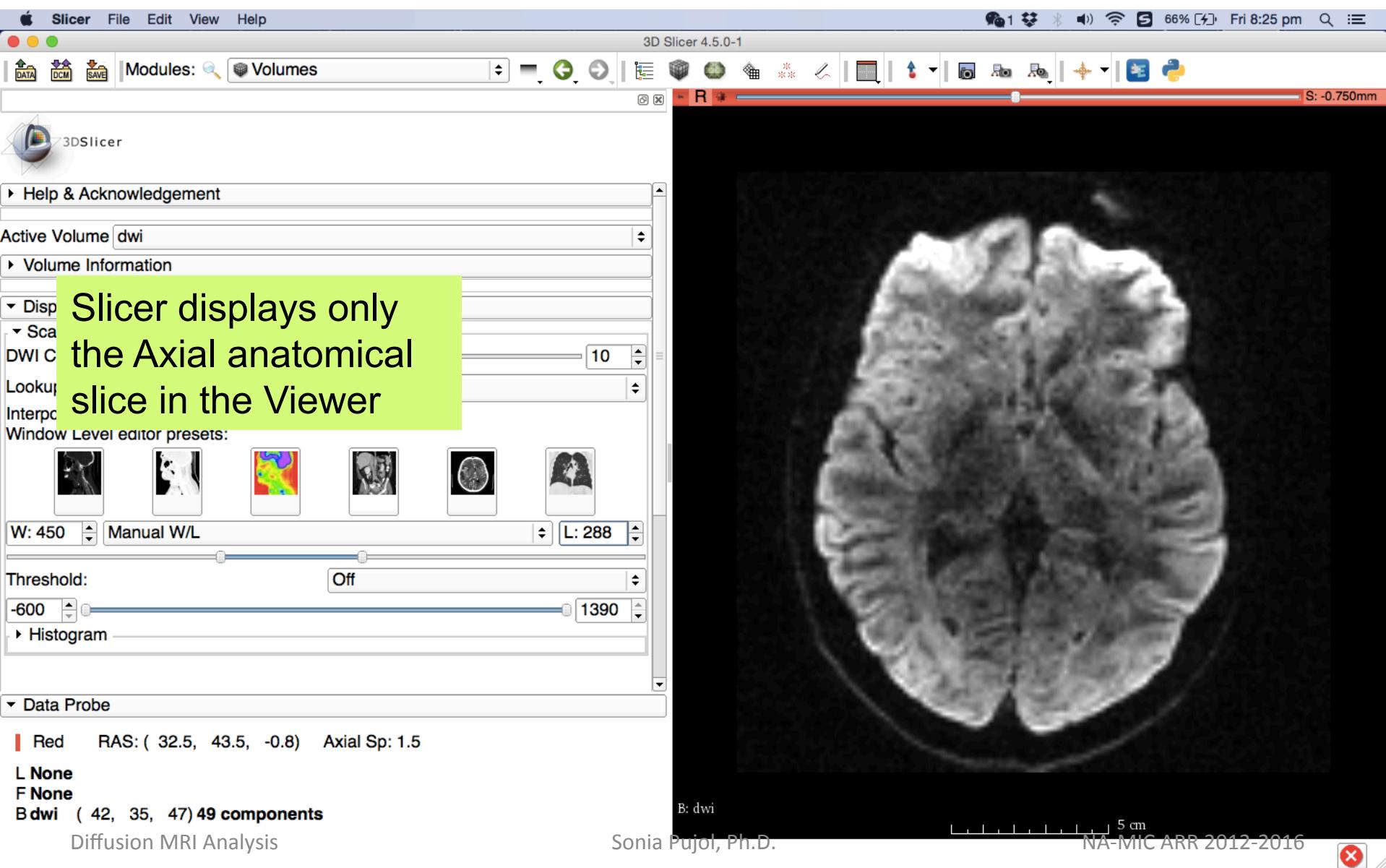
Loading the DWI Dataset



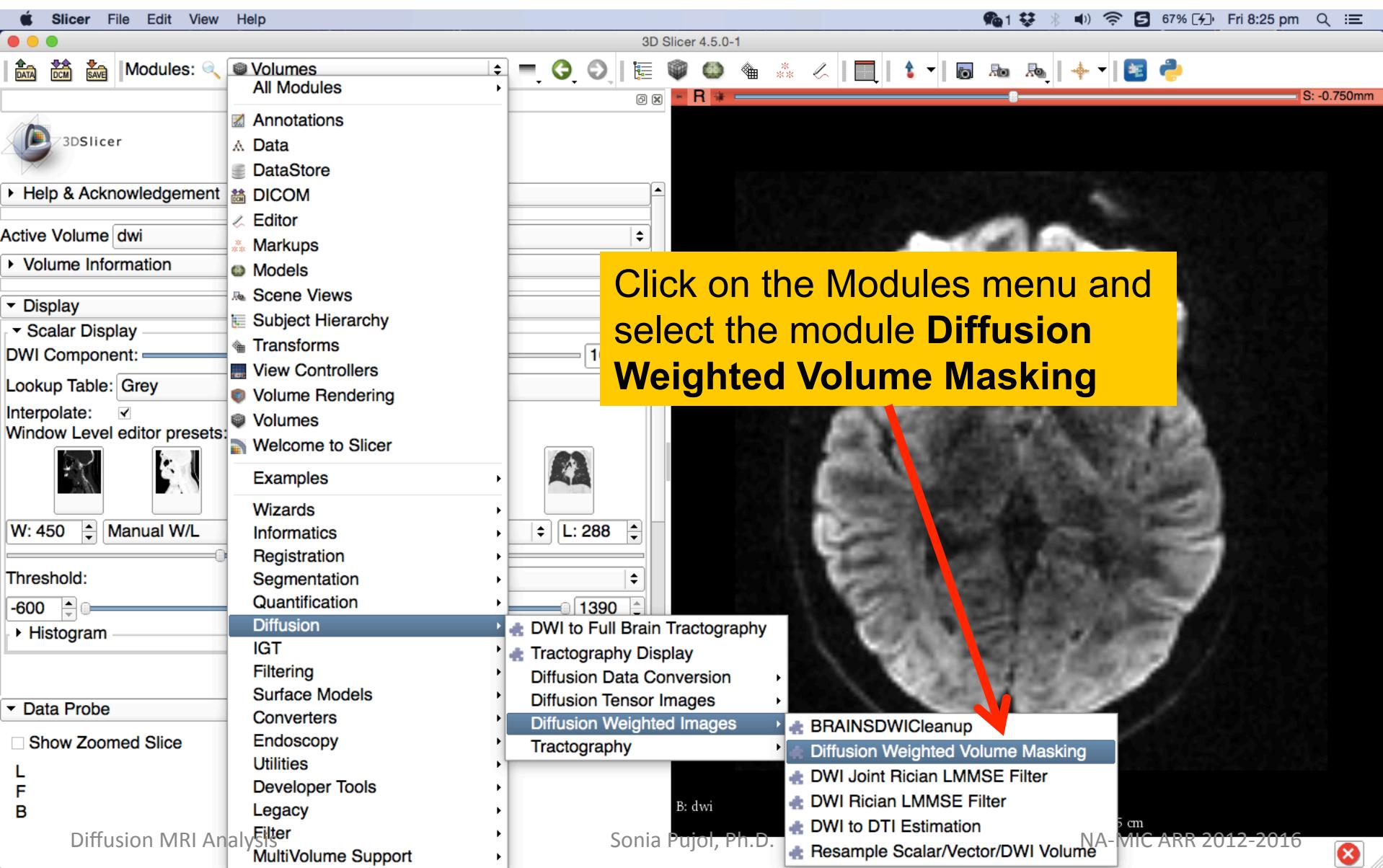
Loading the DWI Dataset



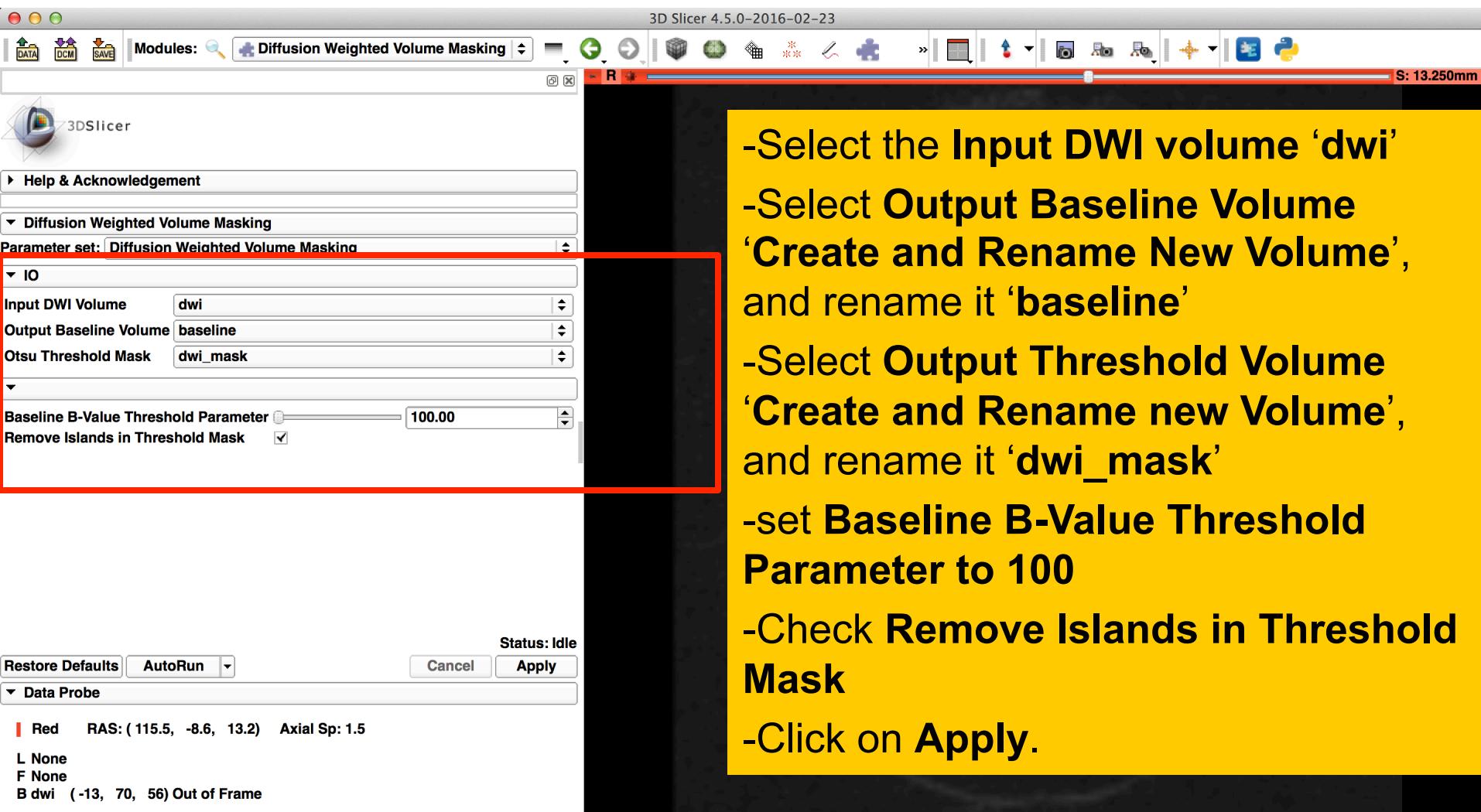
Loading the DWI Dataset



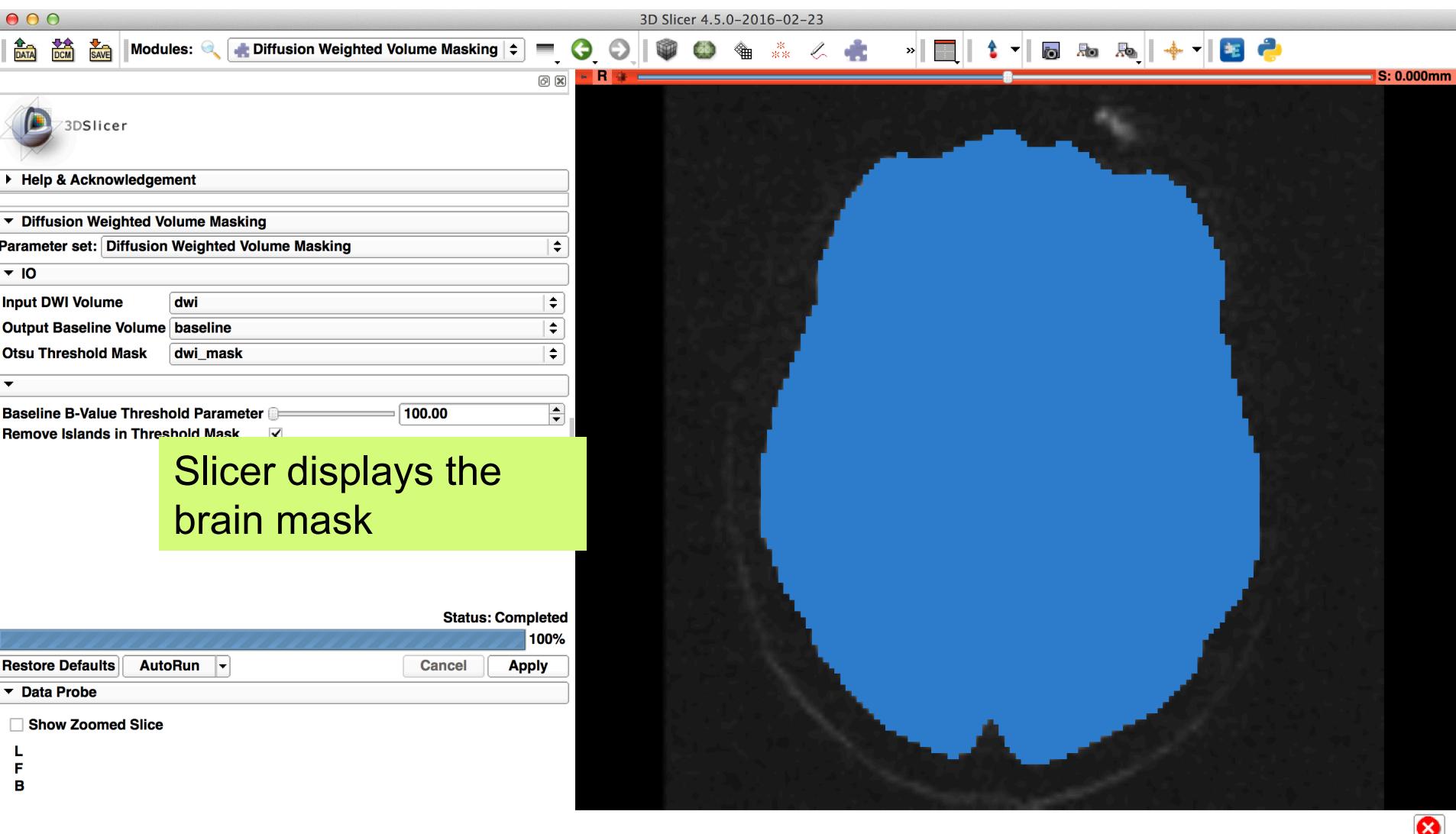
Creating a brain mask



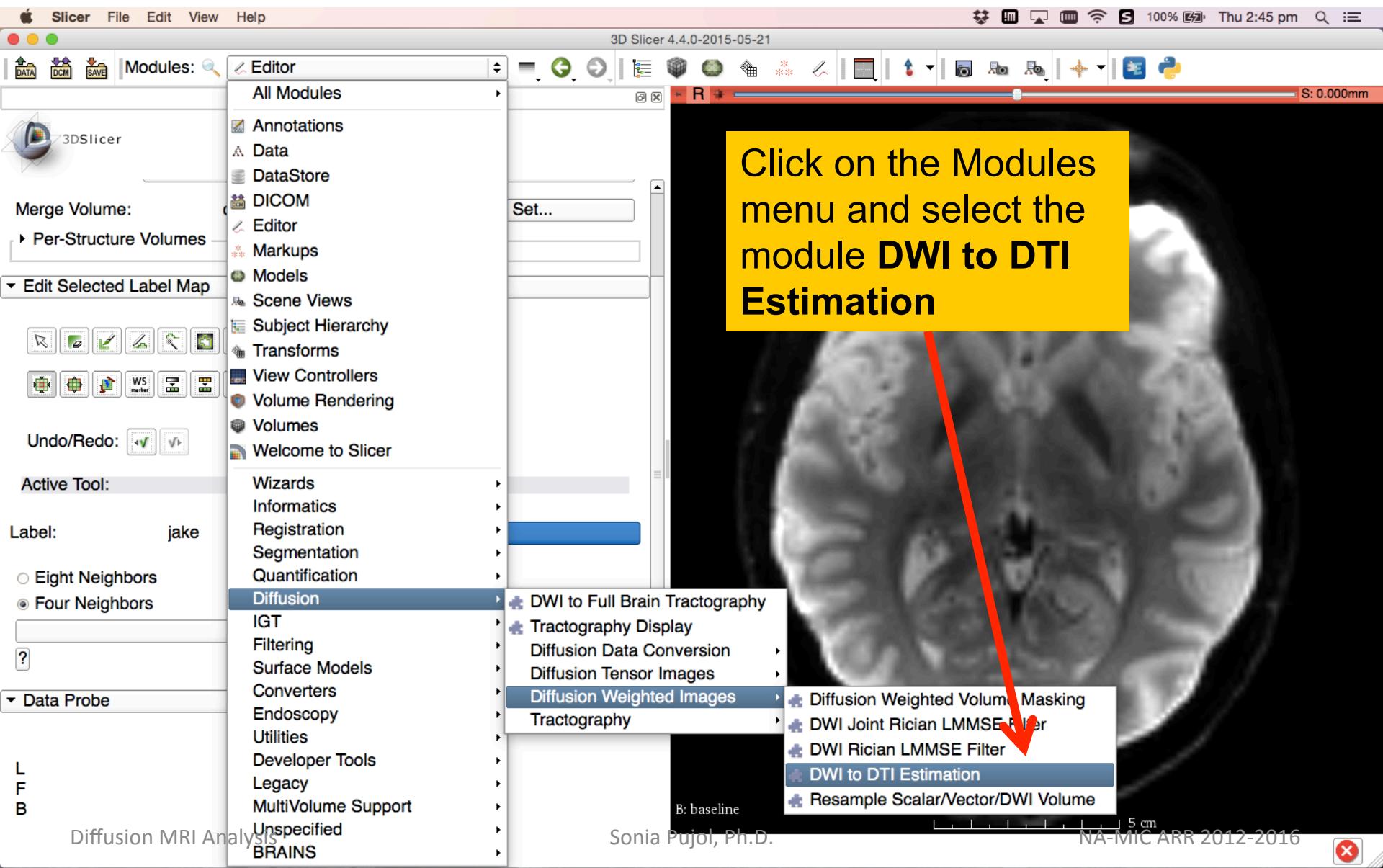
Creating a brain mask



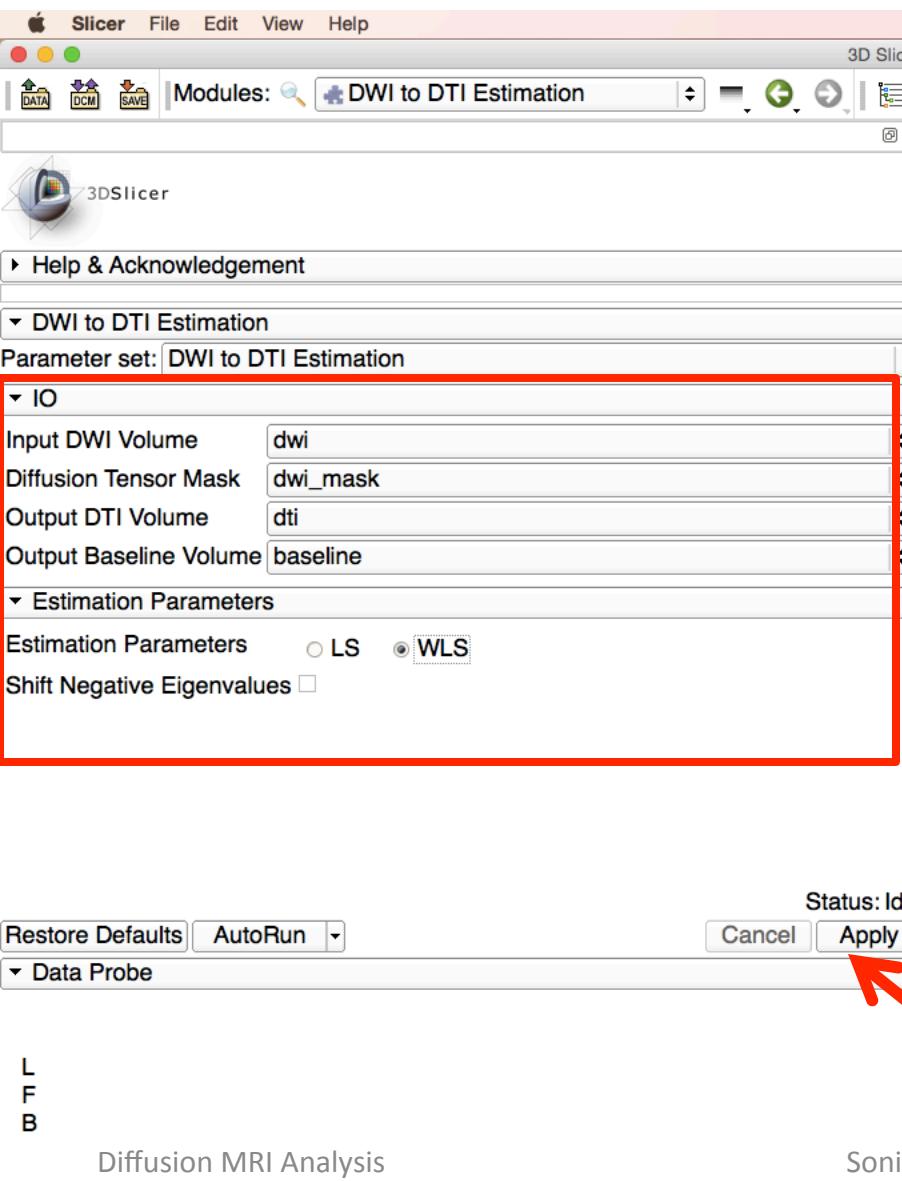
Creating a brain mask



Estimating the tensor



Estimating the tensor



Select the module **DWI to DTI Estimation** in the modules menu:

- Set the **Input DWI volume** to 'dwi'
- Set the **Diffusion Tensor Mask** to '**dwi_mask**'
- Select **Output DTI Volume 'Create and Rename New Volume'**, and rename it '**dti**'
- Set **Output Baseline Volume** to '**baseline**'
- Select the **Estimation Parameters 'WLS'** (Weighted Least Squares) and click on **Apply**.

Estimating the tensor

Position your mouse over the **pin icon** and select the volume **dti**

3D Slicer 4.4.0-2015-05-21

Modules: DWI to DTI Estimation

R Axial

None
dwi
Output Baseline Volume
baseline
dwi_mask
dti
Rename cu DiffusionTensorVolume

3DSlicer

Help & Acknow

DWI to DTI Est

Parameter set: DWI

IO

Input DWI Volume: dwi

Diffusion Tensor Mask: dwi_mask

Output DTI Volume: dti

Output Baseline Volume: baseline

Estimation Parameters: LS (radio button selected)

Shift Negative Eigenvalues:

Status: Completed 100%

Restore Defaults AutoRun Cancel Apply

L F B

Diffusion MRI Analysis

B: baseline

5 cm

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Exploring the DWI Dataset

Slicer displays the DTI volume in color by orientation mode:

- Red: right-left
- Green: anterior-posterior
- Blue: inferior-superior

Status: Completed
100%

Restore Defaults AutoRun Cancel Apply

L F B

Diffusion MRI Analysis

3D Slicer 4.4.0-2015-05-21

Modules: DWI to DTI Estimation

R S: 0.000mm

B: dti

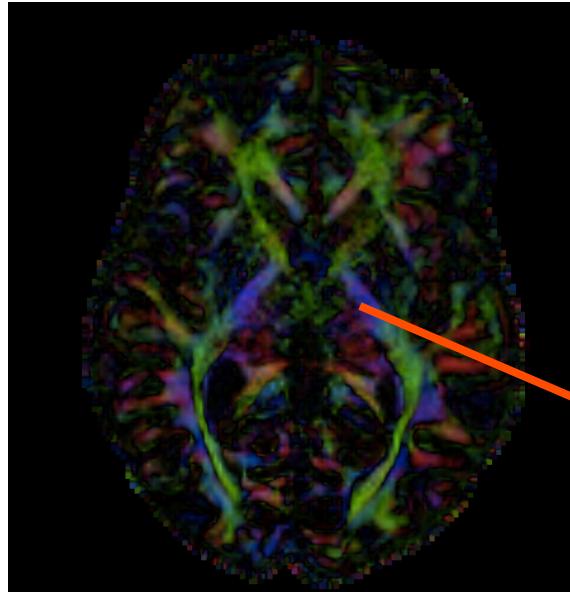
5 cm

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×

Diffusion Tensor Data



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

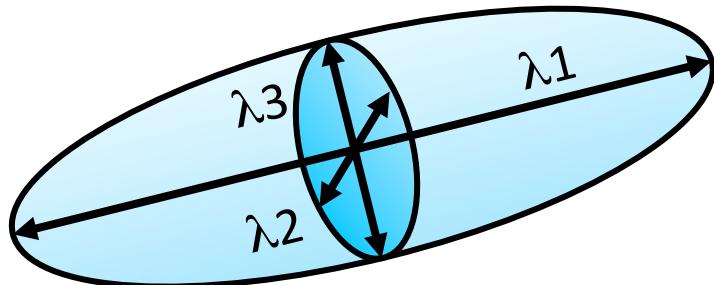
Stejskal-Tanner equation (1965)

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

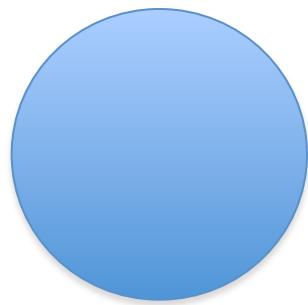
The diffusion tensor \underline{D} in the voxel (I,J,K) is a 3×3 symmetric matrix.

Diffusion Tensor

- The diffusion tensor \underline{D} in each voxel can be visualized as a diffusion ellipsoid, with the eigenvectors indicating the directions of the principal axes, and the ellipsoidal proportional to the square root of the eigenvalues defining the
- Scalar maps can be derived from the rotationally invariant eigenvalues $\lambda_1, \lambda_2, \lambda_3$ to characterize the size and shape of the diffusion tensor.

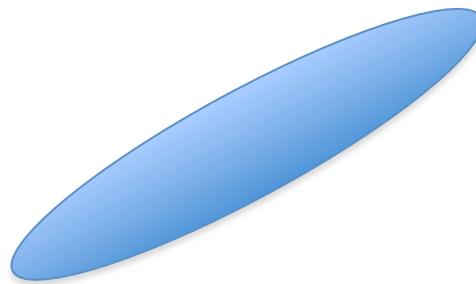


Diffusion Tensor Shape



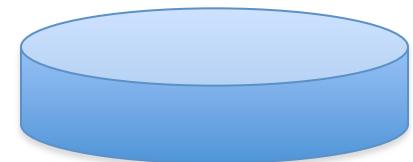
$$\lambda_1 = \lambda_2 = \lambda_3$$

Isotropic media
(Cerebrospinal
Fluid, gray matter)



$$\lambda_1 >> \lambda_2, \lambda_3$$

Anisotropic media
(white matter)



$$\lambda_1 \sim \lambda_2 >> \lambda_3$$

Exploring the DWI Dataset

Slicer File Edit View Help

3D Slicer 4.4.0-2015-05-21

DATA DCM SAVE Modules: DWI to DTI Estimation

R S: 0.000mm

3DSlicer

Help & Acknowledgement

DWI to DTI Estimation

Parameter set: DWI to DTI Estimation

IO

Input DWI Volume dwi

Diffusion Tensor Mask dwi_mask

Output DTI Volume dti

Output Baseline Volume baseline

Estimation Parameters LS

Shift Negative Eigenvalues

Status: Completed 100%

Restore Defaults AutoRun Cancel Apply

Data Probe

L F B

Diffusion MRI Analysis

B: dti

5 cm

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Use the slider to browse through the dti volume, and try to locate the **Corpus Callosum**

Corpus Callosum

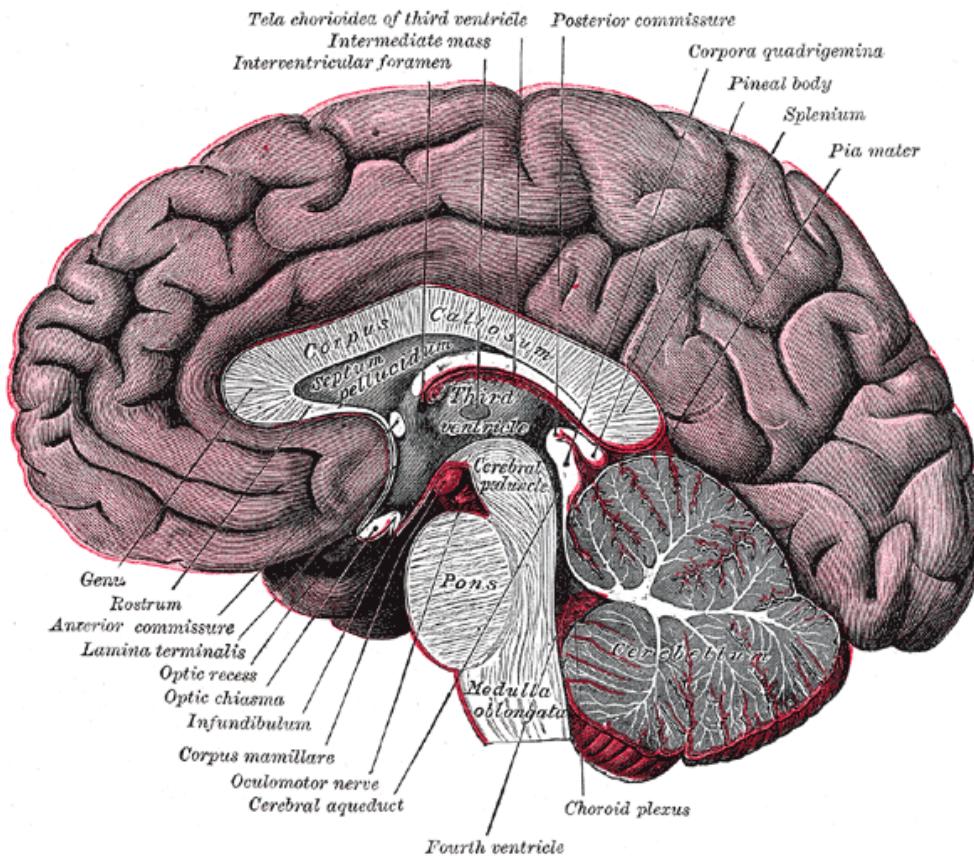


Image from Gray's Anatomy

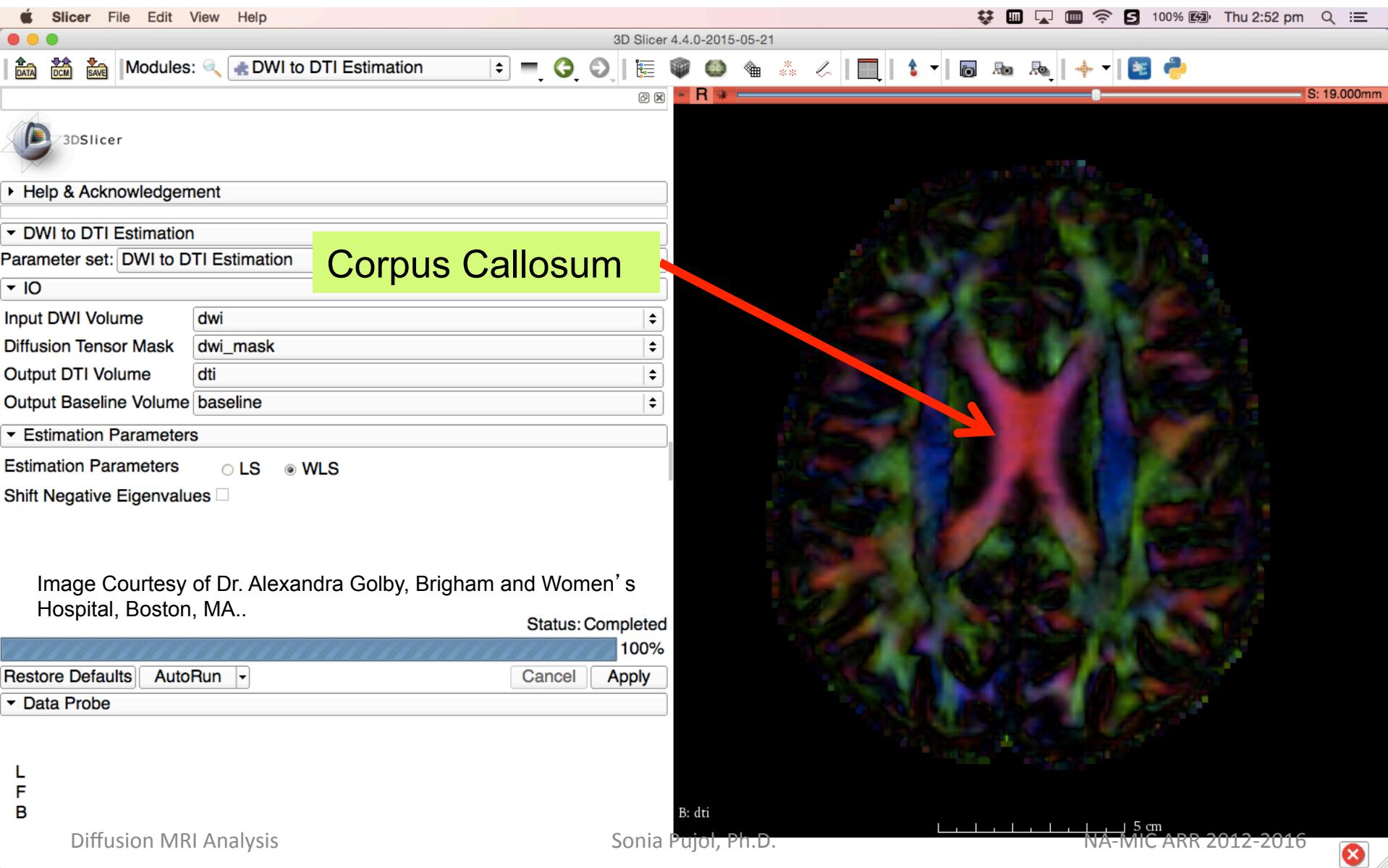
Diffusion MRI Analysis

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The corpus callosum is a broad thick bundle of dense myelinated fibers that connect the left and right hemisphere. It is the largest white matter structure in the brain

Corpus Callosum

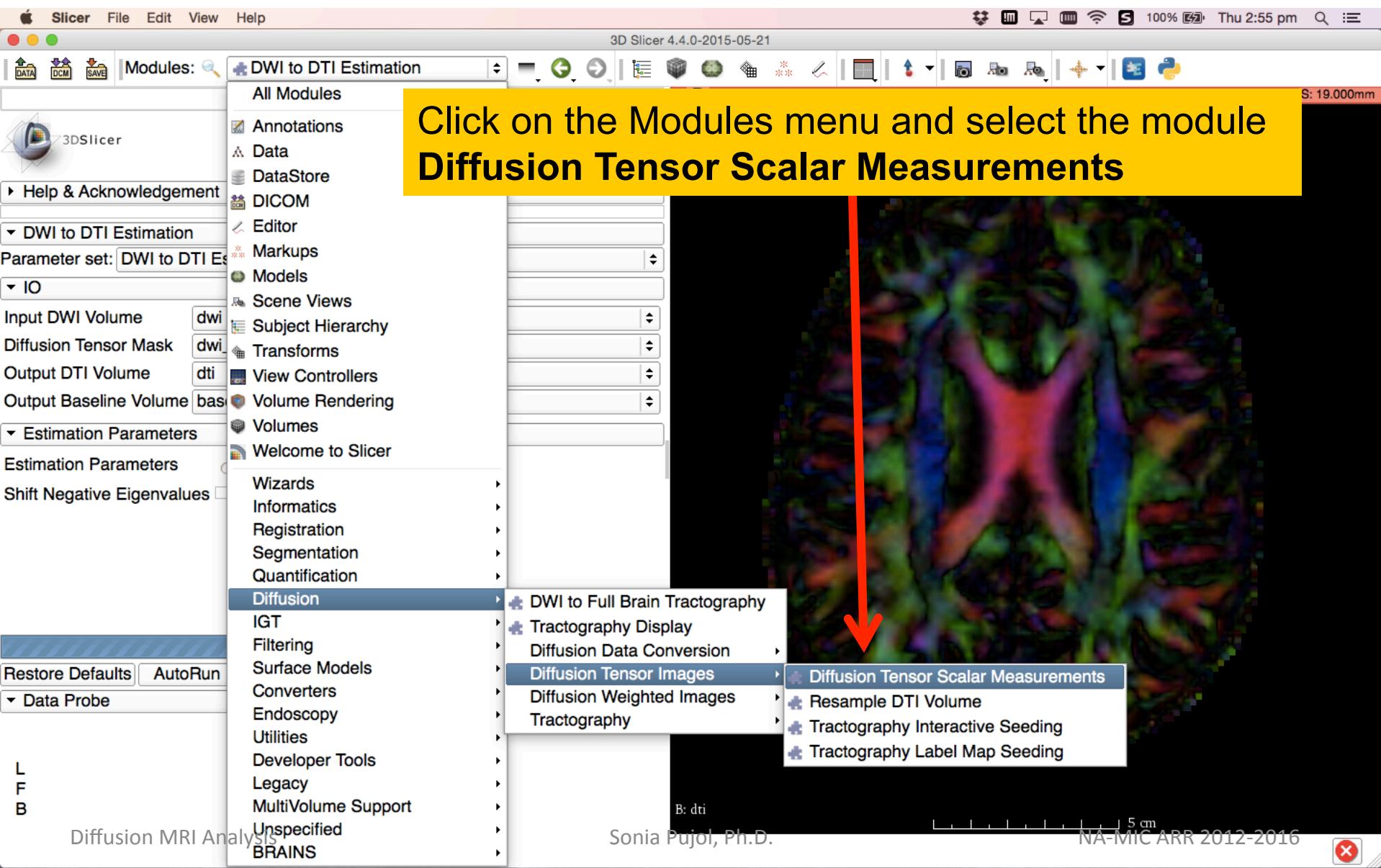


Characterizing the Size of the tensor: Trace

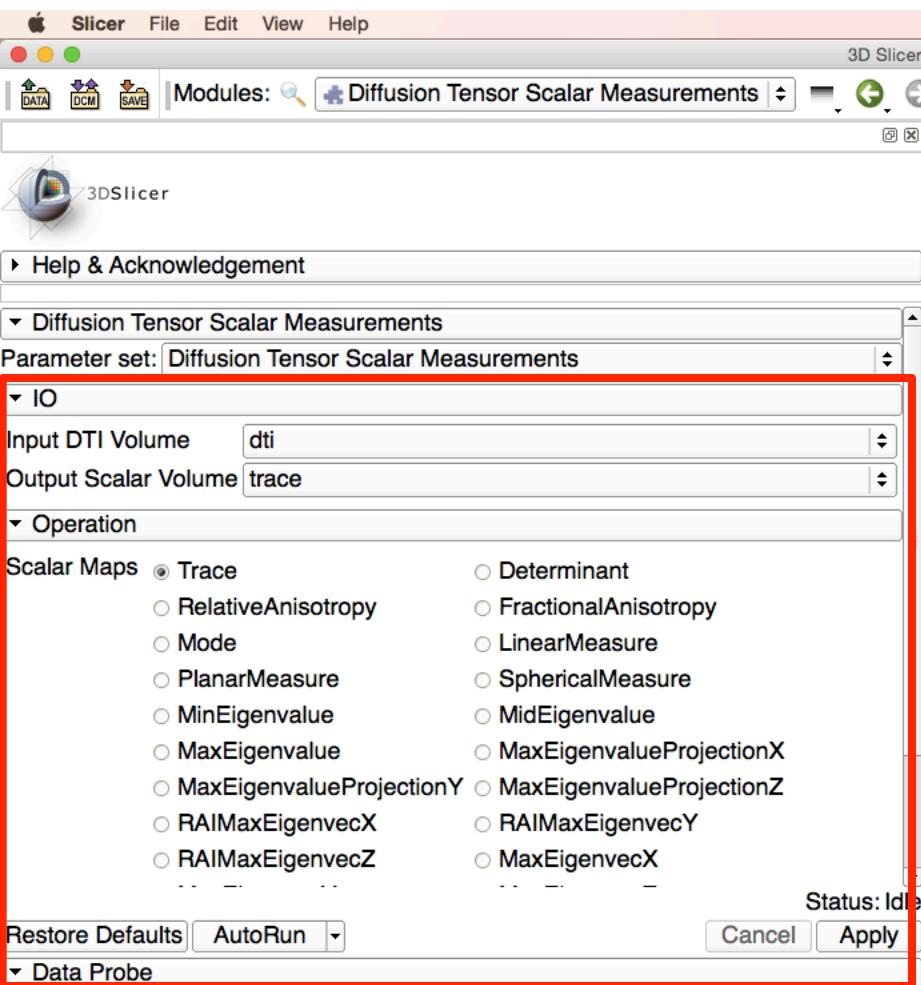
$$\text{Trace}(D) = \lambda_1 + \lambda_2 + \lambda_3$$

- $\text{Trace}(D)$ is intrinsic to the tissue and is independent of fiber orientation, and diffusion sensitizing gradient directions
- $\text{Trace}(D)$ is a clinically relevant parameter for monitoring stroke and neurological condition (degree of structural coherence in tissue)
- $\text{Trace}(D)$ is useful to characterize the size of the diffusion ellipsoid

Trace



Trace



Type in the following information in the IO menu:

- select the Operation '**Trace**'
- set **Input DTI Volume** to '**dti**'
- select **Output Scalar Volume** '**Create and Rename new Volume**' and rename it '**trace**'
- click on **Apply** to calculate the trace map of the tensor volume

Trace

The trace image appears in the red viewer

L
F
B

Diffusion MRI Analysis

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Trace

Position your mouse over the **pin icon** and then select the '**>>**' icon to display this table and fill in the following information:

- Select the volume '**trace**' in the Background viewer
- Select the volume '**dti**' in the Foreground viewer

Set the **opacity** of the **dti** volume to **0.40**

The screenshot shows the 3D Slicer interface. In the foreground viewer, a brain scan is displayed with a complex, multi-colored pattern representing diffusion tensor data. In the background viewer, a grayscale image of a brain is visible. The top toolbar has a red box highlighting the volume selection section. This section includes dropdown menus for 'Axial', 'Coronal', and 'Sagittal' planes, and buttons for 'None', 'dti', and 'trace'. Below the viewer, a progress bar indicates 'us: Completed 100%'. At the bottom, status text reads 'F: dti (40%) B: trace' and '5 cm'.

Slicer File Edit View Help

3D Slicer 4.4.0-2015-05-21

Axial Coronal Sagittal

None dti trace

x z

us: Completed 100%

F: dti (40%) B: trace

5 cm

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Trace

Position your mouse within the region of the Corpus Callosum and observe the trace values in the Data Probe

Parameter set: Diffusion Tensor Scalar Measurements

Input DTI Volume: dti

Output Scalar Volume: trace

Scalar Maps:

- Trace
- Determinant
- RelativeAnisotropy
- FractionalAnisotropy
- Mode
- LinearMeasure
- PlanarMeasure
- SphericalMeasure
- MinEigenvalue
- MidEigenvalue
- MaxEigenvalue
- MaxEigenvalueProjectionX
- MaxEigenvalueProjectionY
- MaxEigenvalueProjectionZ
- RAIMaxEigenvecX
- RAIMaxEigenvecY

Status: Completed 100%

Data Probe

Red RAS: (6.2, 6.7, 19.0) Axial Sp: 1.5

L None

F dti (60, 60, 60) ColorOrientation 0

B trace (60, 60, 60) 0.002111

Diffusion MRI Analysis

S: 19.000mm

3D Slicer 4.4.0-2015-05-21

R

S: 19.000mm

100% Thu 2:58 pm

5 cm

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X

Trace

Note how the Trace values are fairly uniform in both white and gray matter, even if the tissues are different in structure.

Input DTI Volume: dti
Output Scalar Volume: trace

Operation

Scalar Maps:

- Trace
- Determinant
- RelativeAnisotropy
- FractionalAnisotropy
- Mode
- LinearMeasure
- PlanarMeasure
- SphericalMeasure
- MinEigenvalue
- MidEigenvalue
- MaxEigenvalue
- MaxEigenvalueProjectionX
- MaxEigenvalueProjectionY
- MaxEigenvalueProjectionZ
- RAIMaxEigenvecX
- RAIMaxEigenvecY

Status: Completed 100%

Buttons: Restore Defaults, Auto Run, Cancel, Apply

Data Probe

Red RAS: (38.0, -21.2, 19.0) Axial Sp: 1.5

L None

F dti (39, 78, 60) ColorOrientation 0

B trace (39, 78, 60) 0.002008

Diffusion MRI Analysis

R S: 19.000mm

F: dti (40%)
B: trace

5 cm

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Scalar Maps: Fractional Anisotropy

$$FA(D) = \frac{\sqrt{(\lambda_1 - \lambda_2)^2 + (\lambda_1 - \lambda_3)^2 + (\lambda_2 - \lambda_3)^2}}{\sqrt{2} \sqrt{\lambda_1^2 + \lambda_2^2 + \lambda_3^2}}$$

- FA(D) is intrinsic to the tissue and is independent of fiber orientation, and diffusion sensitizing gradient directions
- FA(D) is useful to characterize the shape (degree of ‘out-of-roundness’) of the diffusion ellipsoid
- Low FA:  → High FA: 

Fractional Anisotropy

Slicer File Edit View Help

3D Slicer 4.4.0-2015-05-21

DATA DCM SAVE Modules: Diffusion Tensor Scalar Measurements

R S: 19.000mm

3DSlicer

Help & Acknowledgement

Diffusion Tensor Scalar Measurements

Parameter set: Diffusion Tensor Scalar Measurements

IO

Input DTI Volume: dti

Output Scalar Volume: fa

Operation

Scalar Maps:

- Trace
- Determinant
- RelativeAnisotropy
- FractionalAnisotropy
- Mode
- LinearMeasure
- PlanarMeasure
- SphericalMeasure
- MinEigenvalue
- MidEigenvalue
- MaxEigenvalue
- MaxEigenvalueProjectionX
- MaxEigenvalueProjectionY
- MaxEigenvalueProjectionZ
- RAIMaxEigenvecX
- RAIMaxEigenvecY

Status: Completed 100%

Restore Defaults AutoRun Cancel Apply

Data Probe

L F B

Fill in the following information:
-Set Input DTI Volume to 'dti'
-Select Output Scalar Volume
'Create new Volume' and rename it
'fa'
-Select the Operation 'Fractional Anisotropy'
-Click on Apply to calculate the
Fractional Anisotropy map of the
tensor volume

F: dti (40%)
B: trace

5 cm

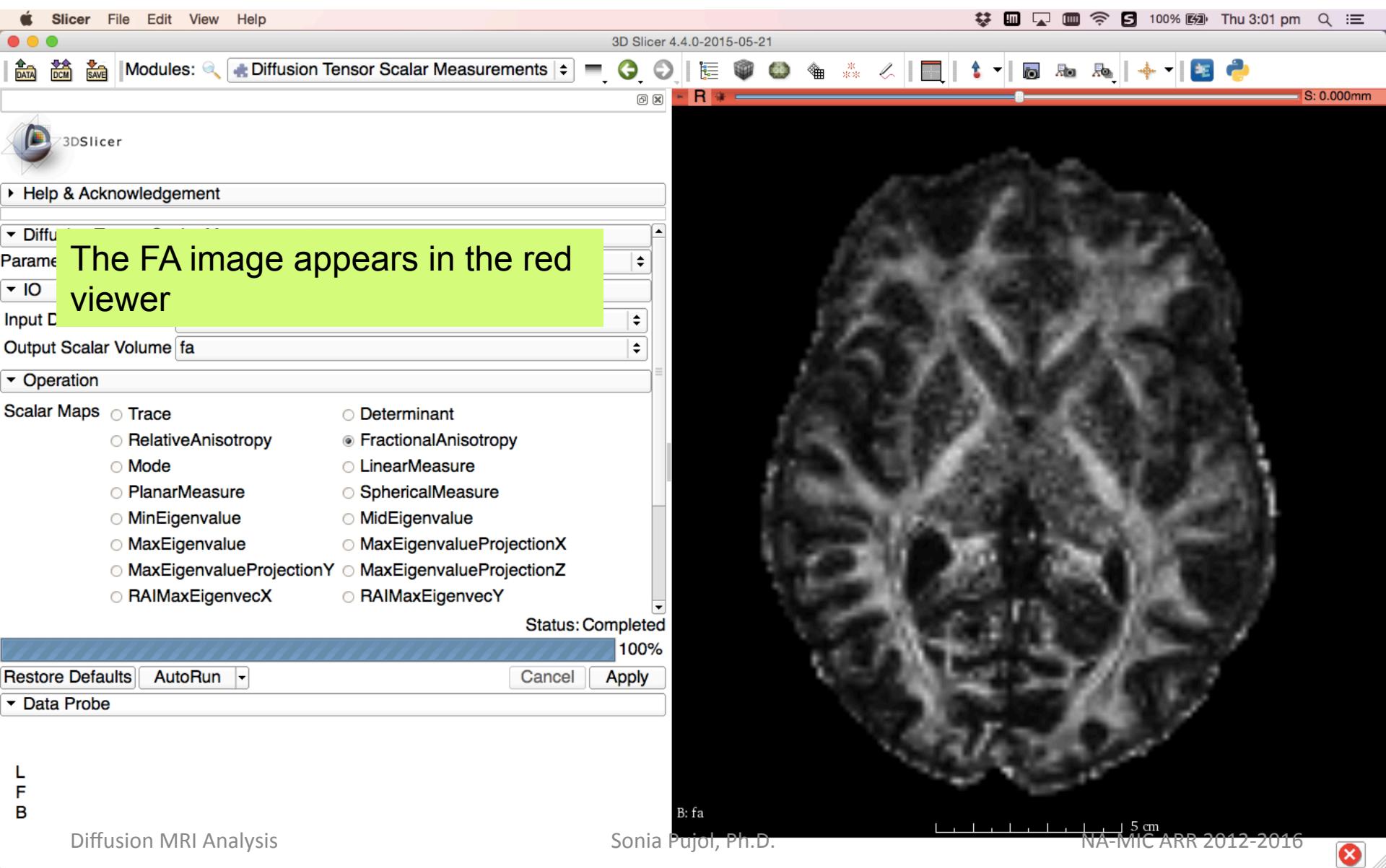
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Diffusion MRI Analysis

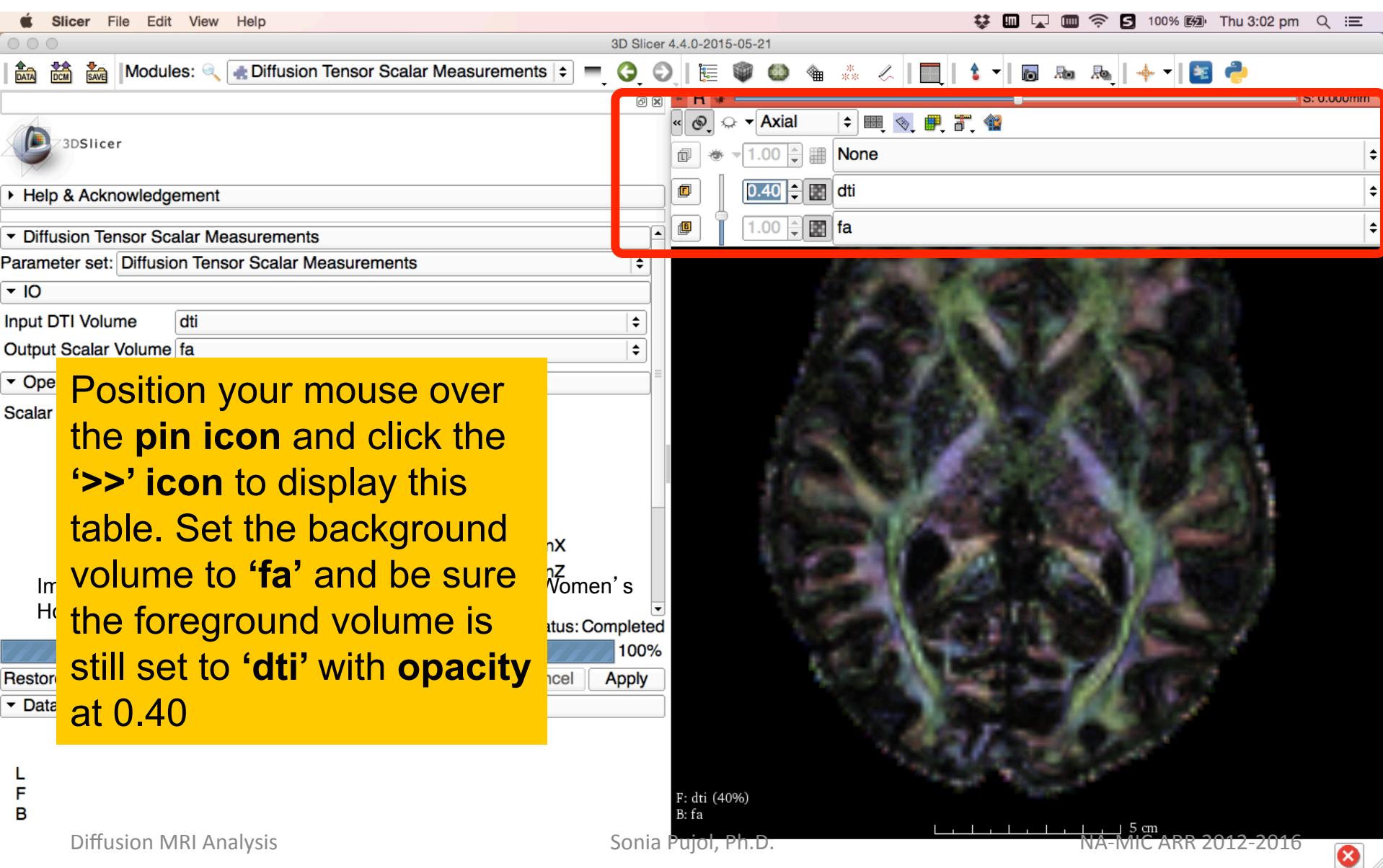
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✖

Fractional Anisotropy



Fractional Anisotropy



Fractional Anisotropy

Explore the FA values in the Corpus Callosum and in adjacent gray matter areas. Note how the FA values are high in the white matter areas, and low in gray matter regions

Output Scalar Volume fa

Scalar Maps

- Trace
- Determinant
- RelativeAnisotropy
- FractionalAnisotropy
- Mode
- LinearMeasure
- PlanarMeasure
- SphericalMeasure
- MinEigenvalue
- MidEigenvalue
- MaxEigenvalue
- MaxEigenvalueProjectionX
- MaxEigenvalueProjectionY
- MaxEigenvalueProjectionZ
- RAIMaxEigenvecX
- RAIMaxEigenvecY

Status: Completed 100%

Buttons: Restore Defaults Auto Run Cancel Apply

Data Probe

Red RAS: (7.7, 8.8, 19.0) Axial Sp: 1.5

L None

F dti (59, 58, 60) ColorOrientation 0

B fa (59, 58, 60) 0.890284

Diffusion MRI Analysis

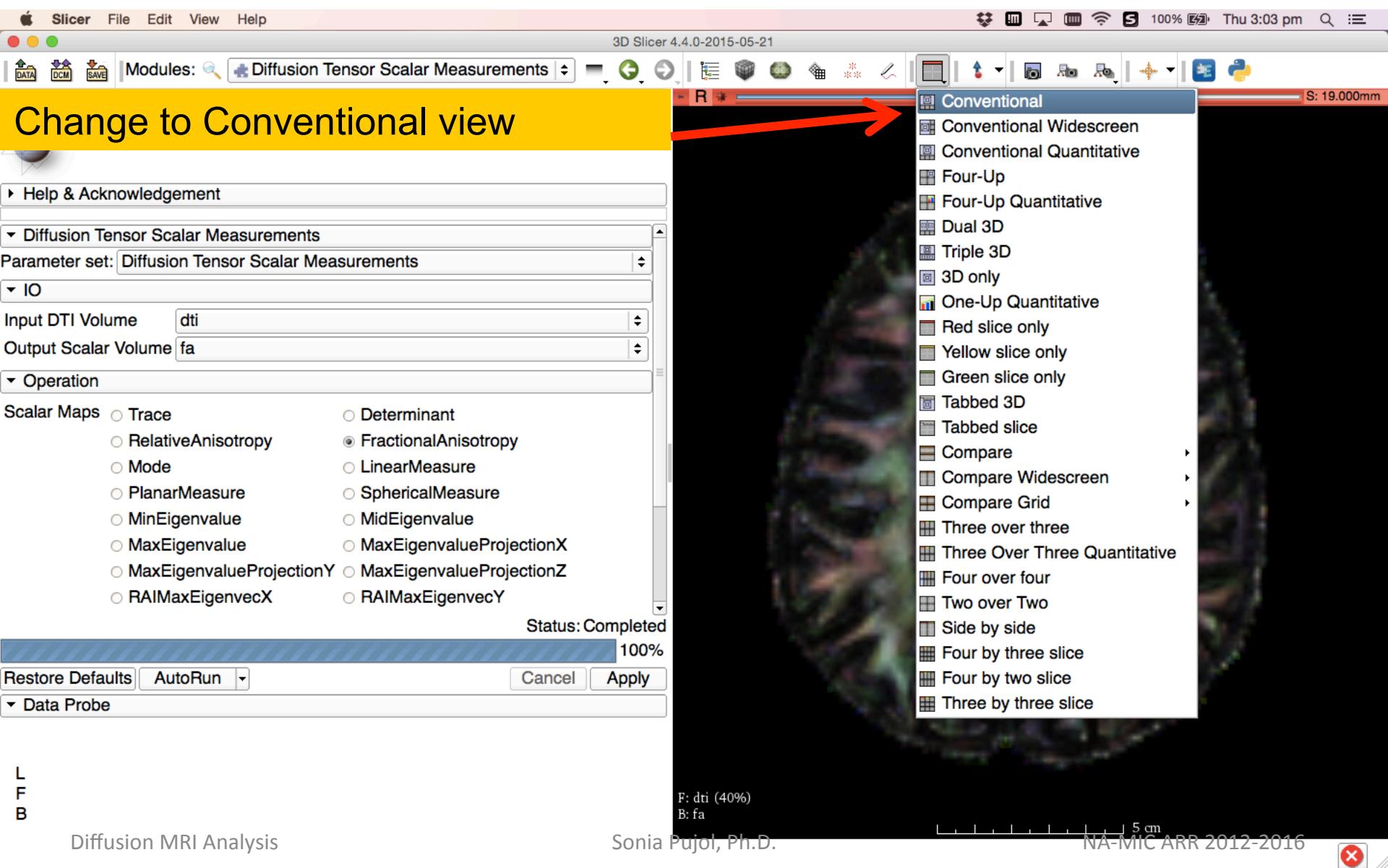
R S: 19.000mm

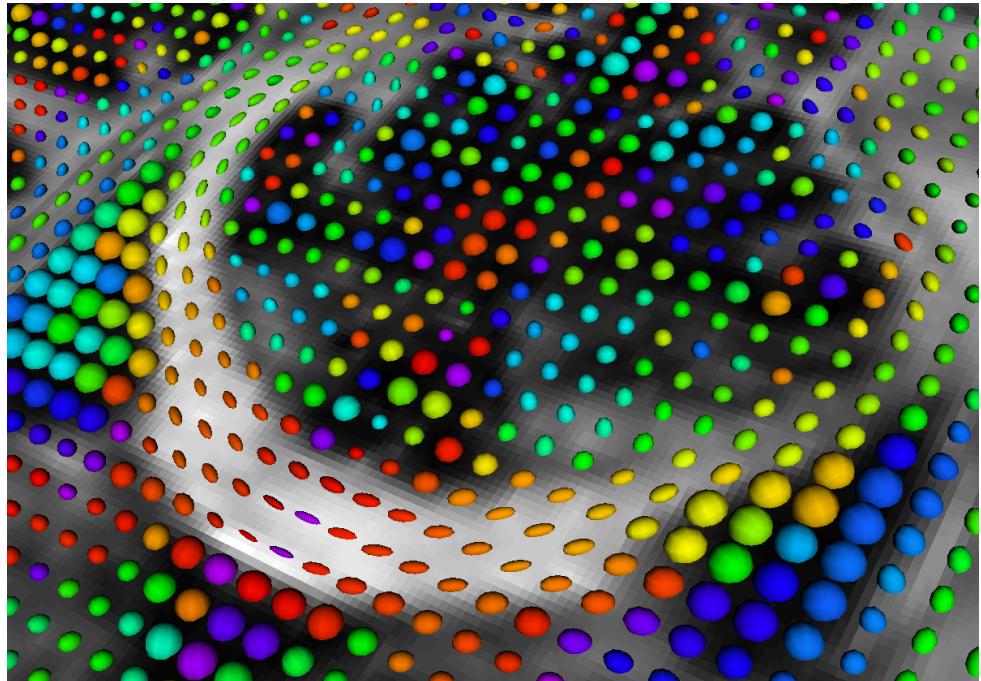
F: dti (40%)
B: fa

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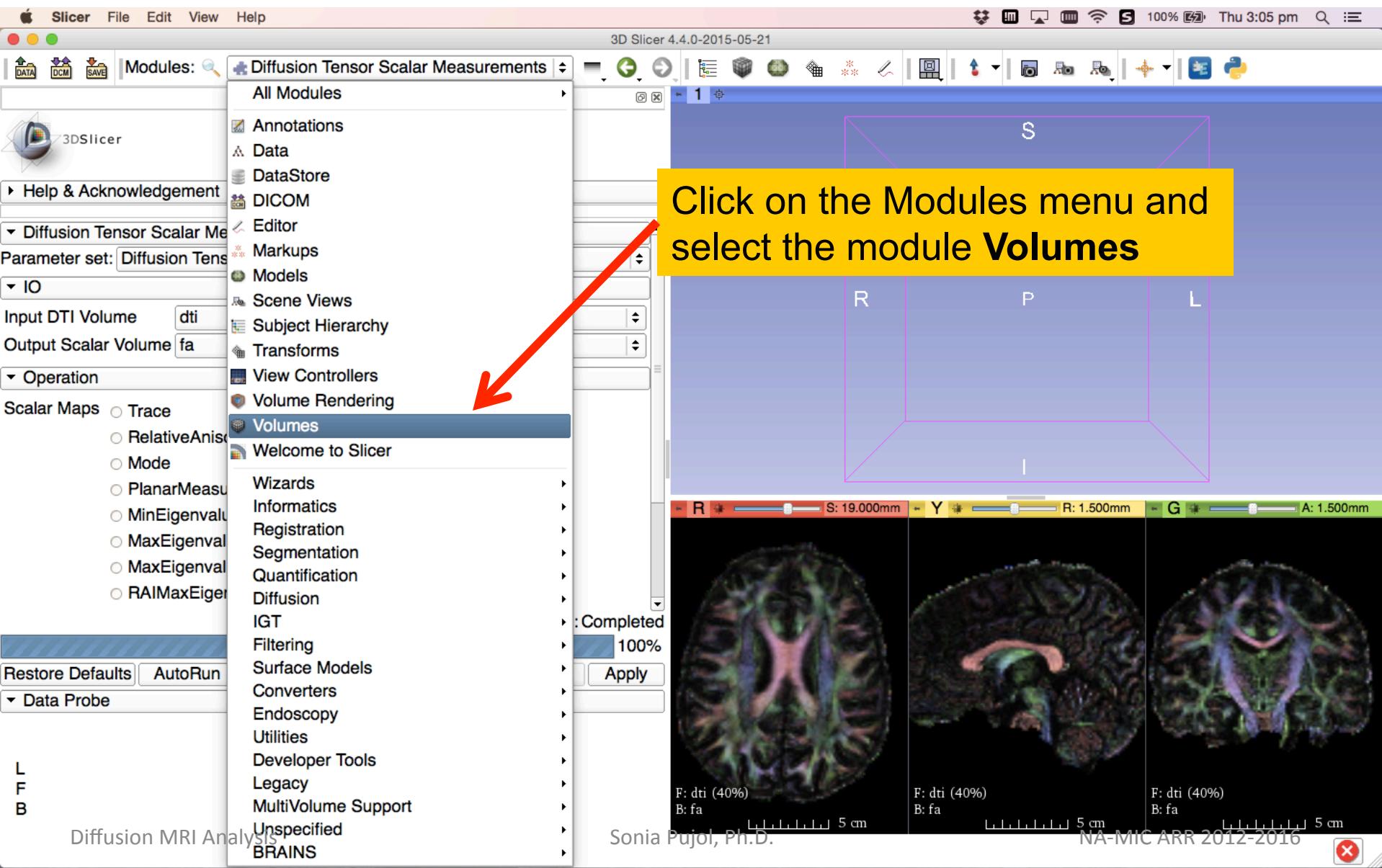
Fractional Anisotropy



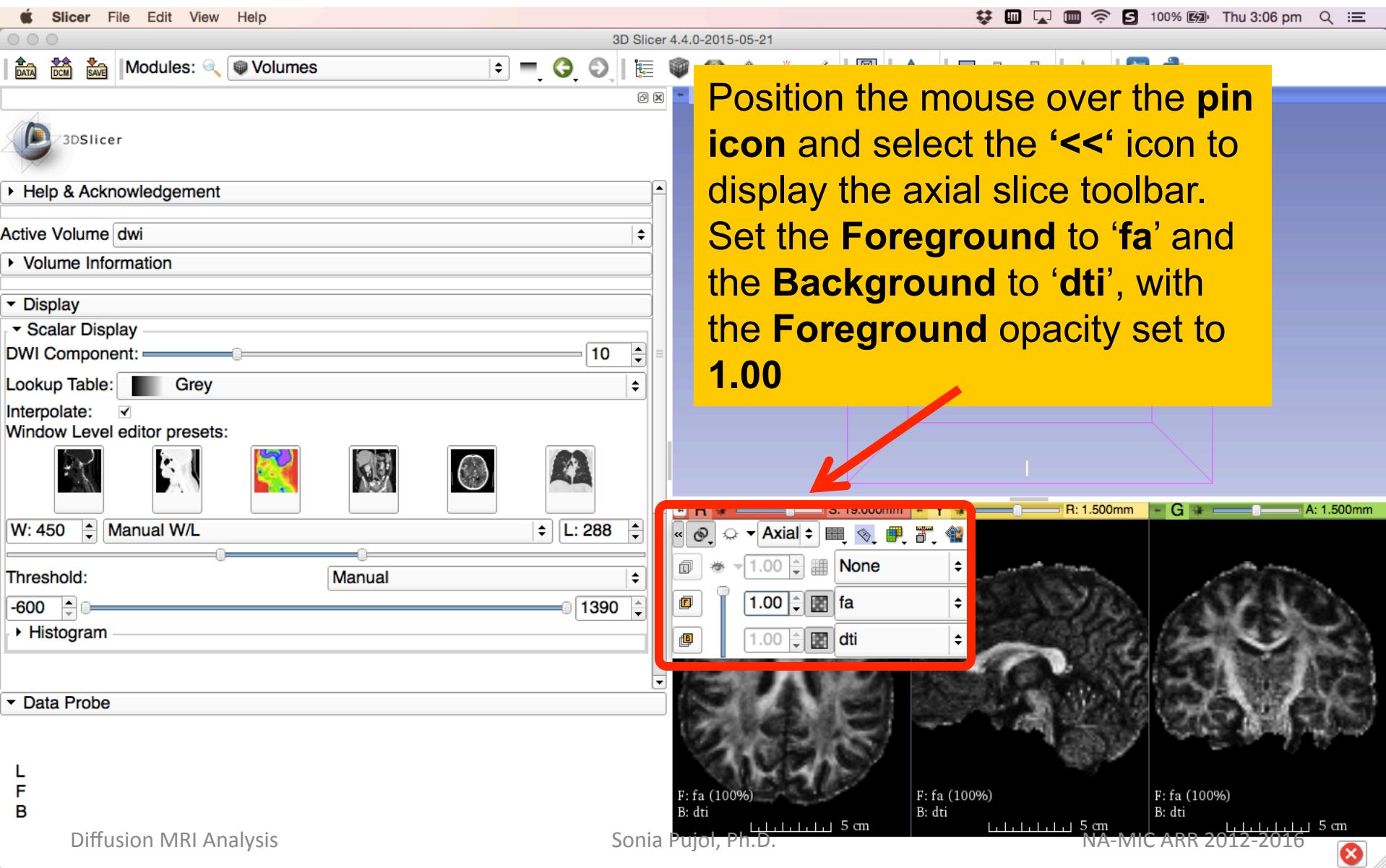


Part 2: Visualizing the tensor data

3D Visualization: Glyphs



3D Visualization: Glyphs



3D Visualization: Glyphs

Slicer File Edit View Help

3D Slicer 4.4.0-2015-05-21

DATA DCM SAVE Modules: Volumes 1

3DSlicer

Help & Acknowledgement

Active Volume dti

Volume Information

Display

Scalar Display

Scalar Mode: ColorOrientation

Lookup Table: Grey

Interpolate:

Window Level editor presets:

W: 255 L: 128

Threshold: Off -600 600

Histogram

Glyphs on Slices Display

Slice Visibility: Red Yellow Green

Data Probe

L F B

Diffusion MRI Analysis

S: 19.000mm Y: R: 1.500mm G: A: 1.500mm

R F: fa (100%) B: dti 5 cm

Y F: fa (100%) B: dti 5 cm

G F: fa (100%) B: dti 5 cm

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Set the Active Volume to 'dti' and the Scalar Mode to 'ColorOrientation'

The image shows the 3D Slicer software interface. On the left, the 'Scalar Display' panel is open, with the 'Scalar Mode' set to 'ColorOrientation'. A red box highlights this setting. On the right, a 3D rendering of a brain volume is shown with pink directional arrows (glyphs) indicating fiber orientation. A yellow callout box contains the text 'Set the Active Volume to "dti" and the Scalar Mode to "ColorOrientation"'. Below the 3D view are three 2D axial slices of the brain, each labeled with 'F: fa (100%)' and 'B: dti'. The bottom right corner features the text 'NA-MIC ARR 2012-2016'.

3D Visualization: Glyphs

Slicer File Edit View Help

3D Slicer 4.4.0-2015-05-21

DATA DCM SAVE Modules: Volumes

3DSlicer

W: 255 Auto W/L L: 128

Threshold: Off -600 600

Histogram

Glyphs on Slices Display

Slice Visibility: Red Yellow Green

Opacity: 1.00

Scalar ColorMap: FullRainbow

Color by Scalar: ColorOrientation

Scalar Range: 0 255

Glyph Type: Ellipsoids

Scale Factor: 50.00

Spacing: 5.00

Data Probe

L F B

Diffusion MRI Analysis

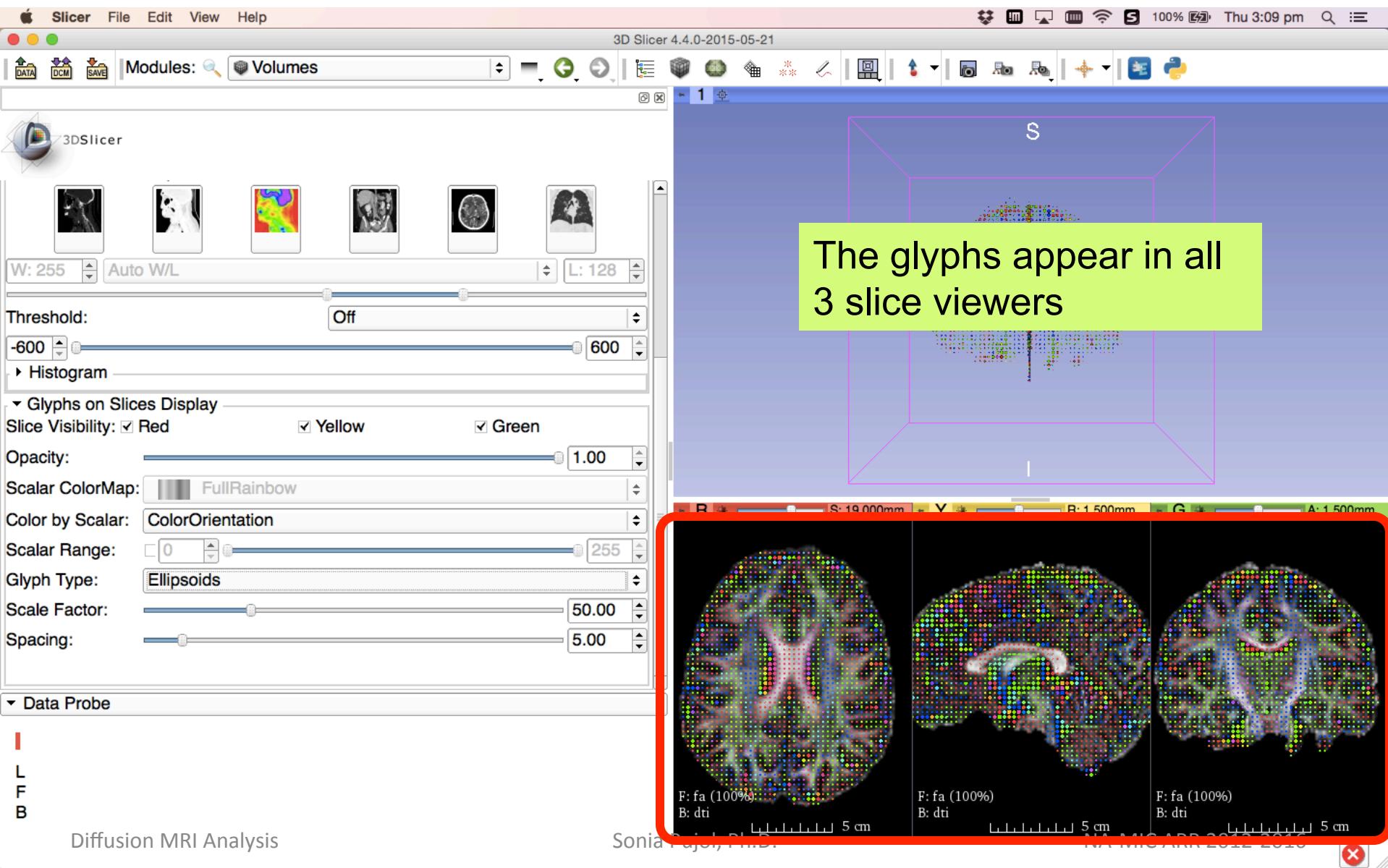
Scroll down the module panel and:

- Check off the option for **Red, Yellow, and Green Slice Visibility**
- Set the **Color by Scalar** parameter to '**ColorOrientation**'
- Set the **Glyph Type** to '**Ellipsoids**'

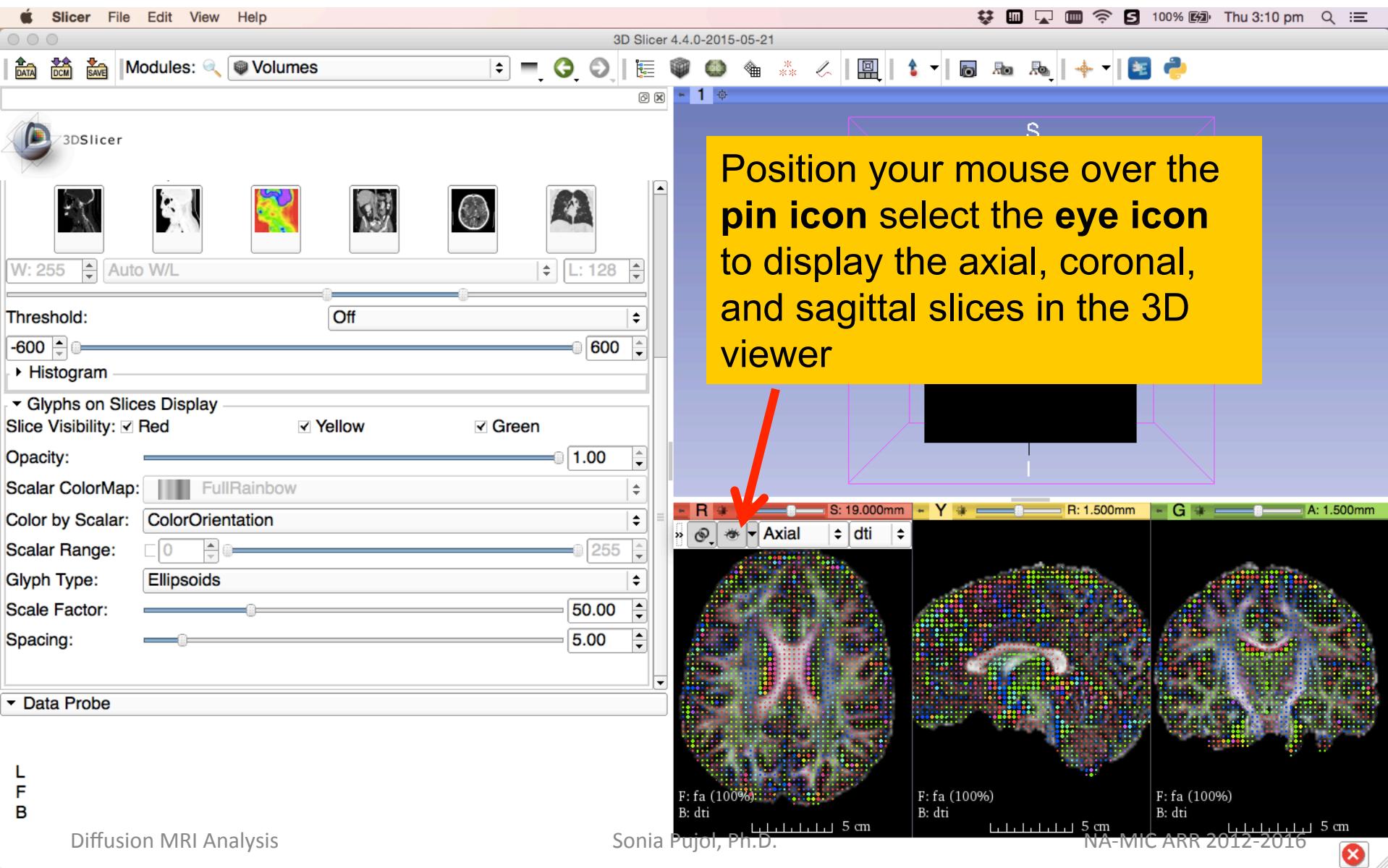
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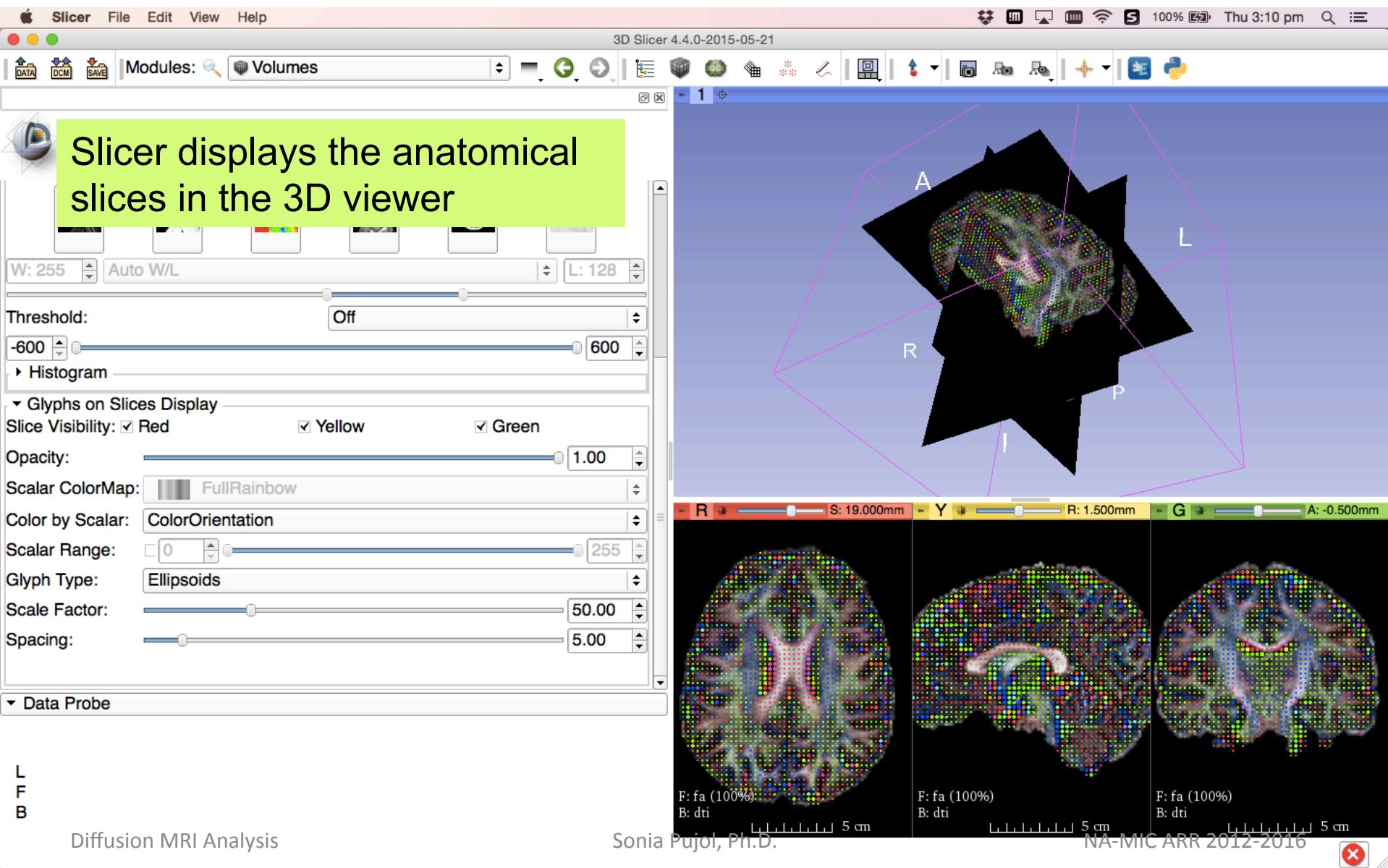
3D Visualization: Glyphs



3D Visualization: Glyphs



3D Visualization: Glyphs



3D Visualization: Glyphs

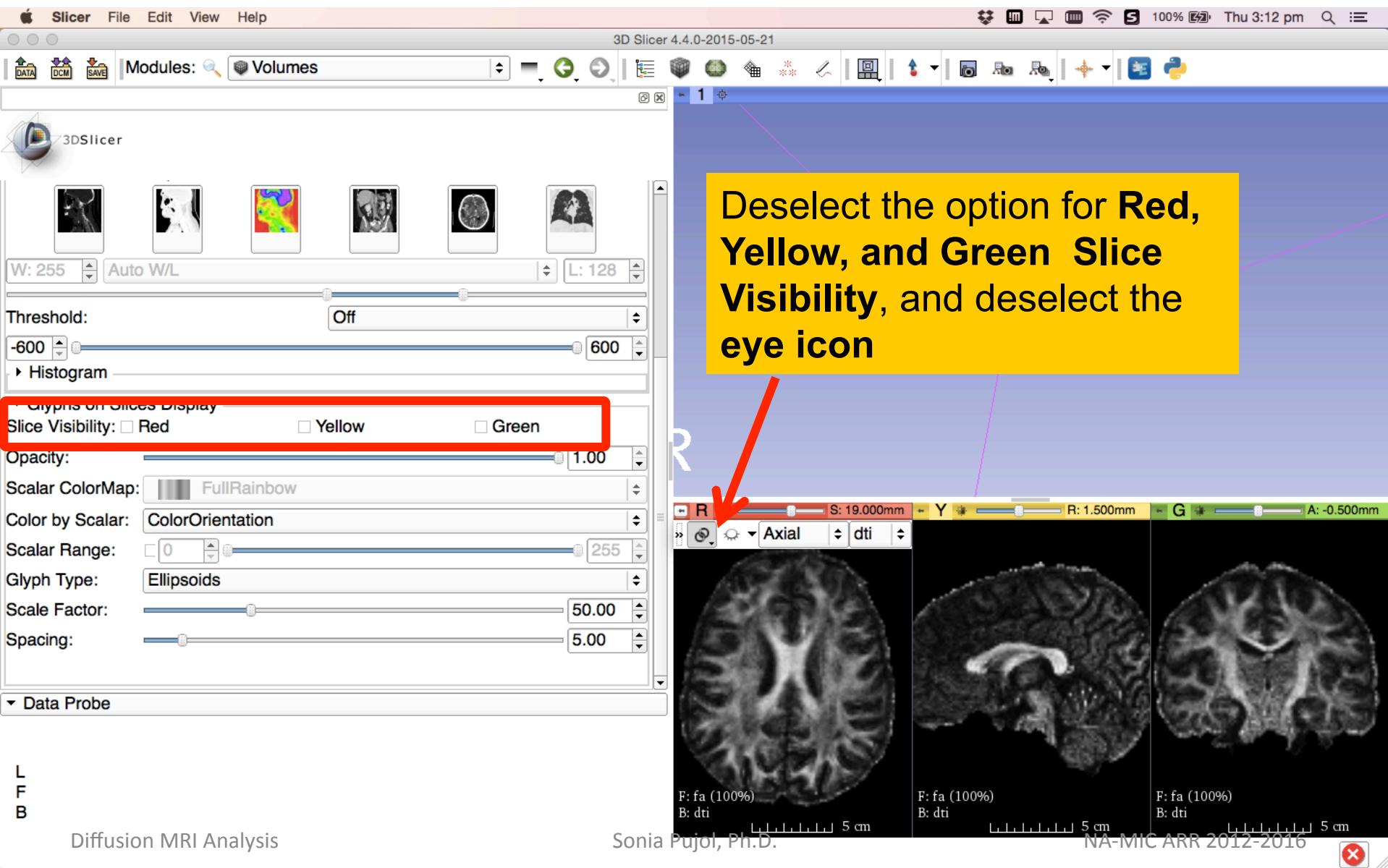
Zoom in to observe the glyphs.
The ellipsoids represent the principal direction of diffusion (main eigenvector)

The screenshot shows the 3D Slicer interface with a 3D brain volume displayed. Overlaid on the brain are numerous small, colored ellipsoids (glyphs) representing the principal direction of diffusion. A green callout box on the left side of the interface contains the text: "Zoom in to observe the glyphs. The ellipsoids represent the principal direction of diffusion (main eigenvector)". The left panel contains various visualization settings:

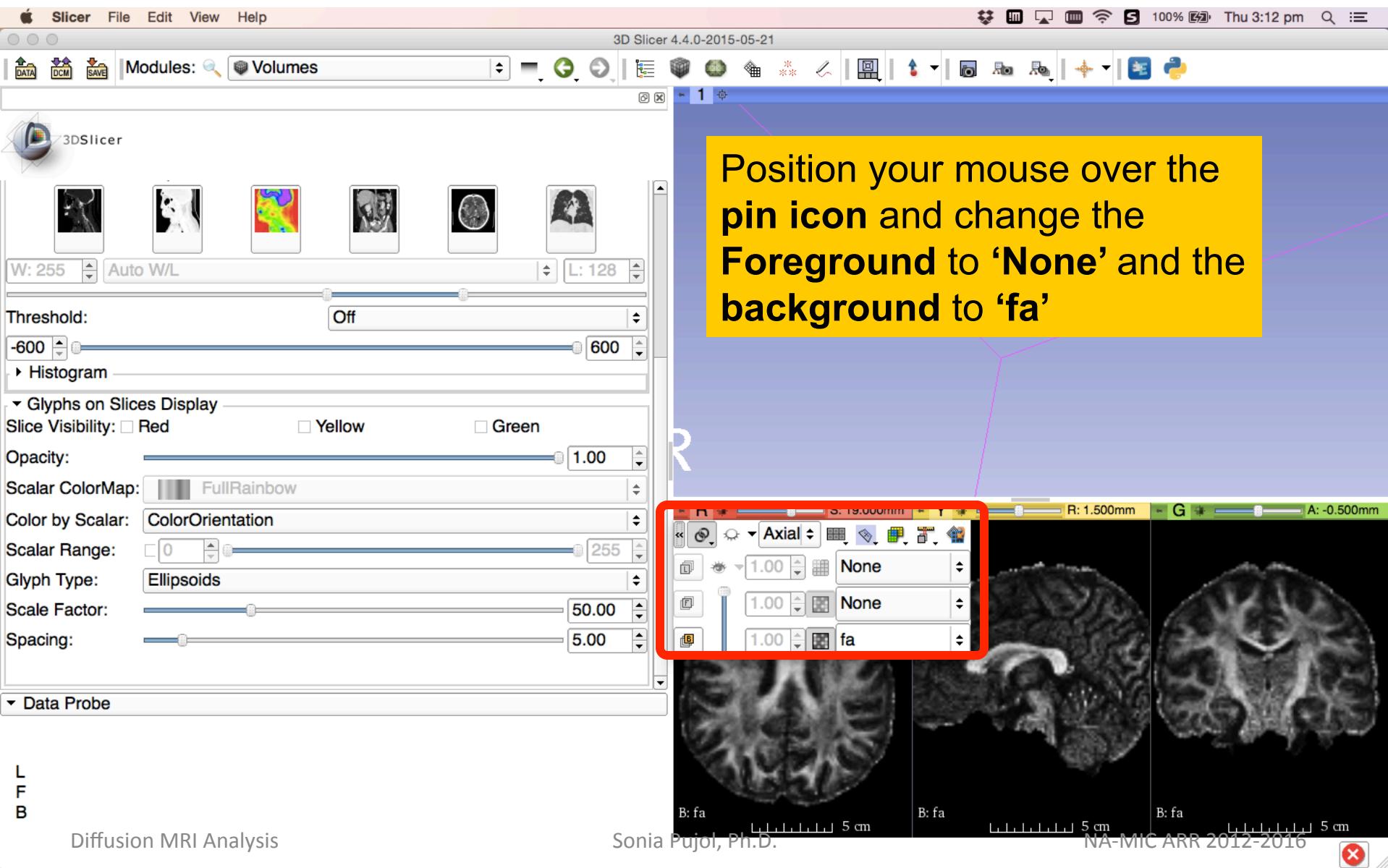
- Threshold: 0 - 0
- Histogram
- Glyphs on Slices Display:
 - Slice Visibility: Red Yellow Green
 - Opacity: 1.00
 - Scalar ColorMap: FullRainbow
 - Color by Scalar: ColorOrientation
 - Scalar Range: 0 - 255
 - Glyph Type: Ellipsoids
 - Scale Factor: 50.00
 - Spacing: 5.00
- Data Probe

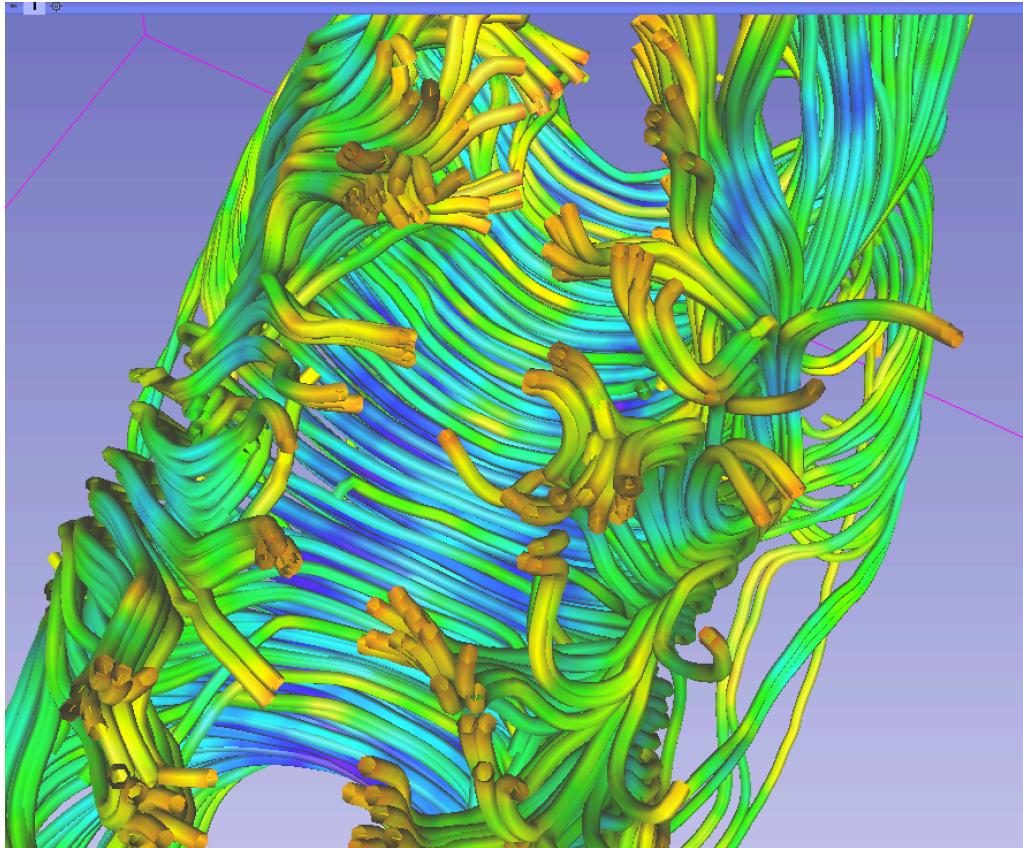
Below the main 3D view, three 2D axial slices of the brain are shown, each with a grid of colored dots corresponding to the 3D glyphs. The slices are labeled with their respective coordinates: R: 10.500mm, Y: 31.500mm, and G: 13.500mm. The bottom right corner of the slide contains the text: "NA-MIC ARR 2012-2016".

Diffusion MRI tractography



Diffusion MRI tractography



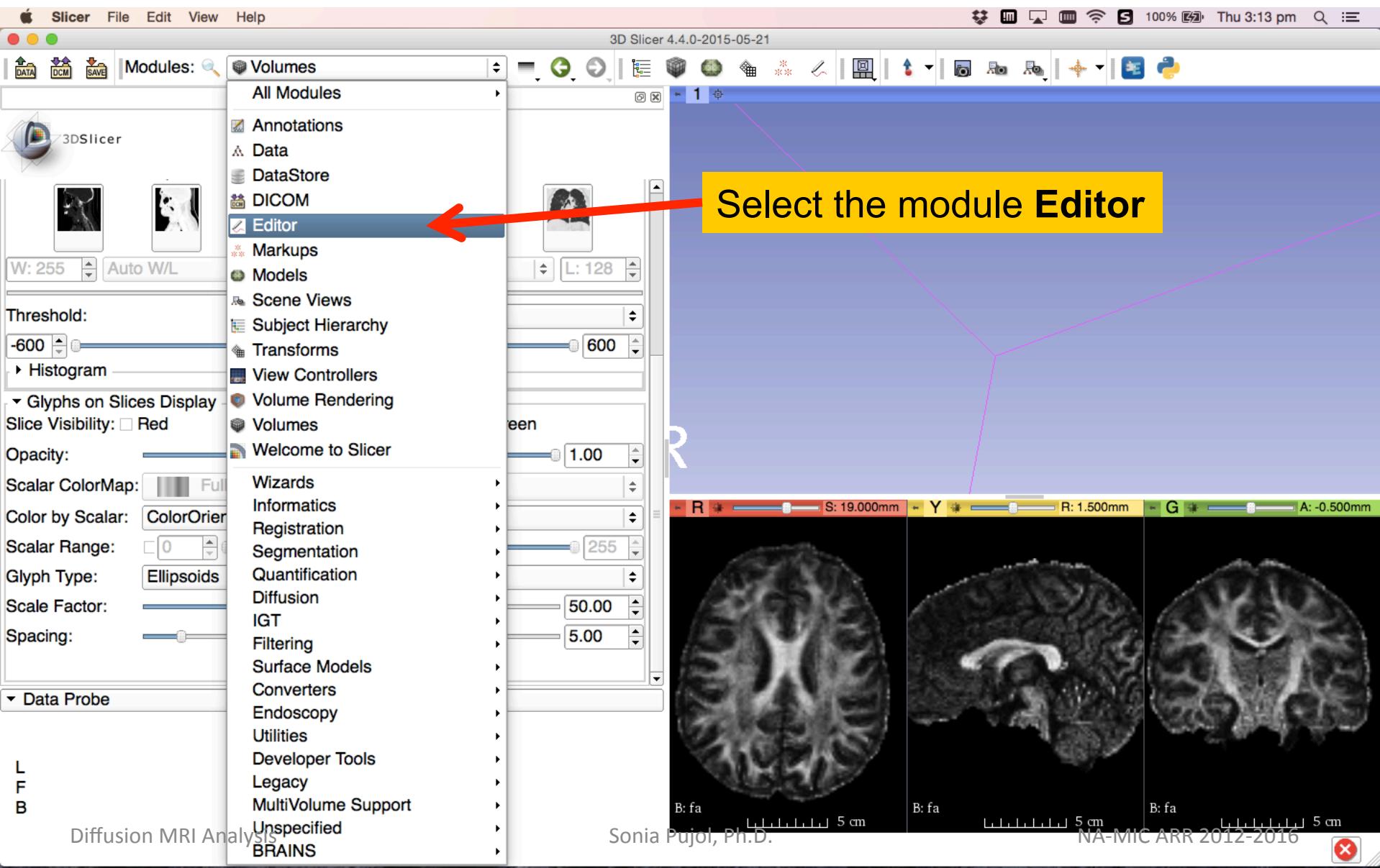


Part 3: From tensors to tracts

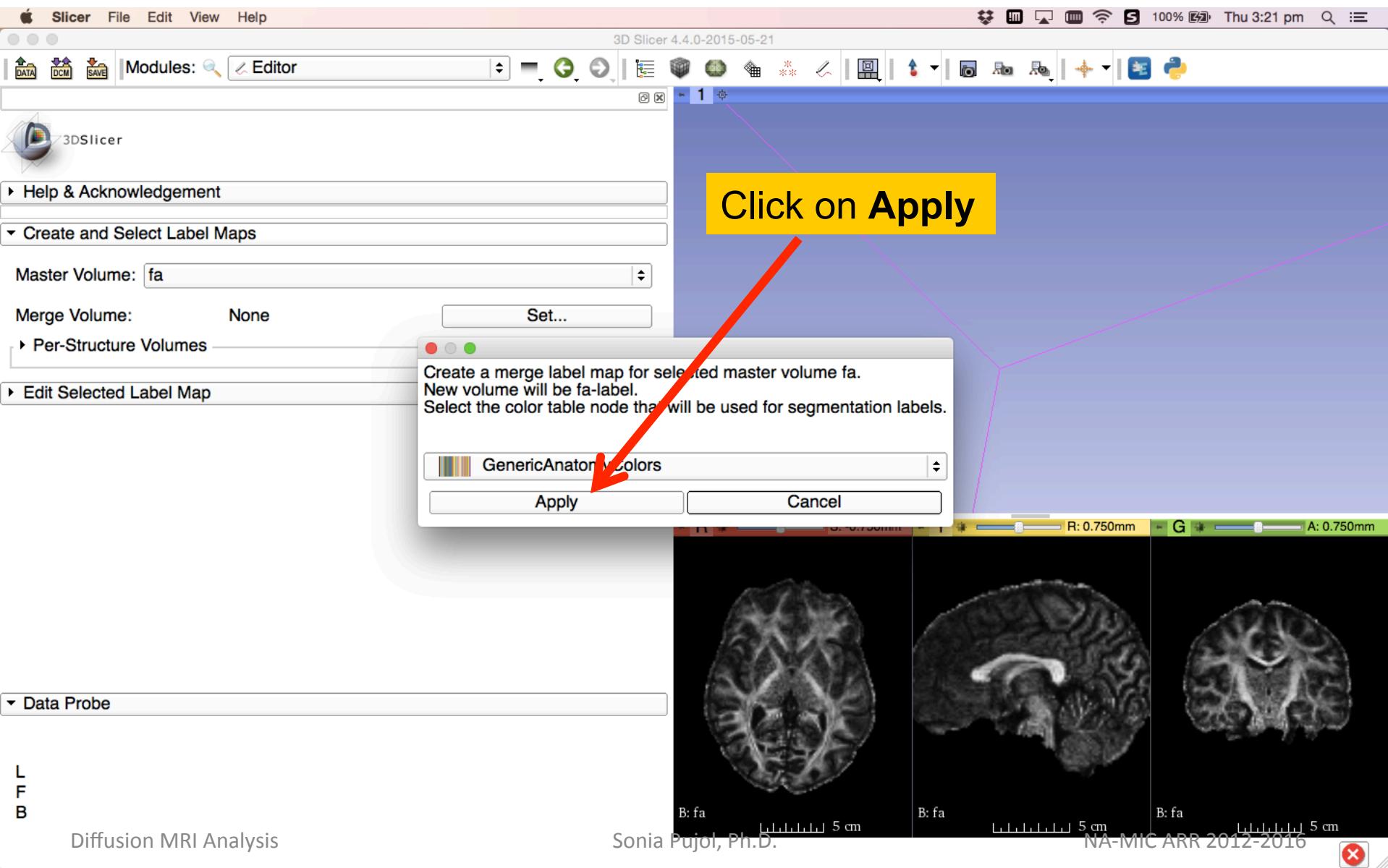
DTI tractography

- Definition of a region of interest (ROI) for seeding tract in an FA map (Editor module)
- Single-tensor tractography (Tractography Interactive Seeding module)
- Fiducial-seeding tractography (Tractography Interactive Seeding module)

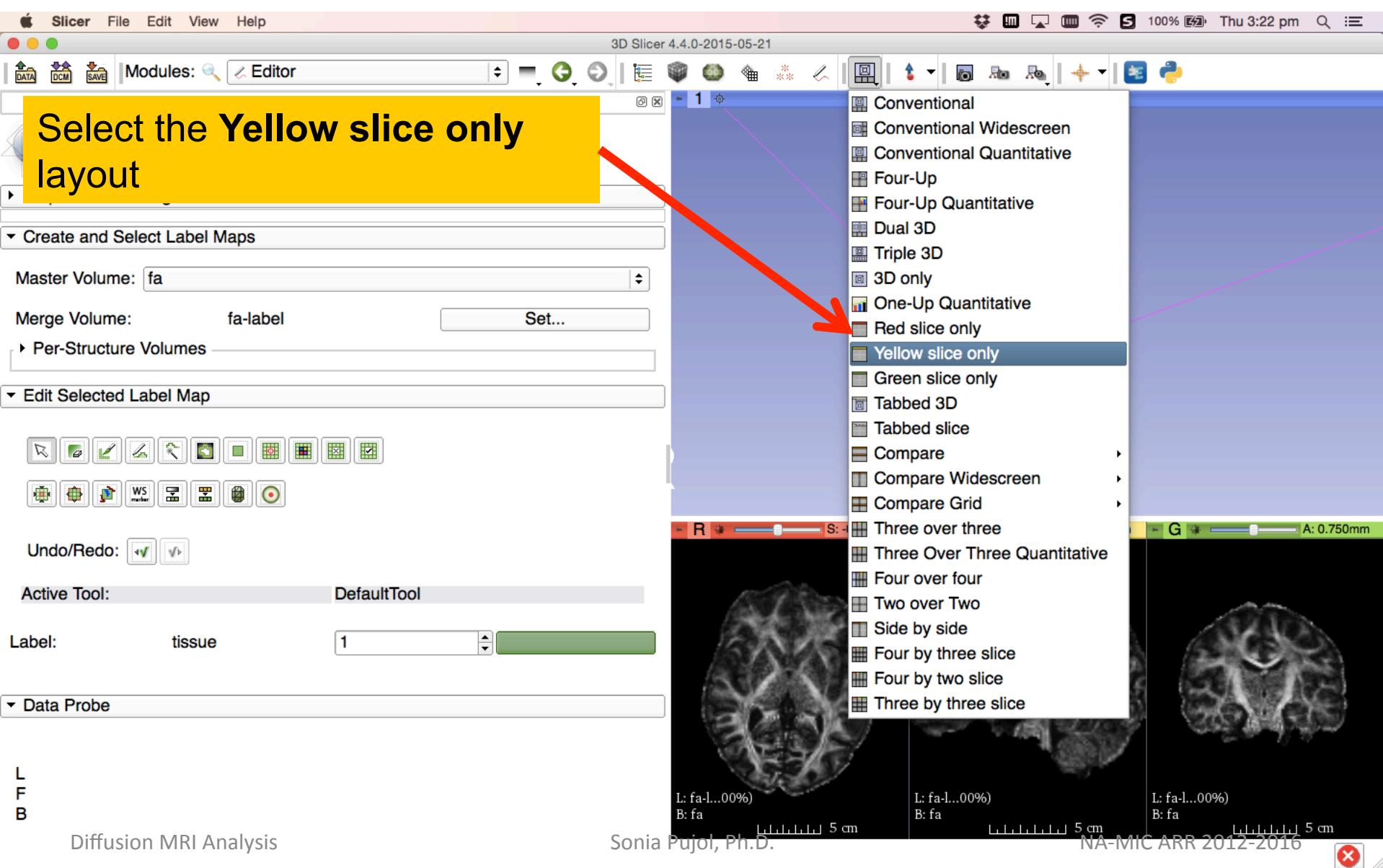
Diffusion MRI tractography



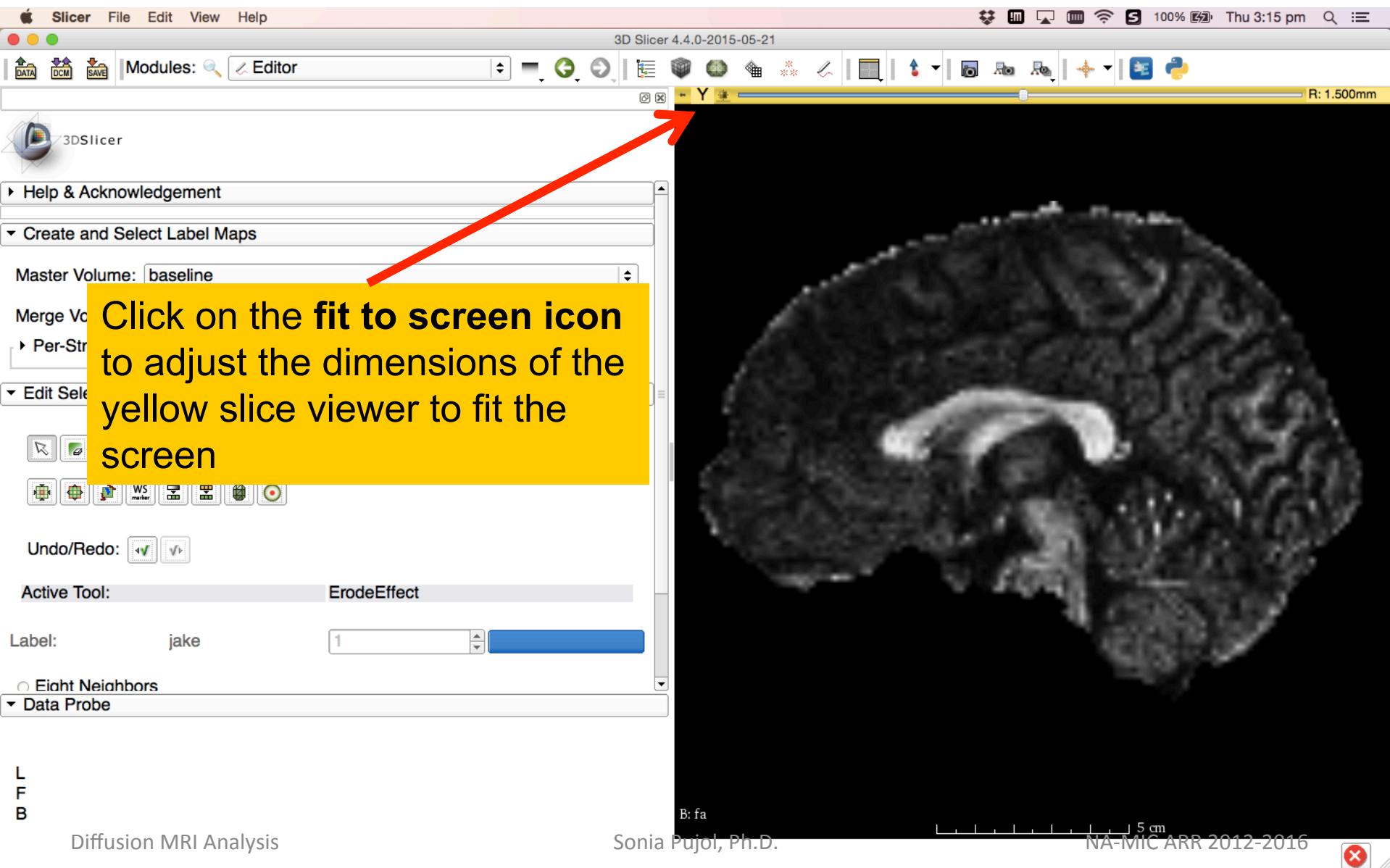
Diffusion MRI tractography



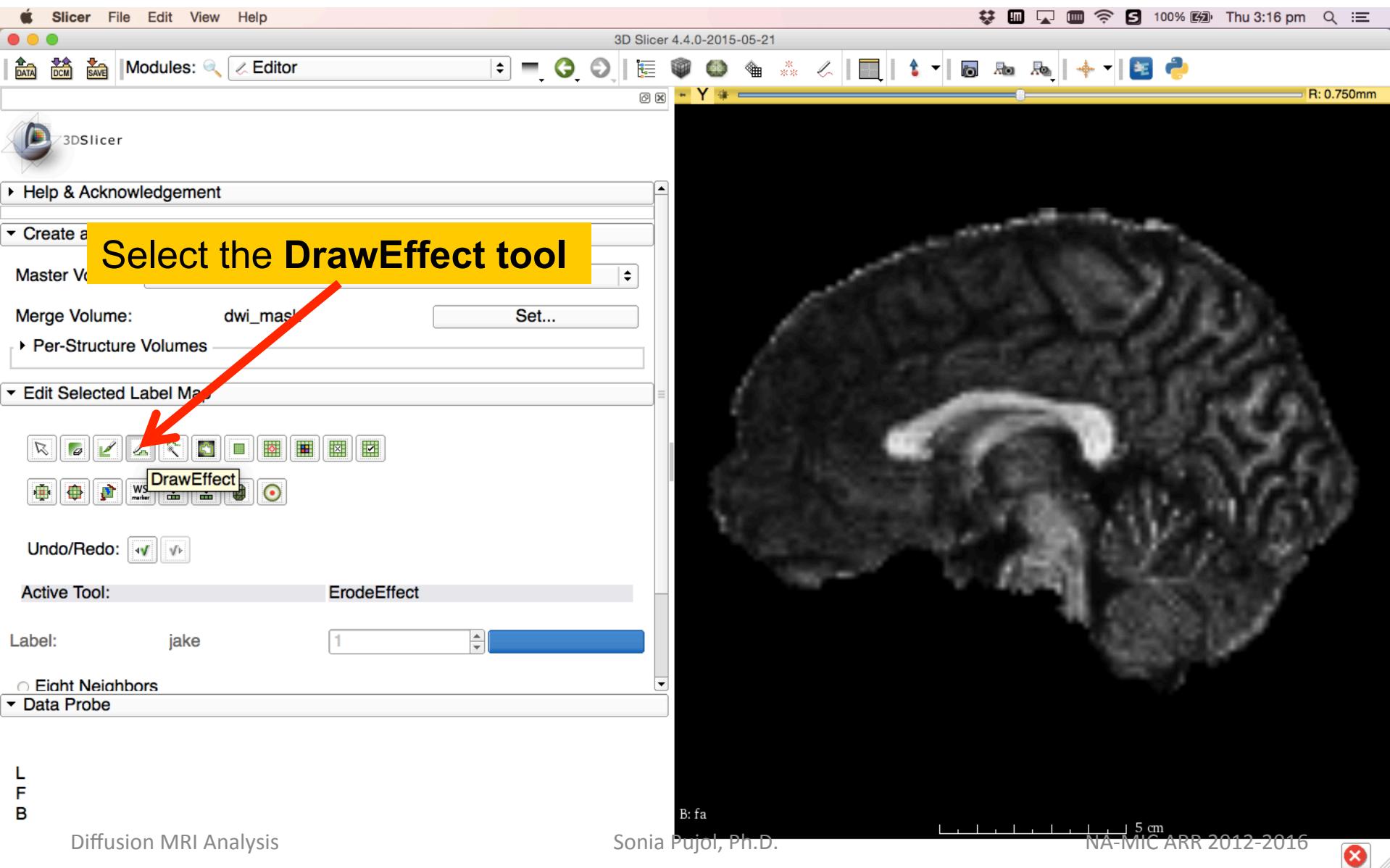
Diffusion MRI tractography



Diffusion MRI tractography



Diffusion MRI tractography



Diffusion MRI tractography

Slicer File Edit View Help

3D Slicer 4.4.0-2015-05-21

DATA DCM SAVE Modules: Editor

Y R: 1.500mm

3DSlicer

Help & Create Master V Merge V Per-S... Edit Se

Outline the contour of the Corpus Callosum with the **DrawEffect tool** and press enter. Repeat this step with 3 adjacent sagittal slices

Undo/Redo:

Active Tool: DrawEffect

Label: tissue 1

Paint Over

Yellow RAS: (1.5, 79.4, 12.2) Sagittal Sp: 1.5

L fa-label (63, 11, 55) background (0)

F None

B fa (63, 11, 55) 0.150501

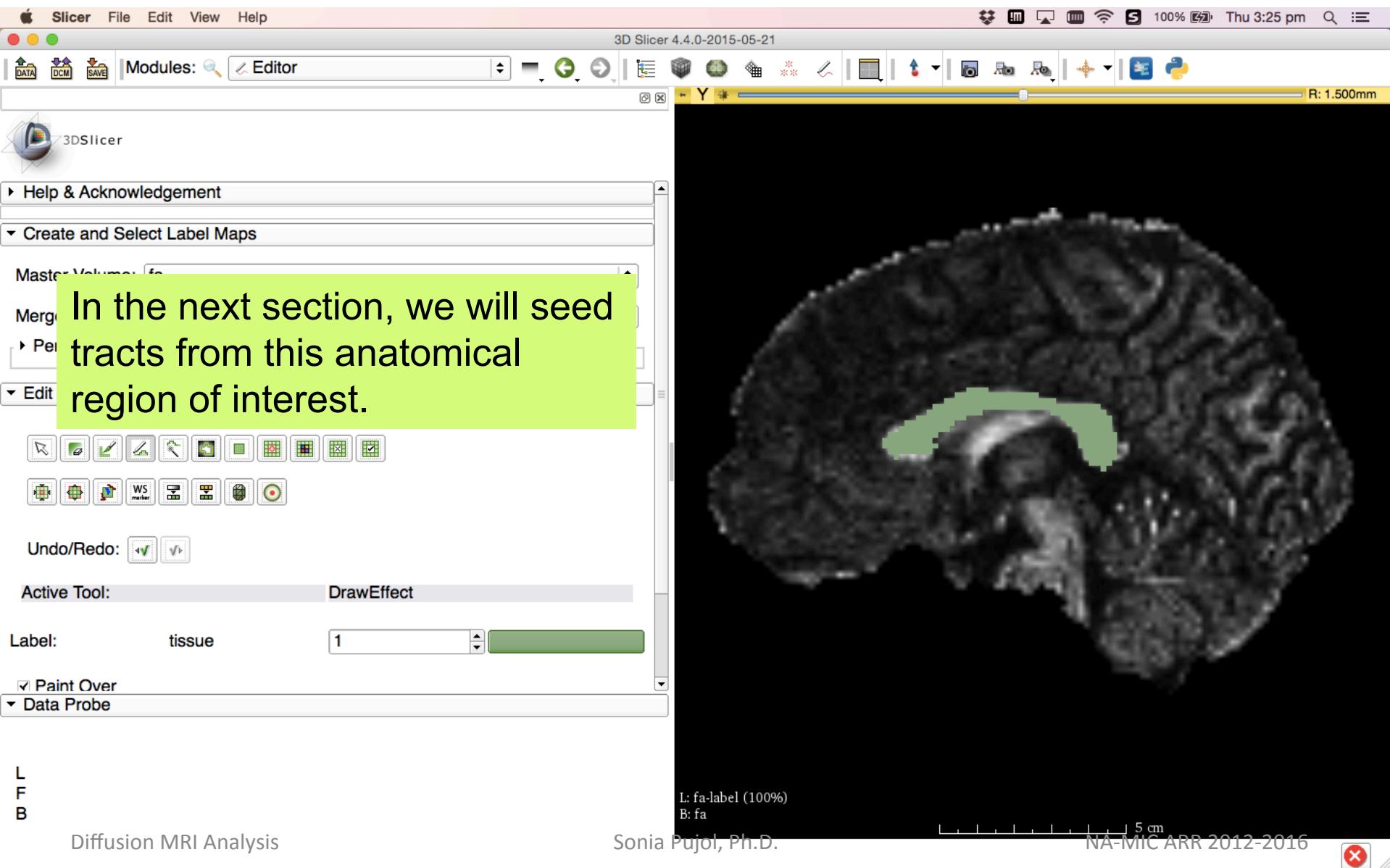
Diffusion MRI Analysis

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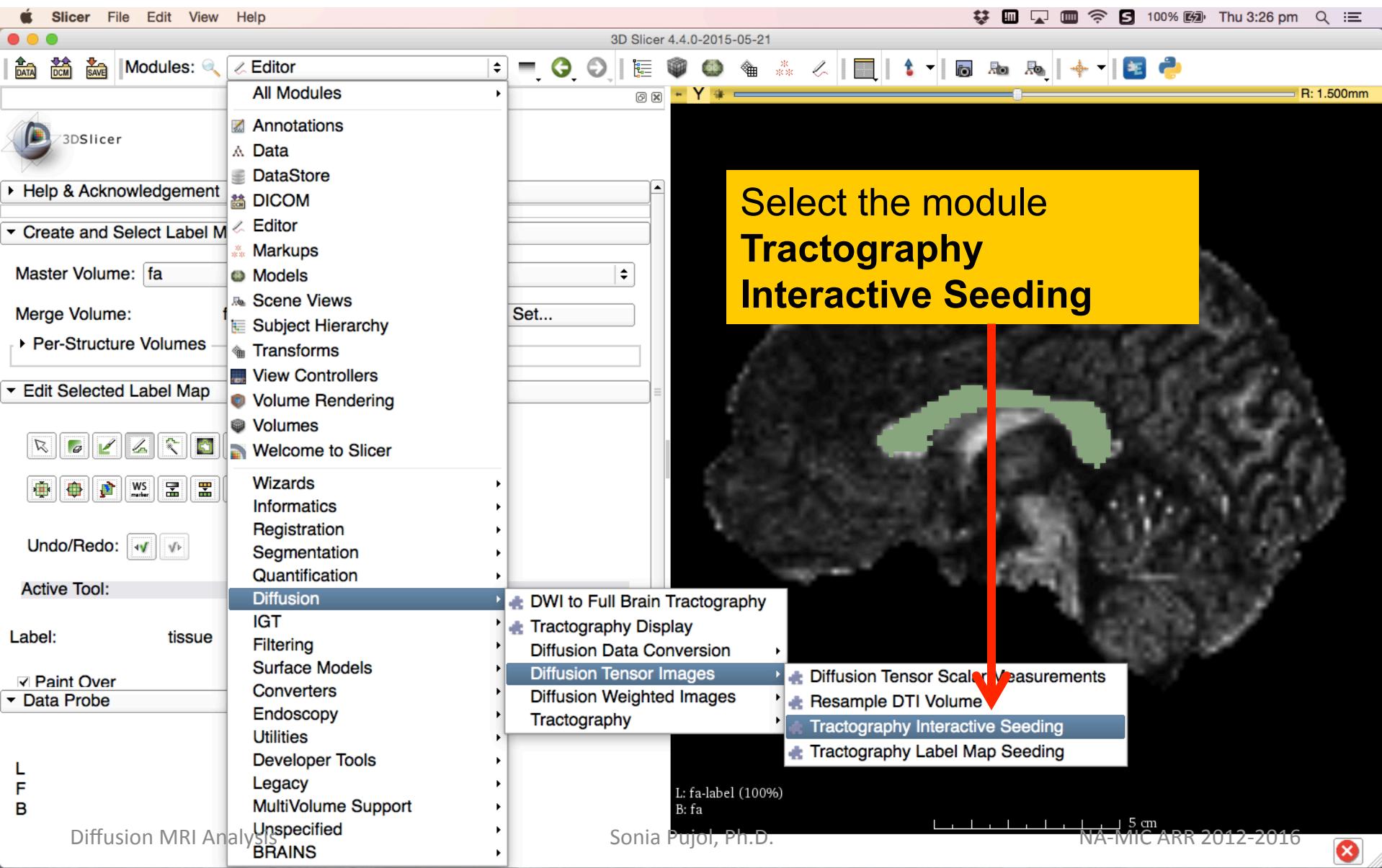
NA-MIC ARR 2012-2016

A screenshot of the 3D Slicer medical image analysis software. The main window displays a grayscale sagittal brain scan. A yellow rectangular box contains the text: "Outline the contour of the Corpus Callosum with the **DrawEffect tool** and press enter. Repeat this step with 3 adjacent sagittal slices". A red arrow points from the bottom right of this text box to the yellow-outlined region of the brain image. The software interface includes a toolbar at the top with various icons, a menu bar with 'File', 'Edit', 'View', 'Help', and a 'Modules' section. On the left, there's a vertical stack of toolbars and a list of modules like 'Master V', 'Merge V', and 'Edit Se'. At the bottom, there are sections for 'Label' (set to 'tissue'), 'Paint Over' (checkbox checked), and some coordinate and label information. The status bar at the bottom right shows 'NA-MIC ARR 2012-2016'.

Diffusion MRI tractography



Diffusion MRI tractography



Labelmap Seeding: Step1: I/O

Change to **Conventional** view

The screenshot shows the 3D Slicer interface with the 'Tractography Interactive Seeding' module selected. A yellow box highlights the 'Parameters' section, which contains the following fields:

- Input DTI Volume: dti
- Input Fiducials, Model or Label Map: fa-label
- Output Fiber Bundle: corpusCallosum
- Enable Seeding Tracts:

A red arrow points from the text 'Change to Conventional view' to the 'Conventional' option in the view selection dropdown menu. The menu also lists other viewing modes such as 'Four-Up', 'Dual 3D', and 'Tabbed 3D'. The main 3D rendering area shows a brain scan with a highlighted region.

- Set the Input DTI Volume to 'dti'

- Set the Input Label Map to 'fa-label'

- Set Output Fiber Bundle to 'Create and Rename New Fiber Bundle' and rename it 'corpusCallosum'

- Uncheck Enable Seeding Tracks

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Labelmap Seeding: Step 2: Seeding parameters

The screenshot shows the 3D Slicer interface with the 'Tractography Interactive Seeding' module selected. On the left, the 'Tractography Seeding Parameters' section is highlighted with a red box. It includes settings for 'Use index Space' (checked), 'Seed Spacing' (2.00), 'Linear Measure Start Threshold' (0.30), 'ROI Labels' (1), 'Output Directory' (/Applications), and 'File Prefix'. Below this, under 'Tractography Seeding Parameters', are sliders for 'Minimum Path Length' (20.000mm), 'Maximum Path Length' (800.000mm), 'Stopping Criteria' (set to 'Fractional Anisotropy'), 'Stopping Value' (0.15), 'Stopping Track Curvature' (0.70), and 'Integration Step Length' (0.500mm). The right side of the interface shows a 3D brain model with a color-coded tractography bundle. A coordinate system (R, S, I) is overlaid on the brain. The bottom status bar shows coordinates R: 1.500mm, S: 0.000mm, Y: 1.500mm, G: 1.500mm, and A: 1.500mm.

Select the default Tractography Seeding parameters:

- Check Use index Space
- Stopping Criteria: FractionalAnistropy
- Stopping Value: 0.15

L
F
B

Diffusion MRI Analysis

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Labelmap Seeding: Step 3: Generate Tracts

Slicer File Edit View Help

3D Slicer 4.4.0-2015-05-21

DATA DCM SAVE Modules: Tractography Interactive Seeding

3DSlicer

Help & Acknowledgement

IO

Parameters FiducialSeedingParameters

Presets Slicer4 Interactive Seeding Defaults

Input DTI Volume dti

Input Fiducials, Model or Label Map fa-label

Output Fiber Bundle corpusCallosum

Enable Seeding Tracts

Label Map Options

Use index Space

Seed Spacing 2.00

Random Grid

Linear Measure Start Threshold 0.30

ROI Labels

File Prefix

Data Probe

L
F
B

Diffusion MRI Analysis

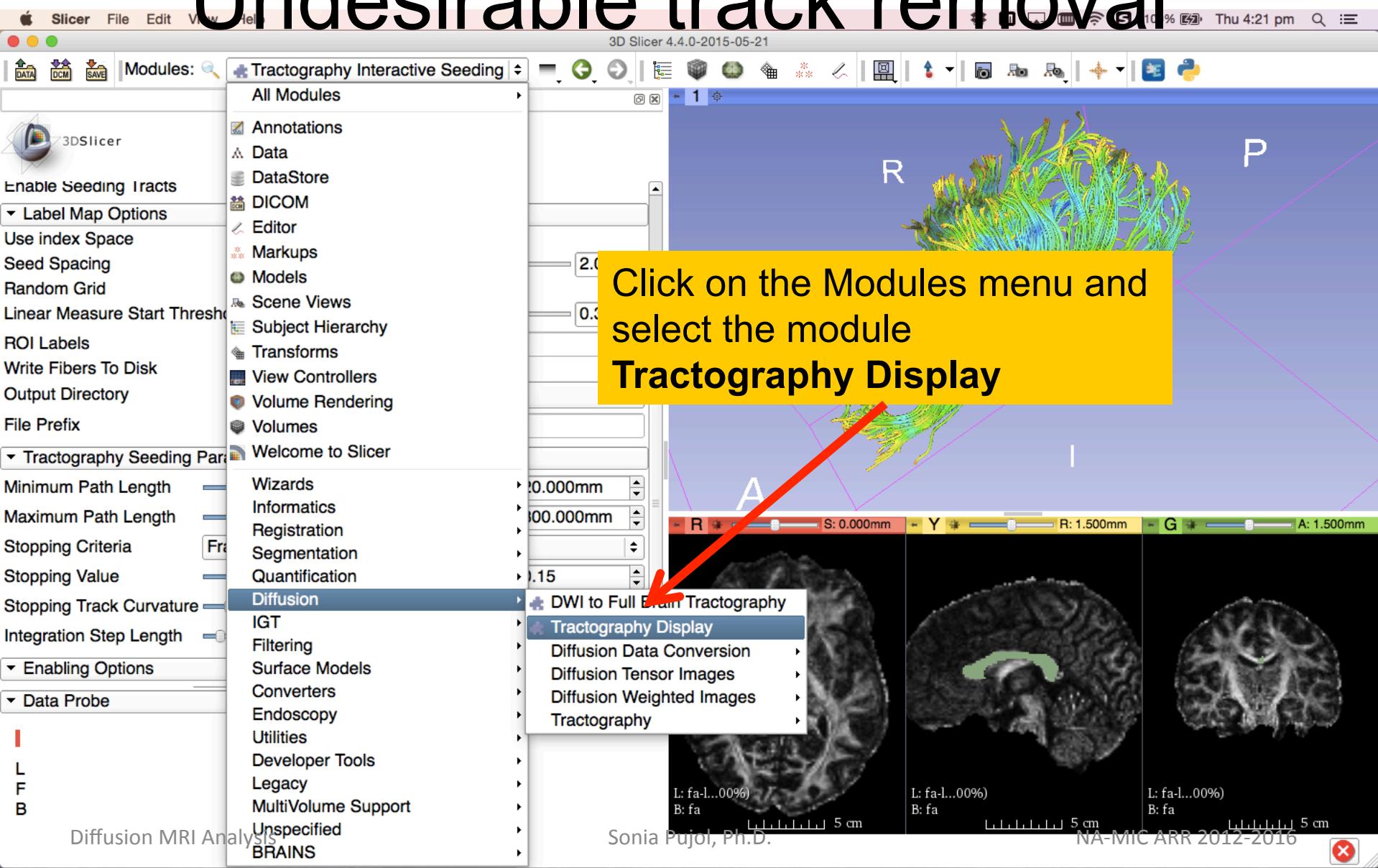
The tracts generated in the corpus callosum area appear in the 3D viewer.

3D Viewer showing the corpus callosum tract bundle. The image shows a 3D reconstruction of the tract bundle in a brain volume. The tract bundle is visualized as a dense cluster of colored fibers (green, yellow, blue) within the central white matter region. The 3D viewer interface includes a coordinate system (R, S, A) and a scale bar (5 cm). Below the 3D viewer are three corresponding axial diffusion MRI slices showing the same anatomical region. Each slice has text overlays indicating "L: fa-l...00%" and "B: fa".

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Labelmap Seeding: Step 4: Undesirable track removal



Labelmap Seeding: Step 4: Undesirable track removal

3D Slicer 4.4.0-2015-05-21

Modules: Tractography Display

3DSlicer

Help & Acknowledgement

Simple Display

Solid Tube Color

Name: corpusCallosum

Lines Tubes Tubes Slice

Percentage of Fibers Shown: 100%

Fiber Bundle Selection

ROI for Fiber Selection: ROI Node

Disable ROI Positive ROI Negative ROI

Interactive ROI ROI Visibility

Extract Bundle From ROI: None

Update corpusCallosum From ROI: Confirm update

Enable Interactive Edit

Advanced Display

Data Probe

L F B

Set ROI for Fiber Select to 'ROI node'

R P A

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

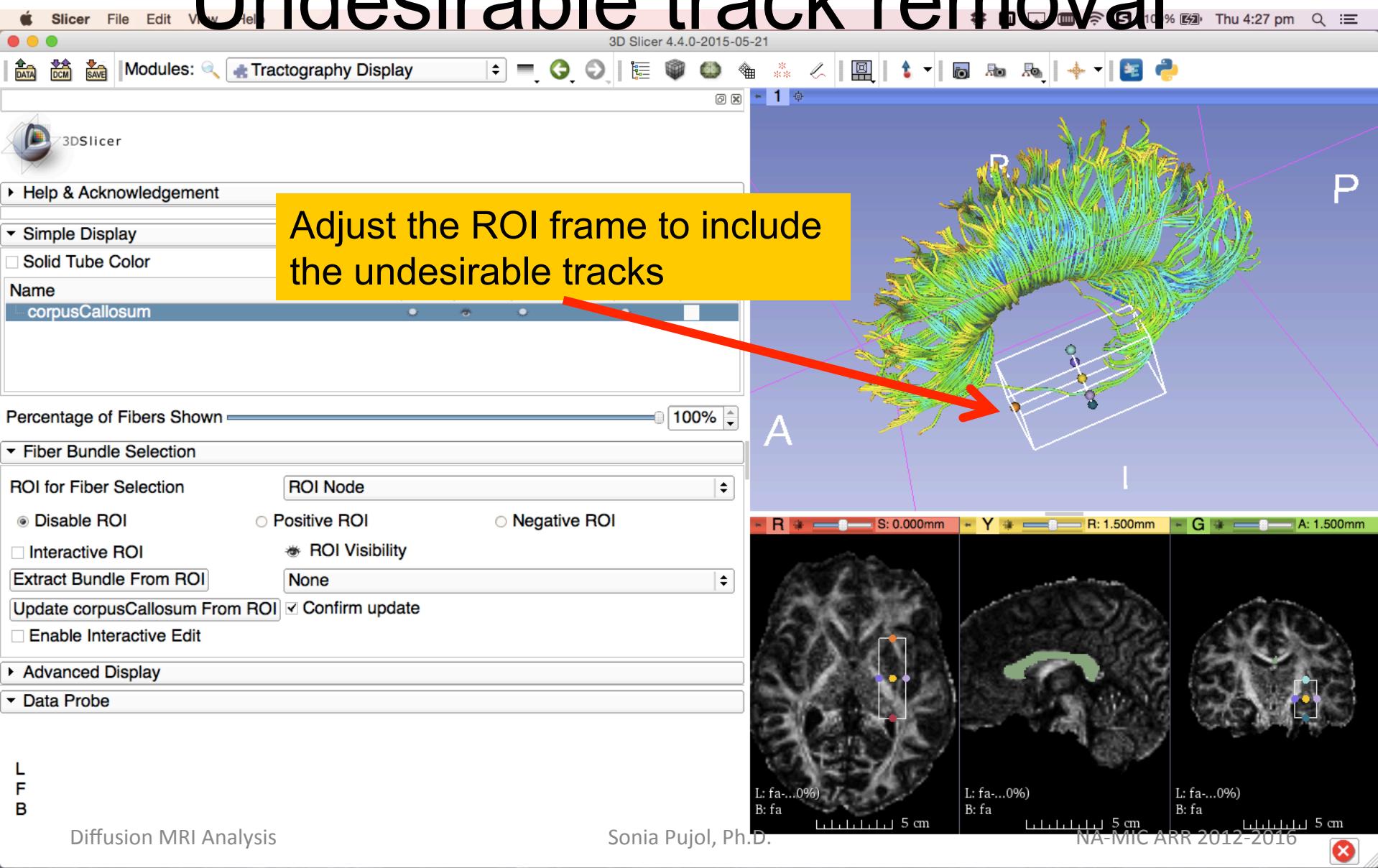
NA-MIC ARR 2012-2016

Diffusion MRI Analysis

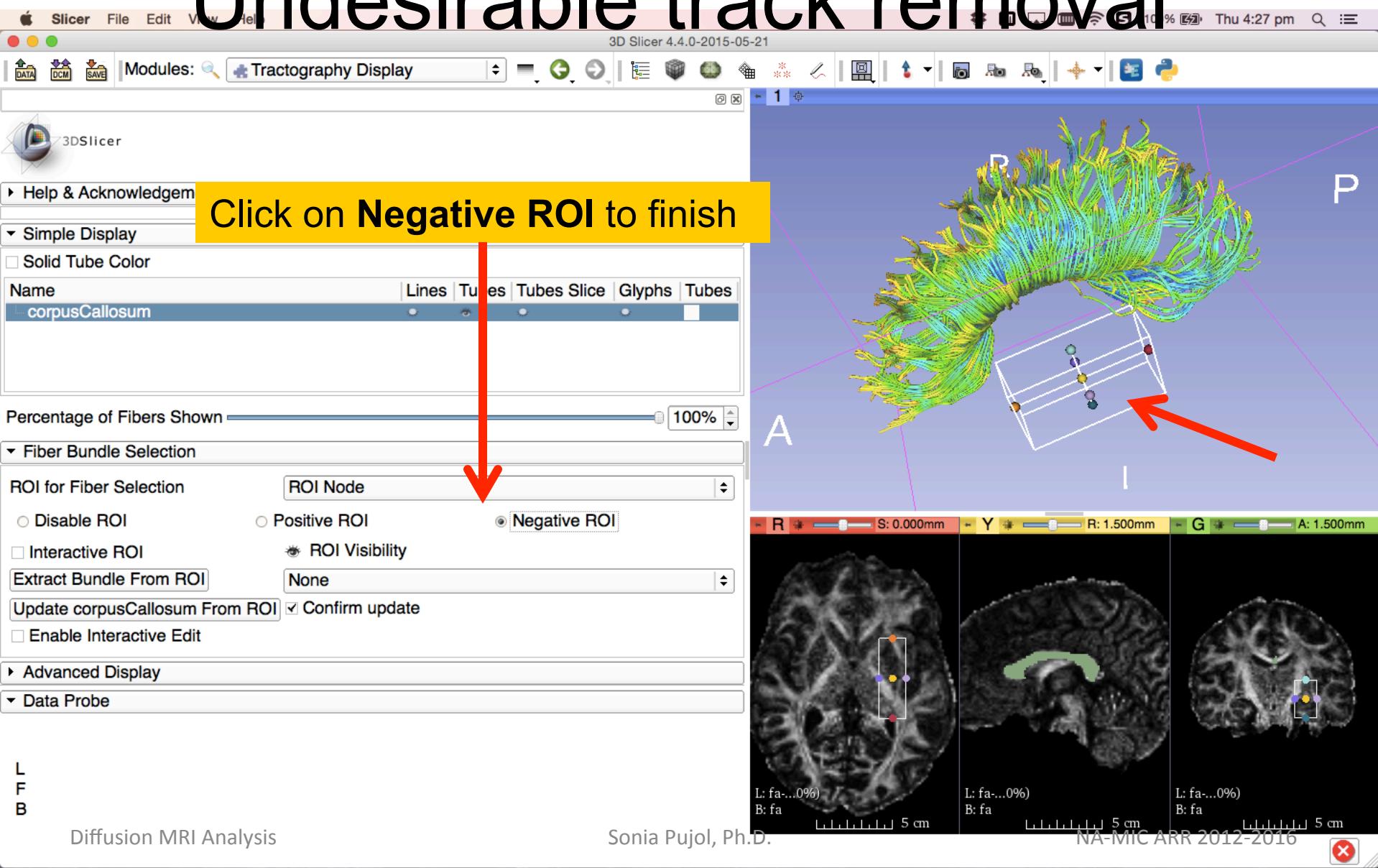
Sonia Pujol, Ph.D.

The screenshot shows the 3D Slicer interface with a brain tractography visualization in the main window. The tractography displays numerous colored fibers representing neural pathways. Below the main window, there are three axial slices of a brain. The left slice shows a green highlighted region, while the middle and right slices show a green highlighted region with a white border. The top left panel contains various settings for tractography display, including a dropdown for 'ROI for Fiber Selection' which is currently set to 'ROI Node'. A yellow callout box with the text 'Set ROI for Fiber Select to 'ROI node'' is overlaid on this panel. A red arrow points from the text box to the 'ROI for Fiber Selection' dropdown. The bottom left corner of the image has the text 'Diffusion MRI Analysis' and 'Sonia Pujol, Ph.D.'. The bottom right corner has the text 'NA-MIC ARR 2012-2016' and a small red X icon.

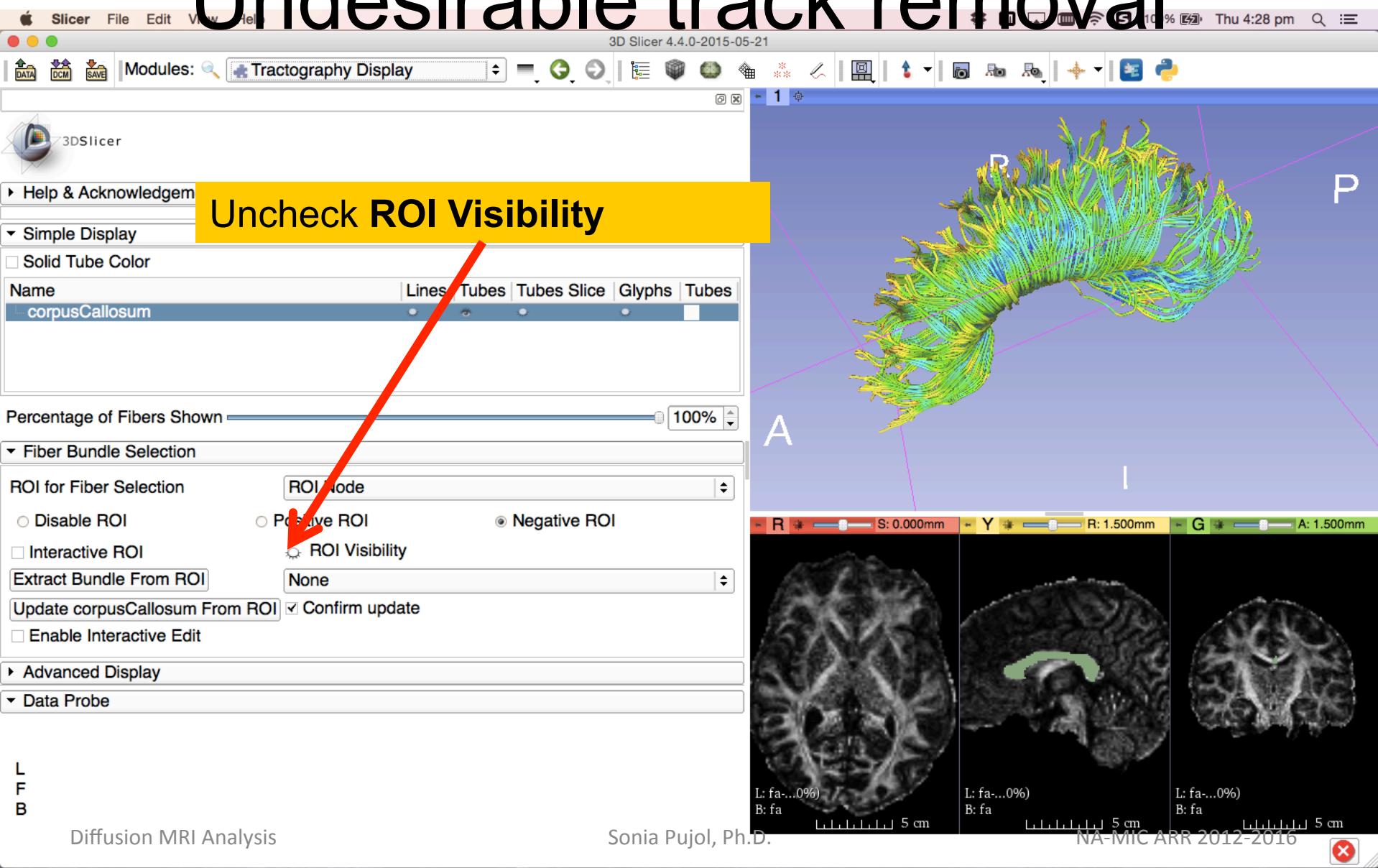
Labelmap Seeding: Step 4: Undesirable track removal



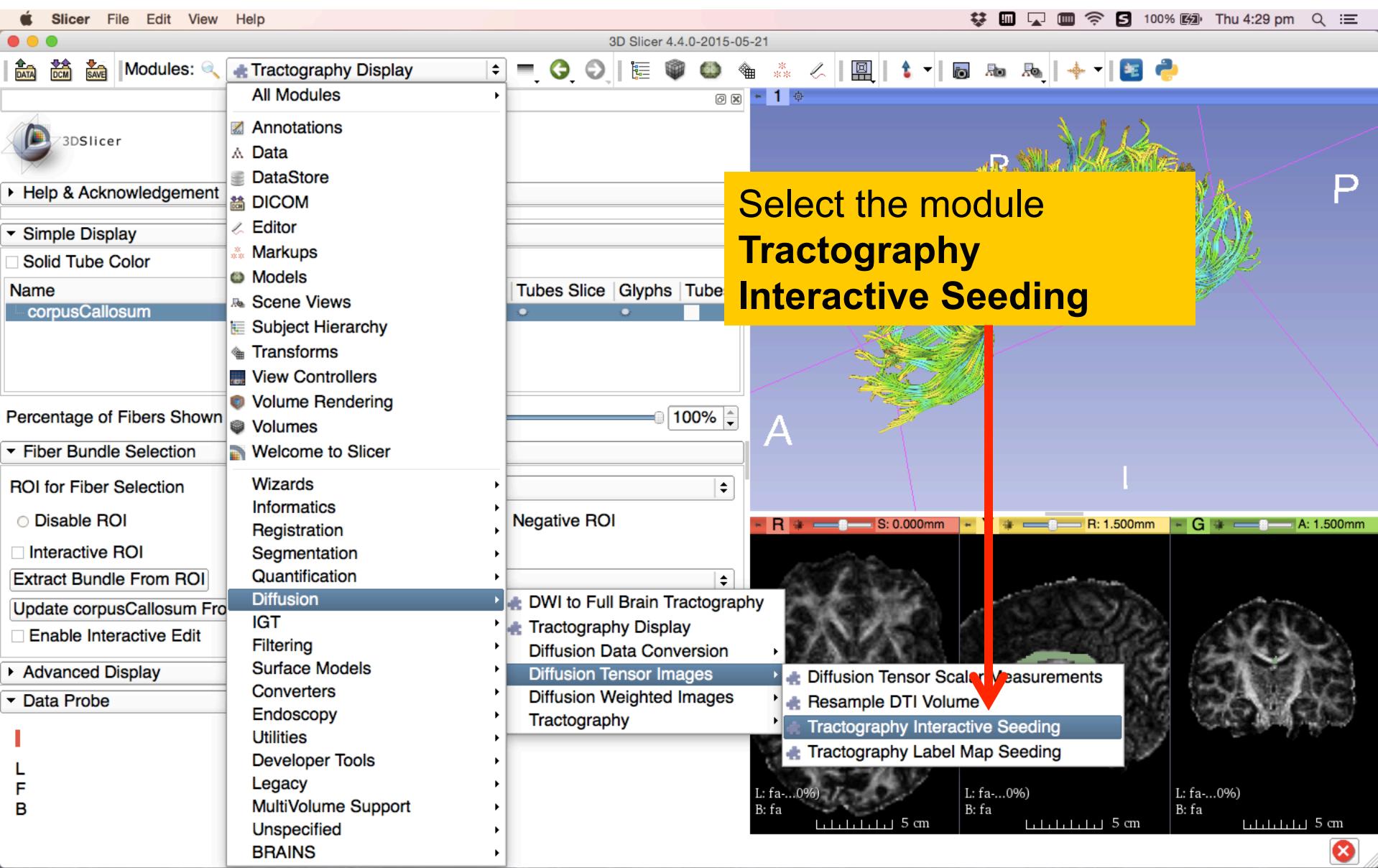
Labelmap Seeding: Step 4: Undesirable track removal



Labelmap Seeding: Step 4: Undesirable track removal



Labelmap Seeding: Tracts



Tractography Results

Position the mouse over the **pin icon** and click on the **eye icon** to display the axial slice in the 3D viewer

Uncheck **Enable Seeing Tracks**

3D Slicer 4.4.0-2015-05-21

Parameters FiducialSeedingParameters

Presets Slicer4 Interactive Seeding Defaults

Input DTI Volume dti

Input Fiducials, Model or Label Map fa-label

Output Fiber Bundle corpusCallosum

Enable Seeding Tracts

Label Map Options

Use index Space

Seed Spacing 0.00

ROI Labels 1

Write Fibers To Disk

Output Directory /Applications

File Prefix

Data Probe

L F B

S: 22.500mm Y: R: 1.500mm G: A: 1.500mm

Toggle slice visibility in 3D view

fa-label None

1.00 fa

L: fa...0% B: fa 5 cm

L: fa...0% B: fa 5 cm

L: fa...0% B: fa 5 cm

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Fiducial Seeding

3D Slicer 4.4.0-2015-05-21

Select the module **Markups**

3DSlicer

File Edit View Help

DATA DCM SAVE

Modules: Tractography Interactive Seeding

All Modules

Annotations Data DataStore DICOM Editor

Markups

Models Scene Views Subject Hierarchy Transforms View Controllers Volume Rendering Volumes Welcome to Slicer

Wizards Informatics Registration Segmentation Quantification Diffusion IGT Filtering Surface Models Converters Endoscopy Utilities Developer Tools Legacy MultiVolume Support Unspecified BRAINS

Parameters FiducialSeeding

Presets Slicer4 Interactive

IO

Input DTI Volume

Input Fiducials, Model or Label

Output Fiber Bundle

Enable Seeding Tracts

Label Map Options

Use index Space

Seed Spacing

Random Grid

Linear Measure Start Threshold

ROI Labels

Write Fibers To Disk

Output Directory

File Prefix

Data Probe

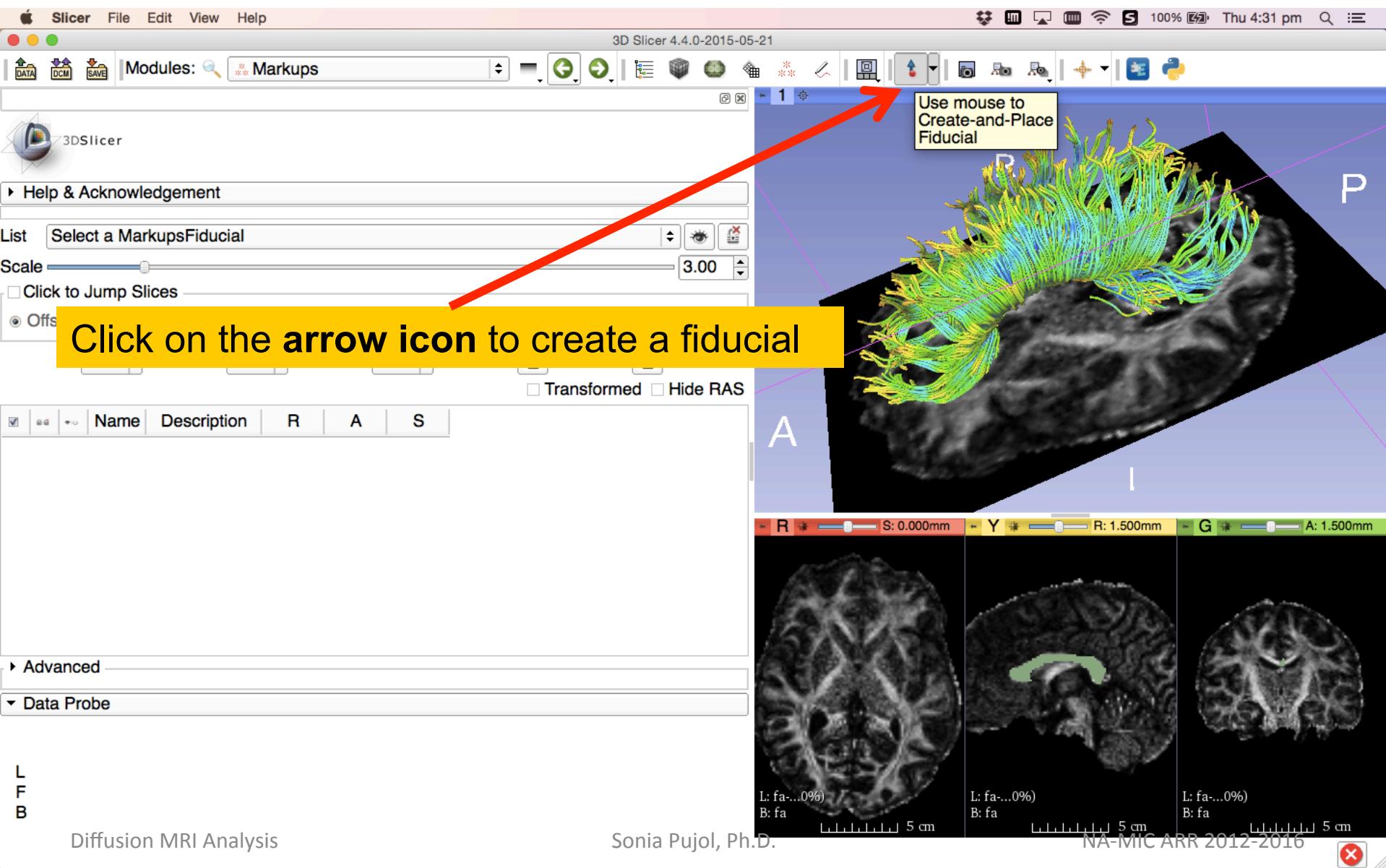
L F B

Diffusion MRI Analysis

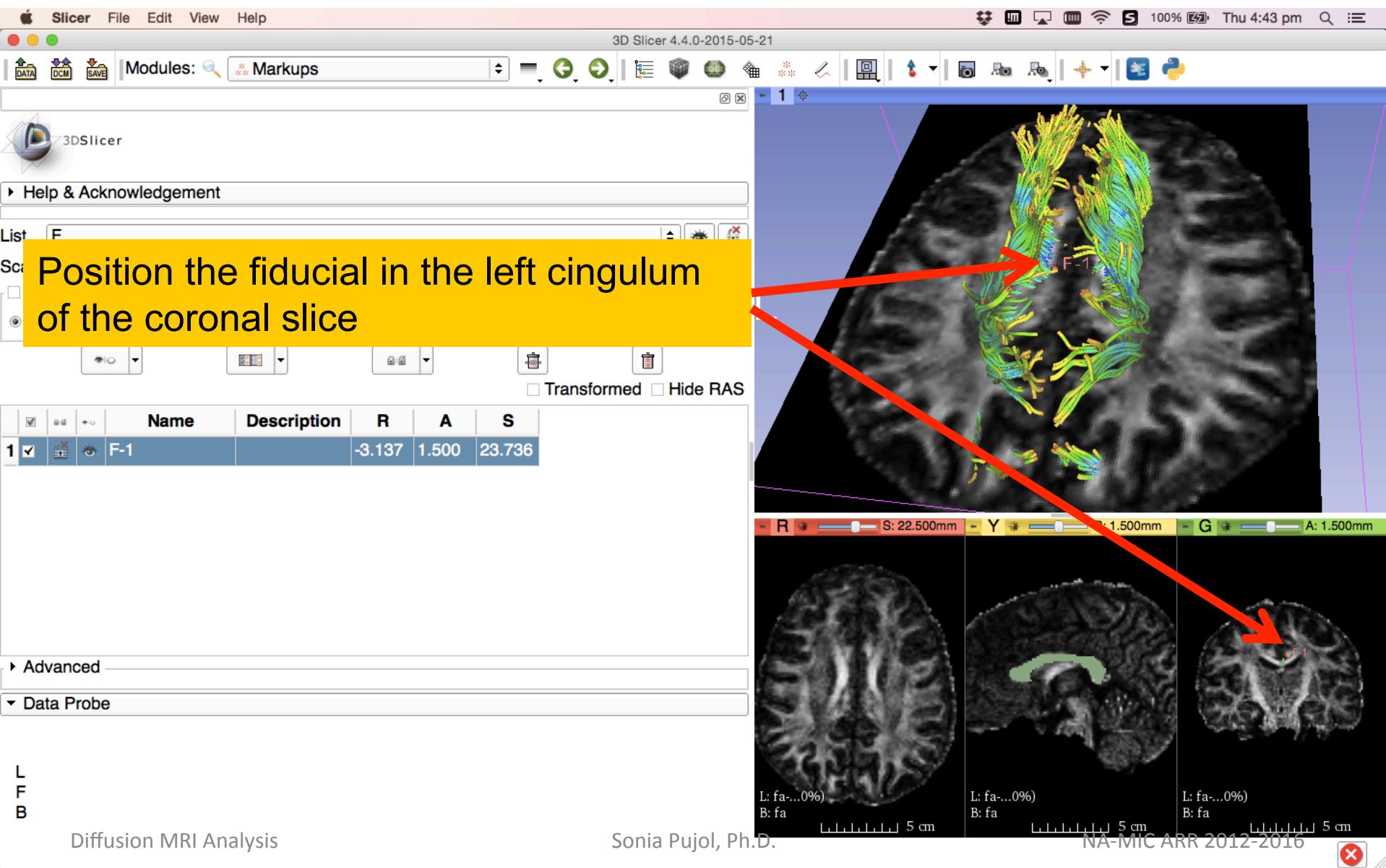
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Fiducial Seeding



Fiducial Seeding



Fiducial Seeding

Double click on the fiducial and change the name to **LeftCingulum**

3D Slicer 4.4.0-2015-05-21

3DSlicer

Help & Acknowledgement

List F

Scal S

1

Name Description R A S

1 LeftCingulum -3.137 1.500 23.736

Transformed Hide RAS

R S: 22.500mm Y R: 1.500mm G A: 1.500mm

L: fa...0% B: fa L: fa...0% B: fa L: fa...0% B: fa

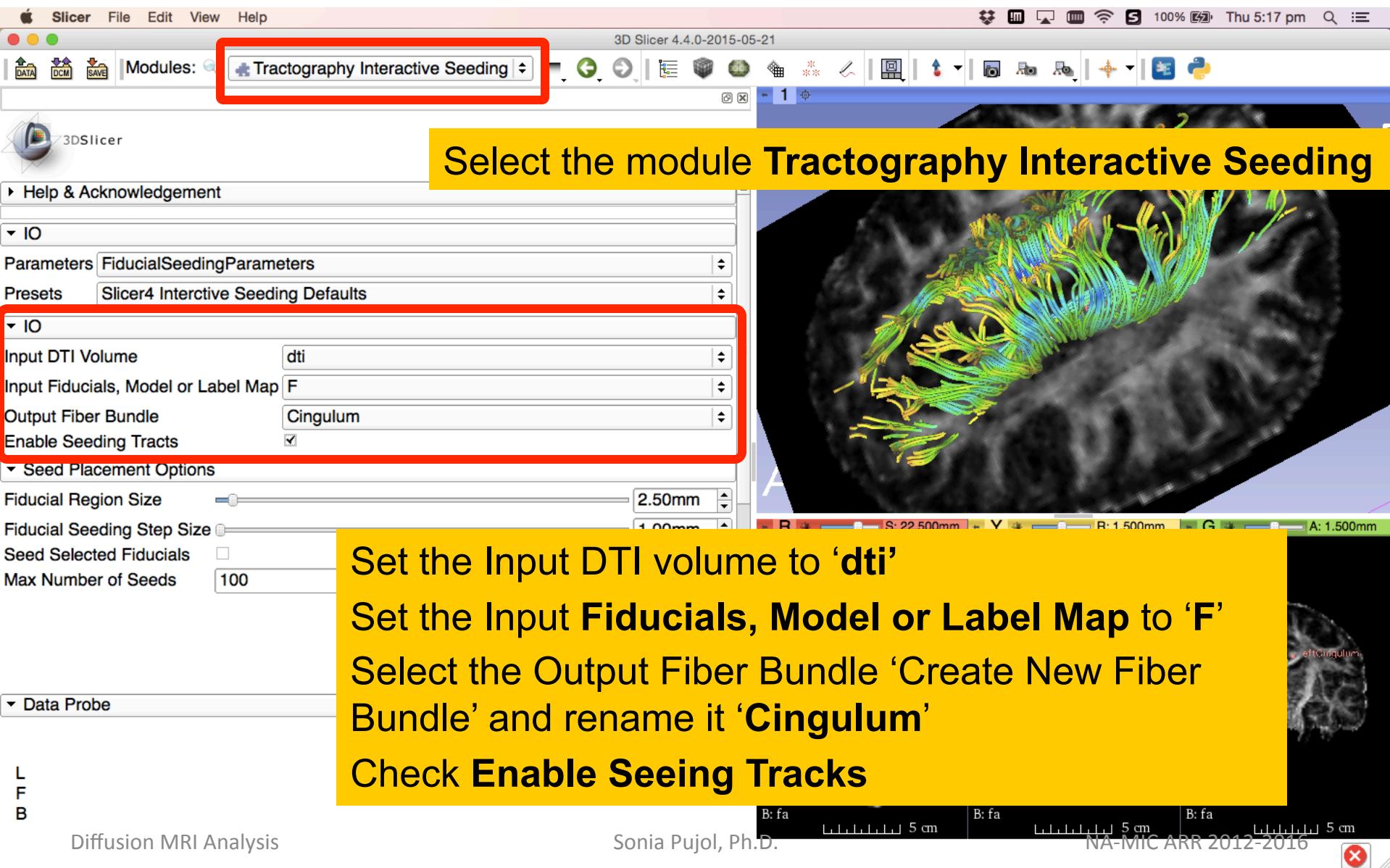
5 cm 5 cm 5 cm

Diffusion MRI Analysis Sonia Pujol, Ph.D. NA-MIC ARR 2012-2016

Fiducial Seeding

Select the module **Tractography Interactive Seeding**

Set the Input DTI volume to '**dti**'
Set the Input **Fiducials, Model or Label Map** to '**F**'
Select the Output Fiber Bundle 'Create New Fiber Bundle' and rename it '**Cingulum**'
Check **Enable Seeing Tracks**



3D Slicer 4.4.0-2015-05-21

Modules: Tractography Interactive Seeding

3DSlicer

Help & Acknowledgement

IO

Parameters FiducialSeedingParameters

Presets Slicer4 Interctive Seeding Defaults

Input DTI Volume dti

Input Fiducials, Model or Label Map F

Output Fiber Bundle Cingulum

Enable Seeding Tracts

Seed Placement Options

Fiducial Region Size 2.50mm

Fiducial Seeding Step Size 1.00mm

Seed Selected Fiducials

Max Number of Seeds 100

Data Probe

L F B

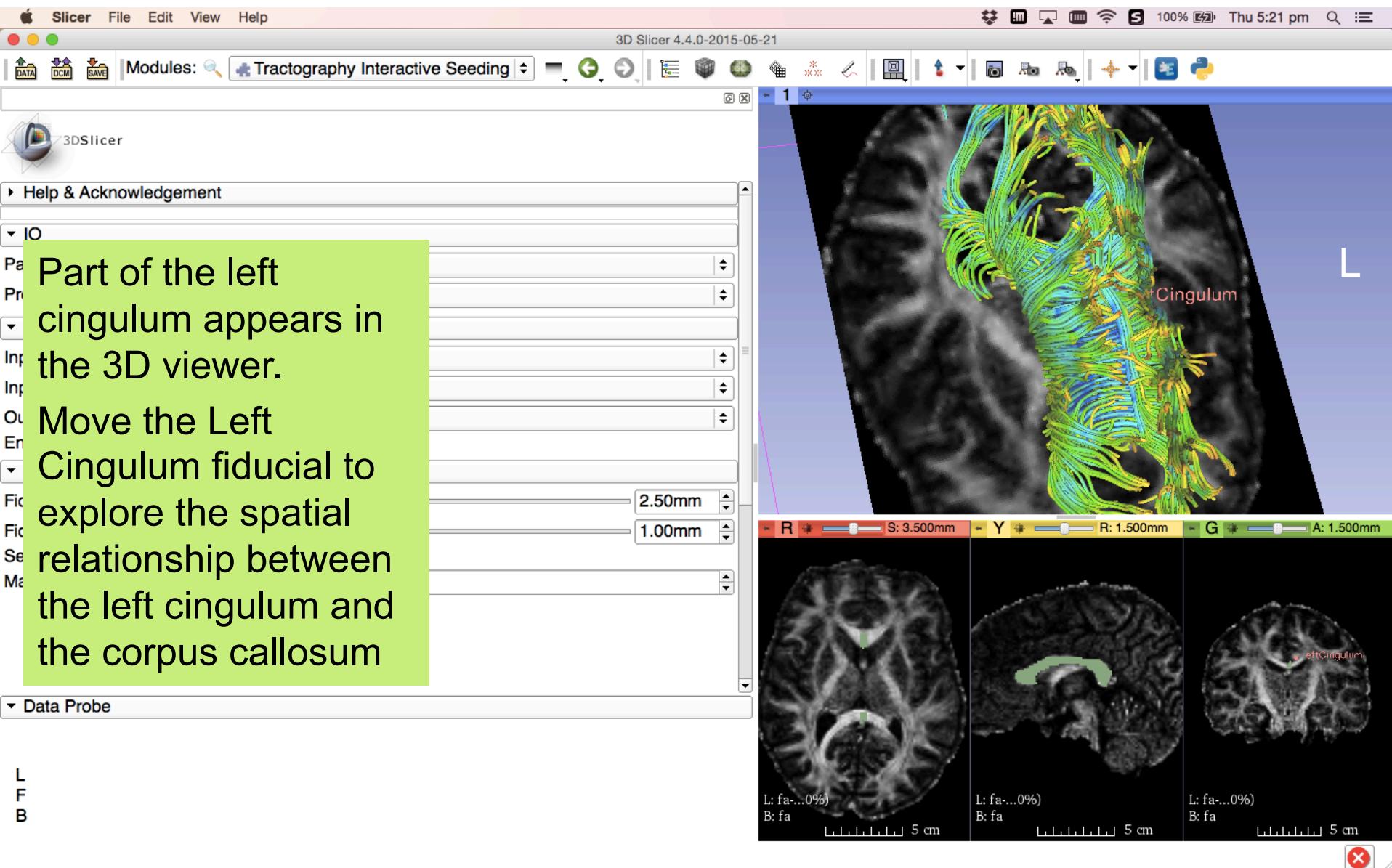
Diffusion MRI Analysis

B: fa 5 cm B: fa 5 cm B: fa 5 cm

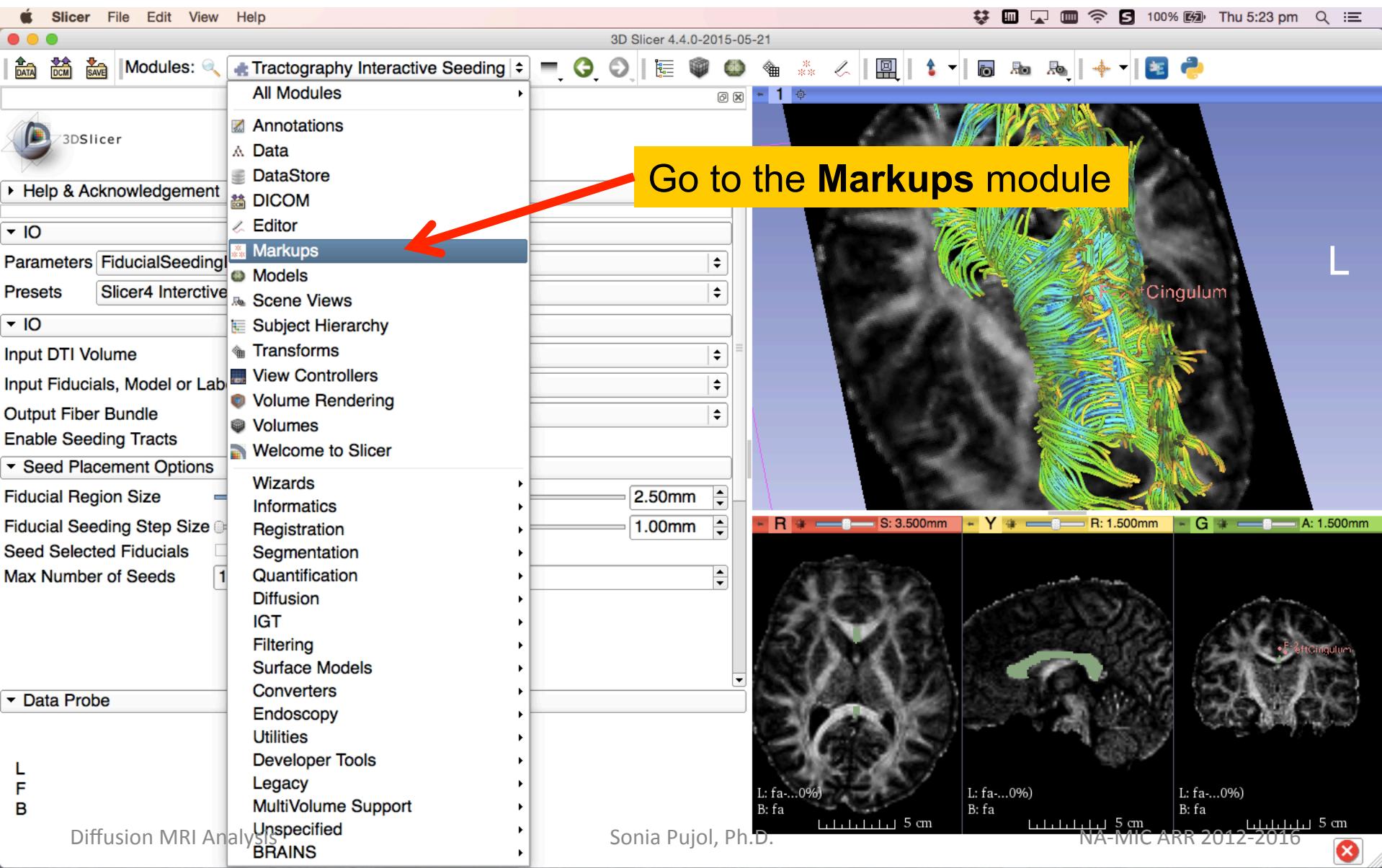
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Fiducial Seeding



Fiducial Seeding



Fiducial Seeding

Slicer File Edit View Help

3D Slicer 4.4.0-2015-05-21

DATA DCM SAVE Modules: Markups

3DSlicer

Help & Acknowledgement

List F Scale 3.00

Click to Jump Slices Offset Centered Show Slice Intersections Transformed Hide RAS

	Name	Description	R	A	S
1	LeftCingulum		-4.691	1.500	
2	RightCingulum		10.055	1.500	

Advanced Data Probe

L F B

Diffusion MRI Analysis

Double click on the Name and change it to **RightCingulum**

3D Slicer interface showing a brain segmentation and a table of fiducial markers. A yellow callout box with a red arrow points to the 'RightCingulum' entry in the table. Another red arrow points from the table to a 3D brain view where the 'RightCingulum' region is highlighted in green. Three axial MRI slices at the bottom show the 'RightCingulum' region highlighted in green.

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Fiducial Seeding

Part of the left and right cingulum appear in the 3D viewer.

Move the fiducials to explore the spatial relationship between the left and right cingulum, and the corpus callosum

Slicer File Edit View Help

3D Slicer 4.4.0-2015-05-21

DATA DCM SAVE Modules: Markups

3DSlicer

Help & Acknowledgement

List F

Scale

Click to Jump Slices

Offset Centered

Name Description

1 LeftCingulum

2 RightCingulum

Advanced

Data Probe

L F B

Diffusion MRI Analysis

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Fiducial Seeding

Click on the arrow icon to create a new fiducial, and position it in the 3D viewer

The screenshot shows the 3D Slicer interface. On the left, a yellow callout box contains the text: "Click on the arrow icon to create a new fiducial, and position it in the 3D viewer". A red arrow points from this text to the "Create Fiducial" button in the top toolbar. Below the toolbar is a table listing three fiducial points:

	Name	Description	R	A	S
1	LeftCingulum		-4.691	1.500	24.513
2	RightCingulum		9.301	1.500	27.622
3	F-3		36.616	-6.073	-5.171

The main window displays a 3D brain volume with colored tracts (green, blue, yellow) representing diffusion pathways. A red arrow points to a specific point labeled "F-3" on the right side of the 3D viewer. The bottom of the screen shows three 2D axial slices of the brain, each with a green outline indicating a region of interest or segmentation. The Slicer interface includes various toolbars, a status bar at the bottom, and coordinate axes (R, S, Y, G) at the bottom right.

Fiducial Seeding

Slicer File Edit View Help

3D Slicer 4.4.0-2015-05-21

DATA DCM SAVE Modules: Markups

3DSlicer

Help & Acknowledgement

List F Scale 3.00

Click to Jump Slices Offset Centered Show Slice Intersections

Transformed Hide RAS

Name Description R A S

1	LeftCingulum	-4.691	1.500	24.513
2	RightCingulum	9.301	1.500	27.622
3				-6.937

Move the fiducial F-3 in the 3D viewer to explore the dti dataset

Advanced

Data Probe

L F B

Diffusion MRI Analysis

P L

R S: -16.500mm Y R: 1.500mm G A: 1.500mm

5 cm

5 cm

5 cm

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Tractography ‘on-the-fly’

Slicer File Edit View Help

3D Slicer 4.4.0-2015-05-21

DATA DCM SAVE Modules: Markups

3DSlicer

Help & Acknowledgement

List F Scale 3.00

Click to Jump Slices Offset Centered Show Slice Intersections

Transformed Hide RAS

	Name	Description	R	A	S
1	LeftCingulum		-4.691	1.500	24.513
2	RightCingulum		9.301	1.500	27.622
3	F-3		35.306	-3.916	-5.110

Advanced Data Probe

L F B

Diffusion MRI Analysis

The Fiducial Seeding functionality allows you to do tractography ‘on-the-fly’ to explore white matter structures interactively

P L

nm G A: 1.500mm

L: fa...% B: fa 5 cm

L: fa...% B: fa 5 cm

L: fa...% B: fa 5 cm

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DTI Analysis

Slicer File Edit View Help

3D Slicer 4.4.0-2015-05-21

DATA DCM SAVE Modules: Data

3DSlicer

Help & Acknowledgement

Display & Modify Scene

Nodes

- Scene
- View1
- Red
- Yellow
- Green
- Default Scene Camera
- dwi
- baseline
- dwi_mask
- dti
- fa
- trace
- fa-label
- All Annotations
- ROI Node
- ROI List
- corpusCallosum
- F
- Cingulum

Scene Model: Transform

Display MRML ID's

Show Hidden nodes

Data Probe

L F B

Volume

Select the module **Data** to display the list of elements that have been generated in this tutorial

P L

R S: -16.500mm Y R: 1.500mm G A: 1.500mm

L: fa...0% B: fa 5 cm

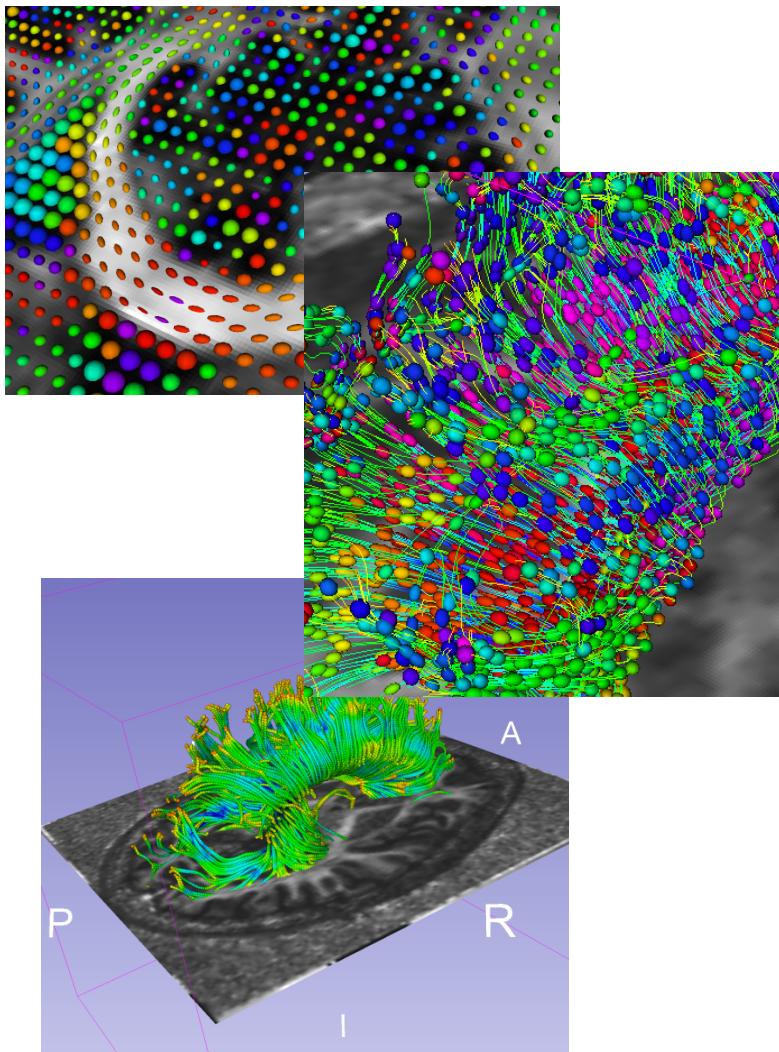
L: fa...0% B: fa 5 cm

L: fa...0% B: fa 5 cm

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Conclusion



This tutorial guided you through the different steps of a Diffusion MR analysis pipeline, from tensor estimation to 3D tracts visualization, for exploring and studying the 3D architecture of the brain white matter.

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