

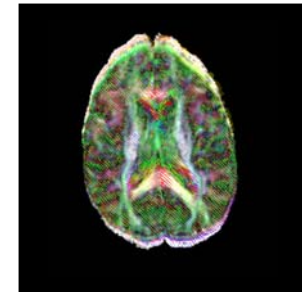
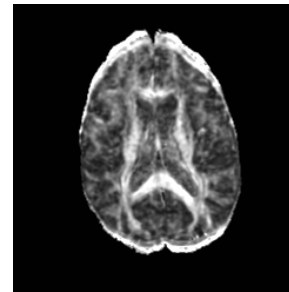
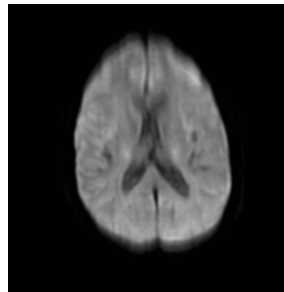
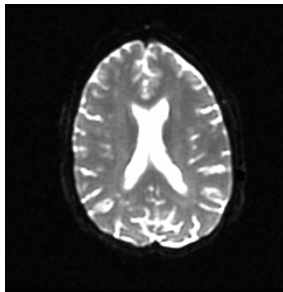
MIT OpenCourseWare  
<http://ocw.mit.edu>

HST.583 Functional Magnetic Resonance Imaging: Data Acquisition and Analysis  
Fall 2008

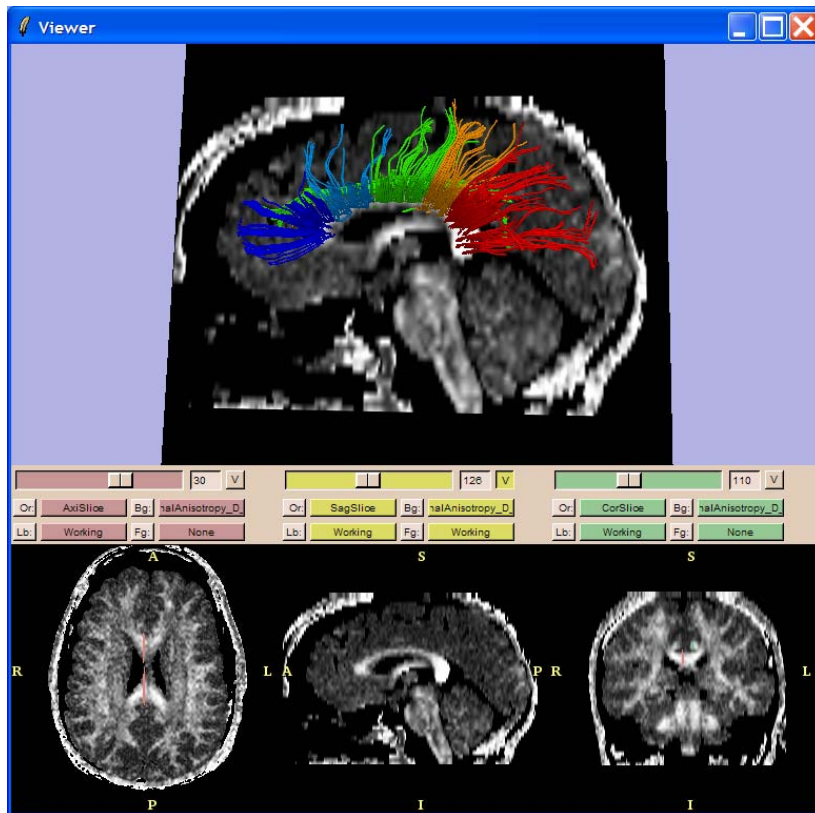
For information about citing these materials or our Terms of Use, visit: <http://ocw.mit.edu/terms>.

# Diffusion Tensor Imaging Analysis

Sonia Pujol, Ph.D.  
Instructor of Radiology  
Surgical Planning Laboratory  
Harvard Medical School  
<http://www.spl.harvard.edu/>



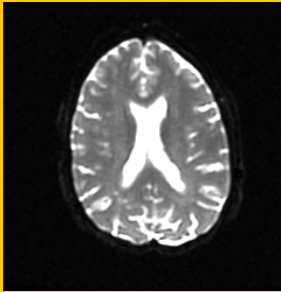
# Diffusion Weighted Imaging



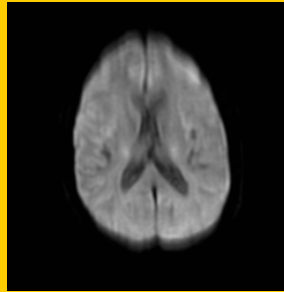
- Non-invasive *in vivo* information on the structure of organized tissues:
  - Brain white matter fiber bundles
  - Myocardium fiber
- Clinical applications
  - Brain ischemia
  - Schizophrenia
  - Multiple Sclerosis

# Diffusion Tensor Imaging Analysis

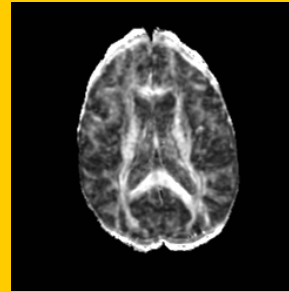
---



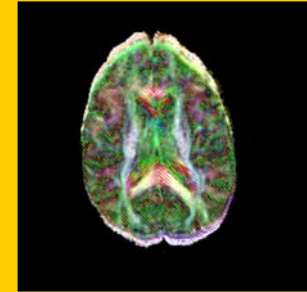
DWI  
Acquisition



Tensor  
Calculation



Scalar  
Maps



3D  
Visualization

# The Life Cycle of Imaging Data

---



Image: NIH

Acquisition

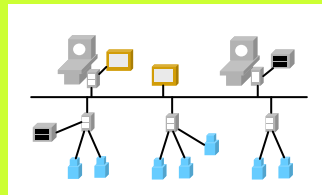
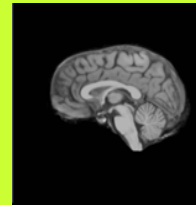
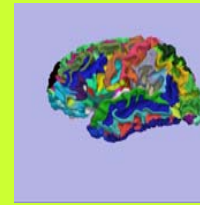


Image by MIT OpenCourseWare.

Storage



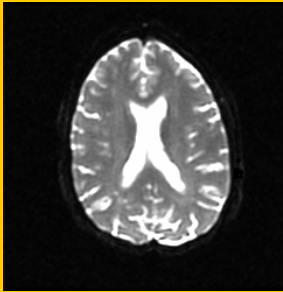
Visualization



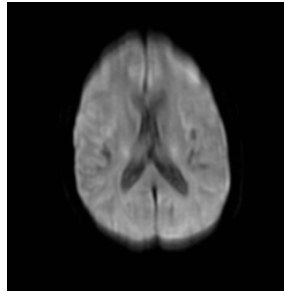
Analysis

# Diffusion Tensor Imaging Analysis

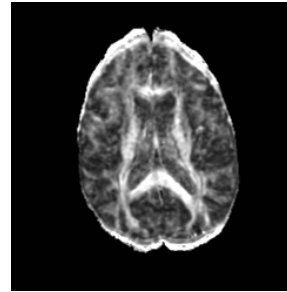
---



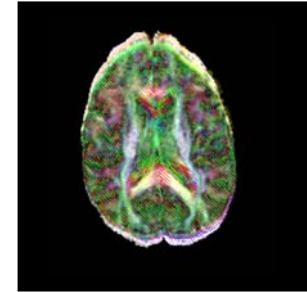
DWI  
Acquisition



Tensor  
Calculation



Scalar  
Maps



3D  
Visualization

# Diffusion Weighted Imaging (DWI)

---

Single-shot Diffusion Weighted Echo-Planar Imaging (EPI)

→ Fast and robust to motion artifacts

Line Scan Diffusion Imaging (LSDI)

→ Robust to magnetic-susceptibility artifacts and geometric distortion

# DWI Acquisition: Example

---

Photo of MRI machine  
removed due to  
copyright restrictions.

## Parameters

- FOV 220 mm x 165 mm
- Slice thickness 4 mm
- Slice spacing 1 mm

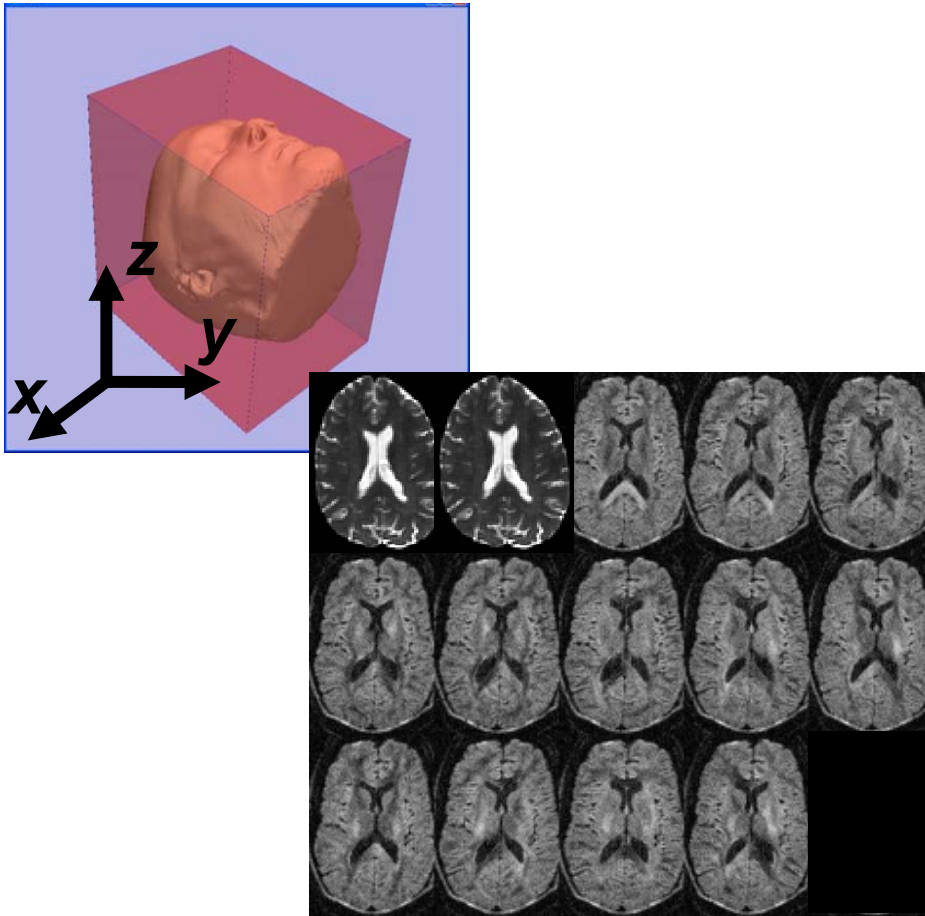
## Acquisition Time

- EPI: 6 minutes
- LSDI: 35 minutes



# DWI Acquisition

---

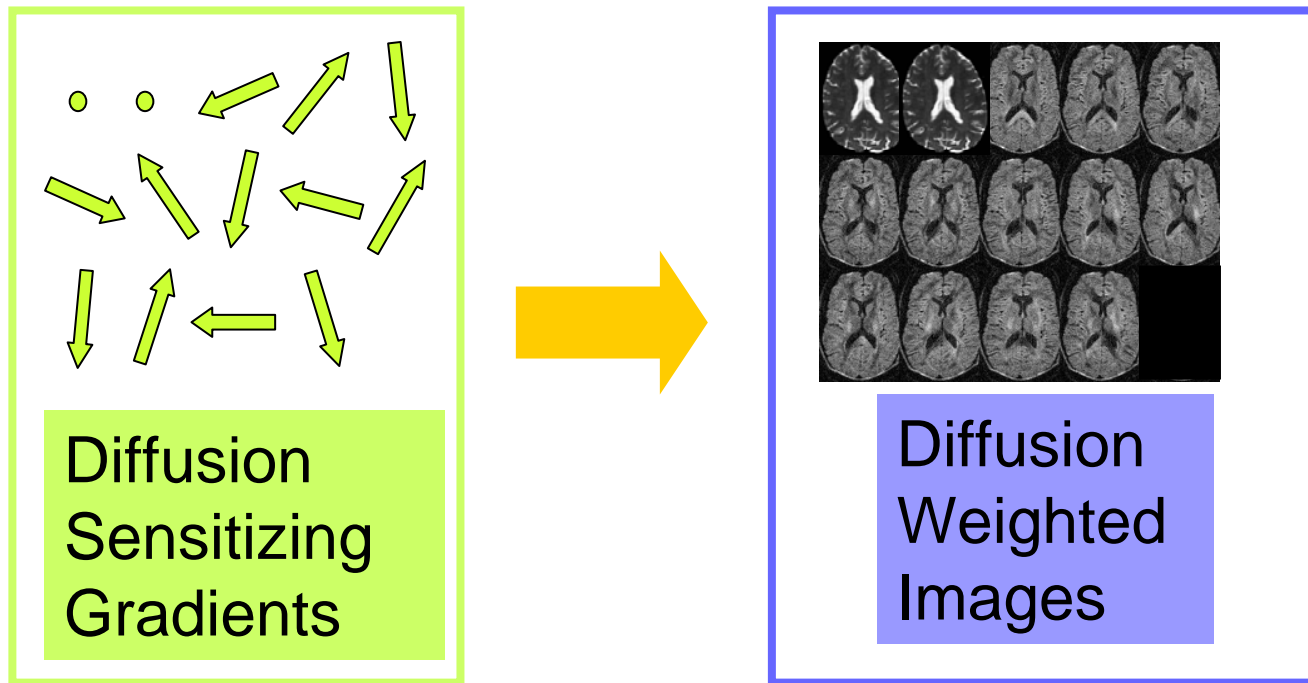


The result of a DWI acquisition is a series of 3D Volumes of data related to the patient, after application of Diffusion Sensitizing Gradients

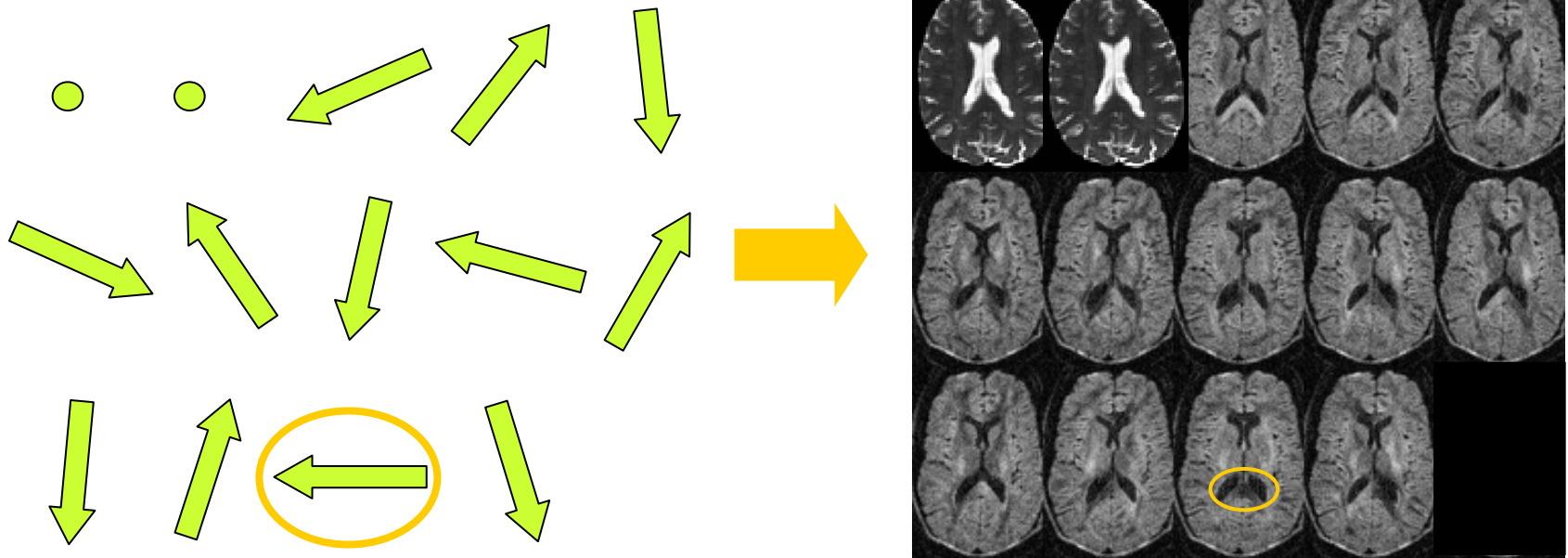
Example: 2 Baselines  
and 12 Gradients

# Diffusion Weighted Imaging

The signal is dimmer when the direction of the applied gradient is parallel to the principal direction of diffusion.



# Diffusion Weighted Imaging



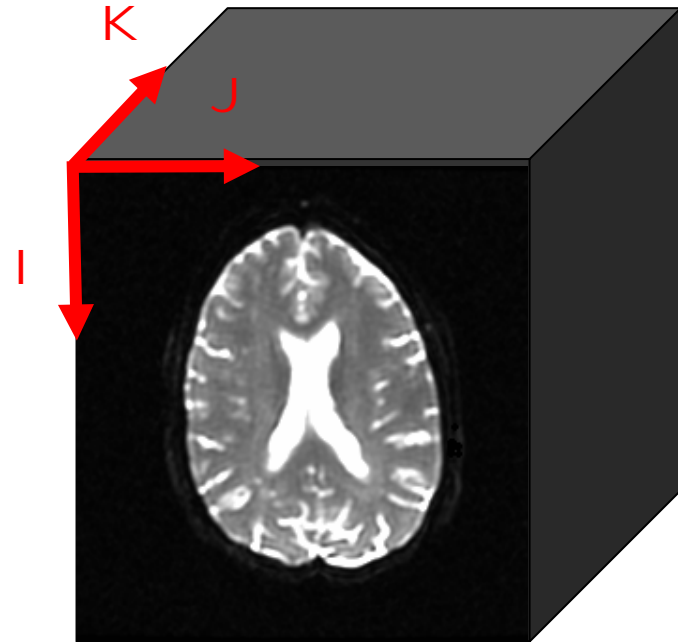
Example: Correlation between the orientation of the 11<sup>th</sup> gradient and the signal intensity in the Splenium of the Corpus Callosum

# Acquisition Parameters (1)

---

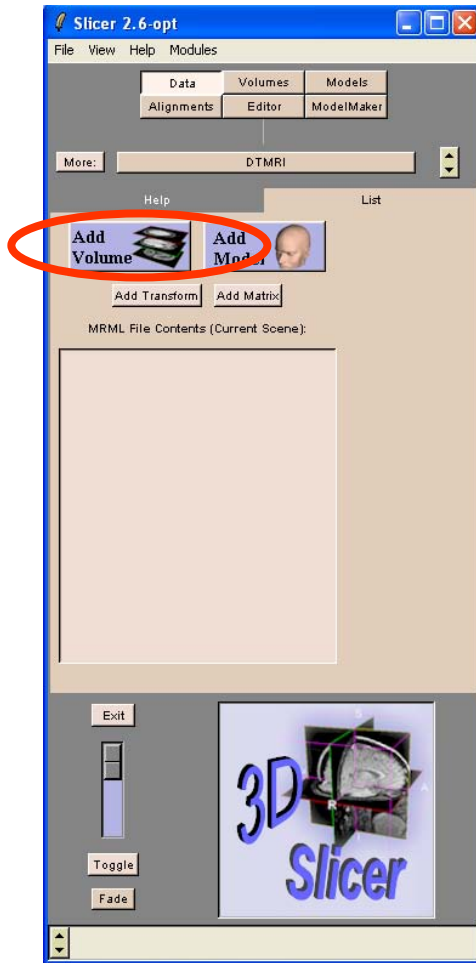
## DWI Volume characteristics

- Image Dimensions
- Slice Spacing
- Slice Thickness
- Pixel size
- Image Origin
- Image Orientation
- Endianness
- Datatype



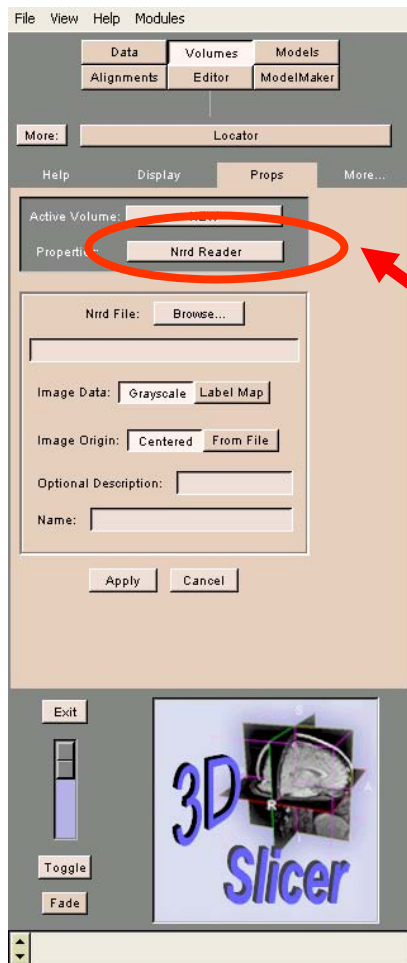
*The Life Cycle of Imaging Data. SPujol (HST.583)*

# Loading the DWI Volume



Click on Add Volume to load the DWI dataset.

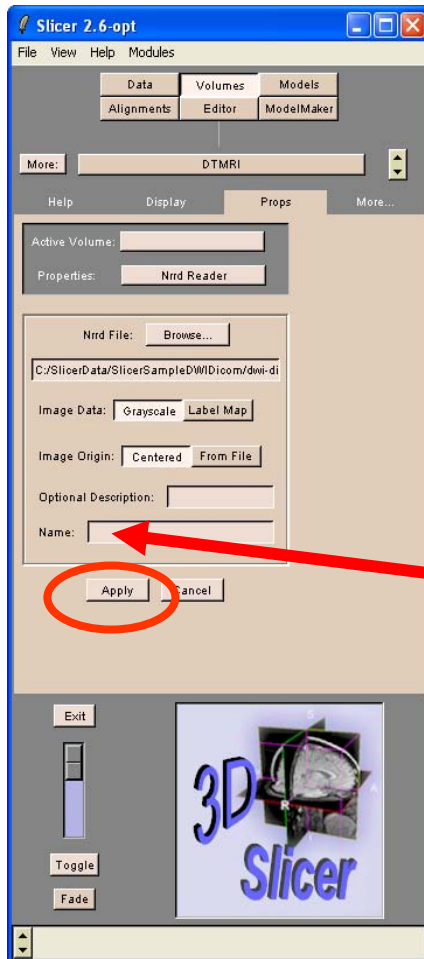
# Loading the DWI Volume



The Props Panel of the module Volumes appears.

Select Nrrd Reader in the Properties field

# Loading the DWI Volume

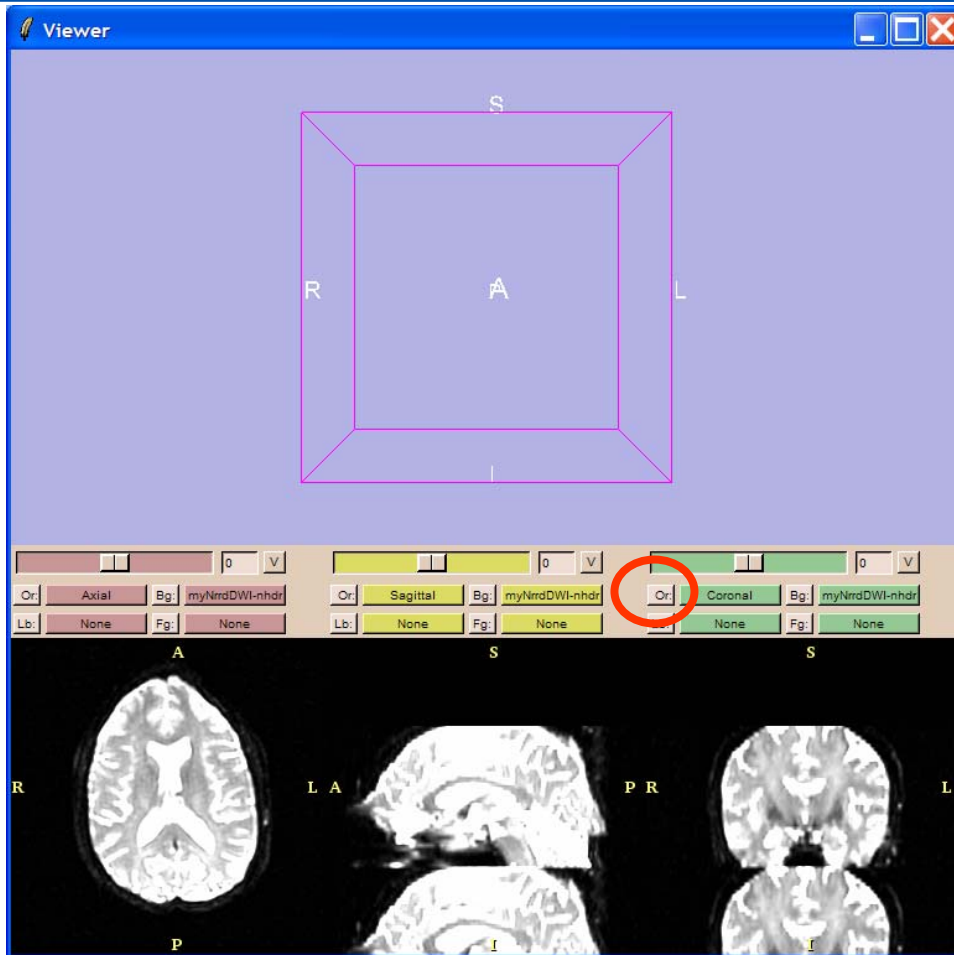


Browse to load the file dwi.nhdr

Check that the path to the file dwi.nhdr is correct. If needed, manually enter it

Enter the name dwi and click on Apply

# Loading the DWI Volume

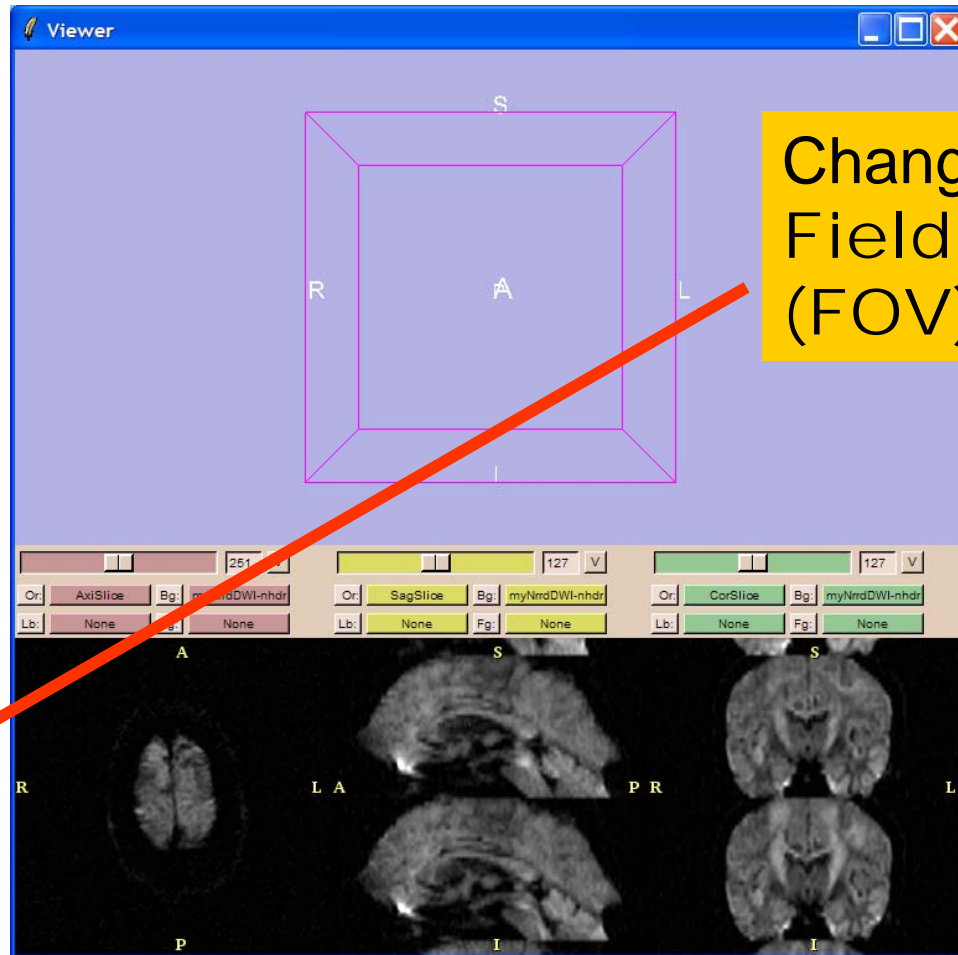
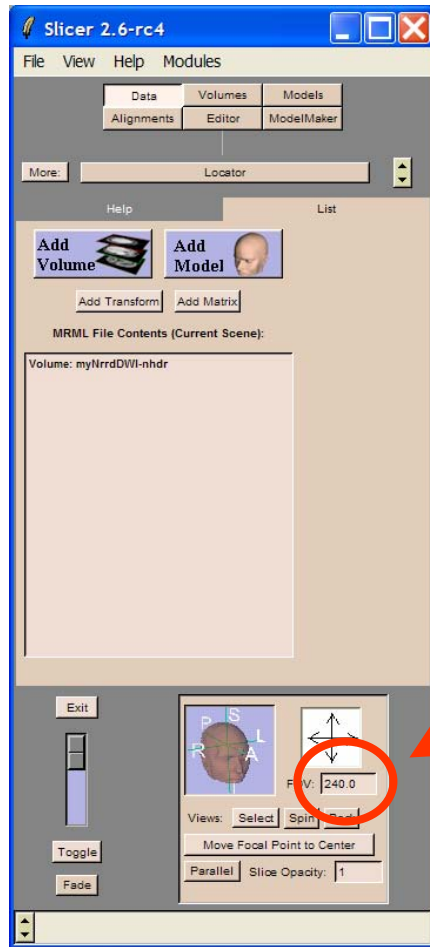


The DWI images appear in the viewer.

Adjust the Window and Level of the images, and left-click on Or to change the orientation to Slices

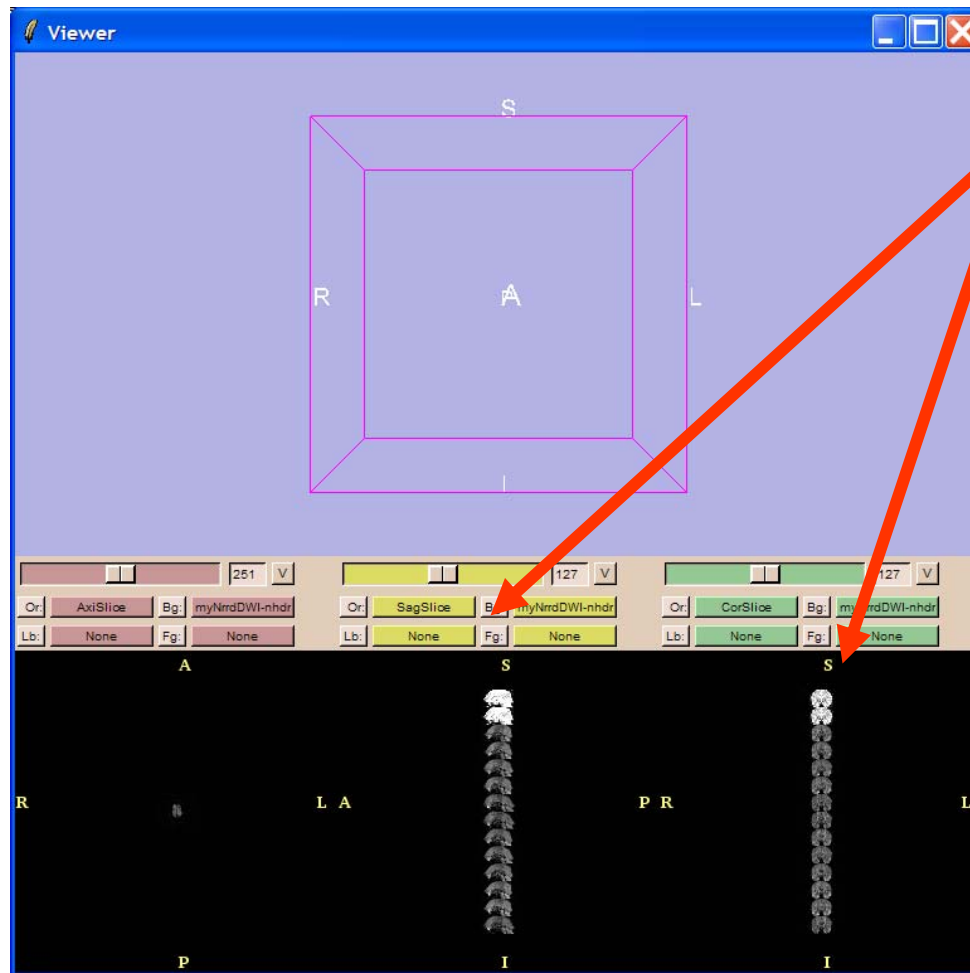


# Loading the DWI Volume



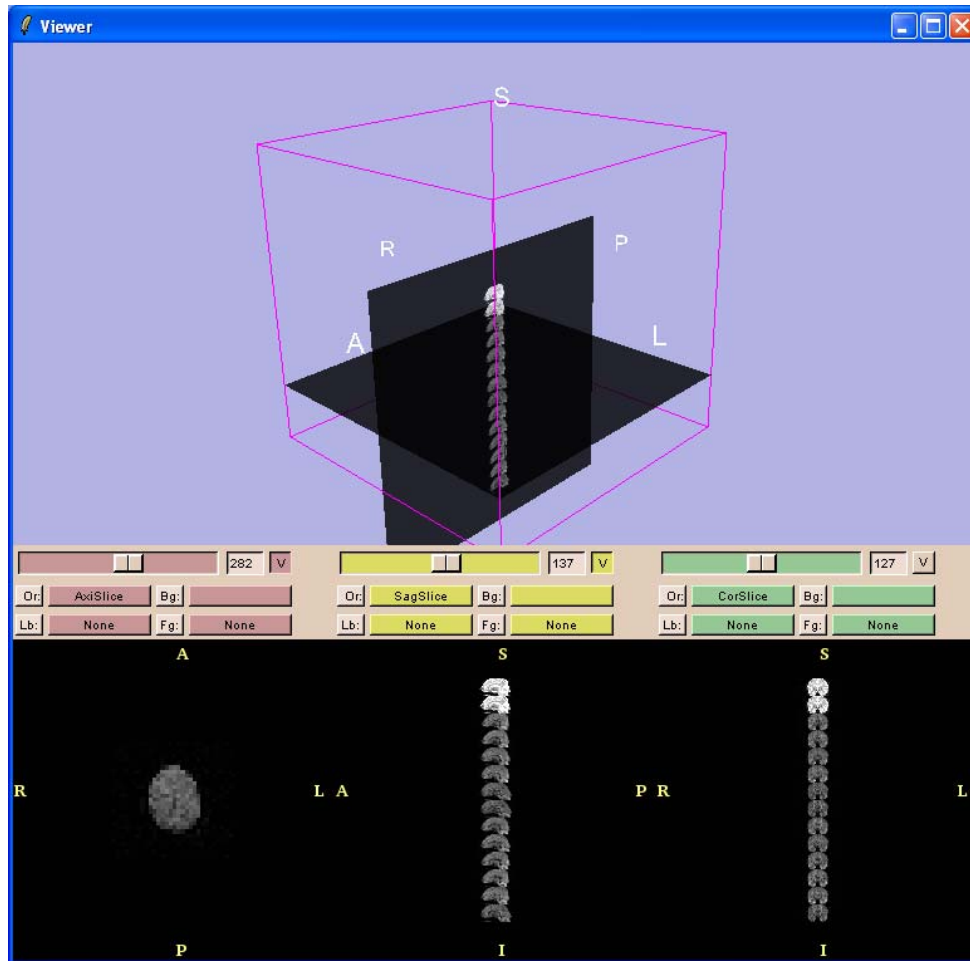
Change the Field Of View (FOV) to 2000

# Loading the DWI Volume



The sagittal and coronal viewers display the 14 DWI volumes: 2 baselines and 12 gradients

# Loading the DWI Volume



Display the axial and sagittal slices inside the viewer.

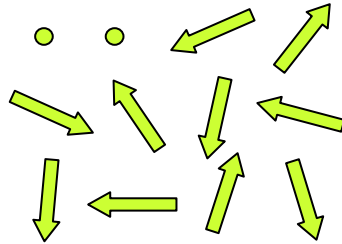
Use the axial slider to observe the baselines and gradient volumes.

# Diffusion Weighted Imaging

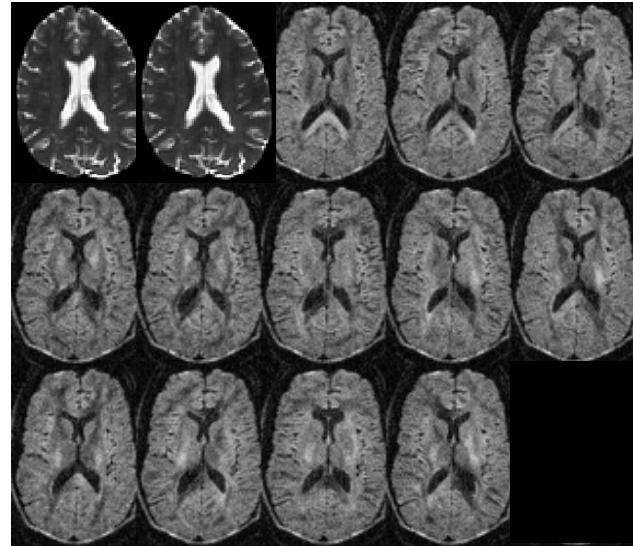
---



Image: NIH

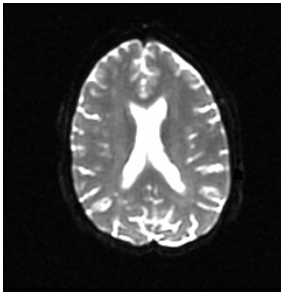


Diffusion  
Sensitizing  
Gradients

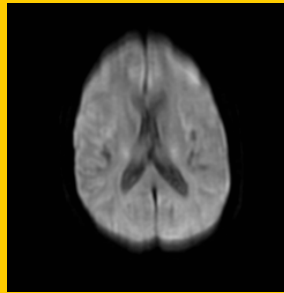


# Diffusion Tensor Imaging Analysis

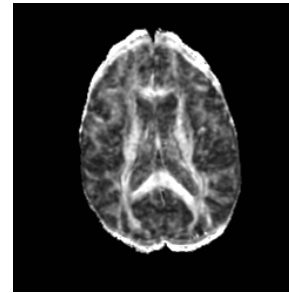
---



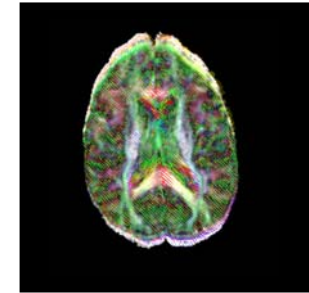
DWI



DTI



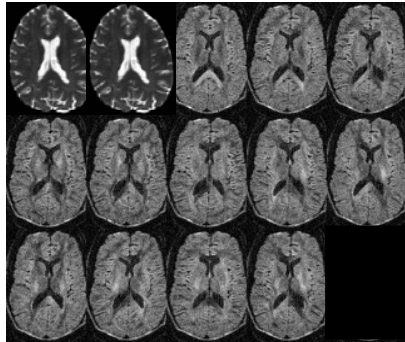
FA



Glyphs &  
Tracts

# Diffusion Weighted Imaging

---



Diffusion  
Weighted  
Images

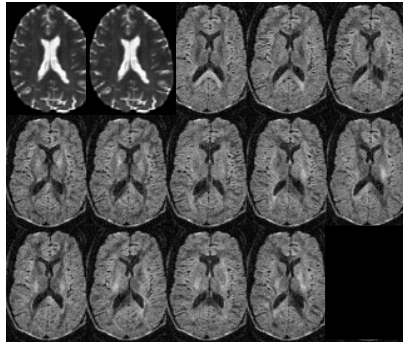
$$S_i = S_0 e^{-b \hat{g}_i^T \underline{D} \hat{g}_i}$$

(Stejskal and Tanner 1965, Basser 1994 )

$\{S_i\}$  represent the signal intensities in presence of the diffusion sensitizing gradients  $\hat{g}_i$ .

# Diffusion Weighted Imaging

---



Diffusion  
Weighted  
Images

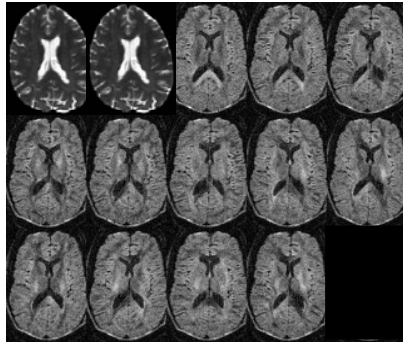
$$S_i = S_0 e^{-b \hat{g}_i^T \underline{D} \hat{g}_i}$$

(Stejskal and Tanner 1965, Bassler 1994 )

$S_0$  is the signal intensity with no gradient.

# Diffusion Weighted Imaging

---



Diffusion  
Weighted  
Images

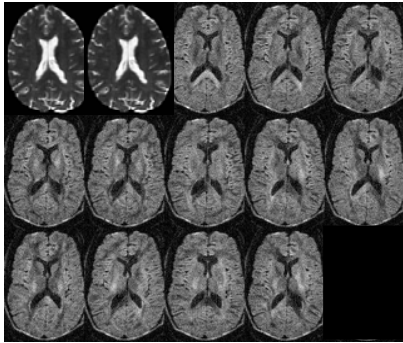
$$S_i = S_0 e^{-b \hat{g}_i^T \underline{D} \hat{g}_i}$$

$\hat{g}_i$  represents the direction of the Diffusion Sensitizing Magnetic Field Gradient.



# Diffusion Weighted Imaging

---

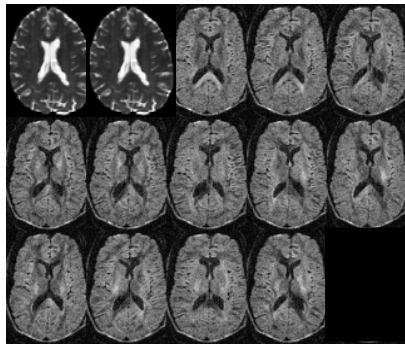


Diffusion  
Weighted  
Images

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

$b$  is the LeBihan's factor describing the pulse sequence, gradient strength and physical constants.

# Diffusion Weighted Imaging



Diffusion  
Weighted  
Images

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

$\underline{D}$  is the Diffusion Tensor

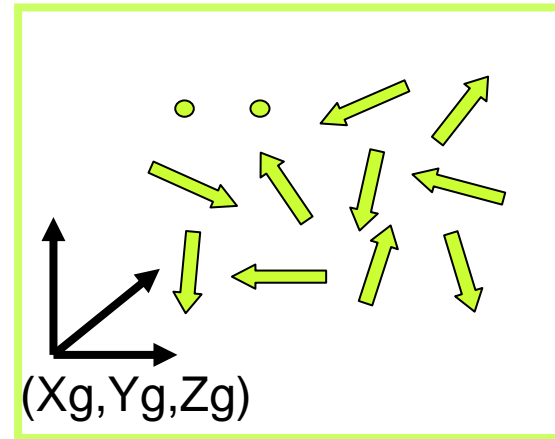
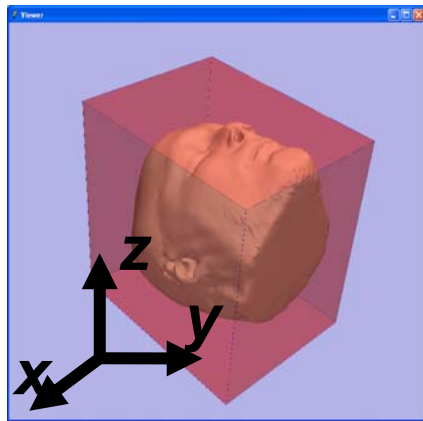
$$\underline{D} = \begin{bmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{yx} & D_{yy} & D_{yz} \\ D_{zx} & D_{zy} & D_{zz} \end{bmatrix}$$

3x3 symmetric matrix

# Acquisition Parameters (2)

---

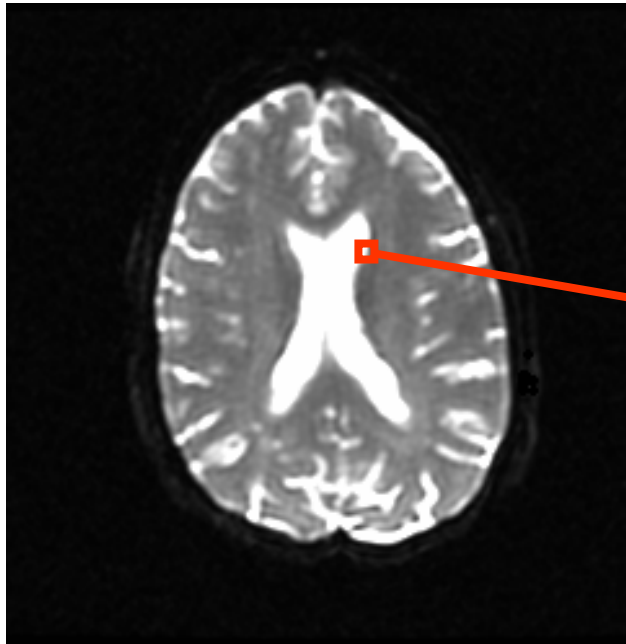
## DWI Volume characteristics



## Diffusion Sensitizing Gradients Orientation

# Tensor Calculation

Step1 : Estimate the **Diffusion Tensor terms**  $D_{ij}$  from the DWI images in each voxel



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

# Tensor Calculation

---

Step 2: Calculate the **main directions of diffusivity** and corresponding **diffusion values** in each voxel

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



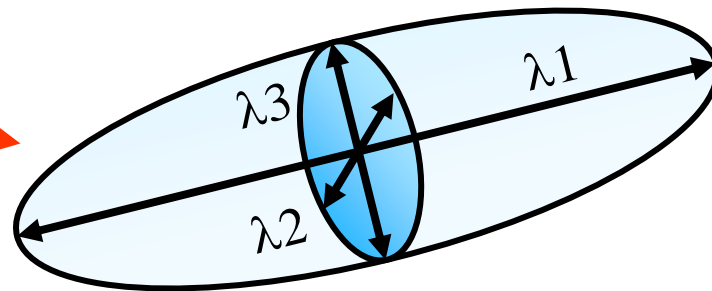
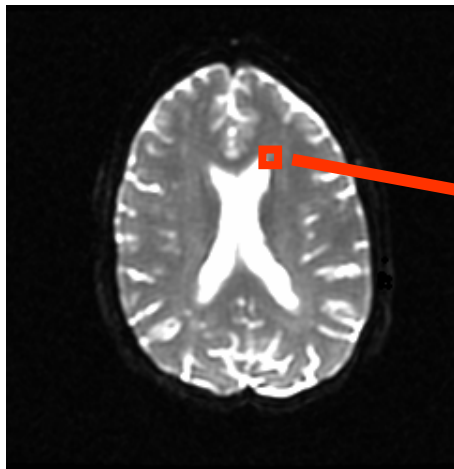
Eigenvectors  $v_1, v_2, v_3$

Eigenvalues  $\lambda_1, \lambda_2, \lambda_3$

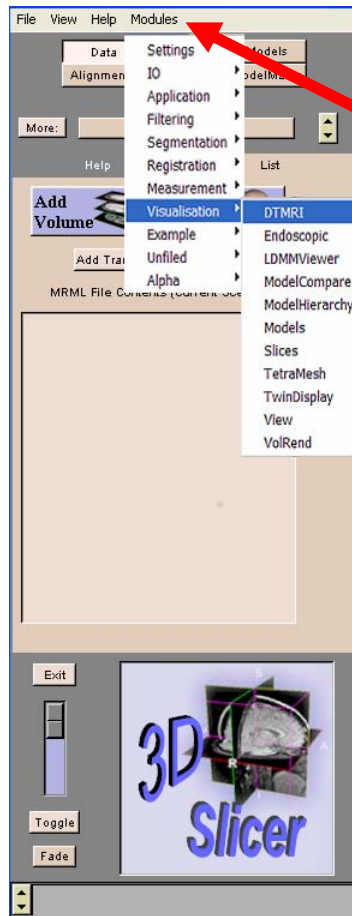
# Physical Interpretation

---

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

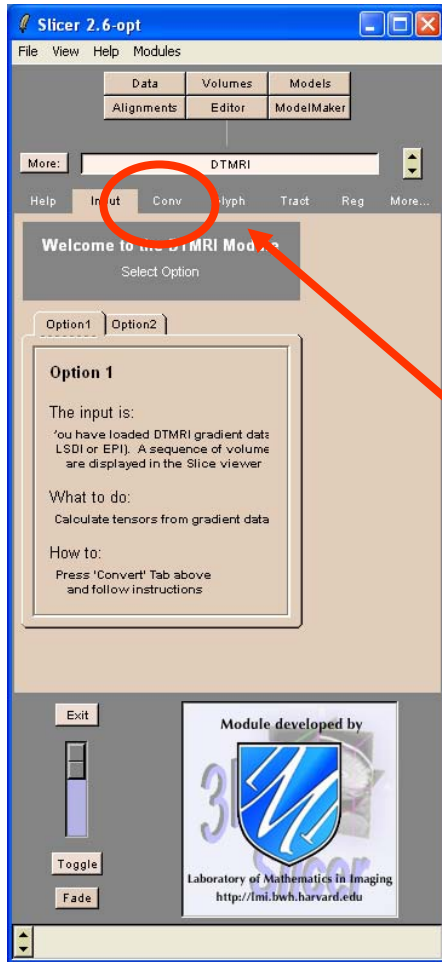


# Tensor Calculation



Click on Modules in the Main Menu, and select Visualisation → DTMRI

# Tensor Calculation

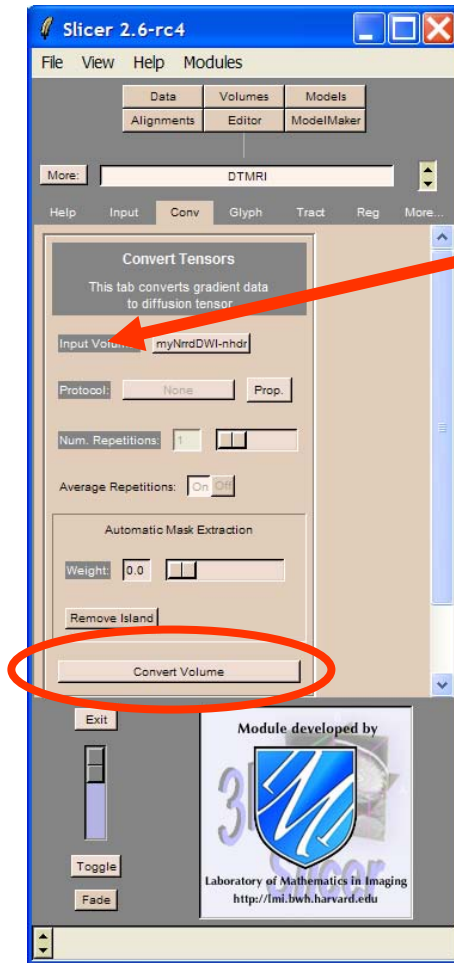


The panel Input of the DTMRI module appears

Click on the tab Conv

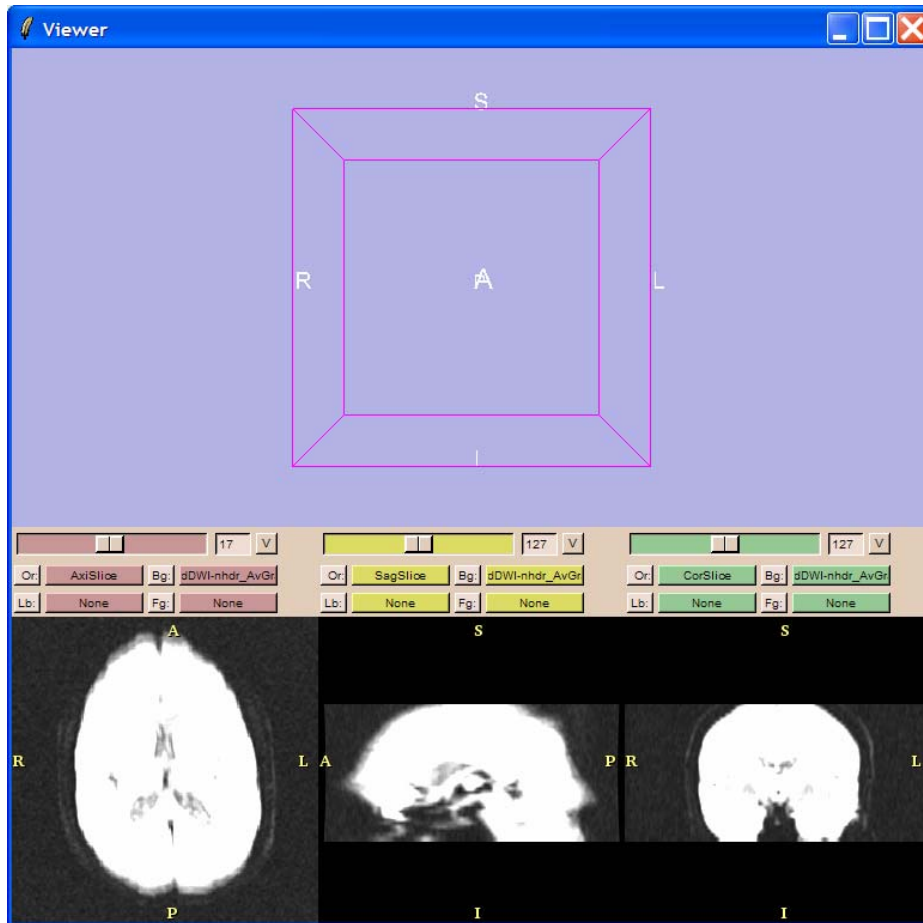


# Tensor Calculation



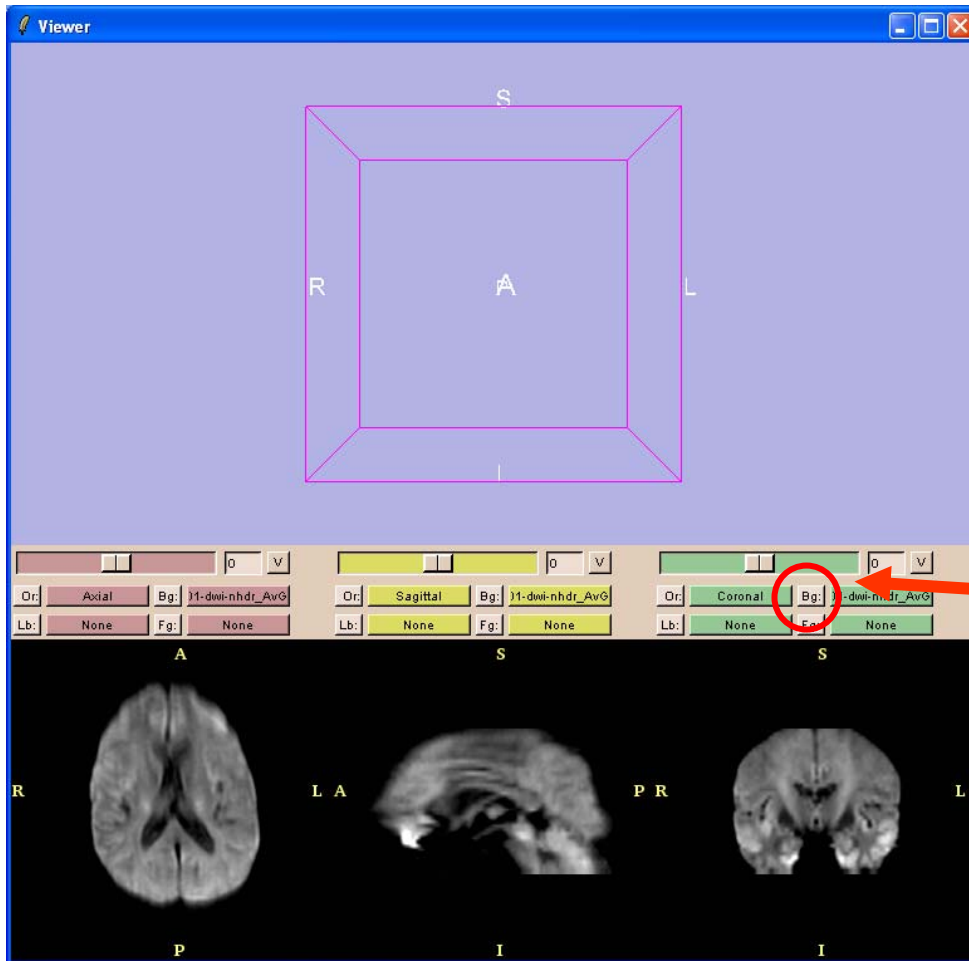
Select the Input volume dwi and click on ConvertVolume

# Tensor Calculation



At the end of the calculation, Slicer displays the average of all diffusion weighted images **dwi\_AvGradient** and the baseline volume **dwi\_Baseline**.

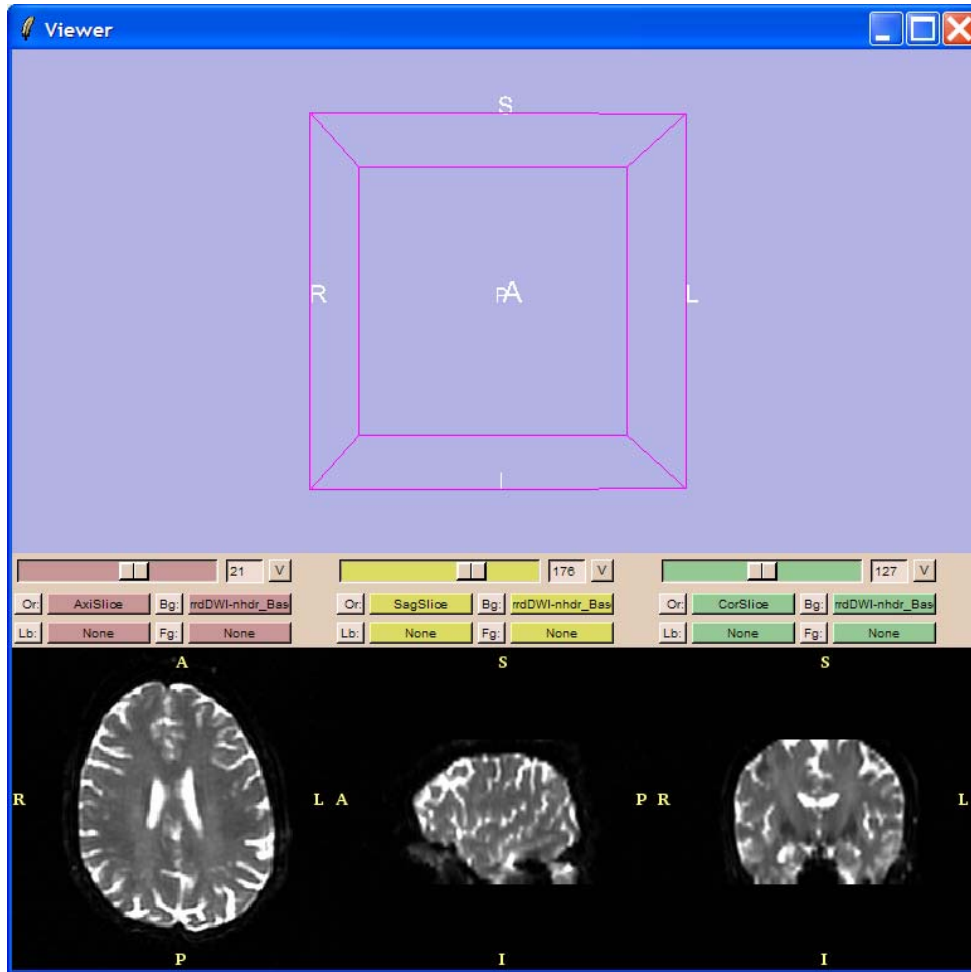
# Tensor Calculation



Adjust the Window and Level of the images

Left-click on Bg and select the volume dwi\_Baseline

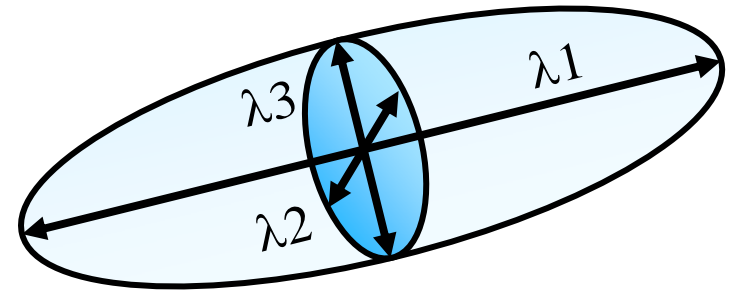
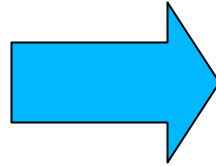
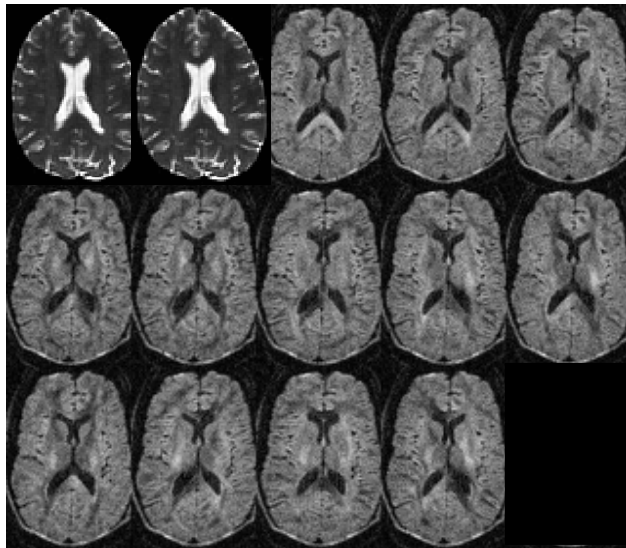
# Tensor Calculation



Browse the baseline images (T2) to check if the anatomy is correct

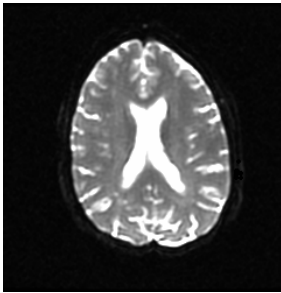
# Diffusion Weighted Imaging

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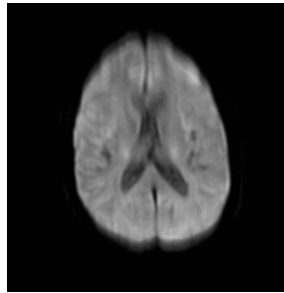


# Diffusion Tensor Imaging Analysis

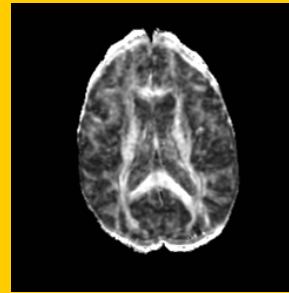
---



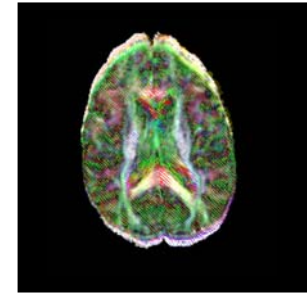
DWI



DTI



FA

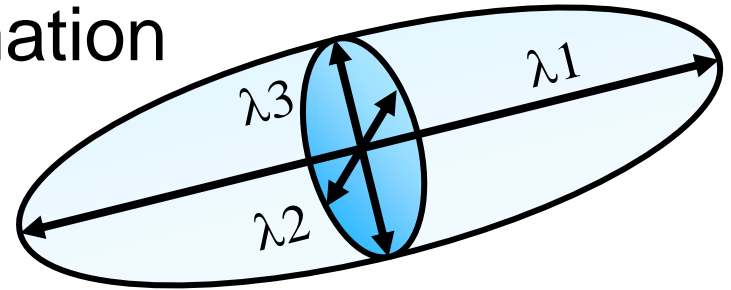


Glyphs &  
Tracts

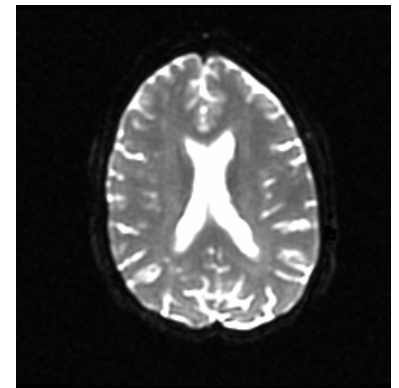
# DWI Data Analysis

---

The tensors data contain information on tissue architecture and microstructure



- Overall displacement of molecules
- Variations of molecular displacements
- Orientation in space of tissues



# Mean Diffusivity

---

- Characterizes the overall mean-squared displacement of molecules

$$\text{Mean Diffusivity} = 1/3 \text{ Trace}(\underline{D})$$



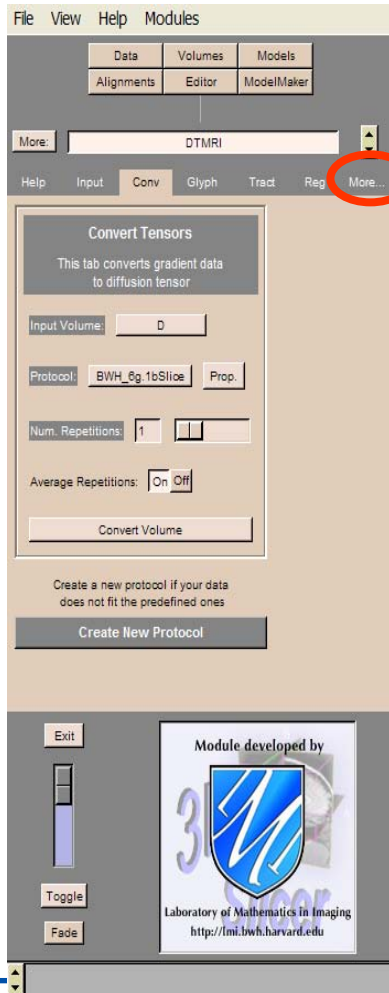
# Fractional Anisotropy

---

- Measure of the diffusion anisotropy

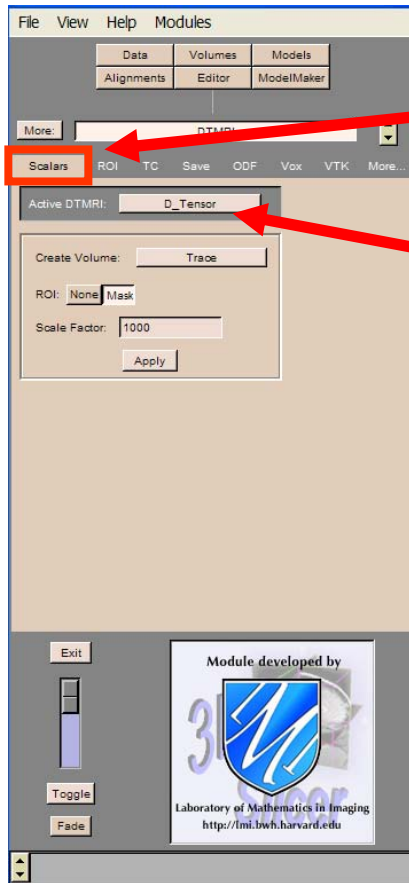
$$FA = \frac{\sqrt{3}}{\sqrt{2}} \frac{\left| D - \frac{1}{3} \text{trace}(D)I \right|}{|D|}$$

# Computing Fractional Anisotropy



In the DT-MRI module, click on More to navigate in the different panels

# Computing Fractional Anisotropy



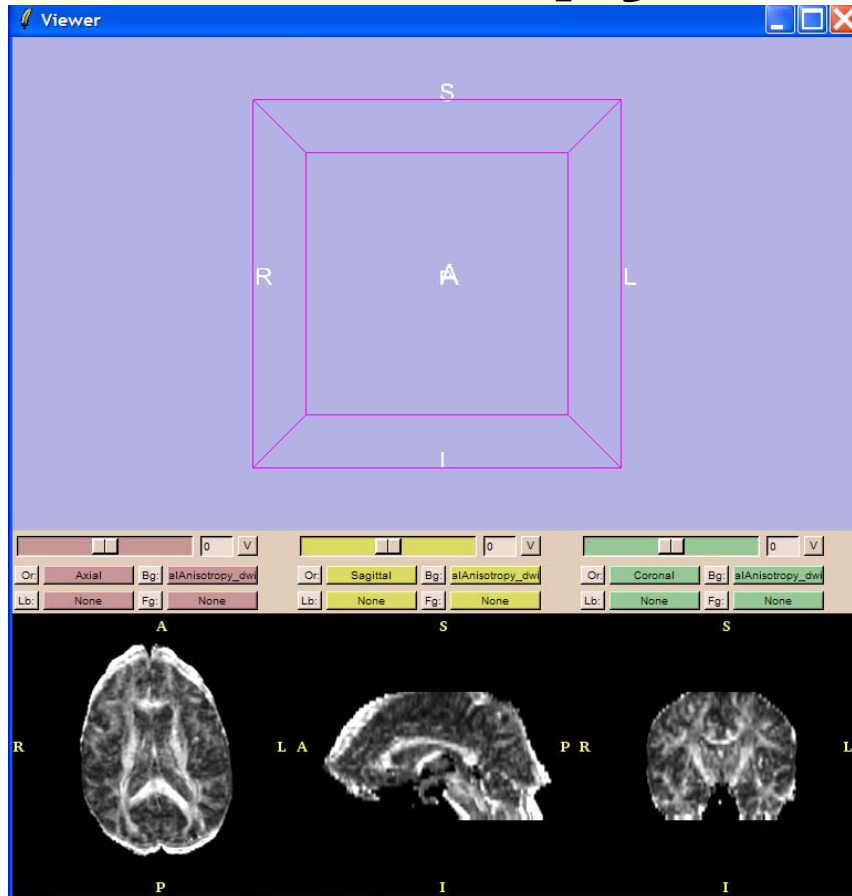
Select the panel Scalars

Browse the menu Create Volume to see the list of calculations that Slicer can perform on the dwi\_Tensor dataset.

Select Fractional Anisotropy

Click on Apply

# Computing Fractional Anisotropy

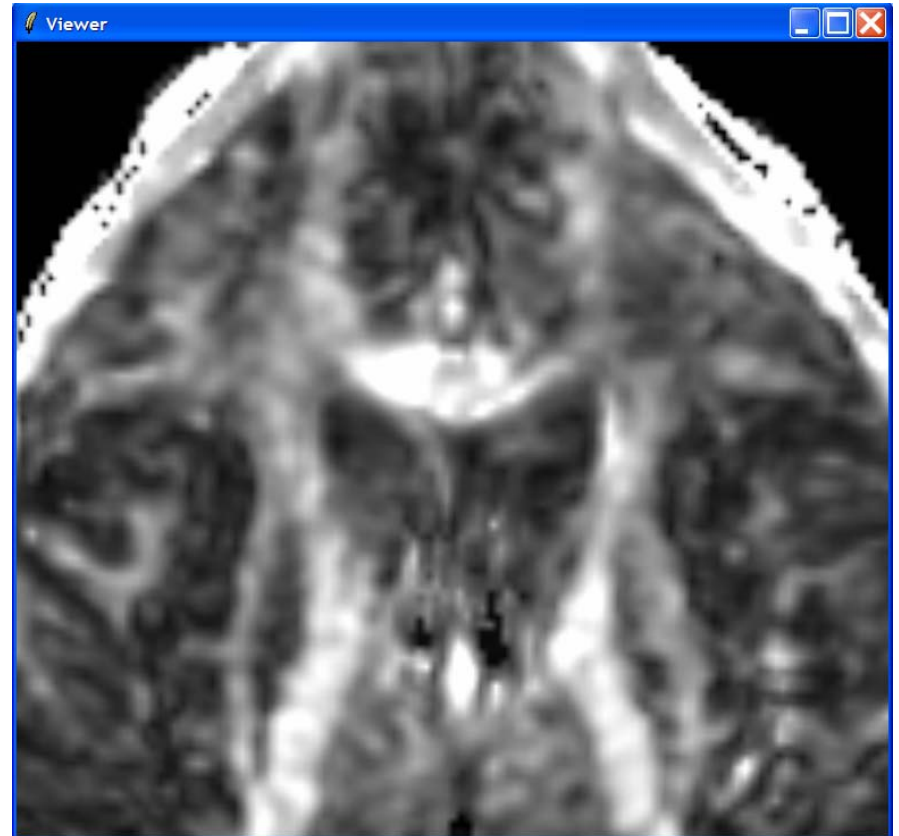
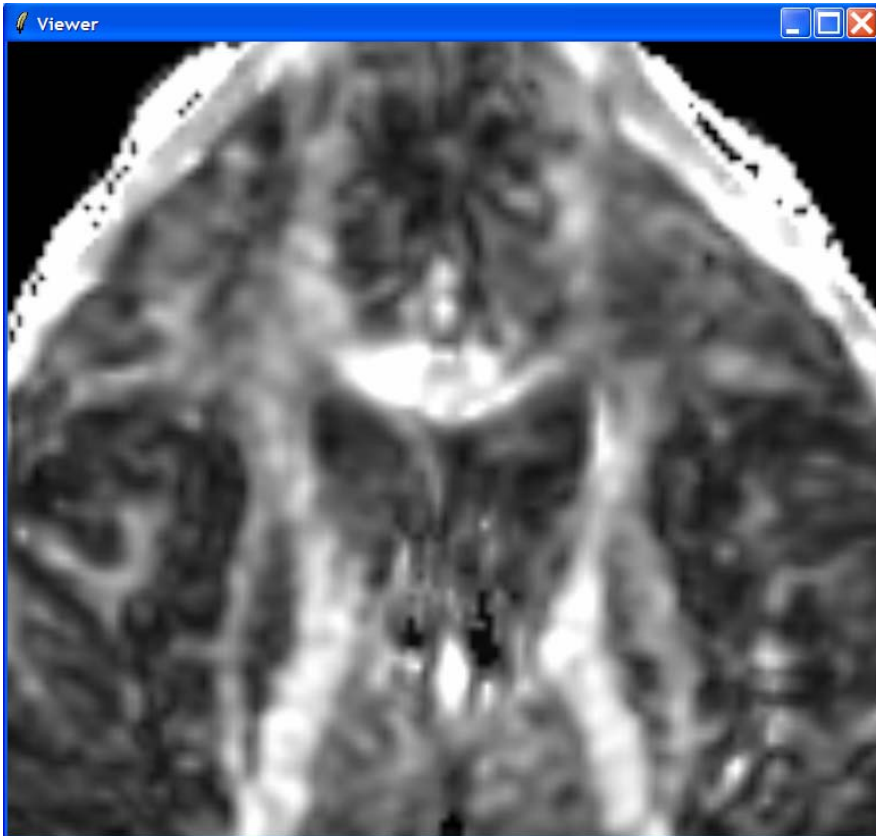


The Viewer displays the FA volume.

Move the mouse in the slices to see FA values for each voxel.

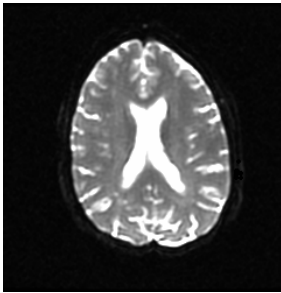
# Which image is correct ?

---

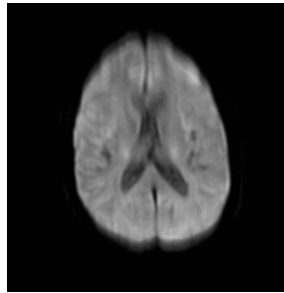


# Diffusion Tensor Imaging Analysis

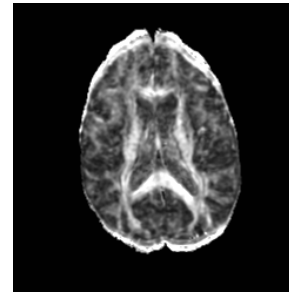
---



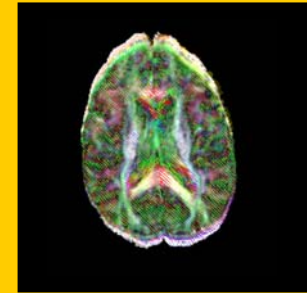
DWI



DTI



FA

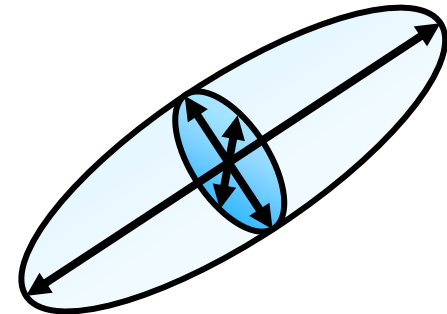
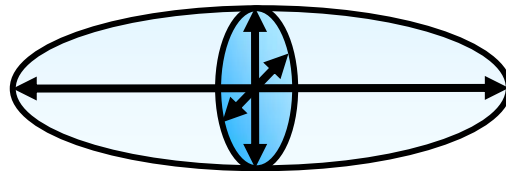
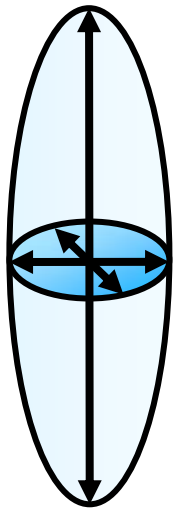


Glyphs &  
Tracts

# 3D Visualization

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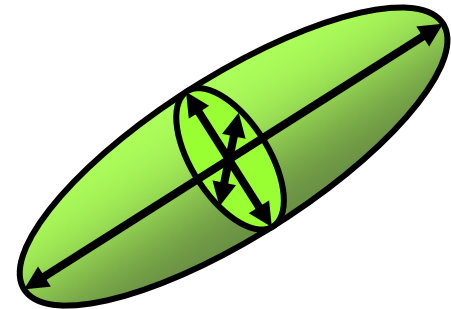
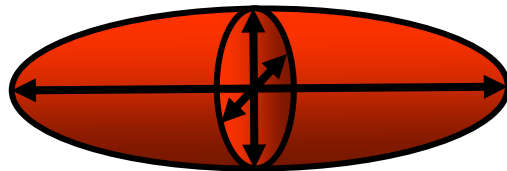
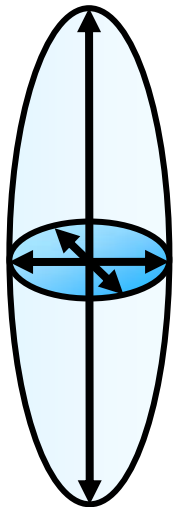
- Hypothesis: the direction of the fibers is collinear with the direction of the eigen-vector associated with the largest eigenvalue.



# Glyphs

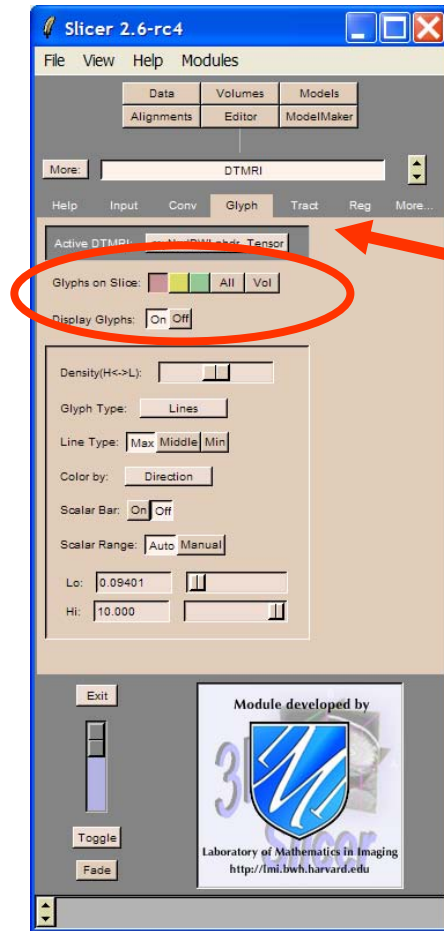
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- Glyphs represent the major eigenvector field within a given slice.





# Glyphs



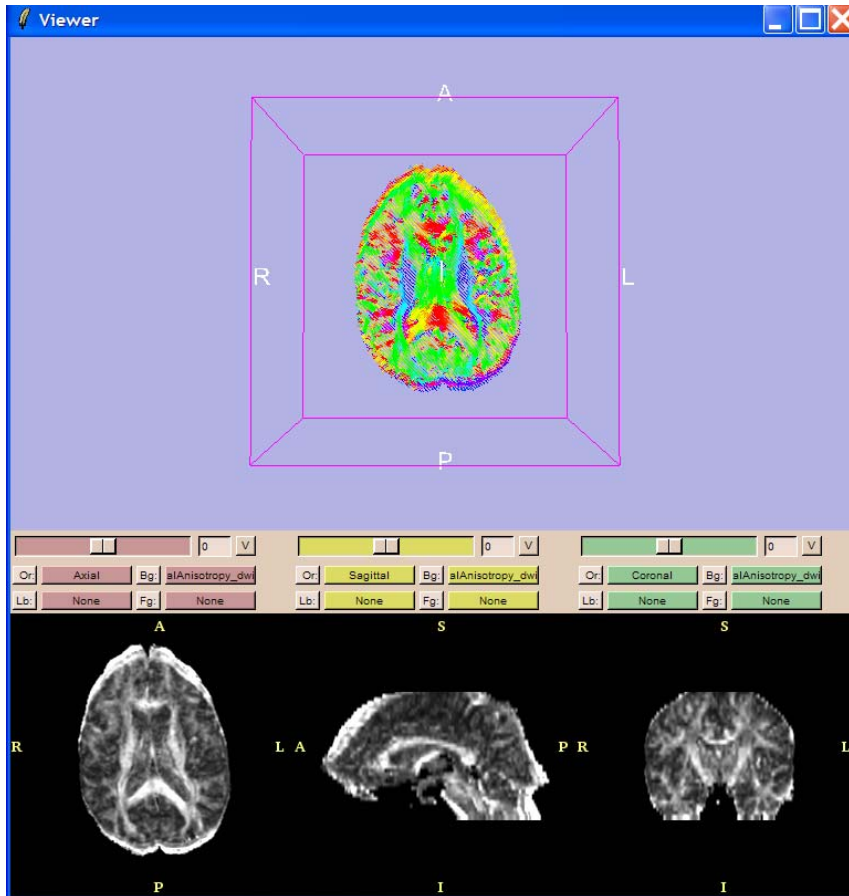
Select the panel Glyphs in the DTMRI module

Select the Active DTMRI volume dwi\_Tensor

Select Glyphs on Slice for the axial (red) view

Set Display Glyphs On

# Glyphs



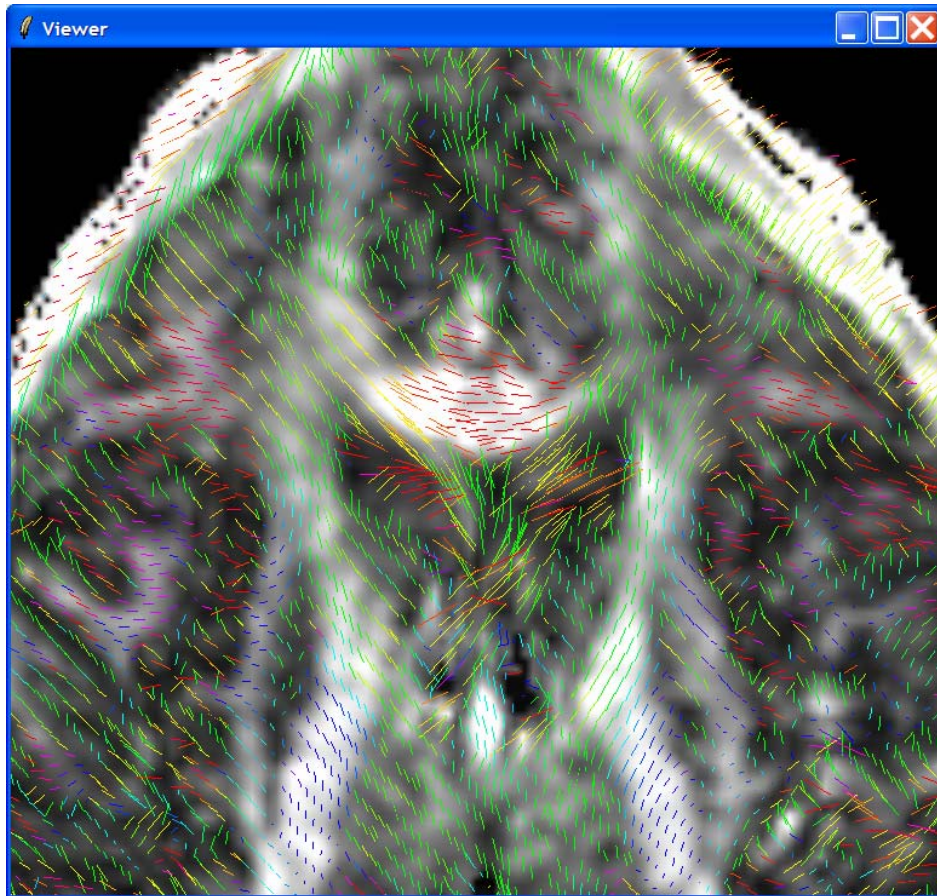
Color code

Blue is Superior-Inferior

Red is Left-Right

Green is Anterior-Posterior

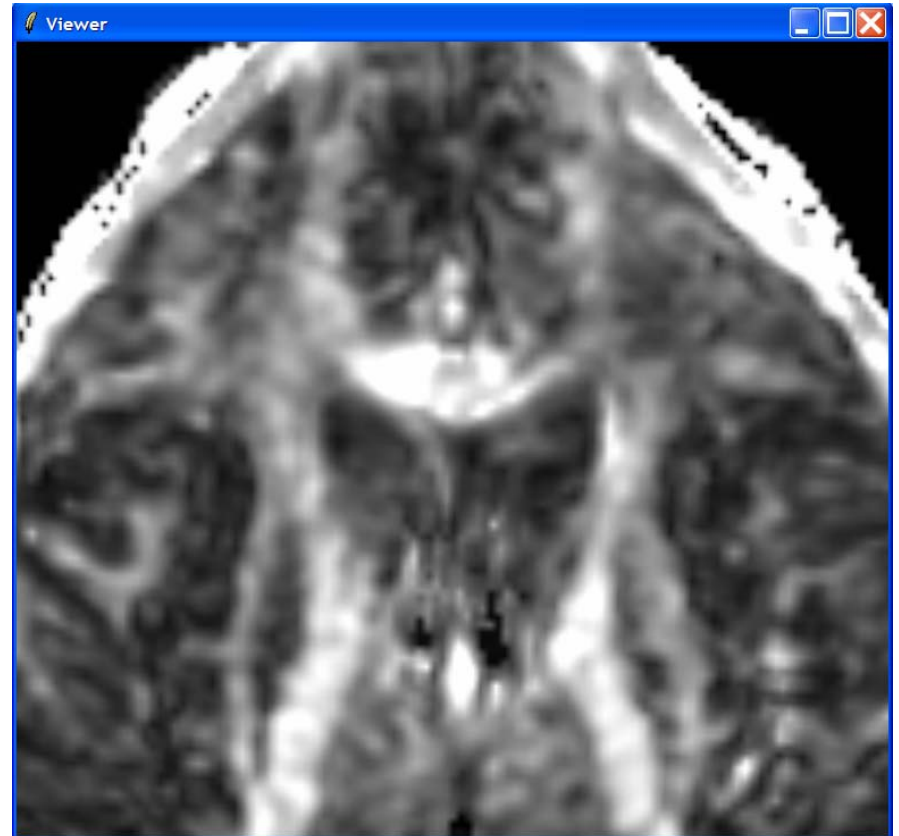
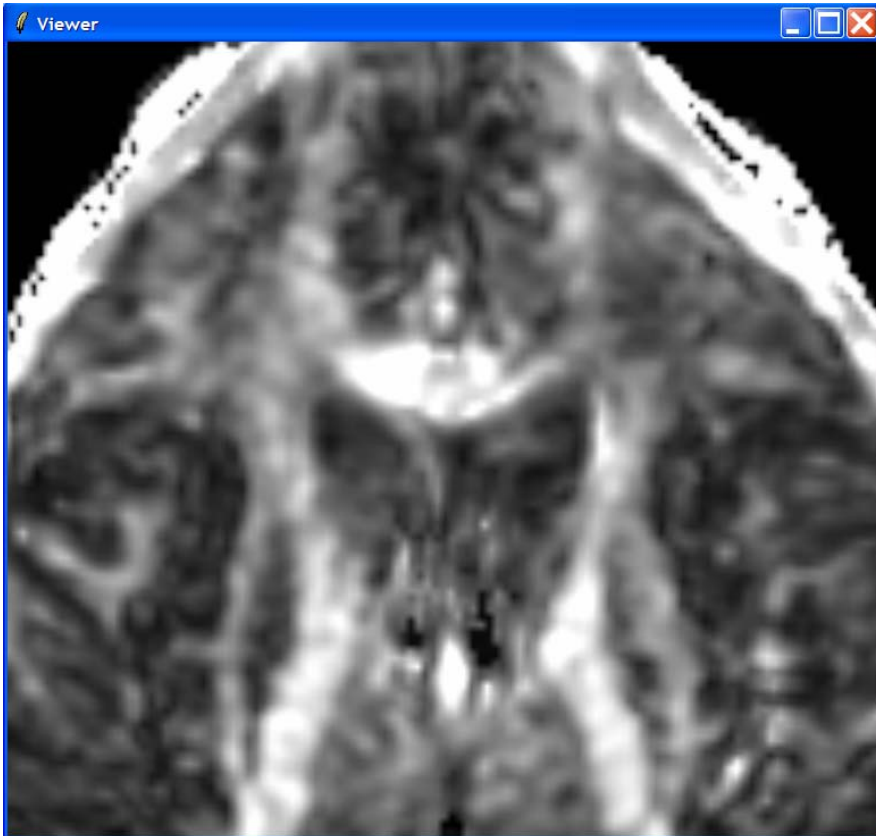
# Data Fusion



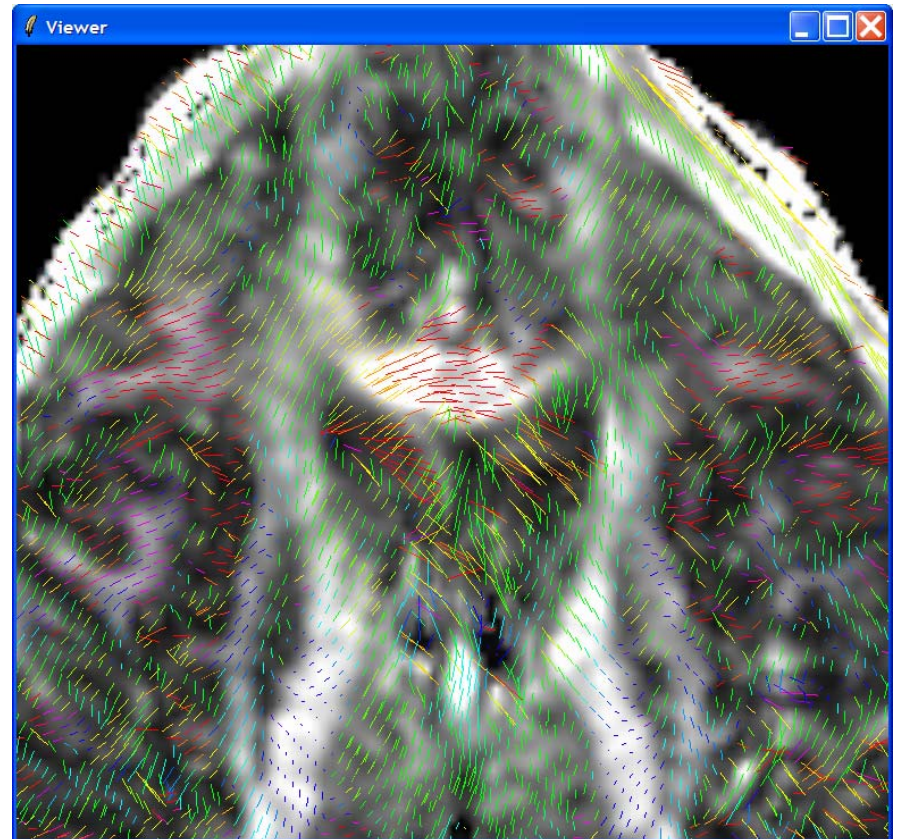
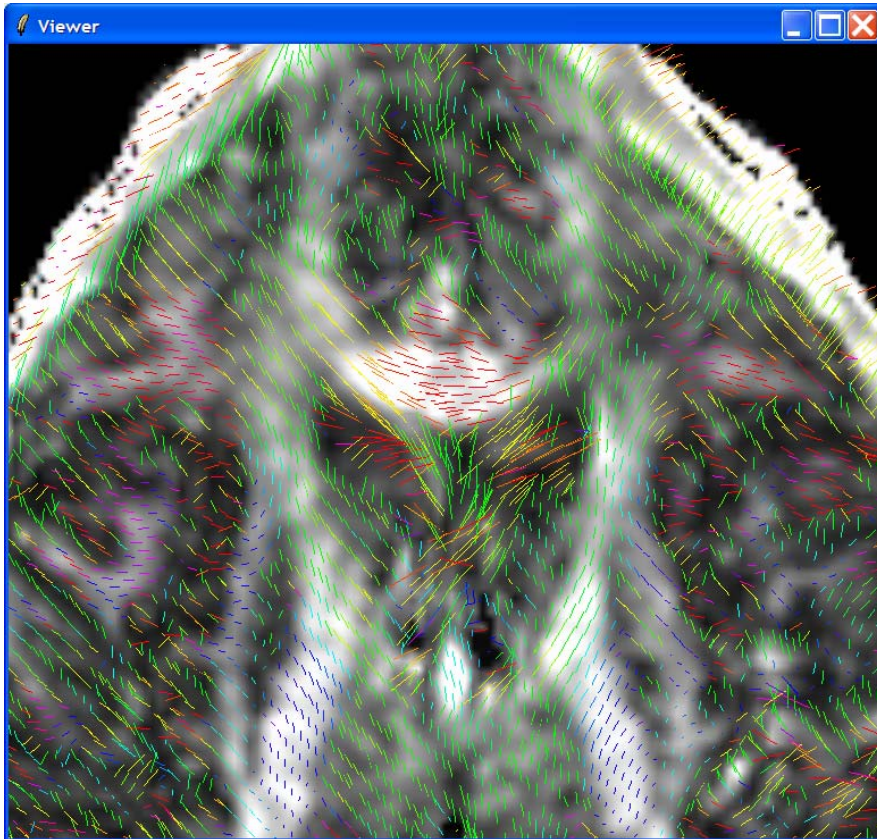
Superimpose the glyphs  
on the Fractional  
Anisotropy Map

# Which image is correct ?

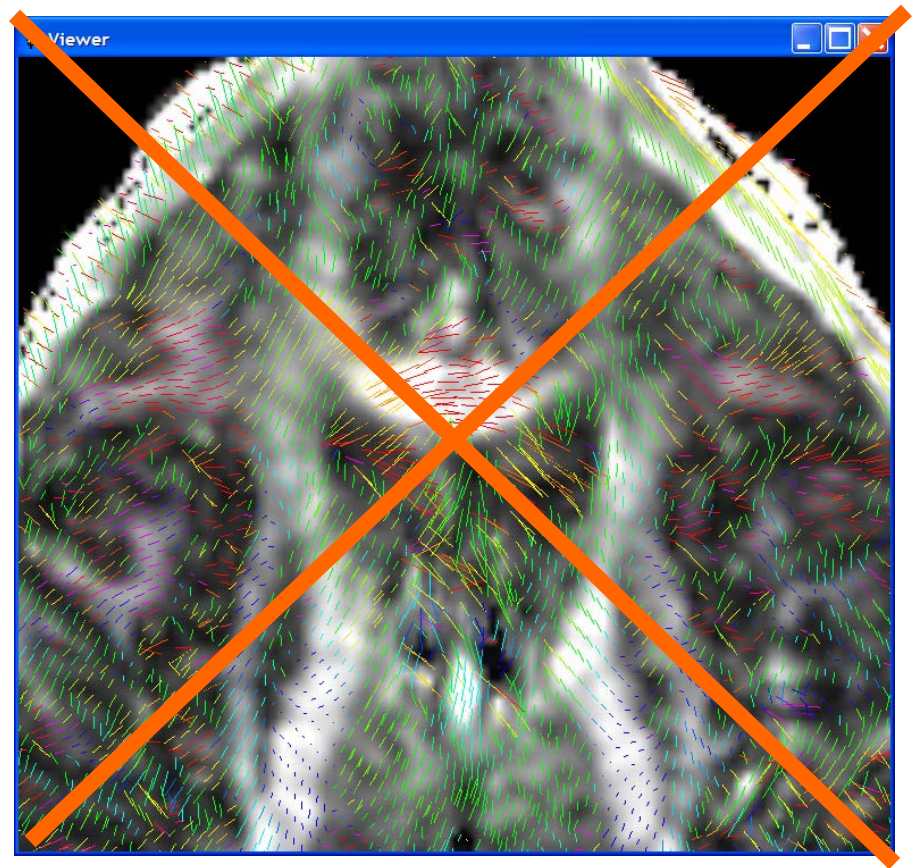
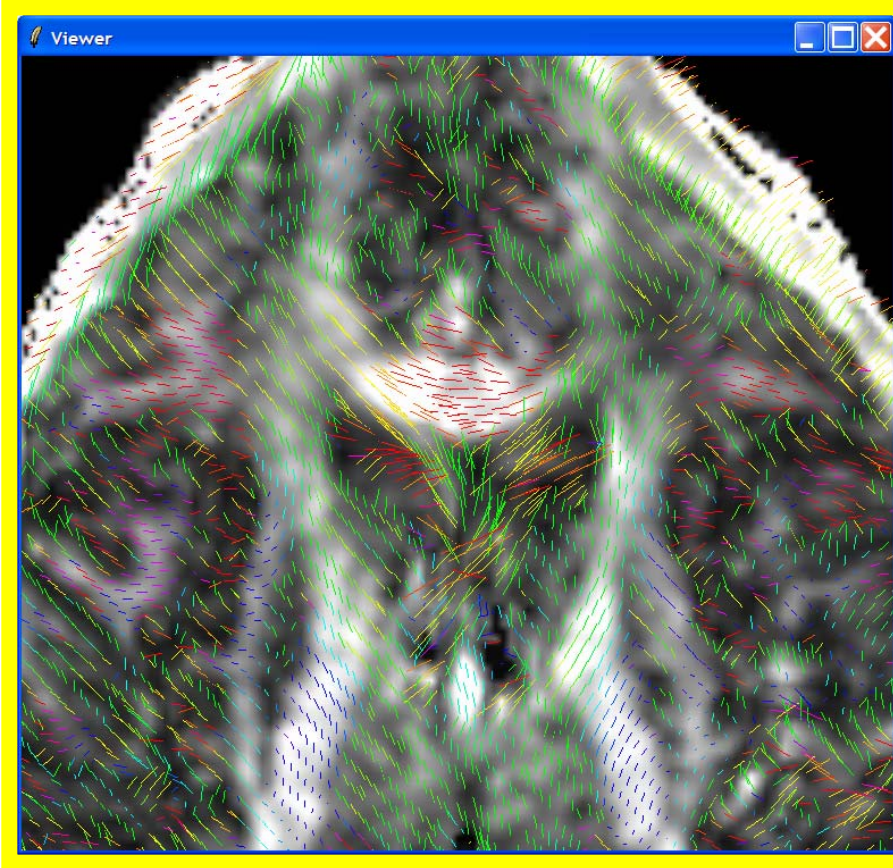
---



# Which image is correct ?



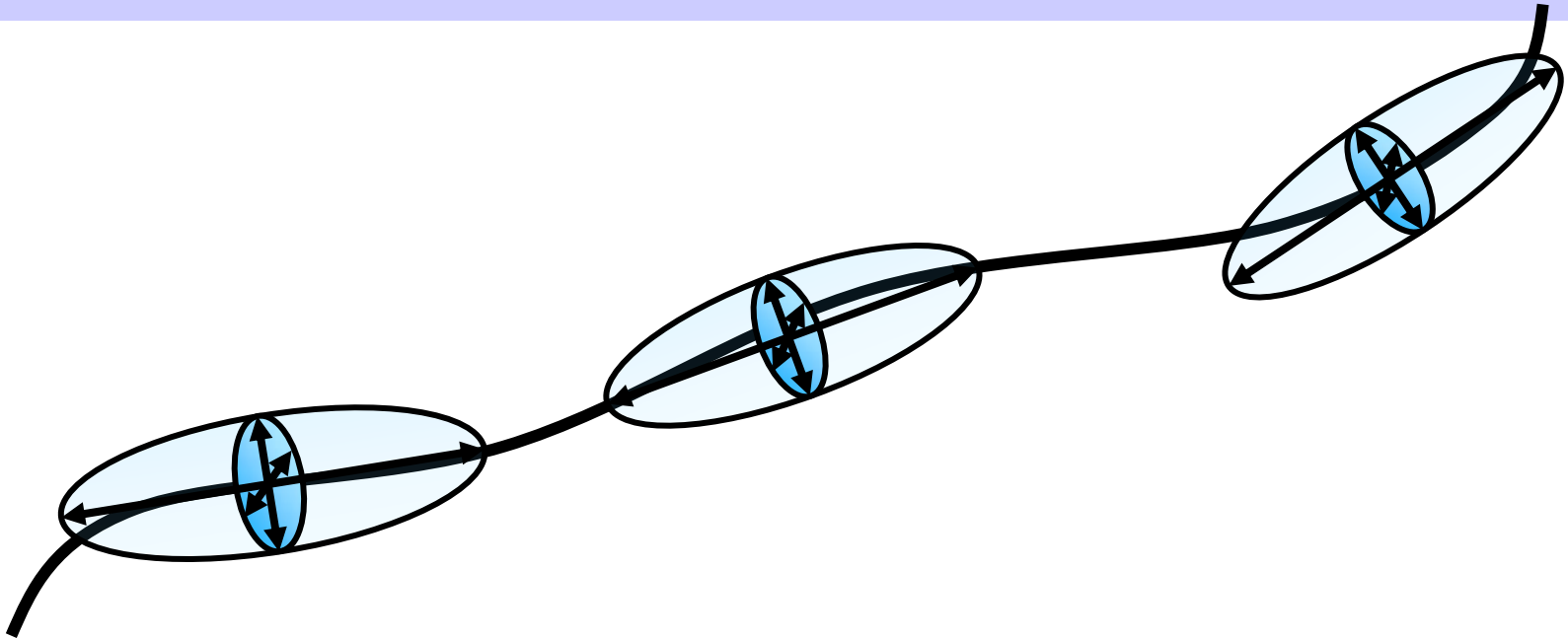
# The left one is correct



# Streamline tractography

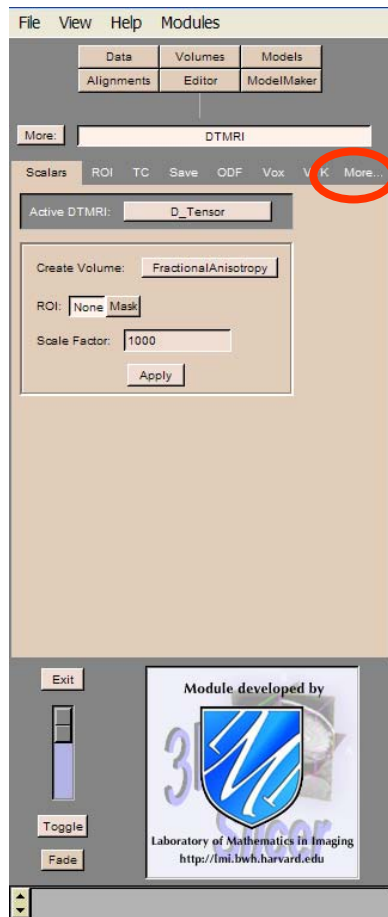
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- Hypothesis: the direction of the fibers is collinear with the direction of the eigen-vector associated with the largest eigenvalue.



# Tractography Panel

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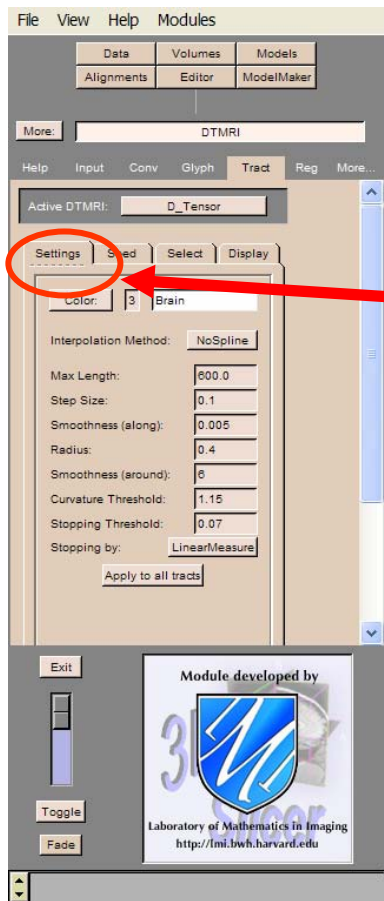


Click on Display Glyphs Off

Click on More and select the Panel Tract in the DTMRI module.



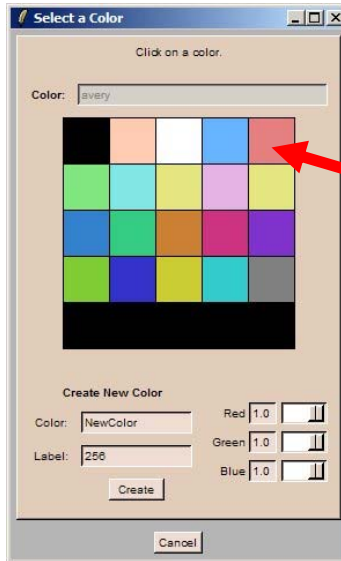
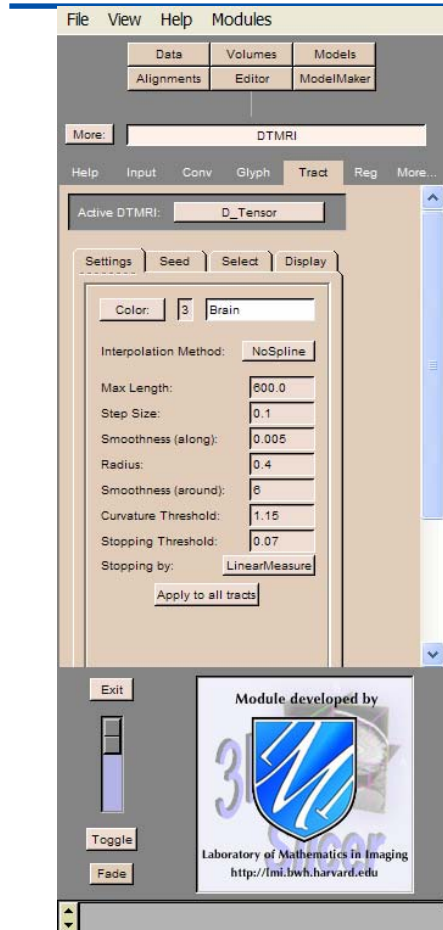
# Tractography Panel



Select the Tab Settings

Left-click on Color

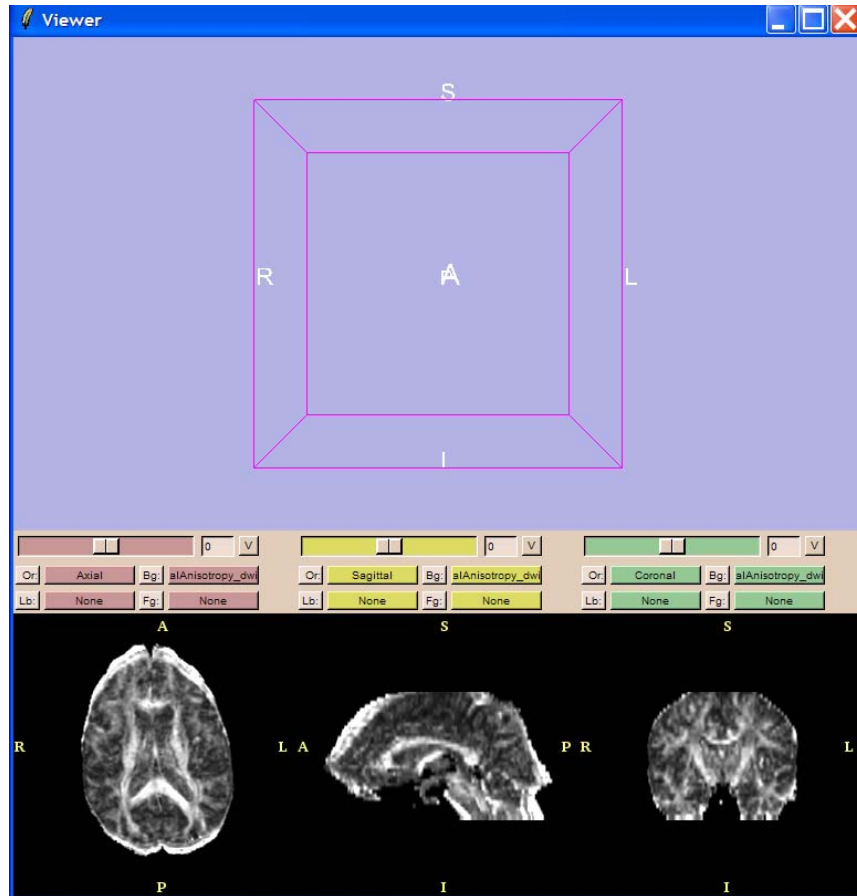
# Tractography Panel



A Color selection panel appears

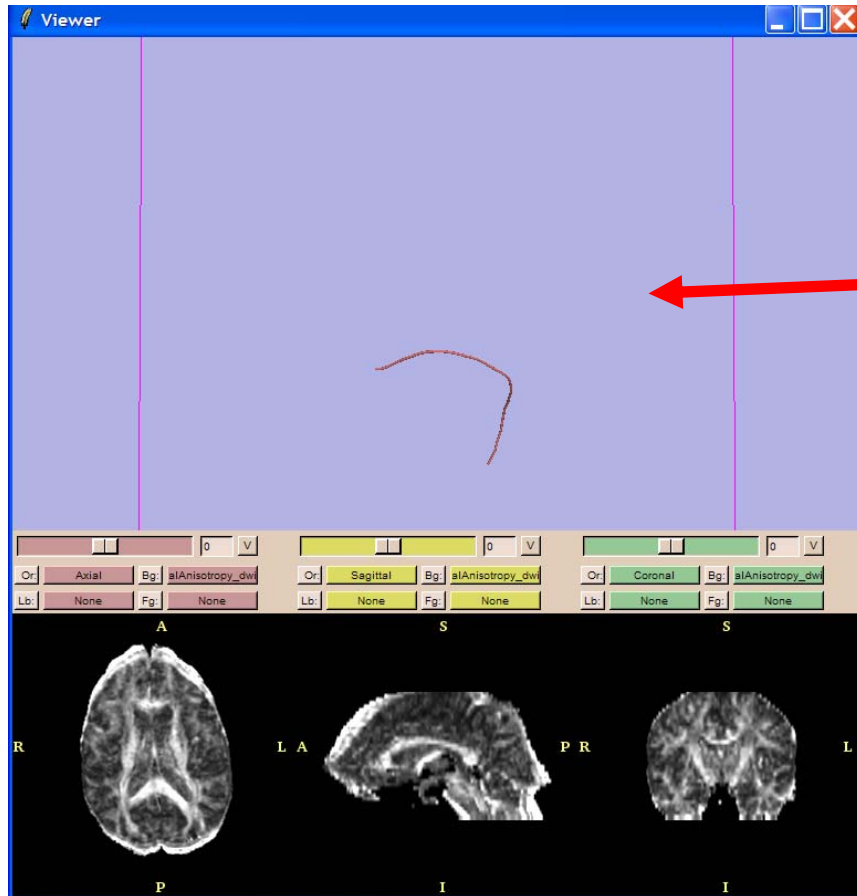
Select a new color for the tracts

# Create a single tract



Position the mouse on a point inside the Corpus Callosum, and hit the s key.

# Create a single tract



A tract appears in the 3D Viewer.

Drag right mouse button down in the 3D Viewer to zoom in.

# ROI Drawing



Select the Editor module in the main Menu.

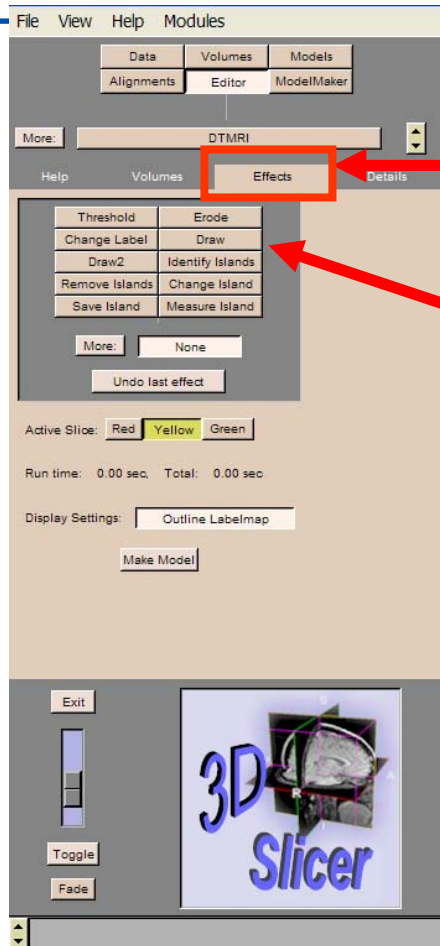
Select the Volumes panel and click Setup

Select the Original Grayscale FractionalAnisotropy\_dwi\_Tensor

Select the Labelmap Working.

Click on Start Editing

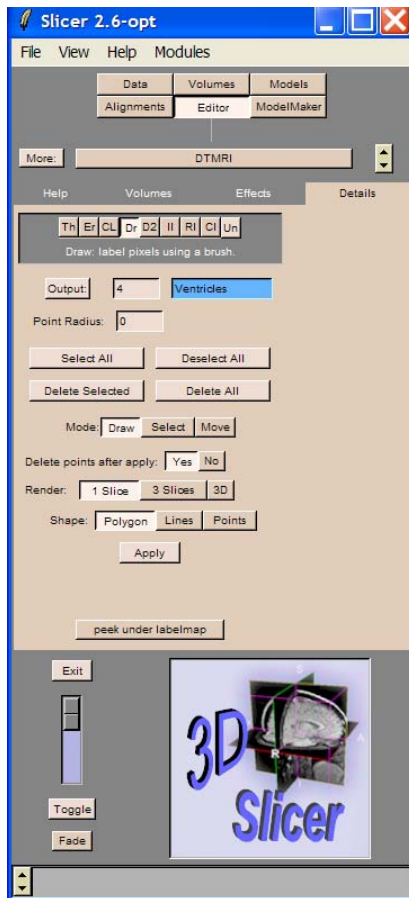
# ROI Drawing



Select the Effects panel

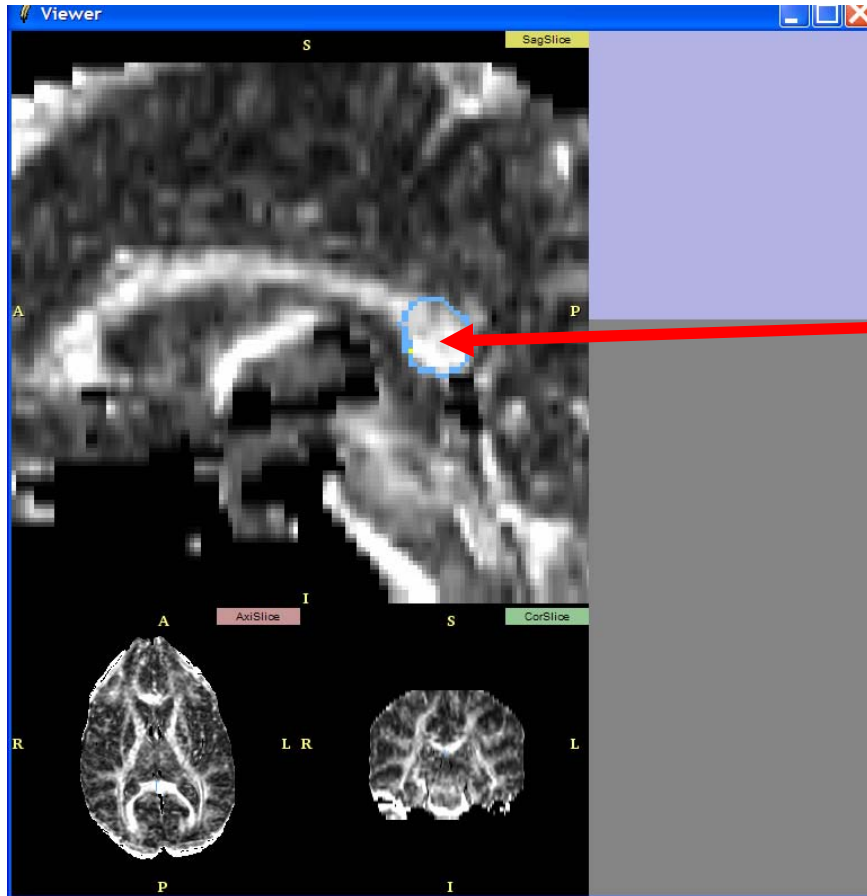
Left click on Draw in the Effects Menu

# ROI Drawing



Select the Output Color #4

# ROI Drawing



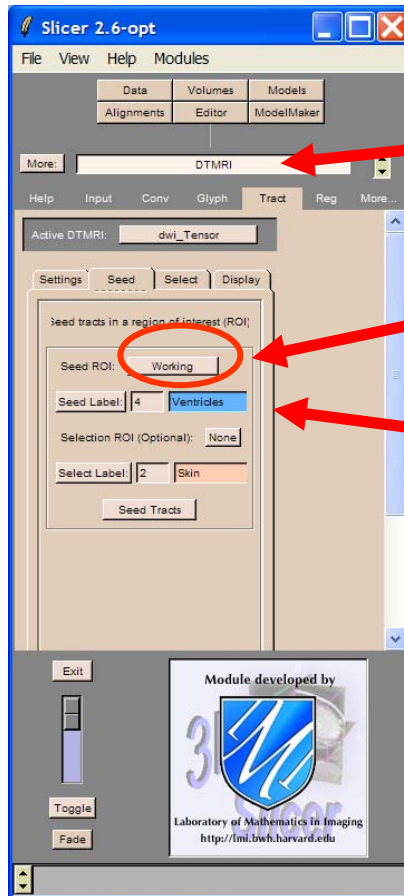
Select View → 1x512  
SAG in the Main Menu.

Draw a region of interest  
in the Splenium of the  
Corpus Callosum

Click on Apply in the  
module Editor.



# ROI Seeding

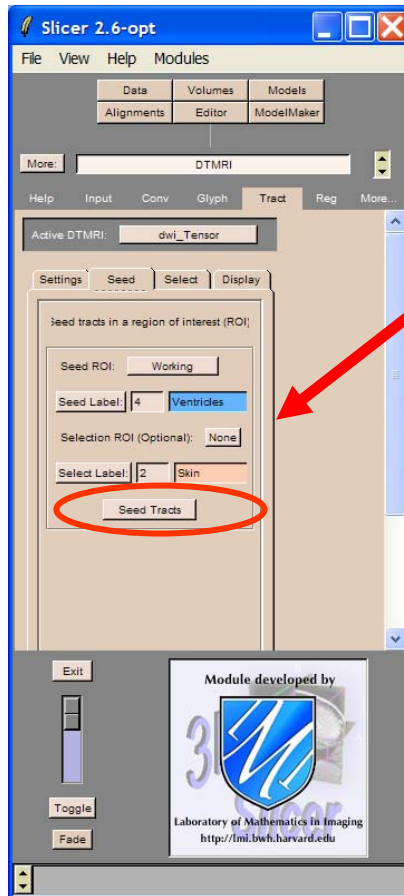


Come back to the DTMRI module and select the panel Tracts.

Click on the tab Seed and select the SeedROI Working

Select the color label #4 corresponding to the ROI

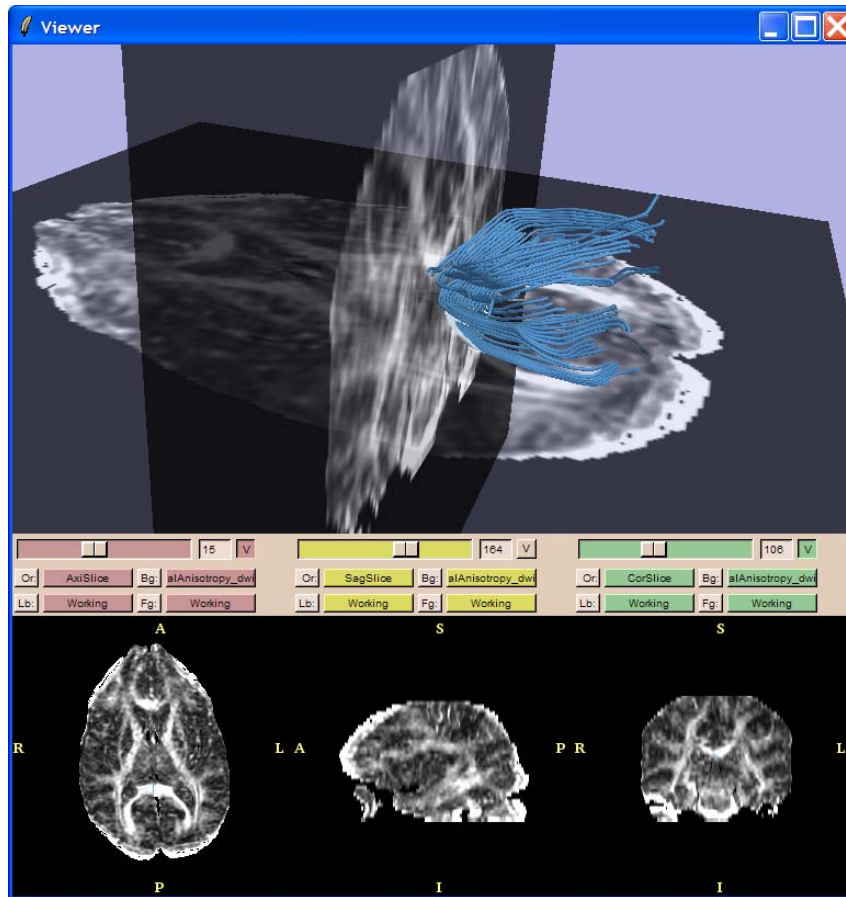
# ROI Seeding



Click on Seed Tracts

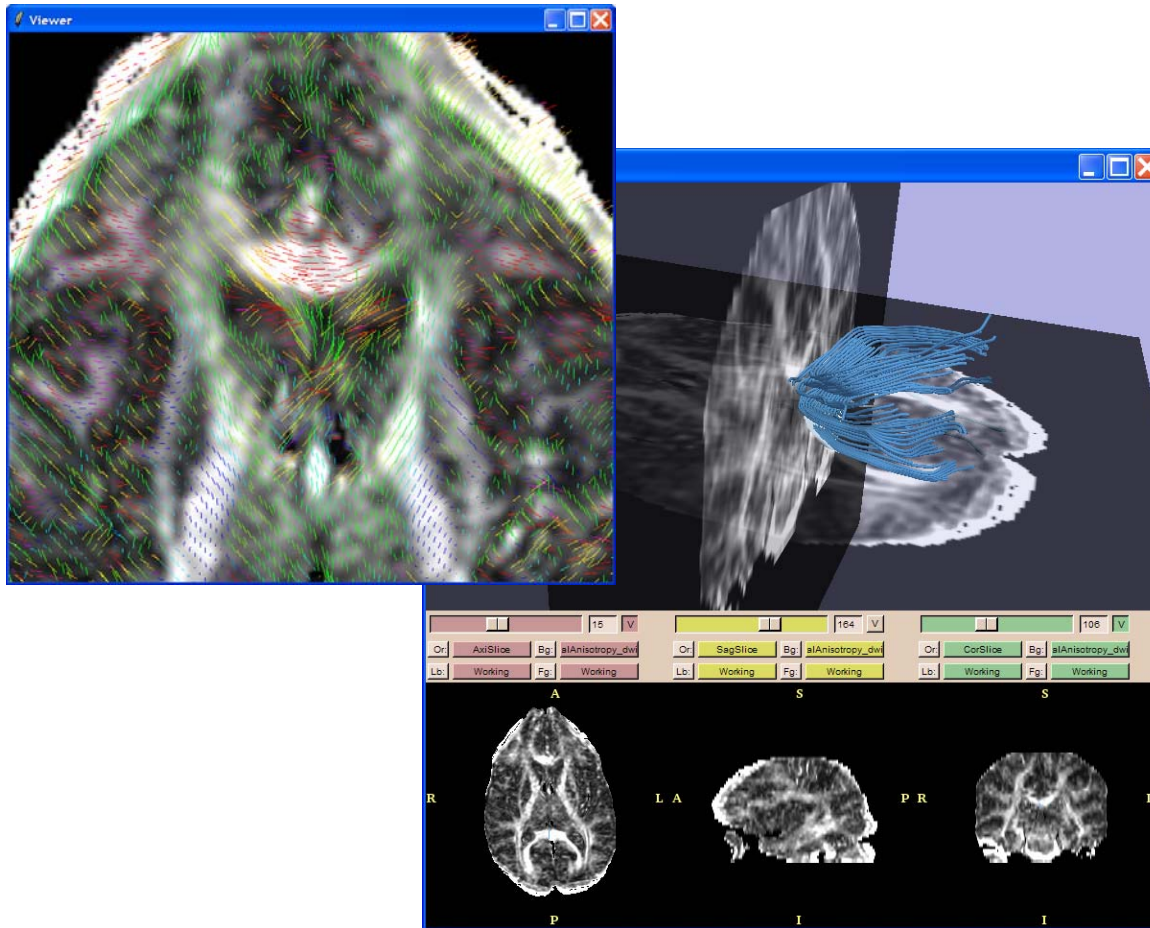
A warning message appears,  
Click Yes if you are ready to  
process the data.

# ROI Seeding



The tracts from the Splenium of the Corpus Callosum appear in the viewer.

# 3D Visualization of tissue orientation



Diffusion Tensor Imaging Data contain information on the three dimensional orientation of the tissues in the brain.

# Conclusion

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- Non-invasive in-vivo exploration of brain microstructures
- Analysis requires a rigorous knowledge of acquisition parameters
- 3D visualization of fiber pathways

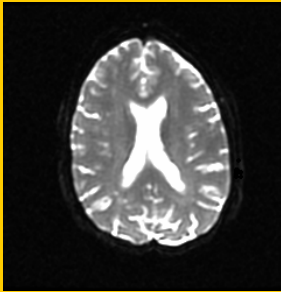
# Real Clinical Situation

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- ...is not straightforward
- DTI describes a Gaussian model of Diffusion
- Uncertainty induced by artifacts
- Fiber crossing remains a challenge

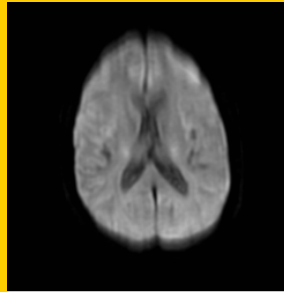
# Diffusion Tensor Imaging Analysis

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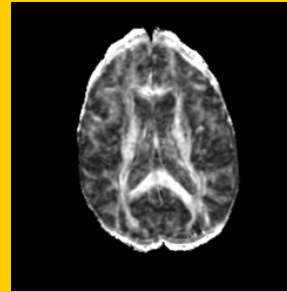
DWI

Acquisition

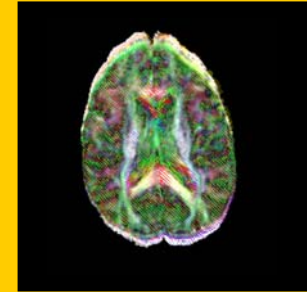


Tensor

Calculation



FA



Glyphs &  
Tracts