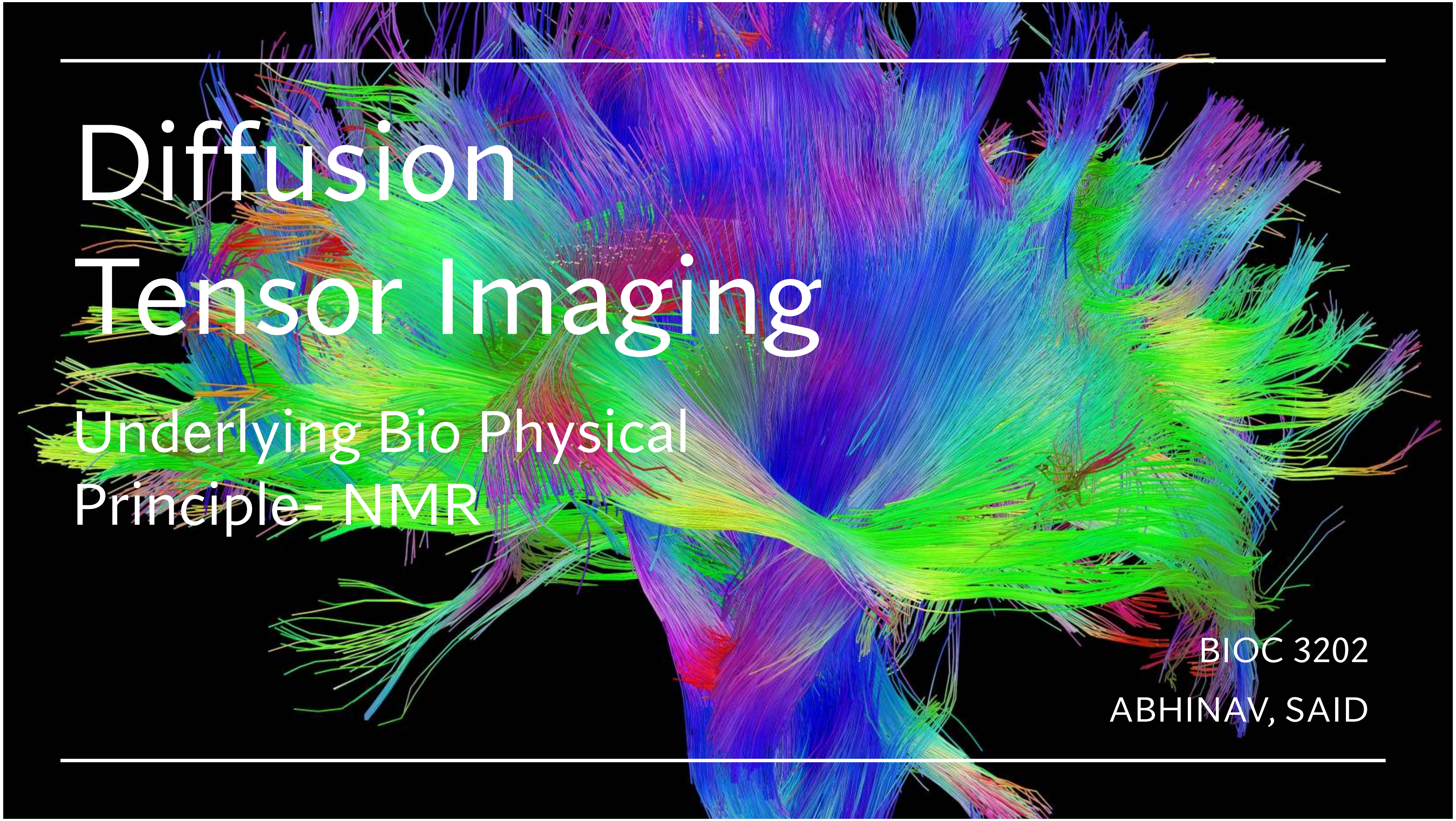
Diffusion Tensor Imaging

Underlying Bio Physical Principle- NMR



BIOC 3202

ABHINAV, SAID

What is it?

AN IMAGING TECHNIQUE UTILIZING PHENOMENA OF NMR

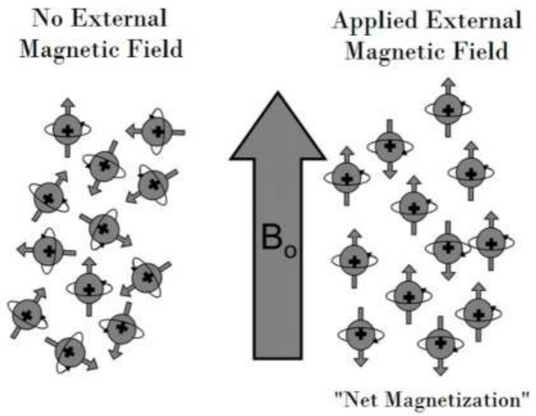
RELIES OF DIFFUSION OF WATER MOLECULES ALONG AXONS TO CREATE IMAGE OF THE BRAIN.

BUILDS ON FOUNDING PRINCIPLES OF MRI AND DIFFUSION WEIGHTED MRI

Table of contents

MRI- Principles

- *Quick Gross Recap*
- *No net magnetization due to random orientation*
- *Introduce an order by applying B_0*
- *Lower energy to align parallel*
- *Generates a net magnetization vector from protons*

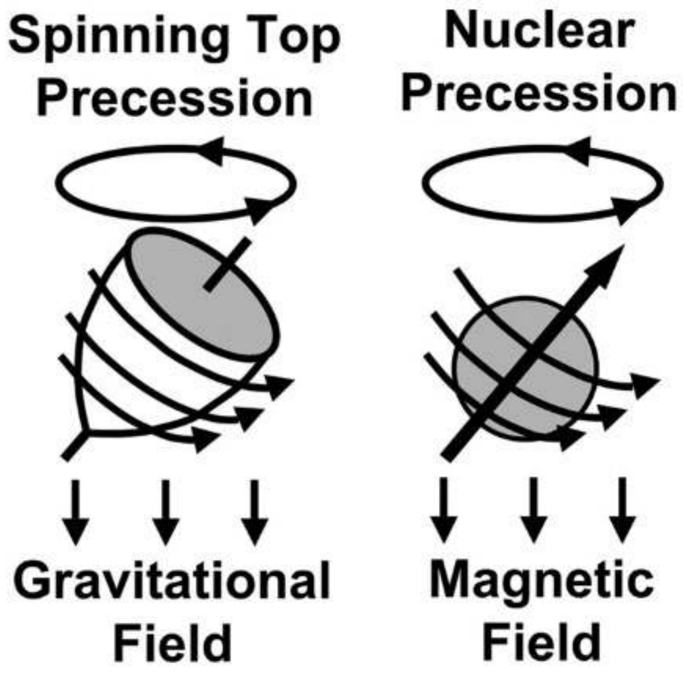


gnment of protons due to an external magnetic field (

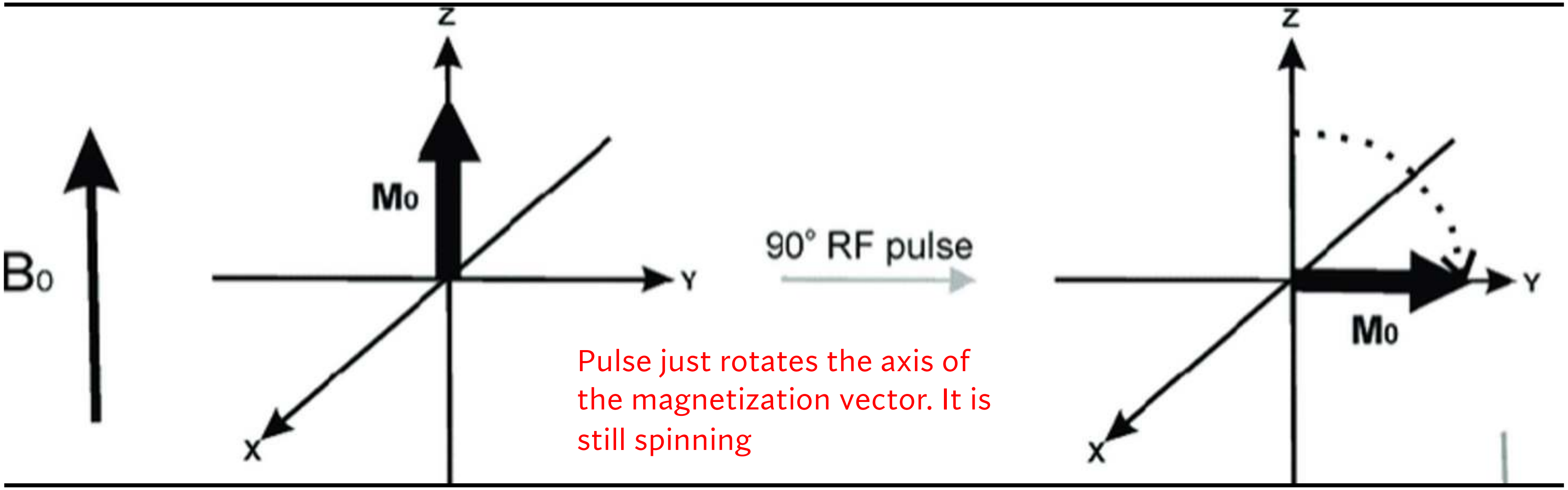
They also wobble like a top.

- *Called Precession* $f = \gamma \times B_0$
- *This happens due to conservation of angular momentum*
- *They are in a kind of equilibrium*

Remember: NET magnetization vector
Is the resultant sum of all protons in our sample.



sion of a spinning top and nuclear precessior

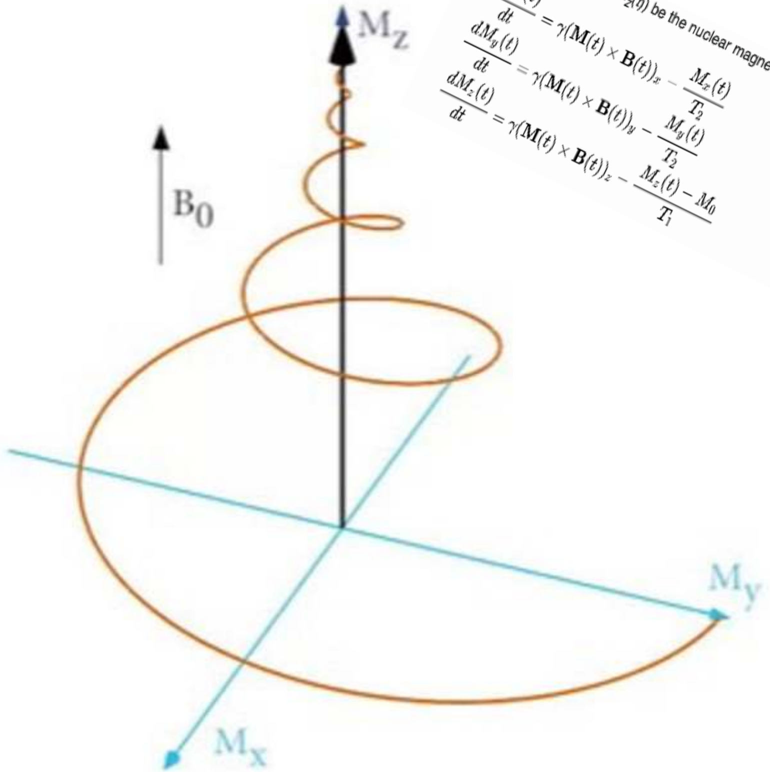


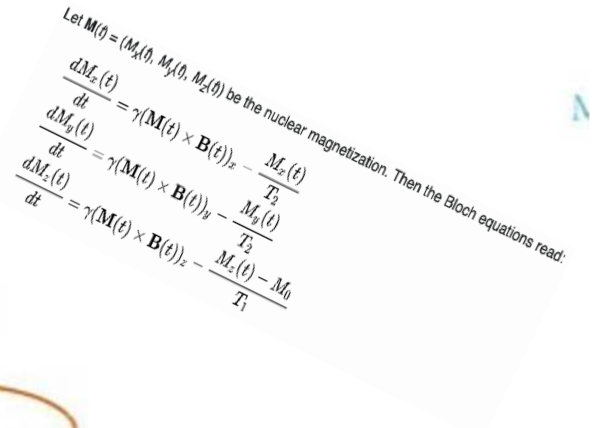
Hitting them with RF Pulse

- *Net Magnetization is aligned with B_0 and cannot be measured.*
- *Disturb them from Equilibrium*
- *All protons in slice spin at same frequency.*
- *2 ways of setting base to capture the echo; aligning all protons with B_0 and making them spin at same frequency with RF*

Restoring Equilibrium

- *The protons spiral back up to previous equilibrium position*
- *They release this energy in form of an electric field/signal*
- *Protons in similar chemical environment relax similarly*
- *Detectors capture this*




Let $\mathbf{M}(t) = (M_x(t), M_y(t), M_z(t))$ be the nuclear magnetization. Then the Bloch equations read:

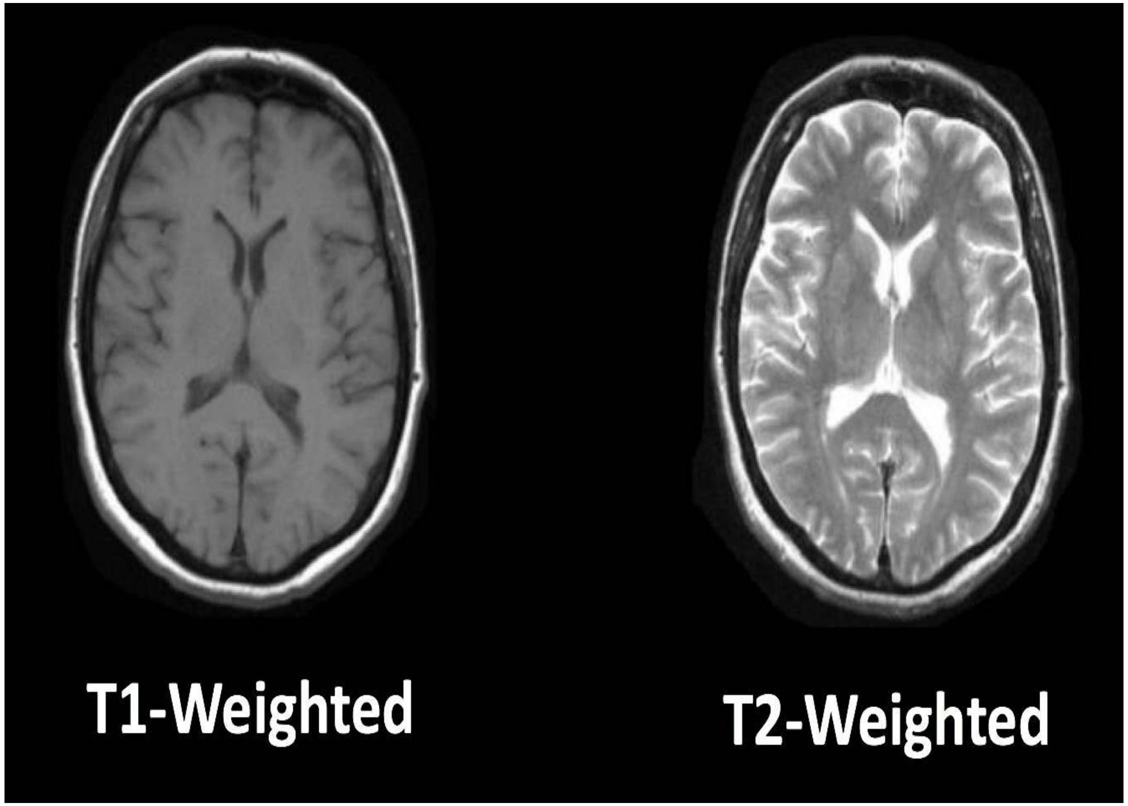
$$\frac{dM_x(t)}{dt} = \gamma(\mathbf{M}(t) \times \mathbf{B}(t))_x - \frac{M_x(t)}{T_2}$$

$$\frac{dM_y(t)}{dt} = \gamma(\mathbf{M}(t) \times \mathbf{B}(t))_y - \frac{M_y(t)}{T_2}$$

$$\frac{dM_z(t)}{dt} = \gamma(\mathbf{M}(t) \times \mathbf{B}(t))_z - \frac{M_z(t) - M_0}{T_1}$$

Interpretation

- *Two ways to interpret this*
- *Time for transverse signal to decay (T2)*
- *Time to restore base longitudinal signal (T1)*
- *Different applications/requirements*
- *Different tissue relax differently-different signal*
- *Image*

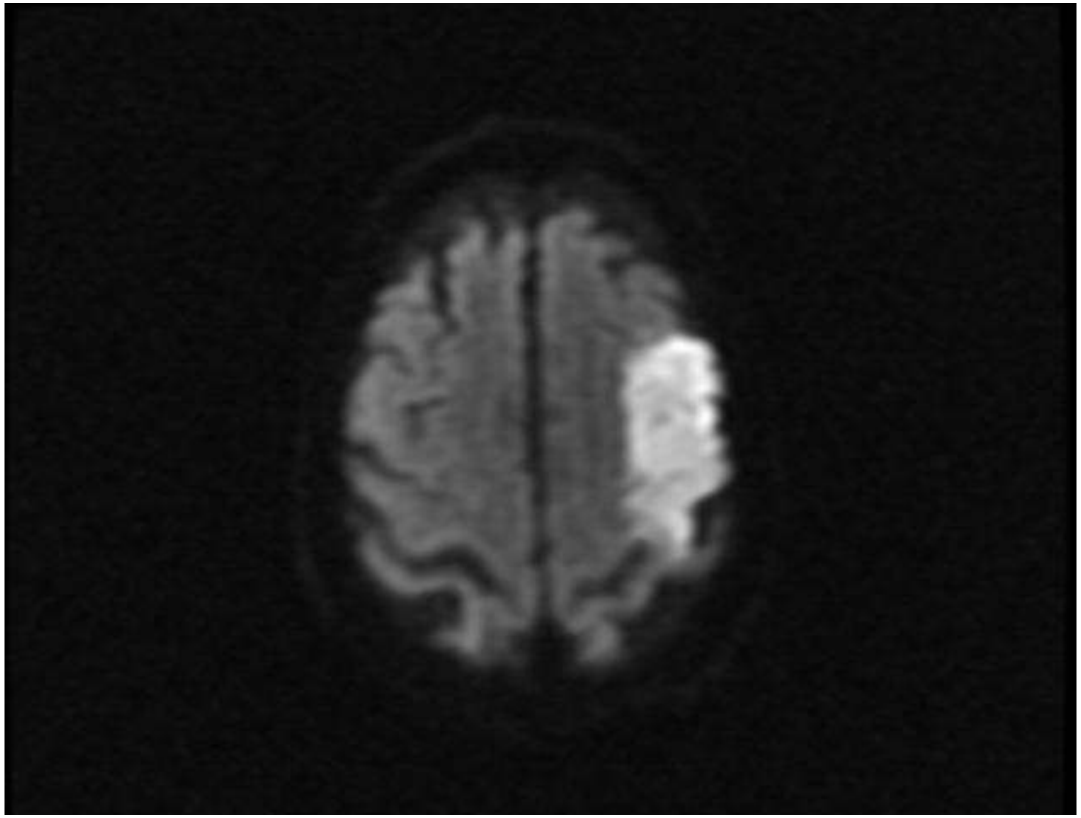


Tracking Water Diffusion

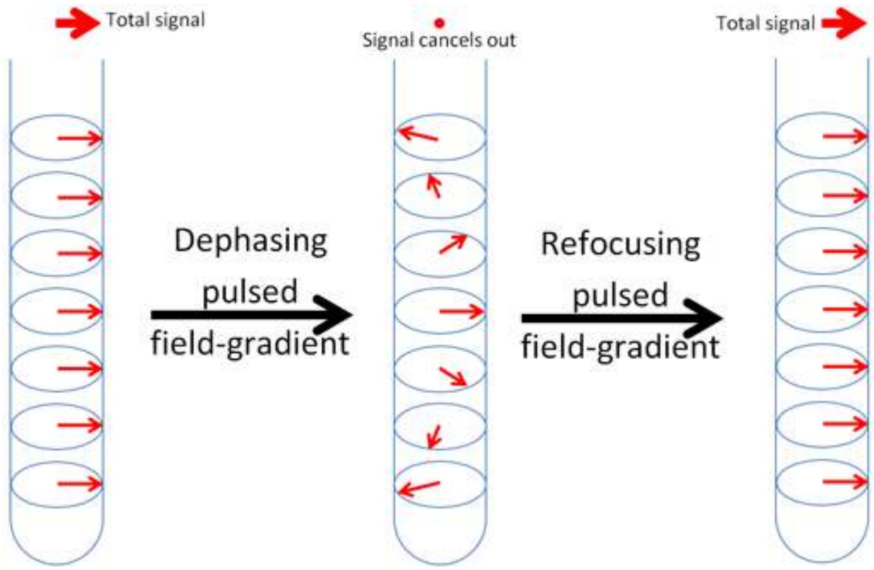
- *Previous method only related to amount of water in tissue.*
- *What if water is leaving or is stagnant in a tissue sample?*
- *What happens to the signal following diffusion?*

How?

- *Remember RF pulse synchronize the frequencies of protons*
- *Instead of going on with the previous method, we do something else*
- *We have coils which generate a gradient magnetic field.*



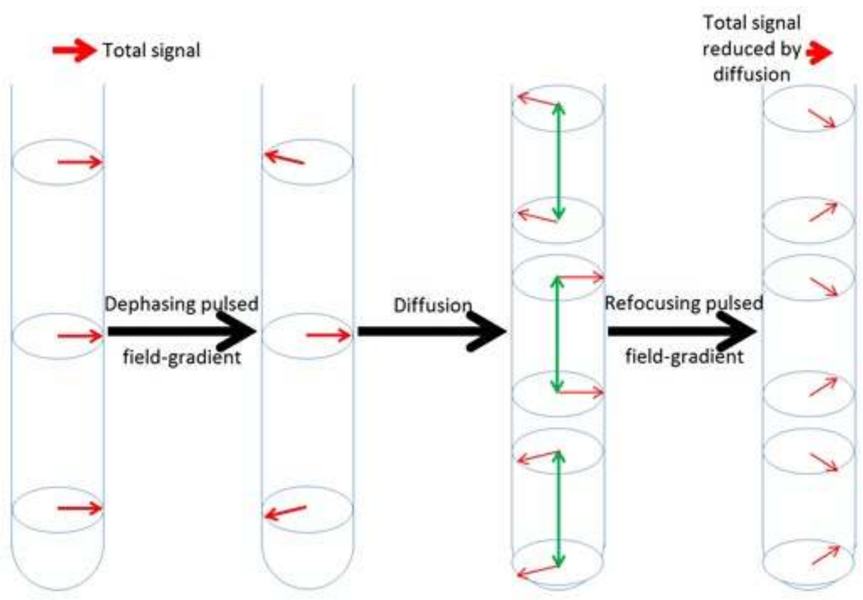
- *2 gradient fields* $f = \gamma \times B_0$
- *Protons spin faster in the direction of increasing gradient*
- *If we remove the field, we see the protons are no longer in phase. We obtain no signal*
- *Inducing a similar but opposite field returns the protons in phase. We obtain back a strong signal*



When the protons move..

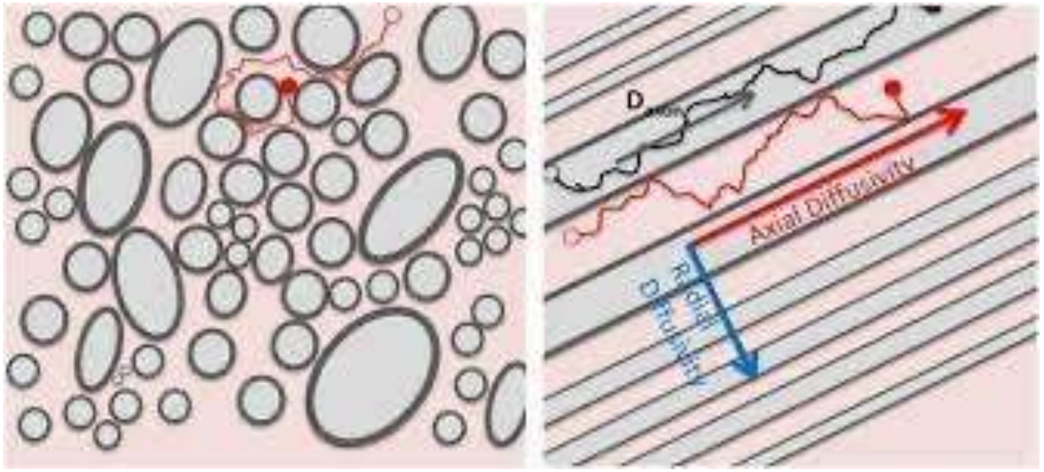
- *In the short window between the dephasing and refocusing pulse water molecules will move.*
- *Moving up or down the gradient field cause the refocusing pulse not to cancel the previous one.*
- *Coherence is not restored, and signal is attenuated*
- *Decrease in signal indicate diffusion*

In previous photo seen that area of reduced diffusion had higher intensity.



More Resolution-DTI

- *Previous method only detected if there was or no diffusion. We want the direction of diffusion too*
- *Track diffusion in xyz directions. [More Detectors]*
- *Diffusion will be easier along axon (anisotropic) than normal to it.*



Previously we mentioned that more diffusion cause less signal. Something else here (out of scope) is the ADC which is kind of the inverse image of DW. More signal for more diffusion. But more complicated…

Some Math Stuff Used

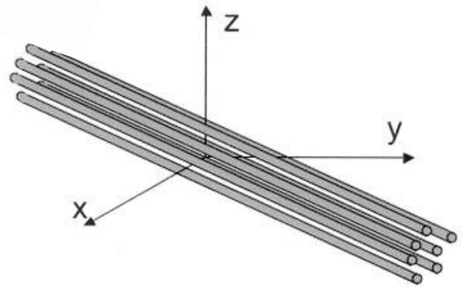
(Too Much..)

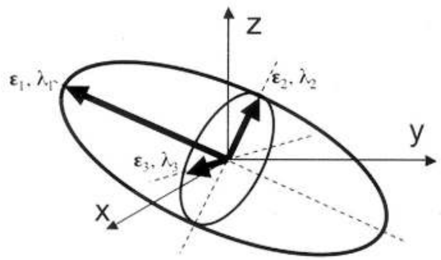
The Frenet–Serret formulas are:

$$\frac{\mathrm{d}\mathbf{T}}{\mathrm{d}s} = \kappa\mathbf{N},$$
$$\frac{\mathrm{d}\mathbf{N}}{\mathrm{d}s} = -\kappa\mathbf{T} + \tau\mathbf{B},$$
$$\frac{\mathrm{d}\mathbf{B}}{\mathrm{d}s} = -\tau\mathbf{N},$$

Diagonalization: Kind of rotating the axes to align with the eigen vectors of the matrix

Eigenvectors have this idea of ‘direction of LT/Matrix’





- *We encode the xyz diffusion signals into a tensor (diffusion tensor is a 3x3 matrix)*
- *Diagonalize the matrix to pull the eigenvector with eigenvalues.*
- *Largest eigenvector indicate direction of diffusion*
- *Knowing diffusion restriction in axons, we can infer the directionality of the axon*

$$\mathbf{J} = -D\nabla\varphi$$

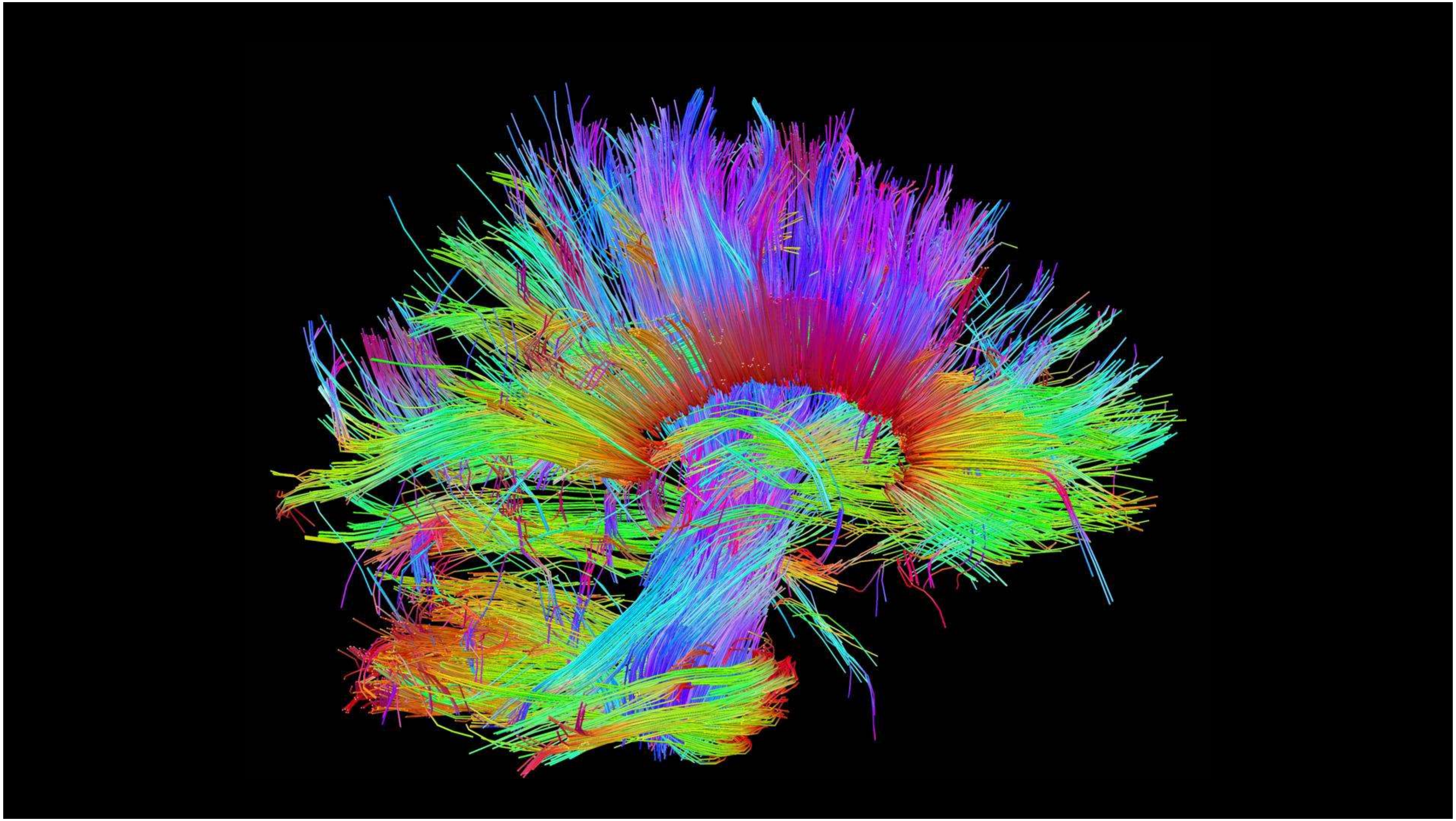
$$\mathbf{D} = \underbrace{\begin{pmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{yx} & D_{yy} & D_{yz} \\ D_{zx} & D_{zy} & D_{zz} \end{pmatrix}}_{\text{Tensor derived from directional diffusivities (ADC's)}} = \mathbf{E}^T \begin{pmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_3 \end{pmatrix} \mathbf{E}$$

Eigenvalues

Matrix of 3 eigenvectors

Result

- *Red indicates x axis*
- *Green indicates y axis*
- *Blue indicates z axis*

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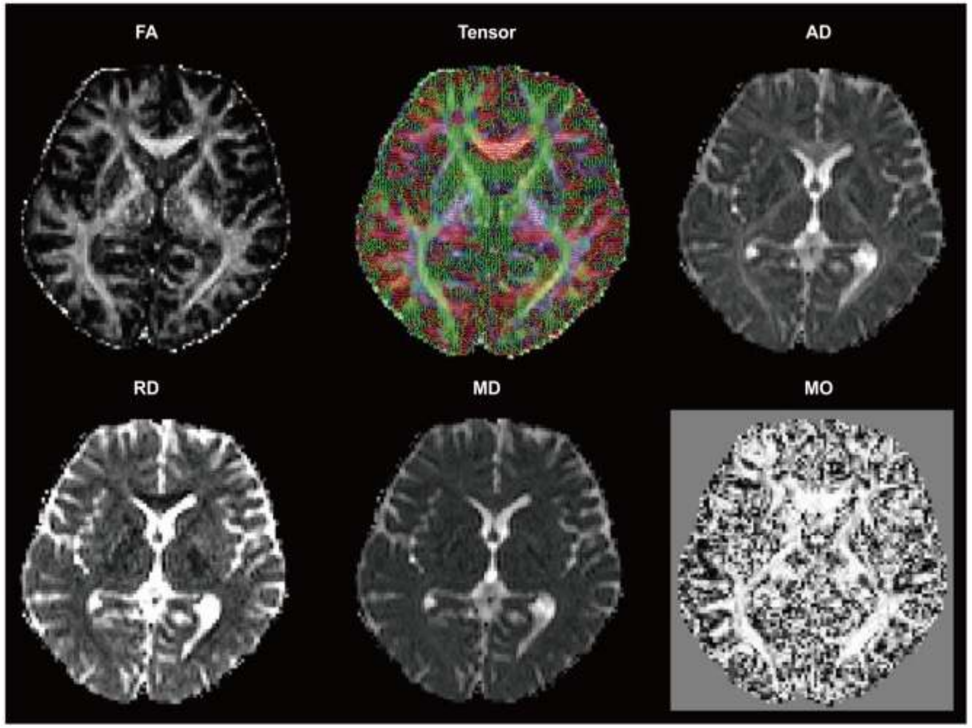
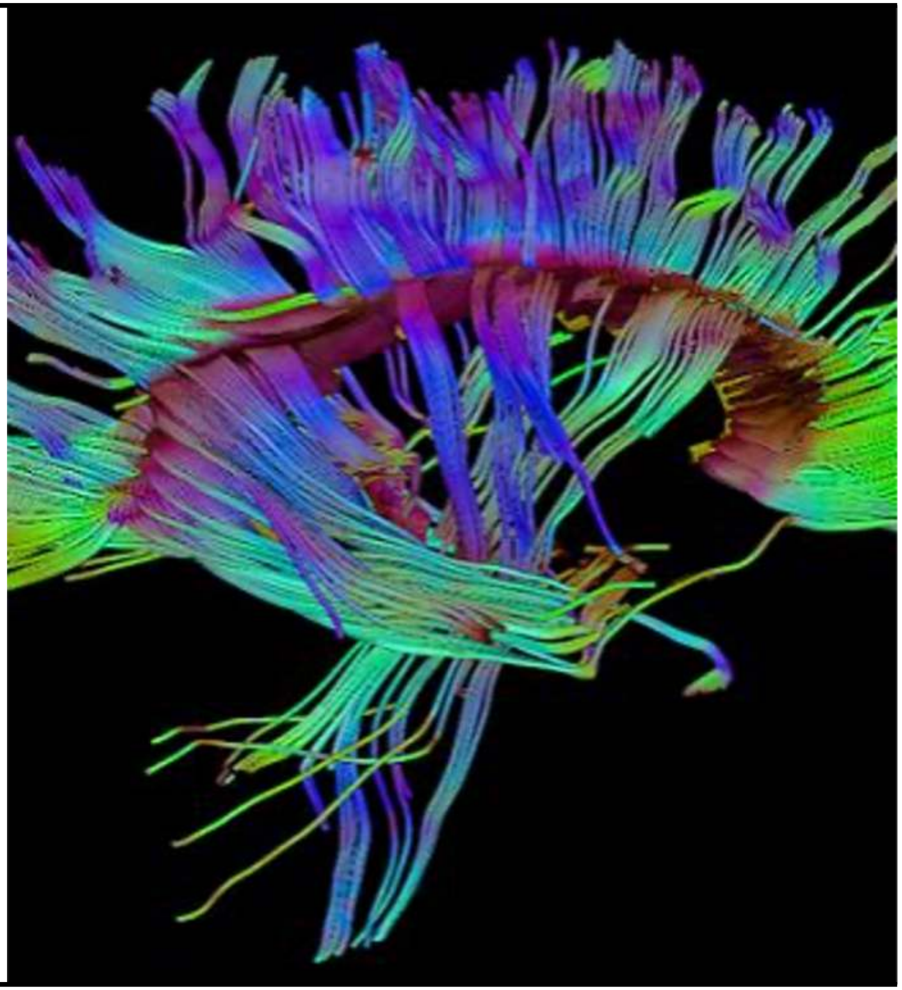
Clinical Application of DTI

- *Tracking neural fiber pathways*
- *Epilepsy*
- *Spinal cord injury*
- *Traumatic brain injury*
- *Alzheimer's disease*
- *Rehabilitation Monitoring:*

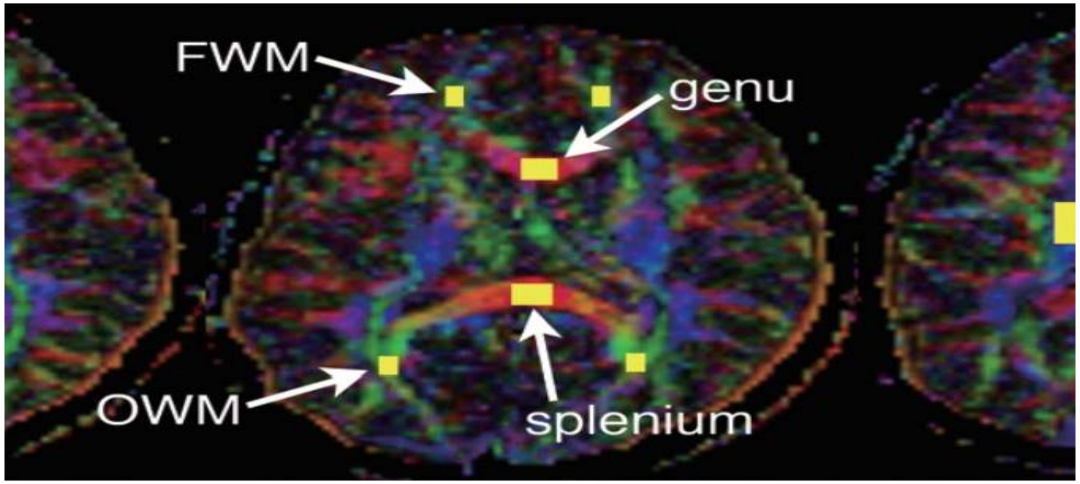


The Clinical Study

- *investigate the specific location of white matter injury in the acute stage of mild to moderate traumatic brain injury*

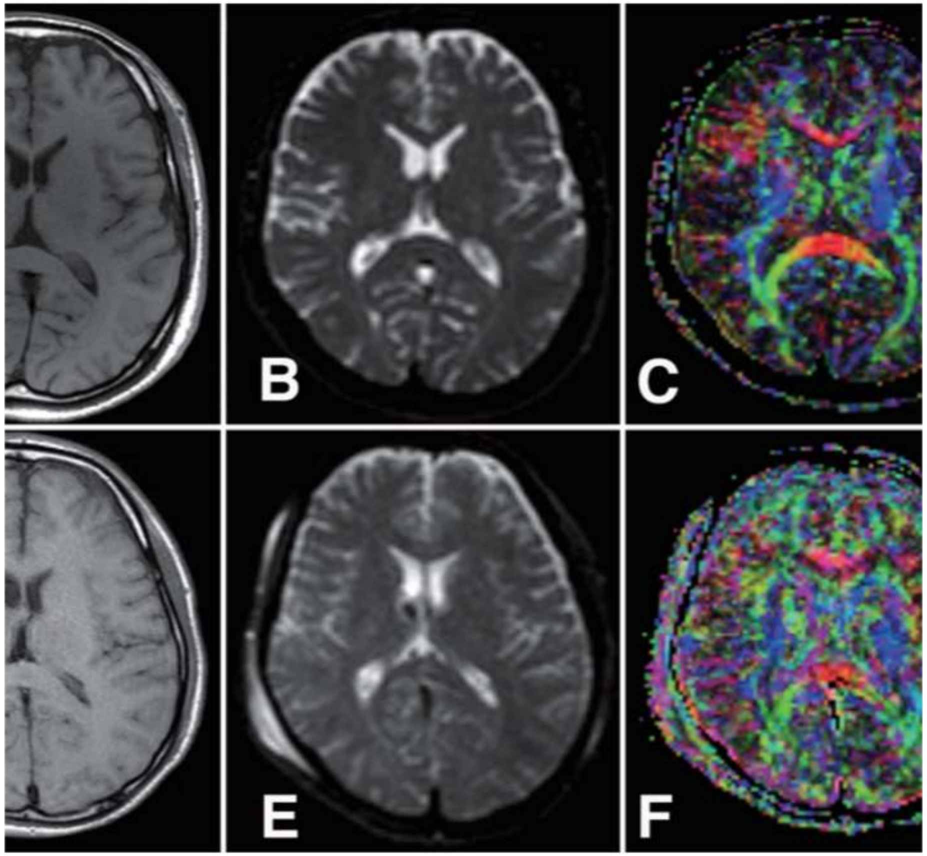


- *Used to dected the white matter lesions in the corpus callosum of patients with mild brain injury.*
- *DTI is able to detect these lesion where may not be visible on conventional imaging such as T1- or T2-weighted MR imaging.*
- *neuropsychological testing showed FA reductions in splenium and frontal white matter in the acute stage of TBI may serve as prognostic factors for long-term cognitive dysfunction.,*



Results

- Only DT imaging clearly demonstrates a reduction of FA in the splenium of the patient with TBI as compared with that in the healthy control.



ː images obtained in a healthy volunteer **(A–C)** and a patient with TBI **(D–F)**. Axial T1-weighted M
eighted images **(B and E)**. Axial DT images **(C and F)**. Only DT imaging clearly demonstrates a
of the patient with TBI as compared with that in the healthy control.

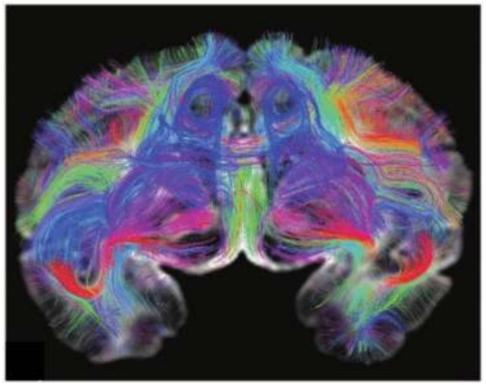
Advantages vs Disadvantges

+ Excellent detail of the brain
+ 3D visualization of neuronal pathways
+ Reduced distortion

- Image disortion
- Lower spatial resolution results in lower pixels blurry images
- Immense computing power and expertise

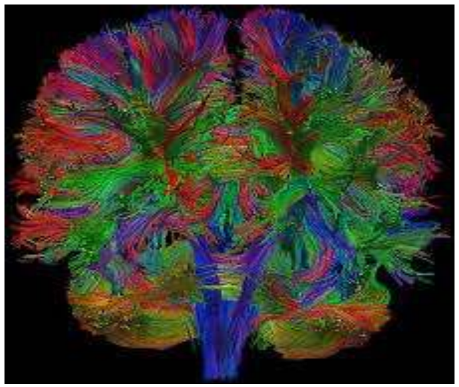
Diffusion Spectrum Imaging

- Captures diffusion in all direction
- High angular resolution, capturing complex fiber orientations accurately.
- Excellent where multiple fiber pathways intersect, providing a more accurate representation of complex fiber structures



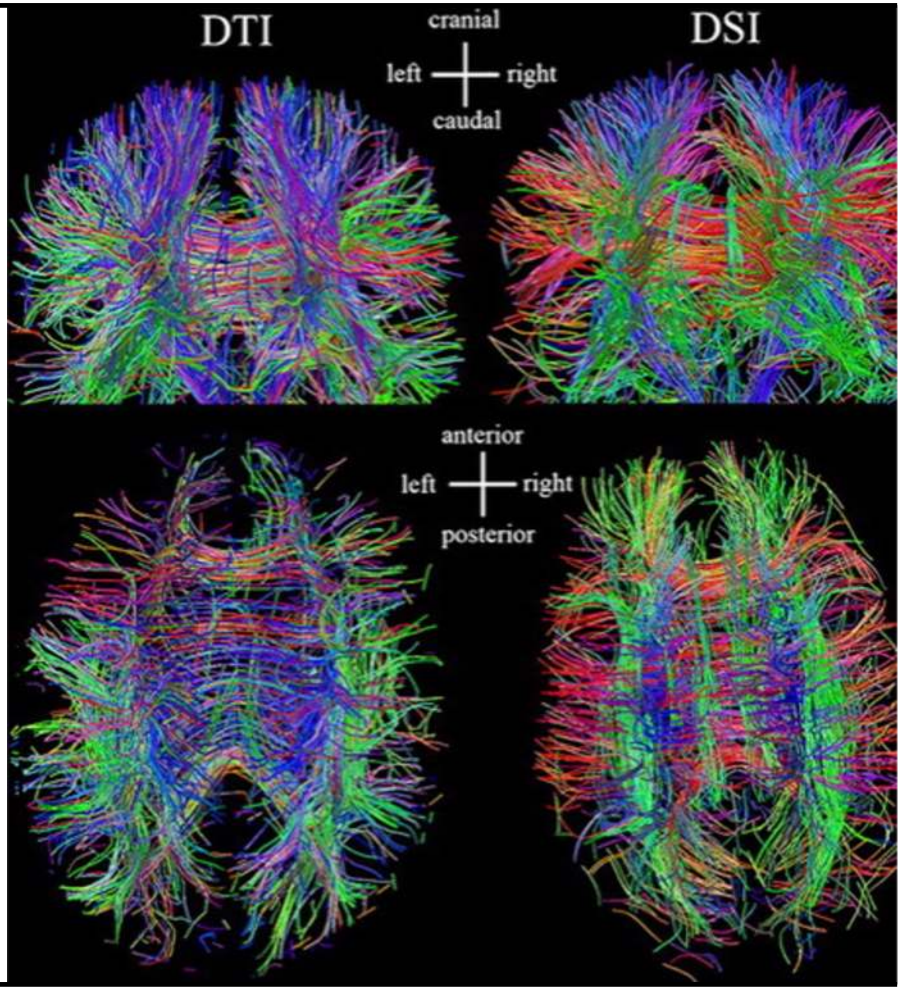
Diffusion Tensor Imaging

- Uses a single tensor for indicating diffusion
- Limited in resolving multiple fiber orientations within a voxel due to its single tensor model.
- Sensitivity struggle with crossing fibers, leading to inaccuracies



Future Direction

The Diffusion Spectrum Imaging



Thank You