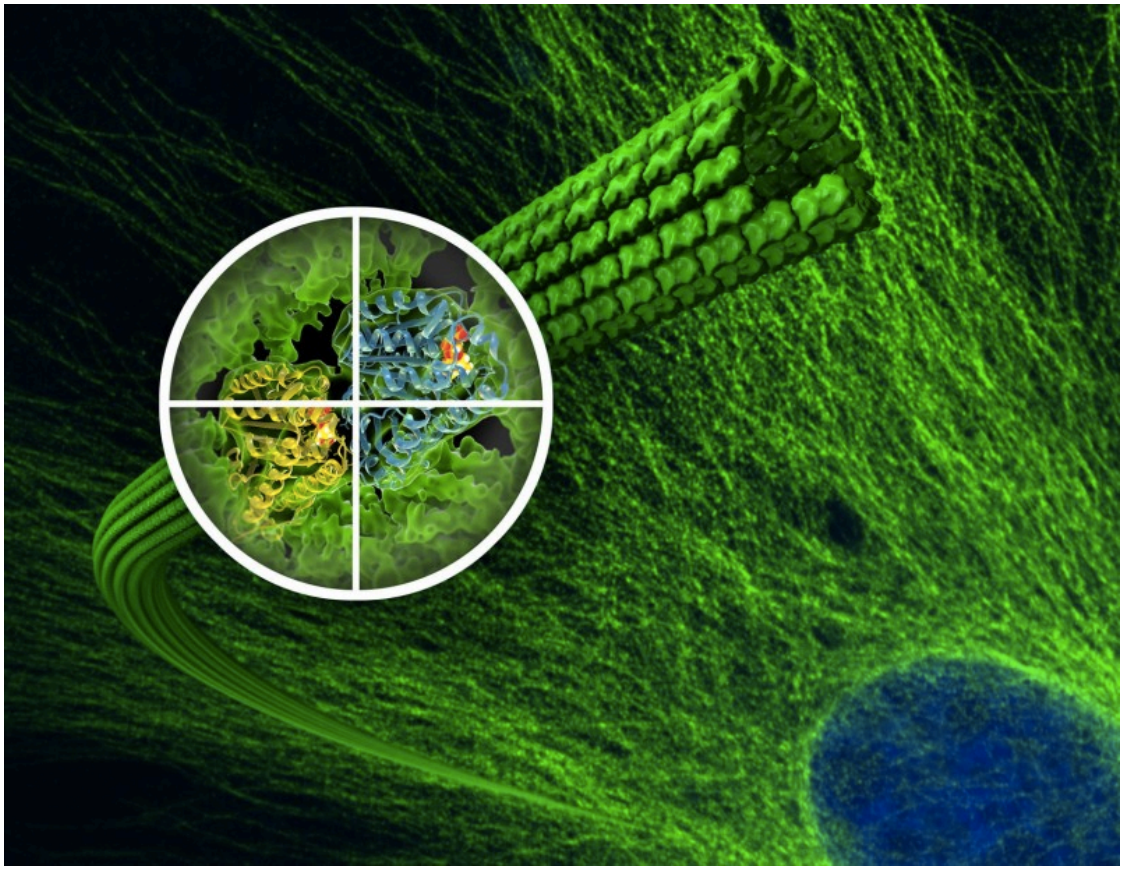
Of microtubules & water molecules:

Physics and physiology of diffusion weighted imaging



Virtual Neuroanatomy

Lecture Date: 08/28/2014

Class website is up!

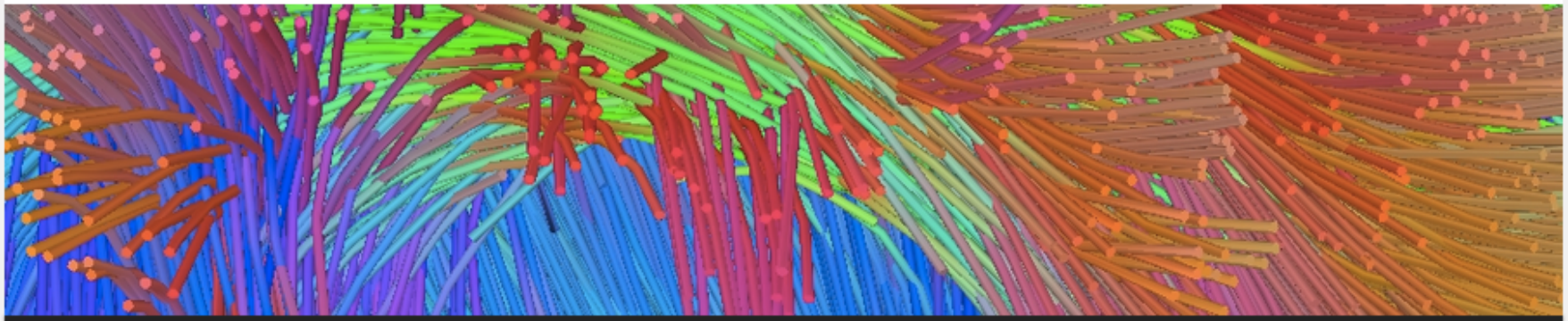
www.psy.cmu.edu/~coaxlab/?page_id=535

Cognitive Axon Lab | 3 | + New | Edit Page | Howdy, coaxlab

Cognitive Axon Lab

Understanding why white matter matters

Search



Home | **Courses** | People | Projects | Publications | Resources | The Media Page

Edit

Location: Tuesdays & Thursdays, 3--4:20pm Baker Hall 332P

Course Overview:

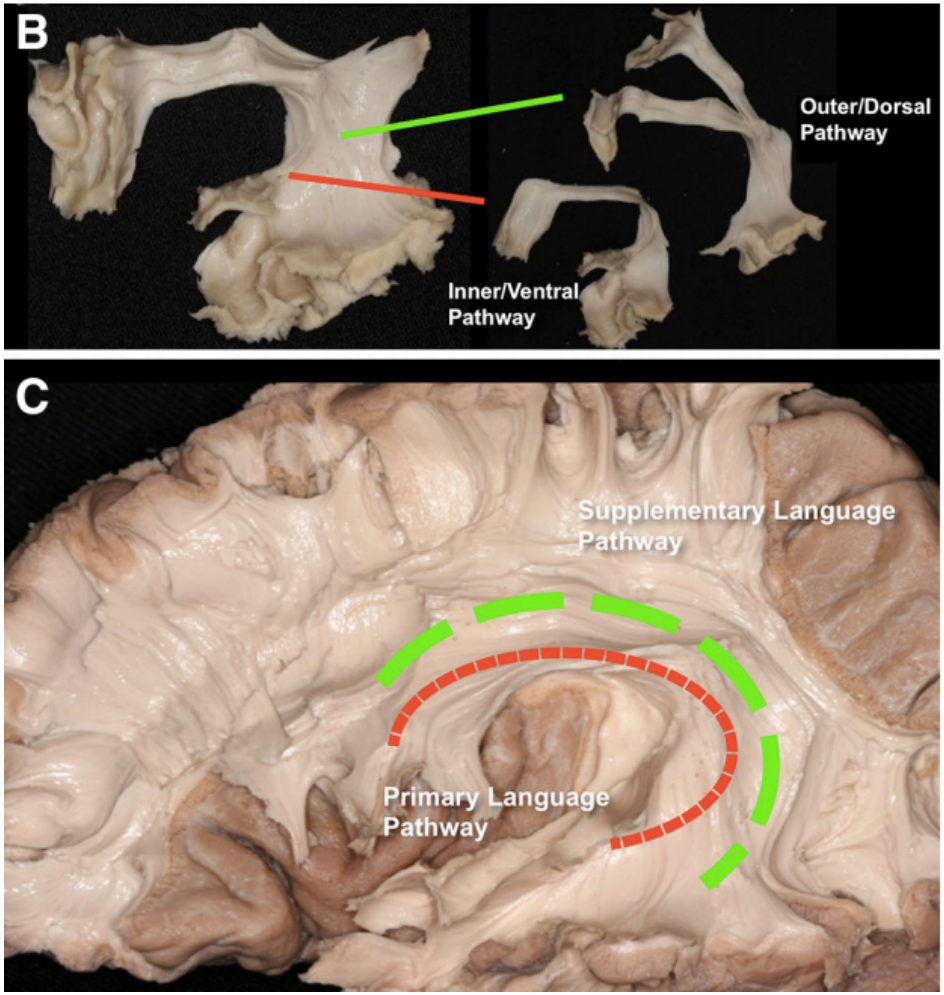
This course will explore the macroscopic organization of the human brain by combining "virtual dissections" of white matter pathways (fiber tractography on diffusion weighted imaging data) with meta--analytic databases of brain--behavior relationships (e.g., www.neurosynth.org) and reviews of functional neuroanatomy texts. Through hands-on data analysis and literature reviews, students will acquire the necessary skills for exploring neuroanatomical connectivity in vivo, using diffusion weighted imaging, as well as learn basic principles of functional organization in the brain

Learning Goals

- How does water diffusion reflect white mattter structure?
- What are the basic principles of NMR?
- How does water diffusion influence the NMR signal in order to detect directionally dependent water?

Why diffusion imaging?

- White matter is organized in bundles.
- Anatomical pathways constrain the types of computations that the brain can perform.
- Need a way to visualize these pathways in the living brain.



Fernandez-Miranda et al,, *Brain Struct Func (in press)*

Physics of MRI

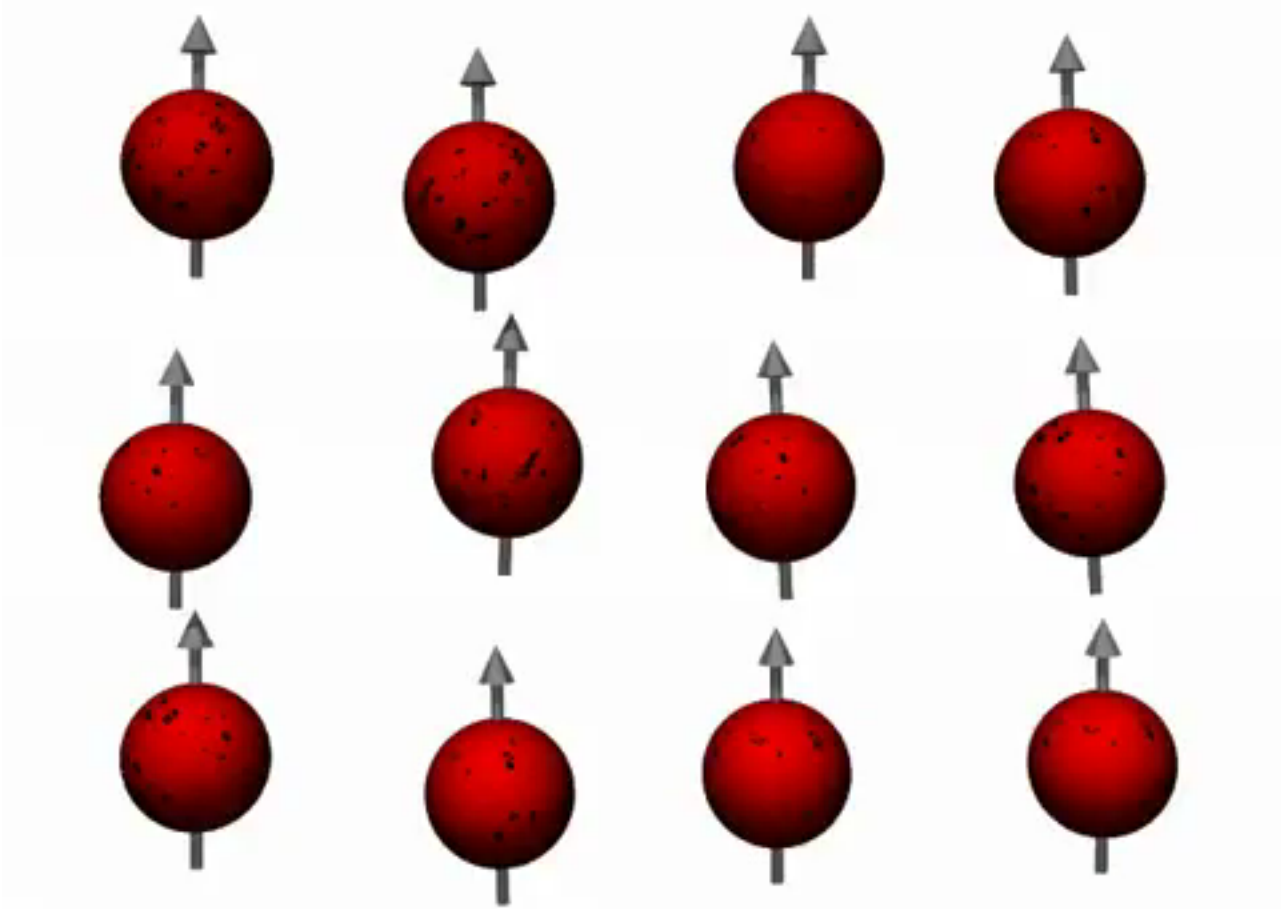
Nuclear Magnetic Resonance (NMR)

Introductory NMR and MRI
with Paul Callaghan

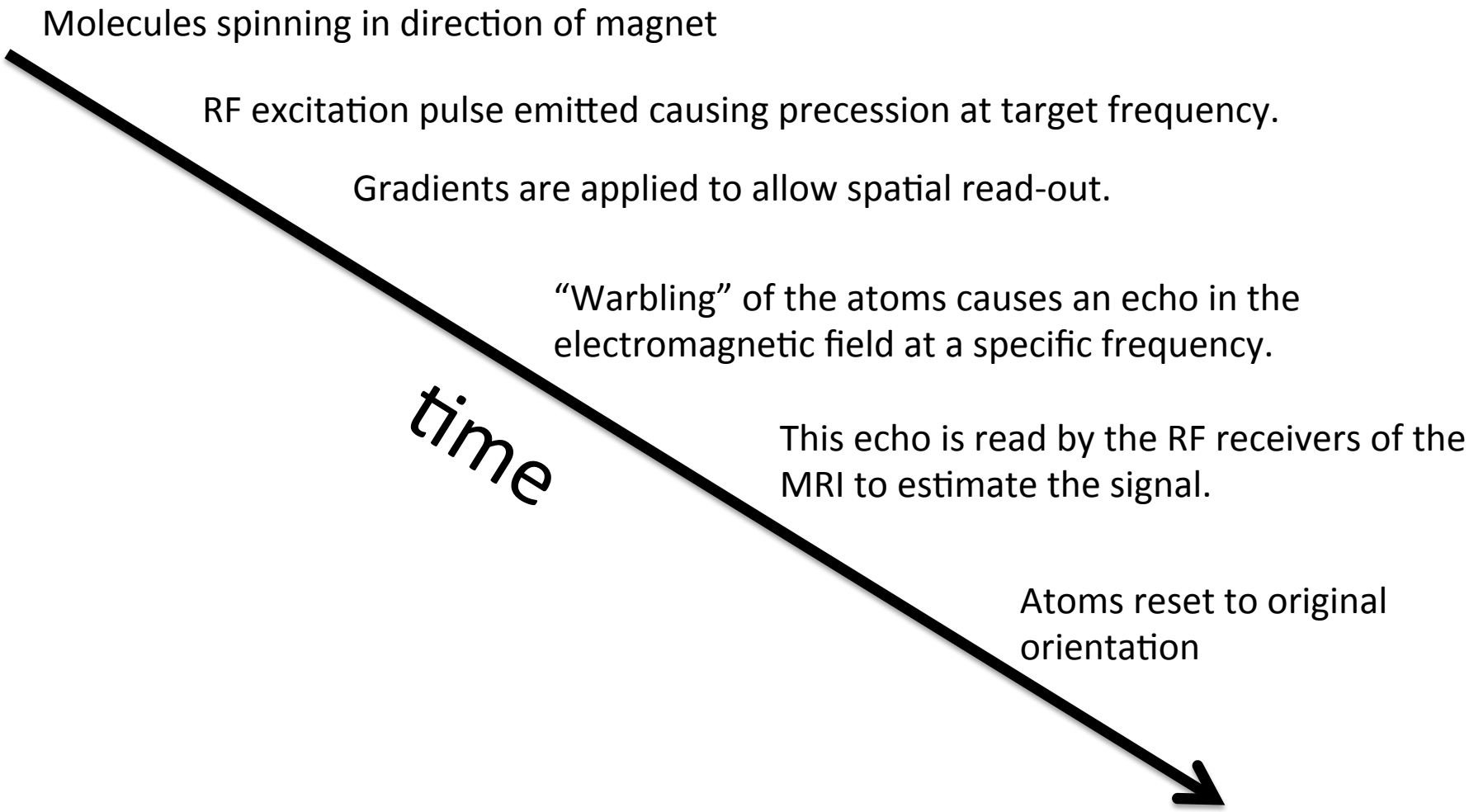
Video 1
Precession and Resonance

A conceptual-level example of NMR

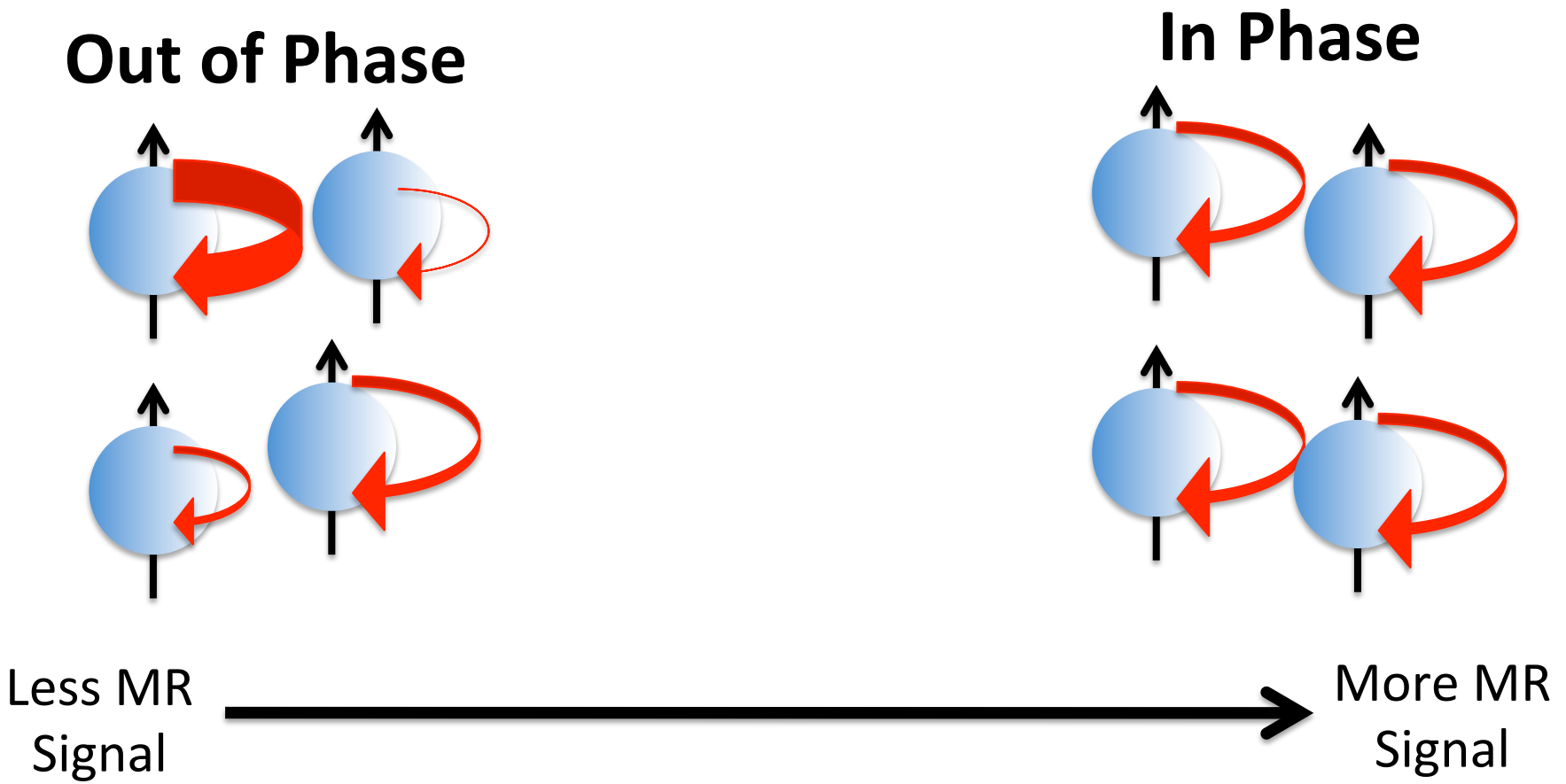
Nuclear Magnetic Resonance (NMR)



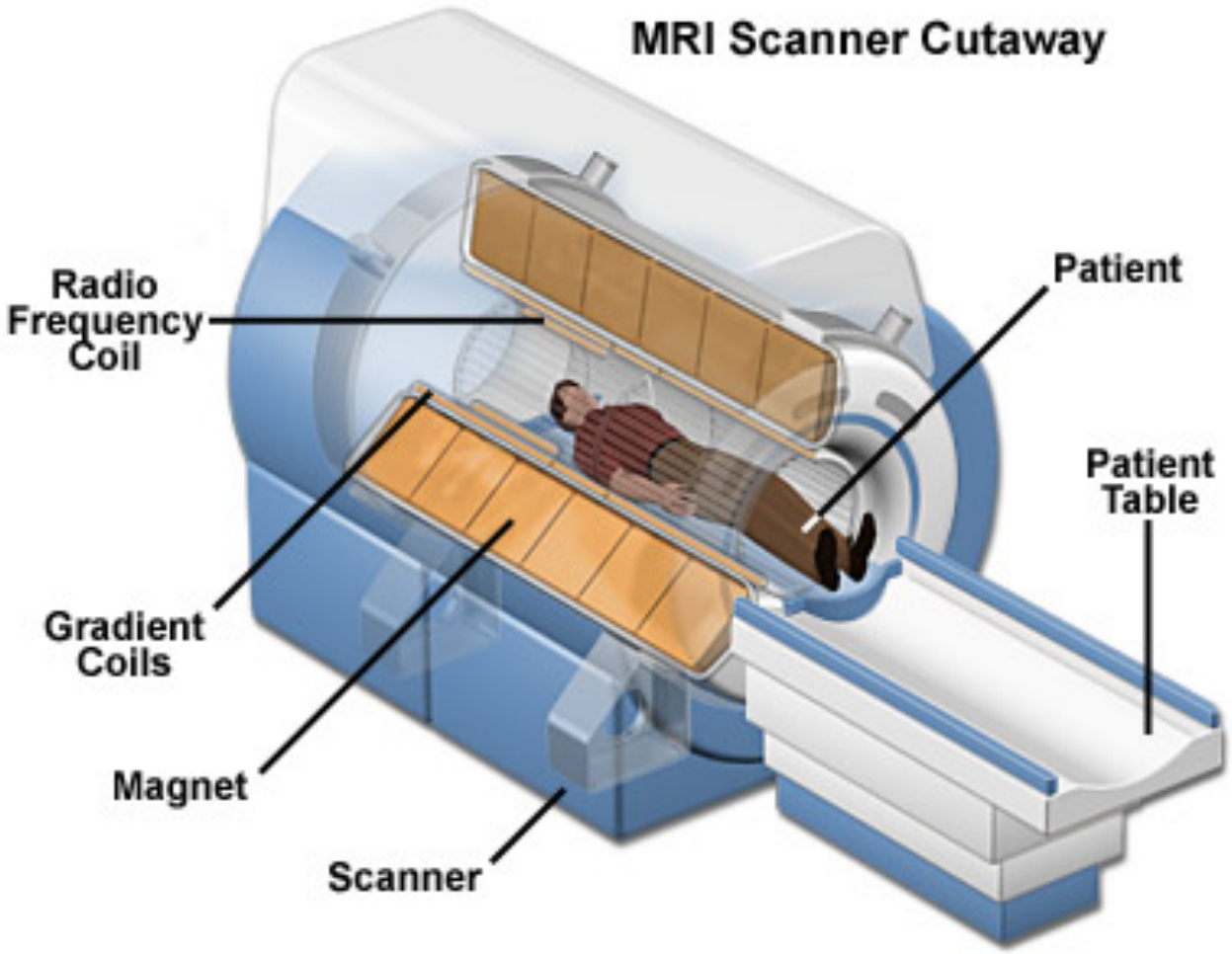
Nuclear Magnetic Resonance (NMR)



Nuclear Magnetic Resonance (NMR)



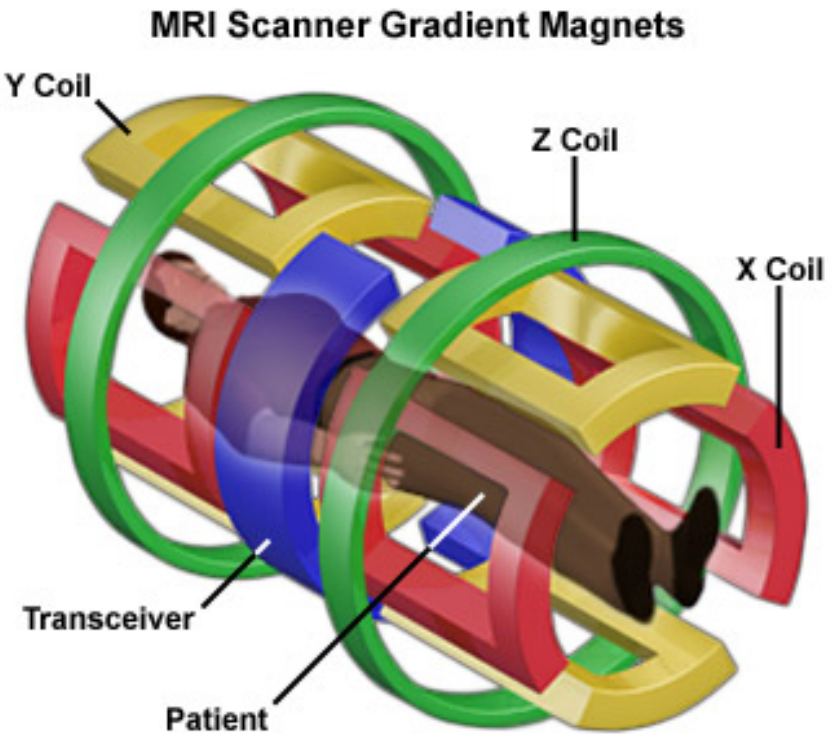
Anatomy of MRI



Anatomy of MRI

- **The Magnet/Bore:** Primary magnet that induces the magnetic field (B0, “b-zero”).
- **The Radio Frequency (RF) Transmitter Coil**: The transmitter that emits RF pulses at specific frequencies in order to cause precession.
- **The Gradient coils**: Three magnets aligned along different planes that modulate the field to allow for you to read out the signal.
- **The RF Receiver Coil**: Reads the signals from the perturbed atoms as they recover their spin.

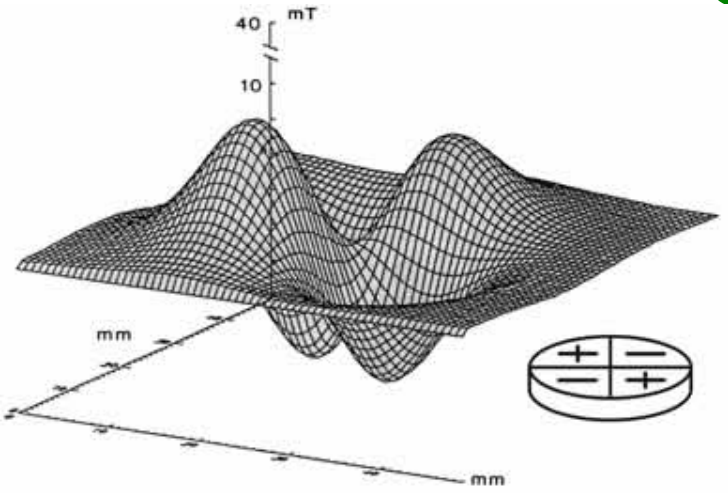
Anatomy of MRI

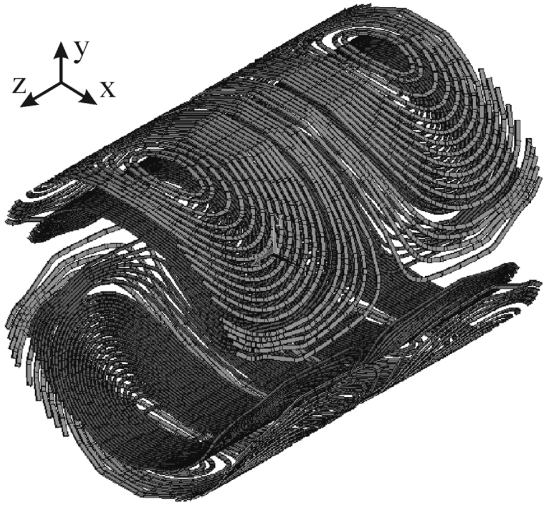


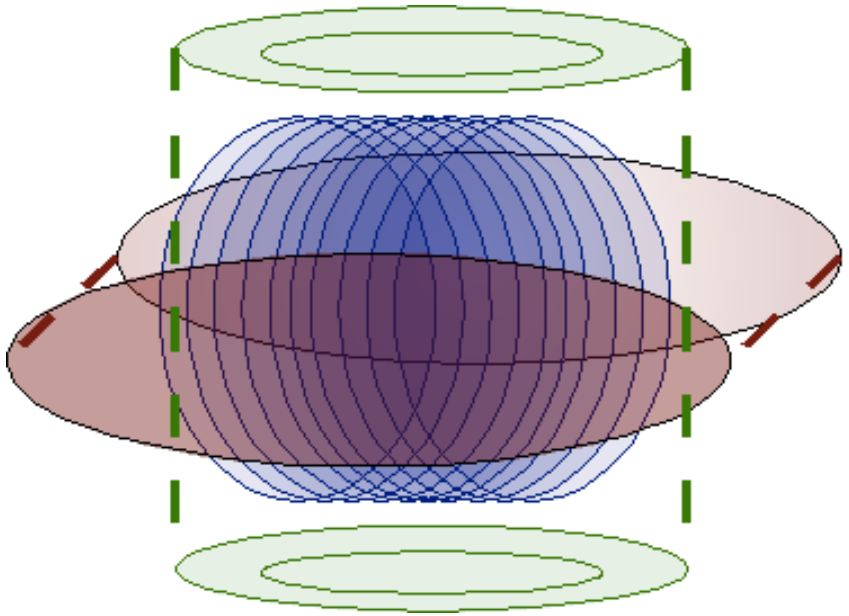
Gx = Slice Selection Gradient
Gy = Frequency-encoding Gradient
Gz = Phase-encoding Gradient

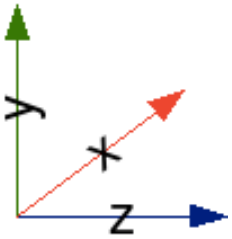
Frequency-encoding (Gy) often referred to as the "read-out" direction.

Gradients



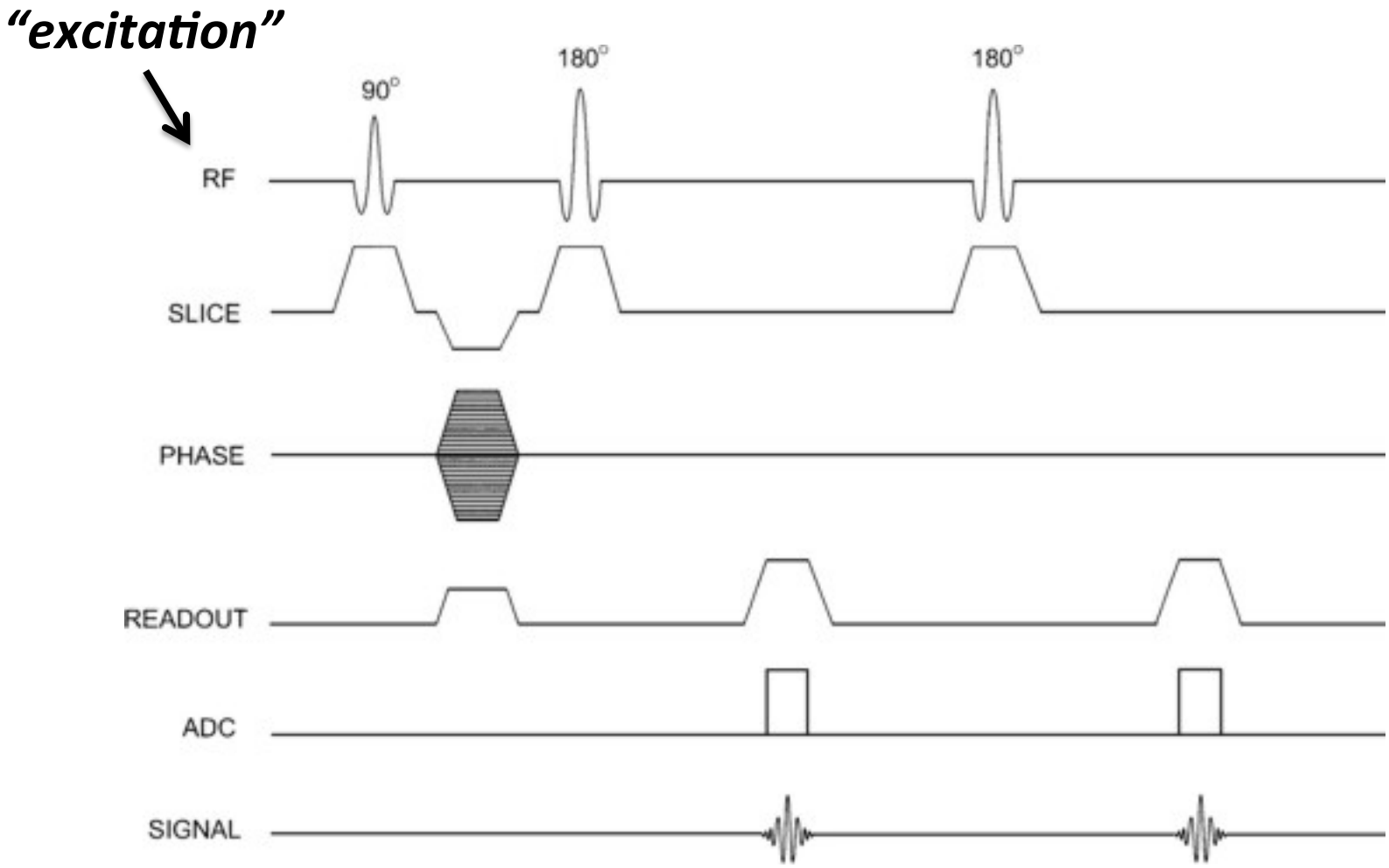






How can you read signal from a particular point in space

Pulse Sequence Diagram



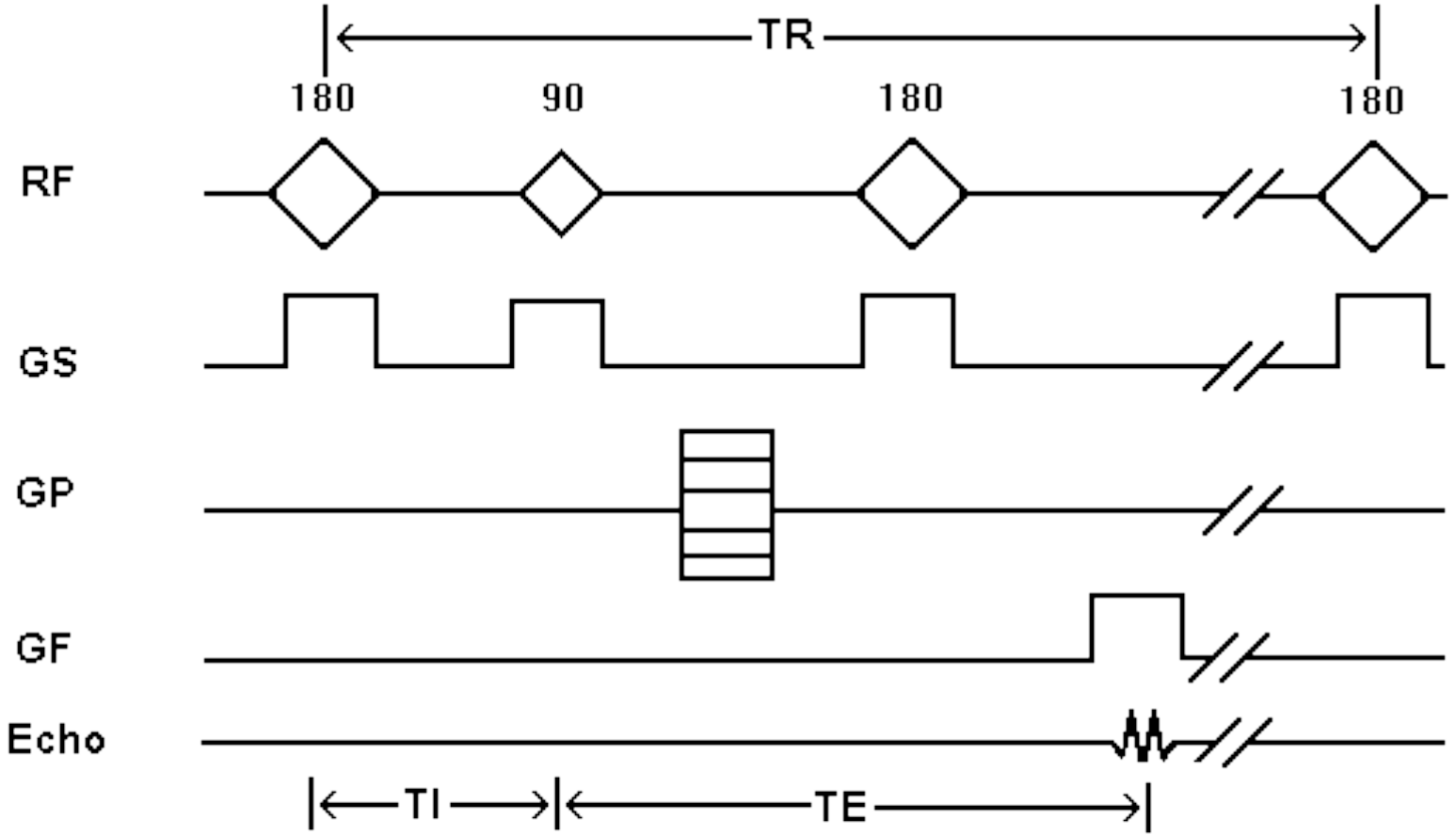
Key Terms

- **Echo Time (TE):** The time interval between an excitation pulse and data acquisition (usually in milliseconds).

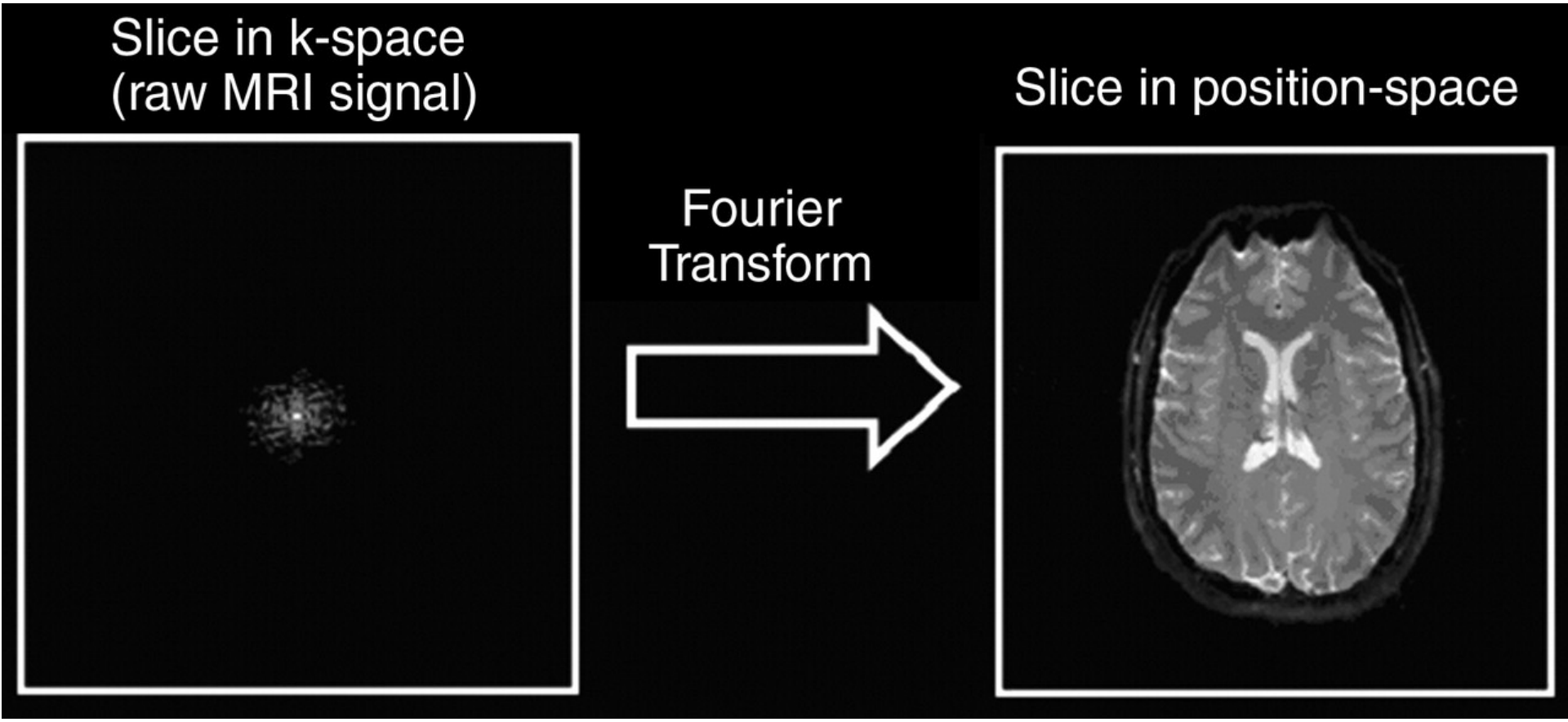
- **Repetition Time (TR)**: The time interval between successive excitation pulses (usually in seconds).

- **Flip Angle**: The change in the precession angle of the net magnetization following excitation (usually in degrees).
  - Think of the torque on the wheel form the video.

Pulse Sequence



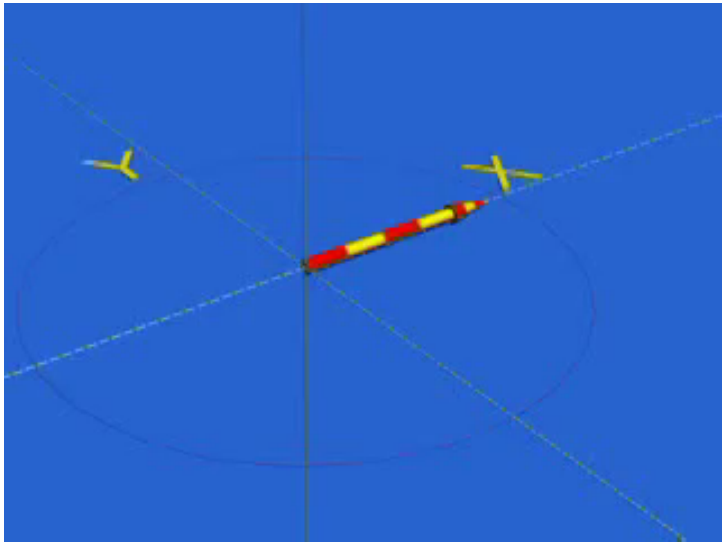
K-Space vs. Image Space



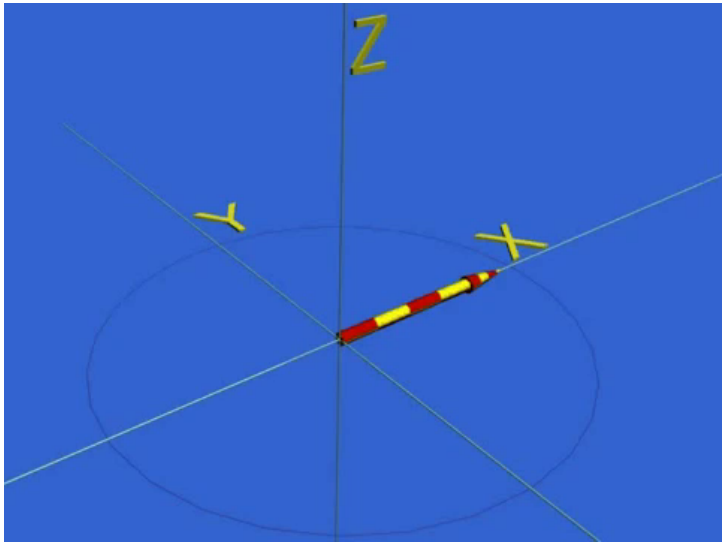
Images are encoded in a frequency space (phase by angle) when they first come off of the scanner and have to be transformed to look like a spatial image.

Types of NMR Images

- **T2-weighted:** Images that provide information about the relative time-constant of recovery of spins along the transverse component of net magnetization.



90-degree RF Pulse



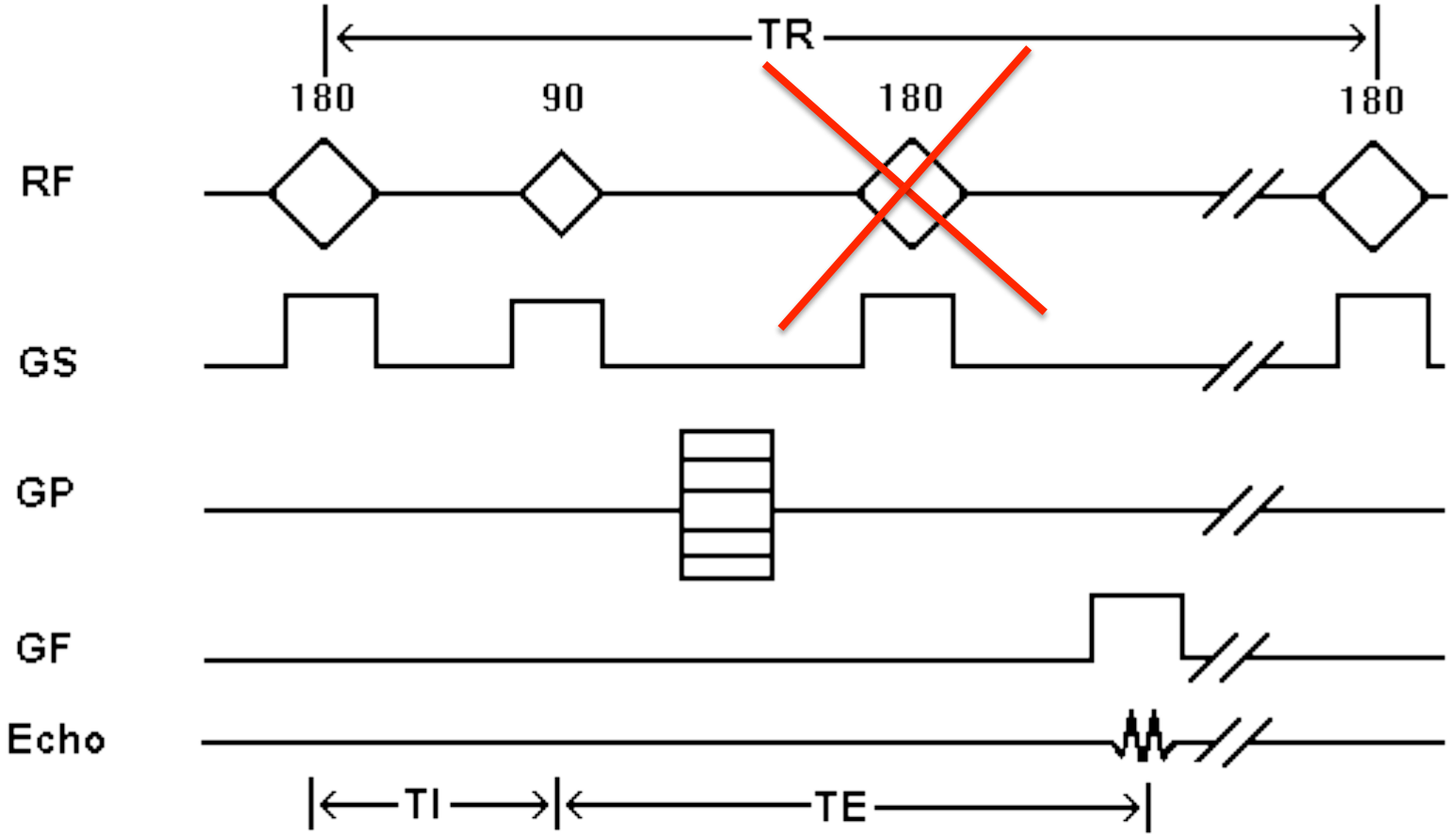
180-degree RF Pulse

Types of NMR Images

- **T2-weighted:** Images that provide information about the relative time-constant of recovery of spins along the transverse component of net magnetization.

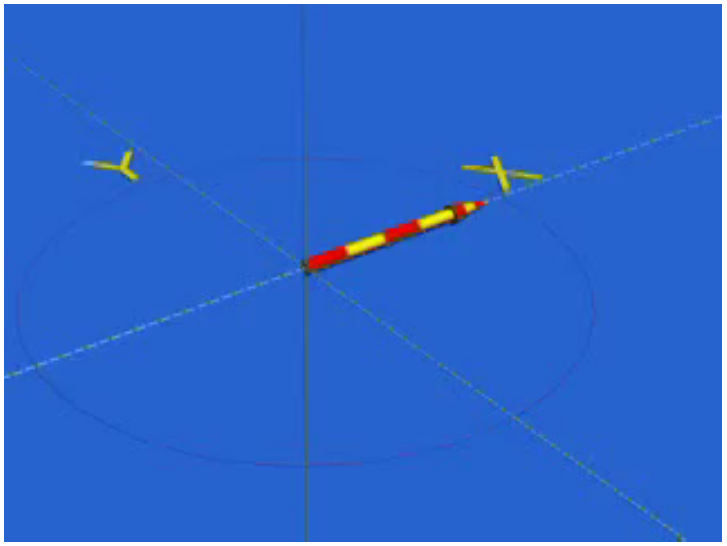
Tissues with more water appear brighter than tissues with more fat.

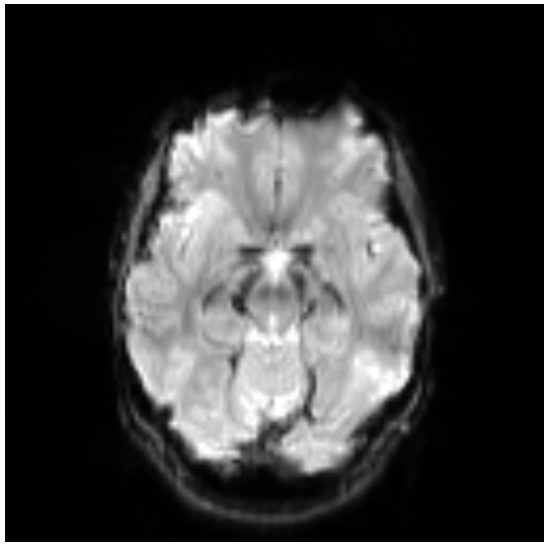
Pulse Sequence



Types of NMR Images

- **T2*-weighted:** Similar to a T2-weighted image, except without the 180-degree refocusing RF pulse. Sensitive to spin interactions and local field inhomogeneities.

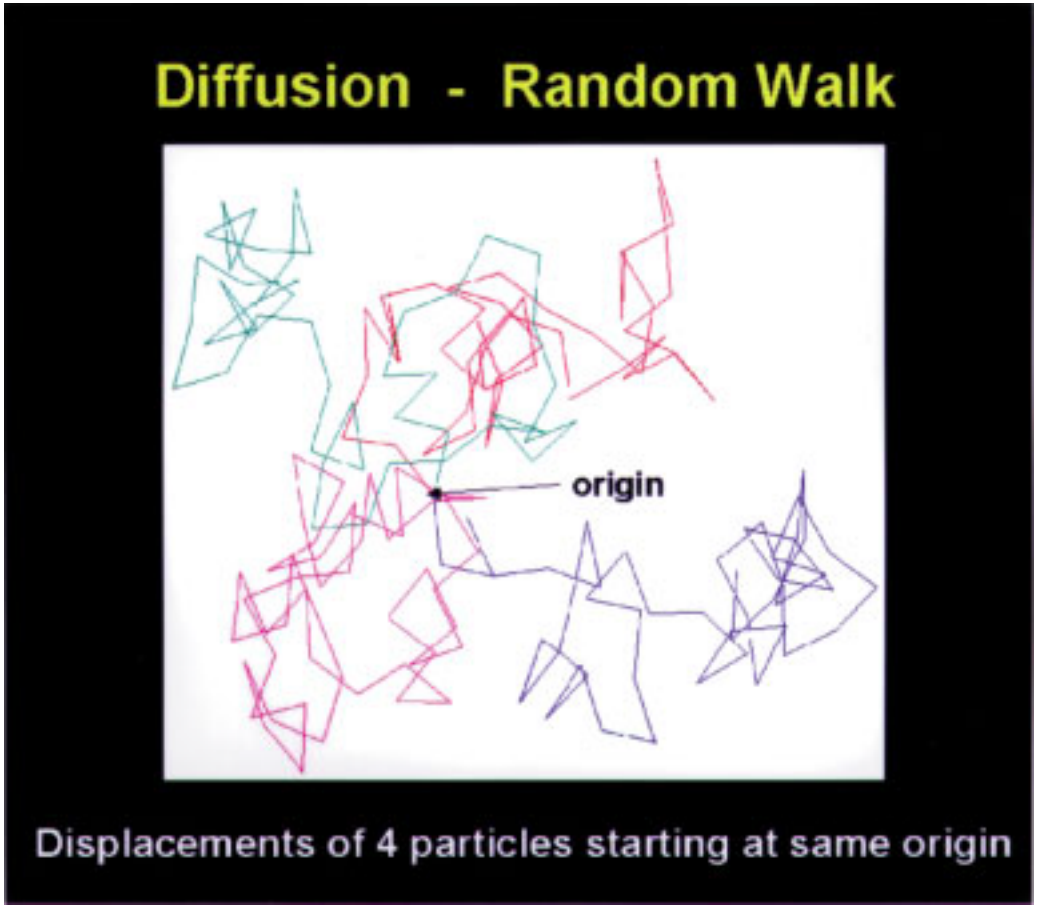




Much faster acquisition time, but lower signal-to-noise.
Are particularly sensitive to changes in deoxygenated hemoglobin.

Principles of water diffusion in the brain

What is water diffusion?

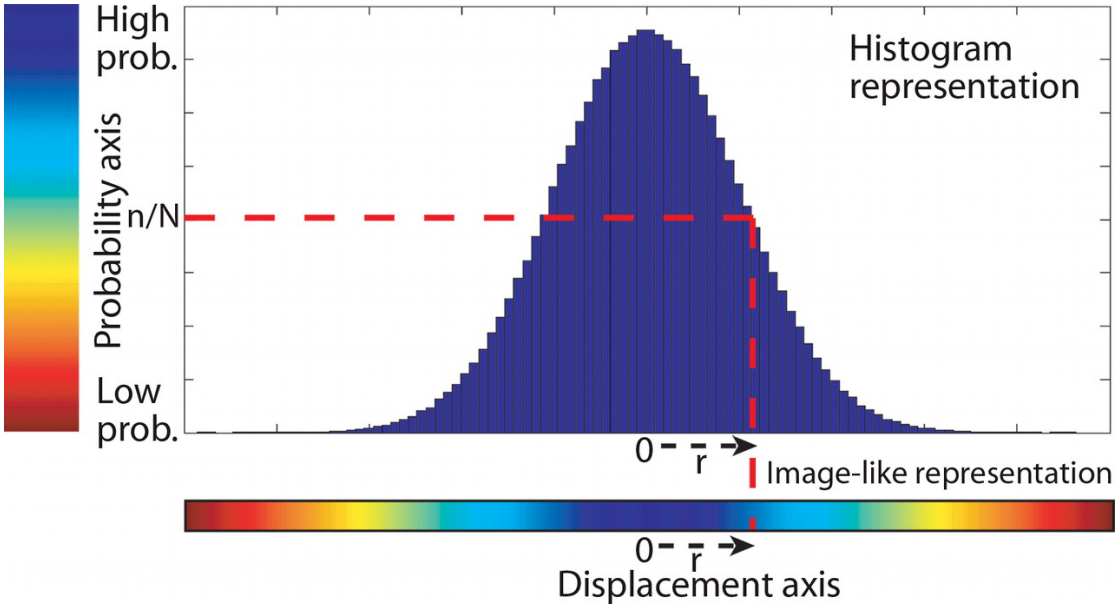


Two things you want to determine from water motion:

1) Distance
2) Direction

Beaulieu NMR in Biomedicine, 2002

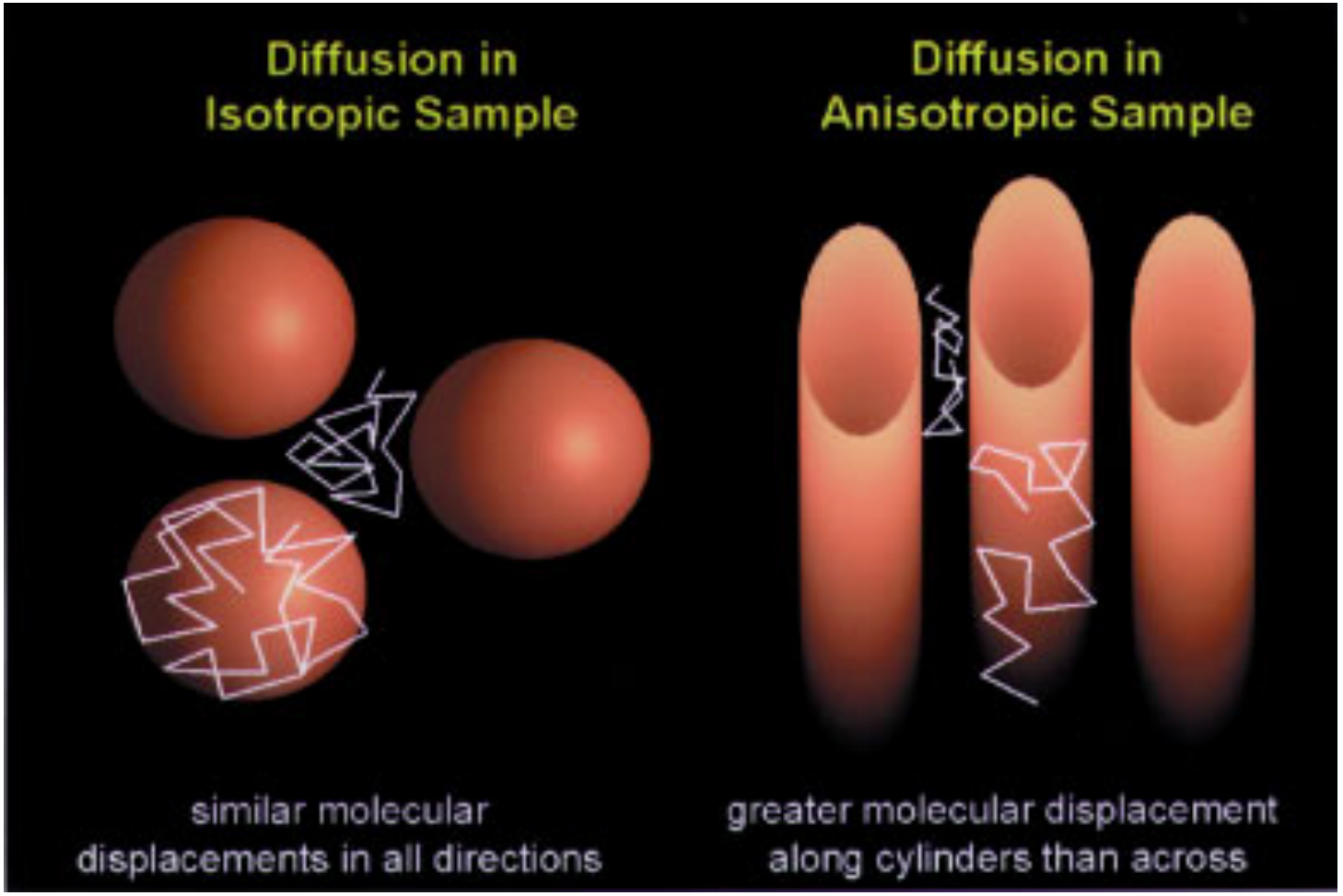
Displacement Distribution



Displacement Distribution: Proportion of molecules that are displaced a specific *distance* and *direction.*

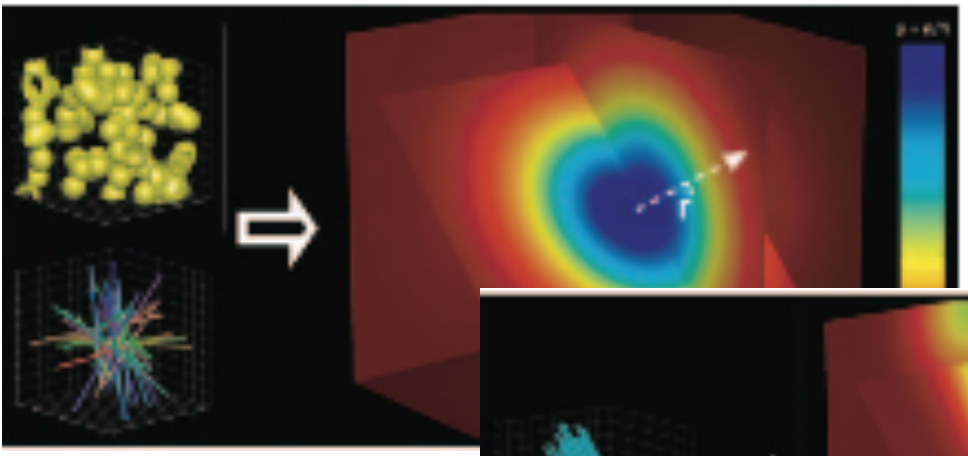
Hagmann P et al. Radiographics 2006;26:S205-S223

Displacement distributions in 3D

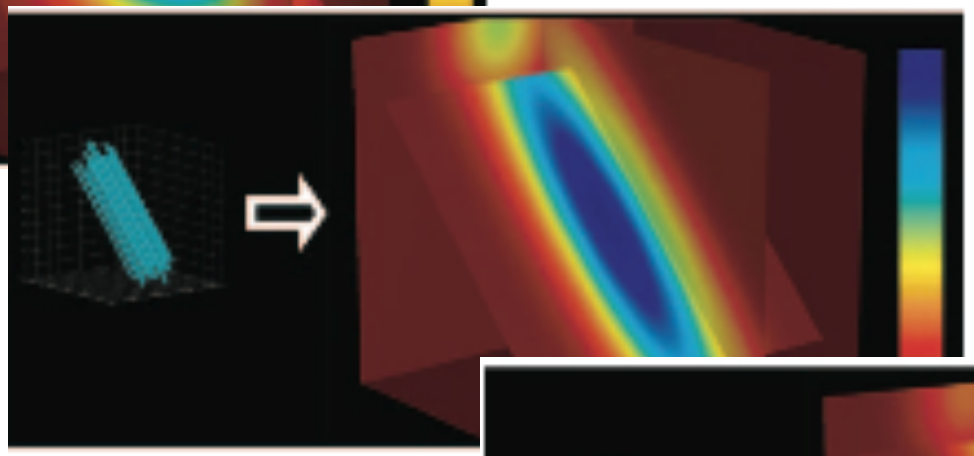


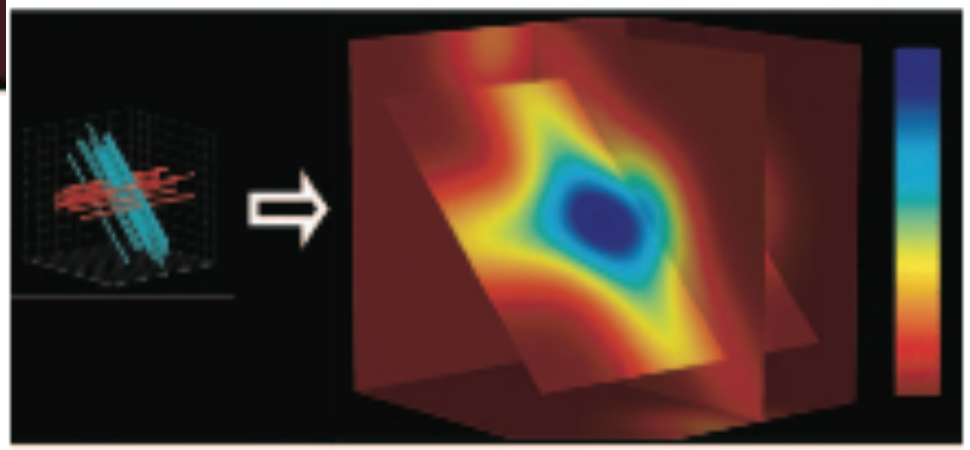
Beaulieu NMR in Biomedicine, 2002

Displacement distributions in 3D



One barrier



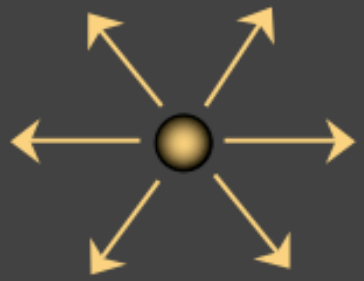


Two crossing barriers

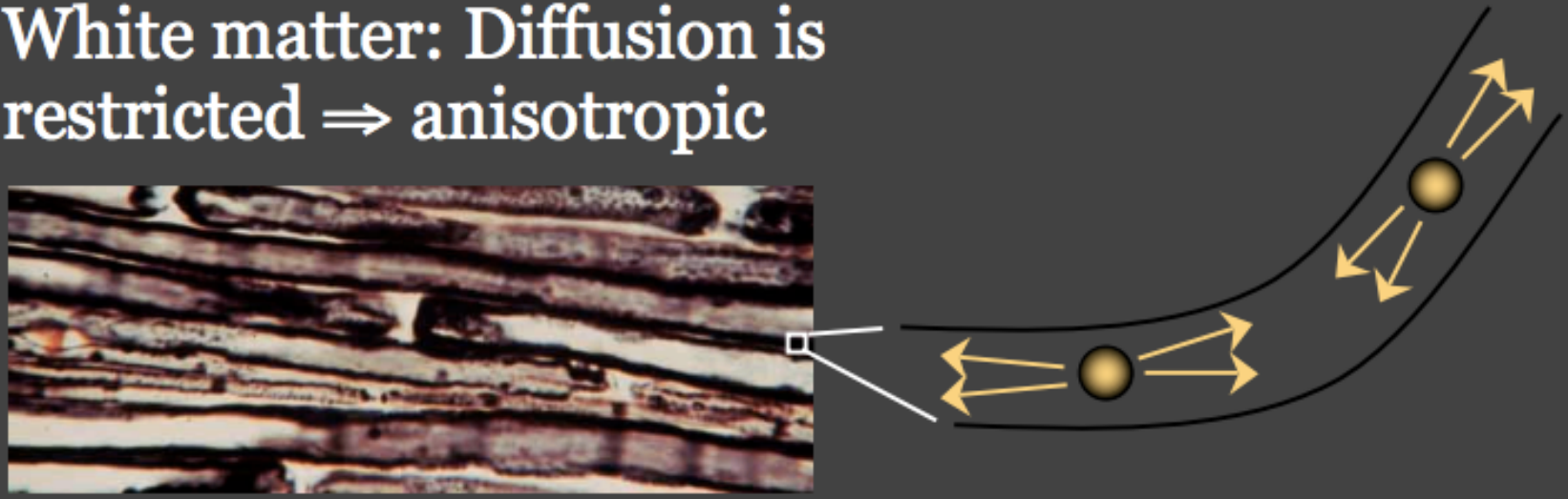
Hagmann P et al. Radiographics 2006;26:S205-S223

Barriers to water diffusion in the brain

- Gray matter: Diffusion is unrestricted ⇒ isotropic

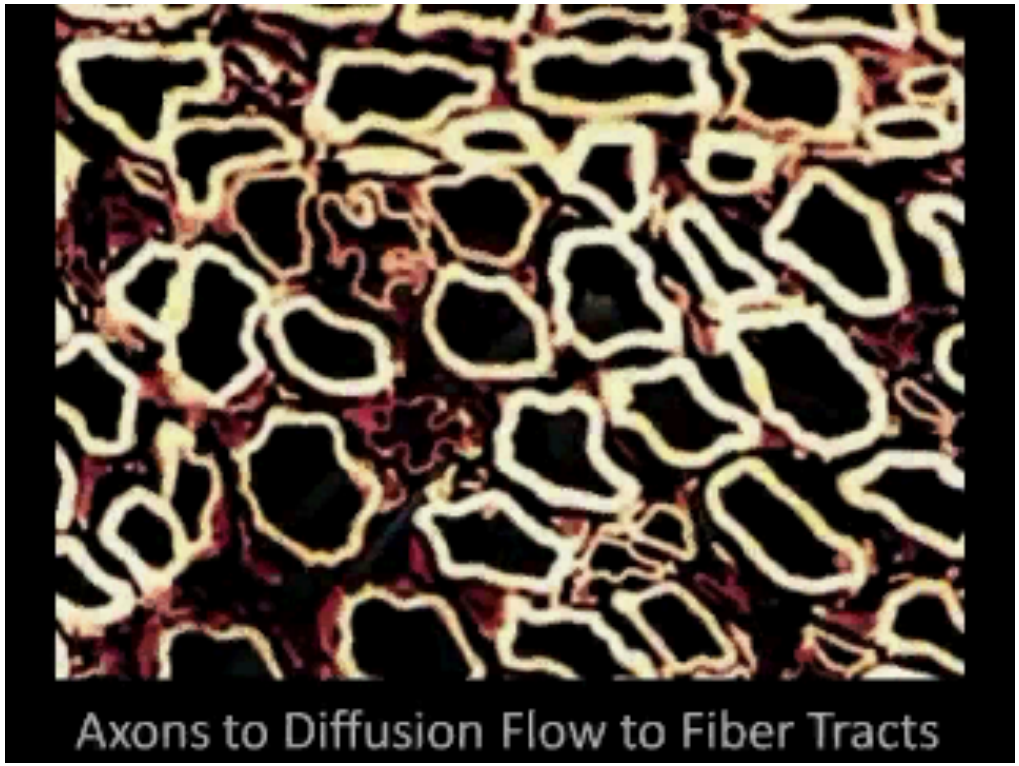


- White matter: Diffusion is restricted ⇒ anisotropic



(courtesy of Anastasia Yendiki)

Barriers to water diffusion in the brain

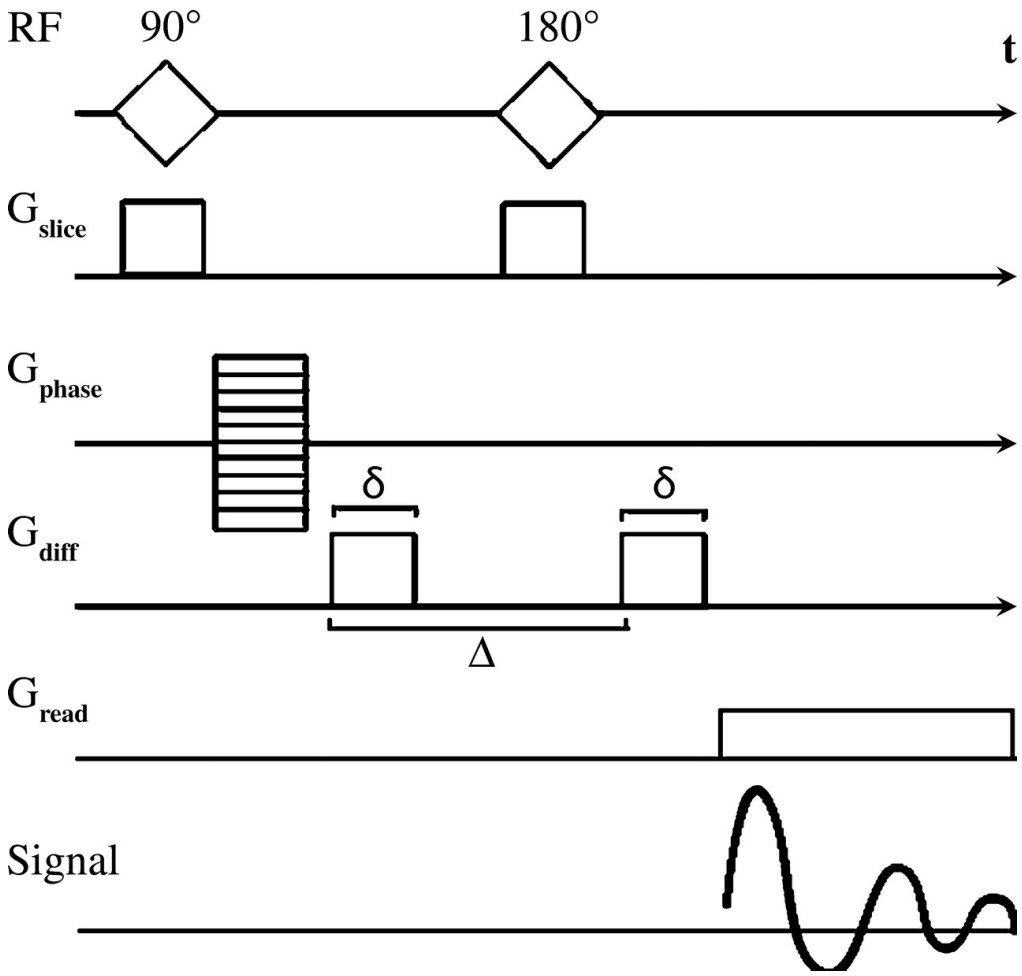


Water in axons is trapped in the microtubules so that it primarily moves along the direction of the axons.

- More MR energy required to only see water in the mircotubules.

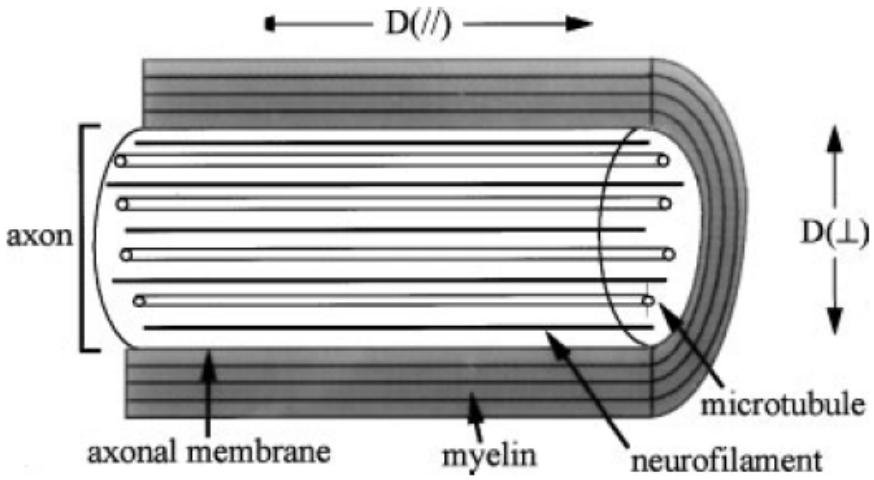
(video courtesy of Concha & Torres)

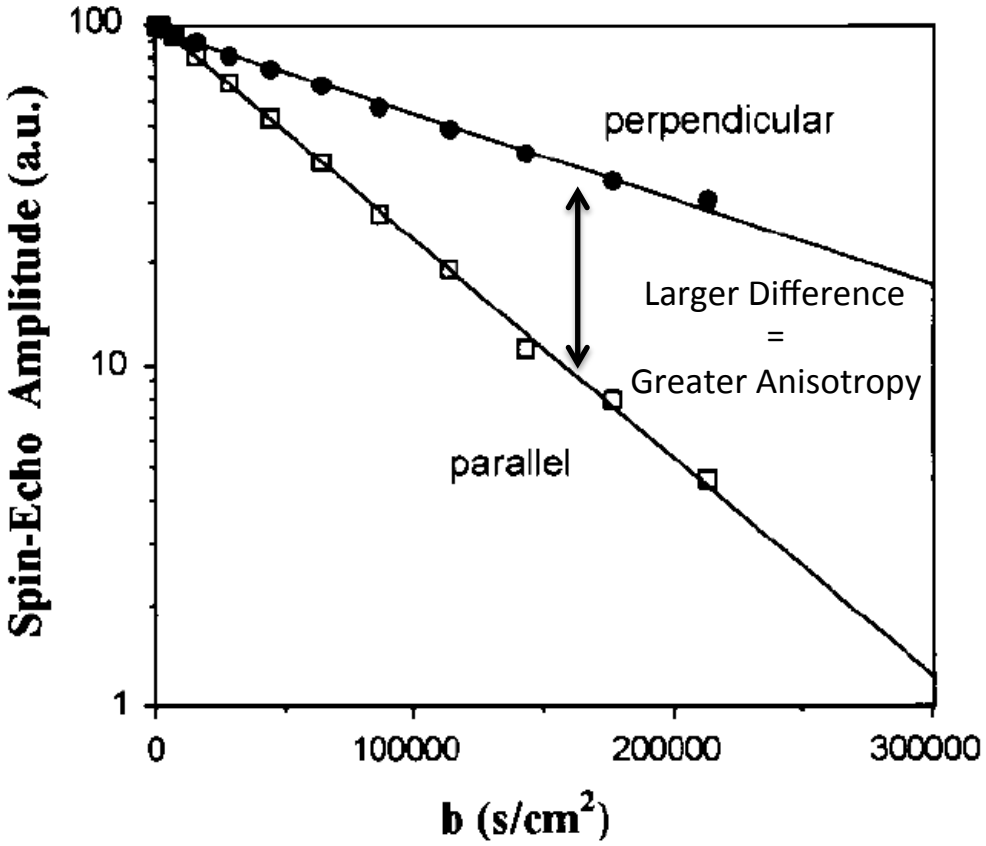
A modified T2* sequence



Hagmann P et al. Radiographics 2006;26:S205-S223

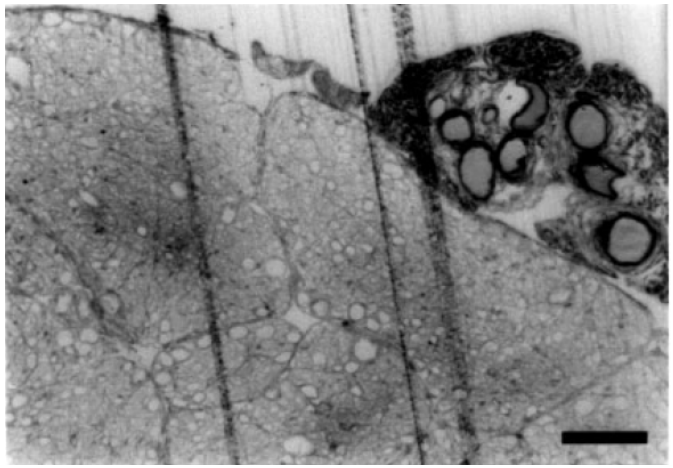
How water diffusion is detected

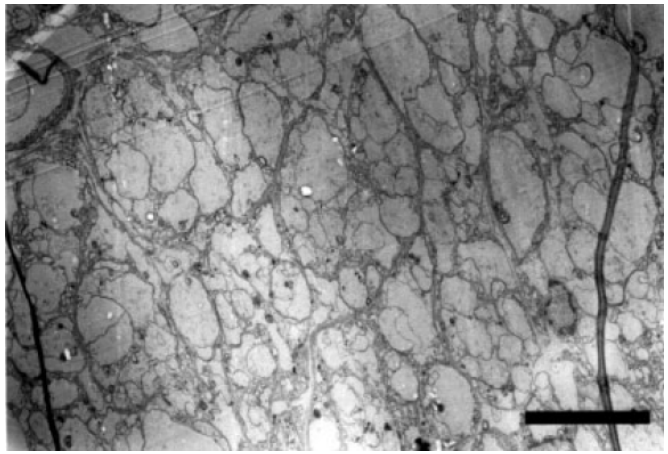




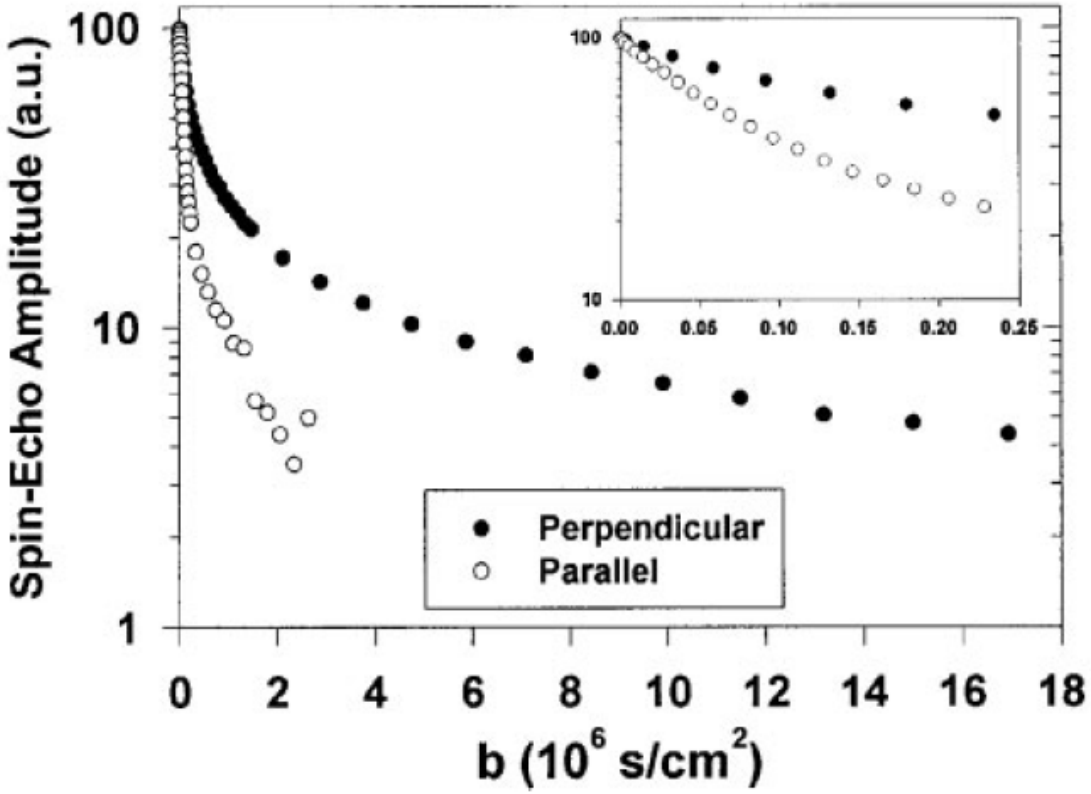
Beaulieu NMR in Biomedicine, 2002

How water diffusion is detected





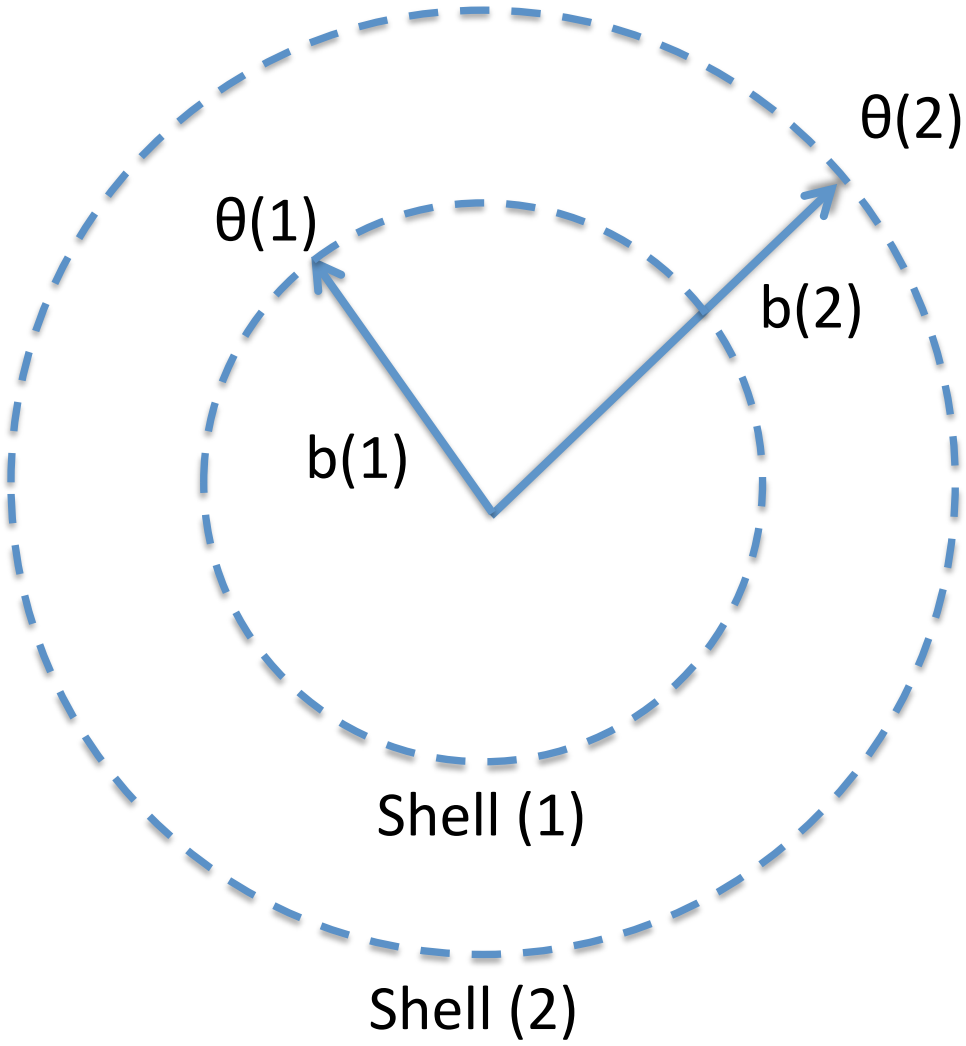
Non-myelinated axons (lobster)



Anisotropy of the signal picked up better at high b-values than low b-values.

Beaulieu NMR in Biomedicine, 2002

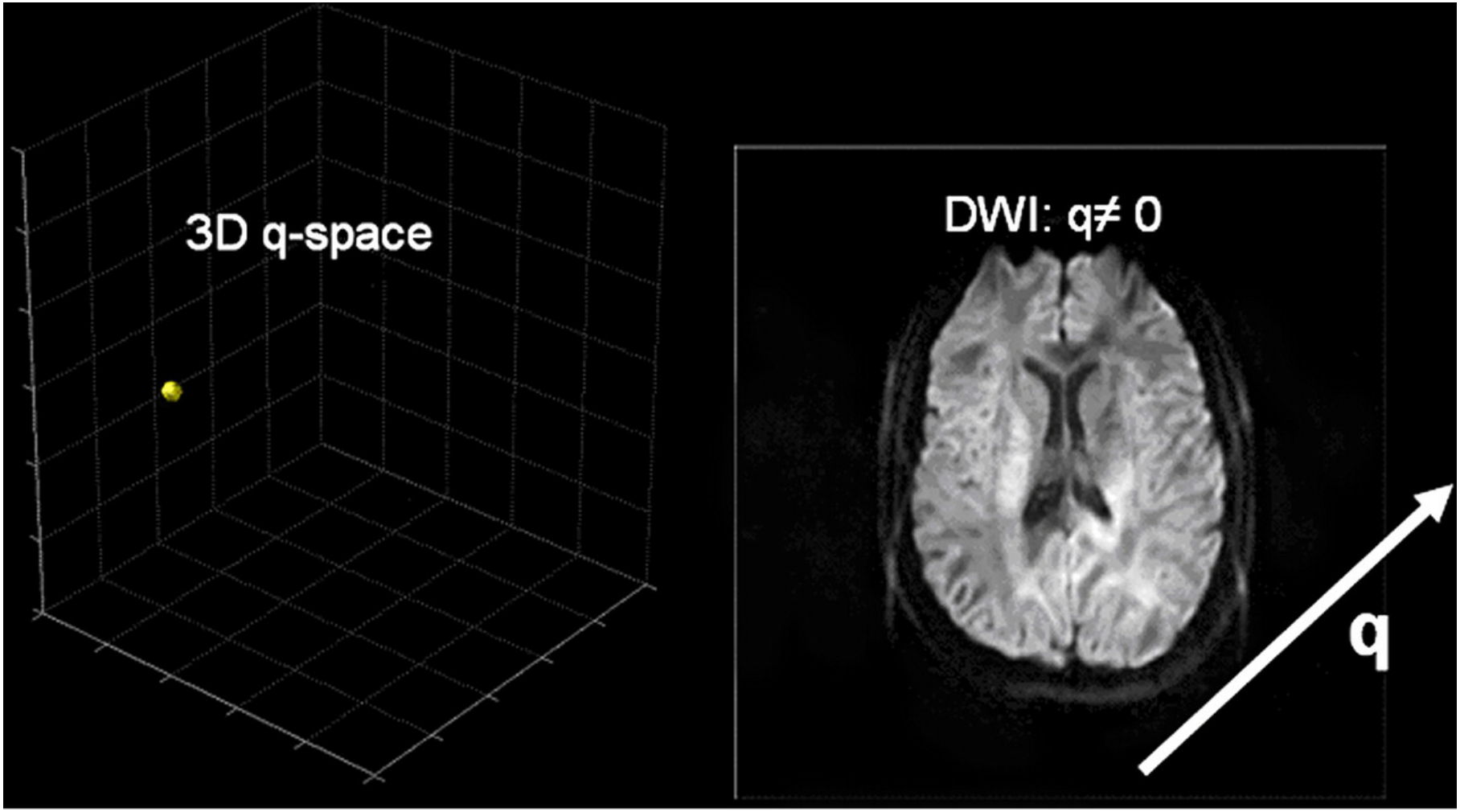
Q-Space



b-value: Strength of the diffusion gradient. Higher values = more energy & smaller compartments.

Shell: Sample of water "energy" that corresponds roughly to distance traveled.

Q-Space



Hagmann P et al. Radiographics 2006;26:S205-S223

Learning Goals

- How does water diffusion reflect white mattter structure?
- What are the basic principles of NMR?
- How does water diffusion influence the NMR signal in order to detect directionally dependent water?

For the Tuesday's class

- Hagmann P, Jonasson L, Maeder P, Thiran JP, Wedeen VJ, Meuli R. Understanding diffusion MR imaging techniques: from scalar diffusion-weighted imaging to diffusion tensor imaging and beyond. Radiographics. 2006 Oct;26 Suppl 1:S205-23

- Daducci, A., Canales-Rodriguez, E., Descoteaux, M., Gur, Y., Mani, M., Merlet, S., Ramirez-Manzanares, A., Rodrigues, P., Reisert, M., Sepehrband, F., 2013. Quantitative comparison of reconstruction methods for intra-voxel fiber recovery from diffusion MRI. IEEE Trans Med Imaging. 2014 Feb;33(2):384-99.

- Identify 3 possible pathways you would like to study.