Imaging Sequences II

M219 - Principles and Applications of MRI

Kyung Sung, Ph.D.

2/26/2024

Course Overview

- 2024 course schedule
  - https://mrrl.ucla.edu/pages/m219_2024
- Assignments
  - Homework #3 is due on 3/6
- Final exam
  - 3/18 at 2-4pm
- TA office hours, 2/28 4-5pm & 2/29 4-5pm
- Office hours, Thursday 10-12pm

Gradient Echoes & Contrast

Gradient Echo Sequences

- Spoiled Gradient Echo
  - SPGR, FLASH, T1-FFE
- Balanced Steady-State Free Precession
  - TrueFISP, FIESTA, Balanced FFE

Principal GRE Advantages

- Fast Imaging Applications
  - **Why?** *Can use a shorter TE/TR than spin echo*
  - **When?** Breath-held, realtime, & 3D volume imaging
- Flexible image contrast
  - **Why?** Adjusting TE/TR/FA controls the signal
  - **When?** Characterize a tissue for diagnosis
- Bright blood signal
  - **Why?** Inflowing spins haven't "seen" numerous RF pulses
  - **When?** Cardiovascular & angiographic applications

Principal GRE Advantages

- Low SAR
  - **Why?** Imaging flip angles are (typically) small
  - **When?** When heating risks are a concern
- Quantitative
  - **Why?** Multi-echo acquisition are practical.
  - **When?** Flow quantification & Fat/Water mapping
- Susceptibility Weighted Imaging
  - **Why?** No refocusing pulse.
  - **When?** T_2^*-weighted (hemorrhage) imaging
- More...

Principal GRE Disadvantages

- Off-resonance sensitivity
  - **Why?** No refocusing pulse
    - Field inhomogeneity, Susceptibility, & Chemical shift

- T_2^*-weighted rather than T_2-weighted
  - **Why?** No re-focusing pulse
    - Spin-spin dephasing is not reversible with GRE

- Larger metal artifacts than SE
  - Why? No refocusing pulse.
    - Large field inhomogeneities aren’t corrected with GRE

Spoiled Gradient Echo Contrast

Contrast depends on tissue's ρ, T_1 and T_2*.

$$A_{echo} \propto \frac{\rho\left(1 - e^{-TR/T_1}\right)}{1 - \cos\alpha e^{-TR/T_1}} \sin\alpha e^{-TE/T_2^*}$$

Contrast adjusted by changing TR, flip angle, and TE

Spoiled Gradient Echo Contrast

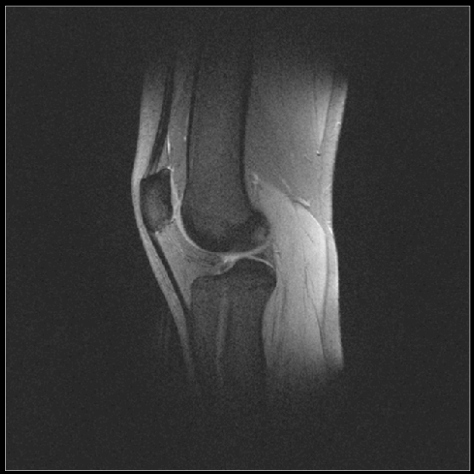
Gradient Echo Parameters

Type of Contrast	TE	TR	Flip Angle
Spin Density	Short	Long	Small
T_1-Weighted	Short	Intermediate	Large
T_2^*-Weighted	Intermediate	Long	Small

T_2*-weighted Gradient Echo MRI

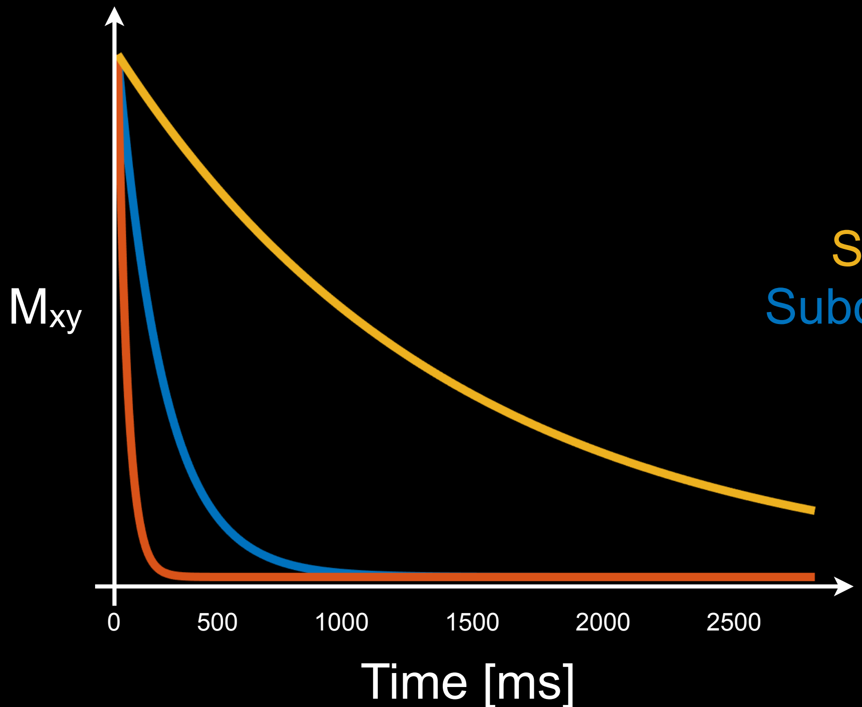
FLASH – TE=4.8ms; TR=200ms

FLASH – TE=14.2ms; TR=200ms



FLASH – TE=24ms; TR=200ms

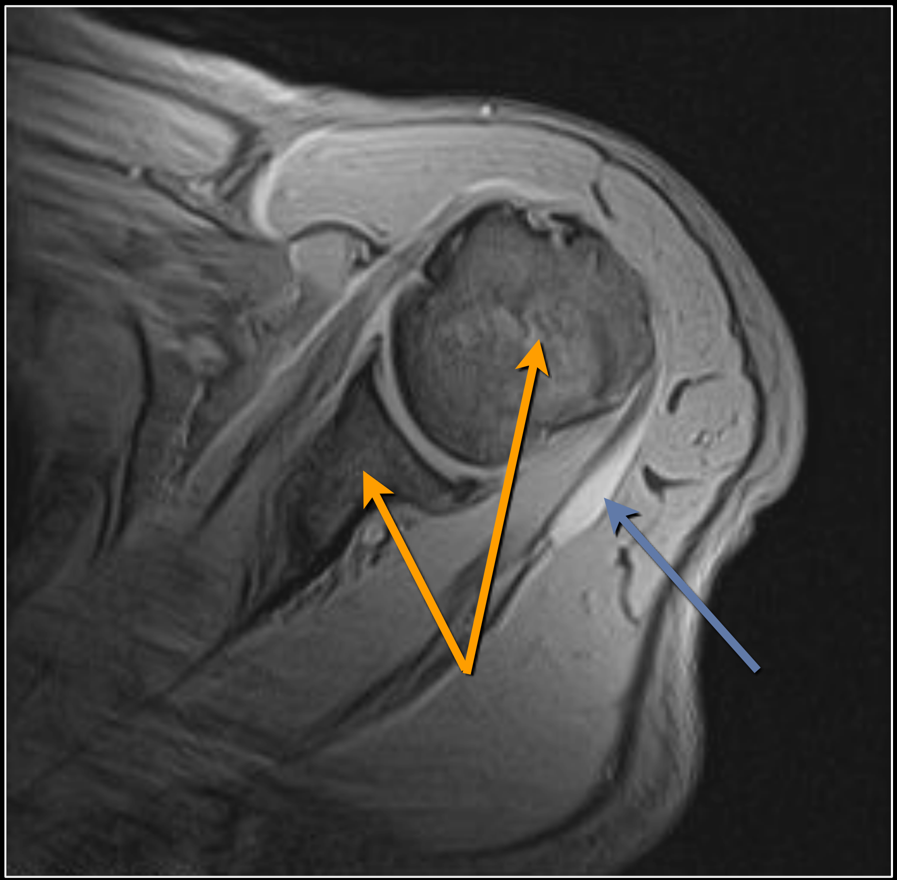
FLASH – TE=49ms; TR=200ms



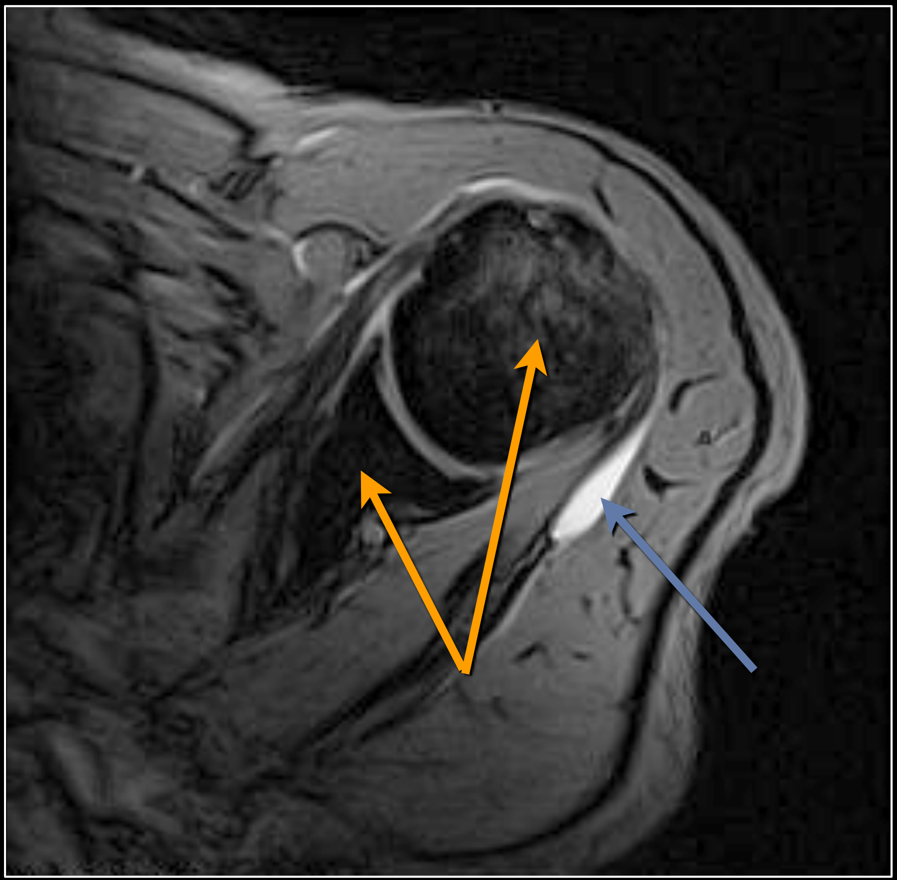
Synovial Fluid T_2~1210ms
Subcutaneous Fat T_2~165ms
Muscle T_2~35ms

Musculoskeletal MRI at 3.0 T: relaxation times and image contrast. AJR Am J Roentgenol. 2004 Aug;183(2):343-51.

T_2*-weighted Gradient Echo MRI



TE=9ms



TE=30ms

Susceptibility Weighting (darker with longer TE)

Bright fluid signal (long T_2* is "brighter" with longer TE)

Images Courtesy of Brian Hargreaves

Gradient vs Spin Echo Contrast

Gradient Echo Parameters

Type of Contrast	TE	TR	Flip Angle
Spin Density	<5ms	>100ms	<10°
T_1-Weighted	<5ms	<50ms	>30°
T_2^*-Weighted	>20ms	>100ms	<10°

Spin Echo Parameters

Type of Contrast	TE	TR	Flip Angle
Spin Density	10-30ms	>2000ms	90+180
T_1-Weighted	10-30ms	450-850ms	90+180
T_2-Weighted	>60ms	>2000ms	90+180

Signal Equation

$$s(t) = \int_x \int_y M(x,y) e^{-i2\pi(k_x(t)\cdot x + k_y(t)\cdot y)} dxdy$$

- With off-resonance:

$$s(t) = \int_x \int_y M(x,y) e^{-i\omega_E(x,y)t} e^{-i2\pi(k_x(t)\cdot x + k_y(t)\cdot y)} dxdy$$

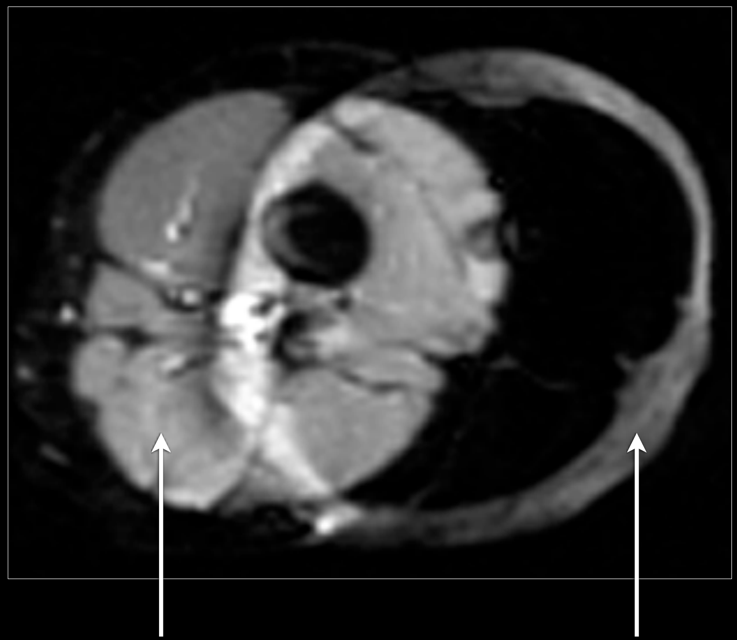
- B0 inhomogeneity
- Susceptibility
- Chemical shift

To the Board

Gradient Echoes & Fat

Chemical Shift - Type 1

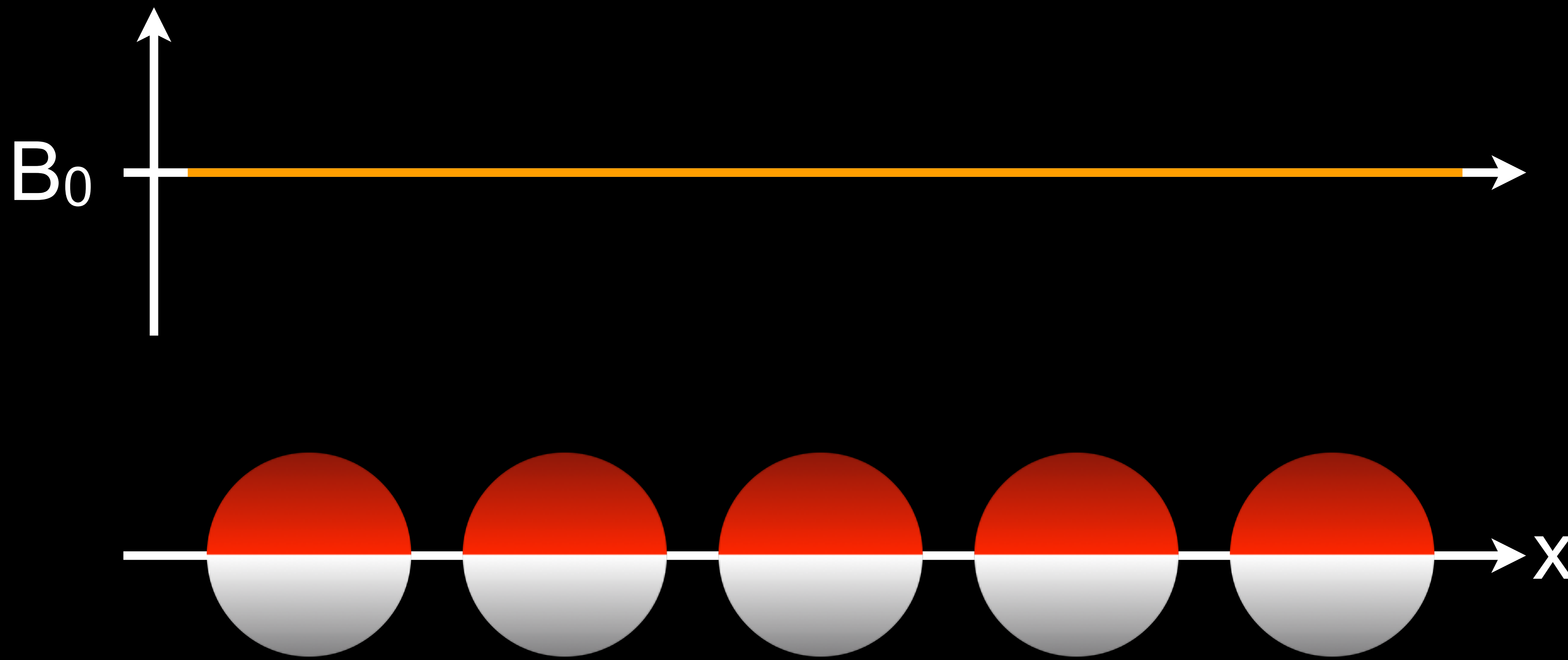
- Fat and water have different Larmor frequencies
  - ~220Hz different at 1.5T
  - ~440Hz different at 3.0T
- Spatial position is related to spin frequency in MRI.
  - Fat is <u>*more*</u> spatially mis-registered @ 3T



Chemical Shift – Fat (–CH_2) is ~220Hz *lower* at 1.5T

Image Courtesy of Brian Hargreaves

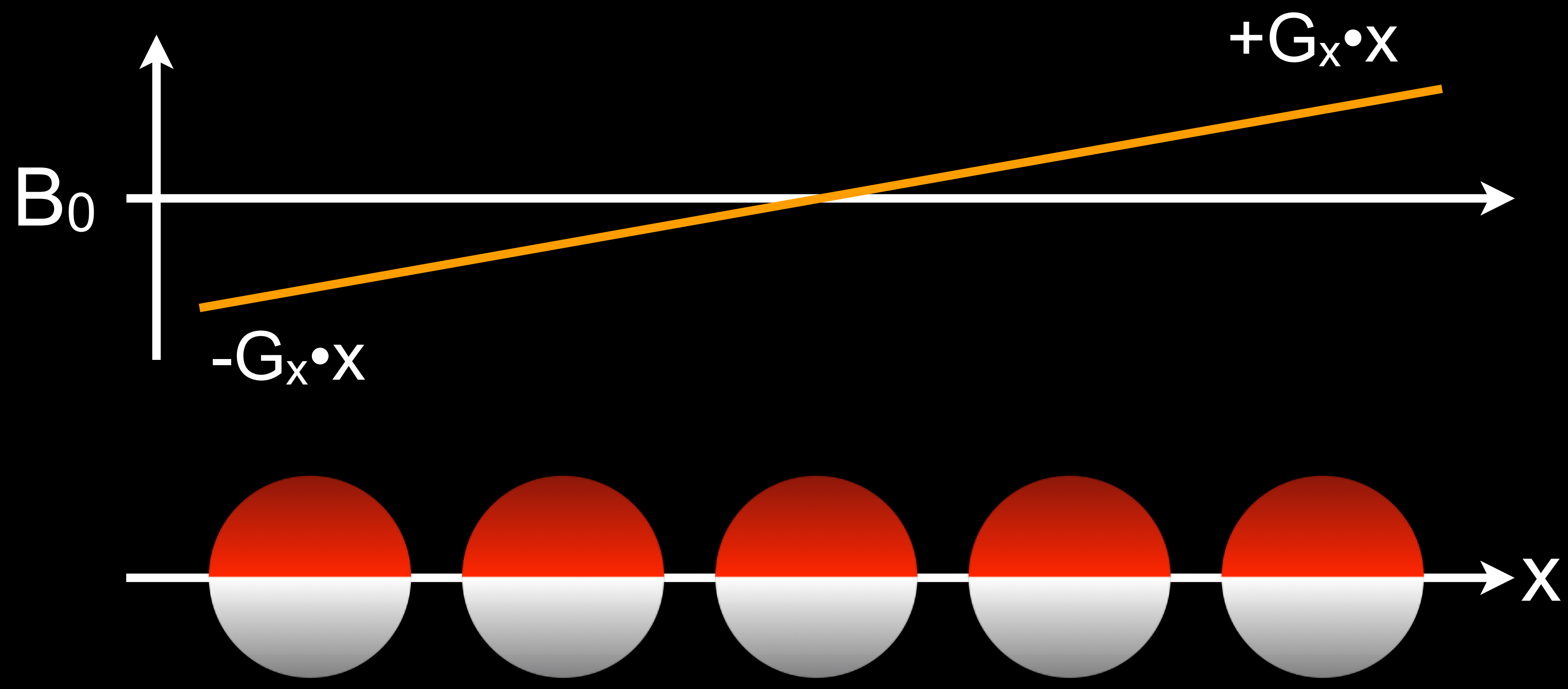
GRE & Fat/Water Frequency



Water Spins in a *Uniform* Field

Water spins precess at the same Larmor frequency in a uniform B_0 field.

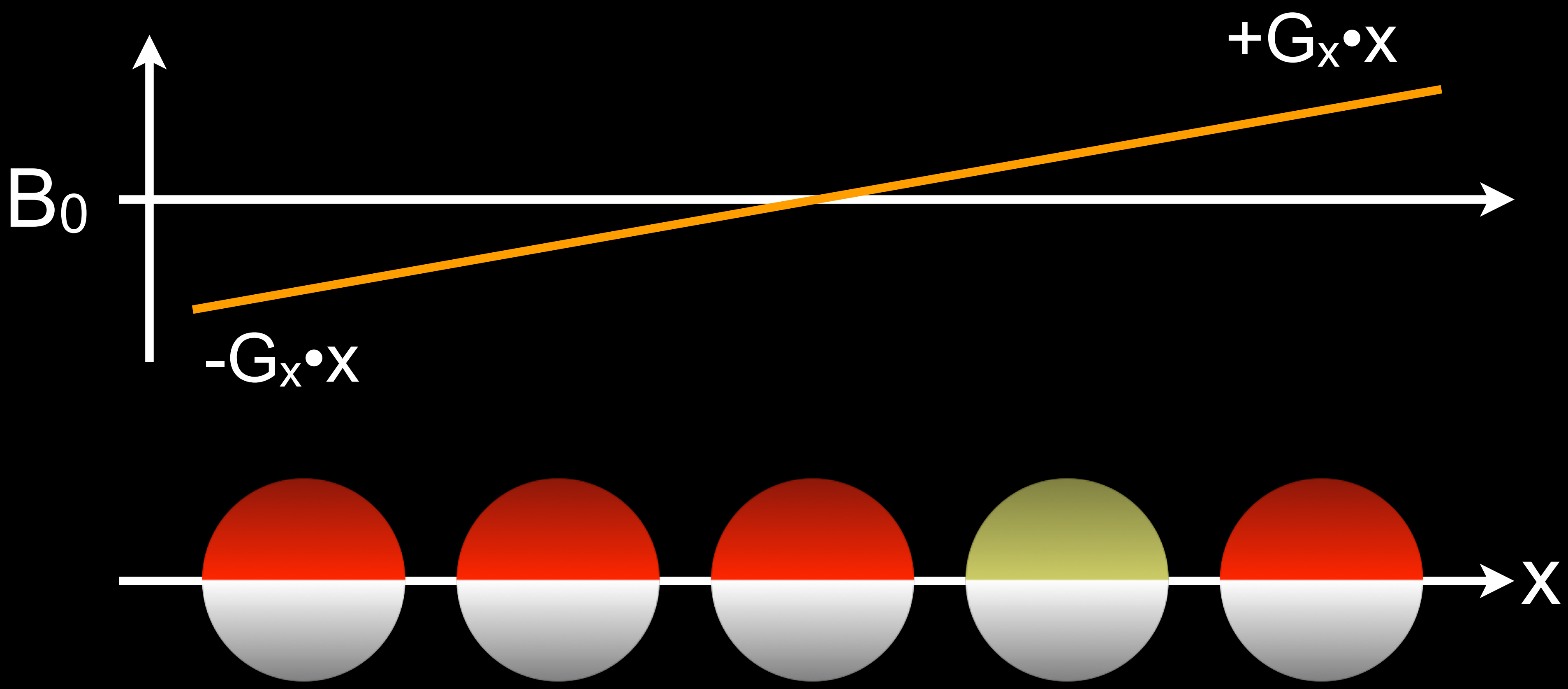
GRE & Fat/Water Frequency



Water Spins in a *Gradient* Field

Water spins precess at ***different*** Larmor frequencies in a non-uniform B_0 field.

GRE & Fat/Water Frequency

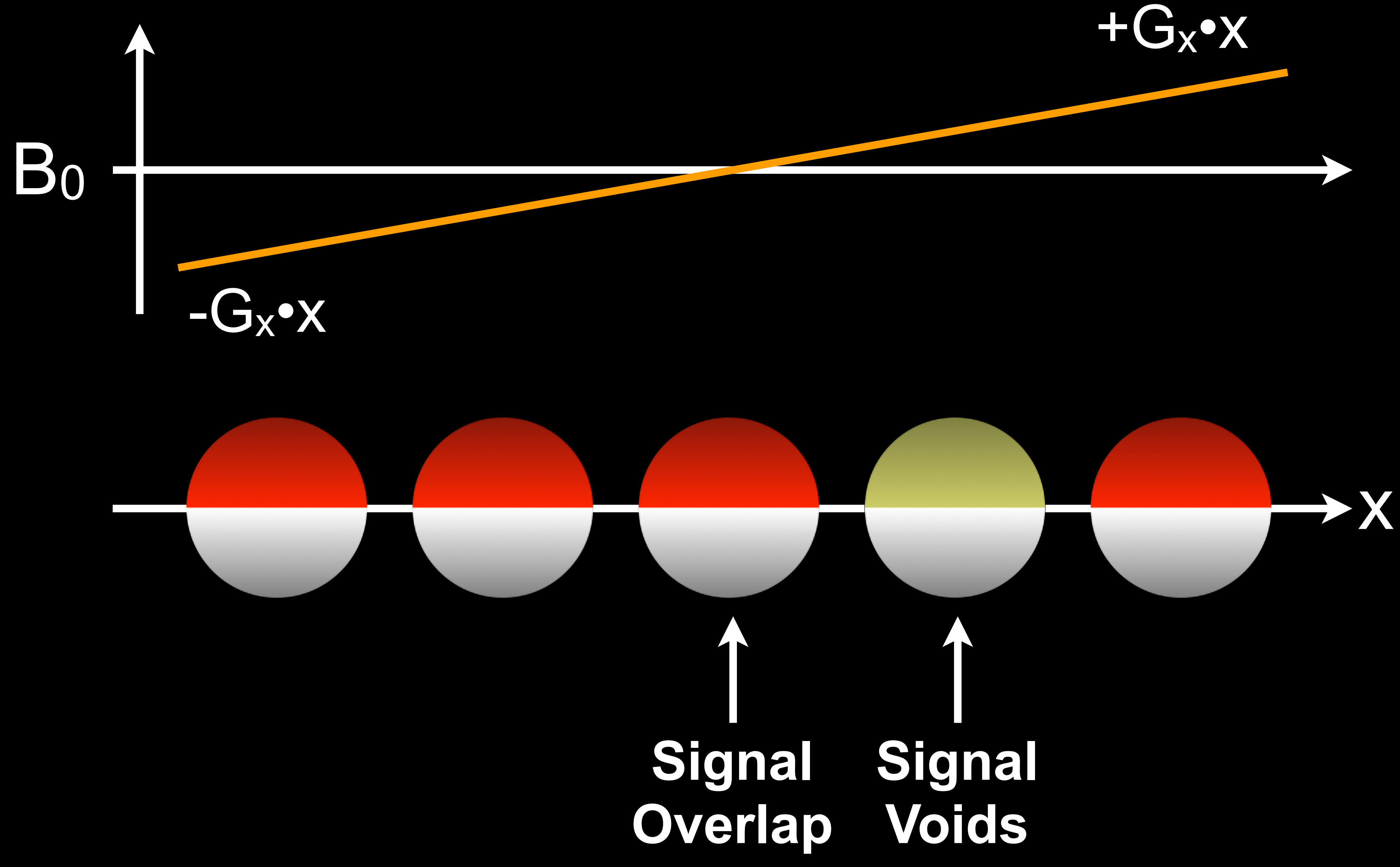


Water & Fat Spins in a Gradient Field

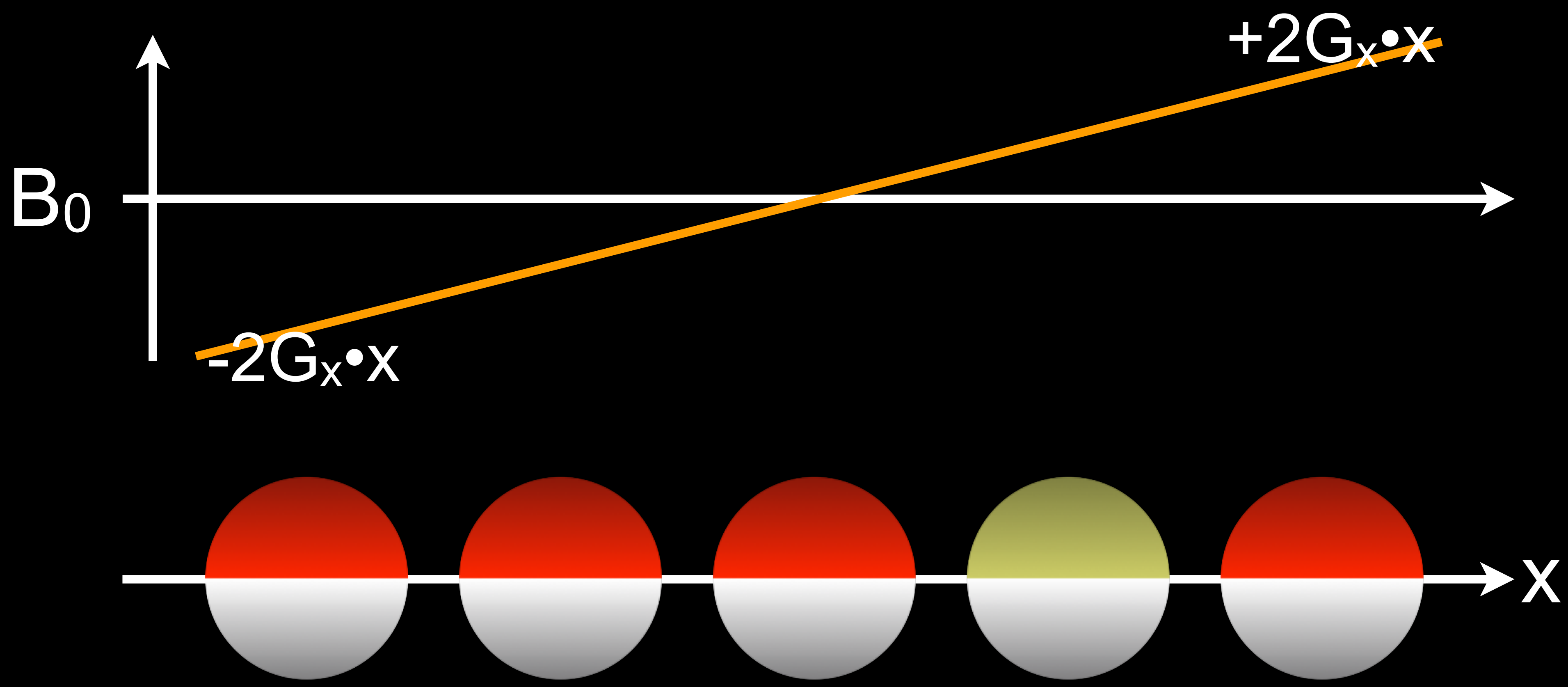
Fat Spins ~220Hz slower than water @ 1.5T

Spatial ***position*** is inferred from Larmor frequency.
Chemical (frequency) shift produces and apparent spatial shift.

GRE & Fat/Water Frequency

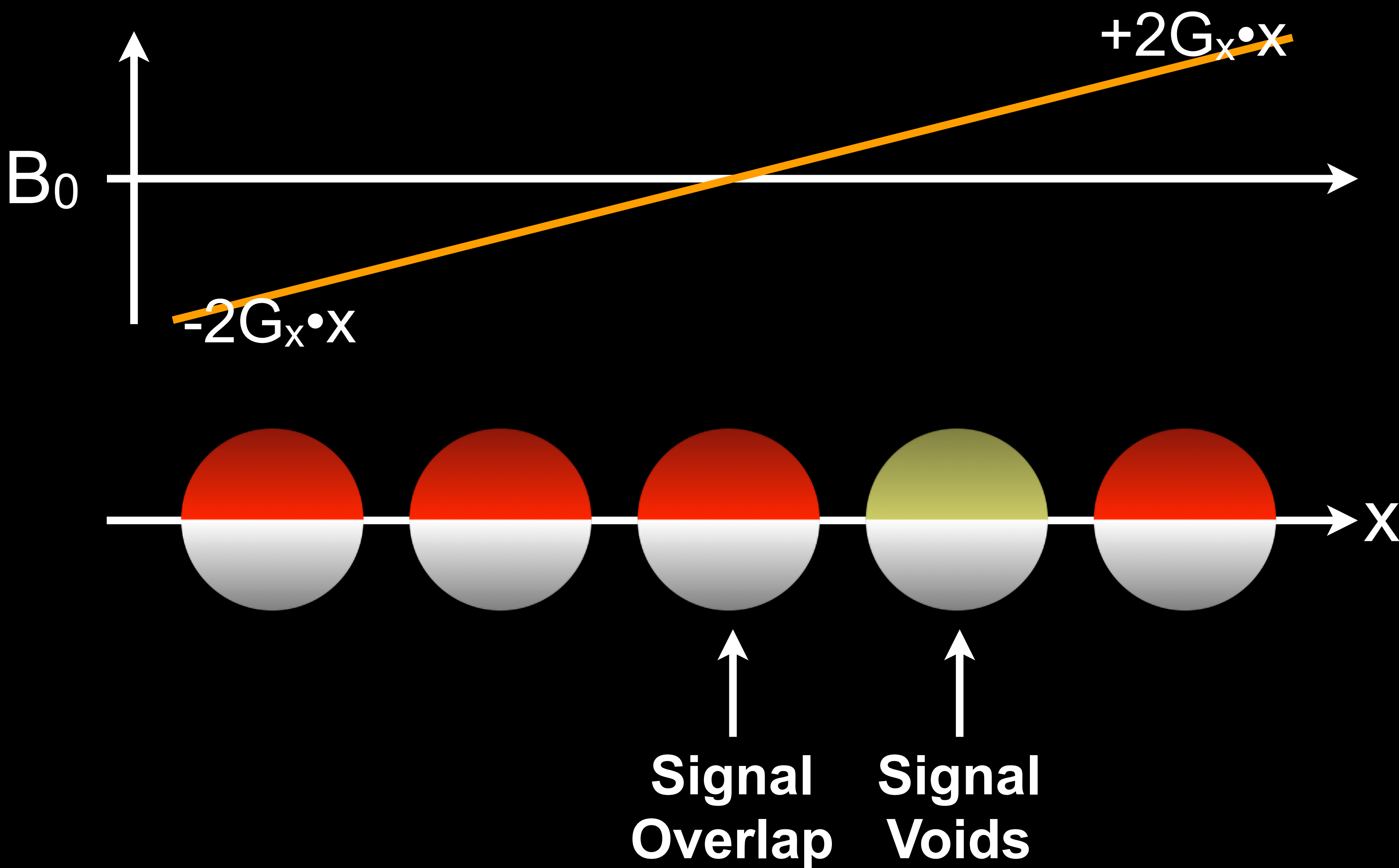


GRE and Bandwidth



Higher bandwidths use stronger gradients and result in larger frequency differences along x.
Chemical shift (frequency) is fixed for B_0, therefore chemical shift (Δx) is a smaller percentage.

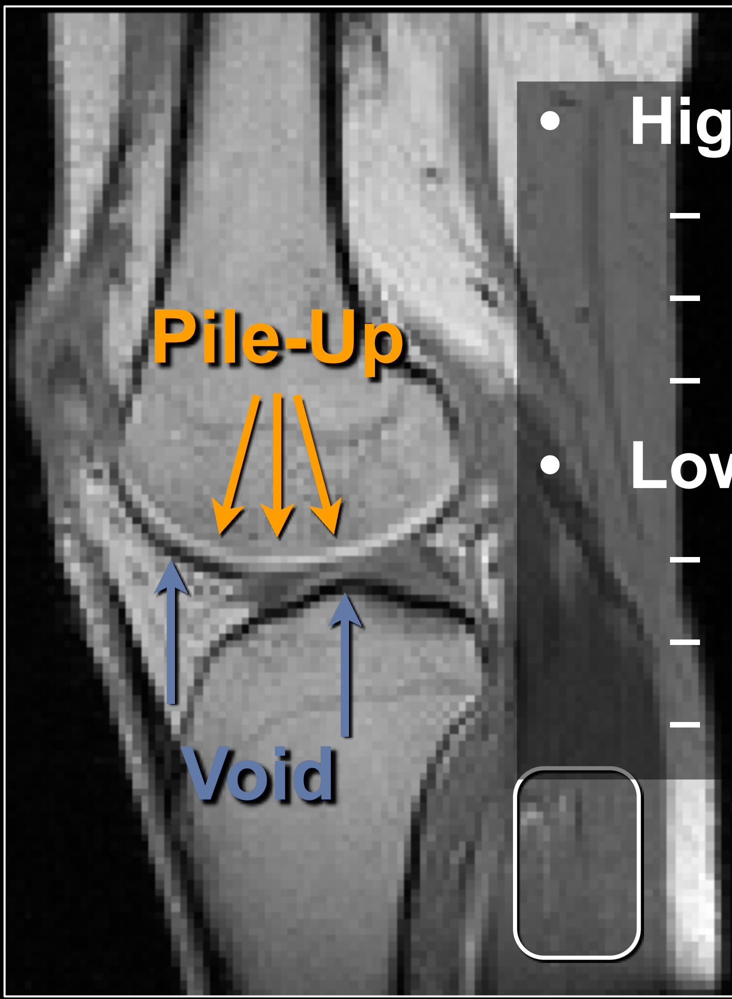
GRE and Bandwidth



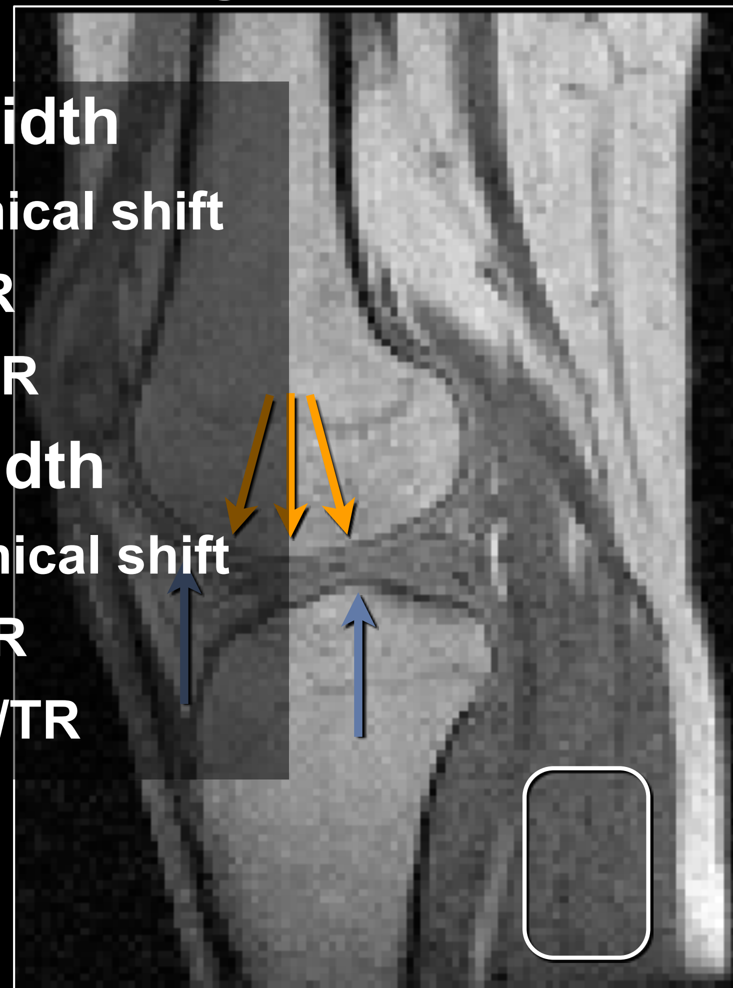
High bandwidth scans have less chemical shift.

GRE, Fat/Water & Bandwidth

Low Bandwidth



High Bandwidth

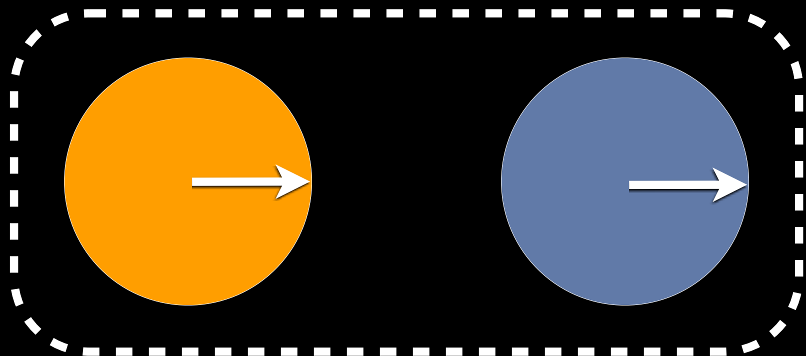


- **High Bandwidth**
  - **Less chemical shift**
  - **Lower SNR**
  - **Short TE/TR**
- **Low Bandwidth**
  - **More chemical shift**
  - **Higher SNR**
  - **Longer TE/TR**

Acquisition ***bandwidth*** is related to the ***speed*** with which an echo is acquired. If the ***bandwidth*** (speed) is high, then there is less time for chemical shift, less time for signal acquisition (lower SNR), and a shorter TE/TR.

Chemical Shift - Type 2

- Pixels are frequently a mixture of fat and water
- Pixel intensity is the vector sum of fat and water



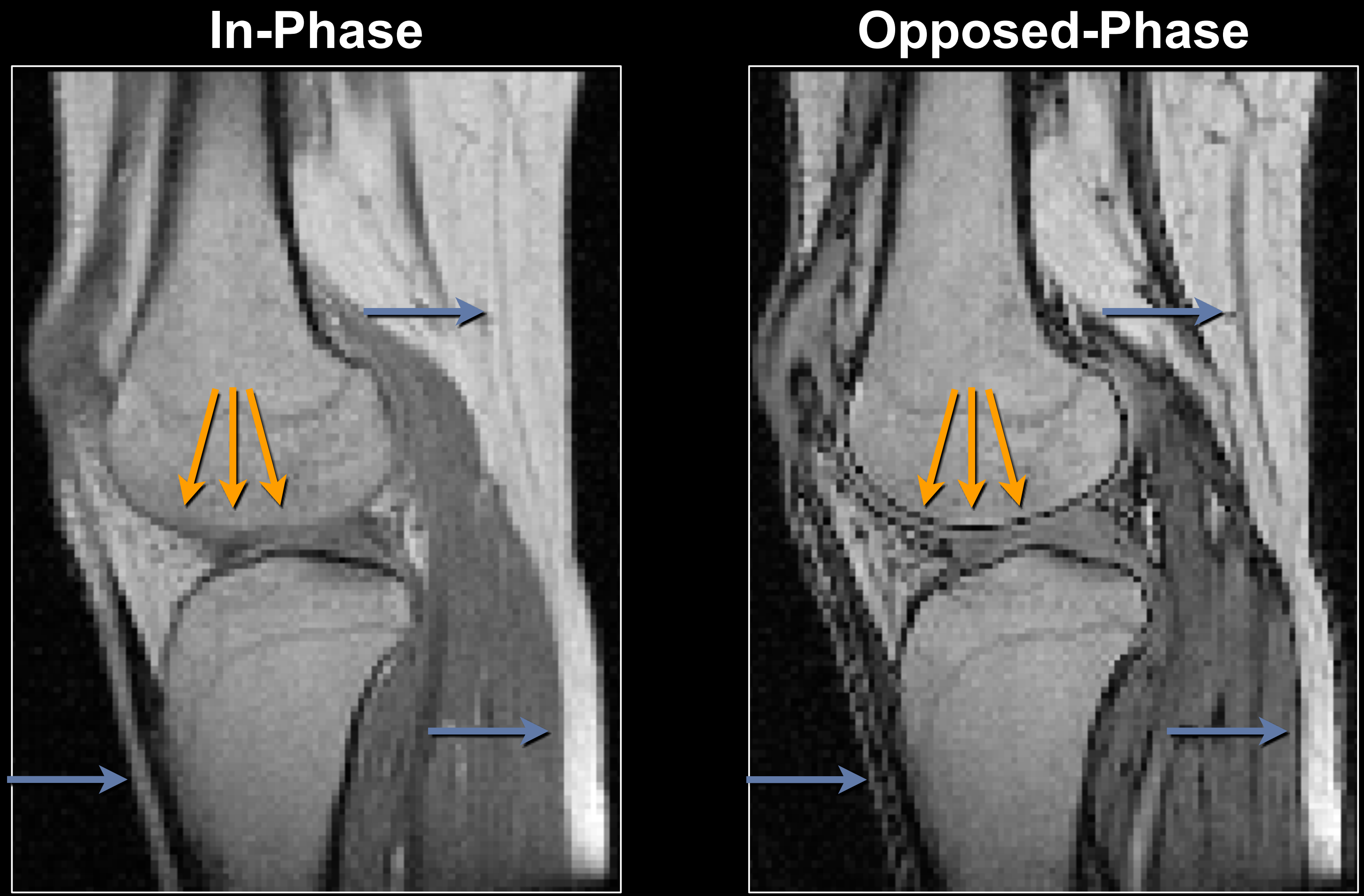
Fat Water

In-Phase Opposed-Phase

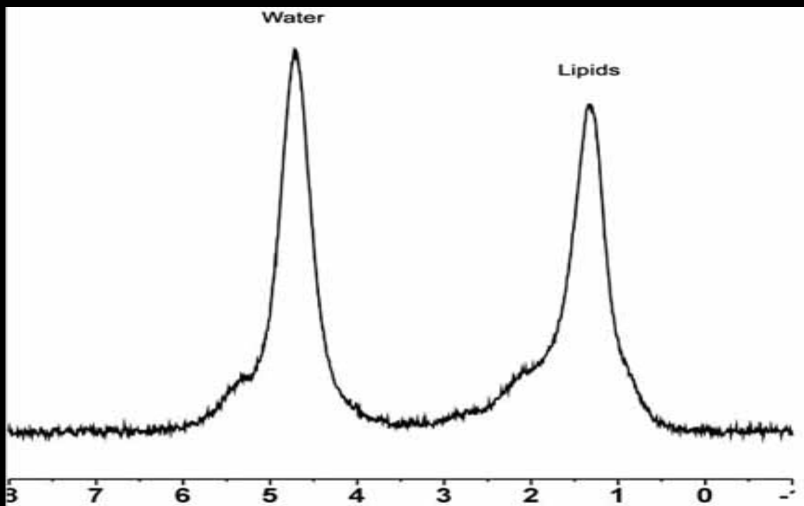
$\longrightarrow + \longrightarrow > 0$ $\longleftarrow + \longrightarrow = 0$

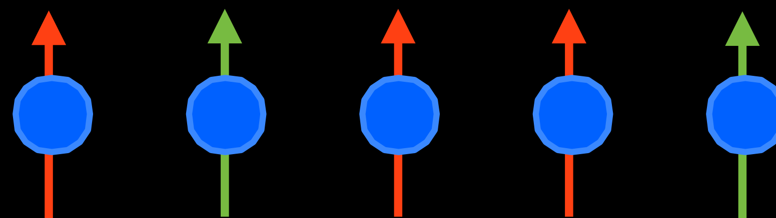
The TE controls the phase between fat and water.

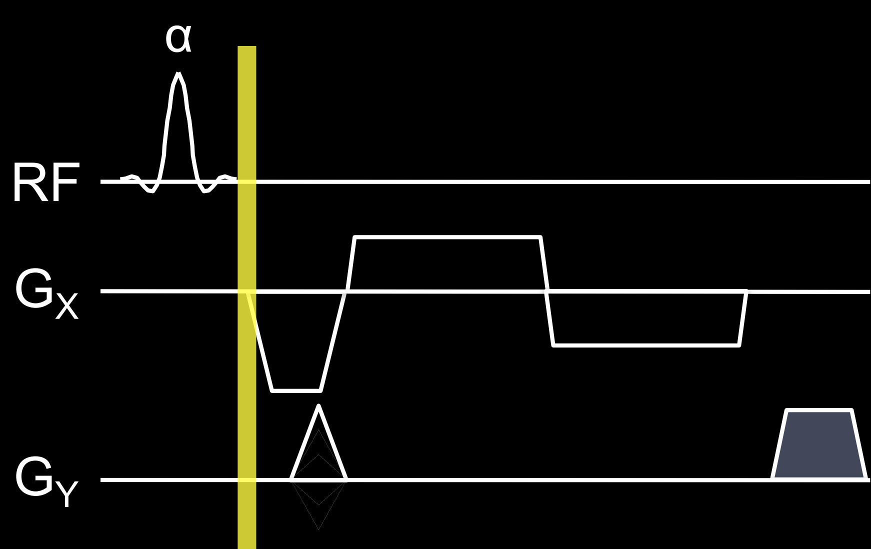
GRE and Fat/Water Phase

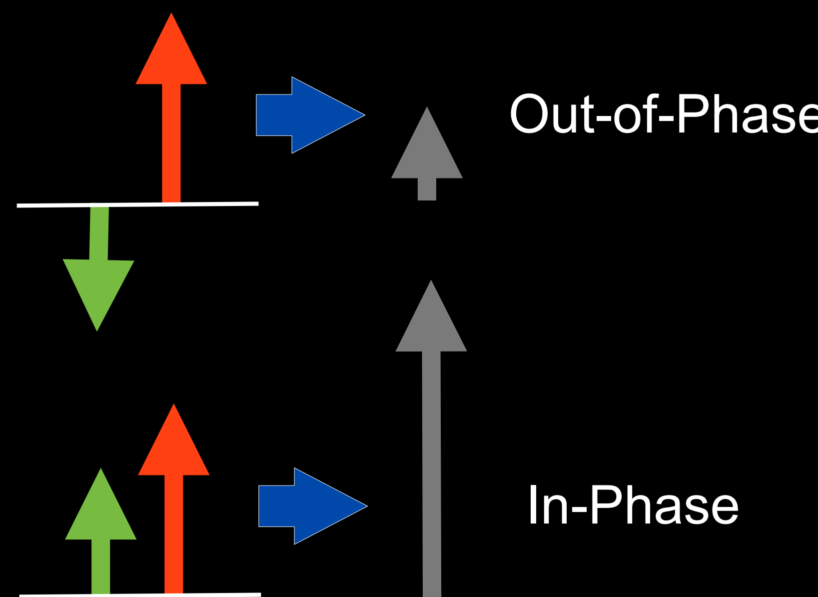


Dual-Echo Acquisition



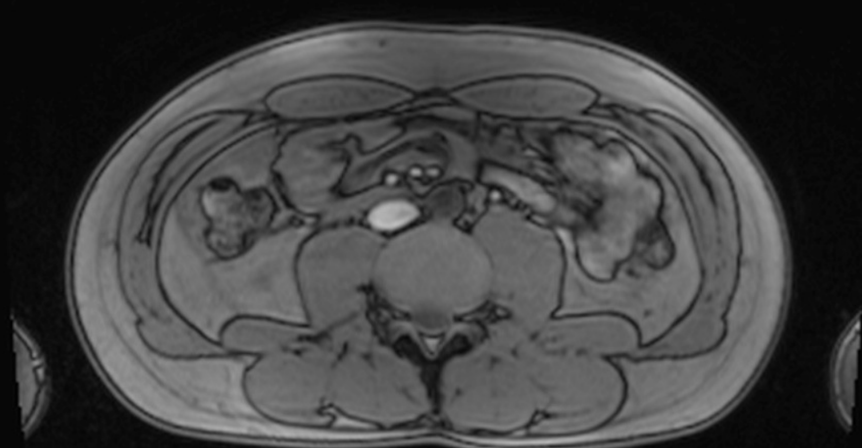




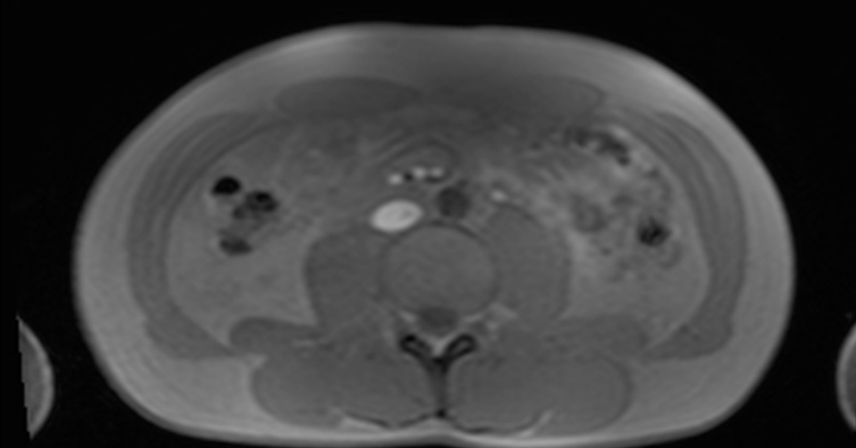


In-phase and Out-of-phase

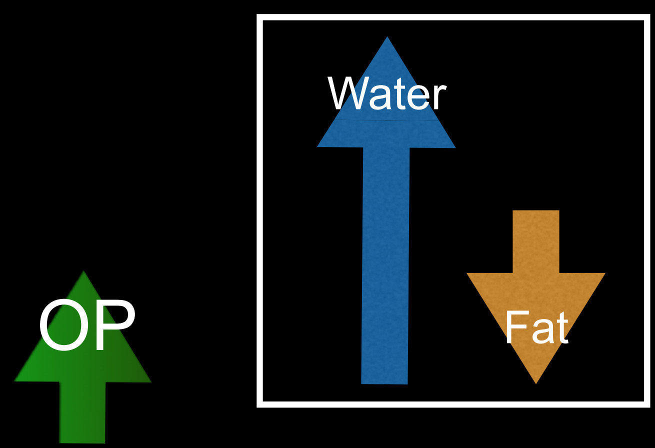
Example: 3 T abdominal scan

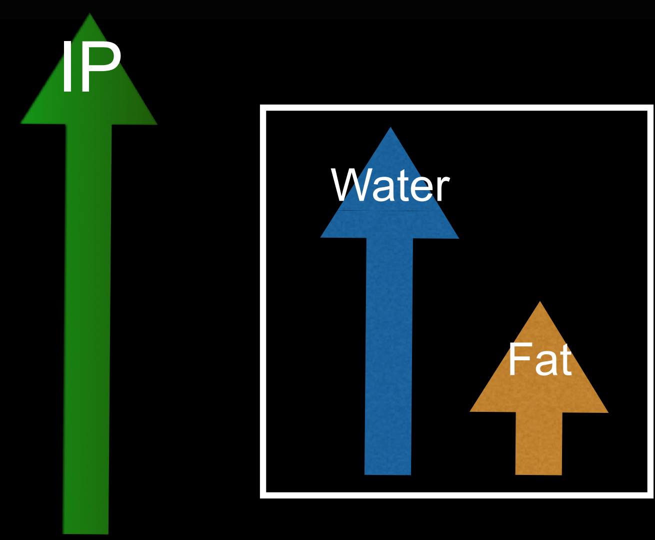


Out-of-phase (3 T), TE = 1.3 ms



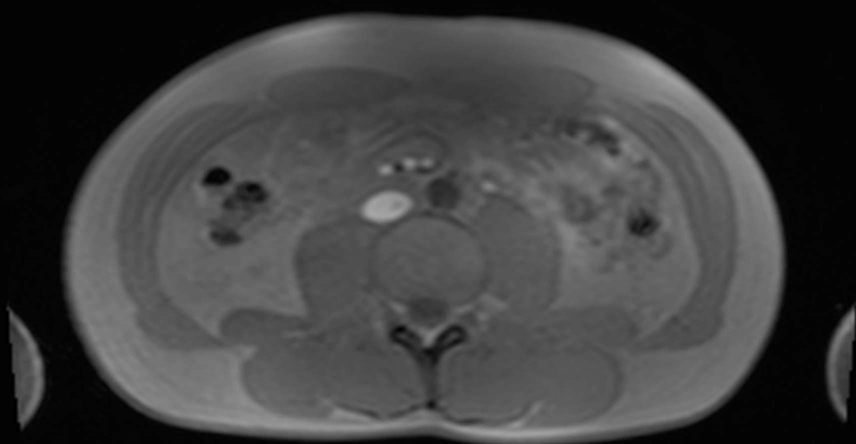
In-phase (3 T), TE = 2.6 ms



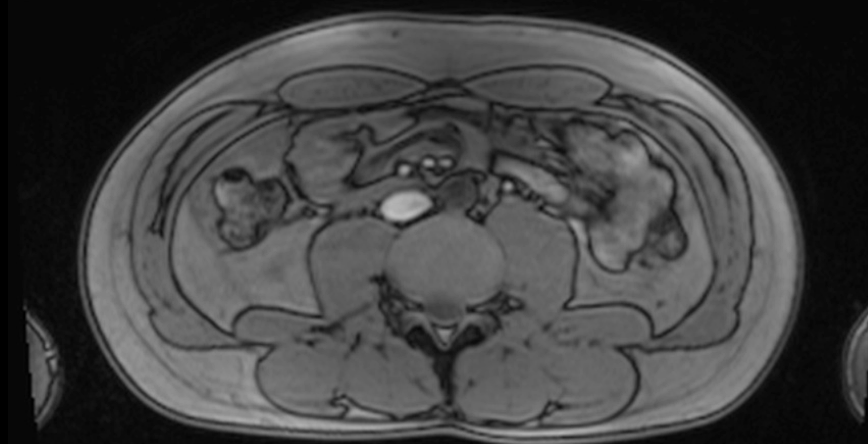


2-Point Dixon

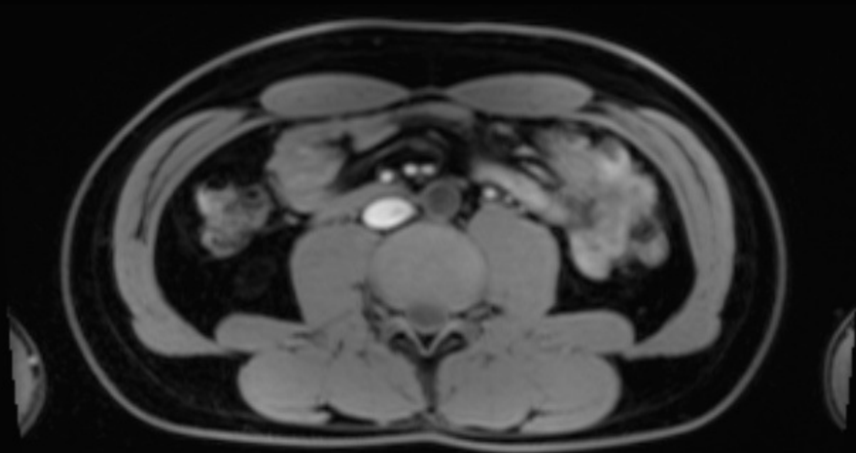
Example: 3 T abdominal scan



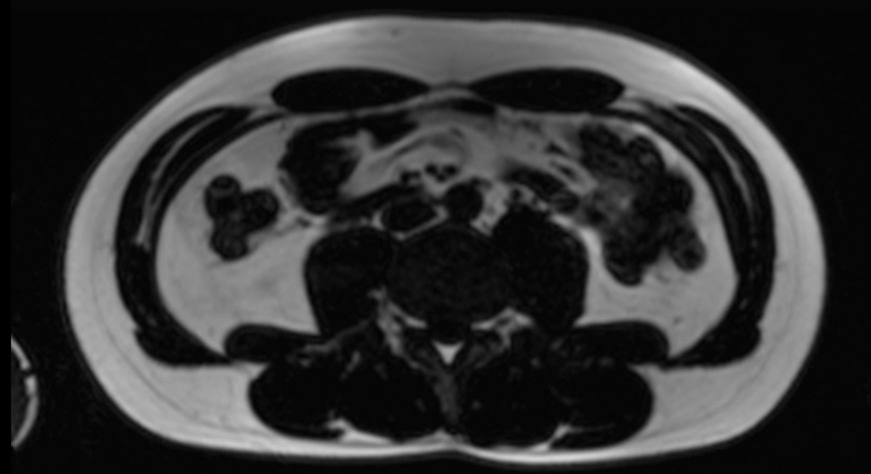
In-phase (3T), TE = 2.6 ms



Out-of-phase (3T), TE = 1.3 ms



Water



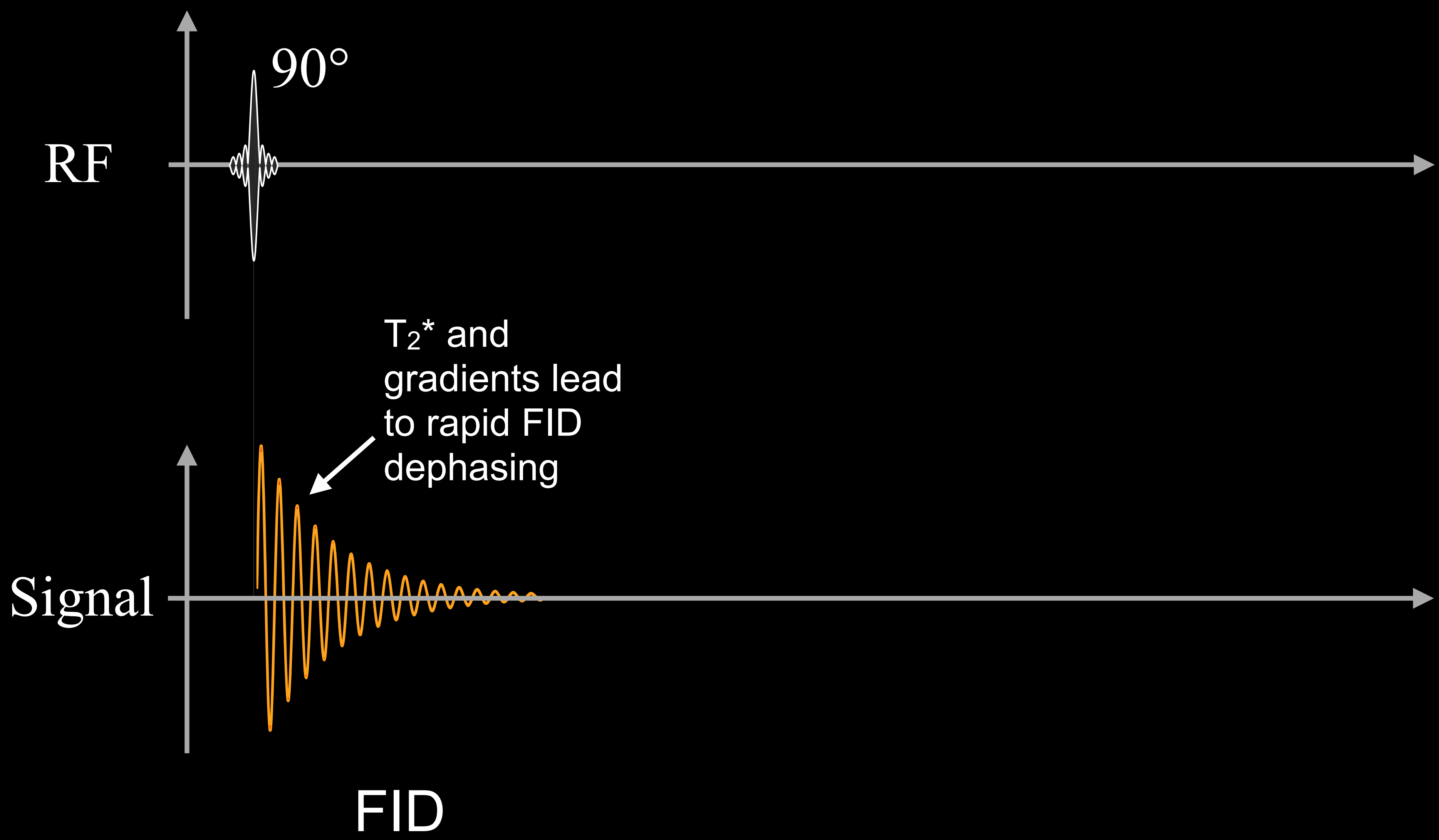
Fat

Gradient Echo – Summary

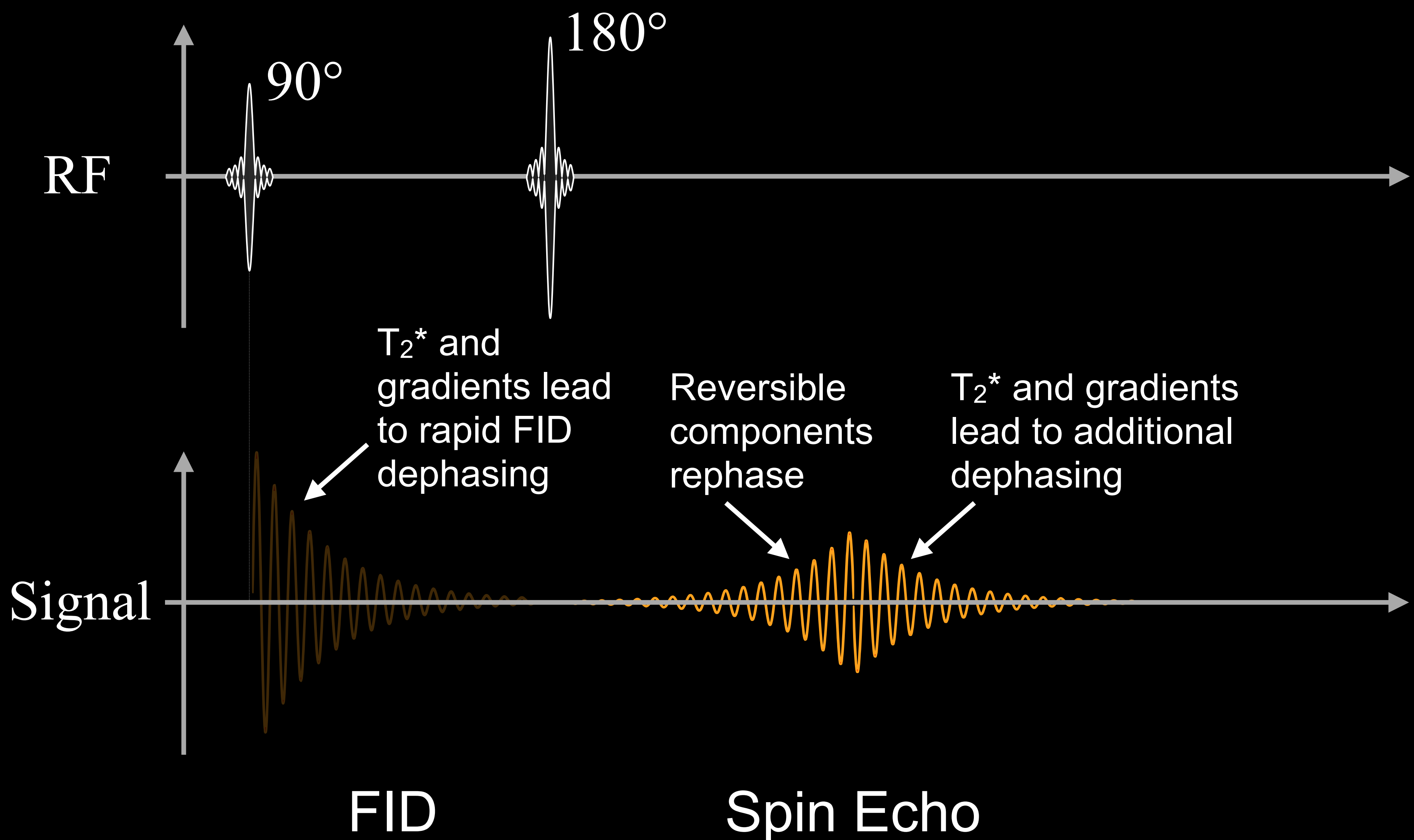
- Advantages
  - Fast Imaging Applications
  - Flexible contrast (T_1 or T_2*)
- Disadvantages
  - Off-resonance sensitivity
  - T_2^*-weighted rather than T_2-weighted

Spin Echo Imaging

Free Induction Decay

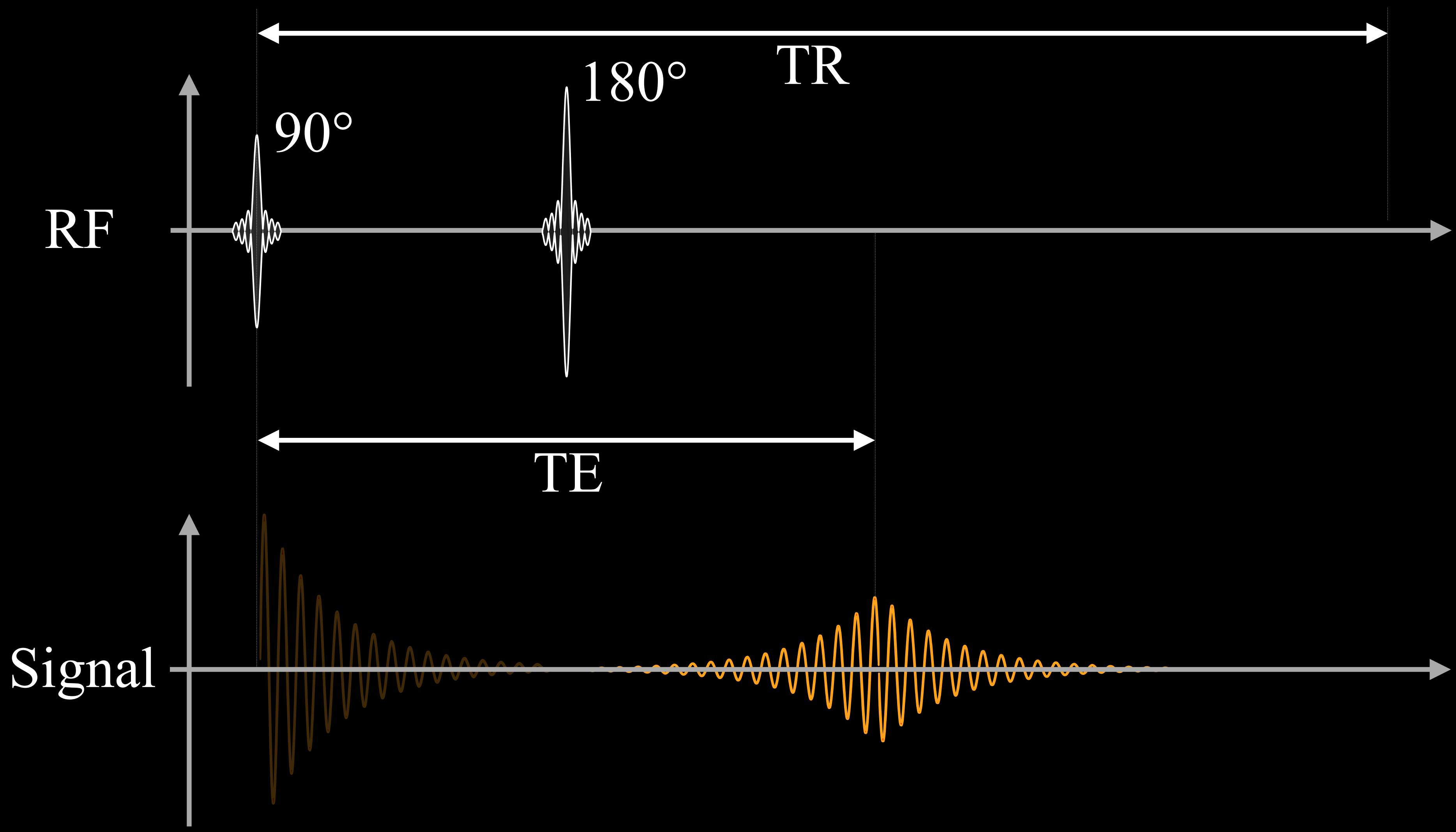


Spin Echo



Record by computer.

Spin Echo



FID

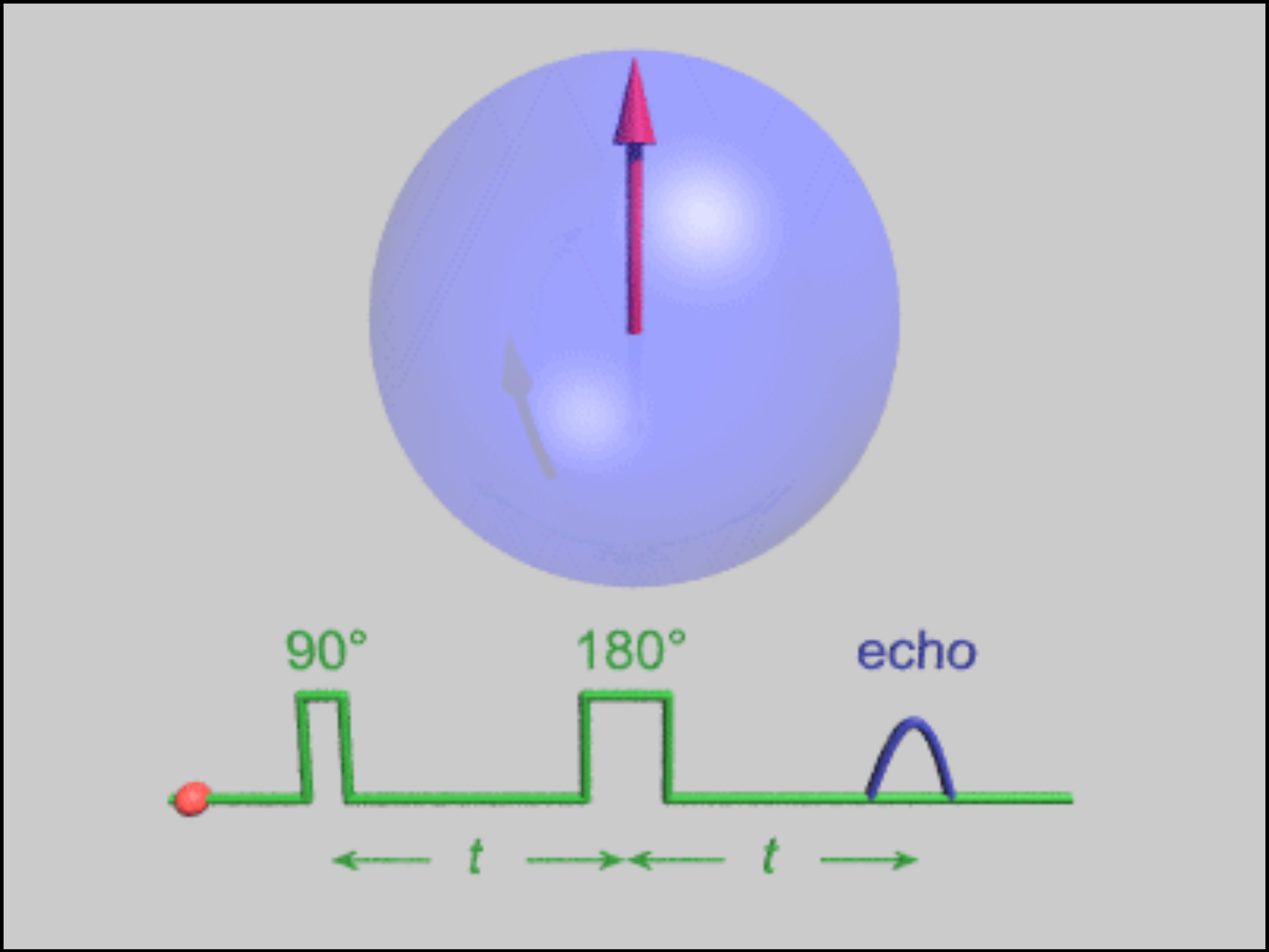
Spin Echo

Record by computer.

Refocusing Pulses

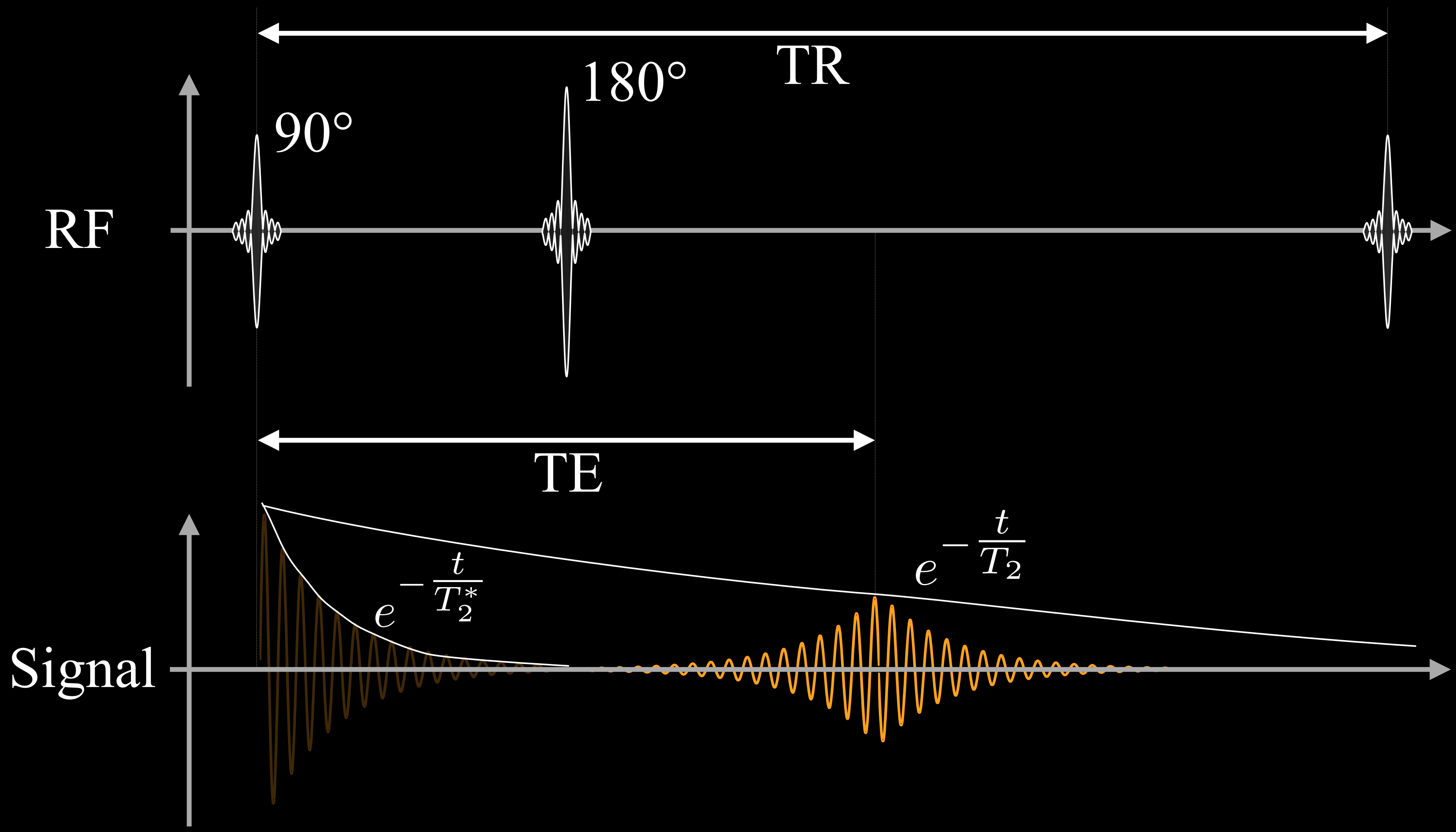
- Typically, 180° RF Pulse
  - Provides optimally refocused M_{XY}
  - Largest spin echo signal
- Refocus spin dephasing due to
  - imaging gradients
  - local magnetic field inhomogeneity
  - magnetic susceptibility variation
  - chemical shift

Spin Echo - Refocusing



http://en.wikipedia.org/wiki/File:HahnEcho_GWM.gif

Spin Echo - Contrast



How do you adjust the TR?
How do you adjust the TE?

Spin Echo Contrast

$$A_{Echo} \propto \rho \left(1 - e^{-TR/T_1}\right) e^{-TE/T_2}$$

Longer TR
minimizes
T1 contrast

Short TE
minimizes
T2 contrast

Intermediate TR
maximizes
T1 contrast

Intermediate TE
maximizes
T2 contrast

Spin Echo Contrast

$$A_{Echo} \propto \rho \left(1 - e^{-TR/T_1}\right) e^{-TE/T_2}$$

Longer TR minimizes T1 contrast

Short TE minimizes T2 contrast

Intermediate TR maximizes T1 contrast

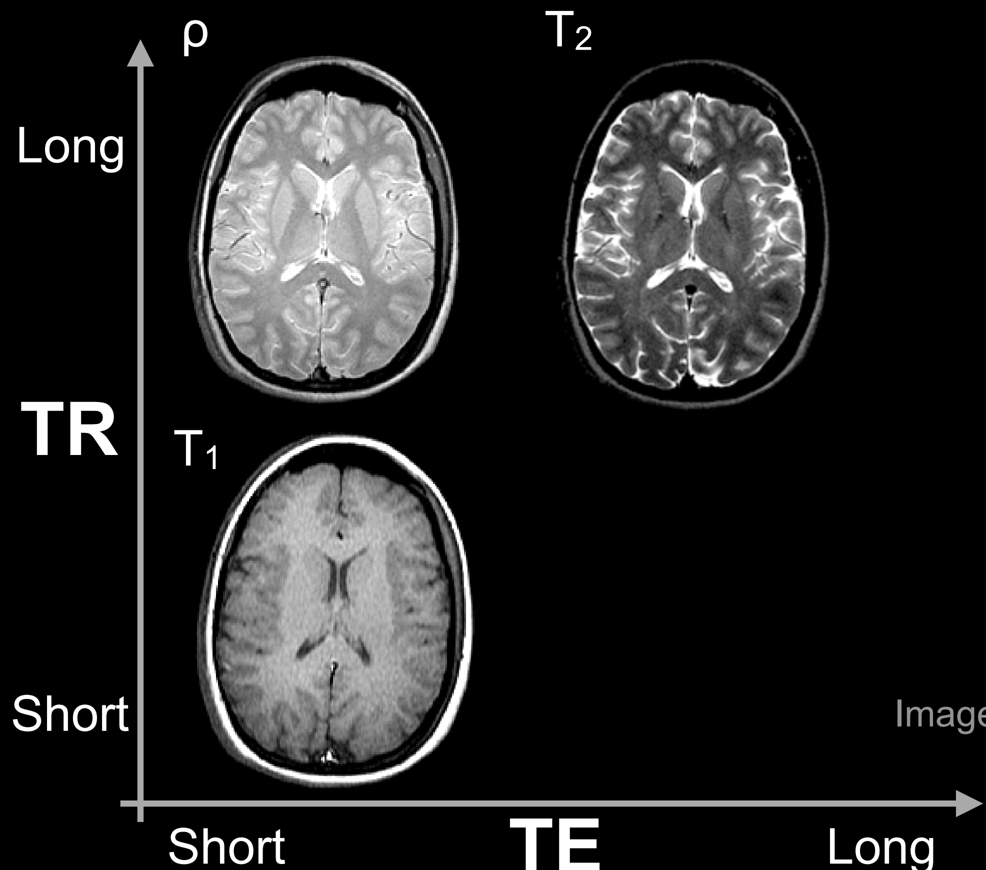
Intermediate TE maximizes T2 contrast

Spin Echo Parameters

	TE	TR
Spin Density	Short	Long
T_1-Weighted	Short	Intermediate
T_2-Weighted	Intermediate	Long

Spin Echo Contrast

	TE	TR
Spin Density	Short	Long
T_1-Weighted	Short	Intermediate
T_2-Weighted	Intermediate	Long



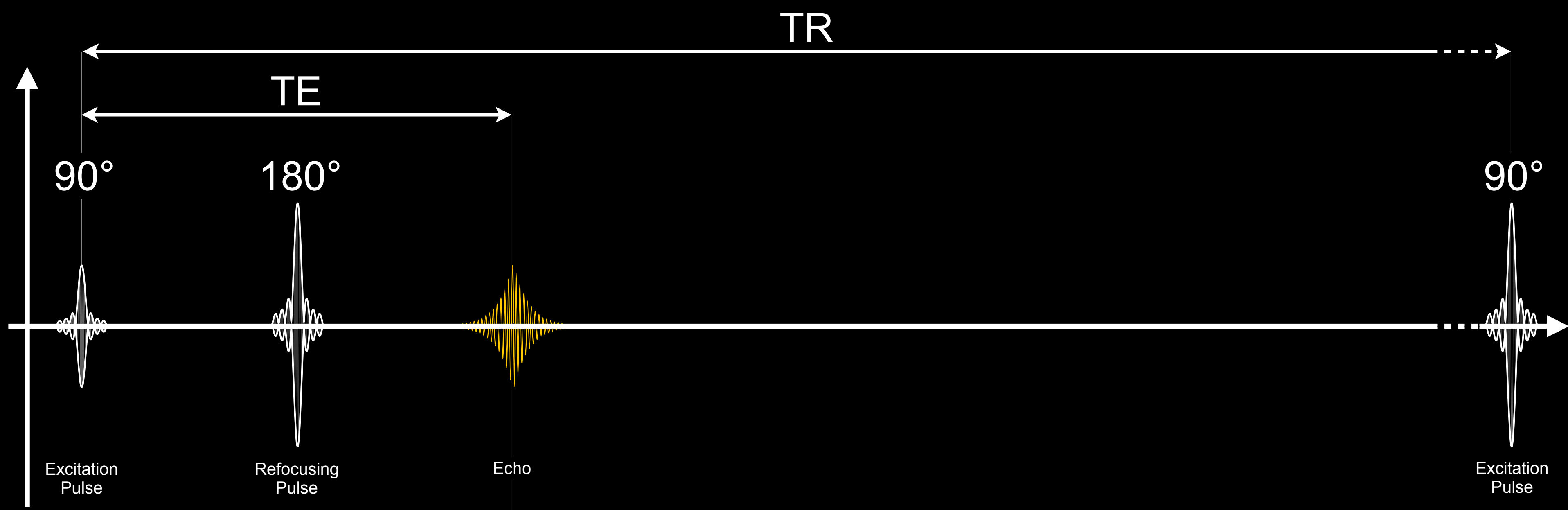
Images Courtesy of Mark Cohen

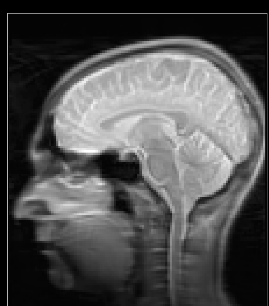
Spin Echo

TE=12ms

Spin Echo: TR=6500ms (ETL=12)

Spin Echo



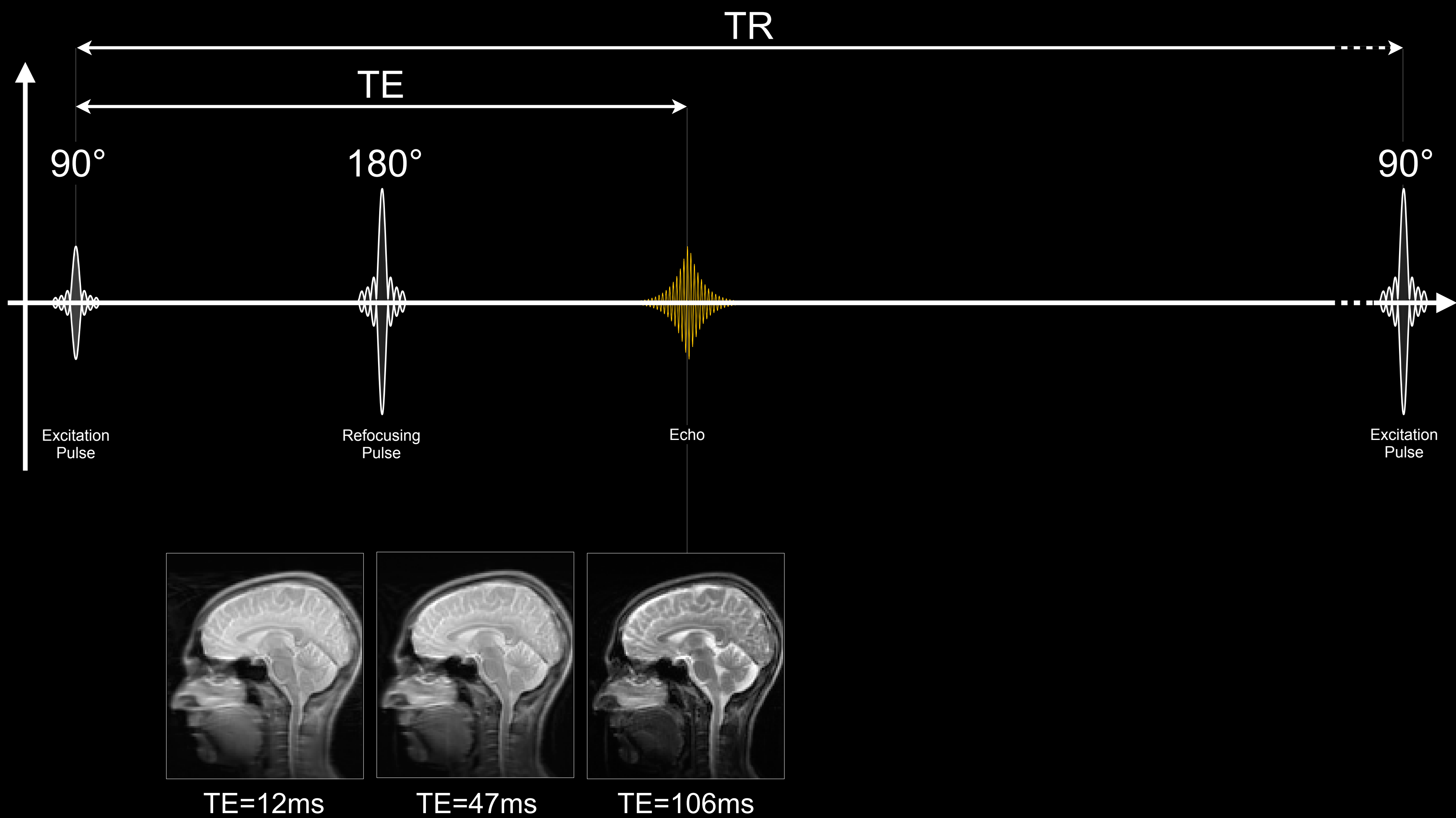


TE=12ms

TE=47ms

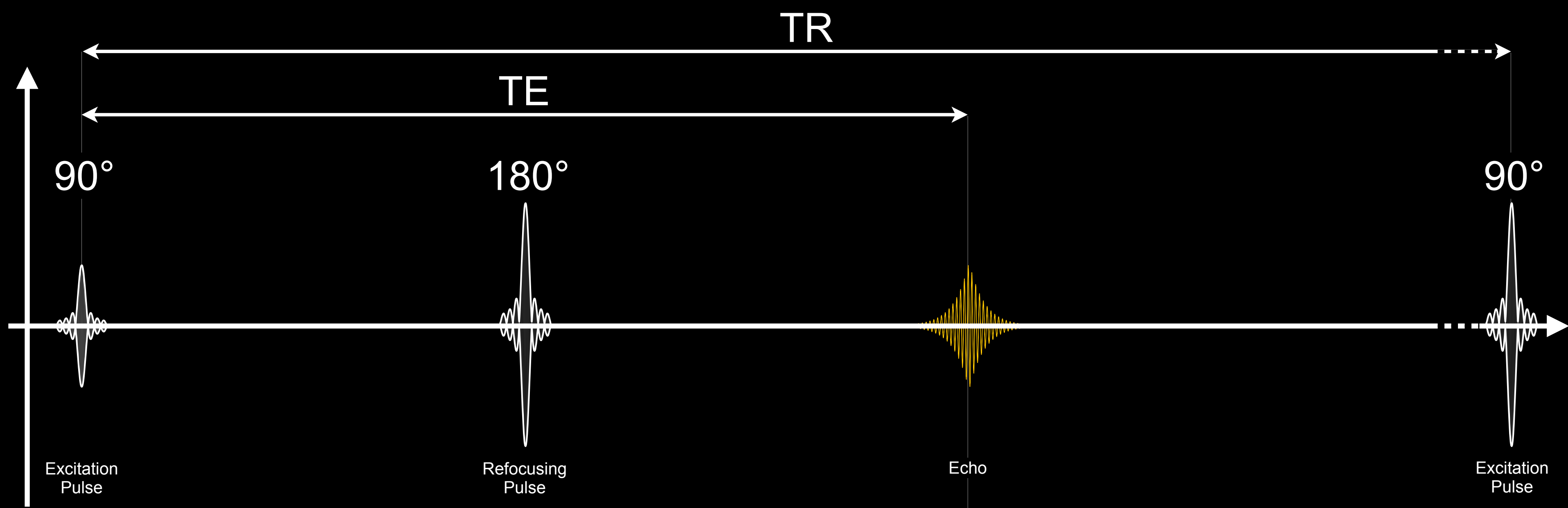
Spin Echo: TR=6500ms (ETL=12)

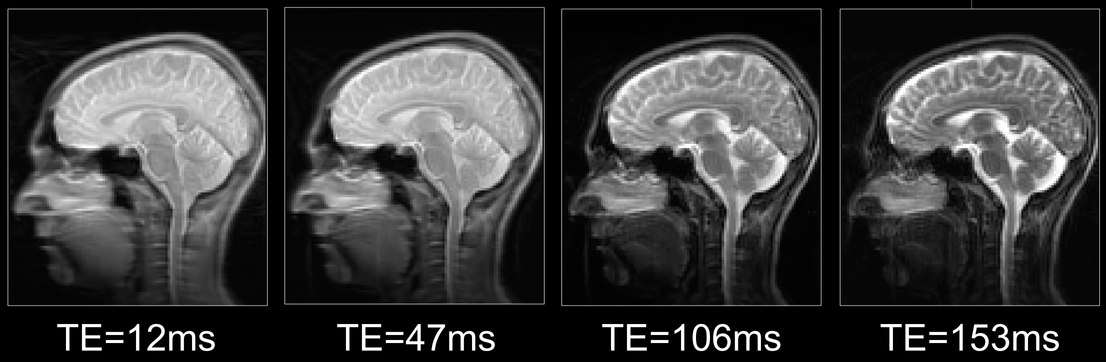
Spin Echo



Spin Echo: TR=6500ms (ETL=12)

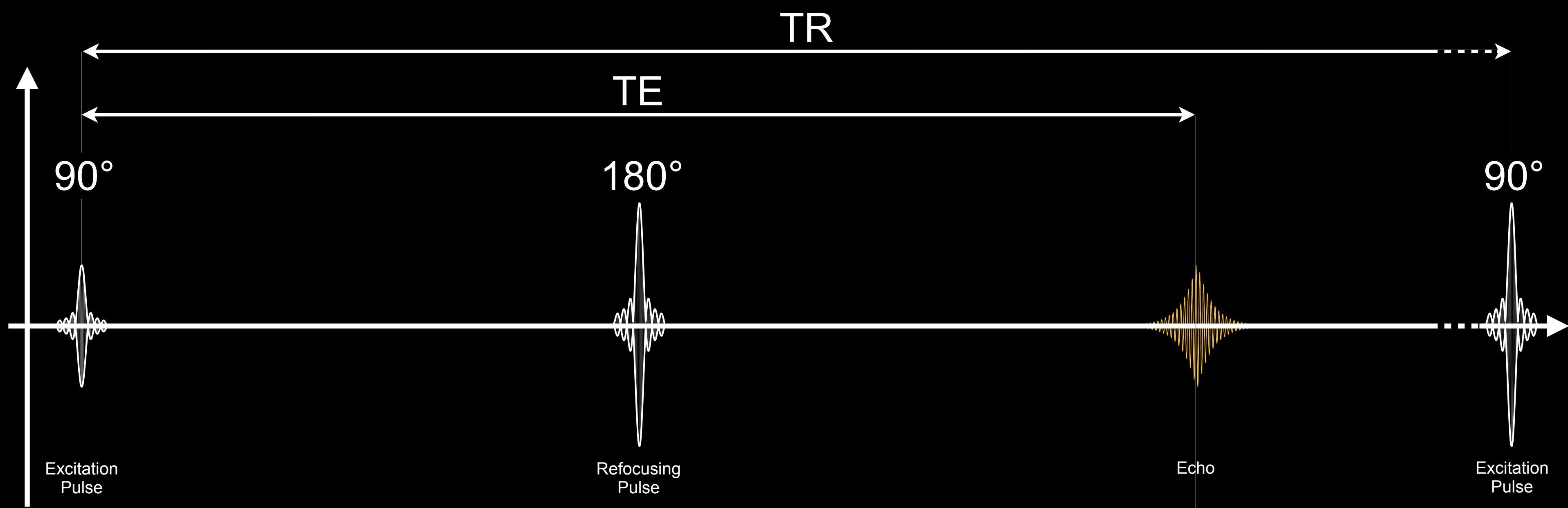
Spin Echo

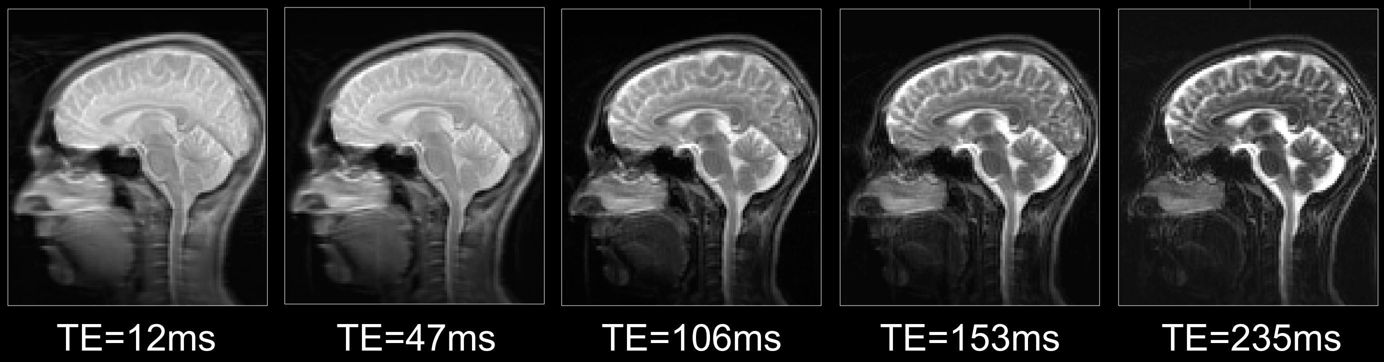




Spin Echo: TR=6500ms (ETL=12)

Spin Echo





Spin Echo: TR=6500ms (ETL=12)

Spin Echo

- Advantages
  - Insensitive to off-resonance
    - Re-focusing rephrases spin dephasing
  - Great for T_1, T_2, ρ contrast (not T_2*)
  - High SNR
- Disadvantages
  - TR can be long
    - Leads to long scan time
  - SAR can be high
    - Lots of 90s and 180s lead to patient heating

Questions?

- Related reading materials
  - Nishimura - Chap 7

Kyung Sung, Ph.D.
KSung@mednet.ucla.edu
http://mrrl.ucla.edu/sunglab