

Imaging Sequences II

M219 - Principles and Applications of MRI

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2/24/2025

Course Overview

- 2025 course schedule
 - https://mrrl.ucla.edu/pages/m219_2025
- Assignments
 - Homework #3 due on 3/5
- Final exam - 3/17 2-4pm

- TA office hours, Mon 4-6pm
- Office hours, Fri 4-5pm

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^* .

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

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

T₂*-weighted Gradient Echo MRI

FLASH – TE=4.8ms; TR=200ms



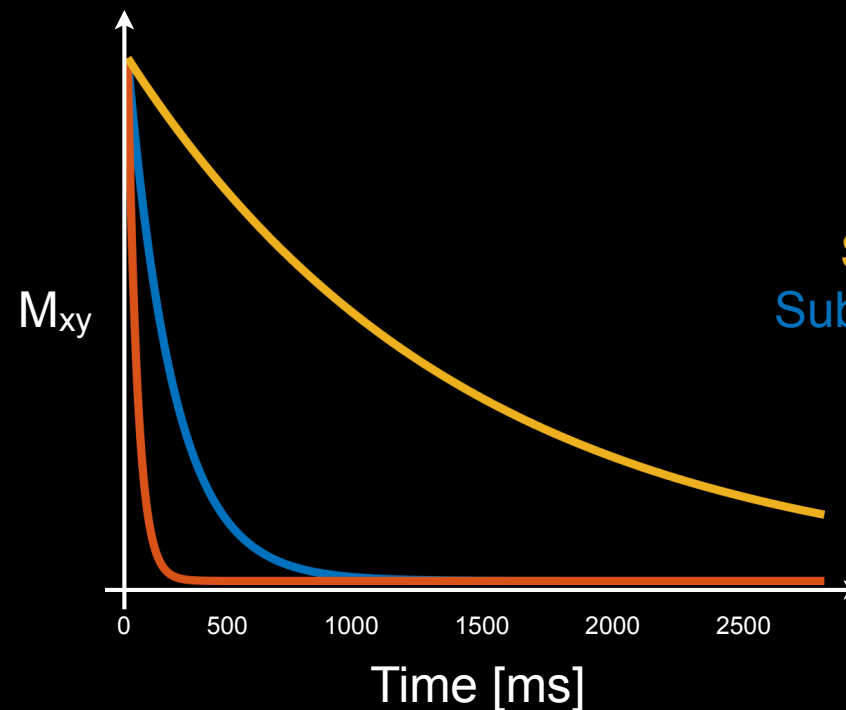
FLASH – TE=14.2ms; TR=200ms



FLASH – TE=24ms; TR=200ms

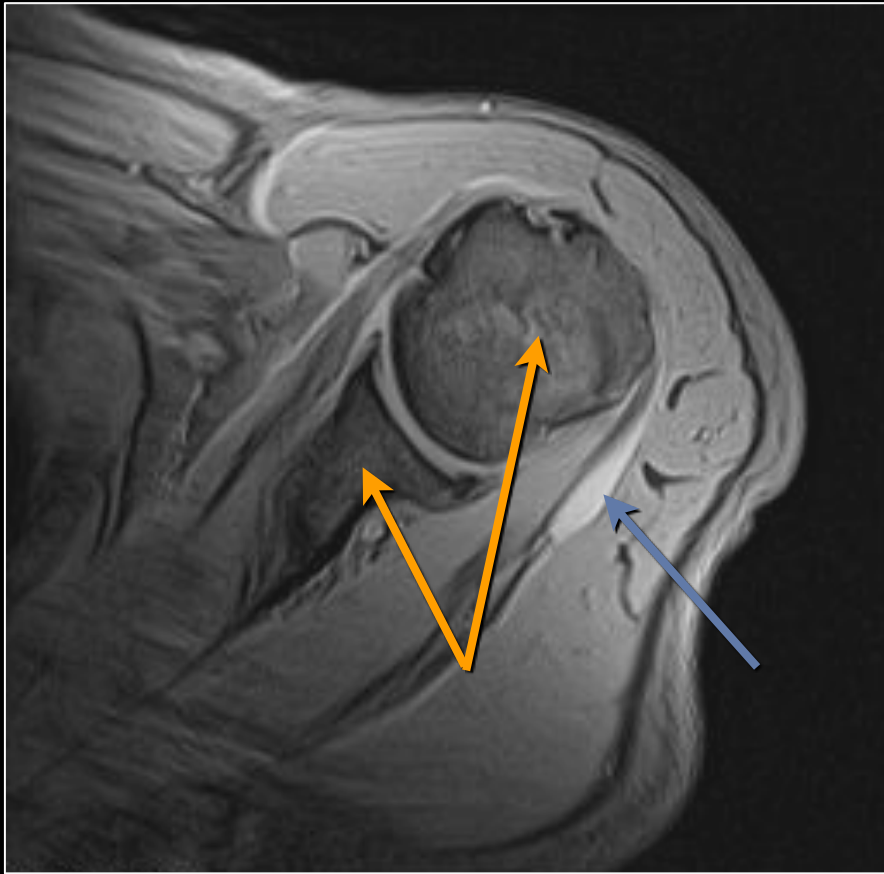


FLASH – TE=49ms; TR=200ms

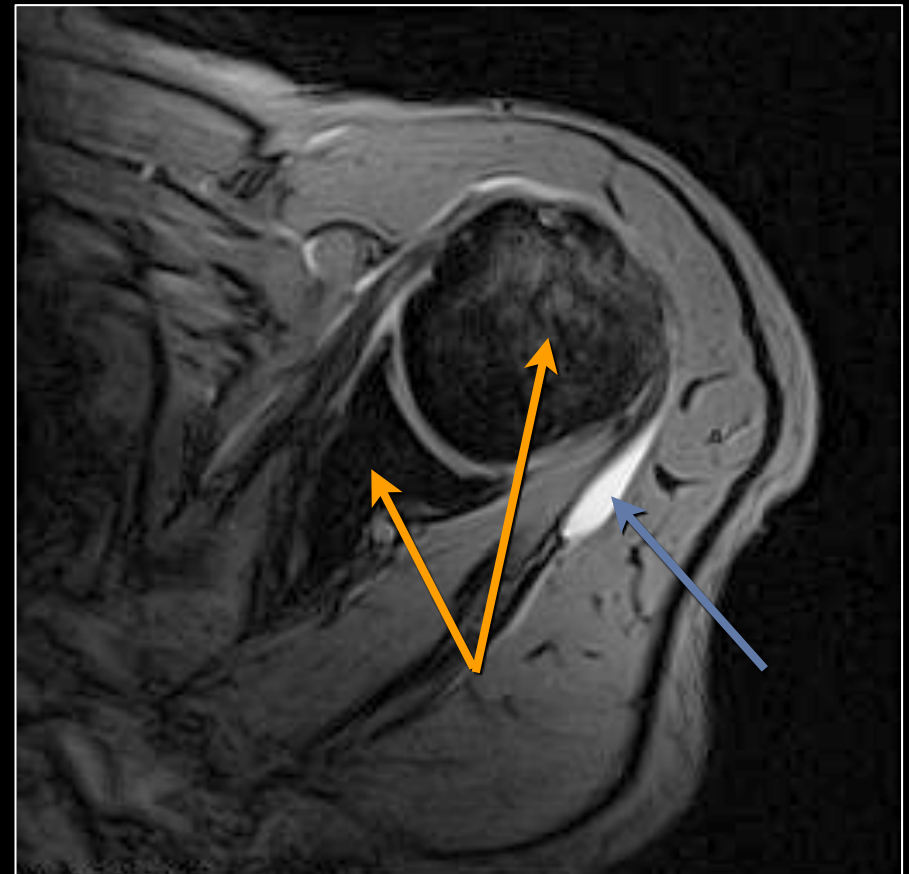


Synovial Fluid T₂~1210ms
Subcutaneous Fat T₂~165ms
Muscle T₂~35ms

T₂*-weighted Gradient Echo MRI



TE=9ms



TE=30ms

Susceptibility Weighting (darker with longer TE)
Bright fluid signal (long T₂* 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

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

- With off-resonance:

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

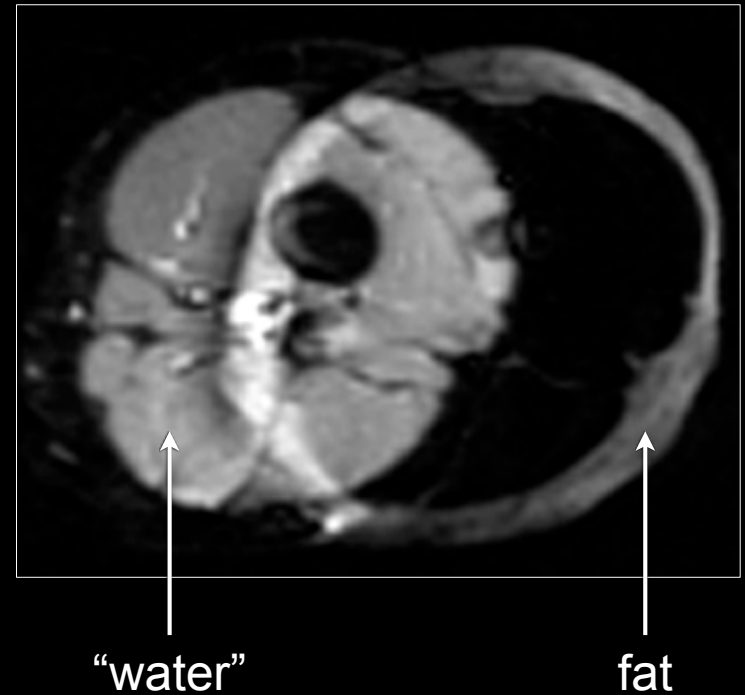
- B0 inhomogeneity
- Susceptibility
- Chemical shift

To the Board

Gradient Echoes & Fat

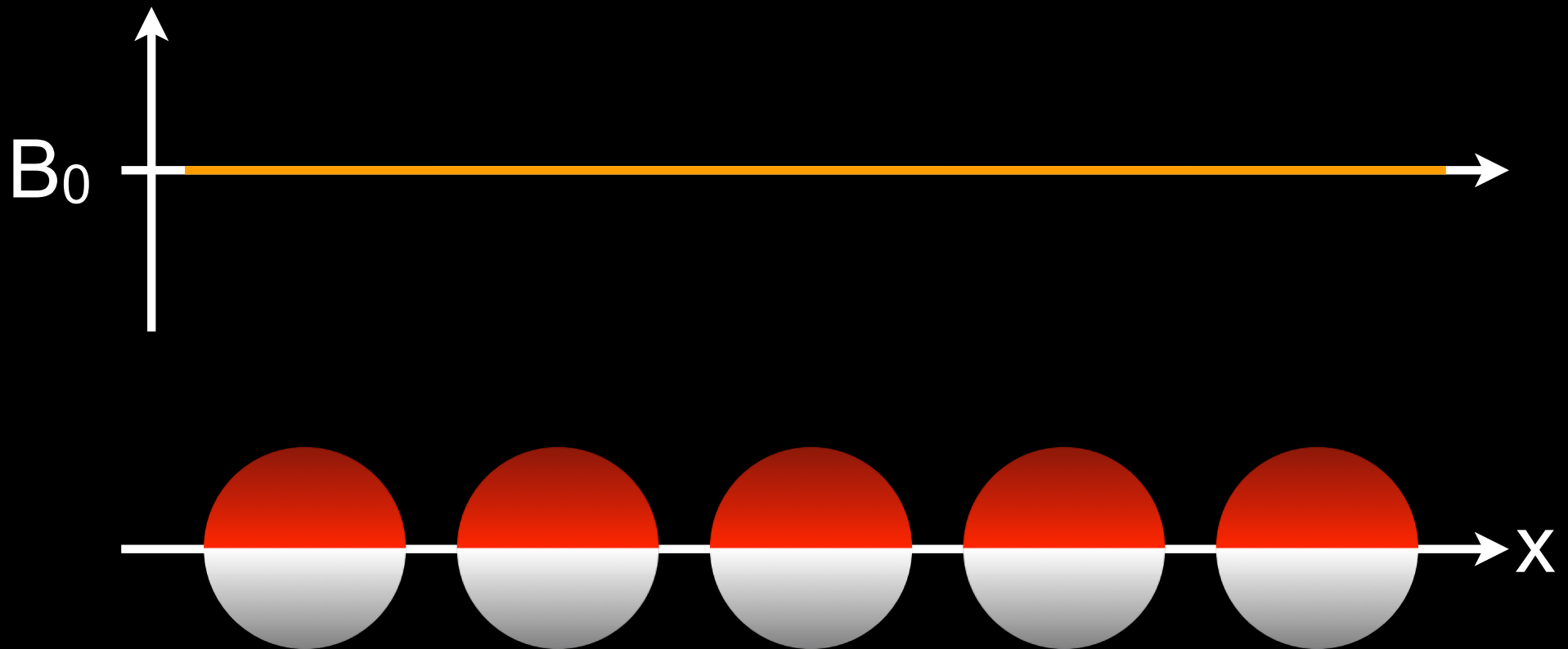
Chemical Shift - Type 1

- 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 more spatially mis-registered @ 3T



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

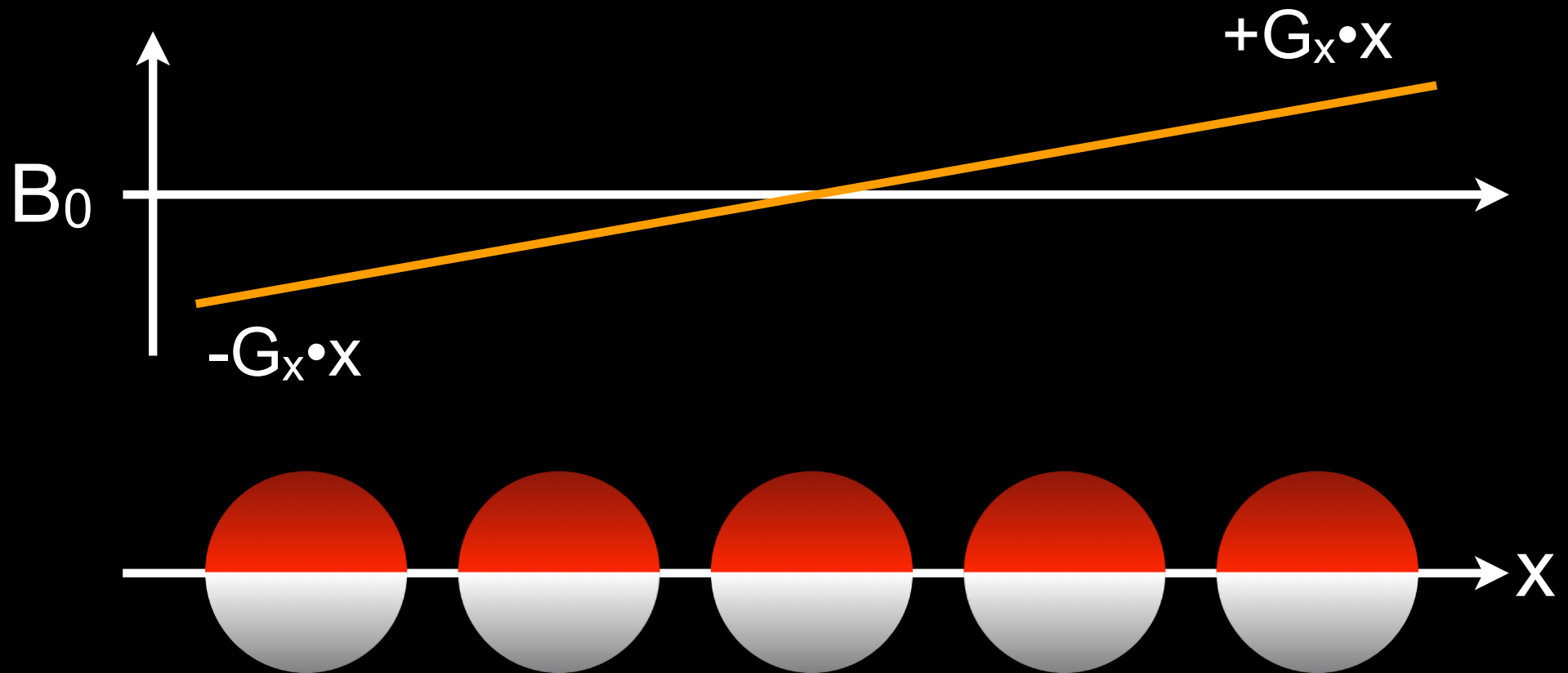
GRE & Fat/Water Frequency



Water Spins in a *Uniform* Field

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

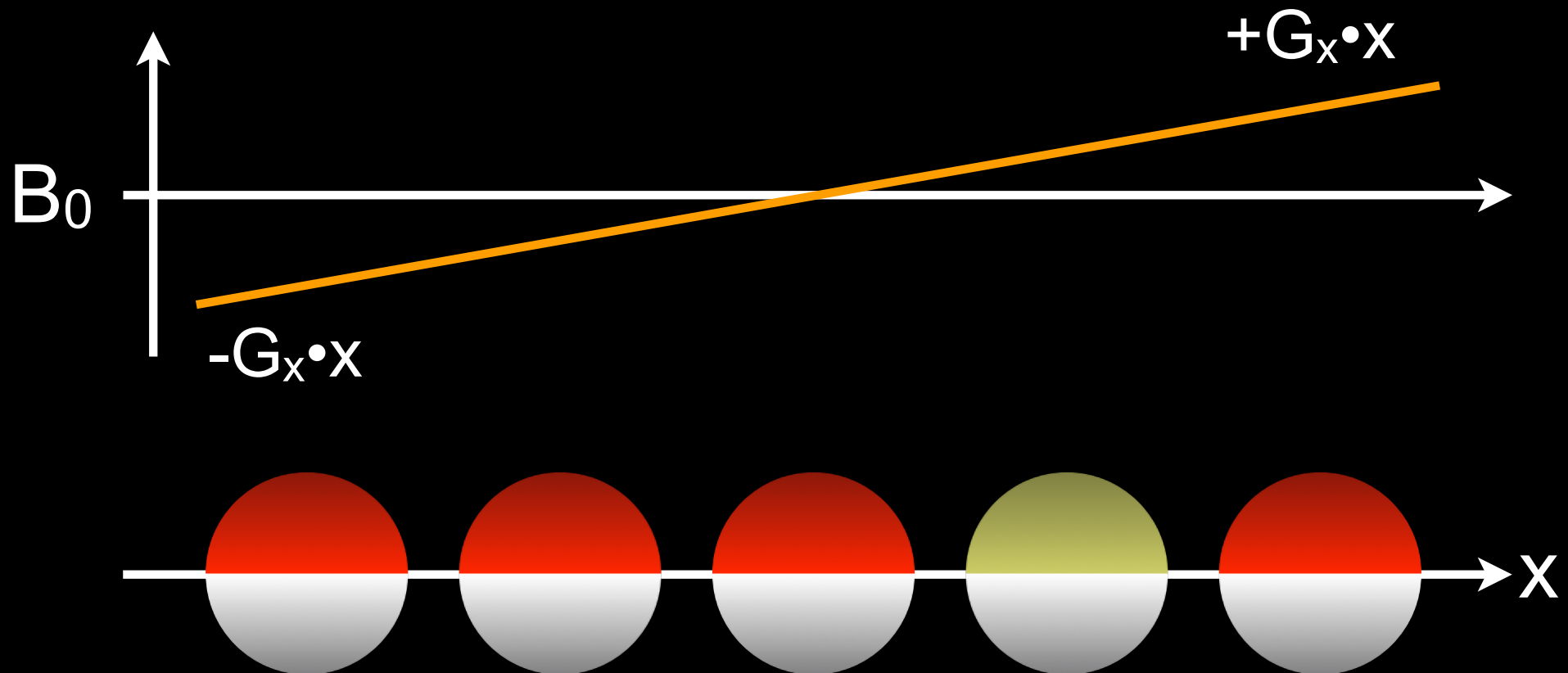
GRE & Fat/Water Frequency



Water Spins in a *Gradient* Field

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

GRE & Fat/Water Frequency

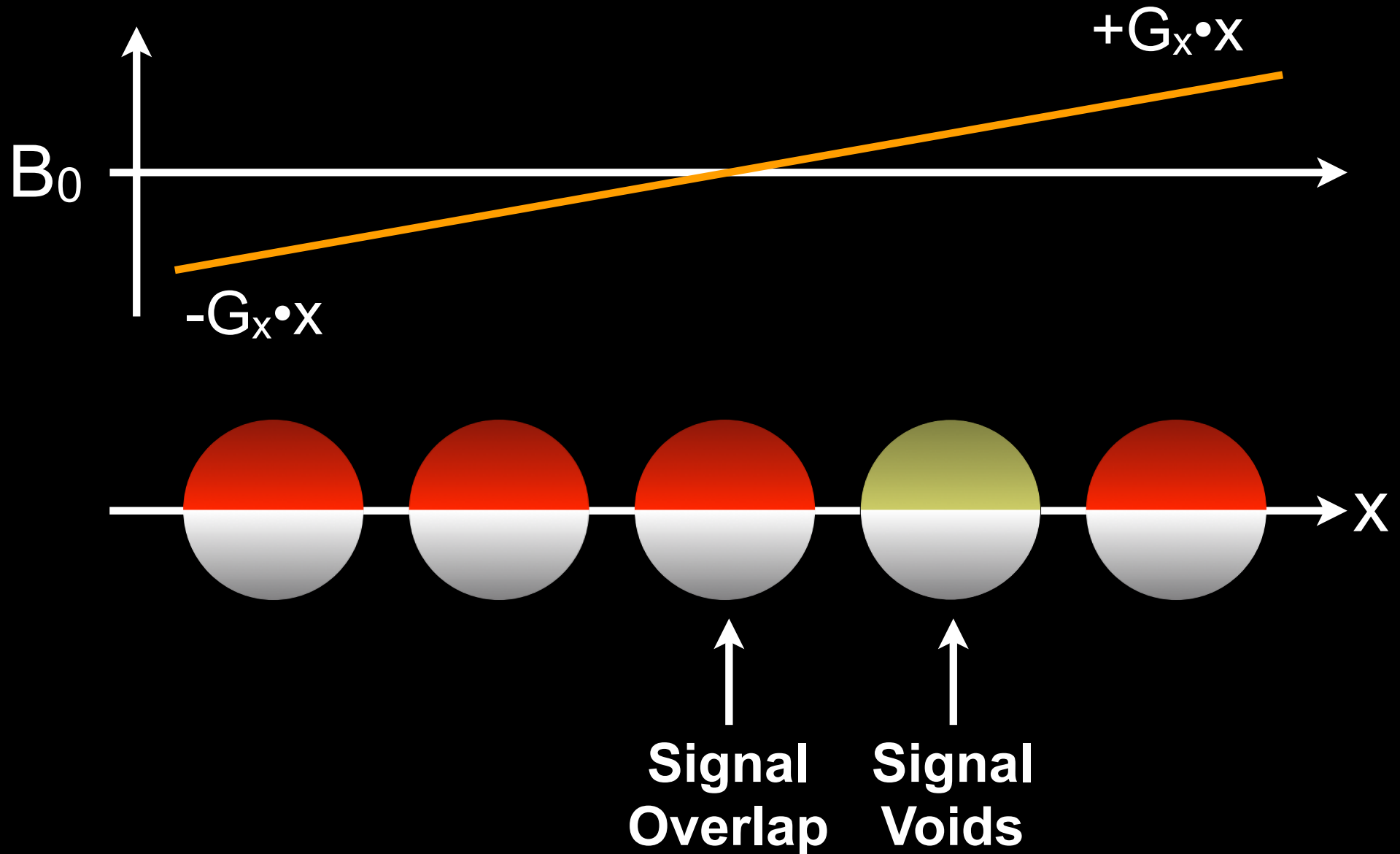


Water & Fat Spins in a Gradient Field

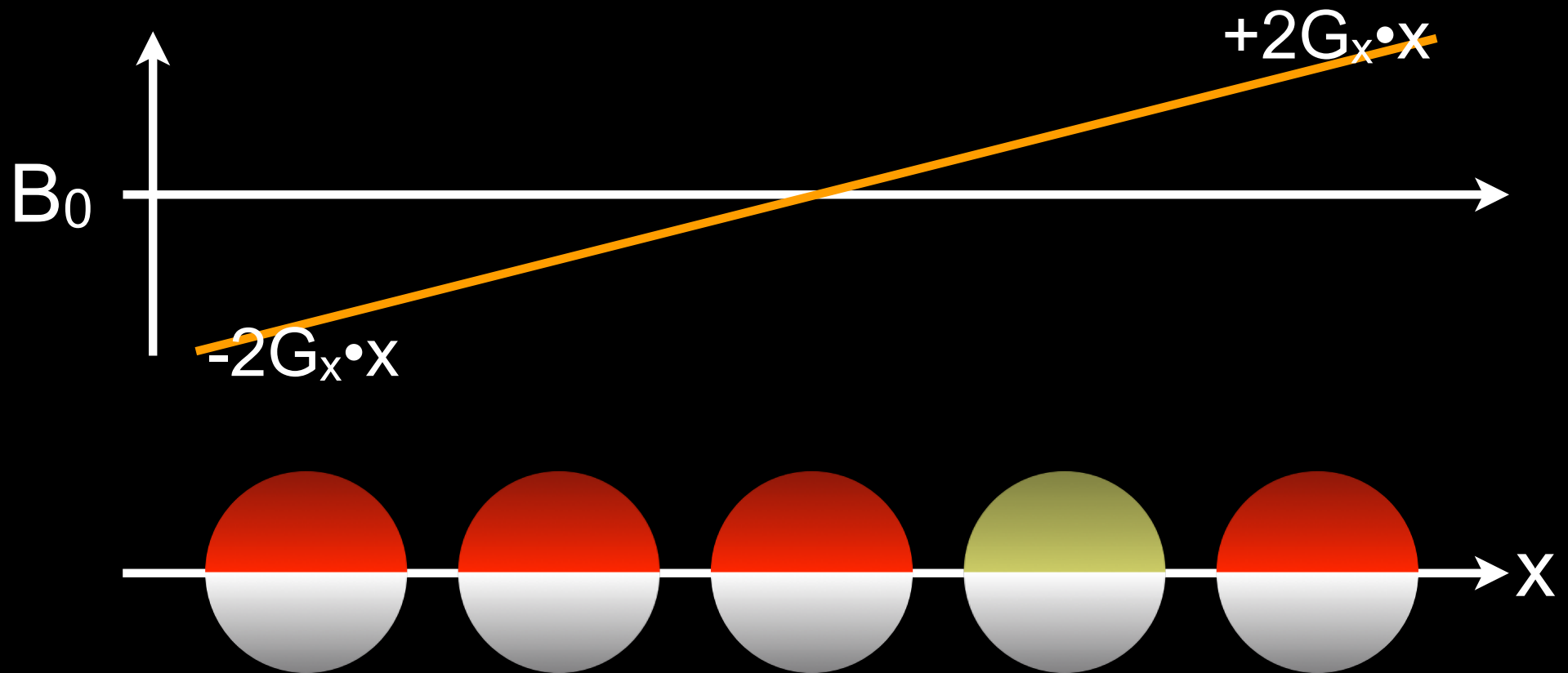
Fat Spins ~220Hz slower than water @ 1.5T

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

GRE & Fat/Water Frequency

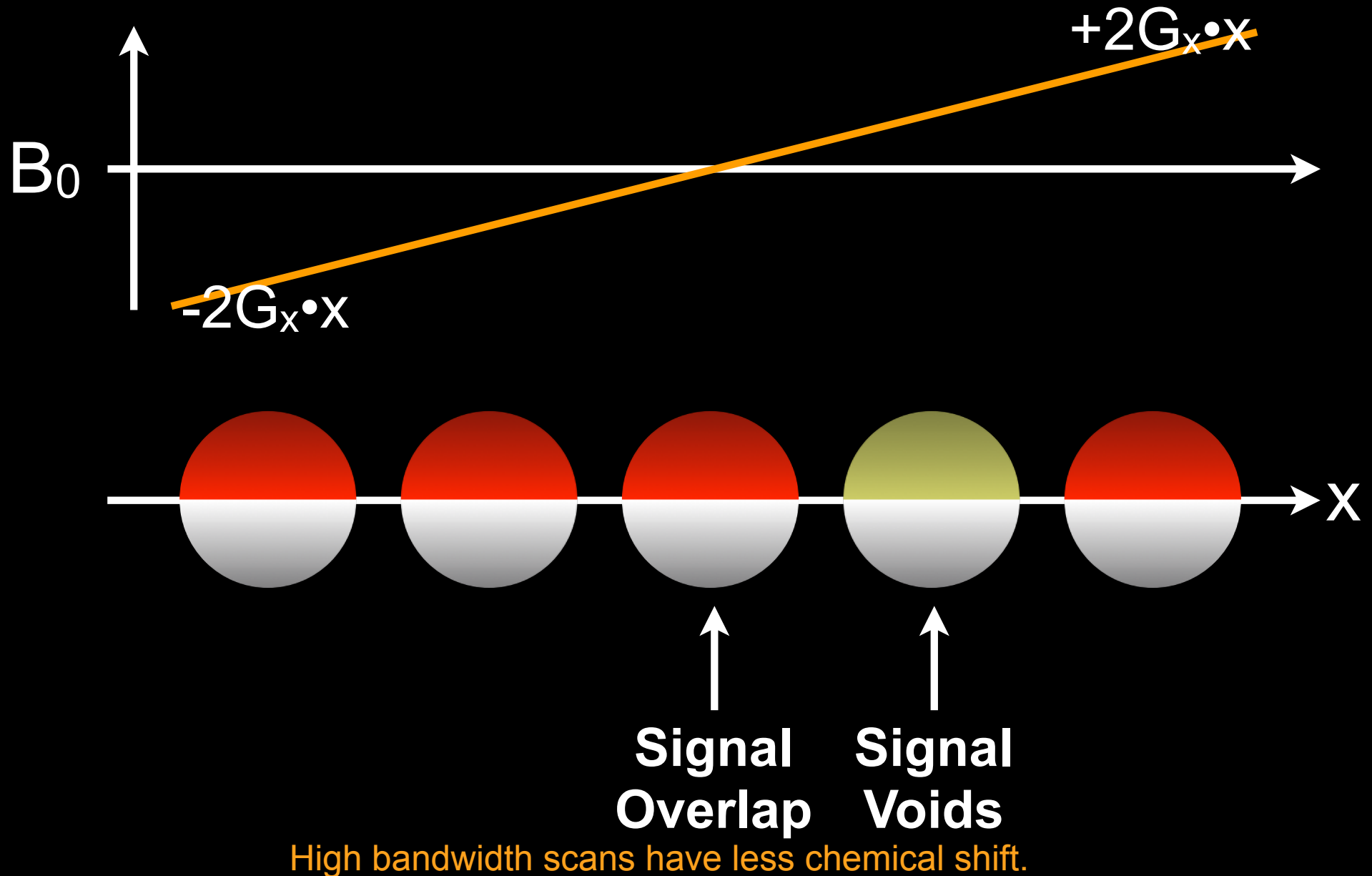


GRE and Bandwidth



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.

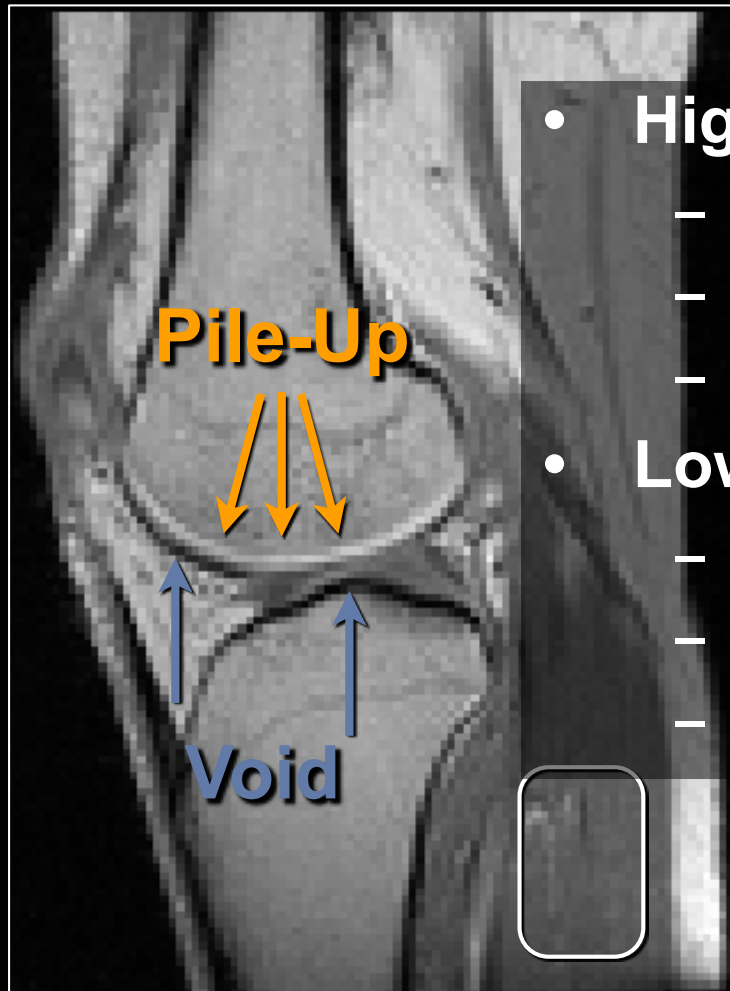
GRE and Bandwidth



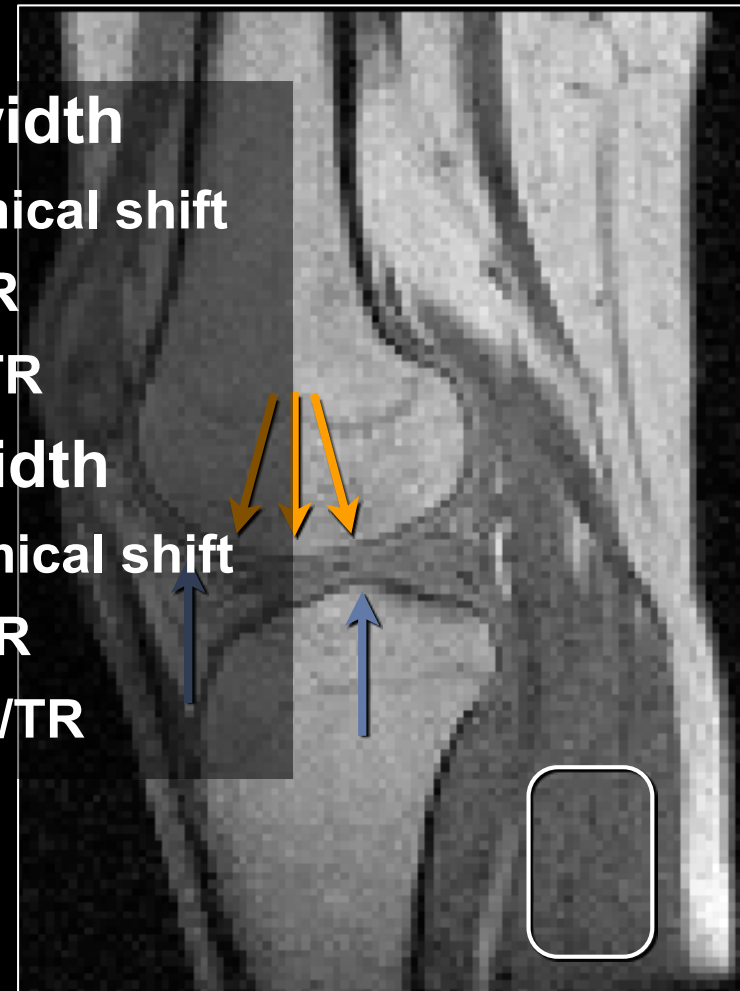
GRE, Fat/Water & Bandwidth

Low Bandwidth

High Bandwidth



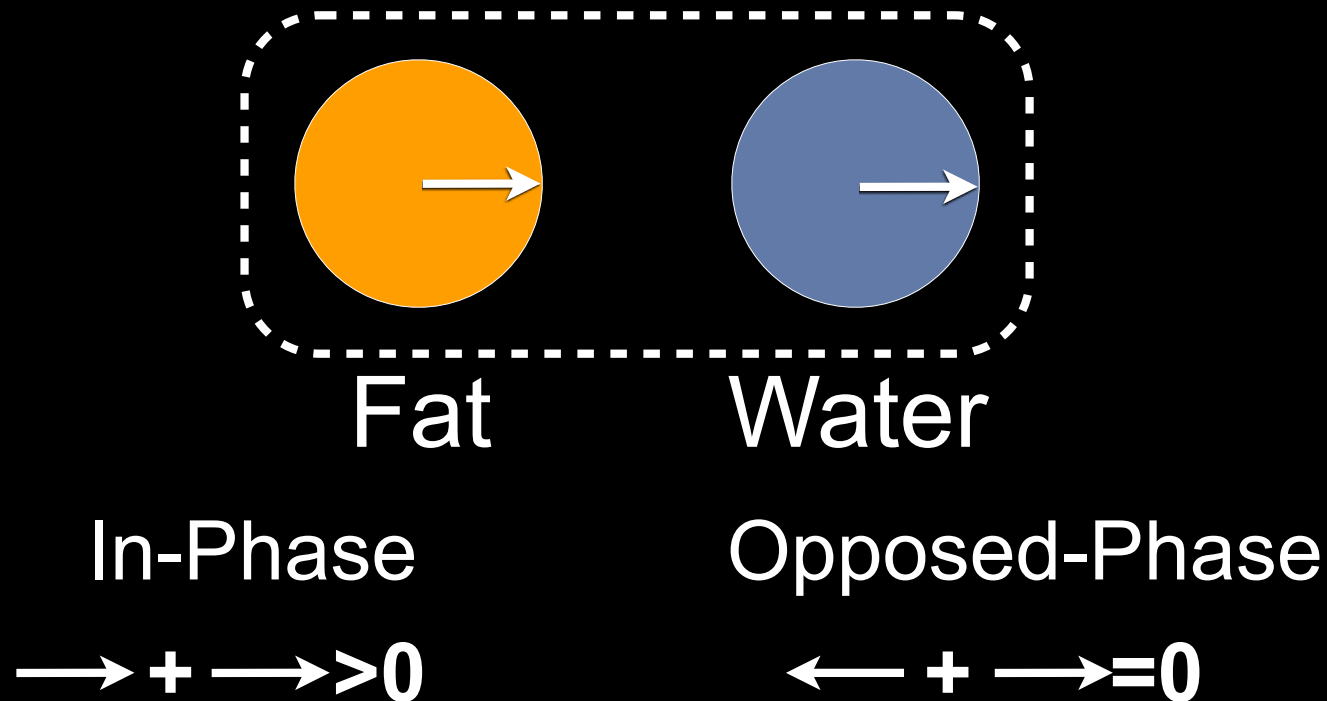
- High Bandwidth
 - Less chemical shift
 - Lower SNR
 - Short TE/TR
- Low Bandwidth
 - More chemical shift
 - Higher SNR
 - Longer TE/TR



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

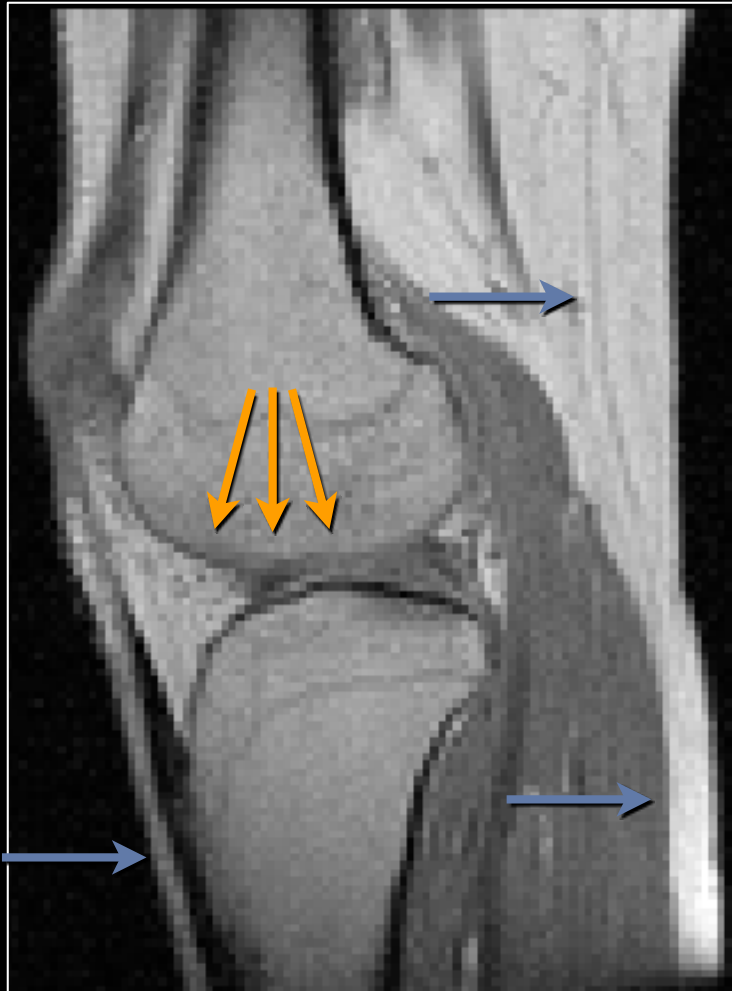
- Pixels are frequently a mixture of fat and water
- Pixel intensity is the vector sum of fat and water



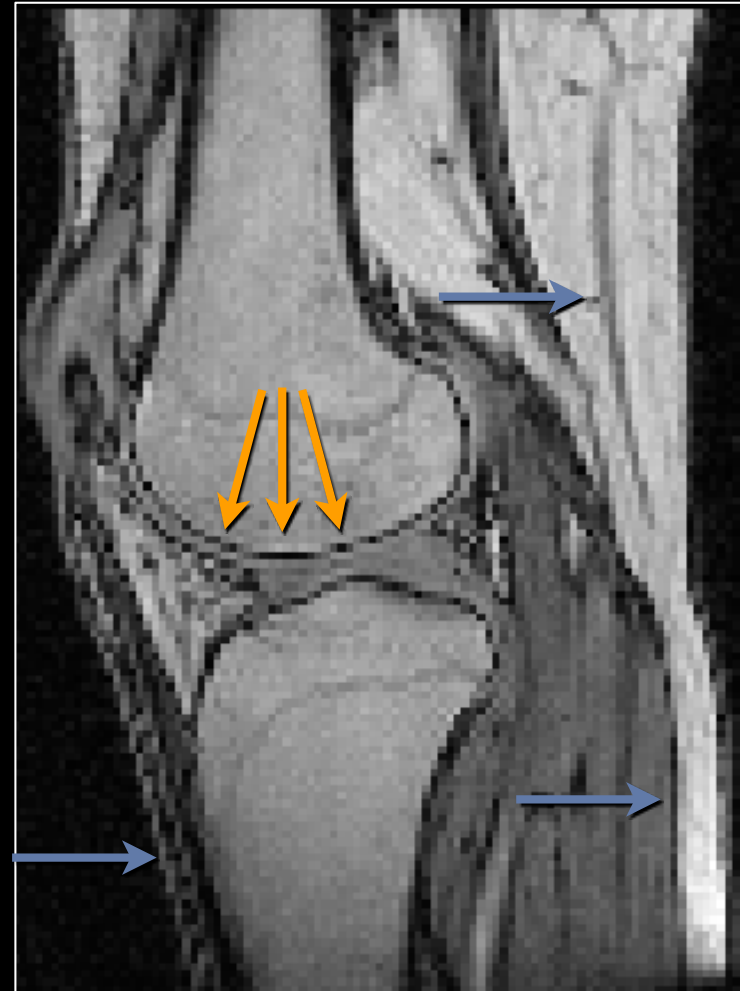
The TE controls the phase between fat and water.

GRE and Fat/Water Phase

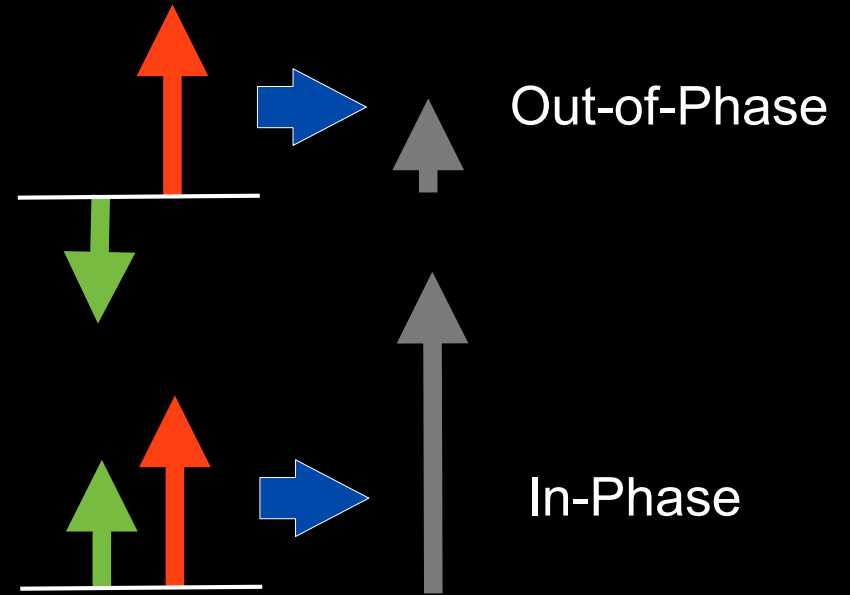
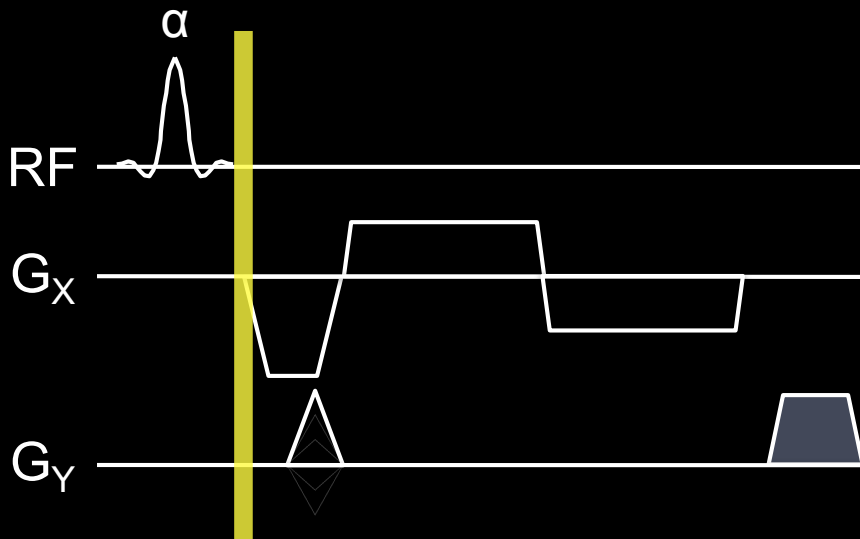
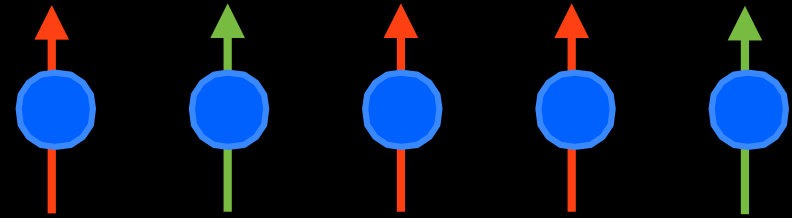
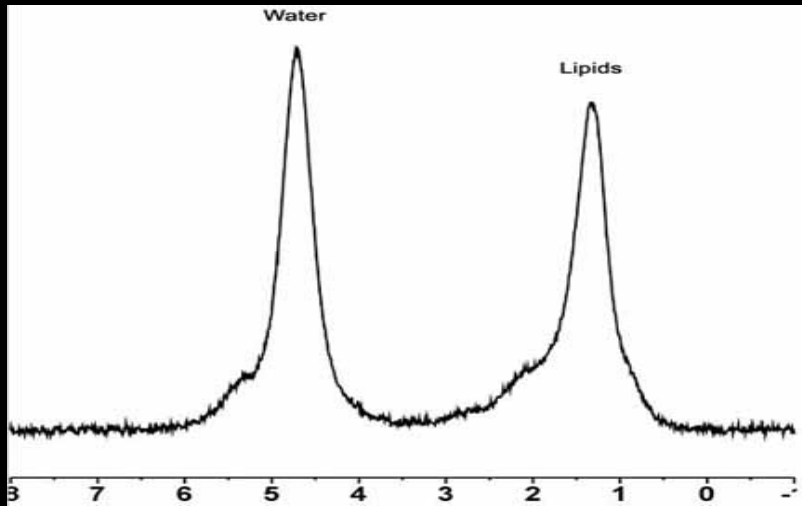
In-Phase



Opposed-Phase

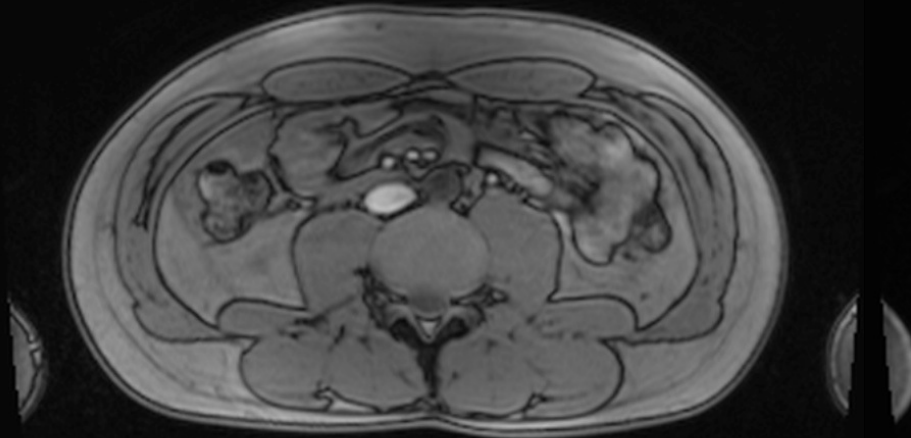


Dual-Echo Acquisition

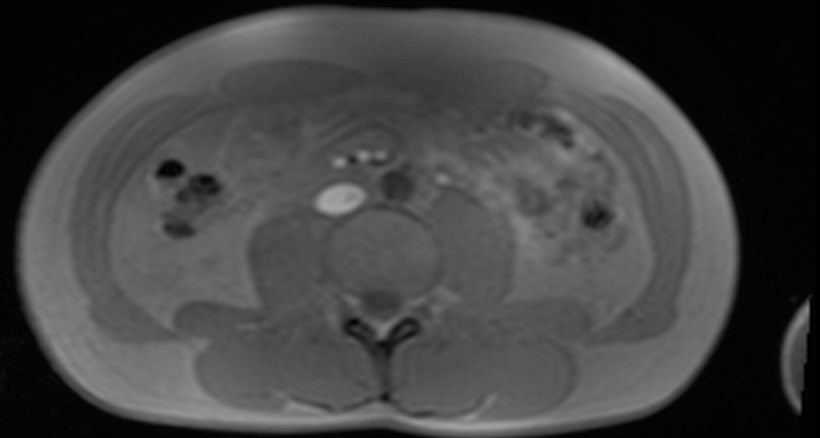


In-phase and Out-of-phase

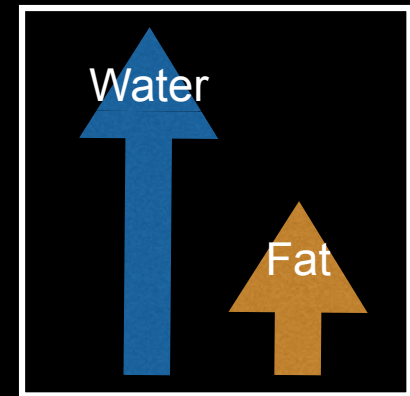
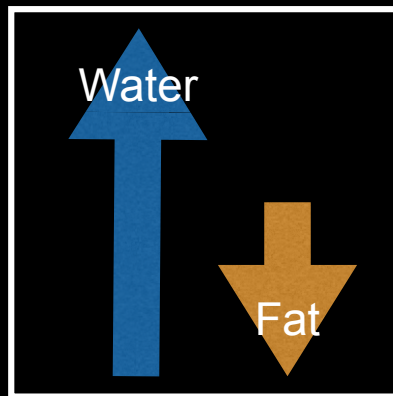
Example: 3 T abdominal scan



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

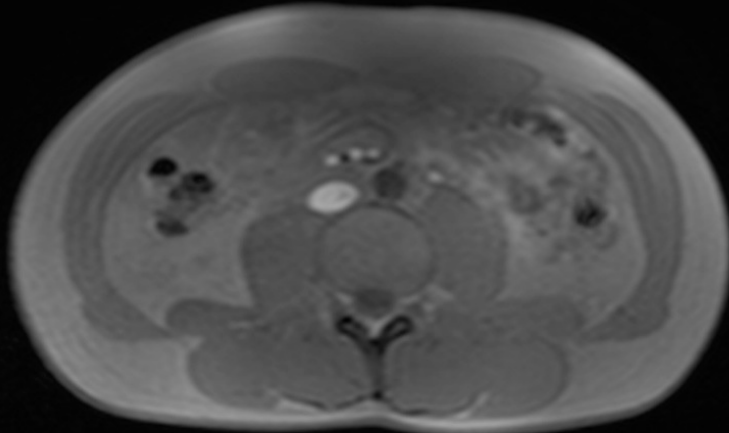


In-phase (3 T), TE = 2.6 ms

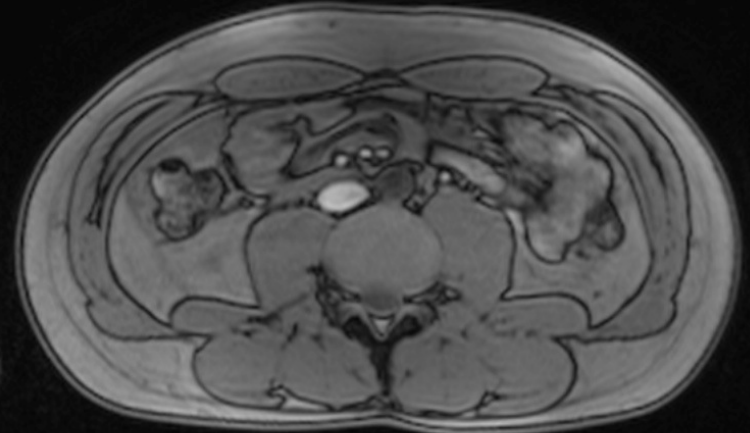


2-Point Dixon

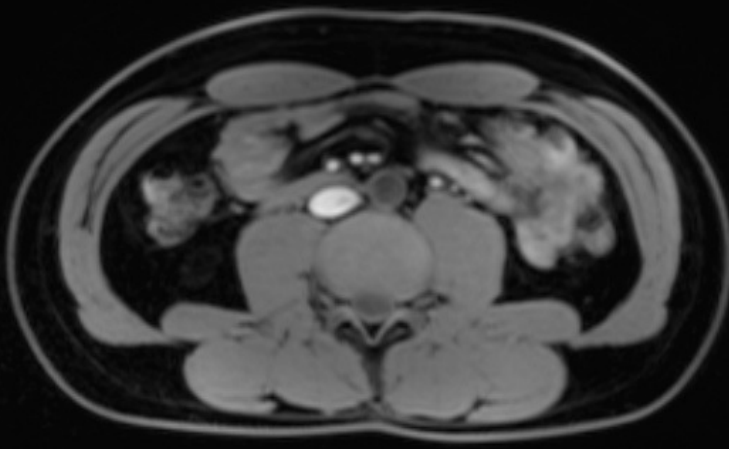
Example: 3 T abdominal scan



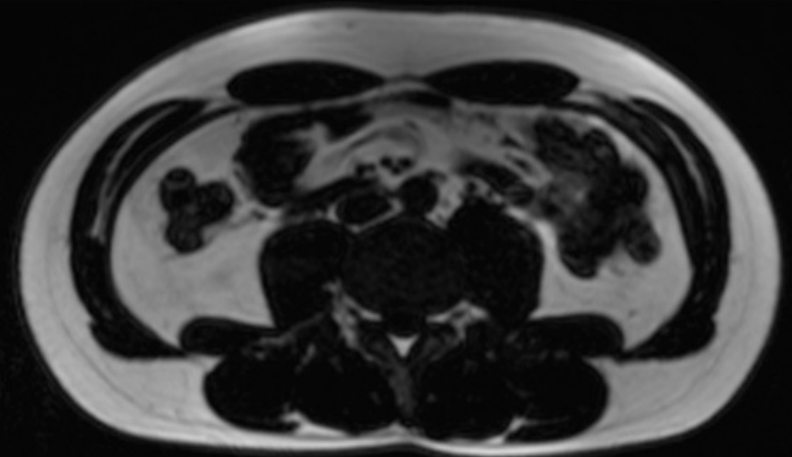
In-phase (3T), TE = 2.6 ms



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

Questions?

- Related reading materials
 - Nishimura - Chap 7

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<http://mrri.ucla.edu/sunglab>