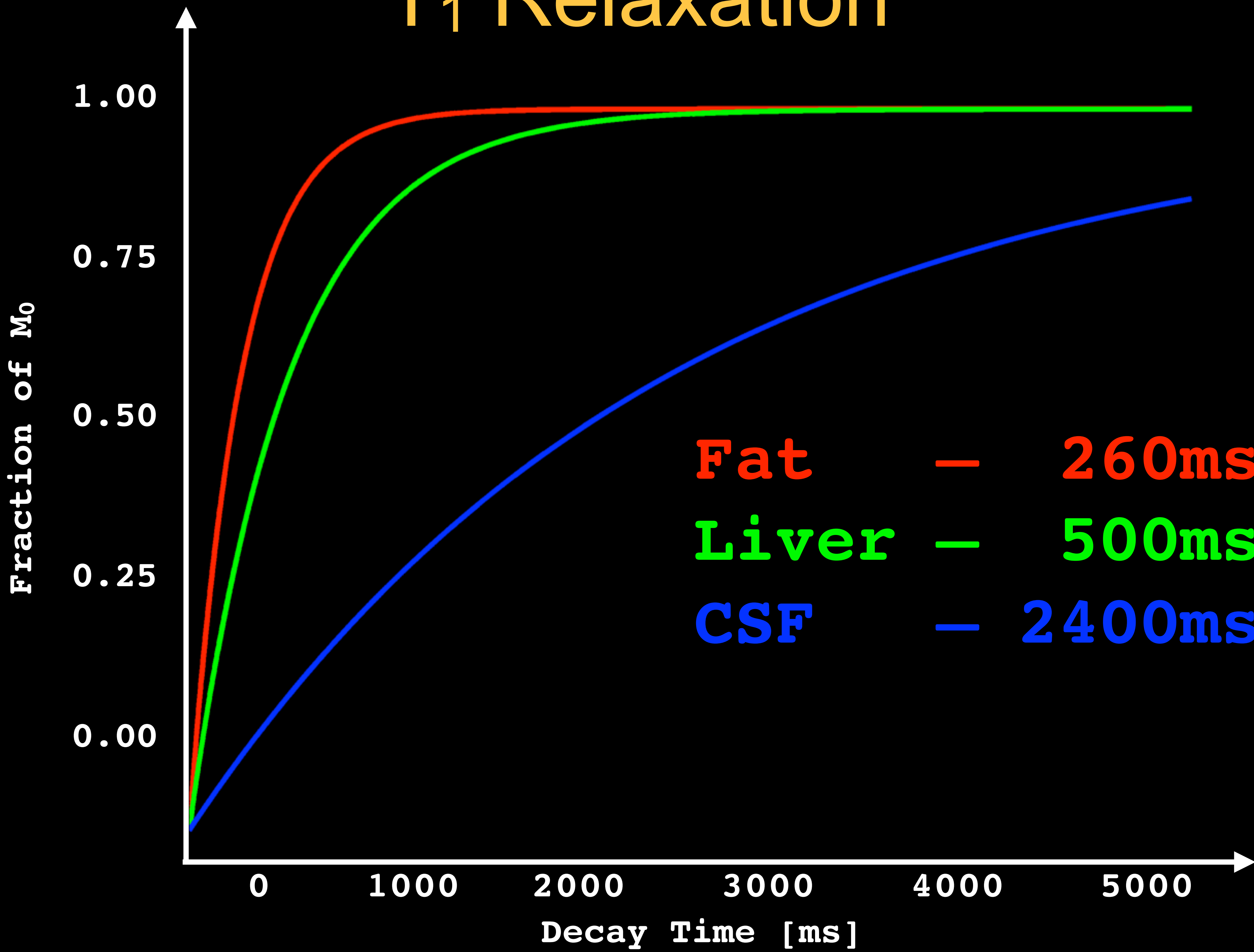
Advanced Medical Imaging:
Spin Echo / Gradient Echo Imaging

2019 Fellows' Lecture Series

Kyung Sung, Ph.D.
Magnetic Resonance Research Labs (MRRL)
Department of Radiological Sciences,
Bioengineering, and Physics & Biology in Medicine
David Geffen School of Medicine
University of California, Los Angeles

T_1 & T_2 Relaxation

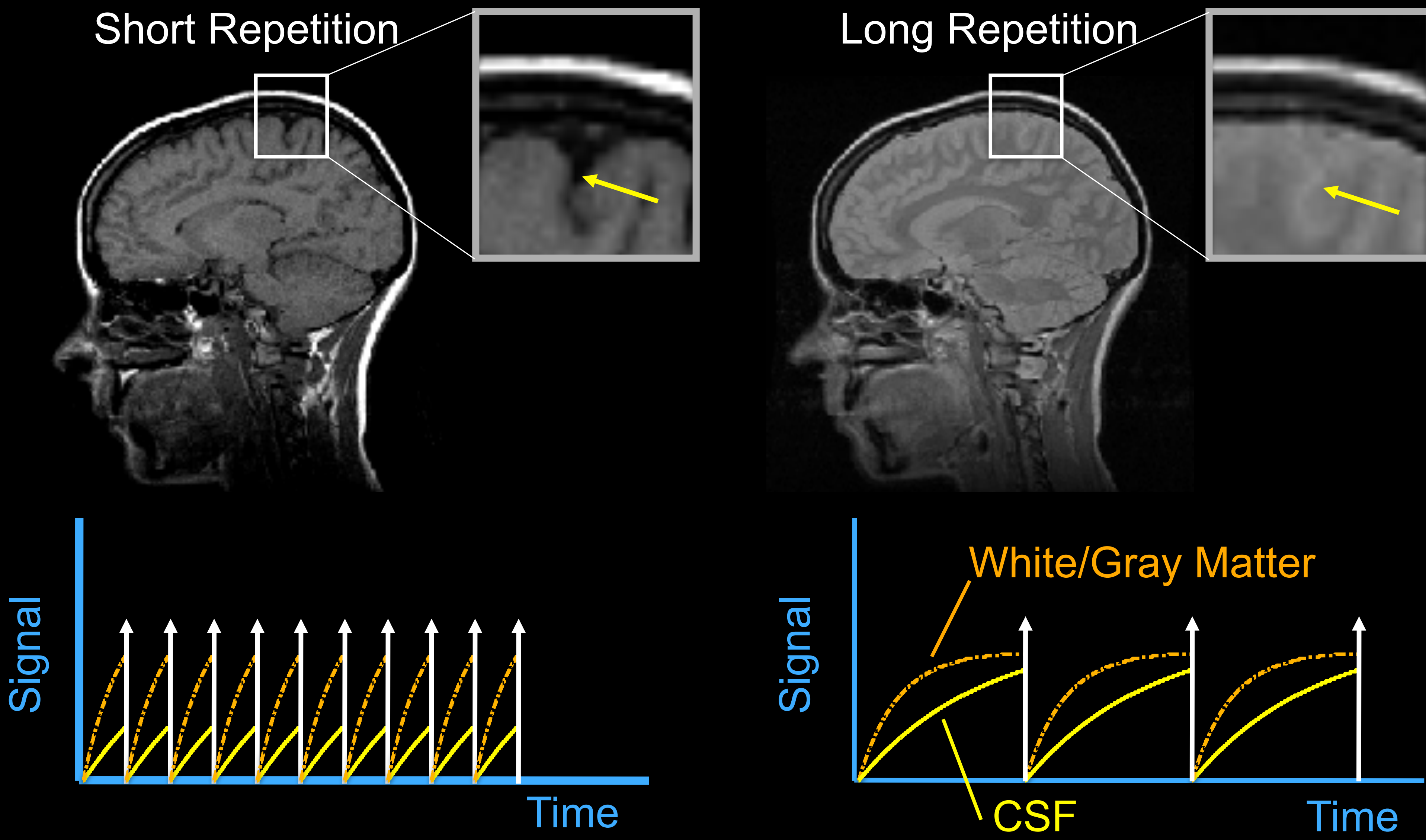
T_1 Relaxation



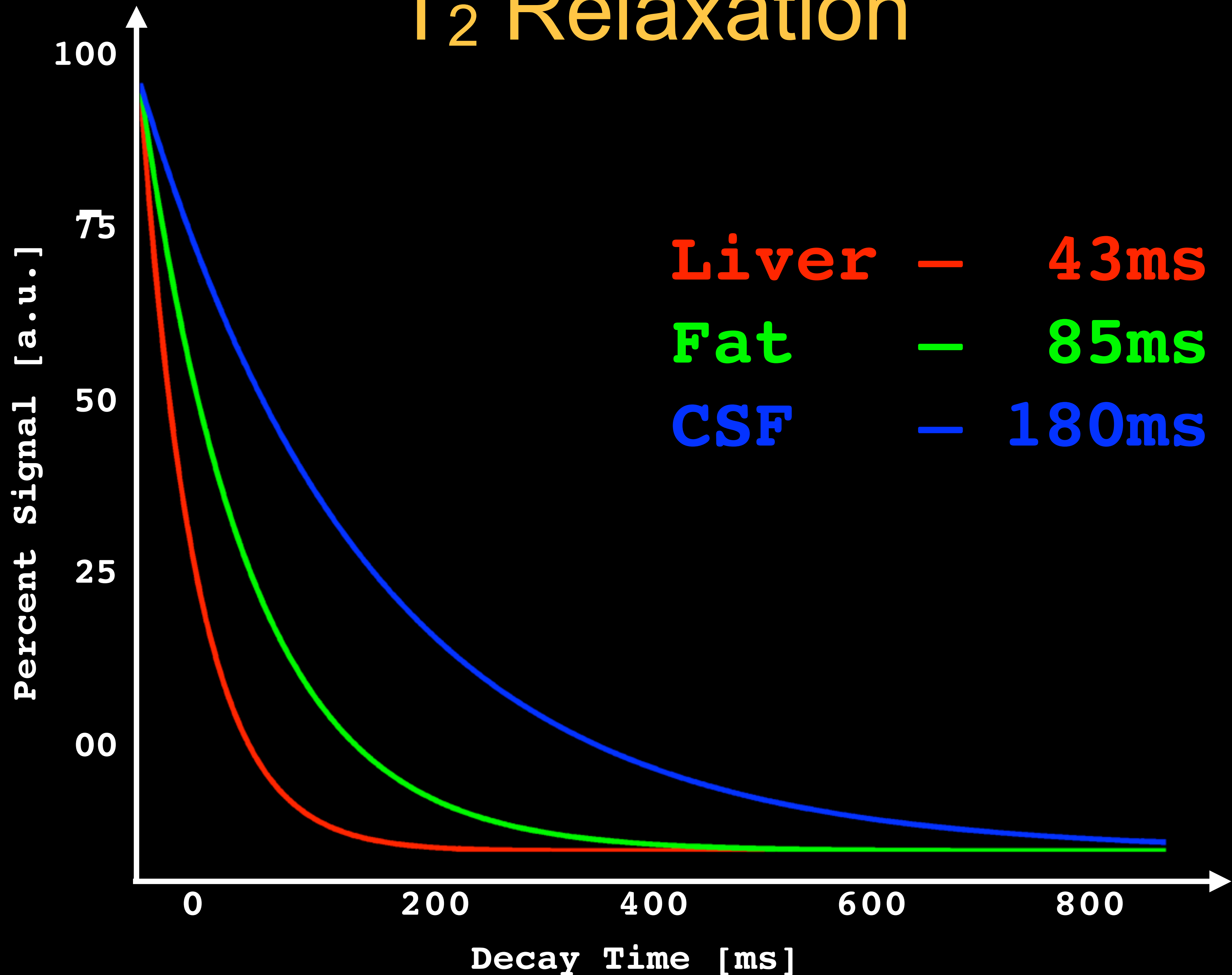
T_1 Relaxation

- Longitudinal or spin-lattice relaxation
  - Typically, (10s ms) < T1 < (100s ms)
- T1 is long for
  - Small molecules (water)
  - Large molecules (proteins)
- T1 is short for
  - Fats and intermediate-sized molecules
- T1 increases with increasing B0
- T1 decreases with contrast agents

T1 Contrast


Short Repetition
Long Repetition
Signal
Time
White/Gray Matter
CSF
Signal
Time

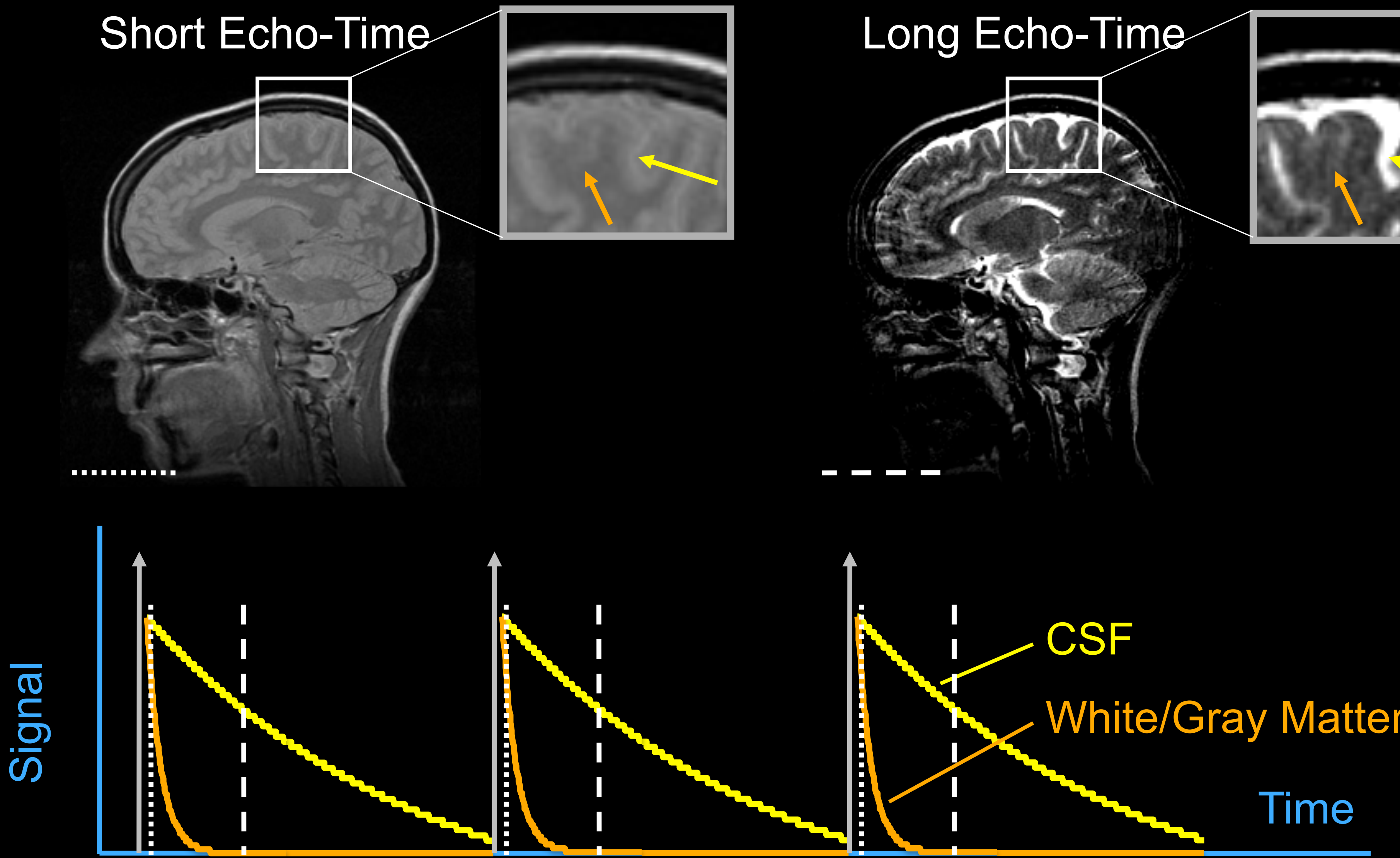
T_2 Relaxation



T_2 Relaxation

- Transverse or spin-spin relaxation
  - Molecular interaction causes spin dephasing
  - Typically, T2 < (10s ms)
- Increasing molecular size, decrease T2
  - Fat has a short T2
- Increasing molecular mobility, increases T2
  - Liquids (CSF, edema) have long T2s
- Increasing molecular interactions, decreases T2
  - Solids have short T2s
- T2 relatively independent of B0

T2 Contrast

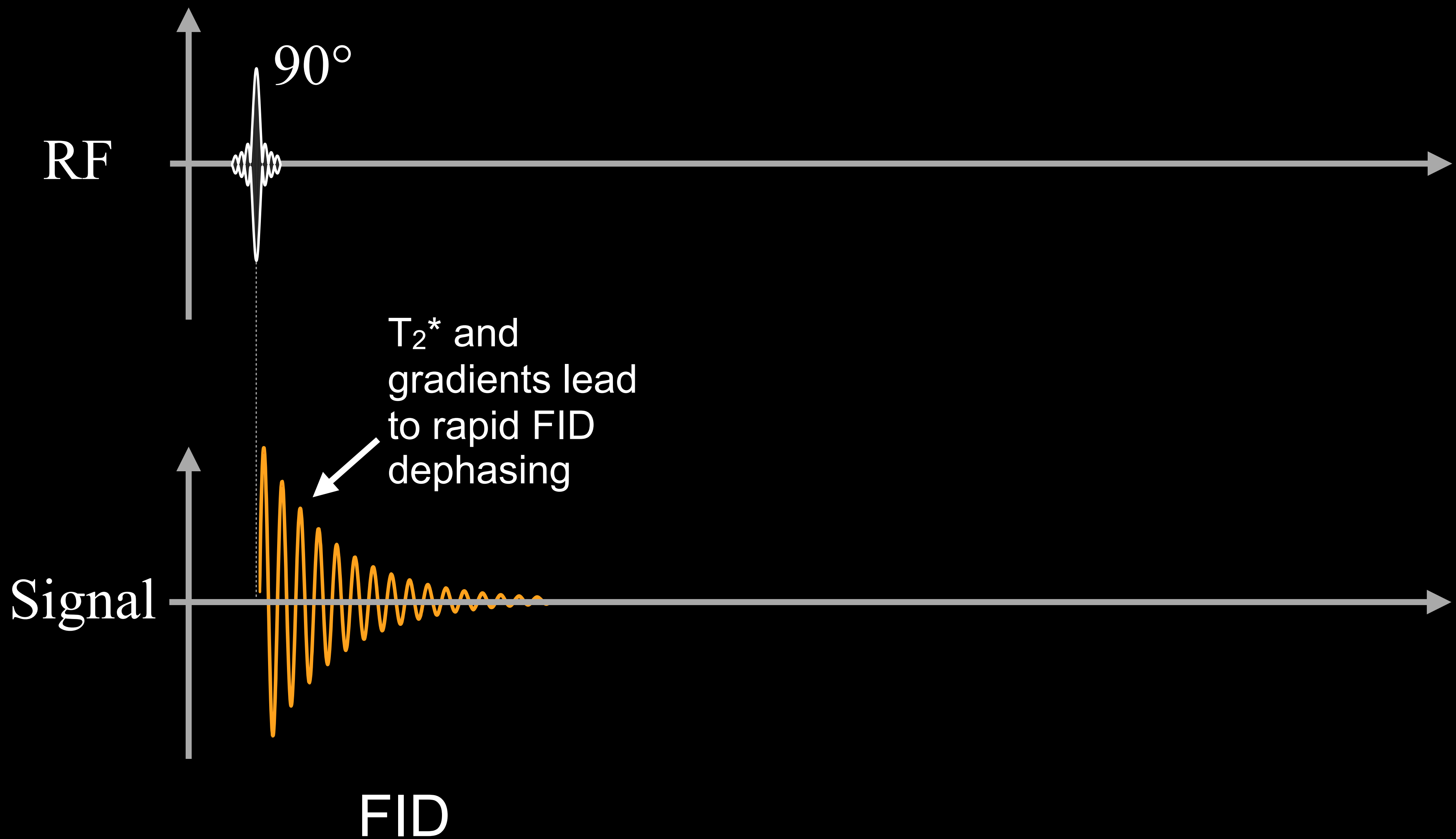

Short Echo-Time
Long Echo-Time
CSF
White/Gray Matter
Signal
Time

T_1 and T_2 Values @ 1.5T

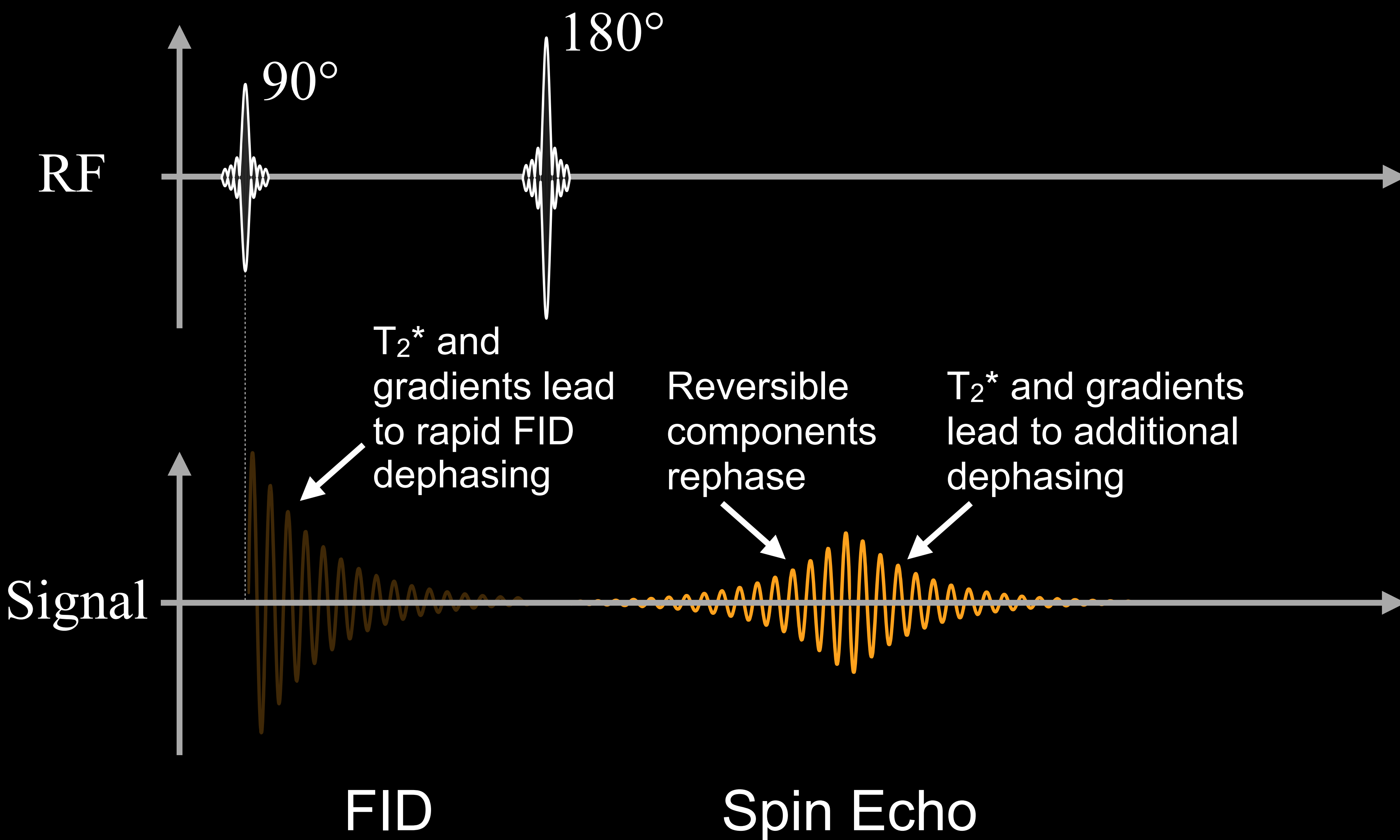
Tissue	T_1 [ms]	T_2 [ms]
gray matter	925	100
white matter	790	92
muscle	875	47
fat	260	85
kidney	650	58
liver	500	43
CSF	2400	180

Spin Echo Imaging

Free Induction Decay

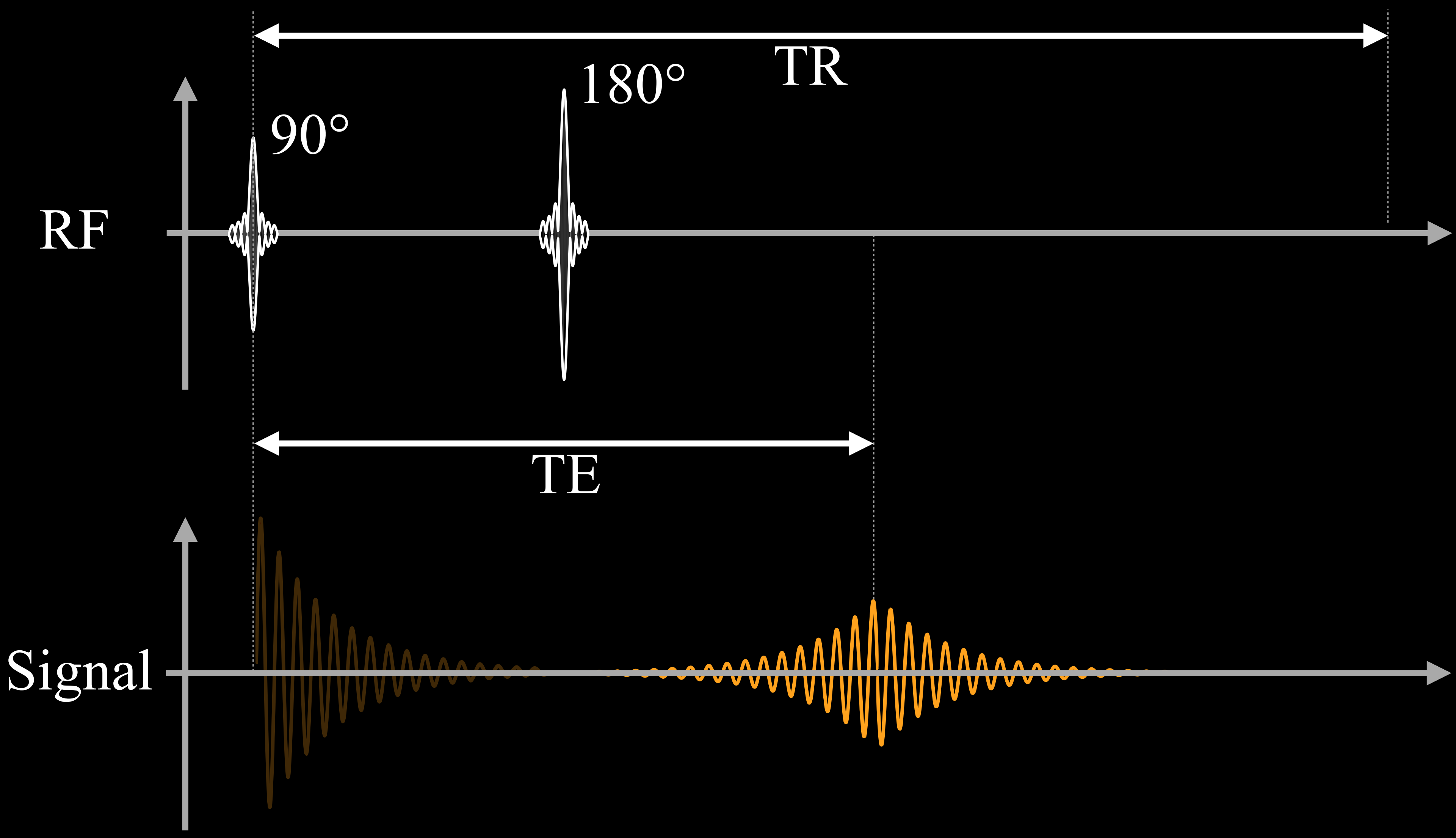


Spin Echo



Record by computer.

Spin Echo

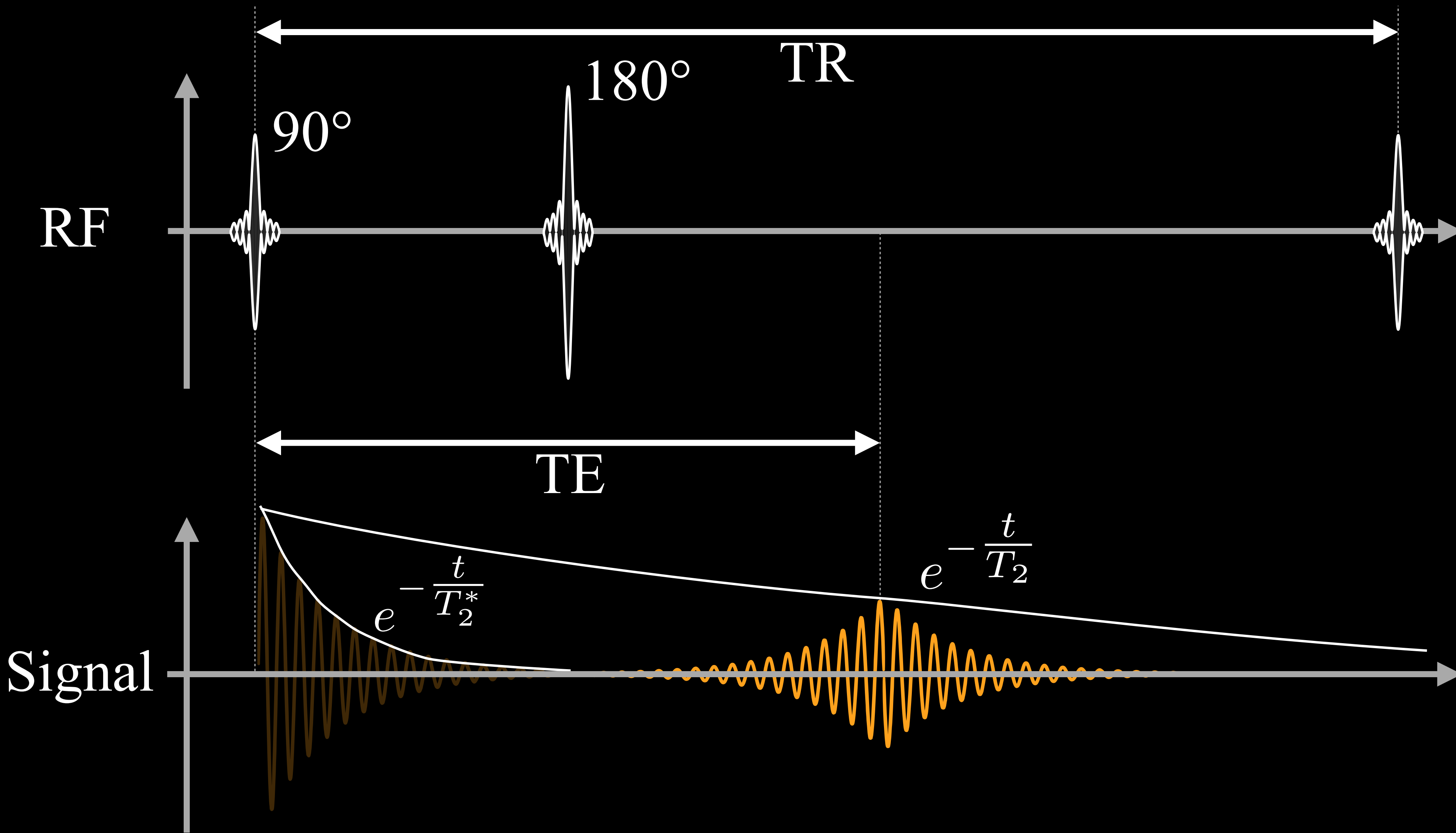


FID

Spin Echo

Record by computer.

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

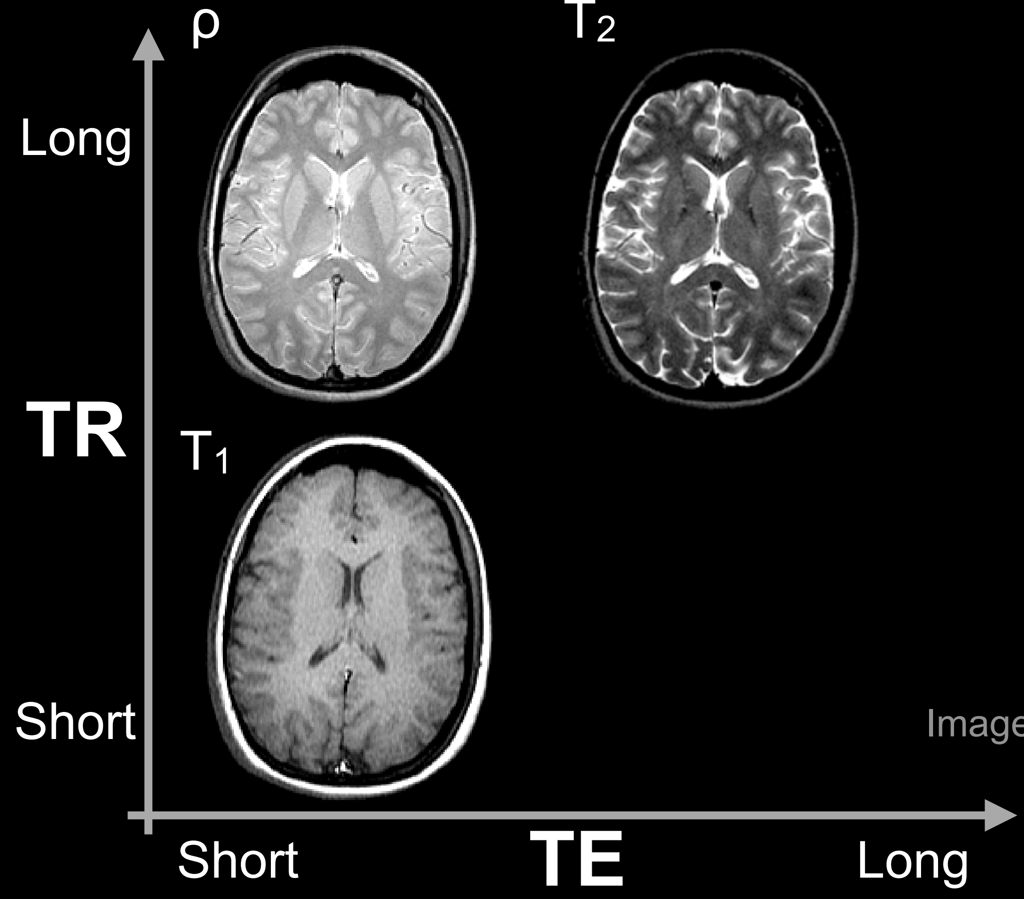
Intermediate TE
maximizes
T2 contrast

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

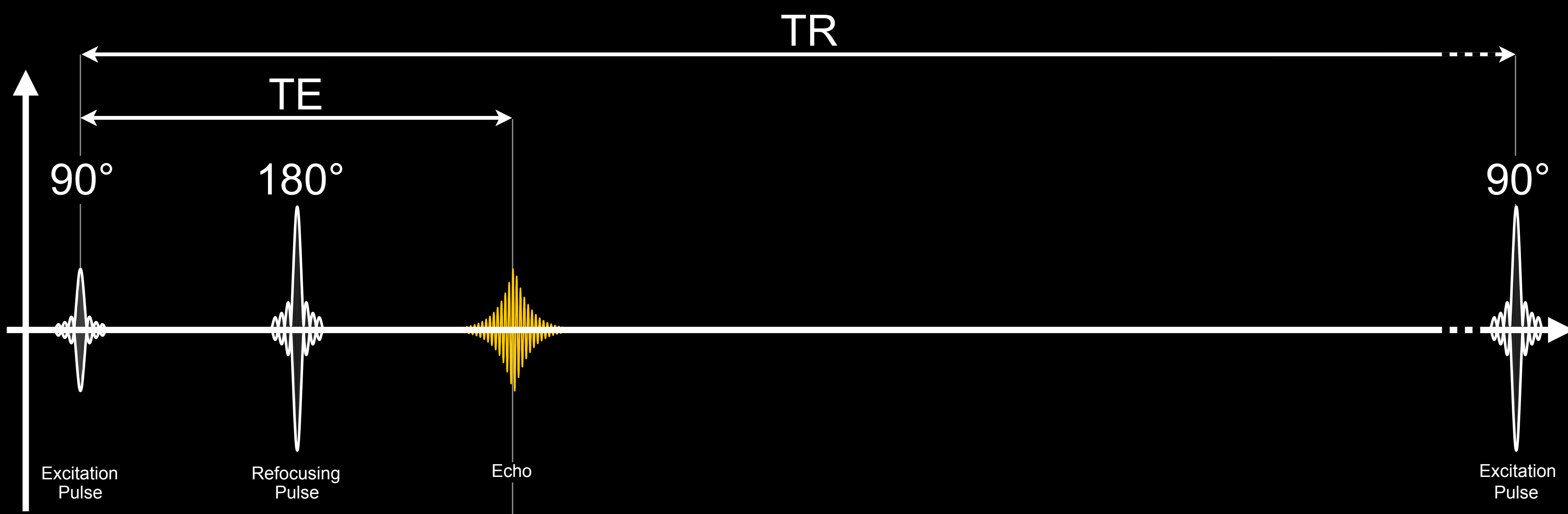


Images Courtesy of Mark Cohen

Spin Echo

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

Spin Echo

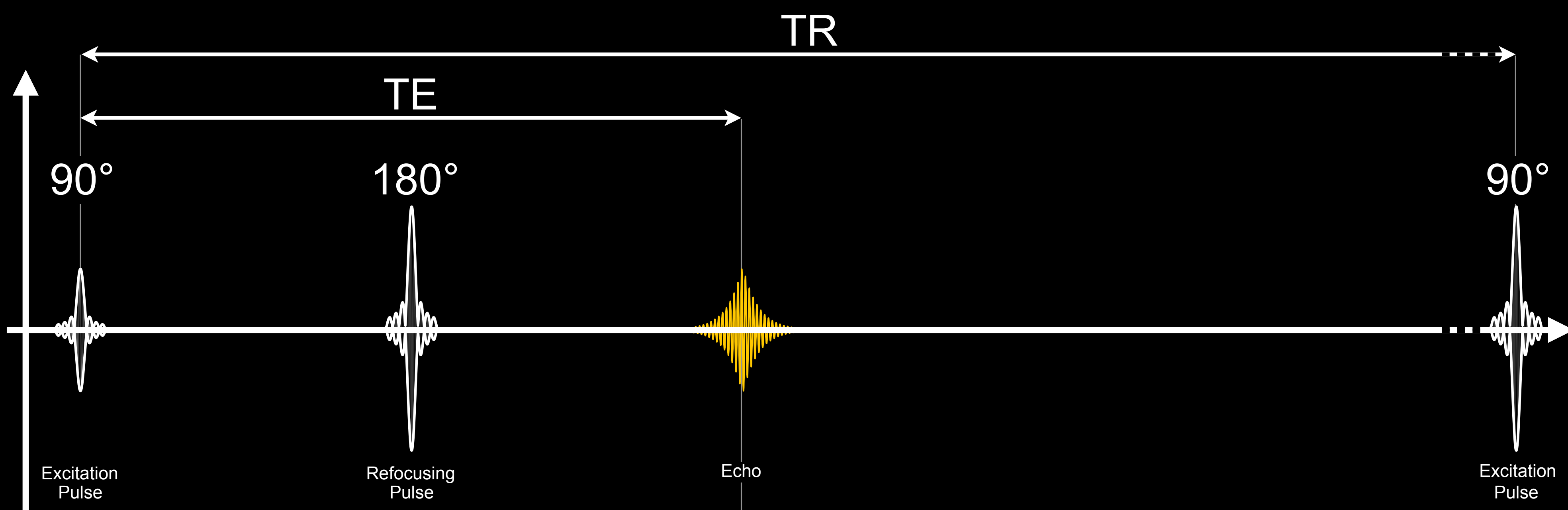


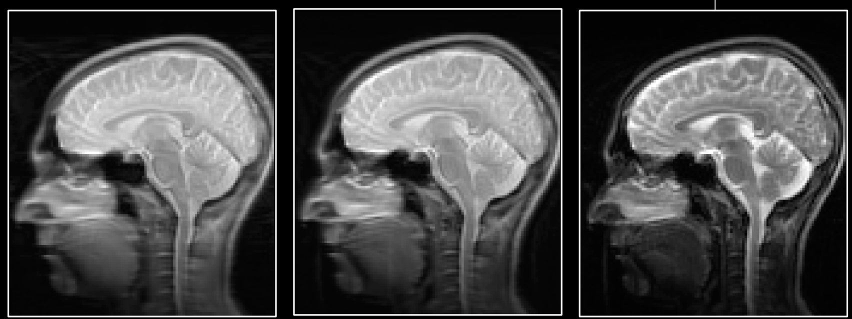
TE=12ms

TE=47ms

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

Spin Echo

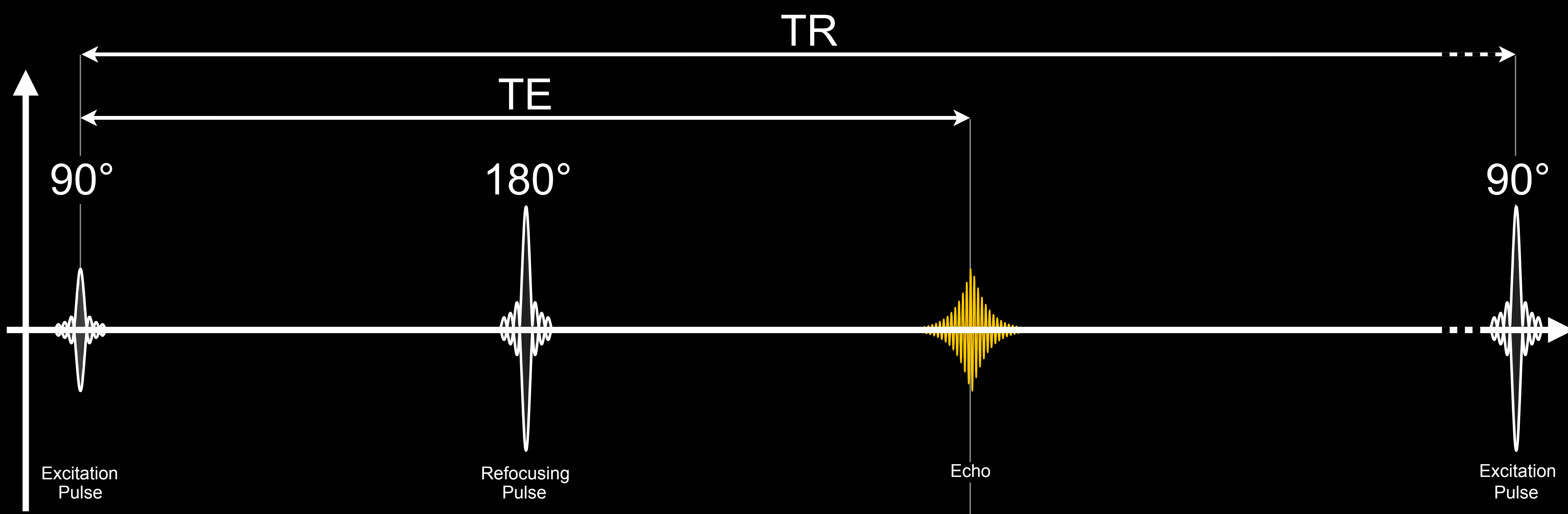


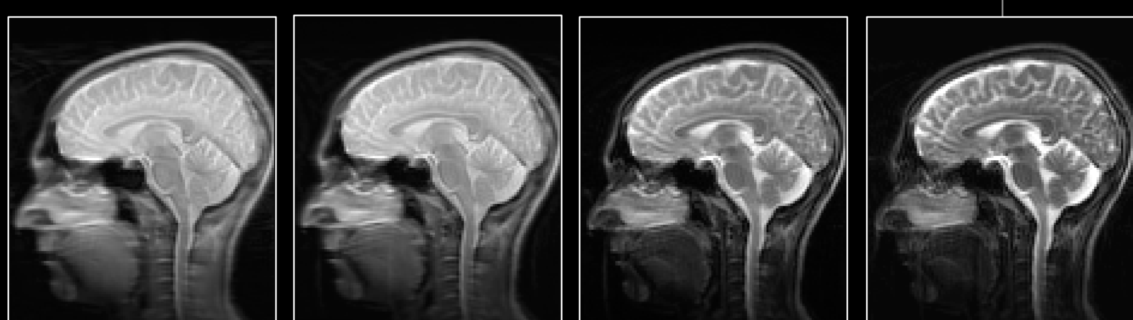


TE=12ms TE=47ms TE=106ms

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

Spin Echo

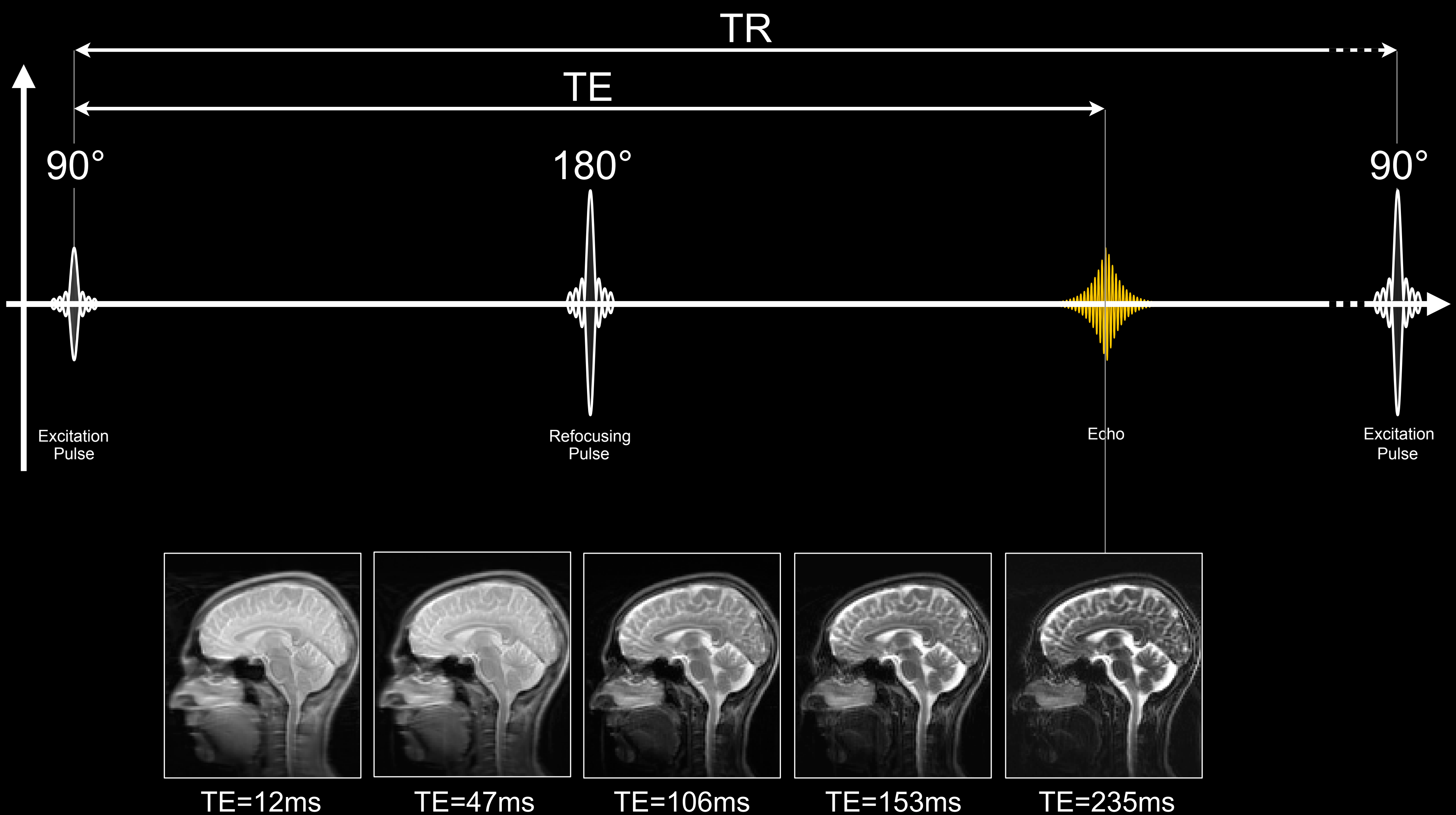




TE=12ms TE=47ms TE=106ms TE=153ms

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

Spin Echo



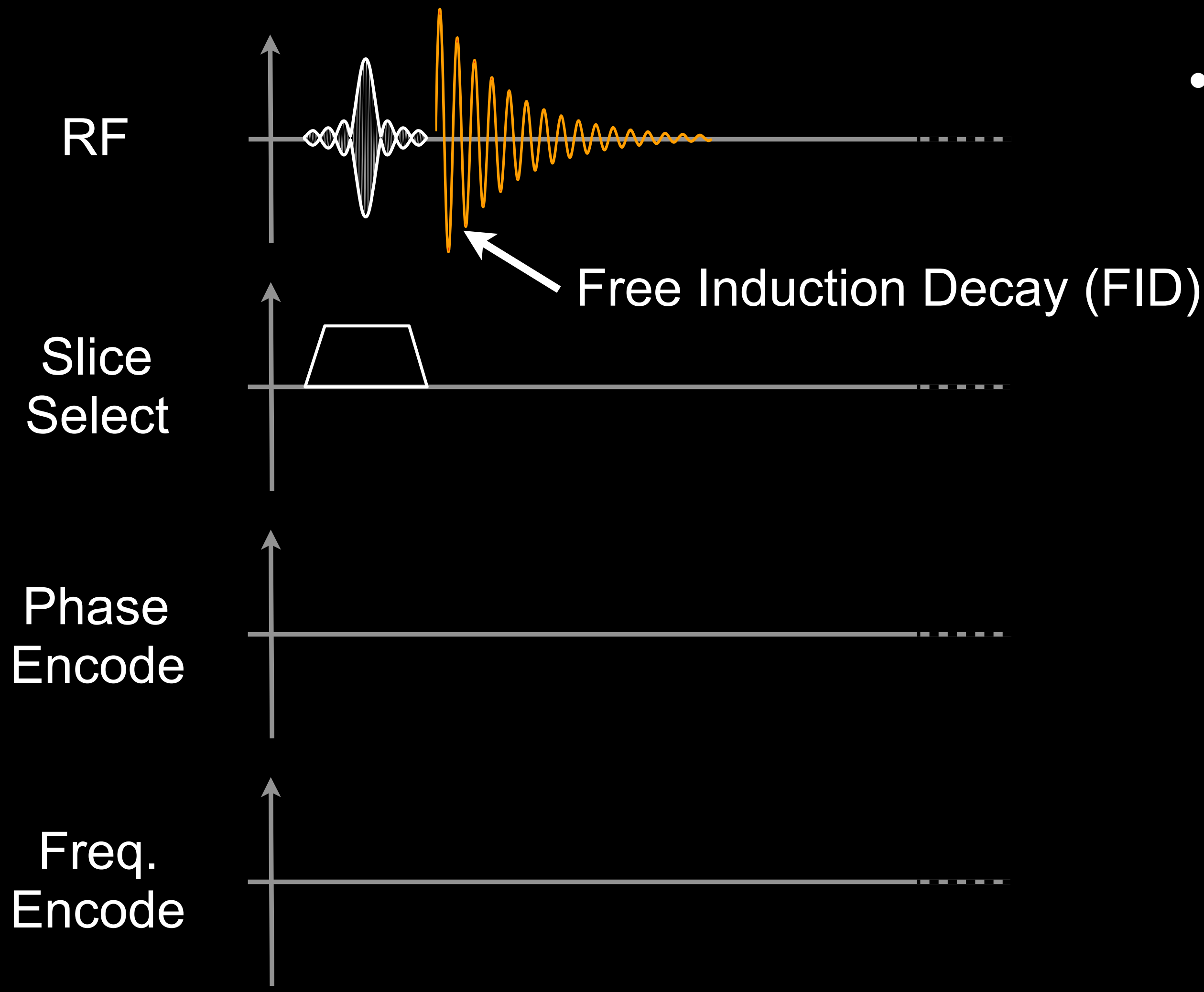
Spin Echo: TR=6500ms (ETL=12)

Gradient Echo Imaging

Gradient Echo Sequences

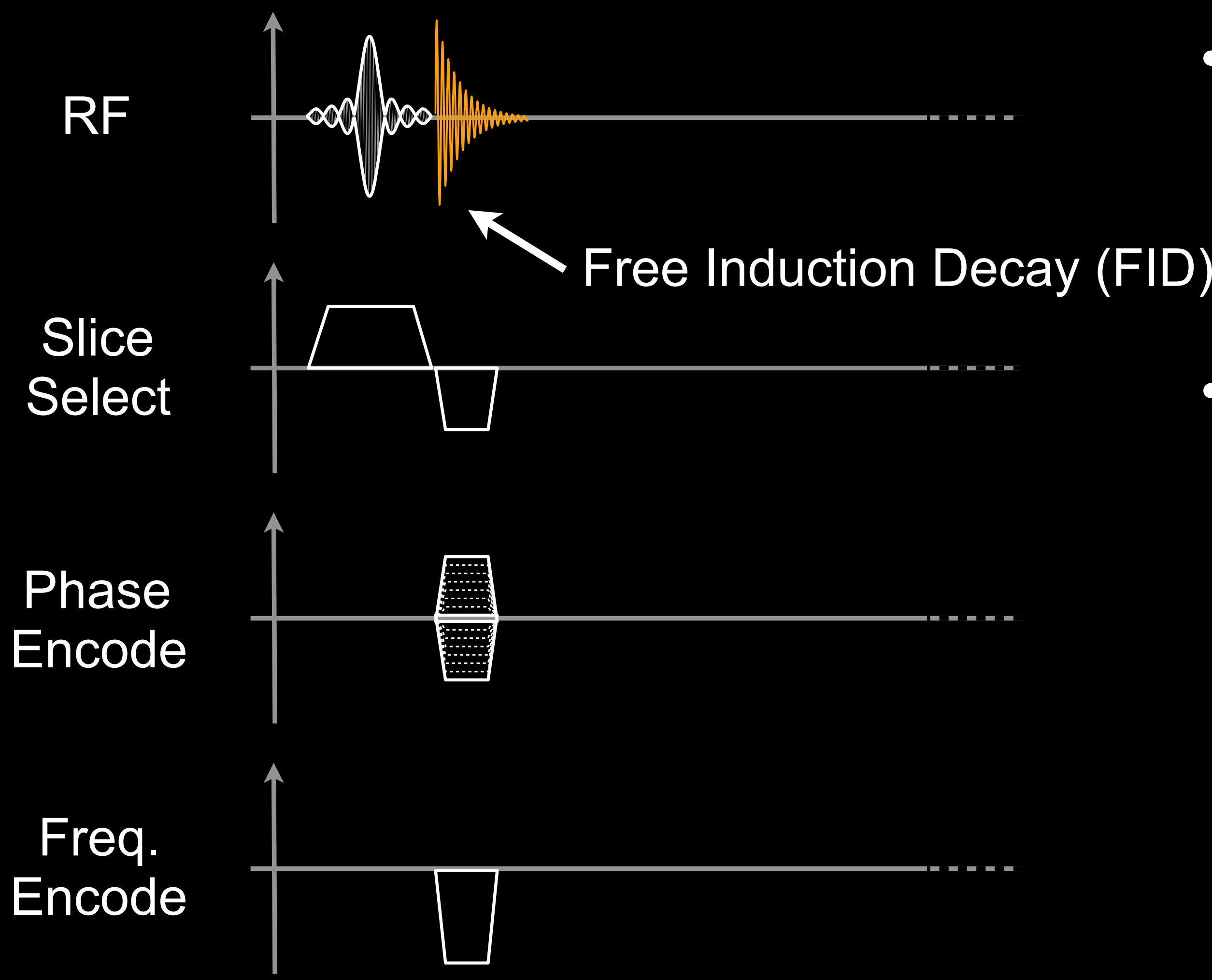
- Spoiled Gradient Echo
  - SPGR, FLASH, T1-FFE
- Balanced Steady-State Free Precession
  - TrueFISP, FIESTA, Balanced FFE

Basic Gradient Echo Sequence



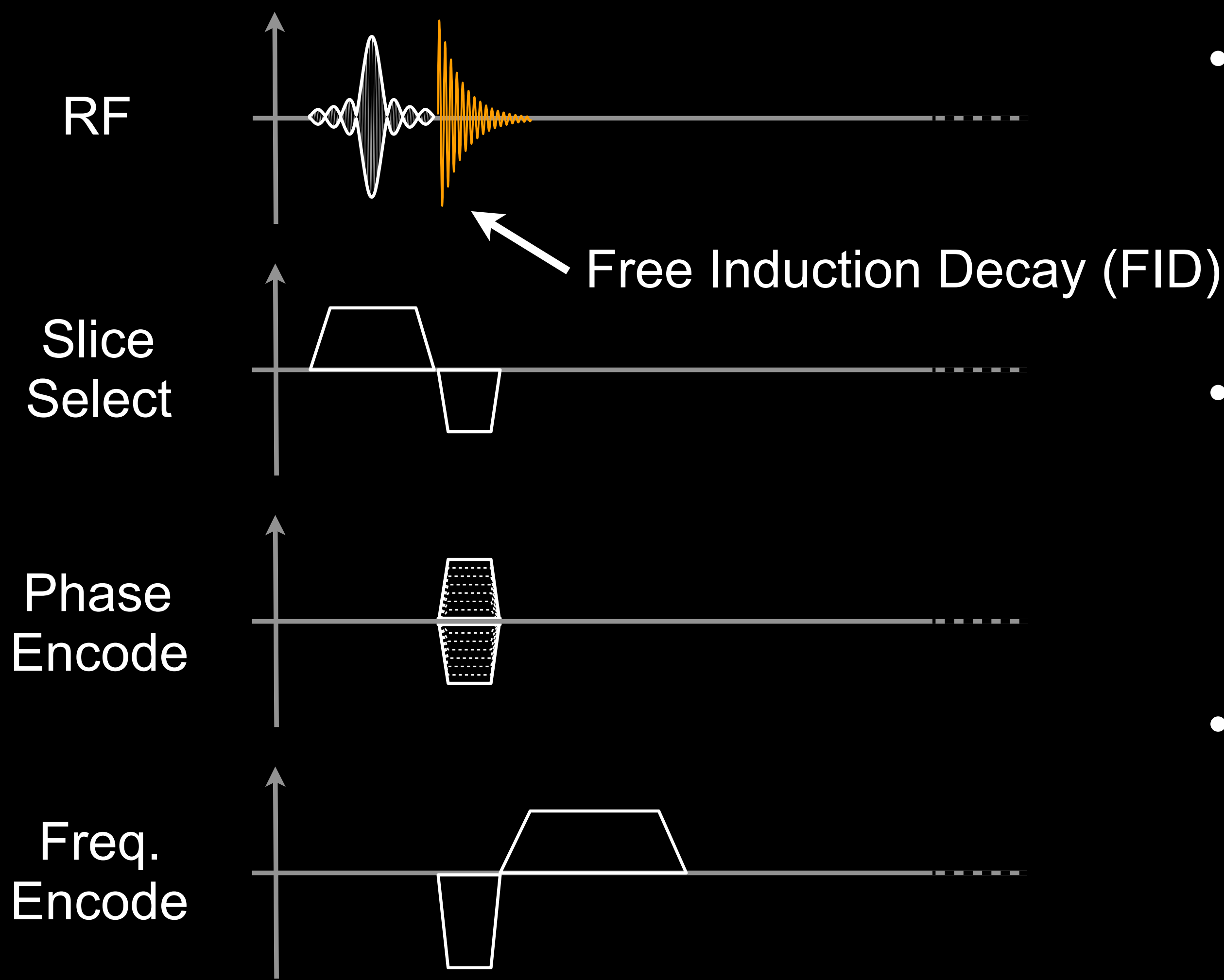
- FID Decay due to
  - T2 decay
  - Spin dephasing

Basic Gradient Echo Sequence



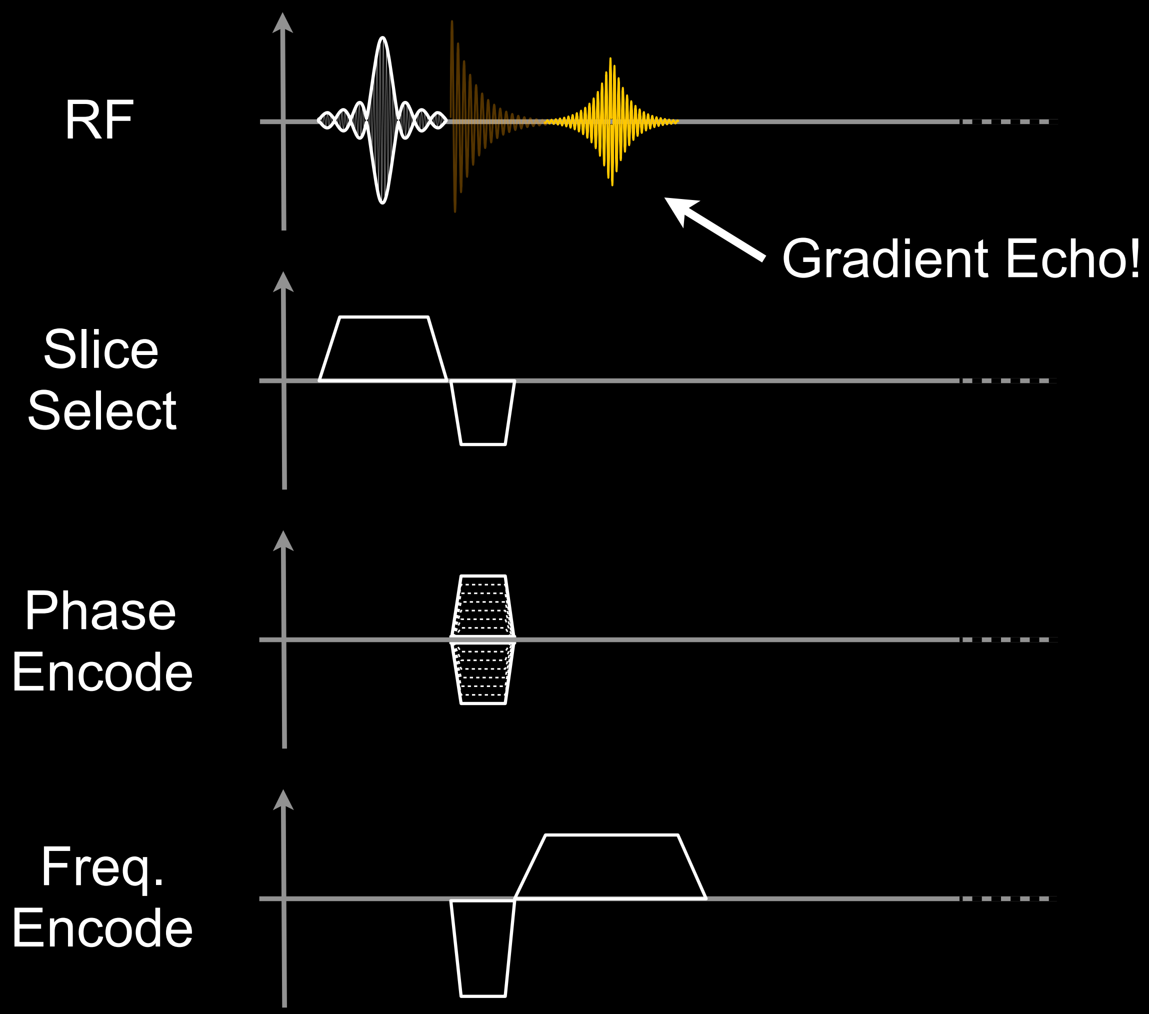
- FID Decay due to
  - T2 decay
  - Spin dephasing
- Gradients accelerate spin dephasing

Basic Gradient Echo Sequence



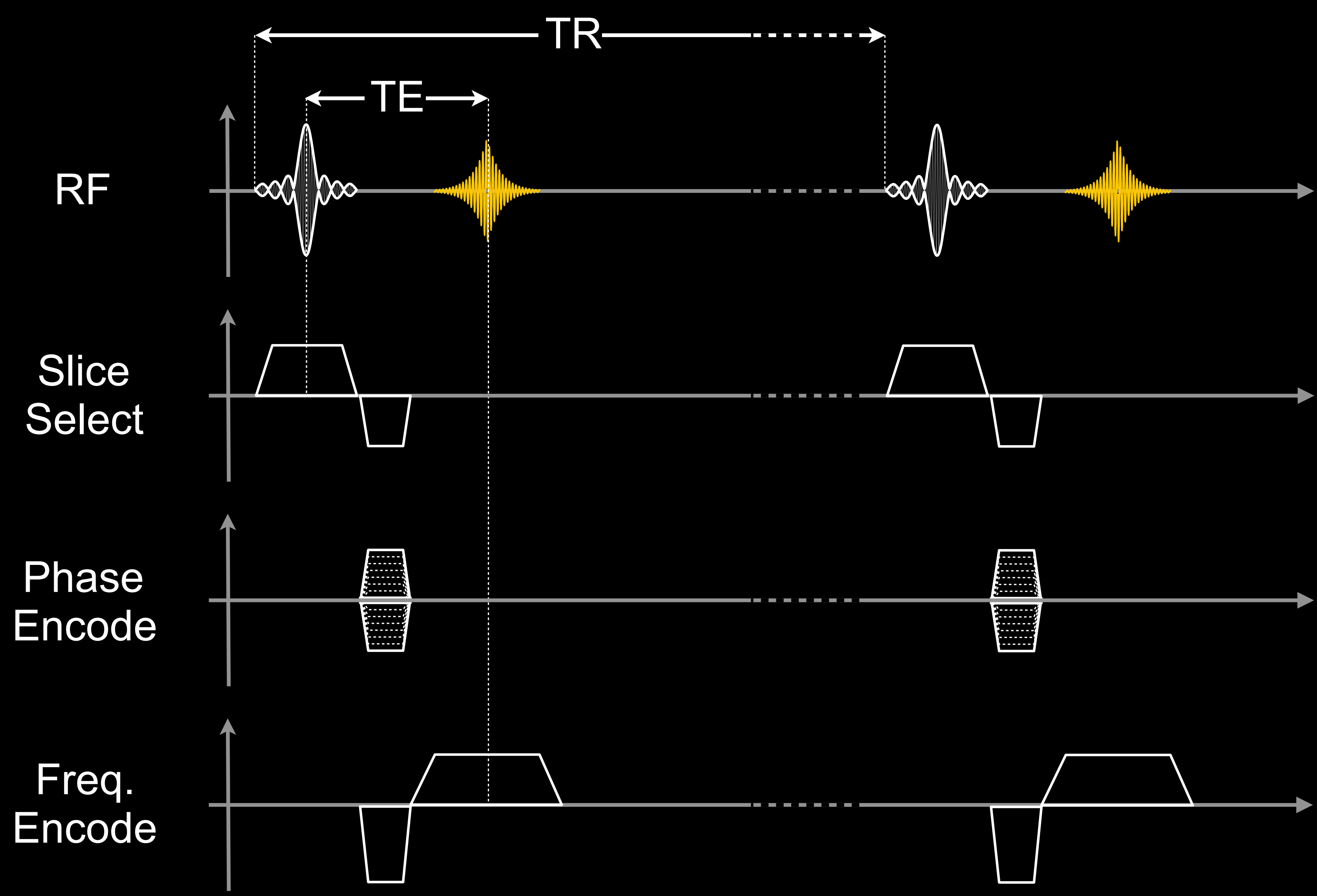
- FID Decay due to
  - T2 decay
  - Spin dephasing
- Gradients accelerate spin dephasing
- Gradients can undo gradient induced spin dephasing

Basic Gradient Echo Sequence



- FID Decay due to
  - T2 decay
  - Spin dephasing
- Gradients accelerate spin dephasing
- Gradients can undo gradient induced spin dephasing

Basic Gradient Echo Sequence



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
- Low SAR
  - **Why?** Imaging flip angles are (typically) small
  - **When?** When heating risks are a concern

Principal GRE Advantages

- 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
- Reduced Slice Cross-talk
  - **Why?** SE hard to match slice profile of 90° & 180°
  - **When?** Little or no slice gap for 2D multi-slice
- 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*.

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

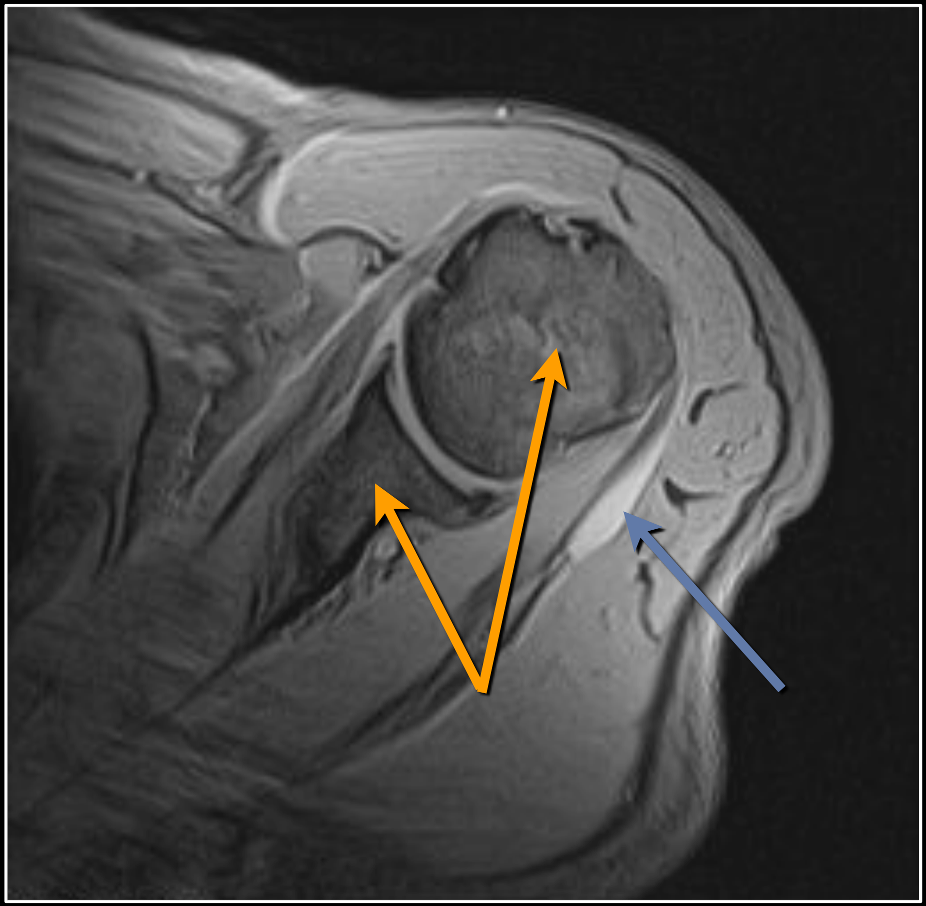
Contrast adjusted by changing TR, flip angle, and TE

Spoiled Gradient Echo Contrast

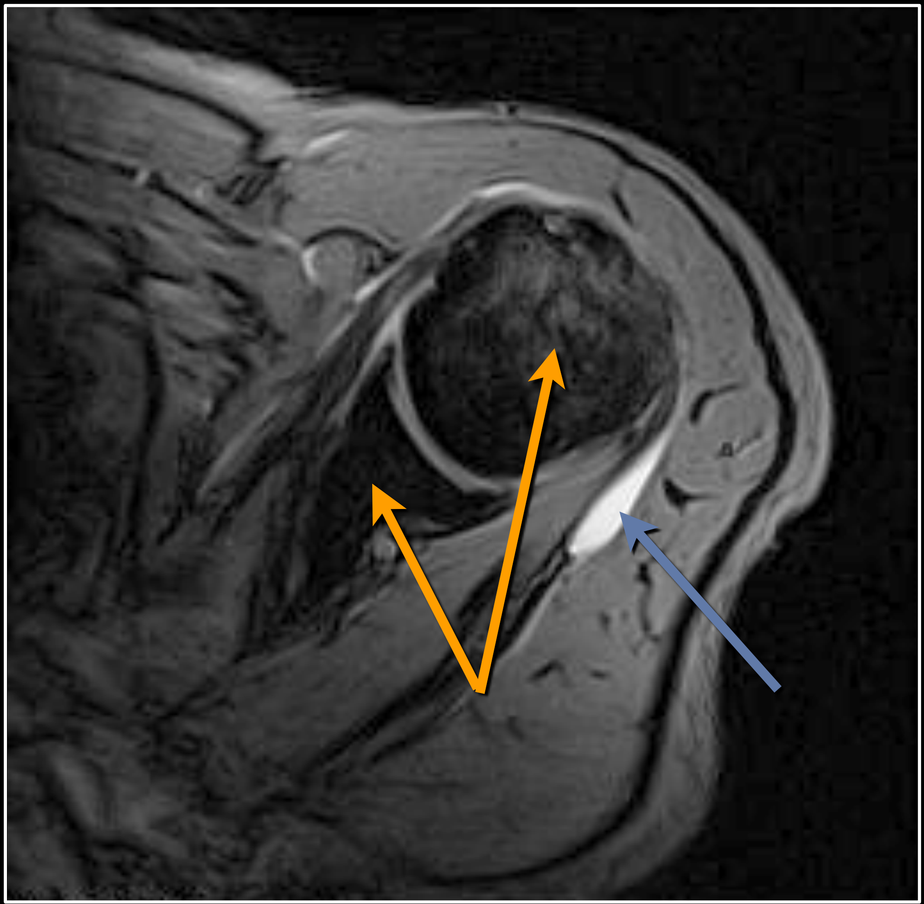
Gradient Echo Parameters

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 Imaging



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

Gradient Echoes & Flip Angle

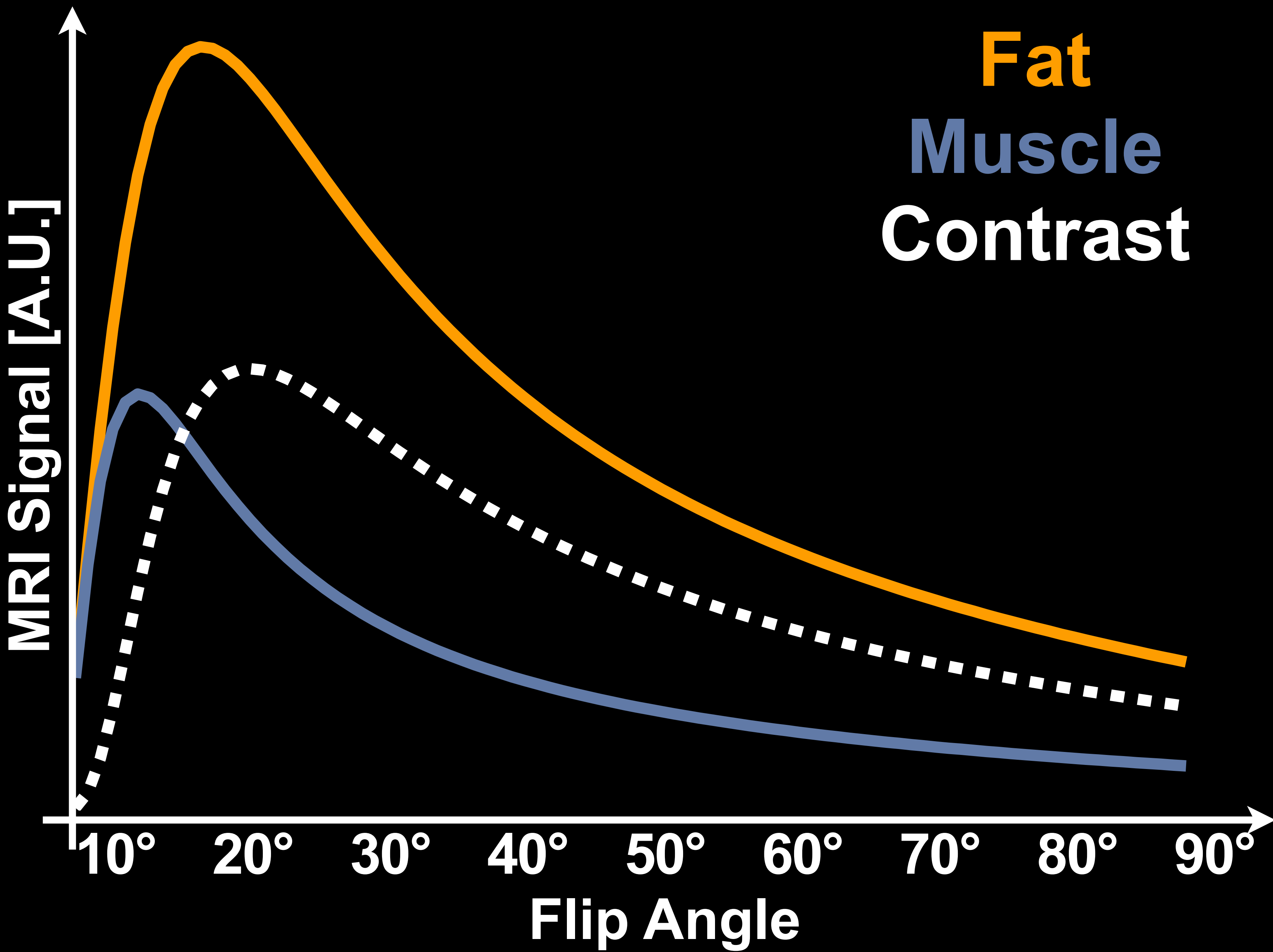
Spoiled GRE & Ernst Angle

$$\alpha_{Ernst} = \arccos\left(e^{-\frac{TR}{T_1}}\right)$$

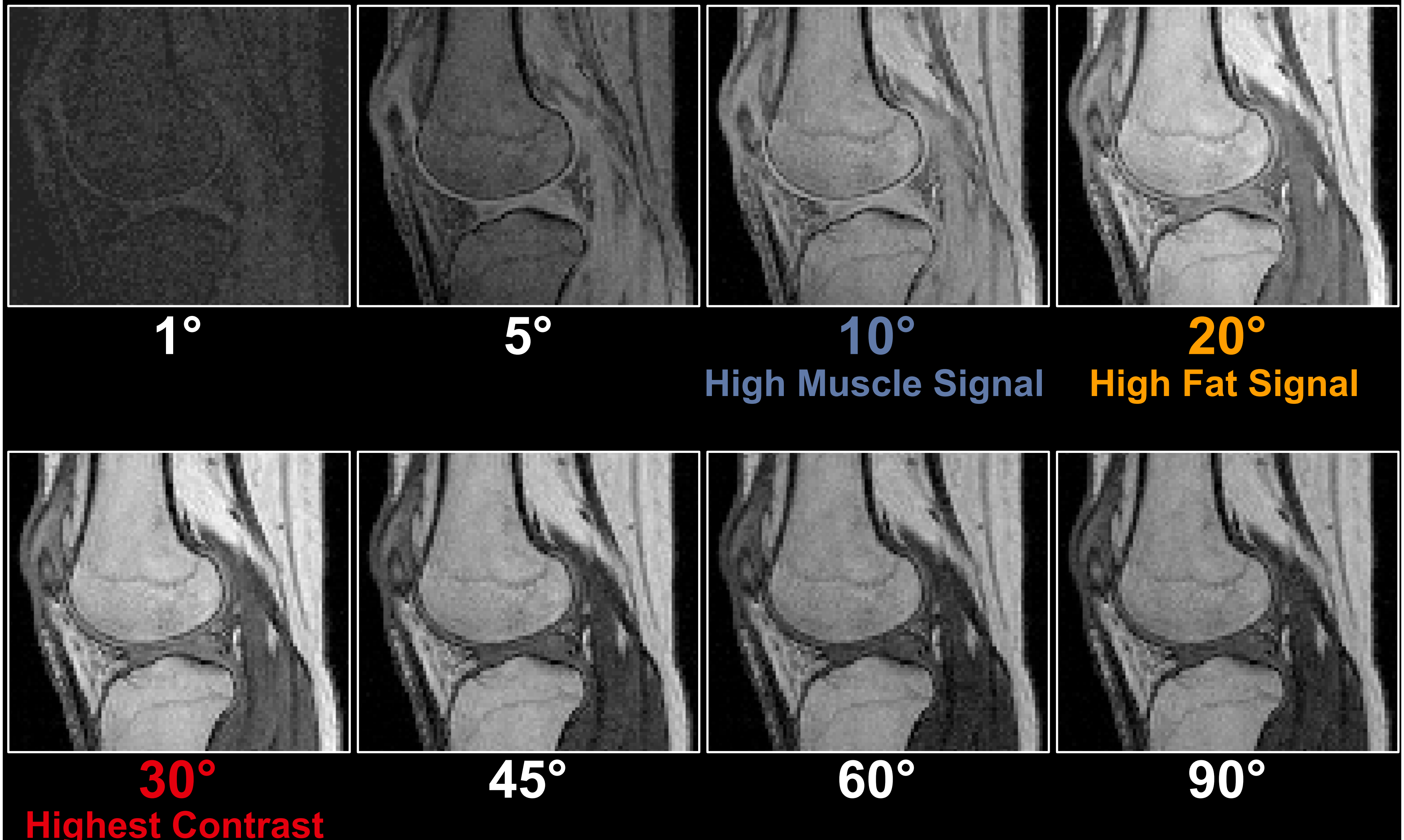
Produces the largest MRI signal for a given TR and T_1

Tissue	T_1 [ms]	T_2 [ms]
muscle	875	47
fat	260	85

Spoiled GRE & Ernst Angle



Spoiled GRE & Ernst Angle



Relaxation - True or False?

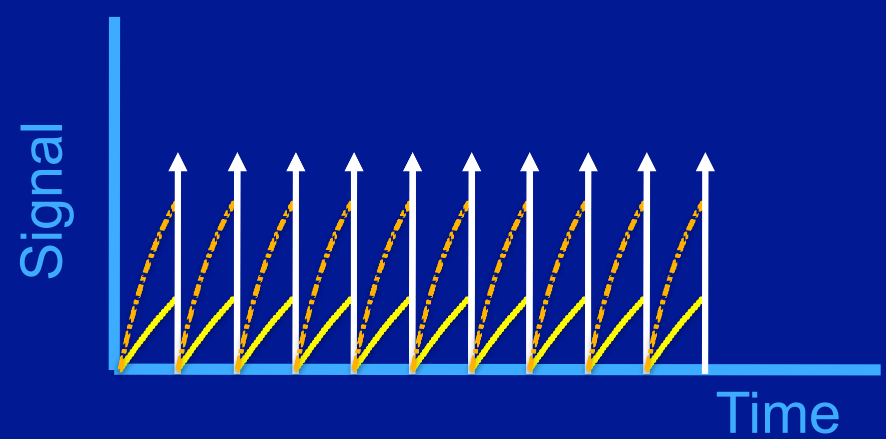
1. $T_2^* > T_2 > T_1$

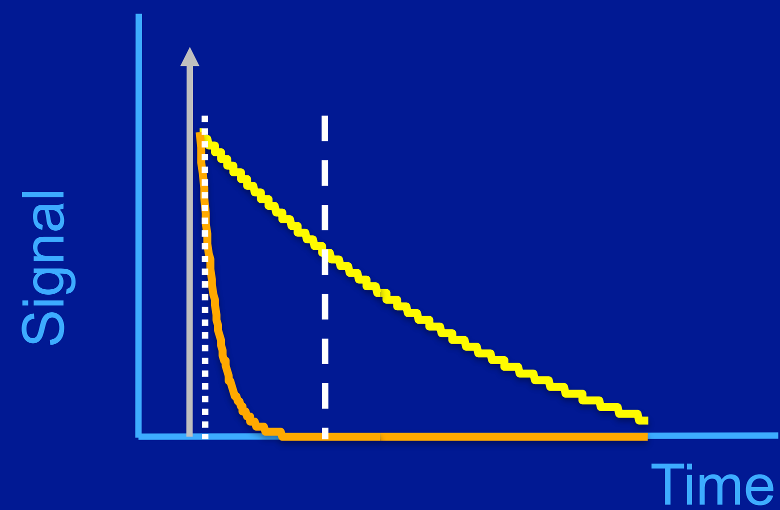
2. Long T_1s appear bright on a T_1-weighted image

3. Short T_2s appear dark on a T_2-weighted image

Relaxation - True or False?

1. $T_2^* > T_2 > T_1$
2. Long T_1s appear bright on a T_1-weighted image
3. Short T_2s appear dark on a T_2-weighted image





Relaxation - True or False?

1. $T_1(\text{CSF}) > T_1(\text{Gray Matter})$

2. $T_2(\text{Liver}) < T_2(\text{Fat})$

Relaxation - True or False?

1. T_1(CSF) > T_1(Gray Matter)

2. T_2(Liver) < T_2(Fat)

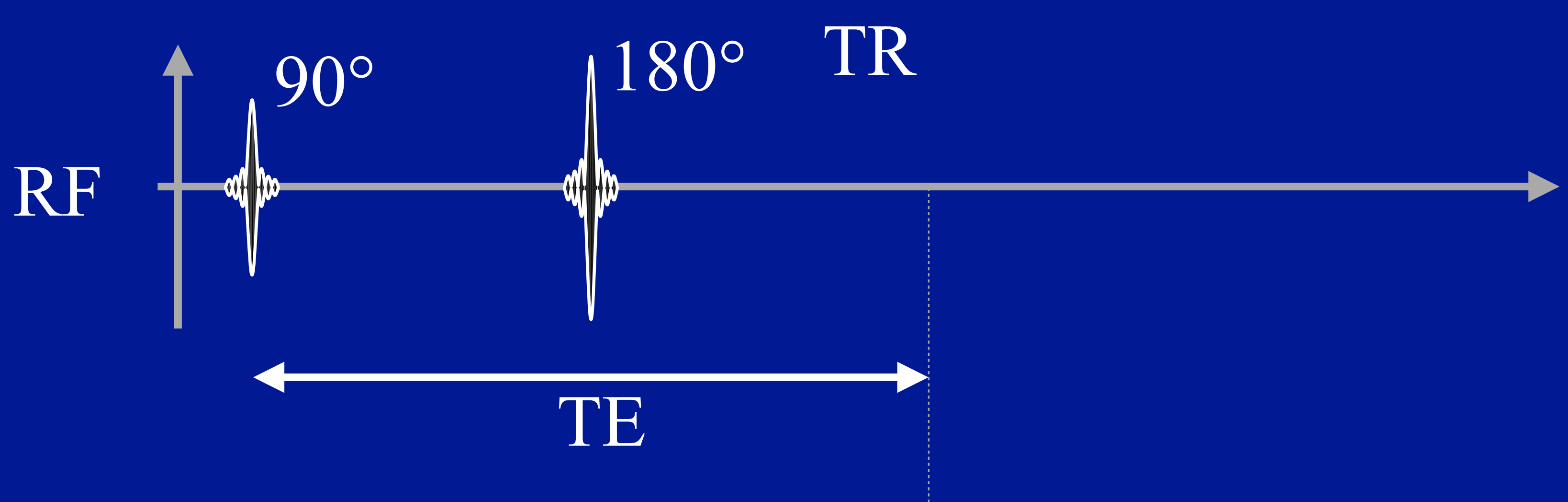
Tissue	T_1 [ms]	T_2 [ms]
gray matter	925	100
white matter	790	92
muscle	875	47
fat	260	85
kidney	650	58
liver	500	43
CSF	2400	180

Spin Echoes - True or False?

1. The 90-180 pair is the hallmark of the spin echo sequence.
2. The 180 pulse is an inversion pulse.
3. Spin echoes are ultrafast sequences that provide T_1 or T_2^* weighted images.

Spin Echoes - True or False?

1. The 90-180 pair is the hallmark of the spin echo sequence.
2. The 180 pulse is an inversion pulse.
3. Spin echoes are ultrafast sequences that provide T_1 or T_2^* weighted images.



Spin Echoes - True or False?

1. Long TE and long TR for T2-weighted.
2. Short TE and short TR for T1-weighted.
3. Spin echoes are low SAR sequences.

Spin Echoes - True or False?

1. Long TE and long TR for T2-weighted.
2. Short TE and short TR for T1-weighted.
3. Spin echoes are low SAR sequences.

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

Longer TR minimizes T1 contrast

Short TE minimizes T2 contrast

Gradient Echo Imaging...

Gradient echo imaging is great for everything except:

A. T_2*-weighted imaging.

B. T_2-weighted imaging.

C. True 3D imaging.

D. Real time imaging.

Gradient Echo Imaging...

Gradient echo imaging is great for everything except:

A. T_2*-weighted imaging
    Yes. GRE can be a T_2*-weighted sequence.
B. **T_2-weighted imaging**
    No. GRE can not be T_2-weighted
C. True 3D imaging
    Yes! GRE is a fast sequence
D. Real time imaging
    Yes! GRE is a fast sequence

Gradient Echo Imaging...

A. ...is great for T_2 imaging

B. ...works well for imaging near metal implants

C. ...is a fast acquisition technique

D. ...is insensitive to off-resonance effects

Gradient Echo Imaging...

A. ...is great for T_2 imaging

GRE is sensitive to T_2^*, whereas SE is sensitive to T_2

B. ...works well for imaging near metal implants

Metal causes large distortions for which SE is useful

C. ...is a fast acquisition technique

Yes! The TE/TR are typically quite short compared to SE

D. ...is insensitive to off-resonance effects.

GRE is sensitive to B_0 inhomogeneity, chemical shift and susceptibility shifts

In Gradient Echo Imaging Always...

A. Use the highest available flip angle.

B. Calculate and use the Ernst angle.

C. Use a flip angle for maximum contrast.

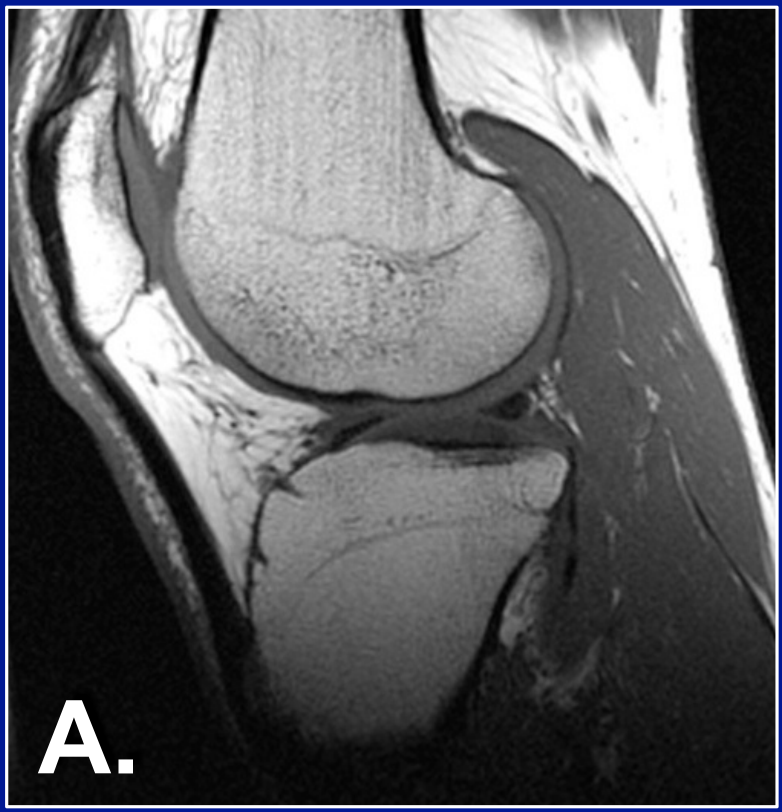
In Gradient Echo Imaging Always...

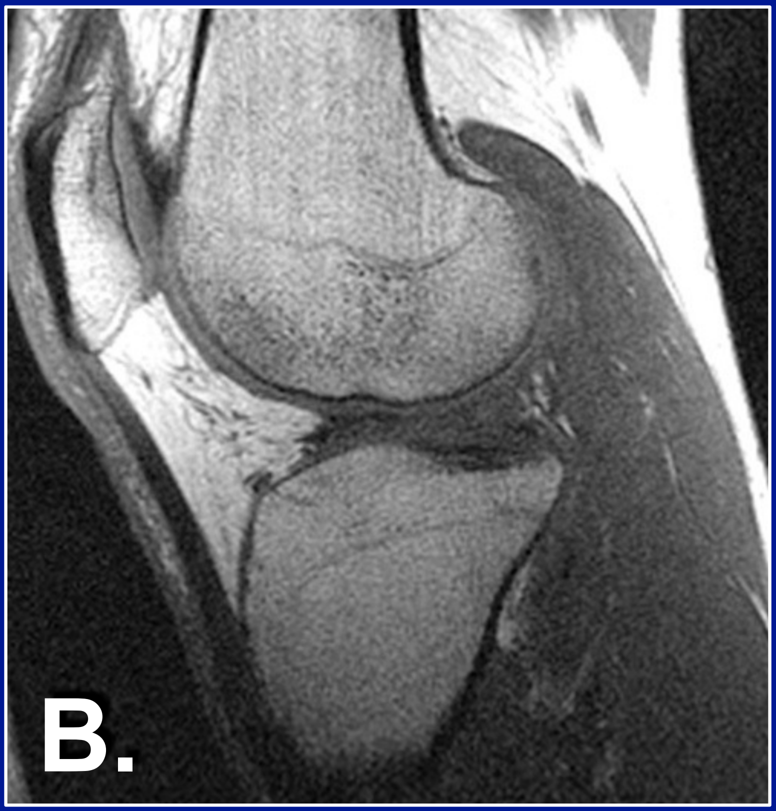
A. Use the highest available flip angle.

B. Calculate and use the Ernst angle.

C. Use a flip angle for maximum contrast.

Gradient vs. Spin Echo

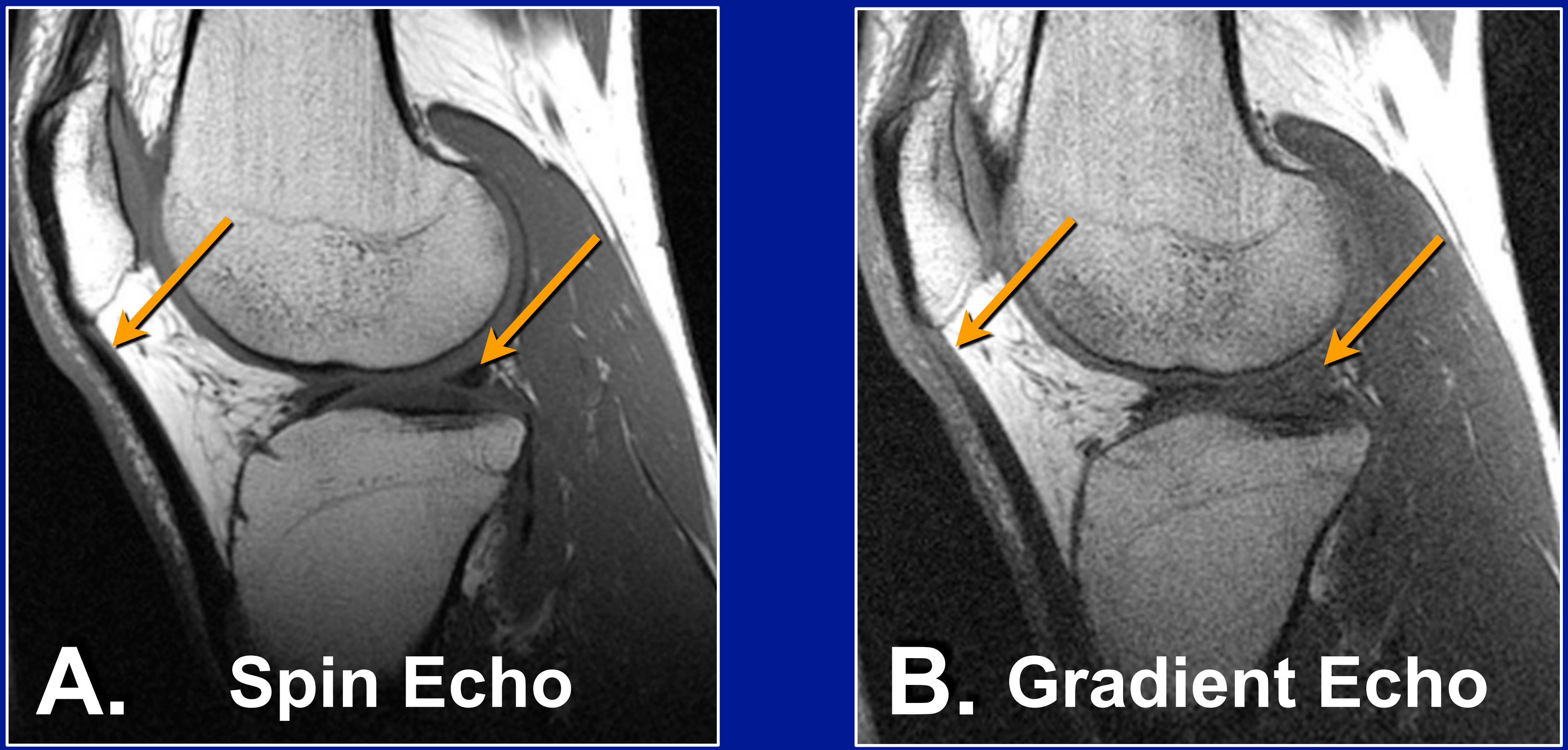




Which image is a gradient echo image?

Images Courtesy of Brian Hargreaves

Gradient vs. Spin Echo



Both are T1-weighted

Spin Echo has higher SNR (longer TR)

GRE has shorter TE (meniscus/tendon is brighter)

Images Courtesy of Brian Hargreaves

Thanks

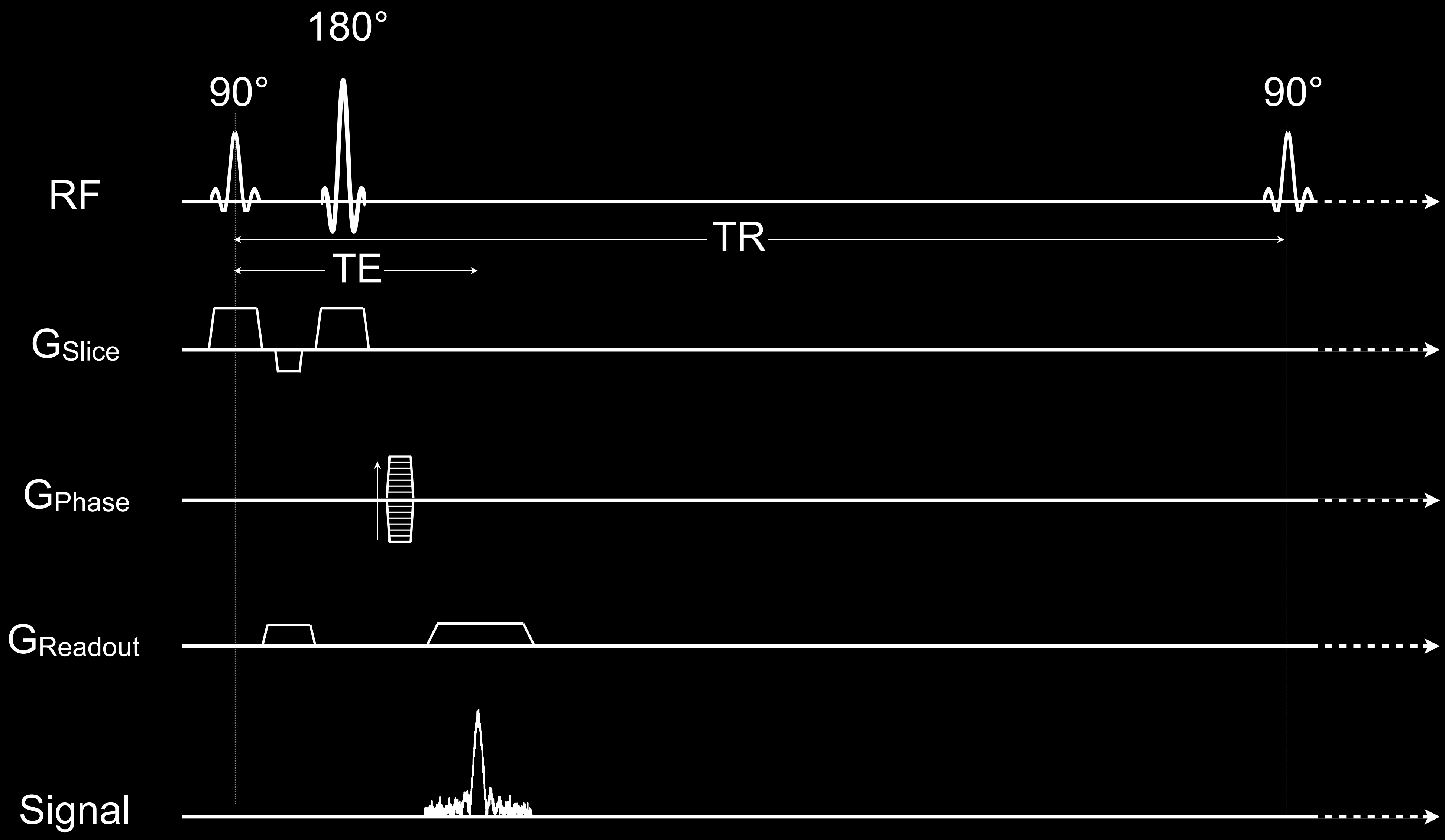
Kyung Sung, PhD

ksung@mednet.ucla.edu

http://mrrl.ucla.edu/sunglab/

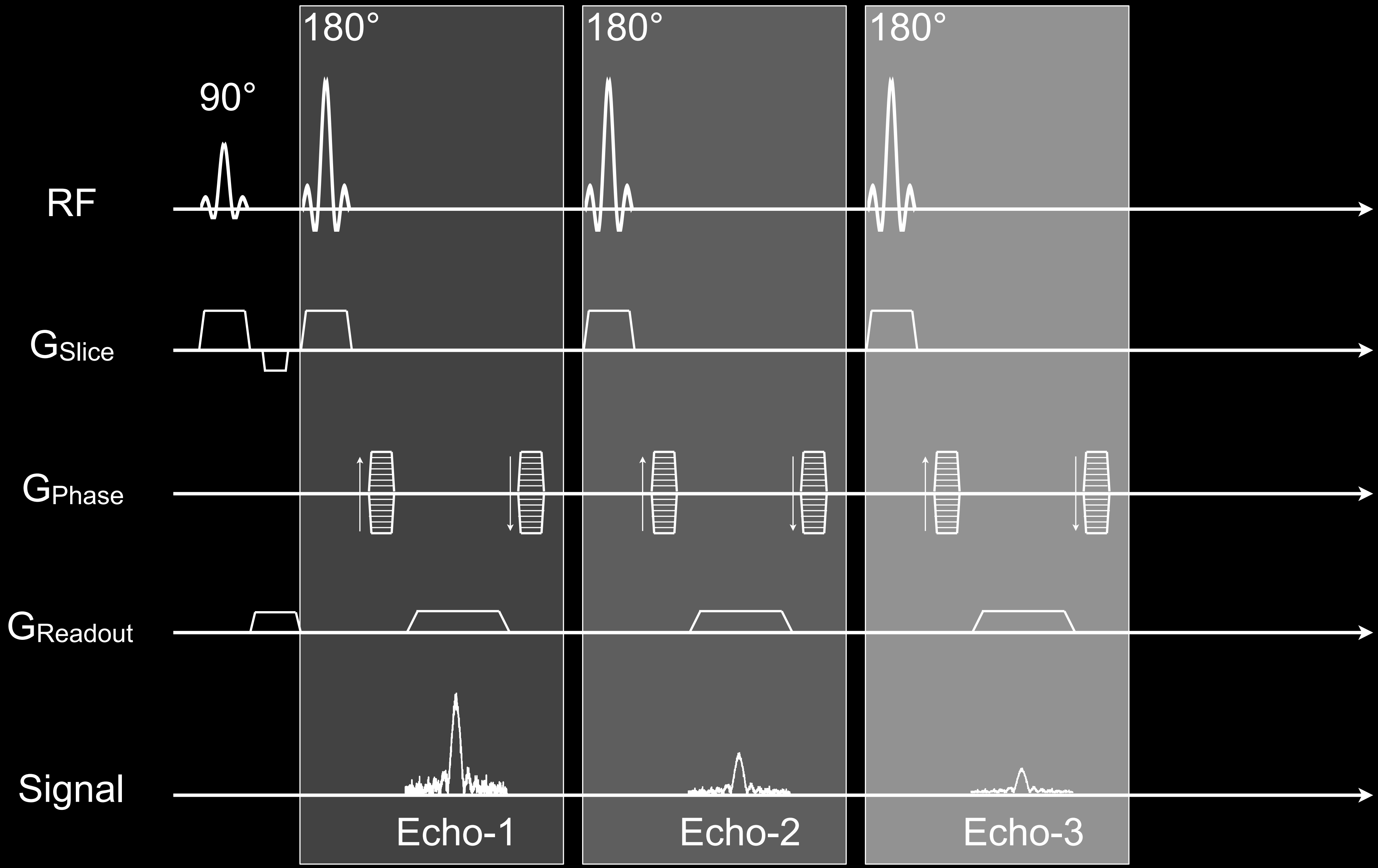
Turbo Spin Echo (TSE) / Fast Spin Echo (FSE)

Spin Echo

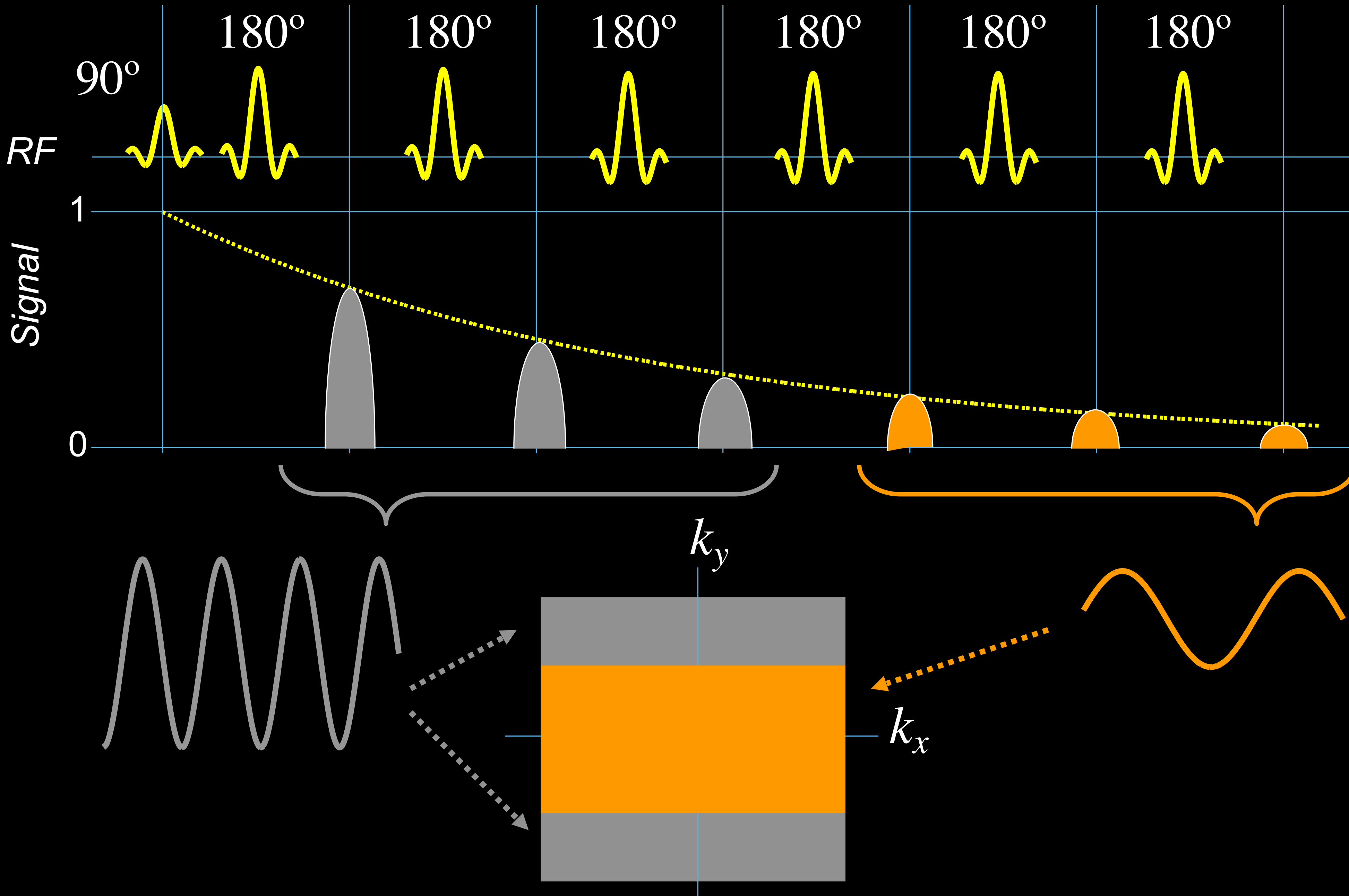


Spin Echo

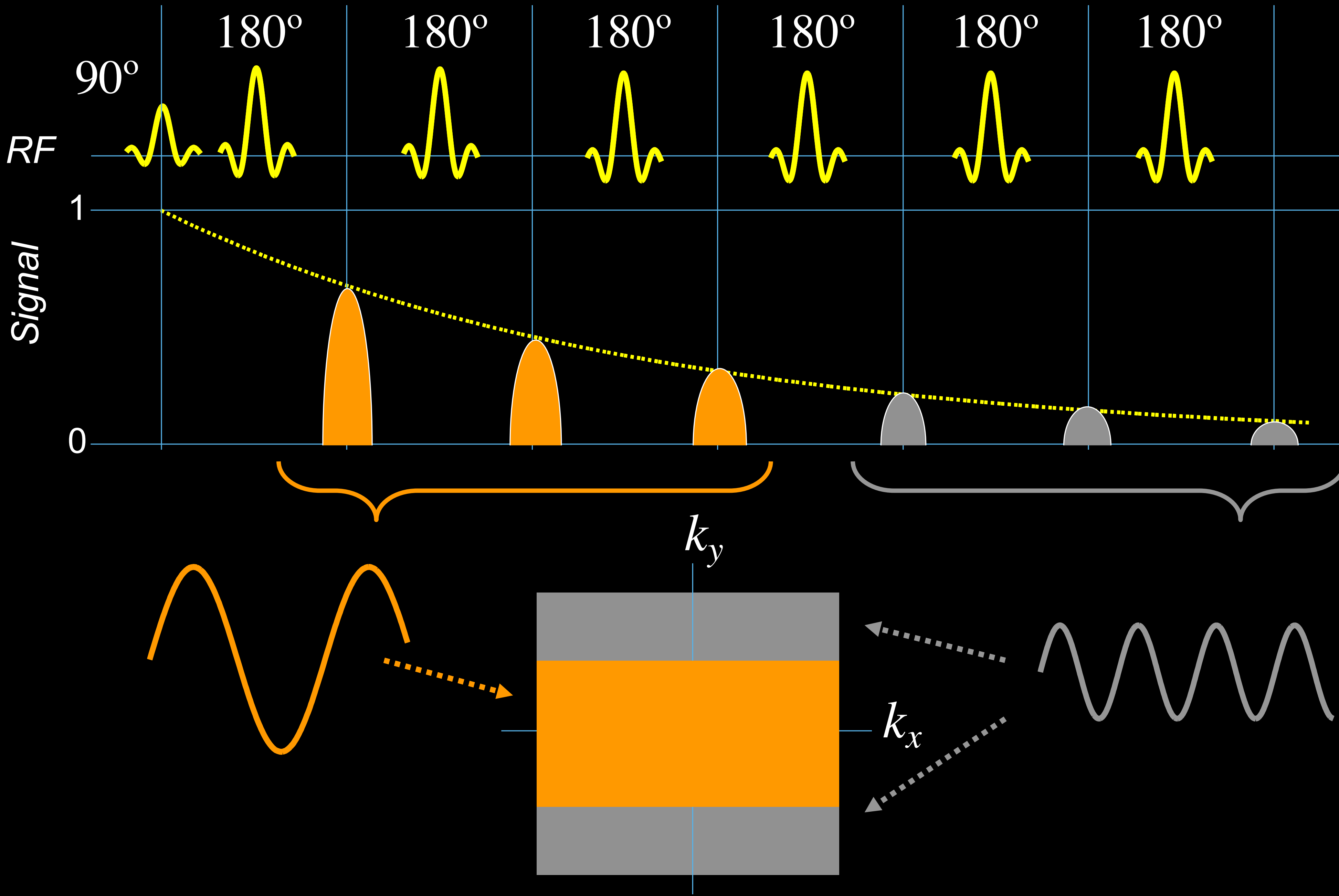
Turbo Spin Echo (TSE)



T_2-weighted TSE

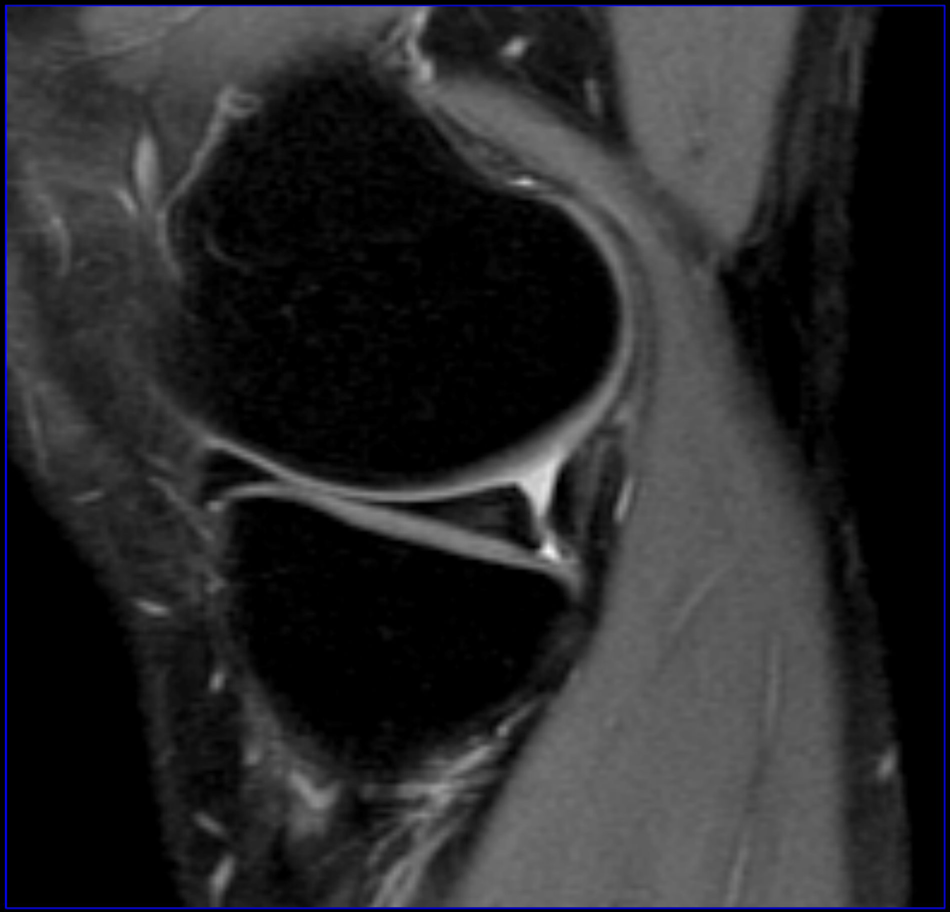


Proton Density Weighted TSE

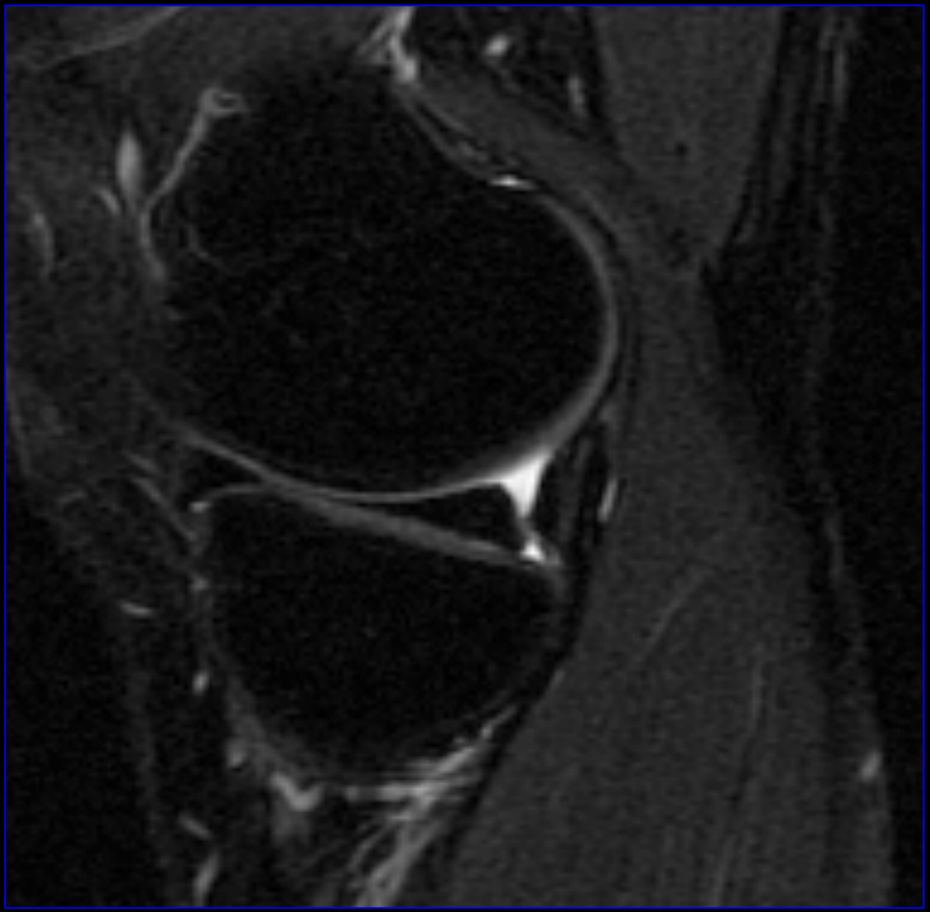


PD vs T_2-weighted TSE

Proton Density Weighted



T_2-weighted



- Good cartilage signal
- Good cartilage/fluid contrast
- Late-Echo Blurring

Summary for TSE

- Pros:
  - Fast, high SNR
  - Less sensitive to B0 inhomogneity
- Cons:
  - T2 weighting varies in k-space
  - RF power limits speed, particularly at 3T

- Multi-echo acquisitions accelerate imaging, but single-shot methods are probably overkill