Basic Pulse Sequence III: Spin Echoes

M219 - Principles and Applications of MRI

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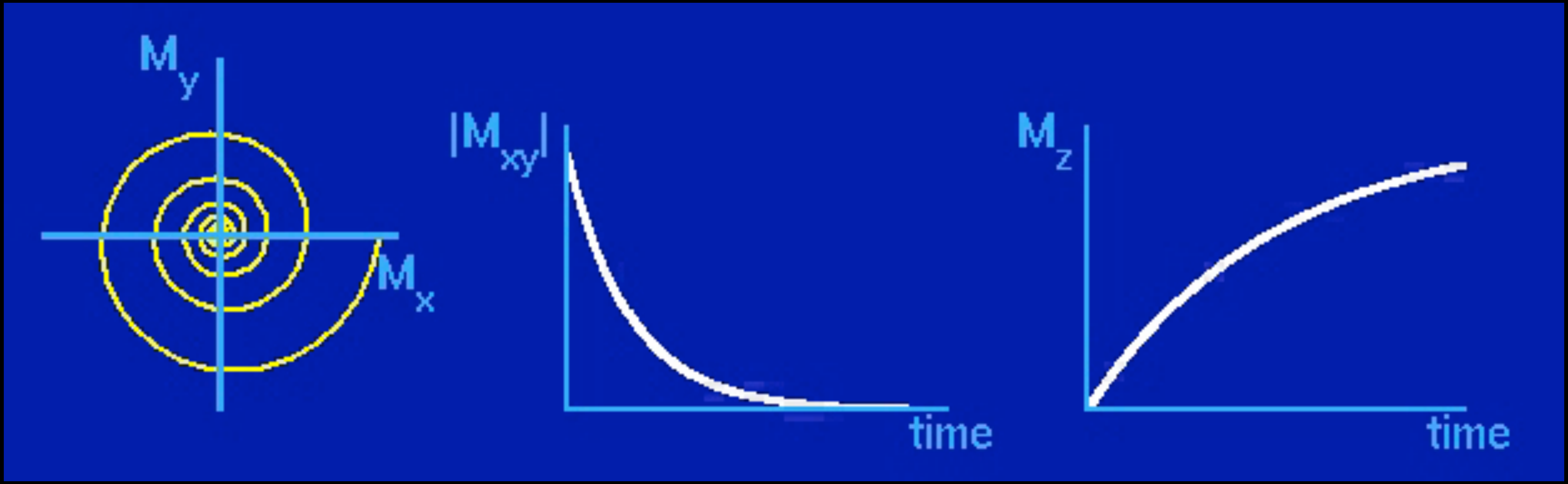
3/2/2022

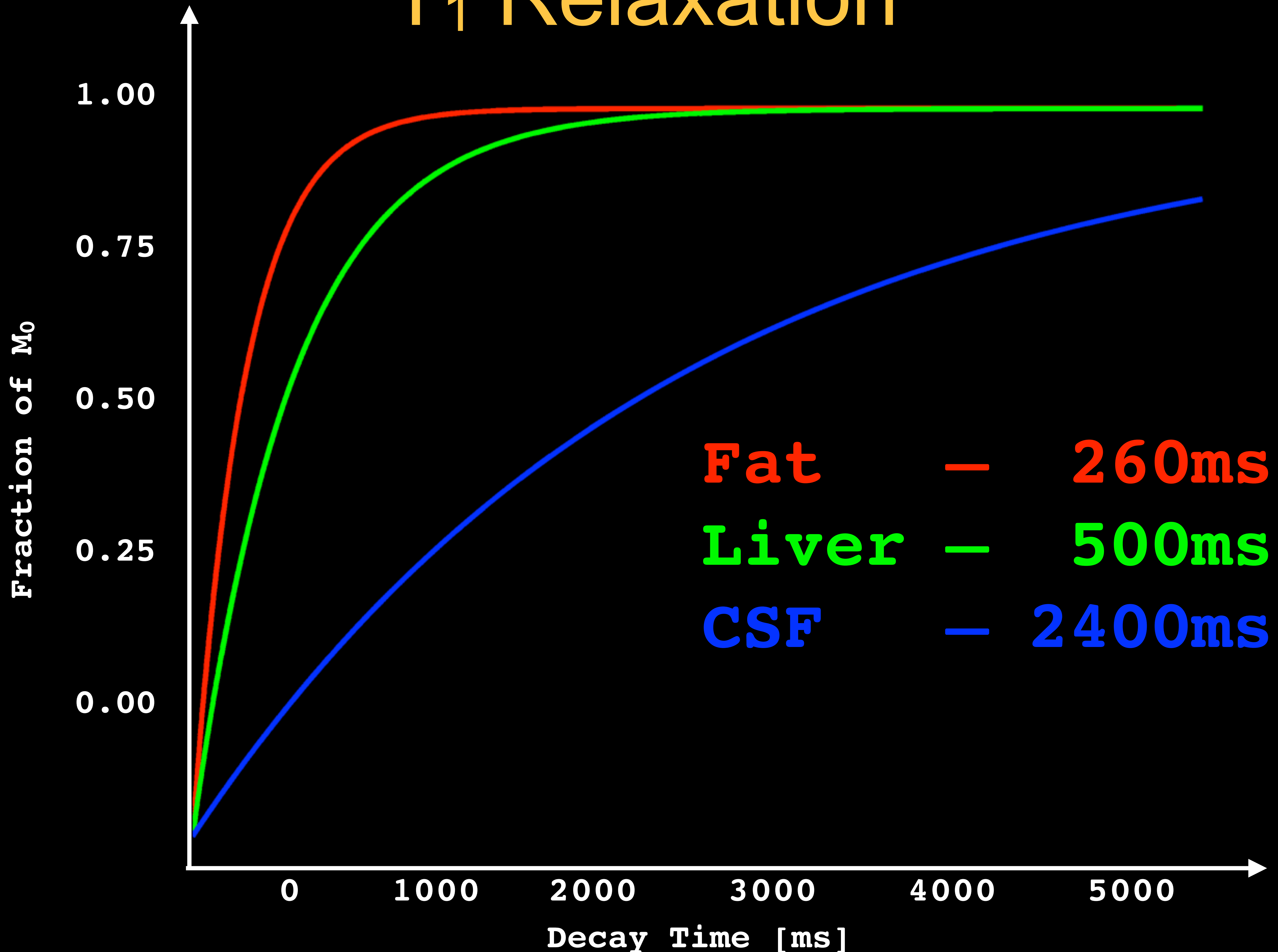
T_1 & T_2 Relaxation

Relaxation

- Magnetization returns exponentially to equilibrium:
  - Longitudinal recovery time constant is T1
  - Transverse decay time constant is T2
- Relaxation and precession are independent



T_1 Relaxation

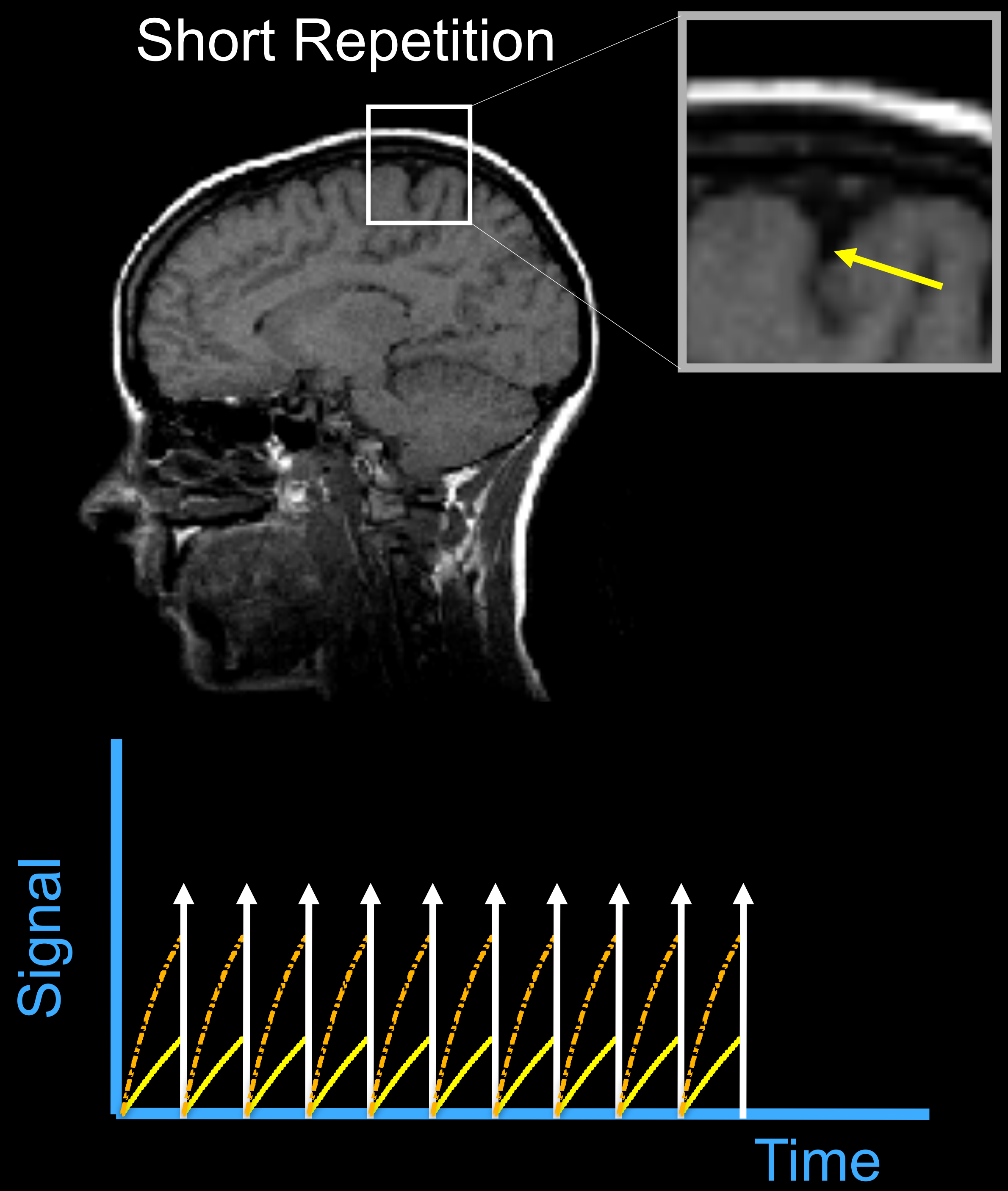


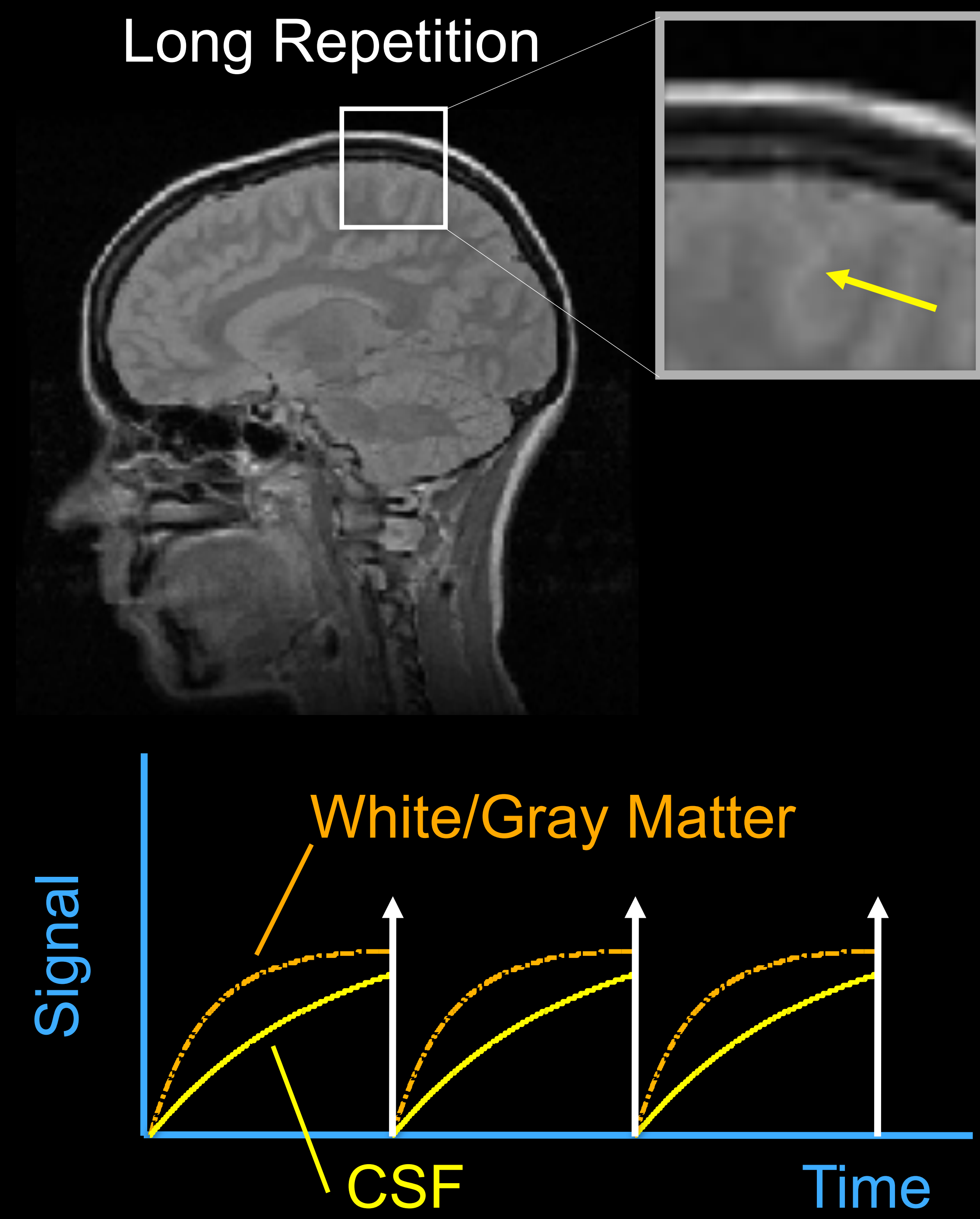
T_1 Relaxation

- 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

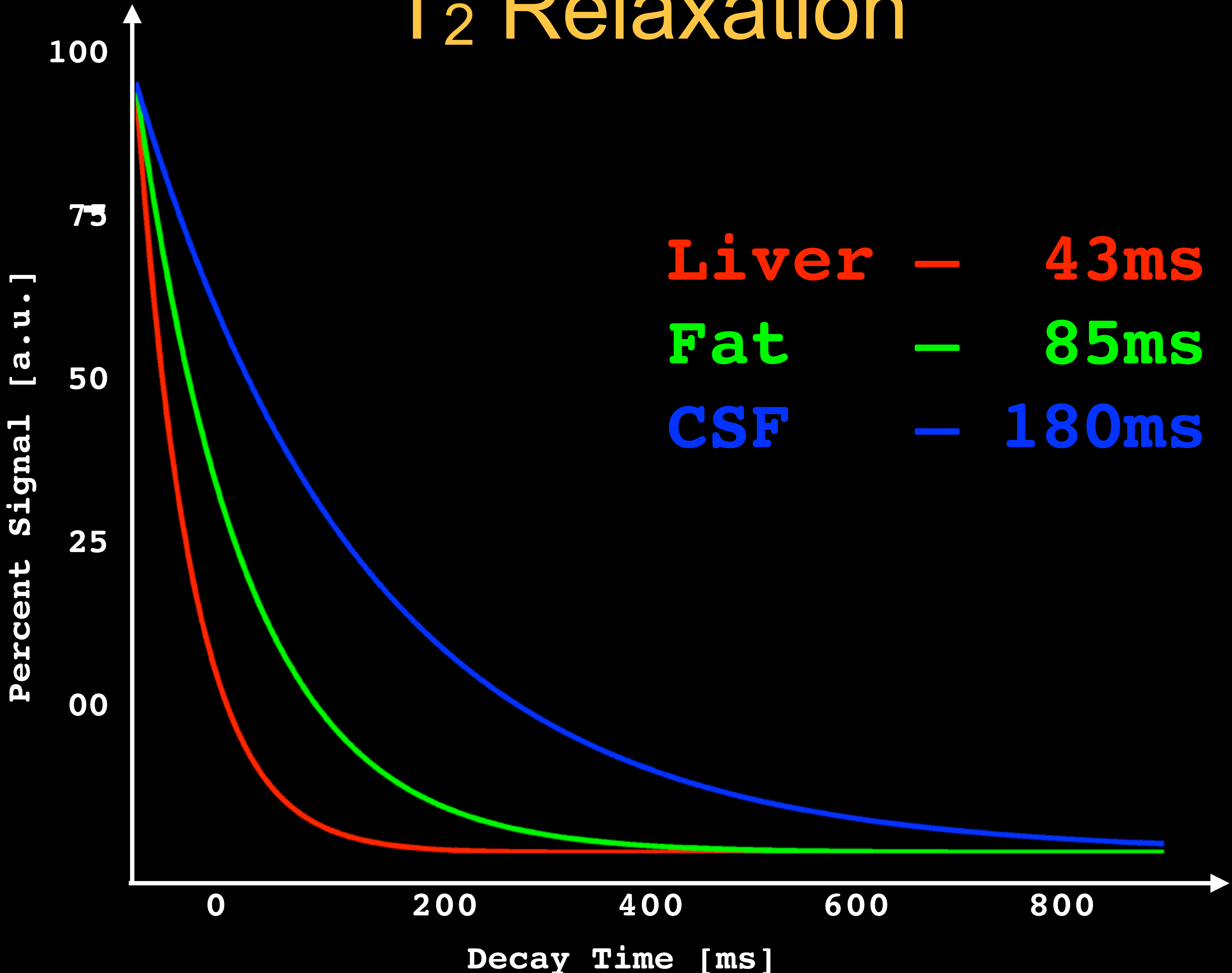
Short T_1s are bright on T_1-weighted image

T1 Contrast


Short Repetition
Signal
Time


Long Repetition
White/Gray Matter
Signal
CSF
Time

T_2 Relaxation

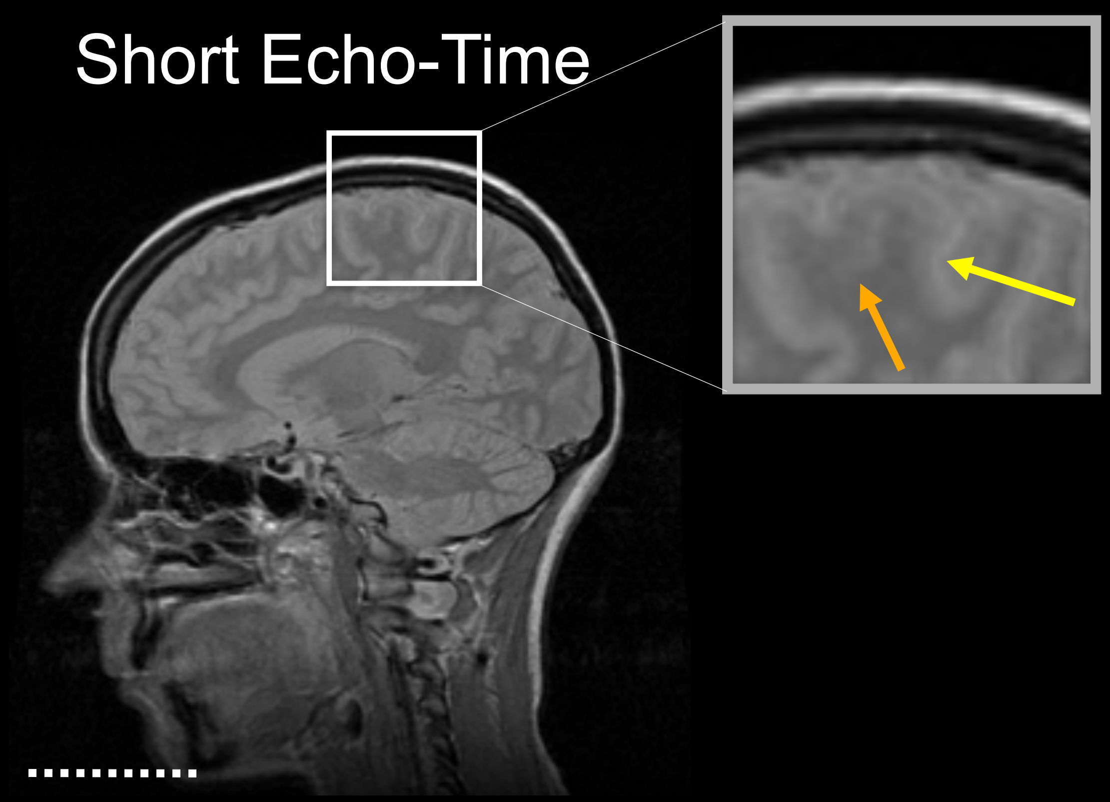


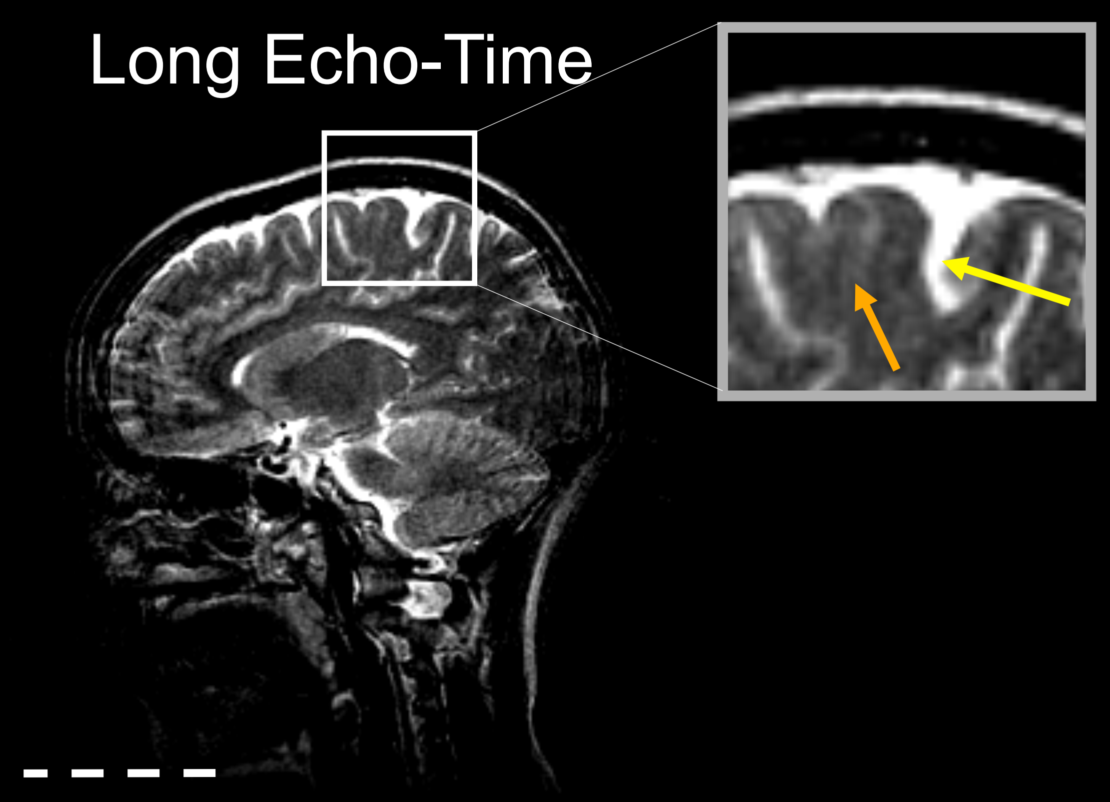
T_2 Relaxation

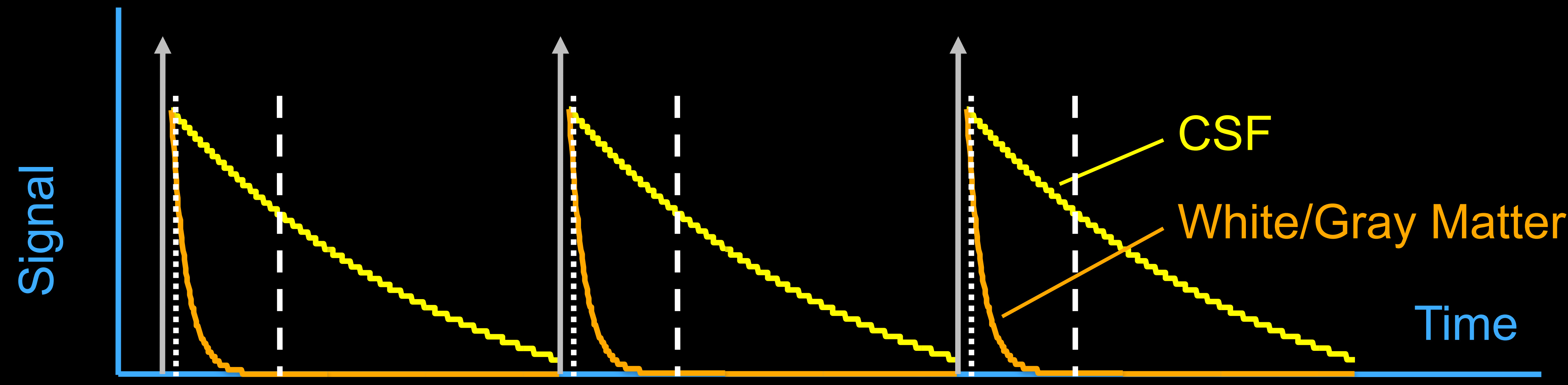
- Transverse or spin-spin relaxation
  - Molecular interaction causes spin dephasing
  - Typically, T2 < (10s ms)
- Increasing molecular size, decrease T2
  - Fat has a short T2
- Increasing molecular mobility, increases T2
  - Liquids (CSF, edema) have long T2s
- Increasing molecular interactions, decreases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

Long T_2 is bright on T_2 weighted image

T2 Contrast


Short Echo-Time


Long Echo-Time


Signal
CSF
White/Gray Matter
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

Each tissue has “unique” relaxation properties, which enables “soft tissue contrast”.

T_2^* Relaxation

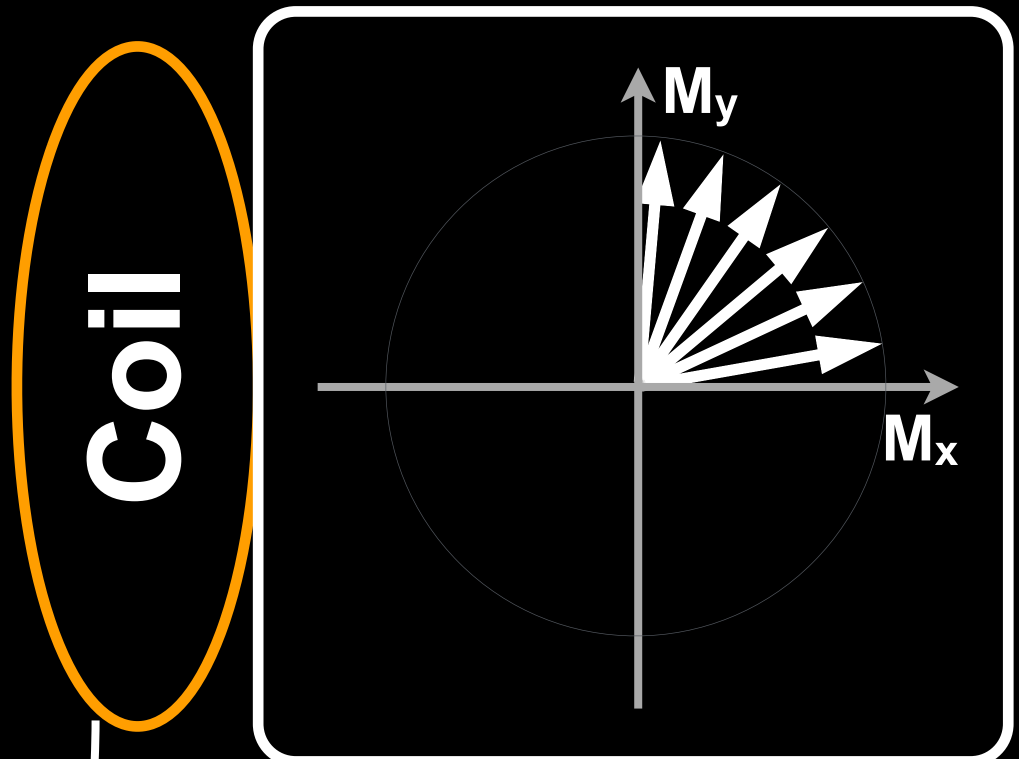
T_2^* Relaxation

$$\frac{1}{T_2^*} = \frac{1}{T_2} + \gamma \Delta B_0$$

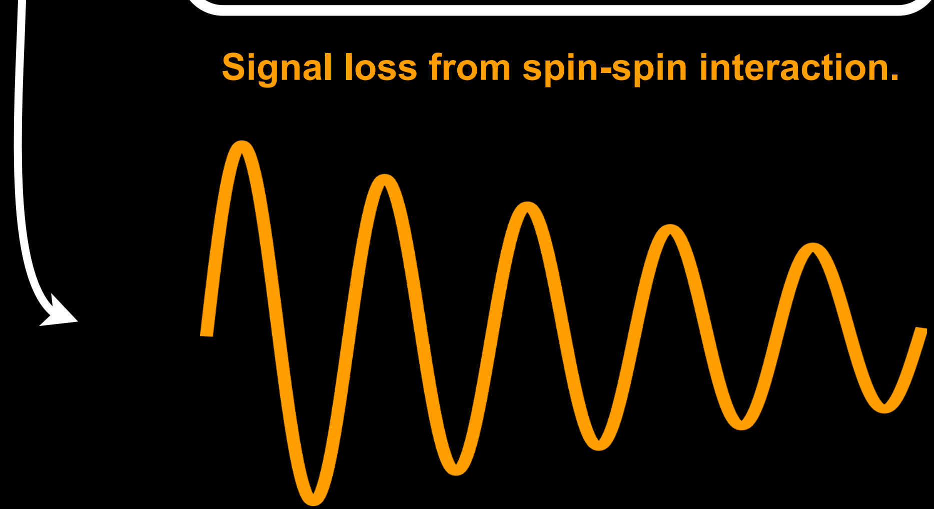
- T_2^* is "observed" transverse relaxation time constant
- T_2^* consists of *irreversible spin-spin (T_2) dephasing* and *reversible intravoxel spin de-phasing* due to off-resonance
- Sources of off-resonance:
  - B_0 inhomogeneity
  - susceptibility differences (e.g. air spaces)

T_2 versus T_2*

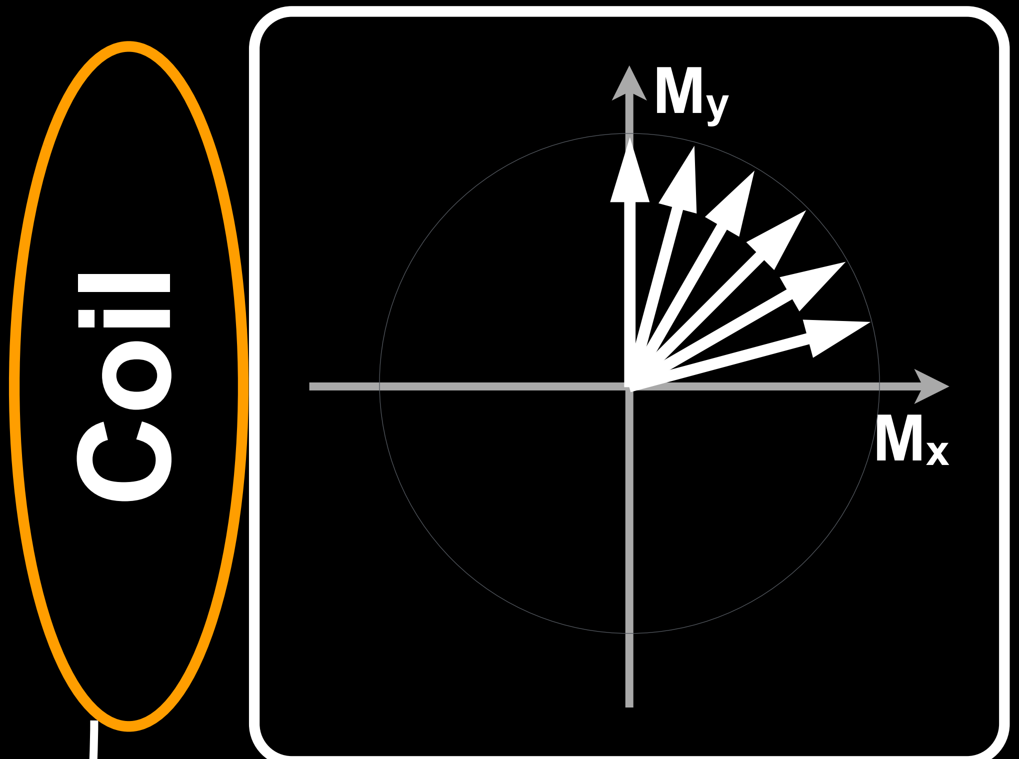
T_2 Decay



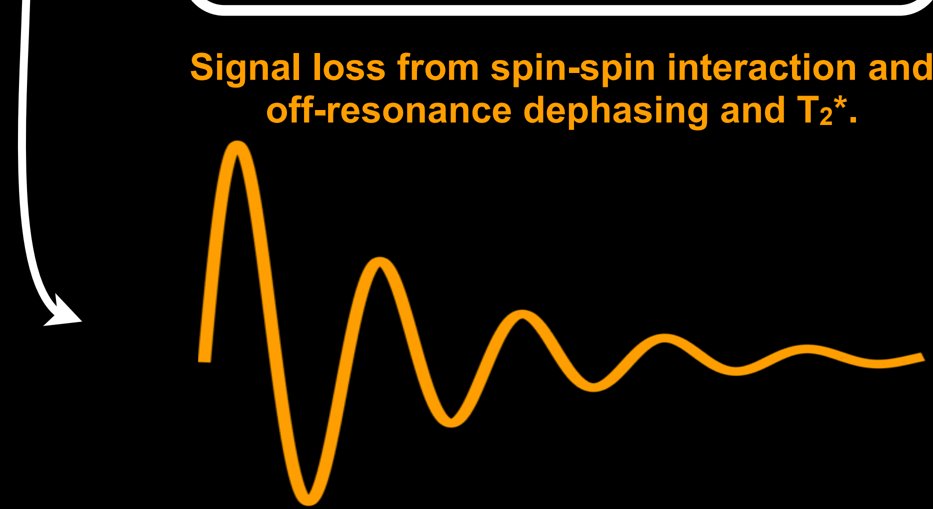
Signal loss from spin-spin interaction.



T_2^* Decay

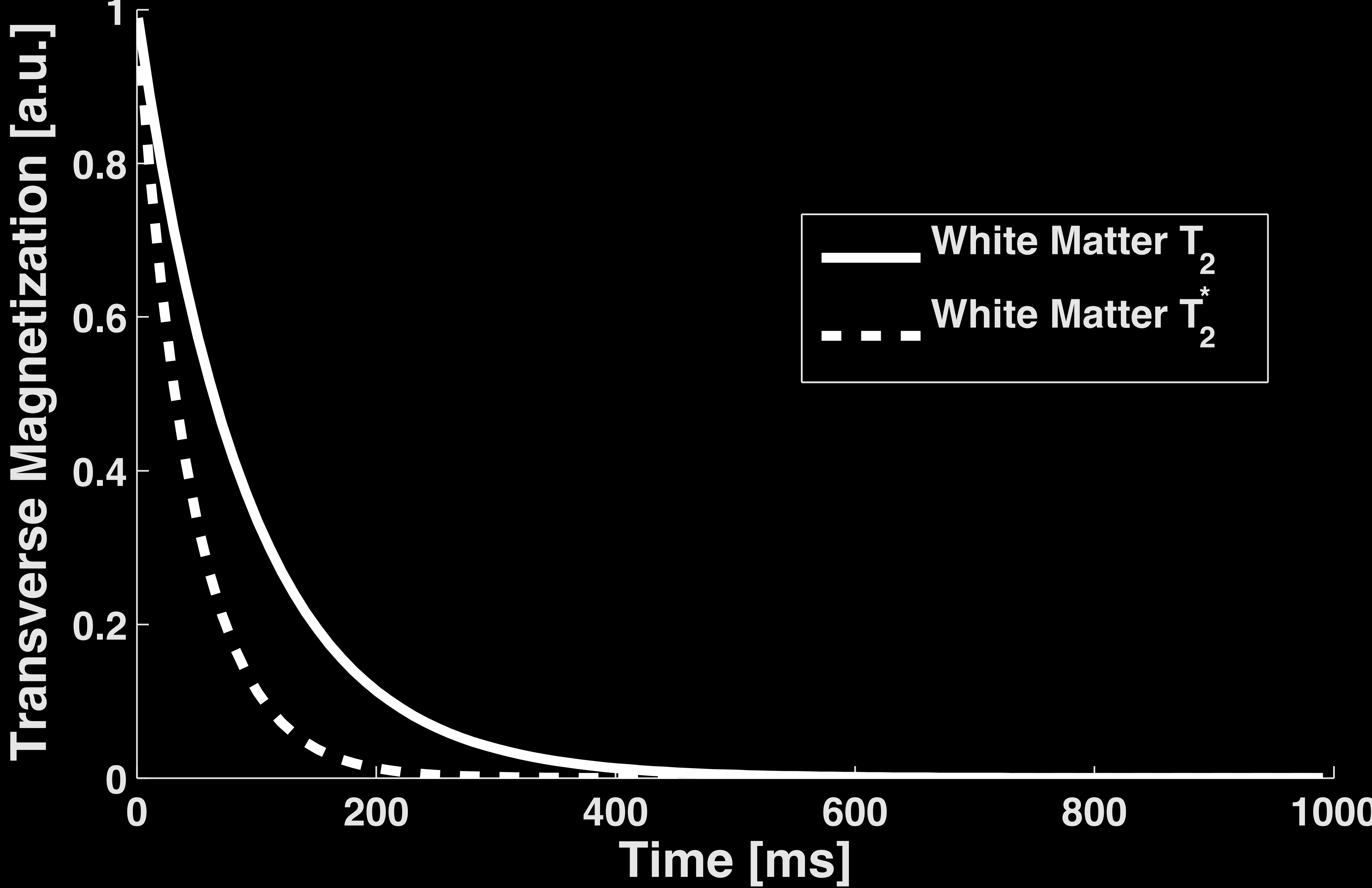


Signal loss from spin-spin interaction and off-resonance dephasing and T_2*.



T_2* is signal loss from spin dephasing and T_2

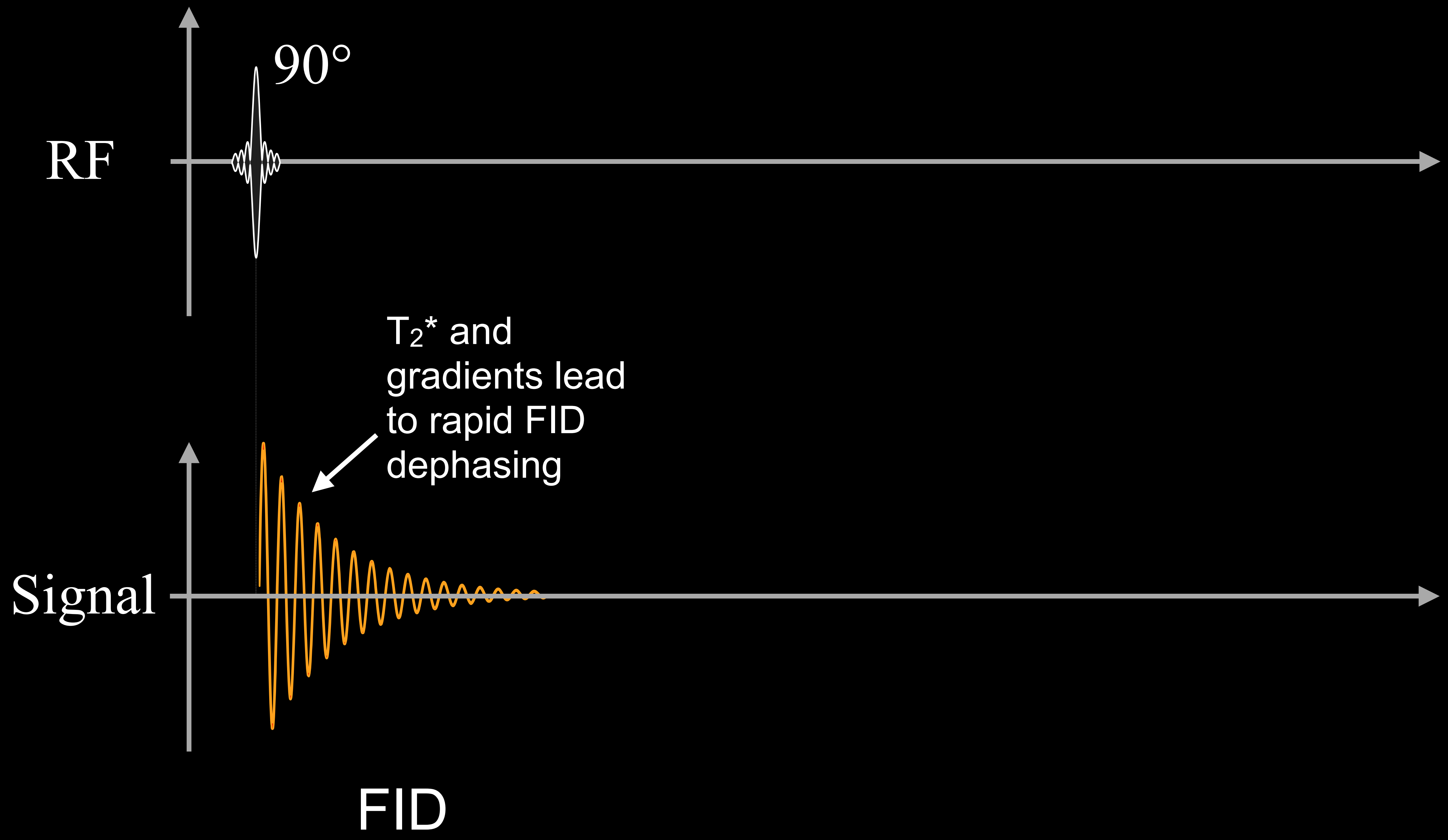
T2*<T2 (always!)



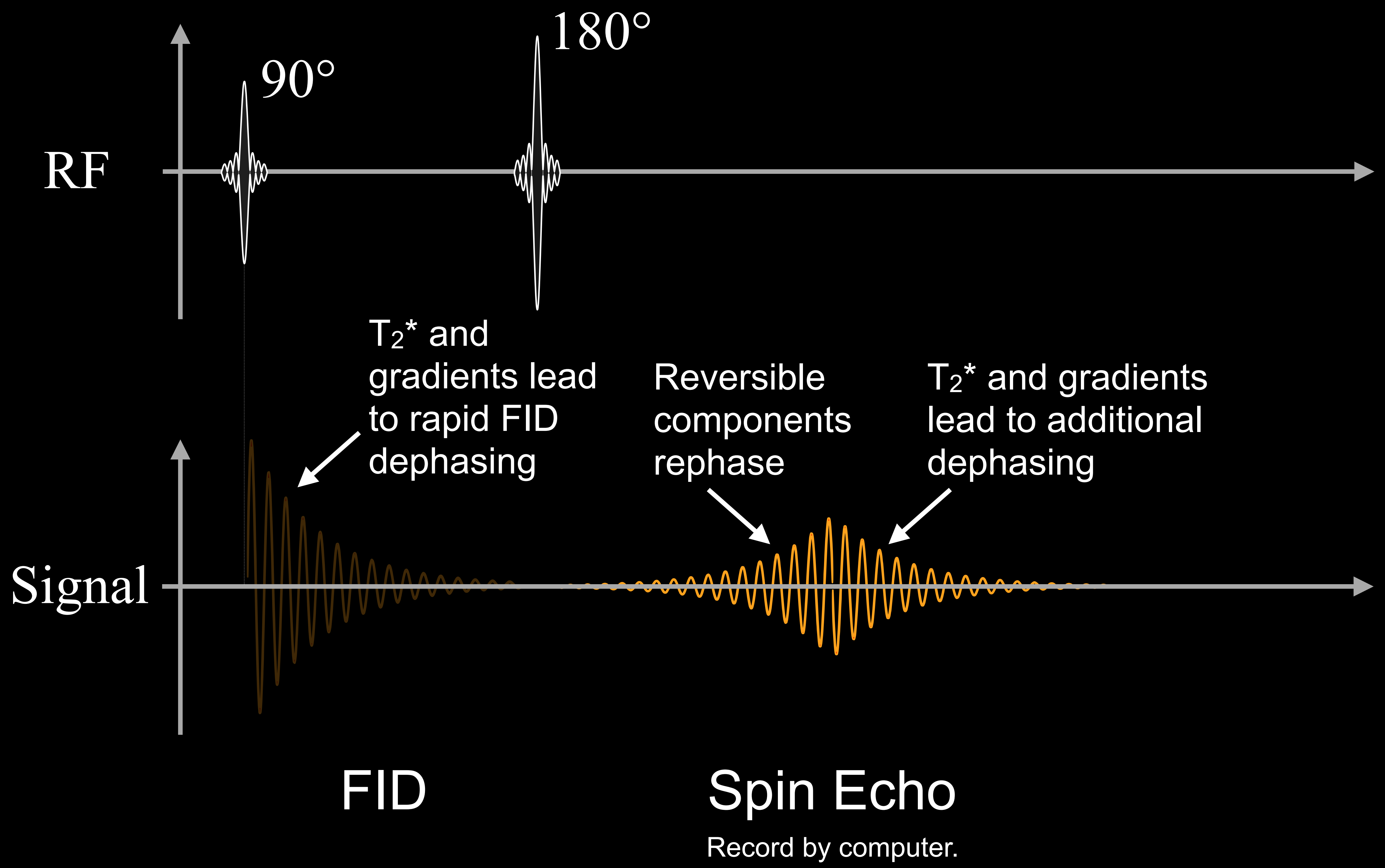
Transverse Magnetization [a.u.]
1
0.8
0.6
0.4
0.2
0
0
200
400
600
800
1000
Time [ms]
White Matter T_2
White Matter T_2^*

Spin Echo Imaging

Free Induction Decay

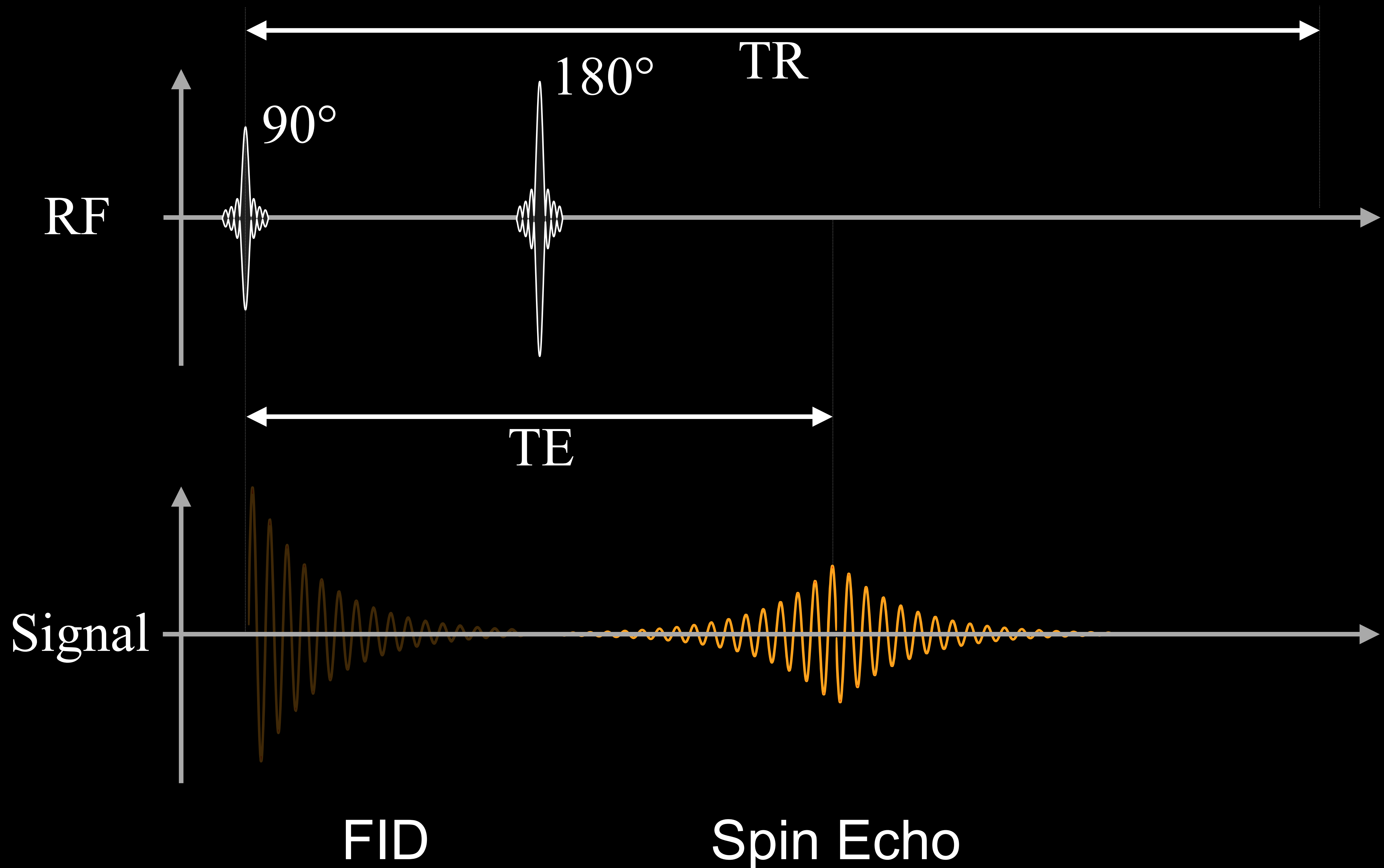


Spin Echo



180°
90°
RF
T2* and gradients lead to rapid FID dephasing
Reversible components rephase
T2* and gradients lead to additional dephasing
Signal
FID
Spin Echo
Record by computer.

Spin Echo

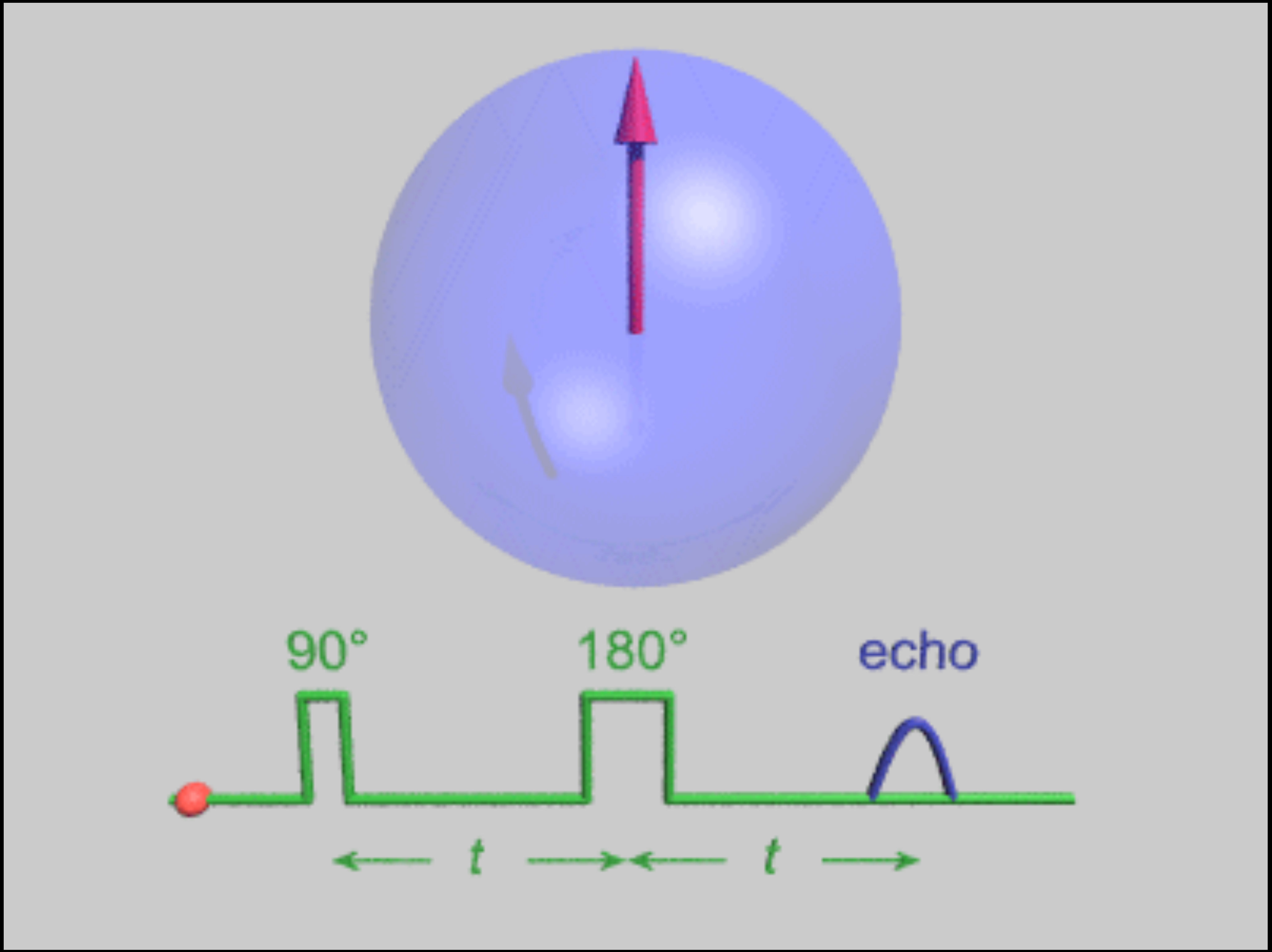


Record by computer.

Refocusing Pulses

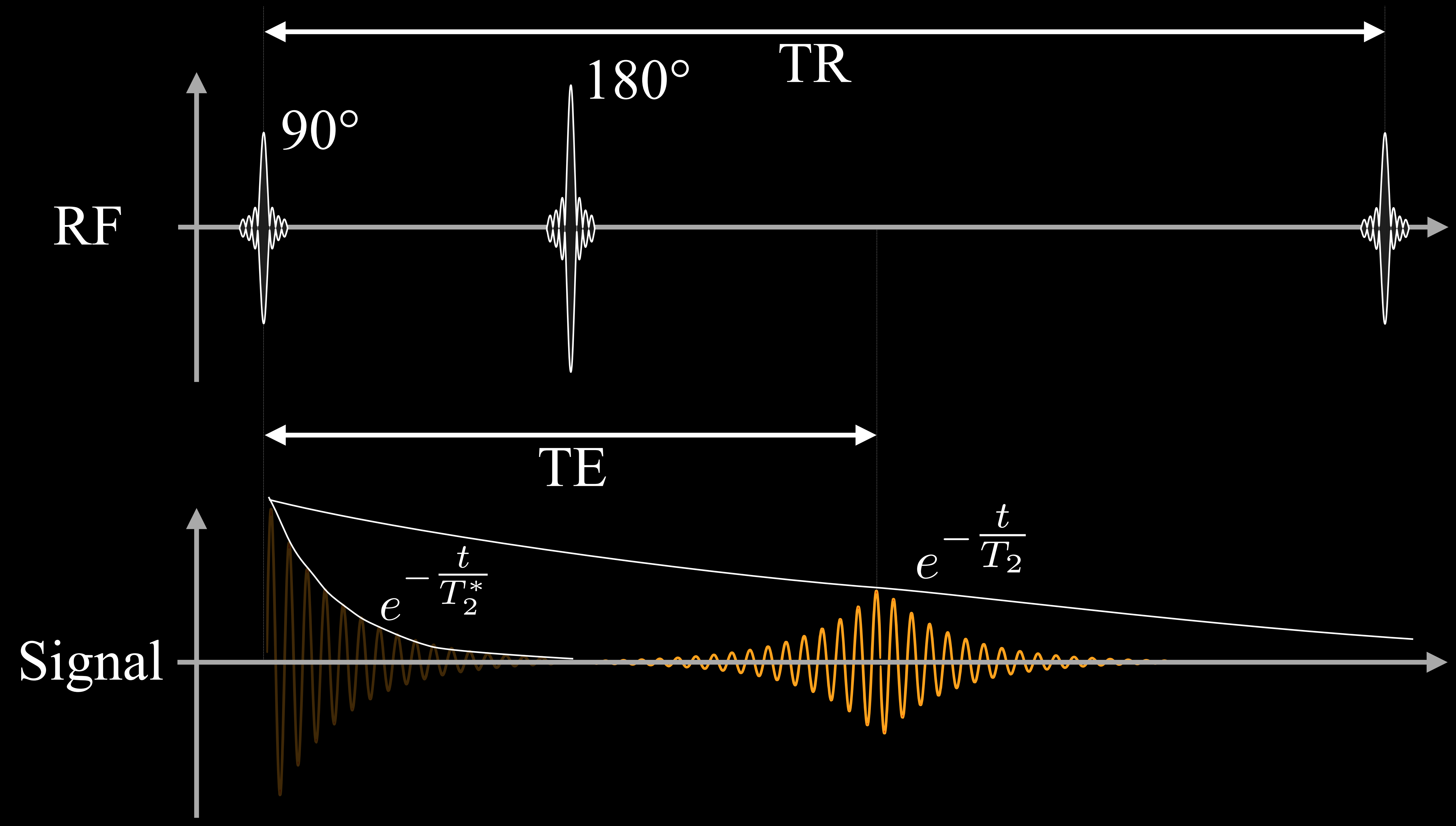
- Typically, 180° RF Pulse
  - Provides optimally refocused M_{XY}
  - Largest spin echo signal
- Refocus spin dephasing due to
  - imaging gradients
  - local magnetic field inhomogeneity
  - magnetic susceptibility variation
  - chemical shift

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

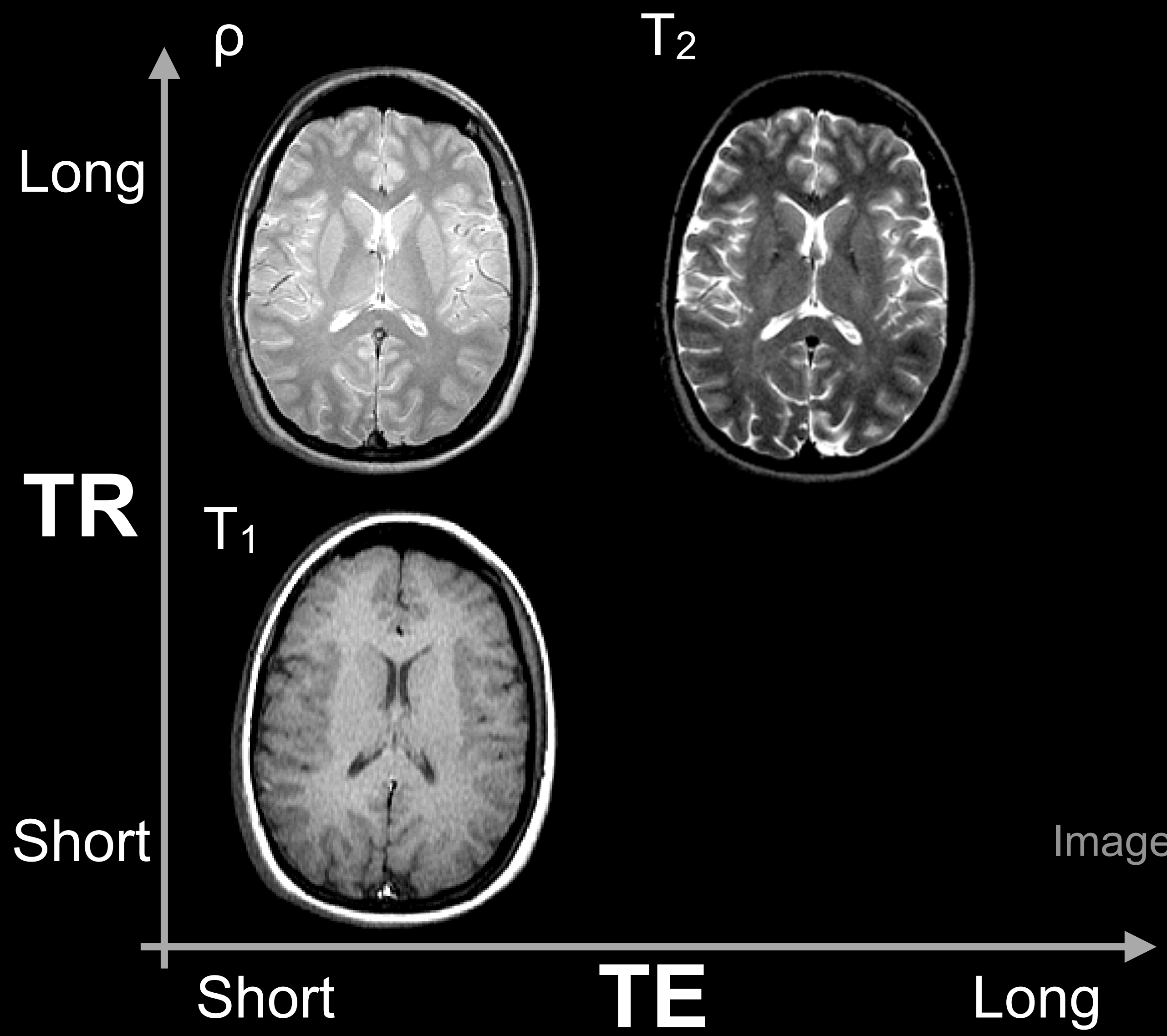
Intermediate TE
maximizes
T2 contrast

Spin Echo Parameters

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

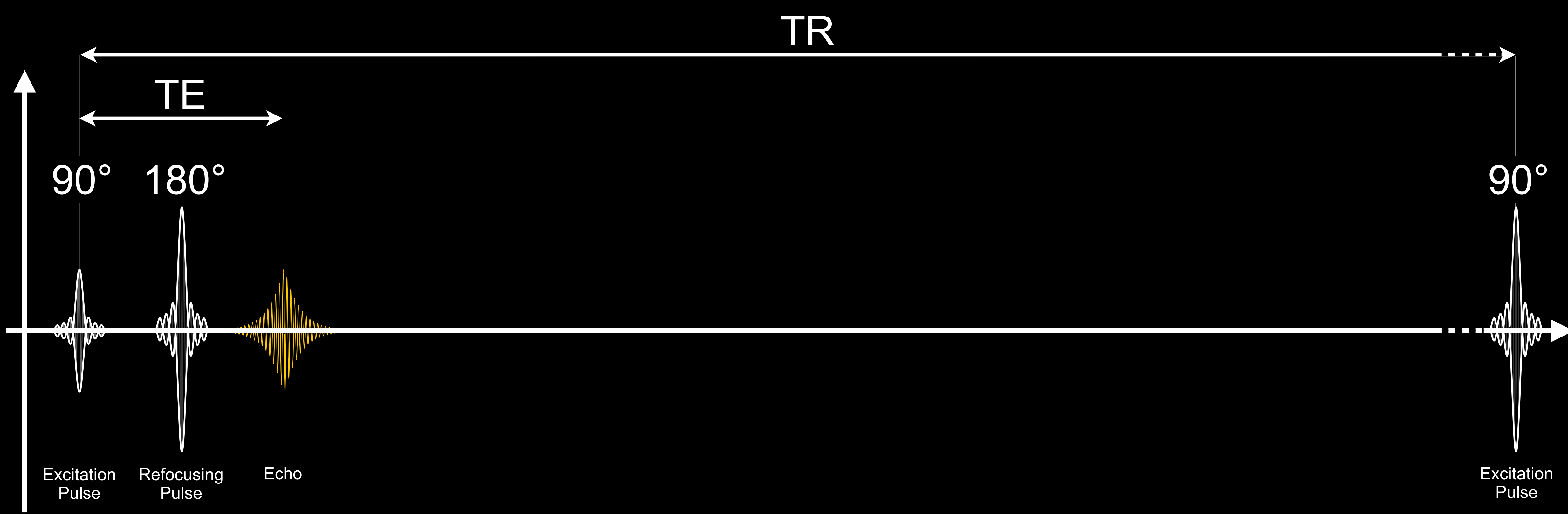
Spin Echo Contrast

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



Images Courtesy of Mark Cohen

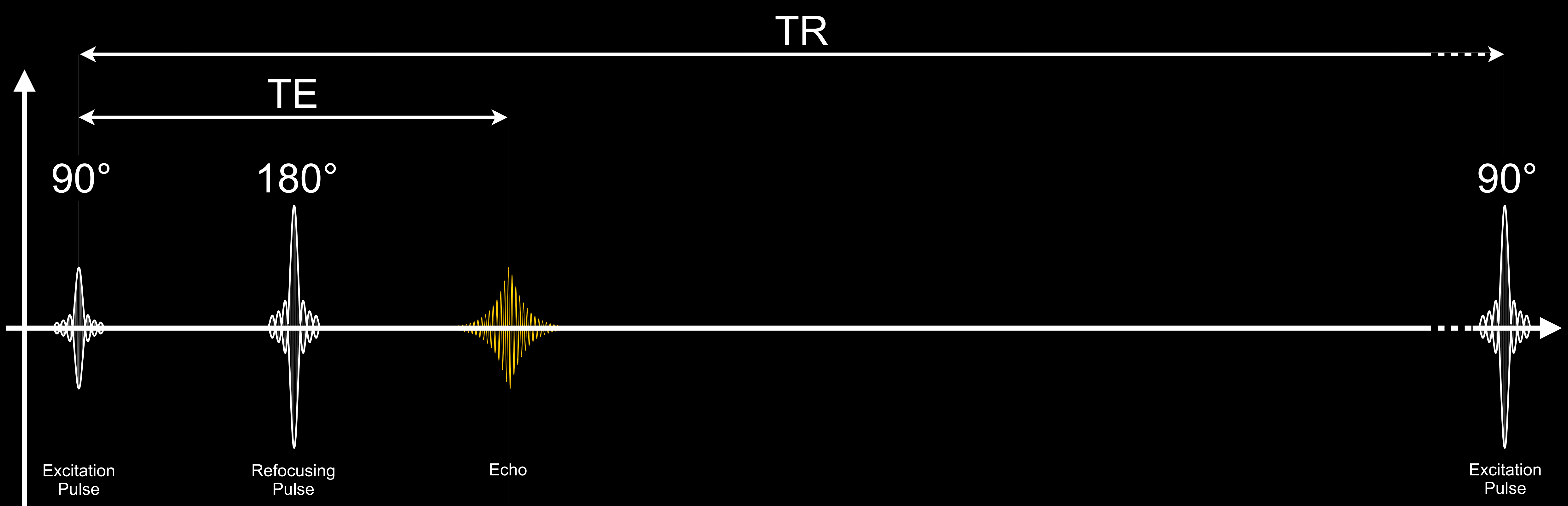
Spin Echo



TE=12ms

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

Spin Echo

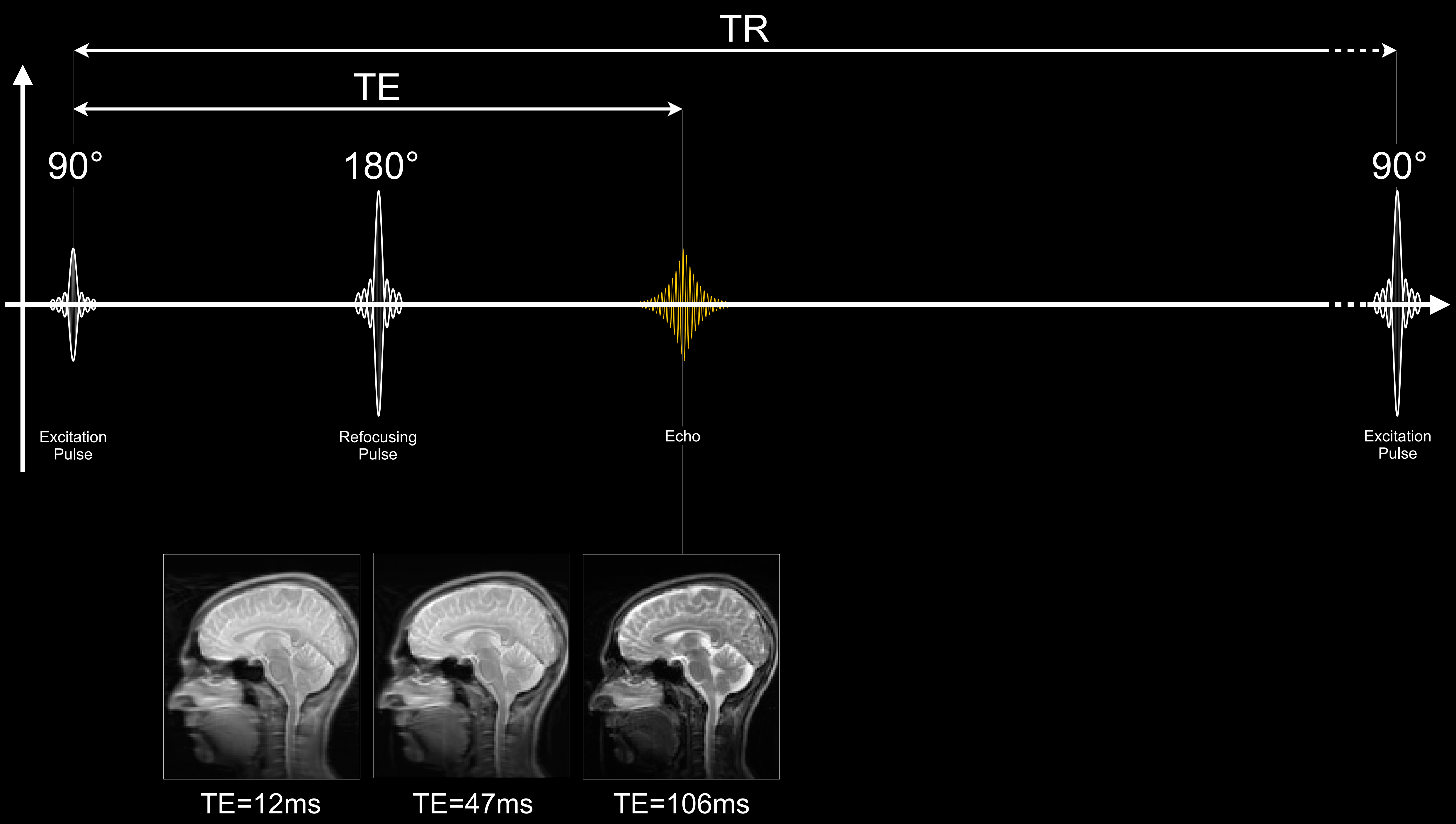



TE=12ms


TE=47ms

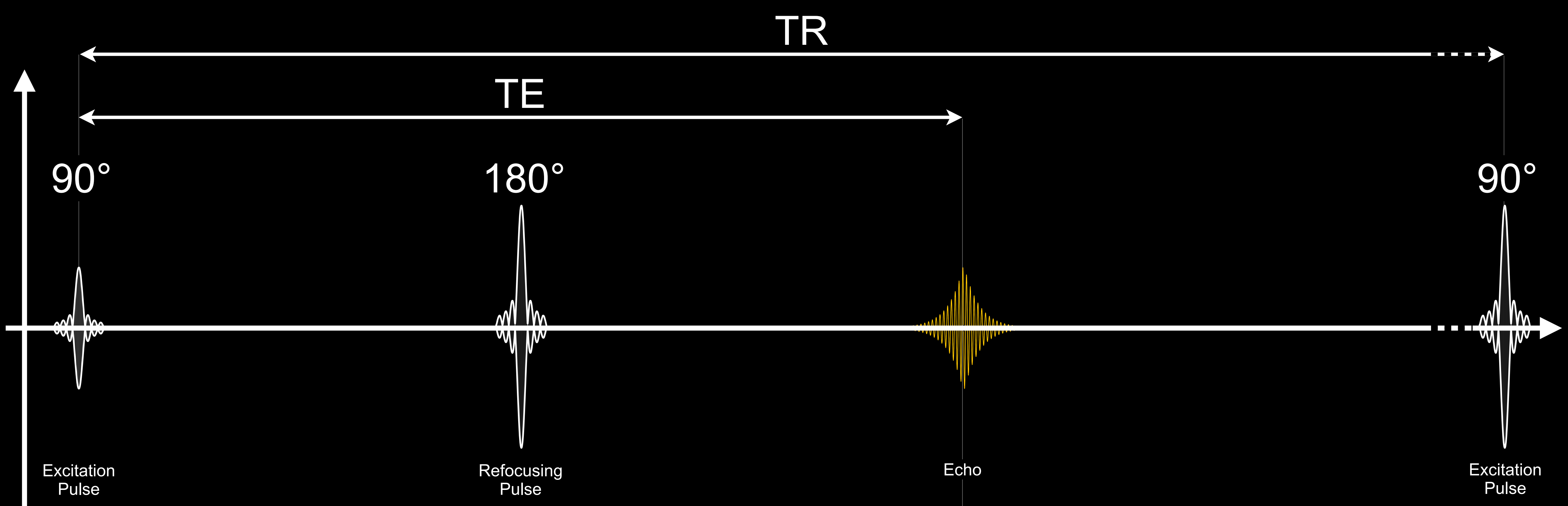
Spin Echo: TR=6500ms (ETL=12)

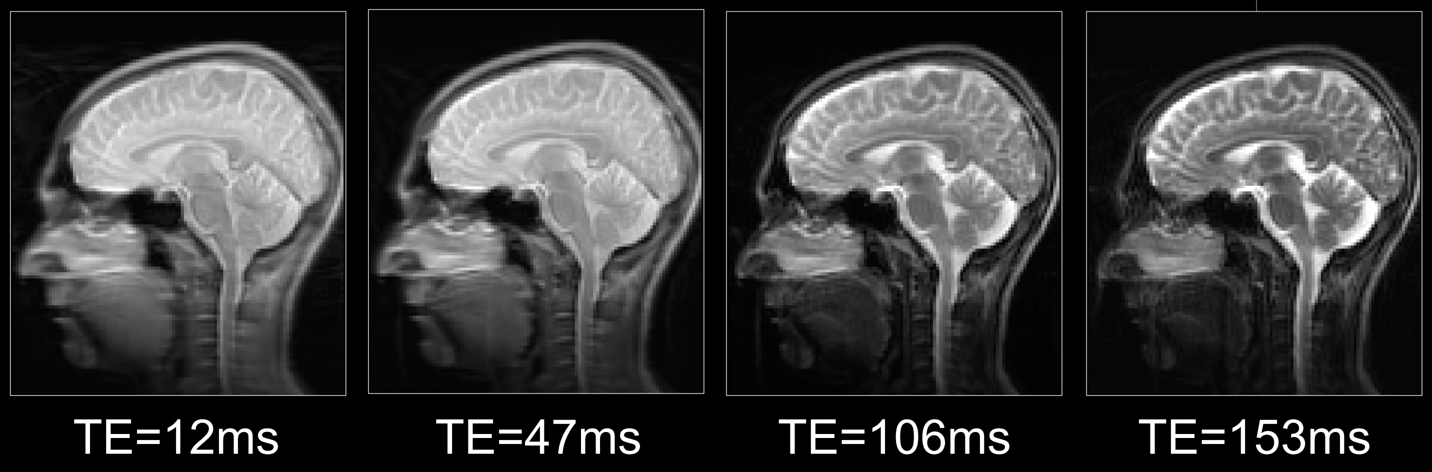
Spin Echo



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

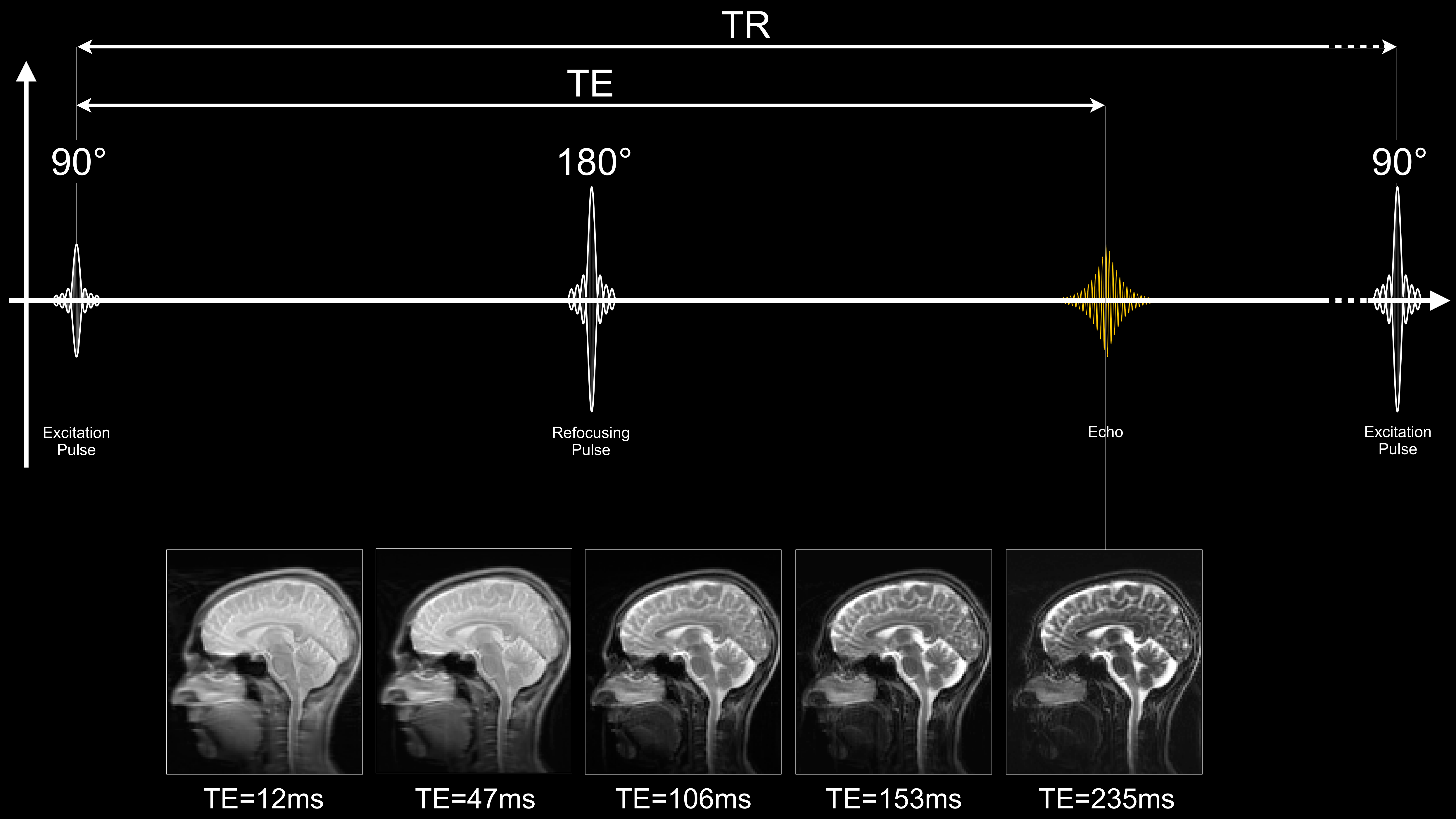
Spin Echo





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

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

How do we calculate scan time?

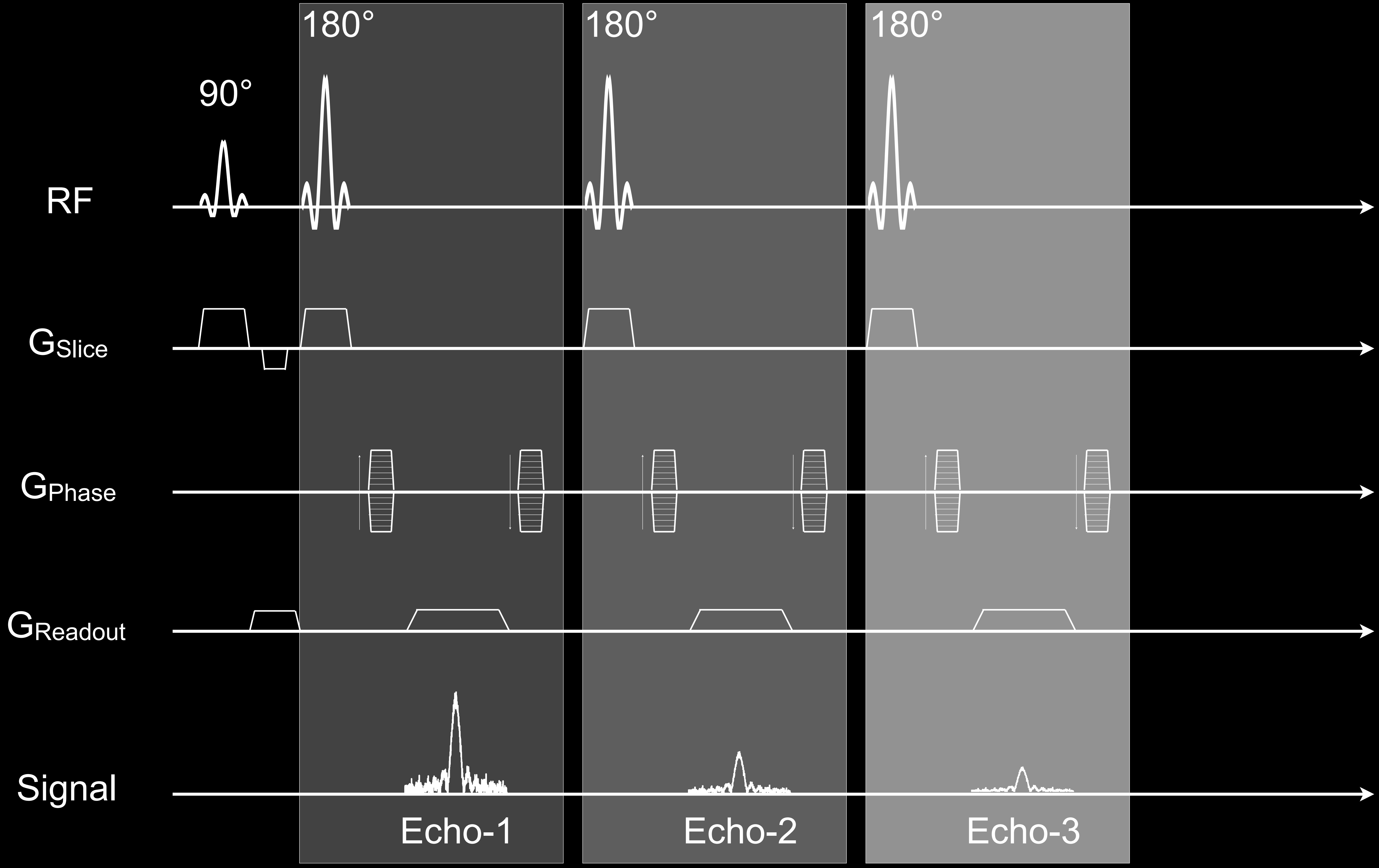
$$T_{Scan} = TR \cdot PE \cdot N_{avg}$$

- T_{Scan}=1000ms•256•1=4:16 [mm:ss]
- Assumes one echo per TR.

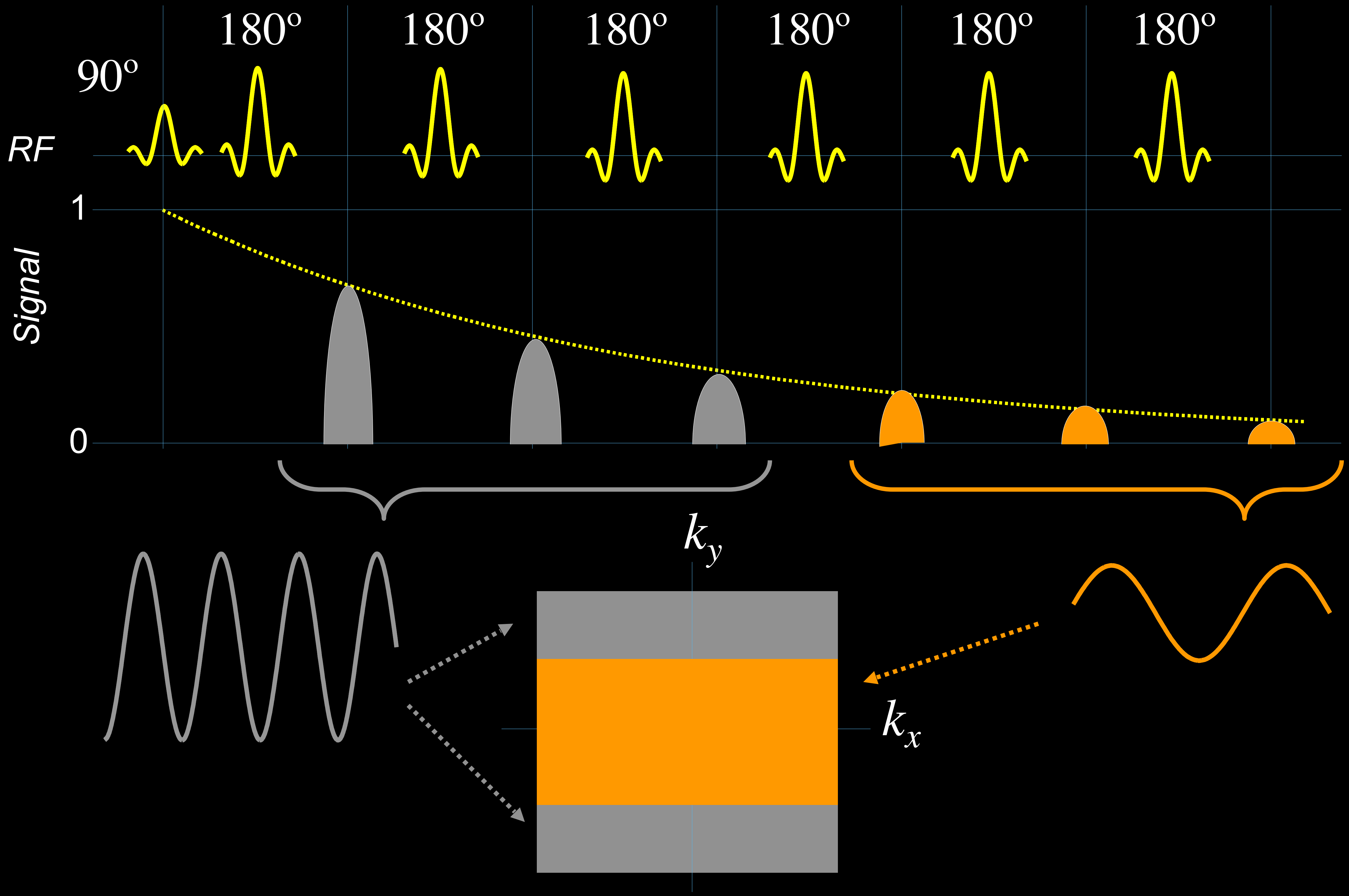
Spin Echo

Spin Echo

Turbo Spin Echo (TSE)



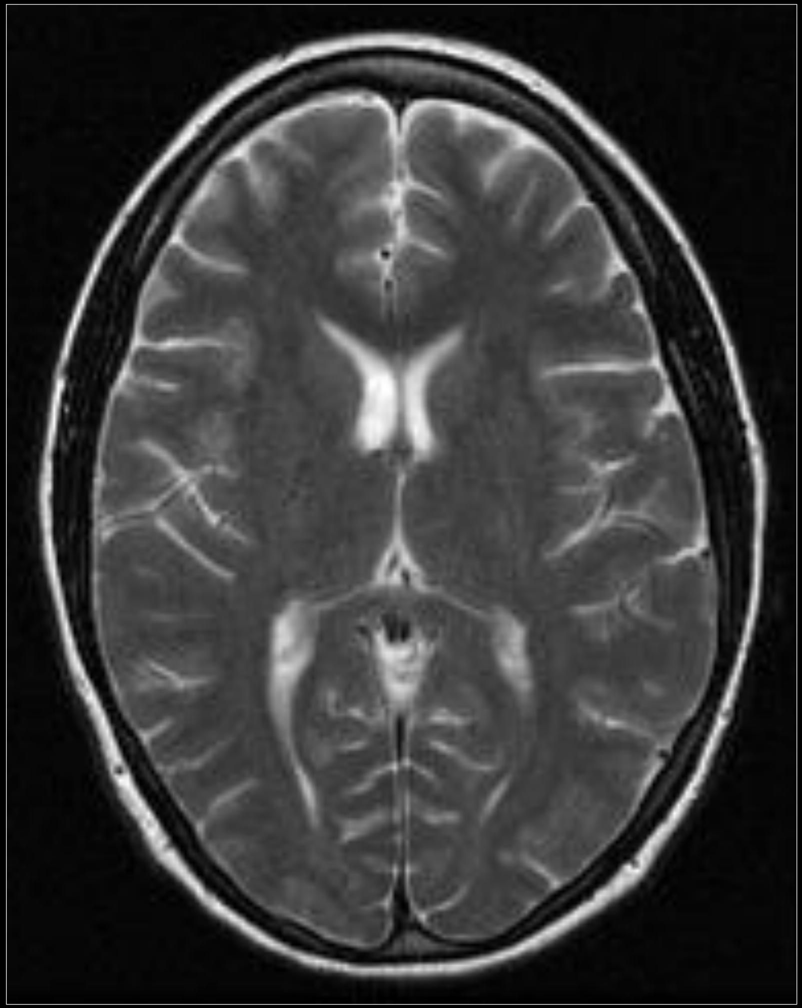
T_2-weighted TSE



Turbo Spin Echo vs. Spin Echo

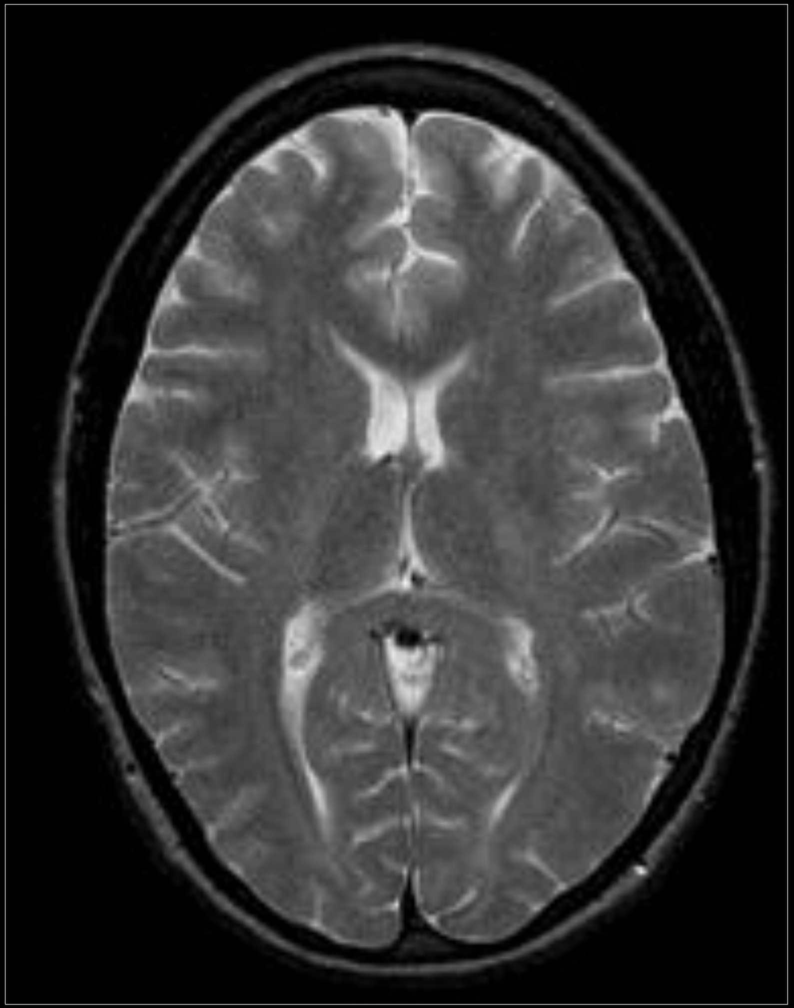
Fast Spin Echo

TR = 2500
TE = 116
ETL = 16
NEX = 2
24 slices
17 slices/pass
2 passes
Time = 2:51



Shorter scan time.
More T2-weighted.
Fat is brighter.
Higher SAR.

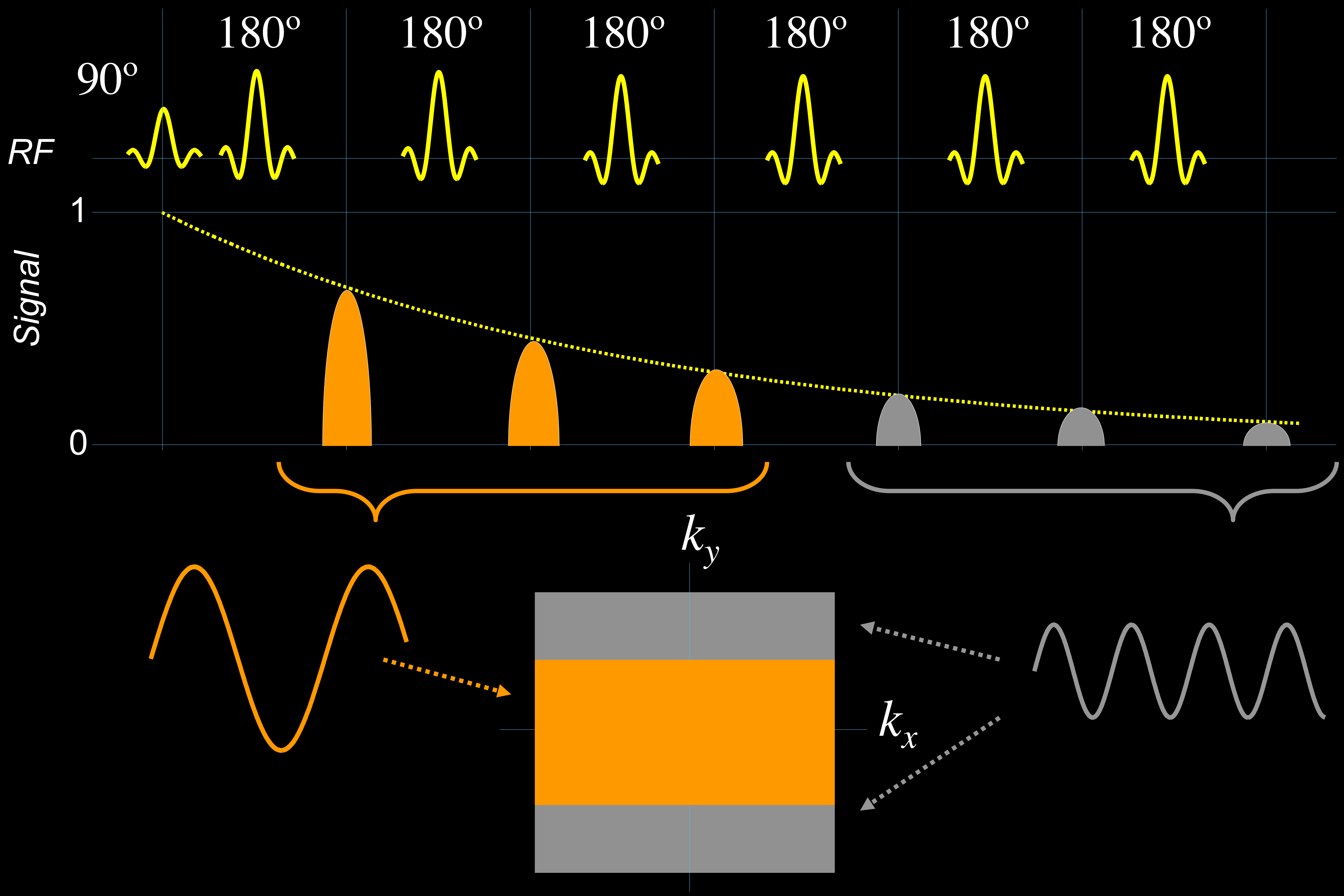
Spin Echo



TR = 2500
TE = 112
ETL = N/A
NEX = 1
24 slices
20 slices/pass
2 passes
Time = 22:21

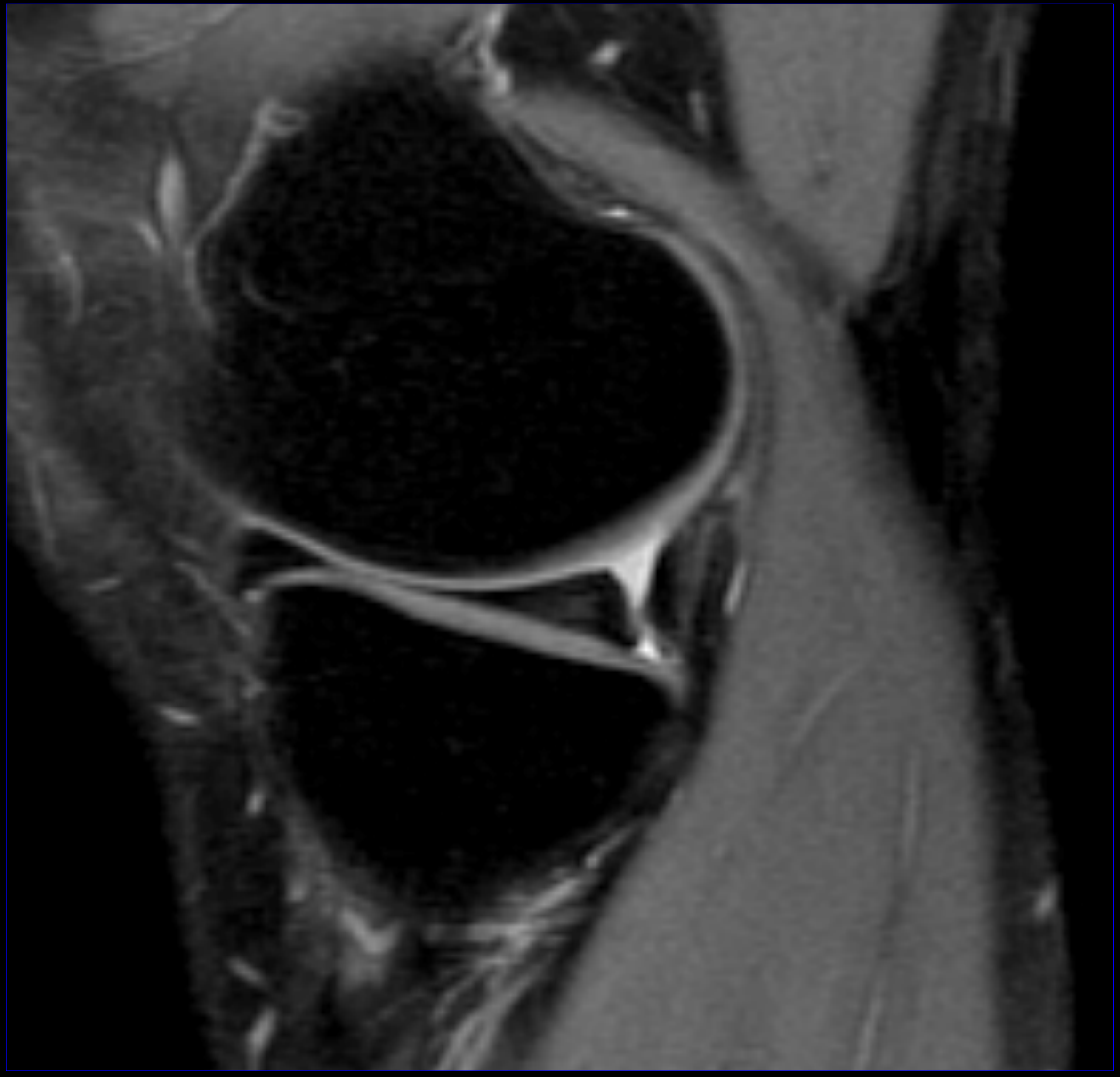
Images: Courtesy Frank Korosec

Proton Density Weighted TSE

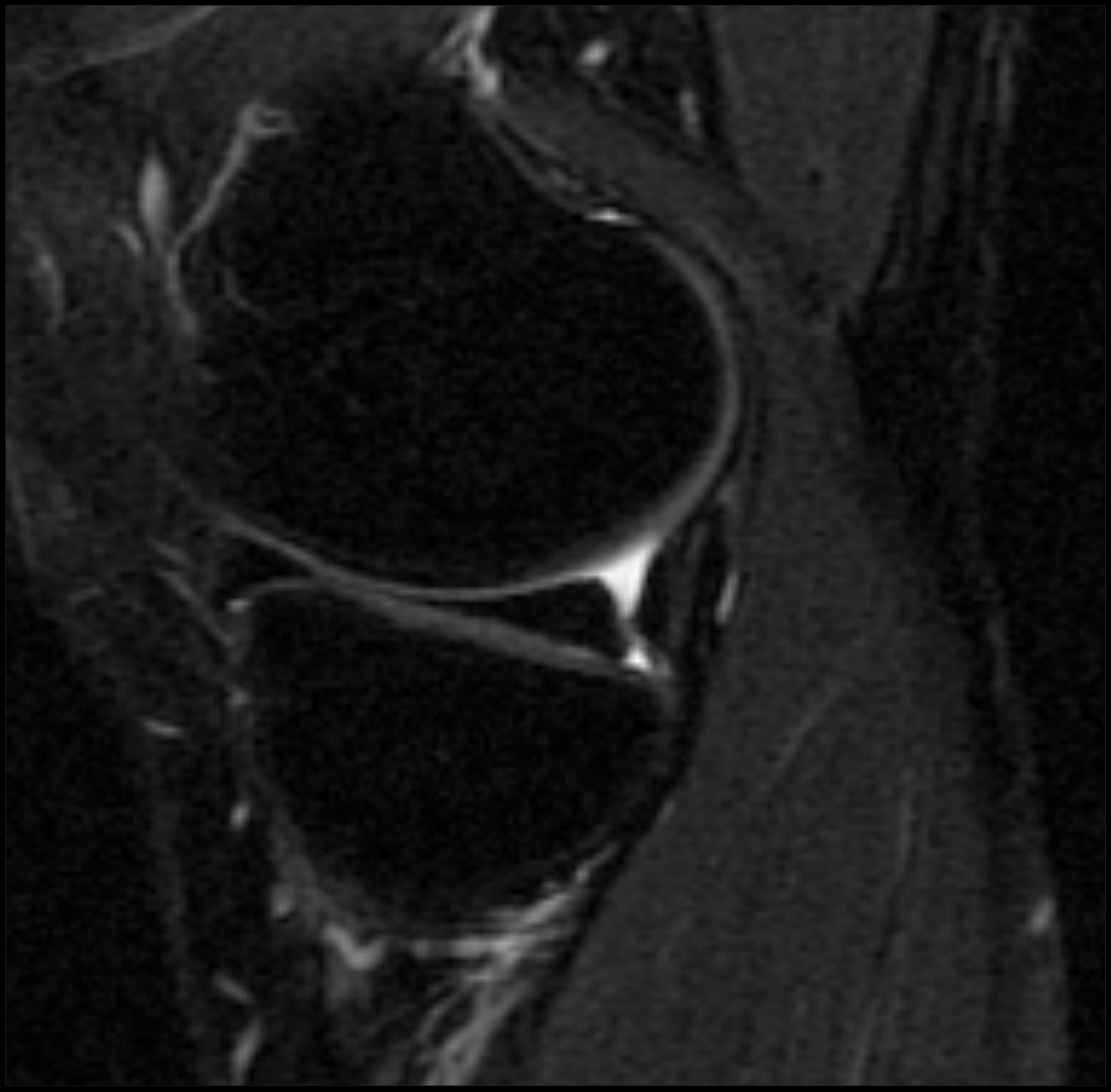


PD vs T_2-weighted TSE

Proton Density Weighted



T_2-weighted



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

Summary for TSE

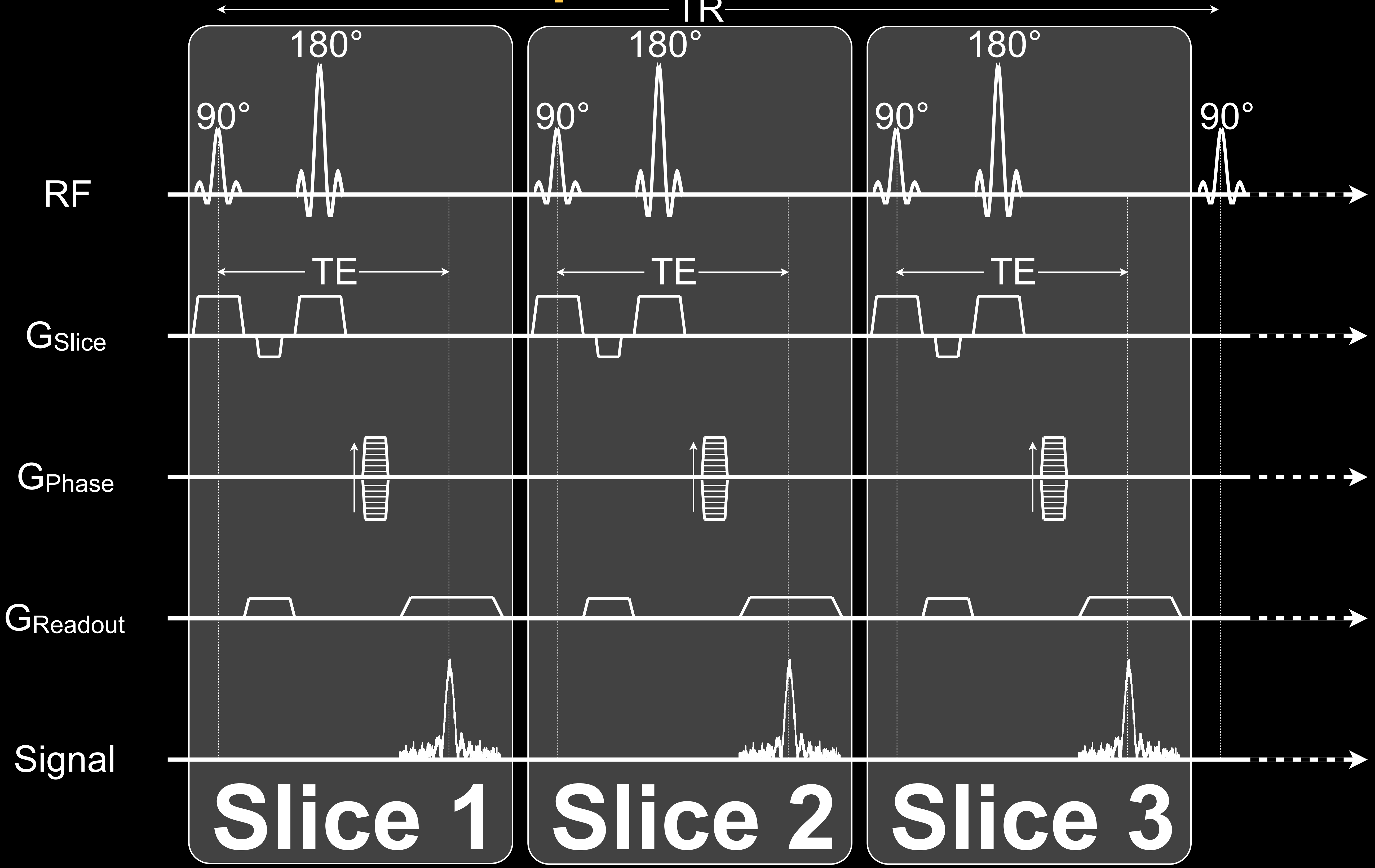
- Pros:
  - Fast, high SNR
  - Less sensitive to B0 inhomogneity
- Cons:
  - T2 weighting varies in k-space
  - RF power limits speed, particularly at 3T

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

2D Slice Interleaving

Spin Echo

Spin Echo

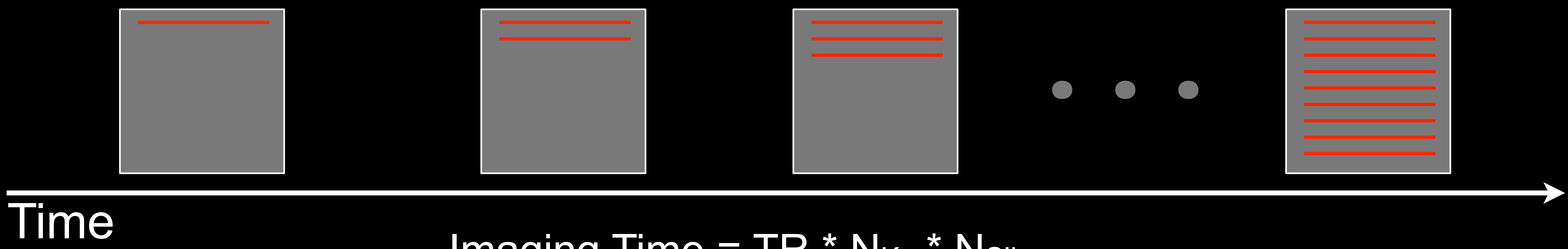


David Geffen School of Medicine

UCLA Radiology

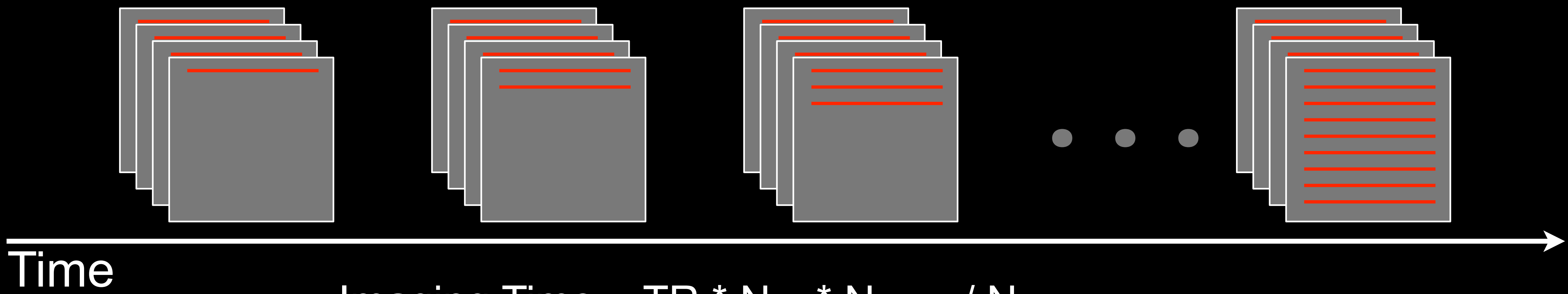
Slice Interleaving

Sequential 2D Imaging



$$\text{Imaging Time} = TR * N_{Ky} * N_{Slices}$$

Slice Interleaved 2D Imaging

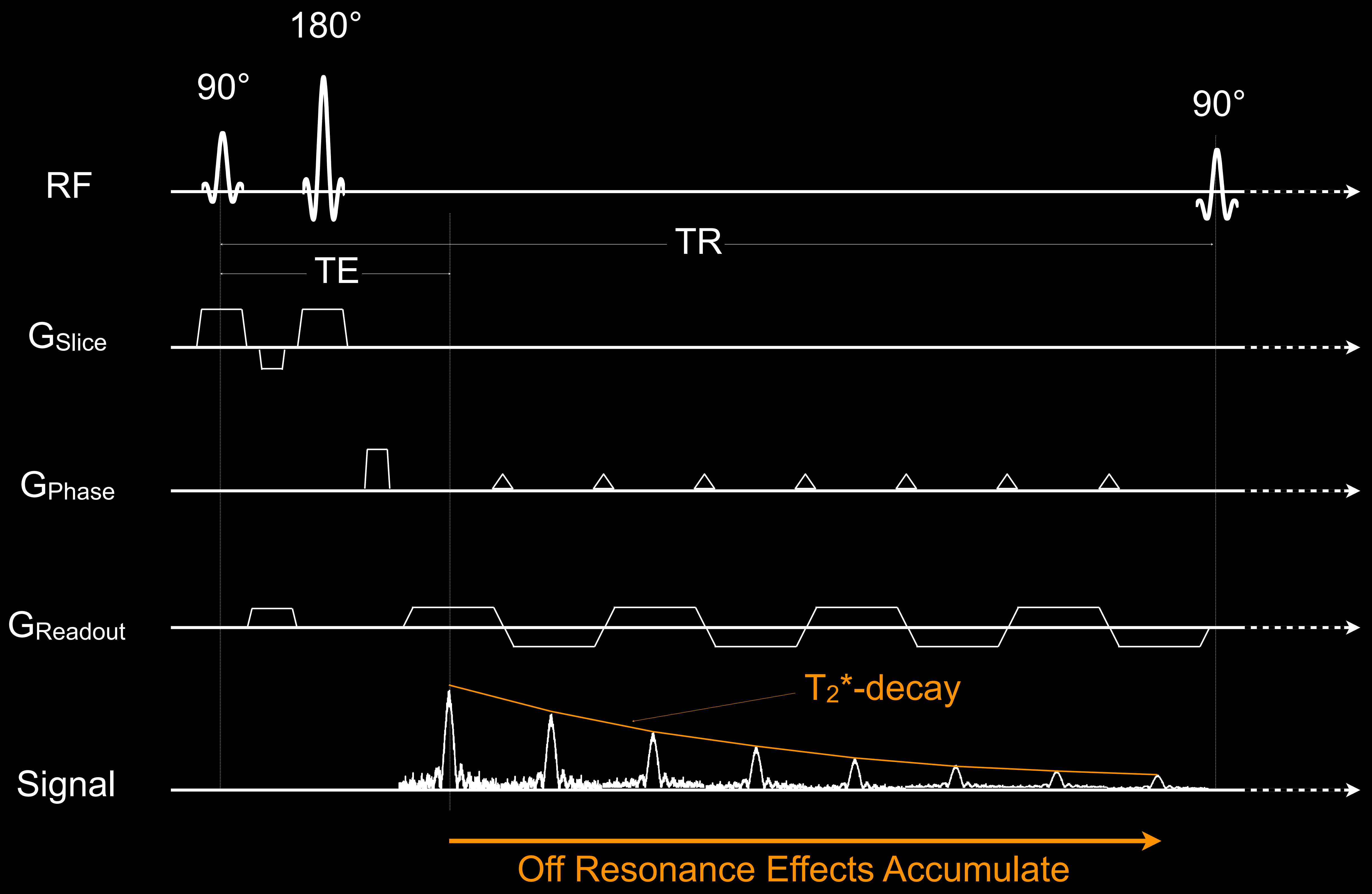


$$\text{Imaging Time} = TR * N_{Ky} * N_{Slices} / N_{Interleaves}$$

2D Slice Interleaving

- **Advantages**
  - Accelerate imaging many times
- **Disadvantages**
  - Acceleration limited by
    - $N_{Interleaves} \sim TR/TE$
    - SAR
  - Difficult to acquire adjacent slices
    - Hard to get good 180° slice-profile to match 90° slice-profile for multi-slice imaging
- **Applications**
  - T_2 imaging
    - TR must be long
  - DWI
    - TR should be long

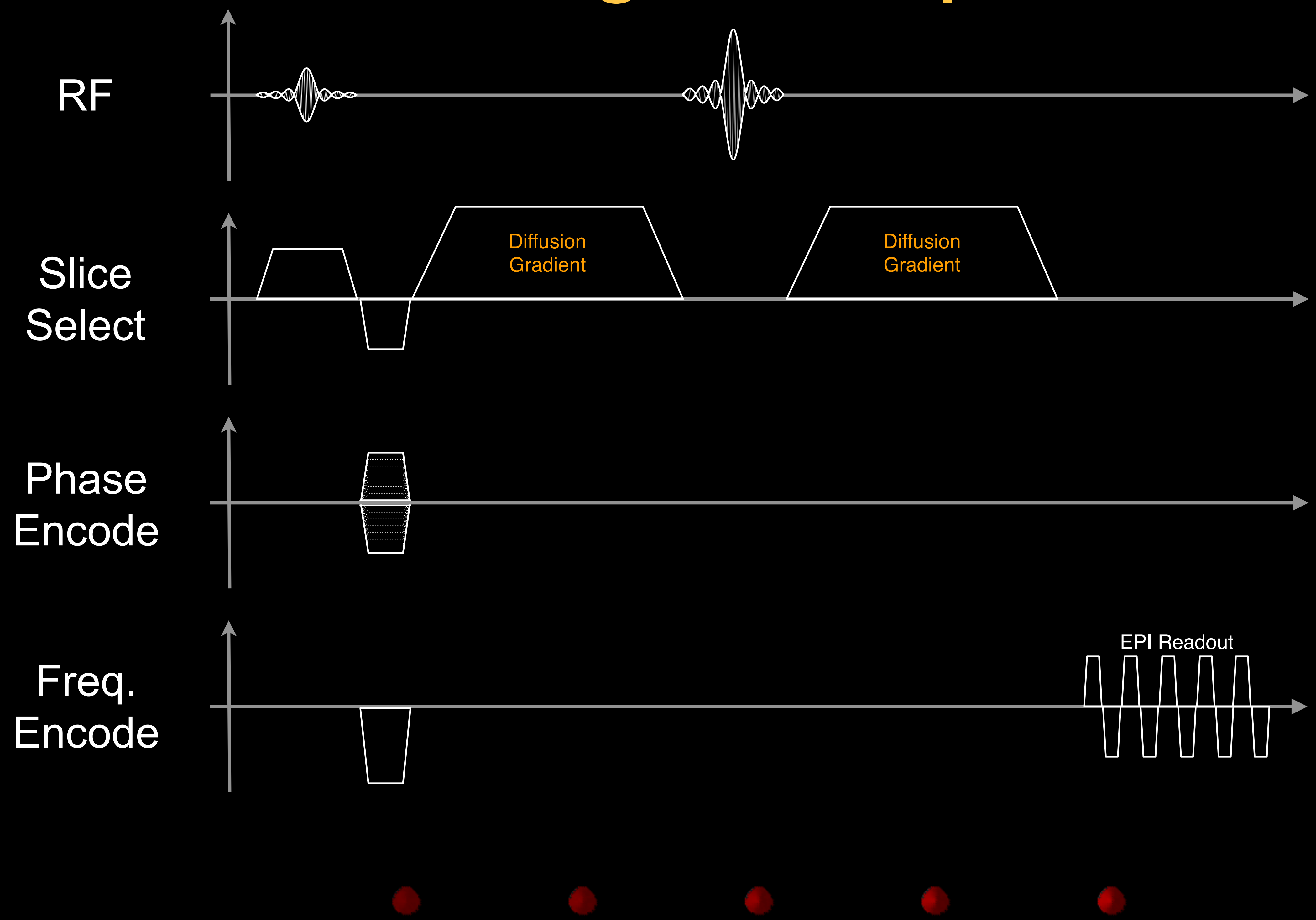
Spin Echo EPI



Summary for Spin Echo EPI

- Advantages
  - Can acquire data in a "single shot"
  - Can be used with 2D slice interleaving
  - Allows T_2^* weighted imaging in a breath hold
- Disadvantages
  - Single Shot EPI
    - Ghosting / Blur images / Image distortion
    - Alter image contrast
  - Multi-shot EPI
    - Slower than single shot
    - Faster than SE

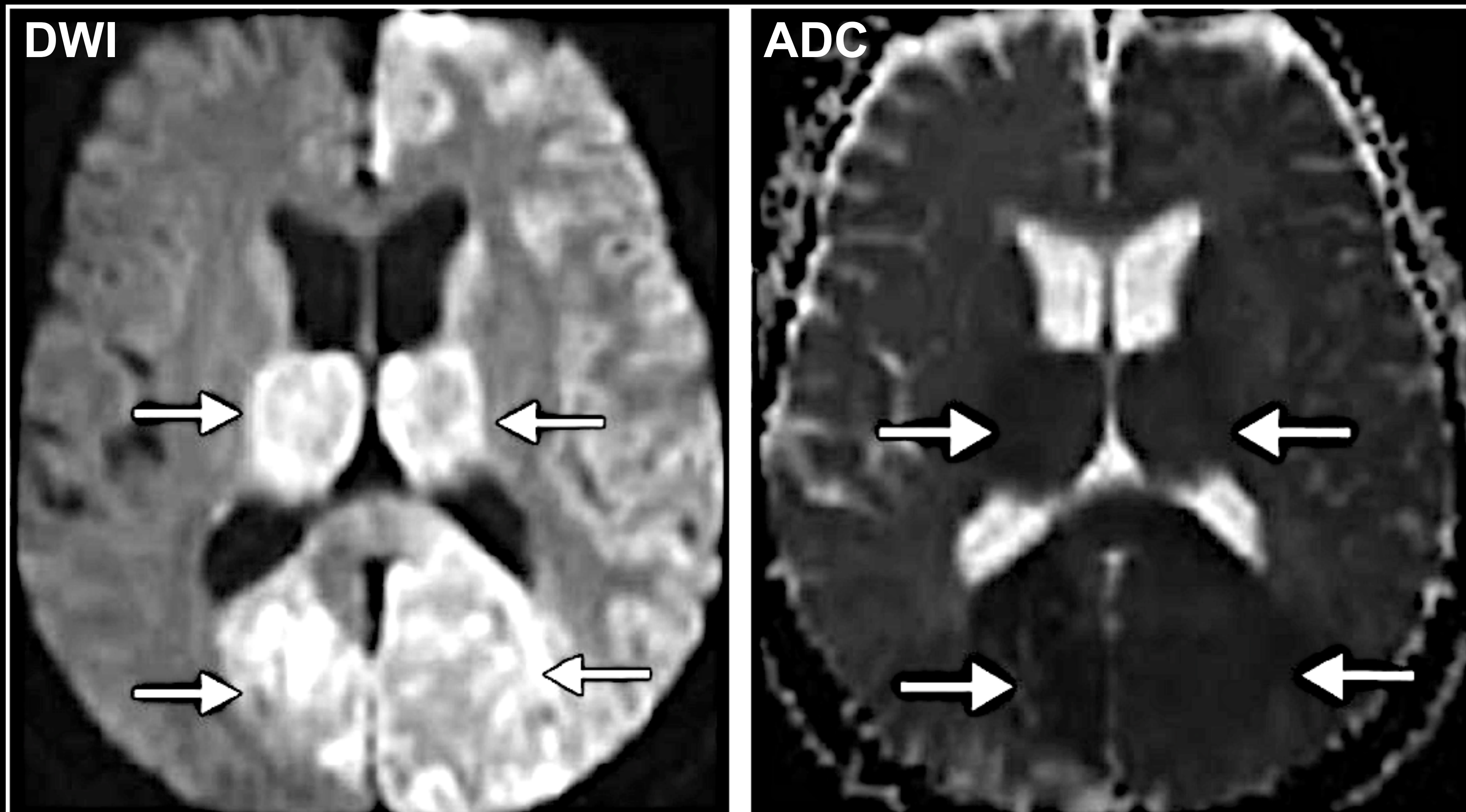
Diffusion Weighted Spin Echo EPI



Very larger gradients can encode diffusion.

DWI SE-EPI in Acute Stroke

Does the lesion have a higher or lower diffusion coefficient?



a. b.

Figure 15. Acute stroke of the posterior circulation in a 77-year-old man. **(a)** Diffusion-weighted MR image ($b = 1000$ sec/mm^2) shows bilateral areas of increased signal intensity (arrows) in the thalami and occipital lobes. **(b)** ADC map shows decreased ADC values in the same areas (arrows). These findings are indicative of acute ischemia.

Srinivasan A, *et al*. State-of-the-art imaging of acute stroke. Radiographics 2006;26 Suppl 1:S75-95.

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?

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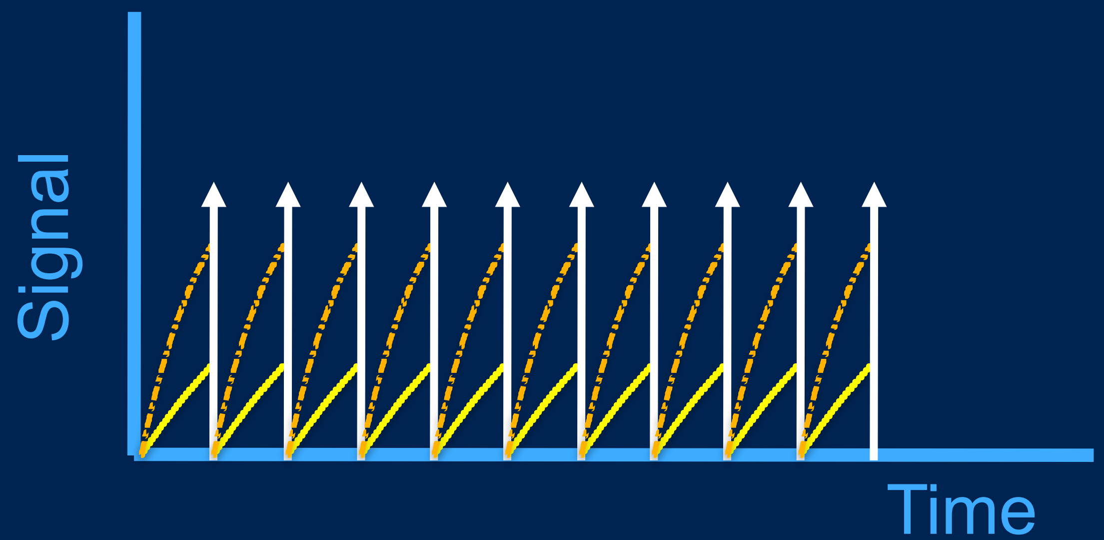

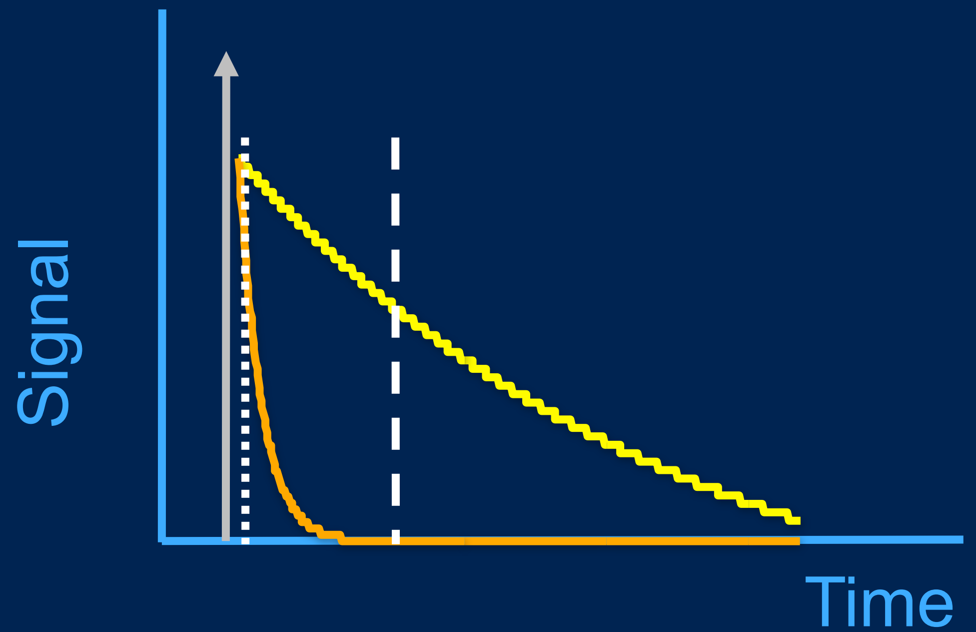

Relaxation - True or False?

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

2. T_2(Liver) < T_2(Fat)

Relaxation - True or False?

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Tissue	**T_1 [ms]**	**T_2 [ms]**
gray matter	925	100
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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?

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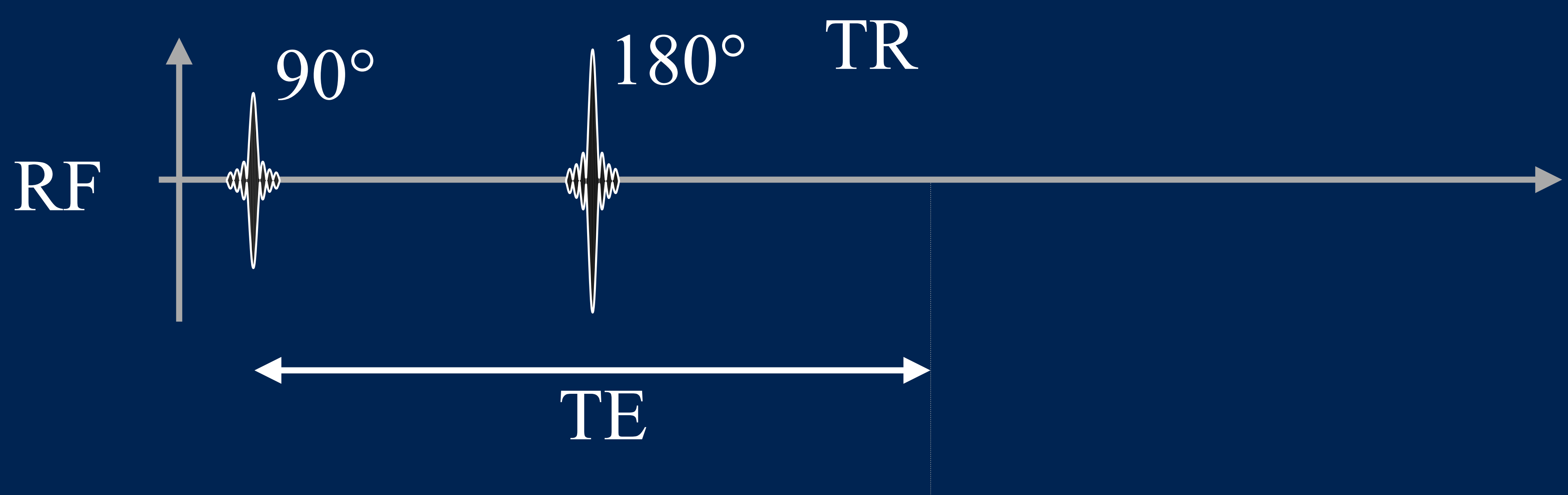


Spin Echoes - True or False?

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.

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

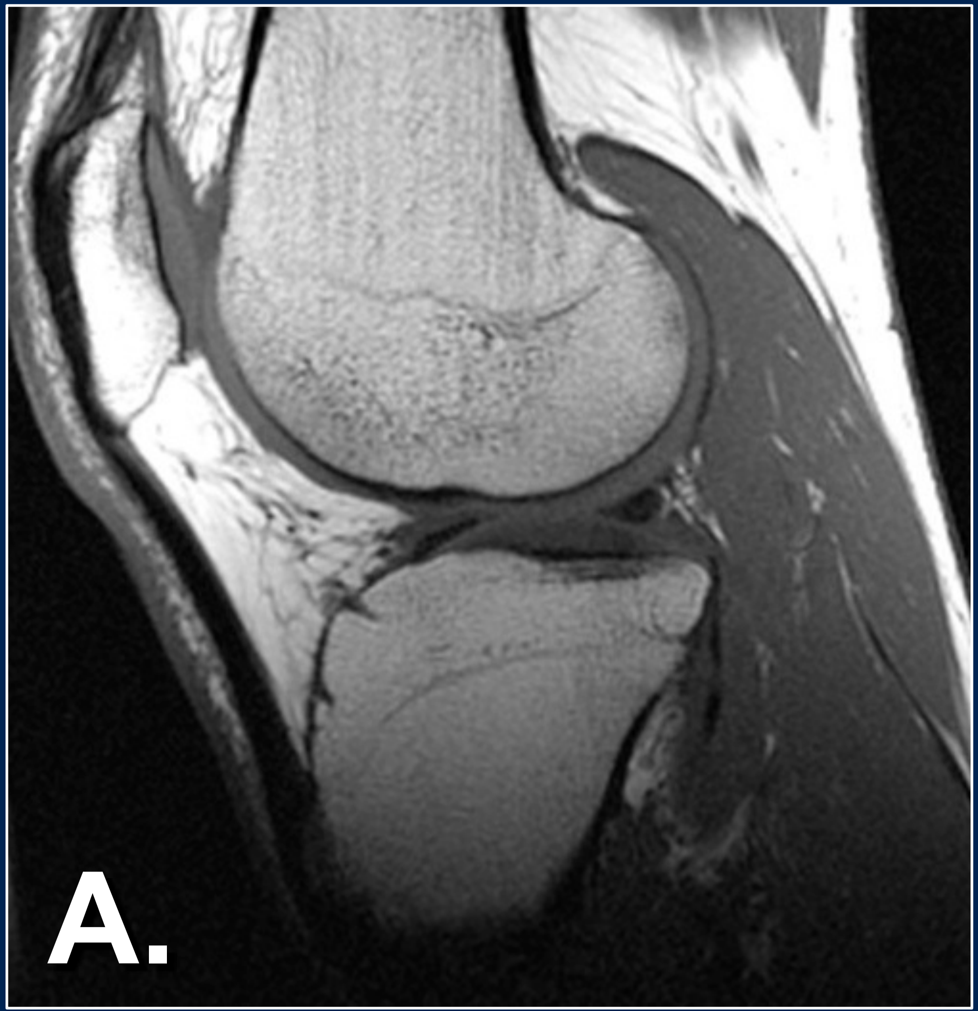
Longer TR minimizes T1 contrast

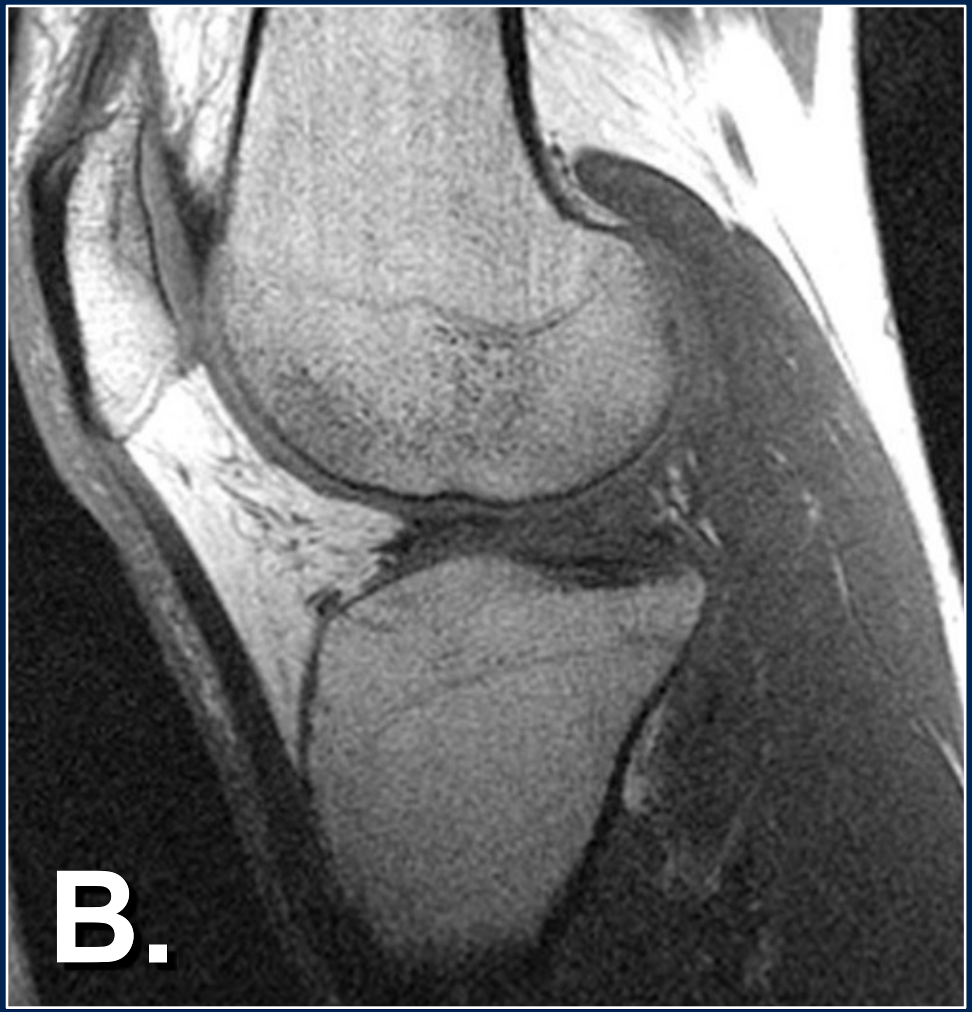
Short TE minimizes T2 contrast

Multi-Echo Imaging - True or False?

1. Multi-echo imaging can decrease scan times by 2x or more
2. Turbo spin echo is excellent for fast T2-weighted imaging
3. Spin Echo EPI is routine for diffusion weighted imaging
4. Long TRs are important for T2 weighted imaging because they eliminate T1-contrast

Gradient vs. Spin Echo

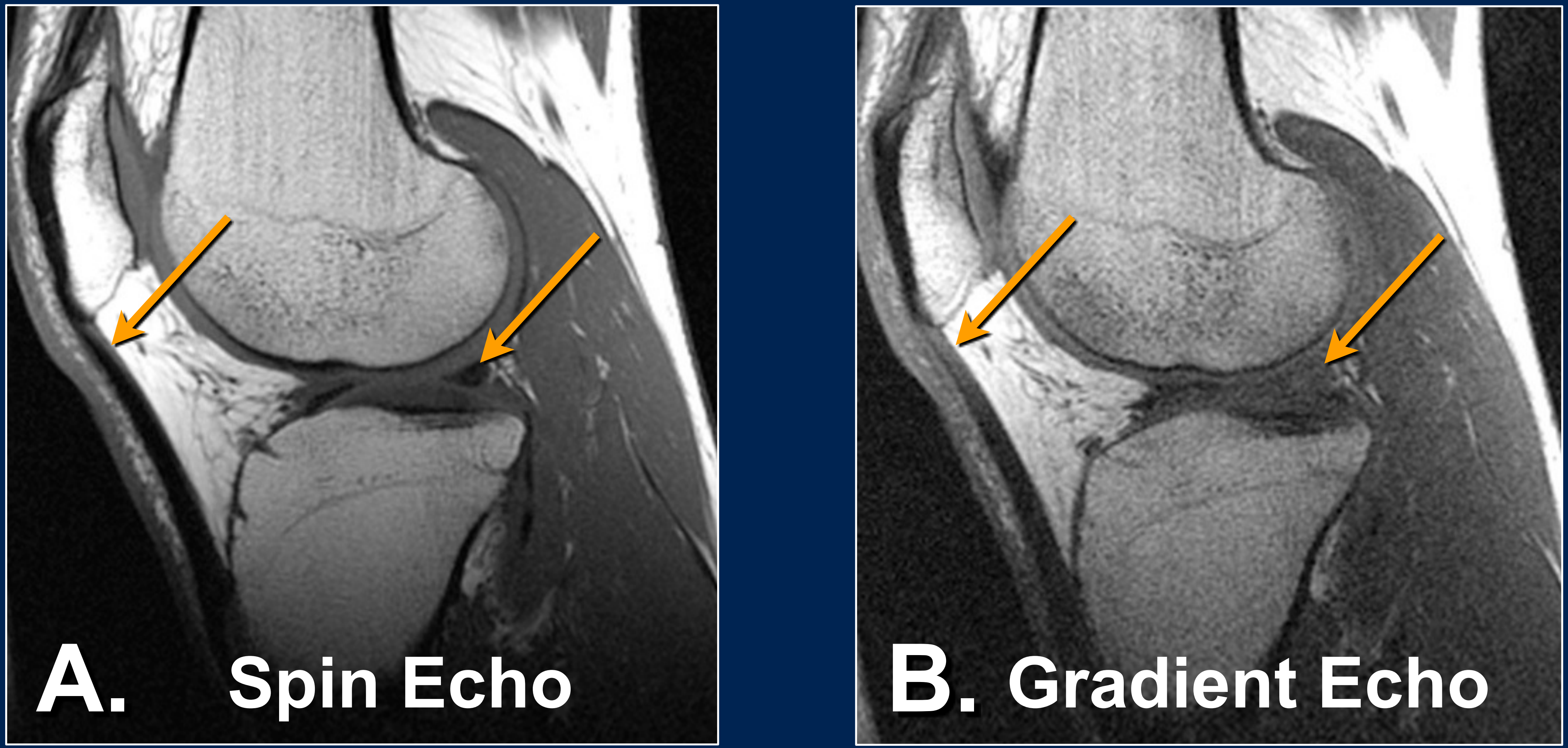




Which image is a gradient echo image?

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

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

Gradient Echoes - True or False?

1. GRE sequences have longer TRs than SE sequences.
2. GRE is great for fast T1-weighted imaging.
3. Metal artifacts on GRE are typically small.
4. GRE is great for T2 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.

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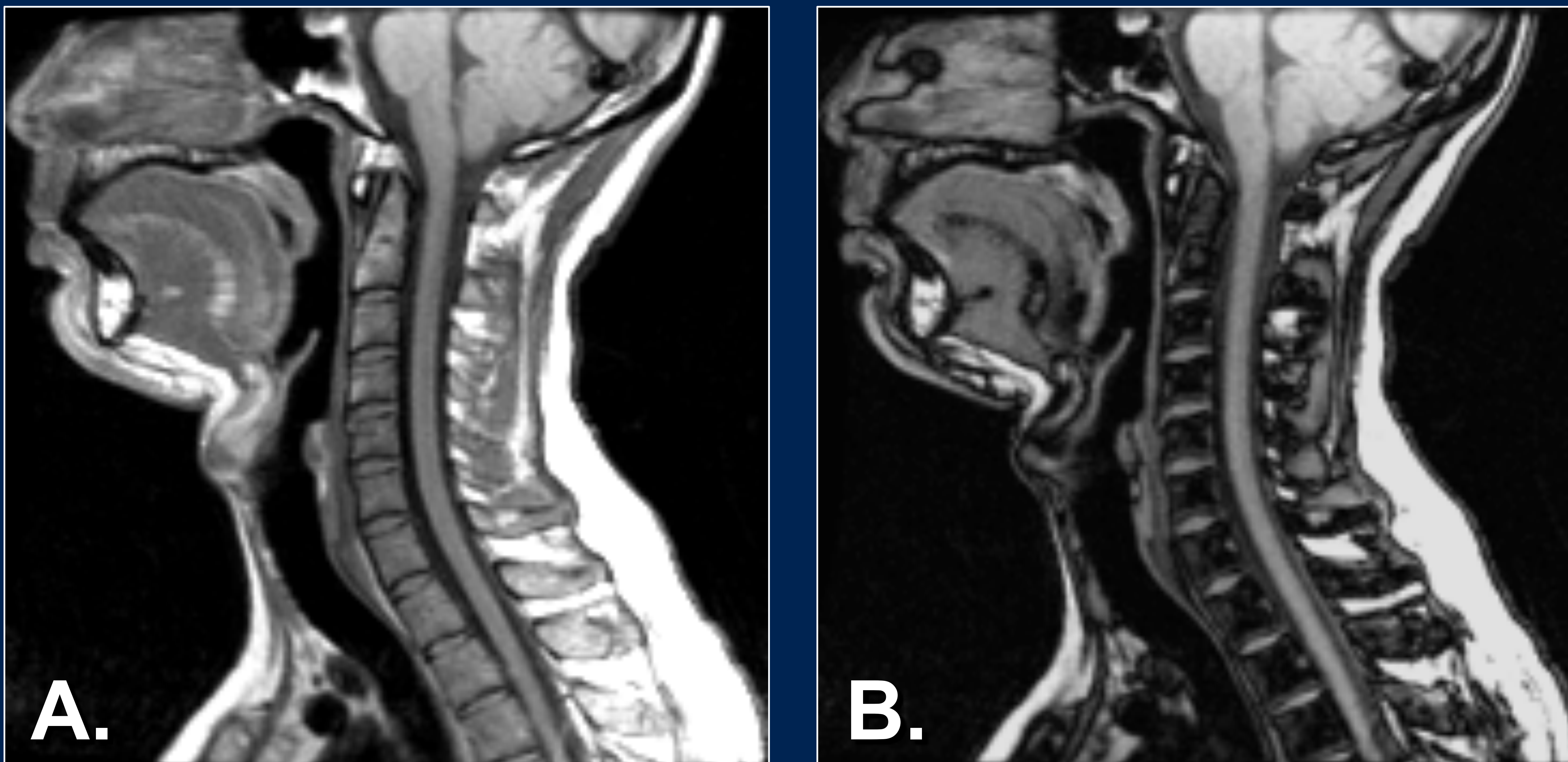
Gradient Echoes - True or False?

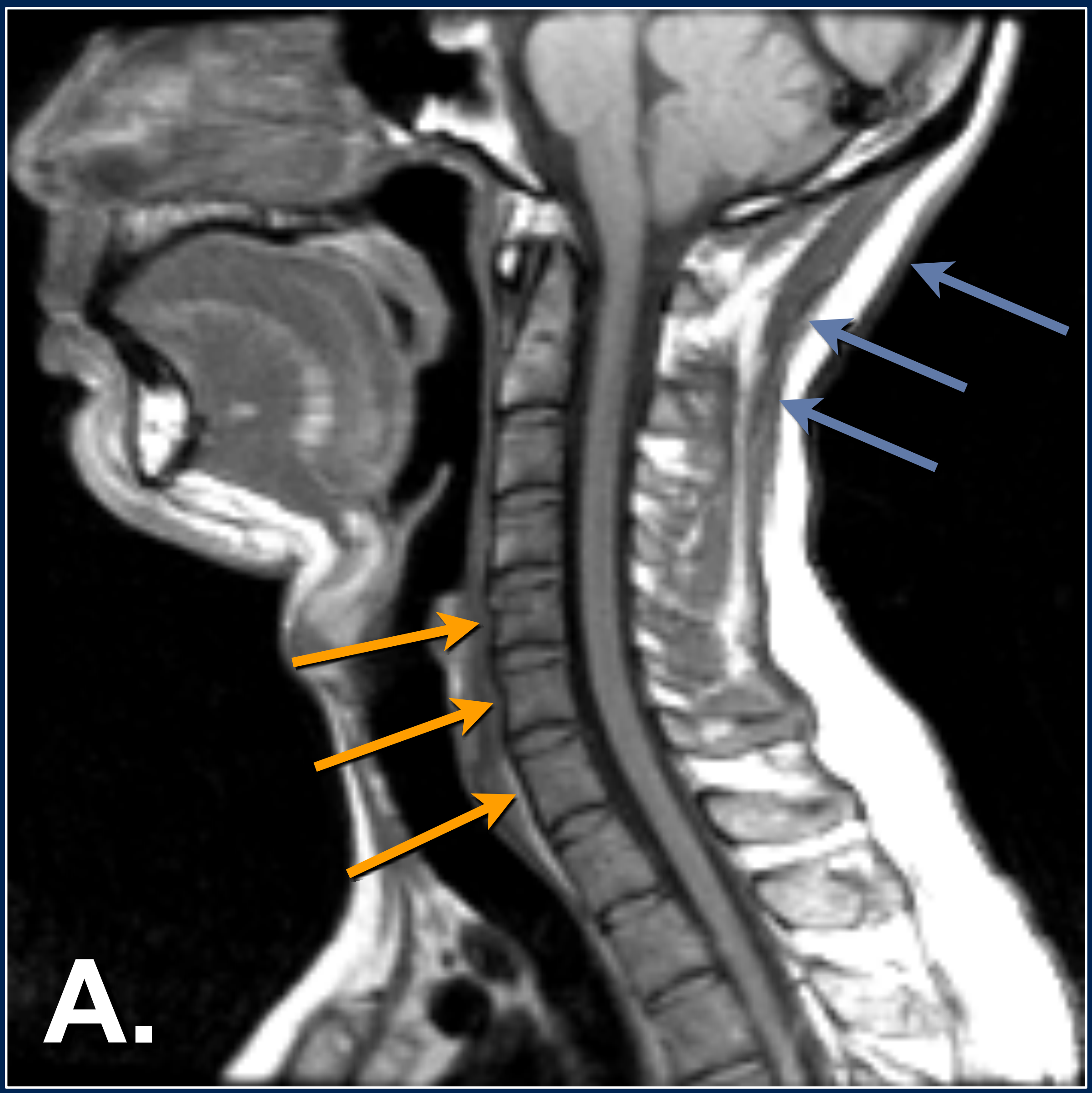
1. GRE and SE can both provide T2* contrast.
2. GRE and SE use the same TE and TR to produce a T1-weighted image.
3. SE is better for visualizing tissues with a very short T2 because of the refocusing pulses.
4. In GRE higher flip angles always produce brighter images.

Which image is the in-phase image?

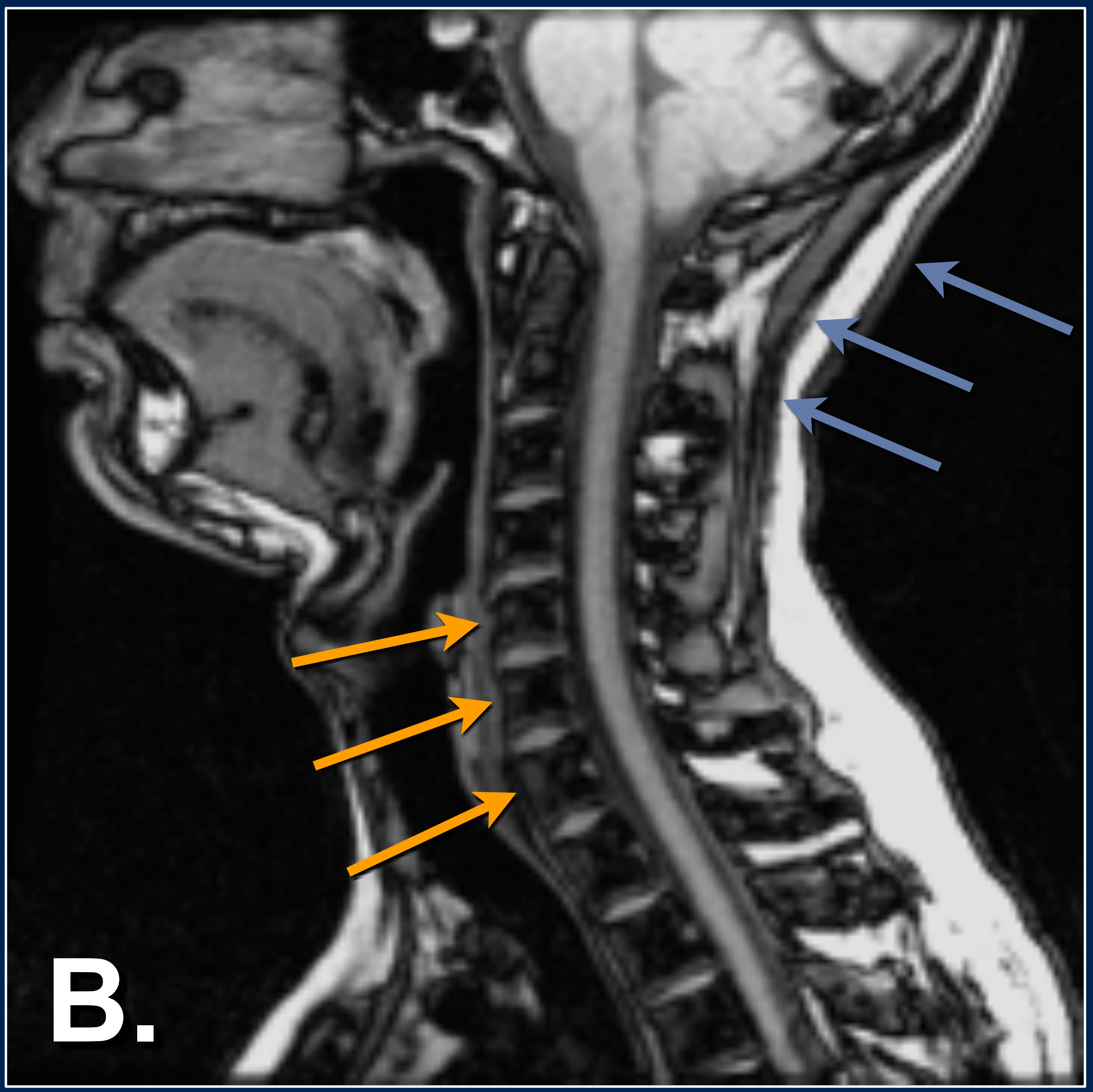


Images Courtesy of Scott Reeder

Which image is the in-phase image?



In-Phase



Opposed-Phase

Images Courtesy of Scott Reeder

Gradient Echoes - True or False?

1. Fat and water precess at frequencies that are >1000Hz different.
2. Fat and water are always out of phase.
3. Fat and water destructively interfere when they are in phase.
4. In-flowing spins are bright because they “see” hundreds of excitation pulses.

Questions?

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