Imaging Sequences III

M219 - Principles and Applications of MRI

Kyung Sung, Ph.D.

2/28/2024

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, Weds 4-6pm
- Office hours, Fridays 10-12pm

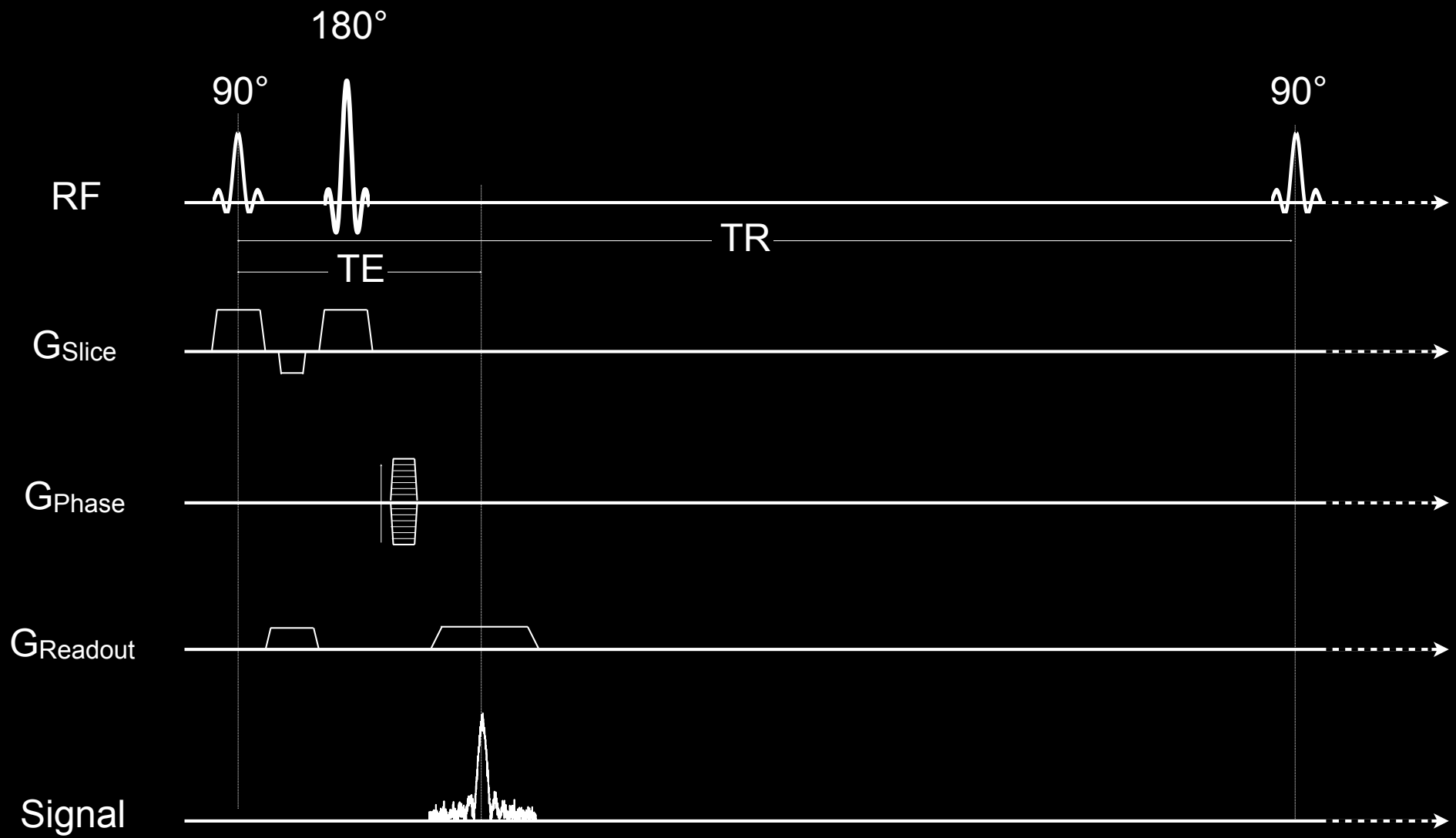
Turbo Spin Echo (TSE) / Fast Spin Echo (FSE)

How do we calculate scan time?

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

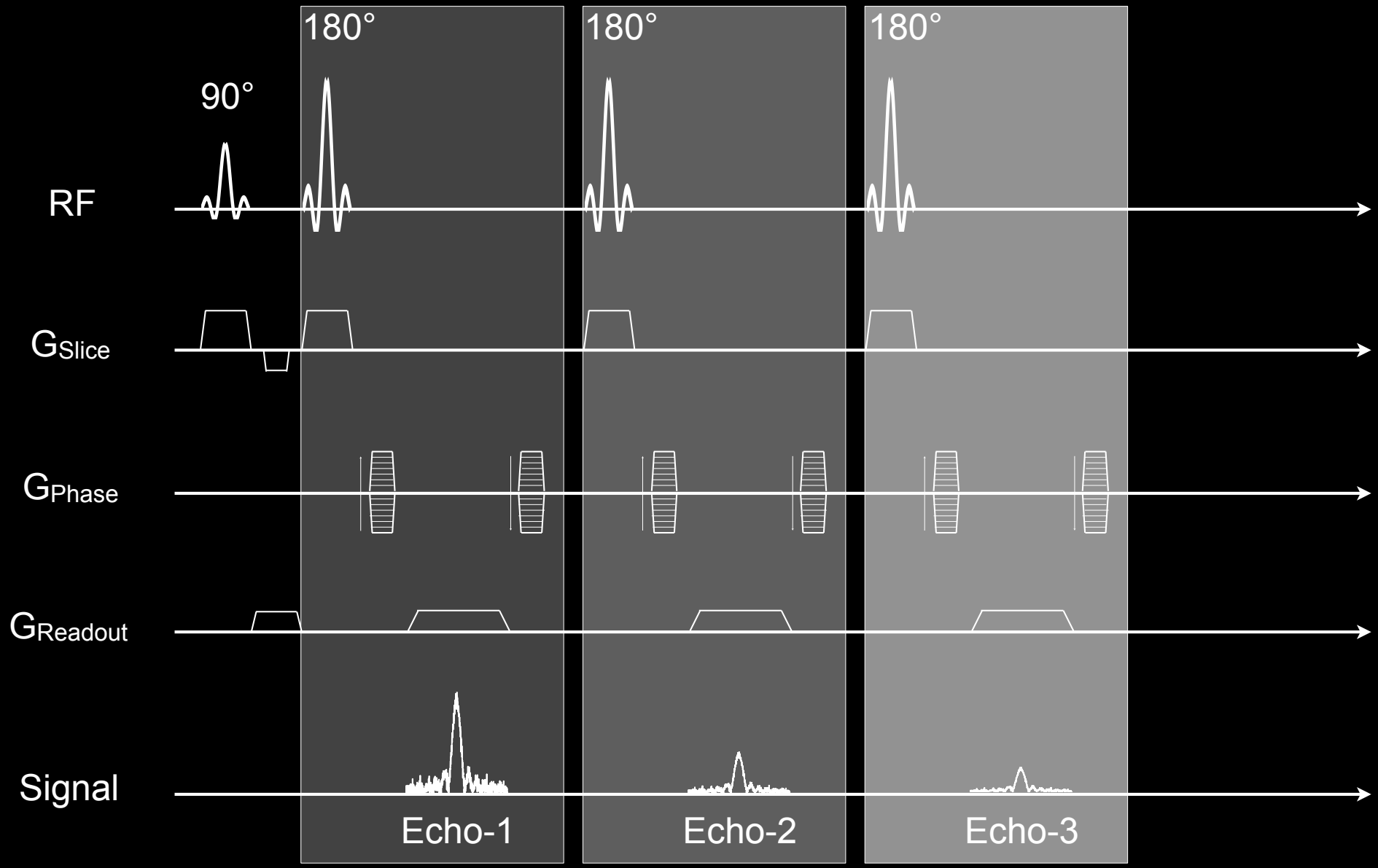
- T_{Scan}=1000ms•256•1=4:16 [mm:ss]
- Assumes one echo per TR.

Spin Echo

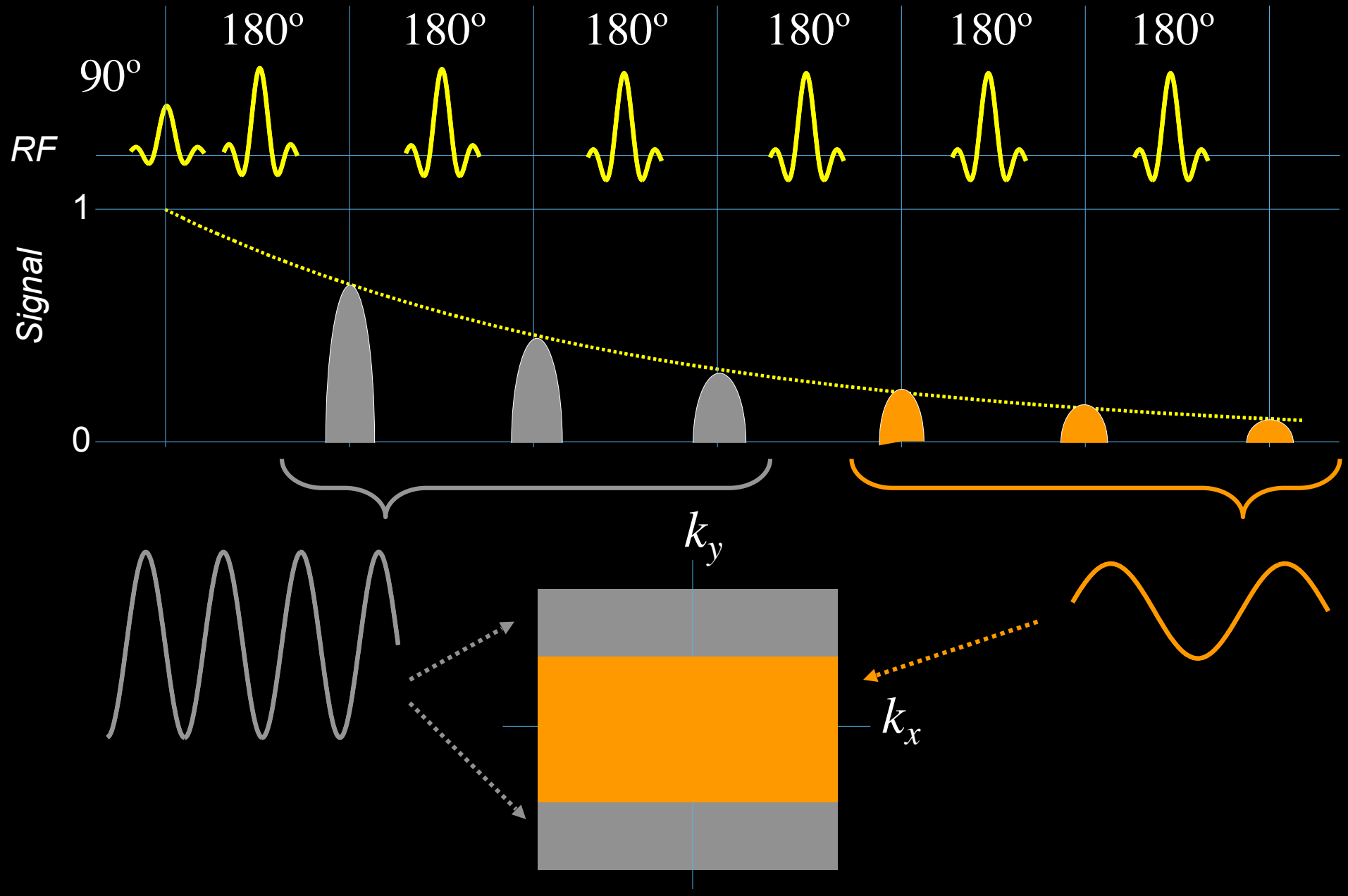


Spin Echo

Turbo Spin Echo (TSE)

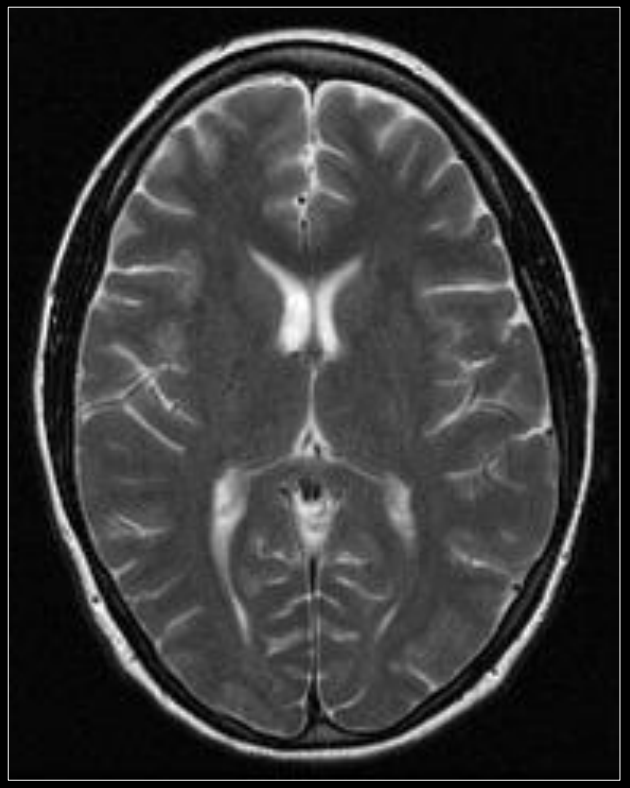


T_2-weighted TSE



Turbo Spin Echo vs. Spin Echo

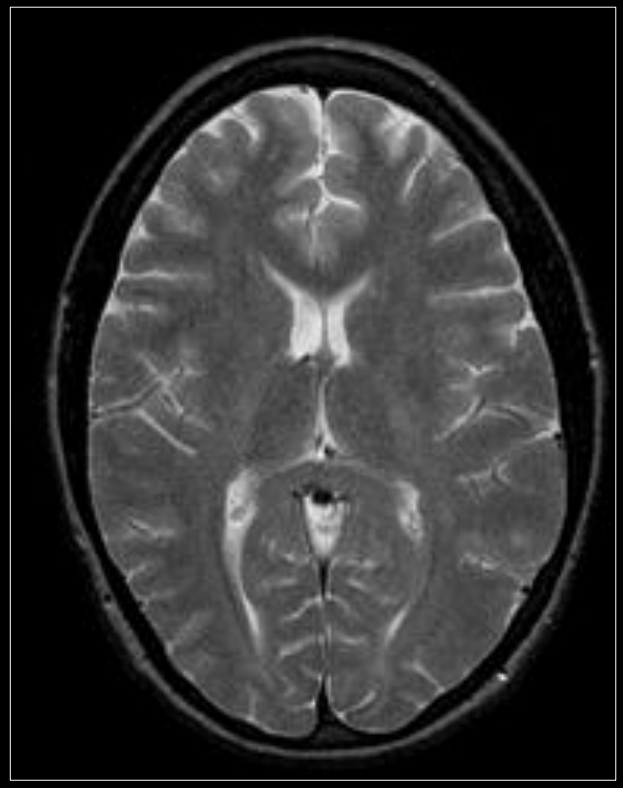
Fast Spin Echo



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.

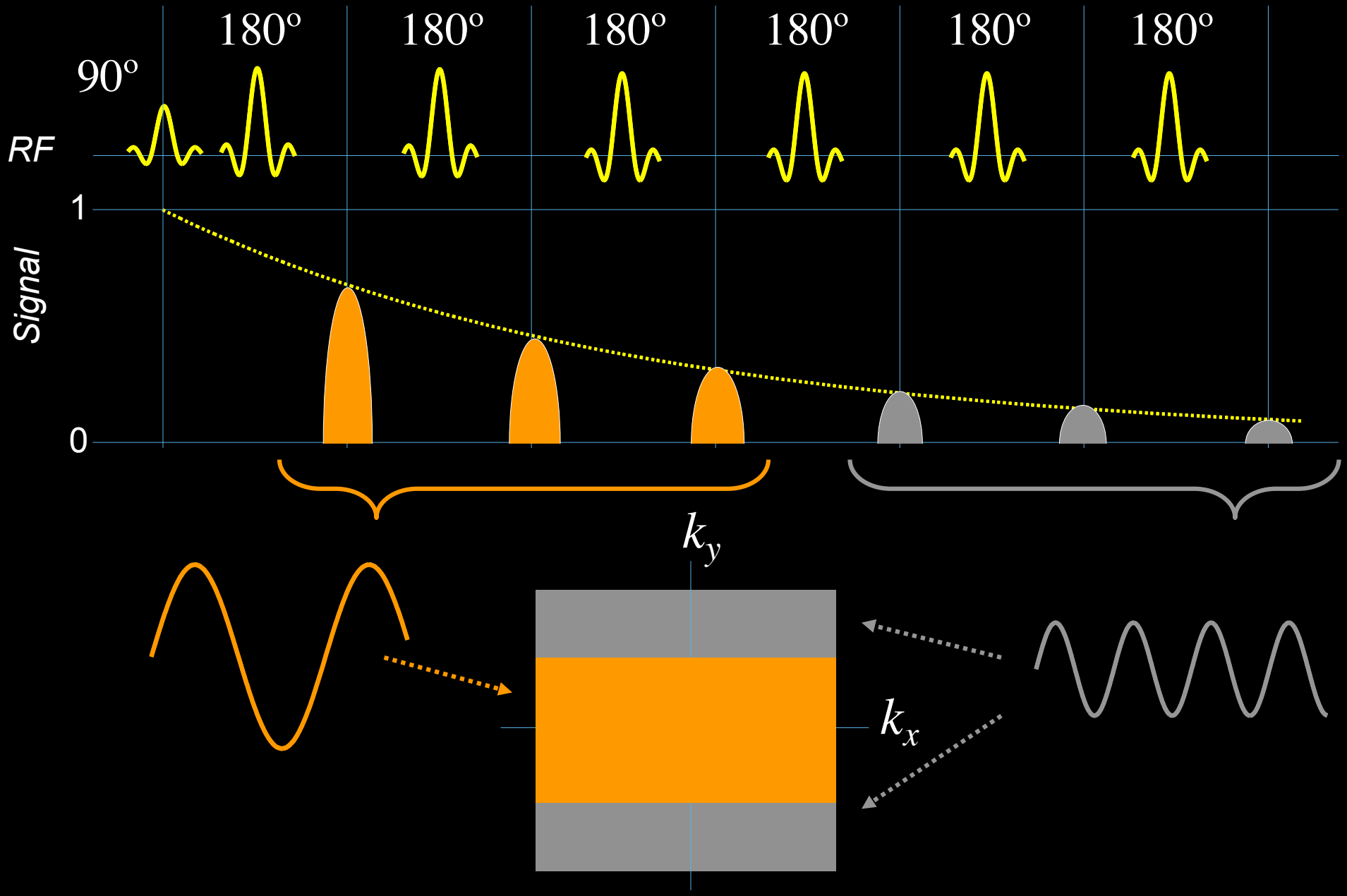
Spin Echo



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

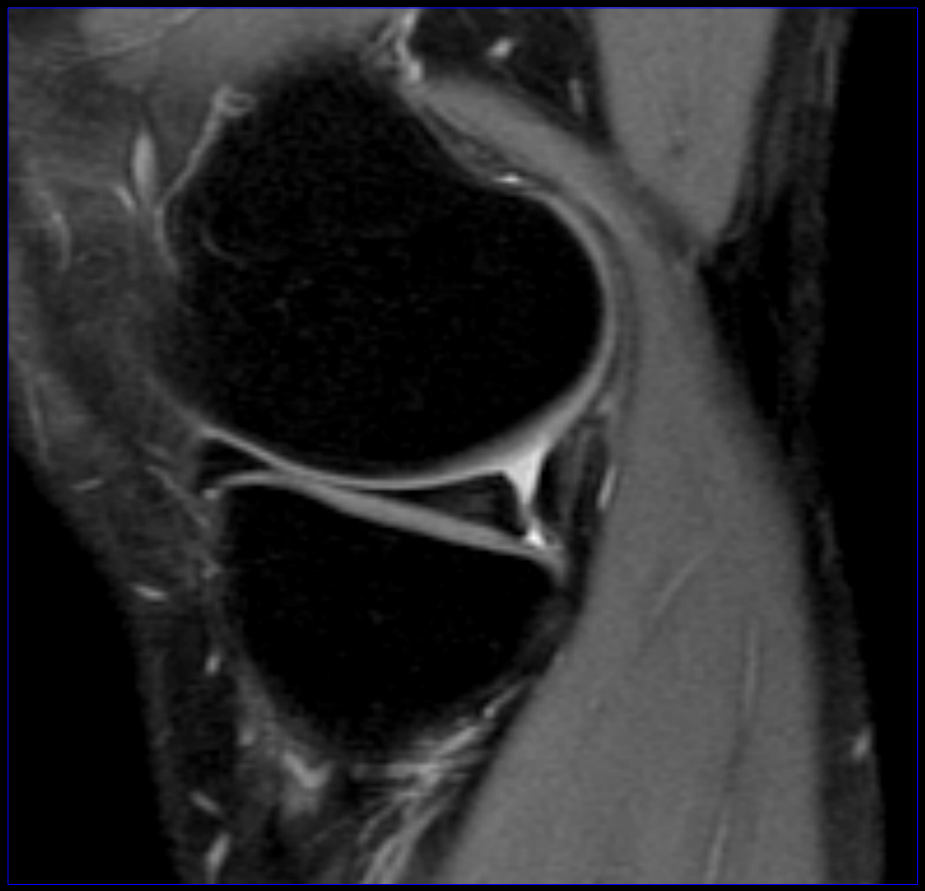
Images: Courtesy Frank Korosec

Proton Density Weighted TSE

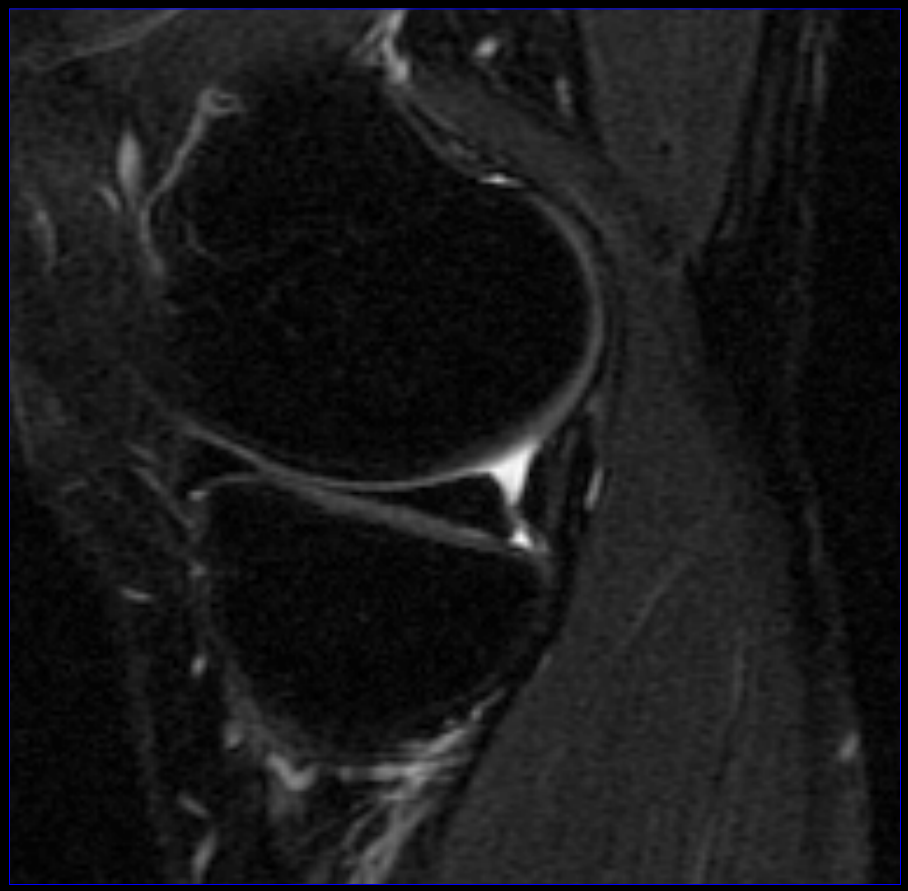


PD vs T_2-weighted TSE

Proton Density Weighted



T_2-weighted



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

Summary for TSE

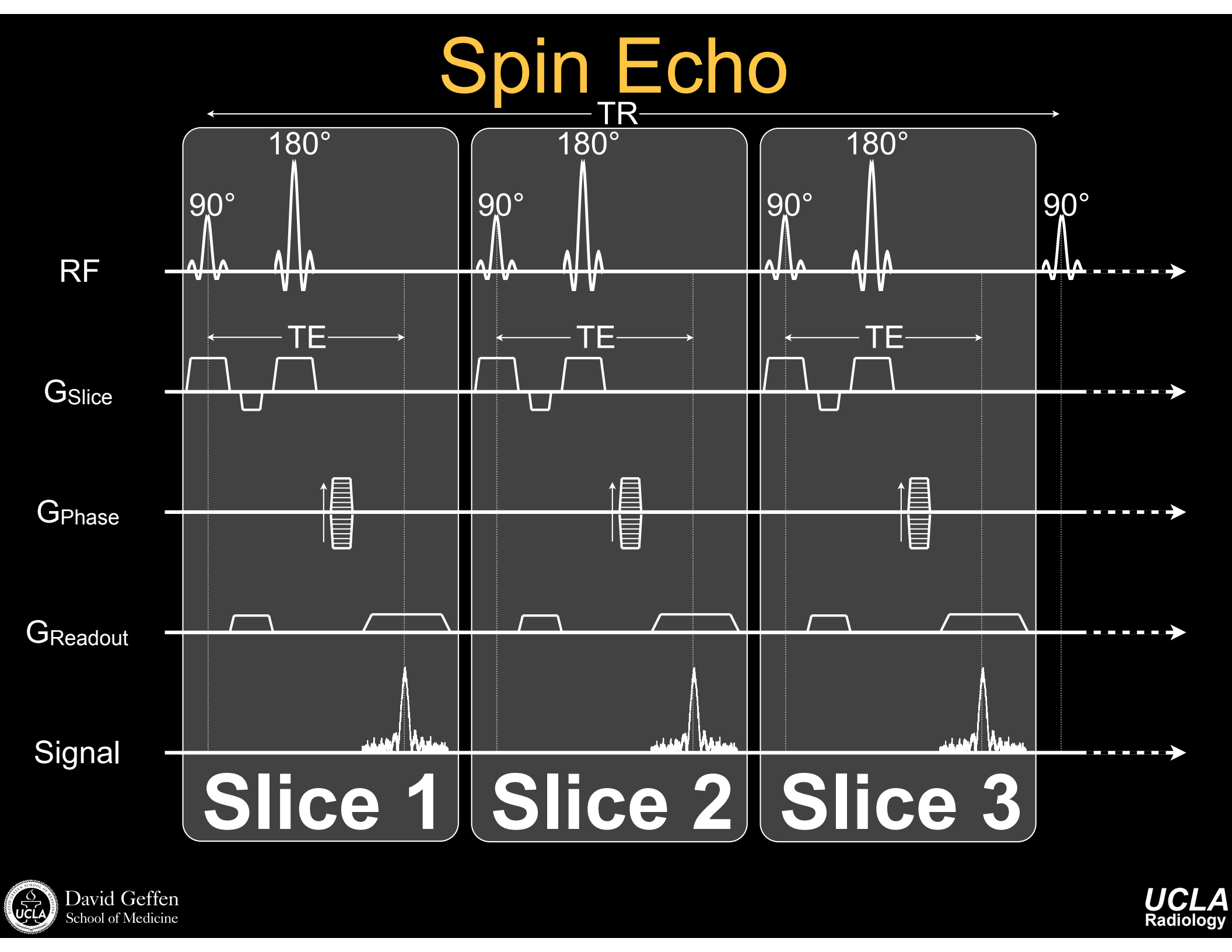
- Pros:
  - Fast, high SNR
  - Less sensitive to B0 inhomogneity
- Cons:
  - T2 weighting varies in k-space
  - RF power limits speed, particularly at 3T

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

2D Slice Interleaving

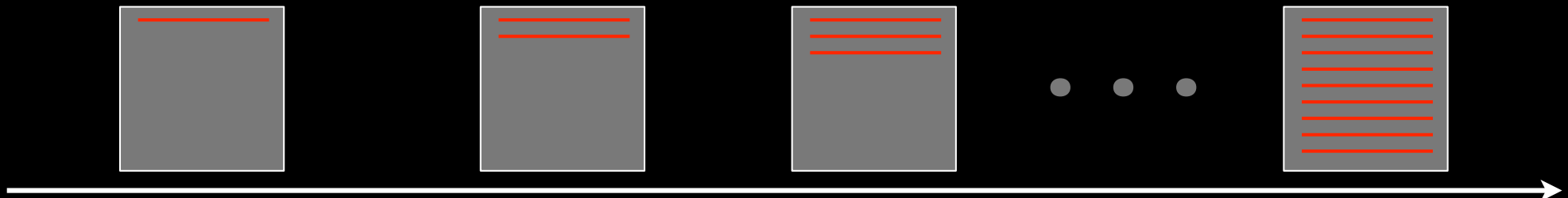
Spin Echo

Spin Echo


TR
180°
180°
180°
90°
90°
90°
90°
RF
TE
TE
TE
GSlice
GPhase
GReadout
Signal
Slice 1
Slice 2
Slice 3

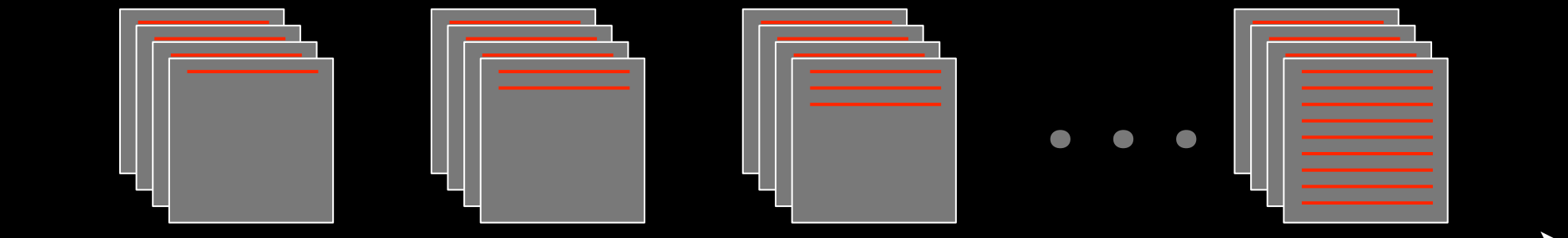
Slice Interleaving

Sequential 2D Imaging



Imaging Time = TR * N_{Ky} * N_{Slices}

Slice Interleaved 2D Imaging

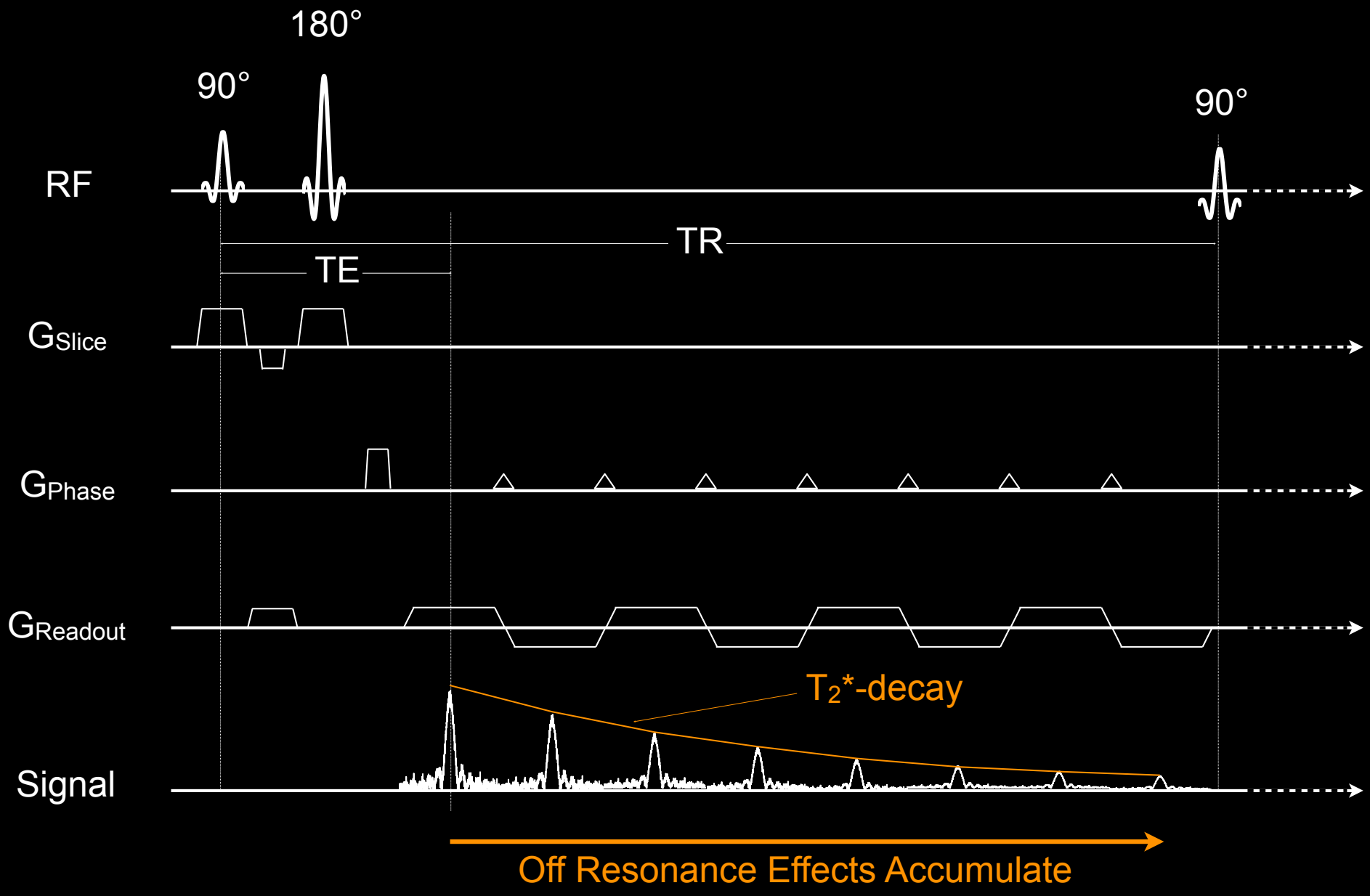


Imaging Time = TR * N_{Ky} * N_{Slices} / $N_{Interleaves}$

2D Slice Interleaving

- **Advantages**
  - **Accelerate imaging many times**
- **Disadvantages**
  - **Acceleration limited by**
    - **$N_{Interleaves}$~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**

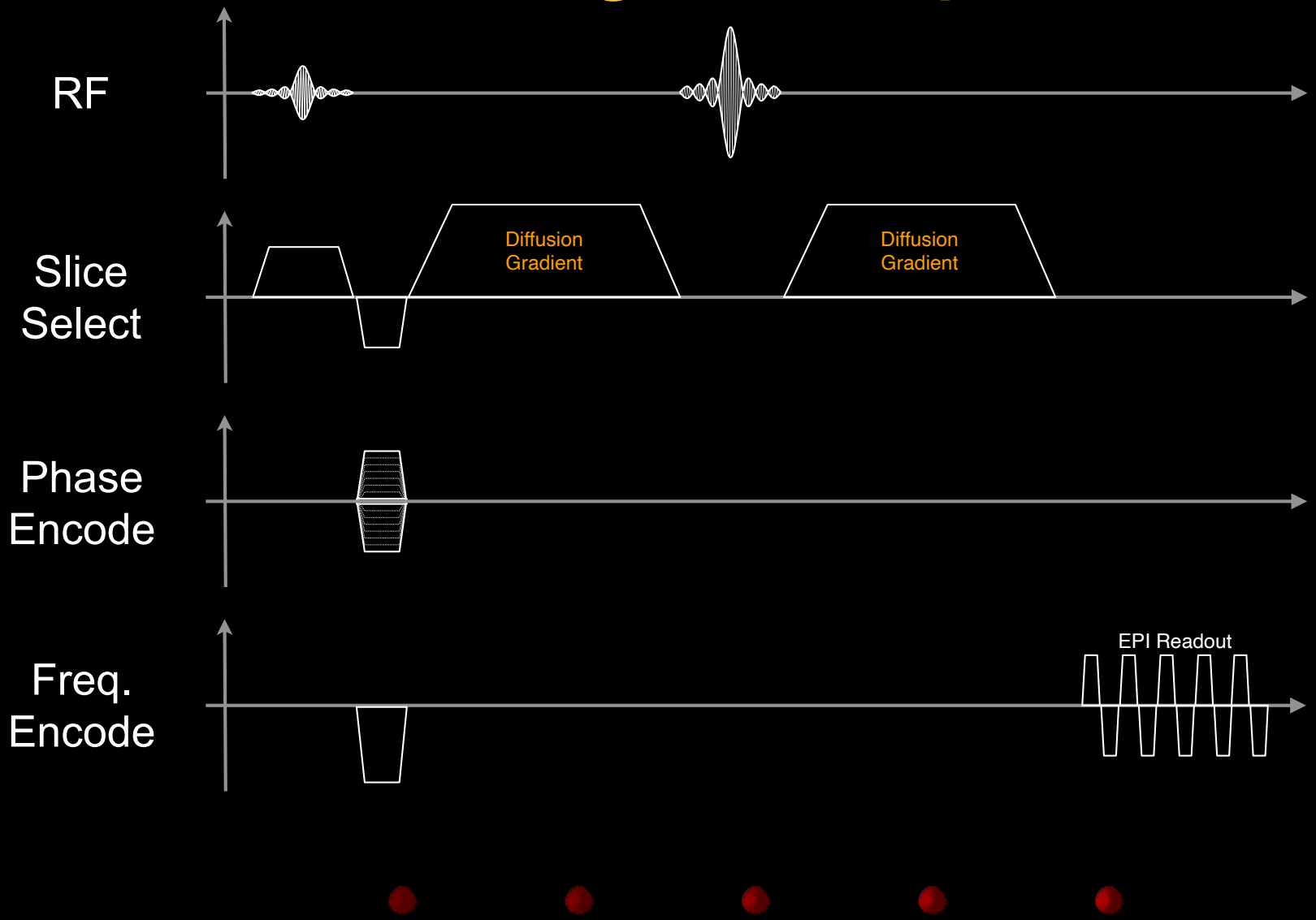
Spin Echo EPI



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?

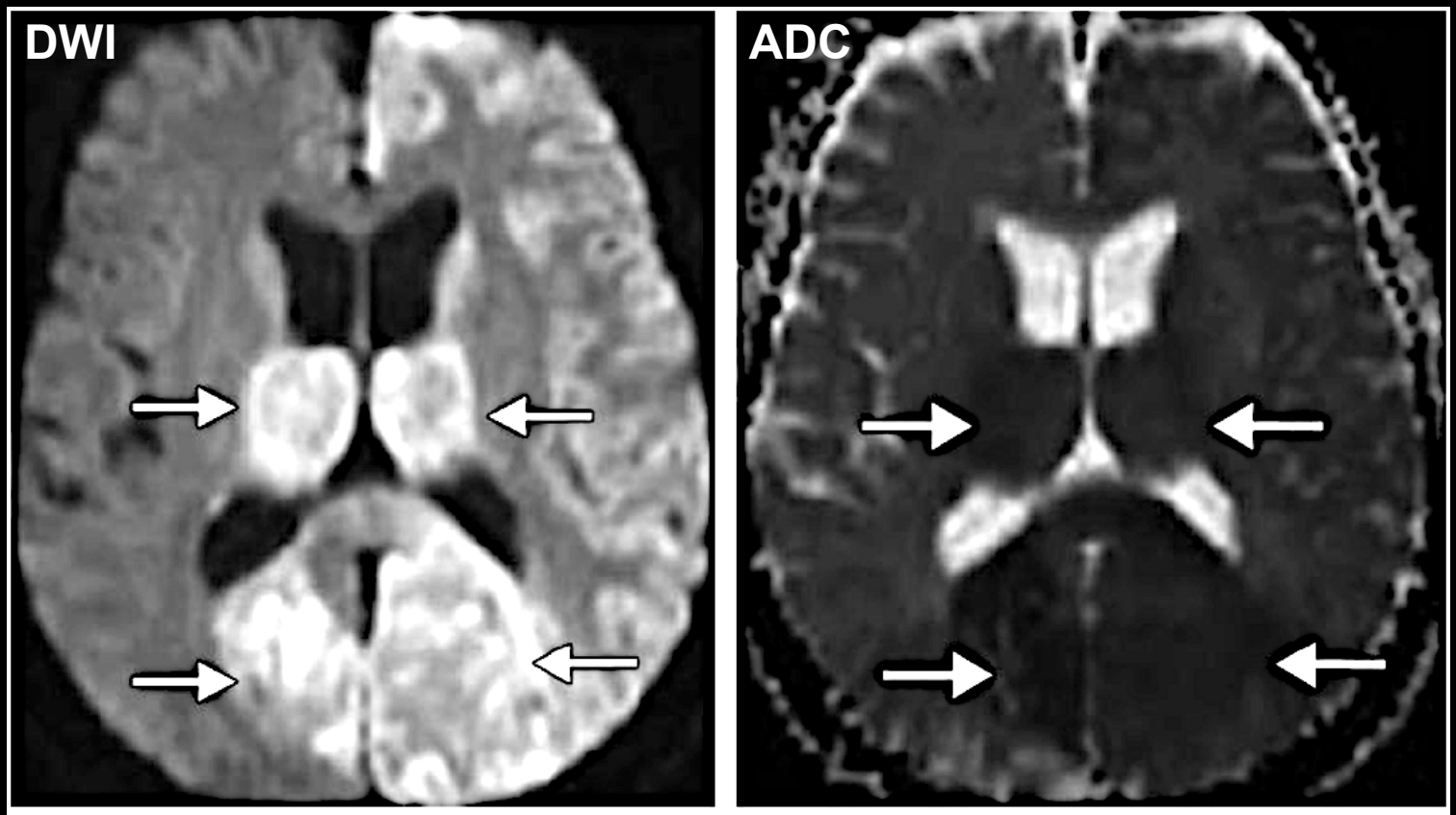
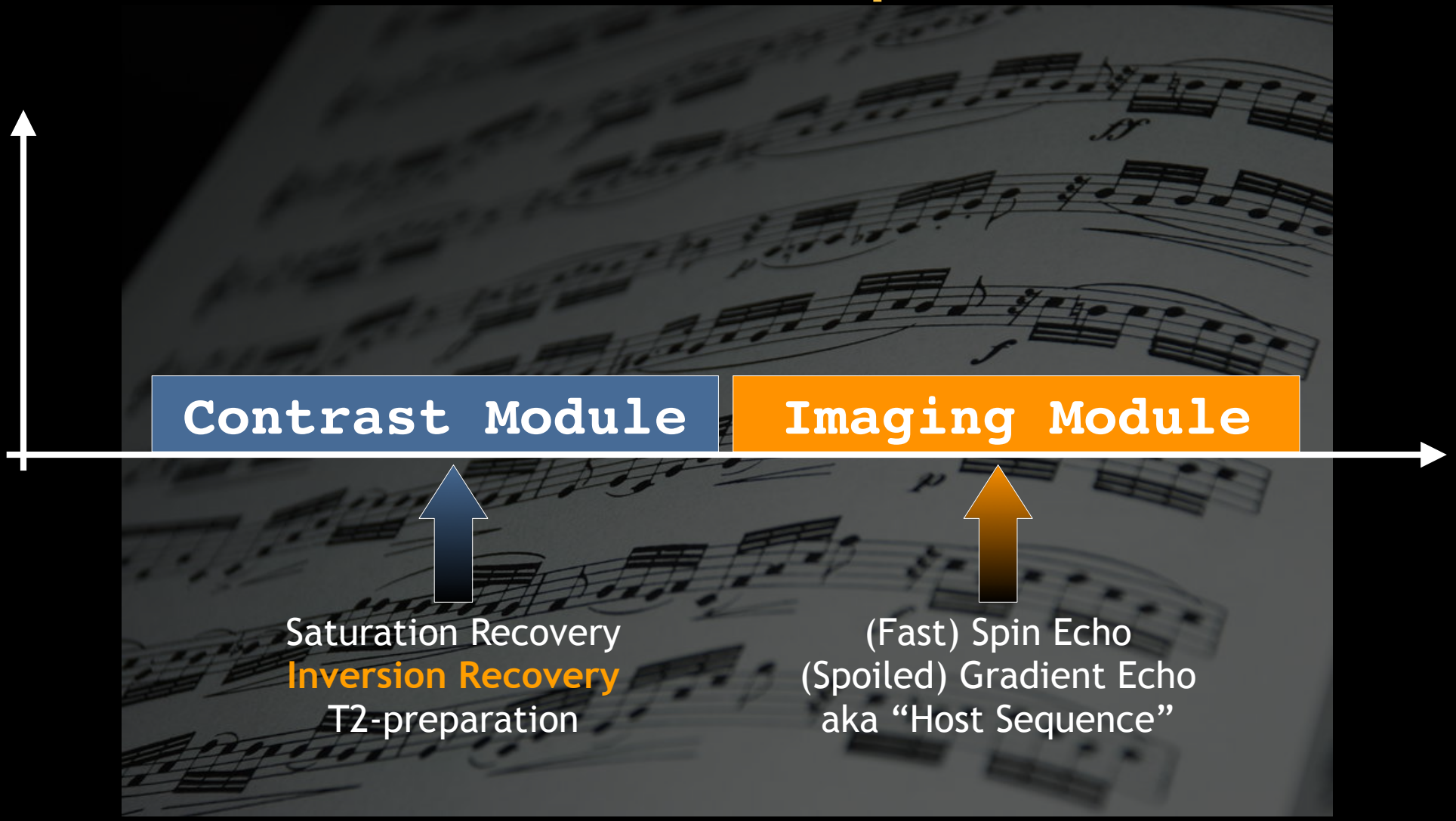


Figure 15. Acute stroke of the posterior circulation in a 77-year-old man. **(a)** Diffusion-weighted MR image (b = 1000 sec/mm^2) shows bilateral areas of increased signal intensity (arrows) in the thalami and occipital lobes. **(b)** ADC map shows decreased ADC values in the same areas (arrows). These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

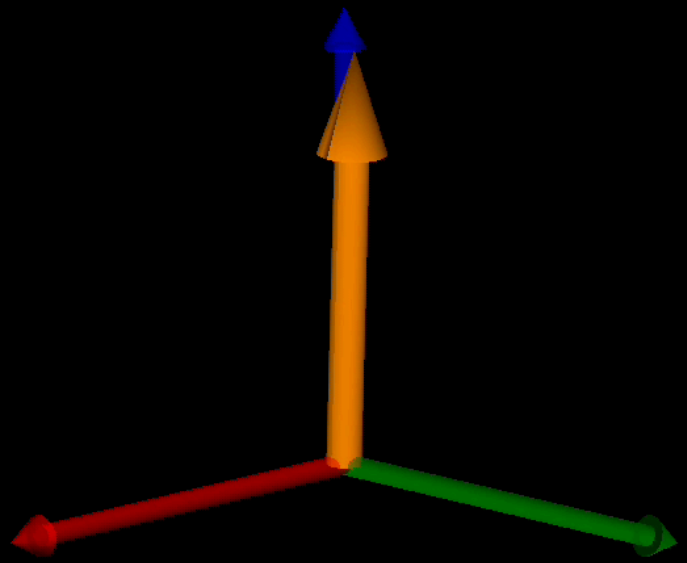
Srinivasan A, *et al*. State-of-the-art imaging of acute stroke. Radiographics 2006;26 Suppl 1:S75-95.

Inversion Recovery Spin Echo MRI

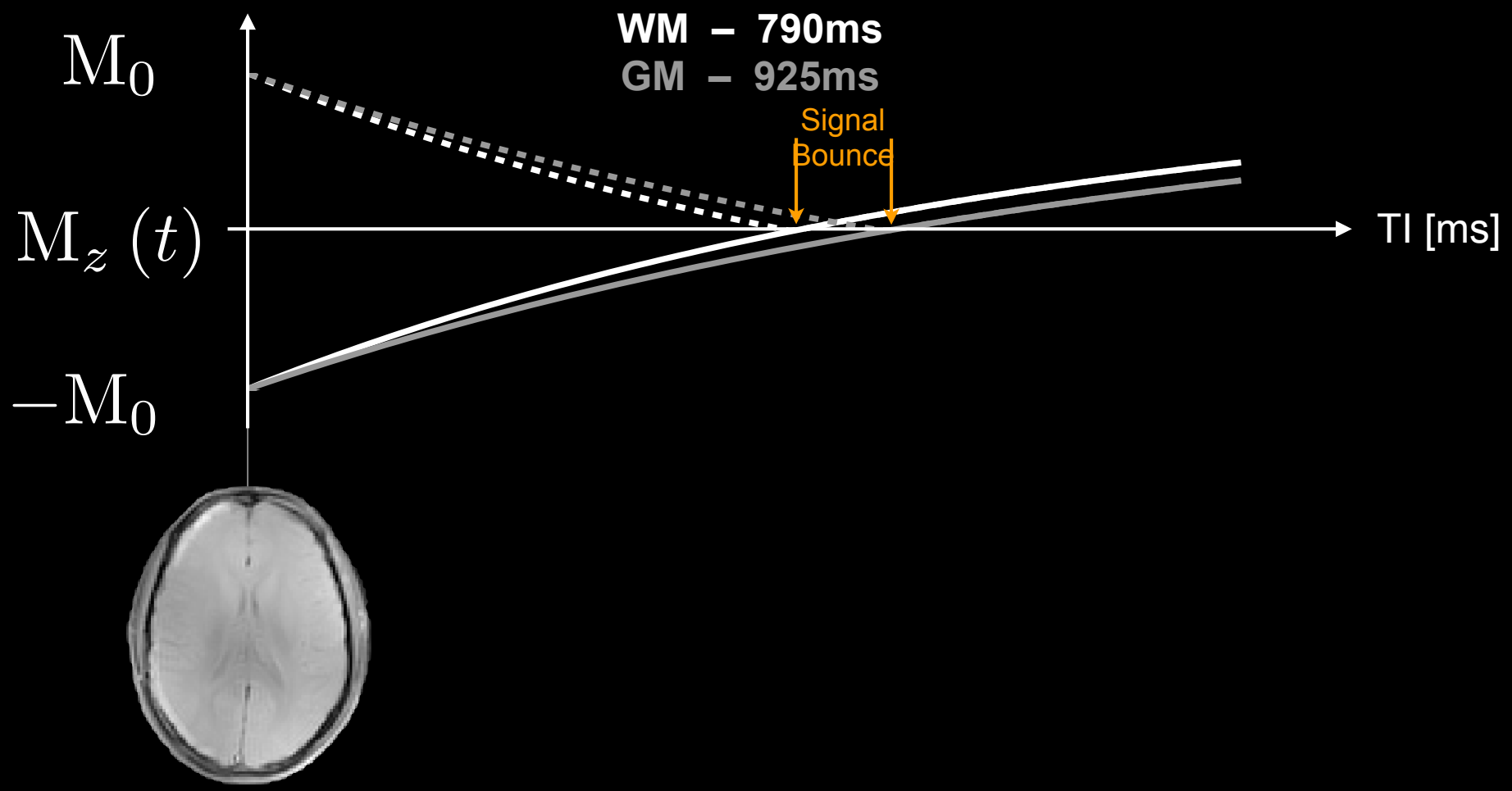
MRI Pulse Sequences



What is an inversion pulse?



Inversion Recovery

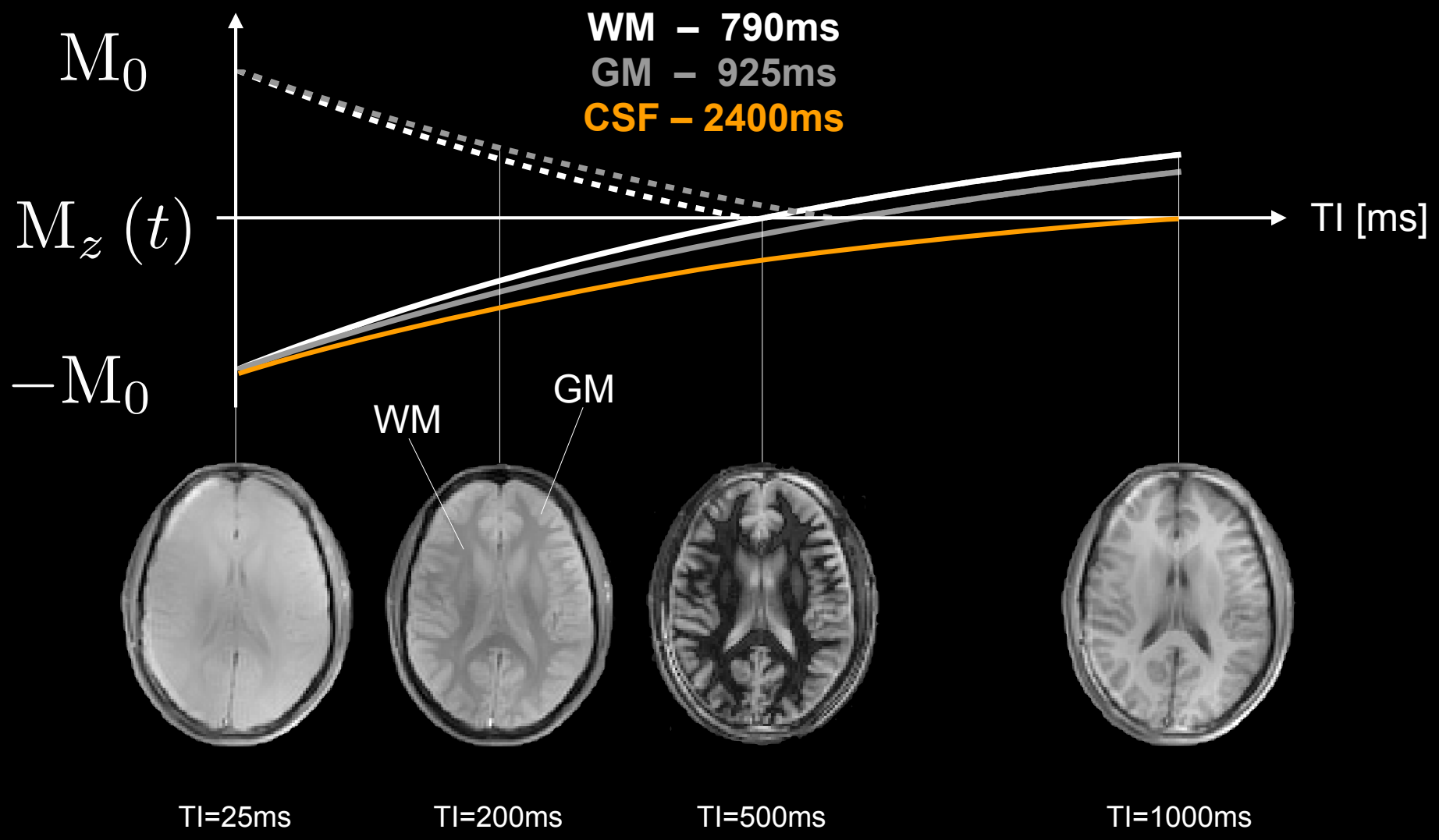


TI=25ms

MRI images are typically ***magnitude*** (absolute value) images.

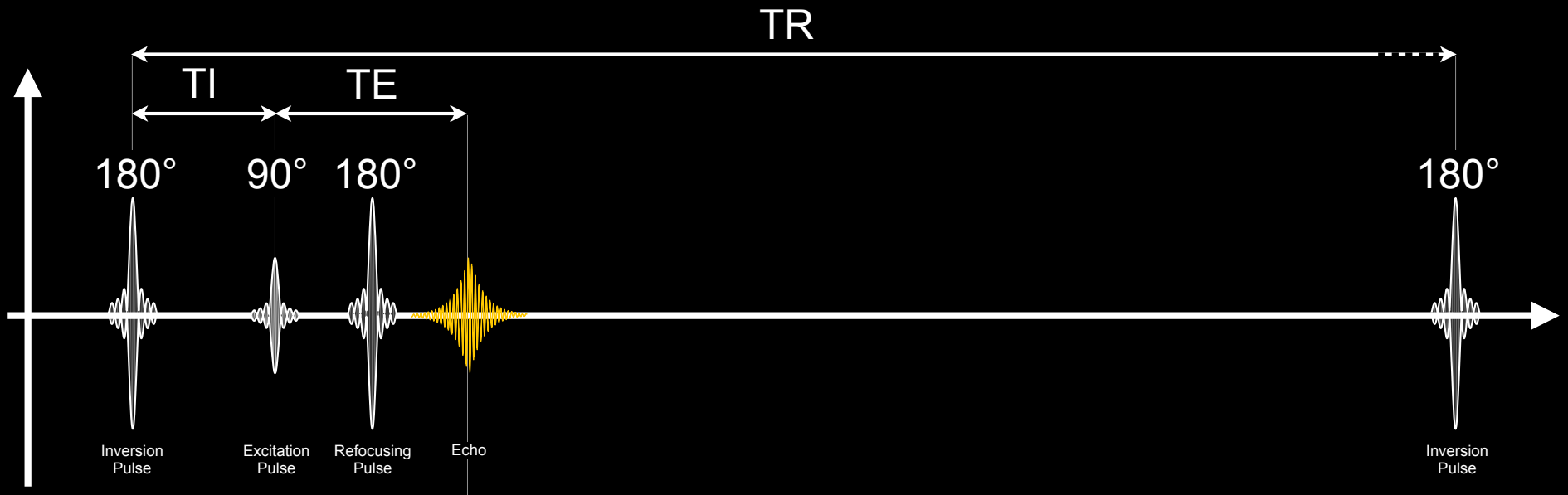
Spin Echo with TE=12ms, TR=2000ms

Inversion Recovery



Spin Echo with TE=12ms, TR=2000ms

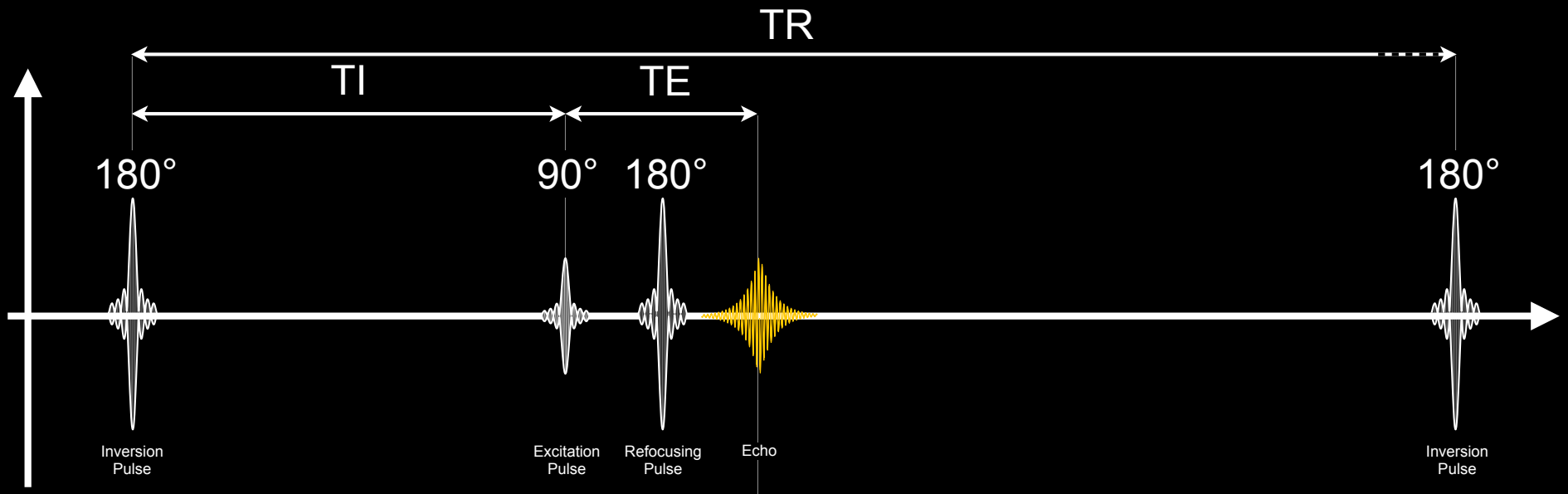
Inversion Recovery + Spin Echo

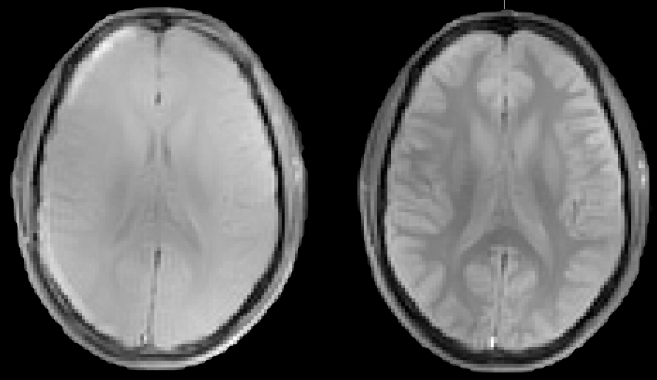


TI=25ms
TE=12ms

Short TI coupled with short TE and Long TR is proton density weighted.

Inversion Recovery + Spin Echo



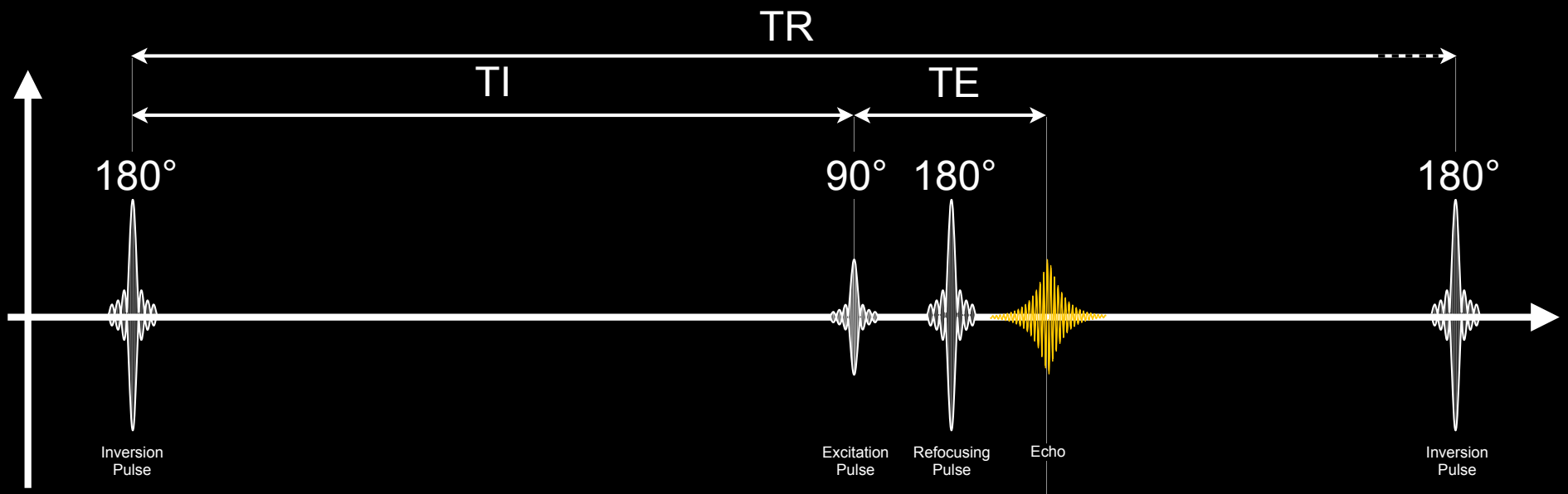


TI=25ms
TE=12ms

TI=200ms
TE=12ms

The TI is made longer by “playing” the 90° excitation pulse later.

Inversion Recovery + Spin Echo



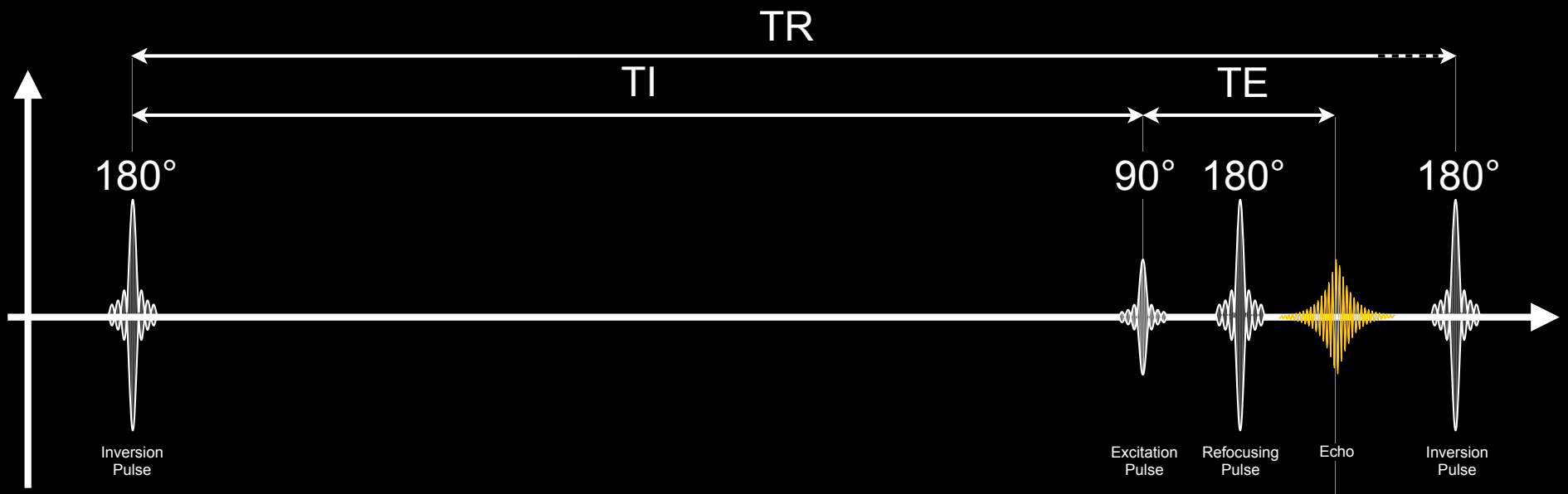
TI=25ms
TE=12ms

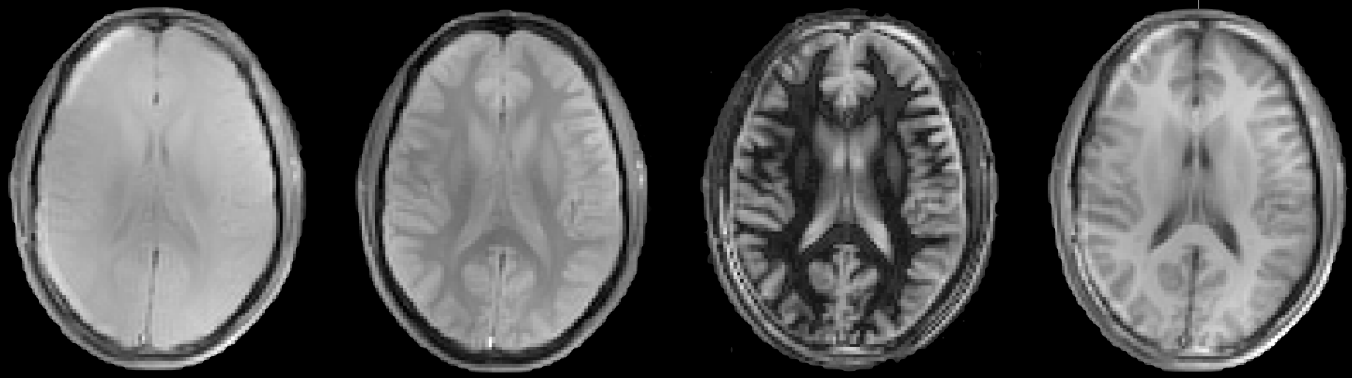
TI=200ms
TE=12ms

TI=500ms
TE=12ms

Longer TIs emphasize T_1-weighting.

Inversion Recovery + Spin Echo





TI=25ms
TE=12ms

TI=200ms
TE=12ms

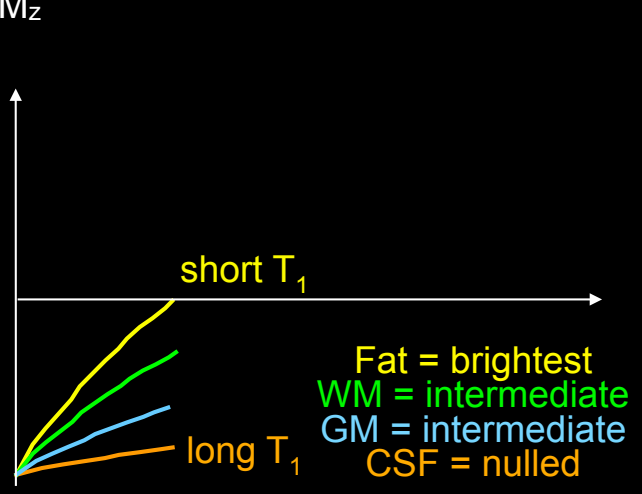
TI=500ms
TE=12ms

TI=1000ms
TE=12ms

Really long TIs can null CSF (FLAIR).

Short Tau Inversion Recovery (STIR)

- **T1 (or T2-weighted) with nulled fat**
  - **Intermediate TR (2,000ms) adds T1-weighting**
  - **Short TE (60ms) limits T2-weighting**
  - **Long TI (120 to 170ms) nulls fat**
- **Applications**: edema, fat sat, MSK,…

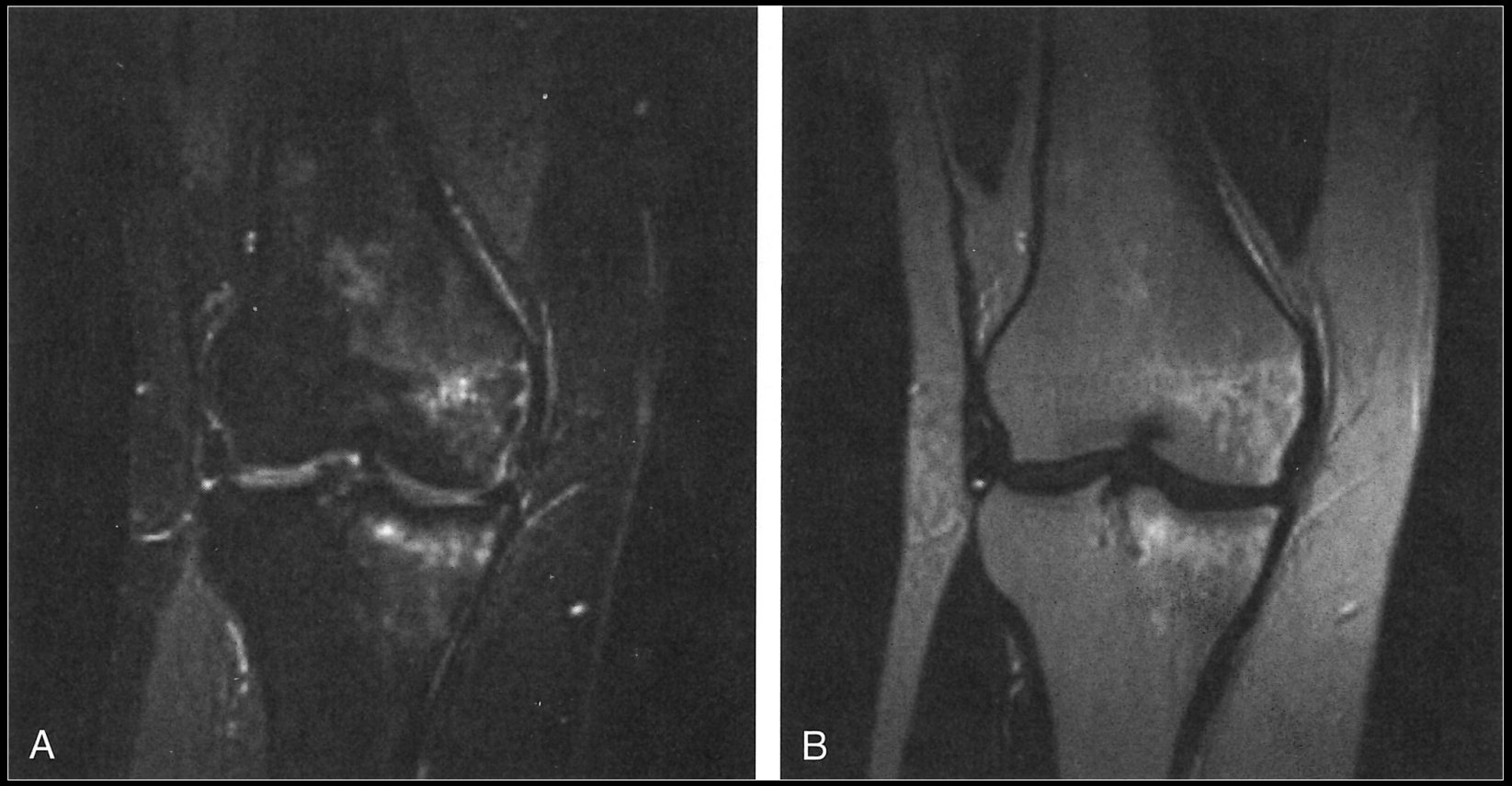



Sagittal T2-weighted Spin Echo


Sagittal T2-weighted STIR

Images Courtesy of Frank Korosec & radiopaedia.org

STIR vs. T2-weighted Fast Spin Echo

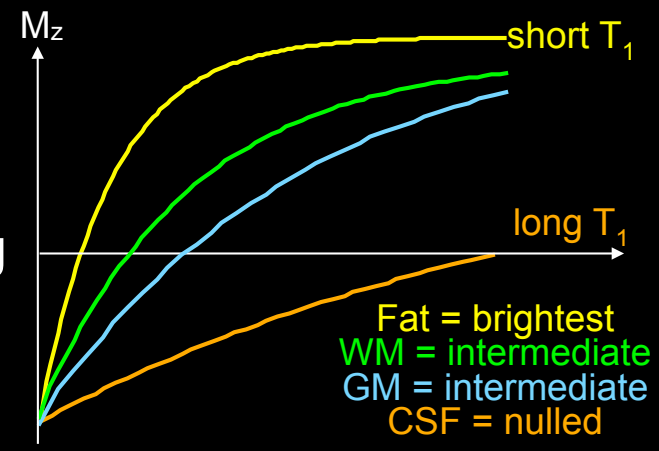


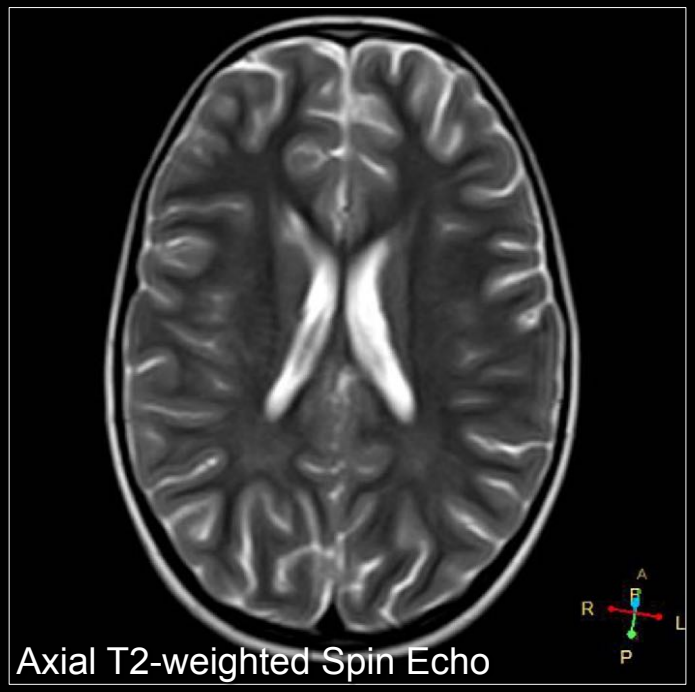
(A) Coronal **STIR** of the knee. **High-signal marrow edema** is identified in the middle of the tibial plateau and medial femoral condyle. Fraying of the lateral meniscus free edge represents a degenerative radial tear. (B) Coronal **T2-weighted FSE** at the same position. The **edema is largely obscured** by the high-signal-intensity marrow.

Duke Review of MRI Principles, p. 88.

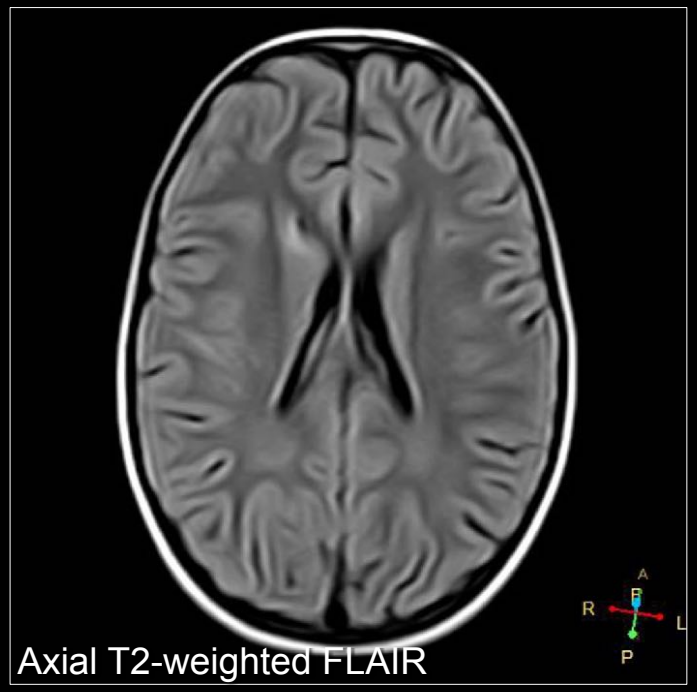
FLuid Attenuated Inversion Recovery (FLAIR)

- **T2-weighted image with nulled CSF**
  - **Long TR (11,000ms) limits T1-weighting**
  - **Long TE (145ms) emphasizes T2-weighting**
  - **Long TI (2200ms) nulls CSF**
- **Applications**: stroke, MS, cancer,…





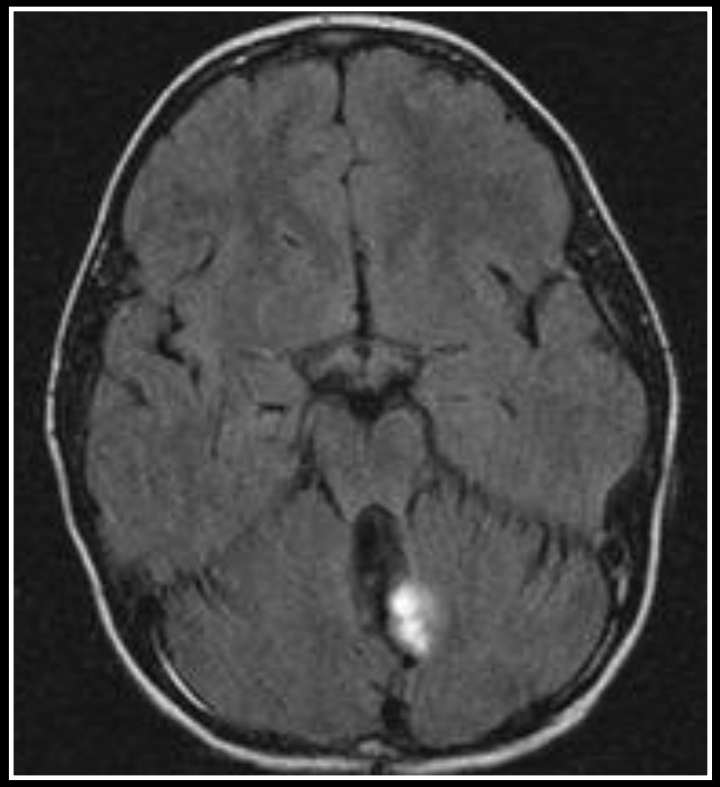
Axial T2-weighted Spin Echo



Axial T2-weighted FLAIR

FLAIR attenuates CSF and improves lesion conspicuity.

FLAIR vs. T2-weighted Fast Spin Echo



T2 Flair (TR = 8000 ms, TE = 127 ms)

Fast Spin Echo

FLAIR attenuates CSF and improves lesion conspicuity.

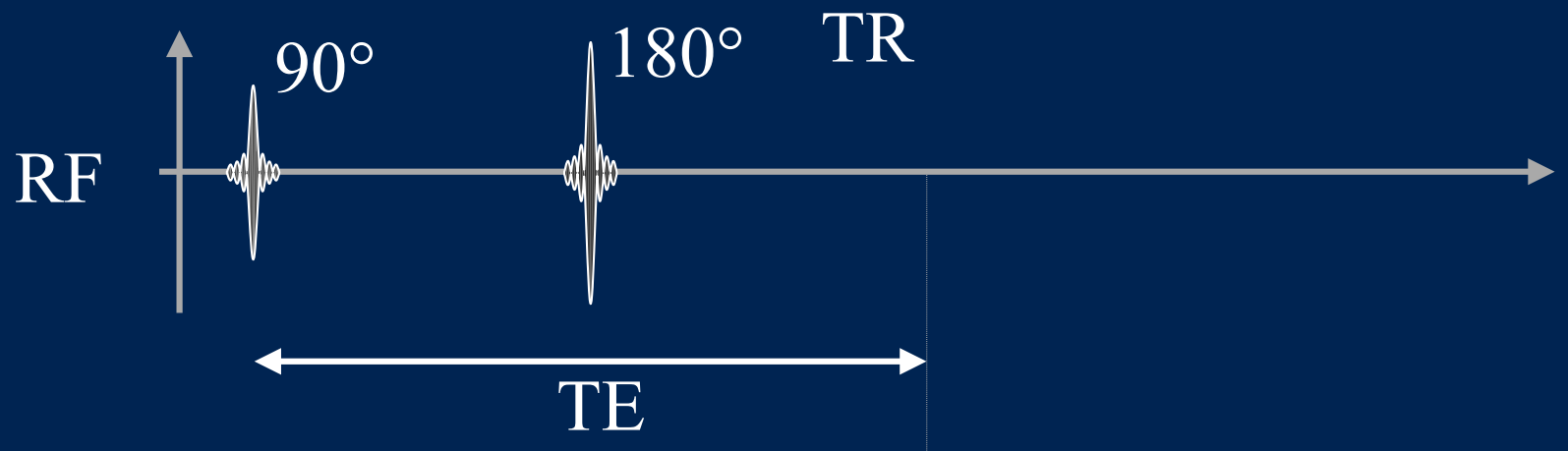
Images Courtesy of Frank Korosec

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

Multi-Echo Imaging - True or False?

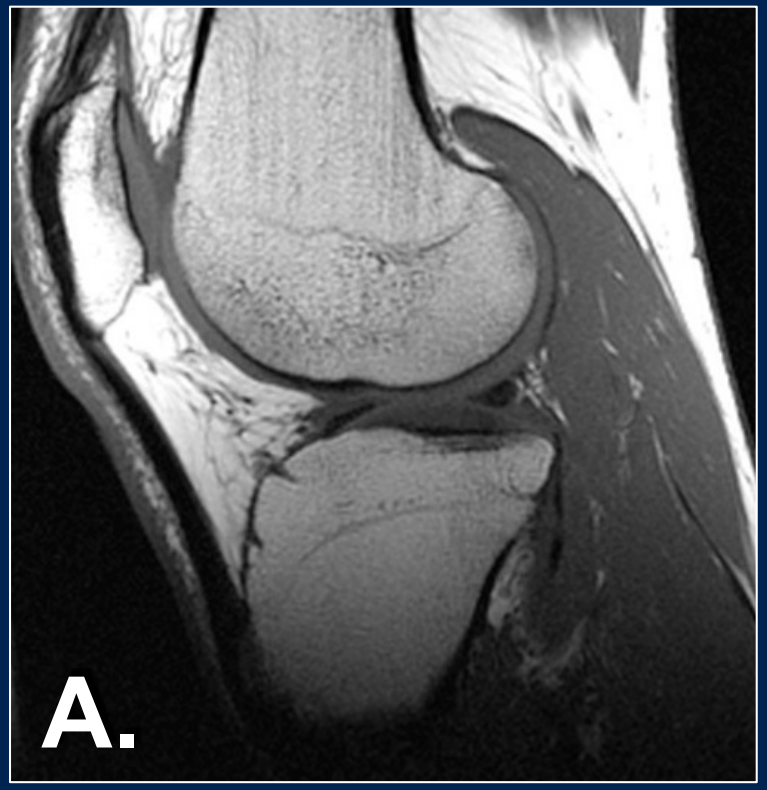
1. Multi-echo imaging can decrease scan times by 2x or more

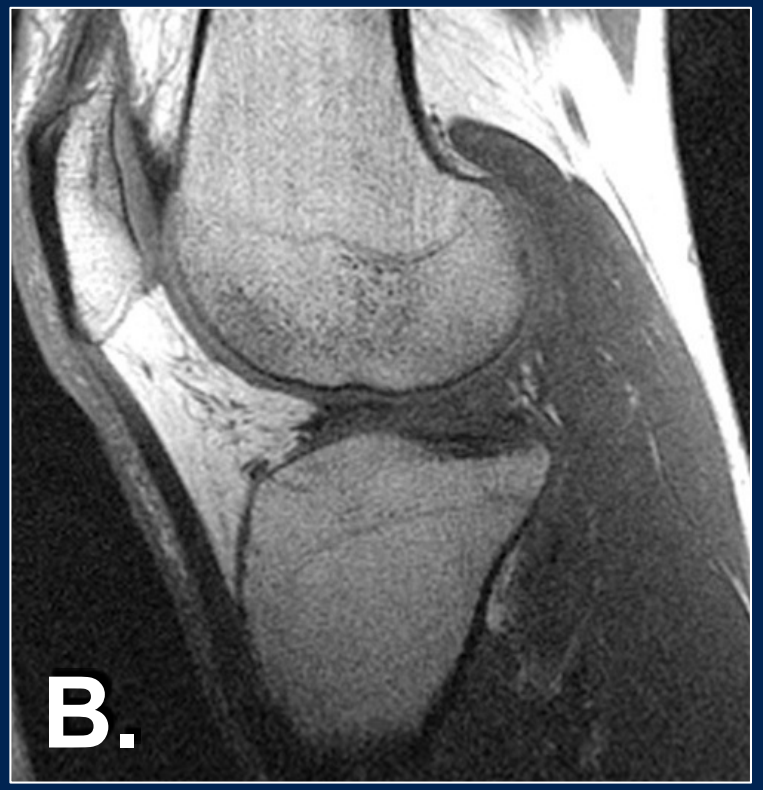
2. Turbo spin echo is excellent for fast T2-weighted imaging

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

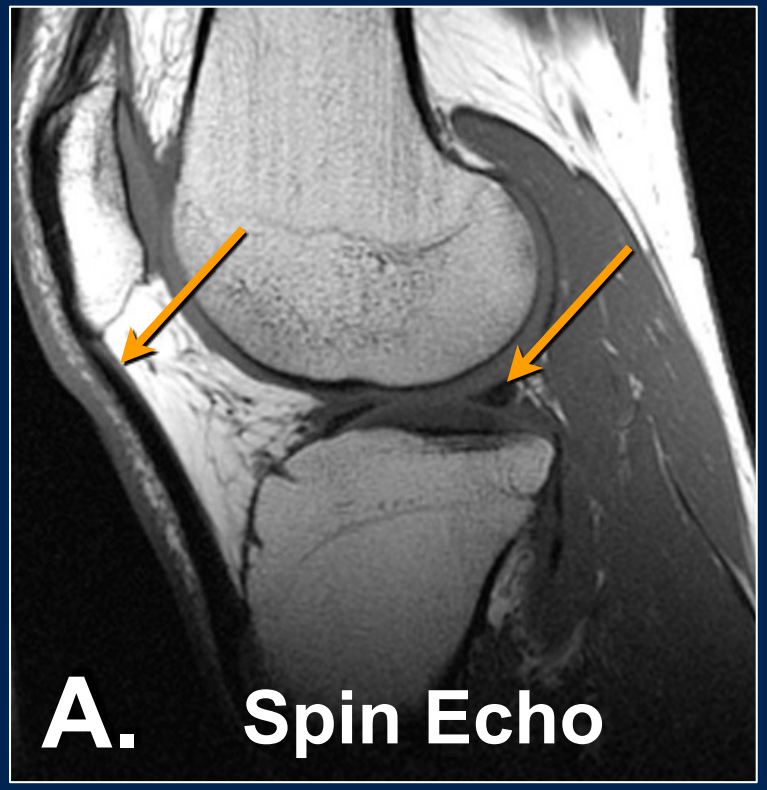


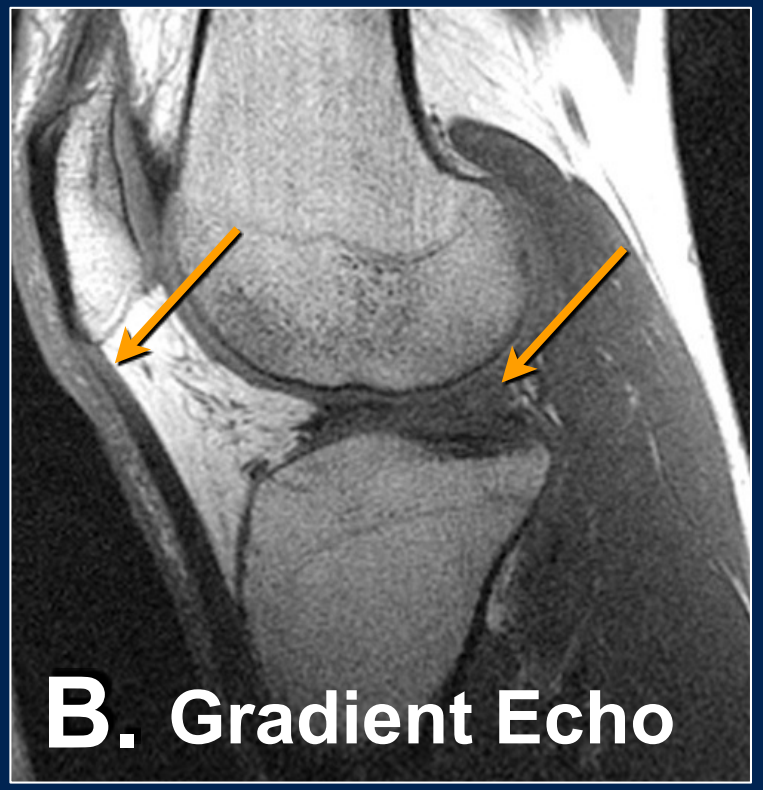


Which image is a gradient echo image?

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.

In Gradient Echo Imaging Always...

A. Use the highest available flip angle.

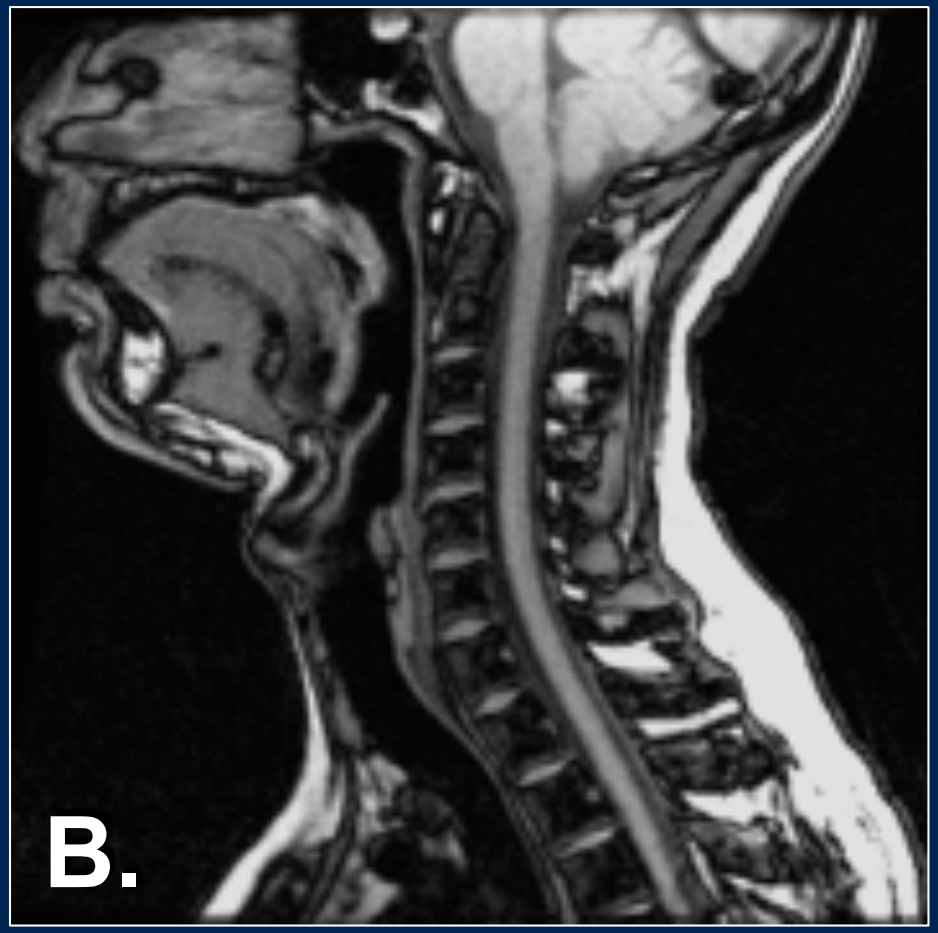
B. Calculate and use the Ernst angle.

C. Use a flip angle for maximum contrast.

Gradient Echoes - True or False?

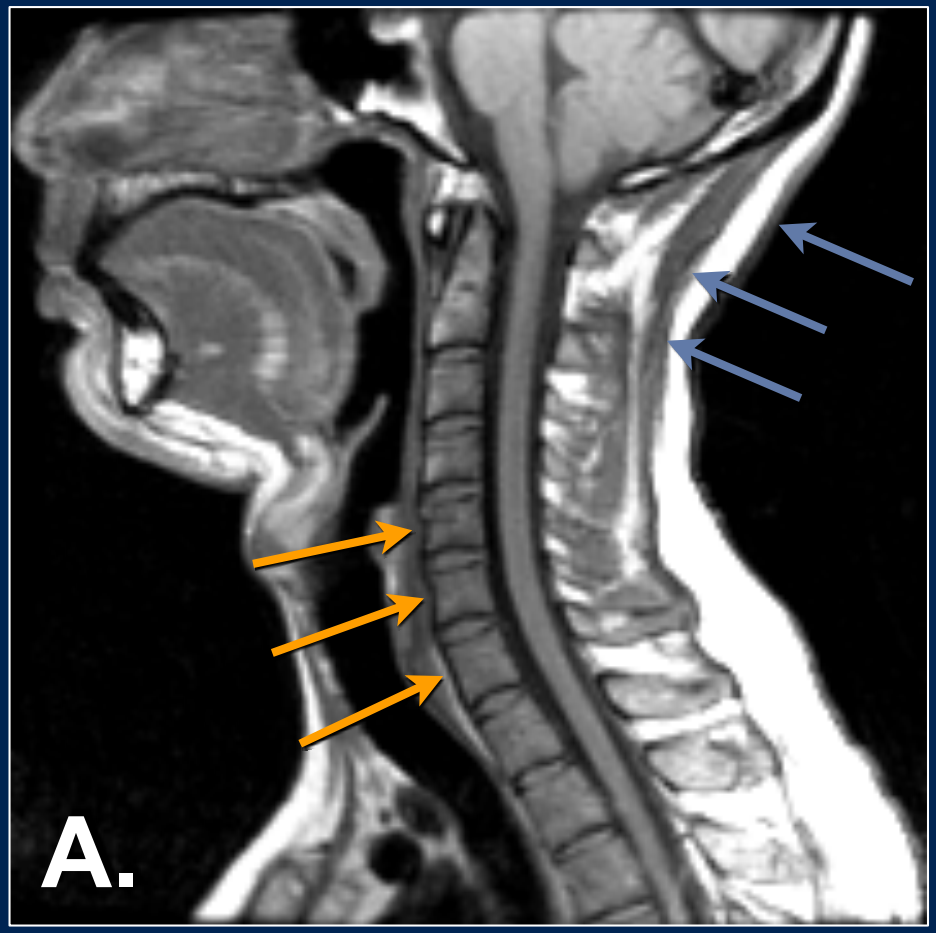
1. GRE and SE can both provide T2* contrast.
2. GRE and SE use the same TE and TR to produce a T1-weighted image.
3. SE is better for visualizing tissues with a very short T2 because of the refocusing pulses.
4. In GRE higher flip angles always produce brighter images.

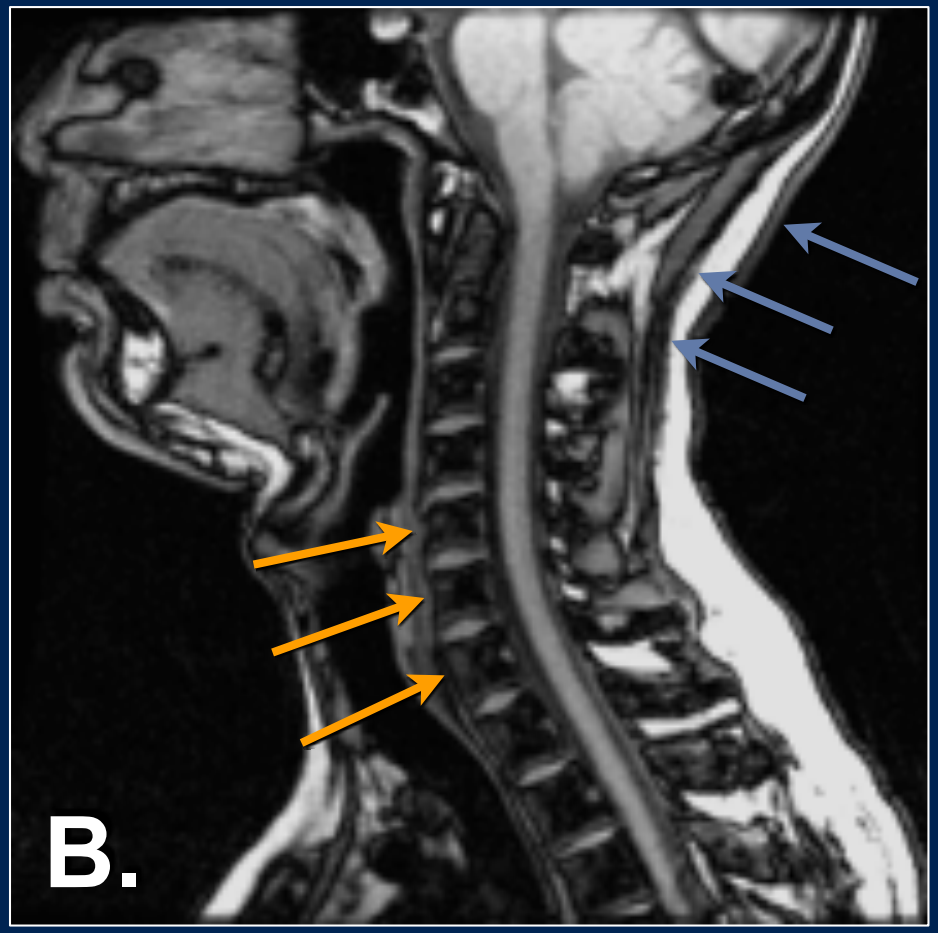
Which image is the in-phase image?



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?

- Related reading materials
  - Nishimura - Chap 7

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