Imaging Sequences III

M219 - Principles and Applications of MRI

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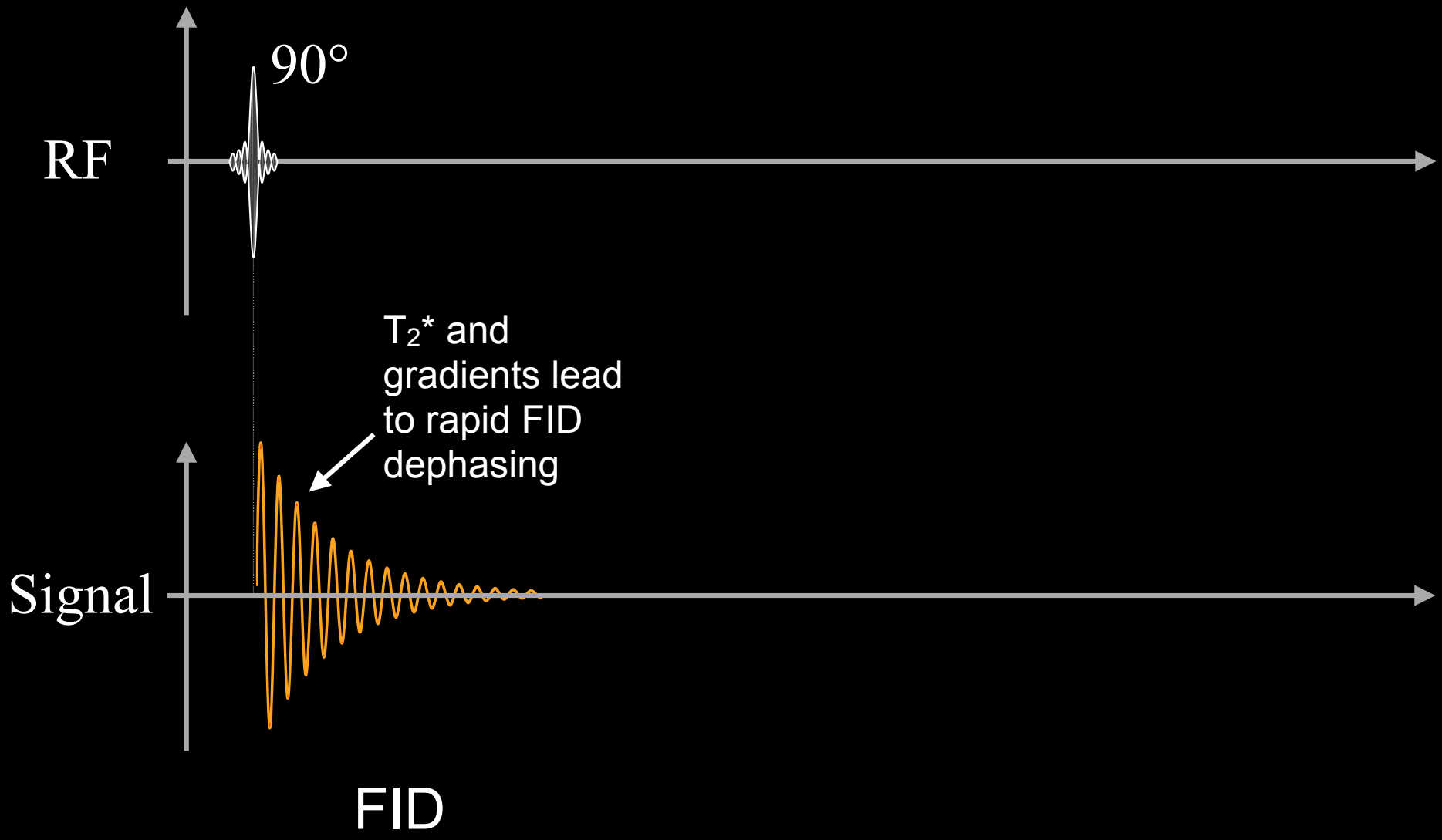
3/1/2023

Course Overview

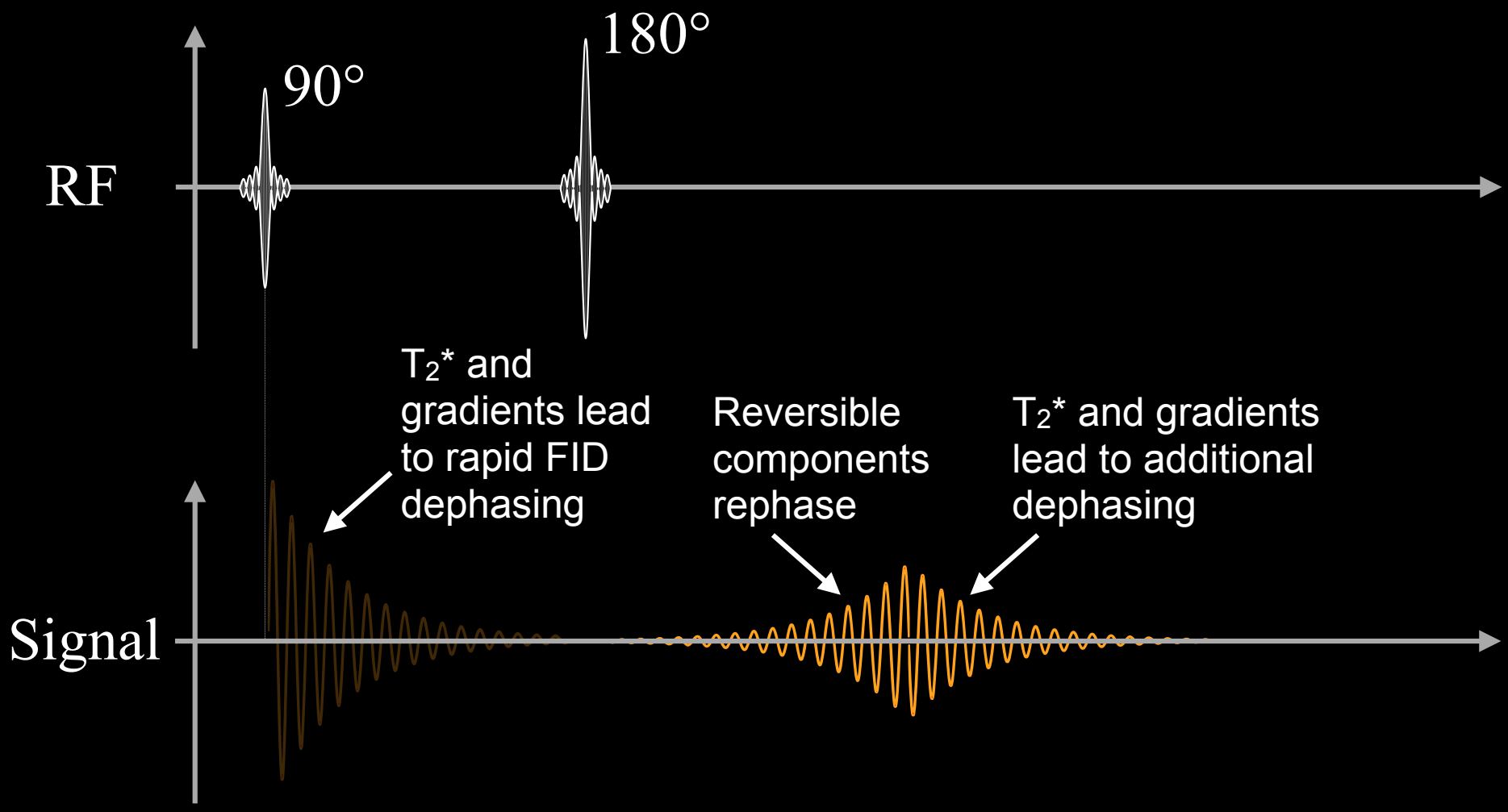
- 2023 course schedule
  - https://mrrl.ucla.edu/pages/m219_2023
- Assignments
  - Homework #3 is due on 3/8
- Final exam
  - 3/20 at 2-4pm
- Office hours, Fridays 10-12pm
  - In-person (Ueberroth, 1417B)
  - Zoom is also available (https://uclahs.zoom.us/j/98066349714?pwd=cnVmV1J5QjR1d3I3cmJkQnVLSFZVZz09)

Spin Echo Imaging

Free Induction Decay



Spin Echo

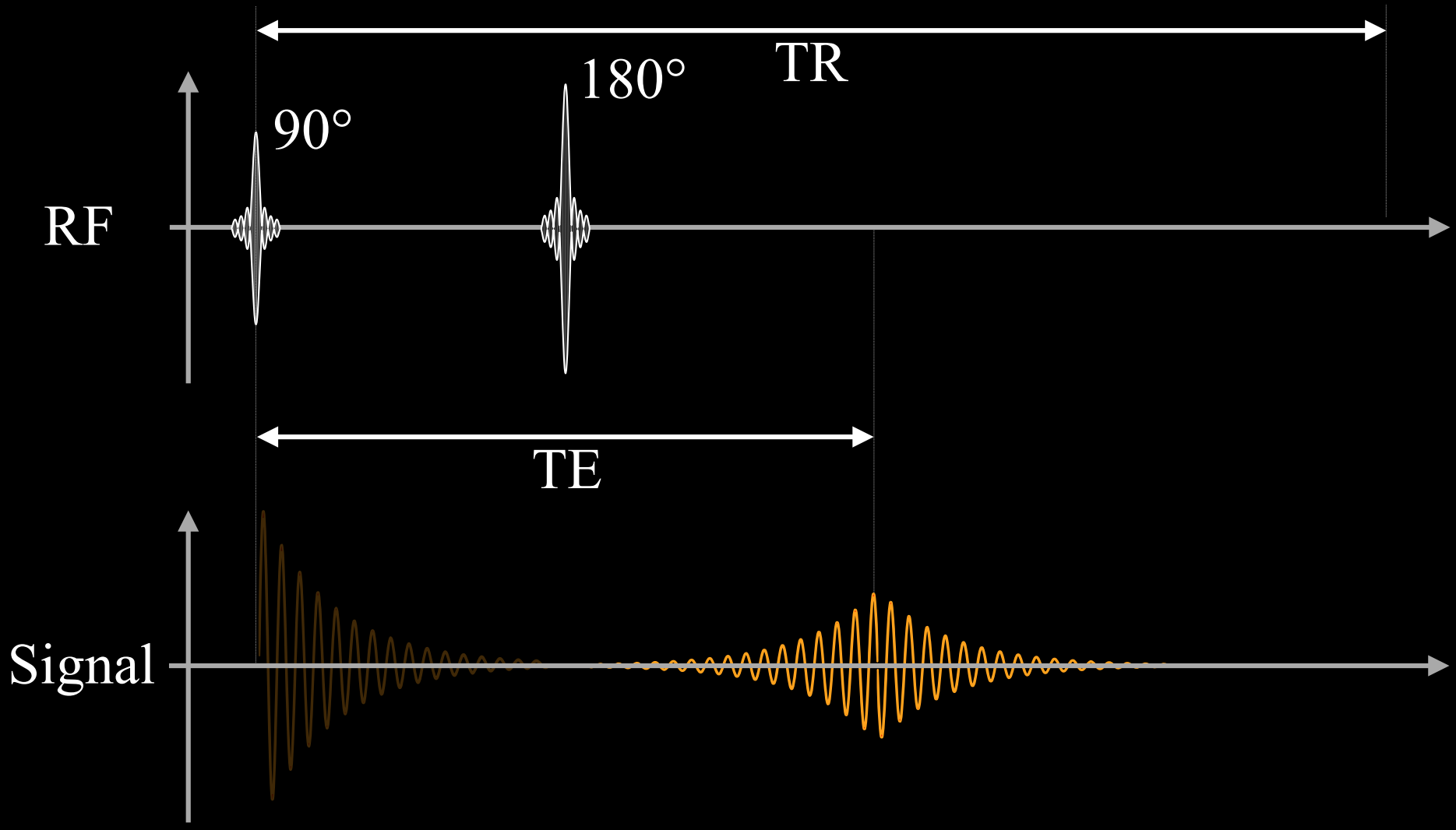


FID

Spin Echo

Record by computer.

Spin Echo



FID

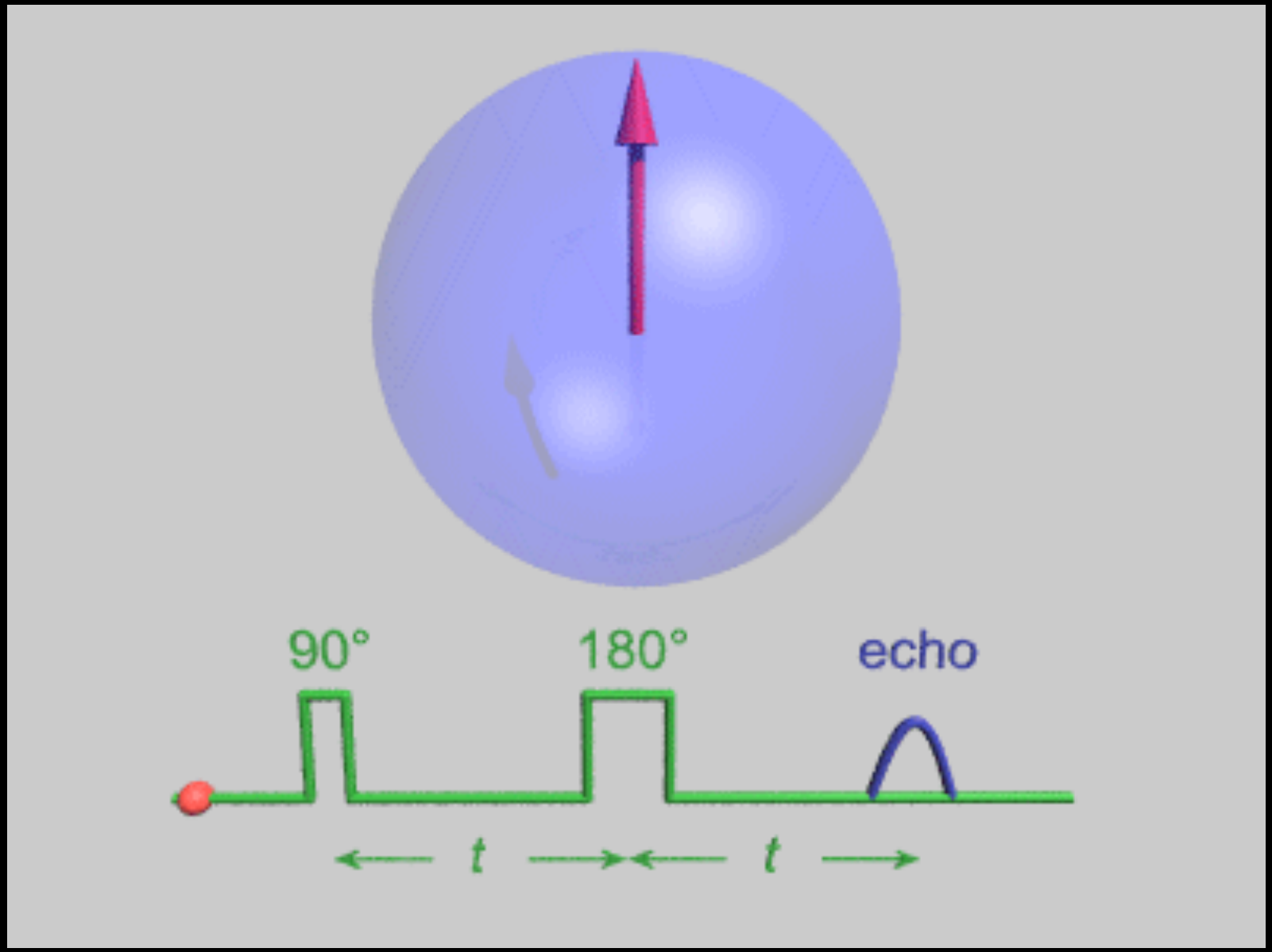
Spin Echo

Record by computer.

Refocusing Pulses

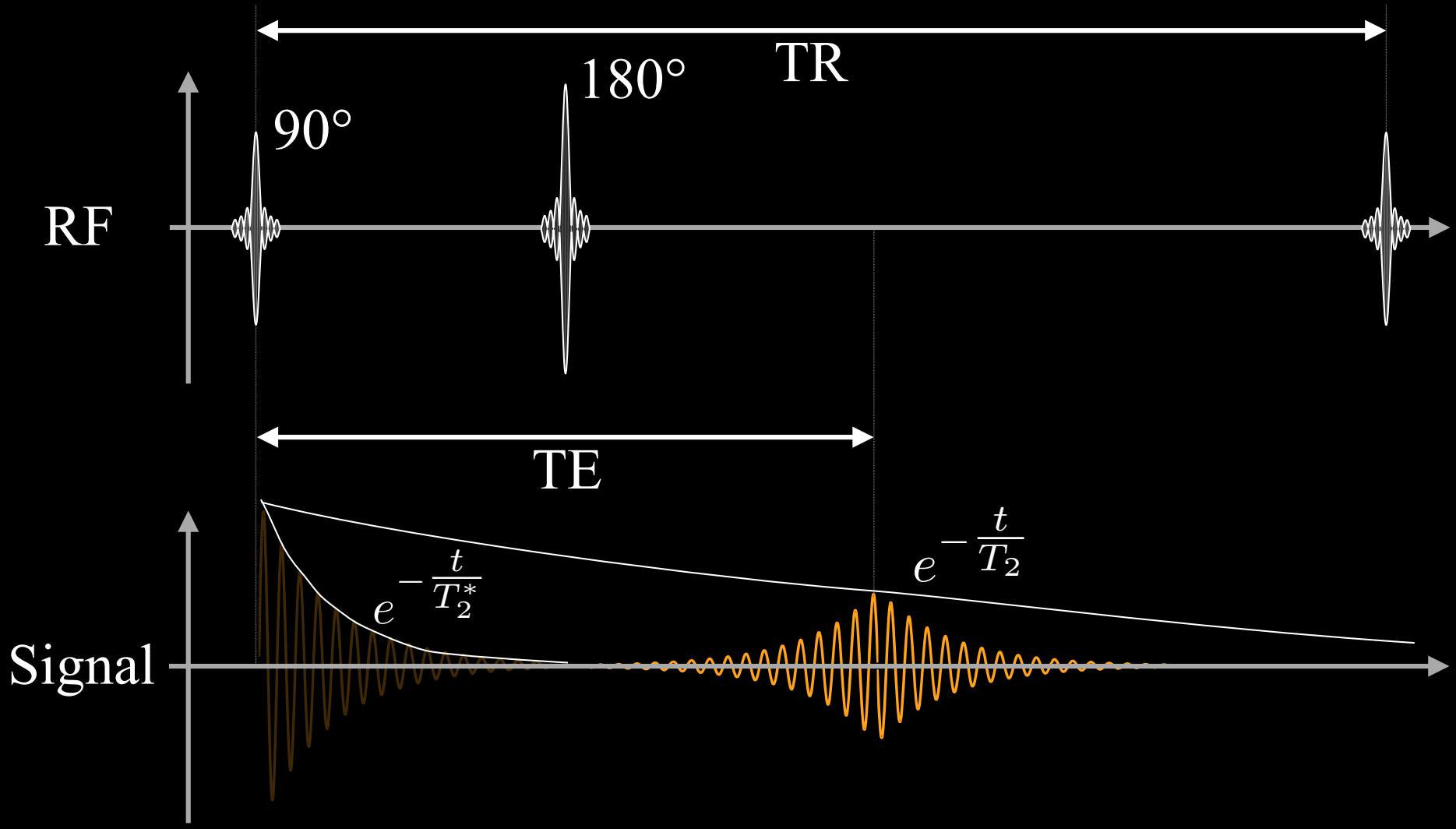
- Typically, 180° RF Pulse
  - Provides optimally refocused M_{XY}
  - Largest spin echo signal
- Refocus spin dephasing due to
  - imaging gradients
  - local magnetic field inhomogeneity
  - magnetic susceptibility variation
  - chemical shift

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

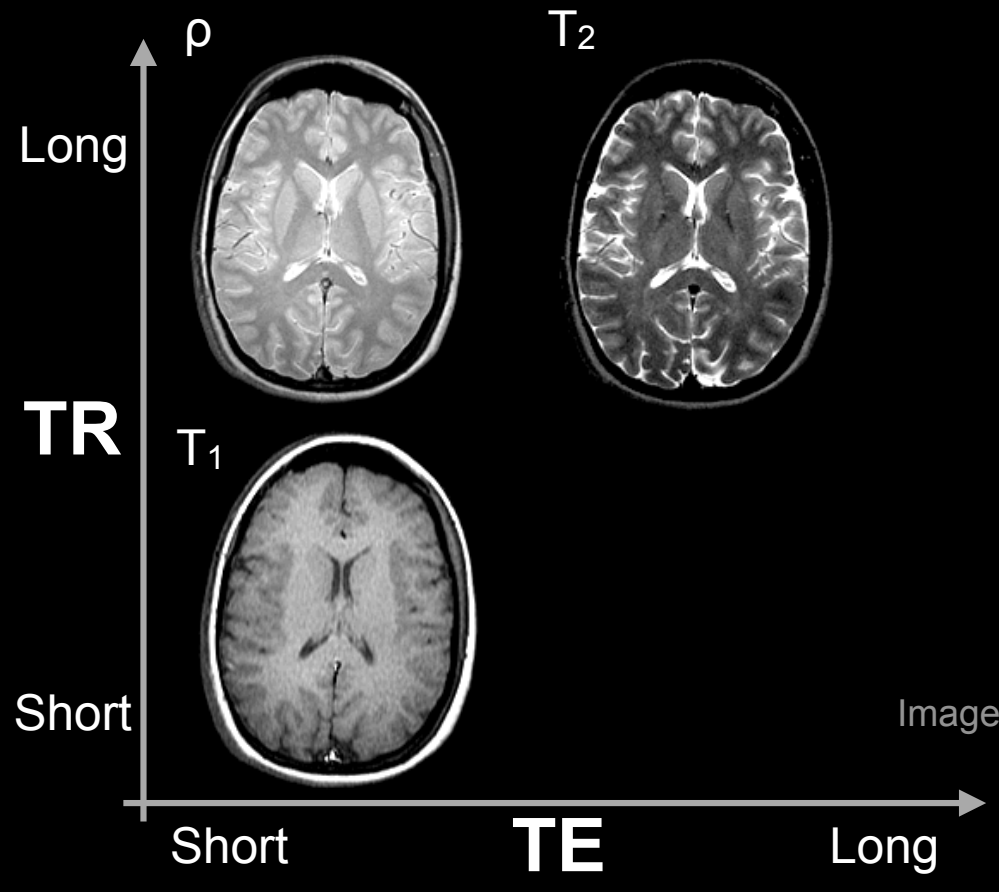
Intermediate TE maximizes T2 contrast

Spin Echo Parameters

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

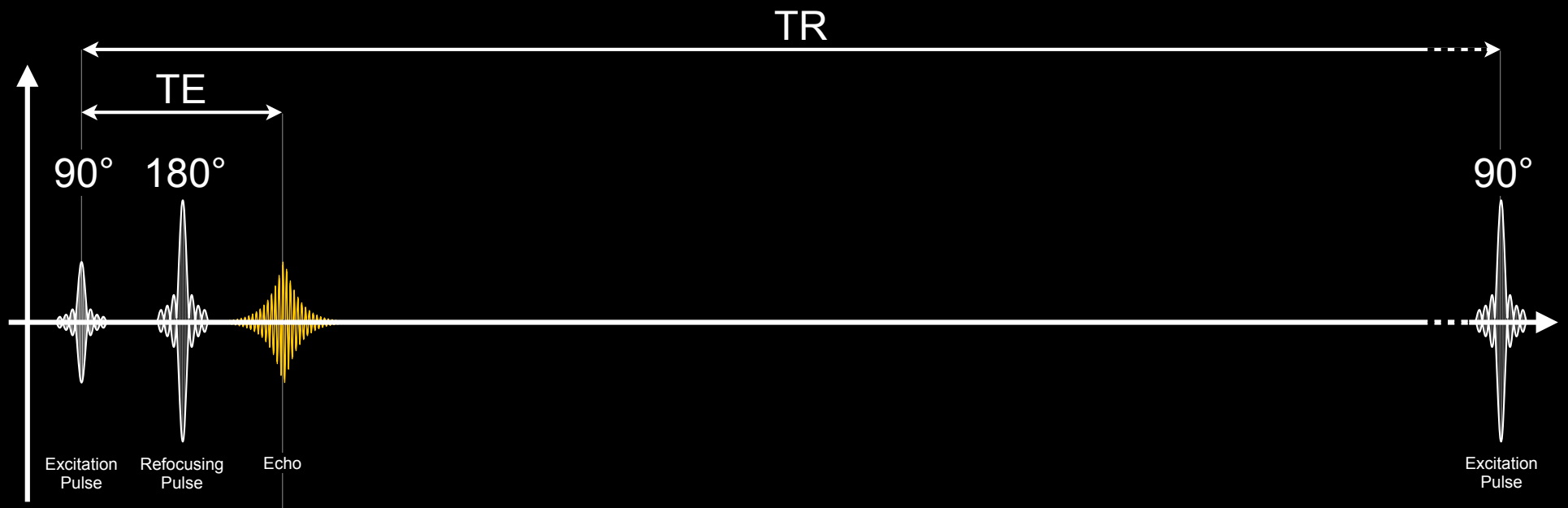
Spin Echo Contrast

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



Images Courtesy of Mark Cohen

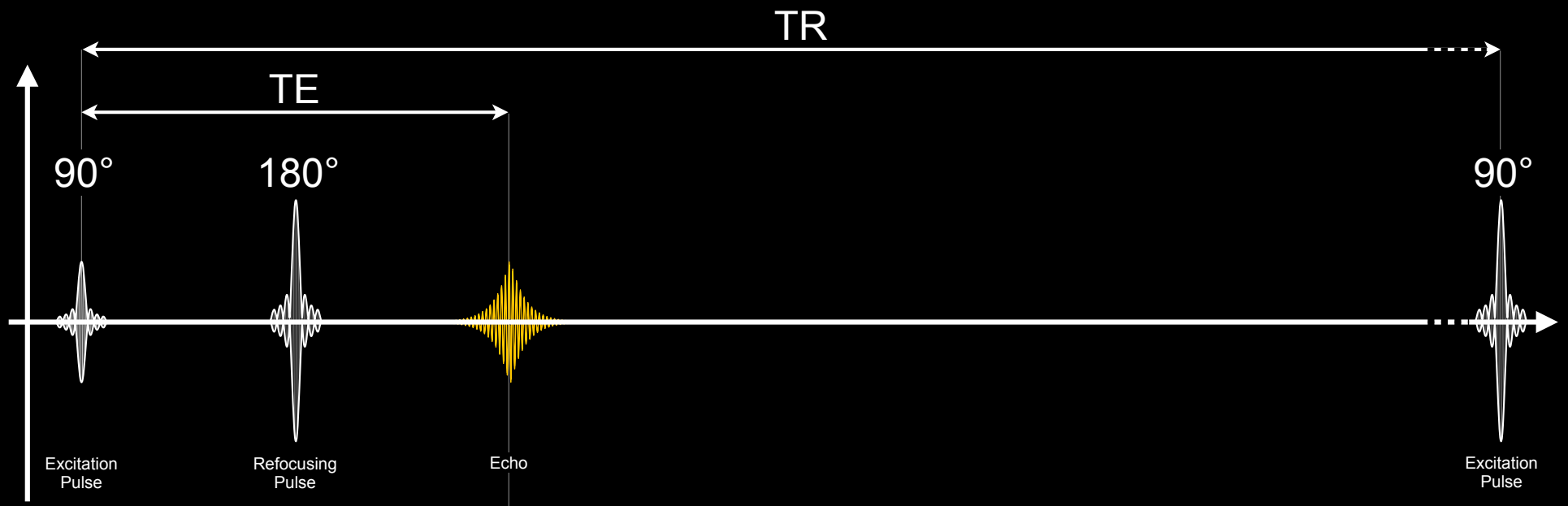
Spin Echo

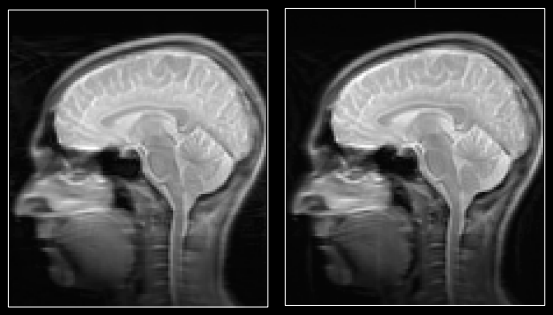


TE=12ms

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

Spin Echo

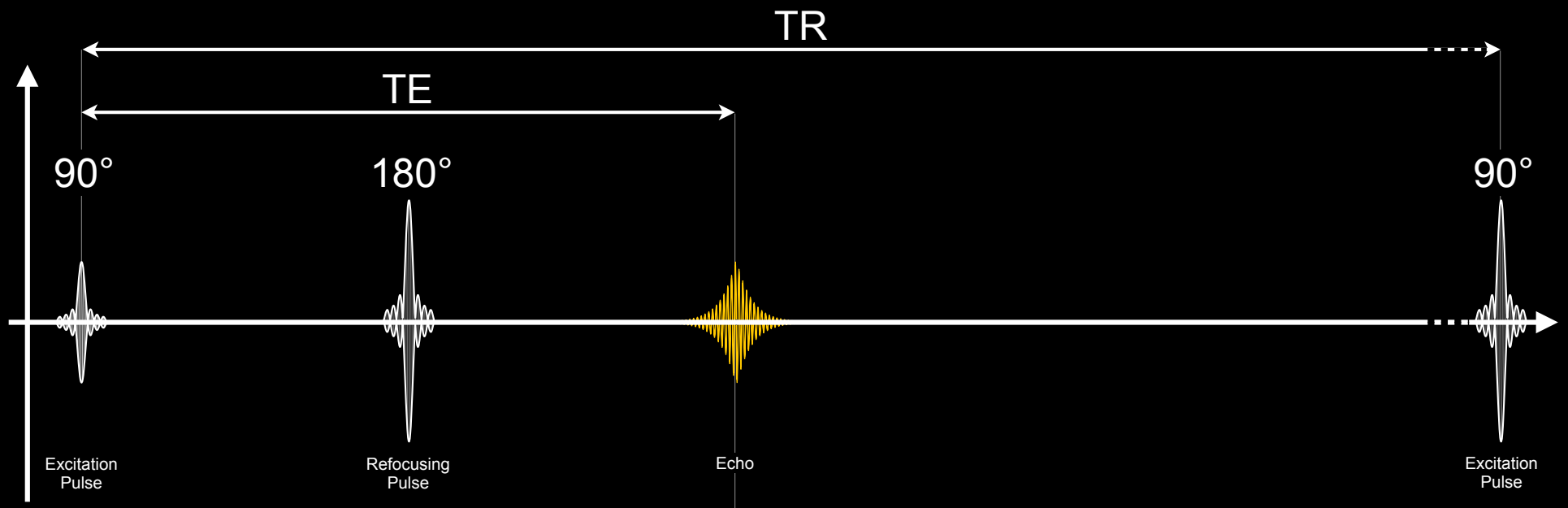


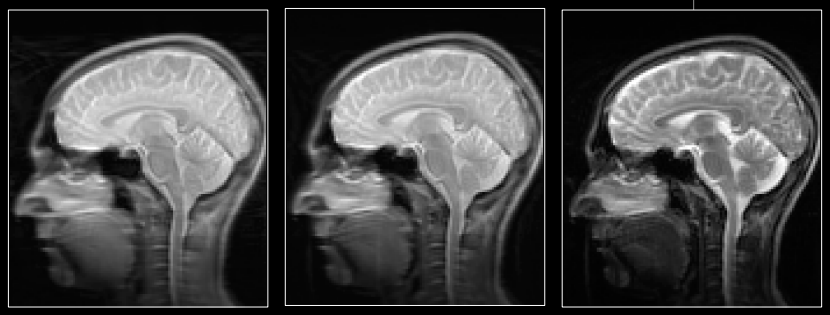


TE=12ms TE=47ms

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

Spin Echo

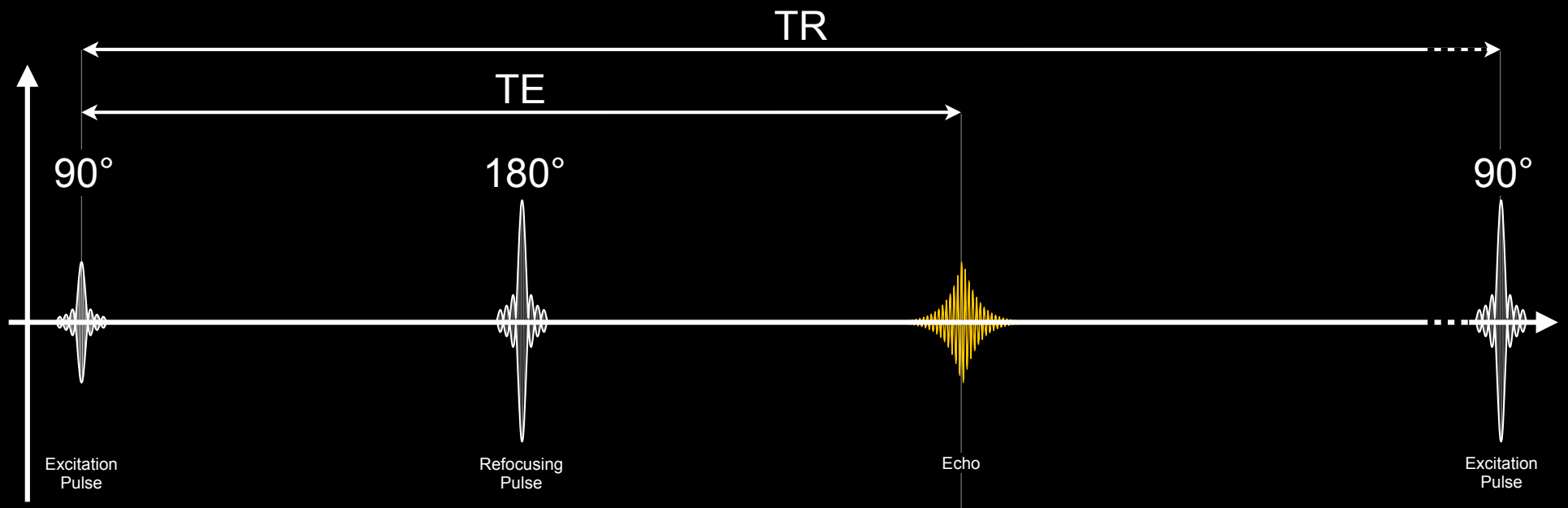


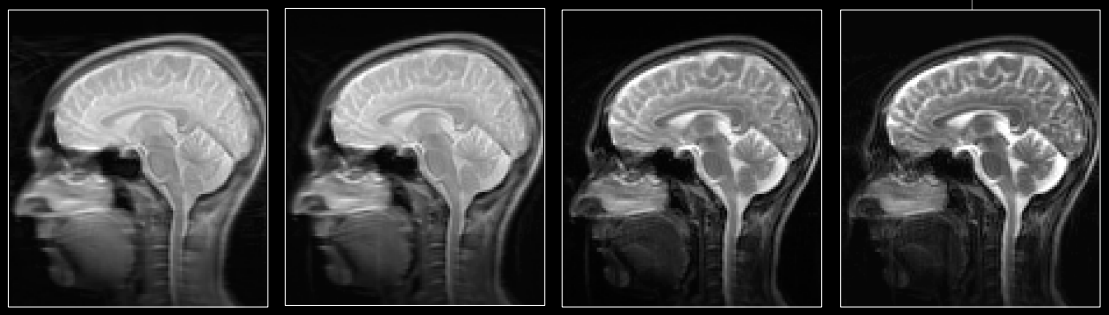


TE=12ms TE=47ms TE=106ms

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

Spin Echo

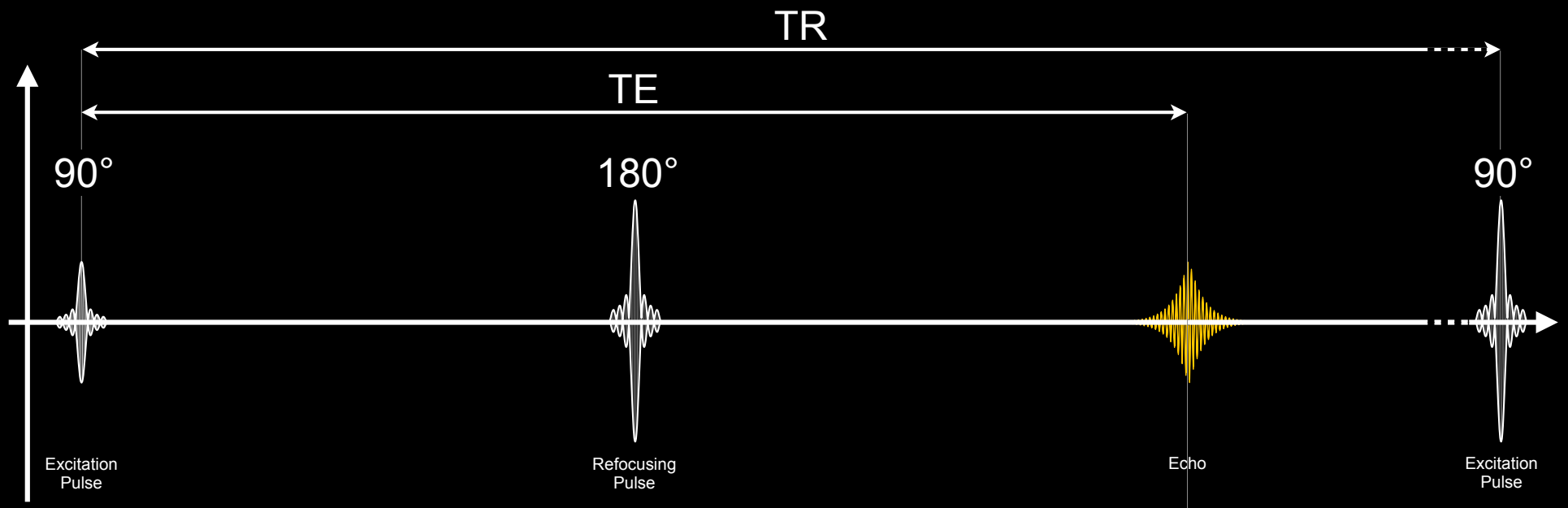




TE=12ms TE=47ms TE=106ms TE=153ms

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

Spin Echo



TE=12ms TE=47ms TE=106ms TE=153ms TE=235ms

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

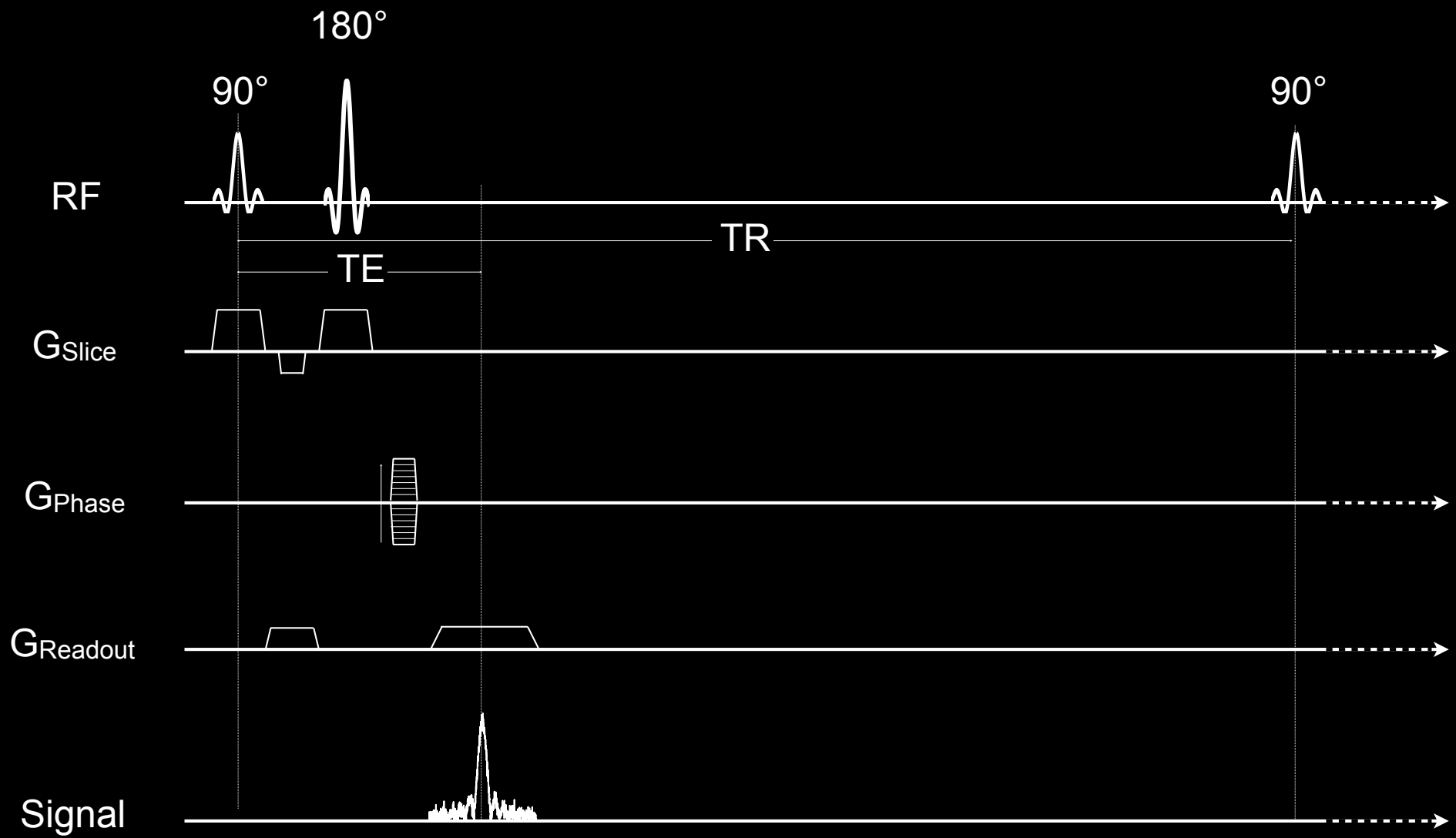
Turbo Spin Echo (TSE) / Fast Spin Echo (FSE)

How do we calculate scan time?

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

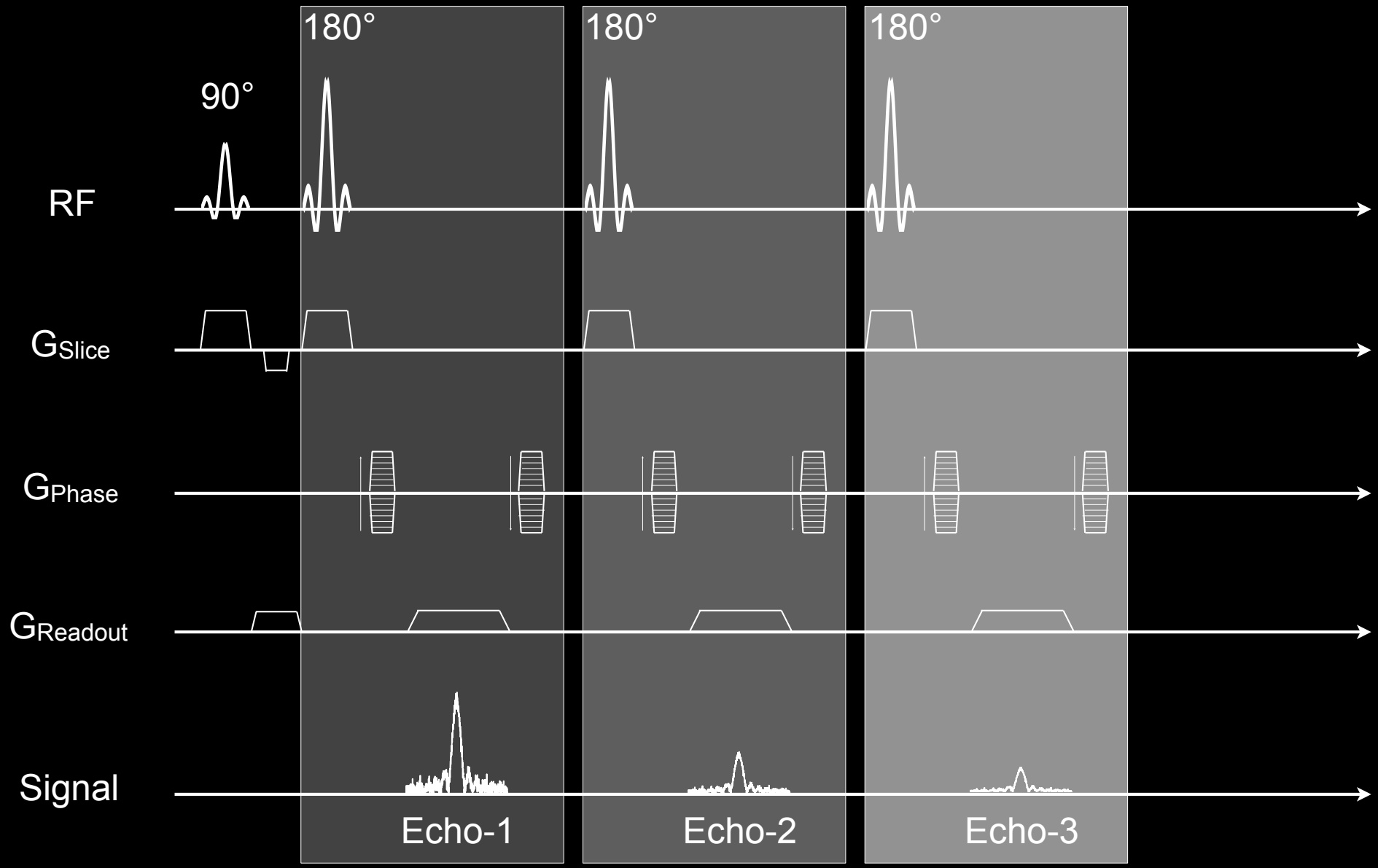
- T_{Scan}=1000ms•256•1=4:16 [mm:ss]
- Assumes one echo per TR.

Spin Echo

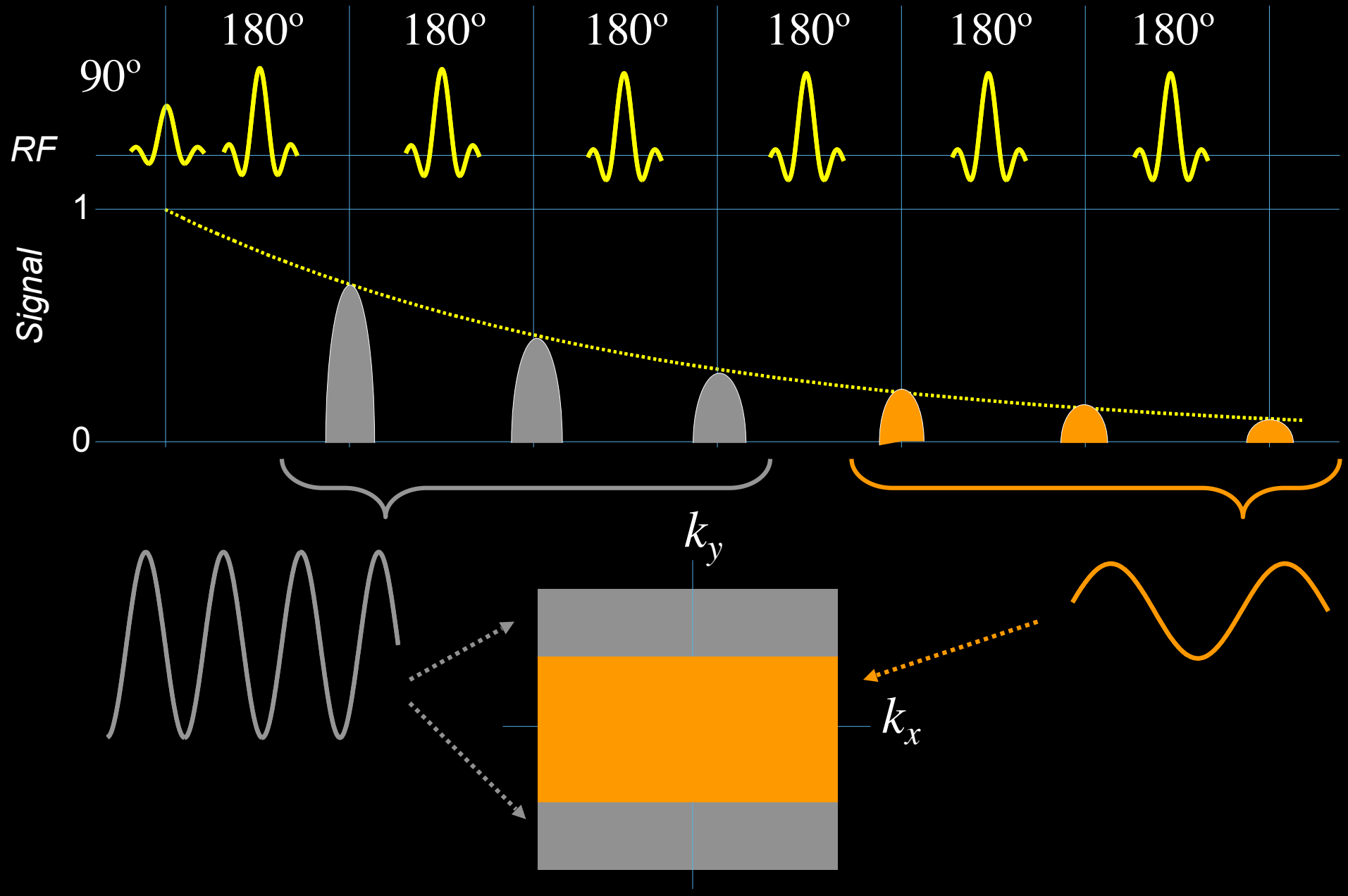


Spin Echo

Turbo Spin Echo (TSE)

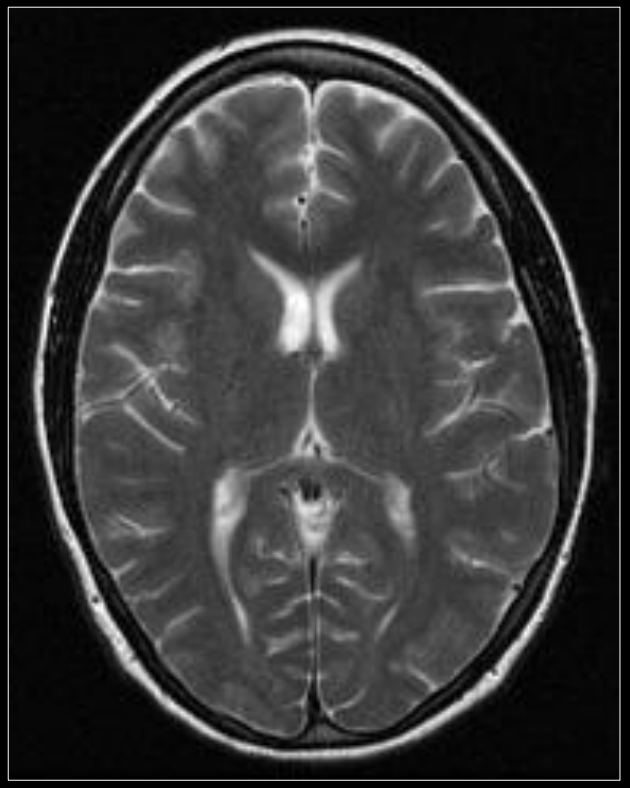


T_2-weighted TSE



Turbo Spin Echo vs. Spin Echo

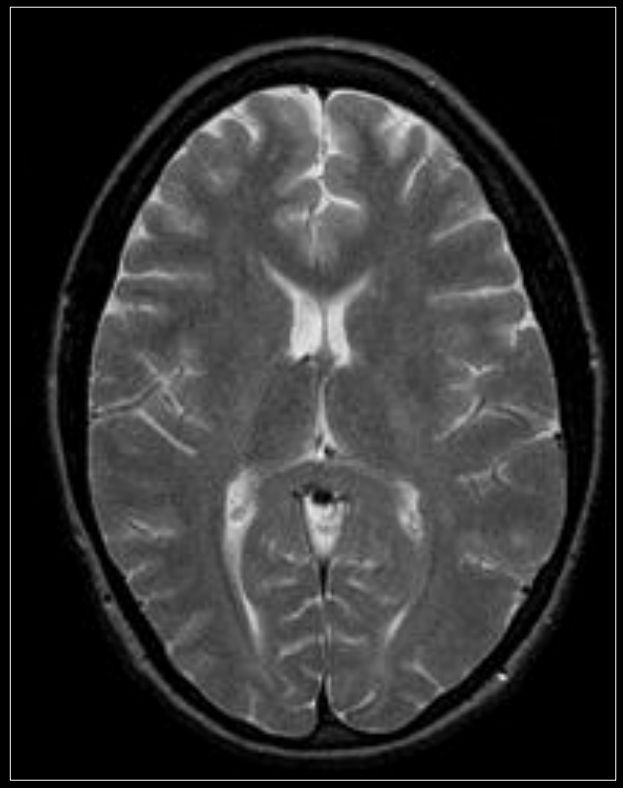
Fast Spin Echo



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.

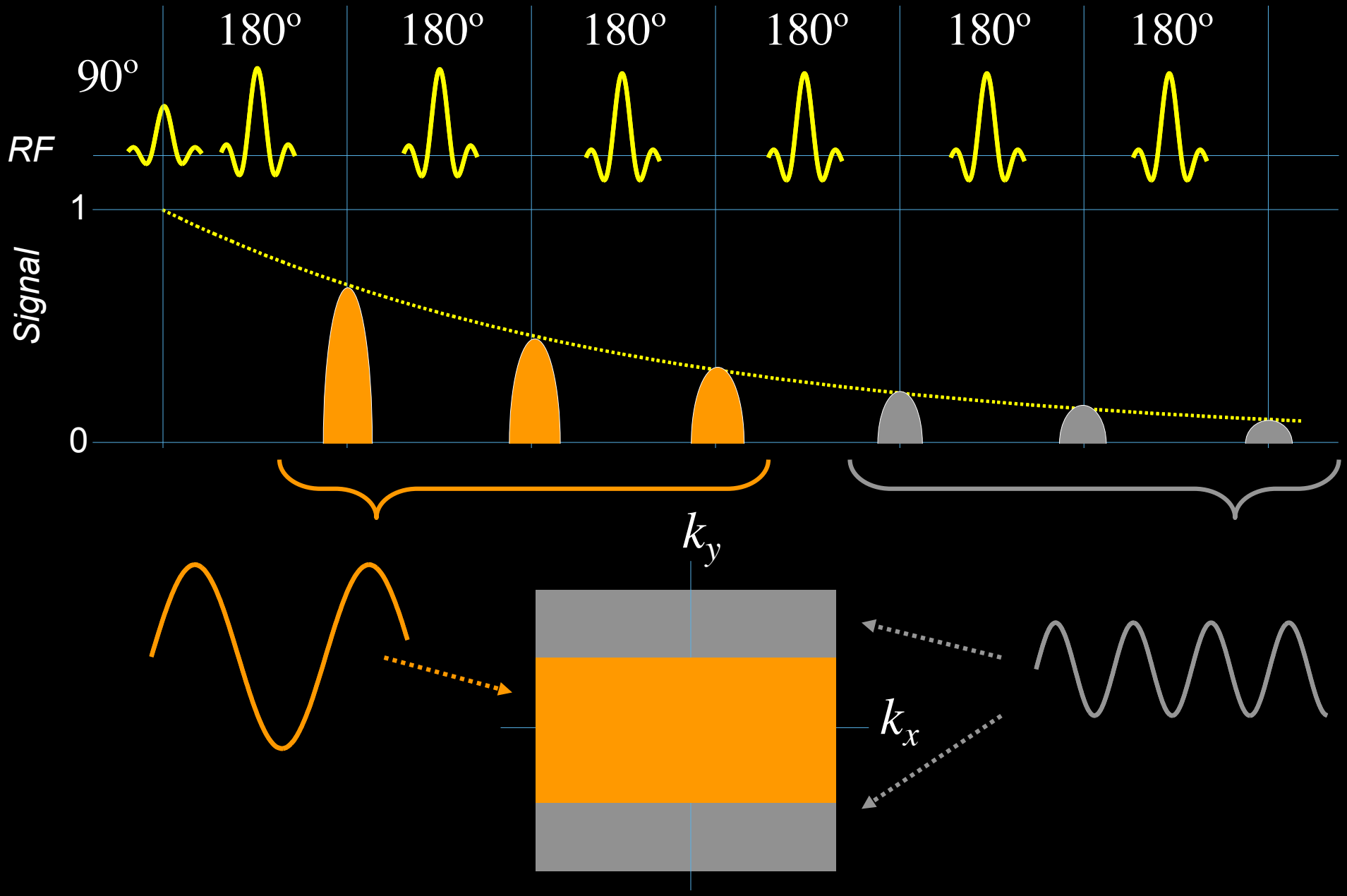
Spin Echo



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

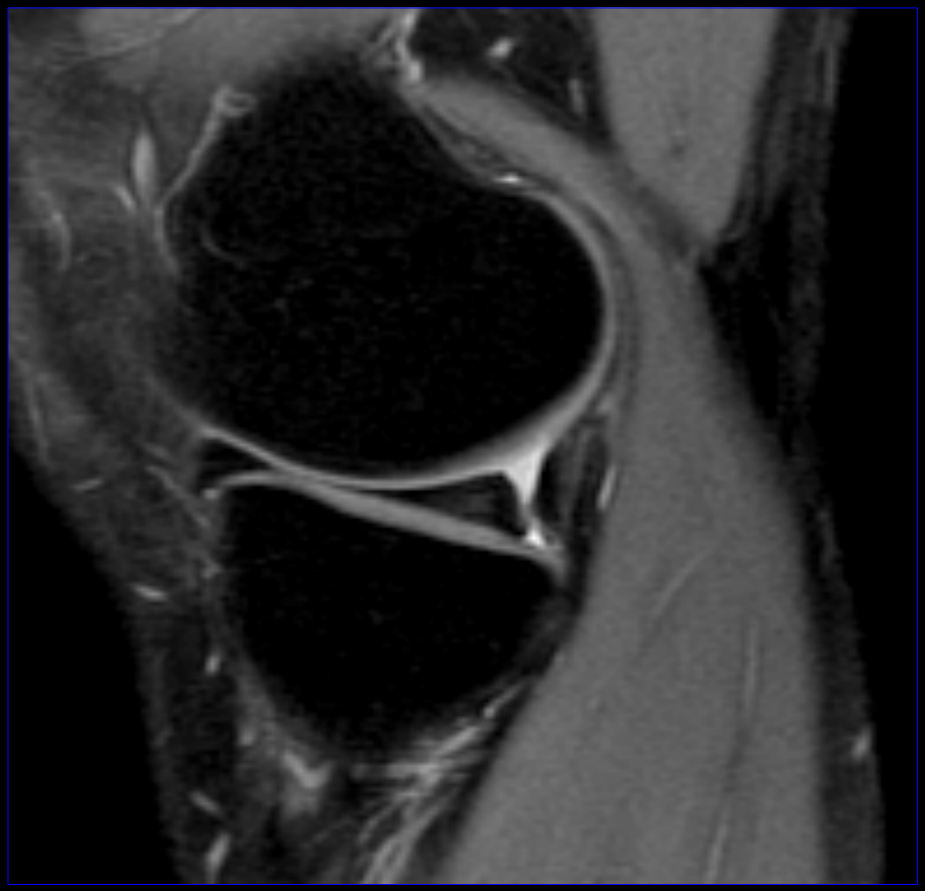
Images: Courtesy Frank Korosec

Proton Density Weighted TSE

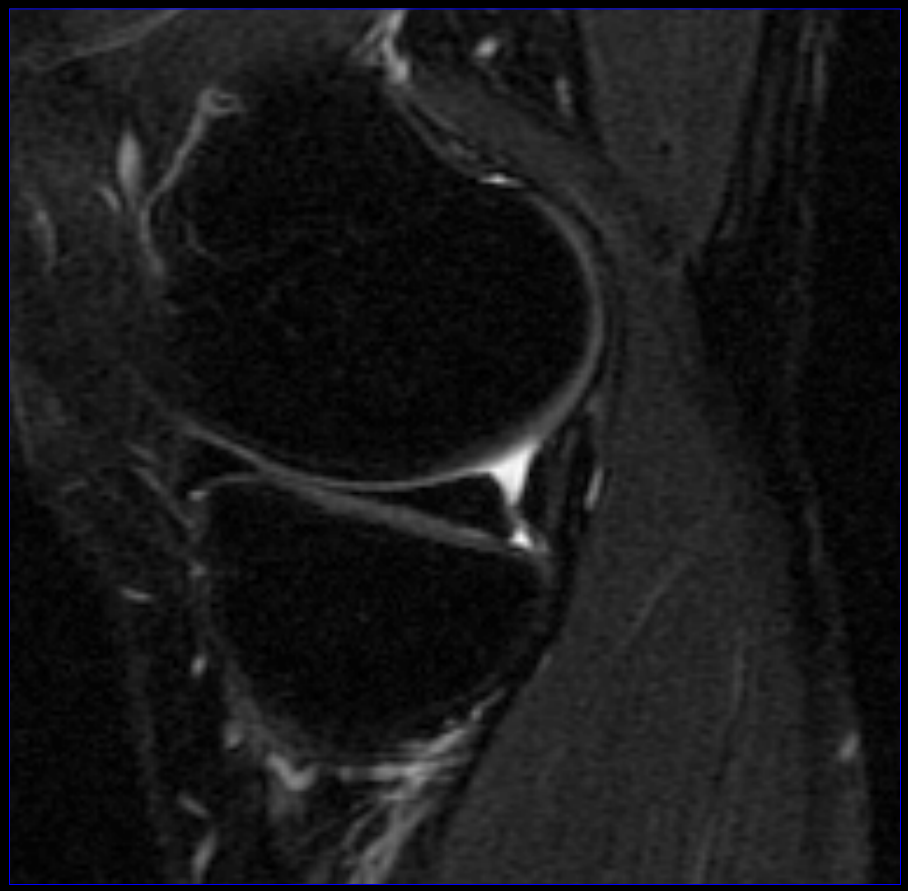


PD vs T_2-weighted TSE

Proton Density Weighted



T_2-weighted



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

Summary for TSE

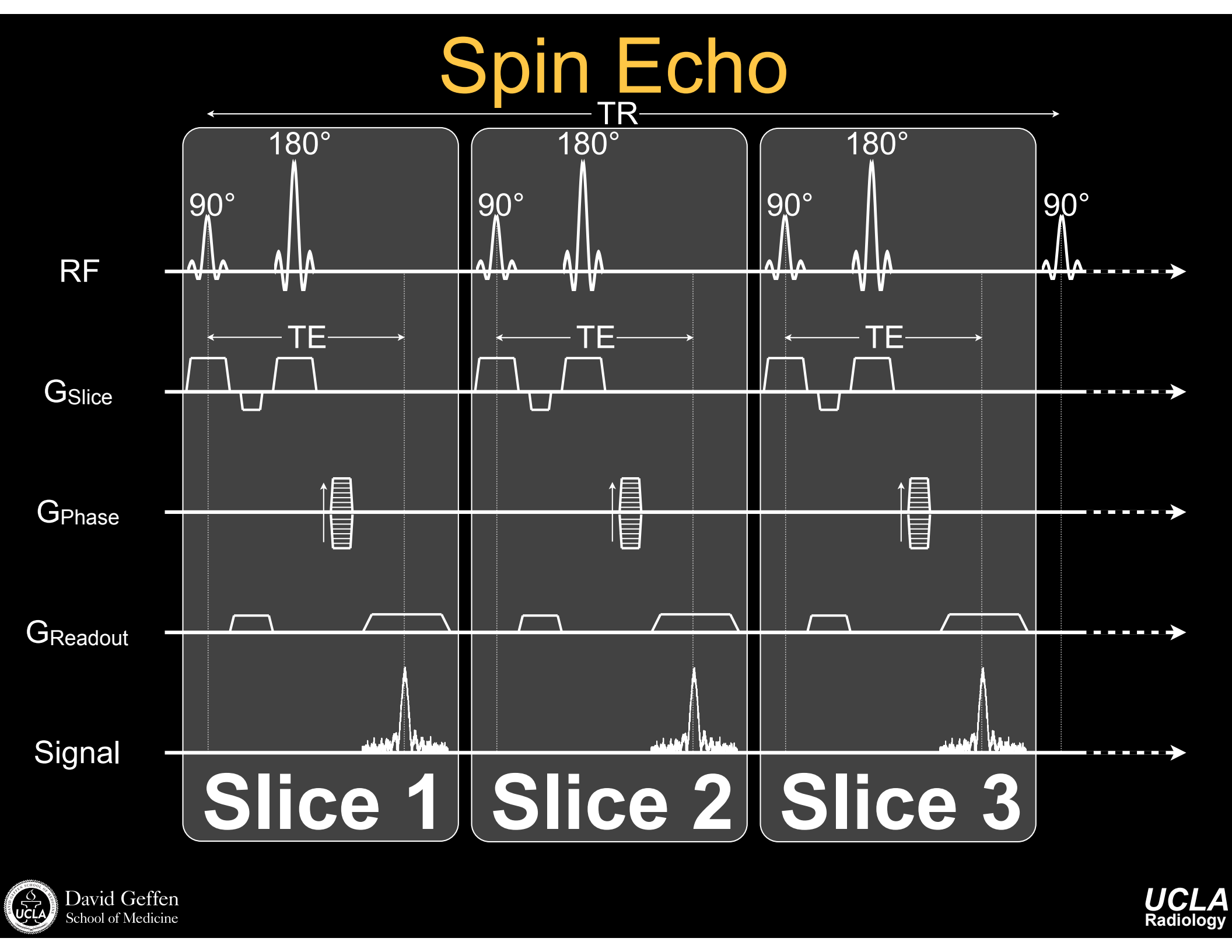
- Pros:
  - Fast, high SNR
  - Less sensitive to B0 inhomogneity
- Cons:
  - T2 weighting varies in k-space
  - RF power limits speed, particularly at 3T

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

2D Slice Interleaving

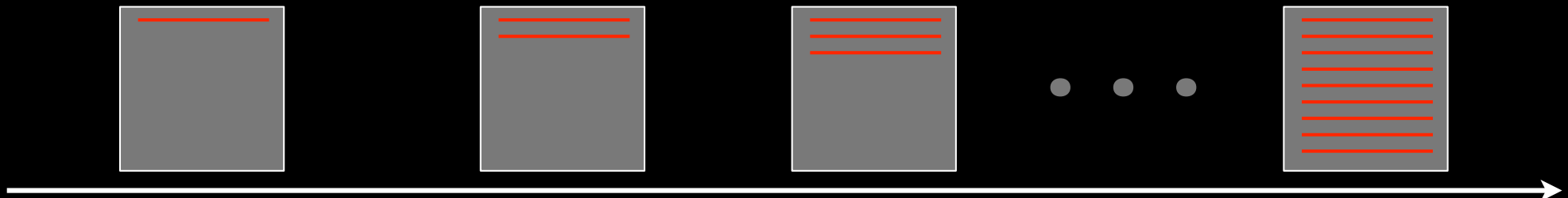
Spin Echo

Spin Echo


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

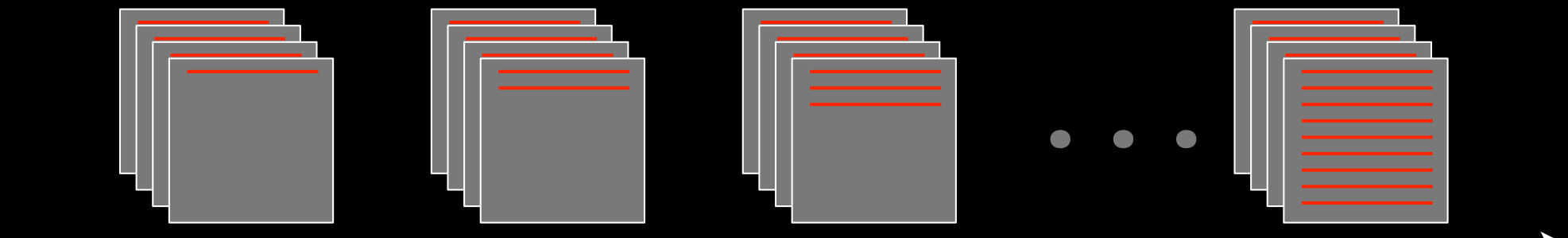
Slice Interleaving

Sequential 2D Imaging



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

Slice Interleaved 2D Imaging

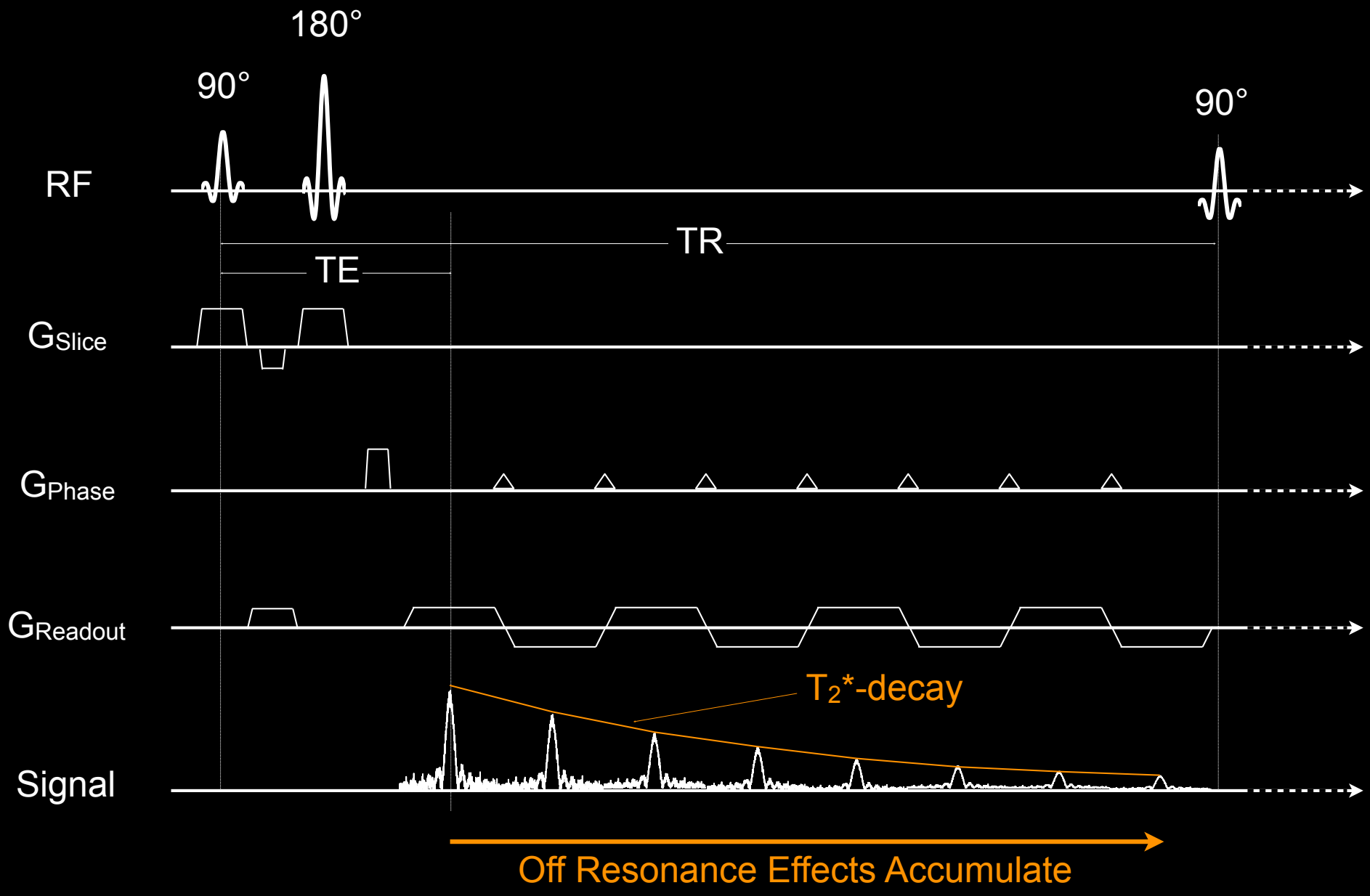


Imaging Time = TR * N_{Ky} * N_{Slices} / $N_{Interleaves}$

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**

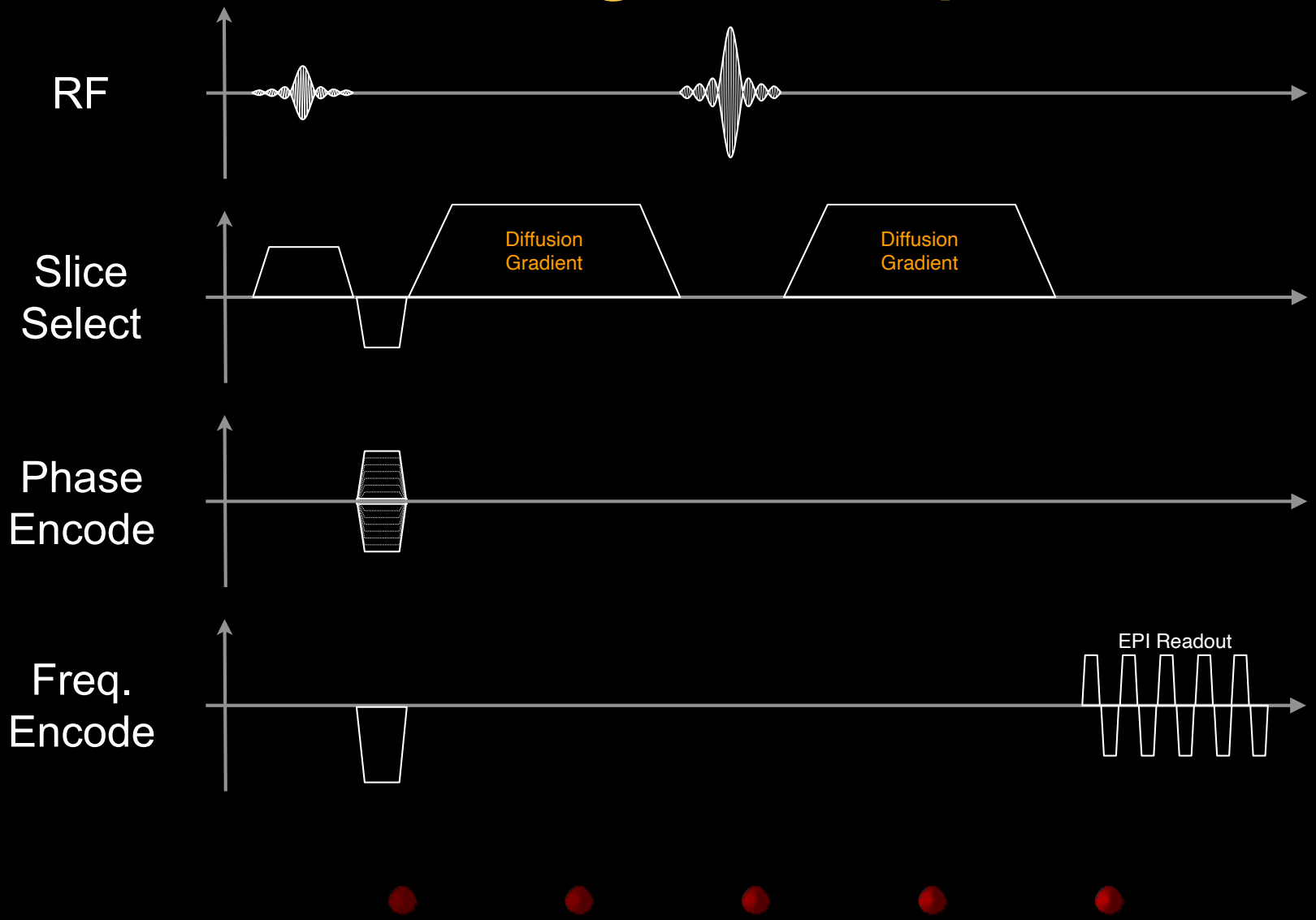
Spin Echo EPI



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?

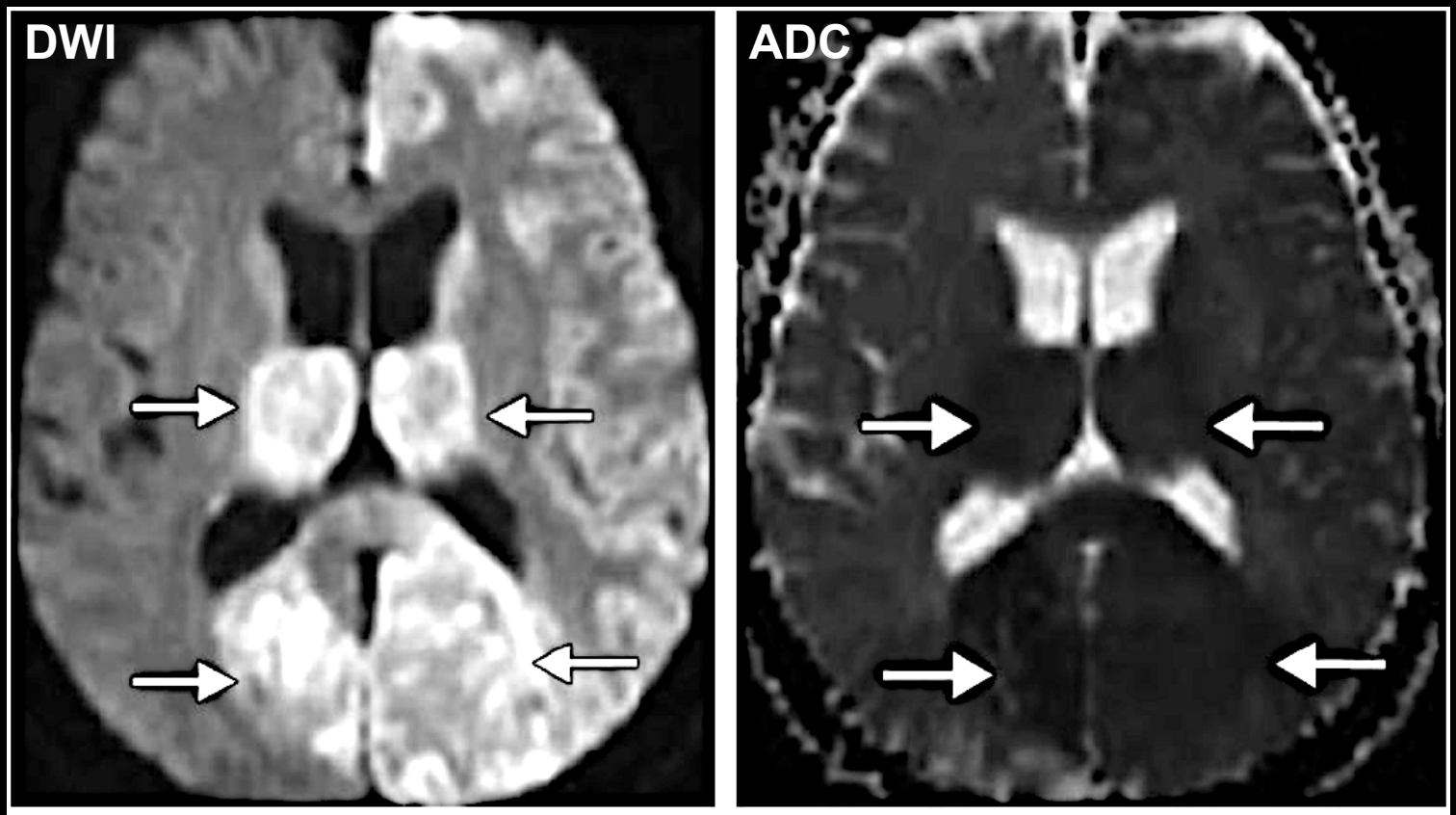
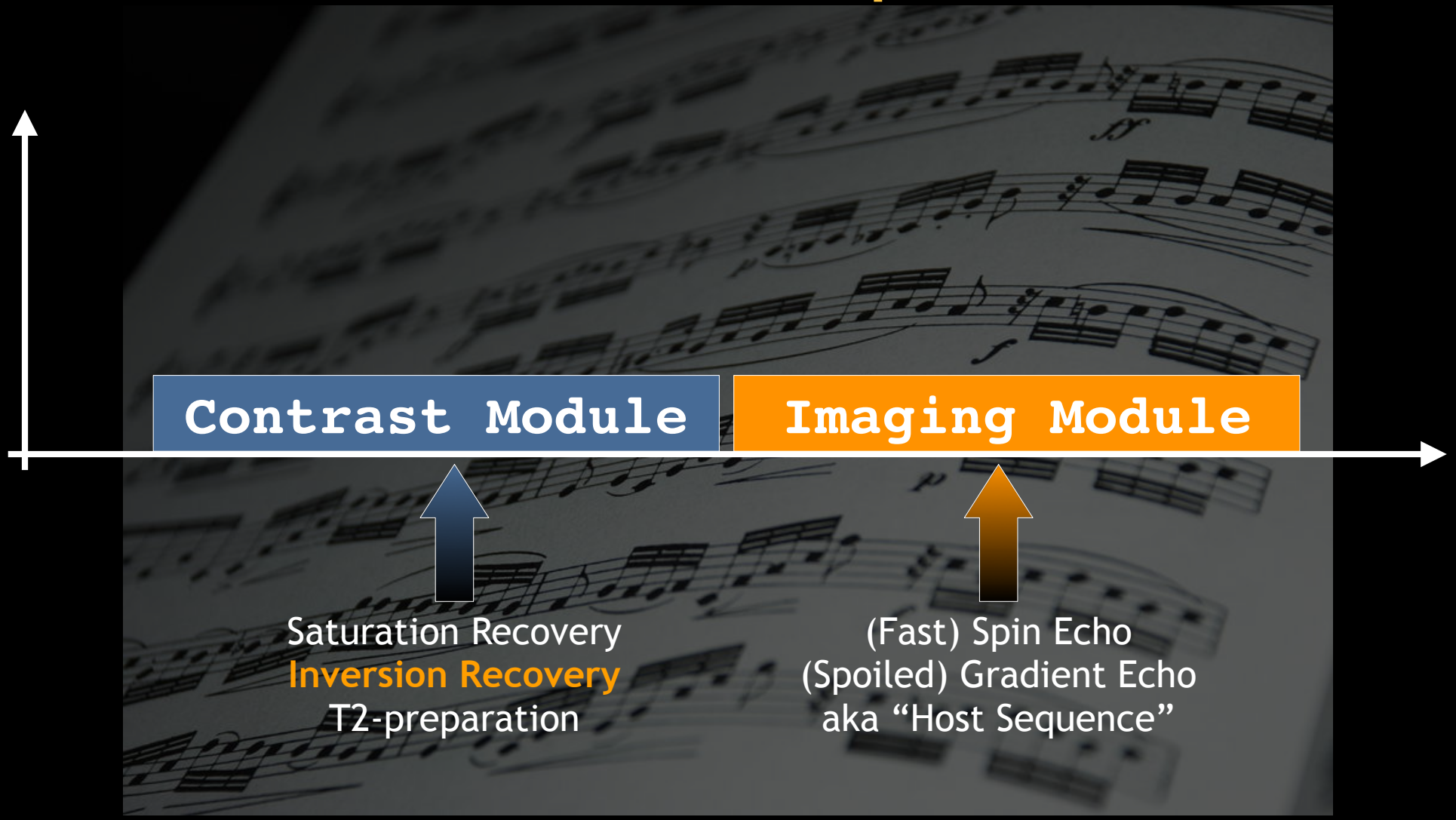


Figure 15. Acute stroke of the posterior circulation in a 77-year-old man. **(a)** Diffusion-weighted MR image (b = 1000 sec/mm^2) shows bilateral areas of increased signal intensity (arrows) in the thalami and occipital lobes. **(b)** ADC map shows decreased ADC values in the same areas (arrows). These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

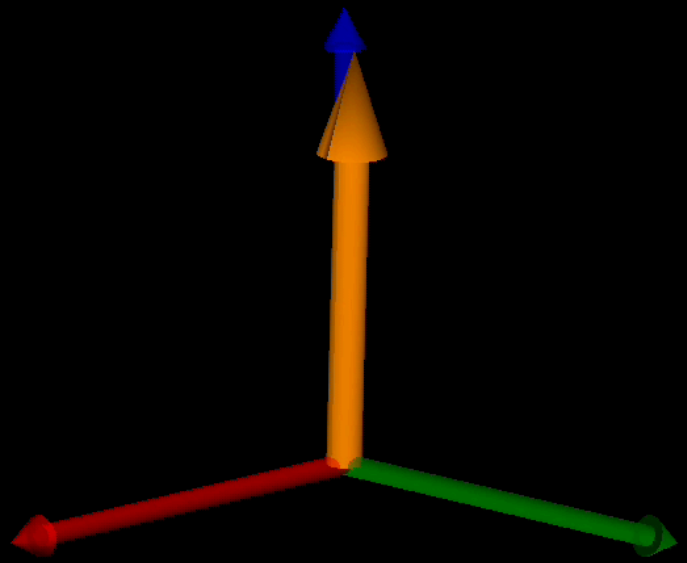
Srinivasan A, *et al*. State-of-the-art imaging of acute stroke. Radiographics 2006;26 Suppl 1:S75-95.

Inversion Recovery Spin Echo MRI

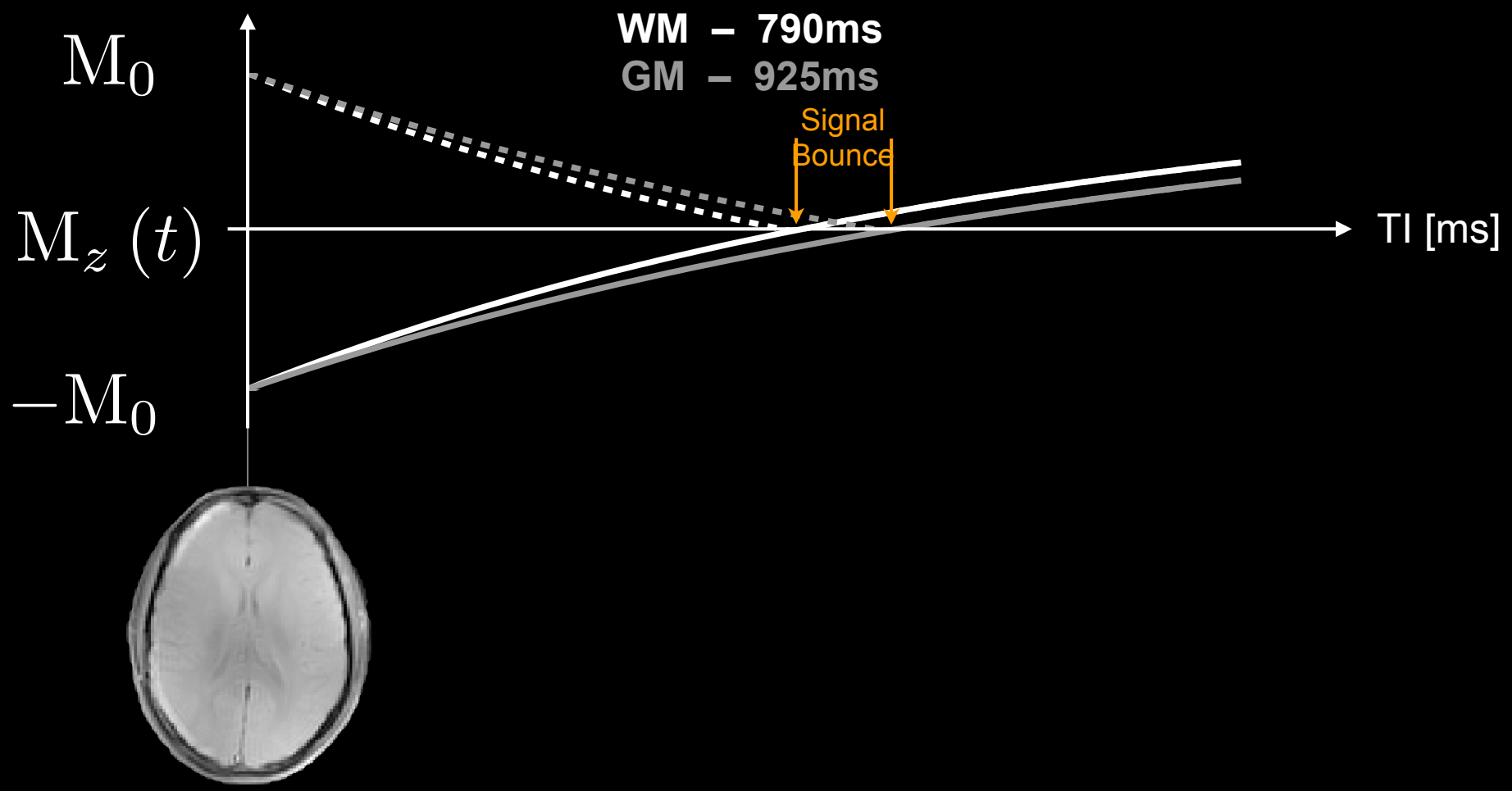
MRI Pulse Sequences



What is an inversion pulse?



Inversion Recovery

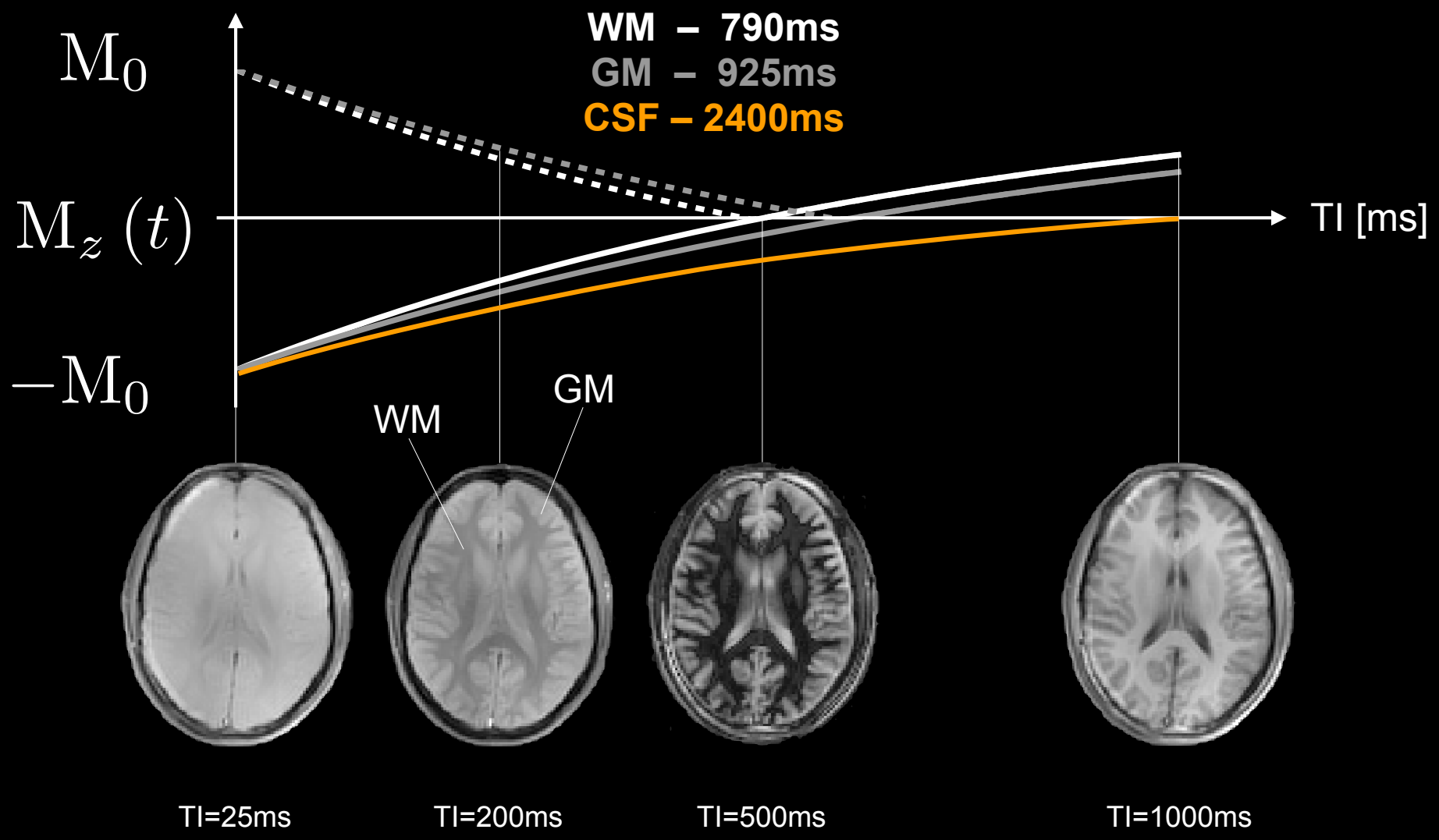


TI=25ms

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

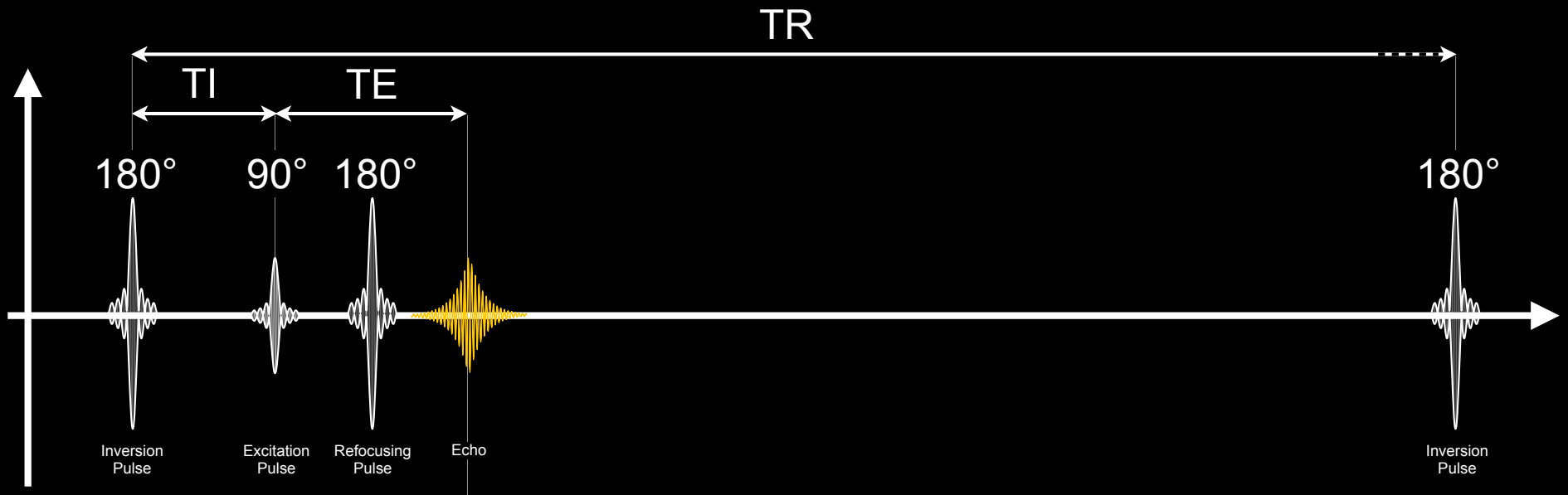
Spin Echo with TE=12ms, TR=2000ms

Inversion Recovery



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

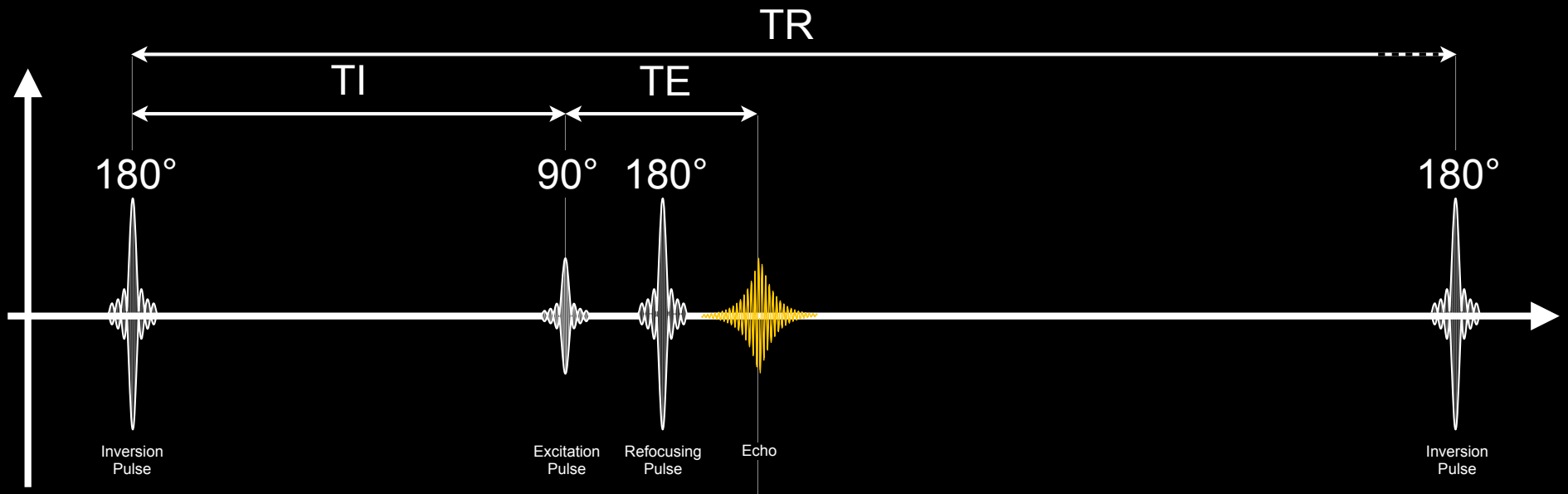
Inversion Recovery + Spin Echo

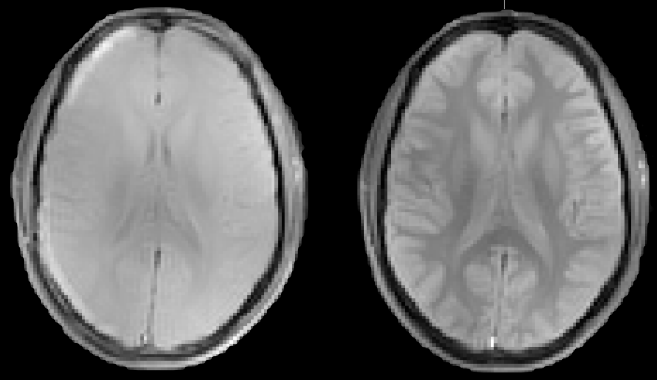


TI=25ms
TE=12ms

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

Inversion Recovery + Spin Echo



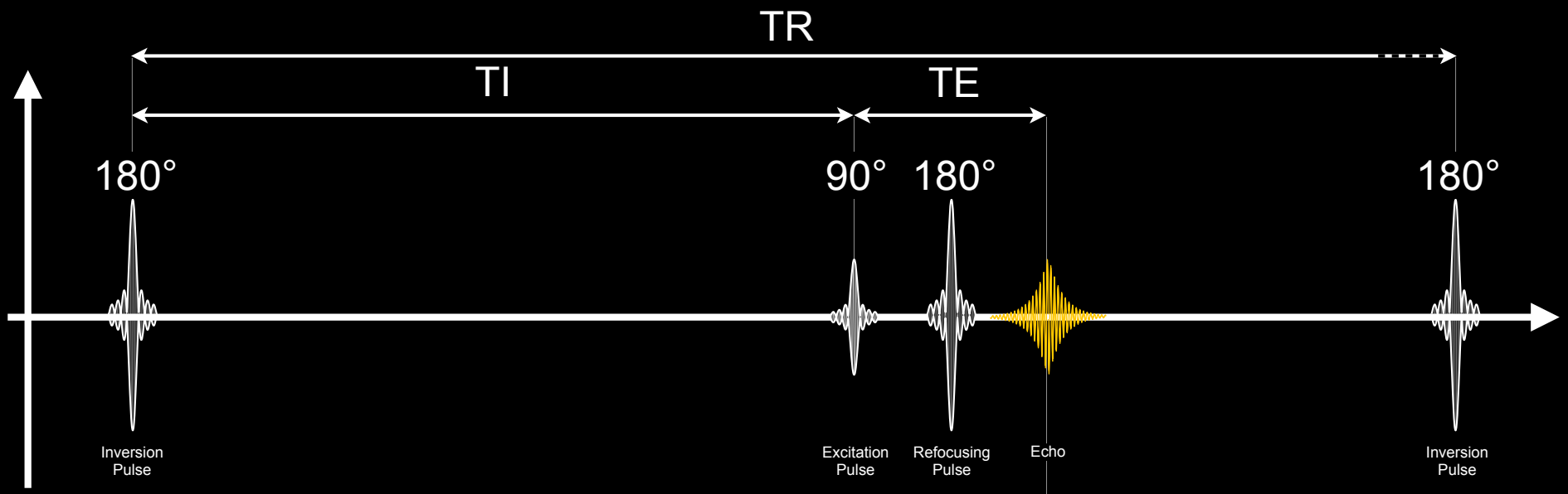


TI=25ms
TE=12ms

TI=200ms
TE=12ms

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

Inversion Recovery + Spin Echo



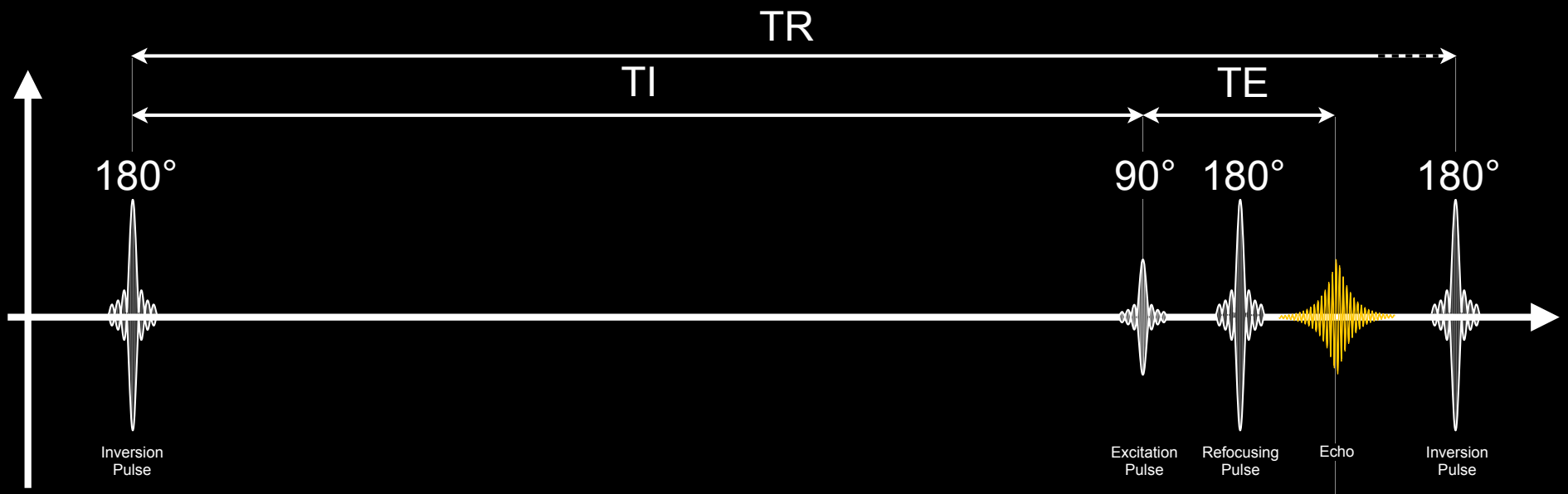
TI=25ms
TE=12ms

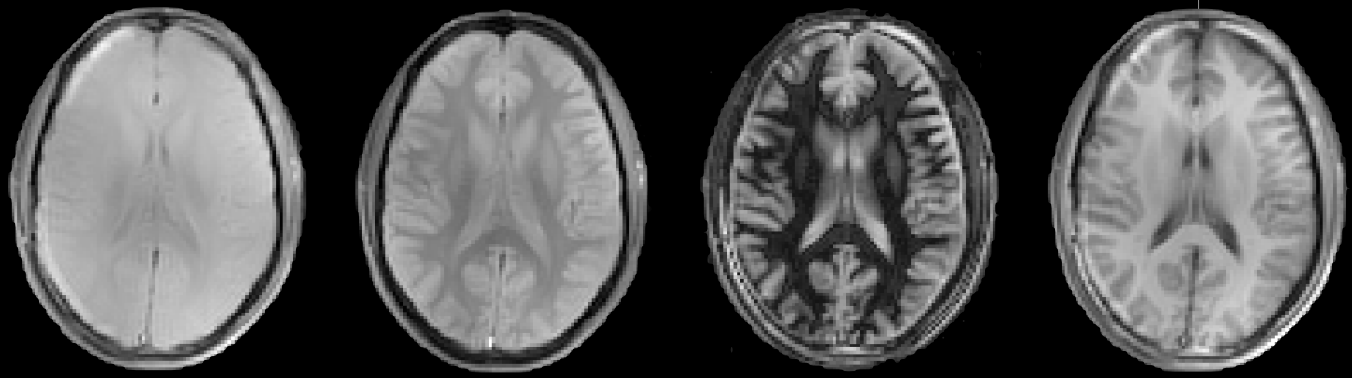
TI=200ms
TE=12ms

TI=500ms
TE=12ms

Longer TIs emphasize T_1-weighting.

Inversion Recovery + Spin Echo





TI=25ms
TE=12ms

TI=200ms
TE=12ms

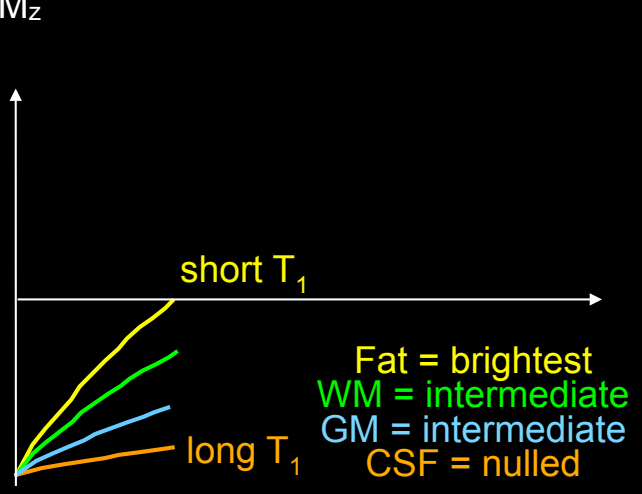
TI=500ms
TE=12ms

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,…

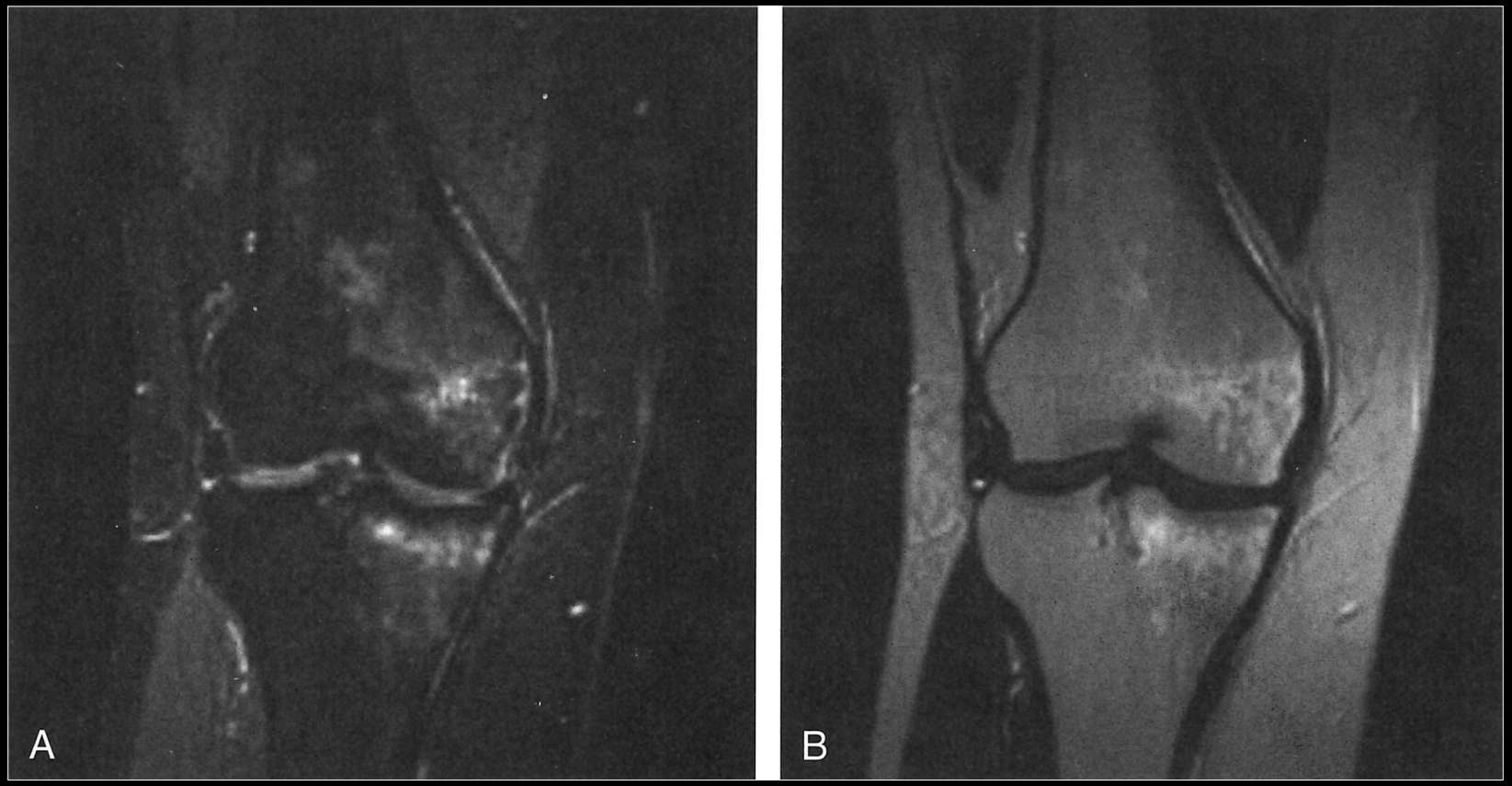



Sagittal T2-weighted Spin Echo


Sagittal T2-weighted STIR

Images Courtesy of Frank Korosec & radiopaedia.org

STIR vs. T2-weighted Fast Spin Echo

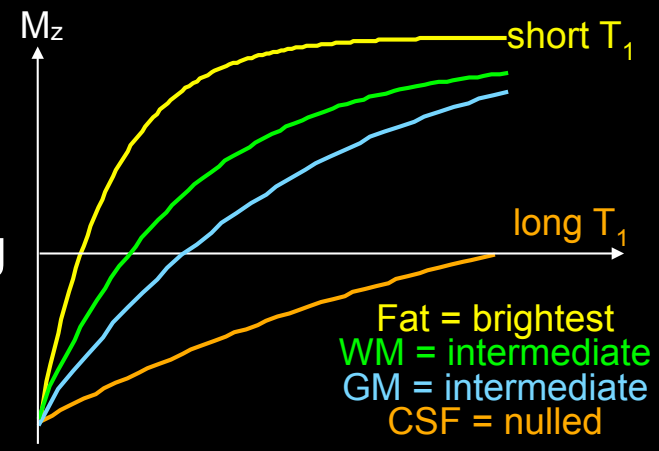


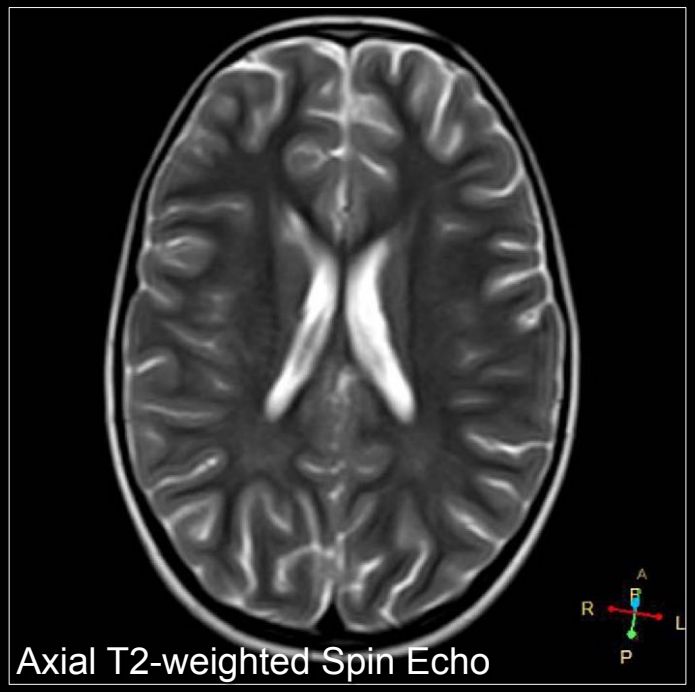
(A) Coronal **STIR** of the knee. **High-signal marrow edema** is identified in the middle of the tibial plateau and medial femoral condyle. Fraying of the lateral meniscus free edge represents a degenerative radial tear. (B) Coronal **T2-weighted FSE** at the same position. The **edema is largely obscured**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

Duke Review of MRI Principles, p. 88.

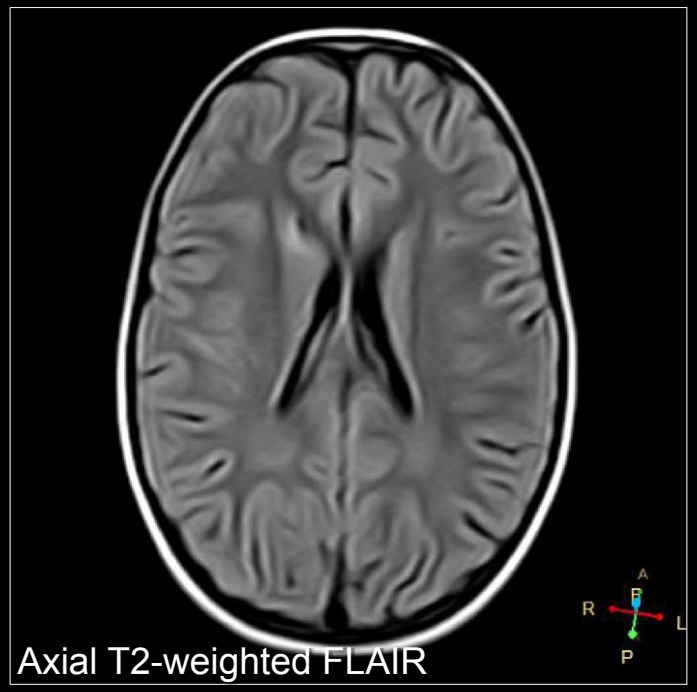
FLuid Attenuated Inversion Recovery (FLAIR)

- **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,…





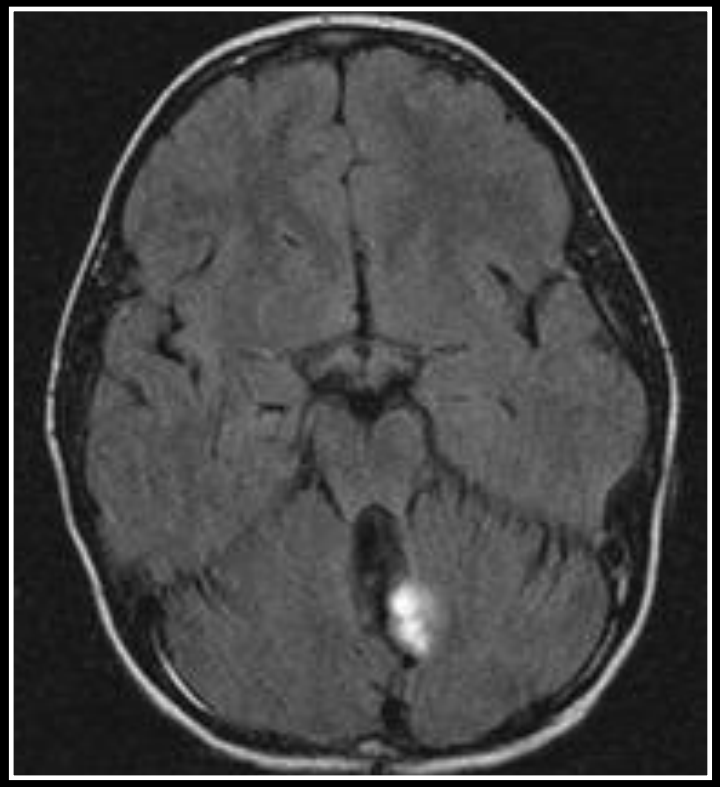
Axial T2-weighted Spin Echo



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

Questions?

- Related reading materials
  - Nishimura - Chap 7

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