# Image Contrast and Spin Echo MRI

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## Review of MRI Basics

- NMR Active Nuclei
  - e.g. $^{1}H$ in $H_{2}0$
- Magnetic Field ($B_0$): Polarizer
- RF System ($B_1$): Exciter
- Coil: Receiver
- Gradients ($G_X$, $G_Y$, $G_Z$): Spatial Encoding

# MRI Hardware

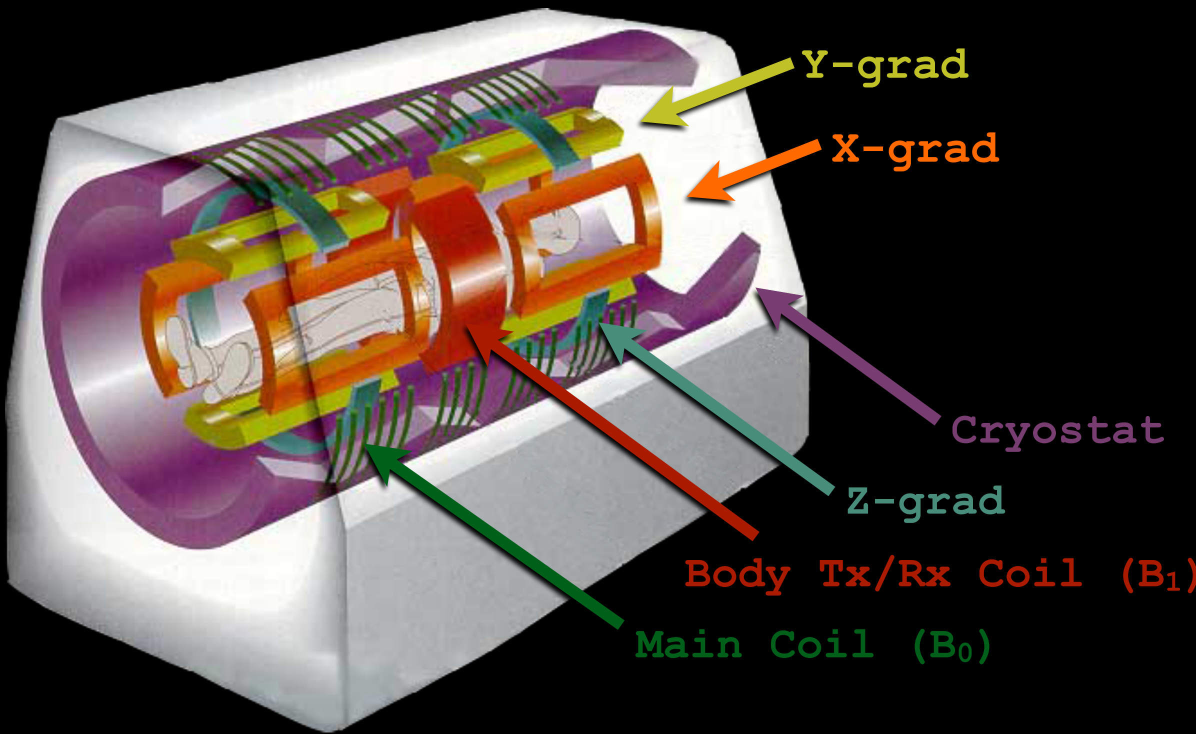
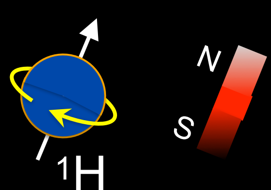
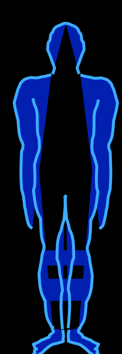


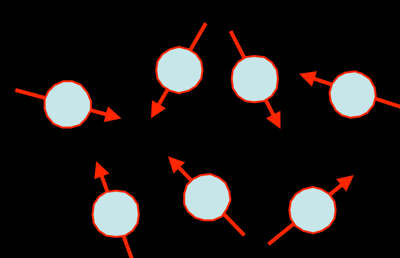

Image Adapted From: http://www.ee.duke.edu/~jshorey

# MRI: Basic Concepts

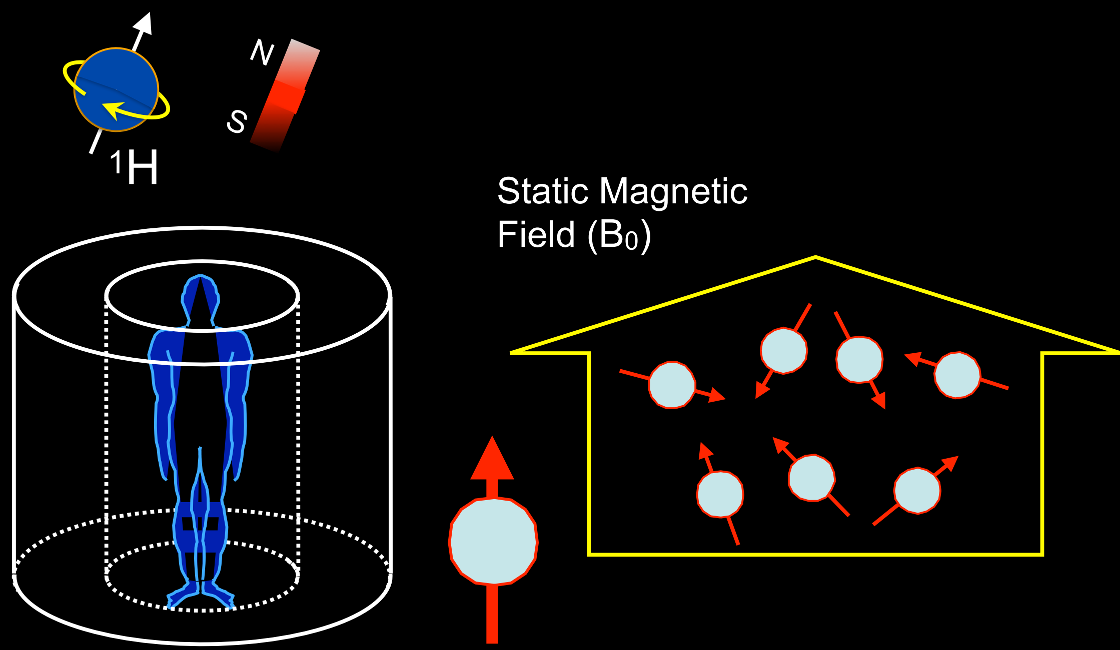



Certain atoms exhibit a spin angular momentum





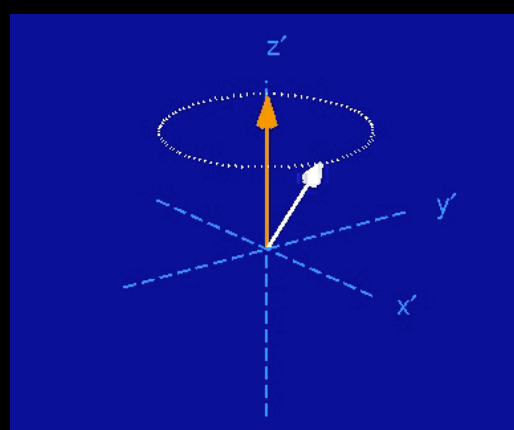
# MRI: Basic Concepts

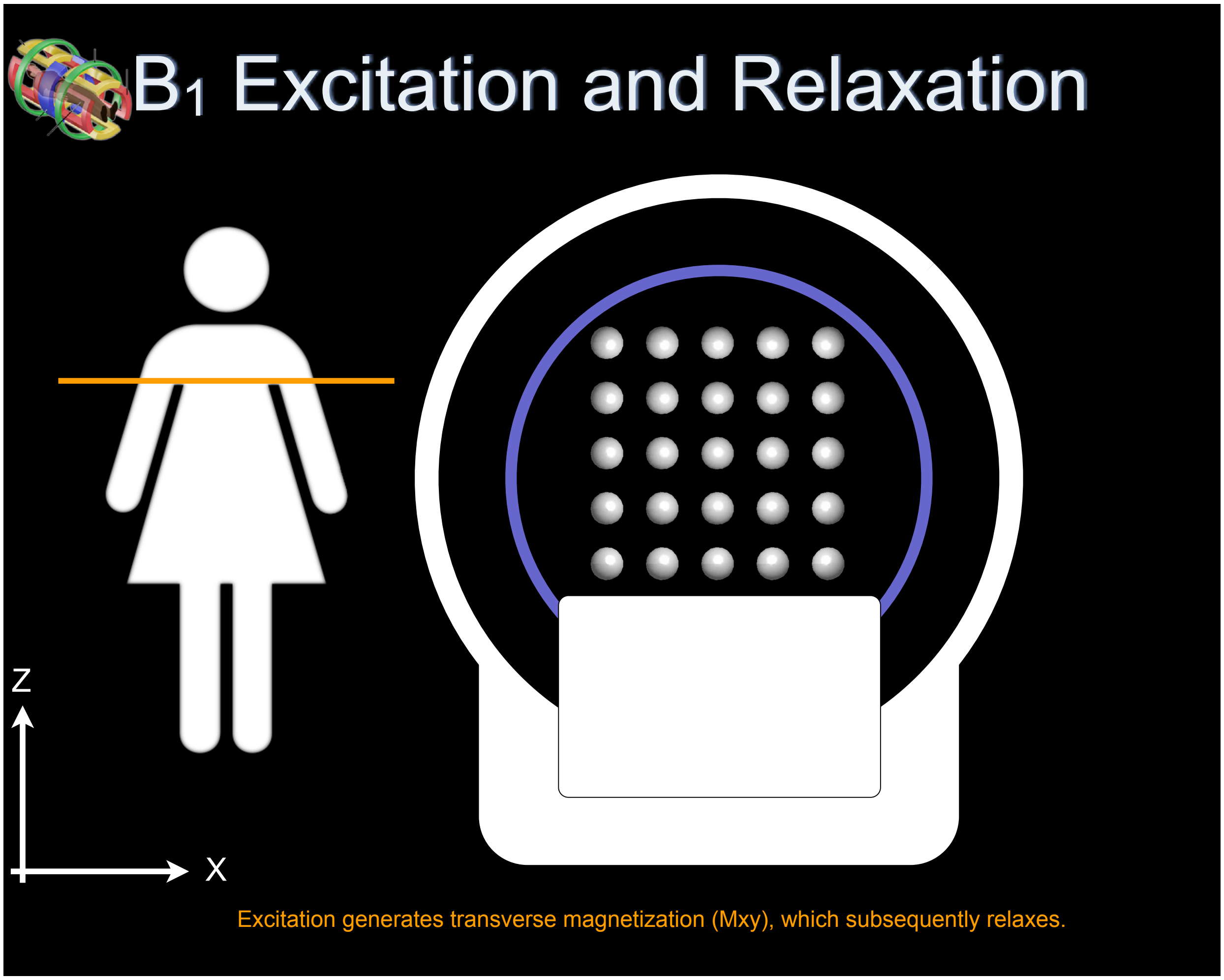


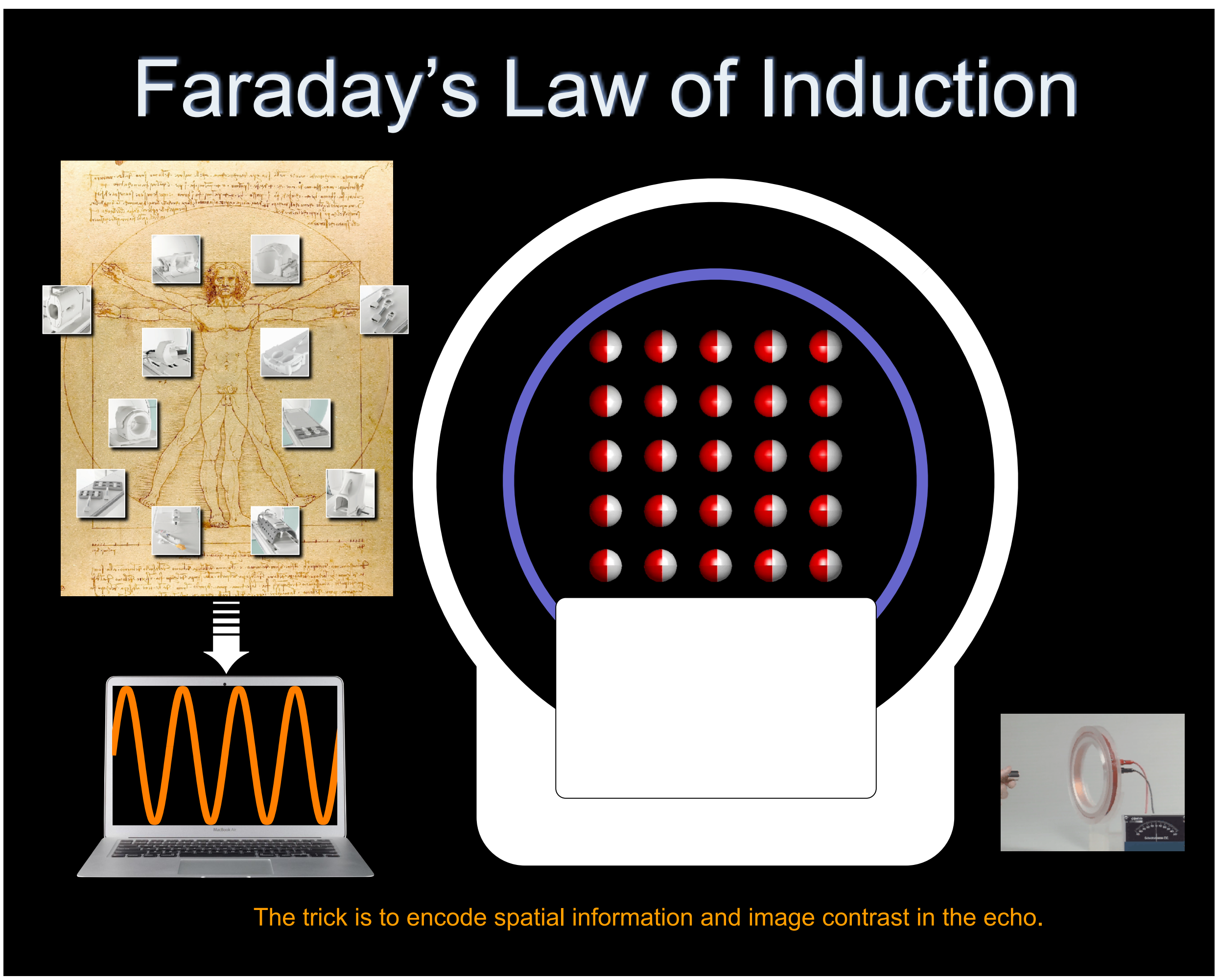

# Precession

- Spins precess about applied magnetic field, B0, that is along z axis.
- The frequency of this precession is proportional to the applied field:

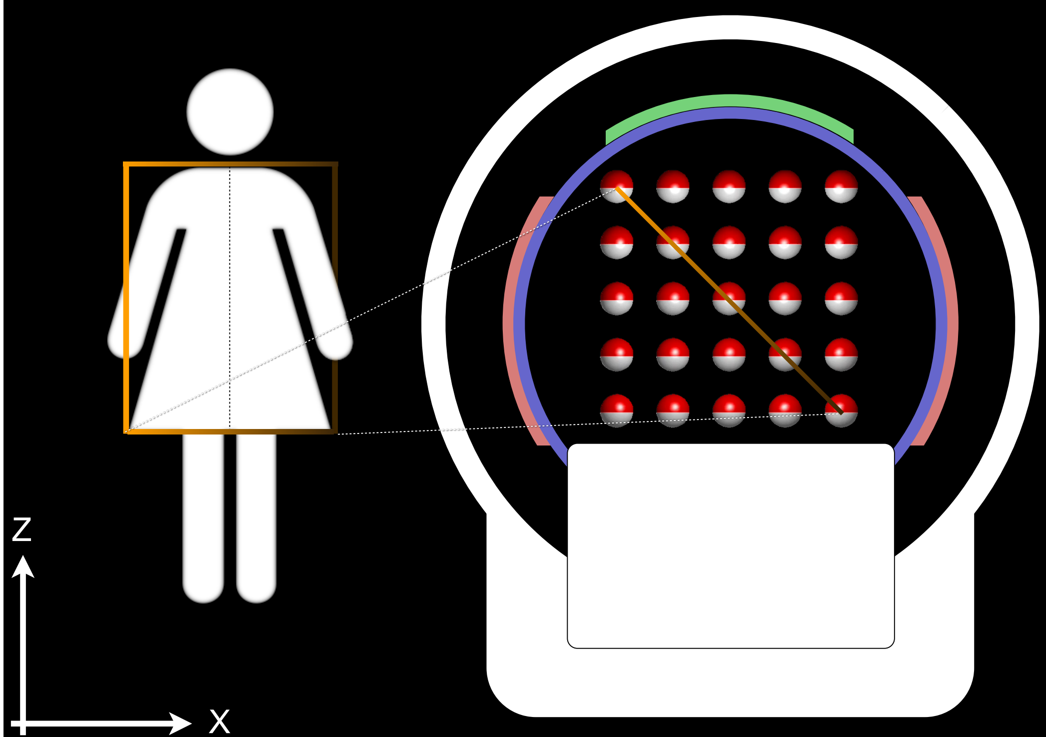
$$\omega = \gamma B_0$$




$B_1$ Excitation and Relaxation
Z
X
Excitation generates transverse magnetization (Mxy), which subsequently relaxes.


Faraday’s Law of Induction
The trick is to encode spatial information and image contrast in the echo.

## Gradients ($G_x$, $G_y$, and $G_z$)




Simultaneous gradients can create an arbitrary isochromat plane.

## Quiz: NMR - True or False?

1. Electron spin is the key to NMR.
2. MRI is *nothing* without speed, charge, and mass.
3. All atomic nuclei are NMR active.
4. Spin and precession are the same.
5. Higher fields lead to faster precession.

## Quiz: Main Field - True or False?

1. $B_0$ is rare earth permanent magnet.
2. 1 Tesla=1000 Gauss.
3. Higher fields increase polarization, which contributes to better image quality.
4. Exams at higher fields have lower SAR.
5. $^1H$ always precesses at the same Larmor frequency.

## Quiz: RF Pulses - True or False?

1. RF pulses are the main source of patient heating.
2. RF pulses excite spins and create transverse magnetization.
3. RF pulses are typically 100s of ms long.

## Quiz: RF Pulses - True or False?

1. Excitation pulses are not required for imaging.
2. Inversion pulses change image contrast.

## Quiz: Coils - True or False?

1. Faraday’s Law of Induction is the principal underlying signal reception.
2. The body coil is typically used for receiving the MRI signals.
3. Surface coils transmit RF excitation pulses.
4. Coils are designed for specific body parts.

## Quiz: Gradients - True or False?

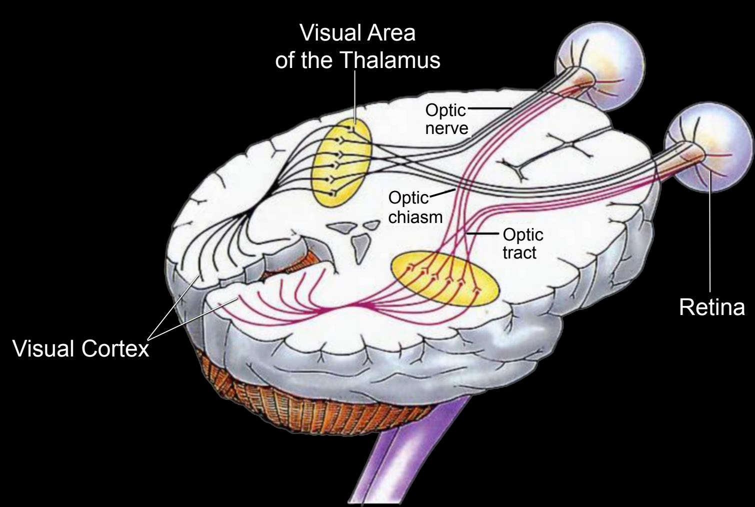
1. Gradients are primarily used to make the $B_0$-field more homogeneous.
2. Gradients are essential to spatial encoding.
3. X, Y, and Z gradients can not be applied simultaneously.

## Quiz: MRI Safety - True or False?

1. Gradients heat the patient and RF pulses causes peripheral nerve stimulation (PNS).
2. RF pulses can dislodge and torque implanted devices.
3. SAR limits constrain scan parameters.
4. Increasing the flip angle and decreasing the TR helps reduce patient heating.
5. MRI contrast agents are 100% safe.

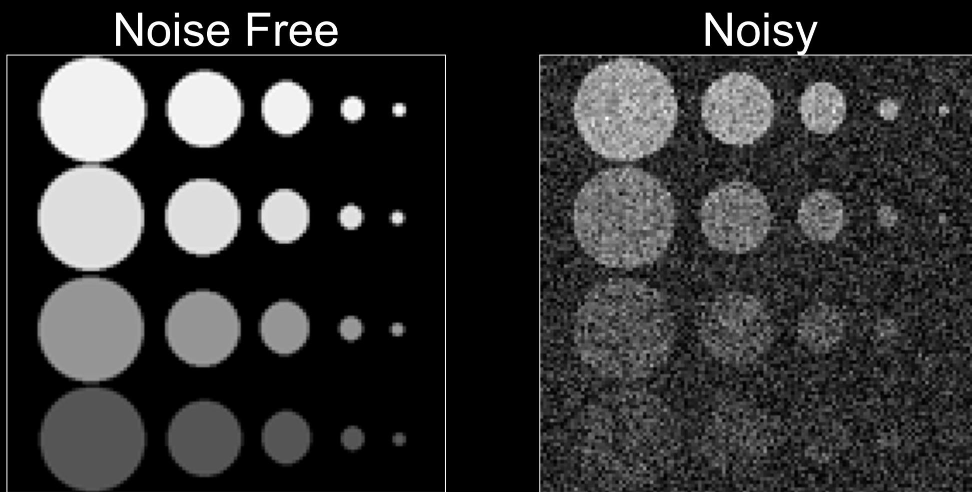
# Image Contrast

# Why Image Contrast?

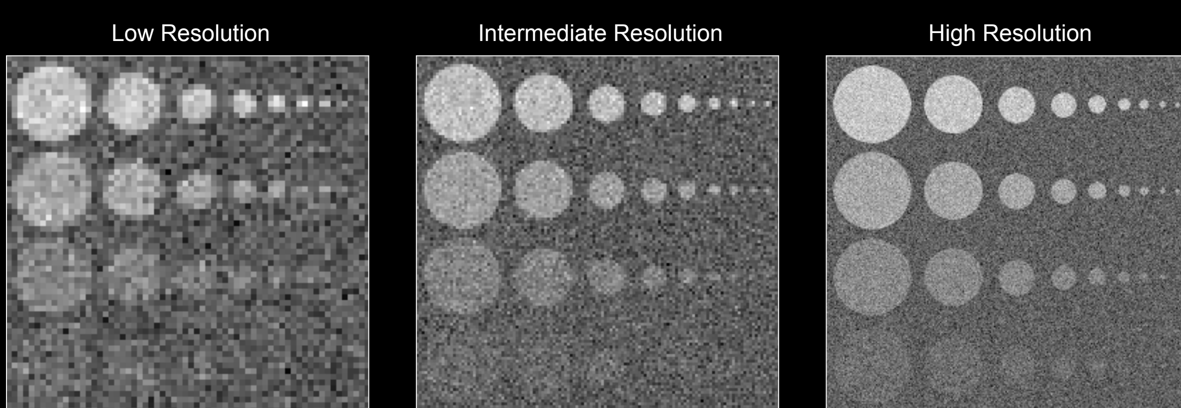



The human visual system is more sensitive to contrast than absolute luminance.

# Signal to Noise Ratio (SNR)



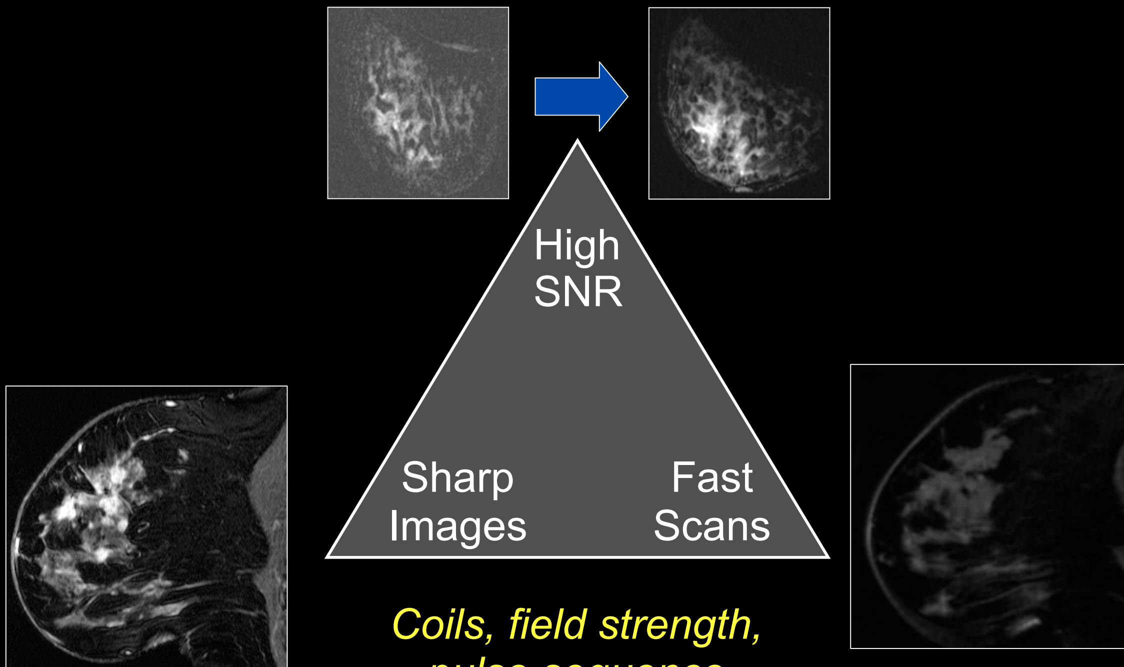

# SNR vs. Resolution




Small low-contrast objects are easier to see with higher resolution.

Image signal-to-noise is constant.

# SNR vs Resolution vs Scan Time



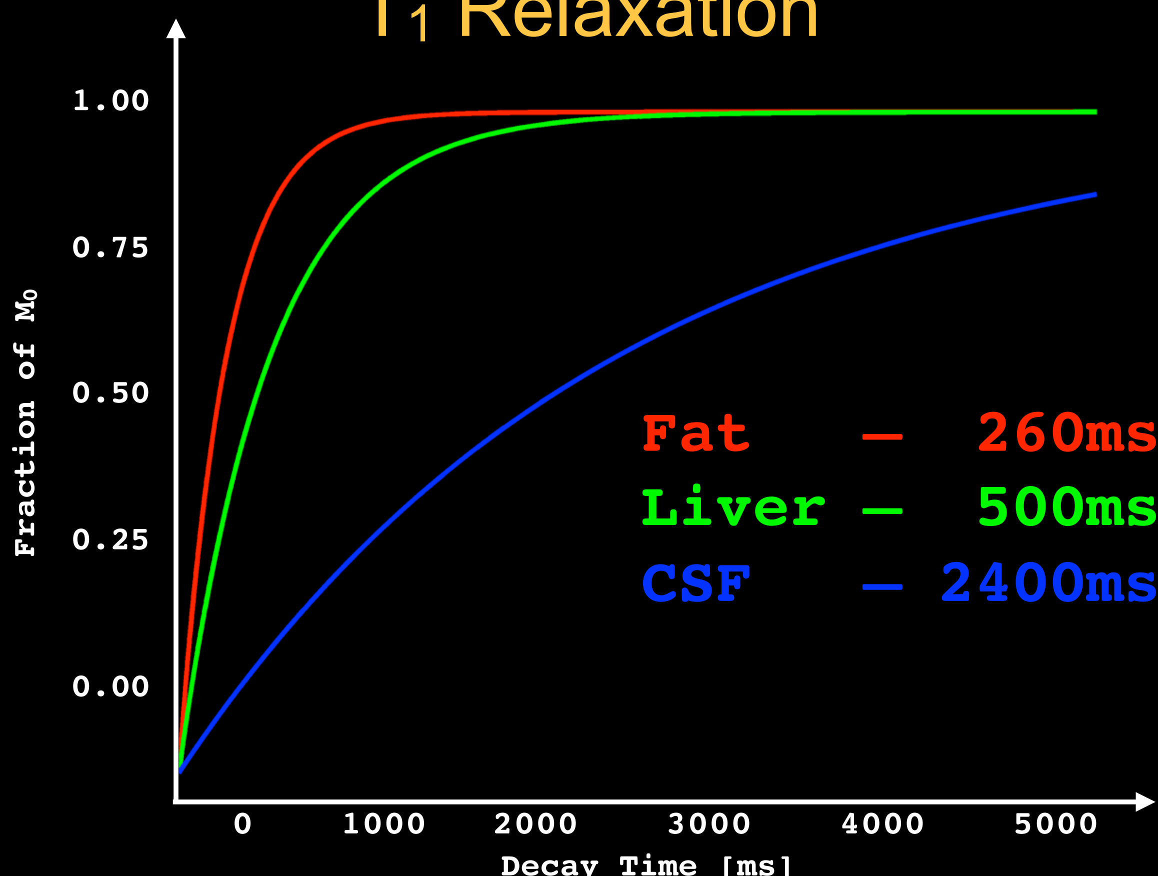

*Coils, field strength, pulse sequence affect starting point!*

# $T_1$ & $T_2$ 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

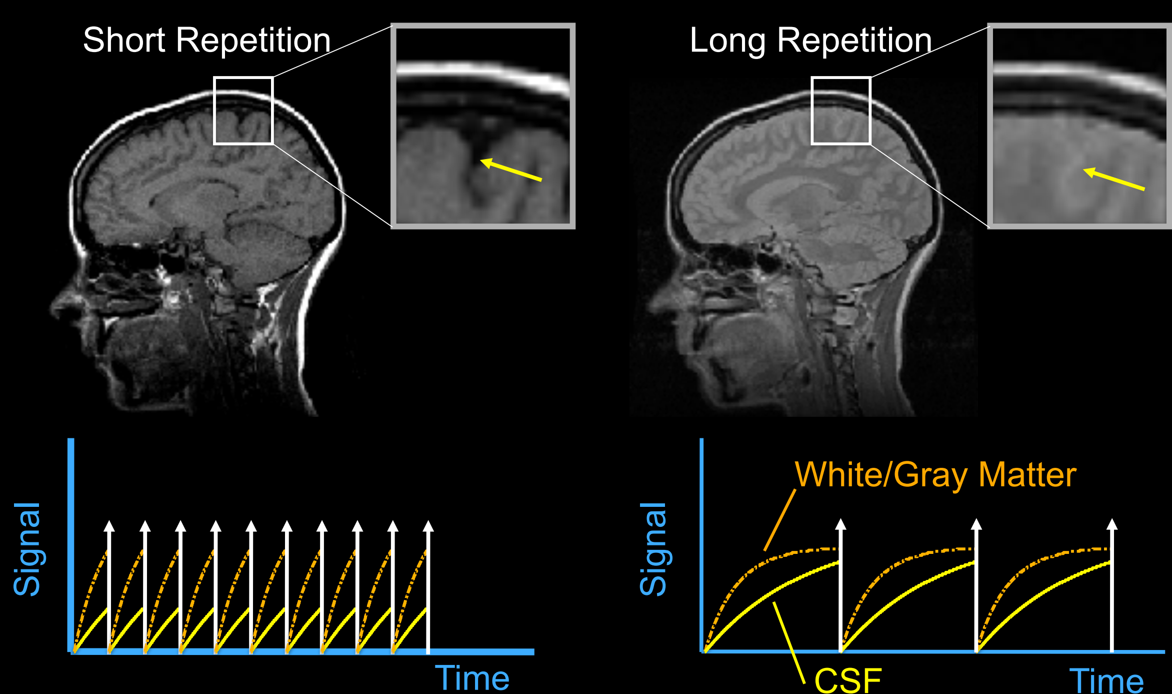


# $T_1$ Relaxation

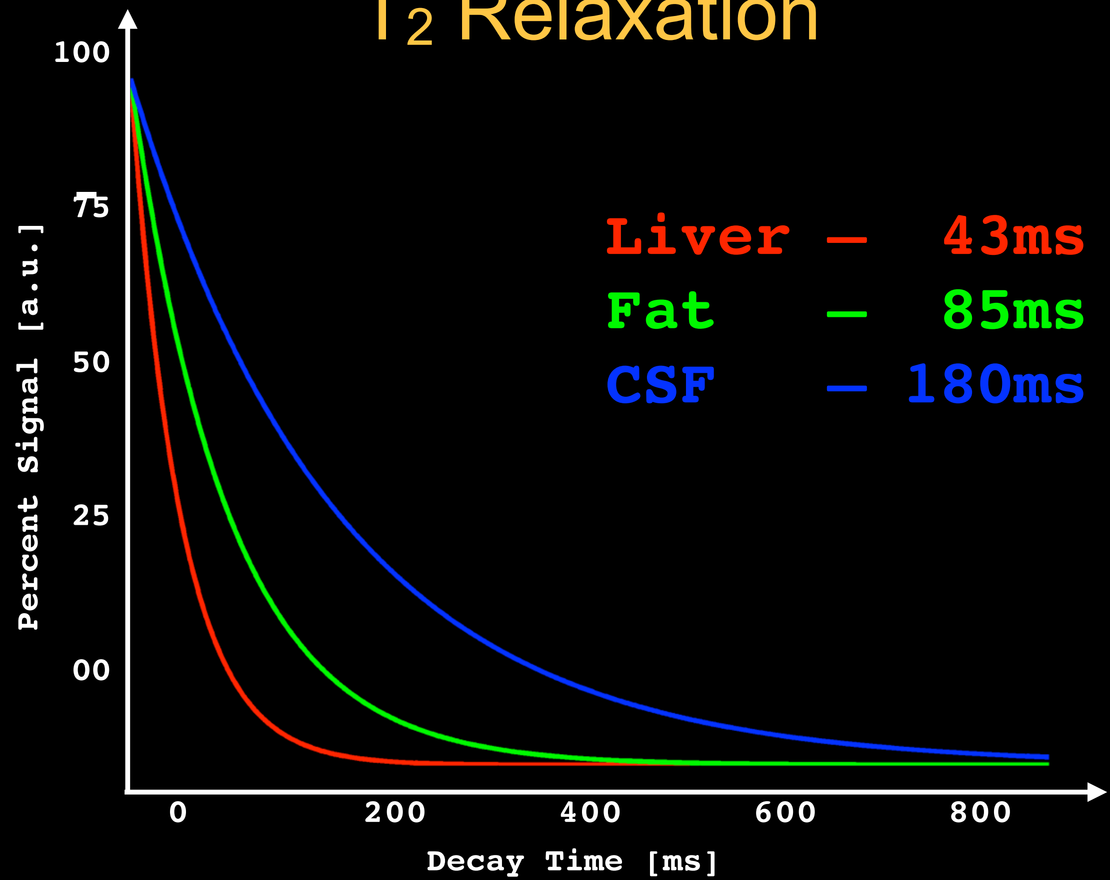
- Longitudinal or spin-lattice relaxation
  - Typically, (10s ms) < T1 < (100s ms)
- T1 is long for
  - Small molecules (water)
  - Large molecules (proteins)
- T1 is short for
  - Fats and intermediate-sized molecules
- T1 increases with increasing B0
- T1 decreases with contrast agents

Short $T_1$s are bright on $T_1$-weighted image

# T1 Contrast



# $T_2$ Relaxation

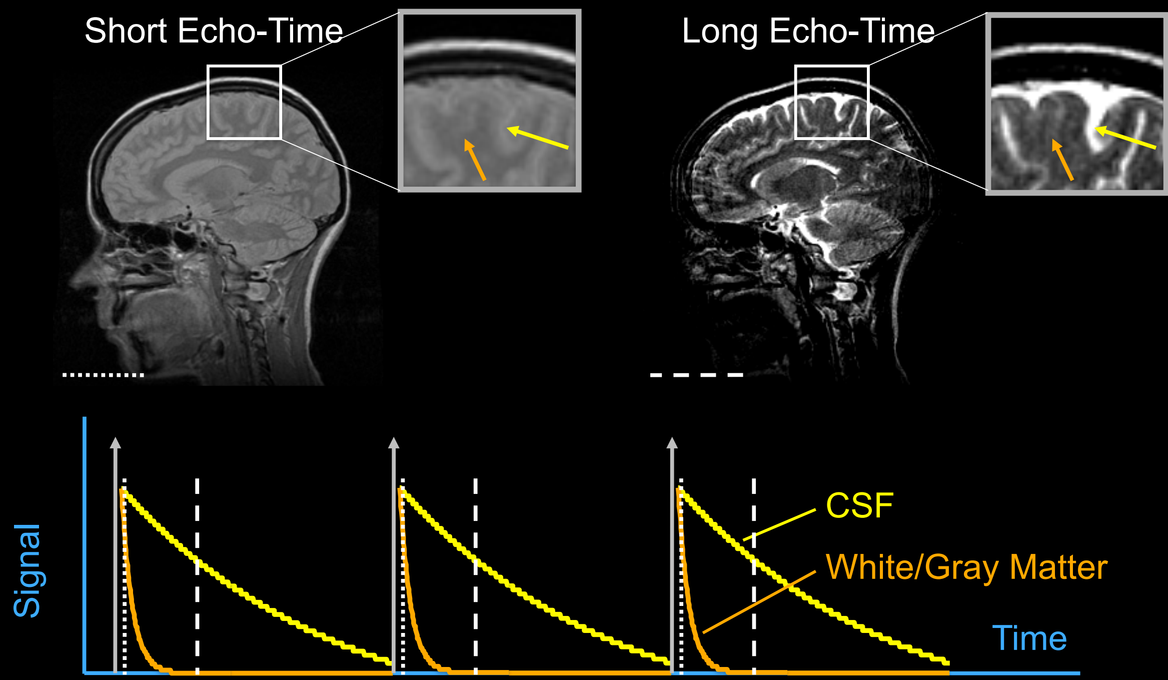



# $T_2$ Relaxation

- 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




# $T_1$ 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 |

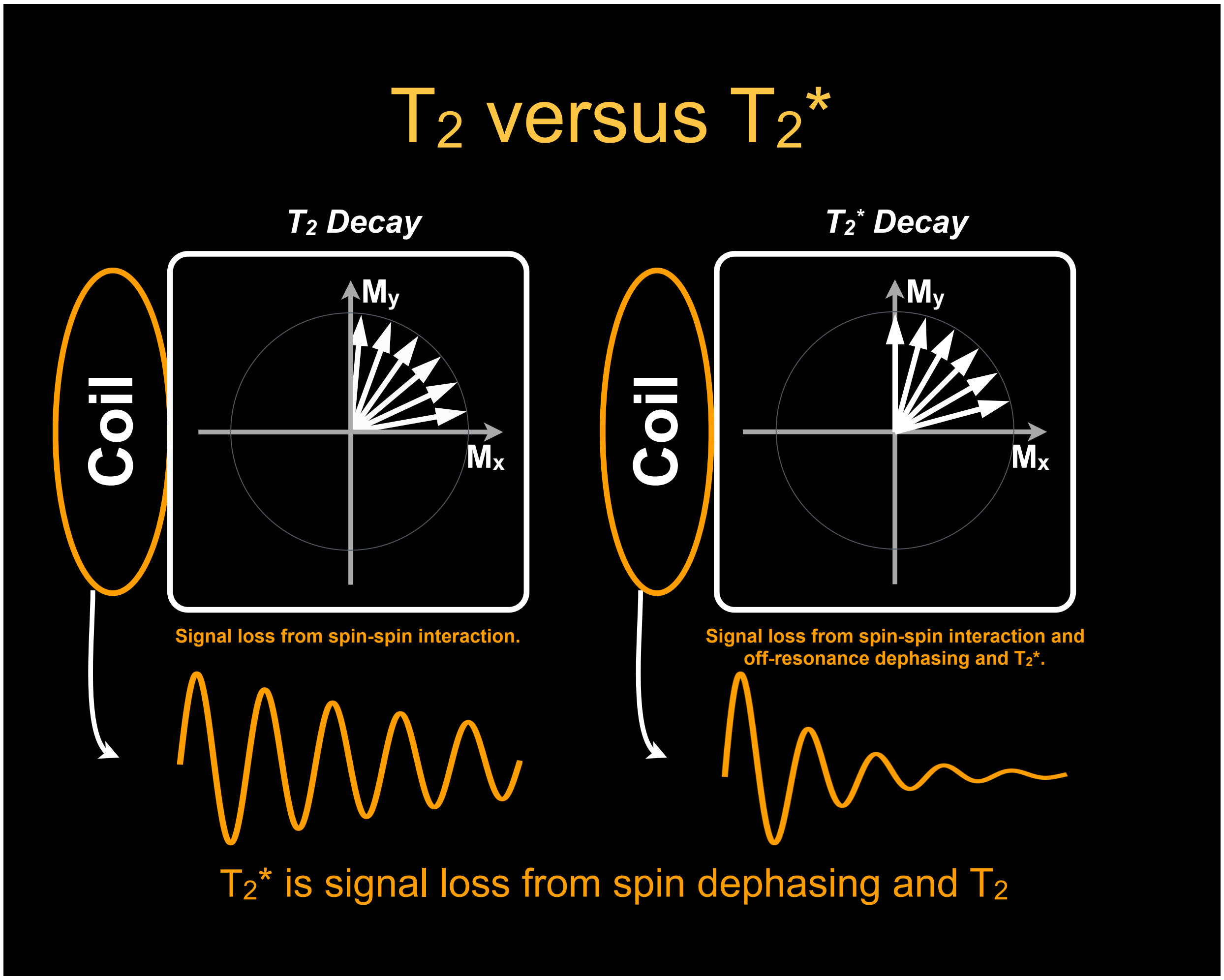
Each tissue has “unique” relaxation properties, which enables “soft tissue contrast”.

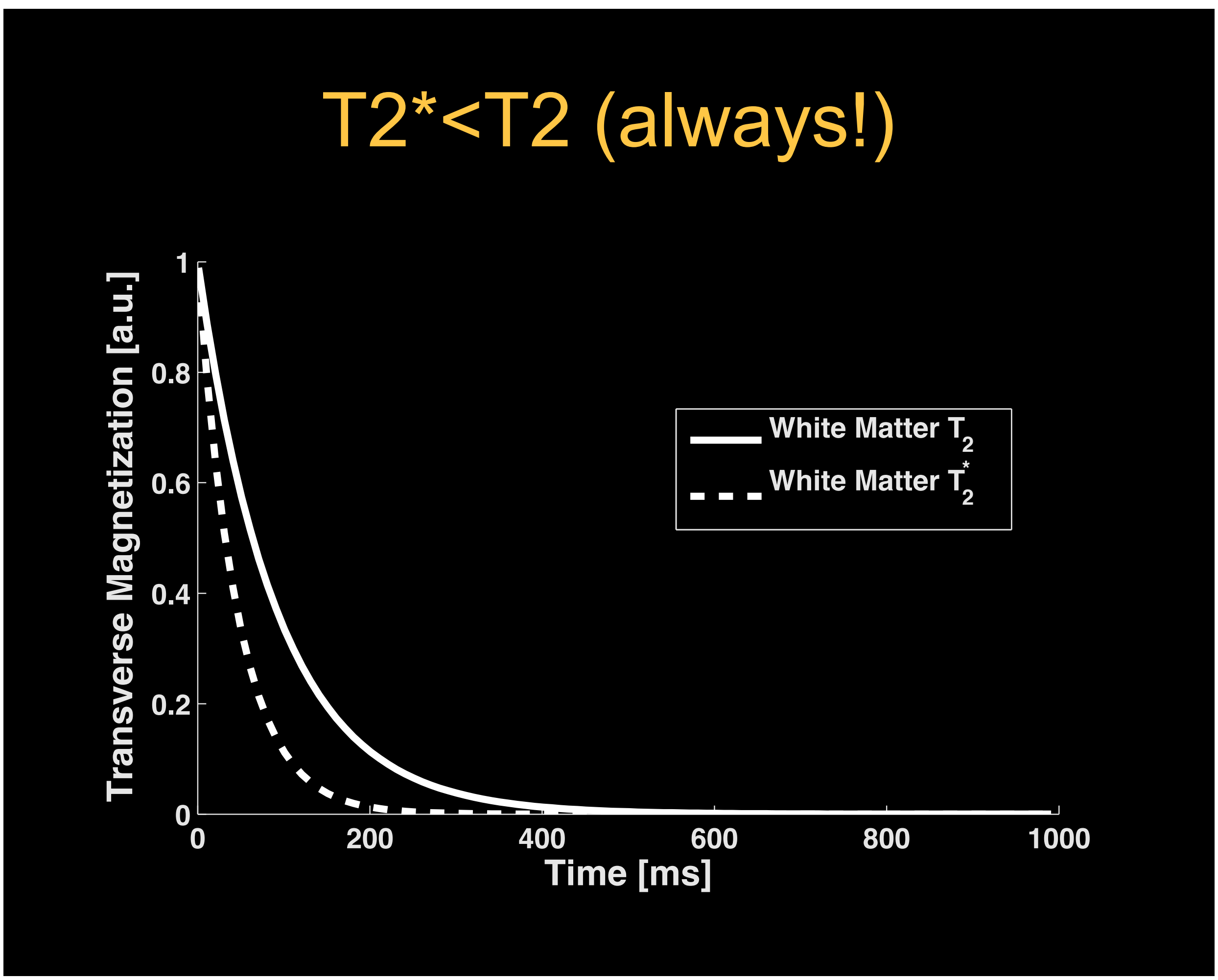
# $T_2^*$ Relaxation

# $T_2^*$ 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)


T2 versus T2*
T2 Decay
T2* Decay
Coil
My
Mx
Coil
My
Mx
Signal loss from spin-spin interaction.
Signal loss from spin-spin interaction and off-resonance dephasing and T2*.
T2* is signal loss from spin dephasing and T2


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 T2
White Matter T2*

# Relaxation - True or False?

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

# Relaxation - True or False?

1. $T_2^* > T_2 > T_1$
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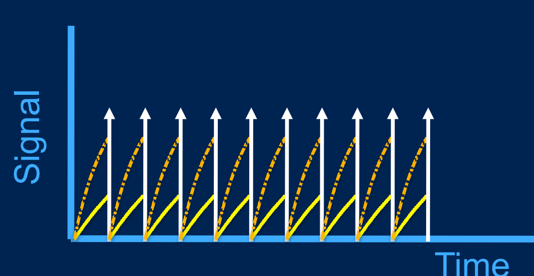


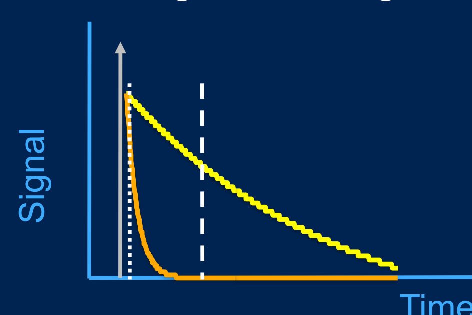

# Relaxation - True or False?

1. $T_1$(CSF) > $T_1$(Gray Matter)
2. $T_2$(Liver) < $T_2$(Fat)

# Relaxation - True or False?

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 |
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| fat | 260 | 85 |
| kidney | 650 | 58 |
| liver | 500 | 43 |
| CSF | 2400 | 180 |

# Contrast Agents

# Contrast Agents

- Enhance image contrast in regions that are perfused by contrast agent.

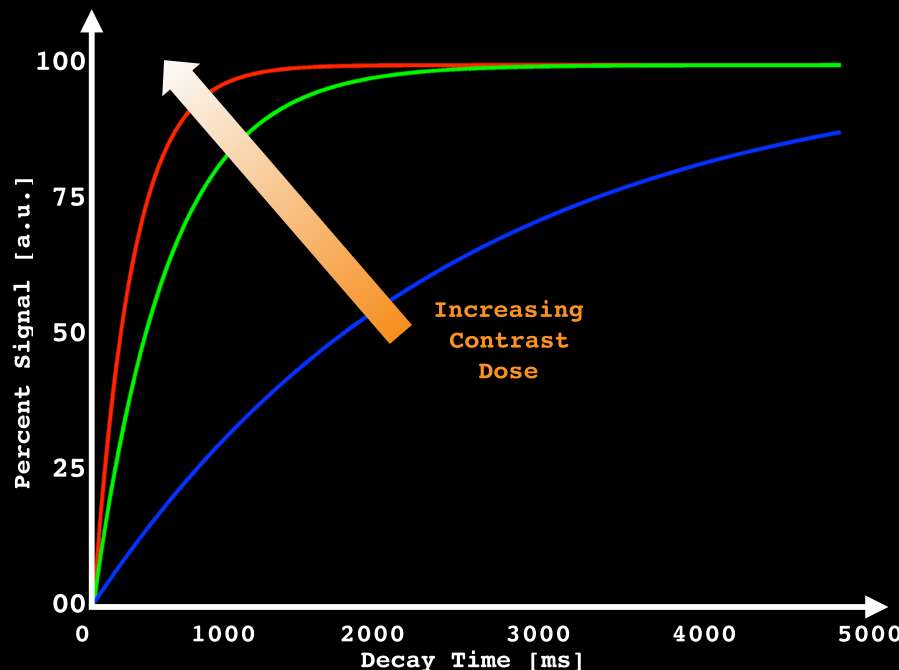
# Gadolinium Based Agent


- $T_1$ shortening agent, administered I.V.
- Hydrophilic
  - Doesn't cross blood brain barrier
- Blood pool agent
  - Excreted via kidneys in ~2-3 hours
  - Extravasates into tumors/infarcts and across leaky BBB
- Paramagnetic
  - Unpaired electrons ⇒ ↑susceptibility ⇒ ↑ field

# Gadolinium Based Agent Safety


- *Nephrogenic Systemic Fibrosis (NSF)*
  - Resembles scleromyxedema and scleroderma
- WHO states ***<u>some</u>*** Gad-based agents are contraindicated:
  - Severe kidney problems (GFR<30mL/min/ 1.73 m$^2$)
  - Scheduled/recent liver transplant
  - Newborn babies up to four weeks of age
- No newly reported cases in several years...

# T1 Shortening Agents




Increasing dose of a T1 shortening agent increases signal, ***but***
too much contrast is unsafe and will compromise image quality.

# Gadolinium Enhanced MRA

Pre-Contrast

Post-Contrast

Images Courtesy of Paul Finn

# Gadolinium Enhanced MRA

Subtracted MIP


Volume Rendering


Gadolinium based MRA courtesy of Paul Finn.

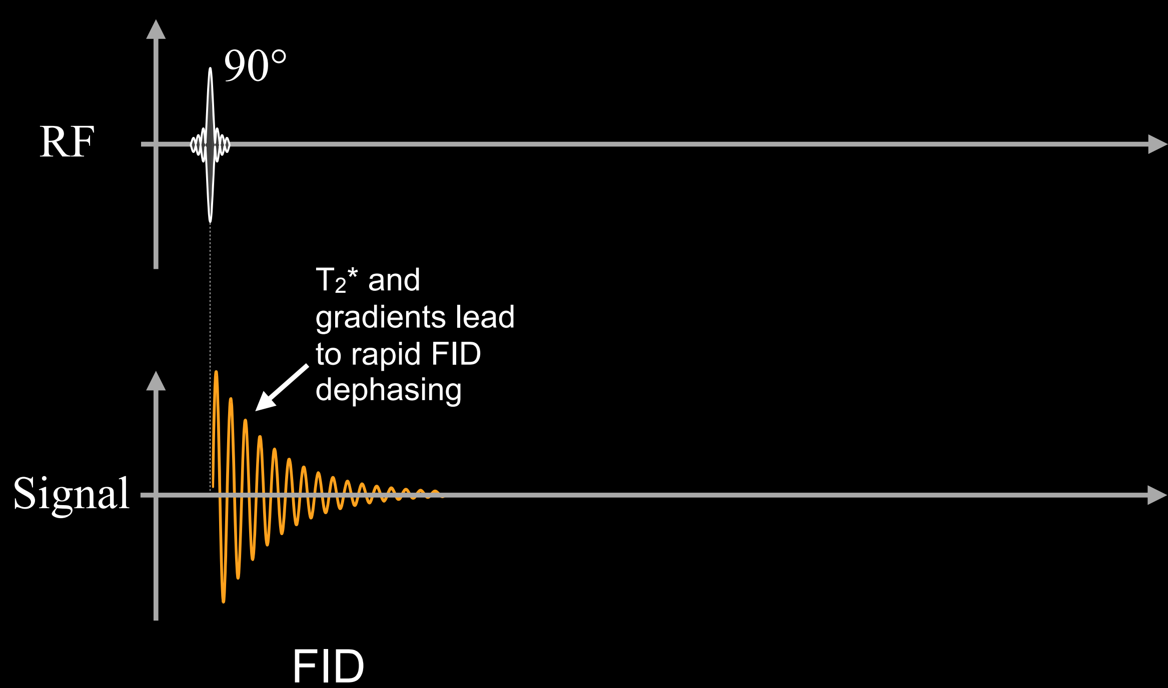
# Quiz: Contrast Agents - True or False?

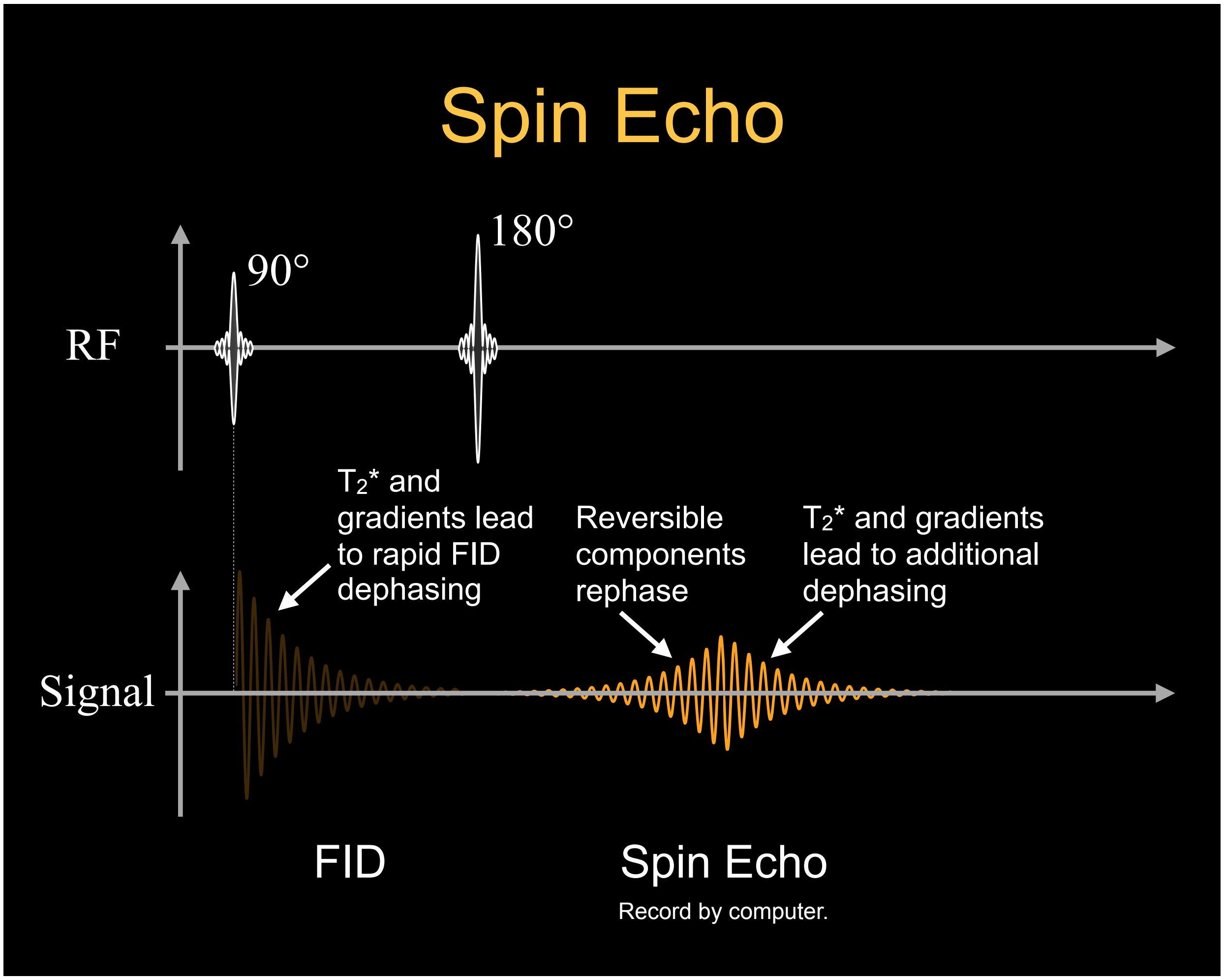
1. Gadolinium-based agents act to lengthen $T_1$.

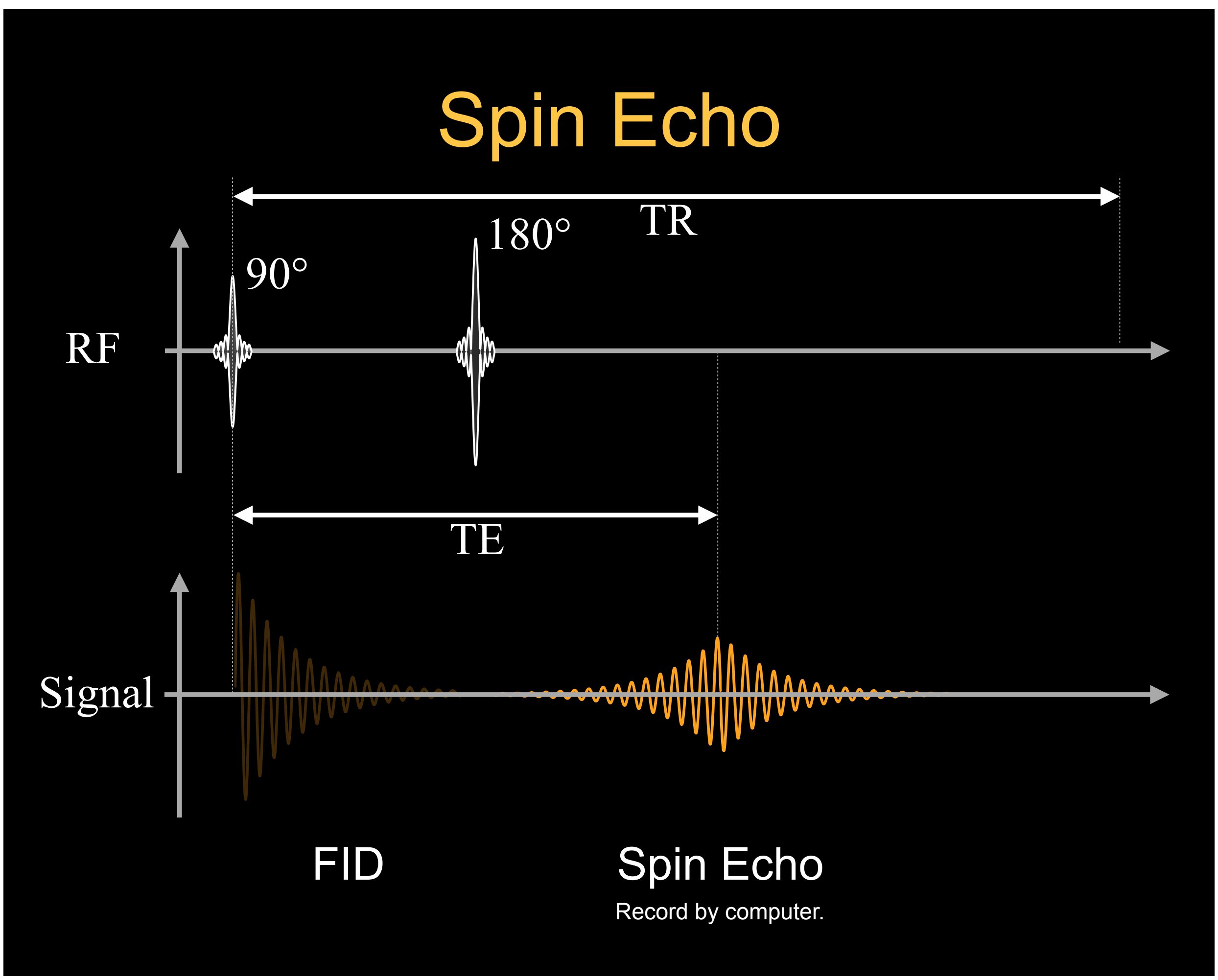
2. MRI contrast agents are widely considered very safe.

# Spin Echo Imaging

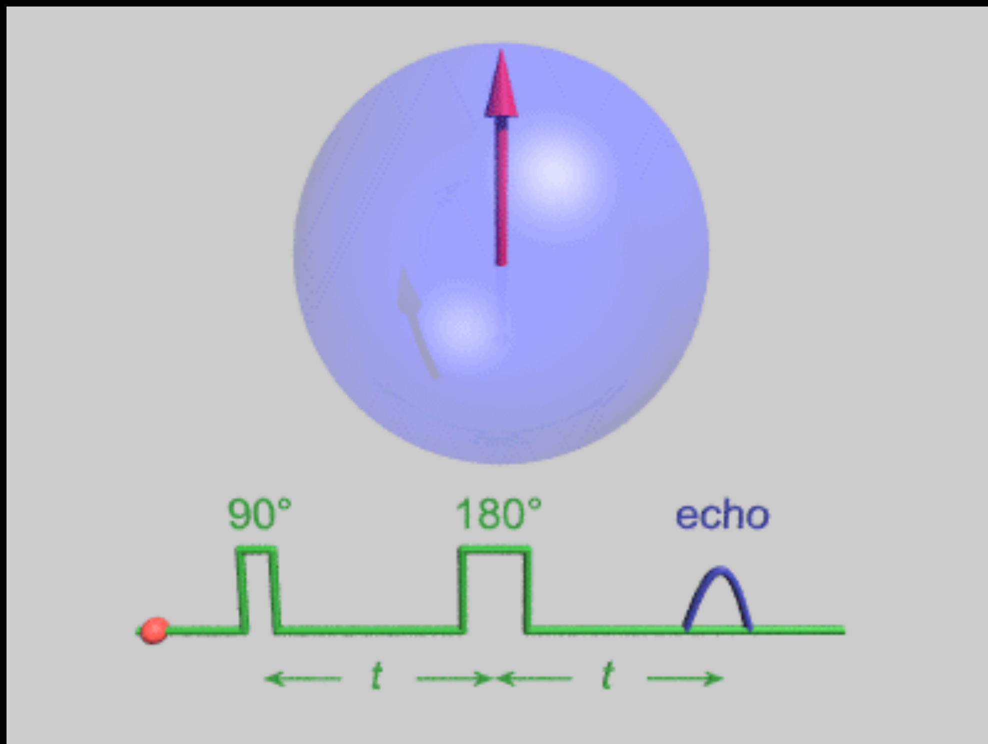
# Free Induction Decay




Spin Echo
180°
90°
RF
T$_2$* and gradients lead to rapid FID dephasing
Reversible components rephase
T$_2$* and gradients lead to additional dephasing
Signal
FID
Spin Echo
Record by computer.

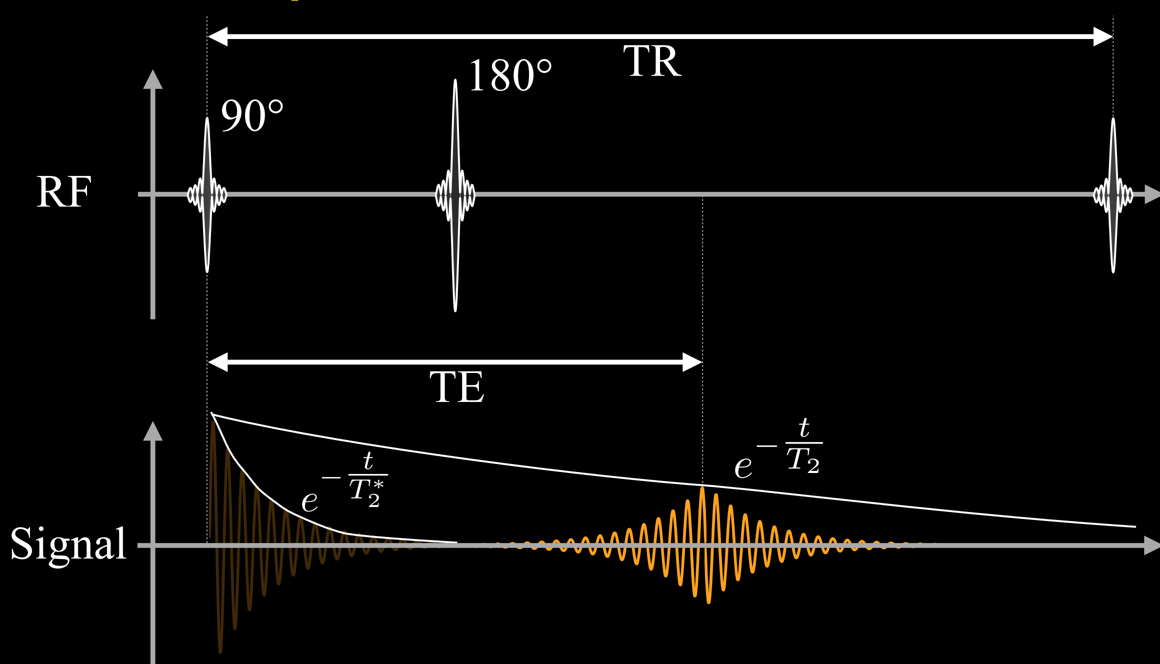

Spin Echo
180°
TR
90°
RF
TE
Signal
FID
Spin Echo
Record by computer.

# 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 |
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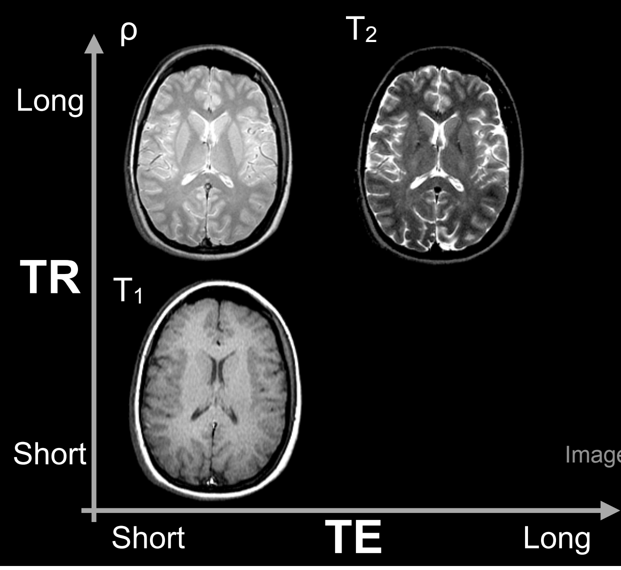
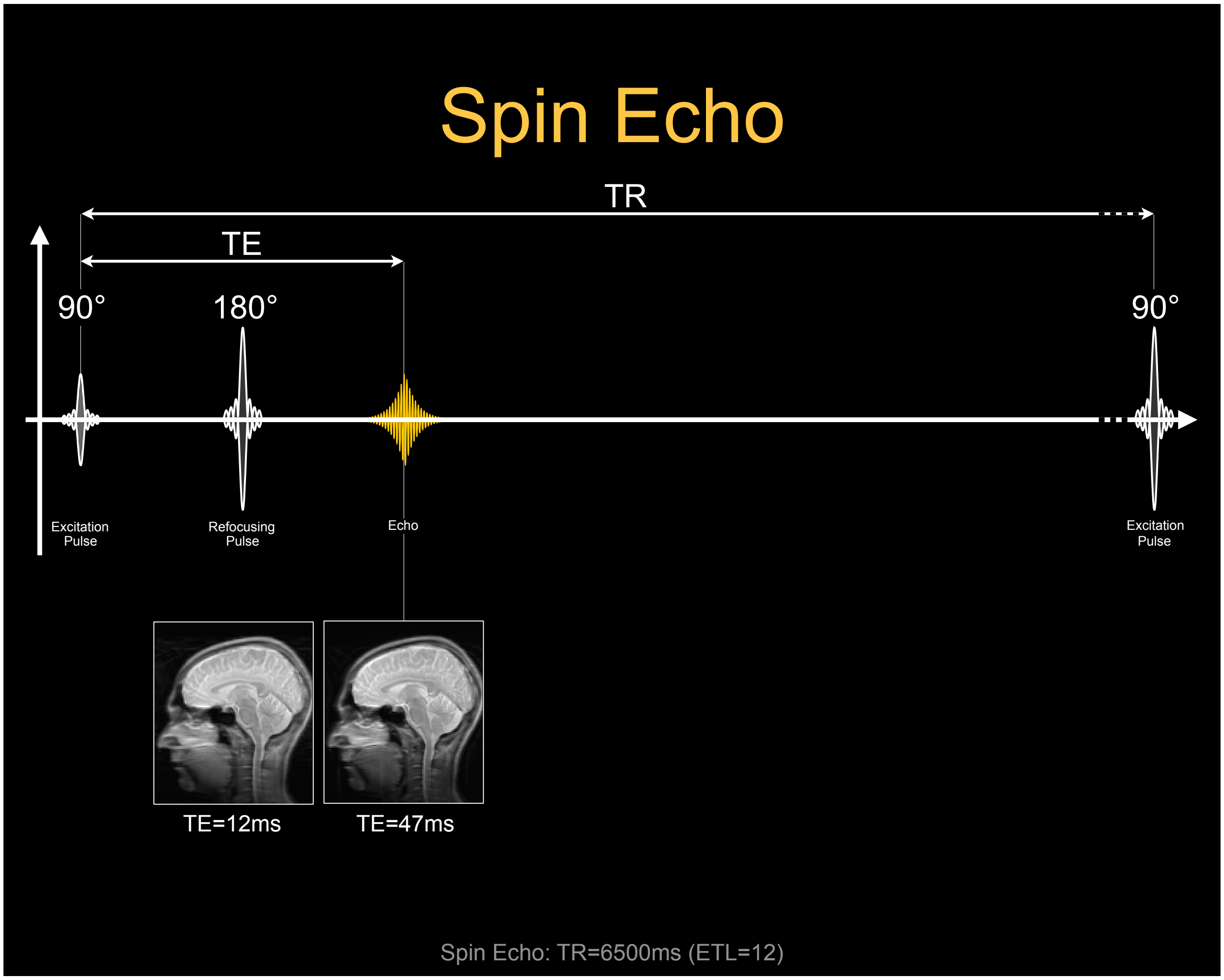
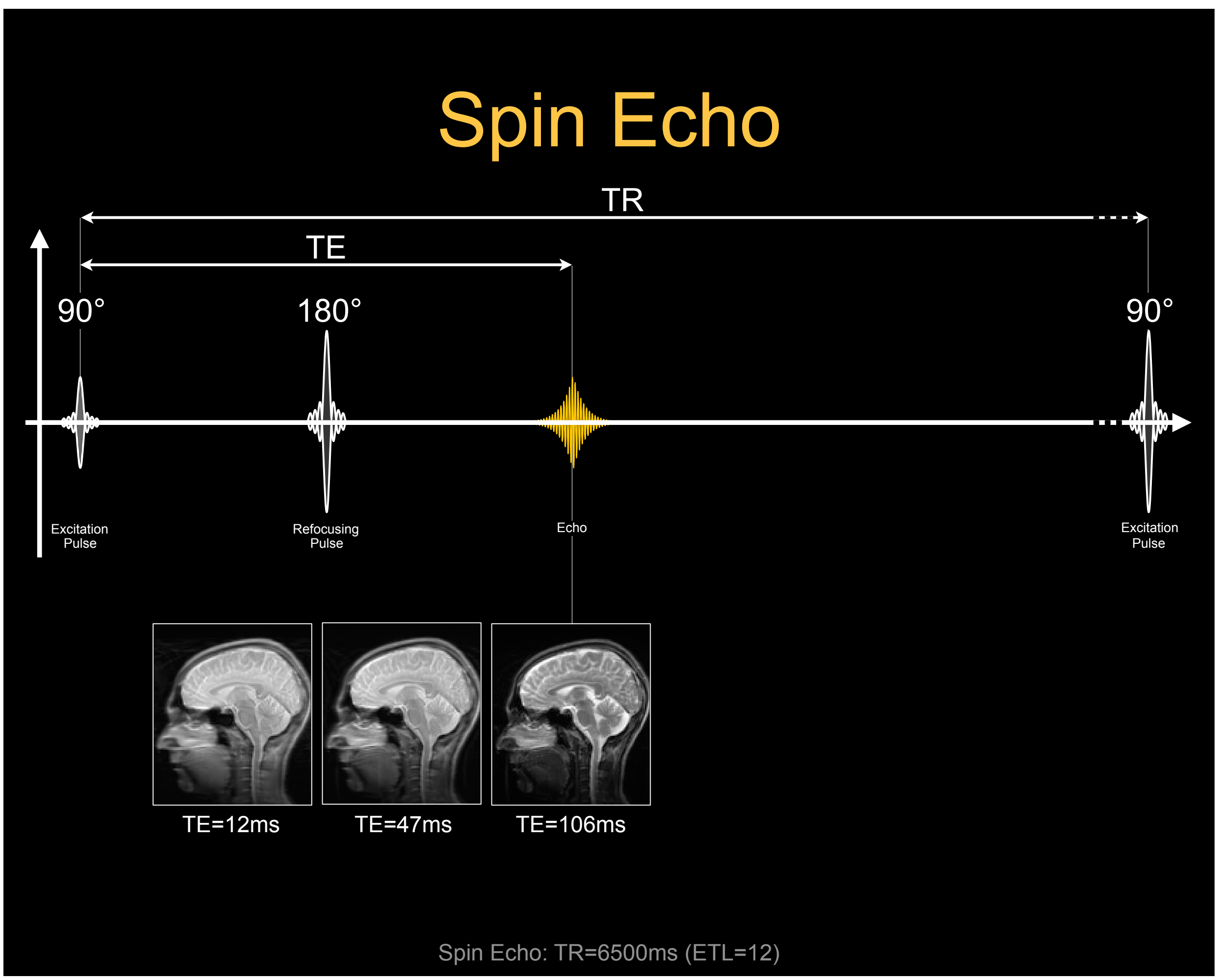


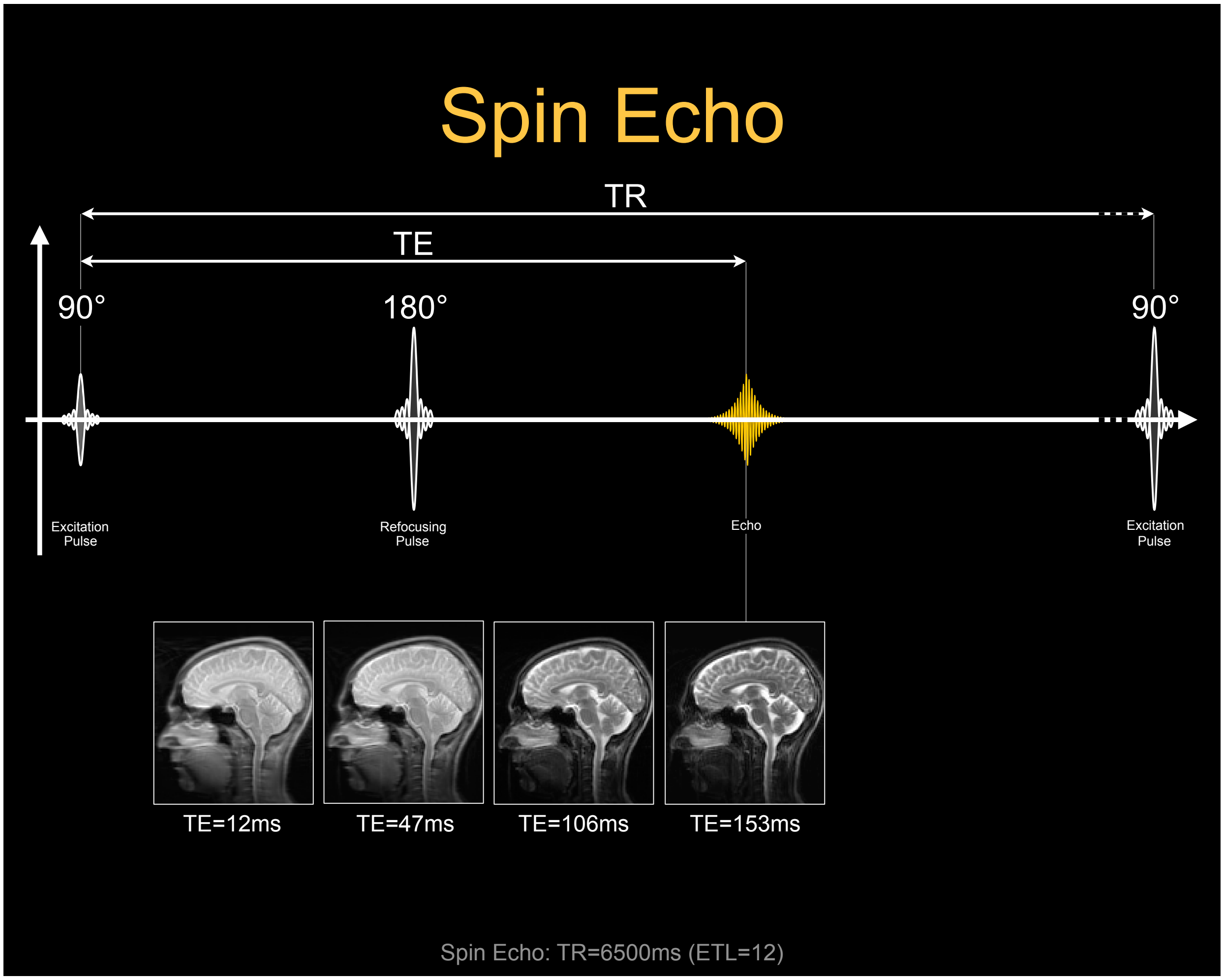

Images Courtesy of Mark Cohen

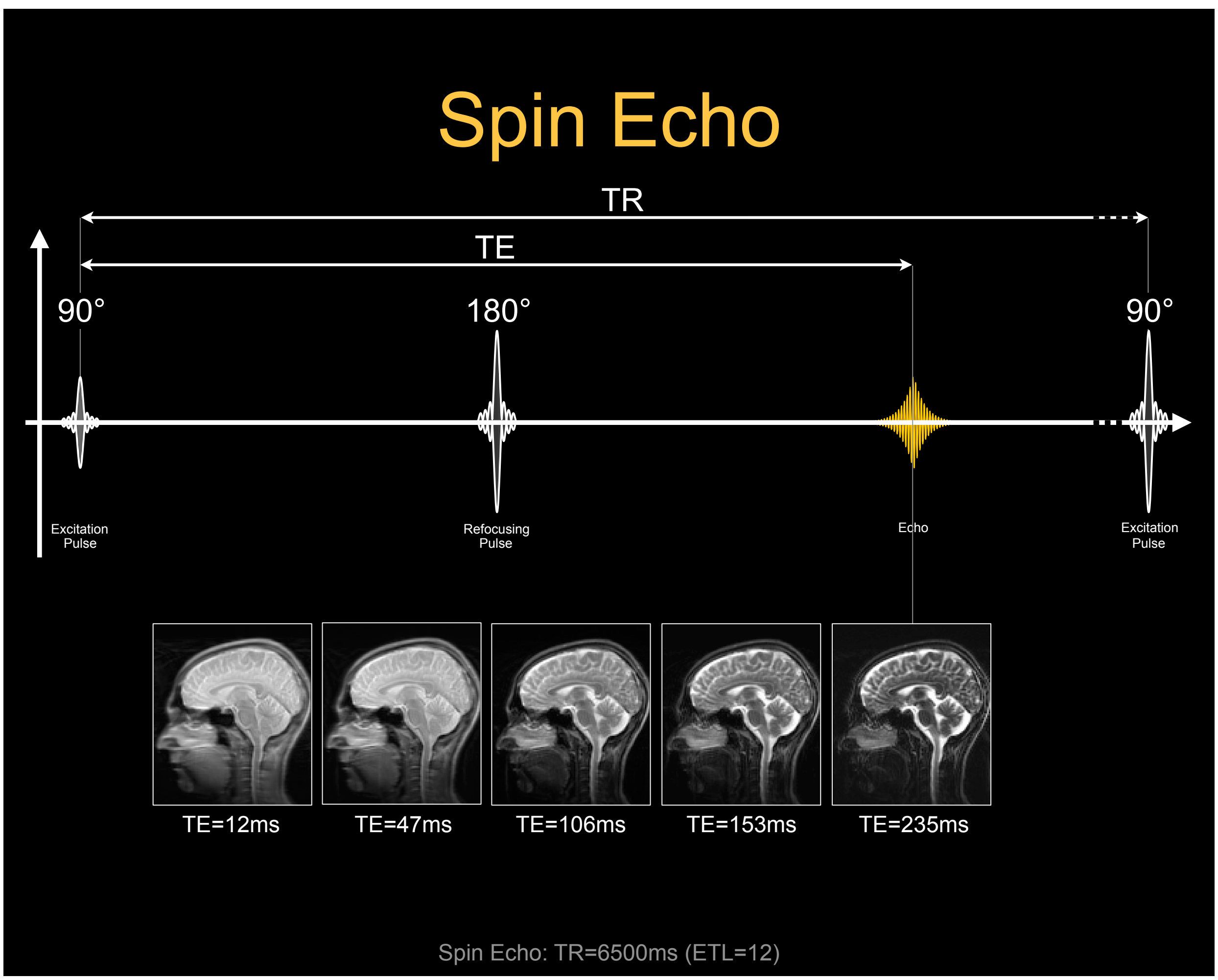
# Spin Echo


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


Spin Echo
TR
TE
90°
180°
90°
Excitation Pulse
Refocusing Pulse
Echo
Excitation Pulse
TE=12ms
TE=47ms
Spin Echo: TR=6500ms (ETL=12)


Spin Echo
TR
TE
90°
180°
90°
Excitation Pulse
Refocusing Pulse
Echo
Excitation Pulse
TE=12ms
TE=47ms
TE=106ms
Spin Echo: TR=6500ms (ETL=12)


Spin Echo
TR
TE
90°
180°
90°
Excitation Pulse
Refocusing Pulse
Echo
Excitation Pulse
TE=12ms
TE=47ms
TE=106ms
TE=153ms
Spin Echo: TR=6500ms (ETL=12)


Spin Echo
TR
TE
90°
180°
90°
Excitation Pulse
Refocusing Pulse
Echo
Excitation Pulse
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 $T_1$, $T_2$, $\rho$ 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

# 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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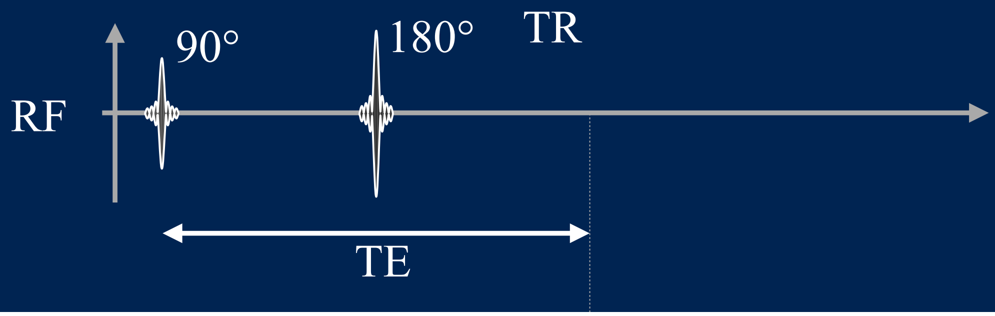



# Spin Echoes - True or False?

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?

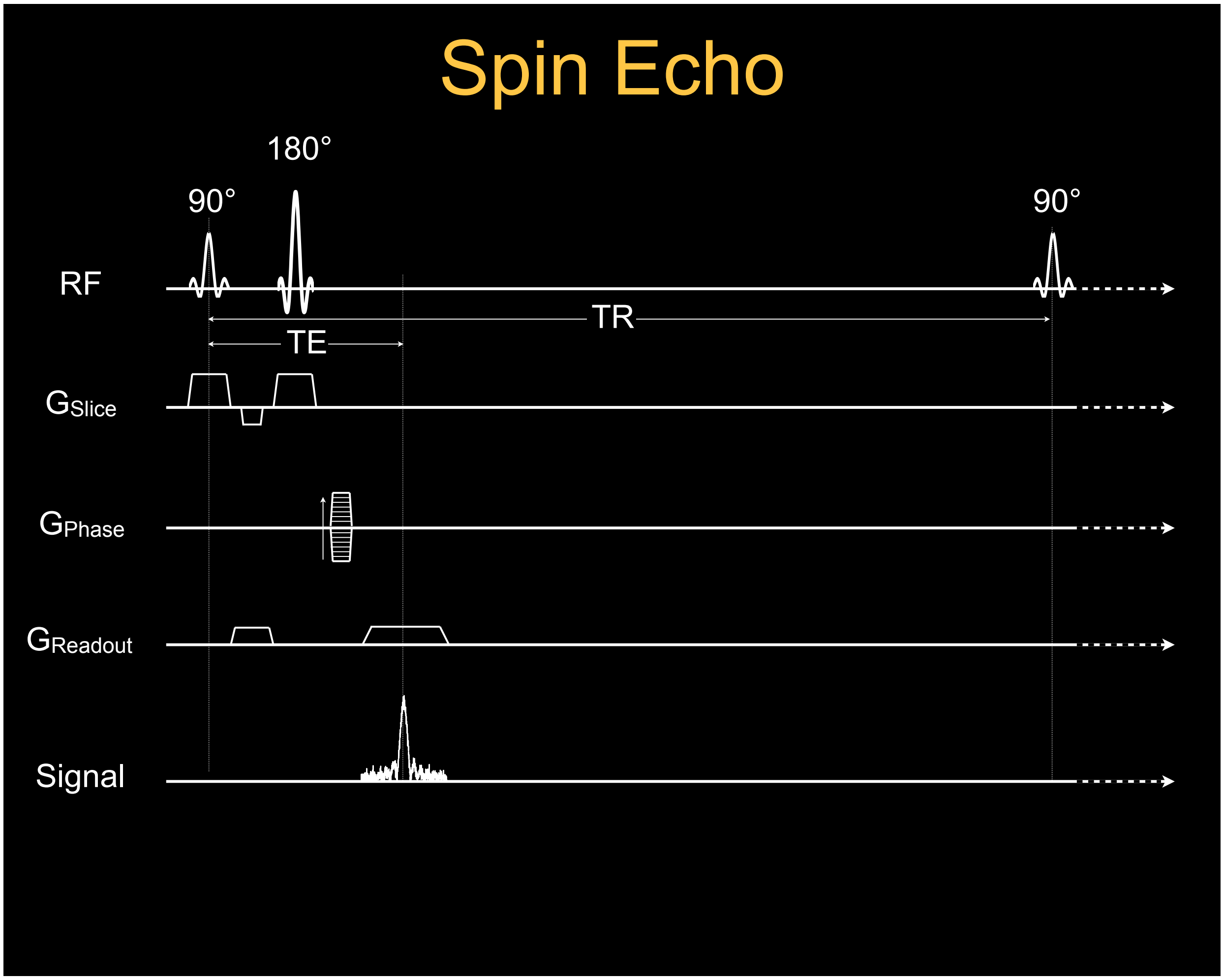
1. Long TE and long TR for T2-weighted.
2. Short TE and short TR for T1-weighted.
3. Spin echoes are low SAR sequences.

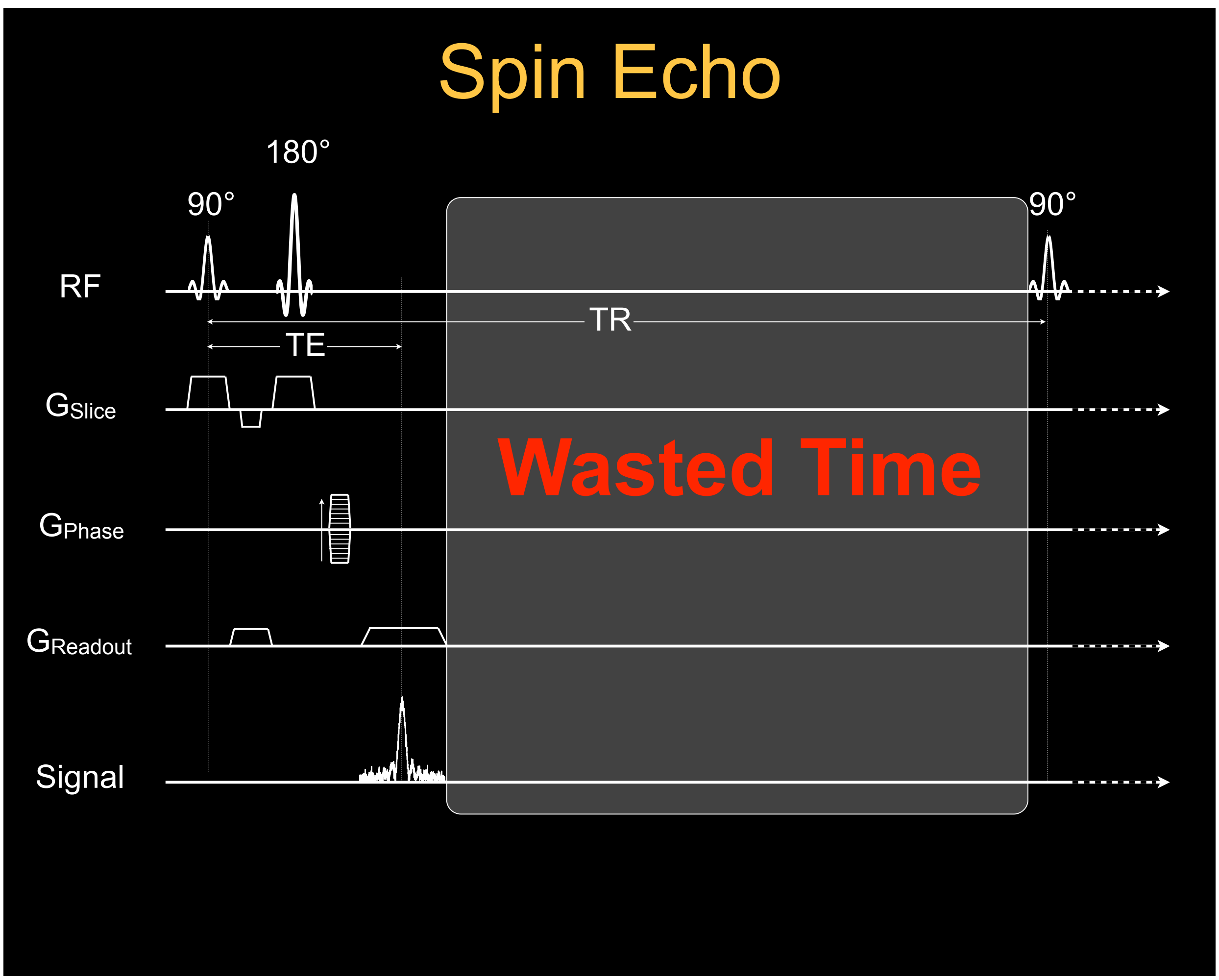
$$A_{Echo} \propto \rho \left(1 - e^{-TR/T_1}\right) e^{-TE/T_2}$$

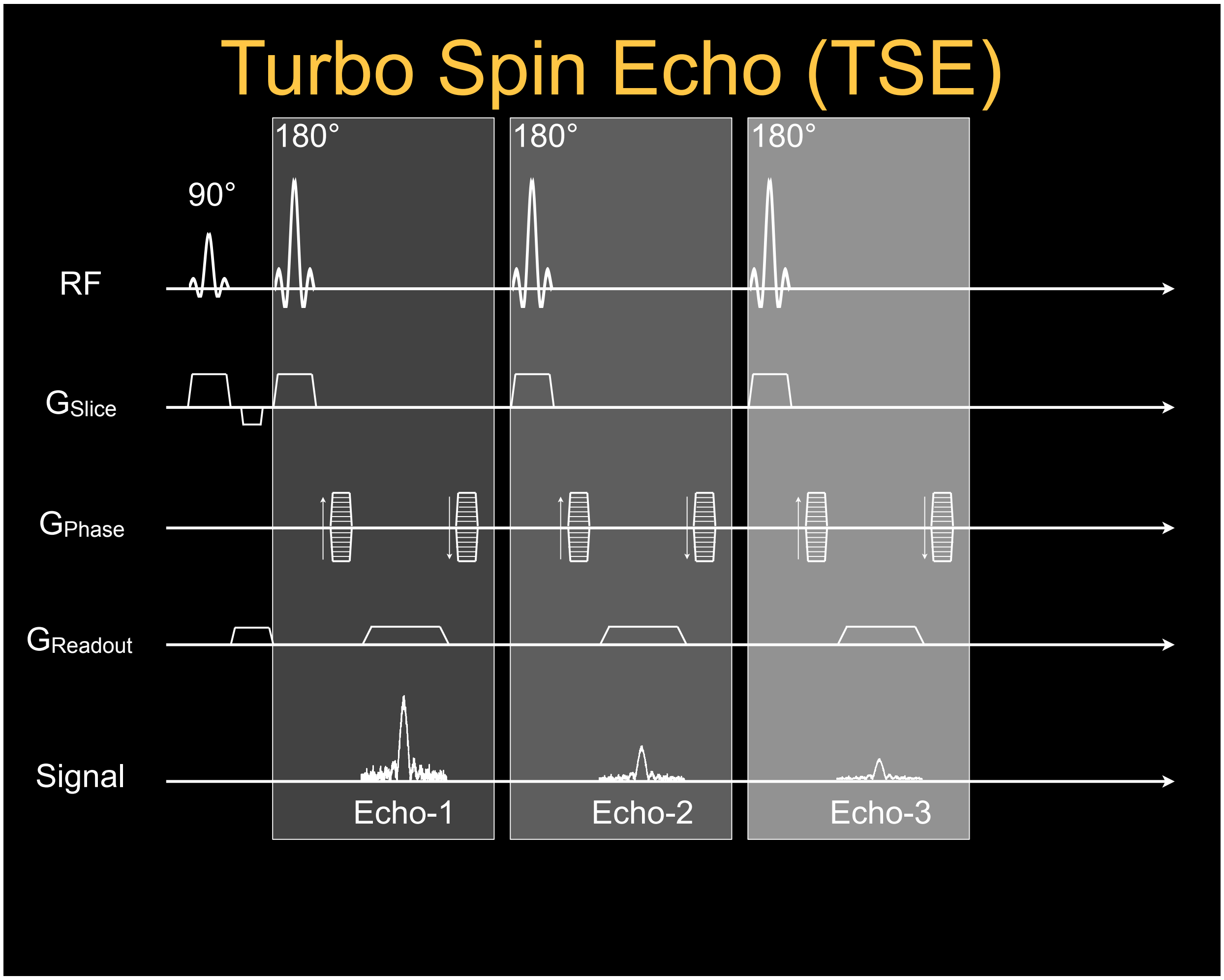
Longer TR minimizes T1 contrast

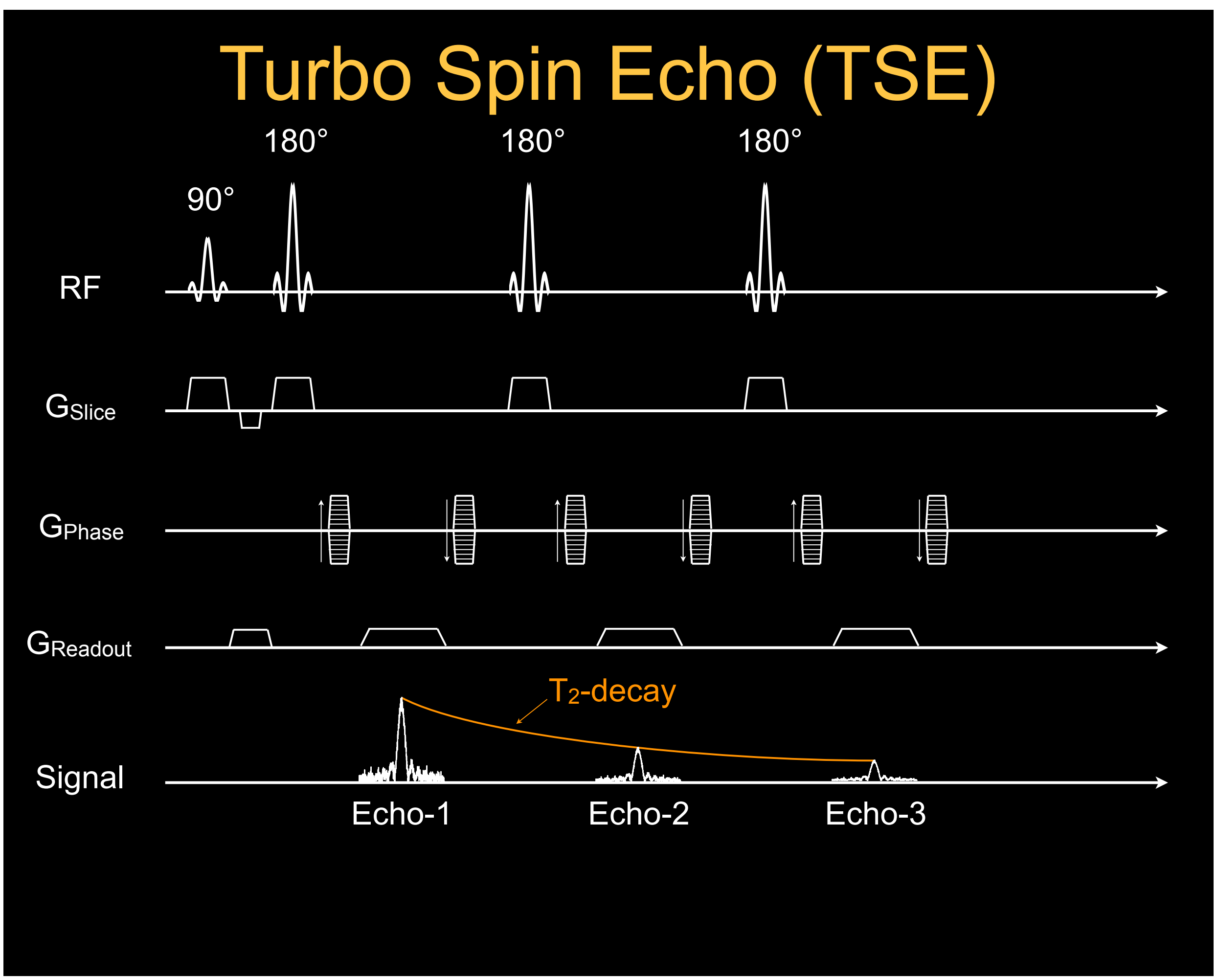
Short TE minimizes T2 contrast

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

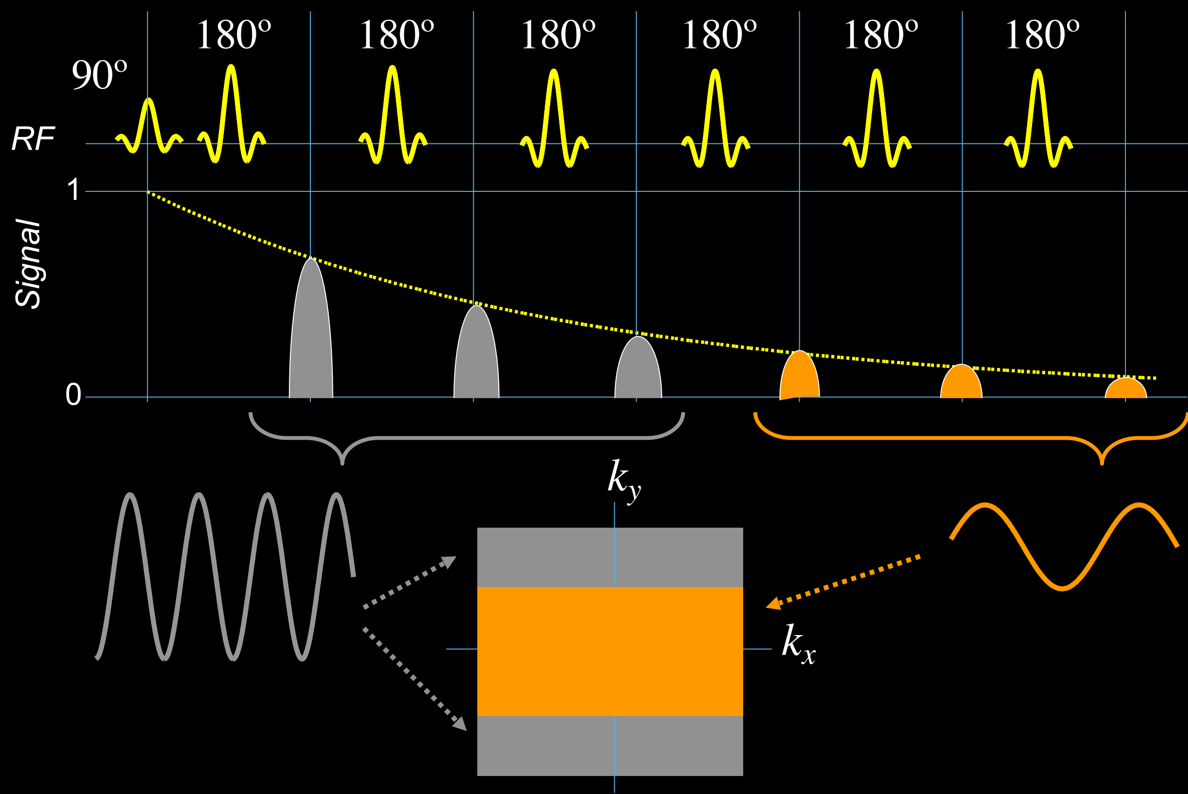

Spin Echo
180°
90°
90°
RF
TR
TE
GSlice
GPhase
GReadout
Signal


Spin Echo
180°
90°
90°
RF
TR
TE
GSlice
Wasted Time
GPhase
GReadout
Signal


Turbo Spin Echo (TSE)
180°
180°
180°
90°
RF
GSlice
GPhase
GReadout
Signal
Echo-1
Echo-2
Echo-3

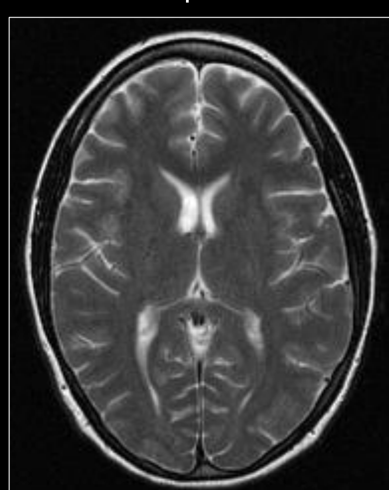

Turbo Spin Echo (TSE)
180°
180°
180°
90°
RF
GSlice
GPhase
GReadout
$T_2$-decay
Signal
Echo-1
Echo-2
Echo-3

# $T_2$-weighted TSE



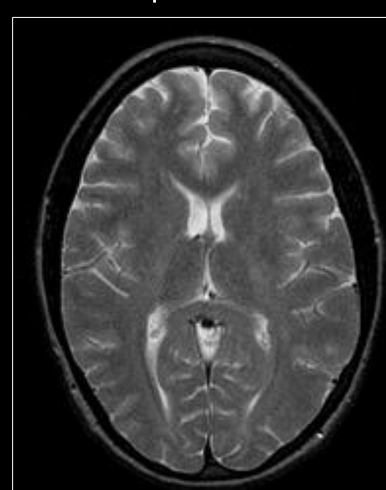

# Turbo Spin Echo vs. Spin Echo

Fast Spin Echo



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

Spin Echo

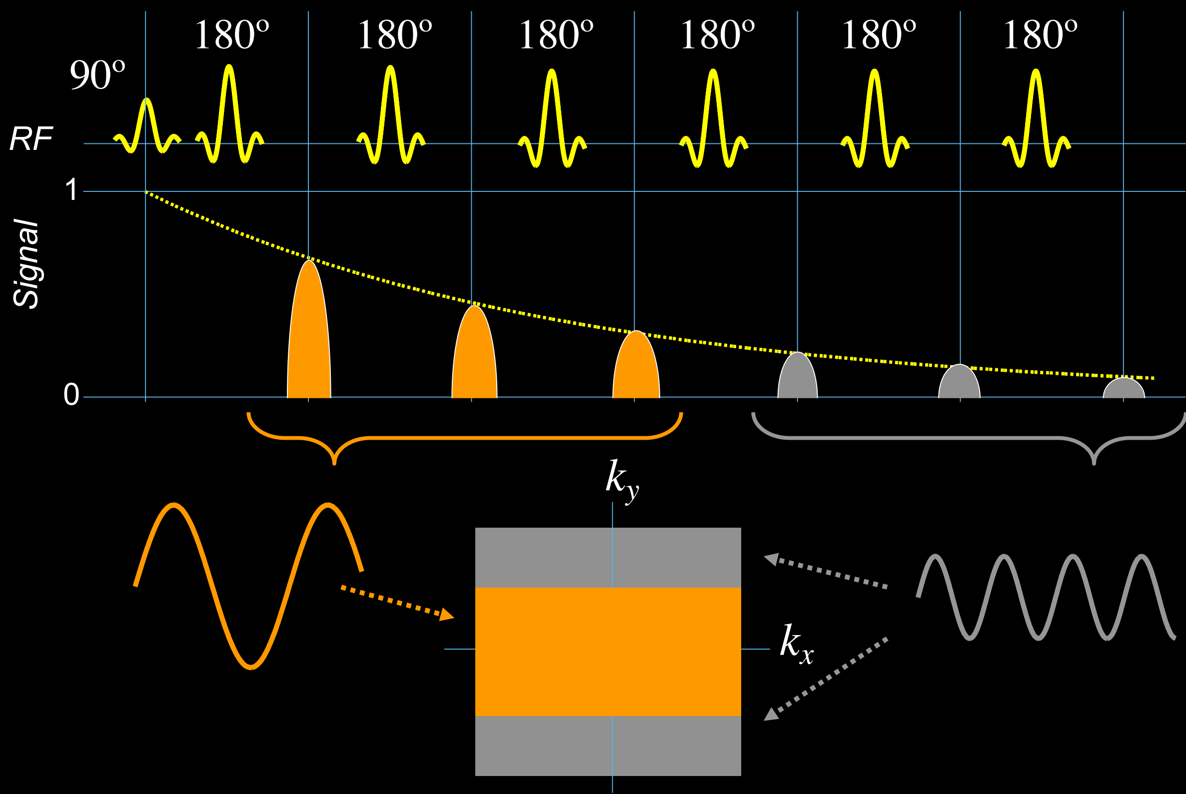


TR = 2500
TE = 112
ETL = N/A
NEX = 1
24 slices
20 slices/pass
2 passes
Time = 22:21

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

Images: Courtesy Frank Korosec

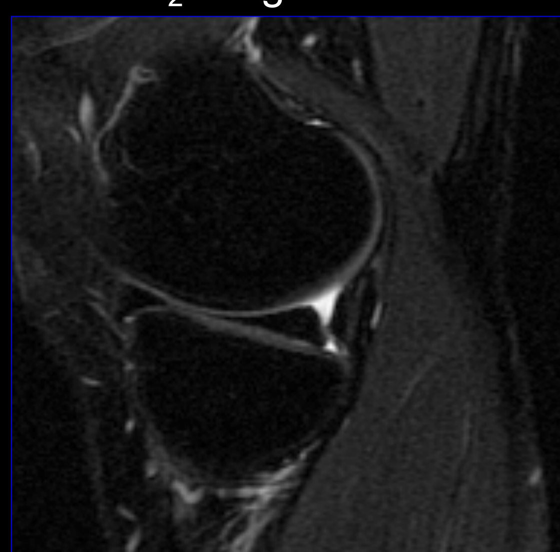
# Proton Density Weighted TSE




# PD vs $T_2$-weighted TSE

Proton Density Weighted

$T_2$-weighted



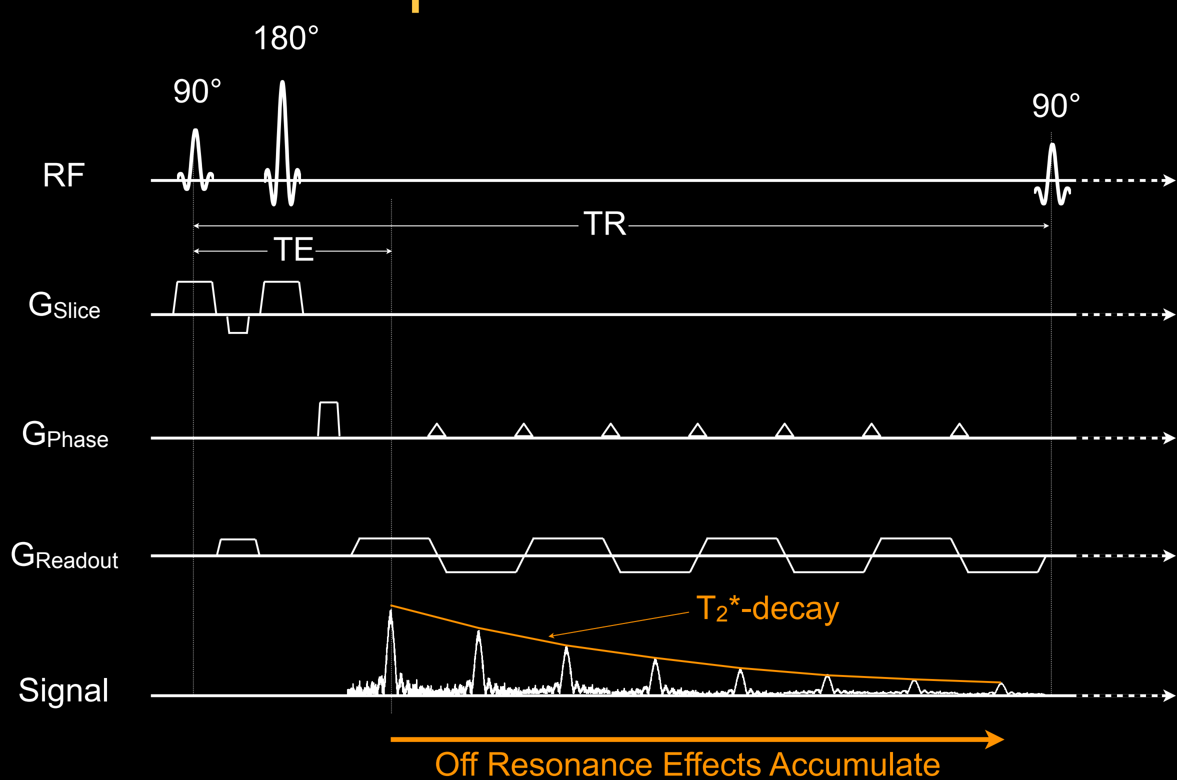
- Good cartilage signal
- Good cartilage/fluid contrast
- Late-Echo Blurring

# 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

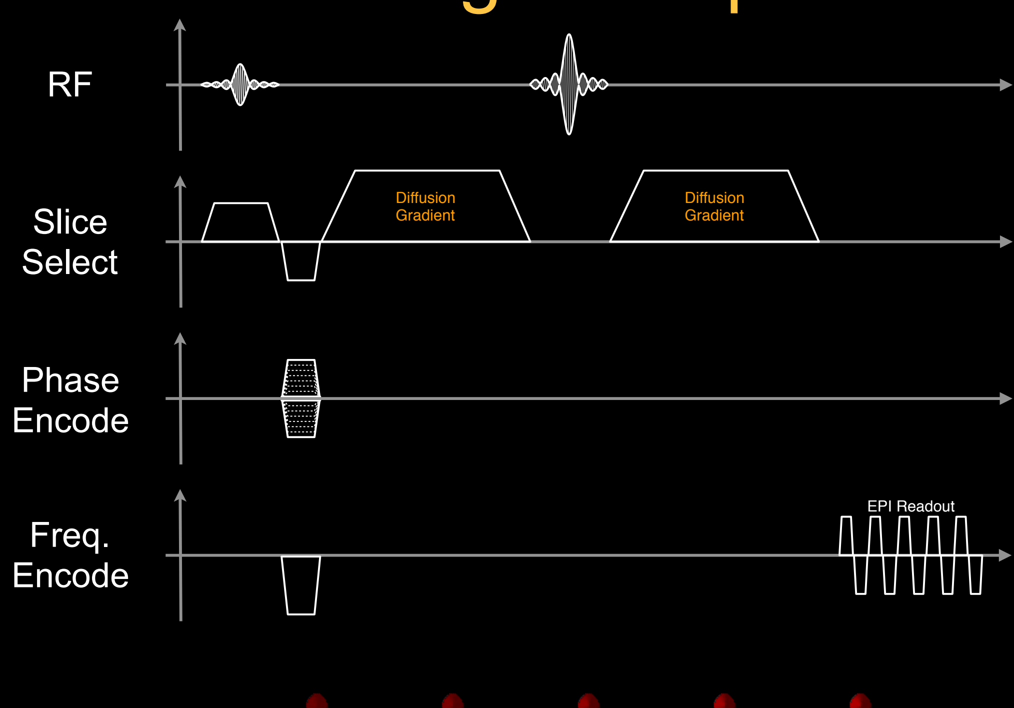
# Spin Echo EPI



# 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?

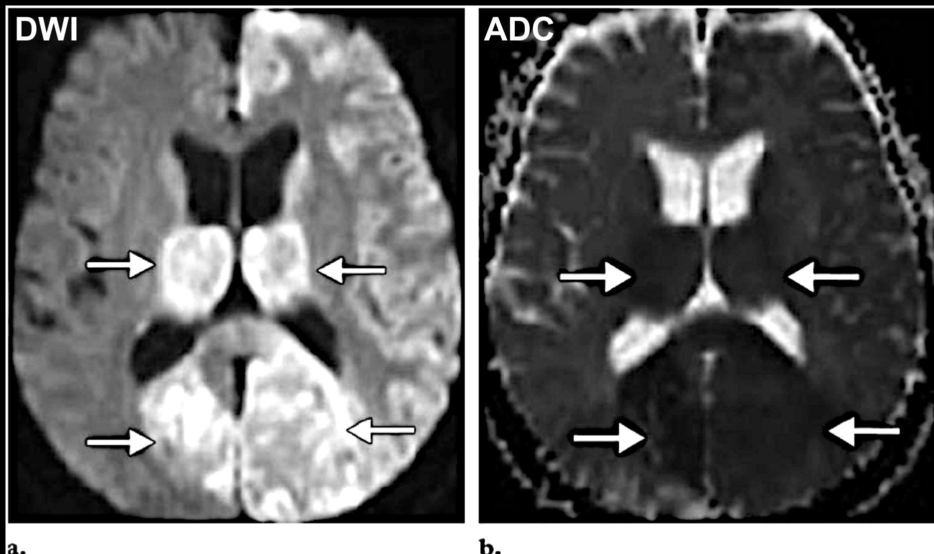



**Figure 15.** Acute stroke of the posterior circulation in a 77-year-old man. **(a)** Diffusion-weighted MR image ($b$ = 1000 sec/mm$^2$) shows bilateral areas of increased signal intensity (arrows) in the thalami and occipital lobes. **(b)** ADC map shows decreased ADC values in the same areas (arrows).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

# 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.

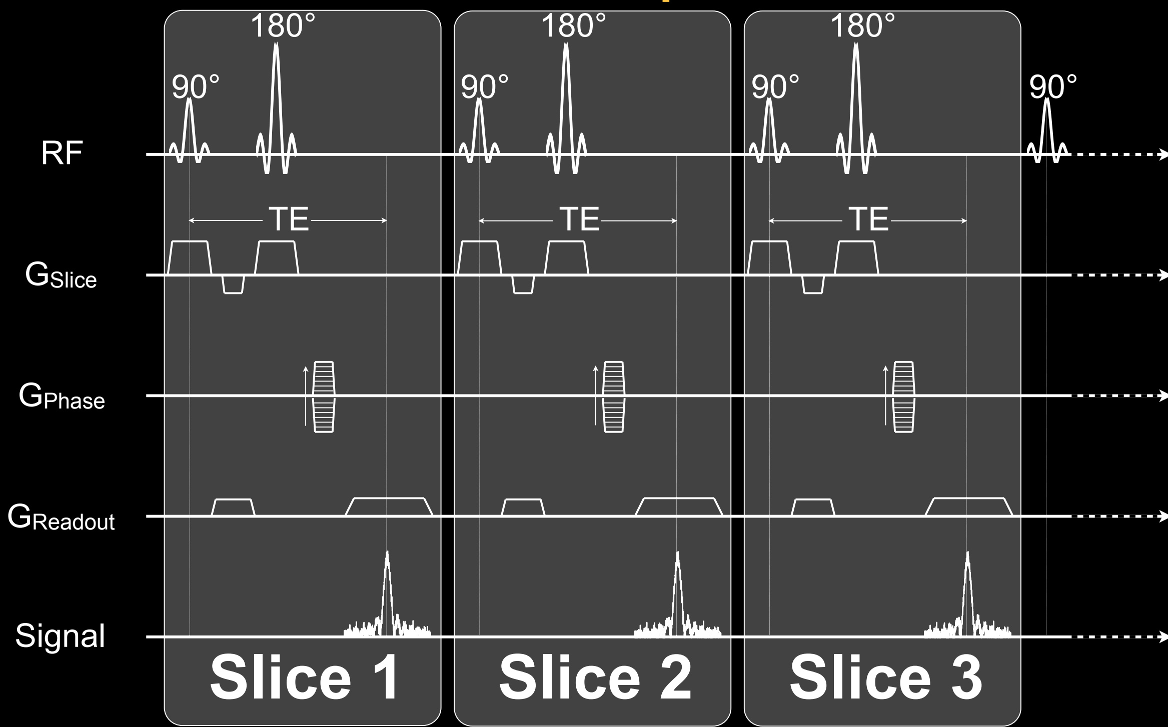
3. Spin Echo EPI is routine for diffusion weighted imaging.

# Multi-slice Acquisitions

## Spin Echo


A long TR is needed to minimize $T_1$-contrast in $T_2$-weighted images.

# Multi-slice Spin Echo

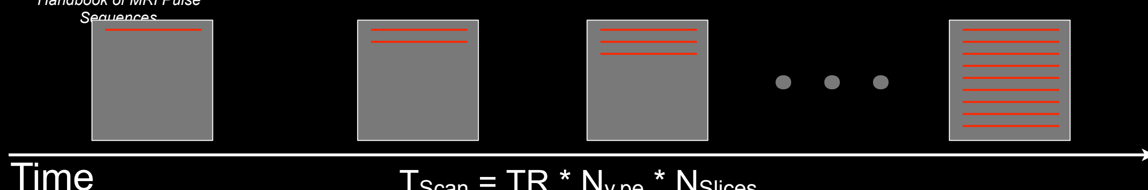



The TR is the time before you excite the ***same*** slice again.

# Slice Interleaving

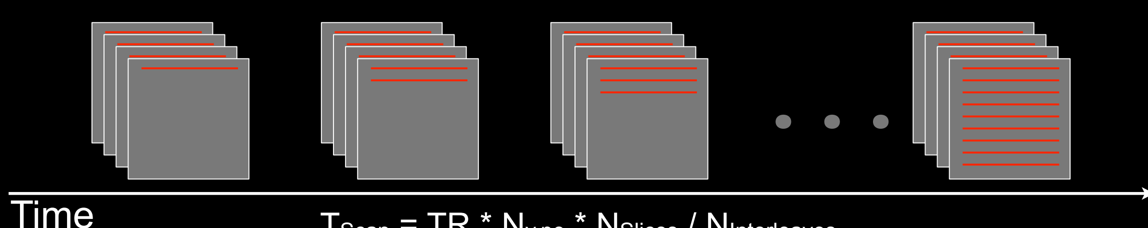
Adapted From Bernstein's
*Handbook of MRI Pulse Sequences*

**Sequential Slice 2D Imaging**




$T_{Scan} = TR * N_{y,pe} * N_{Slices}$

**Slice Interleaved 2D Imaging**




$T_{Scan} = TR * N_{y,pe} * N_{Slices} / N_{Interleaves}$

Slice interleaving excites a new slice while the others are relaxing.

## 2D Slice Interleaving

- Applications (TR must be long)
  - $T_2$-weighted imaging
  - DWI
- Advantages
  - Accelerate imaging many times ($N_{Interleaves}$)
- Disadvantages
  - Acceleration limited by SAR
  - Difficult to acquire adjacent slices
    - Hard to get good 180° slice-profile to match 90° slice-profile for multi-slice imaging.

## Quiz: Fast Imaging - True or False?

1. Long TRs are important for T2 weighted imaging because they eliminate T1-contrast.
2. Slice interleaving is better suited for T2-weighted imaging than T1-weighted.
3. Multi-echo imaging can be combined with multi-slice imaging.

# Thanks

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