MRI Physics:

Data Acquisition and Echoes

Nicole Seiberlich
Associate Professor, Radiology
Co-Director of MIITT

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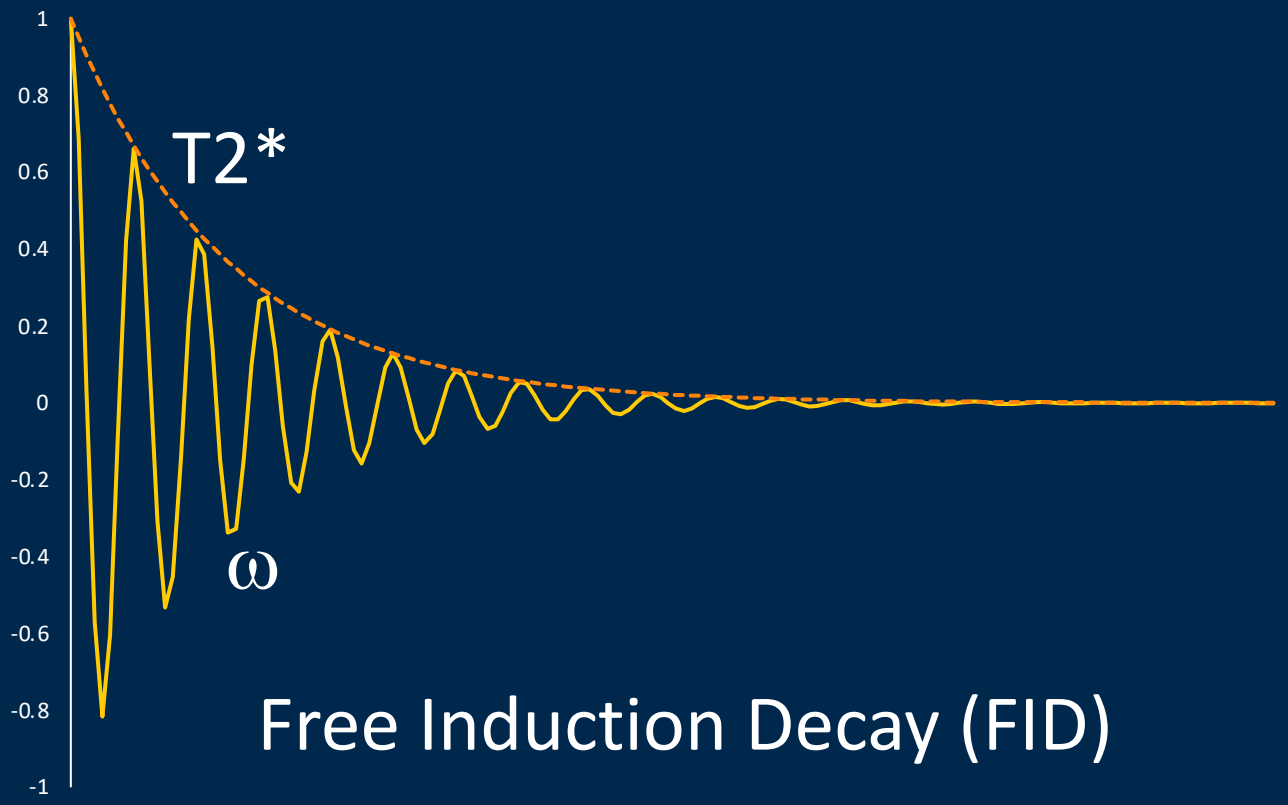
Data Collection for Imaging

Data must be collected while magnetization is in transverse plane

→ before significant T1 relaxation occurs

→ before significant T2/T2* relaxation occurs



Free Induction Decay (FID)

To allow data collection with more flexible timing, we generate an “echo”

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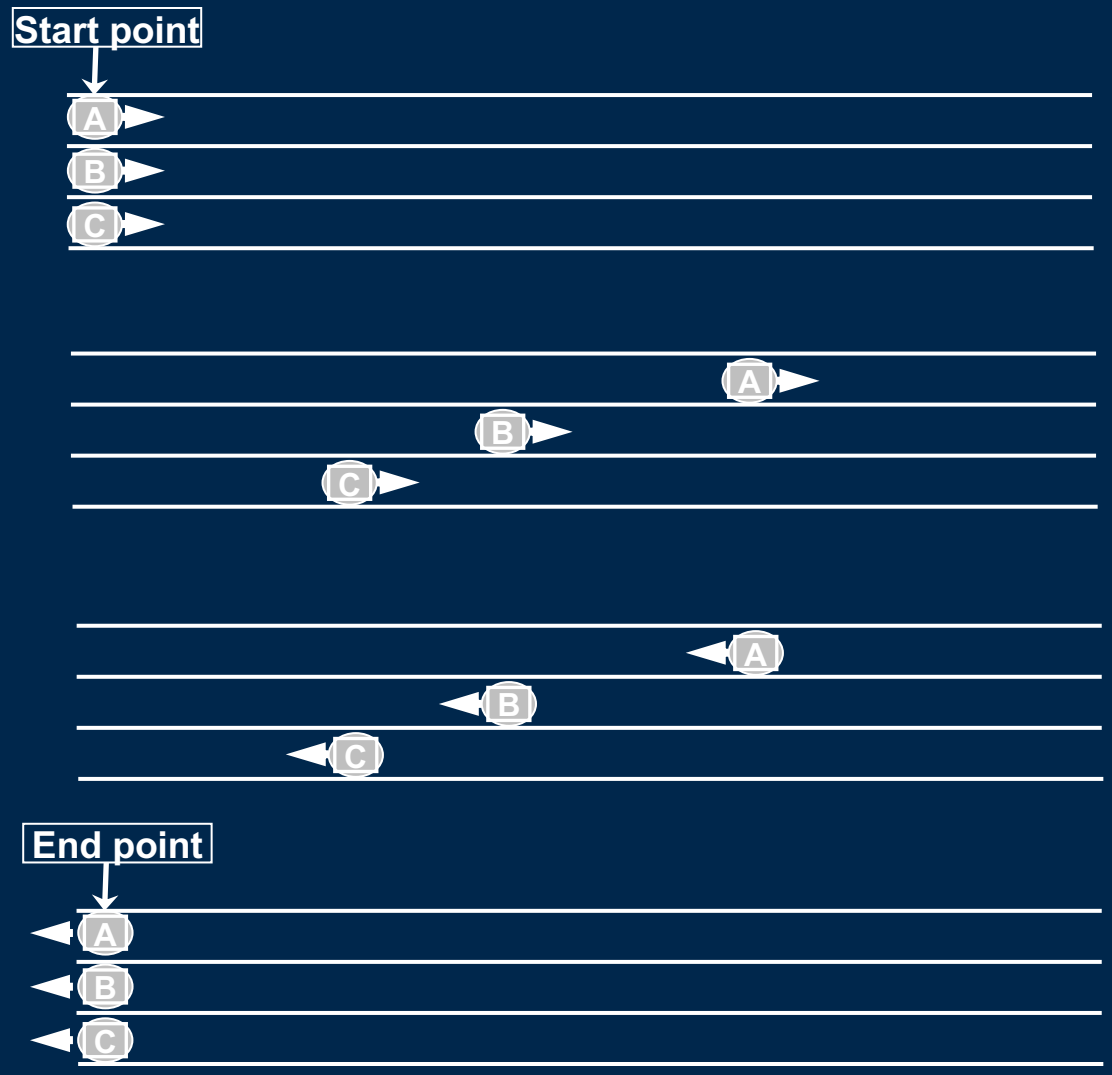
Spin Echo Foot Race Analogy



They soon spread-out due to speed difference
they are "dephased"

Halfway thru race, runners turn around and head back toward starting line

At end of race, all runners cross starting line at same time
they are "rephased"

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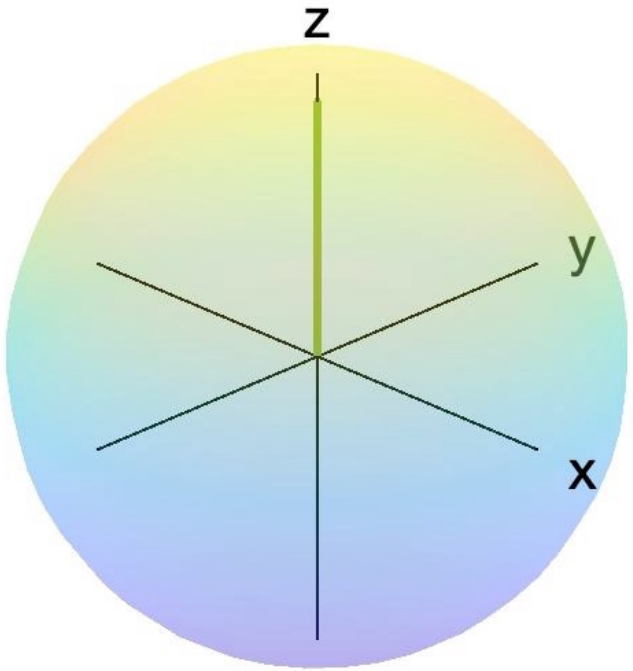
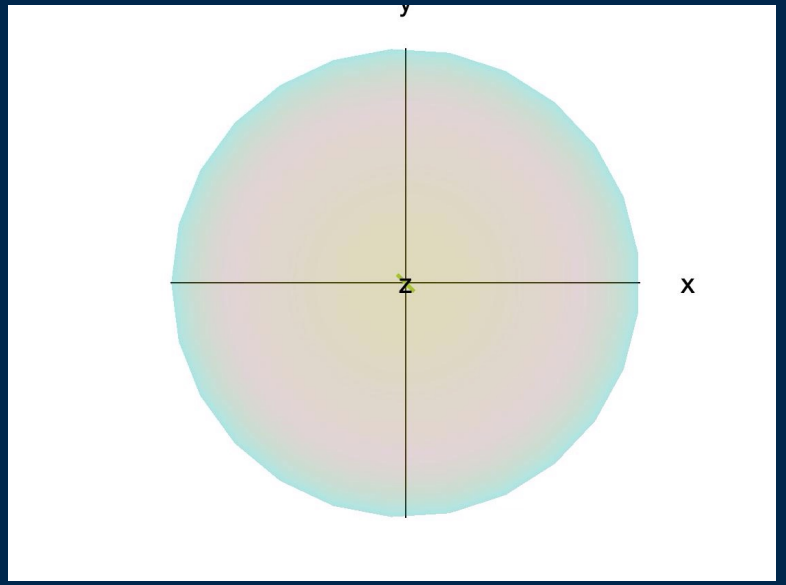
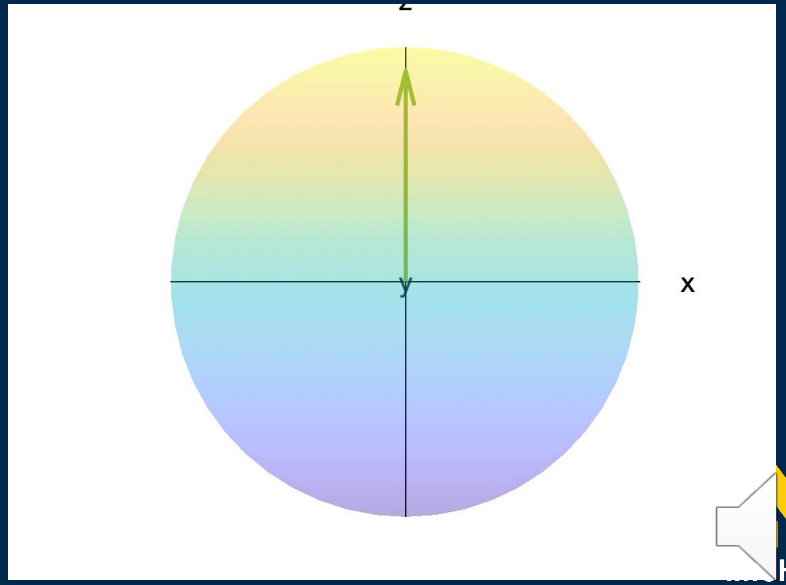
Forming an “Echo”







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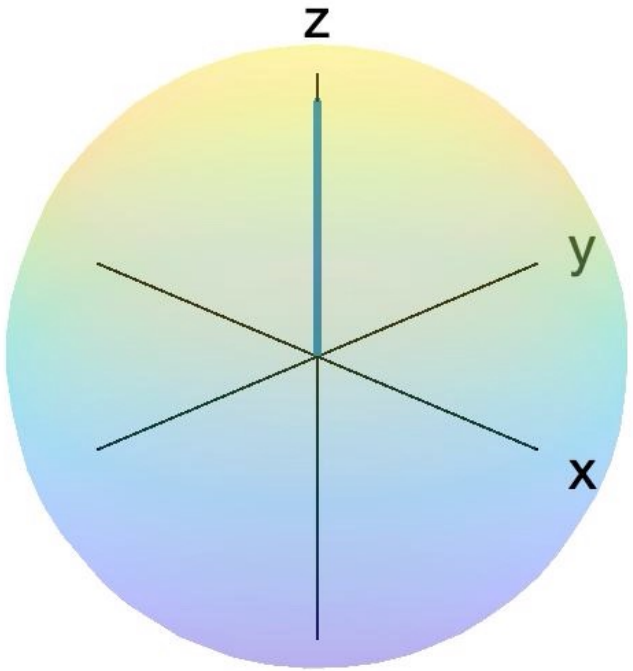
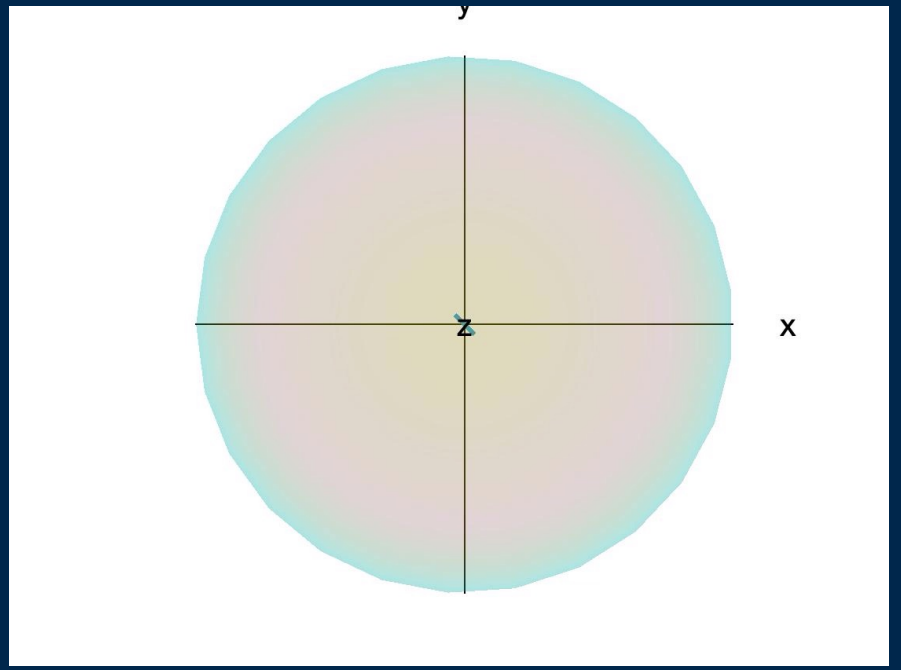
Vector sum of magnetization (what we measure)





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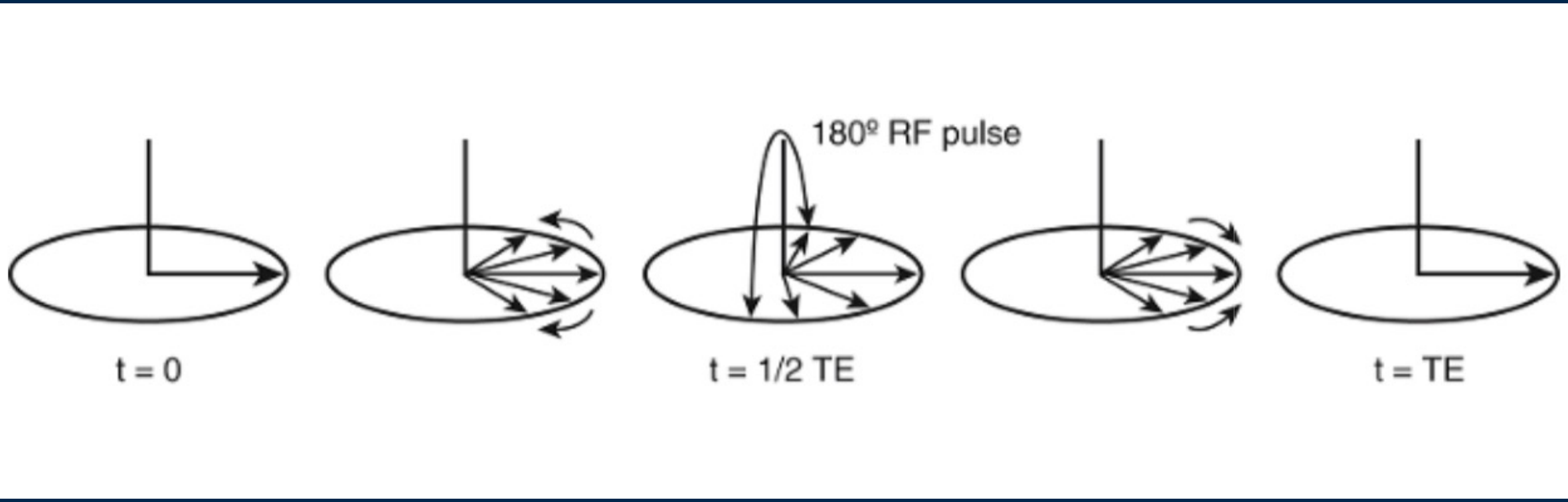
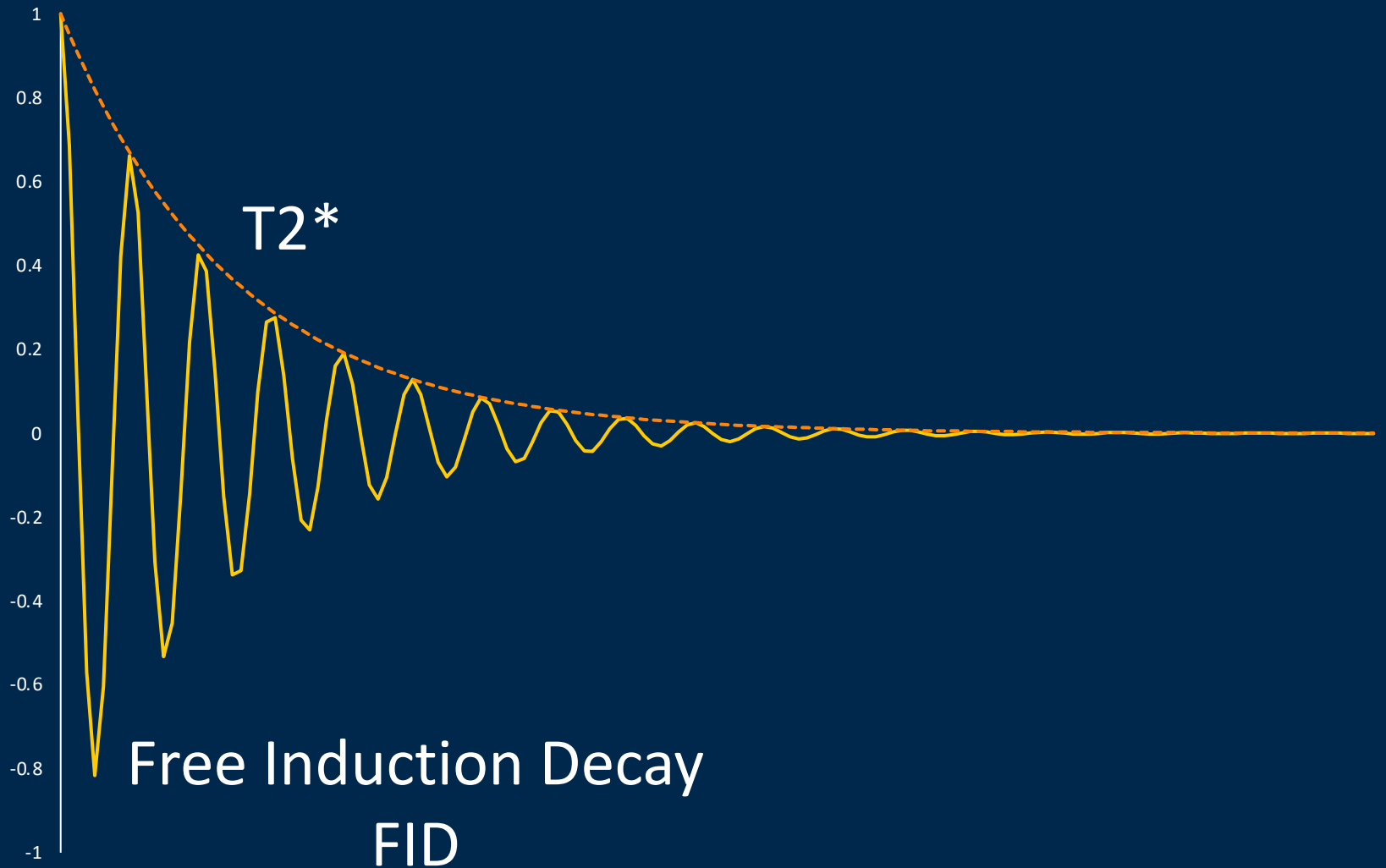
Alternative View of Echo



What does an echo look like?



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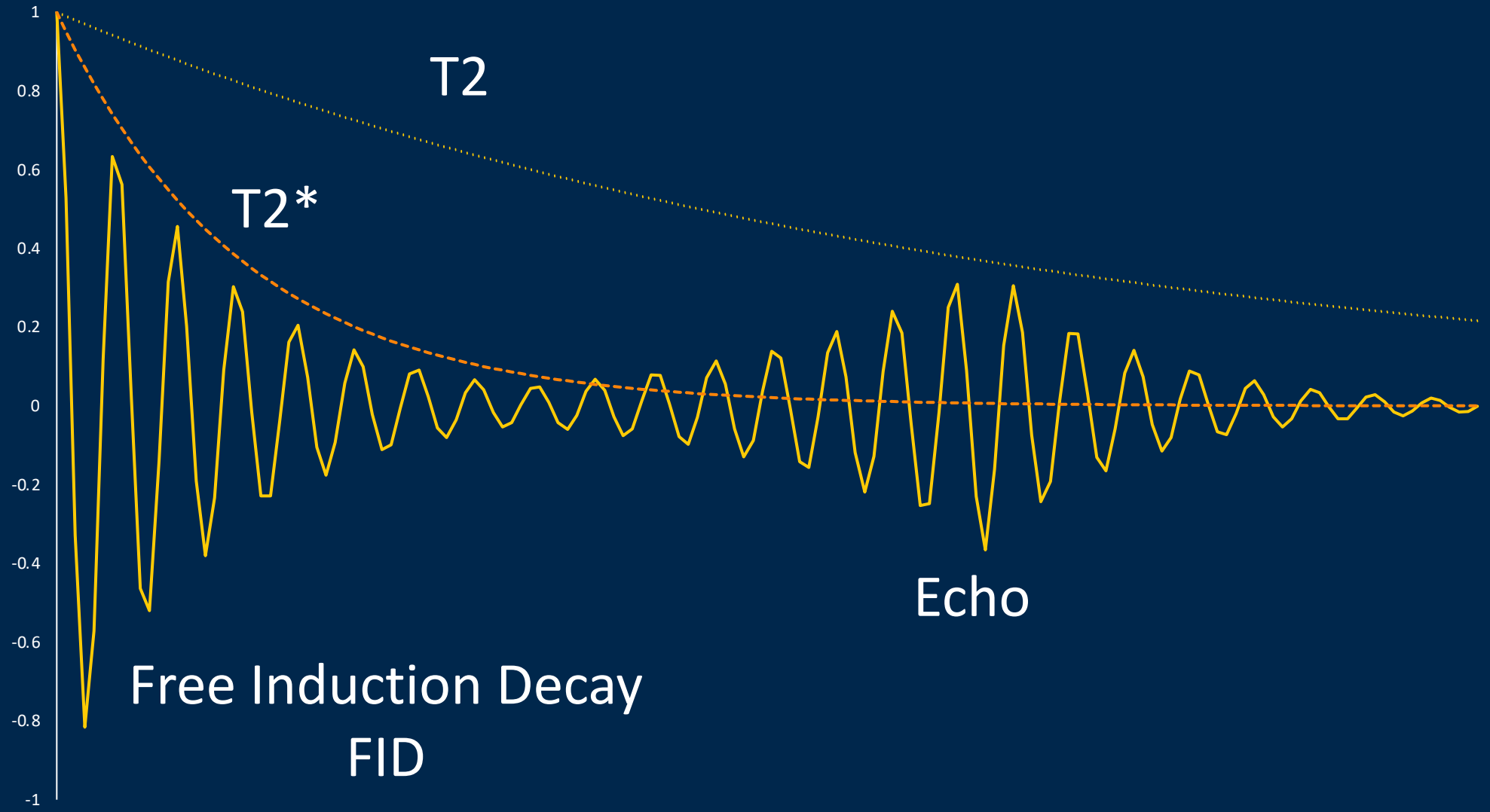

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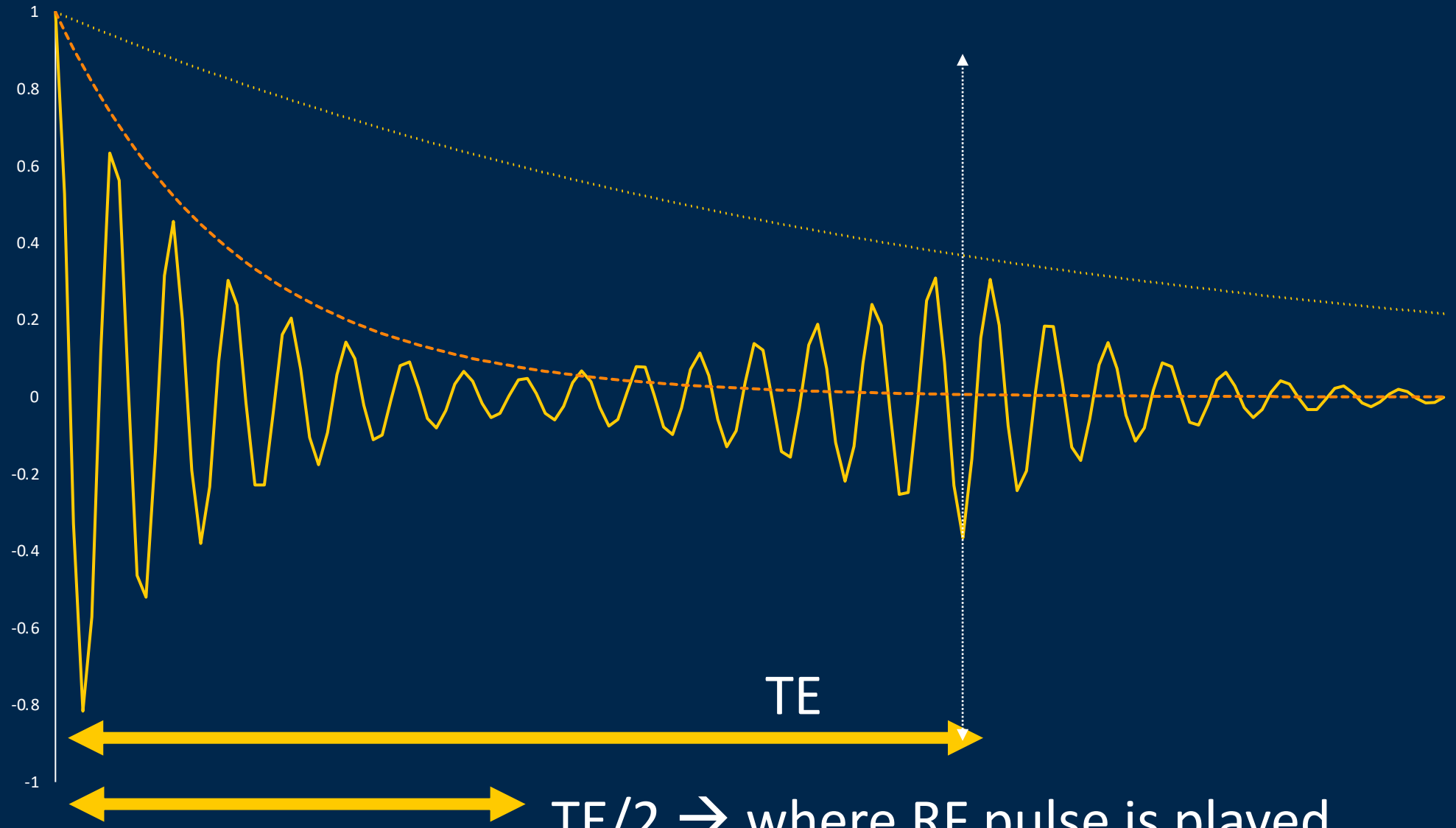
What does an echo look like?



TE/2 → where RF pulse is played

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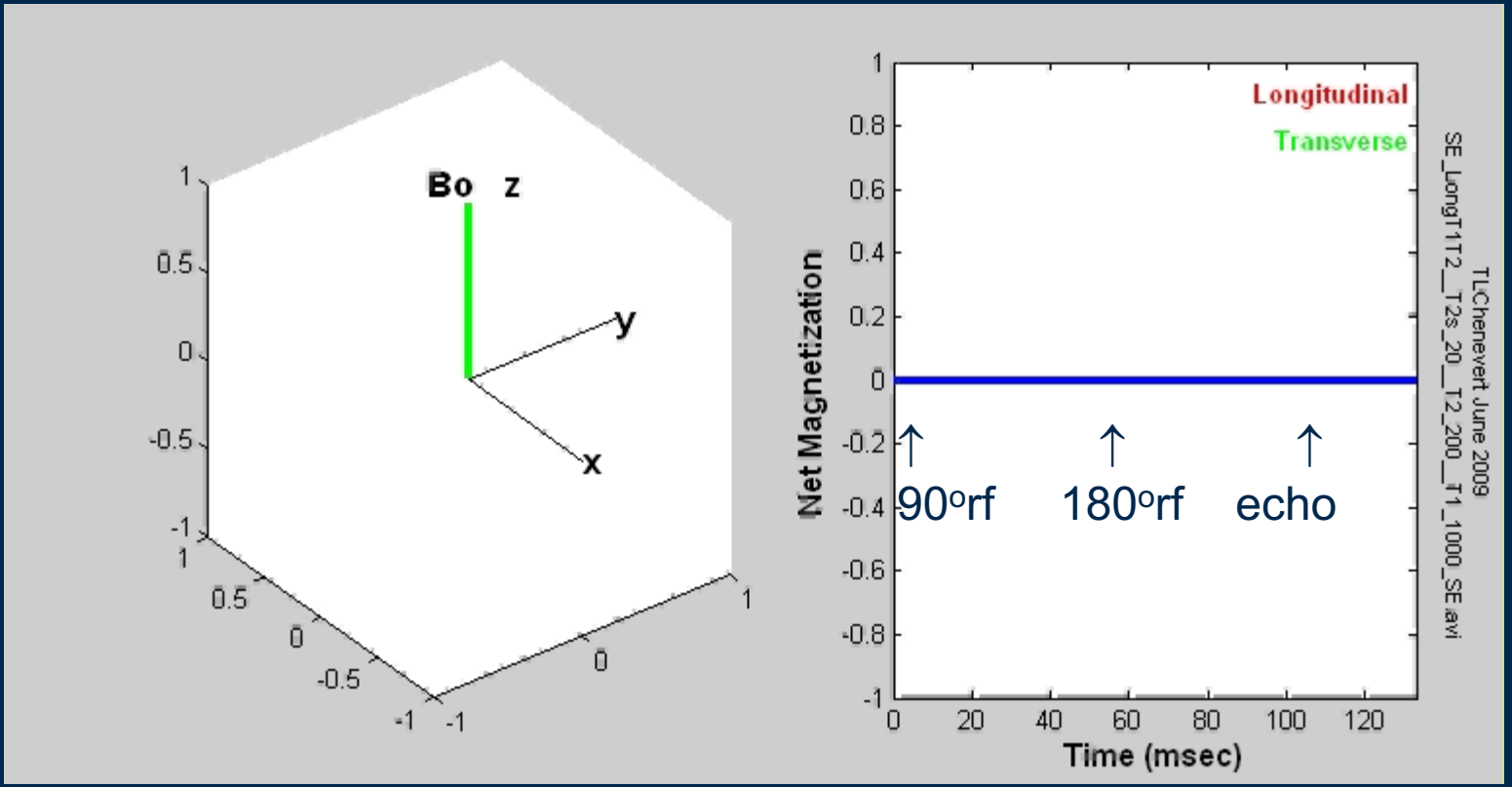
Spin echo: a 2nd RF pulse (typically a 180o pulse) rephases spins (undoes T2*) to form an "echo"



Isochromats

Net Longitudinal Magnetization

Net Transverse Magnetization (signal)

SE_LongT1T2__T2s_20__T2_200__T1_1000_SE.avi

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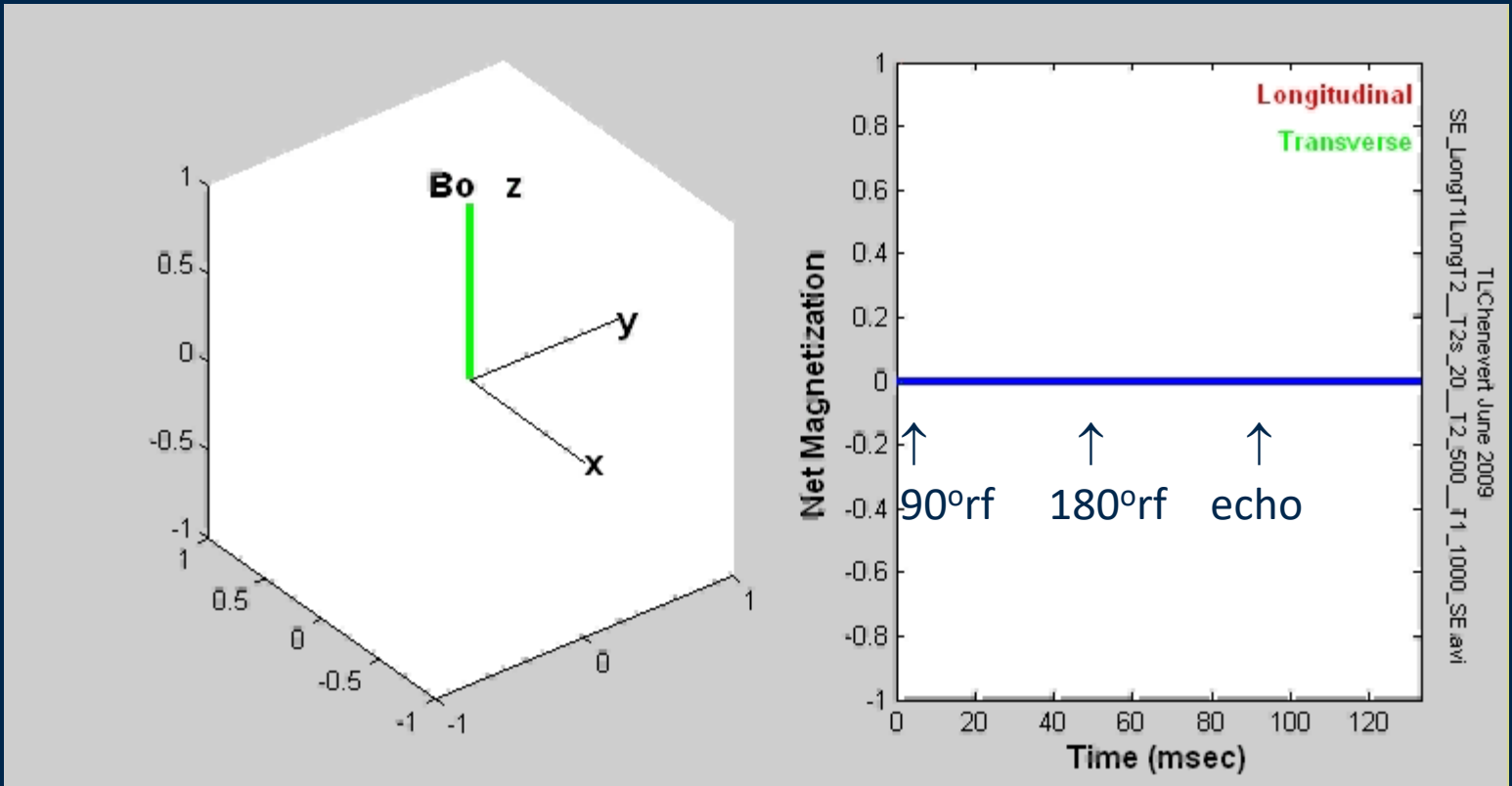
T2 Relaxation - Spin-Echo

An example of “Long” T2~200-1000ms



Isochromats

Net Longitudinal Magnetization

Net Transverse Magnetization (signal)

SE_LongT1LongT2__T2s_20__T2_500__T1_1000_SE.avi

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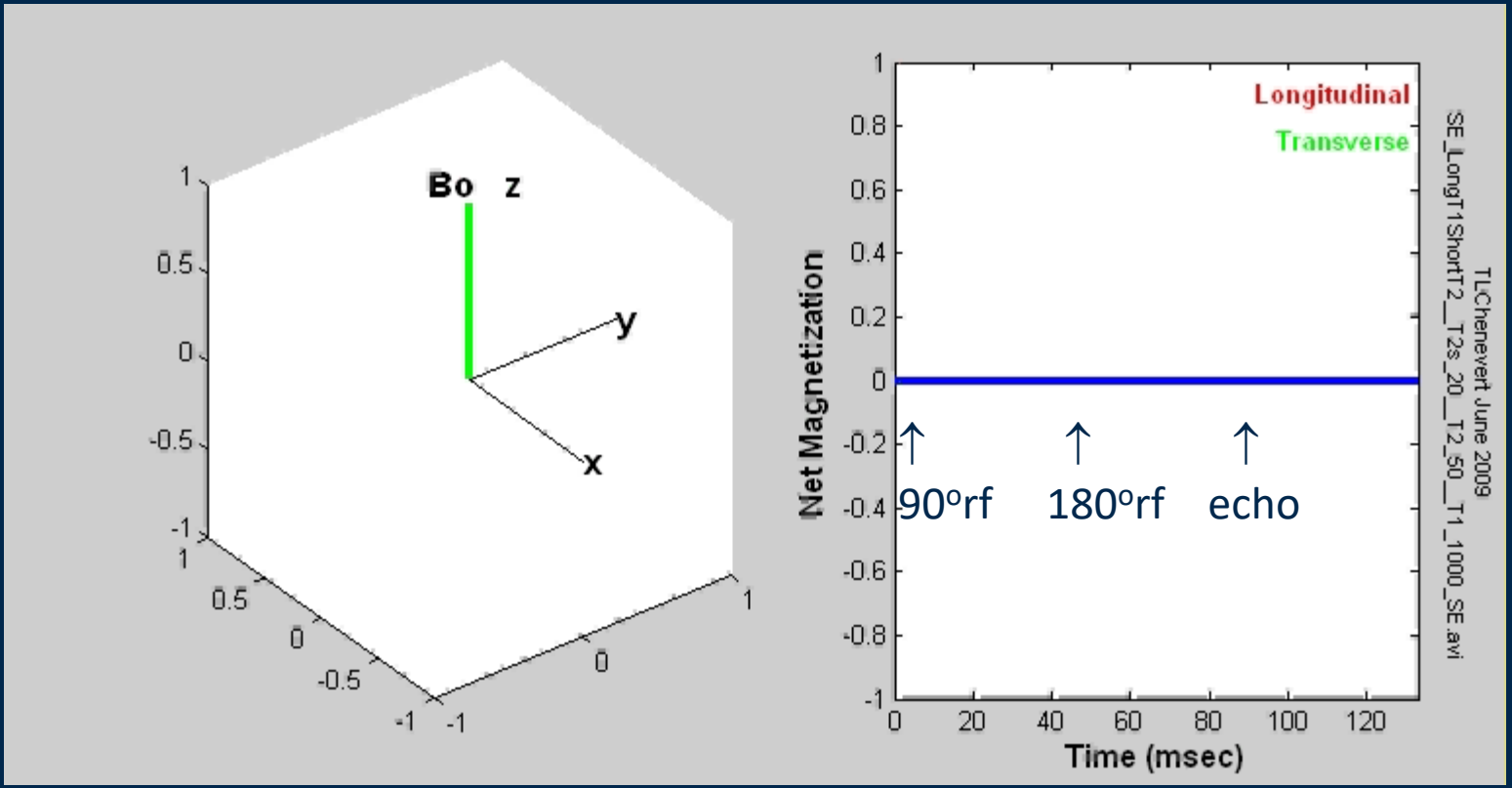
T2 Relaxation - Spin-Echo

An example of “Short” T2~10-50ms



Isochromats

Net Longitudinal Magnetization

Net Transverse Magnetization (signal)

SE_LongT1ShortT2__T2s_20__T2_50__T1_1000_SE.avi

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Two different ways to make an echo

- Spin Echo → “rewinds” T2’ effects, leaving T2 effects
  180° RF pulse used to flip magnetization

- Gradient Echo → sensitive to both T2 and T2’ (i.e. T2*)
  Magnetic field gradient used to rewind magnetization
  GRE / FFE

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MRI Physics:

The Pulse Sequence

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Pulse Sequence

RF

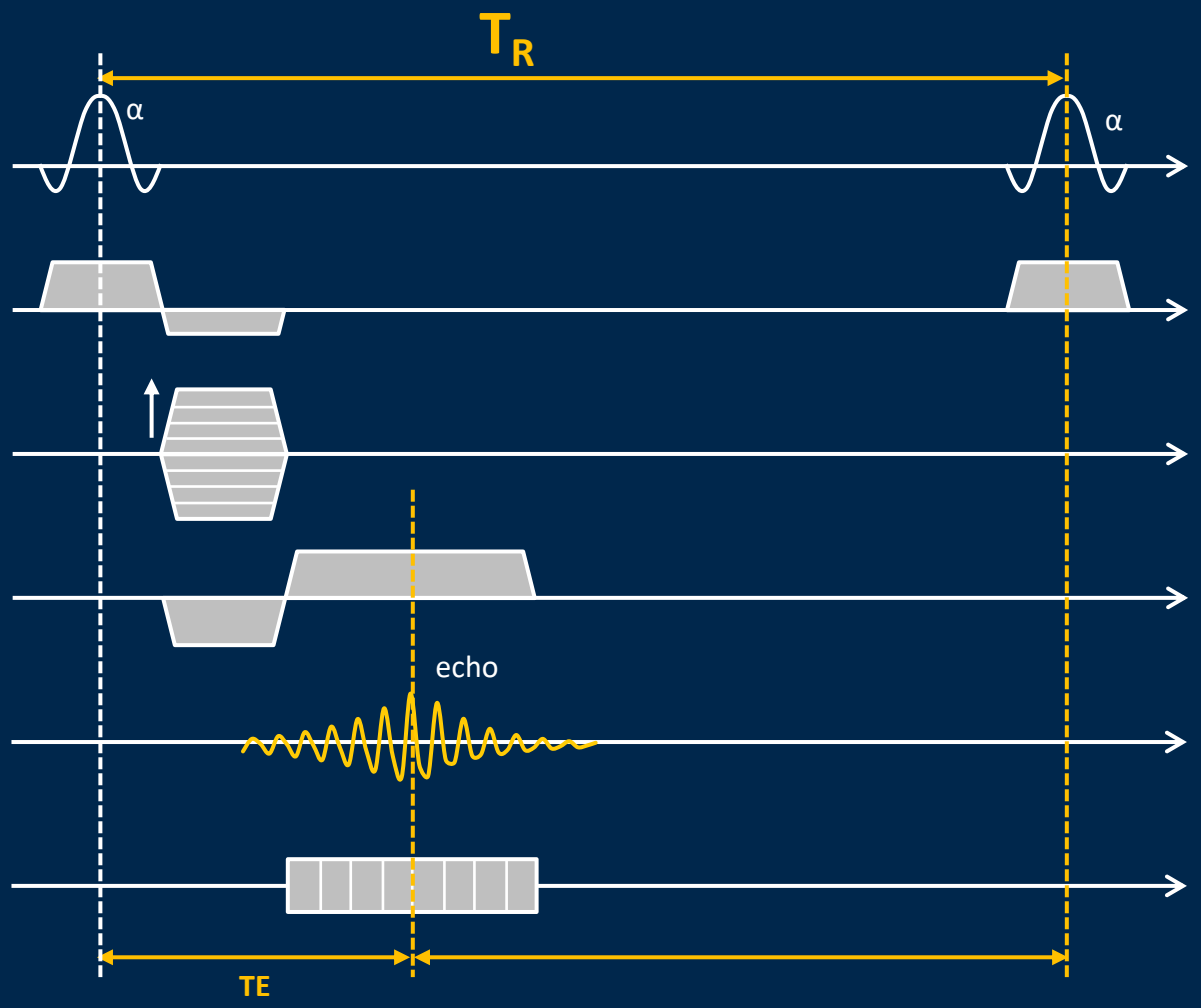
slice selection

phase encoding

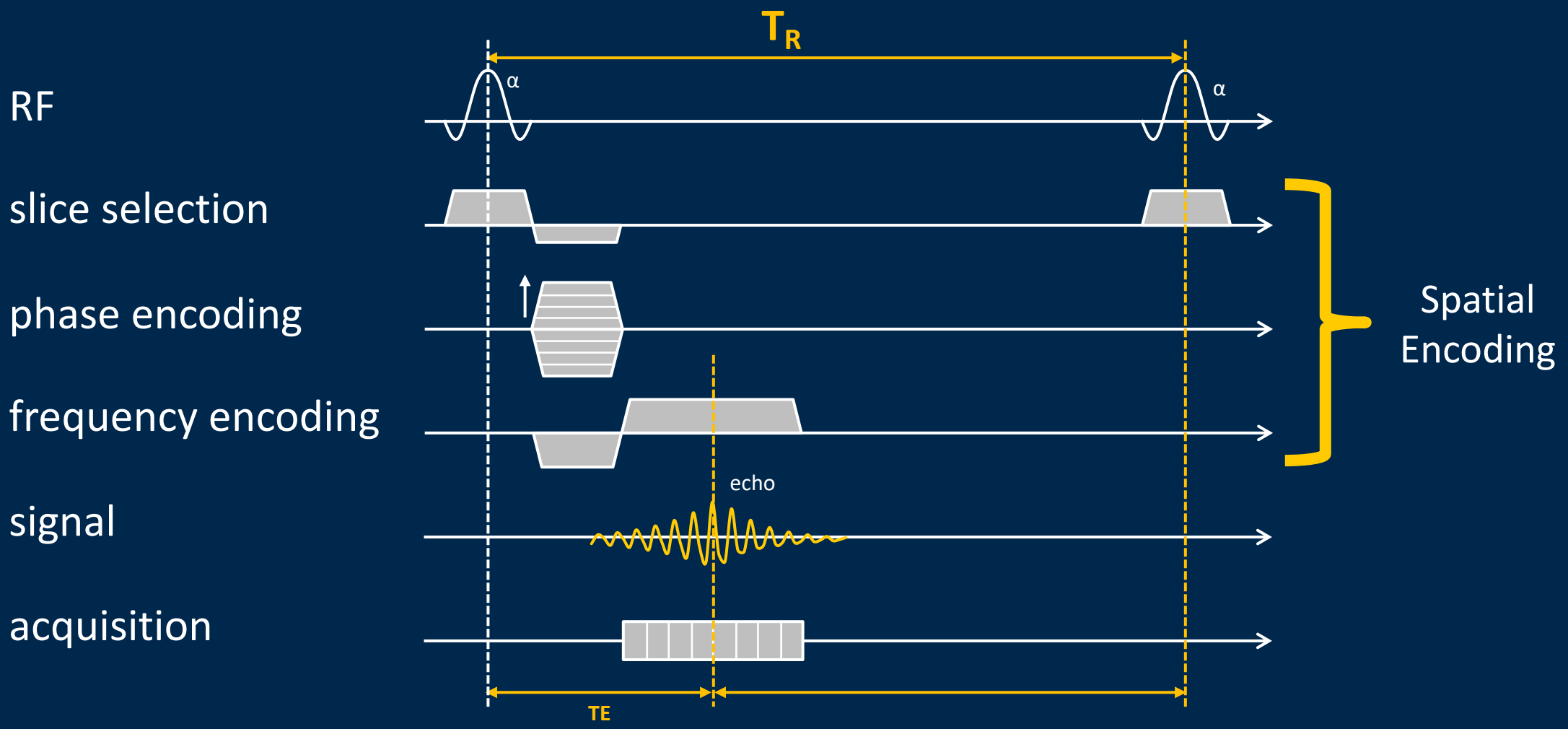
frequency encoding

signal

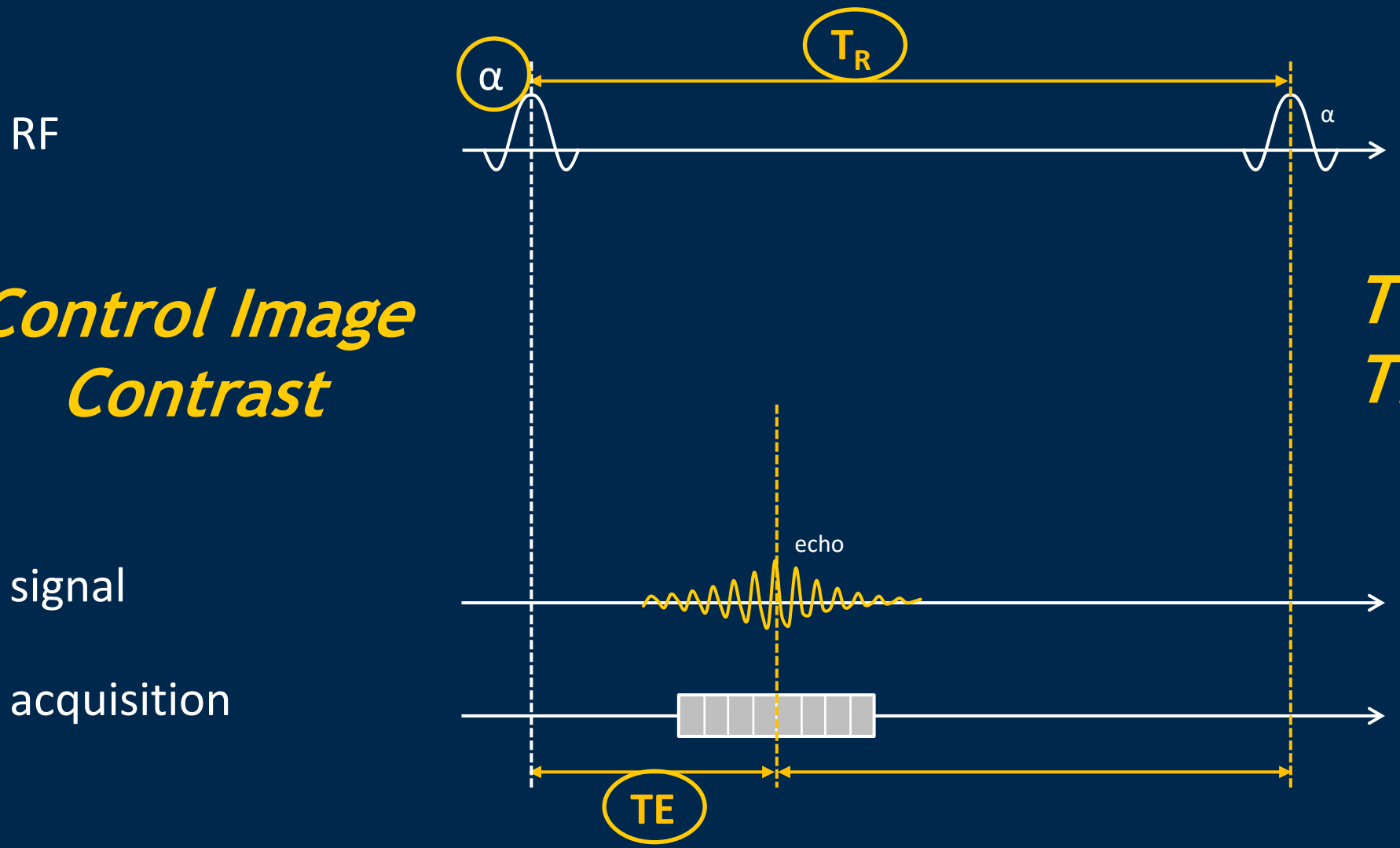
acquisition



Pulse Sequence



Pulse Sequence



Control Image Contrast

T1-weighted
T2-weighted

TR = Repetition Time

TE = Echo Time

α =Flip Angle

Remember: Values we control and values we don't

Scanner Parameters	*Tissue Properties*
TR = Repetition Time	T1
TE = Echo Time	T2
α =Flip Angle	Proton Density (ρ)

MRI Physics:

Image Contrast

Nicole Seiberlich
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MRI Contrast "Weighting"

- We typically DO NOT make images of actual T1 or T2 values in tissue
- We DO make images that *accentuate* T1 and T2 differences between tissues
  - "T1-weighted" MRI ⇒ enhance effect of T1 differences via short TR while minimizing T2 influences via short TE
  - "T2-weighted" MRI ⇒ enhance effect of T2 differences via long TE while minimizing T1 influences via long TR
  - "Proton Density-weighted" MRI ⇒ minimize T1 influences via long TR AND minimize T2 influences via short TE
- Long T1 tends to reduce relative signal intensity, especially upon T1-weighing
- Long T2 tends to increase relative signal intensity, especially upon T2-weighing
- High proton density (e.g. pure water) increases relative signal intensity, especially on proton density weighted MRI

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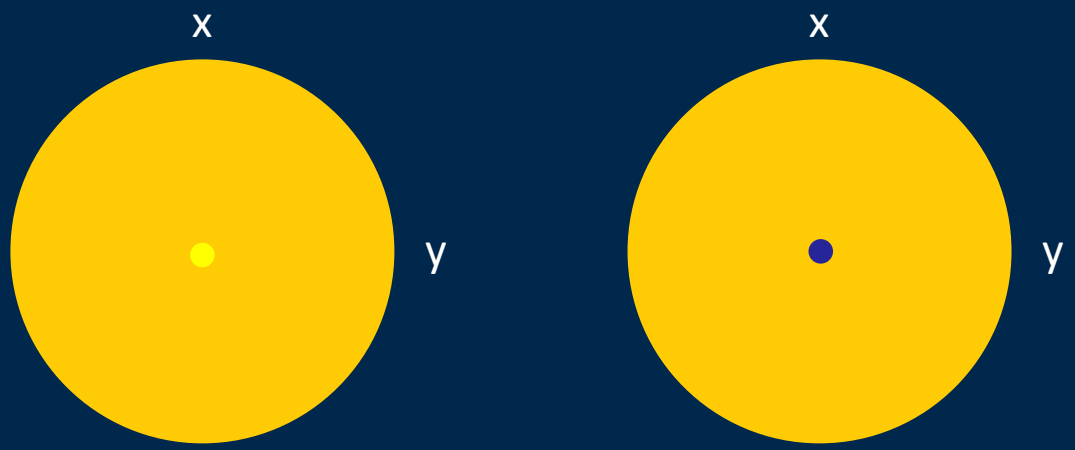
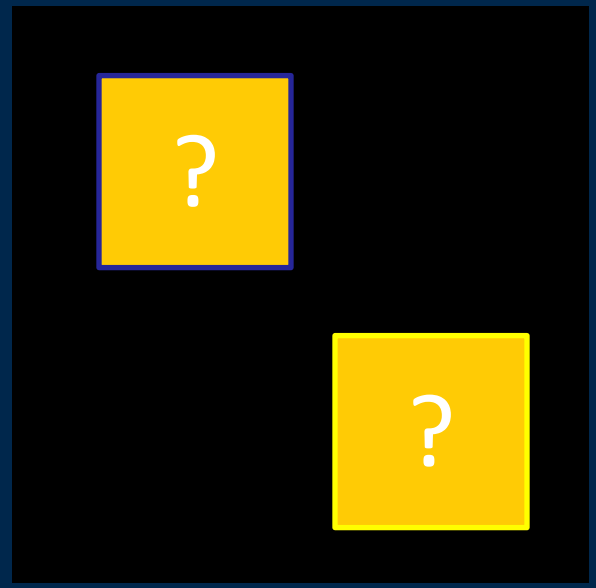
Image contrast → Differences in Transverse Magnetization





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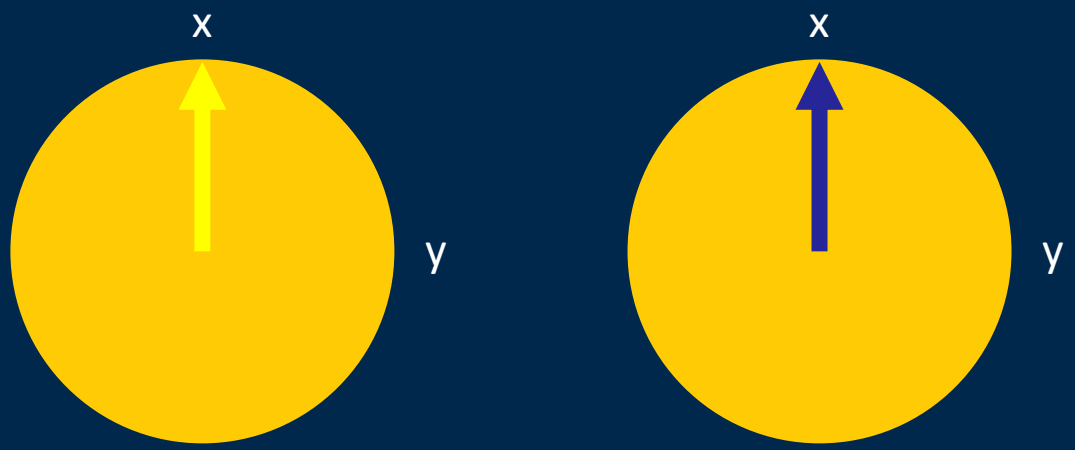

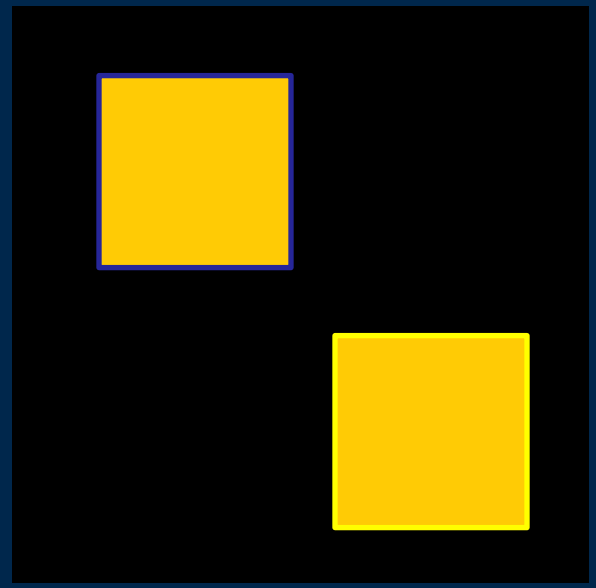

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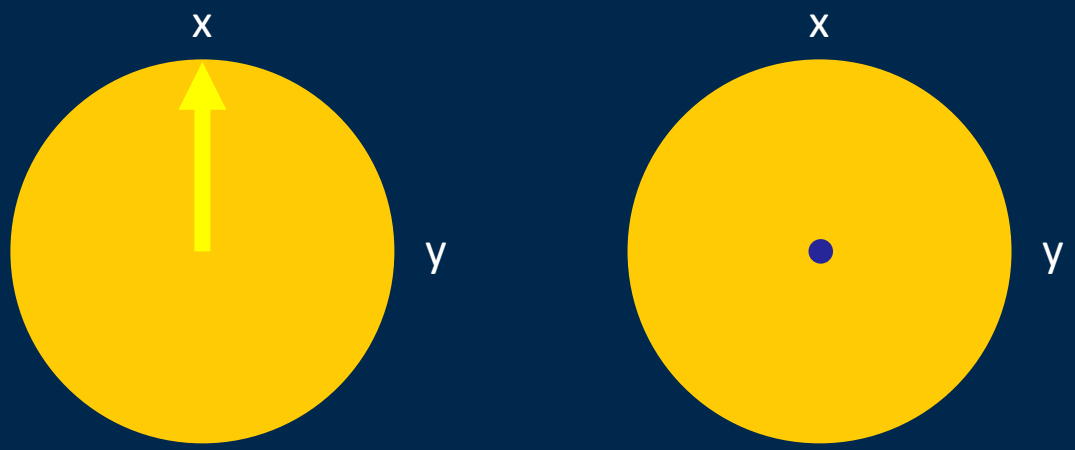

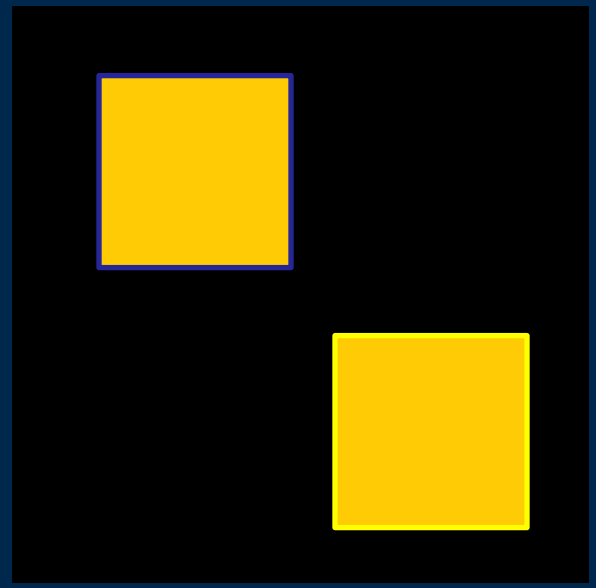

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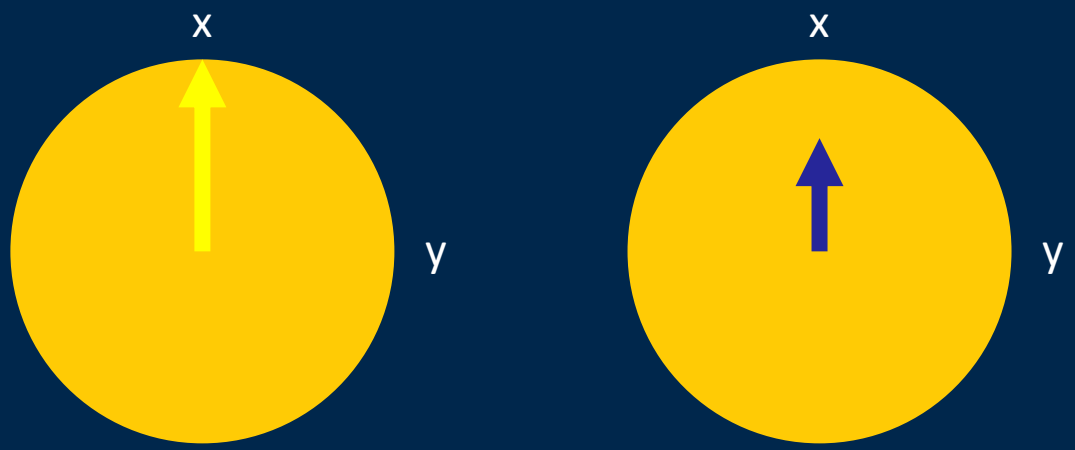

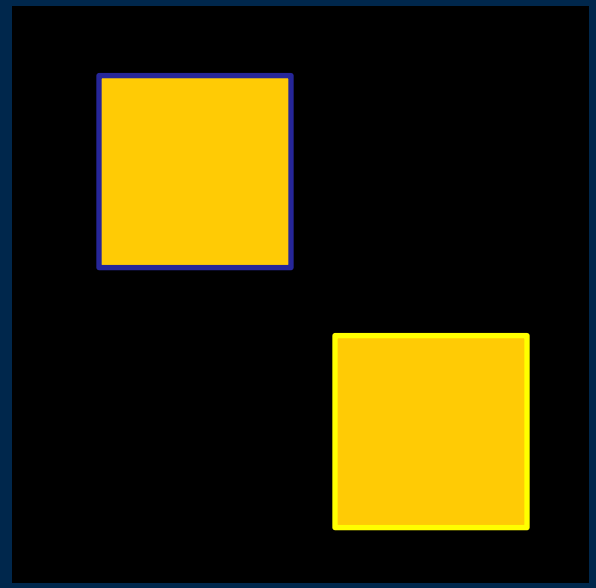

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We use differences in T1 and T2 to generate contrast

- Which tissues do we want to differentiate from one another?
- Which property can we use to tell them apart?
- How do we measure signal weighted by that property?
- How can we maximize that contrast?

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Contrast Manipulated by Sequence Timing

$T1_{WM} < T1_{GM} << T1_{CSF}$

"T1 Weighted":
Short TR (eg. TR = 500ms)
Short TE (eg. TE = 15ms)

"Proton Density (PD) Weighted":
Long TR (eg. 4000ms)
Short TE (eg. 15ms)

$T2_{WM} < T2_{GM} << T2_{CSF}$

"T2 Weighted":
Long TR (eg. 6000ms)
Long TE (eg. 100ms)

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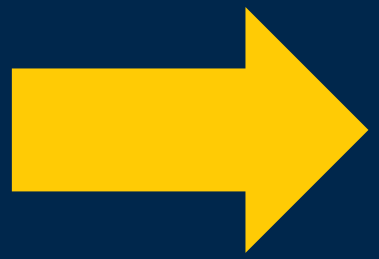
We select scanner parameters to emphasize differences in tissue properties

- Sequence settings depend on the properties of tissues we want to differentiate

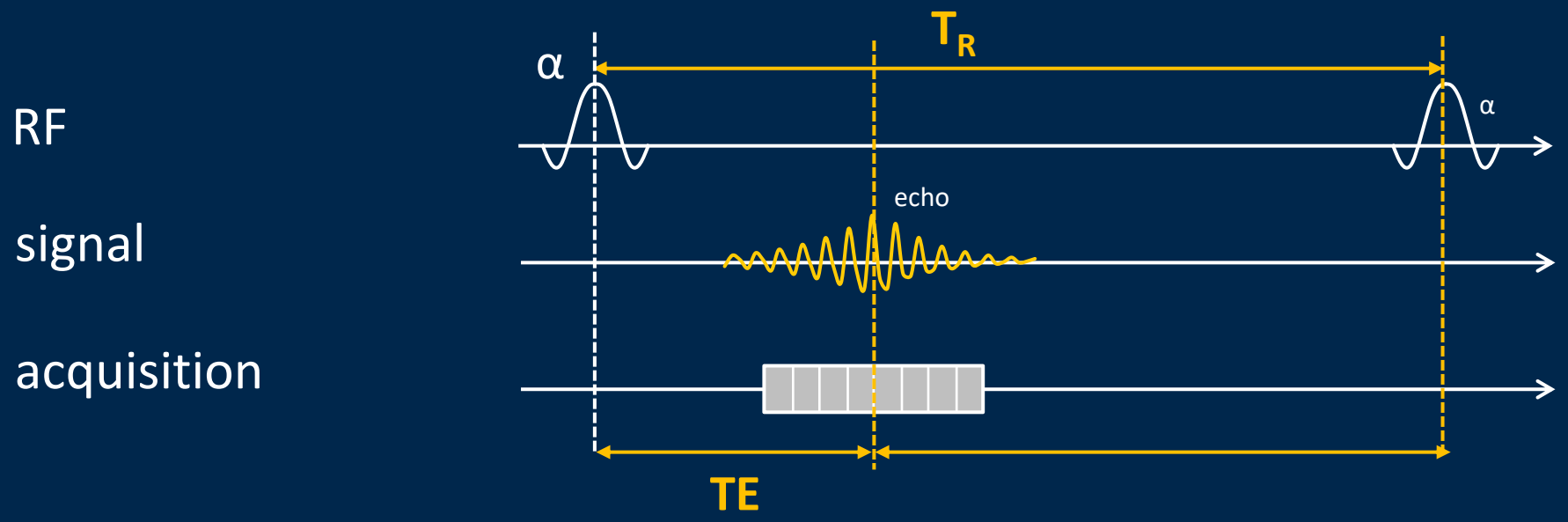
- It isn't possible to create images with ONLY one contrast mechanism, but we can try to highlight one tissue property

Tissue 1→ T1 = 1000 ms, T2=20 ms
Tissue 2→ T1 = 500 ms, T2=20 ms



T1-Weighted

Pulse Sequence

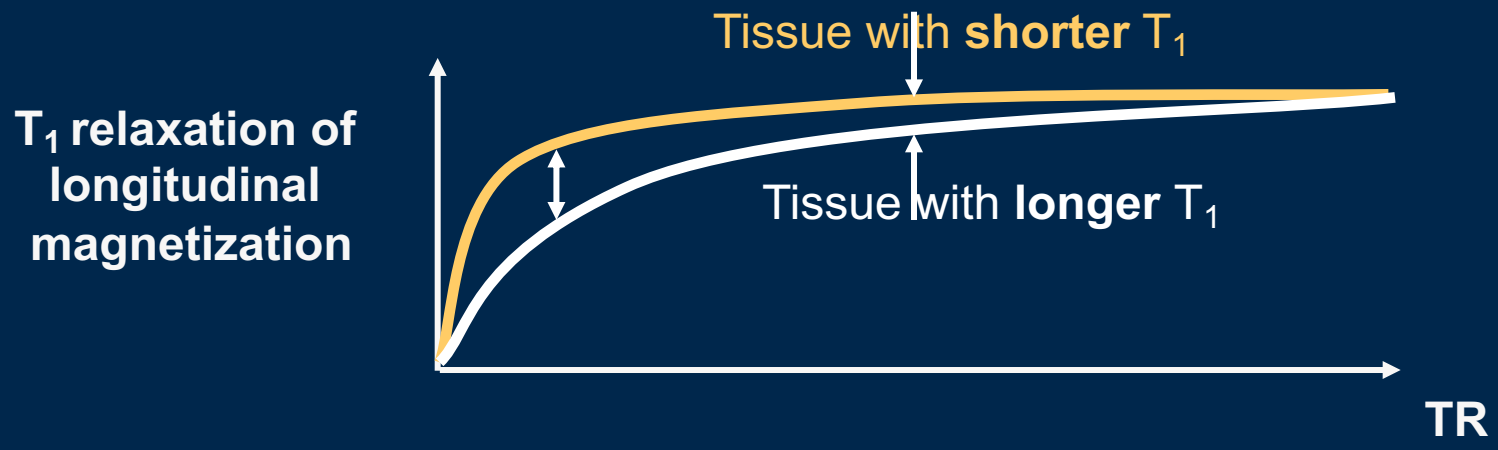


TR = Repetition Time TE = Echo Time α =Flip Angle

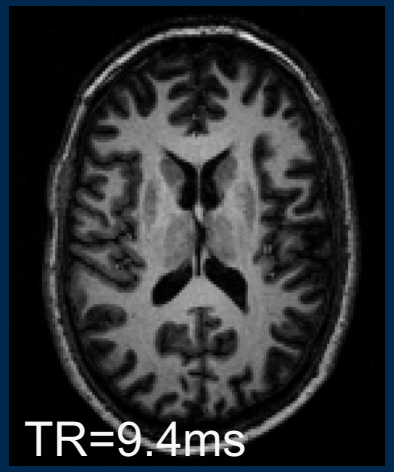
Long TR → Complete T1 Relaxation, Little T1 weighting

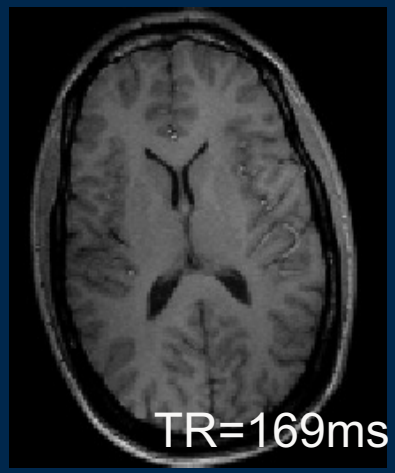
Shorter TR → Different amounts of T1 relaxation, T1 weighting

T1 Contrast can be controlled using TR



Larger difference
for **short** repetition time (TR)





Smaller difference
for **long** repetition time (TR)

More T_1 weighting

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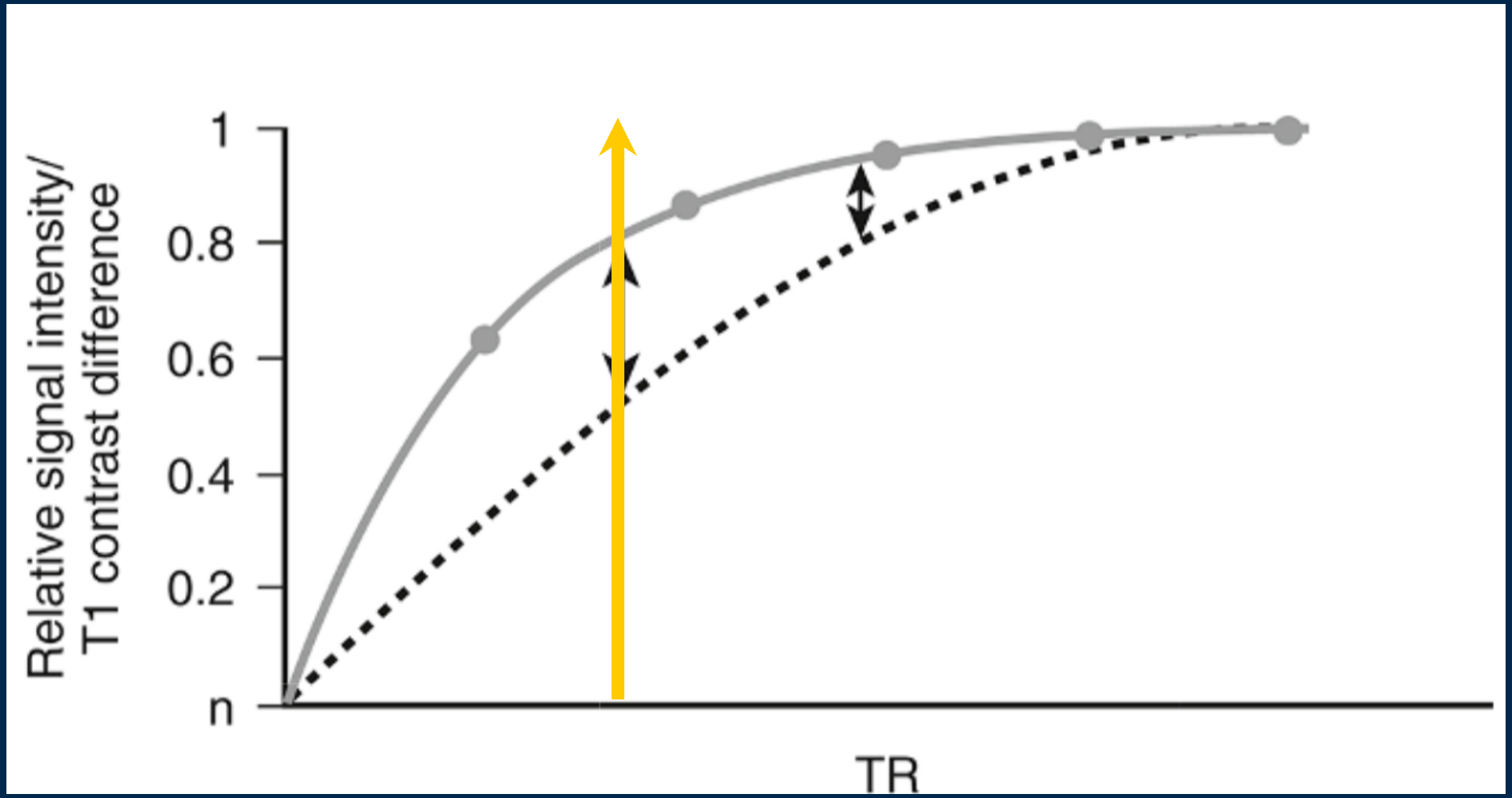
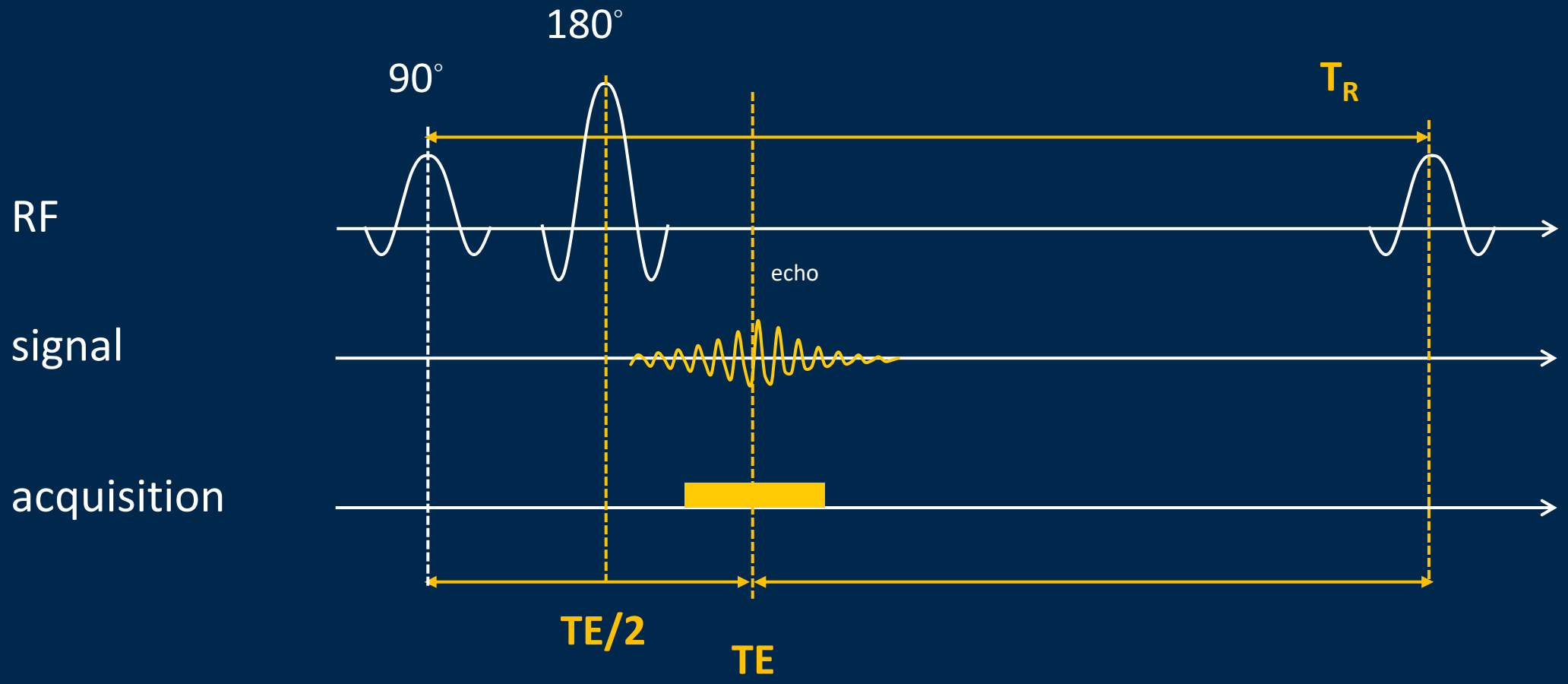
Selecting a TR to maximize T1 contrast



T1-Weighting: Sequences

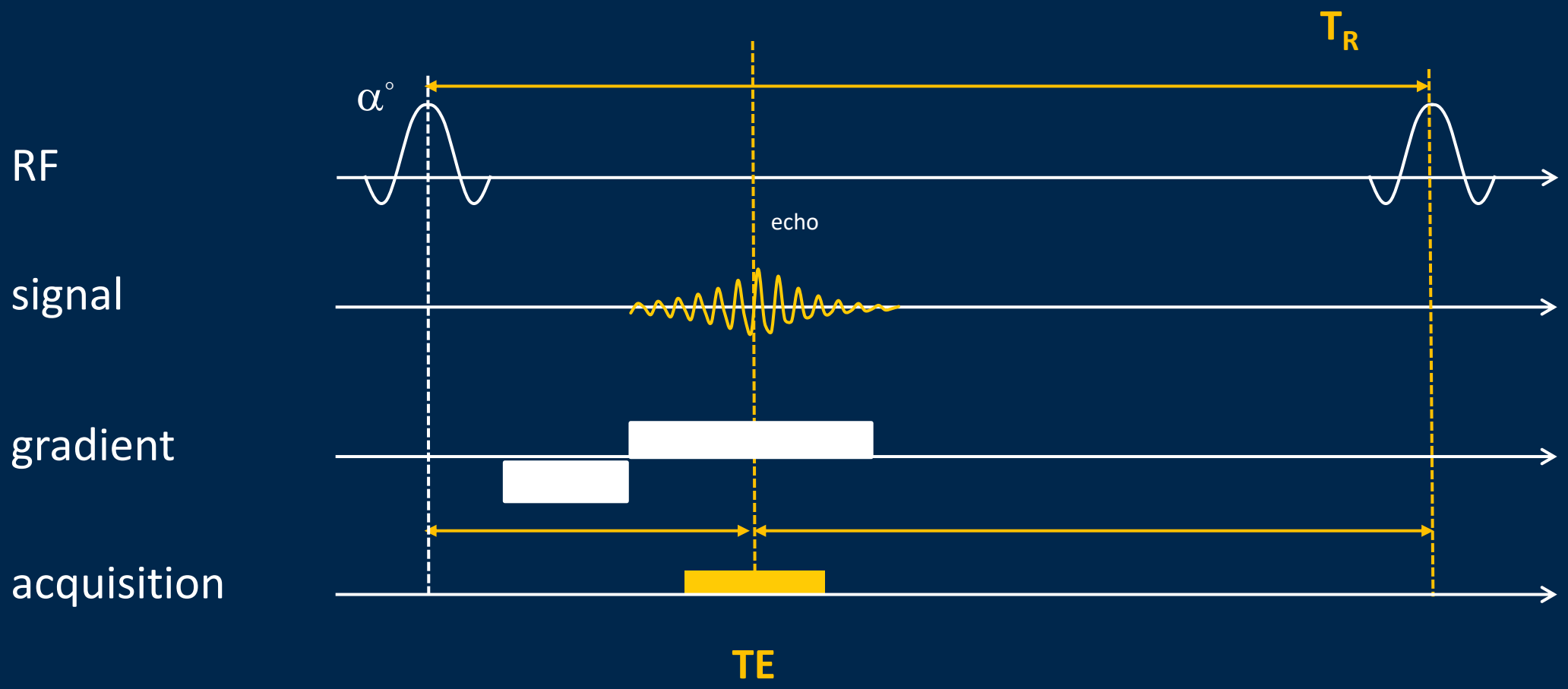


Spin Echo with Short TE and Short TR

High SNR

Long scan time

T1-Weighting: Sequences

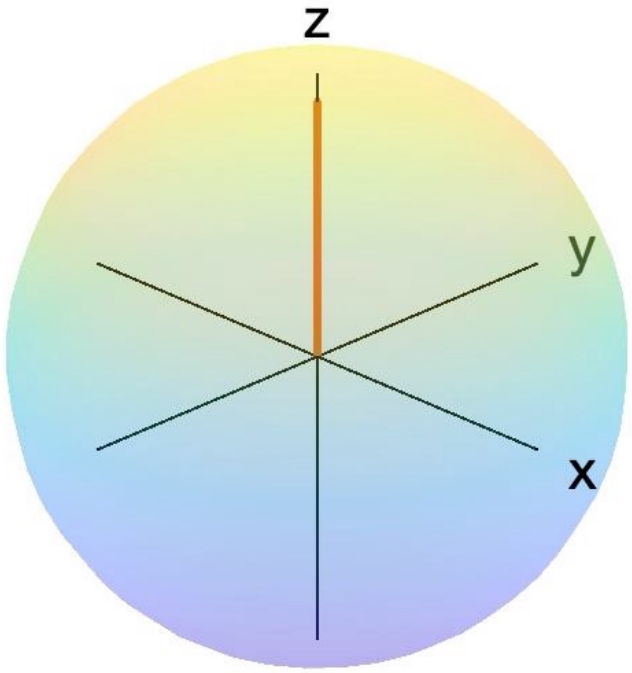


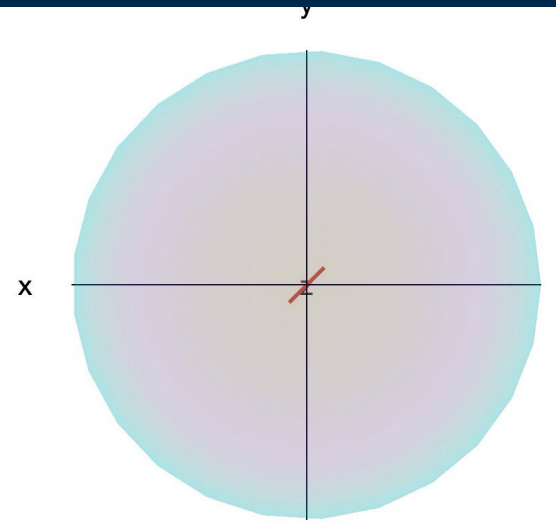
Gradient Echo with Short TE and Very Short TR, small flip angle

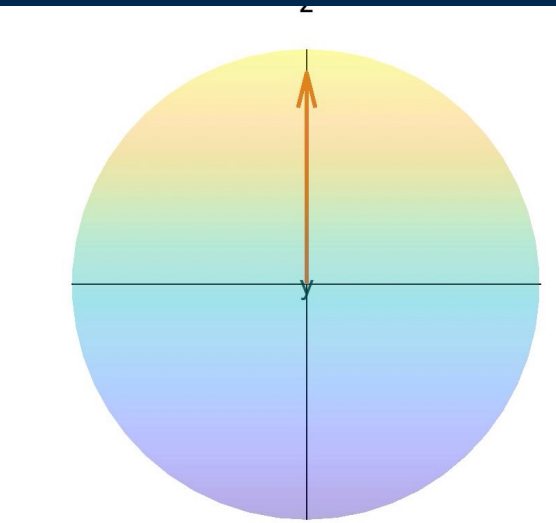
Lower SNR

Fast data collection

Very Short TR, Short TE, small flip angle (GRE)





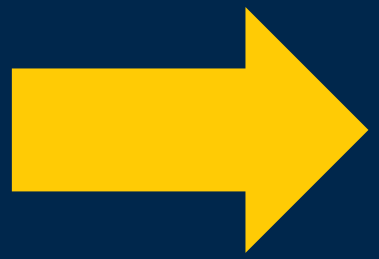


We select scanner parameters to emphasize differences in tissue properties

- Sequence settings depend on the properties of tissues we want to differentiate

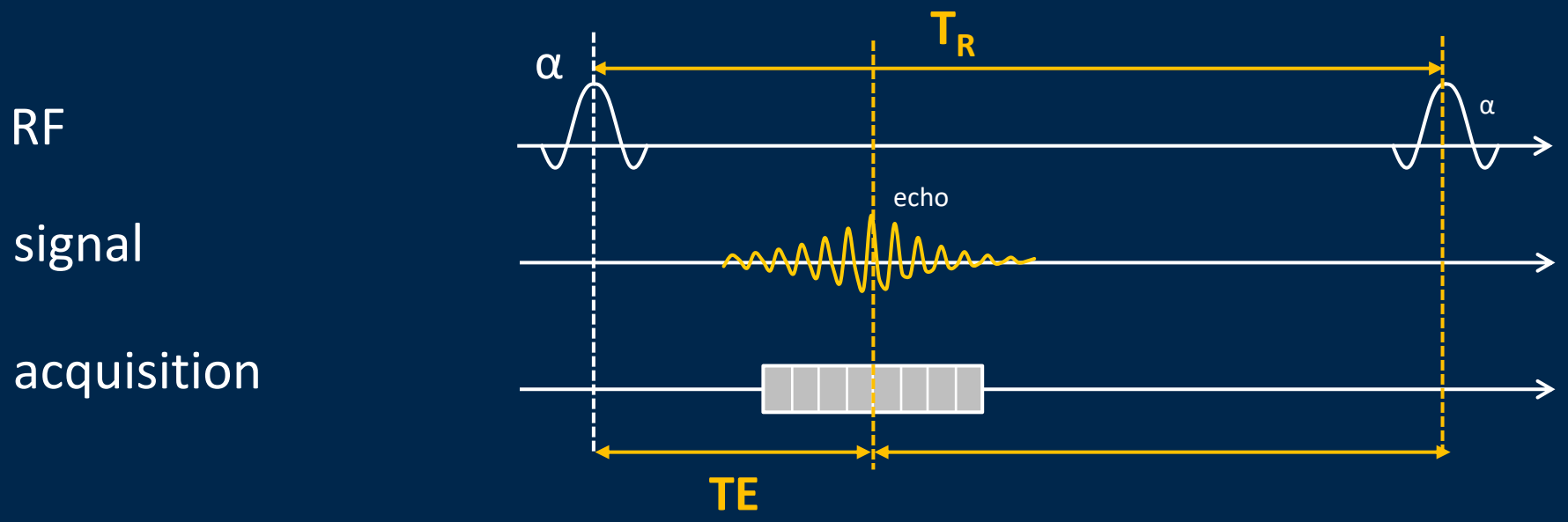
- It isn't possible to create images with ONLY one contrast mechanism, but we can try to highlight one tissue property

Tissue 1→ T1 = 1000 ms, T2=50 ms
Tissue 2→ T1 = 1000 ms, T2=20 ms



T2-Weighted

Pulse Sequence



TR = Repetition Time TE = Echo Time α =Flip Angle

Short TE → Similar levels of T2 relaxation, low T2 weighting

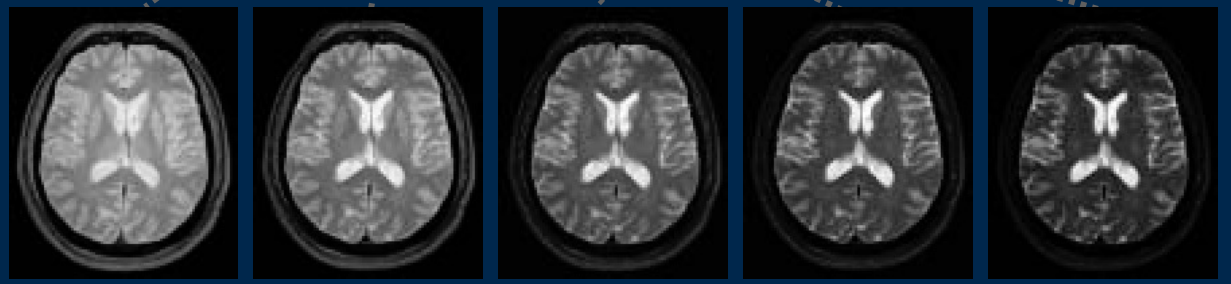
Longer TE → Different levels of T2 Relaxation, T2 weighting

T2 contrast can be controlled with TE

T_2 decay of transverse magnetization

Tissue with **longer** T_2

Tissue with **shorter** T_2



Short echo time (TE)

Long TE

More T_2 weighting

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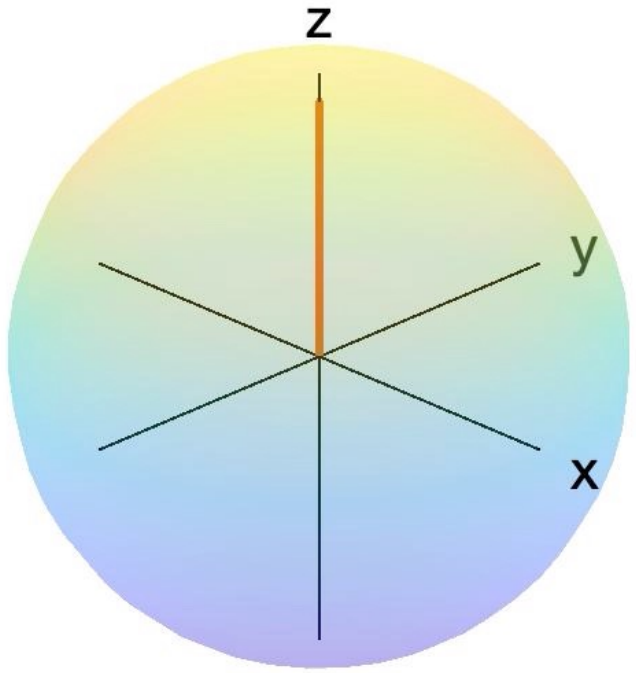
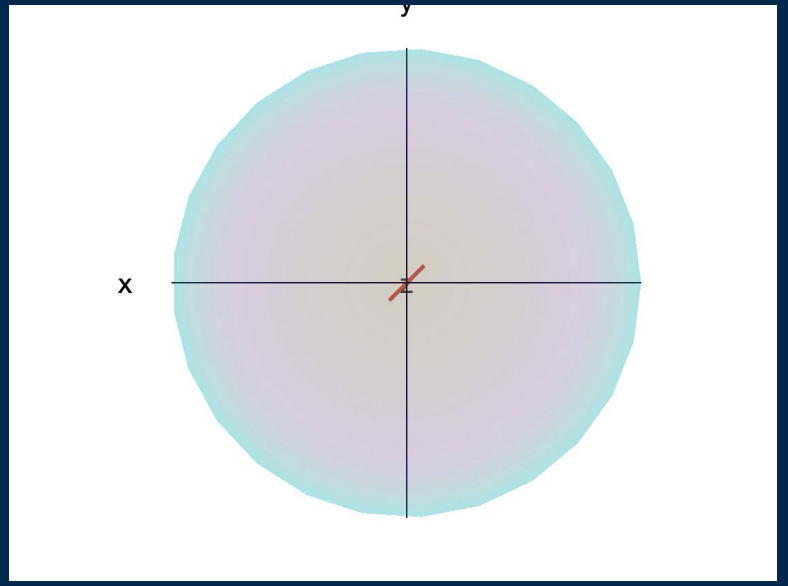
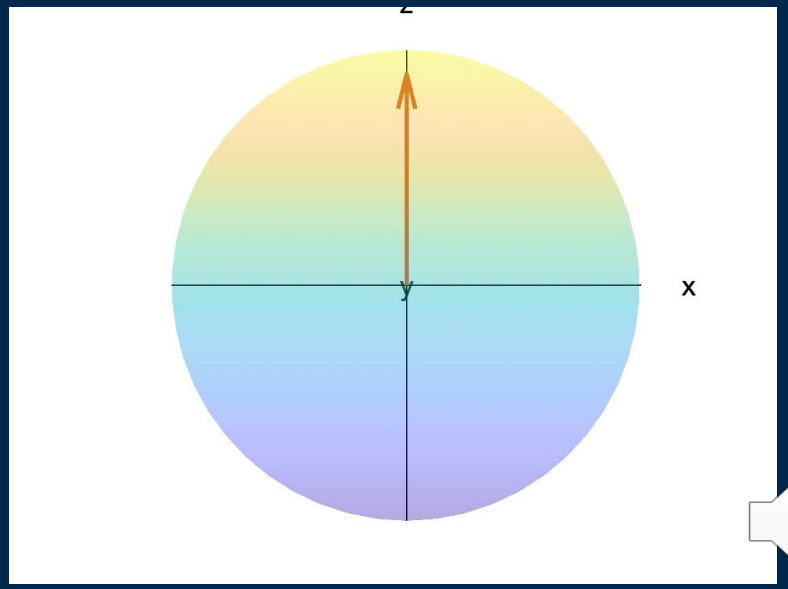
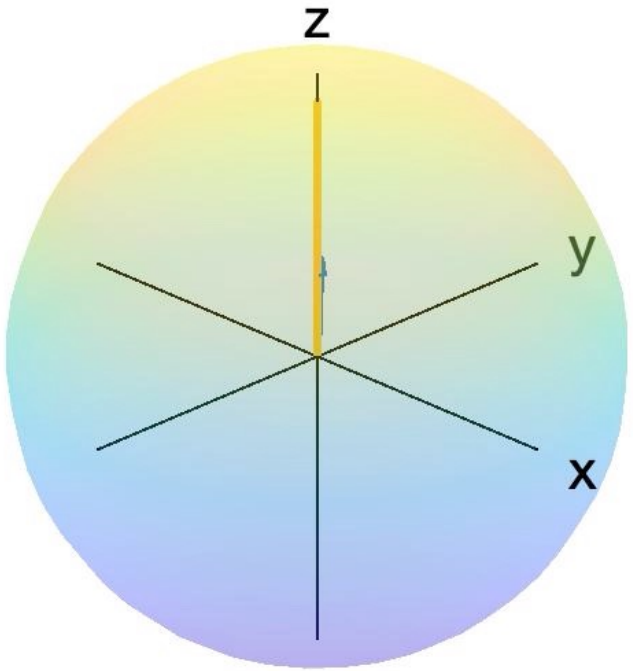
Long TE, Long TR (spin echo)

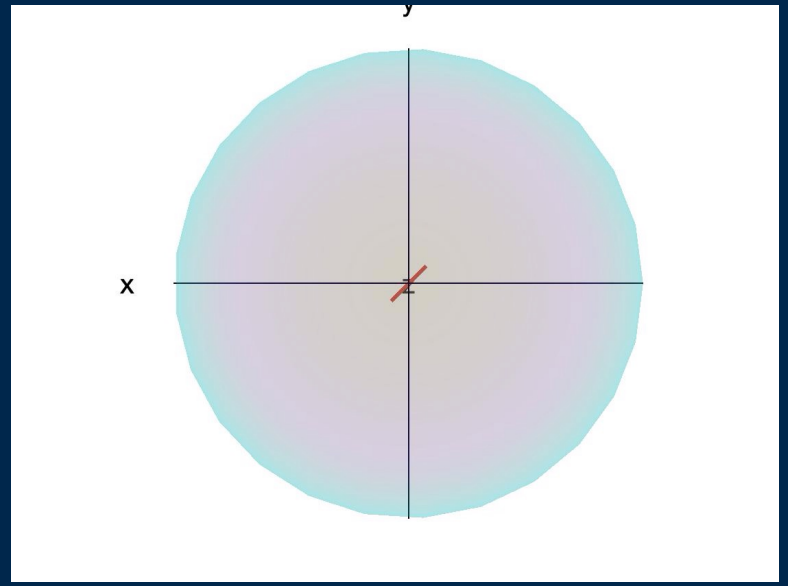


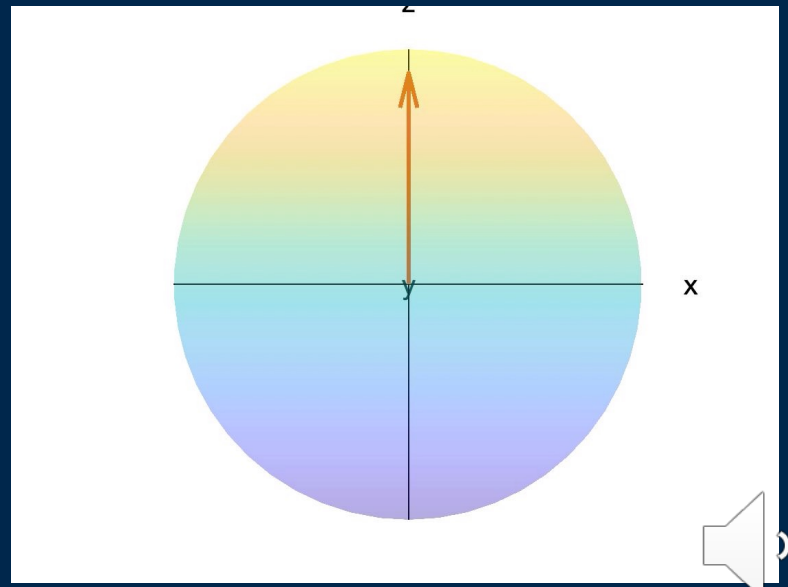




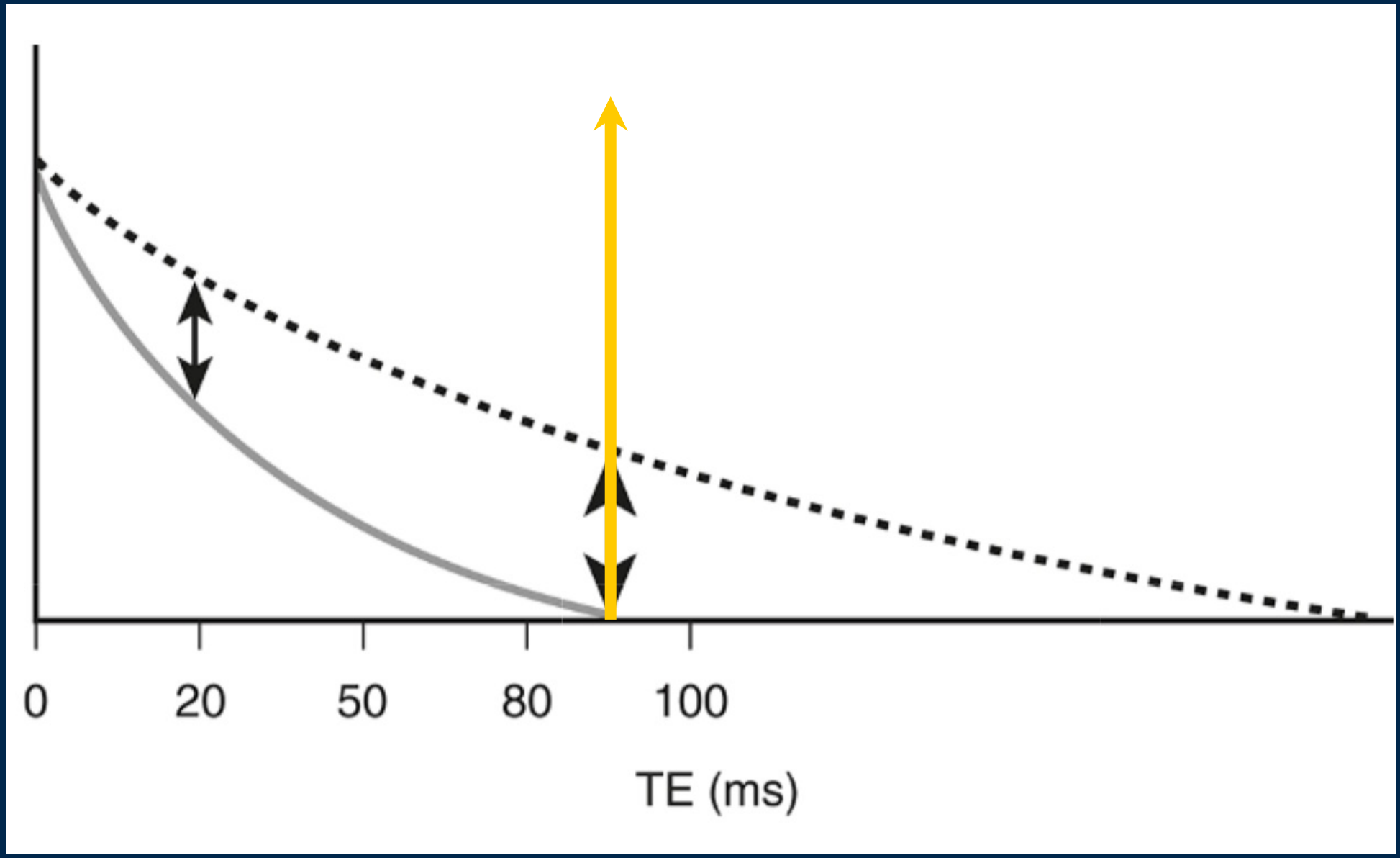
Short TE, Long TR (spin echo)







Selecting the Echo Time



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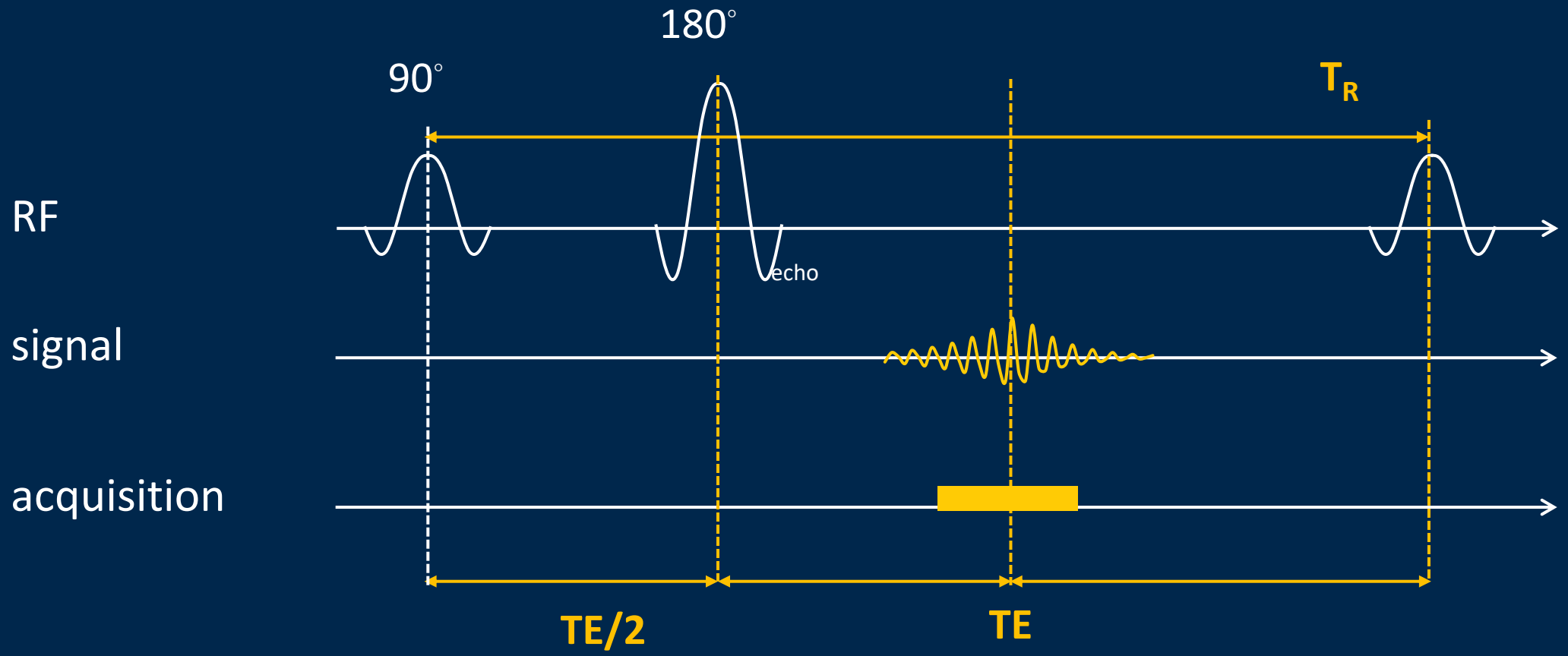
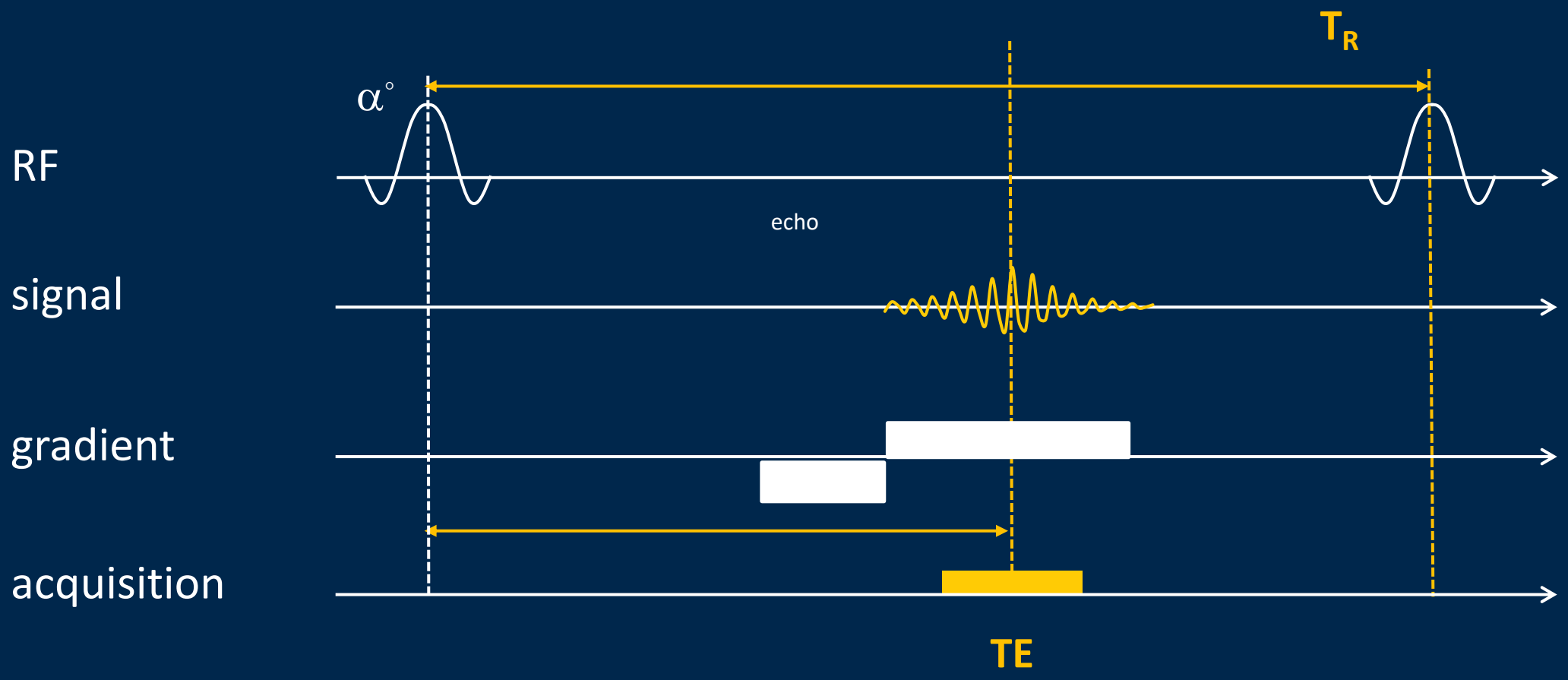
T2-Weighting: Sequences



Spin Echo with Long TE and Long TR
T2 Contrast

T2*-Weighting: Sequences



Gradient Echo with Long TE
T2* Contrast

Remember: What is ”long” and what is “short”?

Scanner Parameters

TR = 3 ms – 5000 ms

TE = 0.1 ms – 100ms

$\alpha = 4^{\circ} – 90^{\circ}$

Tissue Properties

T1 = 10 ms – 5000 ms

T2 = 10 ms – 500 ms

Proton Density = 80% - 100%

T2* = 1 ms – 50 ms

Contrast Manipulation Beyond TR, TE and flip angle

- Magnetization preparation pulses
- Choice of T1-specific delay times
- Chemical shift (i.e. water vs fat) sensitive pulses
- Water vs Fat “in-phase” vs “out-of-phase”
- Magnetization transfer pulses
- Contrast agents
- Others methods …

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A few notes on T1 and T2 contrast

- T1 Contrast → Tissues with *long T1* are DARK
- T2 Contrast → Tissues with *long T2* are BRIGHT

- Tissues almost always will differ in T1 and T2

- All sequences will be sensitive in some way to these parameters (and others such as diffusion/perfusion/etc)

- The contrast to select (and scan parameters to choose) depend on these differences

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