MRI Physics:

Spin Echo Pulse Sequences

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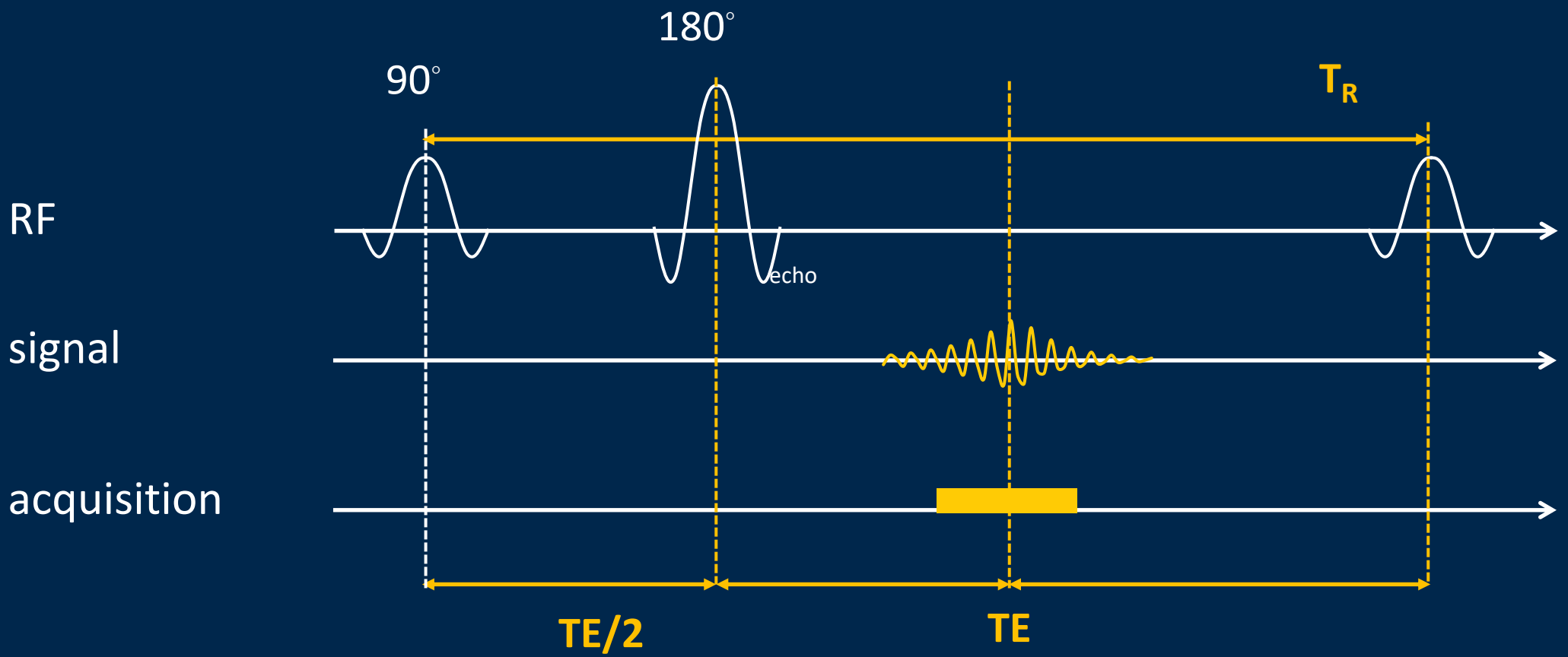
Pulse Sequences: What do we use?

- Spin Echo
- Gradient Echo
  - Spoiled Gradient Echo
  - Balanced Gradient Echo
- SE / GE + Prep Pulses to boost contrast

Spin Echo Pulse Sequence Diagram



Spin Echo MRI Contrast

$$S = S_o\left[1 - e^{-TR/T1}\right] e^{-TE/T2}$$

- TR → very long, then exp→ 0 — Image is T2-weighted
- TR → medium — Image is T1-weighted
- TR → 0 — No signal

- TE → 0, then exp→ 1 — Image is T1-weighted
- TE → medium — Image is T2-weighted
- TE → very long — No signal

Spin Echo MR Images

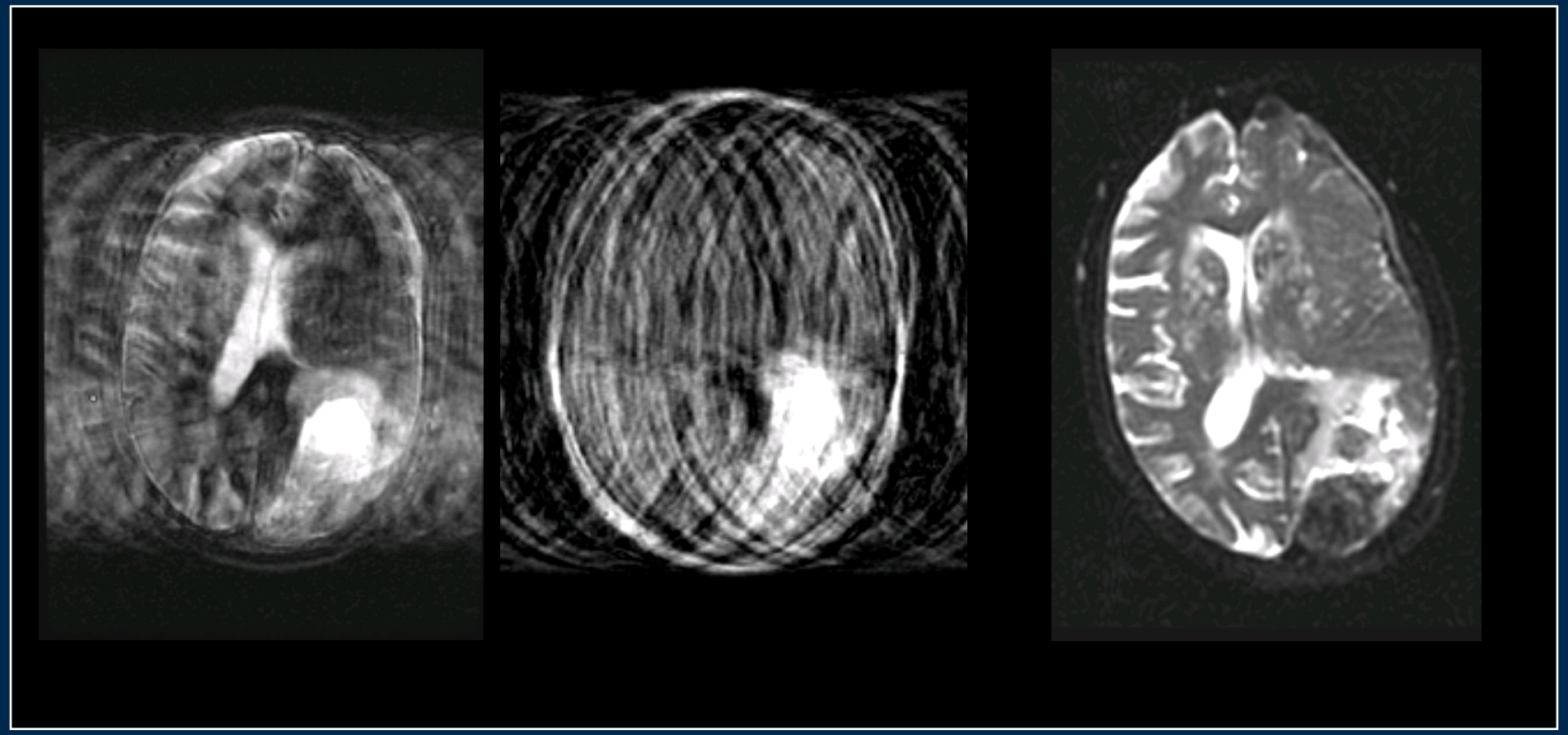
Conventional contrast:

PD-weighted

TR=4000ms

TE=15ms

Spin Echo MRI is SLOOOOW



Spin-Echo
~ minutes

Single-Shot EPI
~ 0.1sec

Spin Echo MRI is just very slow

- SLOW⇒ Long scan duration

  Scan time = TR x N_y (x Nave)

  Typically TR in range 300ms → 4000ms

  Given TR = 2000ms, Matrix = 256, Nave = 1

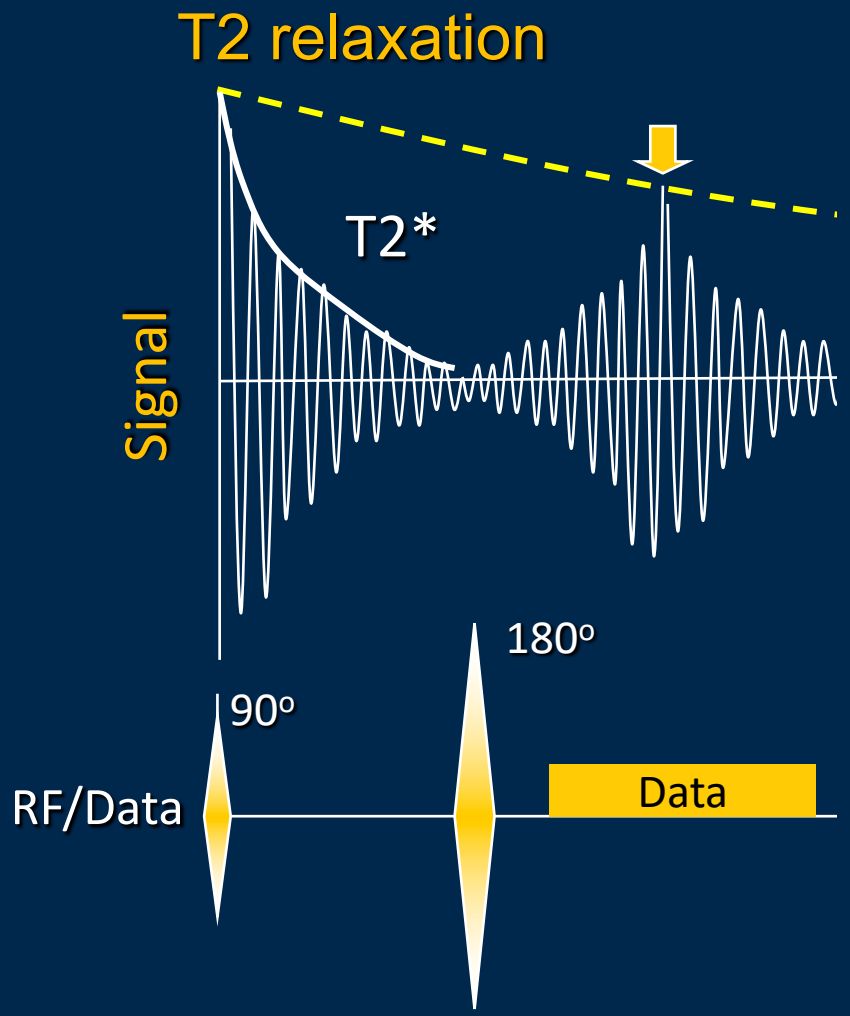
  Scan time = 2000ms x 256 = 512sec = 8.6 min

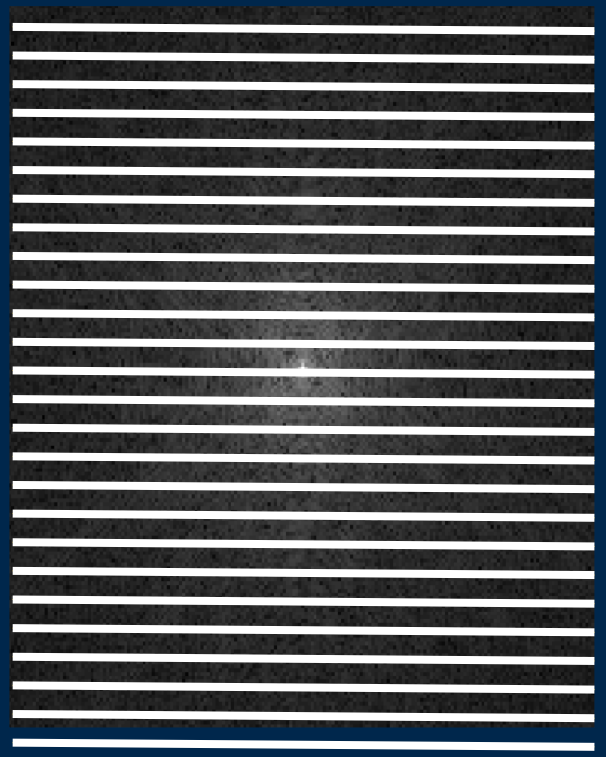
  For ”pure” T2 or PD weighting, TR > 5xT1 to minimize T1 effects

  TR ~ 5000ms ⇒ 21 min for 256 matrix size

- Long scan time ⇒ artifacts due to motion

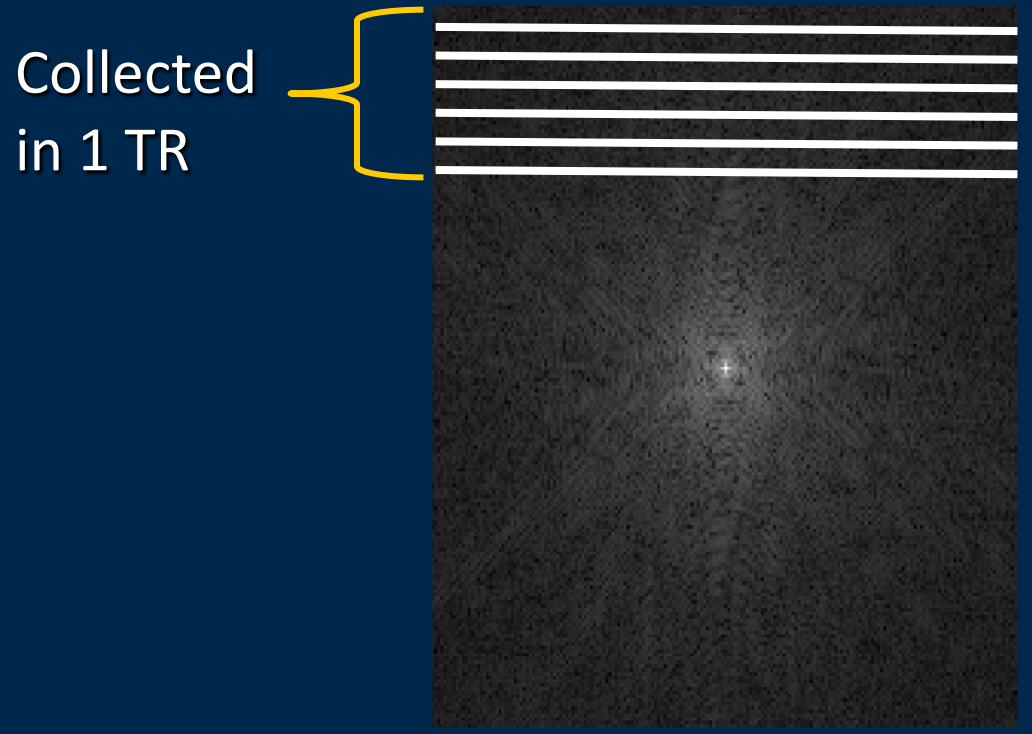
Spin Echo Variant: Multiecho SE MRI





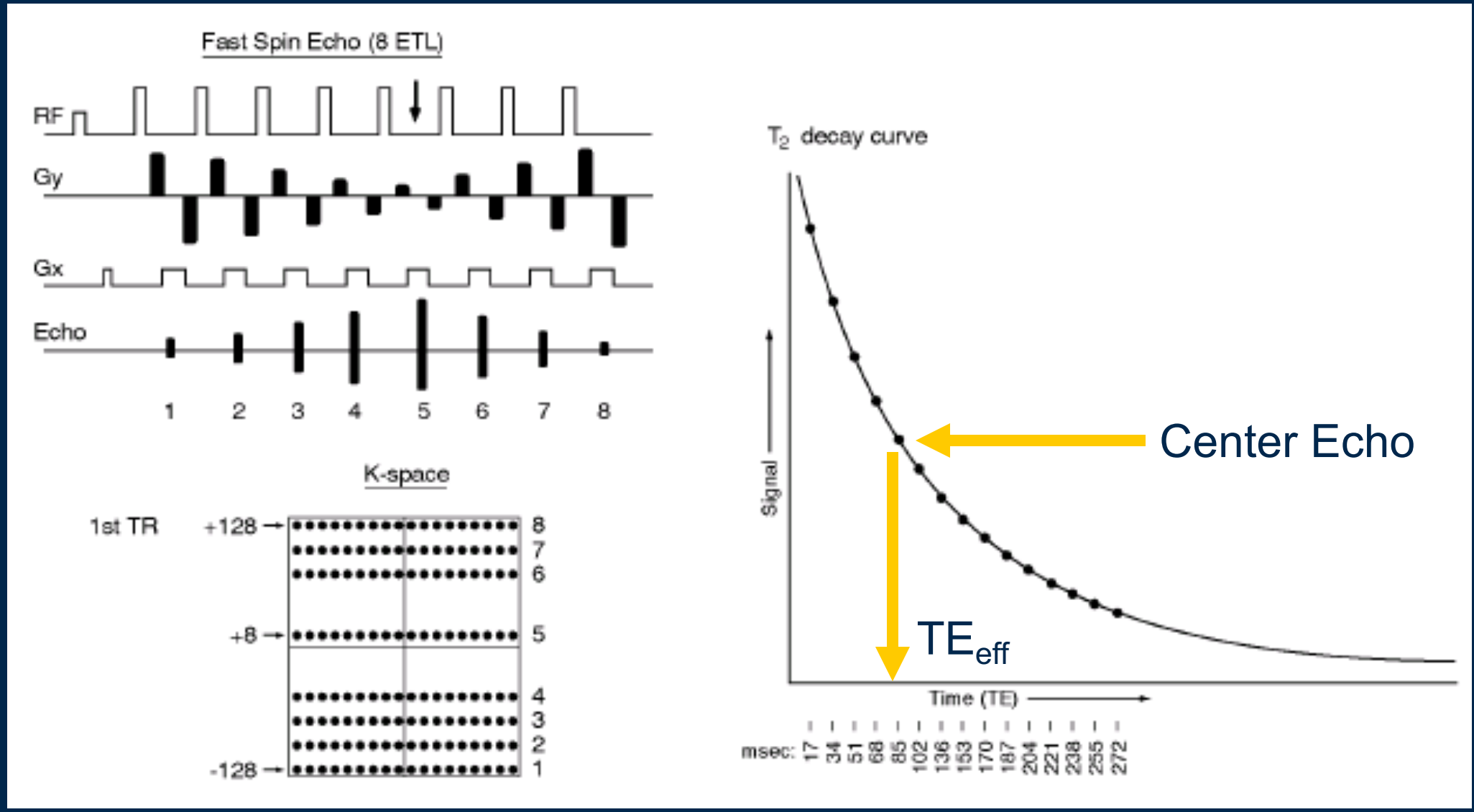
Spin Echo Variant: Multiecho SE MRI

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



- Way faster than Spin Echo
  - Turbo Factor/Echo Train Length→6
  - Number of echoes collected
  - Factor by which scan is accelerated

T2 Contrast Determined by Center of k-Space

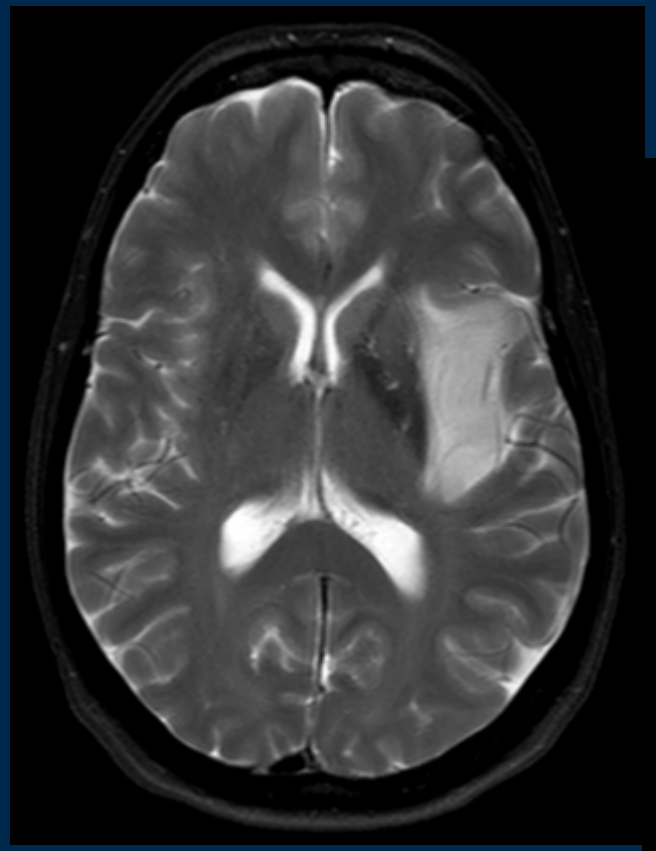


Potential Disadvantages of TSE

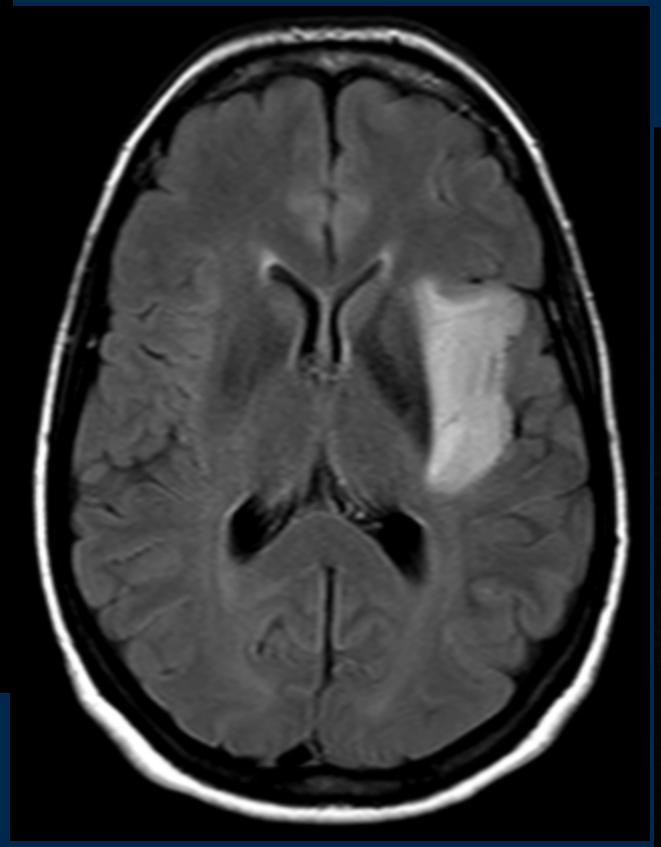
- Complex T2 weighting (not all of image data is weighted the same way)
- Some “blur” or “edge-enhancement” occurs since T2-decay and spatial encoding coincide
- Fat exceptionally bright due to funny physics (J-coupling effect)
- High RF power deposited in tissue (high SAR) due to multiple 180° pulses

  → May not be possible at 3T

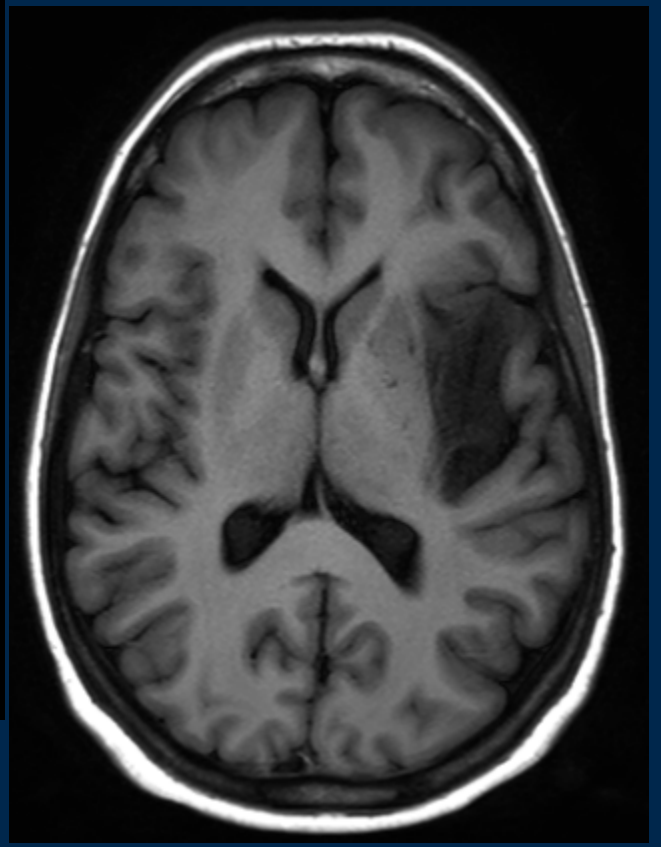
FSE / TSE MRI - Examples



T2wt FSE / TSE
TR=3600ms TE=80ms
ETL = 16



T2wt FLAIR FSE / TSE
TR=11000 TE=125 TI=2800
ETL = 27

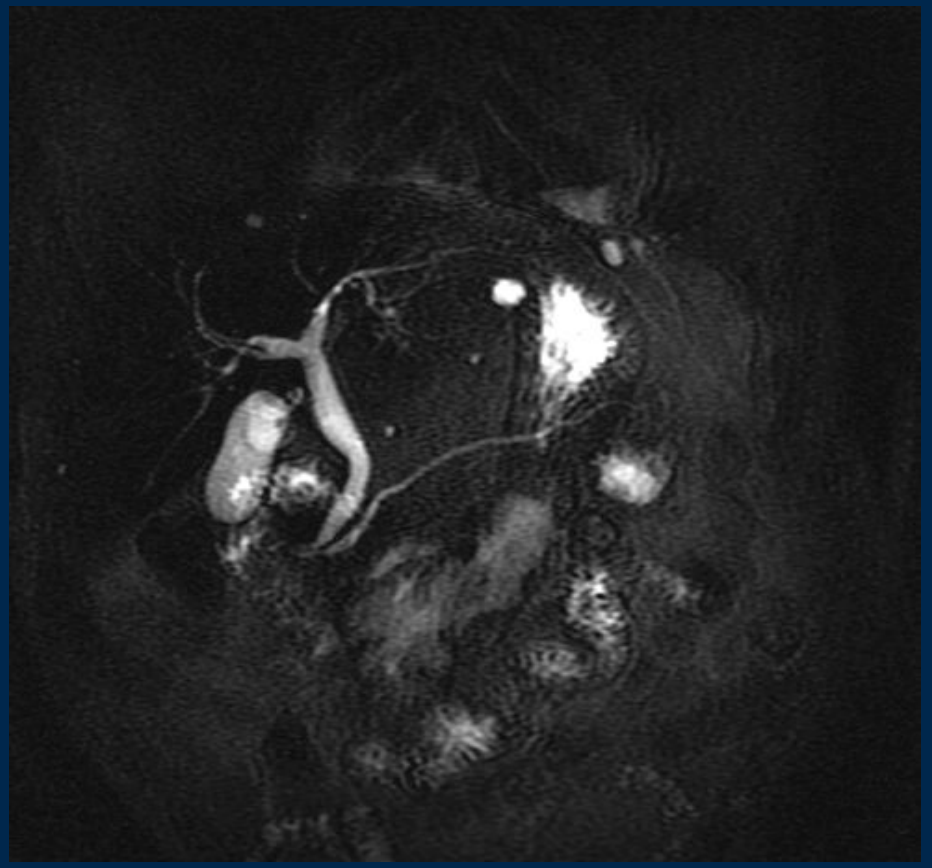


IR-prep T1wt FSE / TSE
TR=2100 TE=20 TI=800
ETL = 7

FSE MRI

Single-Shot FSE (ETL~64-128)

Breathhold T2w



MRCP

Spin Echo Pulse Sequences

- TR controls T1 weighting
- TE controls T2 weighting
- Can be combined with “preparation pulses”
- Lack of T2*→ fewer distortions/artifacts than other sequences
- Often used in multi-echo format

- Conventional Spin Echo is VERY Slow
- Multi-echo → High SAR due to many 180° pulses
- Multi-slice → Dead time during TR used to scan additional slices

MRI Physics:

Gradient Echo Pulse Sequences

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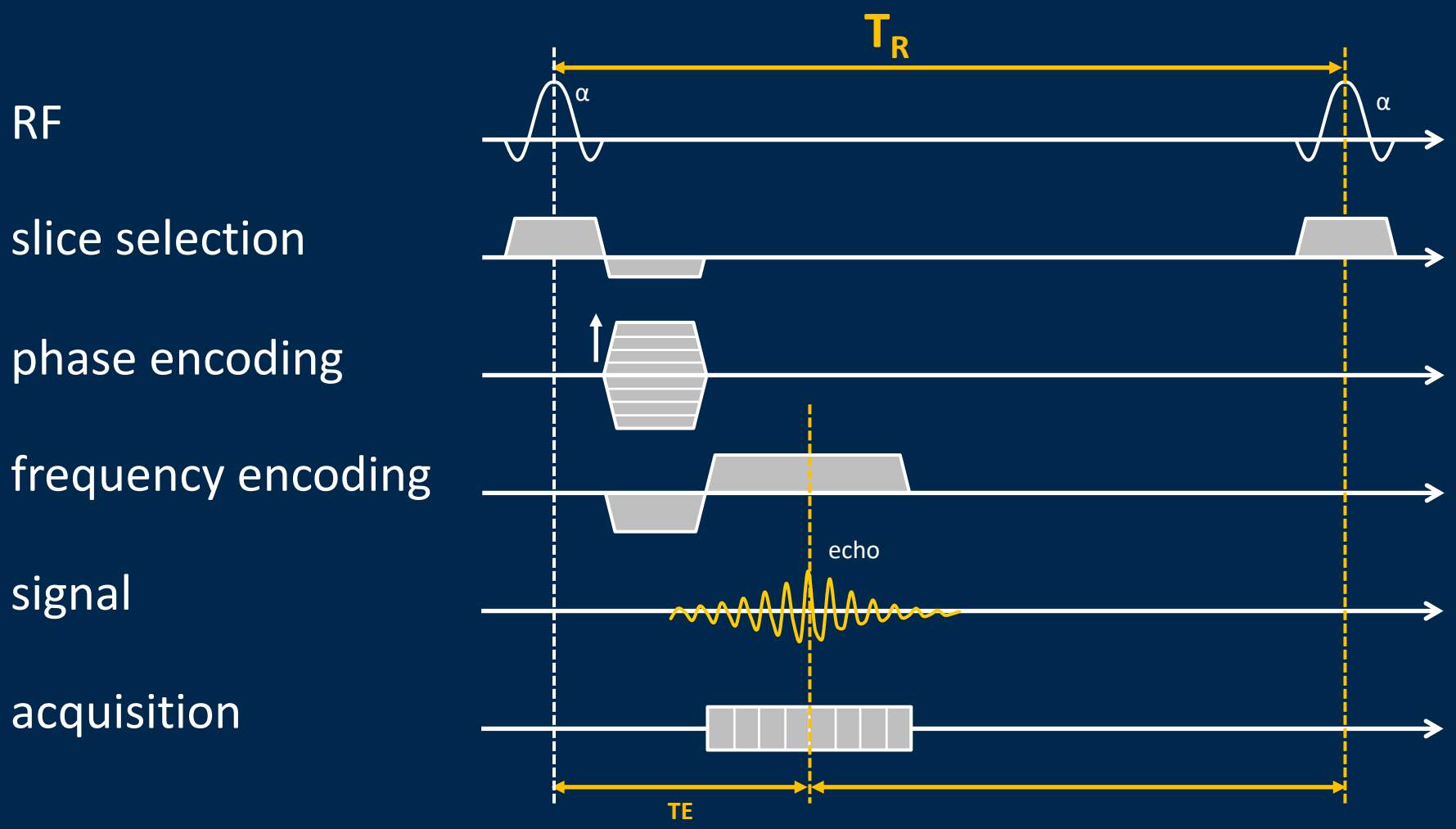
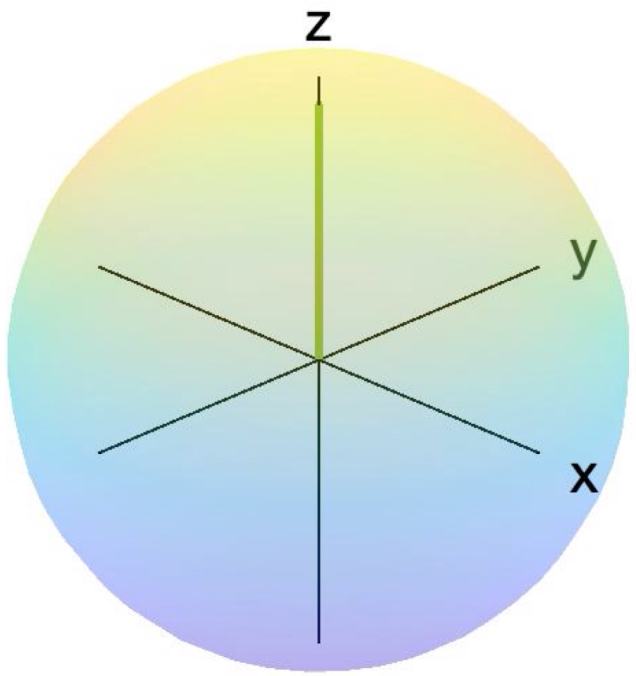
Gradient Recalled Echo (GRE) Pulse Sequence

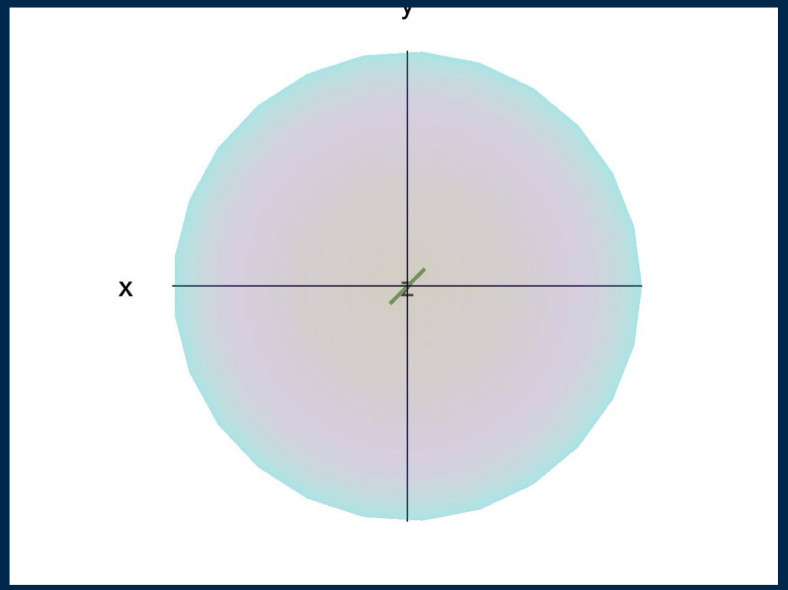


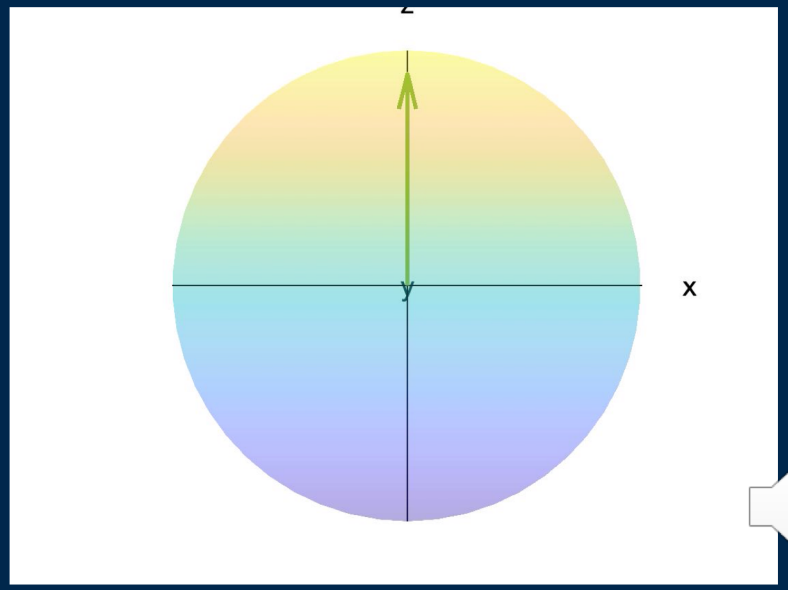
Compared to Spin Echo:

1) No 180 pulse 2) Flip angle less than 90 3) Additional gradient to make echo

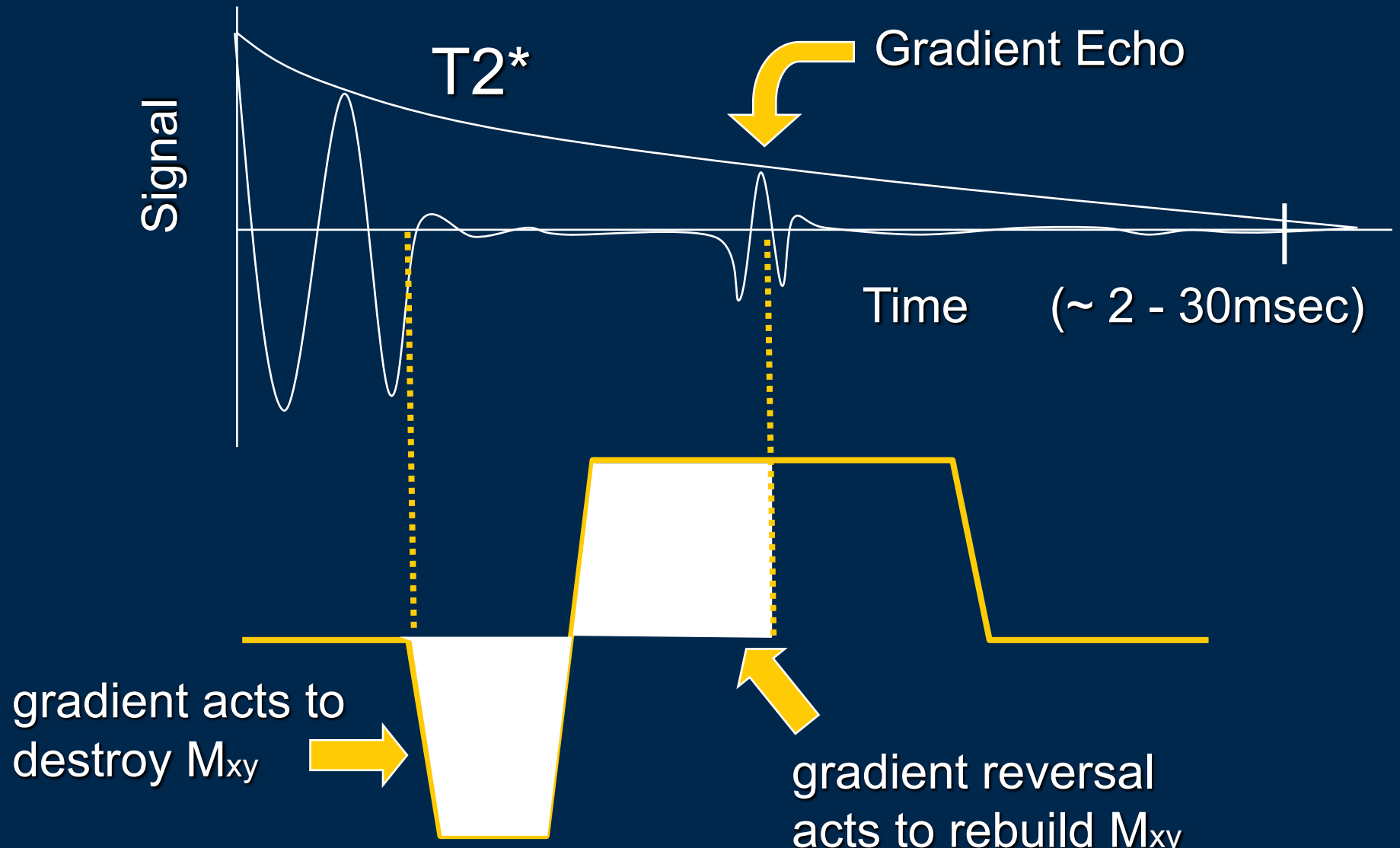
T_2^* Relaxation Dephases Magnetization (signal loss)







T2* Decay of signal following RF pulse



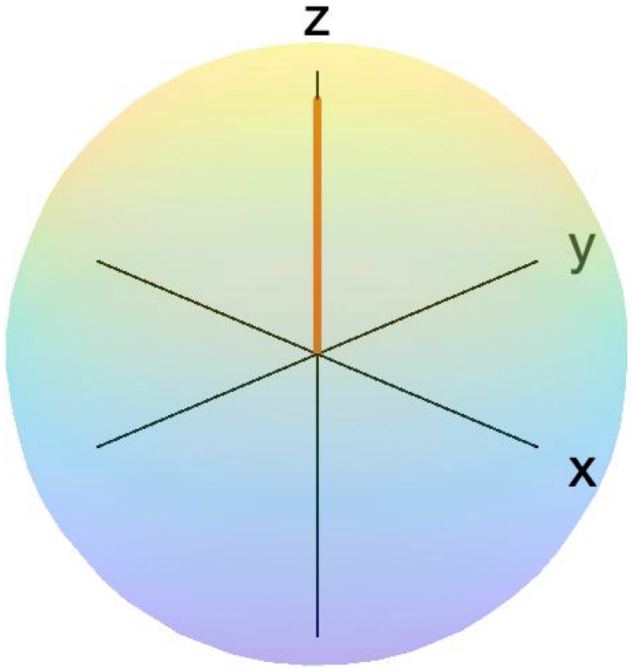
GRE Sequence

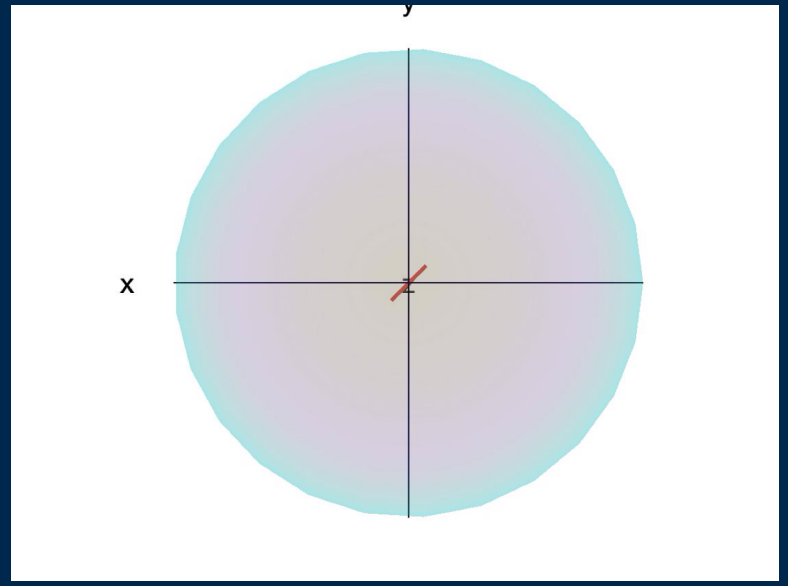
- T2* Weighting, not T2 (but can be altered)

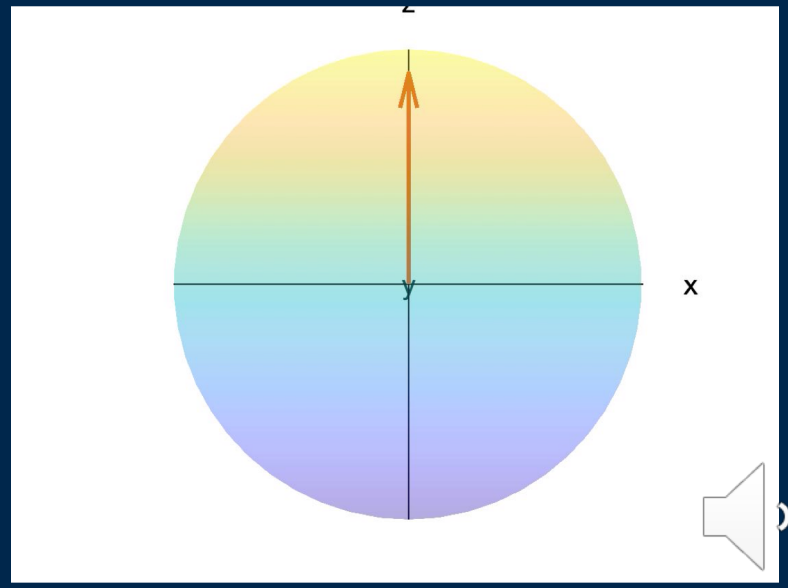
- Use of small flip angles
- → significant residual M_z after RF pulse
  → data can be collected at much shorter times
  TR (200ms $\rightarrow$ 2ms) and TE (50ms $\rightarrow$ 0.5ms)

- Signal moves into a “steady state” of low SNR

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







Sub-Classes of GRE

Many sub-classes GRE sequences with *very* different contrast behavior

- FLASH: Fast Low-Angle Shot (multiple versions Siemens)
- GRASS: Gradient Recalled Acquisition in the Steady State (General Electric)
- FFE: Fast Field Echo (Philips)
- FISP: Fast Imaging w/ Steady Precession (Siemens)
- TrueFISP (Siemens); FIESTA (GE); Balanced FFE (Philips)
- SPGR: Spoiled GRASS; Spoiled FLASH; T1-FFE
- SSFP: Steady-state free precession
- many others …

Sub-Classes of Gradient Echo Sequences

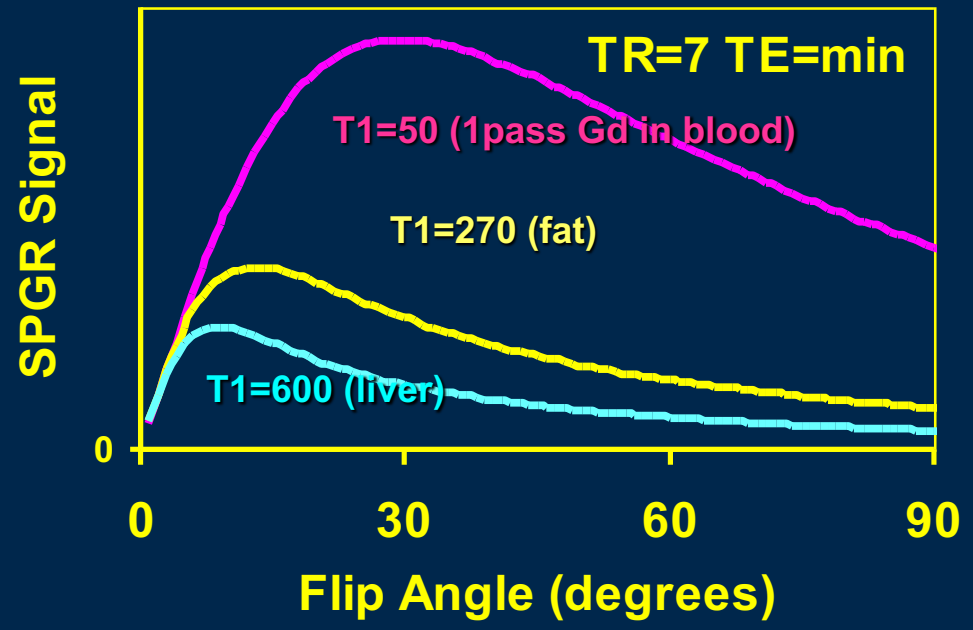
SEQUENCE TYPE	GE	PHILIPS	SIEMENS
Gradient Echo	GRE	FFE	GRE
Coherent Gradient Echo	GRASS	FE	FISP
Spoiled Gradient Echo	SPGR	T1-FFE	FLASH
Steady-State Free Precession	SSFP	T2-FFE	PSIF
True FISP	FIESTA	Balanced-FFE b-FFE	TrueFISP
Fast Gradient Echo	Fast GRE; Fast SPGR	Turbo-FFE; TFE	TurboFLASH
Fast T1wt 3D GRE	3D FGRE; 3D FSPGR; LAVA	3D TFE; THRIVE	MPRAGE; VIBE

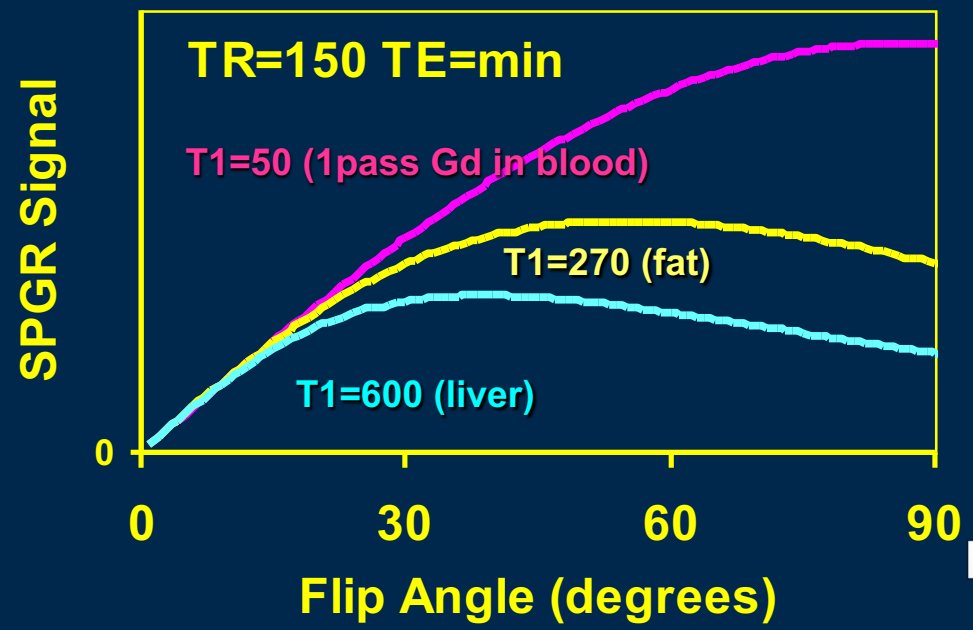
Can have very different contrast behavior
(depending on steady-state and sequence settings)

Spoiled Gradient Echo MRI (SPGR and FLASH)

$$S = \frac{So\left[1 - e^{-TR/T1}\right]\sin(\theta)}{1 - \cos(\theta)\, e^{-TR/T1}}\, e^{-TE/T2^*}$$

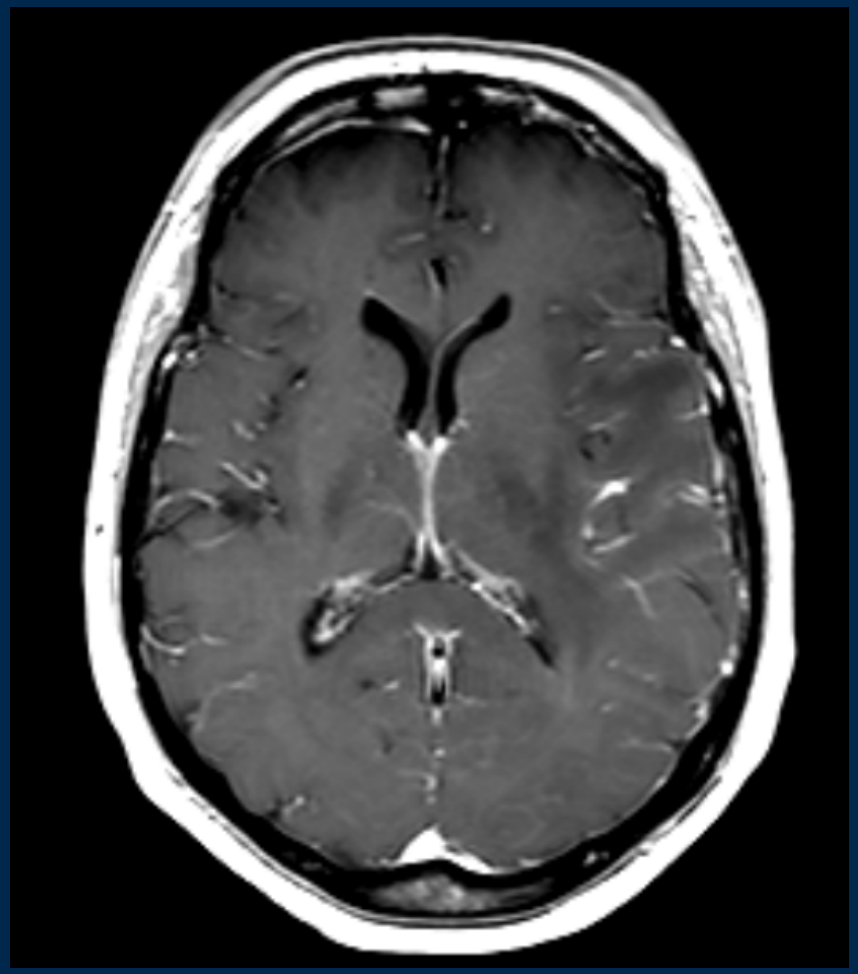
Control T1 contrast by flip angle and TR (min TE):



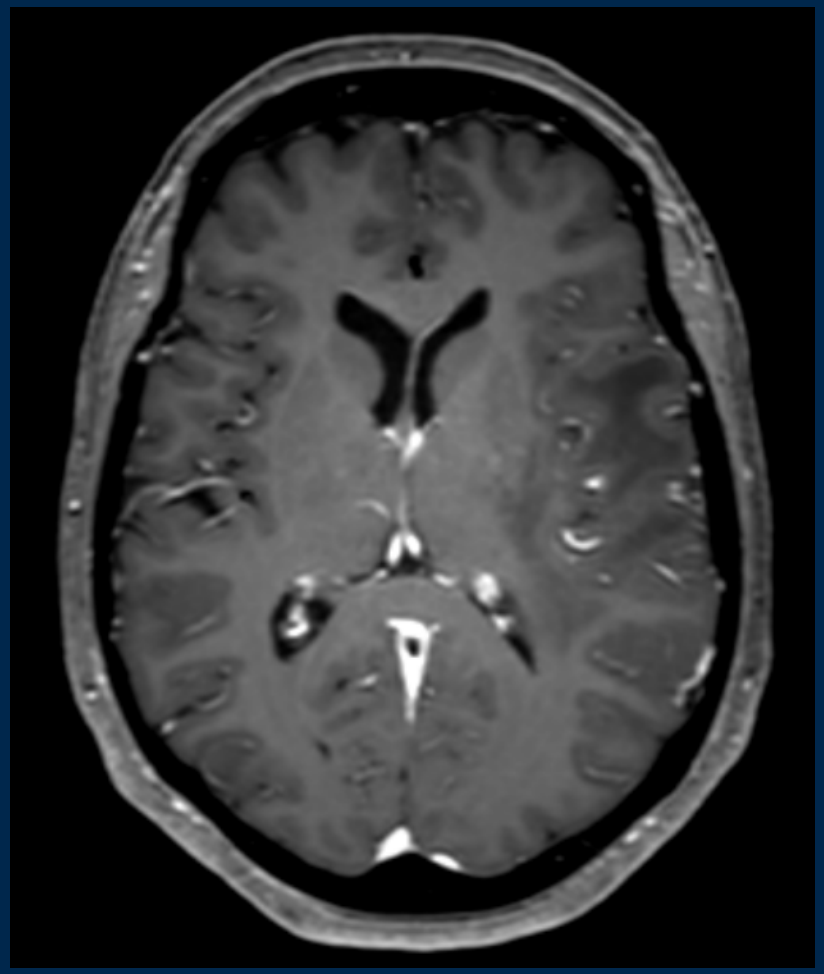


Two options for T1-weighted Imaging (+Gd)

256 x 0.5 s
2.1 min



2D Spin-Echo
TR=500ms TE=10ms

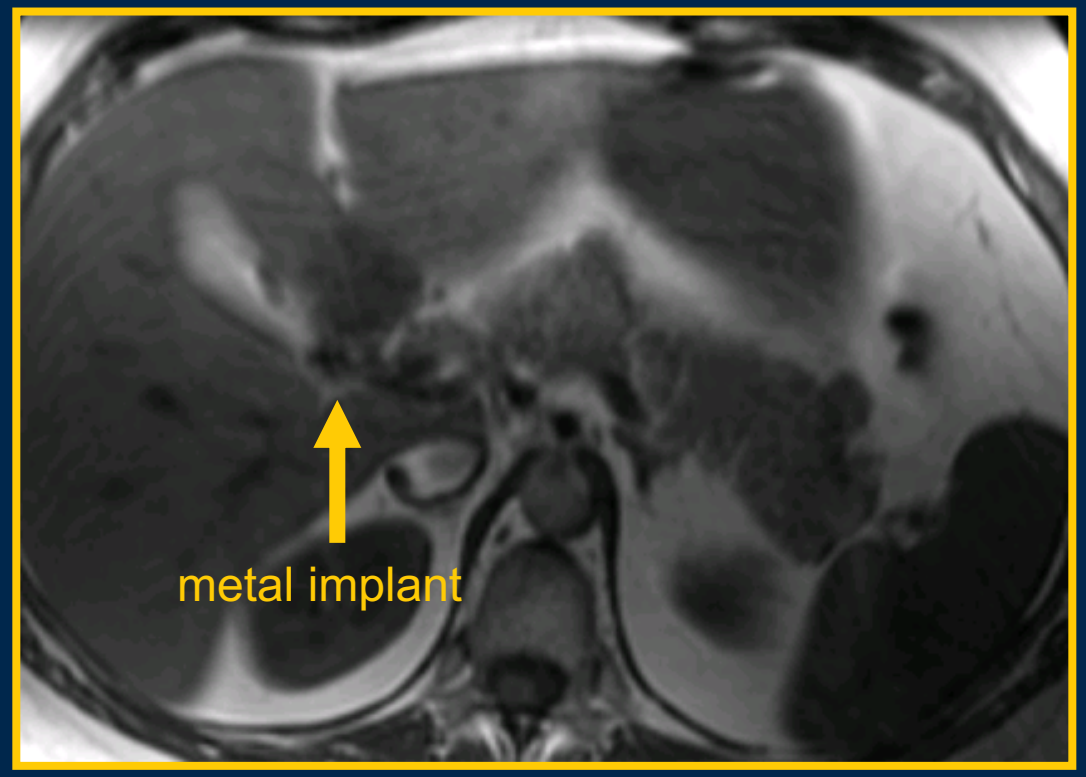


3D Spoiled GRE (SPGR)
TR=10ms TE=6ms Flip = 8°

256 x 0.01 s
2.5 sec

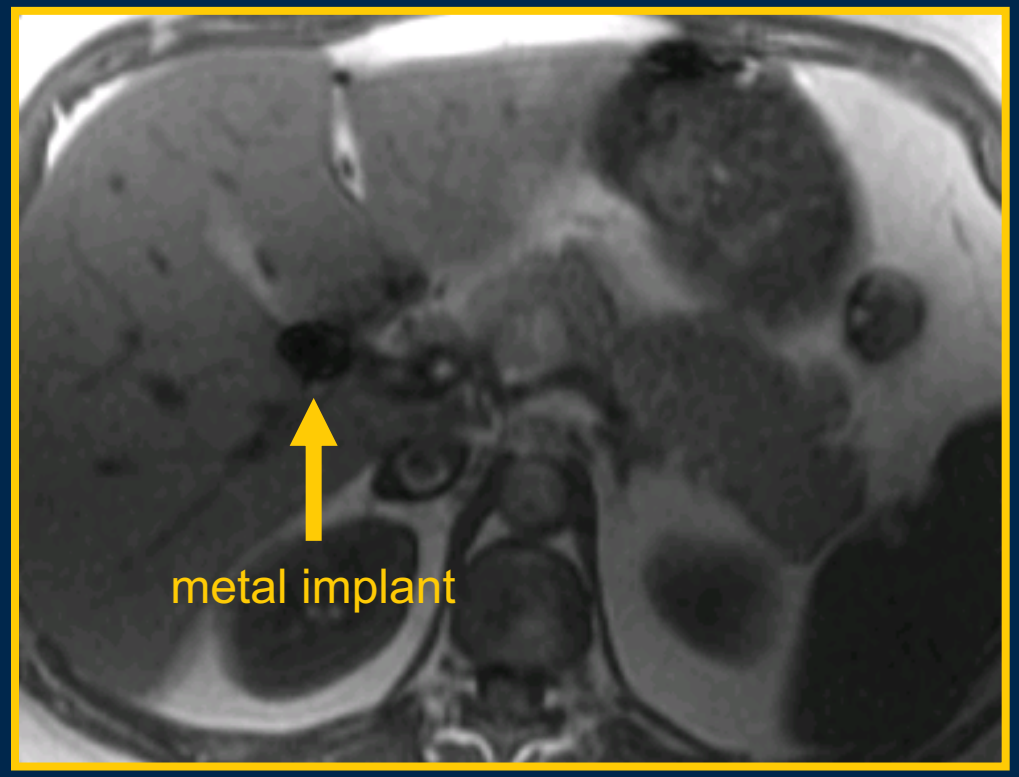
3D
256 x 64 x 10ms
2.67min

Spin Echo vs GRE: Local Signal Dephasing



Spin Echo

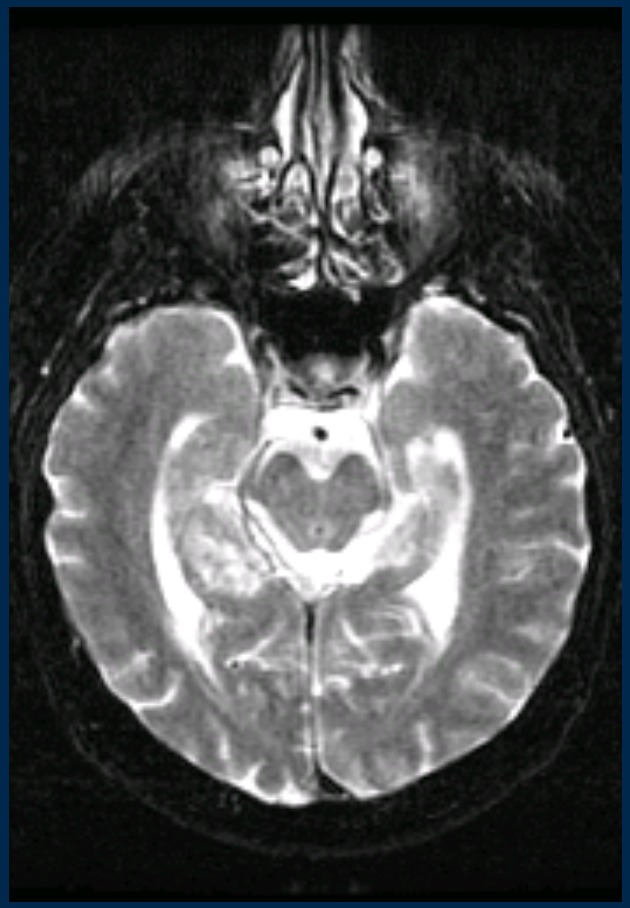
less sensitive to local distortion and signal loss



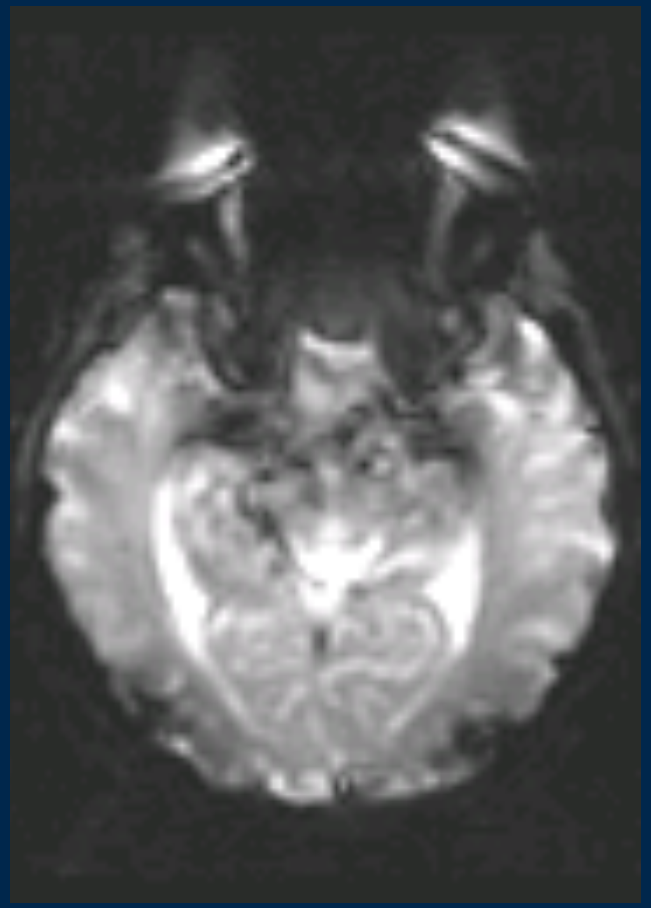
(Spoiled) GRE

more sensitive to local distortion and signal loss due to T2* sensitivity

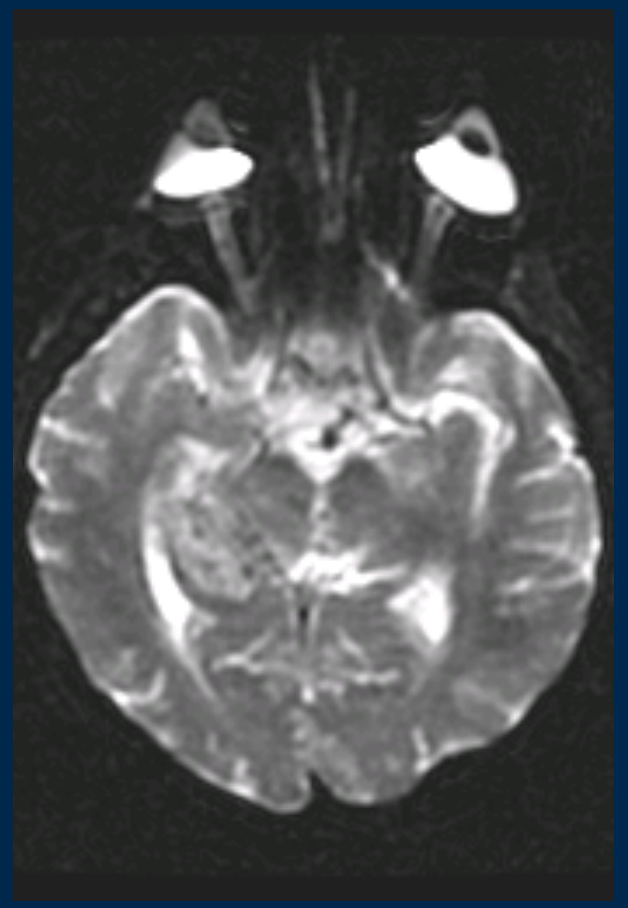
Spin-Echo vs EPI: Geometric Distortion and Local Signal Dephasing



SE



SS GRE



SS SE

Spoiled Gradient Echo

- Very fast, primarily T1-weighted imaging

  → Contrast controlled by FA and TR

- Enables full 3D imaging

  → Great for dynamic imaging or for breathhold scans

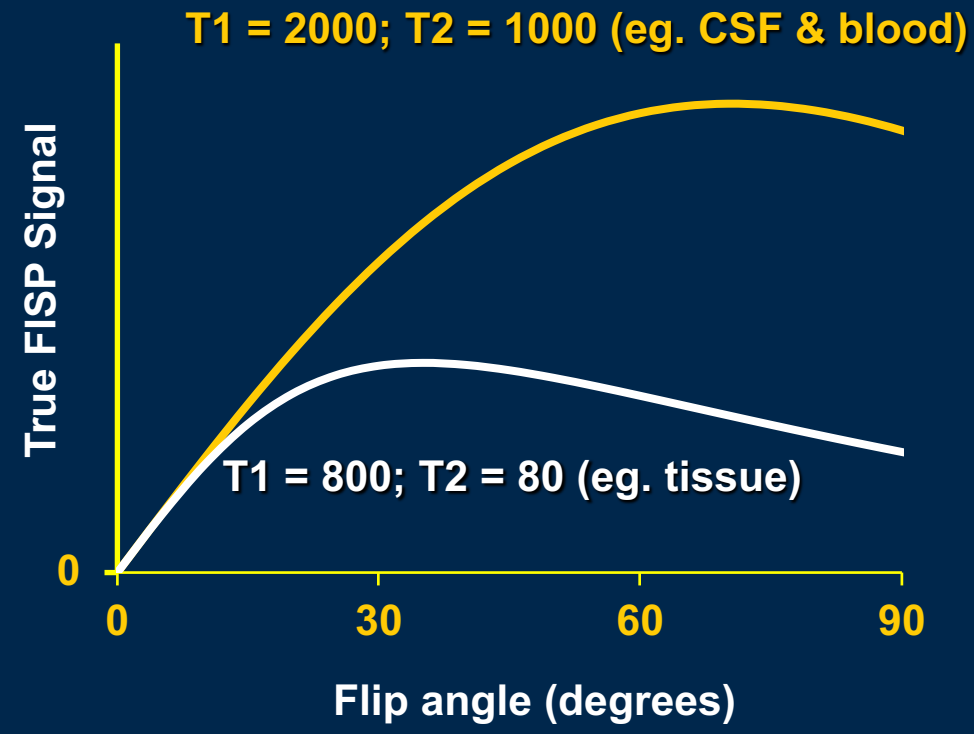
- Slower but can be used for T2*-weighted imaging
- Low SNR (can be boosted by using 3D acquisition)
- Signal loss/Distortion around sources of magnetic field inhomogeneities

Fully Balanced Gradient Echo MRI (bSSFP, TrueFISP, FIESTA, bFFE)

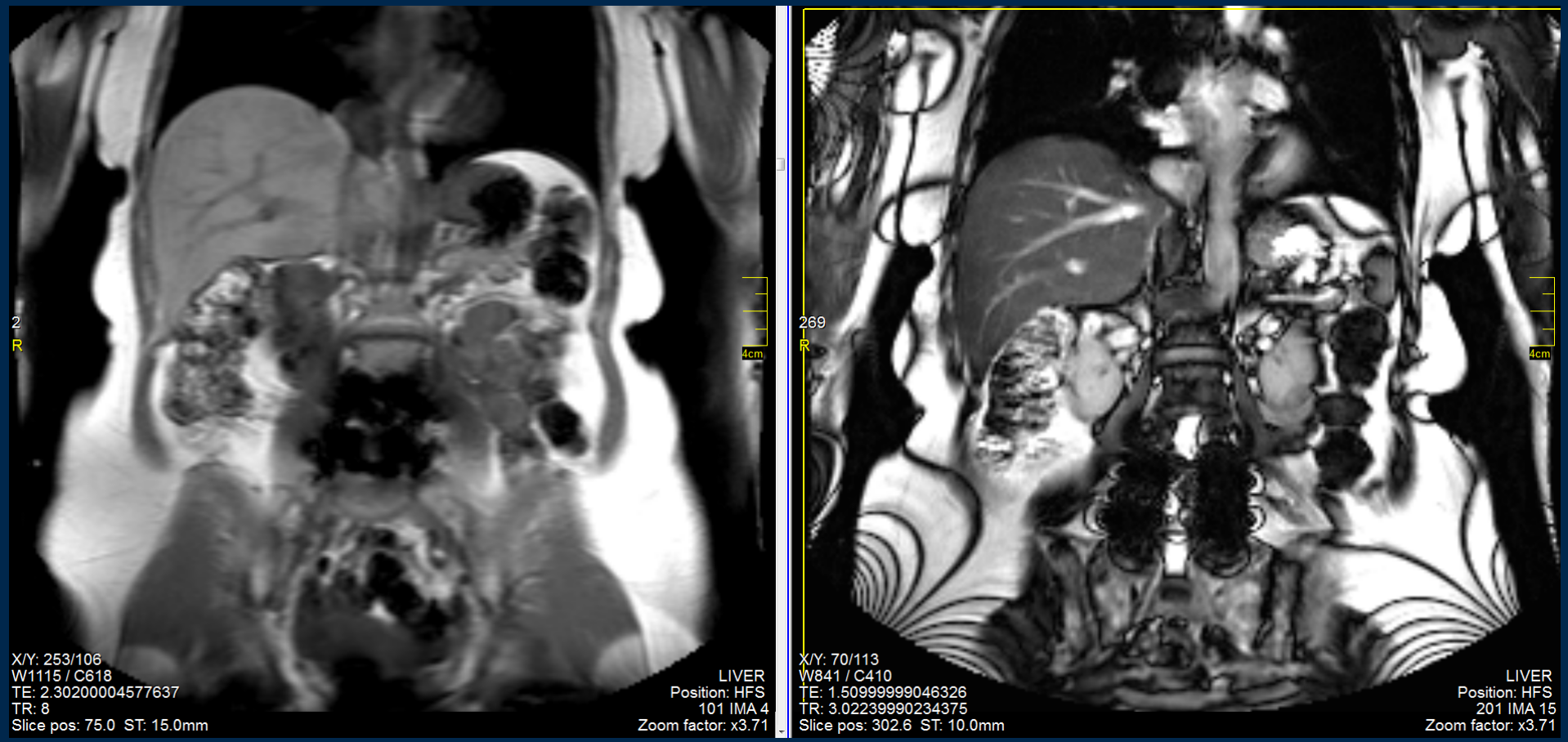
$$S = \frac{So \sin(\theta)}{[1 + (T1/T2)] + [1 - (T1/T2)] \cos(\theta)}$$

NO dependence on TR or TE
BUT
TE must be TR/2
TR short due to “banding artifacts” from magnetic field inhomogeneities

T2/T1 contrast



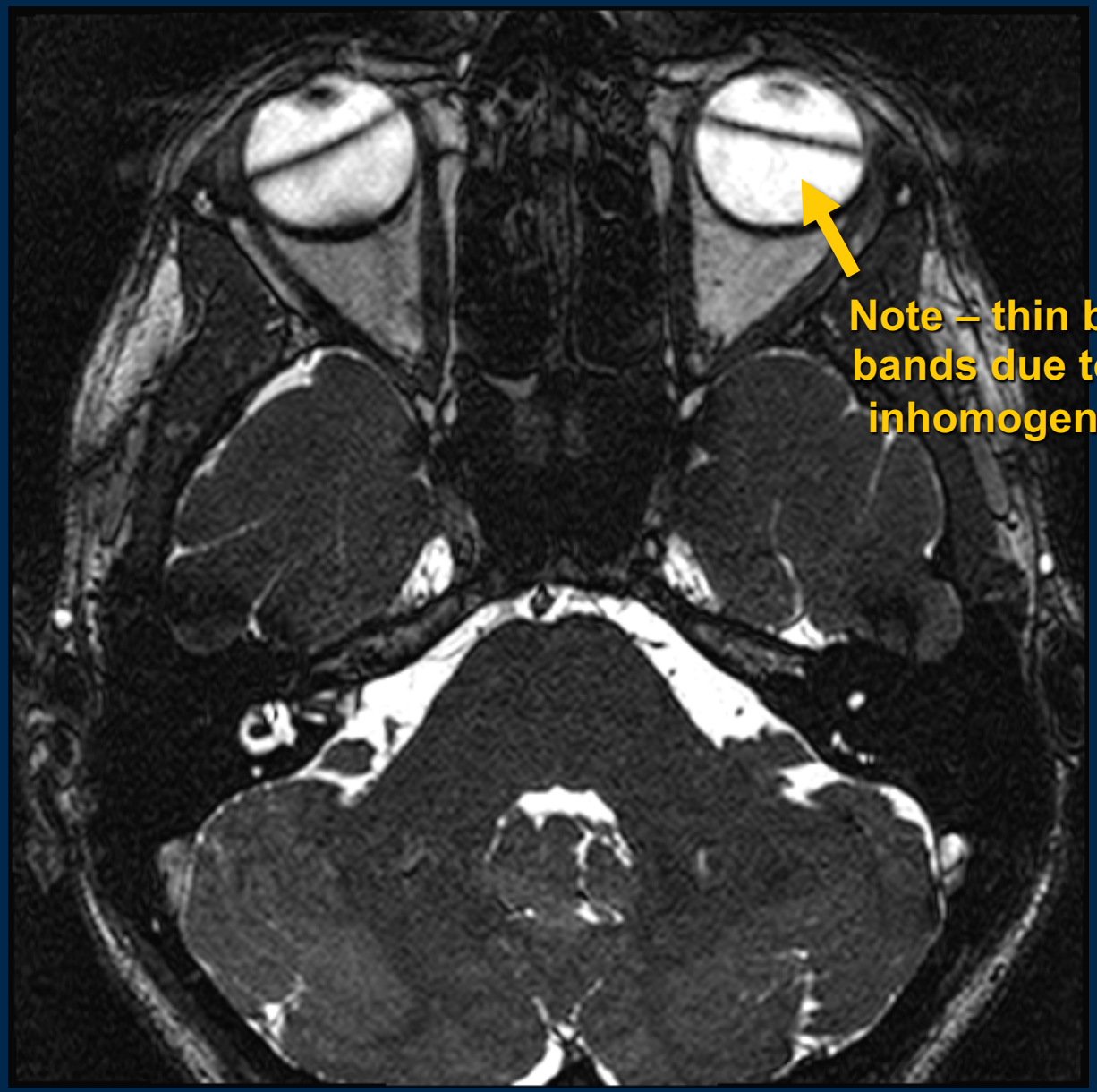
T1-FFE vs Balanced-FFE
Single-shot locator scans



TR = 8ms
TE = 2.3ms
Flip = 15°
"T1-enhanced" (Spoiled)

TR = 3ms
TE = 1.5ms
Flip = 60°
"Fully Balanced"

Examples Balanced FFE / FIESTA / TrueFISP



3D bFFE

TR=6ms, TE=3ms, flip=45,

0.5mm slices

Balanced Gradient Echo

- bSSFP, FIESTA, TrueFISP, bFFE
- Very fast, T2/T1 contrast

  → Contrast not significantly affected by TR, TE, even flip angle
- High SNR
- TE = TR/2
- Short TR best (2-5 ms)

  → Longer TR leads to “banding” artifacts near at field inhomogeneities