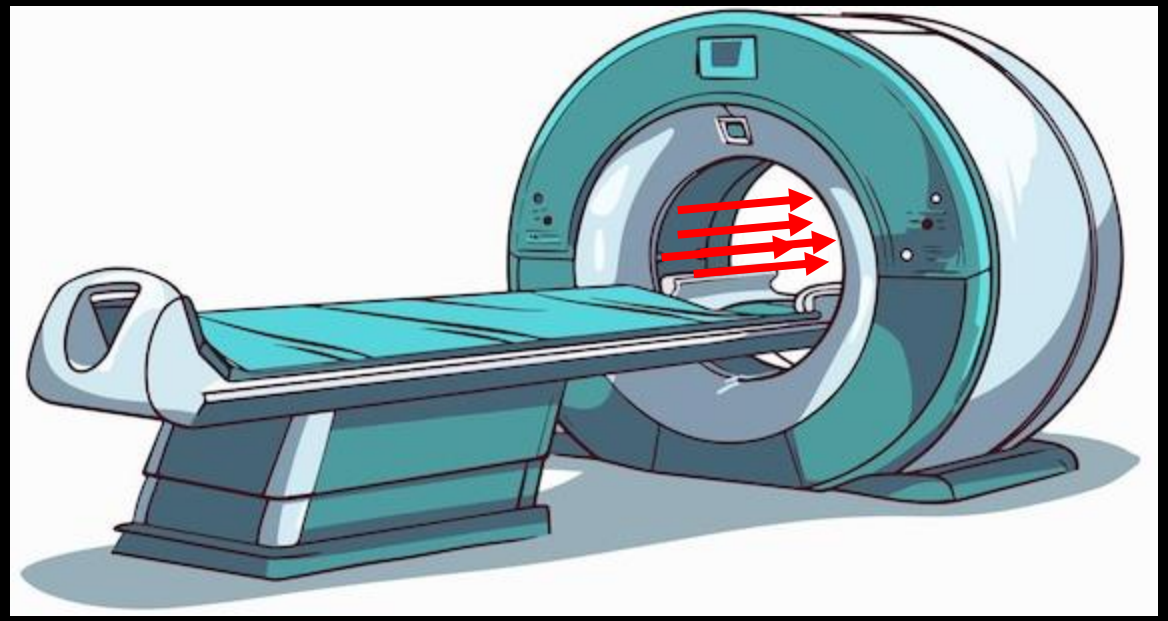
Memorial Sloan Kettering Cancer Center

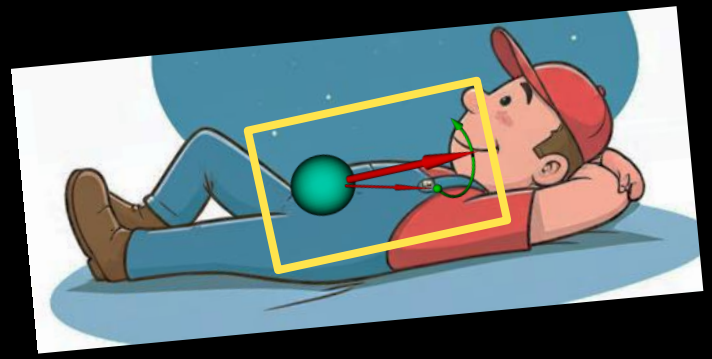
MRI Imaging Basics and Formation

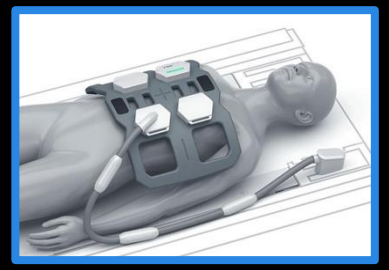
Eric Aliotta

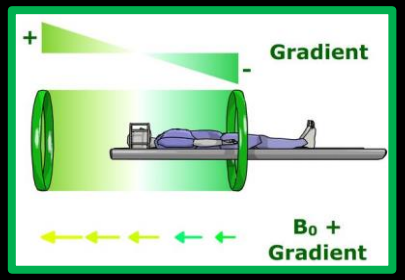
2/19/2026

How does a magnet make an image?









1. Strong + uniform magnetic field along Z (B0)
2. Protons in body H20 tend to align parallel to B0, producing a coherent signal
3. When protons are excited with RF energy, their behavior is highly tissue-dependent
4. Magnetic field gradients localize signals spatially and form an image

1.5 / 3 Tesla (~500x a typical refrigerator magnet)

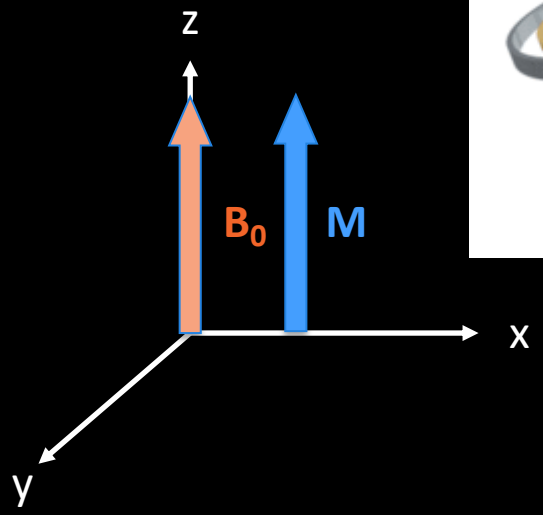
The higher the B0 field, the more they "want" their spins to align.

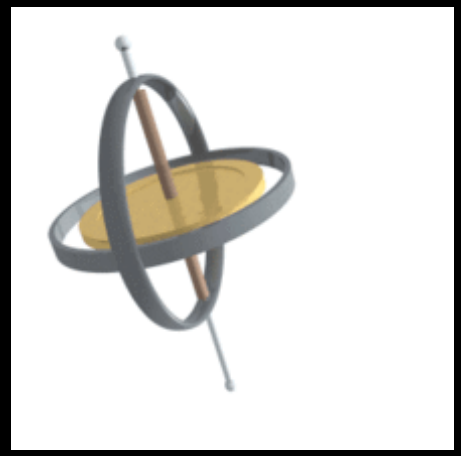
Protons eventually "relax" to their initial state, but the rate varies between fat/muscle/brain/etc.

Gradient fields are parallel to B0, but vary linearly with position (x, y, or z)

Nuclear Magnetic Resonance

- Magnetic fields cause nuclear *spin* to align preferentially (parallel to the field)
- Spins *precess* around the field axis
- The frequency of this precession is proportional to the magnetic field
  - Frequency = $\gamma * B_0$, where γ = 42.58 MHz/Telsa for Hydrogen
  - For B_0=3.0T, frequency = 127.74 MHz
- This is known as the *resonant frequency* for Hydrogen at 3.0T

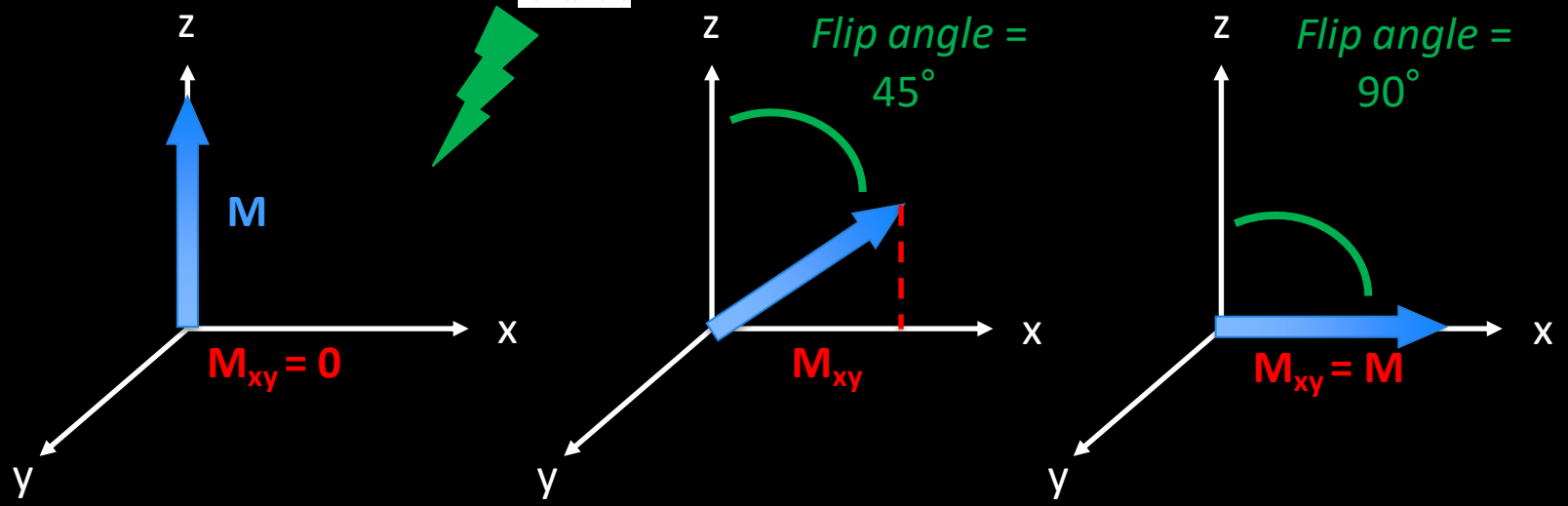




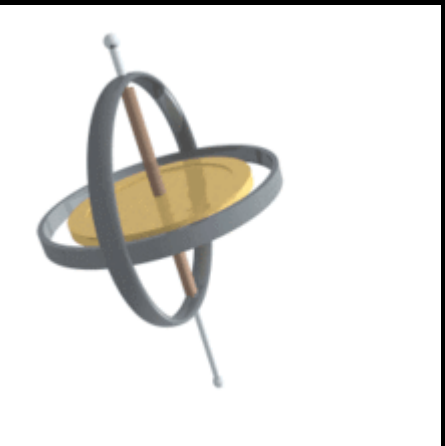
Excitation

RF Pulse
Tuned to resonant frequency
(127.74 MHz)

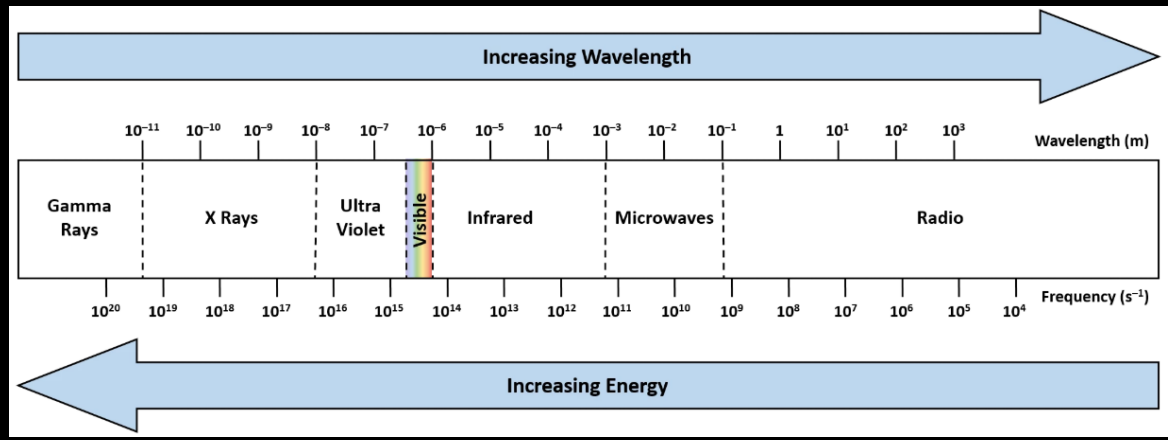




Measurable signal = M_{xy}



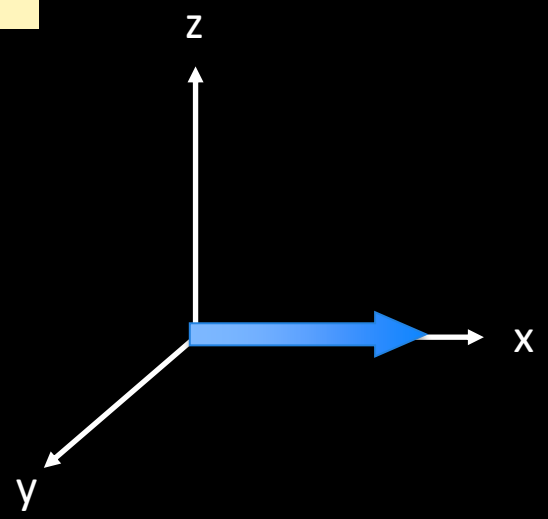
- 127.74 Mhz is in the microwave range
  - energy=0.5 micro eV
- This is far lower than the energy required for ionization and is the reason that *MRI is free of ionizing radiation*



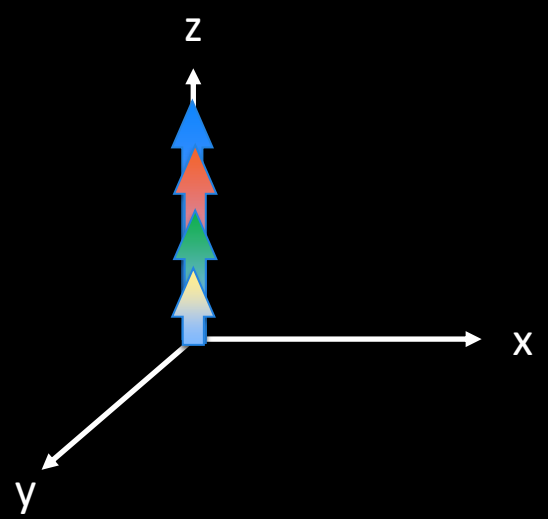
Relaxation

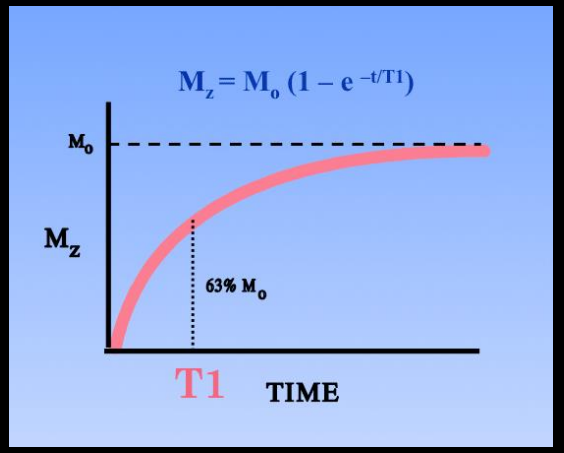
Over time, the excited signal returns to its original state.
Two simultaneous processes:

Excited signal

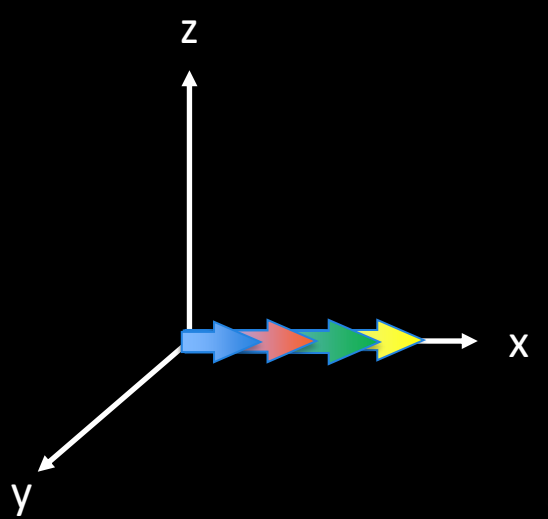


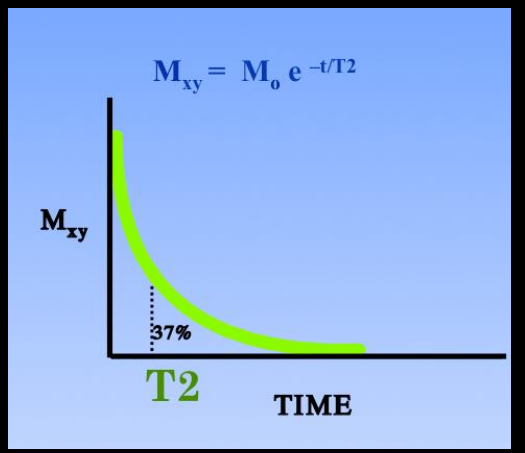
1. M_z recovers (*T1 recovery)*





2. M_{xy} decays to 0 (*T2 decay)*

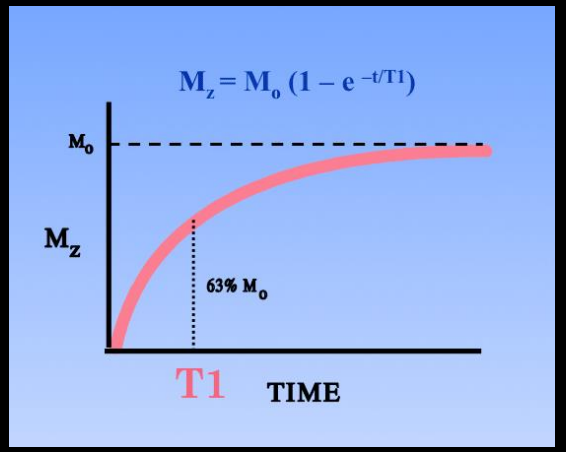


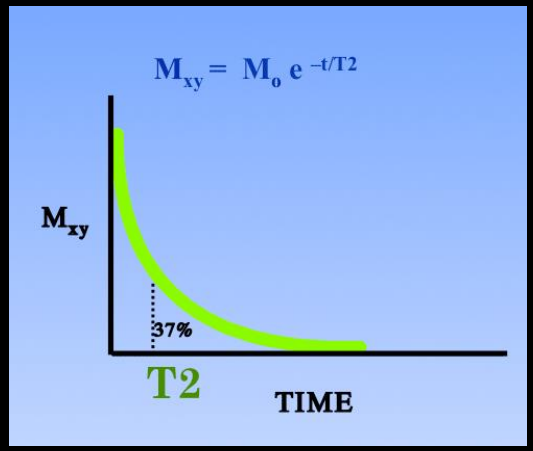


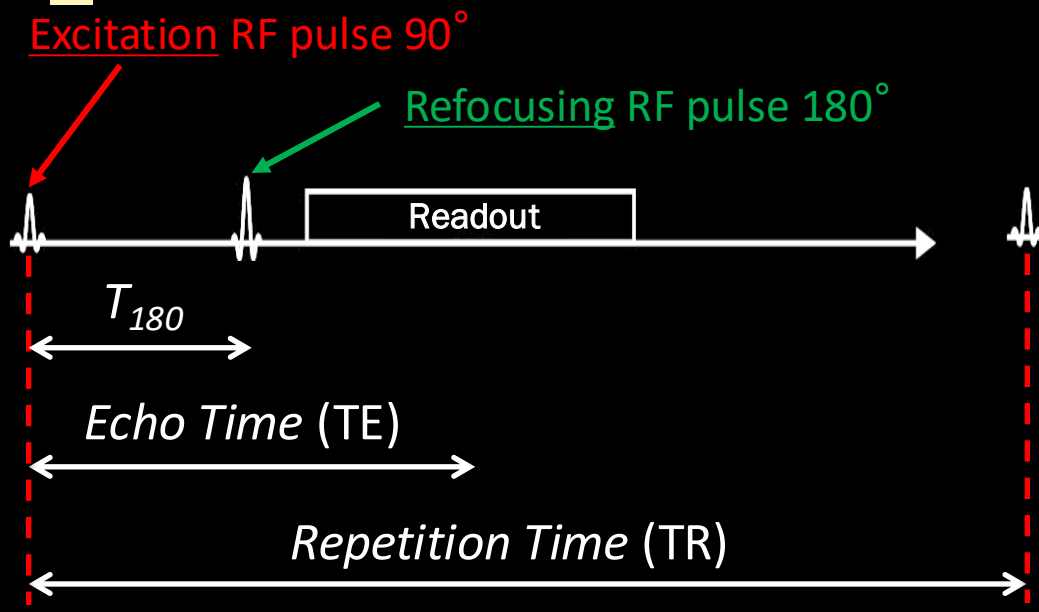
T1 and T2 time constants differ between tissues. This is the main source of contrast in MRI



Pulse Sequences: Spin Echo





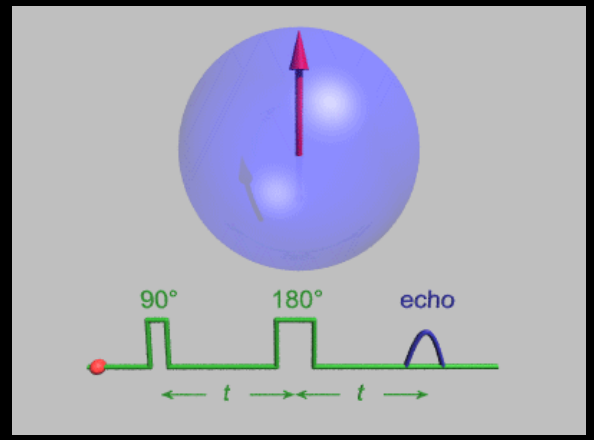




TE = time between excitation and echo, generally dictates T2 contrast

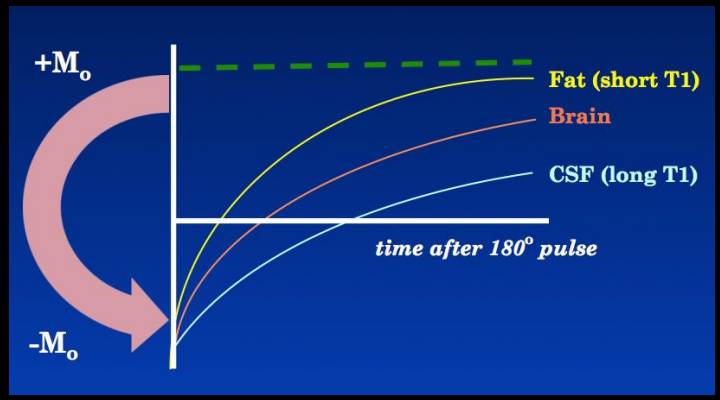
TR = time between subsequent excitations, dictates T1 recovery

- Why do we need the refocusing pulse? Why not just excite and read out?
- Answer: the “free induction decay” after excitation decays very fast due to local field effects (according to something called “T2*”). We need to refocus to remove field-related effects and focus on tissue-associated T2 decay

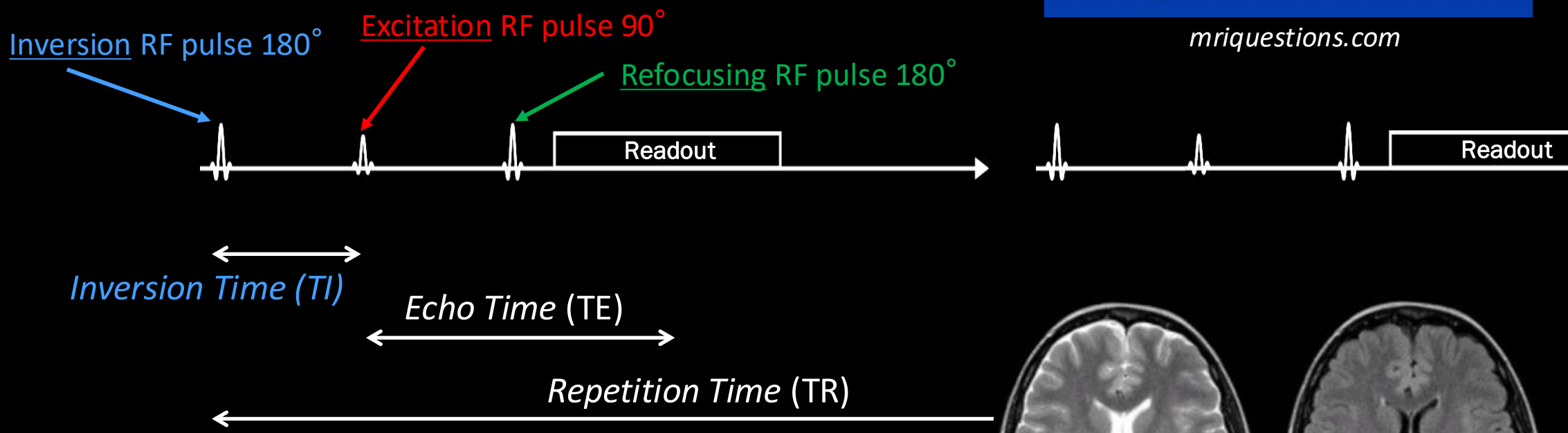


Formation of the spin echo from Wikipedia, created by Gavin W. Morley.

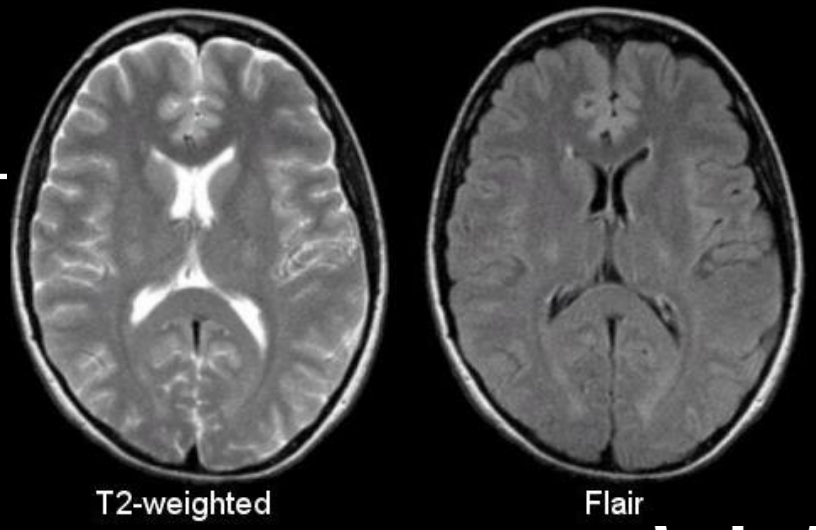
Pulse Sequences: Inversion Recovery



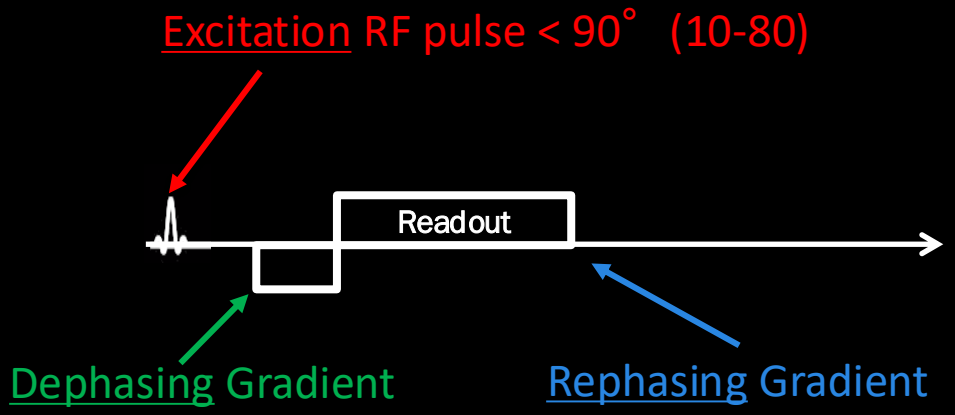
mriquestions.com

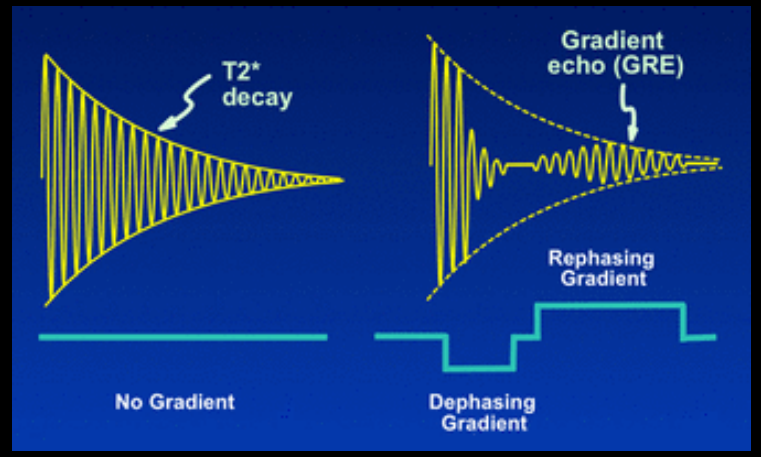


- What is the point of an inversion pulse?
- Answer: it can be timed to null signal from particular tissues. Classic example is Fluid Attenuated Inversion Recovery (FLAIR) which nulls signal from CSF



Pulse Sequences: Gradient Echo

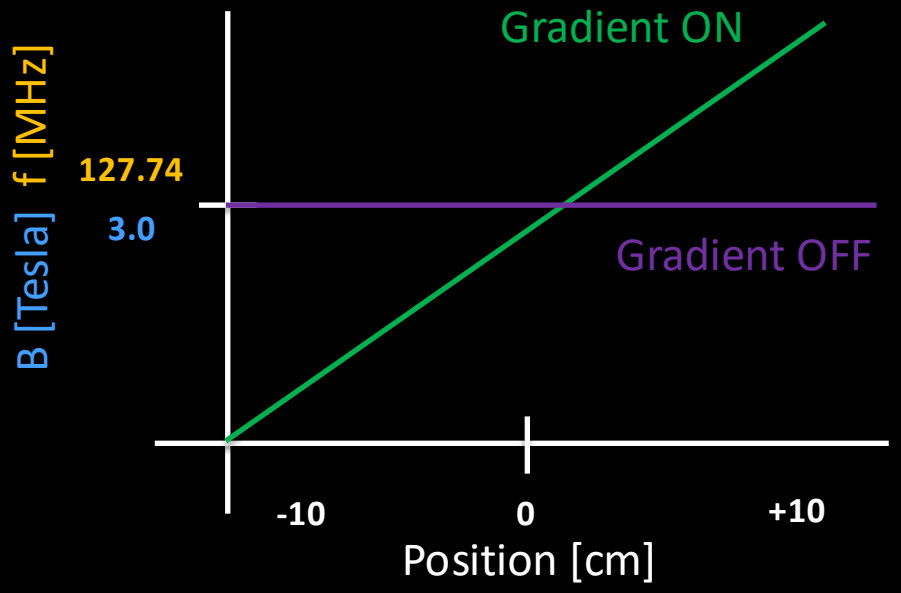


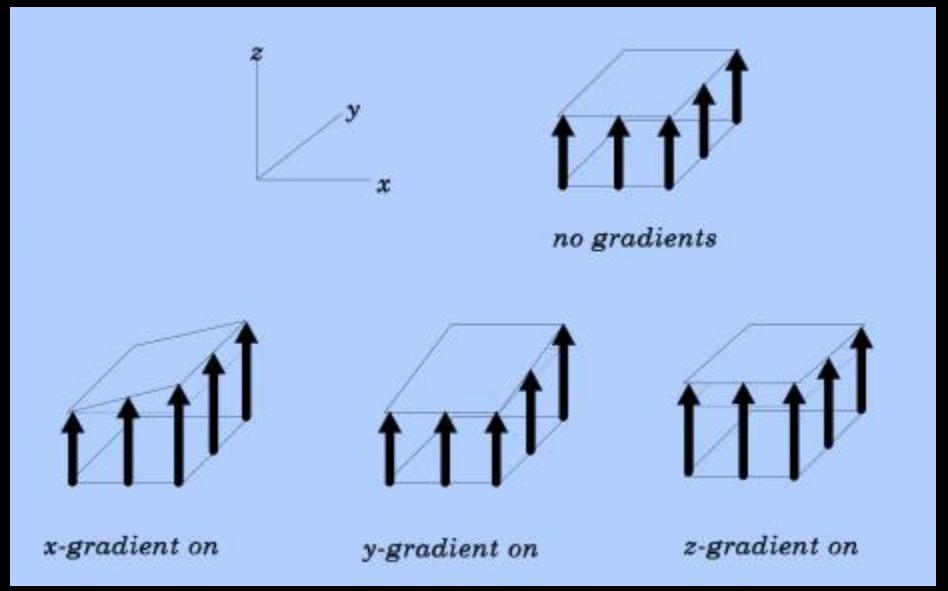


- Faster scans than spin echo
  - Only one RF pulse = shorter TE, low flip angle = shorter TR
- Cannot image T2 contrast (only T2*)
  - Due to lack of refocusing RF pulse

Spatial Localization and Gradients

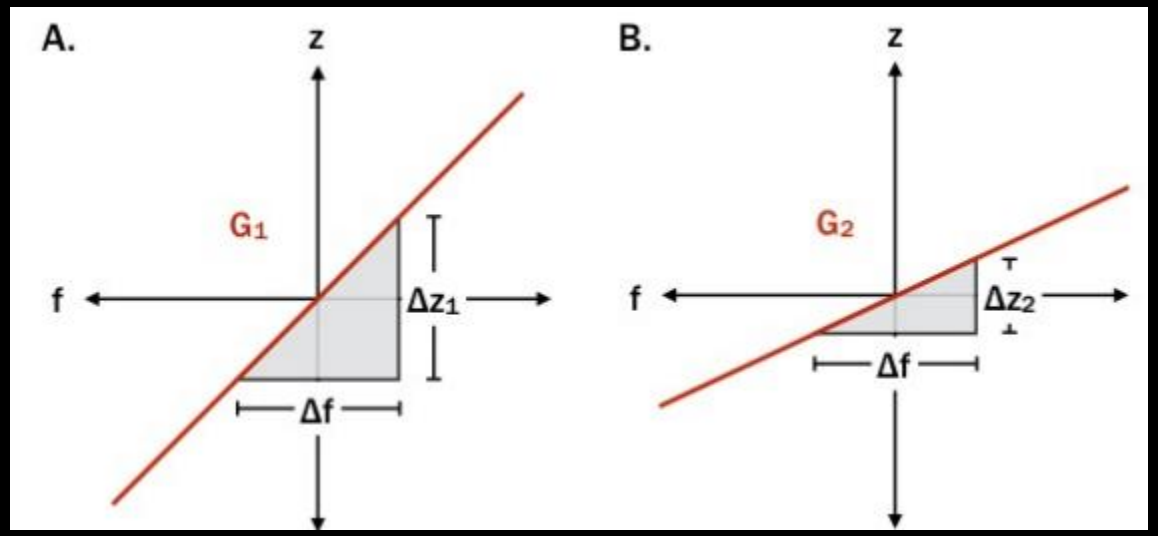
- Gradients apply a temporary magnetic field that varies linearly with position
  - The field itself is always along z (parallel to B0)
  - But the magnitude can vary along x, y, and z
  - Note that the magnitude of gradient fields are significantly lower than that of B0 (total variability typically <0.05 T over 50cm FOV)

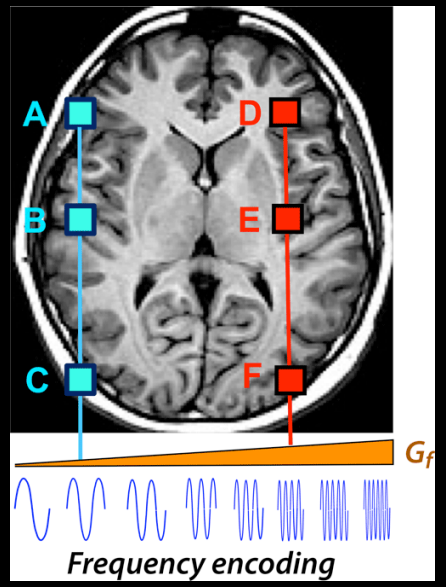




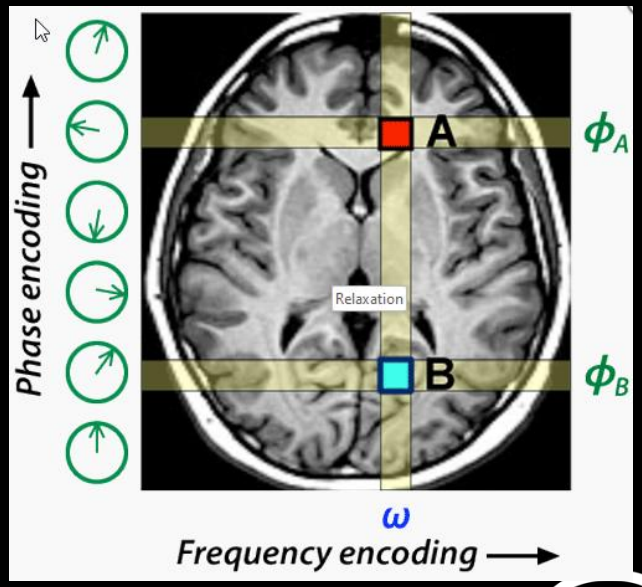
Spatial Localization and Gradients

- Gradients can spatially localize data in multiple ways
  - Slice Selection (z)
  - Frequency encoding (x)
  - Phase encoding (y)





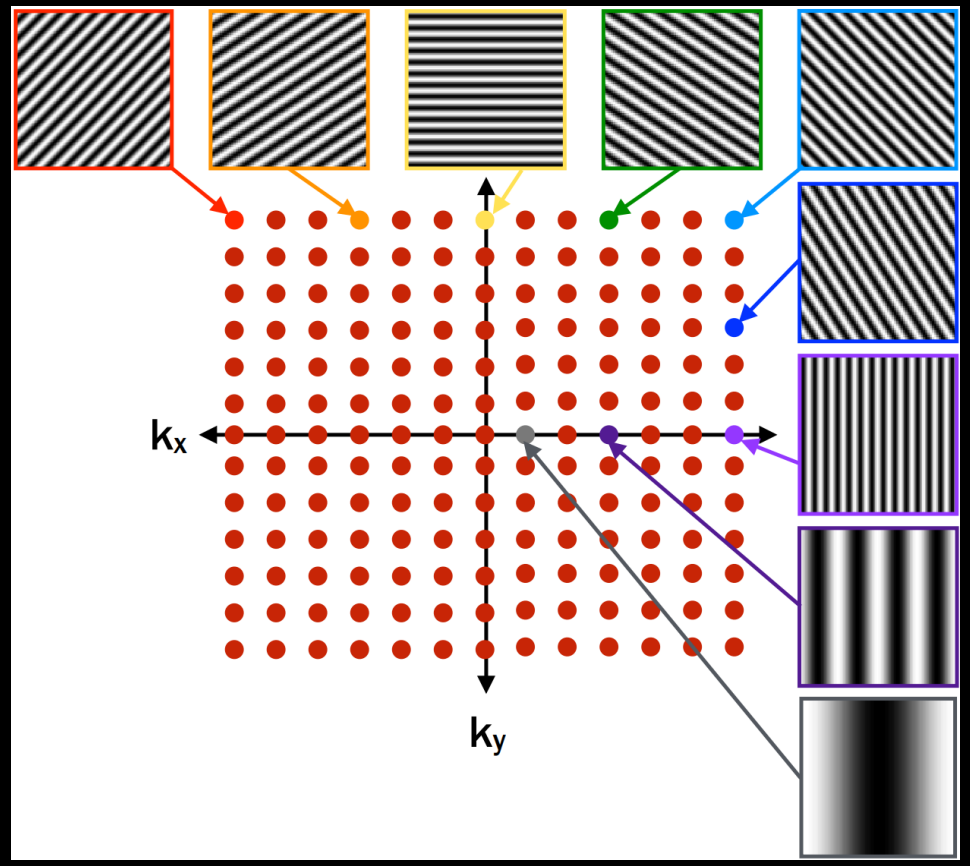
mriquestions.com

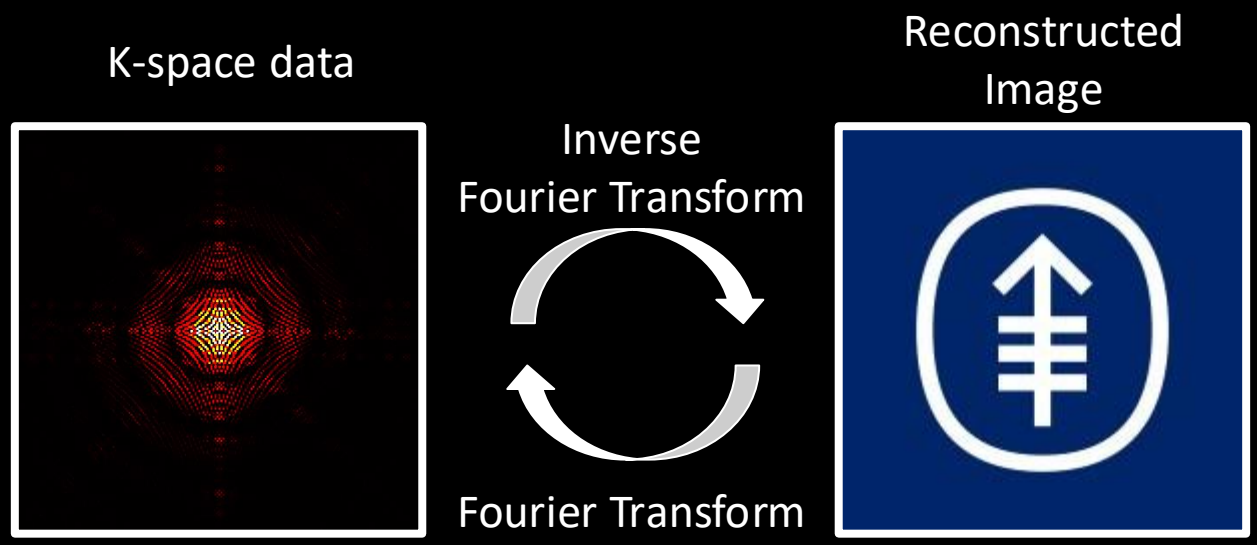


mriquestions.com

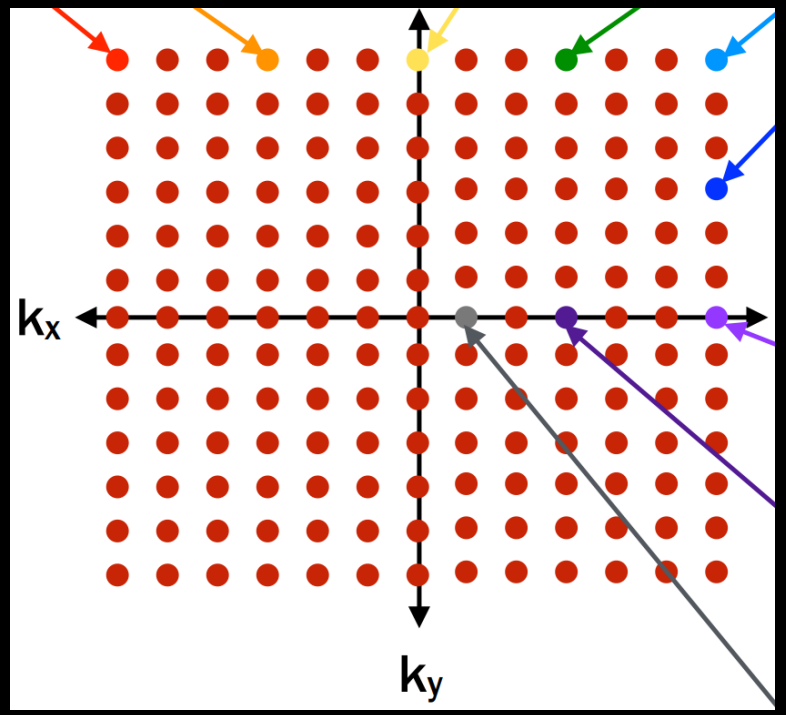
K-space

- MRI signals are collected as *spatial frequencies* to fill what is referred to as *k-space*
- K-space data is then converted to *image space* during reconstruction





K-space



K-space sampling dictates the resulting image properties:

Resolution = $1/2*K_{max}$

FOV = $1/\Delta k$

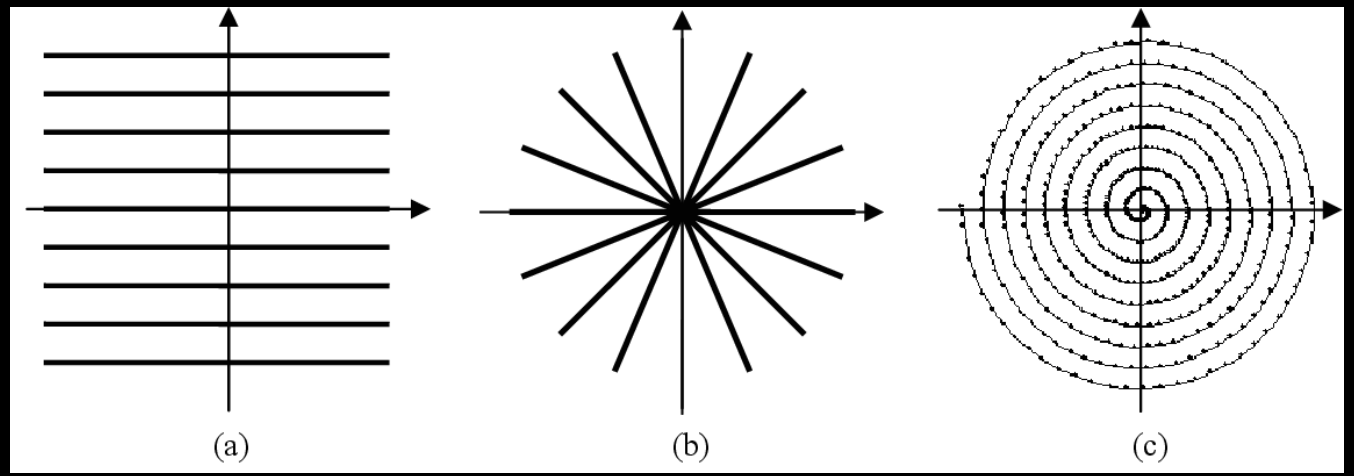
Different strategies can be used to “move through” k-space

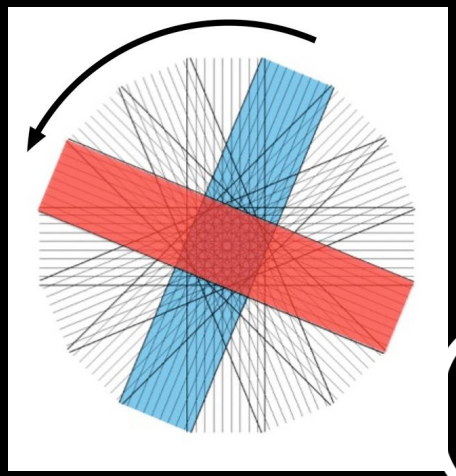
Cartesian

Radial

Spiral

PROPELLER



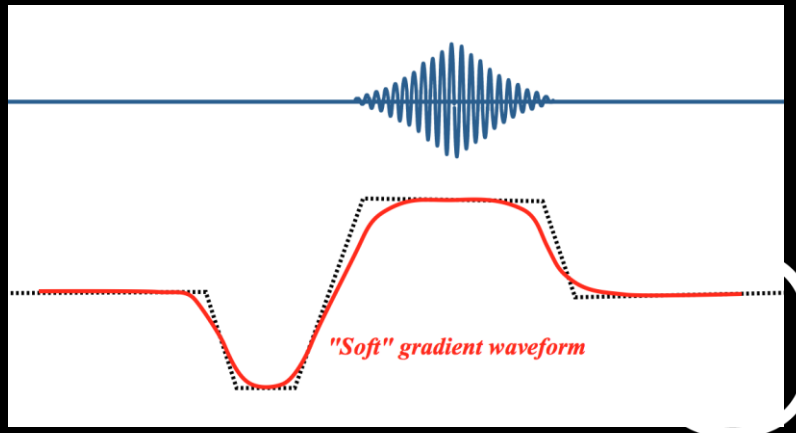


CONTINUOUS SAMPLING IN MAGNETIC RESONANCE IMAGING, Bookwalter et al. 2008

Acoustic Noise

- MRI can be very loud (>100 dB)
  - Ear protection is necessary for patients
- Largest source of noise: gradient coil switching
  - Large currents are produced when gradients switch on/off
  - Vibrations are produced which lead to acoustic noise
- Echo planar imaging (EPI) and diffusion weighted imaging gradients are among the loudest
  - Rapid switching to/from maximum gradient power
- Noise can be reduced with more “gradual” ramps

https://mriquestions.com/whats-that-noise.html



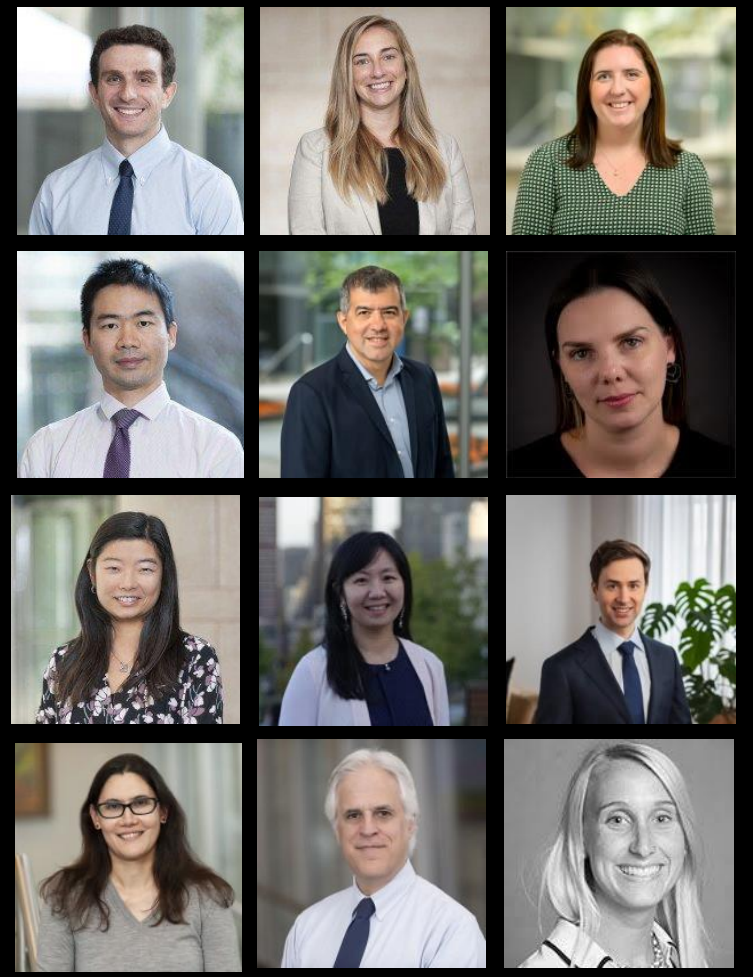
Questions

- What is the direction of the main (B0) magnetic field?
  - Assume x = L/R, y = A/P, z = S/I
  - Answer: z
- What is the direction of the field produced by Gradients?
  - Answer: z
  - **the magnitude of the field varies along x, y, or z
- What aspect of a spin echo acquisition dictates T2 contrast?
  - Answer: Echo Time (TE)
- True or False: RF pulses are the main source of acoustic noise in MRI.
  - Answer: False. Gradients are the loudest component



Memorial Sloan Kettering Cancer Center

MRgRT Physics at MSKCC:



Thank You!

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