MR Physics Basics

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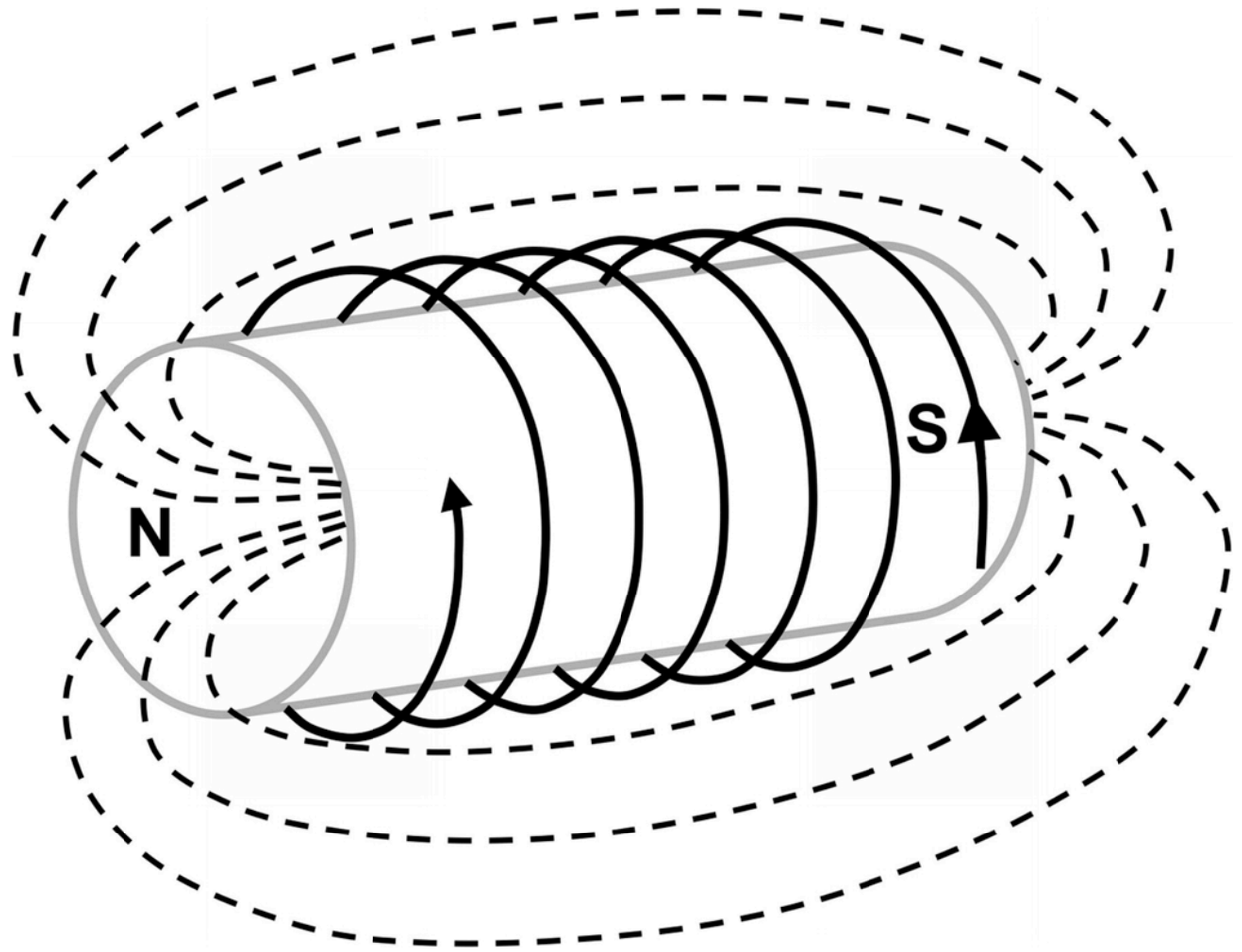
Why.N.How

Scope

- Magnetism Preliminaries
- Creating an MR signal
- Detecting an MR signal
- Creating contrast
- Image encoding (at least slice select & frequency encode)

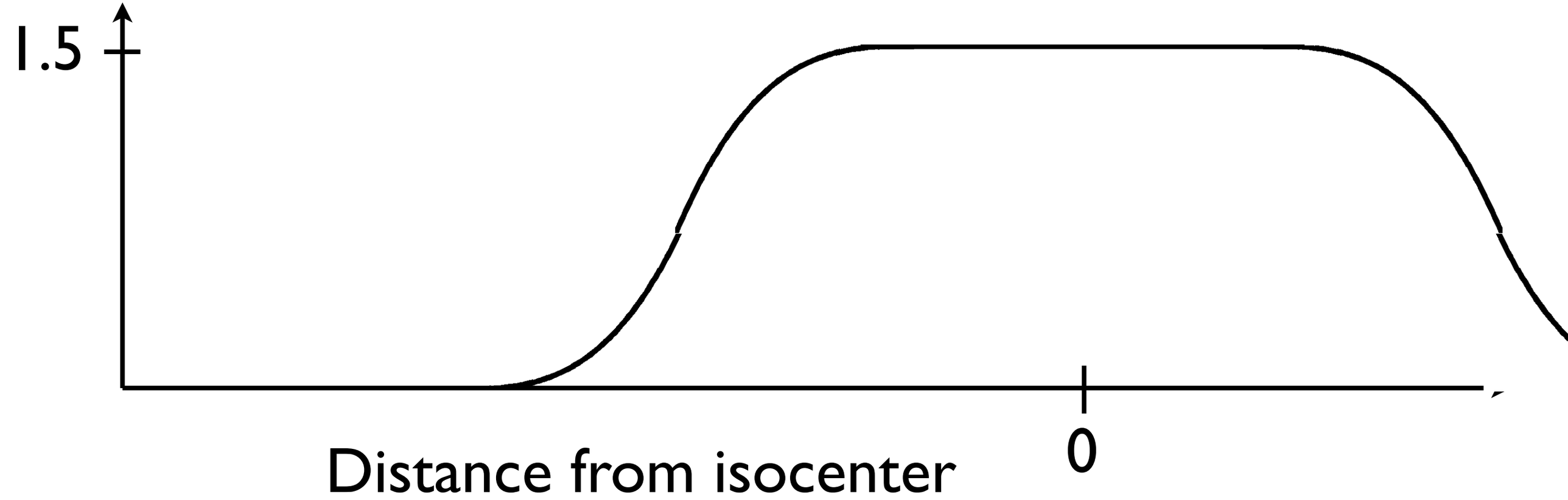
B_0 magnetic field

- Very high strength magnetic field:
  > 1 Tesla (> 20,000x B_{earth})
- Constant (as opposed to time-varying)
- Directed along the bore axis (z direction)
- Approximately spatially uniform **inside the bore**



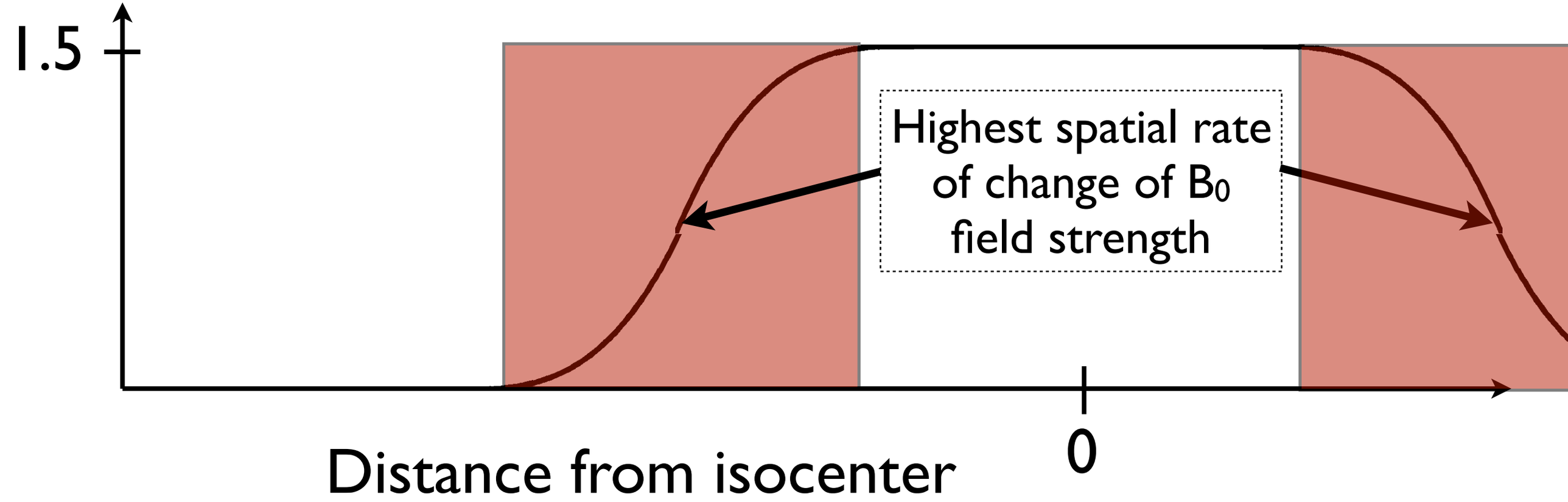
Ferromagnetic object in spatially varying B field

B_0 field strength



Ferromagnetic object in spatially varying B field

B_0 field strength



Ferromagnetic object in spatially varying B field

$$\vec{F}_{\mathrm{mag}} = \nabla([U - U_0]V)$$

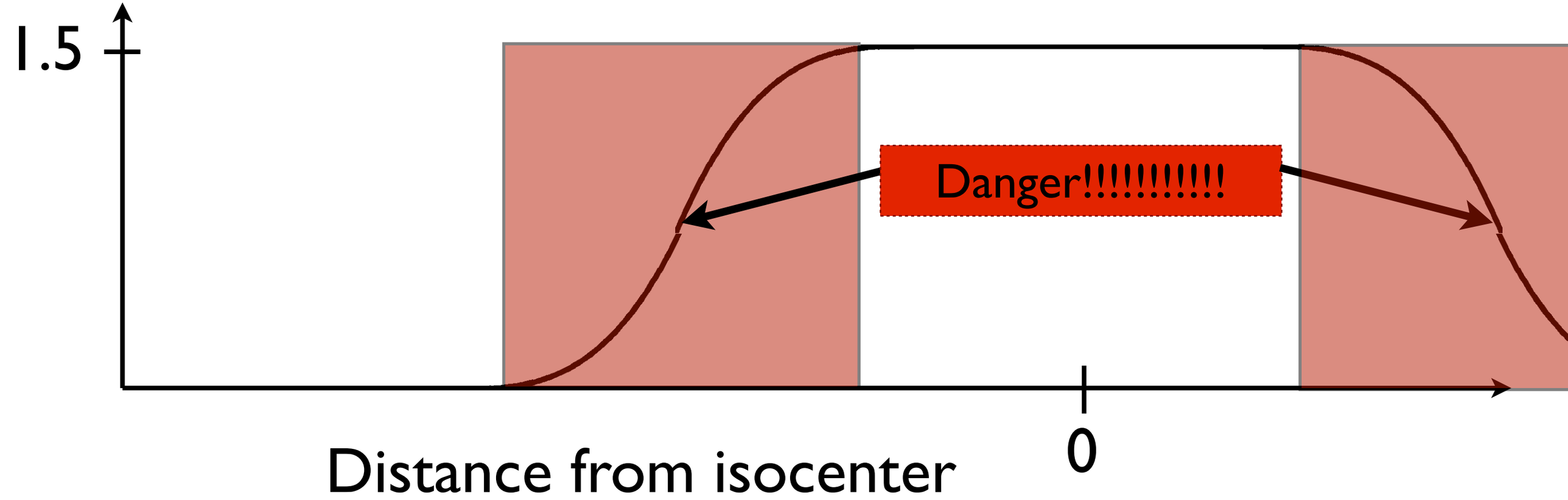
$$\vec{F}_{\mathrm{mag}} = C_{\mathrm{material}} \frac{2V}{\mu_0} B_0 \frac{dB_0}{dz}$$

This factor depends on shape & material:
~1 for a ferrous sphere
~500 for a ferrous cylinder!

Depends on both field strength and spatial derivative!

Ferromagnetic object in spatially varying B field

B_0 field strength



Ferromagnetic object in spatially varying B field

$$\vec{F}_{\mathrm{mag}} = \nabla([U - U_0]V)$$

$$\vec{F}_{\mathrm{mag}} = C_{\mathrm{material}} \frac{2V}{\mu_0} B_0 \frac{dB_0}{dz}$$

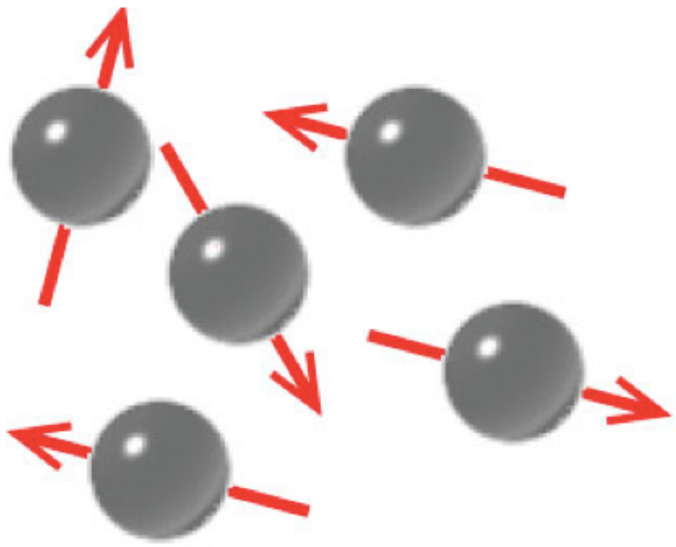
Ballpark numbers using a 100 gram screwdriver near a 1.5T scanner:

F > 2000 N, or easily 2000x gravity

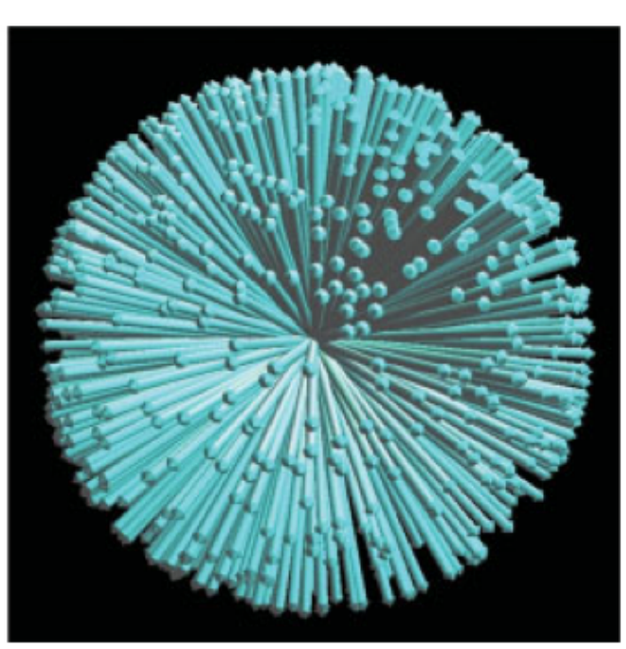
(imagine if the screwdriver suddenly weighed 440 lbs)

That screwdriver would quickly reach **60 mph** inside the bore: do you want any living thing in the way?

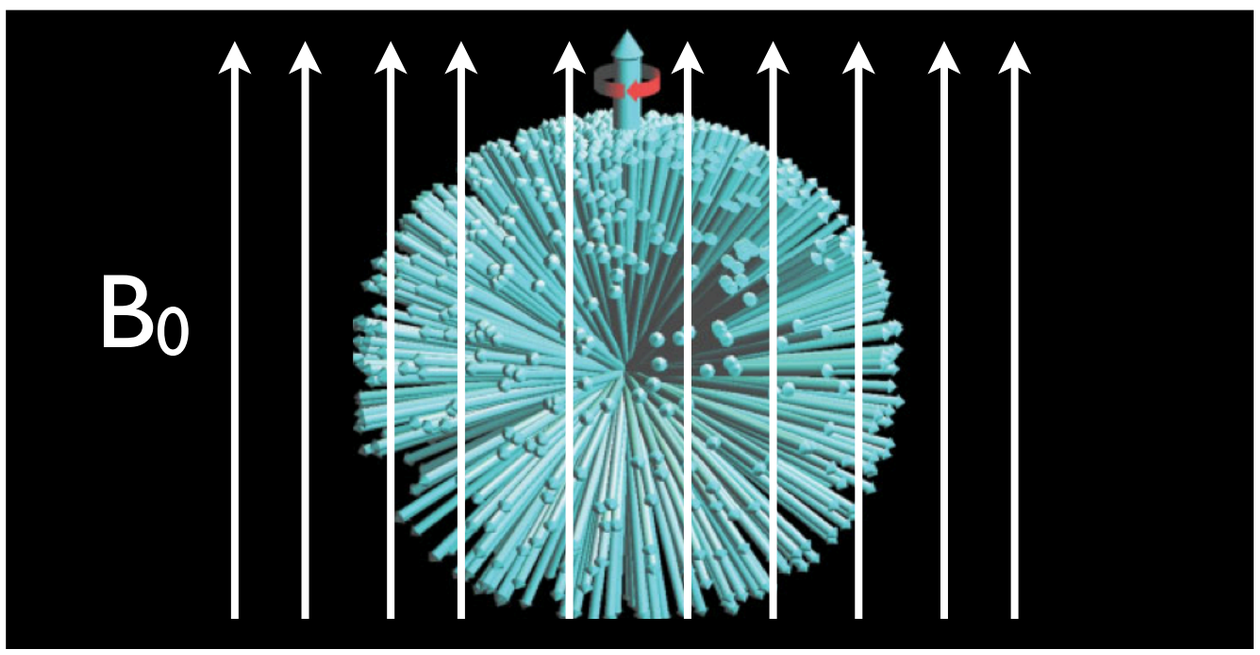
Hydrogen nuclei in the B_0 field



Each hydrogen nucleus has a magnetic moment: it will be affected by the large B_0 field

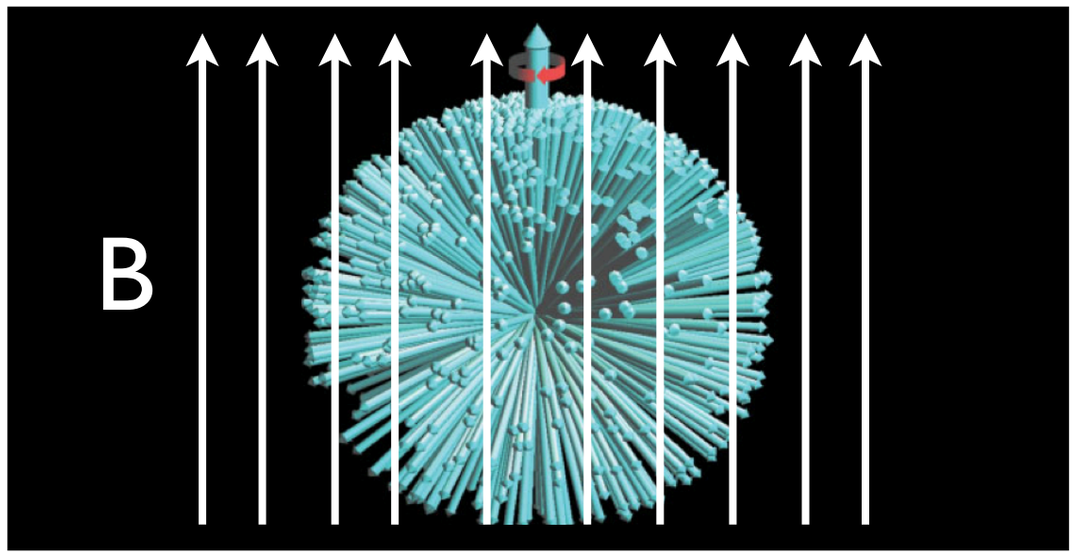


The nuclei "compasses" point in random directions in the absence of the B_0 field



The B_0 field creates a **small** net magnetization along the field

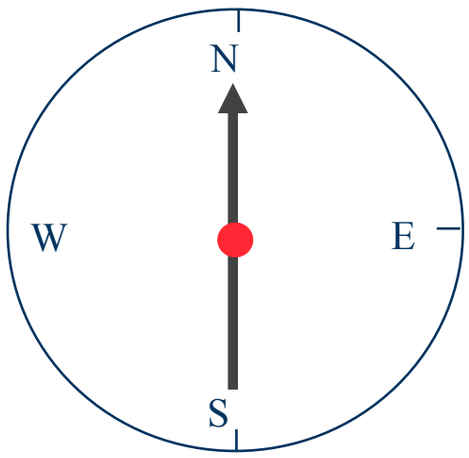
Hydrogen nuclei in the B_0 field



Why don't they all point straight up like compasses (presumably) would?

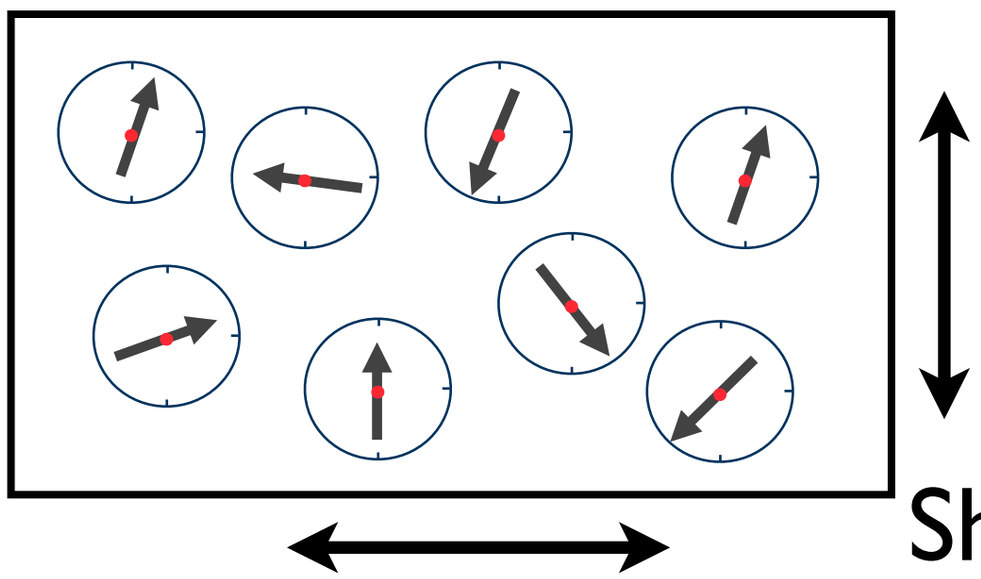
The nuclei carry a great deal of thermal energy: i.e., shaking and rotating and vibrating around on their own.

1)



Stationary compass in B field

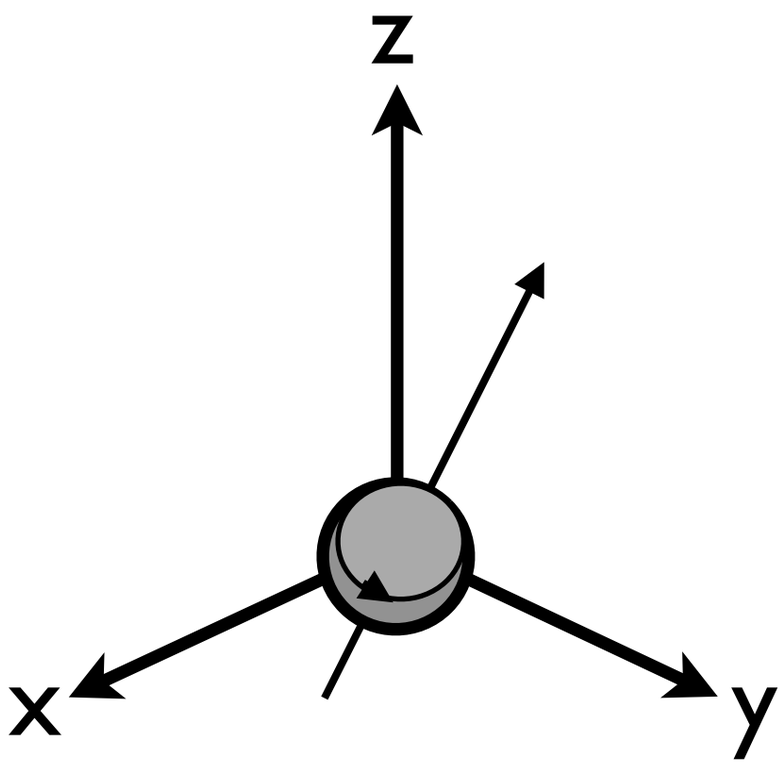
2)



Shake!

Hydrogen nucleus in a B_0 field

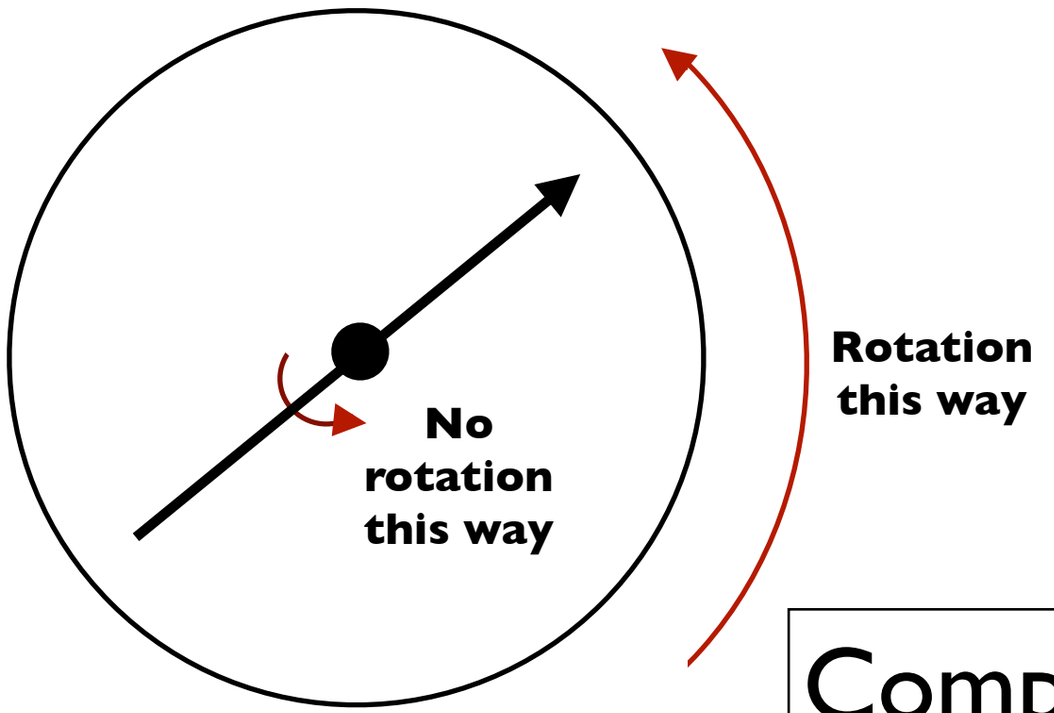
Take a nucleus pointing in any direction



Nucleus

What effect will the B_0 field have?

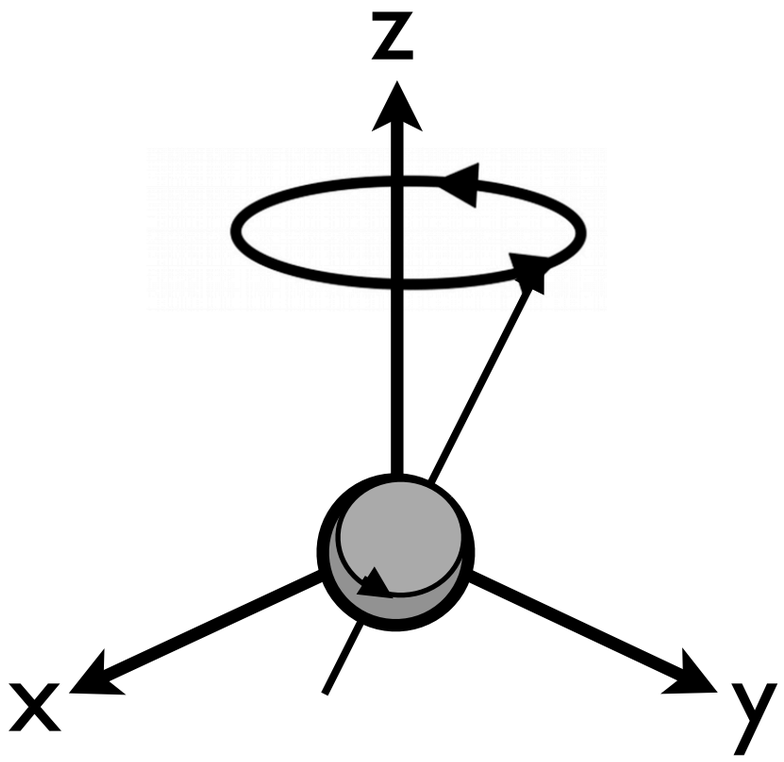
Here it's useful to switch from the compass analogy because a compass has no intrinsic angular momentum: the needle isn't spinning about its length axis

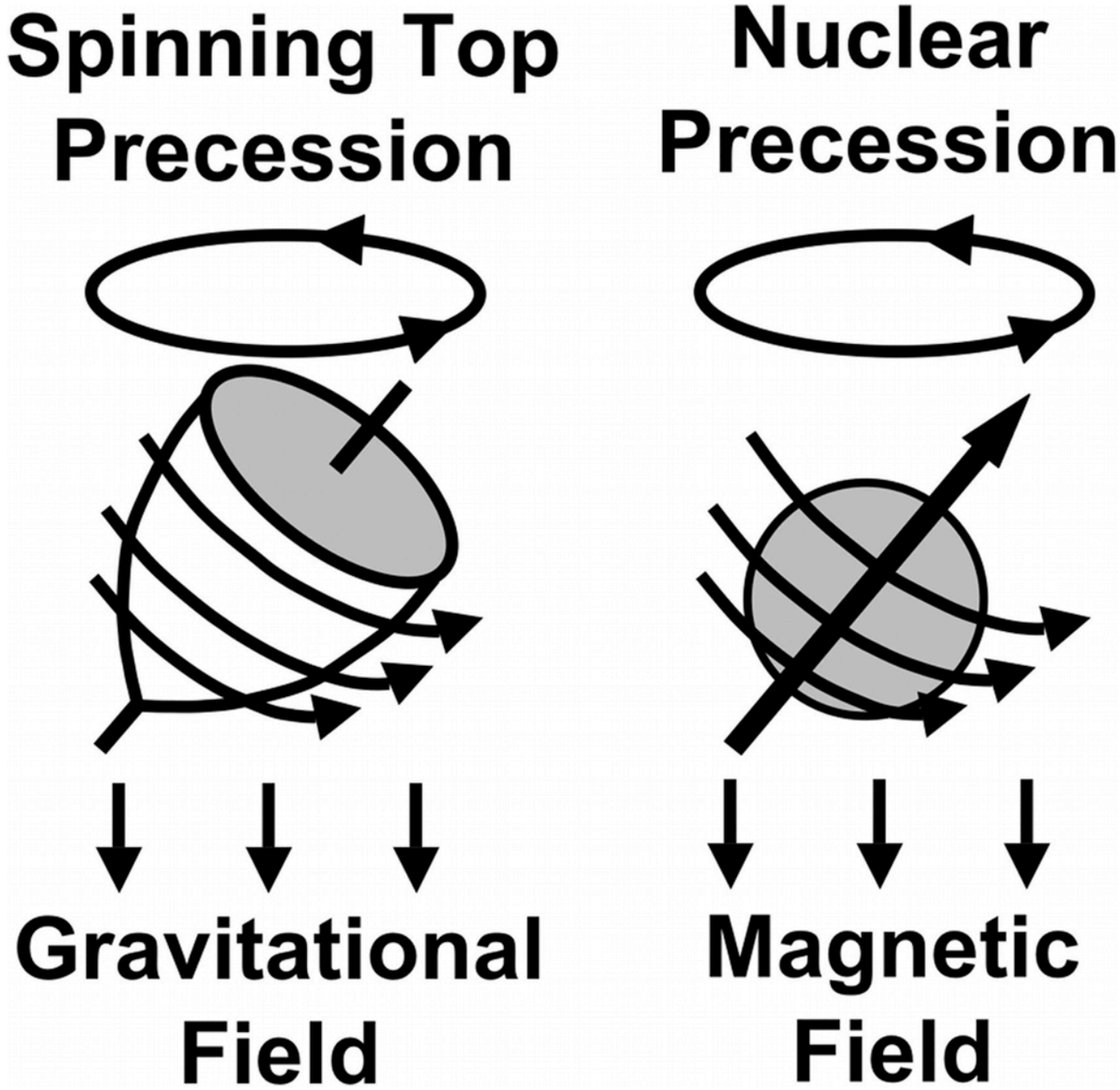


Compass

Spinning top analogy

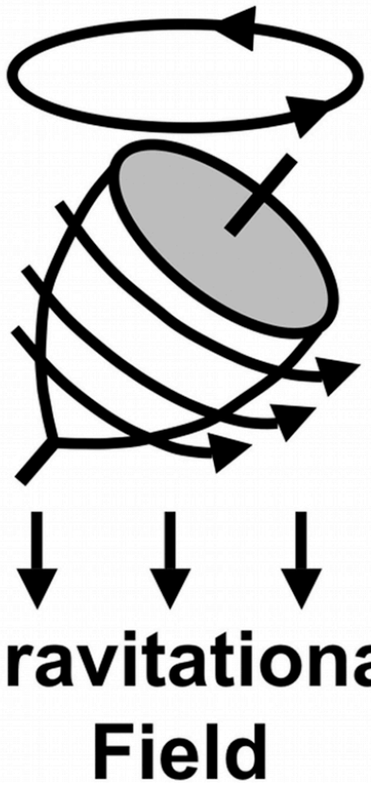
Direction of magnetic moment will precess around z





Spinning top analogy

Spinning Top Precession



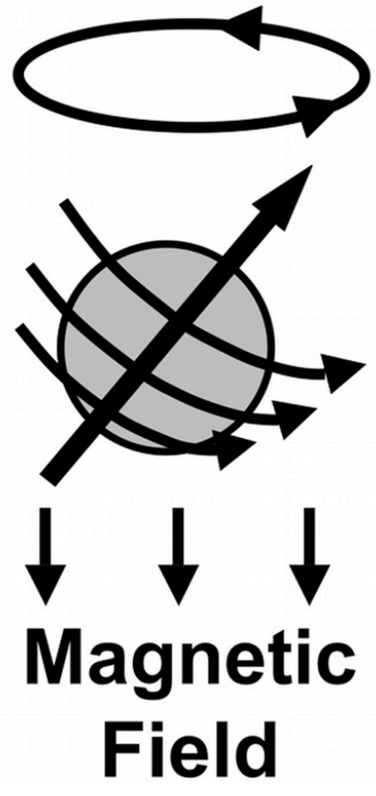
Gravitational Field

Frequency of precession

1. Proportional to field

2. α and γ encapsulate dependence on properties of what's spinning

Nuclear Precession



Magnetic Field

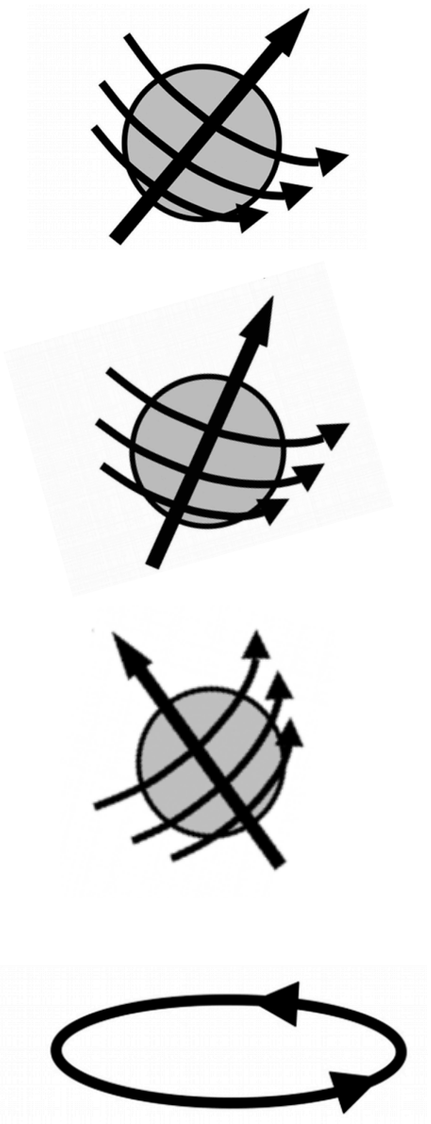
$$\omega = \alpha G_{\text{field}}$$

$$\omega = \gamma B_0$$

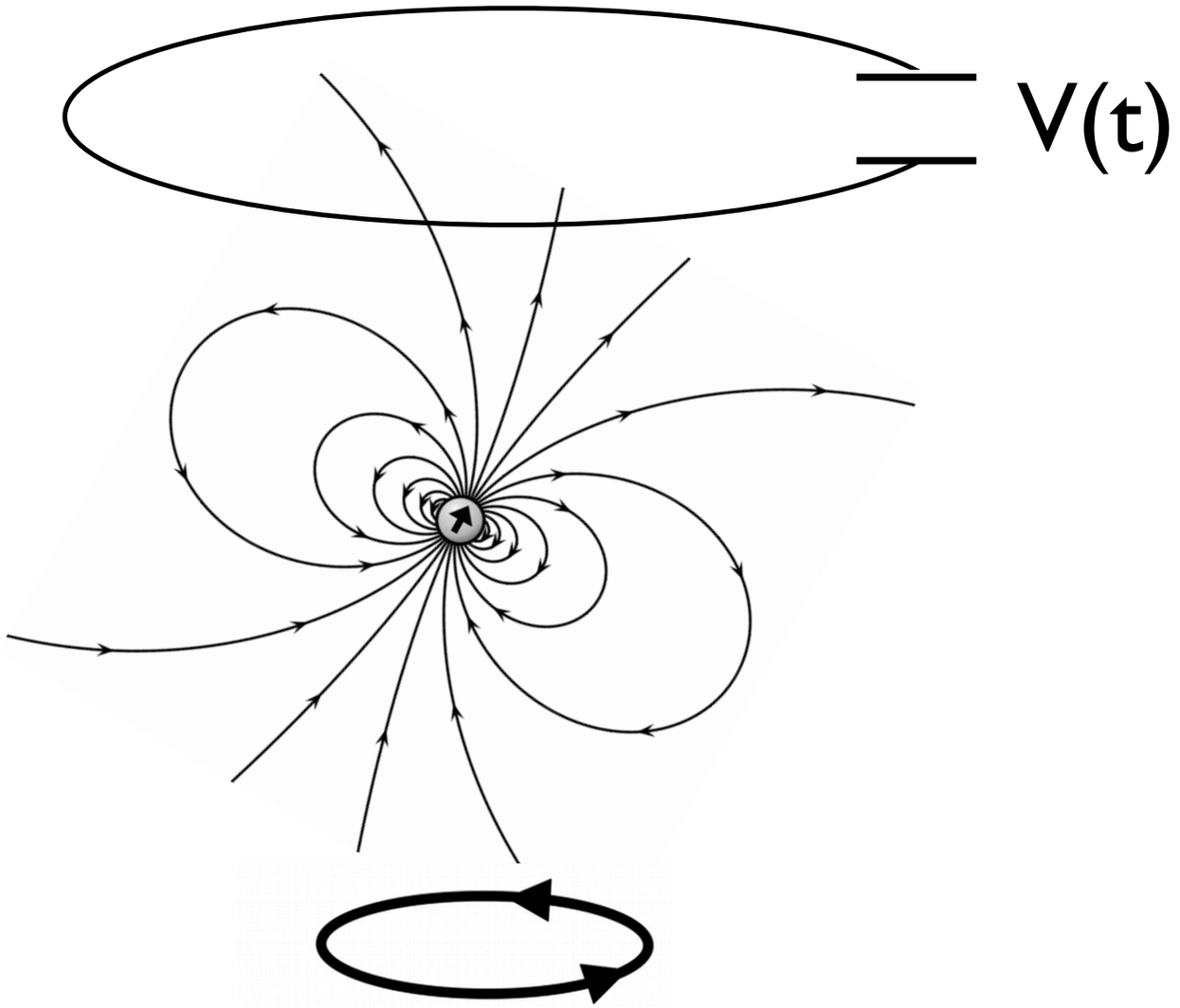
$$\gamma = 42.58 \text{ MHz/T}$$ (H nuclei)

Adding a coil for signal detection

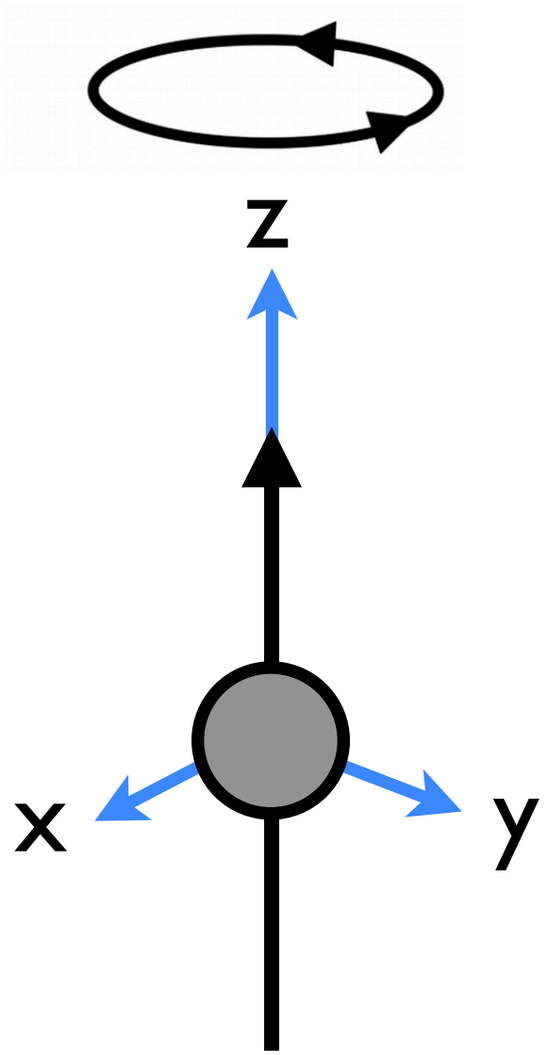
Remember that the nuclei are like dipole magnets



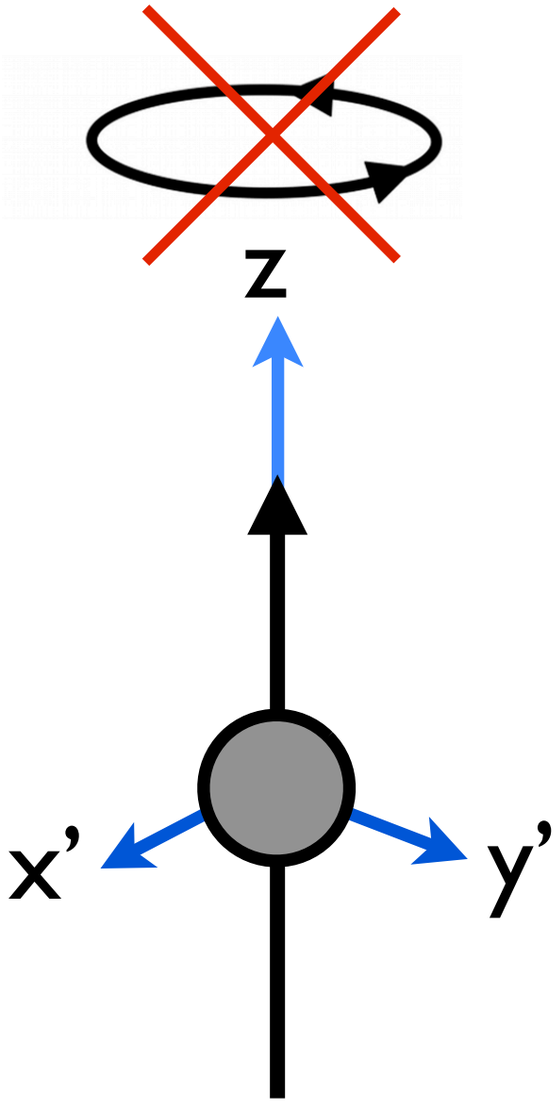
Changing magnetic flux through a coil induces a detectable V(t)



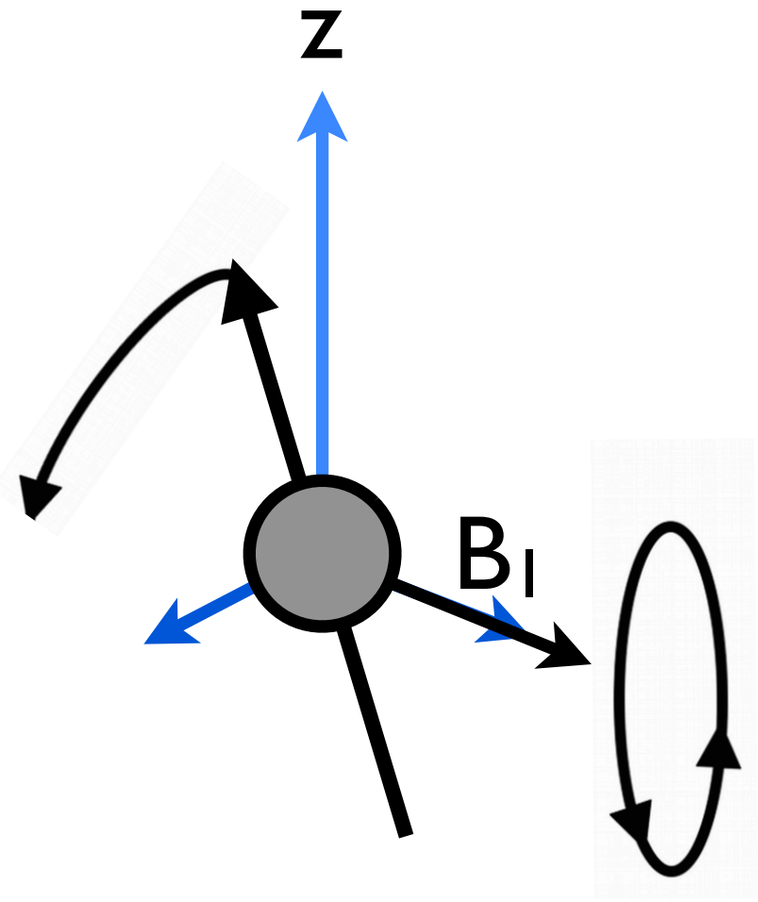
Creating an MR signal: Excitation



Lab frame



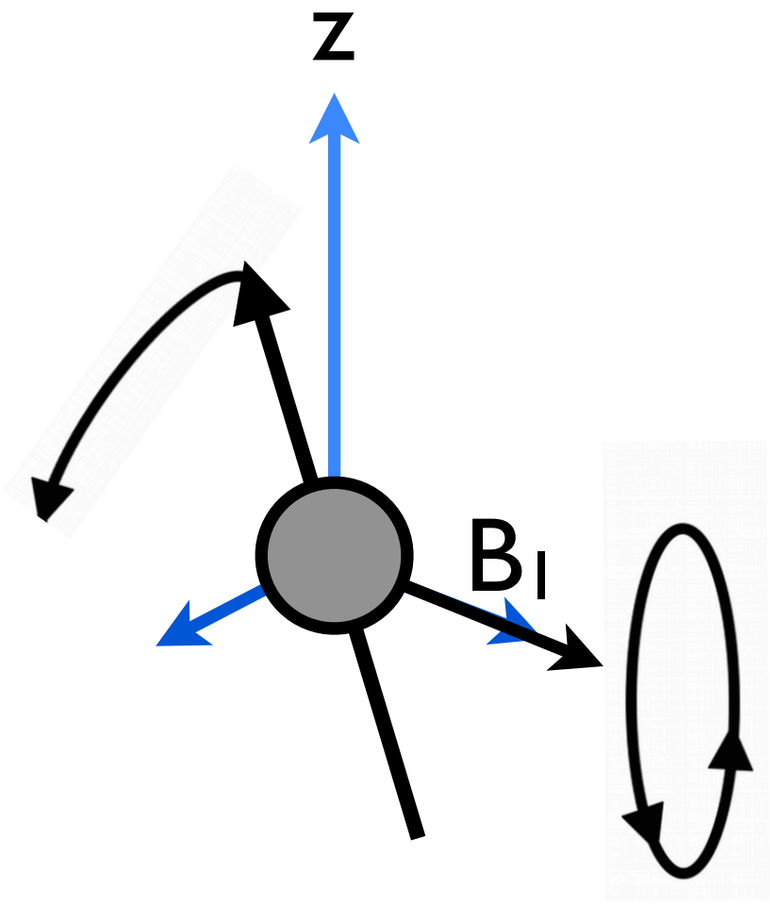
Rotating frame



Rotating frame + B_1

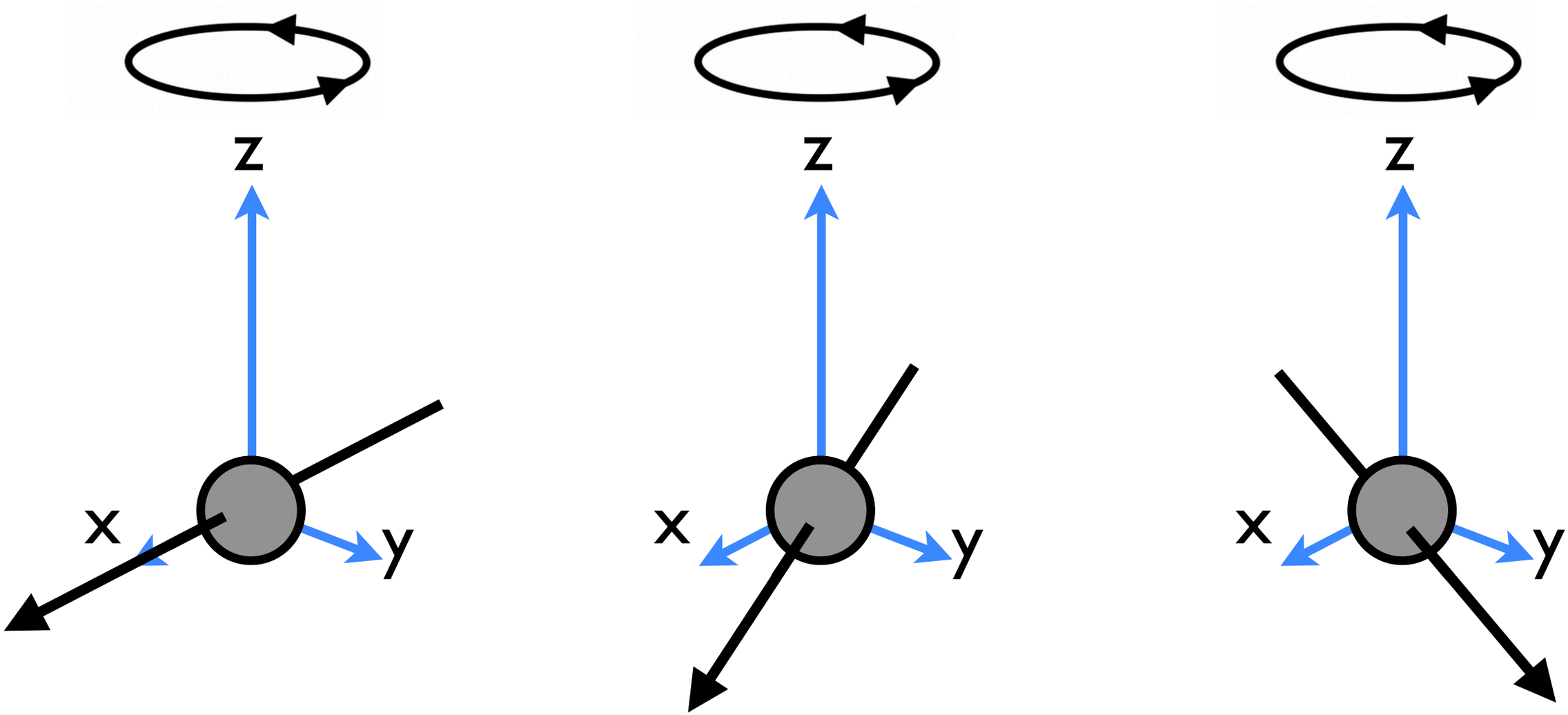
Creating an MR signal: Excitation

B_1 field has to be rotating at same frequency as the nuclei, or they will not "see" it



Rotating frame + B_1

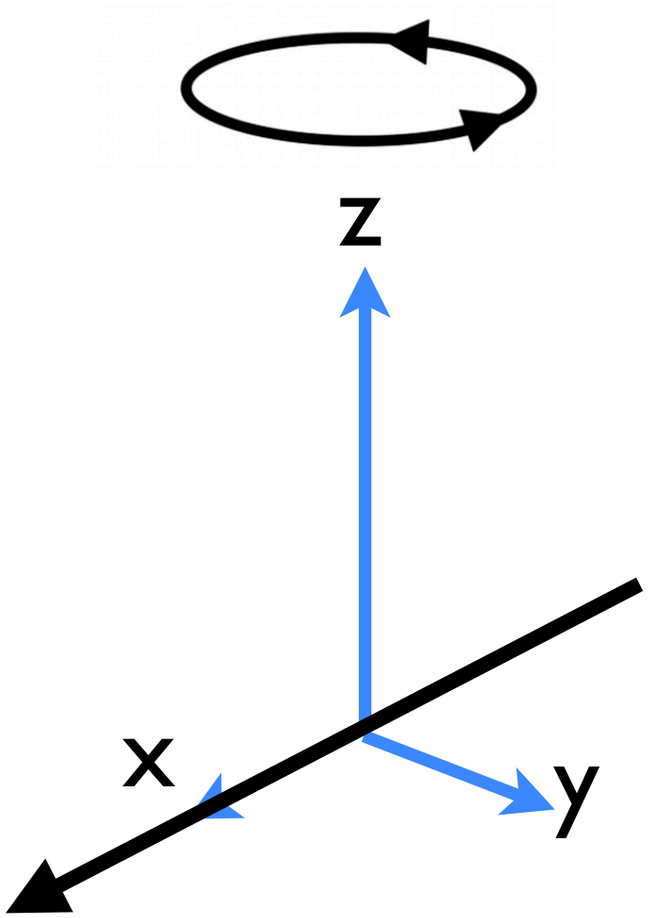
After the excitation (90°) I : precession

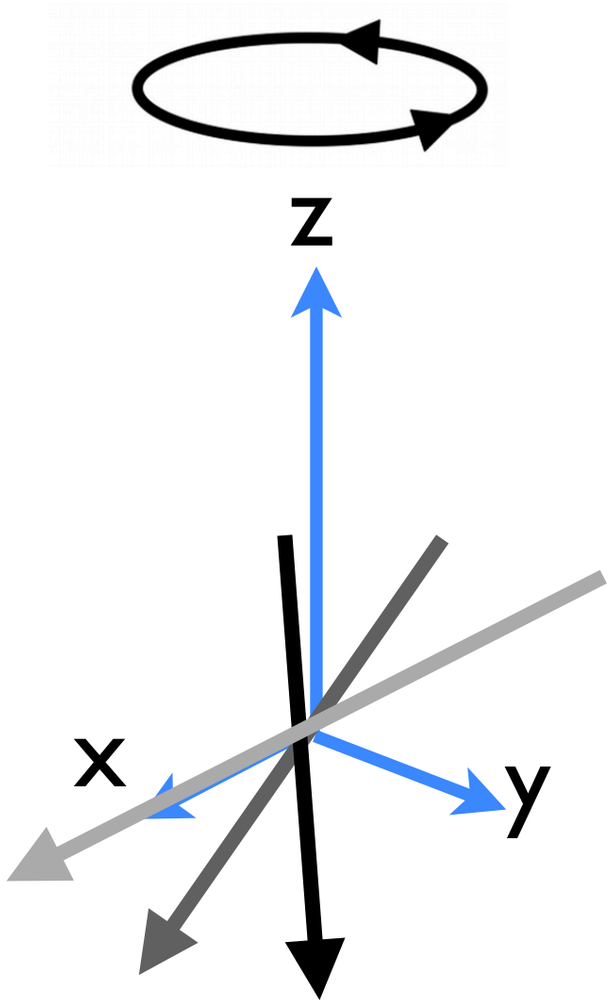


All lab frame

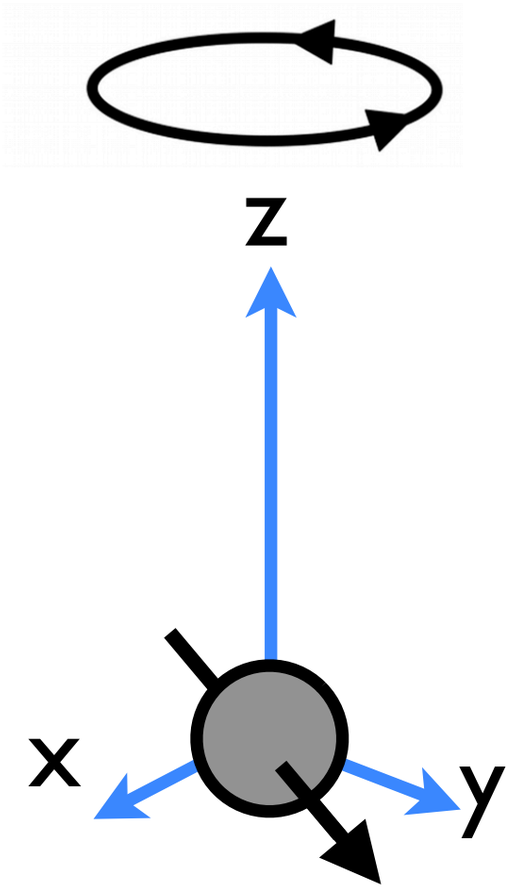
After the excitation 2: dephasing (T2*)

T2* due to *static* differences in effective B.





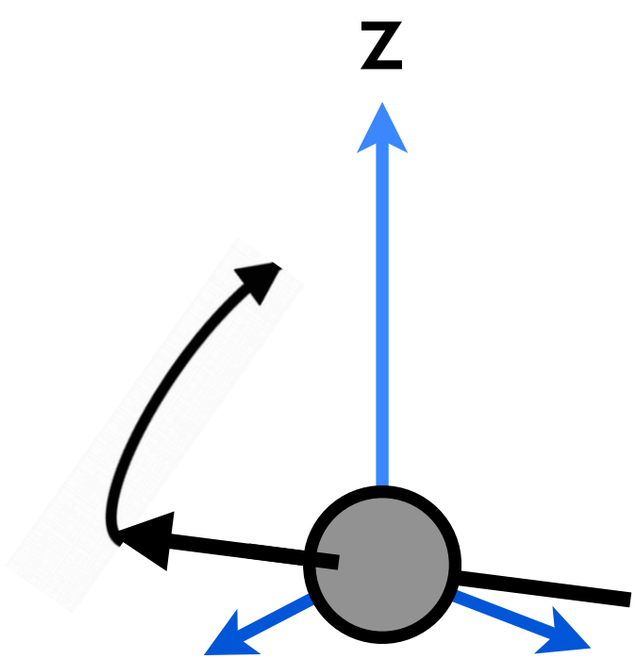
Some nuclei will precess faster than others



Net magnetization is smaller

After excitation 3: return to z (T1)

Rotating frame

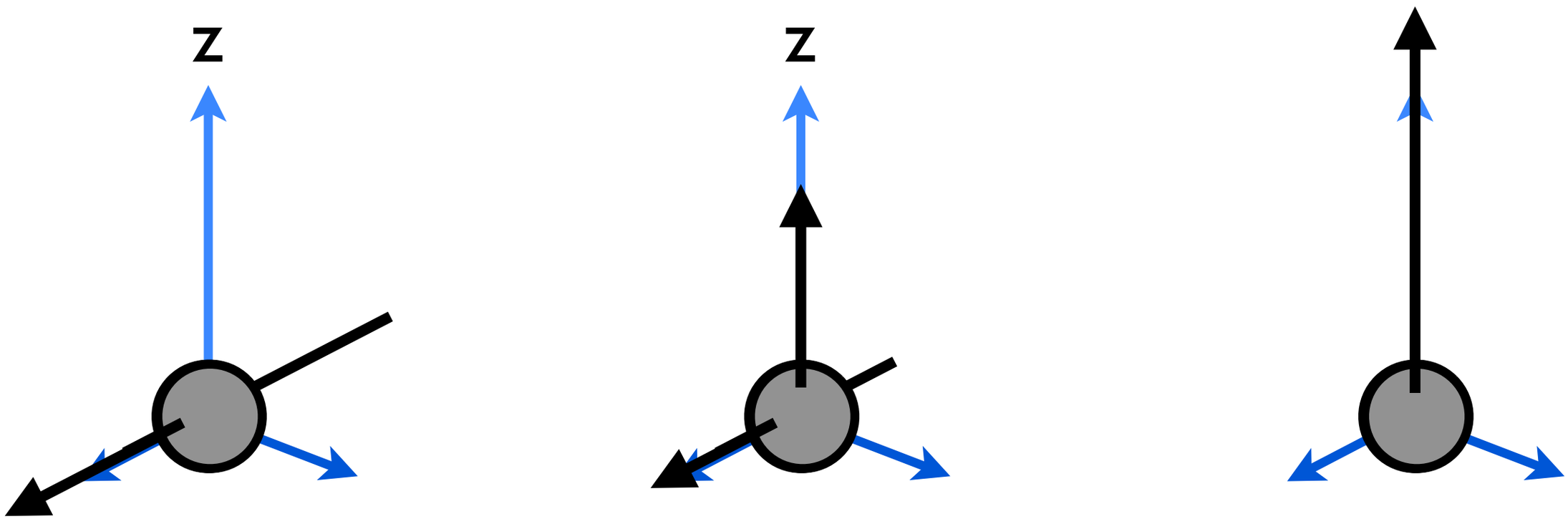


Technically, Mxy goes to 0, and Mz goes back to original value

e.g. what about 180° flip?

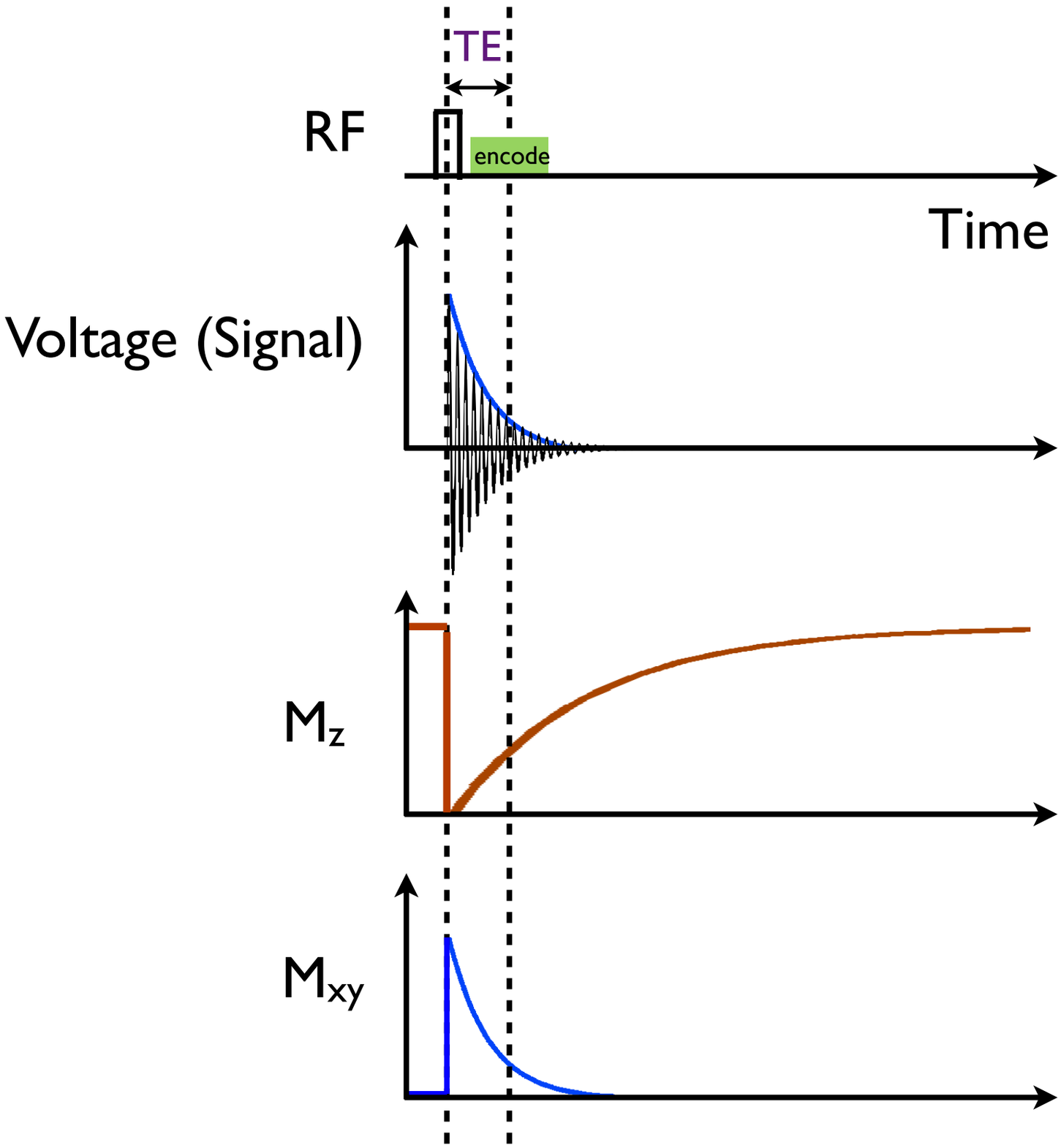
After excitation 3: return to z (T1)

Rotating frame



(Video demonstration of all 3 + spin echo!)

Detecting the signal & contrast



RF excitation pulse

Oscillating voltage detected at receive coil: the MR signal

Z magnetization returning to equilibrium with time constant T1

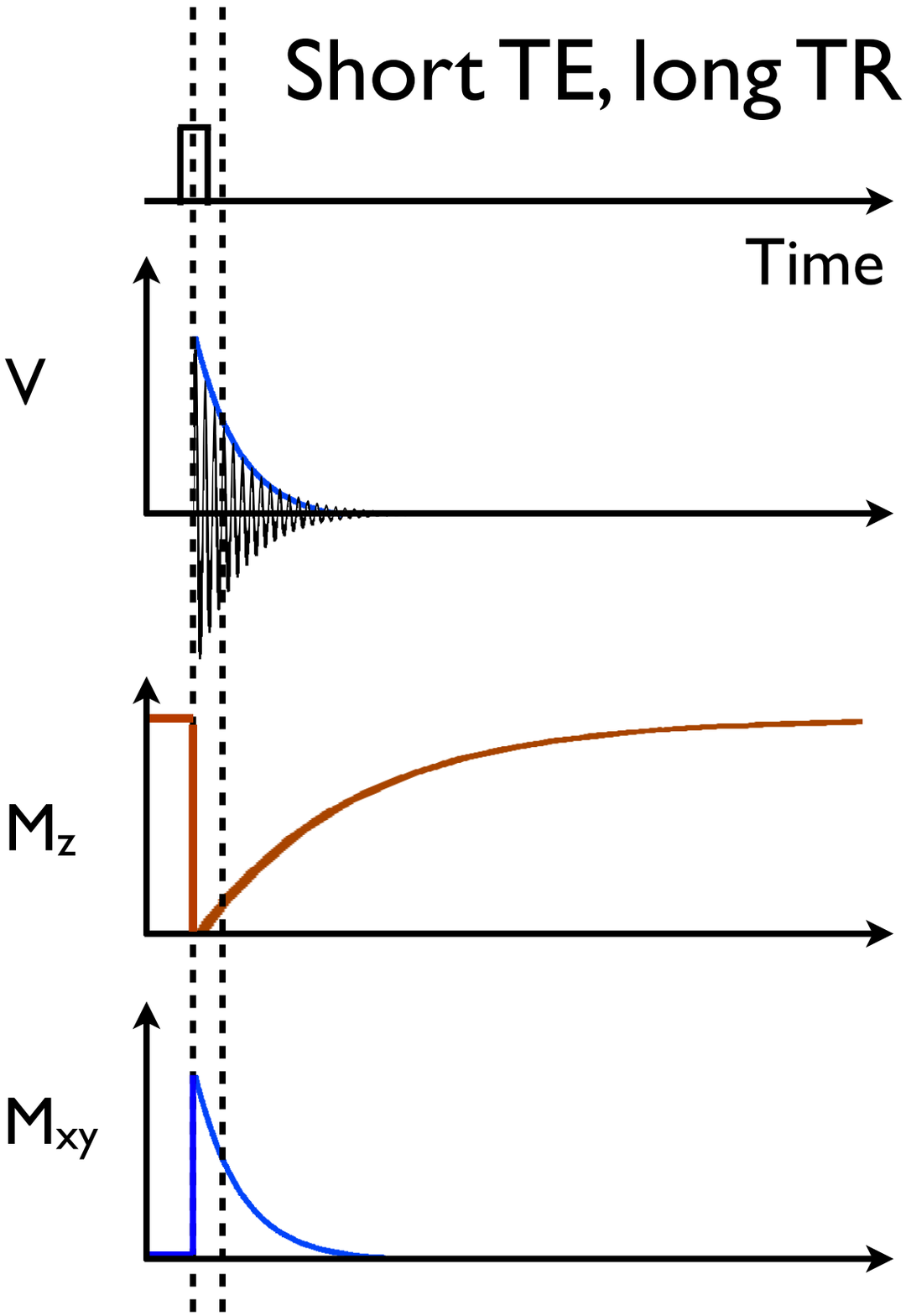
XY magnetization decaying b/c of dephasing with time constant T2*

Detecting the signal & contrast

<u>When in this process do we record an image?</u>

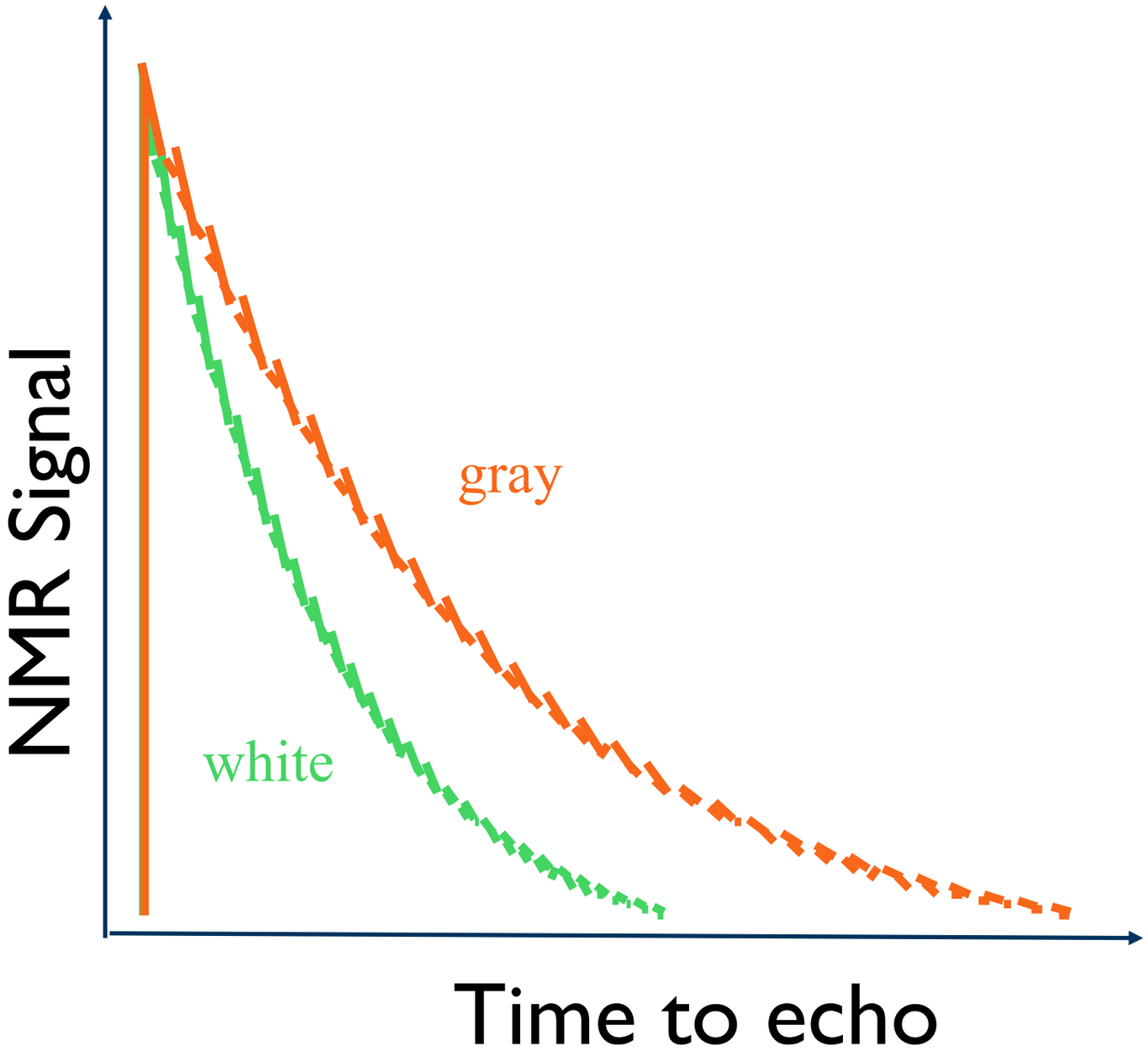
- Equilibrium
- RF Excitation ← Proton density weighting
- Precession & dephasing ← T2 weighting
- Return to equilibrium ← T1 weighting

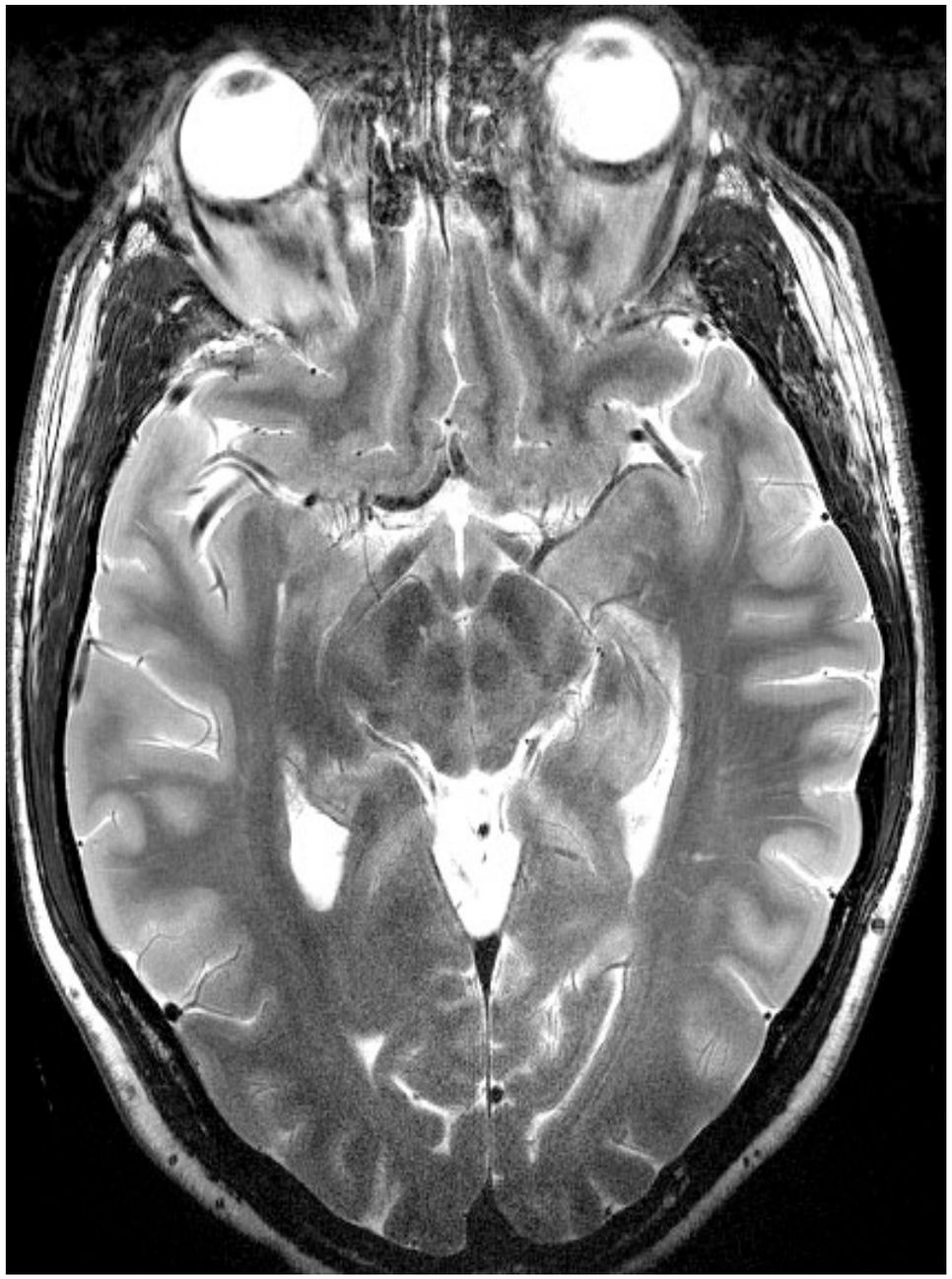
Proton density weighting



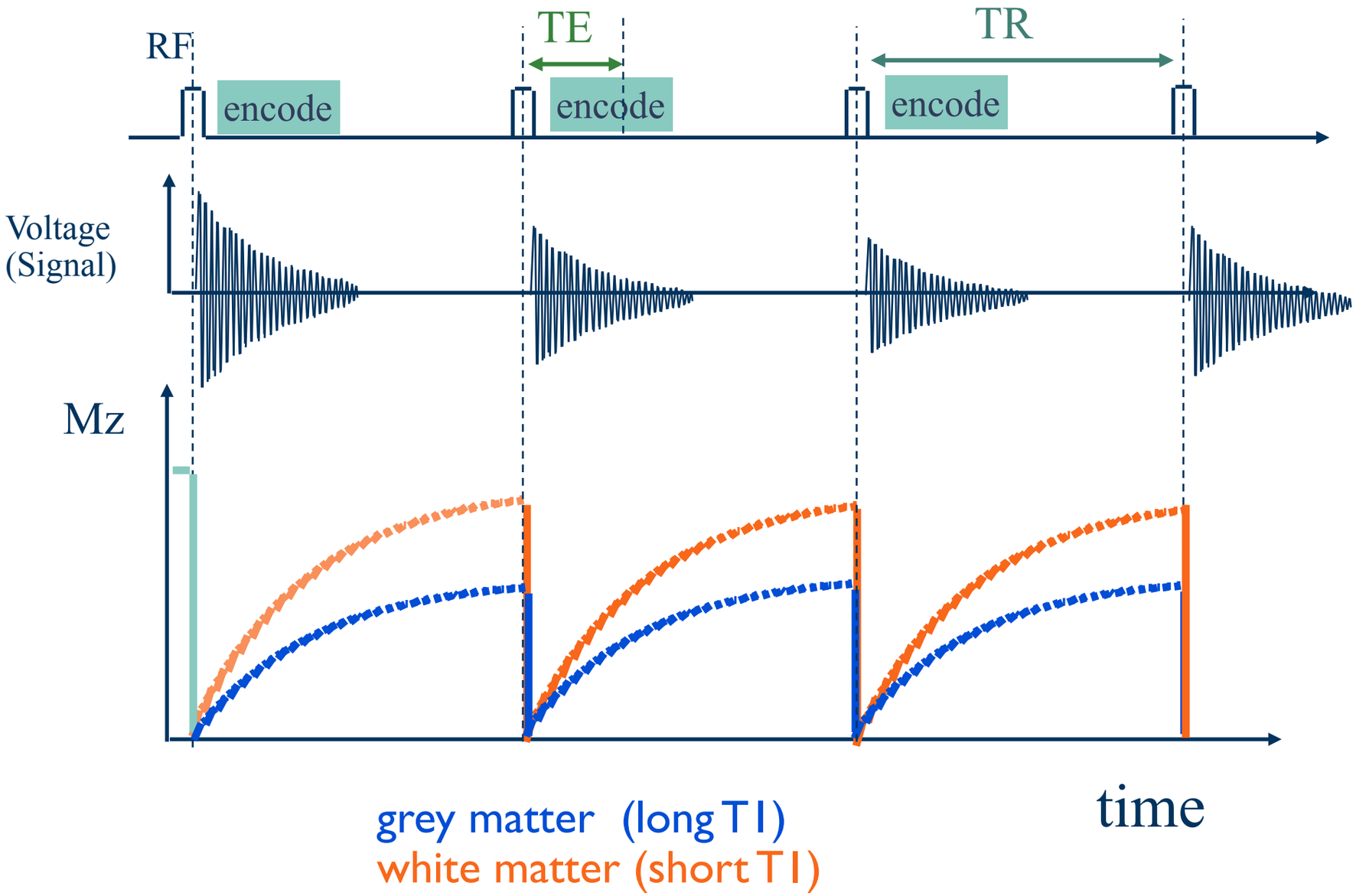
CSF > gray > white

T2-weighted spin echo image

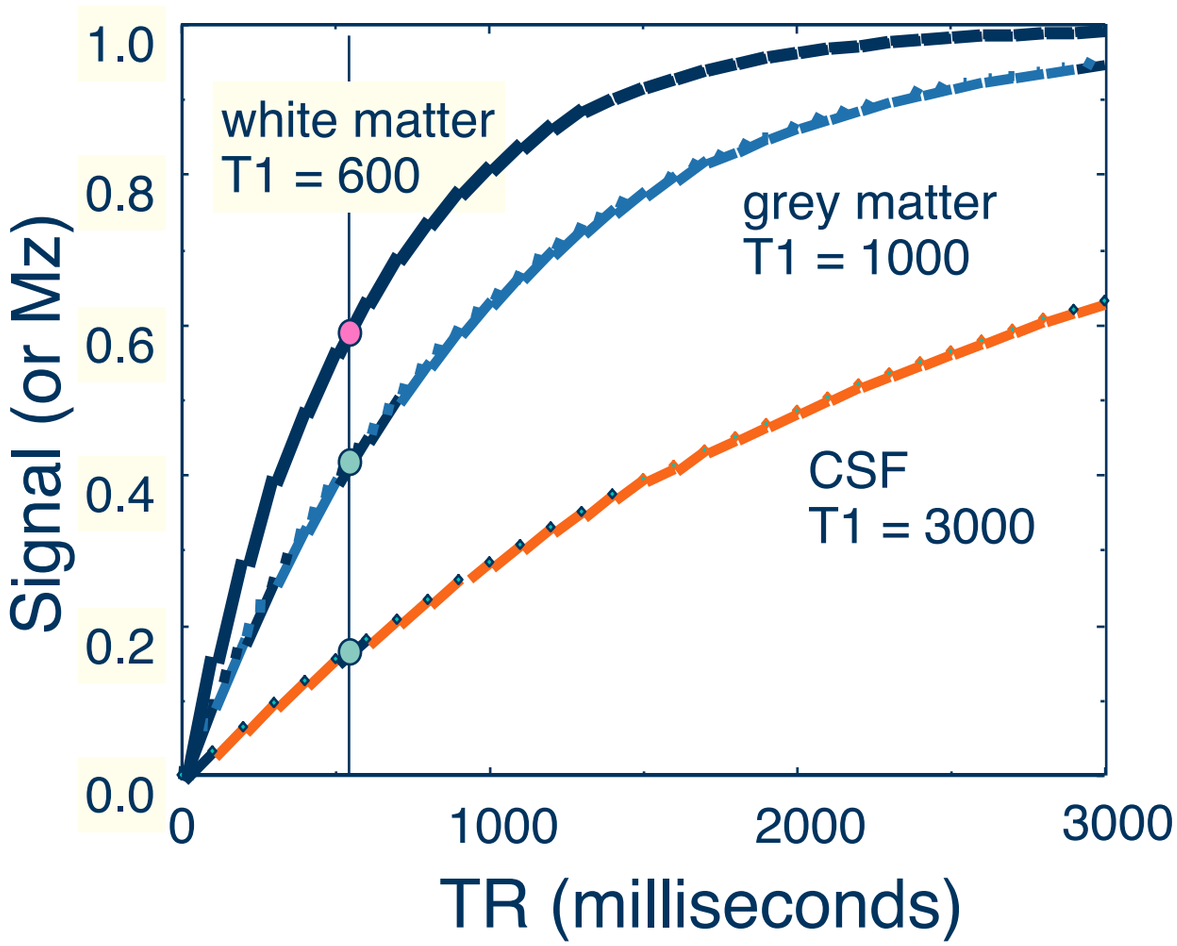


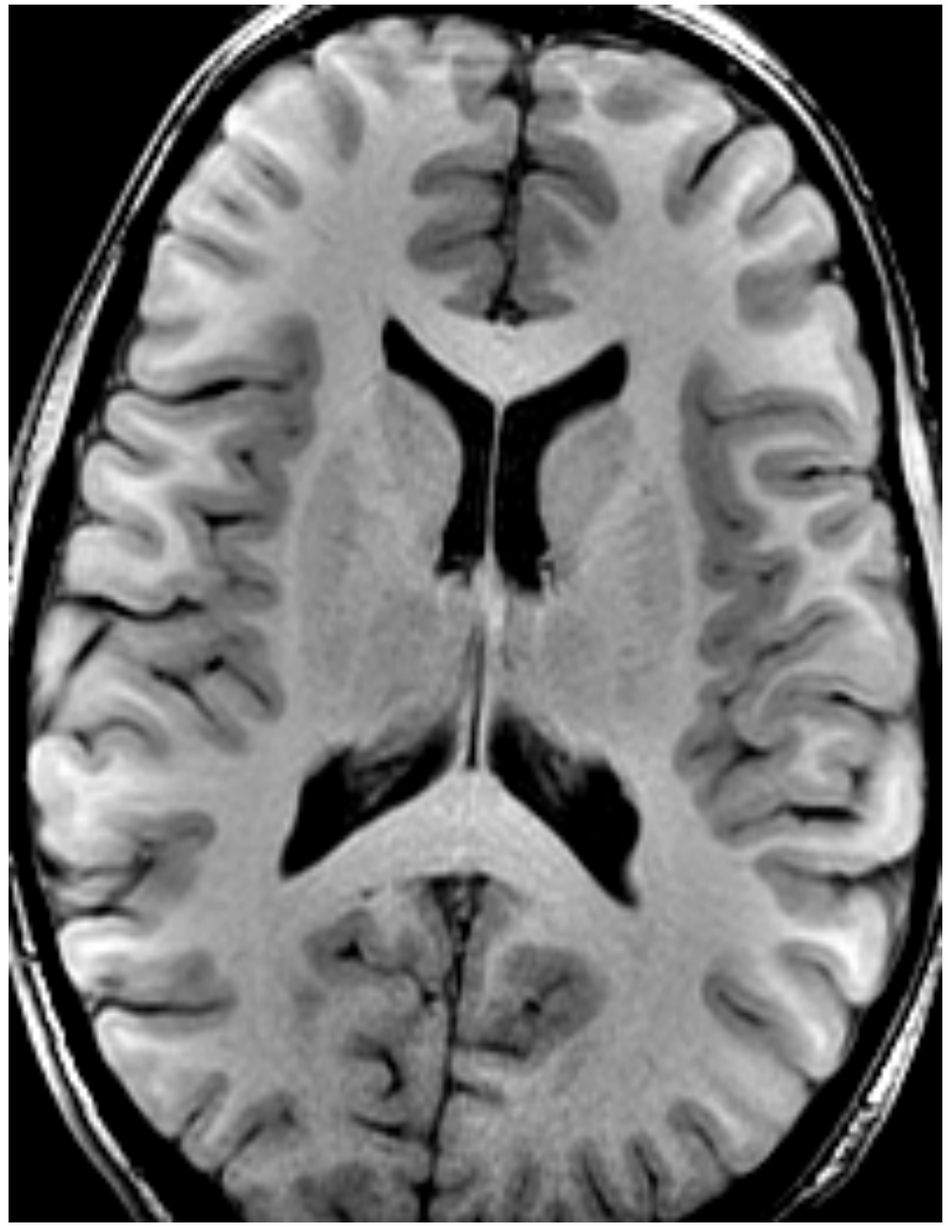


T1 weighting



T1 weighting





Contrast summary

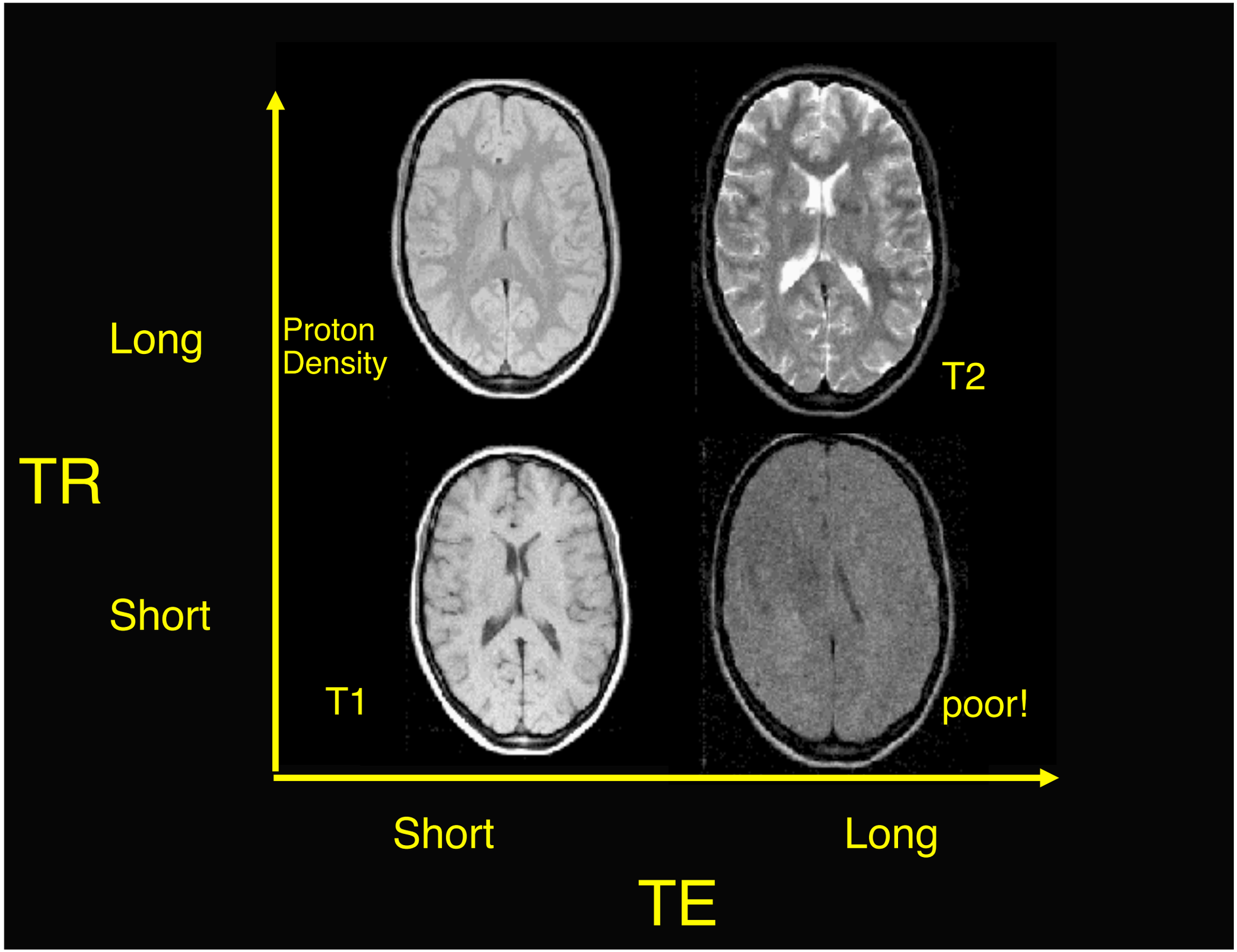
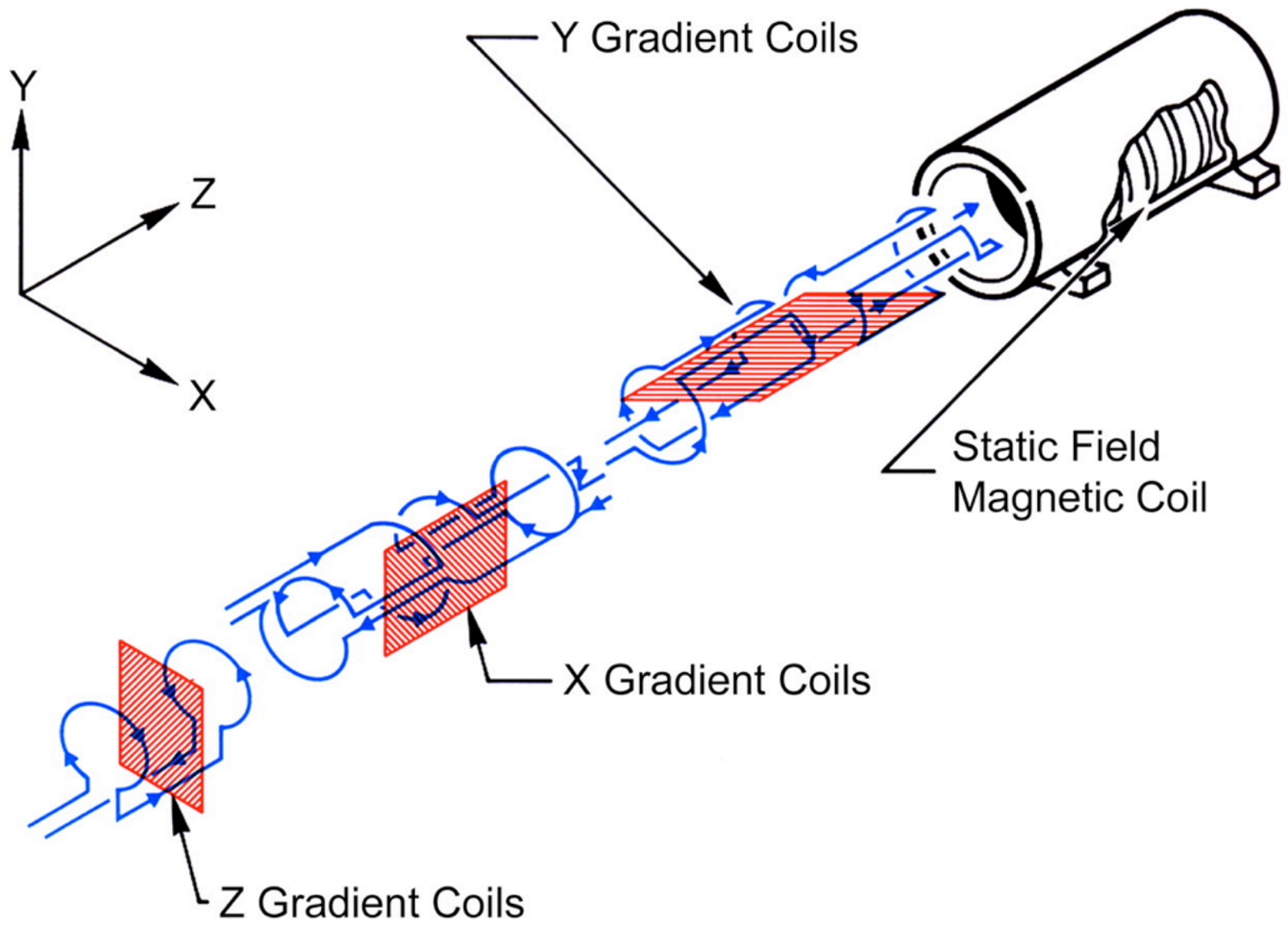


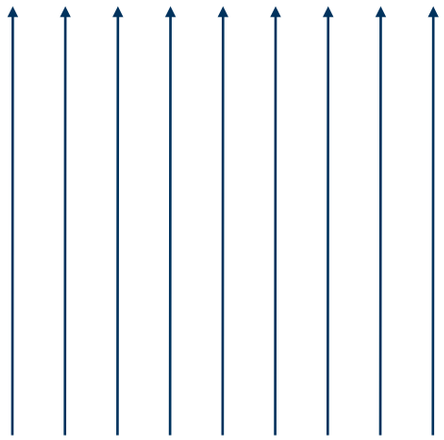
Image encoding: gradients



Gradient field add a linear space dependent B field to the original B_0 (still in z direction!)

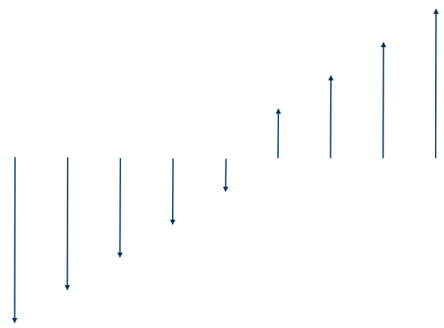
Effect of a gradient field

B_0



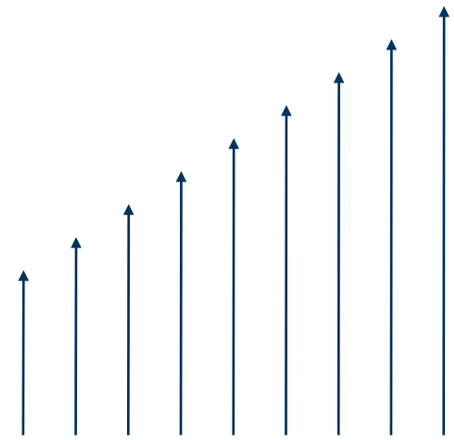
Uniform magnet

$G_x\ x$



Field from gradient coils

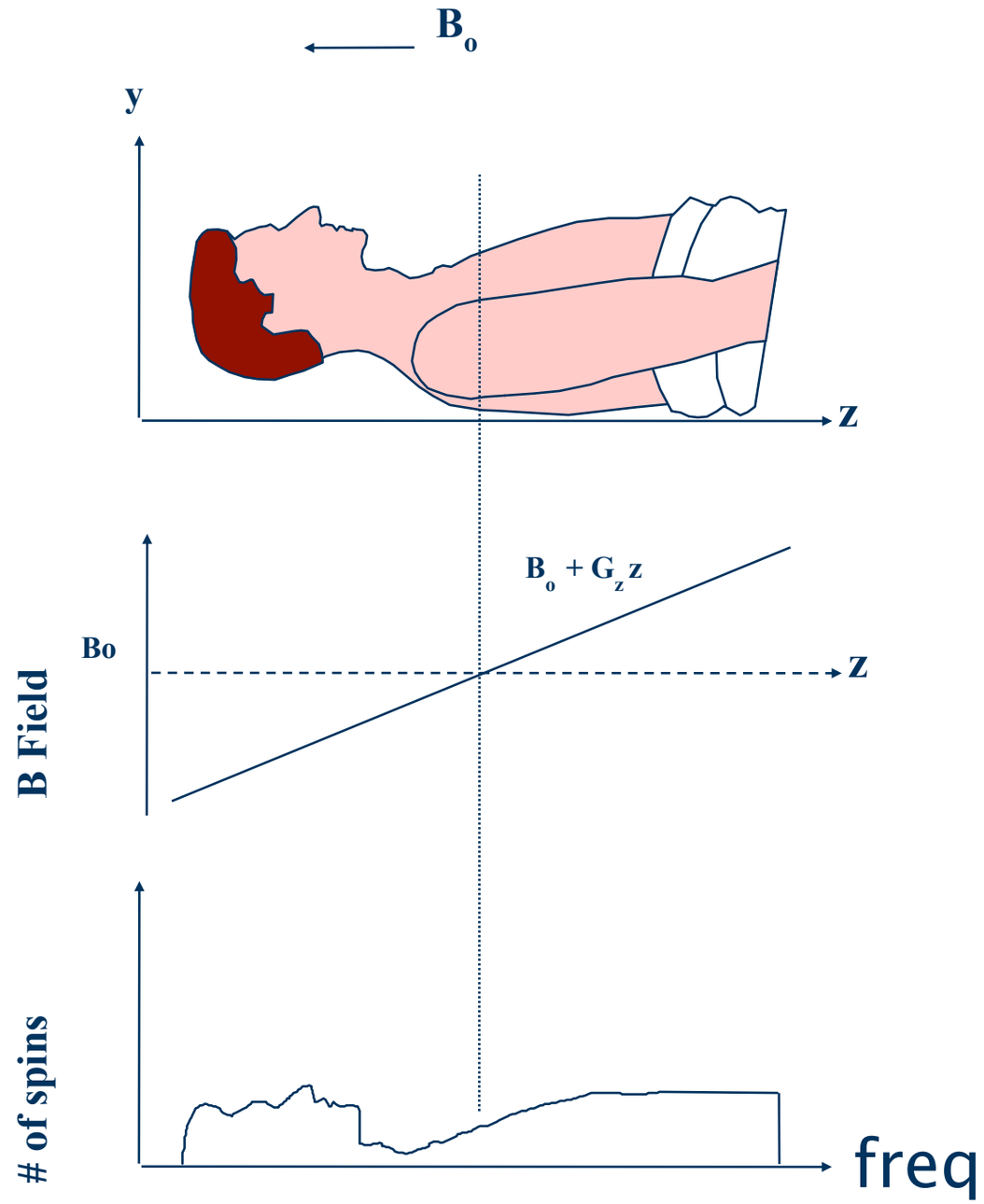
$B_0 + G_x\ x$



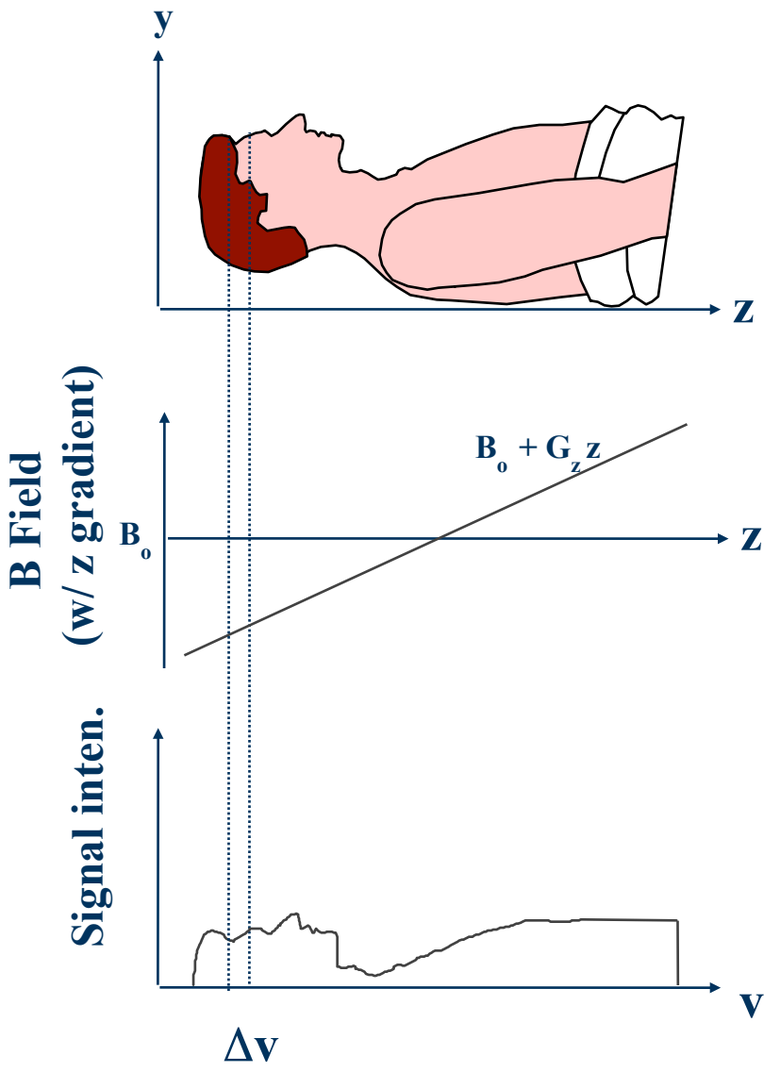
Total field

Frequency of precession w/ gradient

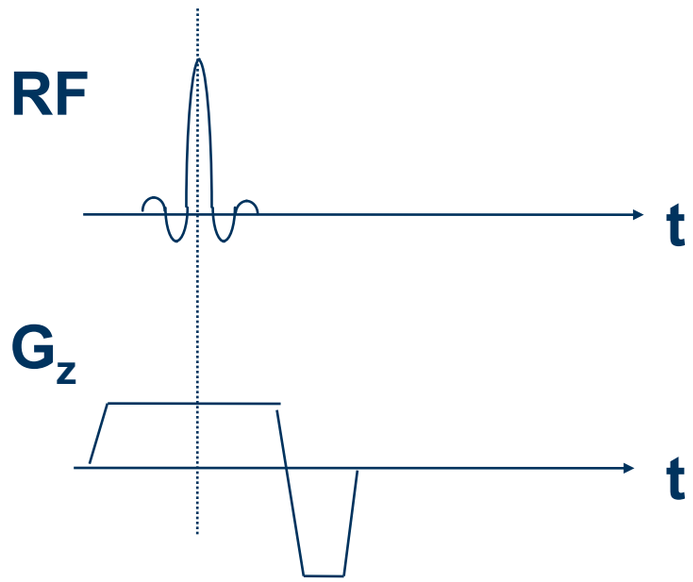
Precession frequency is proportional to the total B field (B_0 + gradient field)



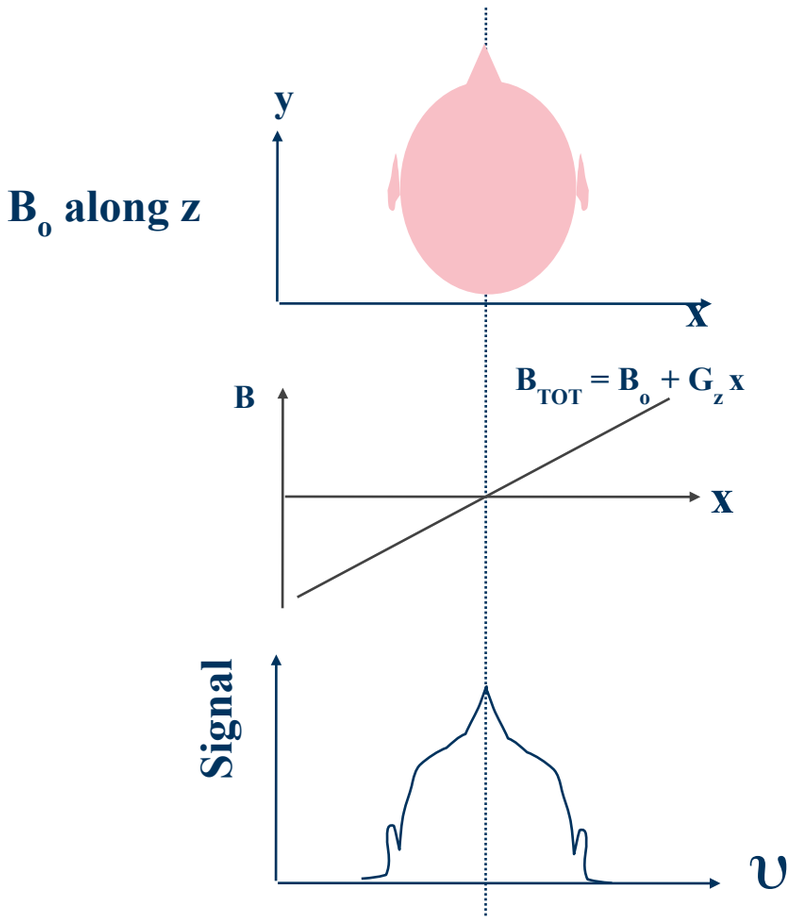
Slice selection (here w/ z gradient)



While the gradient is on, excite only band of frequencies.

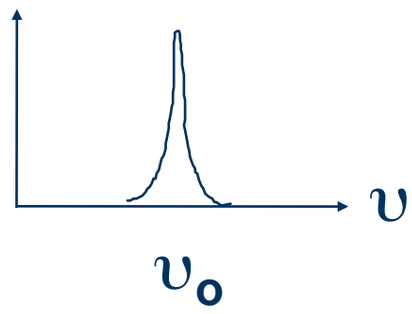


Frequency encoding



with gradient

"Frequency encoding"



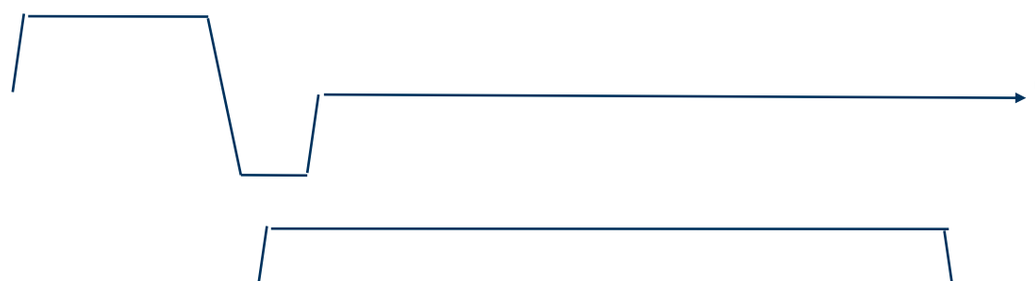
without gradient

Pulse sequence at this point

RF

"slice select"

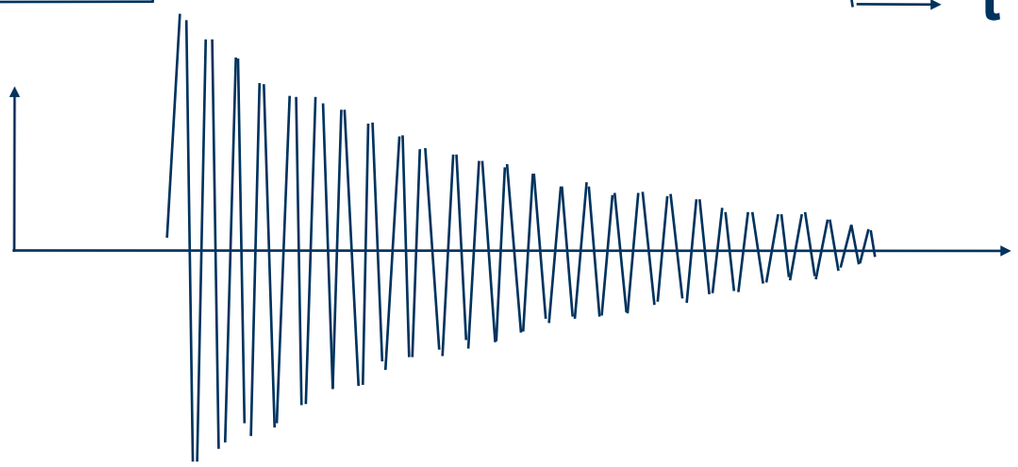
G_z



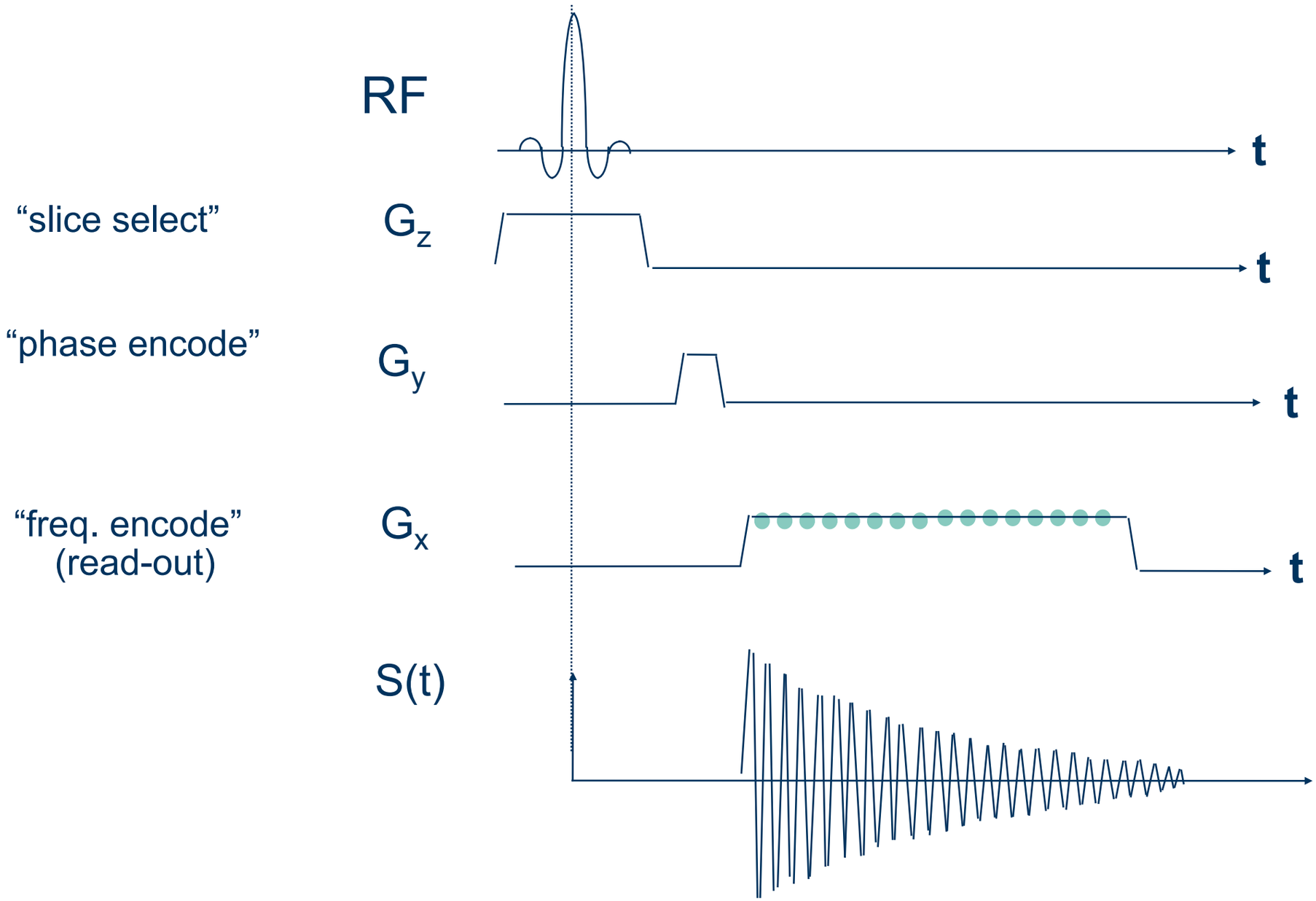
"freq. encode"
(read-out)

G_x

S(t)



Phase encode



Phase encode....

For the full explanation, we need to look at this not in the image space, but in the spatial frequency space, i.e. k-space

Thanks!

Questions?