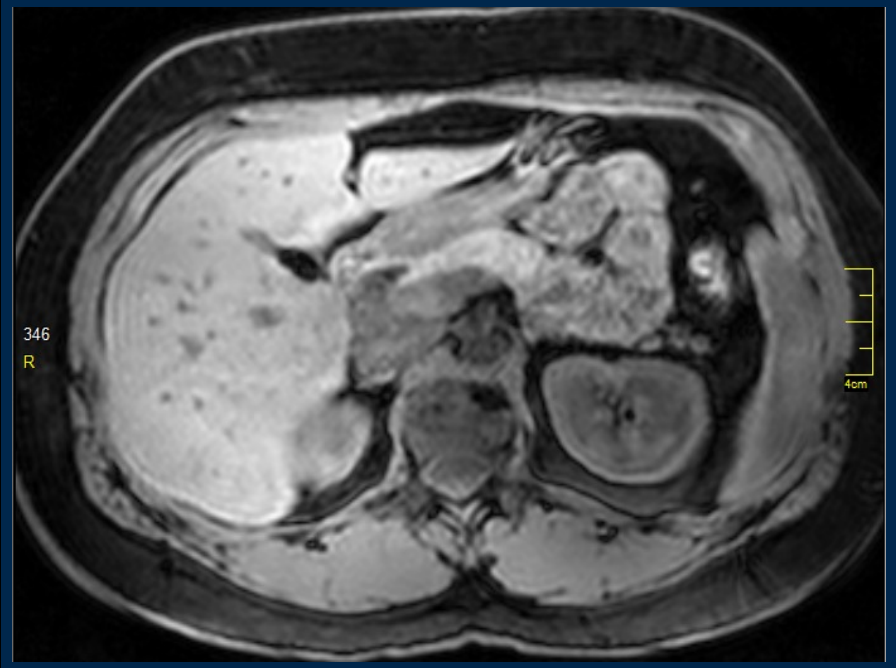
MRI Physics:

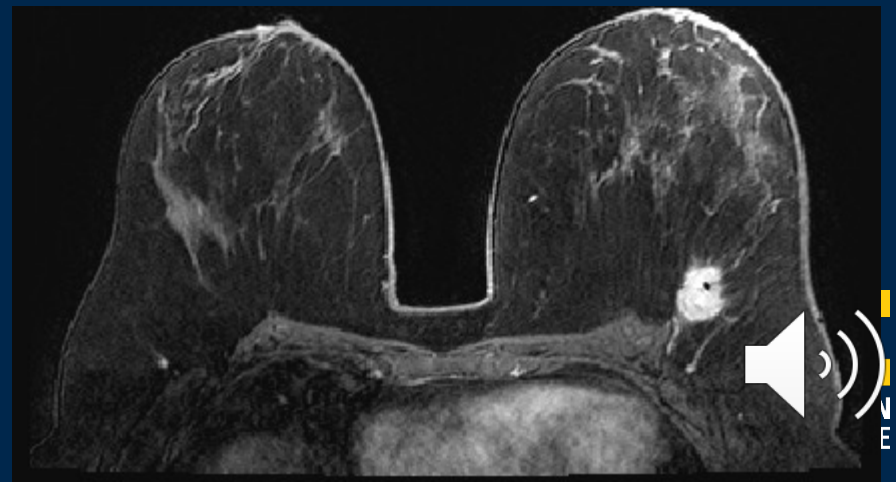
MRI Basics

Nicole Seiberlich
Associate Professor, Radiology
Co-Director of MIITT

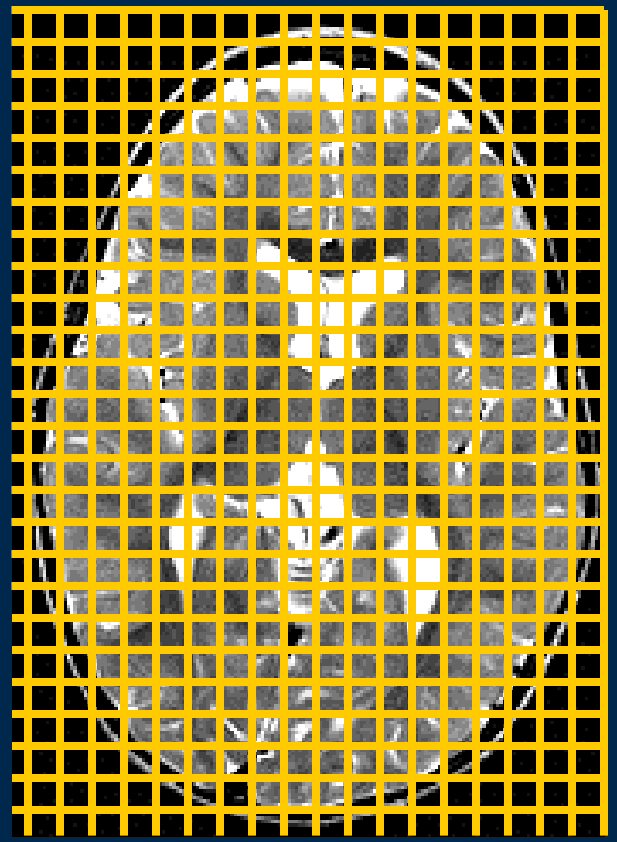
MICHIGAN MEDICINE

MRI is Amazing!





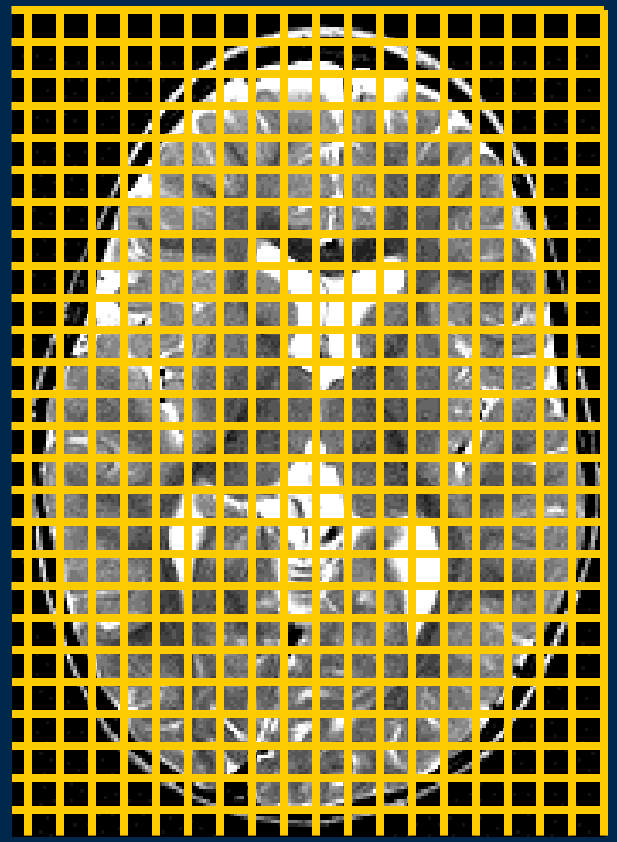
What is an MR Image?



2	102	54	51	49	97
5	103	52	48	47	99
3	105	49	54	52	50
1	99	102	47	50	51
2	5	100	96	101	99
1	3	5	2	1	3

MICHIGAN MEDICINE

What is an MR Image?



2	102	54	51	49	97
5	103	52	48	47	99
3	105	49	54	52	50
1	99	102	47	50	51
2	5	100	96	101	99
1	3	5	2	1	3

MICHIGAN MEDICINE

What do we care about in MR images?

- Contrast → high between tissues of interest
- Resolution → high, small voxels
- Signal-to-Noise Ratio (SNR) → high
- Data Collection Time → rapid

MICHIGAN MEDICINE

Contrast in MRI

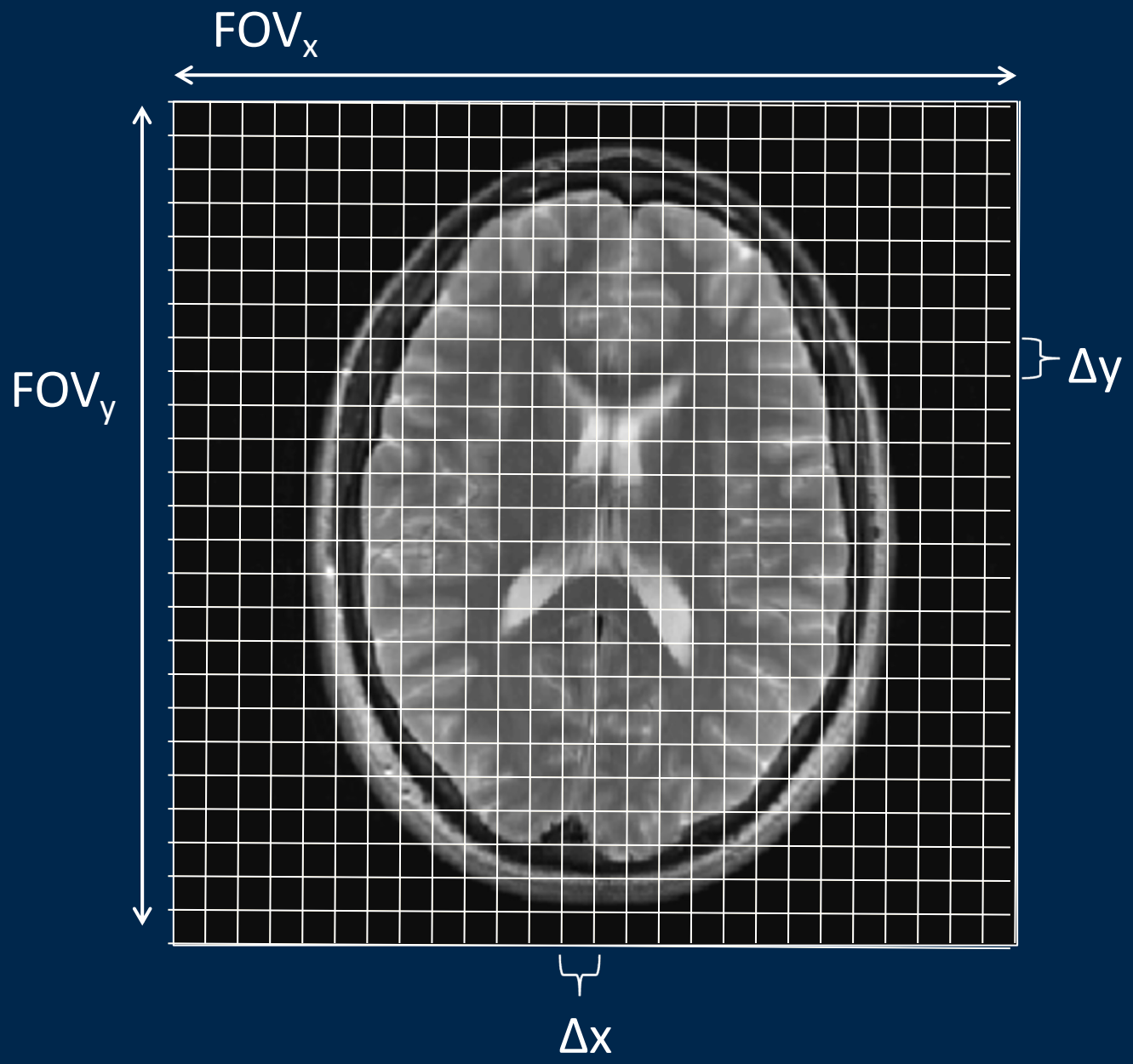
"T1 Weighted":

"Proton Density (PD) Weighted":

"T2 Weighted":

MICHIGAN MEDICINE

Resolution



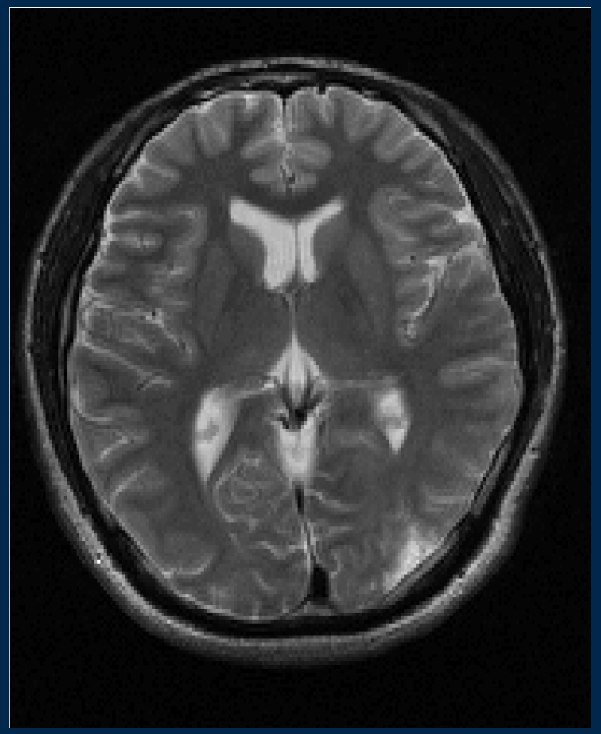
$$N_x = \frac{FOV_x}{\Delta x}$$

$$N_y = \frac{FOV_y}{\Delta y}$$

MICHIGAN MEDICINE

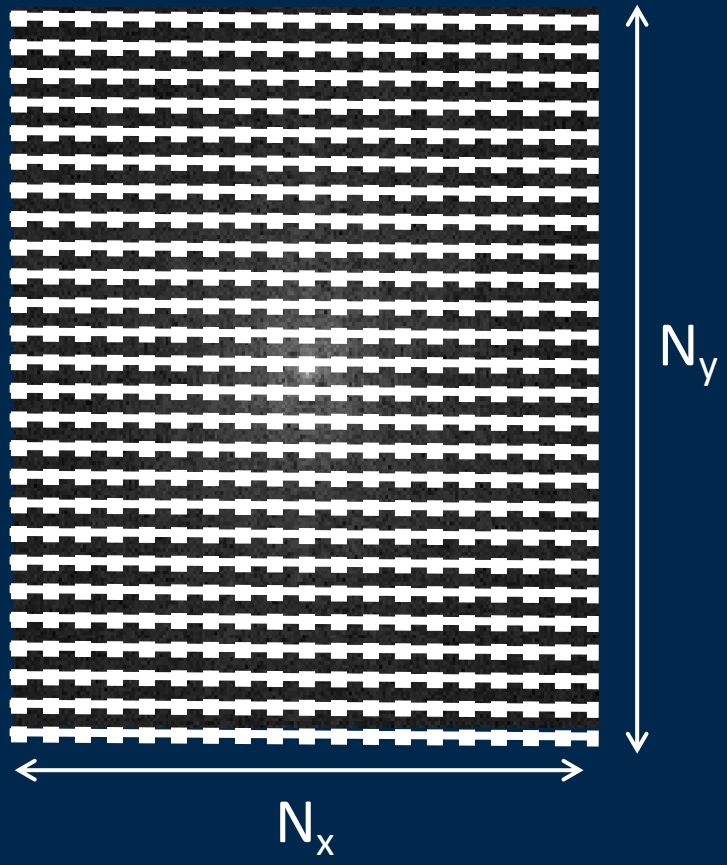
MRI Data Collection

Image



2D DFT

Data, “k-Space”



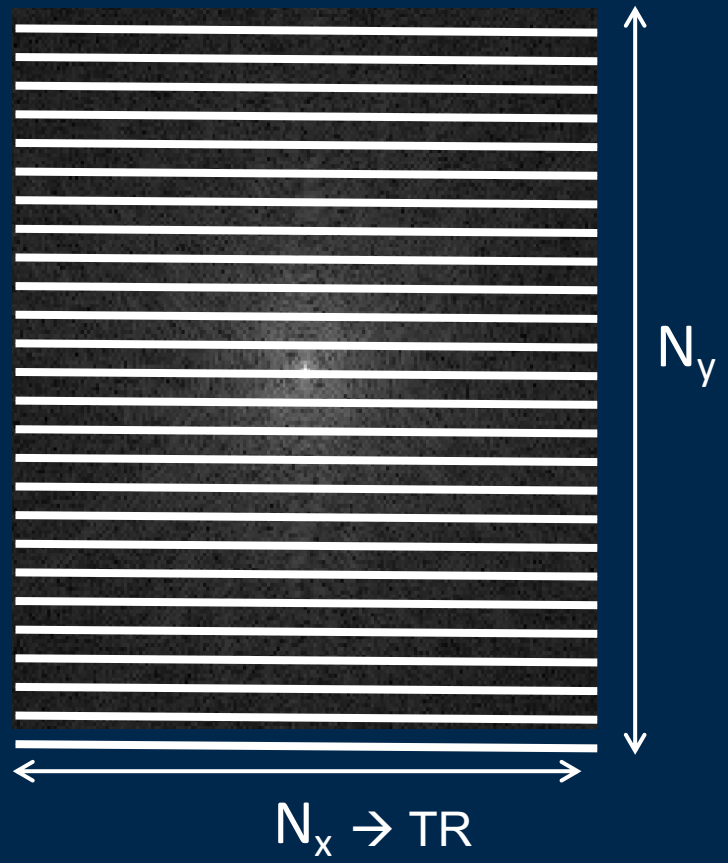
MICHIGAN MEDICINE

MRI Data Collection Time

Ny x (Time per Line) = Total Acquisition Time

Ny x TR = Total Acquisition Time

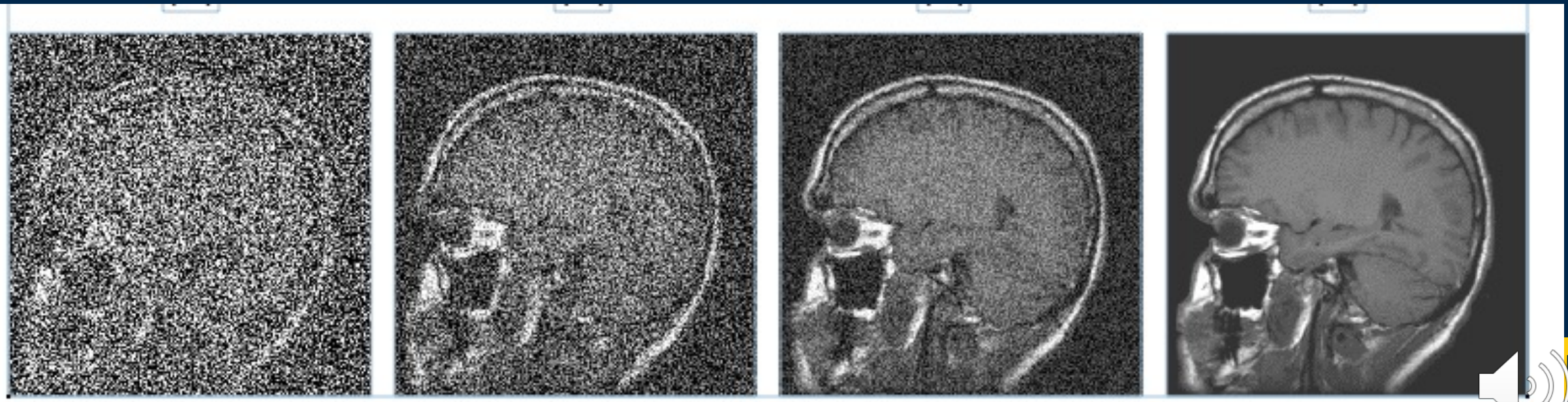
Ny x TR x N_{ave} = Total Acquisition Time



MICHIGAN MEDICINE

Signal-to-Noise Ratio

- SNR is a measure of the ratio of true signal to the amount of unwanted, erroneous signal collected
- SNR can be enhanced by collecting more data, repeating experiment (N_{ave}), filtering, etc



SNR

Resolution

Speed

MICHIGAN MEDICINE

MRI Physics:

Magnetization Basics

Nicole Seiberlich
Associate Professor, Radiology
Co-Director of MIITT

MICHIGAN MEDICINE

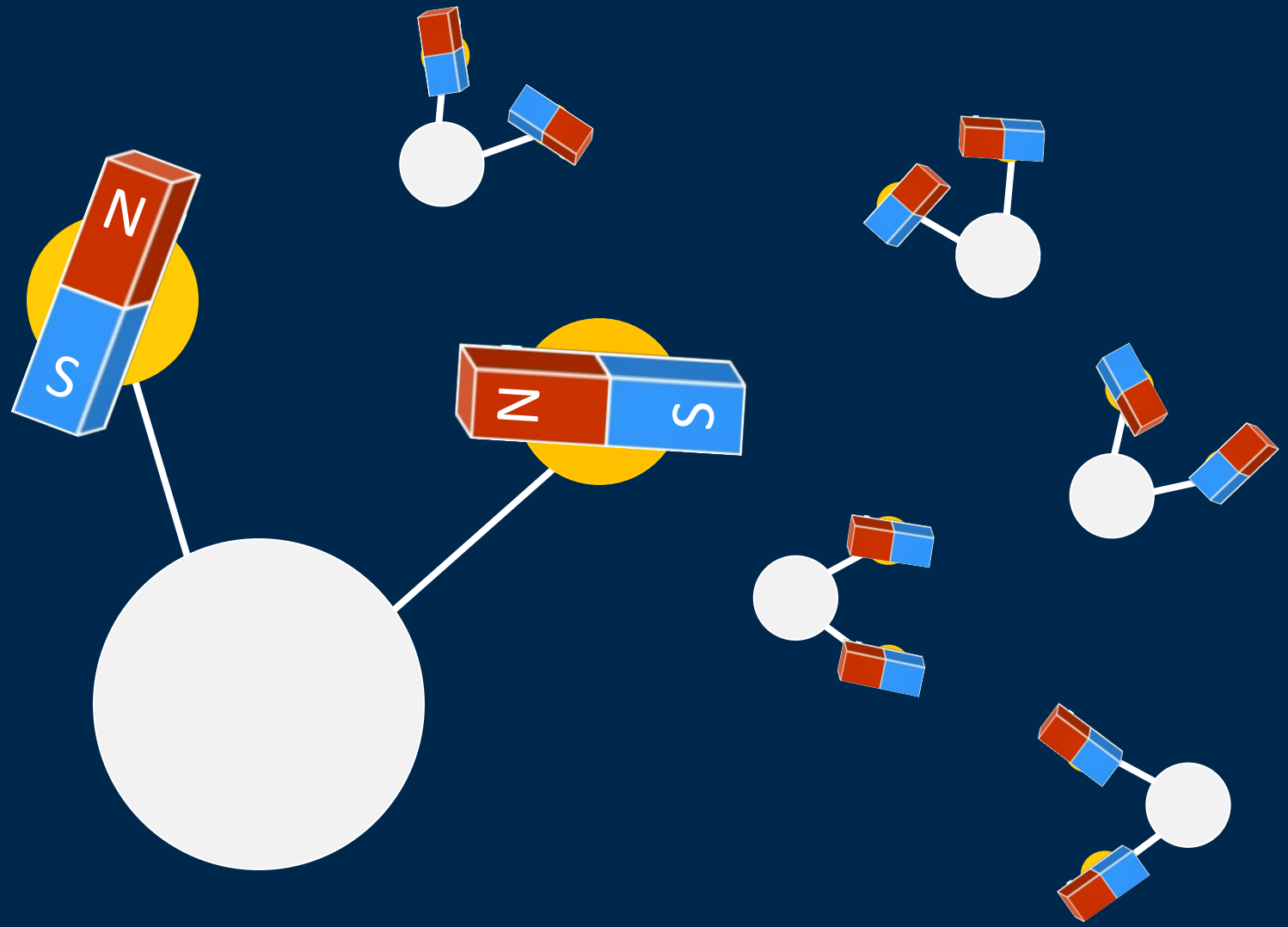
MRI Signals Come from Protons

Hydrogen Nuclei in the clinic
^{1}H, ^{13}C, ^{17}O, ^{31}P

“Spins”

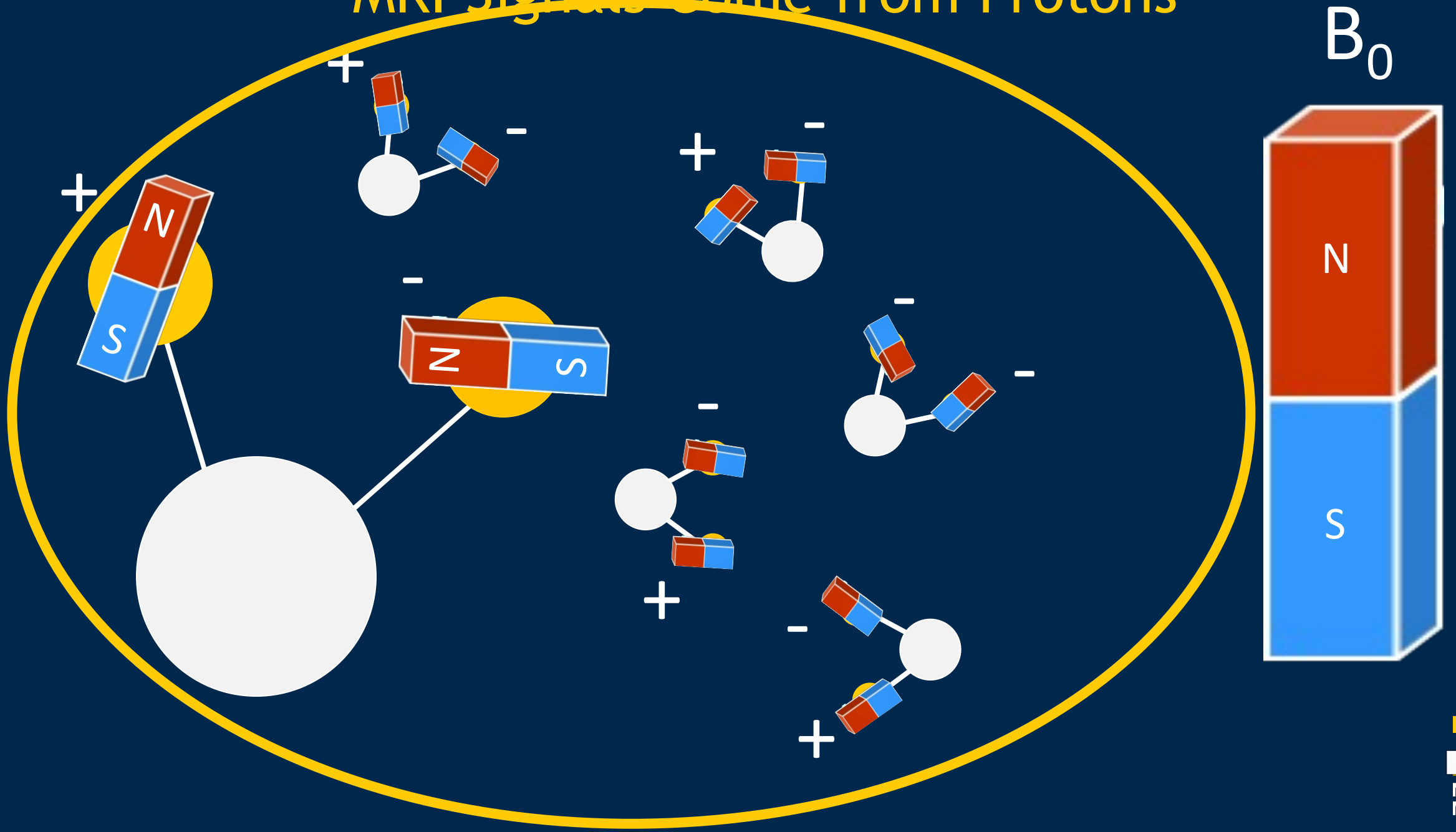
Typically collect signal from water
→ Also fat/lipids

MRI Signals Come from Protons



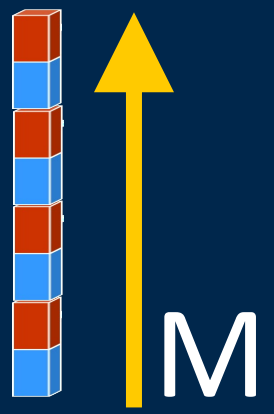
MICHIGAN MEDICINE

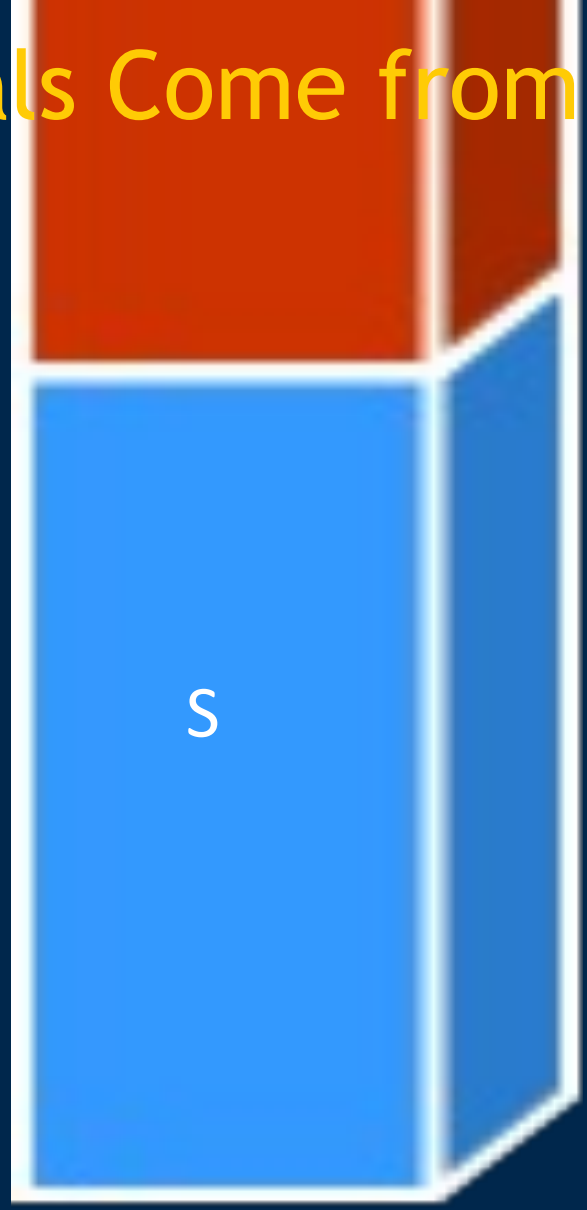
MRI Signals Come from Protons

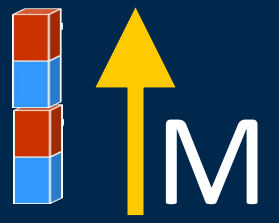


MICHIGAN MEDICINE

MRI Signals Come from Protons



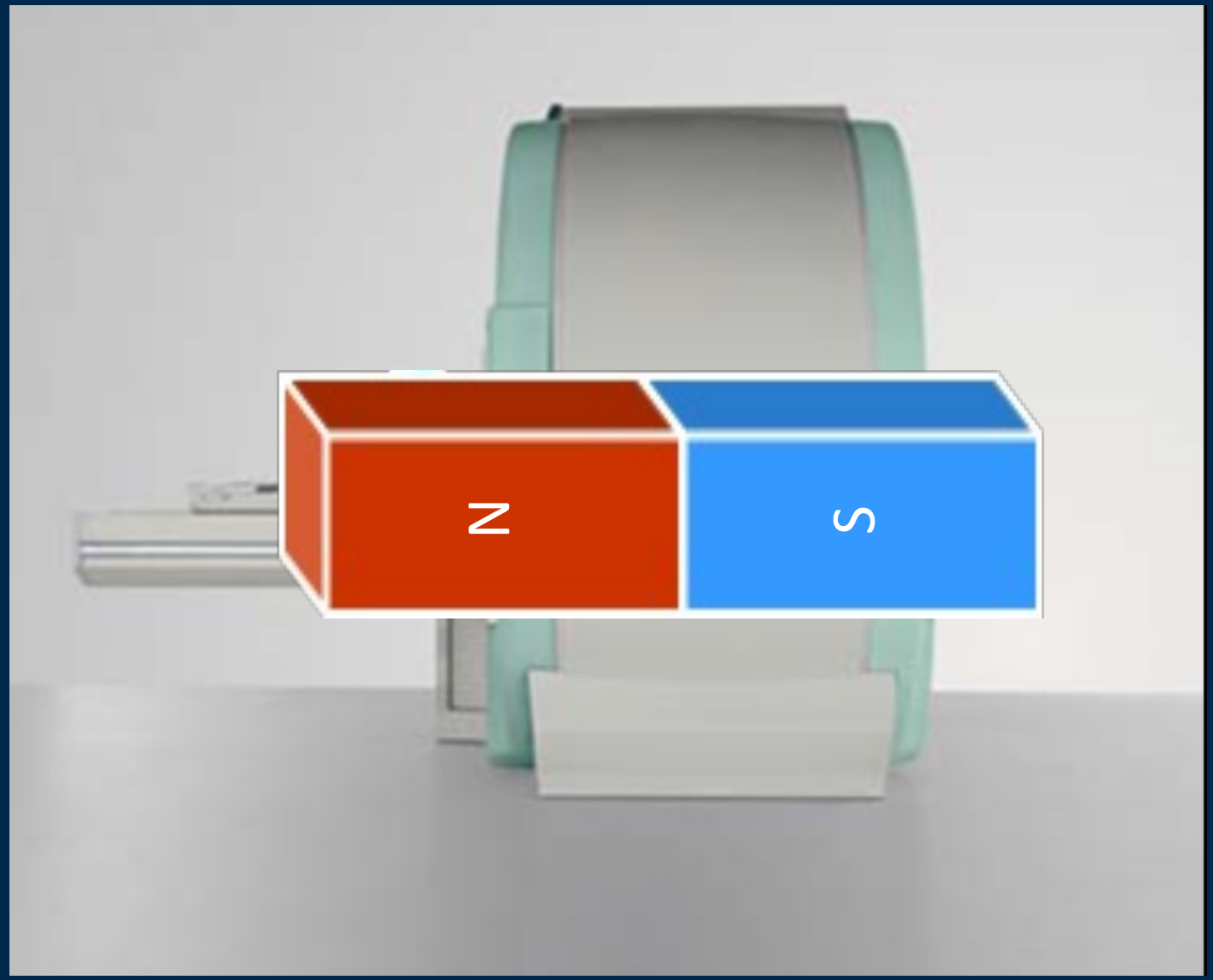




Magnetization Vector
Aligned with B_o
z-Axis → Longitudinal Magnetization
Stronger field → Increased Magnetization

MICHIGAN MEDICINE

Magnetic Field in MRI



B_0

MICHIGAN MEDICINE

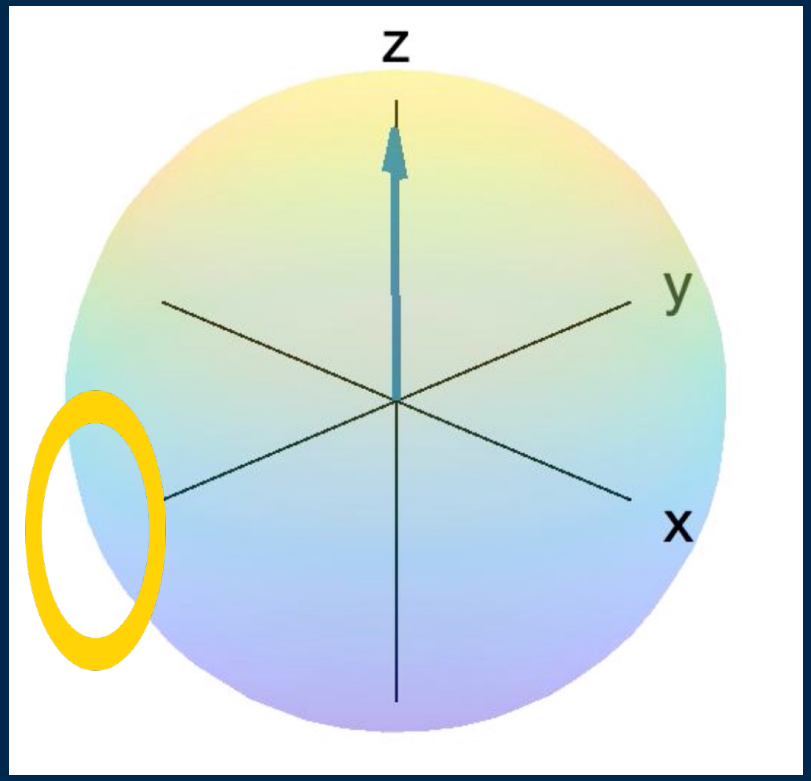
Magnetization Vector in Magnetic Field

Magnetization along magnetic field

Magnetization in z-direction

Longitudinal Magnetization

Cannot be detected

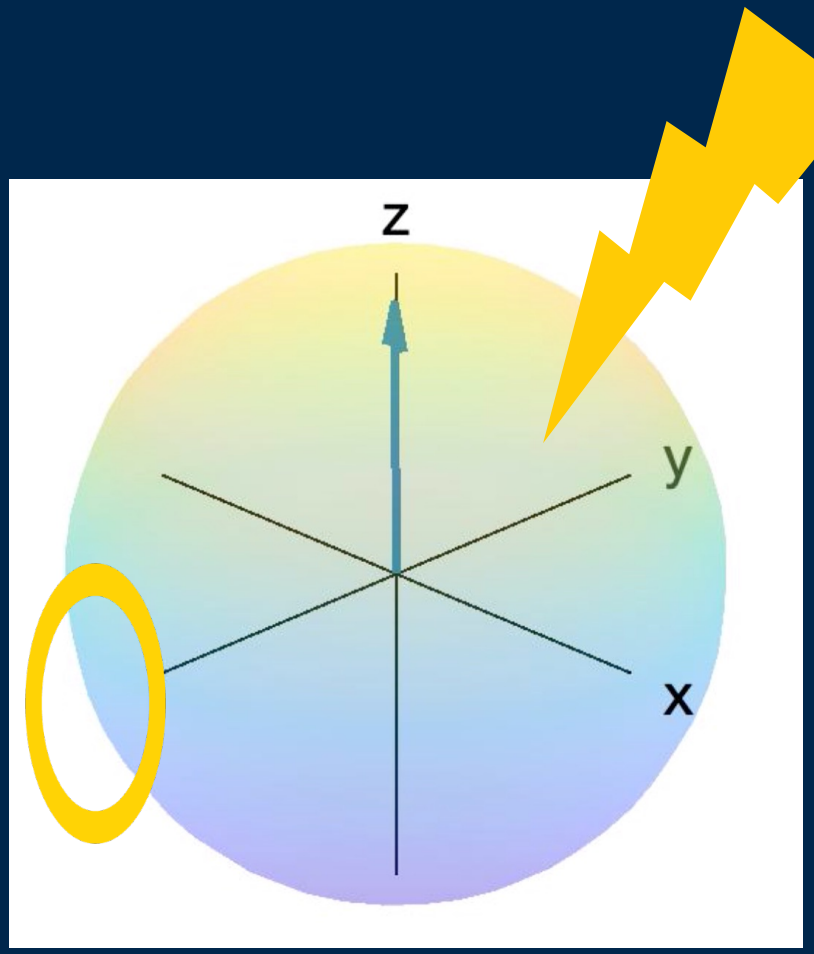


B_0

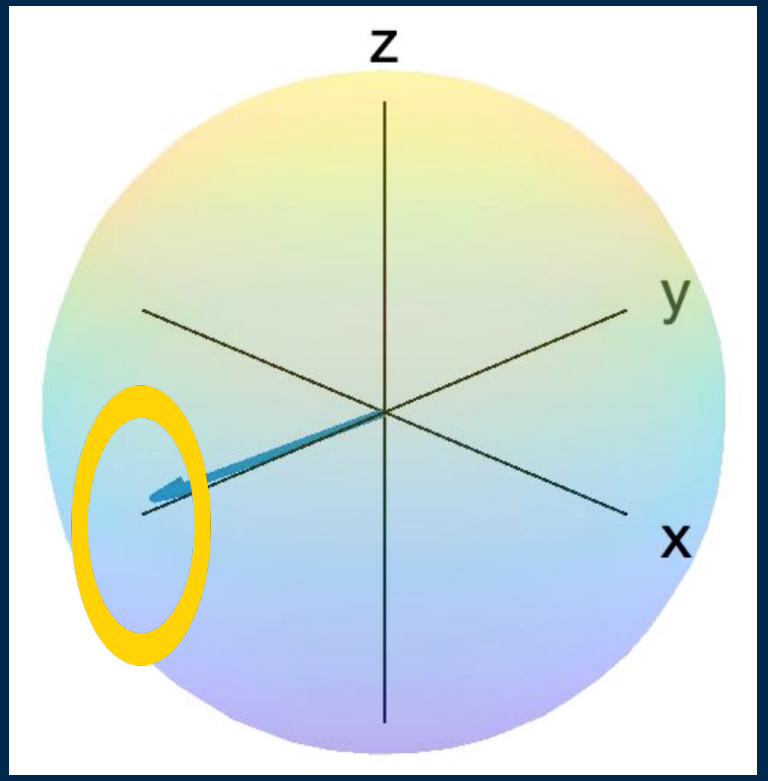
MICHIGAN MEDICINE

Magnetization Vector in Magnetic Field

Apply RF Pulse to Tip Magnetization into x-y plane
Longitudinal Magnetization → Transverse Magnetization



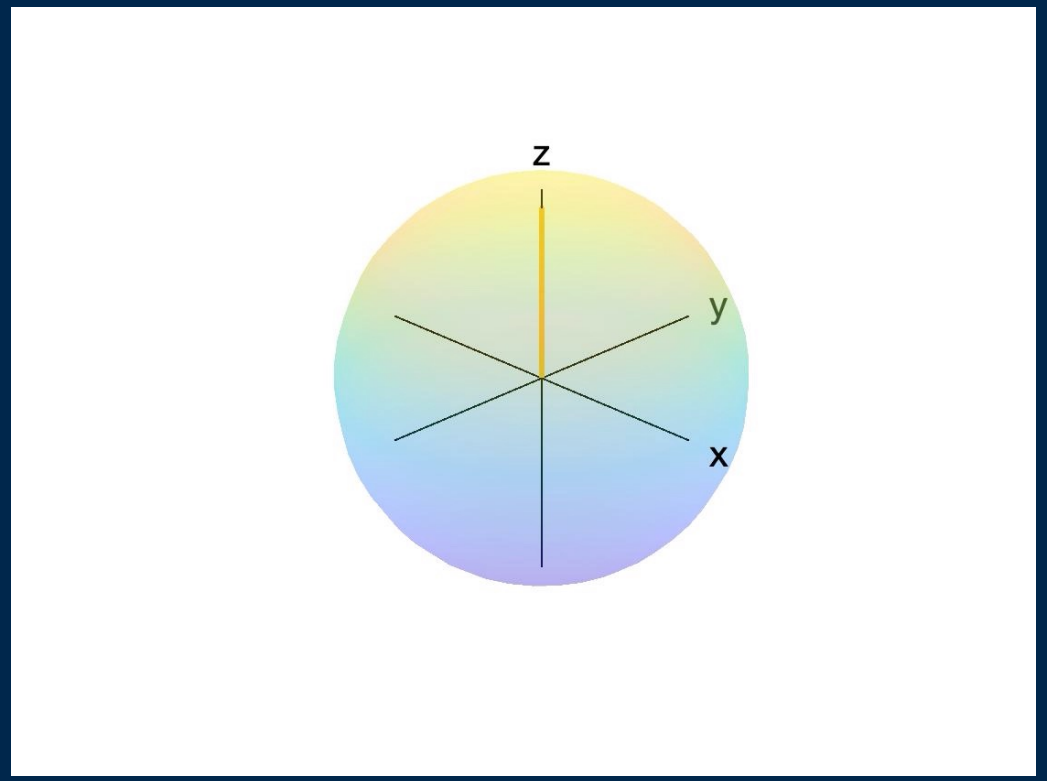
90°



B_0

MICHIGAN MEDICINE

Precession



$$\omega = \gamma \cdot B_0$$

Larmor Frequency
Angular Frequency

Gyromagnetic Ratio

Main Magnetic Field

B_0=1.5T → ω = 64 MHz → 64 million rounds/sec

B_0=3.0T → ω = 128 MHz → 128 million rounds/sec

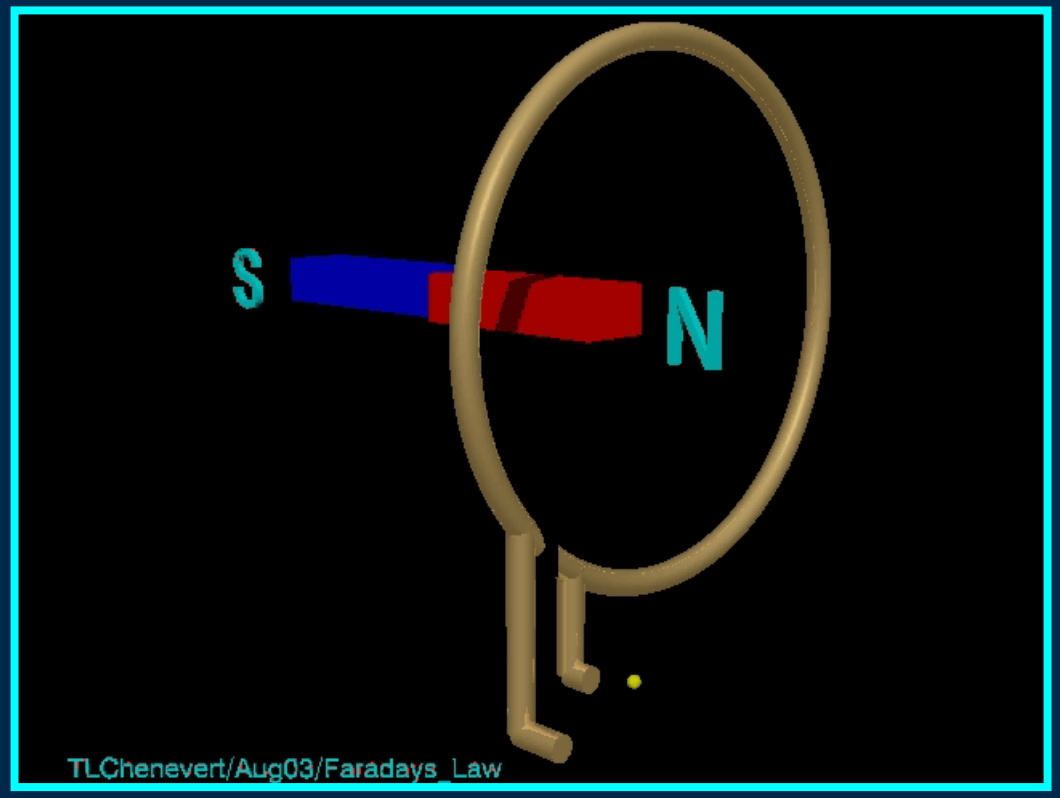
Stronger Magnetic Field = Faster precession

MICHIGAN MEDICINE

MRI Signal Detection

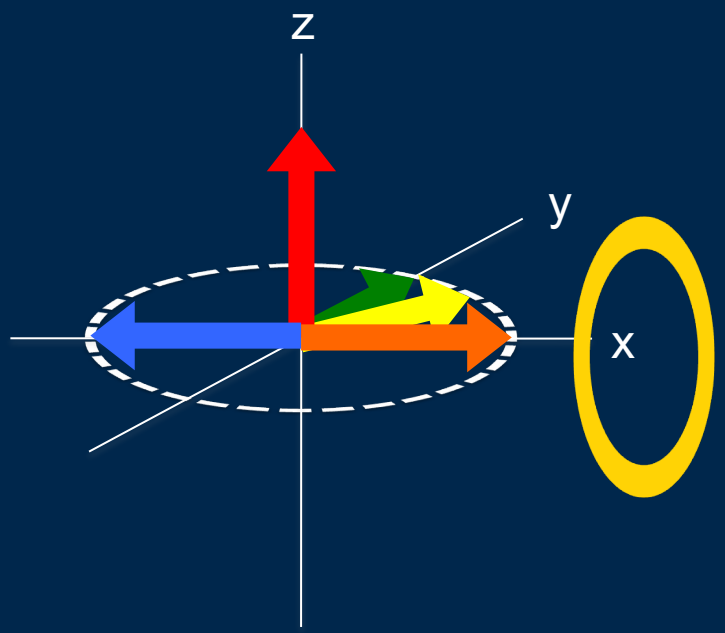
Once the magnetization M is tipped away from B_0 direction:

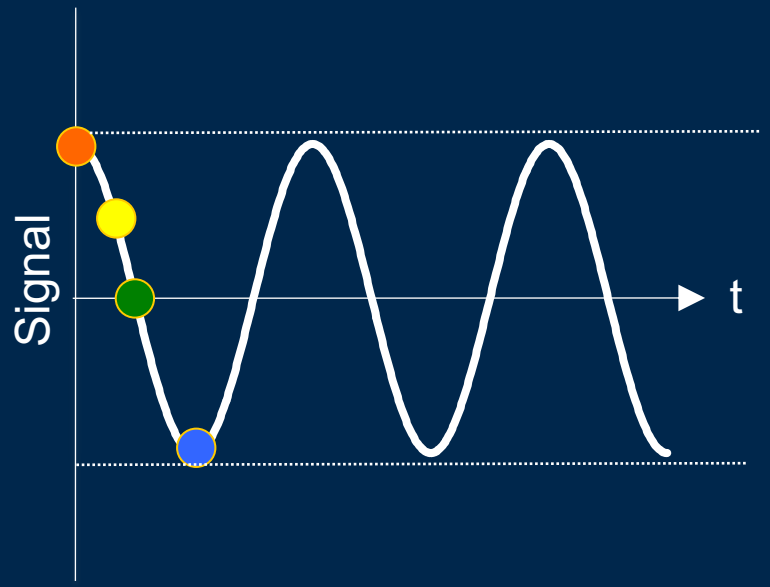
- Net Magnetization precesses
- Conductor nearby (receiver coil) sees changing magnetic field
- Current is induced in coil via *Faraday's Law of Induction*



MICHIGAN MEDICINE

What does the signal look like?

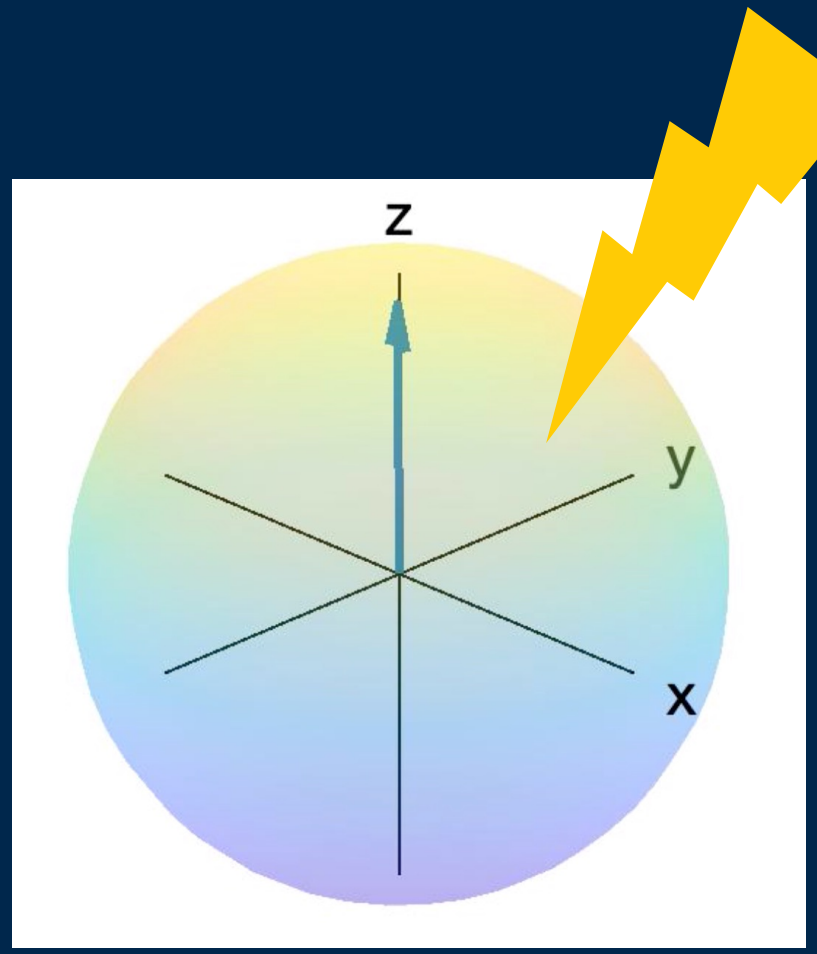




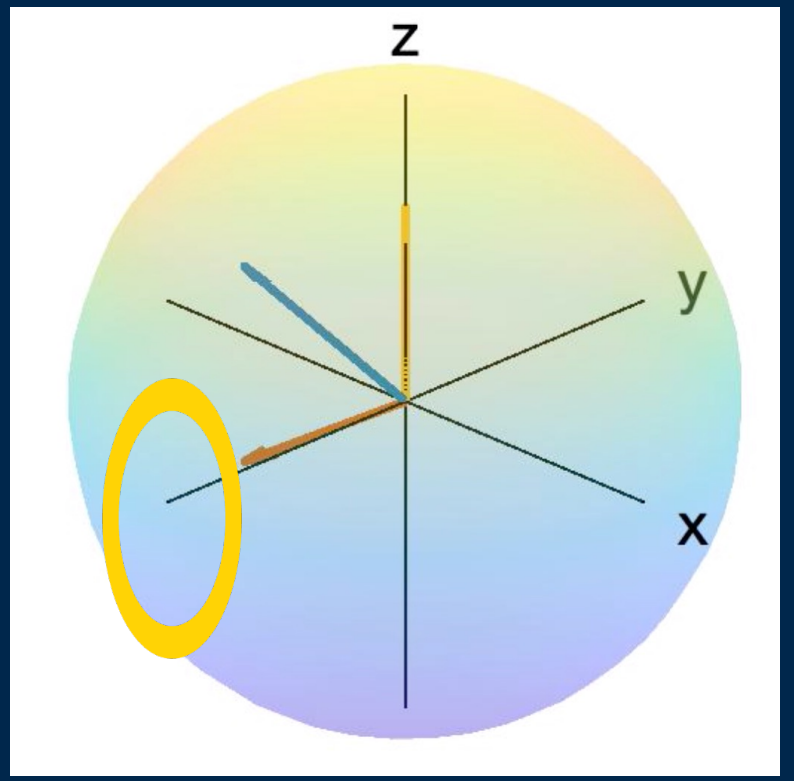
MICHIGAN MEDICINE

Altering flip angle changes measured signal

Apply RF Pulse to Tip Magnetization into x-y plane
Longitudinal Magnetization → Transverse Magnetization



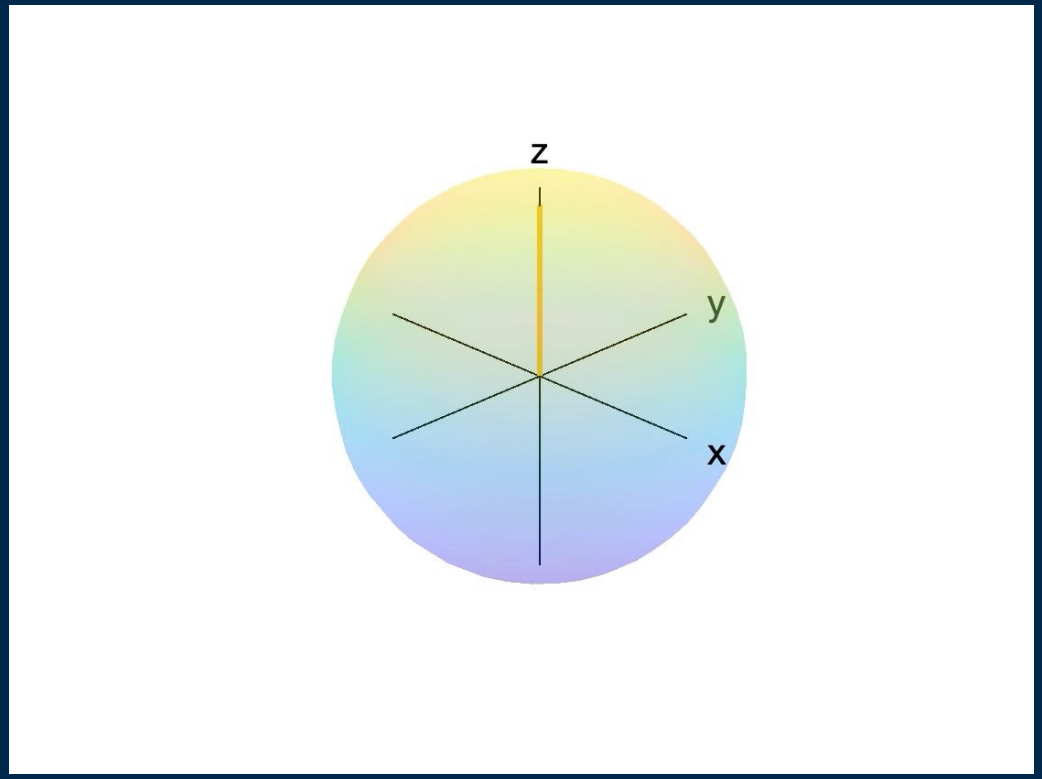
45°

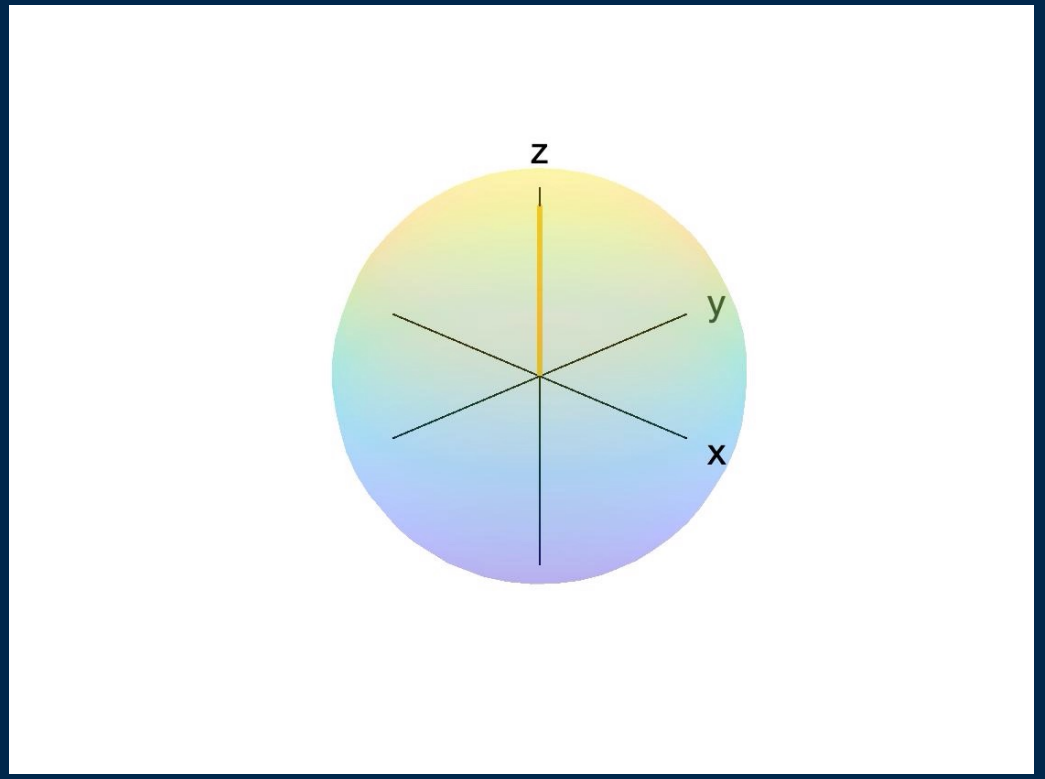


B_0

MICHIGAN MEDICINE

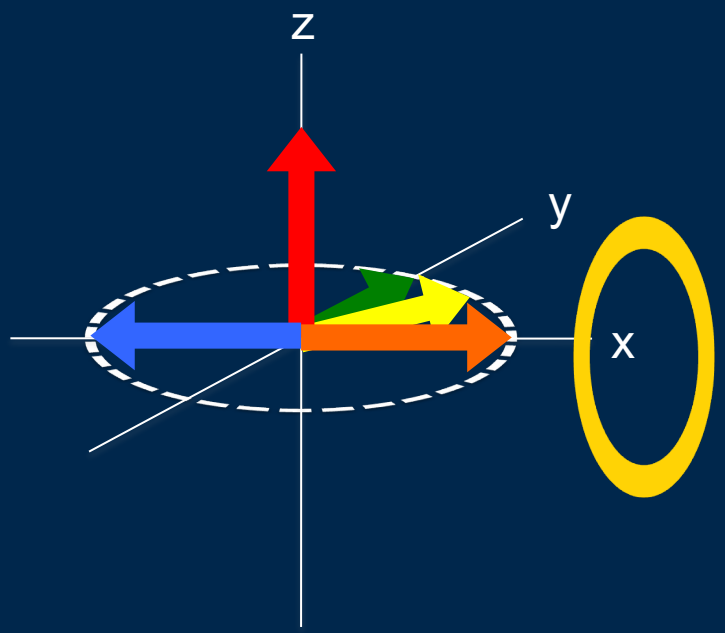
Precession

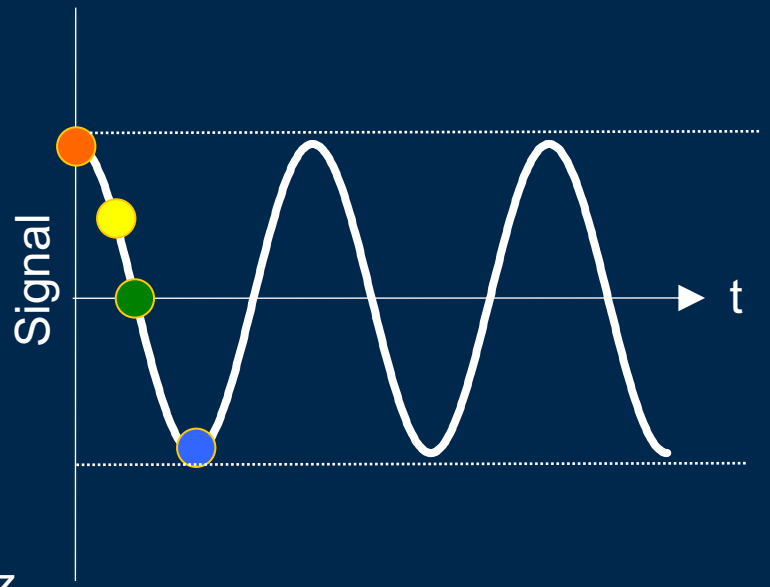


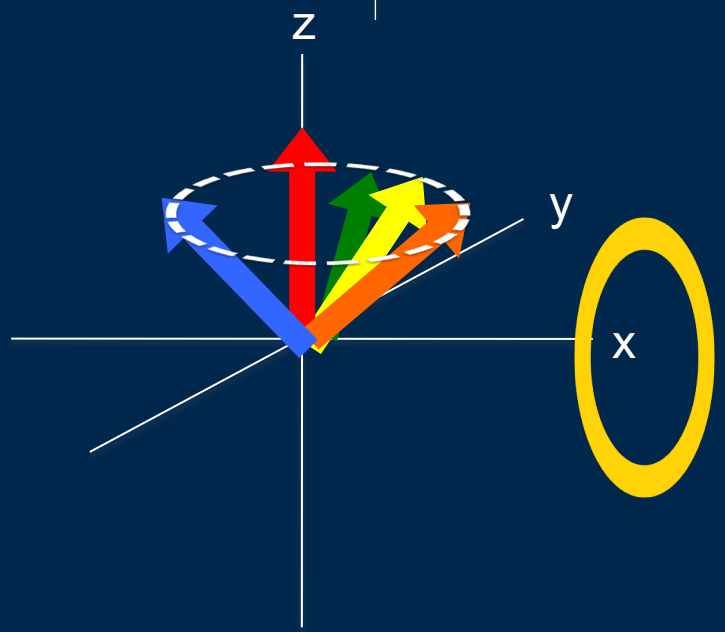


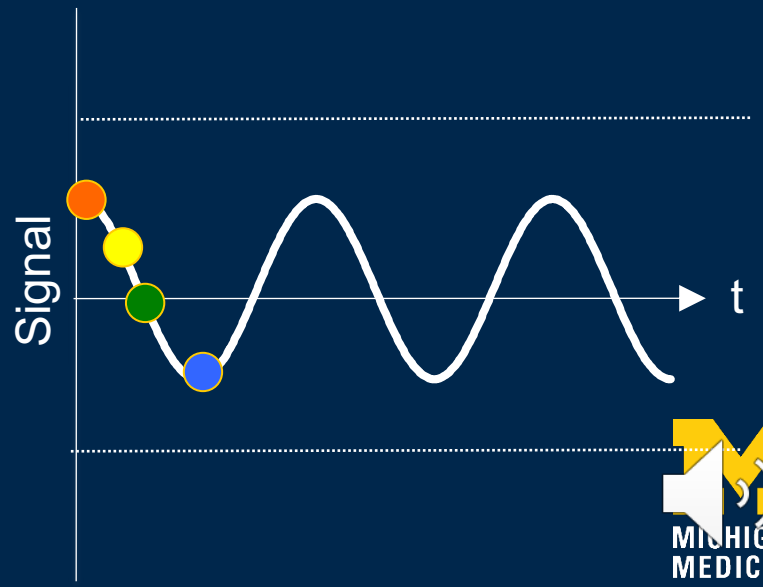
MICHIGAN MEDICINE

What does the signal look like?









MICHIGAN MEDICINE

Recap

- Main Magnetic field leads nuclei to align parallel/antiparallel to field
- Sum over all protons = magnetization vector
- Higher B_0 → More magnetization → Higher Signal
- Magnetization vector points along direction of B_0: Longitudinal Magnetization
- RF pulse can be used to tip magnetization into the x-y plane: Transverse Magnetization
- Only transverse magnetization can be detected by receiver coil
- 90° pulse leads to the largest signal amplitude
  → smaller flip angles can also be used
- Magnetization precesses at the Larmor frequency in transverse plane
- Signal = sinusoidal shape