MRI Physics:

T1 Relaxation

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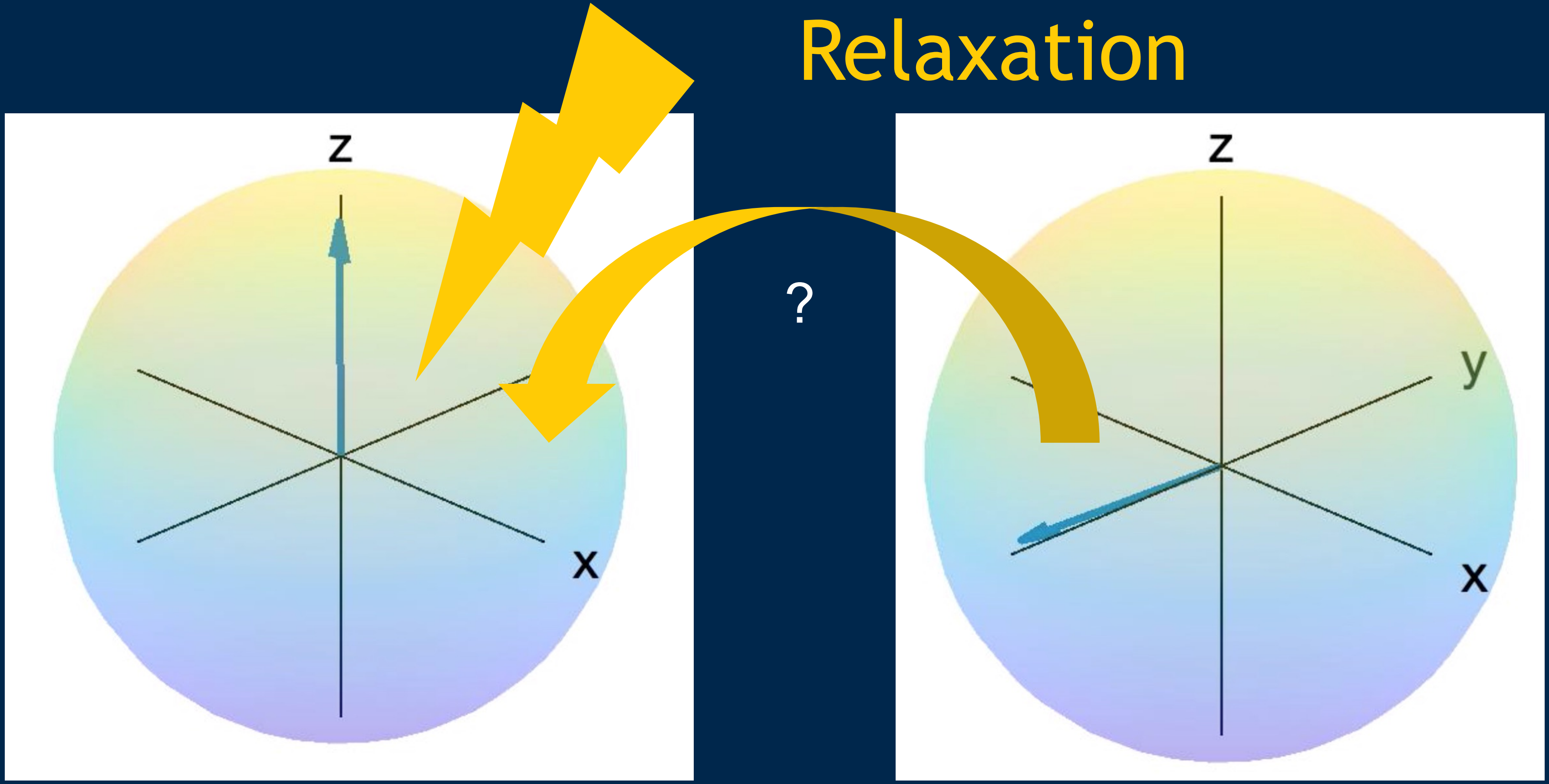
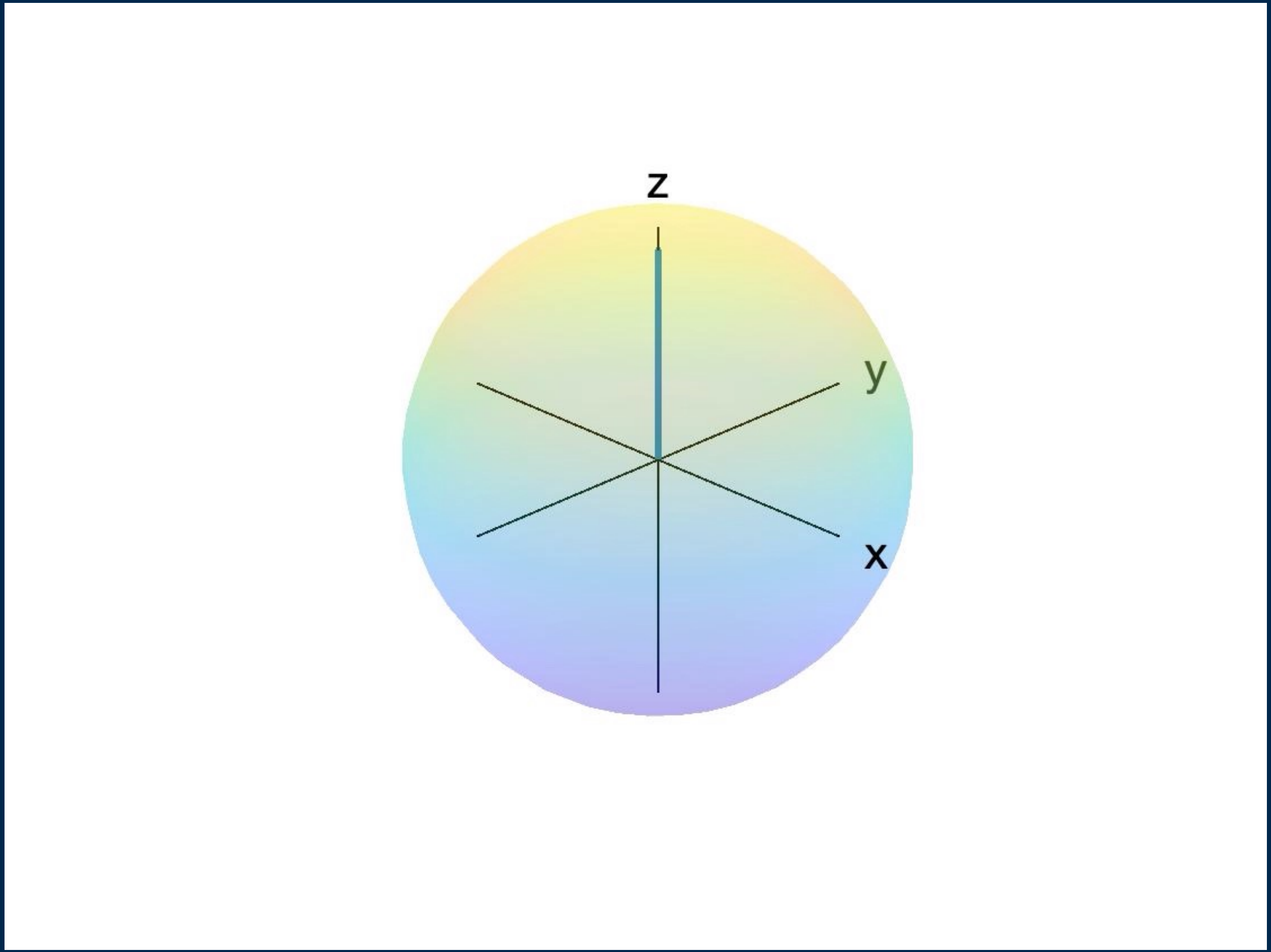
We tip magnetization into x-y plane for signal acquisition

Apply RF pulse to tip magnetization from the z-axis into x-y plane

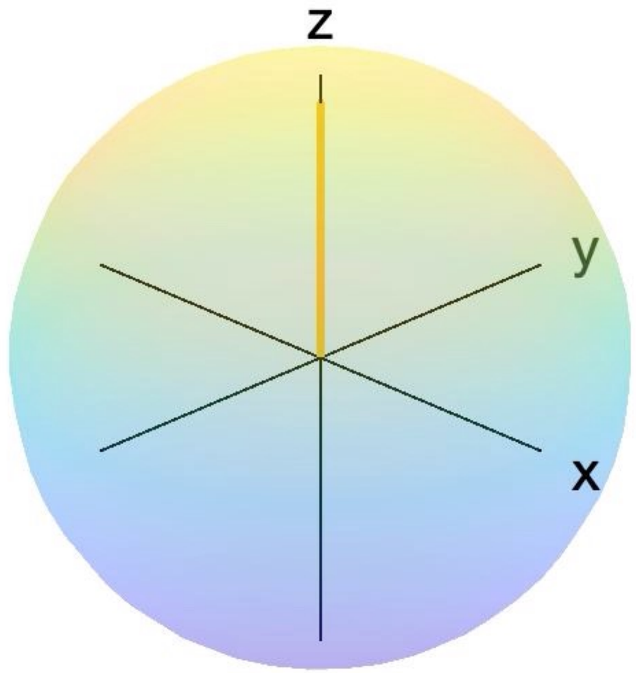
Longitudinal Magnetization → Transverse Magnetization



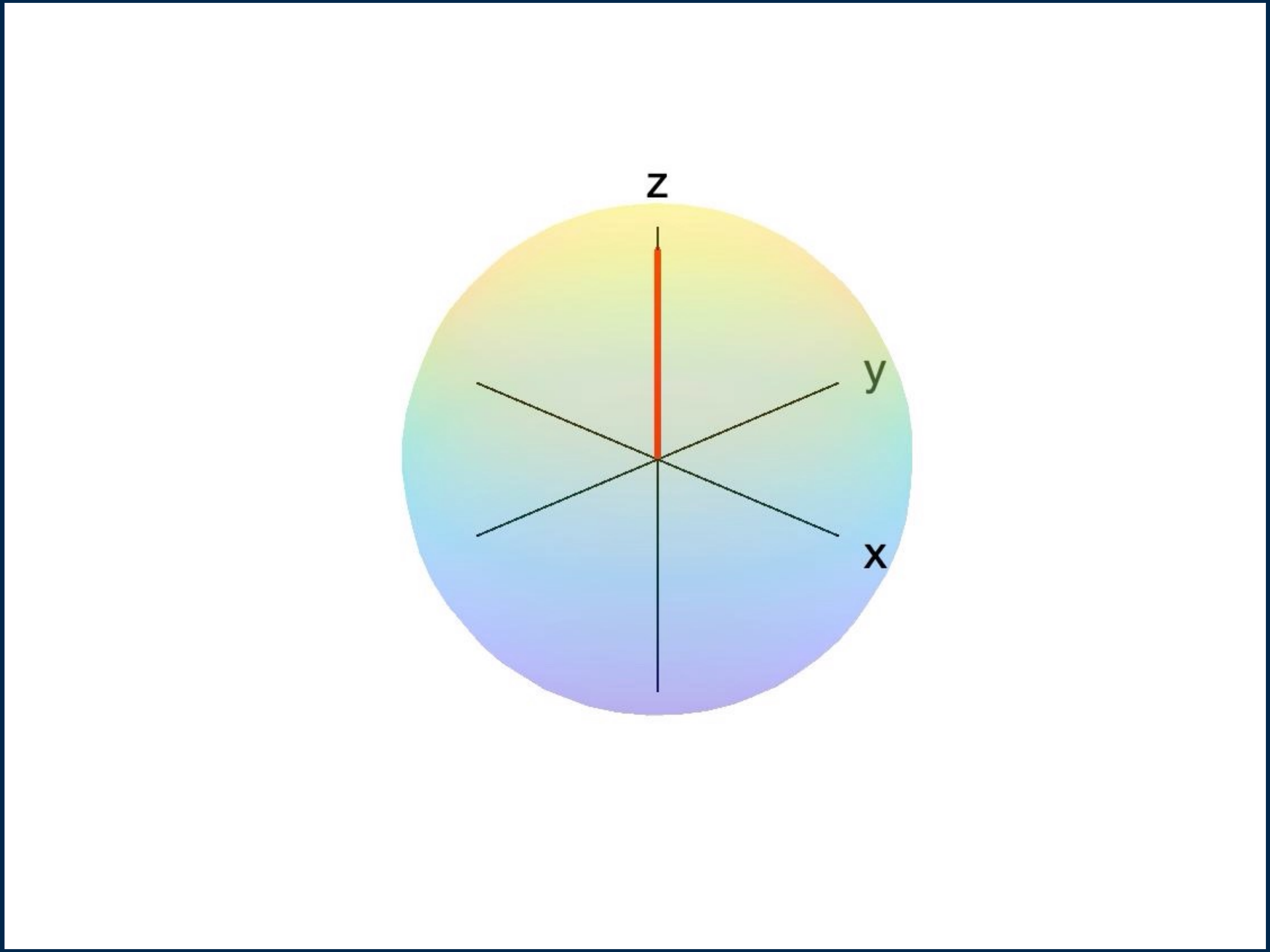
Spin Lattice Relaxation: T_1



Spin Lattice Relaxation: T_1

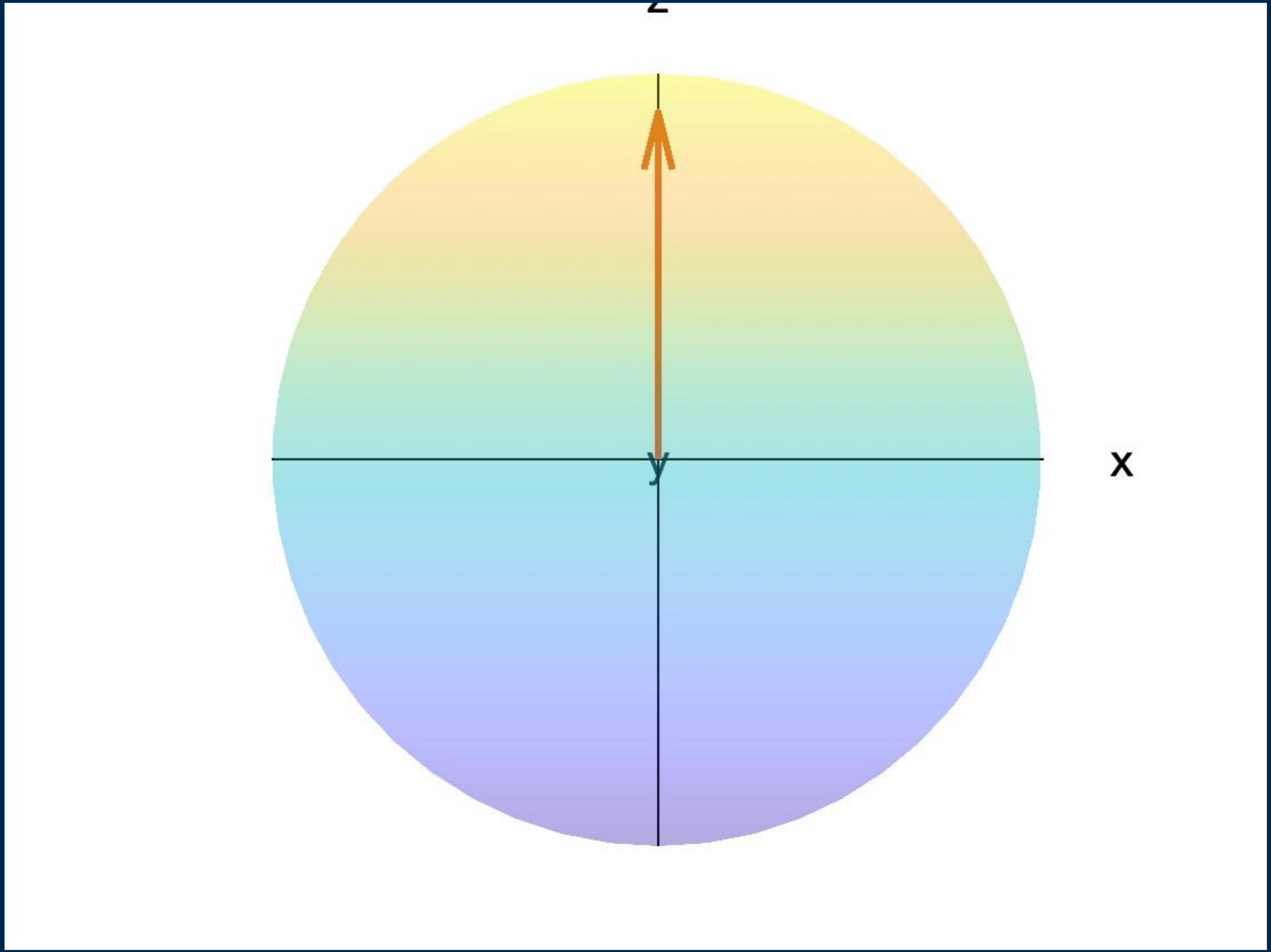


Different Tissues Have Different T_1 Values



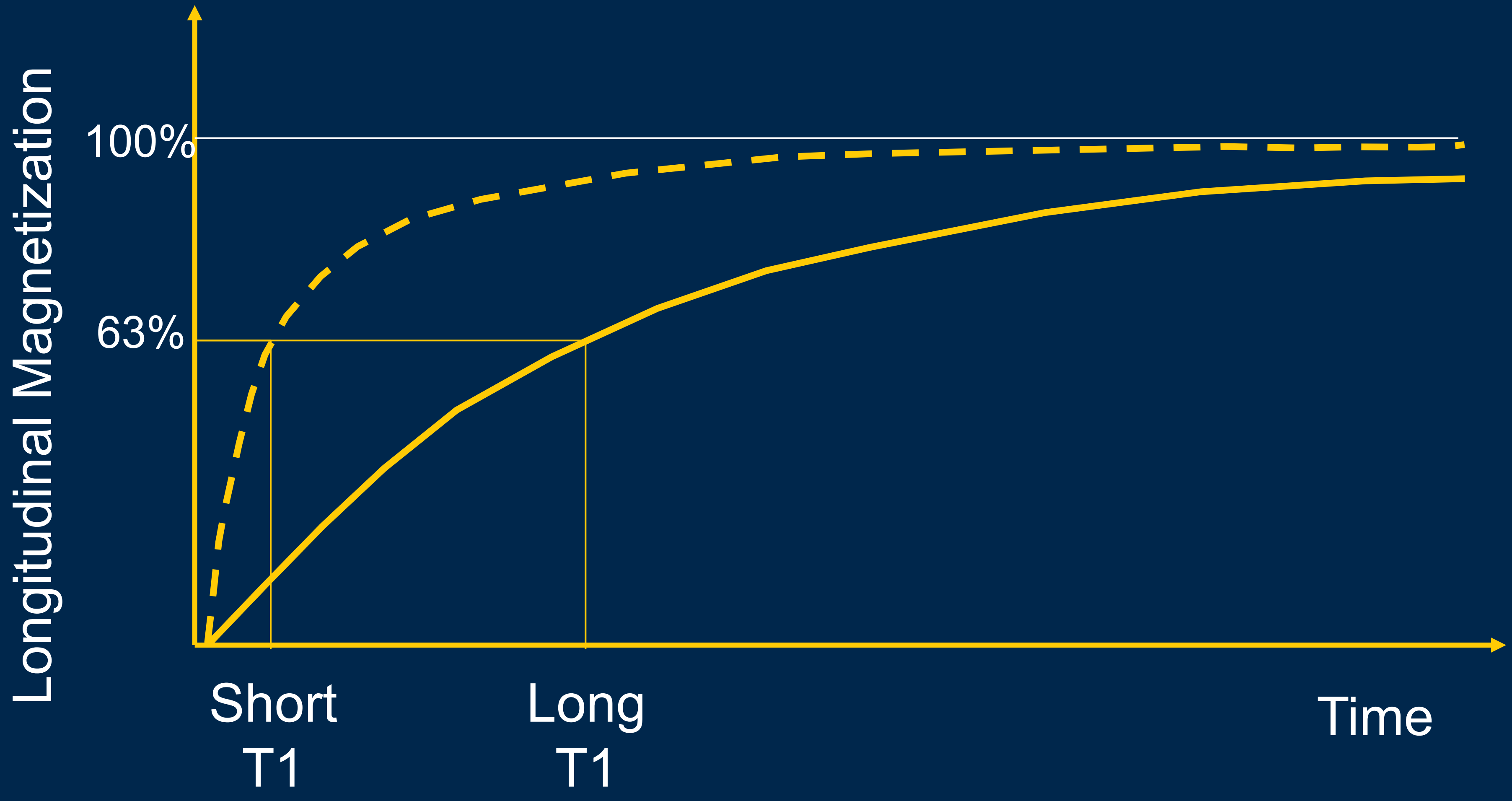
- Red→Short T1
- Blue→Long T1

Different Tissues Have Different T_1 Values



- Red→Short T1
- Blue→Long T1

Plot of Magnetization on z-axis after 90º Pulse



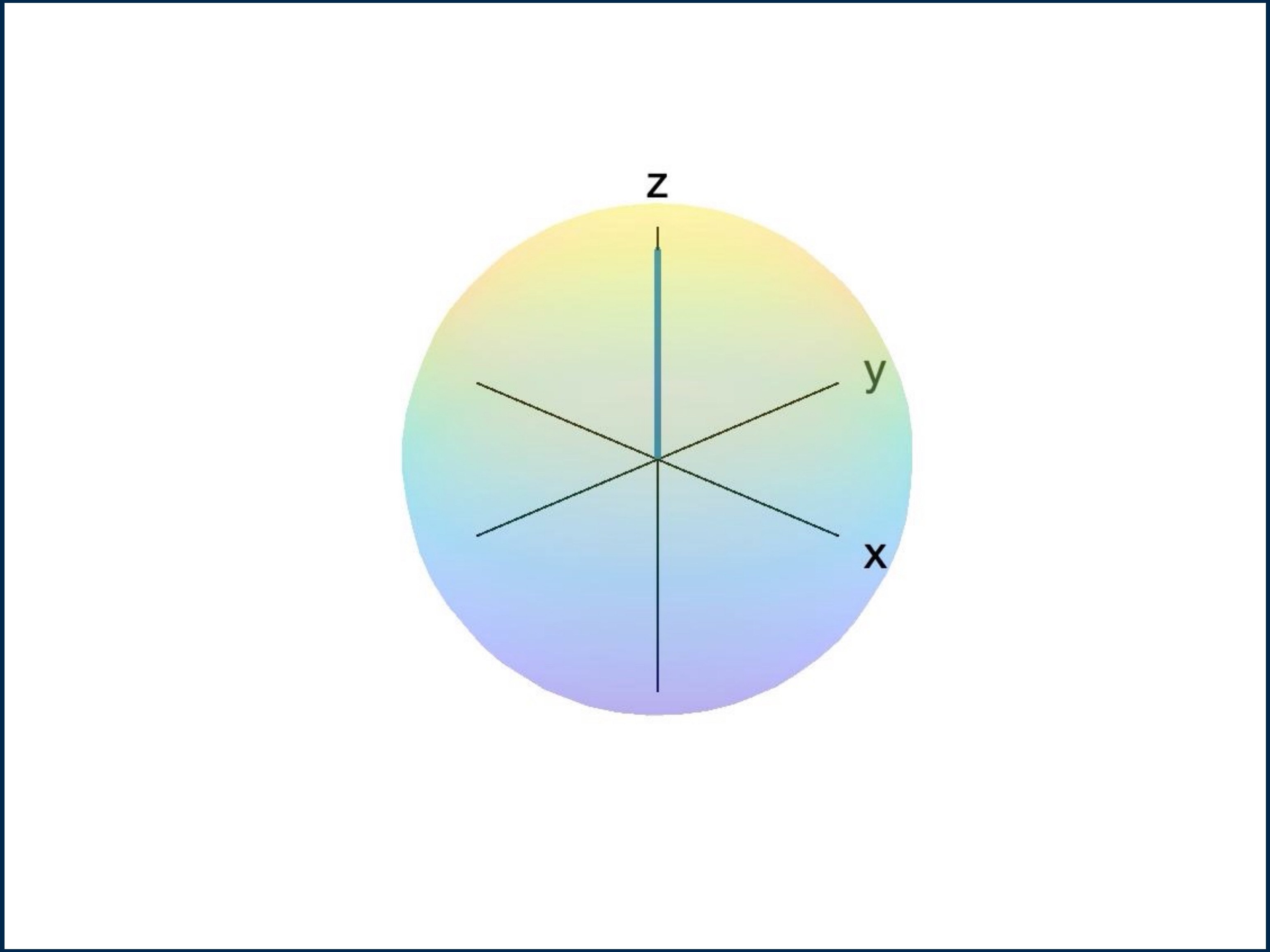
Info about T1 times

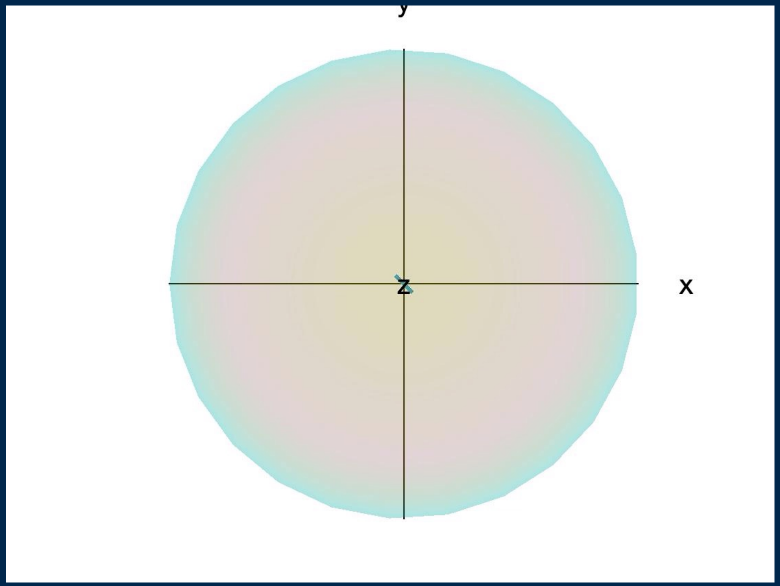
- Not easily explained in terms of tissue content (molecular tumbling rates)
- Water content
- Measured in seconds or ms
- Different at different main field strengths
- Pure water → Long T1
- Fat → Shorter T1

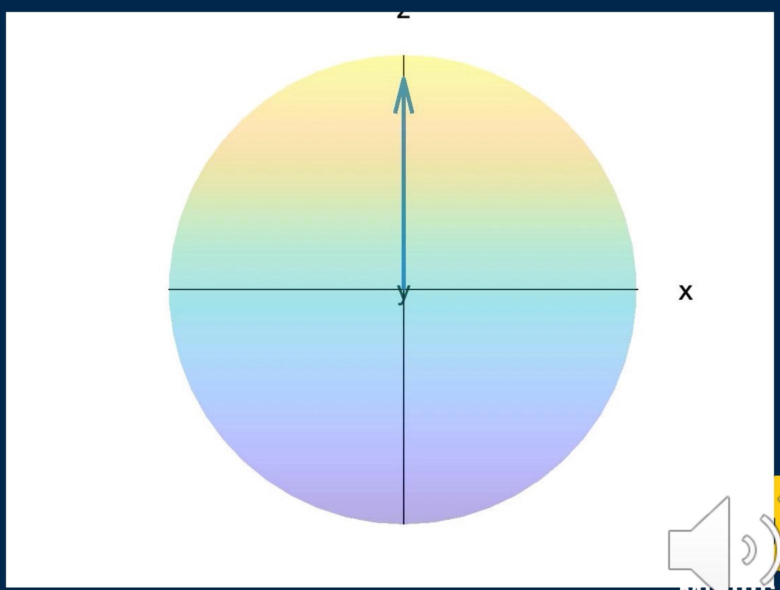
Tissue	T1 (msec)
Water/CSF	4000
Gray matter	900
Muscle	900
Liver	500
Fat	250
Tendon	400
Proteins	250
Ice	5000

https://mri-q.com/why-is-t1--t2.html

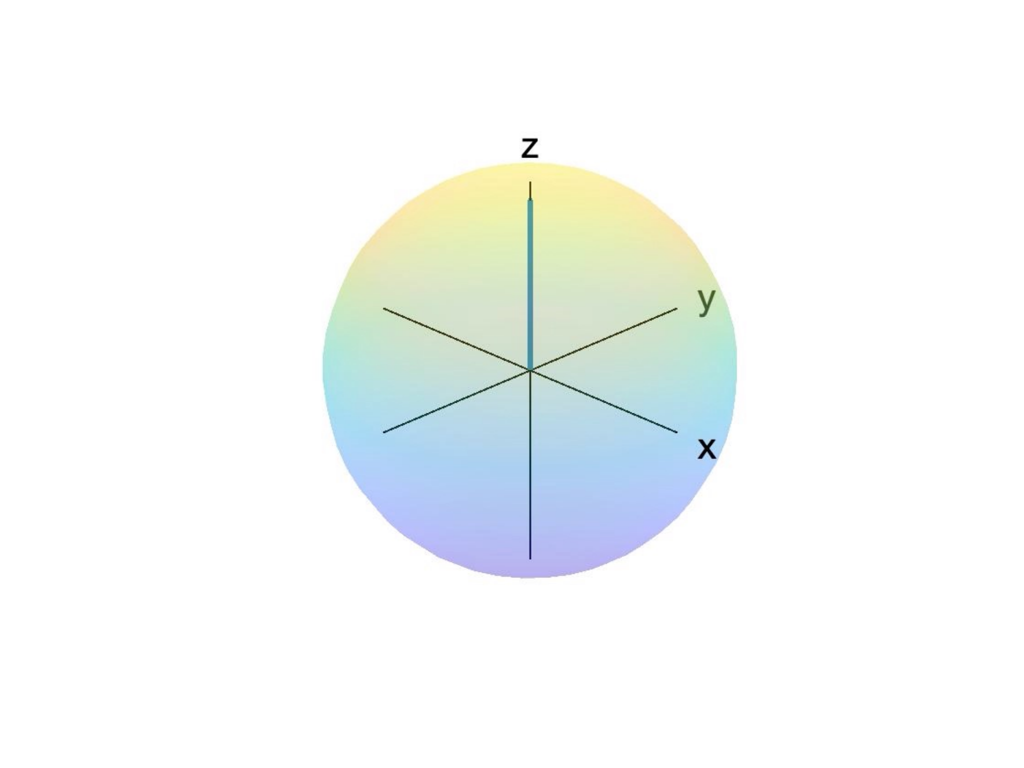
Precession with T1 relaxation



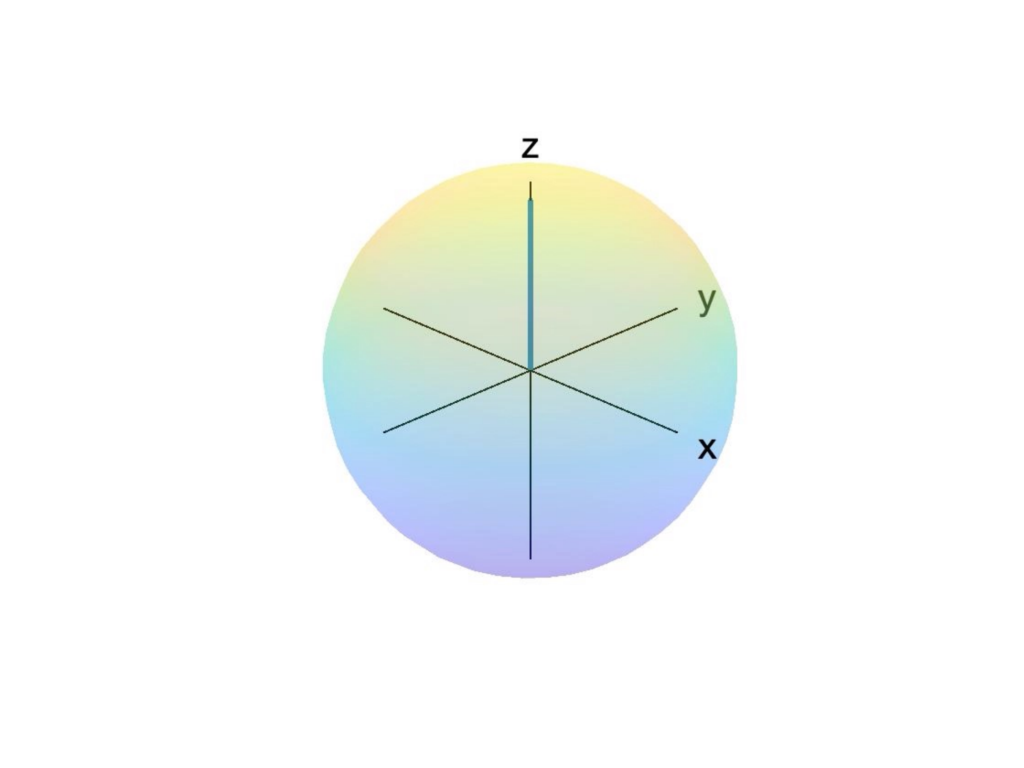




Rotating Reference Frame



Lab Reference Frame



Rotating Reference Frame

T1 Relaxation Summary

- T1 Relaxation (Spin-Lattice Relaxation)
  - →Exponential recovery of Transverse to Longitudinal Magnetization
- Different tissues have different T1 relaxation rates
- ~ 250 ms – 5 seconds
- Main contrast mechanism in clinical imaging
- Pure water has a long T1

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MRI Physics:

T2 Relaxation

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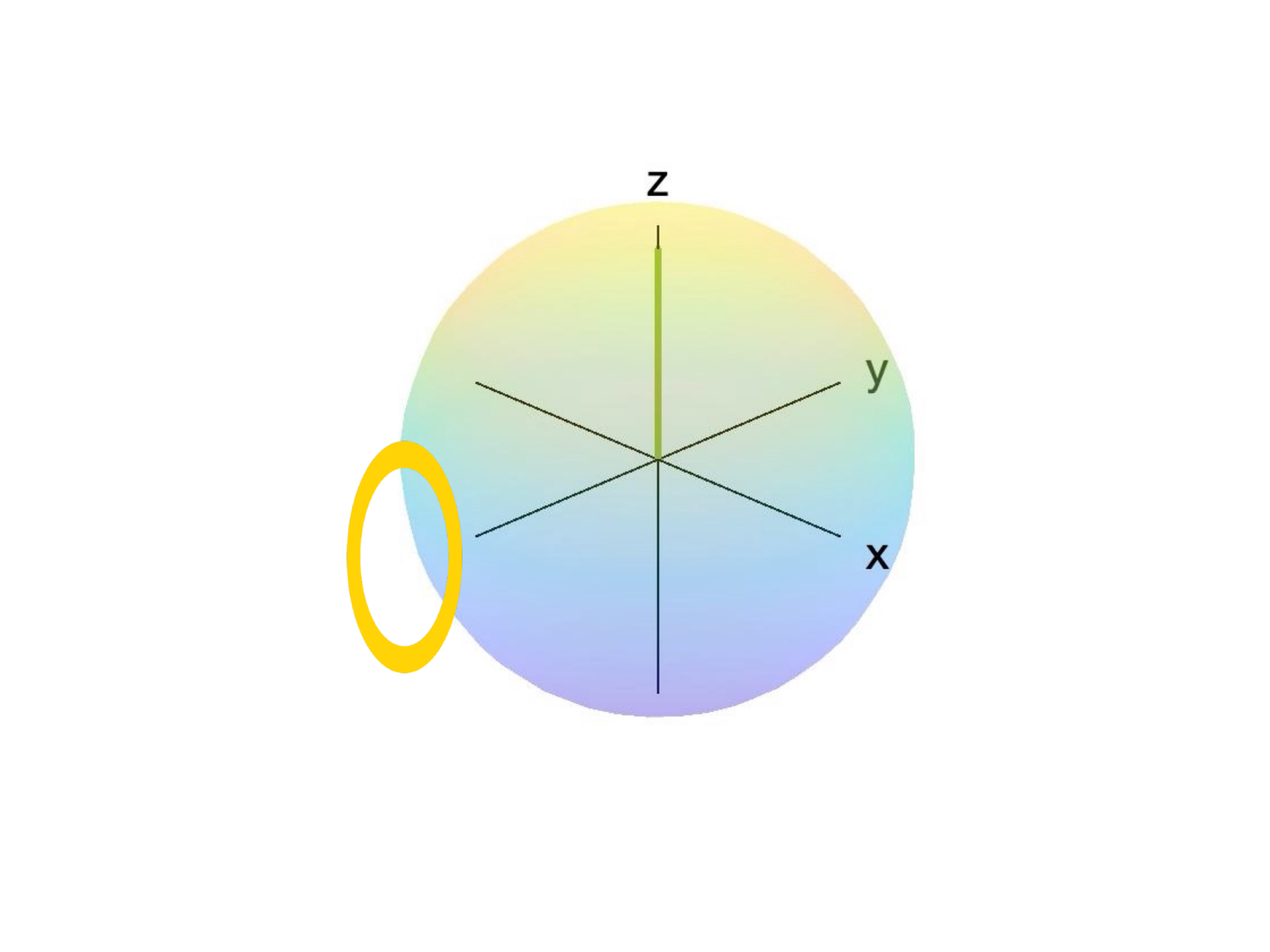
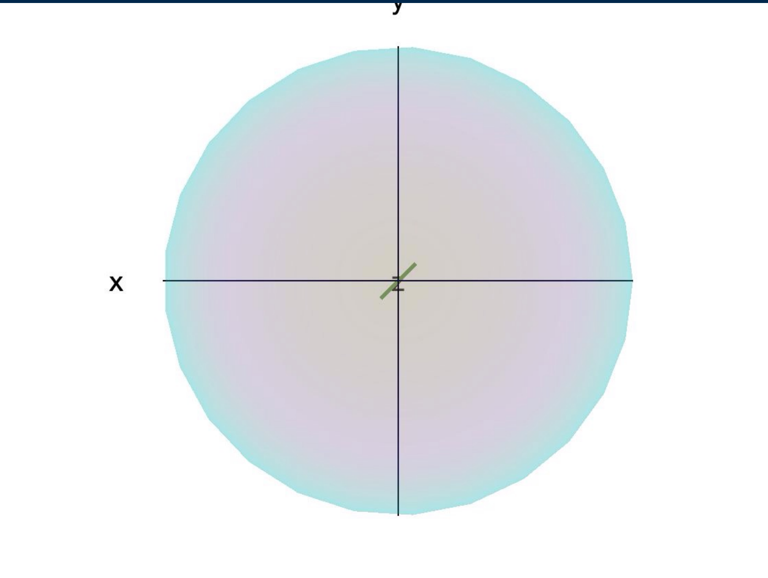
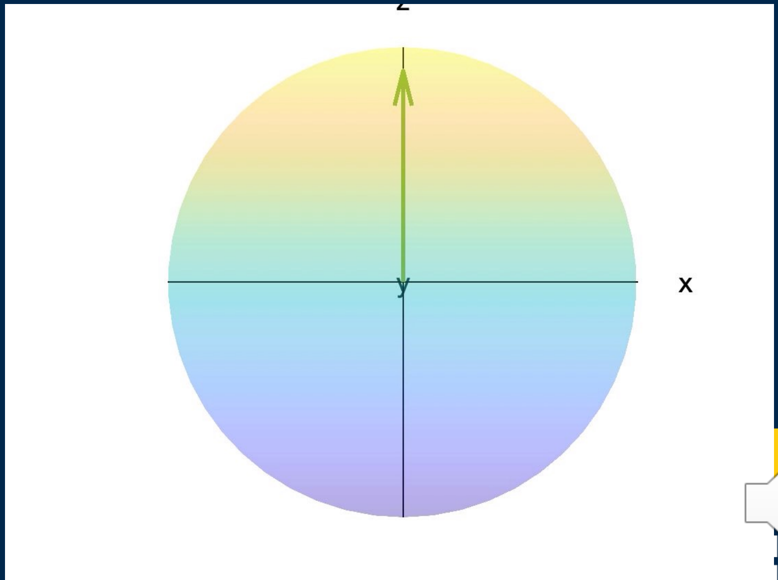
Spin-Spin Relaxation: T_2 (rotating reference frame)







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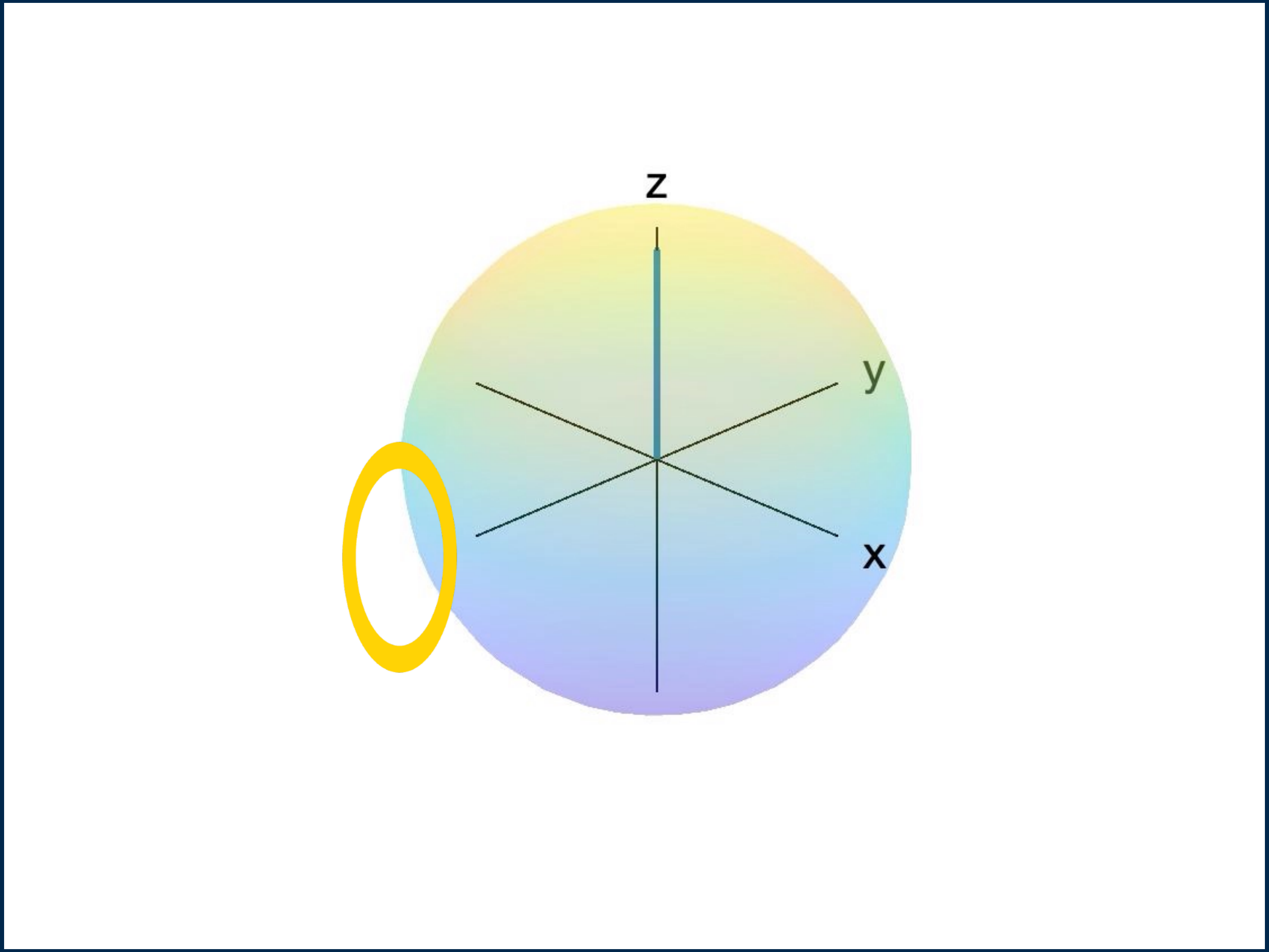
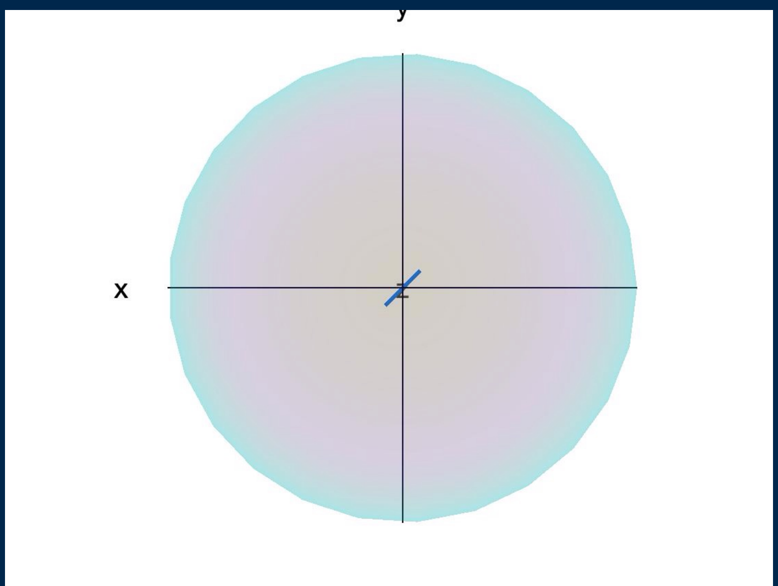
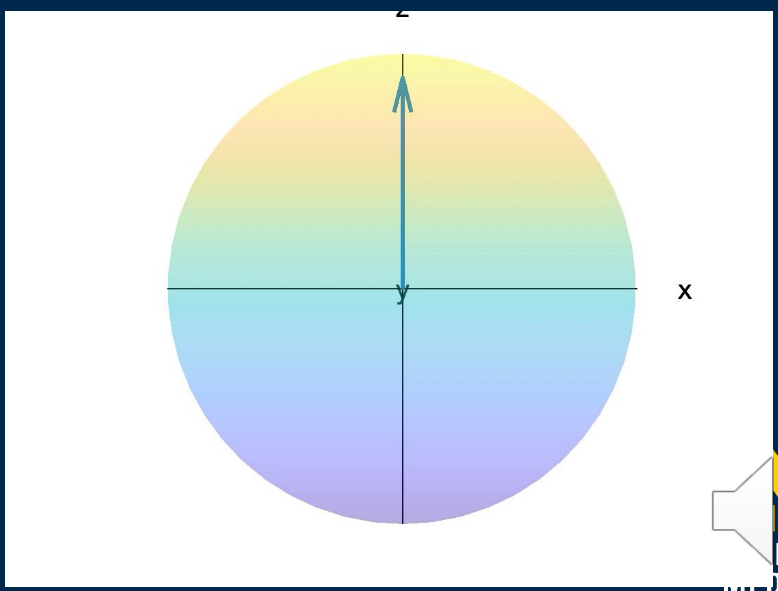
We see vector sum of magnetization as signal







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Spin-Spin Relaxation: T_2

- Magnetization precesses according to Larmor frequency

- Precession freq of individual spins can be slightly altered due to small local magnetic field fluctuations
  → Spins fan out
  → "Dephasing"

- When measured together, this dephasing leads to signal loss

- Occurs at the same time (and faster than) T1 relaxation

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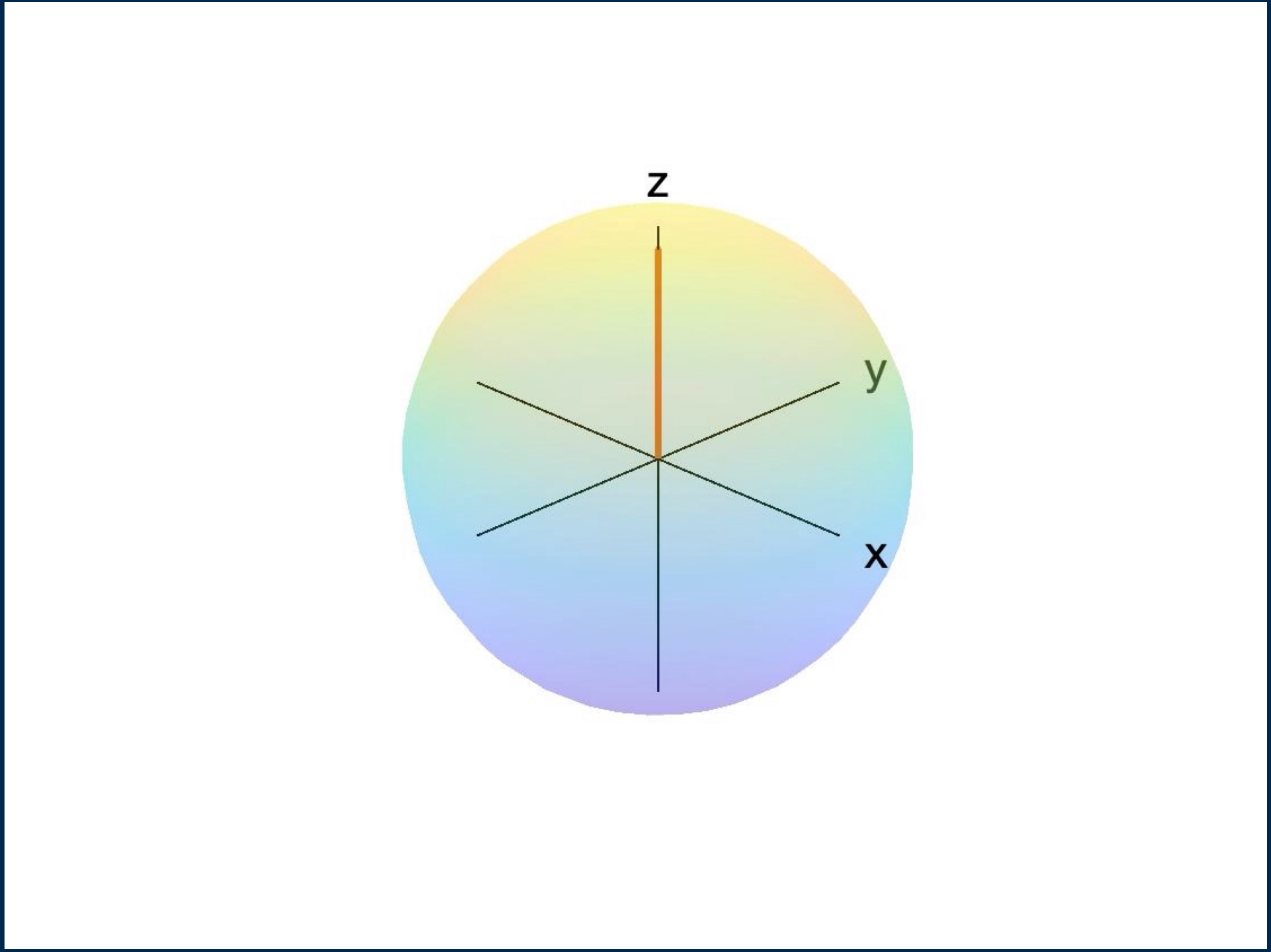
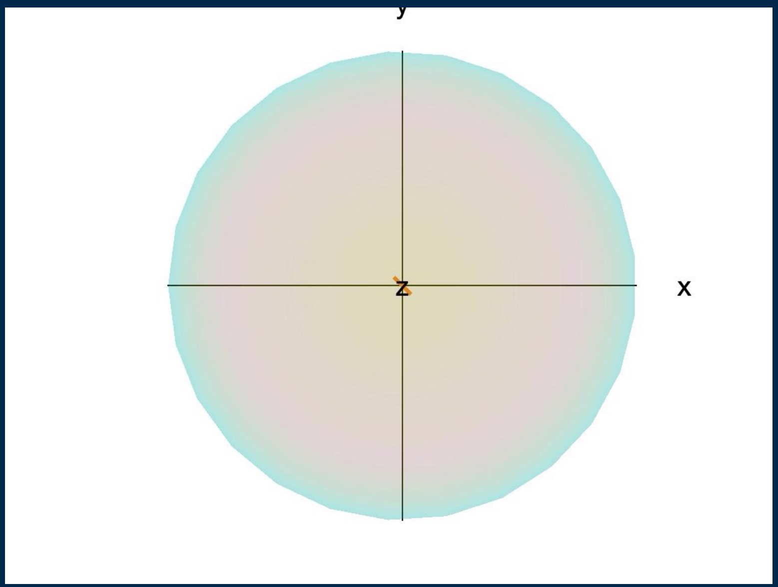
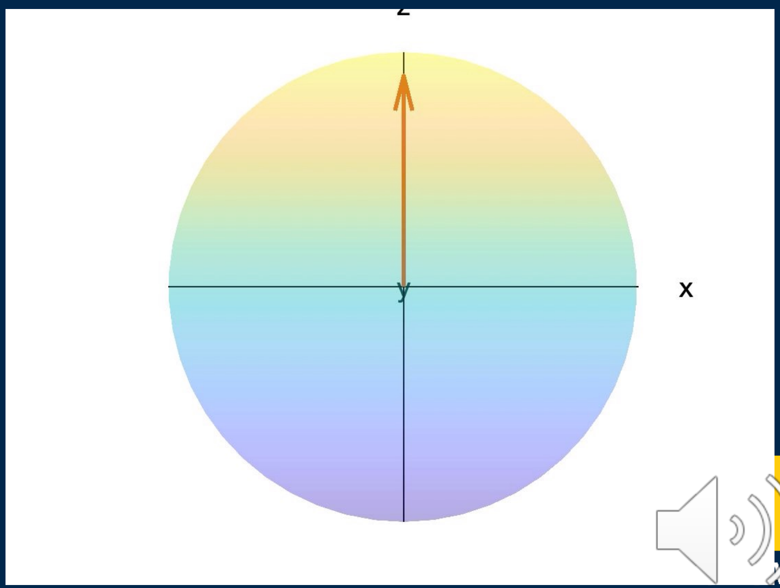
Different tissues have different T_2 values







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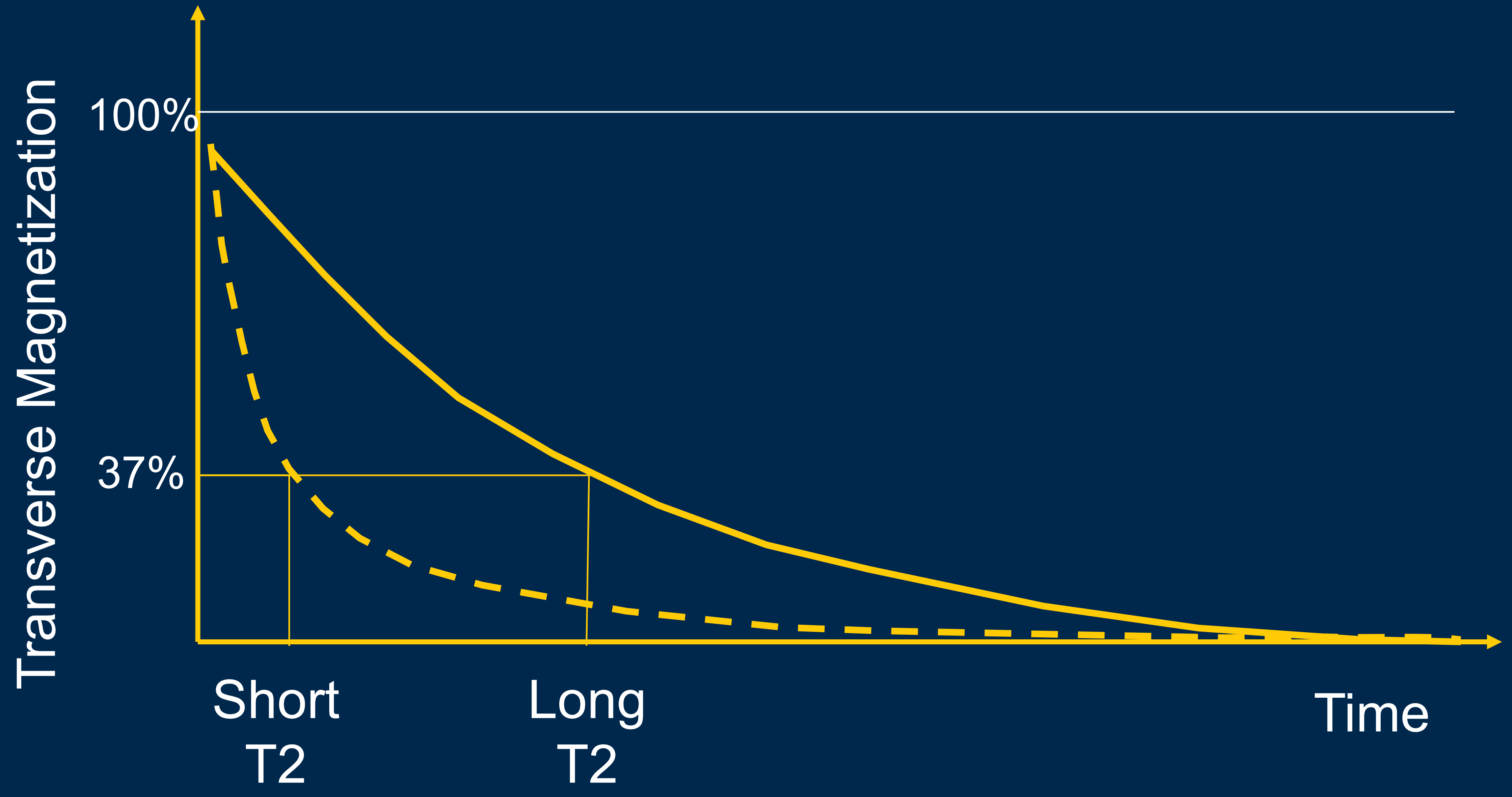
Plot of Magnetization on xy-axis after 90º Pulse



Facts about T_2 Relaxation

- Not easily explained in terms of tissue content
  - Much shorter in "solids"
- Measured in seconds or ms
- Different at different main field strengths
- Always shorter than T1
- Pure water → Long T2

Tissue	T1 (msec)	T2 (msec)
Water/CSF	4000	2000
Gray matter	900	90
Muscle	900	50
Liver	500	40
Fat	250	70
Tendon	400	5
Proteins	250	0.1 [illegible] 0
Ice	5000	0.001

More Facts about T_2 Relaxation

- T2 relaxation is a result of disorder in the system, not loss of magnetization
  → Cannot be recovered

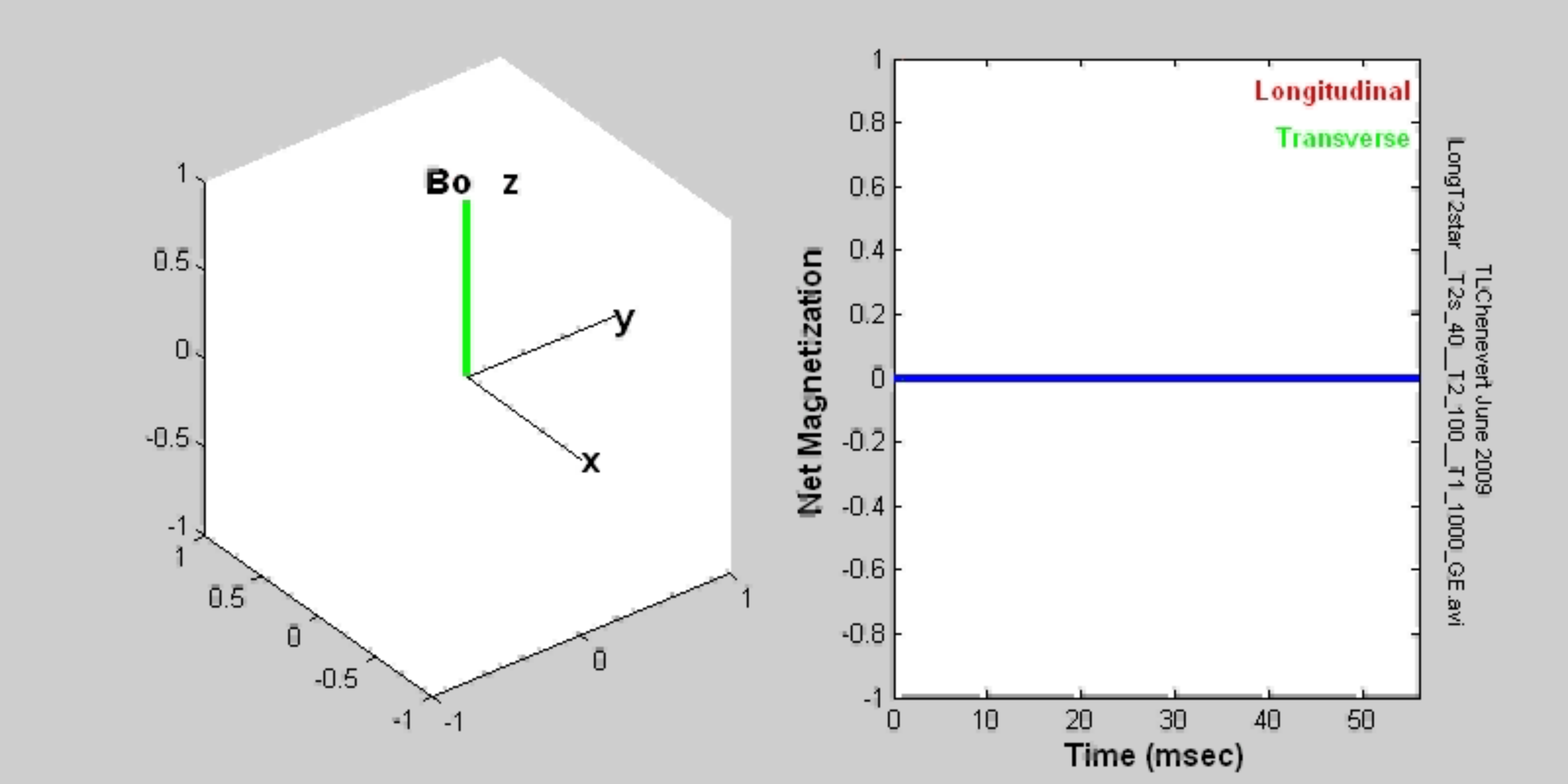
- T2' is a result of inhomogeneities in the magnetic field
  metal clips/objects nearby, level of iron-content in tissue, differences in "magnetic susceptibility" (eg. bone vs air vs tissue)
  → Can in some cases be recovered

- T2 vs. T2* contrast
  1/T2* = 1/T2 + 1/T2'
  T2* always shorter than T2

Tissue	T1 (msec)	T2 (msec)
Water/CSF	4000	2000
Gray matter	900	90
Muscle	900	50
Liver	500	40
Fat	250	70
Tendon	400	5
Proteins	250	0.1 [illegible].0
Ice	5000	0.001

T2* Relaxation: decay of transverse magnetization following an RF-pulse (aka free induction decay 'FID')

An example of "Long" T2*~20-40ms



"Isochromats"

(sub-voxel group of spins in equivalent local field)

Net Longitudinal Magnetization

Net Transverse Magnetization (signal)

LongT2star__T2s_40__T2_100__T1_1000_GE.avi

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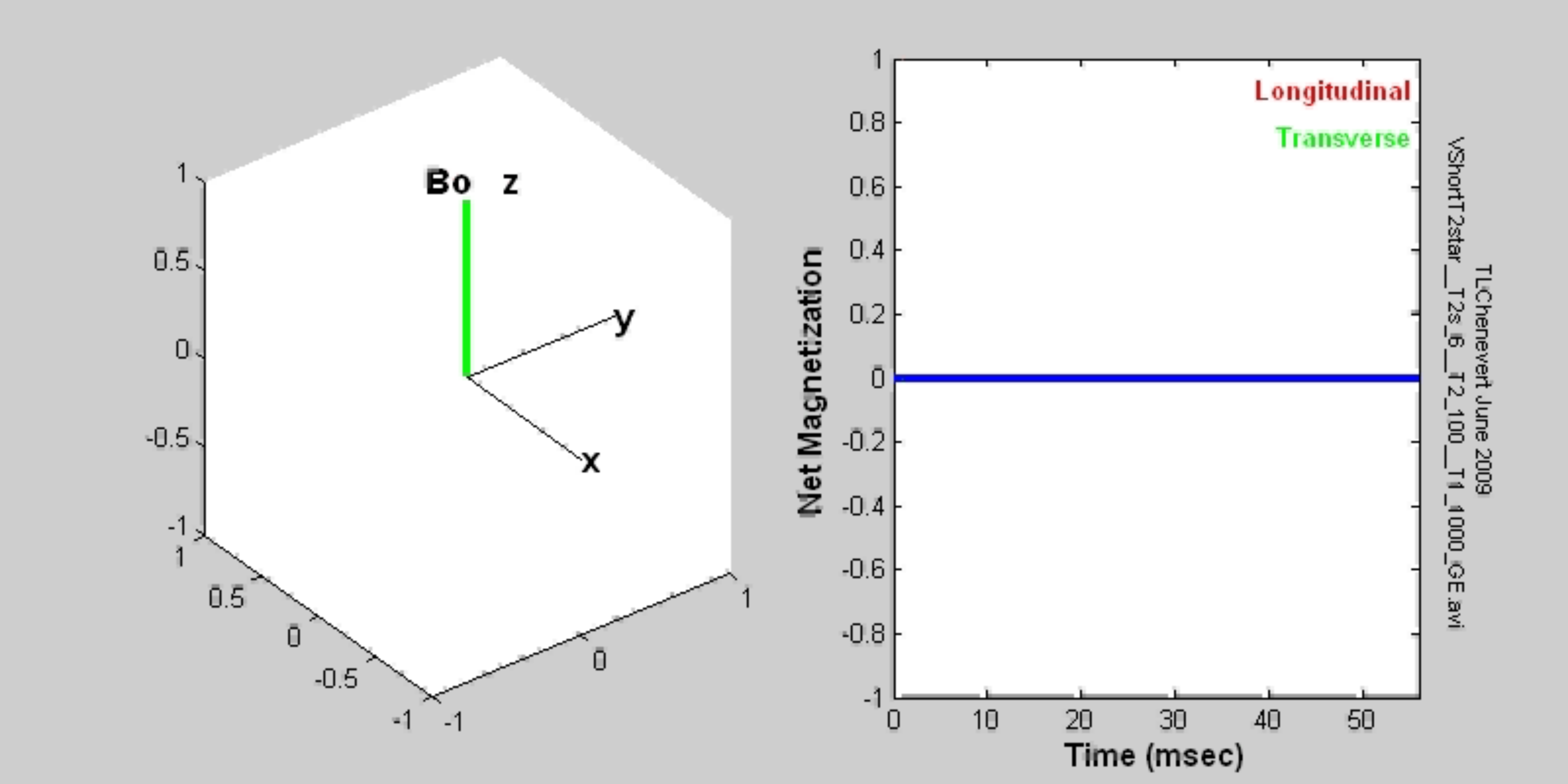
T2* Relaxation

An example of "Short" T2*~1-10ms



Isochromats

Net Longitudinal Magnetization

Net Transverse Magnetization (signal)

VShortT2star__T2s_6__T2_100__T1_1000_GE.avi

Recap: Magnetization

- Aligns along z-axis in direction of B_0 field

- Can be tipped into x-y plane using an RF pulse

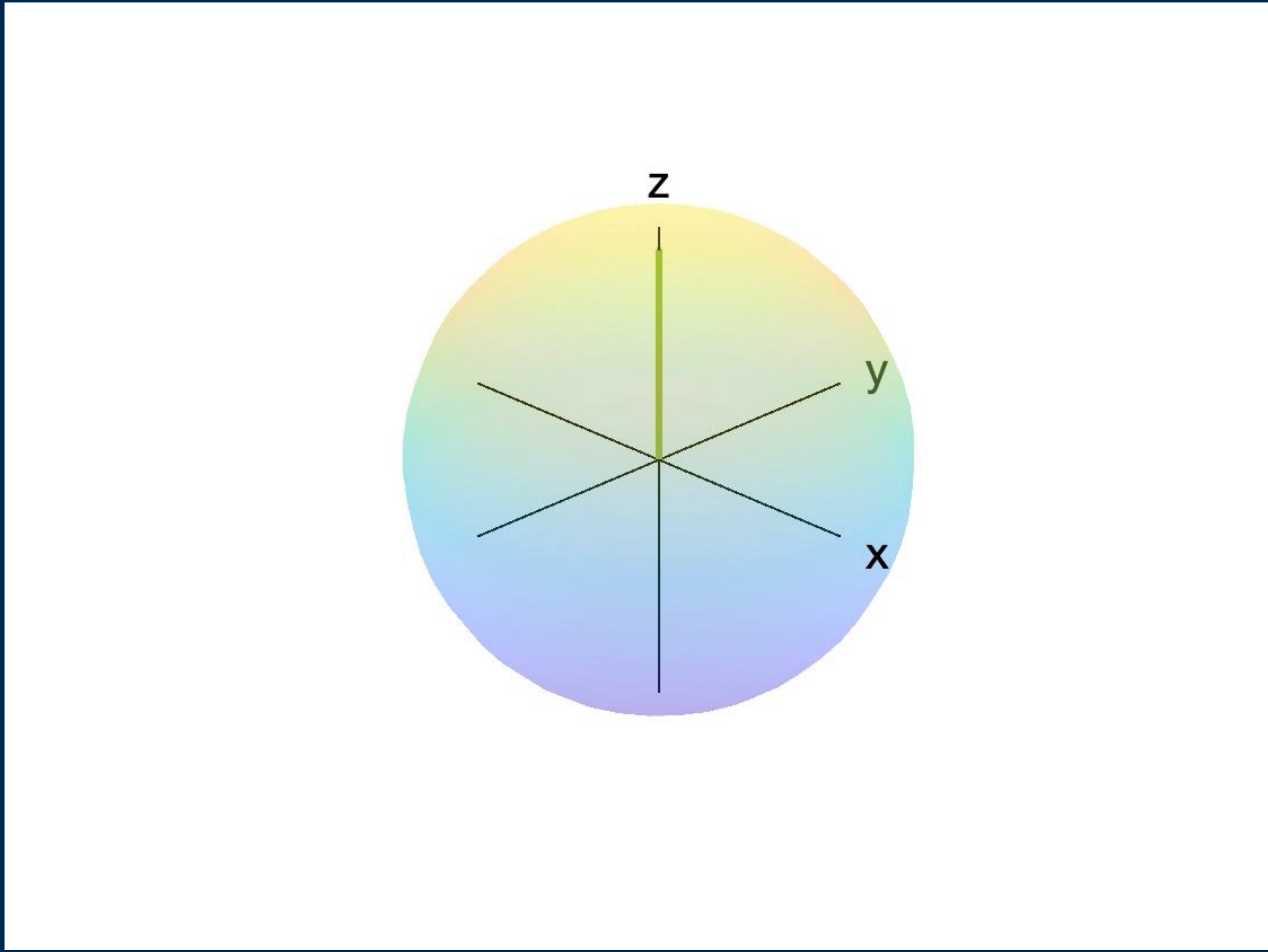
- Only transverse magnetization gives rise to signal

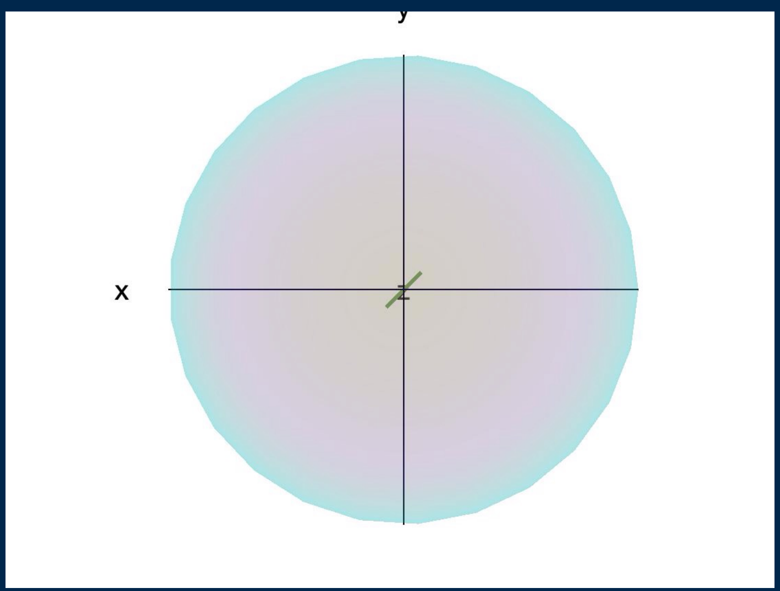
- Once in x-y plane, will precess at Larmor frequency (different for fat/$H_2$0)

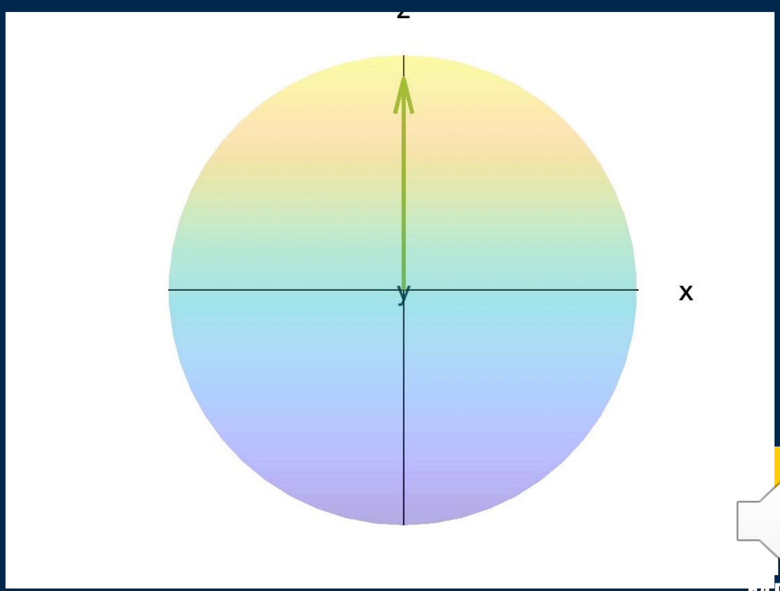
- Slowly recovers back to the z-axis according to T1 value
  → Loss of transverse magnetization, gain in longitudinal magnetization

- Dephases in x-y plane according to T2/T2* value
  → Loss of transverse magnetization

All Effects Together (Precession, T1 and T2 Relaxation)







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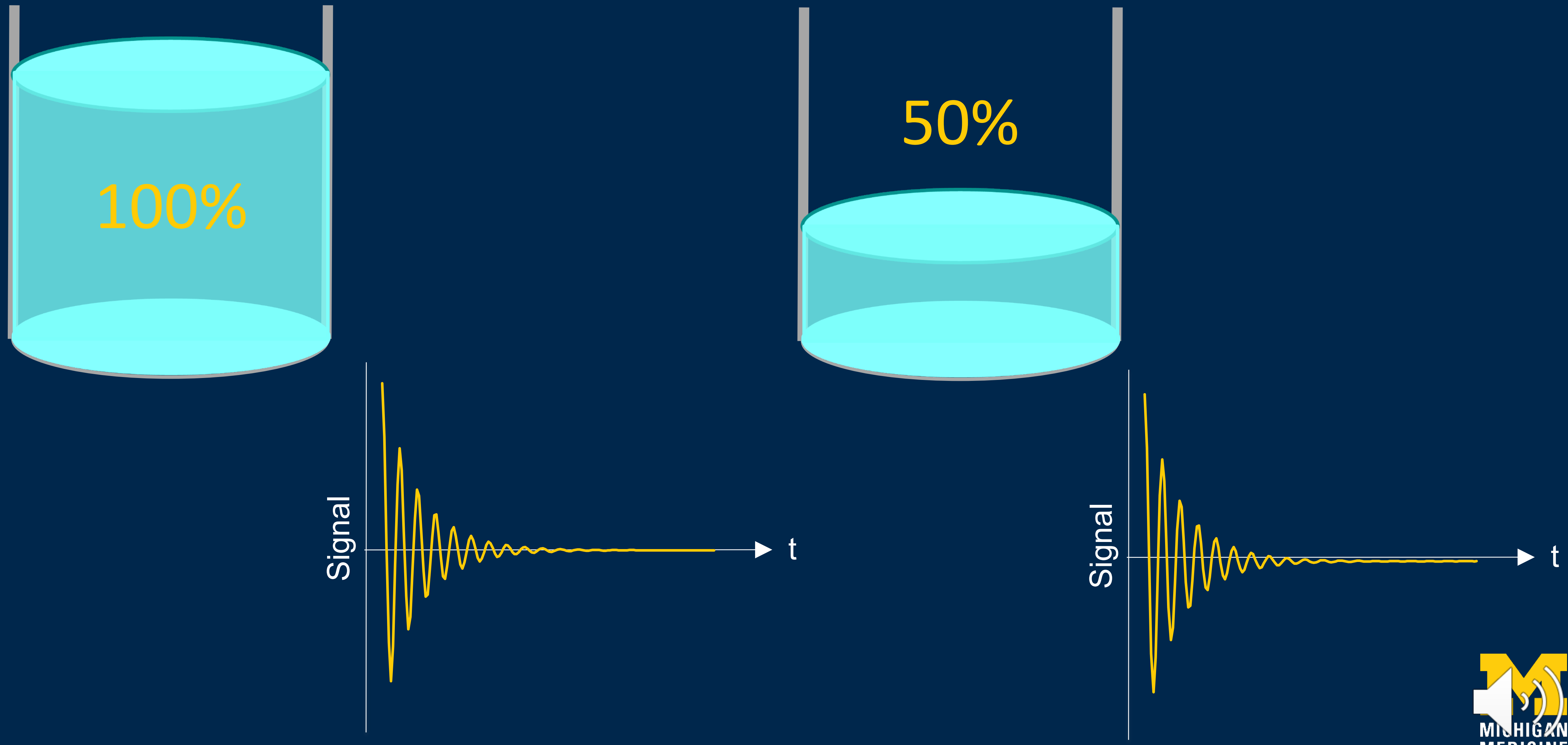
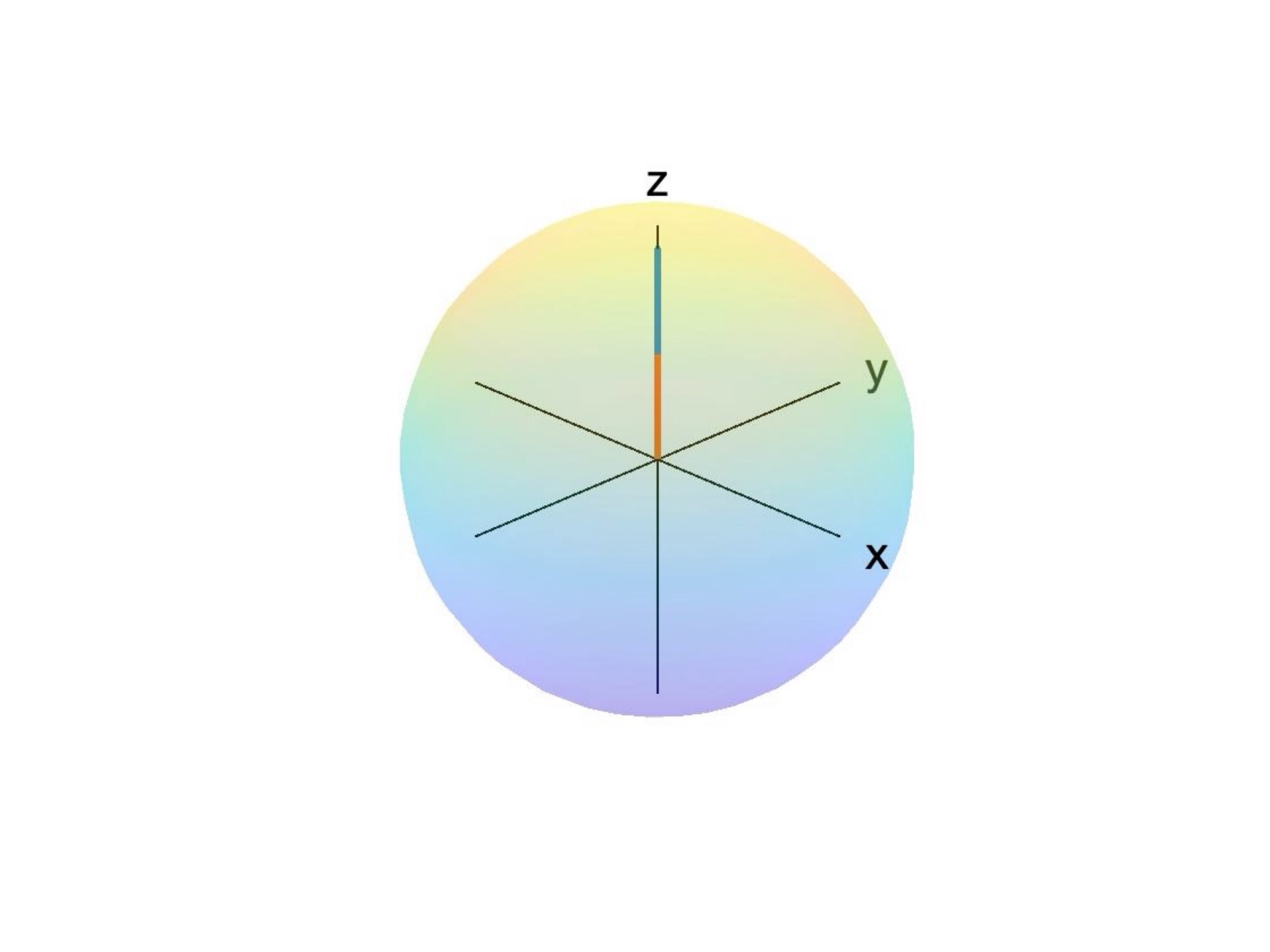
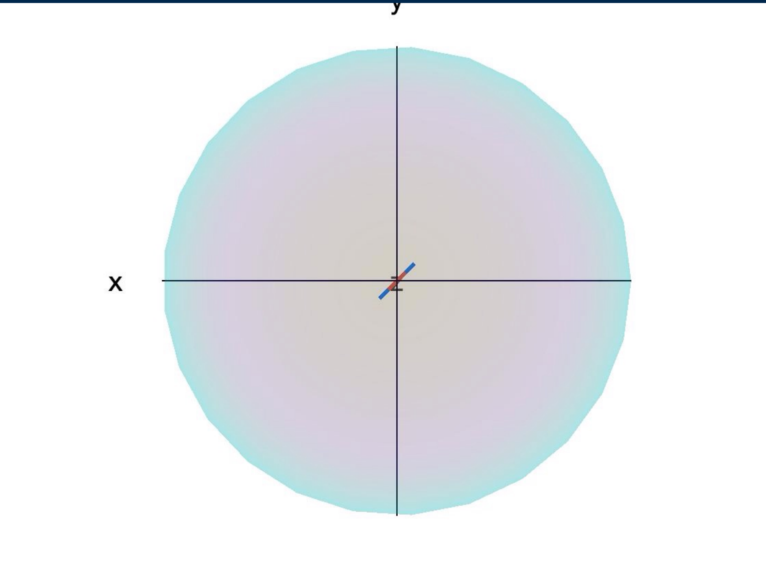
Proton Density

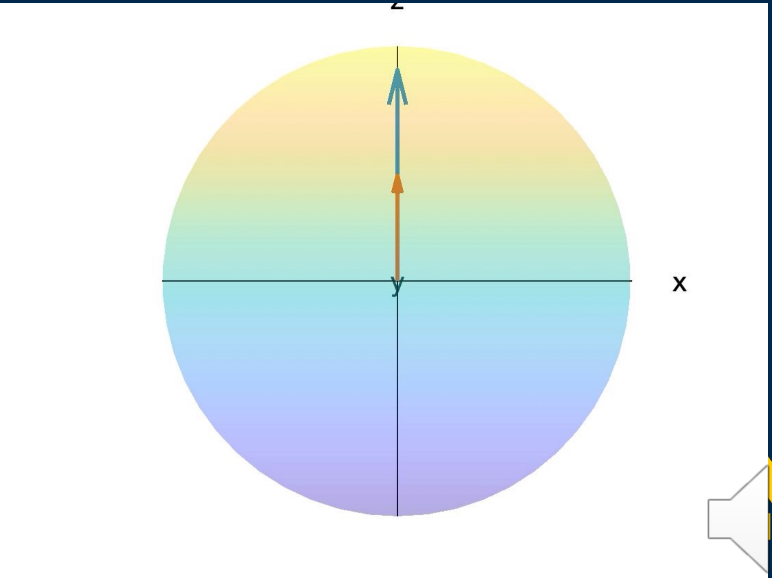
The more protons, the more signal



Differences in Proton Density give rise to contrast







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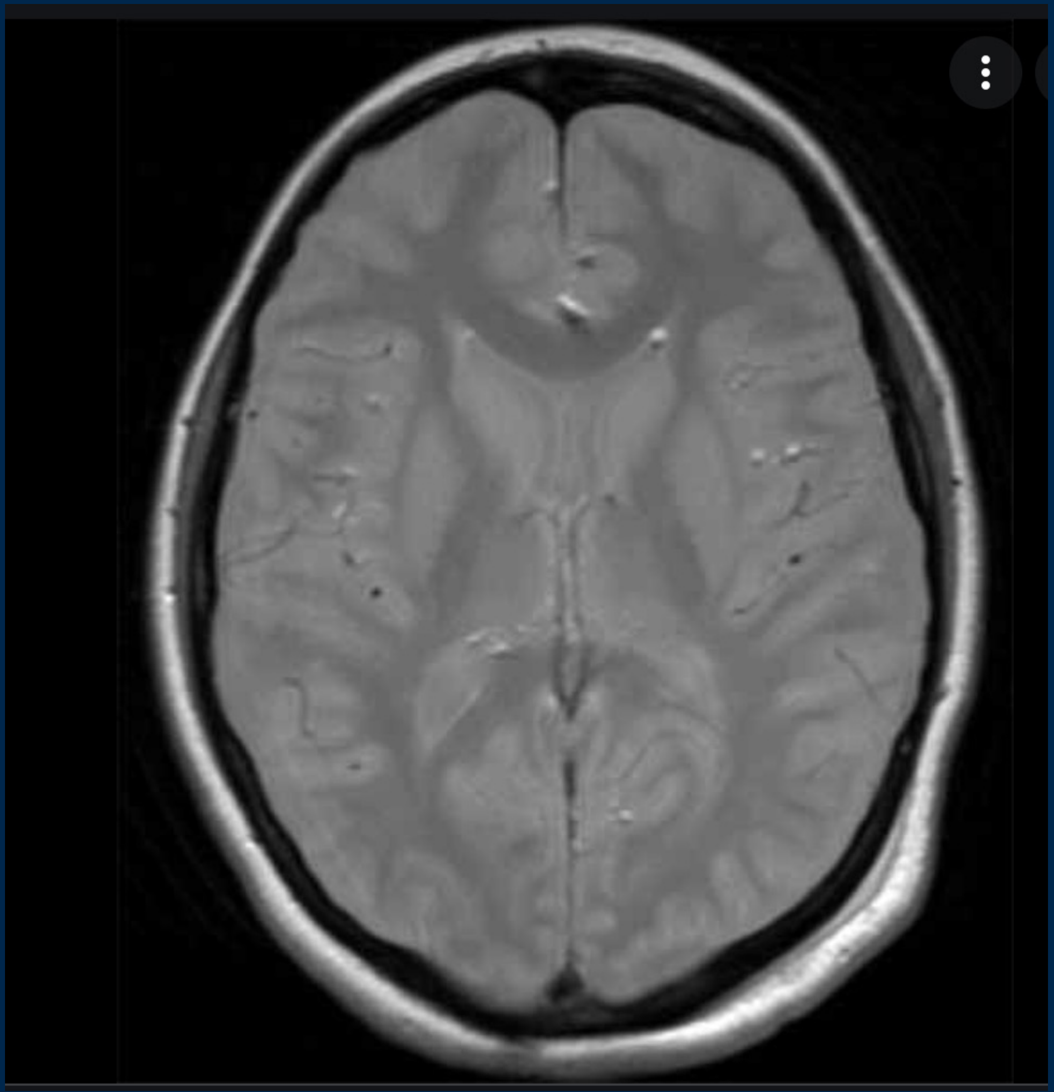
Differences in Proton Density give rise to contrast



But it is usually boring as most soft tissues have similar water content

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Summary of Proton Density (ρ)

- In addition to T1 and T2, MR images all contain "proton density" contrast

- Called Proton Density, M_0, ρ … all the same

- MRI signal is directly proportional to "number of protons" in a voxel

- Can also be used as a contrast mechanism (but usually fairly boring)

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