Introduction and safety of MRI

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Outline

- Excitation
- Relaxation: T1, T2
- Image contrast: T1WI, T2WI, PDWI
- Scan parameters: TR, TE
- Bioeffect and safety

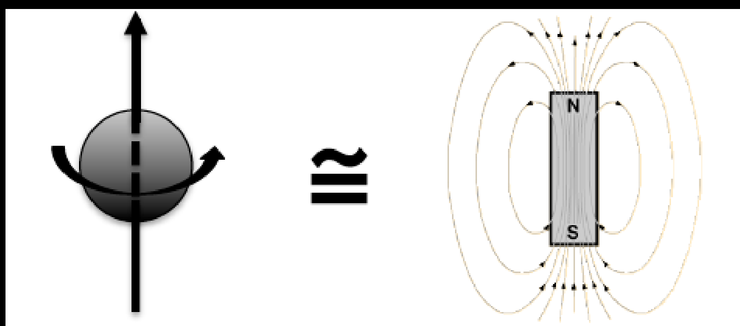
Magnetic Resonance Imaging (MRI)

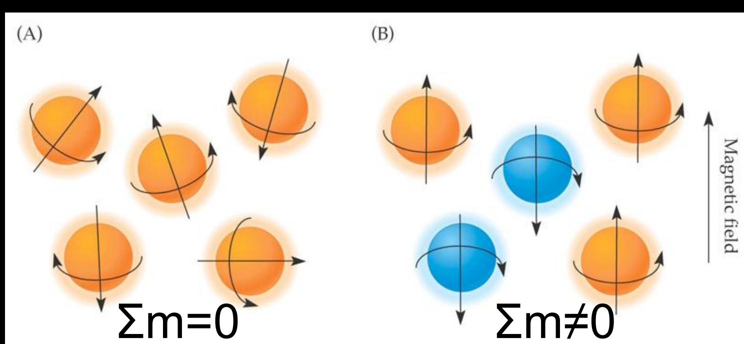
- Magnetic
  - There are small magnet in human body
  - A static magnetic field makes bulk magnetic effect
  - The bulk magnet (magnetization) rotates in Larmor frequency ω_0
- Resonance
  - Apply RF (with the same ω_0) to excite the magnetization
  - Magnetization release energy after remove RF
  - Receive energy using MR coil
- Imaging
  - Apply gradient field to have magnetization spatial variation
  - Spatial encoding according to spatial variation
  - Solve the variation using Fourier Transform

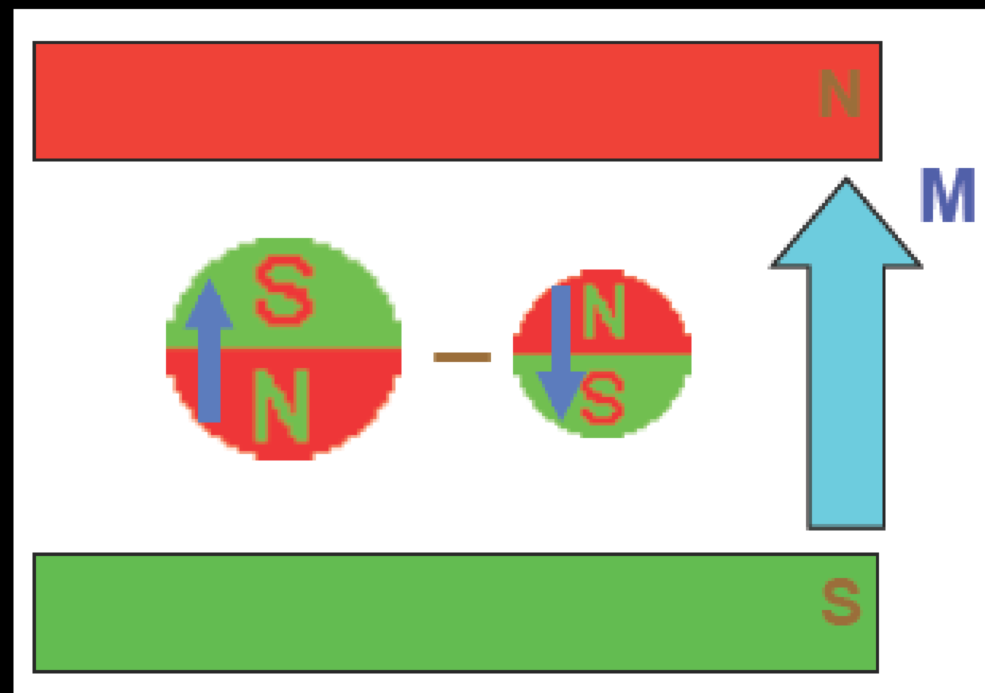
Formation of MRI

- Source of MR signals
- RF excitation
- Image contrast (PD, T1, & T2)
- Signal detection
- Spatial encoding
- Image reconstruction

Influence of the main magnetic field on the proton



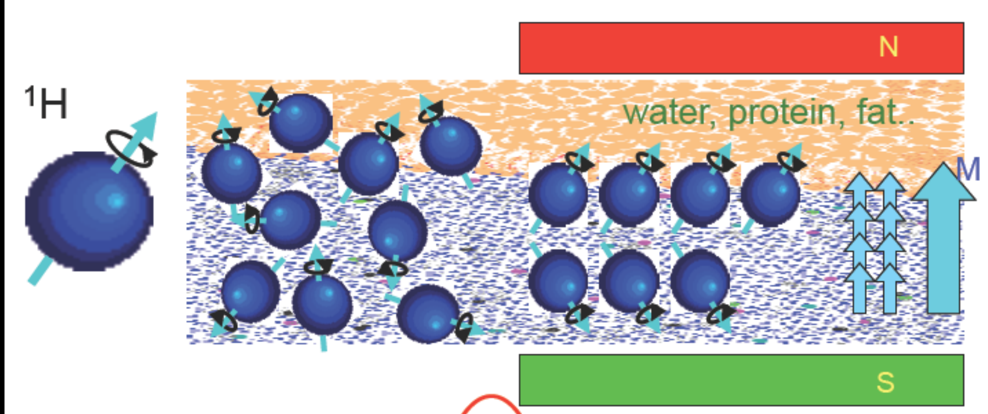




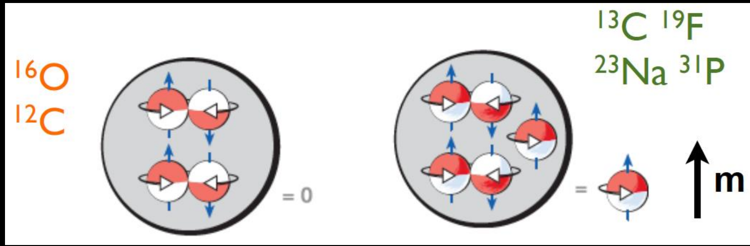
Irregular alignment -> regular alignment

Which atom has spin?

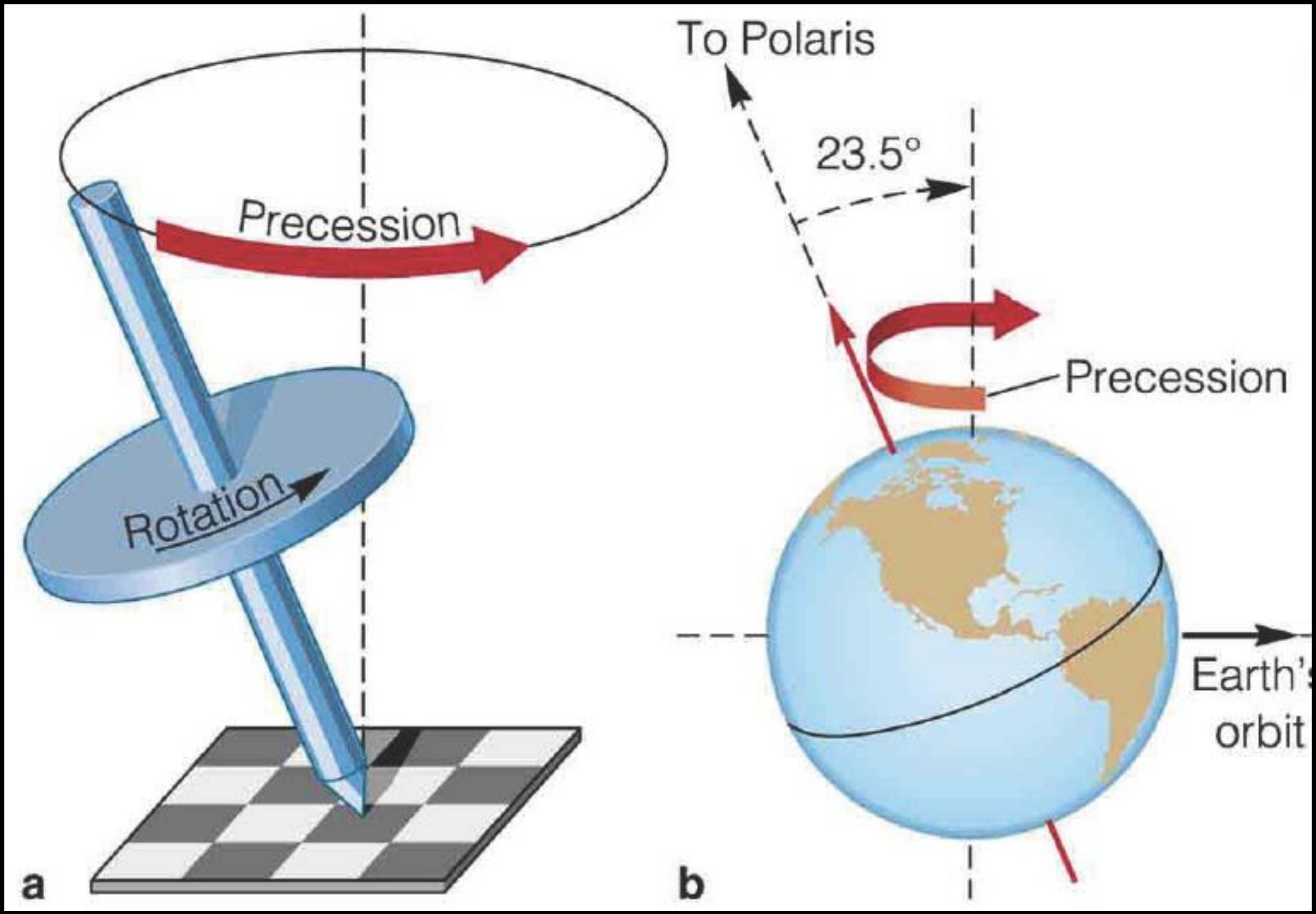
- Anyone which has uneven number of protons / neutrons



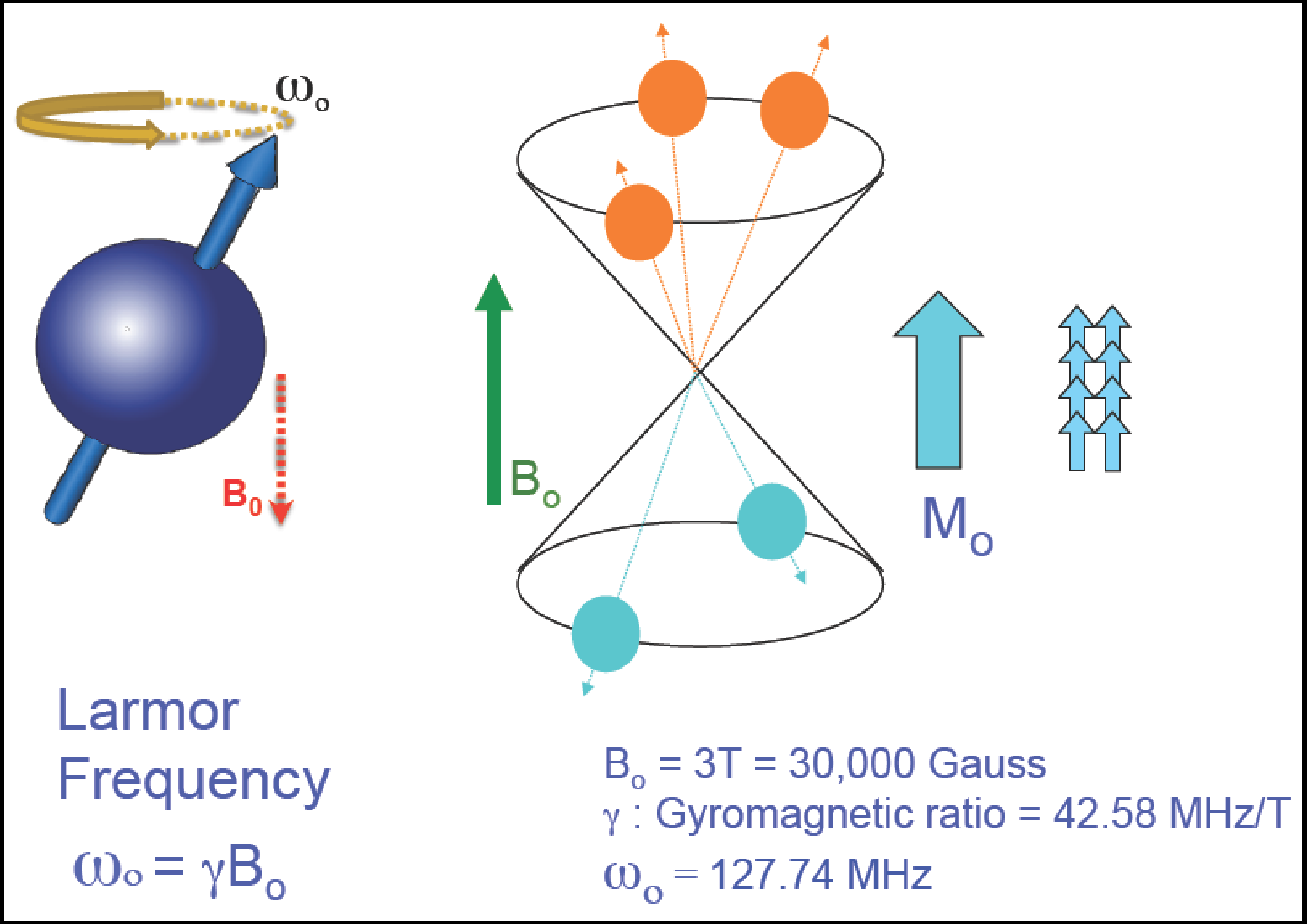
	^{1}H	^{13}C	^{19}F	^{31}P
γ (MHz/T)	42.58	10.71	40.05	17.23
Concentration (mole/l)	99	0.10	0.0066	0.35
Related Sensitivity	1.00	0.016	0.83	0.066
Wo @ 3T (MHz)	127.74	32.13	120.15	51.69



Precession of proton in the magnetic field

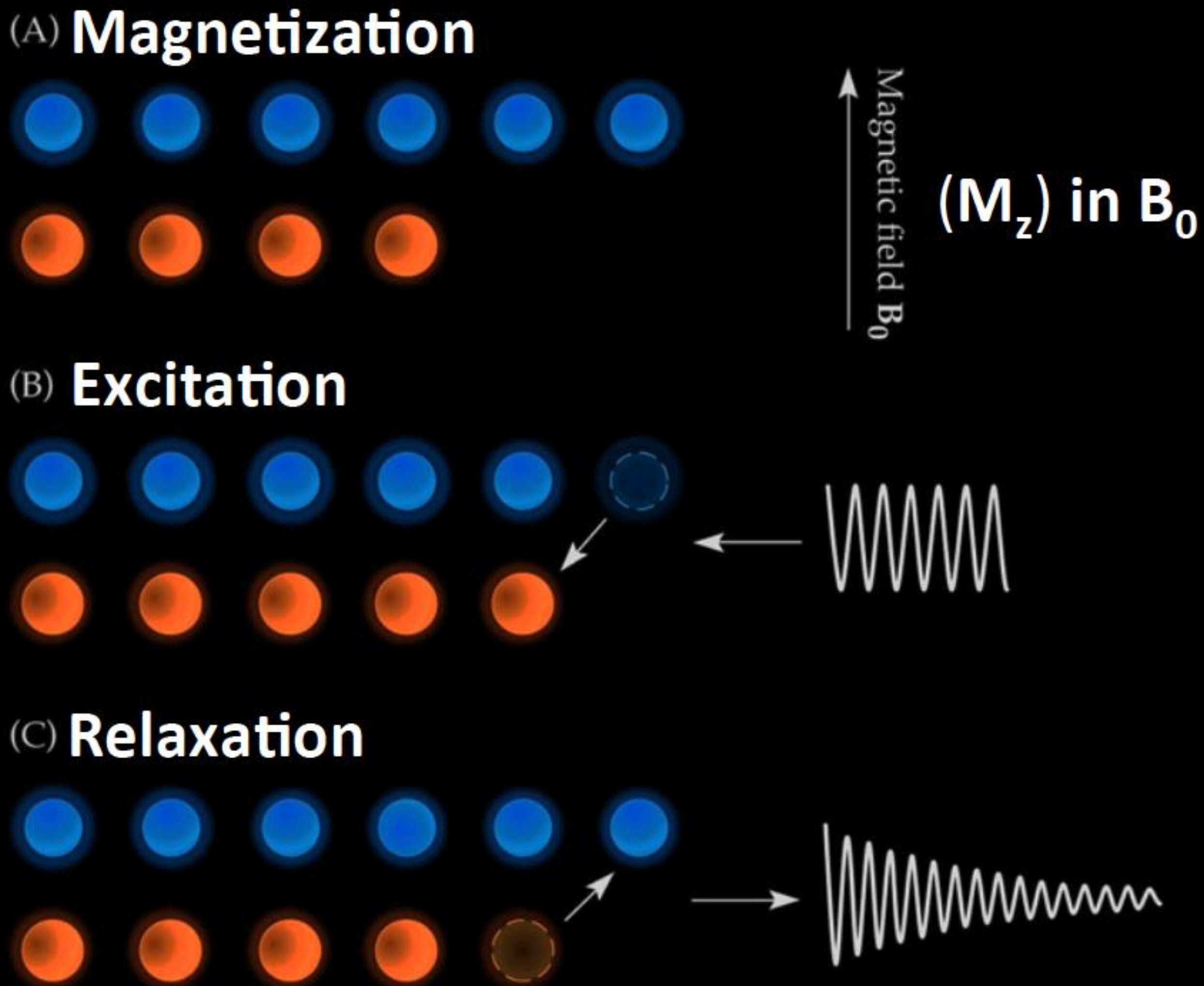


Precession of proton in the magnetic field



- A proton rotates about the axis of B_0

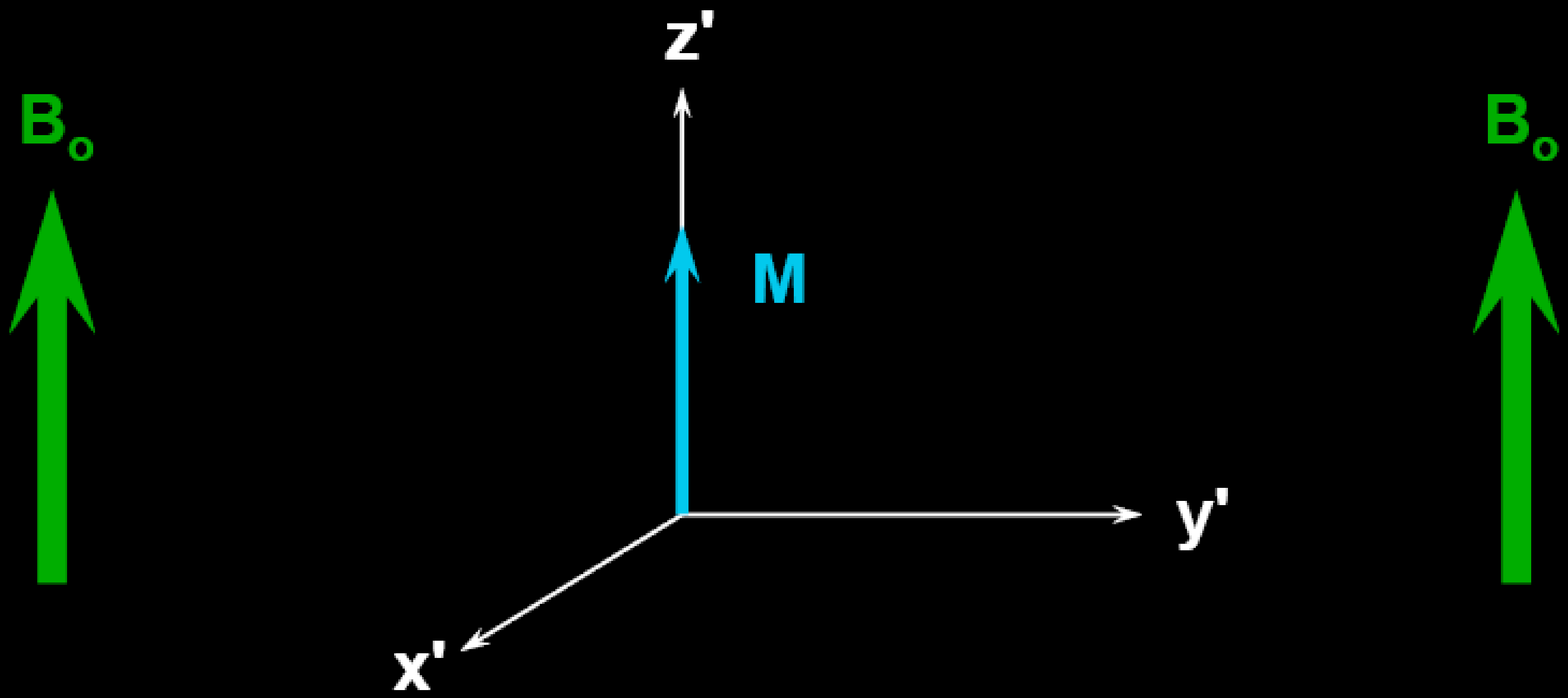
RF excitation and relaxation



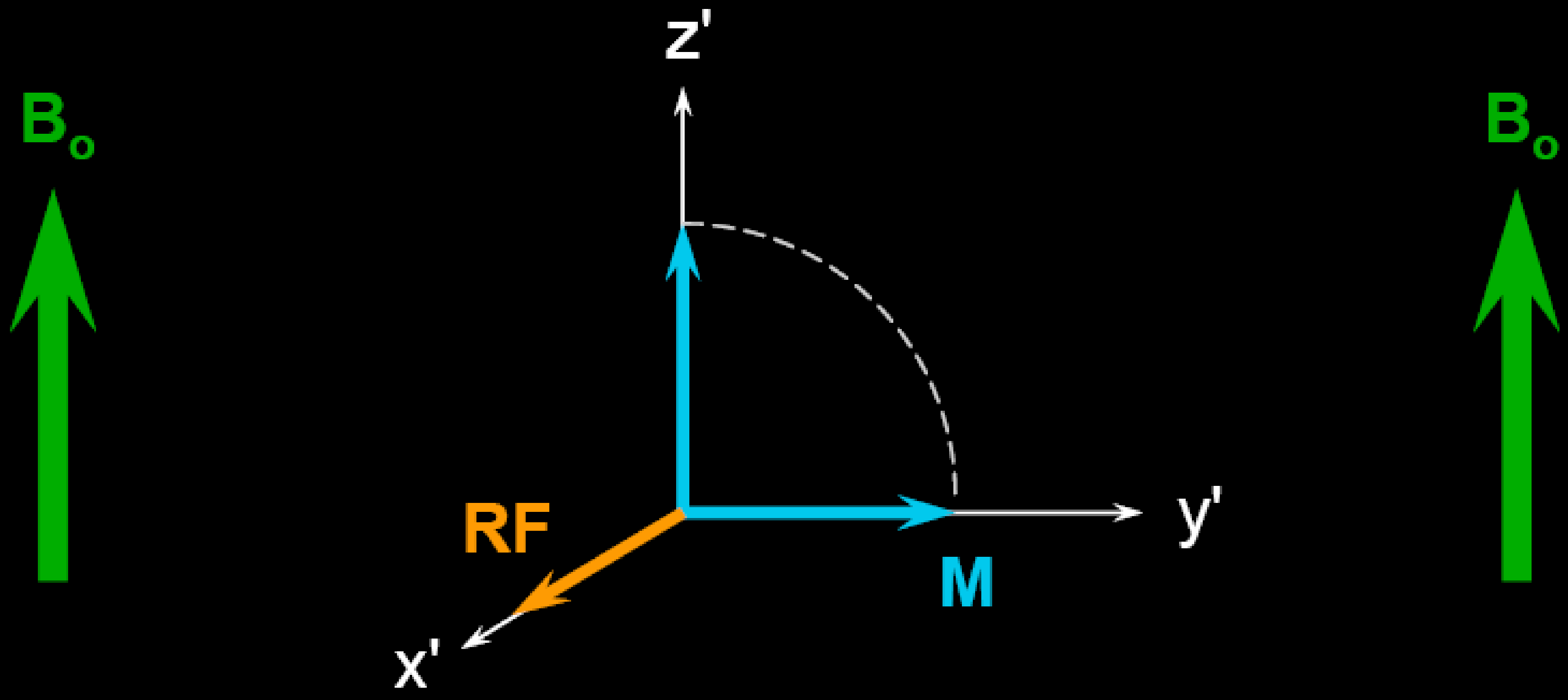
Precession

- Larmor Precession
- Precession frequency is proportional to the main magnetic field
- $\omega = \gamma B$ (Larmor equation)
- Basic of resonance

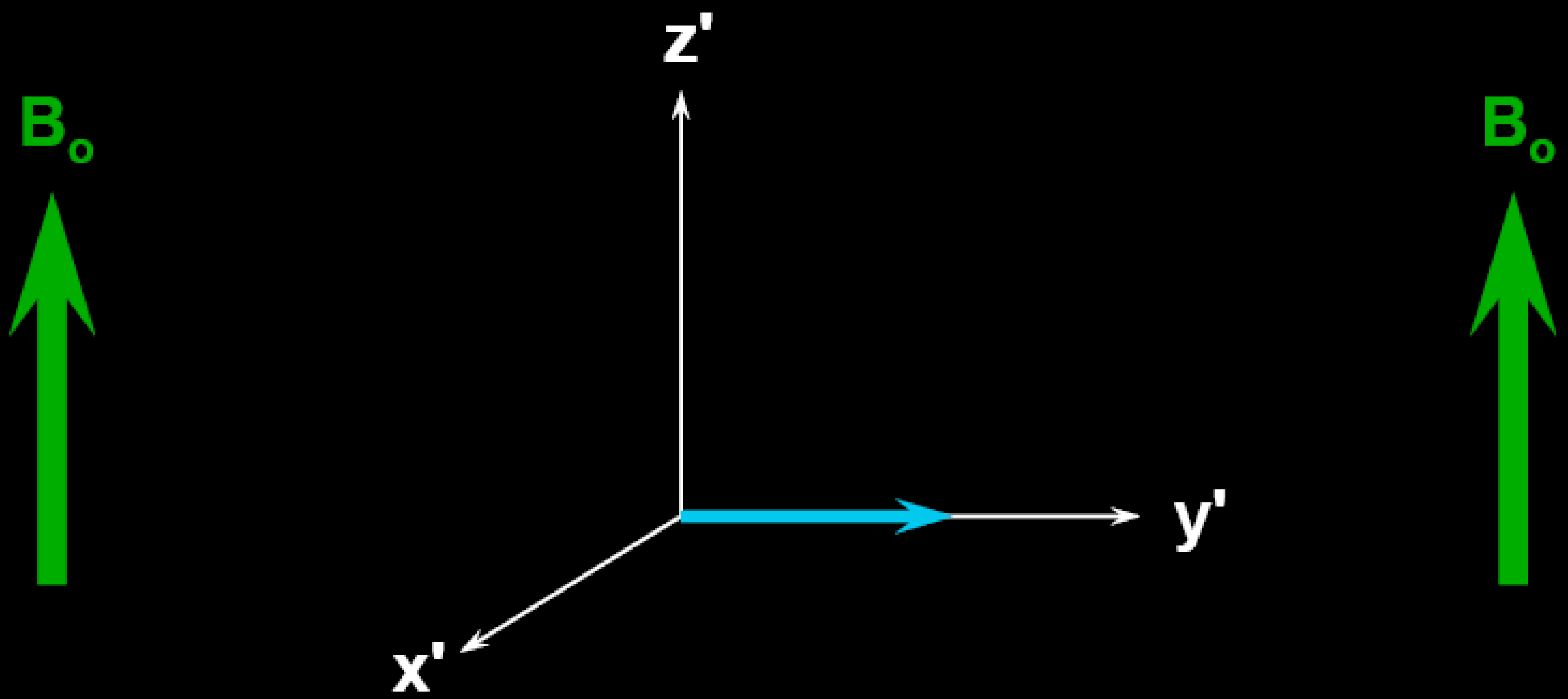
Magnetization at Thermal Equilibrium



RF Excitation

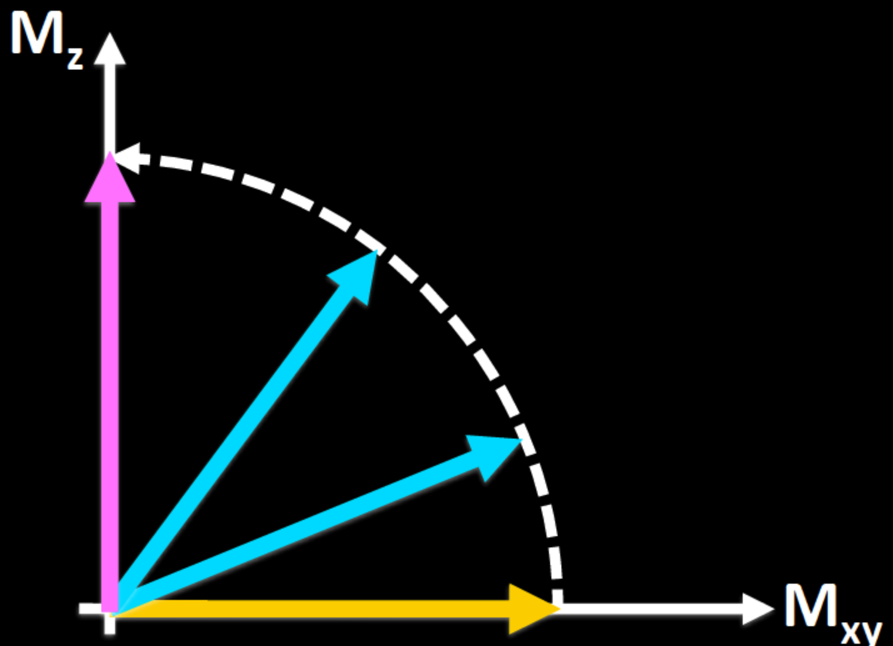


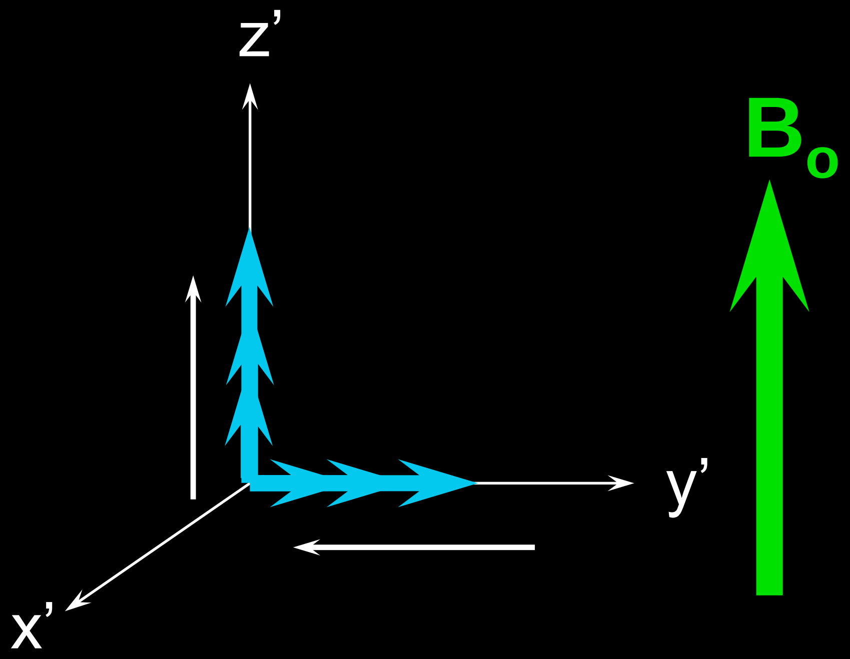
Precession



- On-resonance: (no deviation from the y' axis)

Relaxation



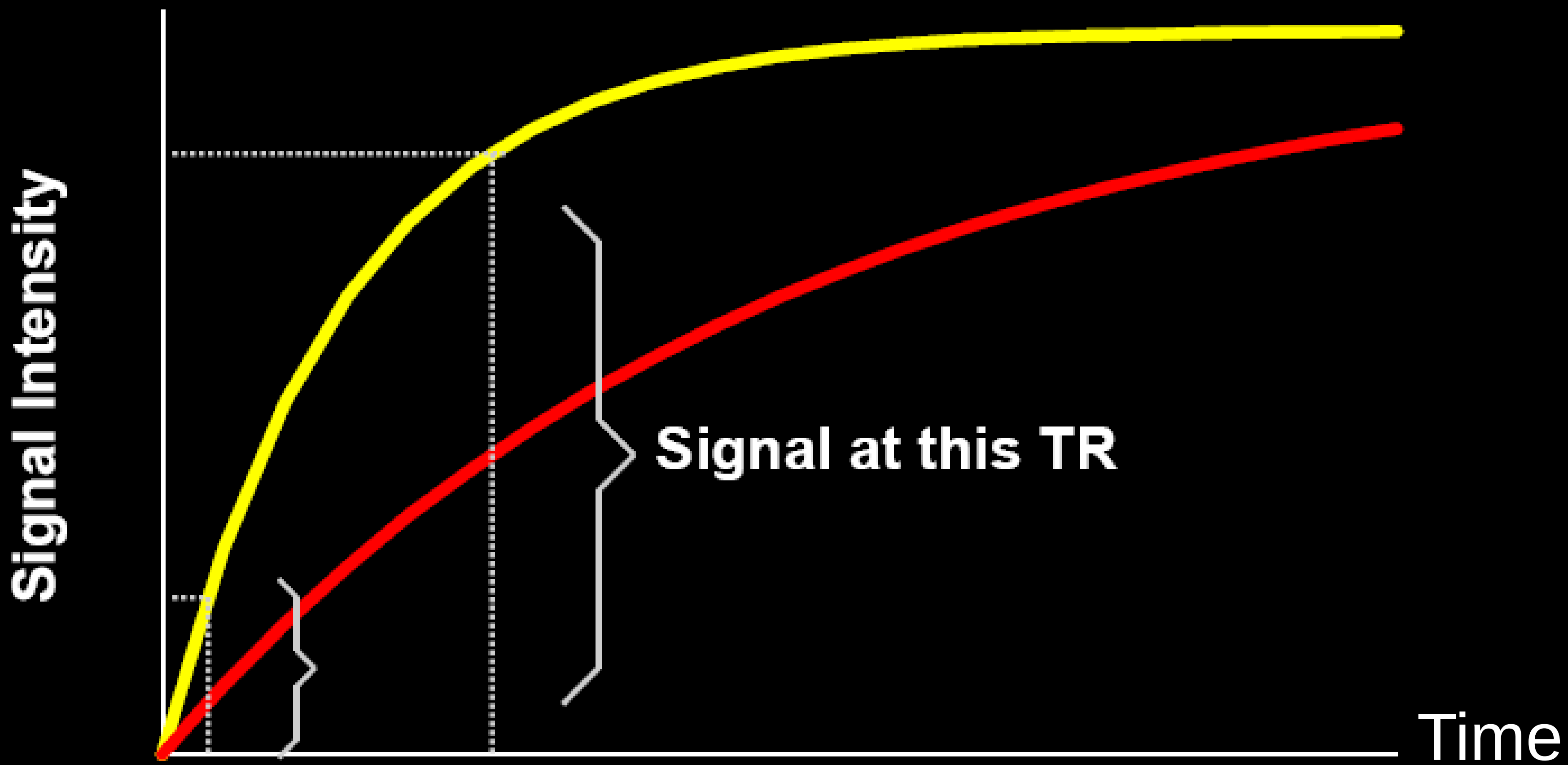


T1 and T2 relaxation

- T1 (z-axis)
  - Longitudinal relaxation time
  - Spin-lattice relaxation time

- T2 (xy plane)
  - Transverse relaxation time
  - Spin-spin relaxation time

T1 recovery of tissue magnet



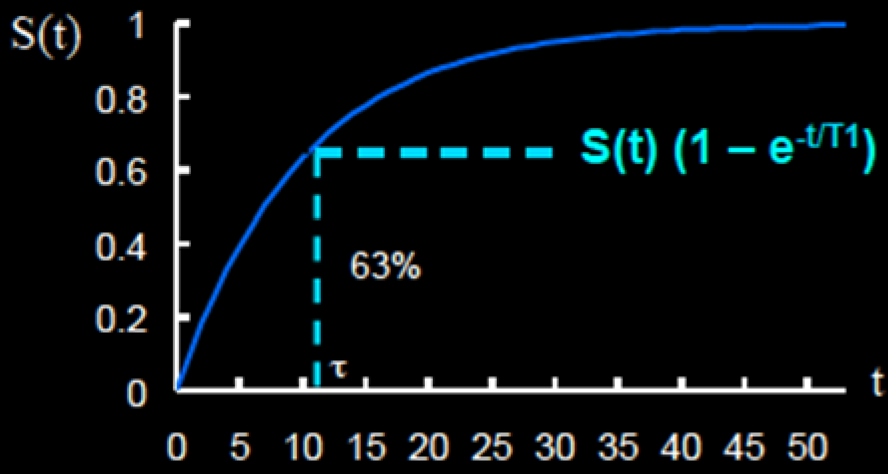
- Substantial increase in TR leads to SNR gain

Spin-lattice relaxation time (T1)

- The time interval for the spins to realign along the longitudinal (z) axis
- Signal source: energy exchange between spin and lattice
- The time for the spin to give the obtained RF energy to the surrounding lattice

Spin-lattice relaxation time (T1)

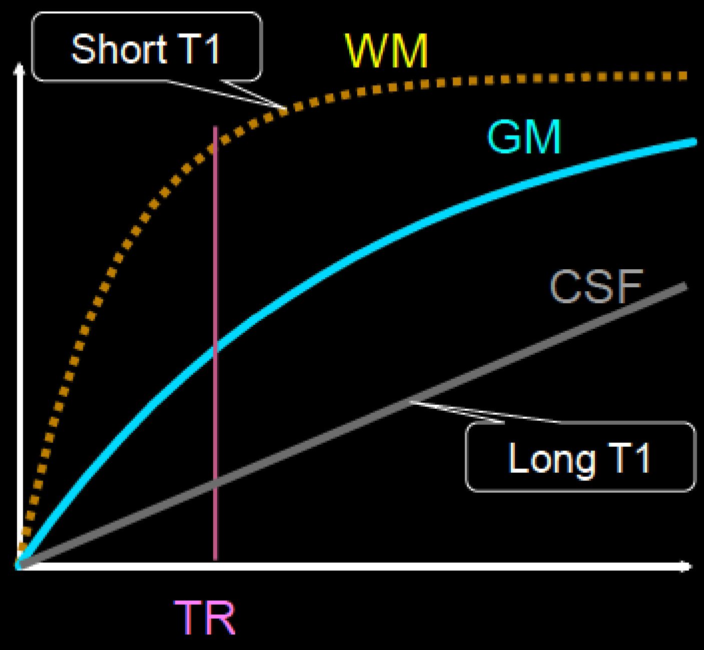
- $M_z = M_0 (1\text{-exp}(\text{-TR/T1}))$
- $\exp(-1) = 1/e = 0.37$
- T1: the time interval for 63% signal recovery
- Almost cost 5xT1 to recover 100% signal



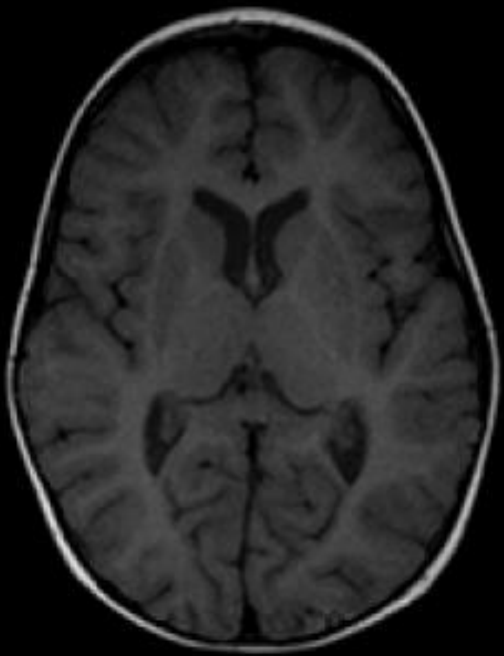
Spin-lattice relaxation time (T1)

- Different T1 in different tissues

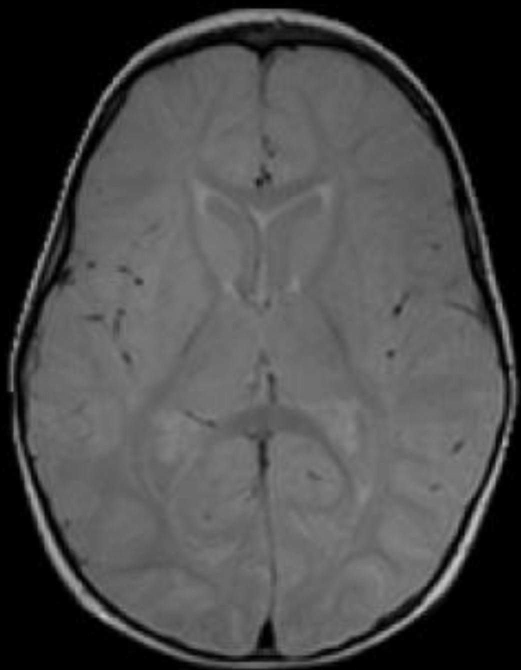
Tissue	T1 (ms) @1.5T	T1 (ms) @1.0T
Fat	250	220
Liver	490	420
Kidney	650	590
Muscle	860	730
White matter	780	680
Gray matter	920	810
CSF	3000	2500



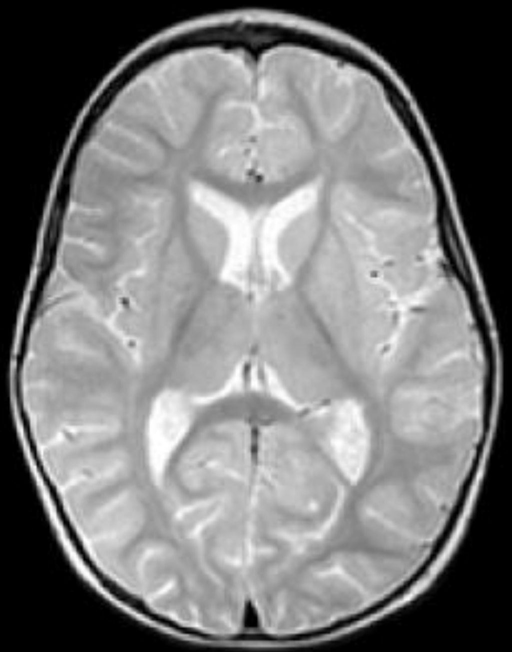
Effects of TR onT1 Contrast



TR = 600



TR = 2400



TR = 4200ms

Factors affect T1

- Coupling between spin and adjacent median
  - Tight coupling makes energy release quickly (shorten T1)
  - T1 of solid < T1 of liquid
- Molecular size
  - Molecule tumbling frequency ~ Larmor frequency → hasten energy release (shorten T1)
  - Small molecule has high tumbling frequency
  - Median molecule (e.g. fat) has tumbling frequency close to Larmor frequency

Factors affect T1

- Macromolecular environment
  - Interaction between hydrogen atom among macromolecule will promote energy release
  - Soft tissue, protein (shorten T1)

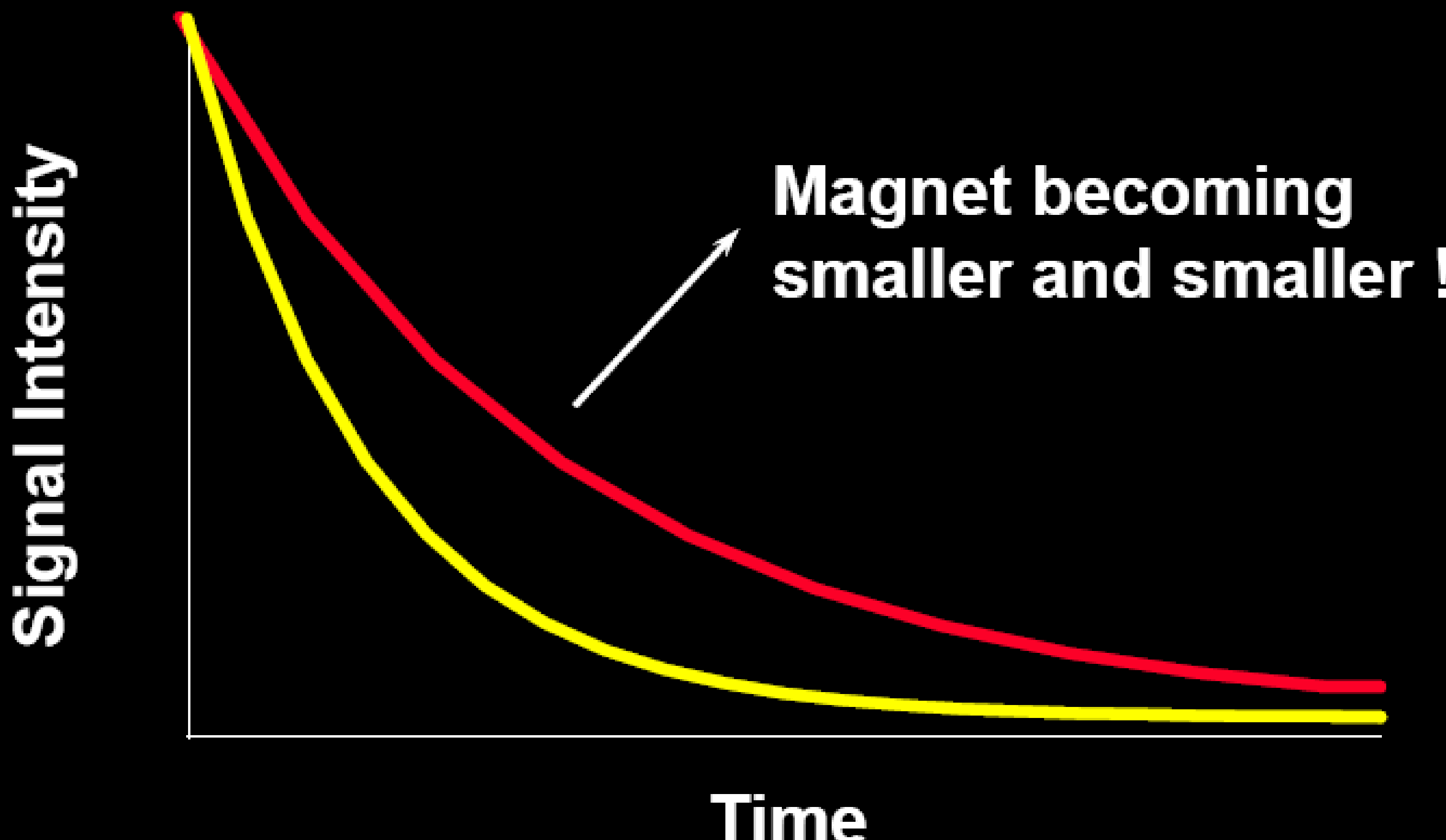
- Magnetic intensity
  - Larmor frequency increases at high field ≠ Molecule tumbling frequency
  - Slow energy release (lengthen T1)

Factors affect T1

- Paramagnetic ion/molecule
  - Local magnetic tumbling created by unpaired ion create makes spin hardly stay at high energy level (shorten T1)
  - Mn^{2+}, Cu^{2+}, Fe^{2+}, Fe^{3+}, Gd^{3+}, free radical…

- Temperature
  - Lower temperature makes molecular motion slow (shorten T1)

T2 decaying of tissue magnet



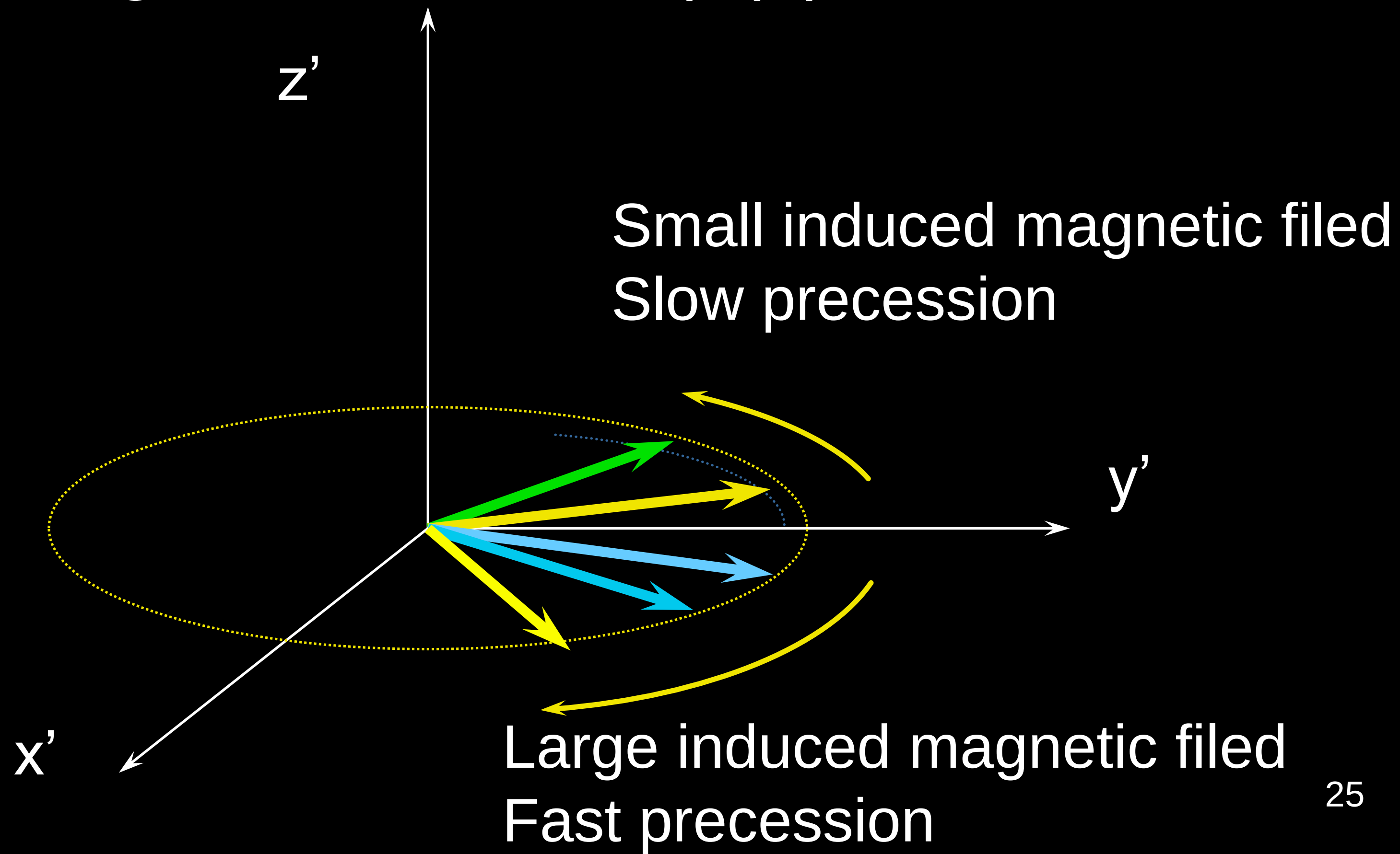
- Substantial reduction in TE leads to SNR gain

Spin-spin relaxation time (T2)

- The time for the spins dephasing along the transverse axis
- Neighbor spins cause small change of magnetic field, which cause signal decay (dephase) due to slightly frequency changed

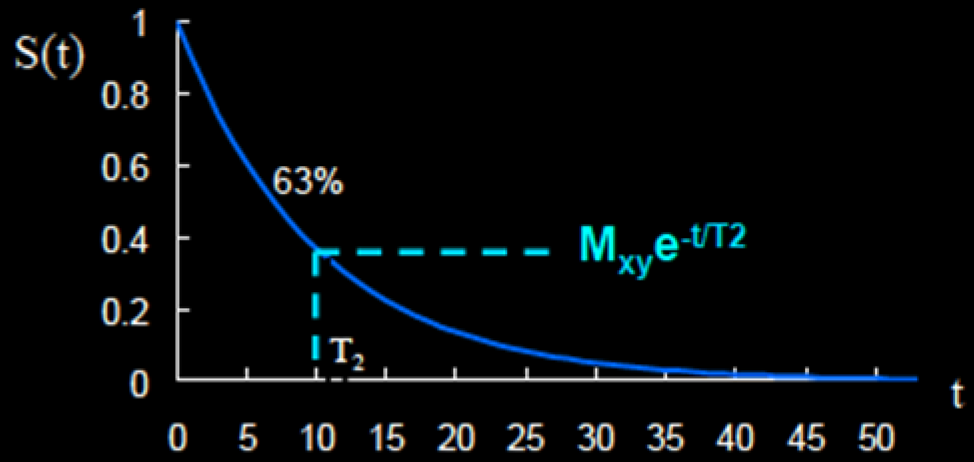
Spin-spin relaxation time (T2)

- Phase angle = 0 -> in-phase
- Phase angle = 180º -> out-(of)-phase



Spin-spin relaxation time (T2)

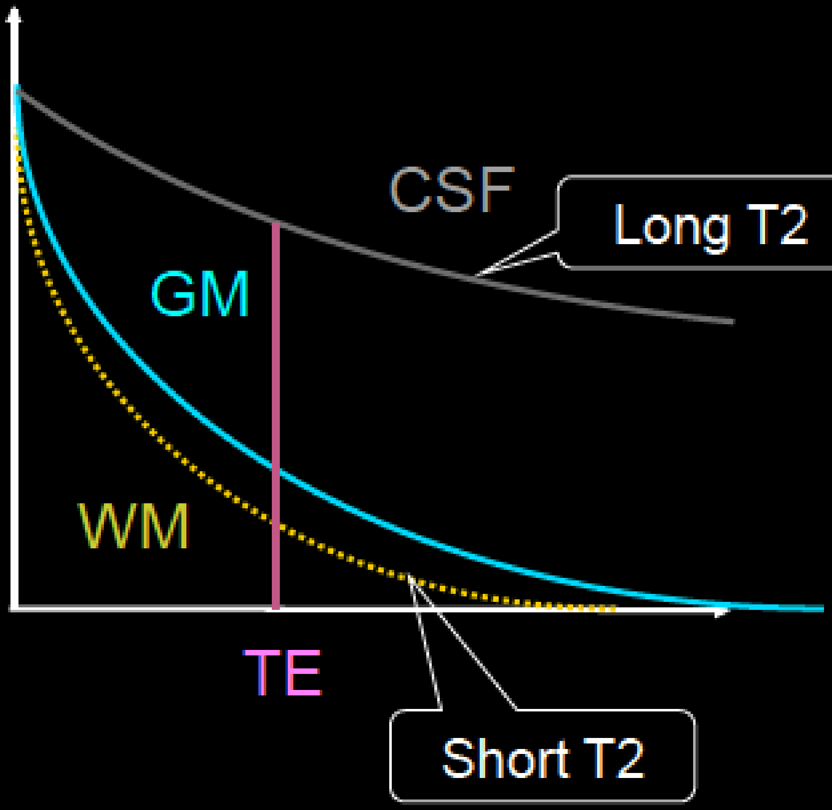
- $M_{xy} = M_0 \exp(-TE/T2)$
- $\exp(-1) = 1/e = 0.37$
- T2: the time interval for 63% signal decay
- Almost cost 5xT2 to attenuate 100% signal



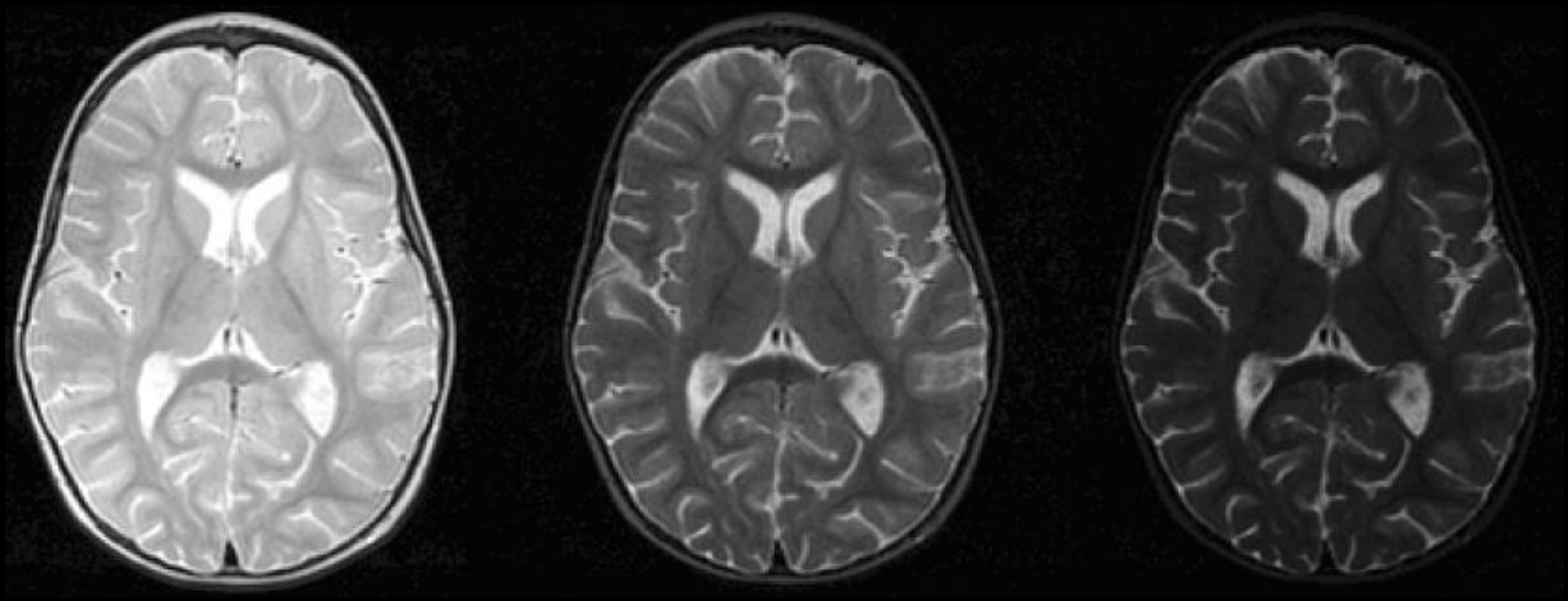
Spin-spin relaxation time (T2)

- Different T2 in different tissues

Tissue	T2 (ms)
Fat	80
Liver	40
Kidney	60
Muscle	50
White matter	90
Gray matter	100
CSF	1400



Effects of TE on T2 contrast



TE = 30ms TE = 90ms TE = 150 ms

Factors affect T2

- Local magnetic field disturbed by tissues
  - Mobility
    - Molecule with low mobility has strongly magnetic disturbance (shorten T2)
    - Solid T2 << Liquid T2
    - Big molecule has low mobility and therefore has short T2. e.g. protein
  - Isotropy
    - Tissue with lower isotropy has stronger magnetic disturbance (shorten T2)
    - collagen (< 1ms)

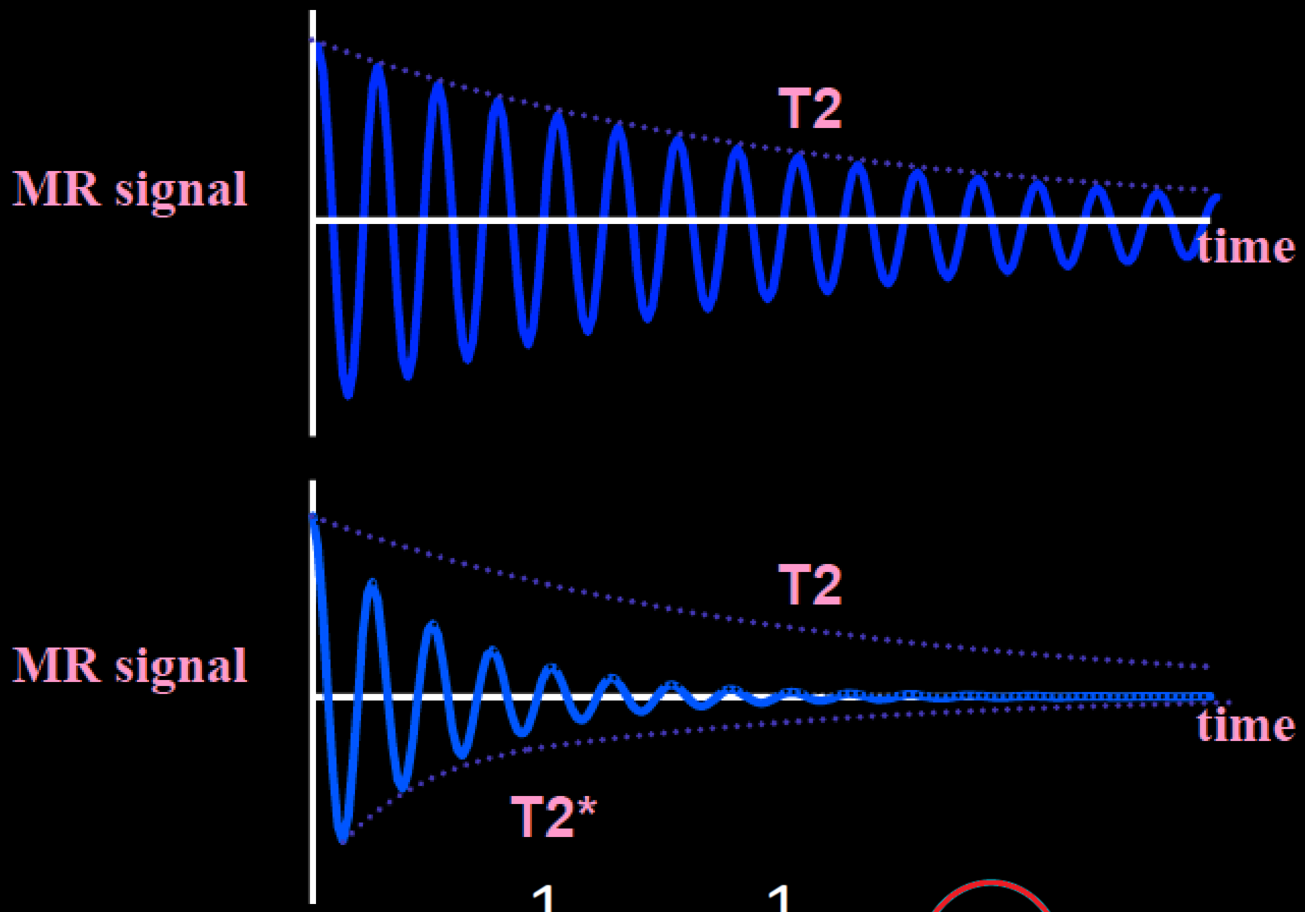
Factors affect T2

- Any factor makes local magnetic disturbance
  - Paramagnetic materials
- Magnetic intensity
  - High magnetic intensity (shorten T2)
- Temperature
  - Lower temperature makes molecular mobility slow (shorten T2)
- Molecular diffusion

T2* decay

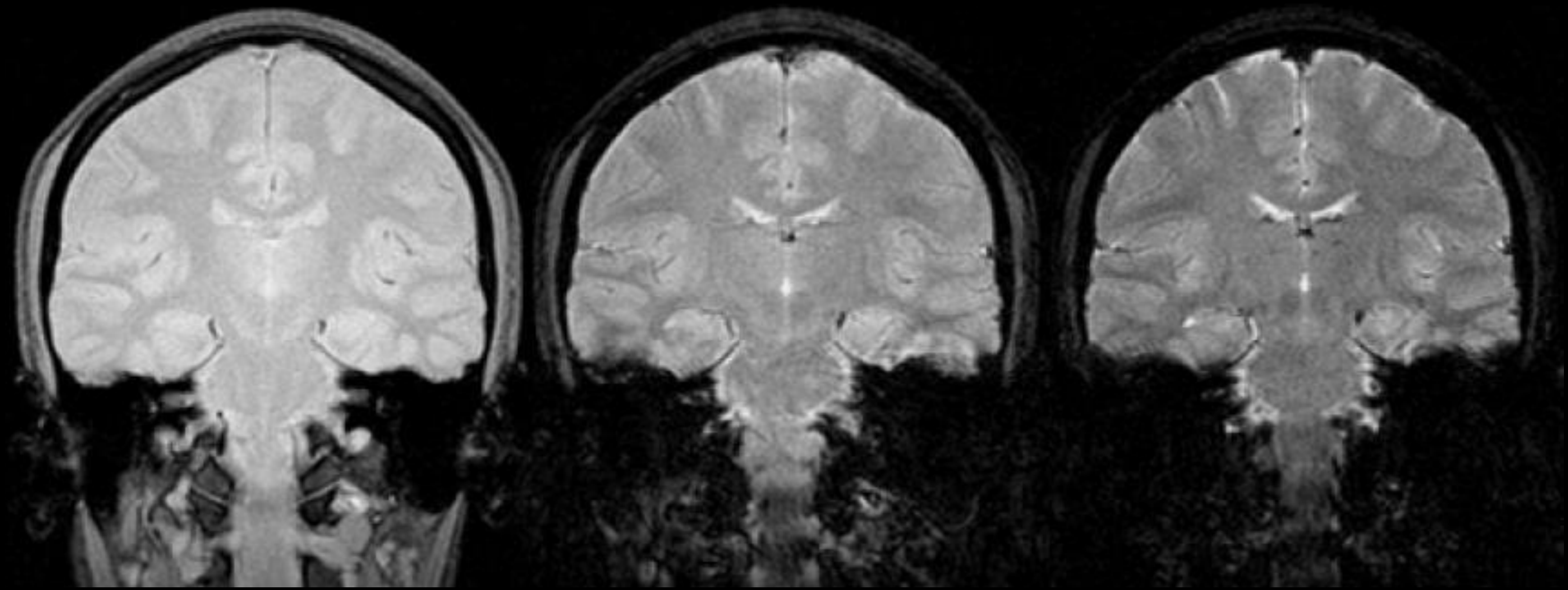
- Magnetic field inhomogeneous
  - Increasing of spin procession speed makes the stronger dephase
- Source
  - Magnetic field can not achieve 100% homogeneous
  - Gradient field makes magnetic field inhomogeneous
  - Subject itself also disturbs the magnetic field

T2* decay



$$\frac{1}{T2^*} = \frac{1}{T2} + \gamma \Delta B$$

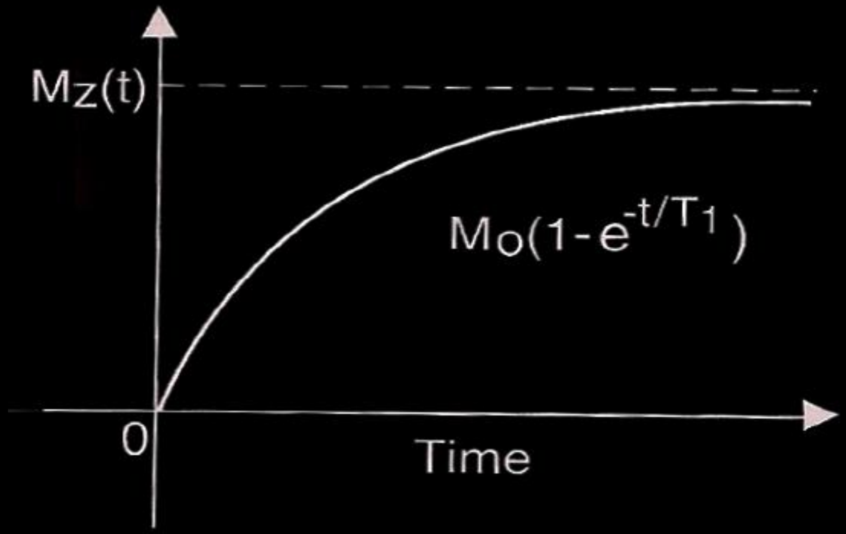
Effects of TE on SNR & T2* Contrast

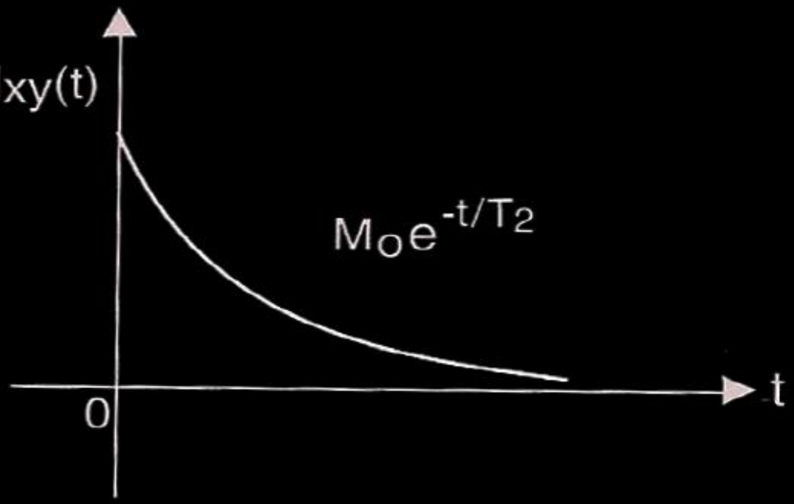


TE = 10 TE = 30 TE = 50ms

T1 and T2 relaxation

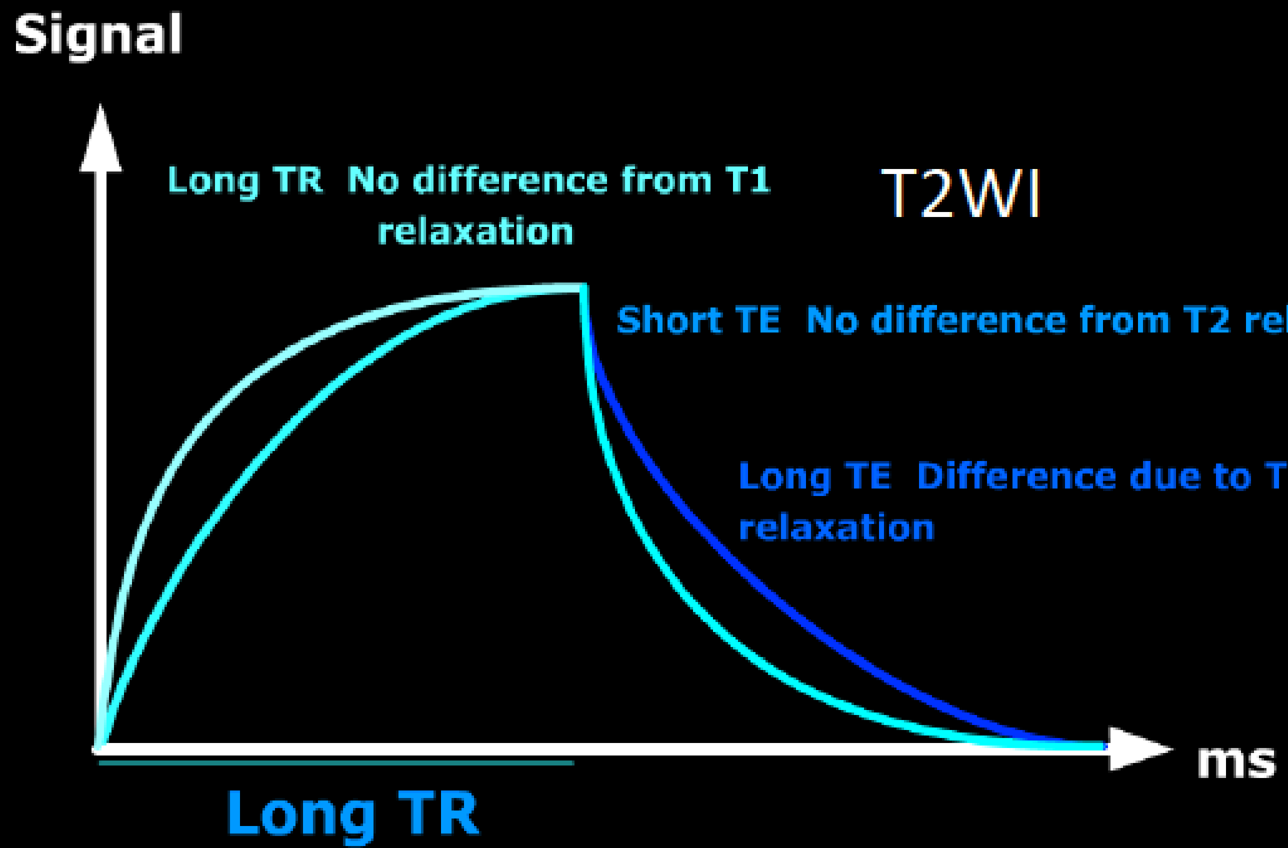
- T1 recovery: $M_z = M_0\ (1\text{-}\exp(\text{-}TR/T1))$
- T2 decay: $M_{xy} = M_0\ \exp(\text{-}TE/T2)$



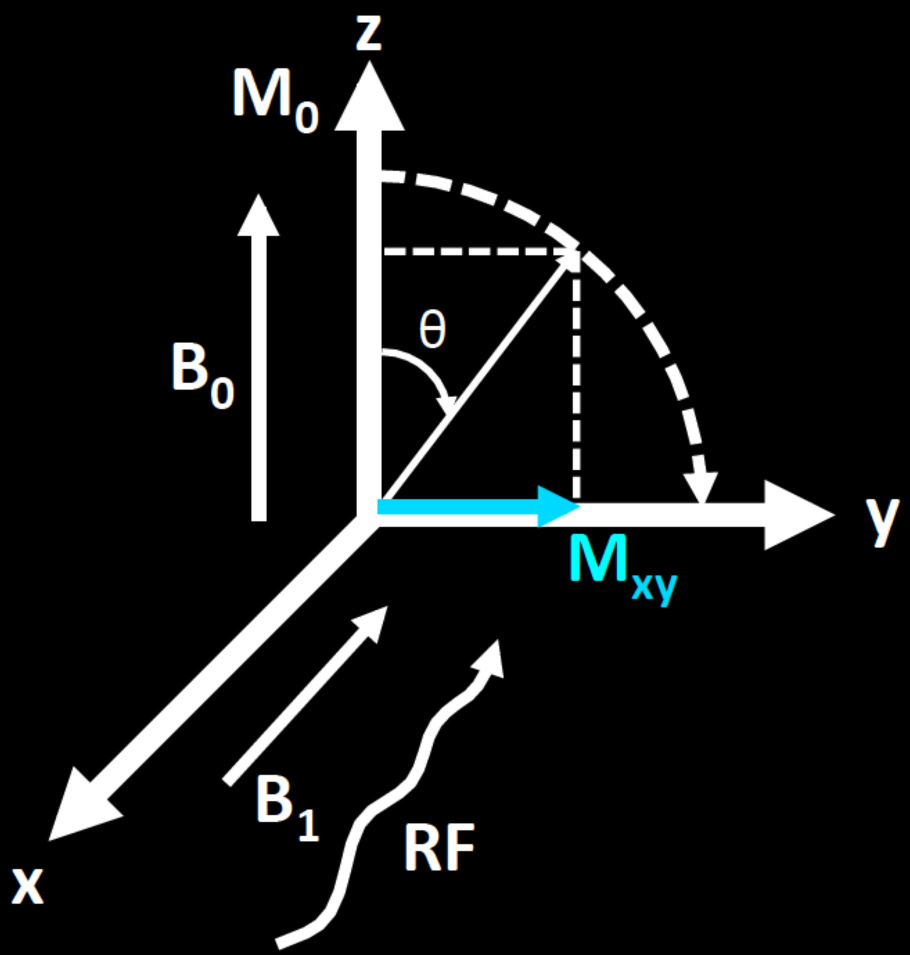


T1 and T2 relaxation

- Signal = M_0 (1-exp(-TR/T1)) exp(-TE/T2)



Excitation and relaxation



$\theta = \gamma B_1 \tau$

$M_{xy} = M_0 \sin\theta$

γ: gyromagnetic ratio

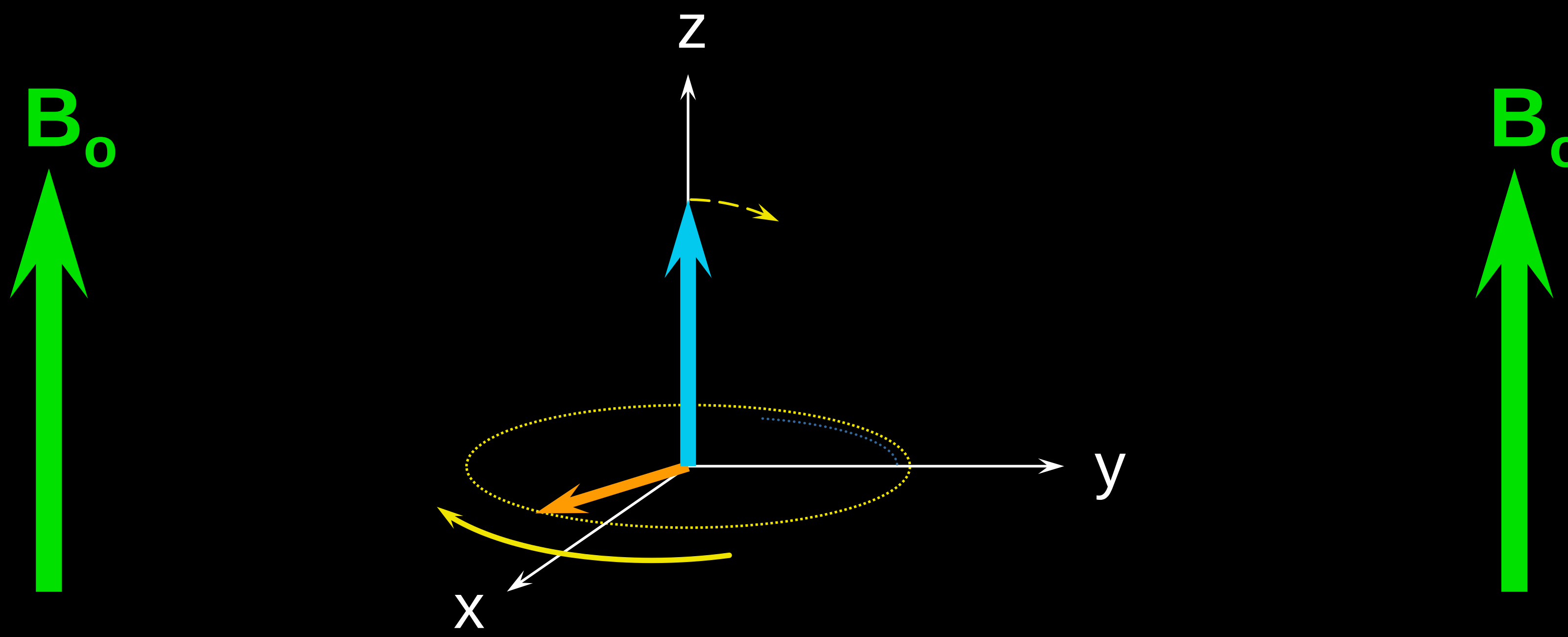
B_1 : RF pulse strength

τ: RF pulse duration

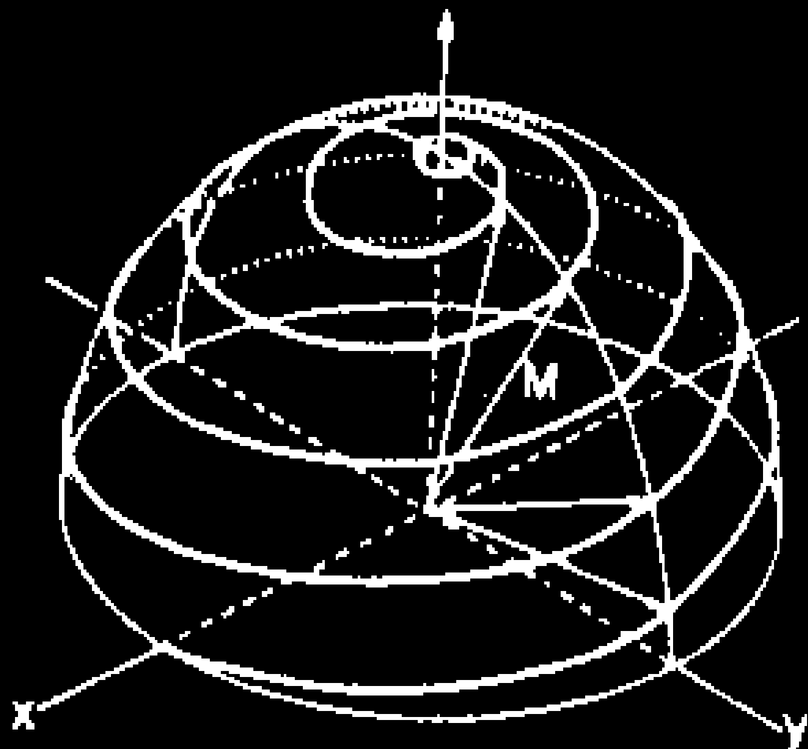
M_0 : net magnetization along z-axis

θ: flip angle

Real RF Excitation

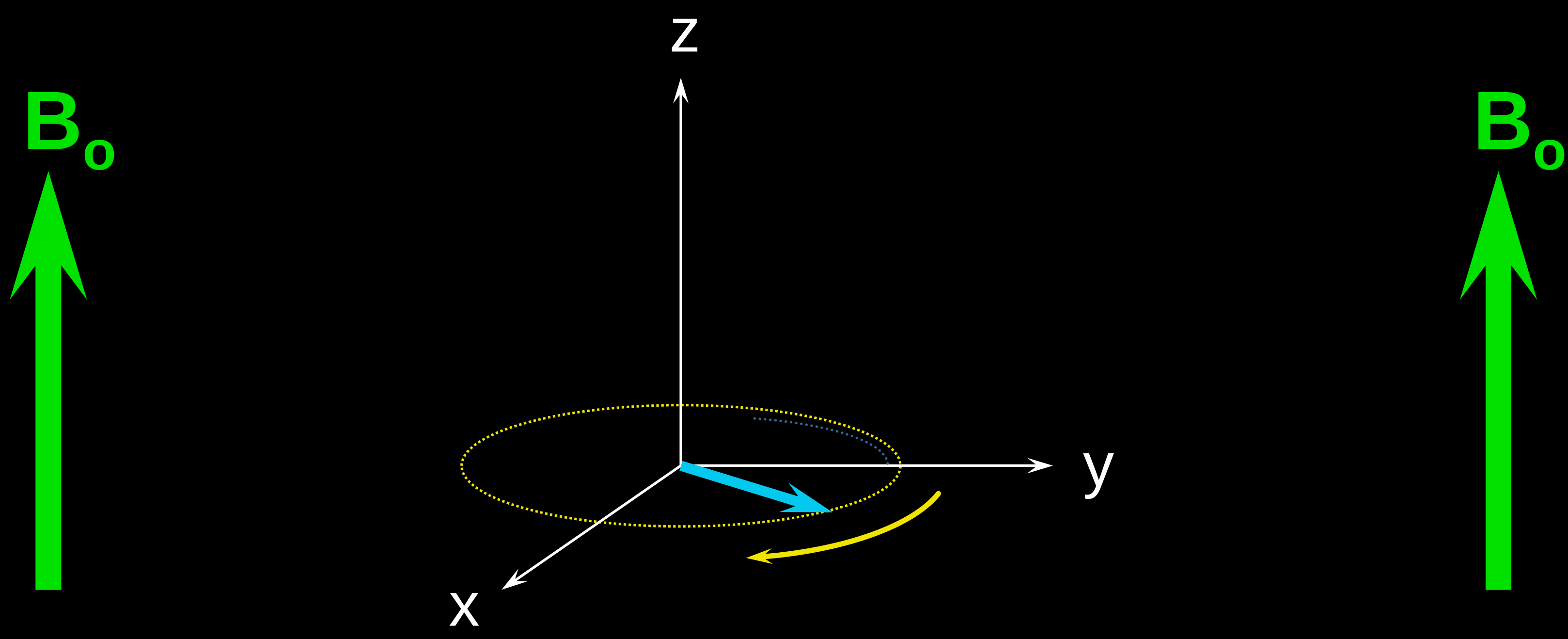


Real RF Excitation



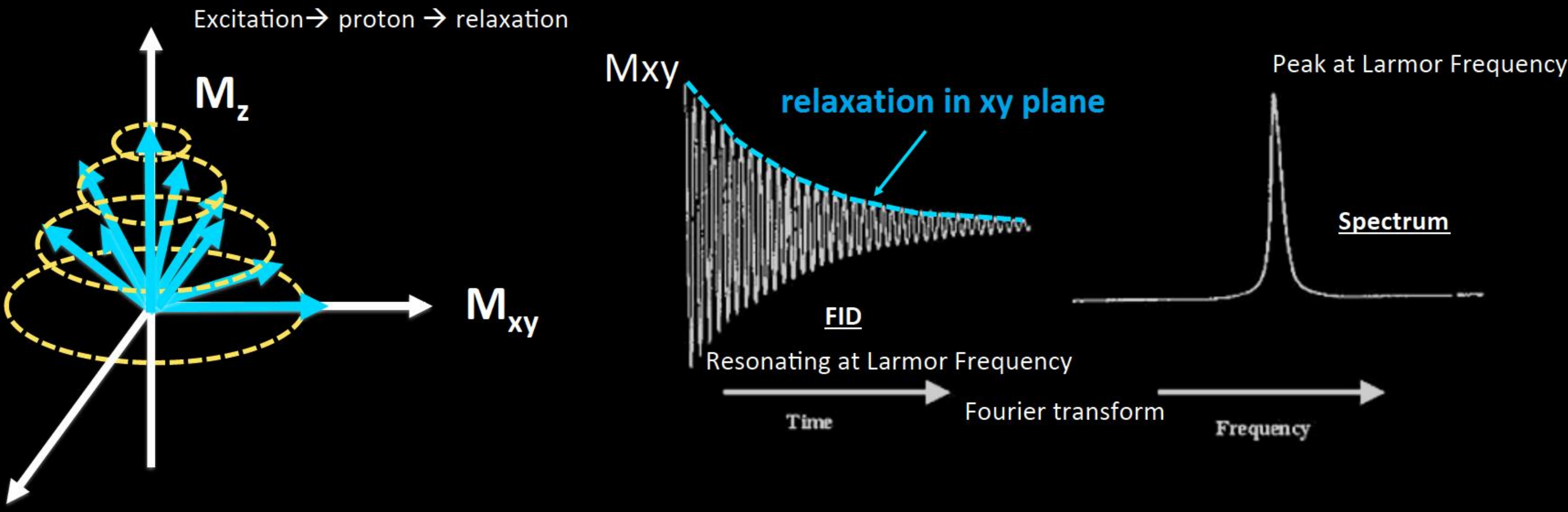
- Spiral trajectory

Real Precession

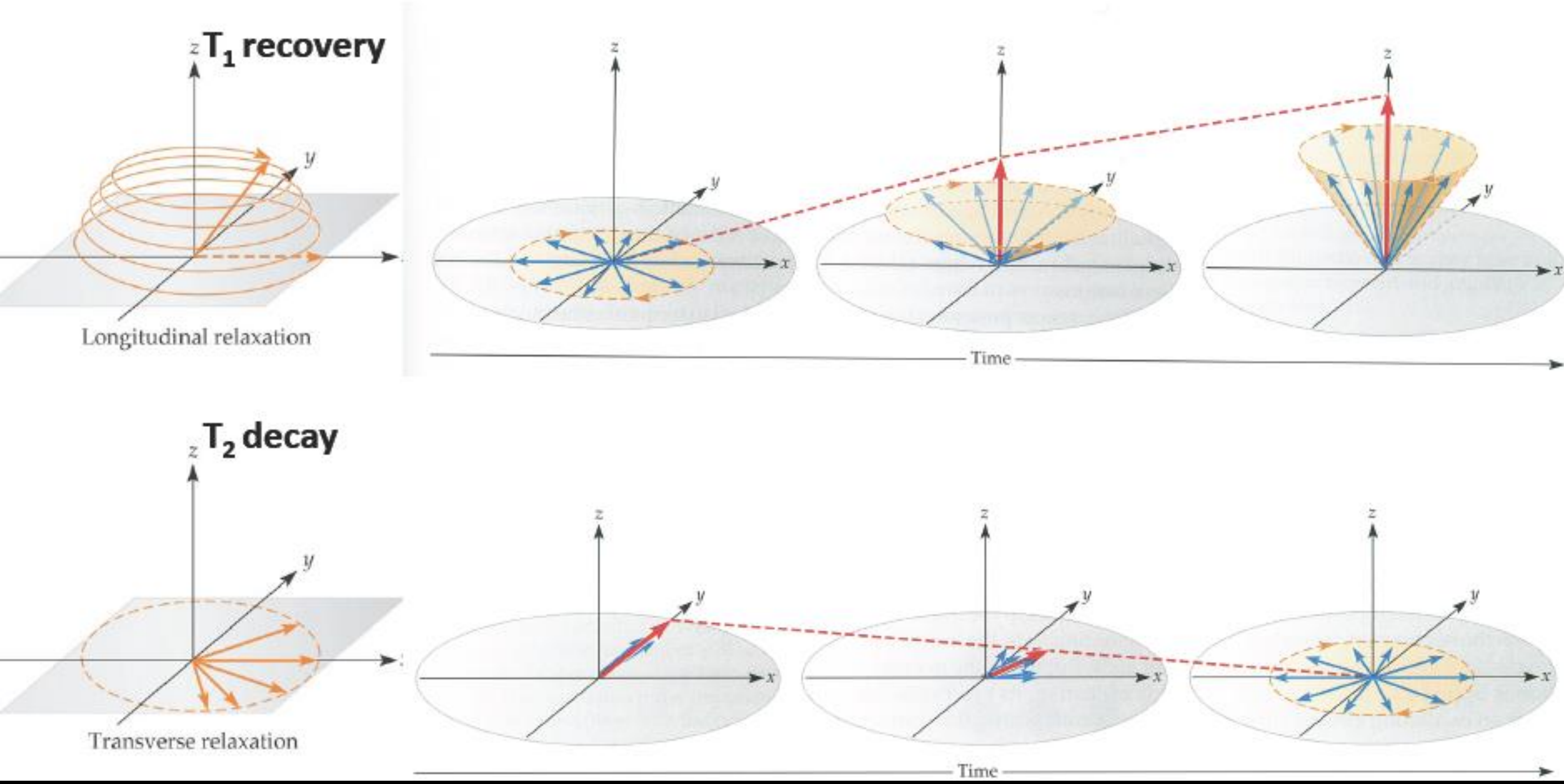


NMR signal

- Free induction decay (FID)

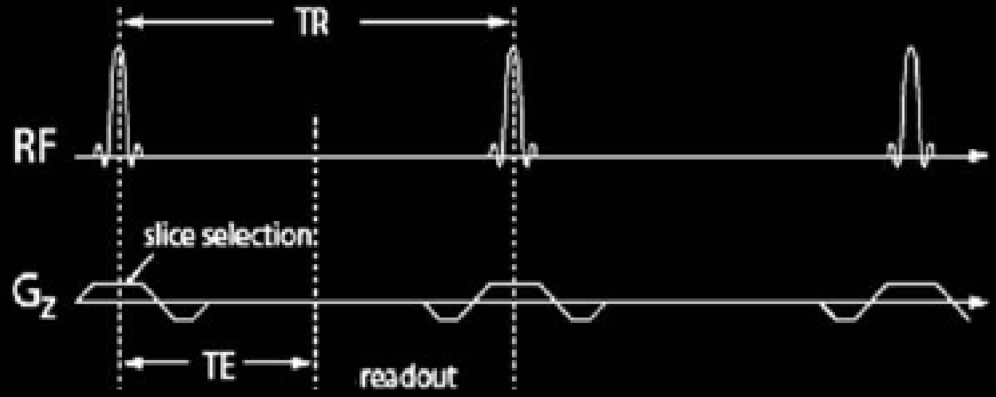


Real Relaxation



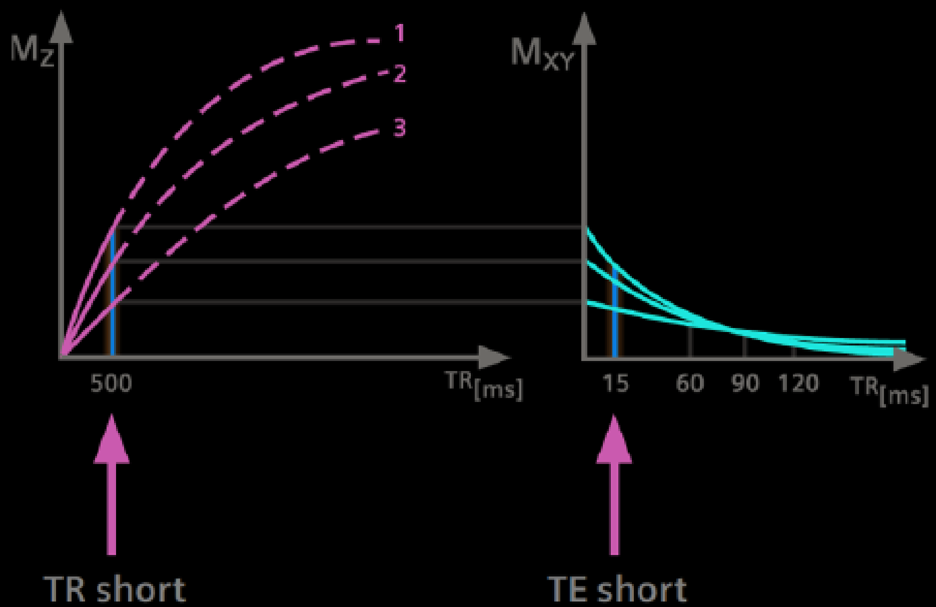
TR and TE

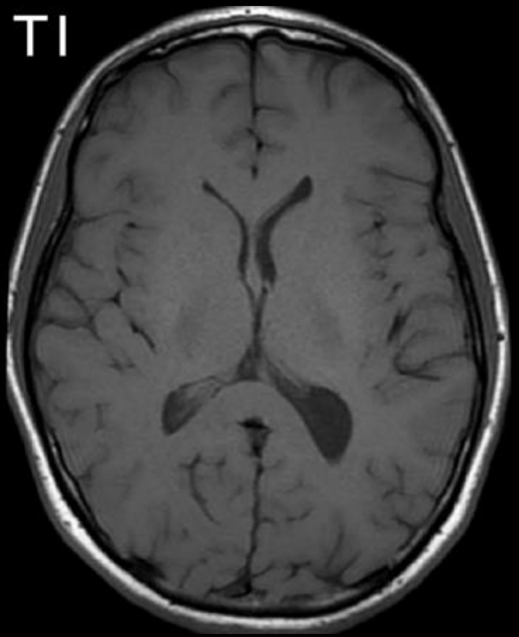
- Repetition time (TR)
  - The time from one RF to the next for each slice (in msec)
  - Determines T1 relaxation
- Echo time (TE)
  - The time from RF to the peak of signal induced in coil
  - Determines how much decay of transverse magnetization is allowed to occur (T2)



T1 weighted image (T1WI)

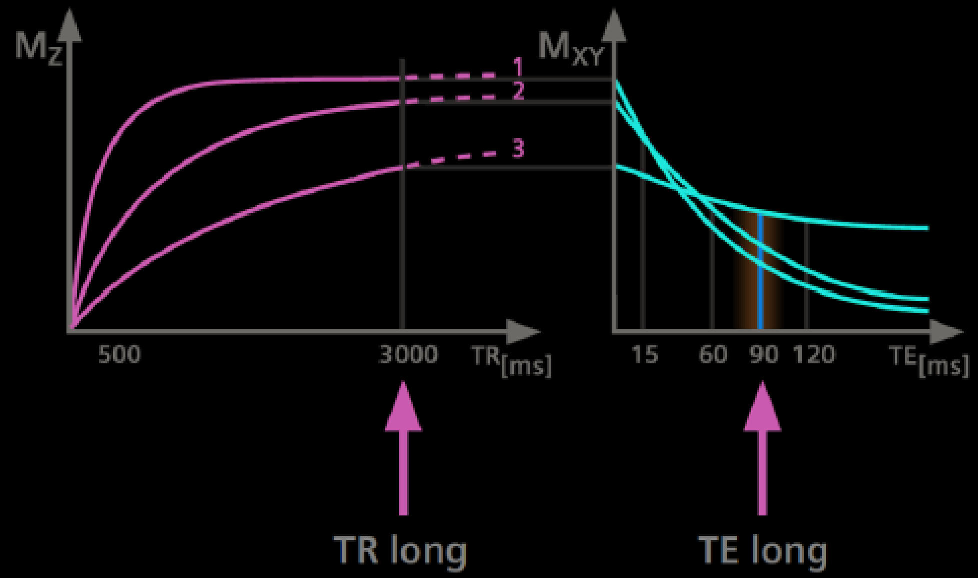
- Short TR
  - Maximizes T1 contrast due to different degrees of saturation
- Short TE
  - Minimizes T2 influence, maximizes signal

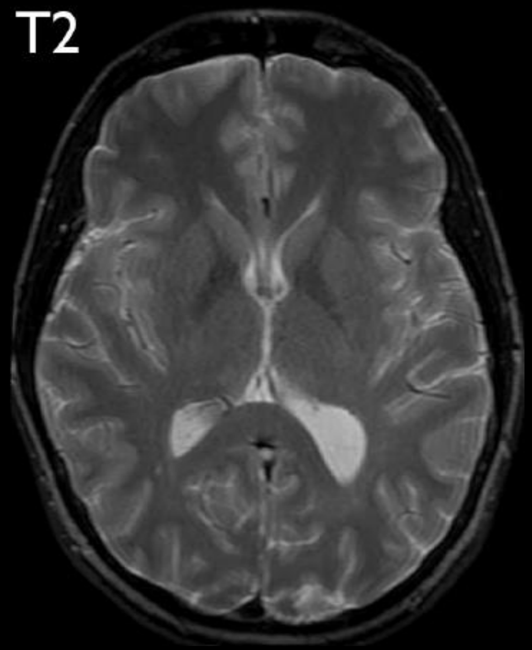




T2 weighted image (T2WI)

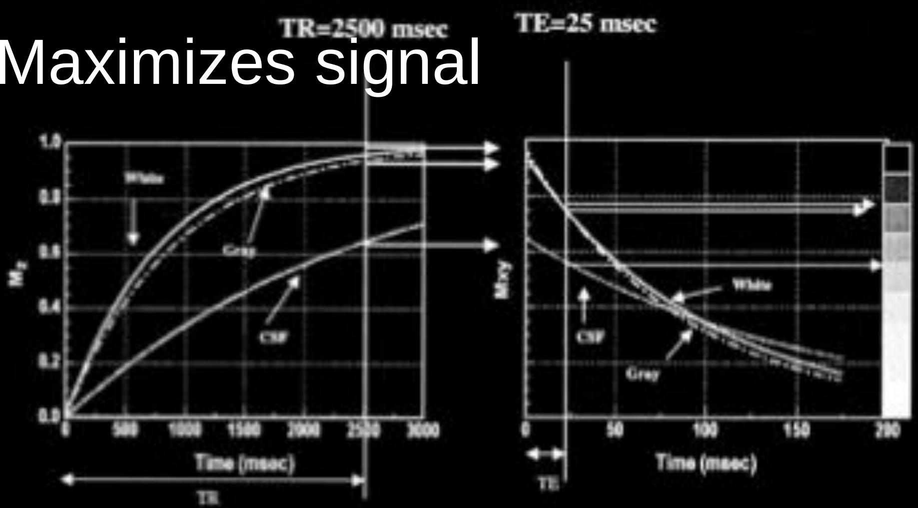
- Long TR
  - Reduces saturation and minimizes influence of different T1
- Long TE
  - Maximizes T2 contrast
  - Relatively poor SNR

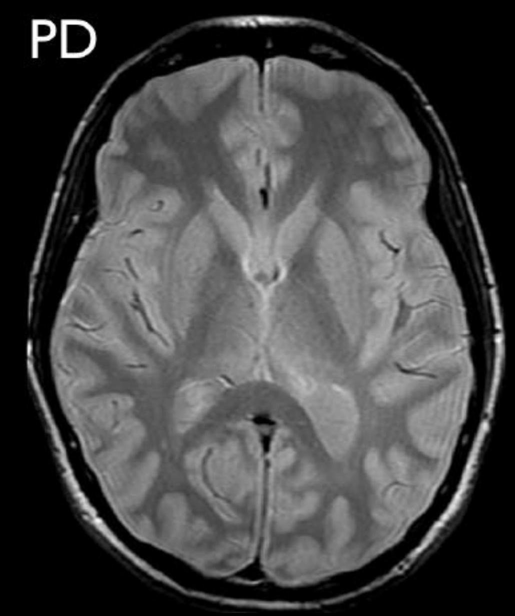




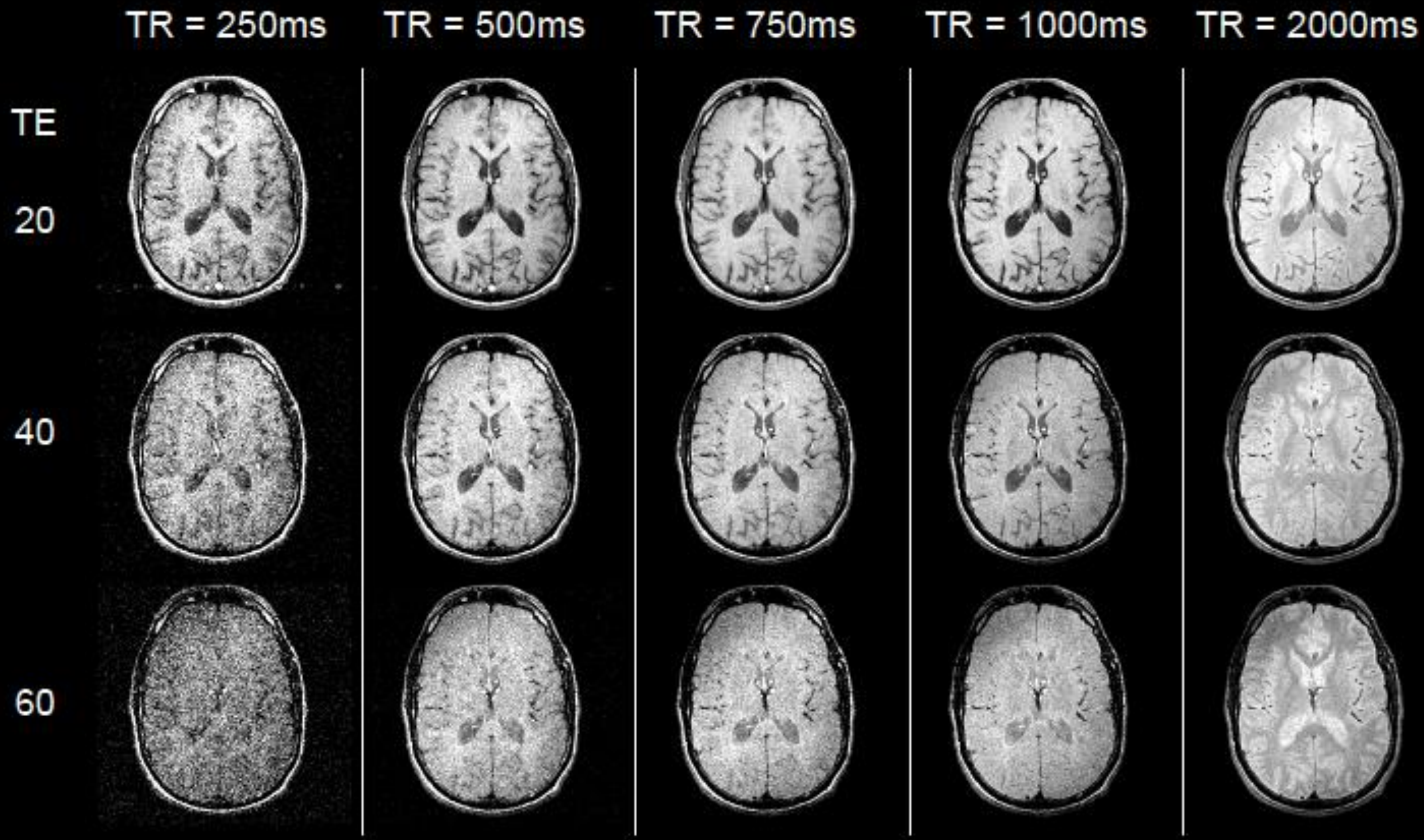
Proton density weighted image (PDWI)

- Long TR
  - Minimizes effects of different degrees of saturation (T1 contrast)
  - Maximizes signal
- Short TE
  - Minimizes T2 contrast
  - Maximizes signal





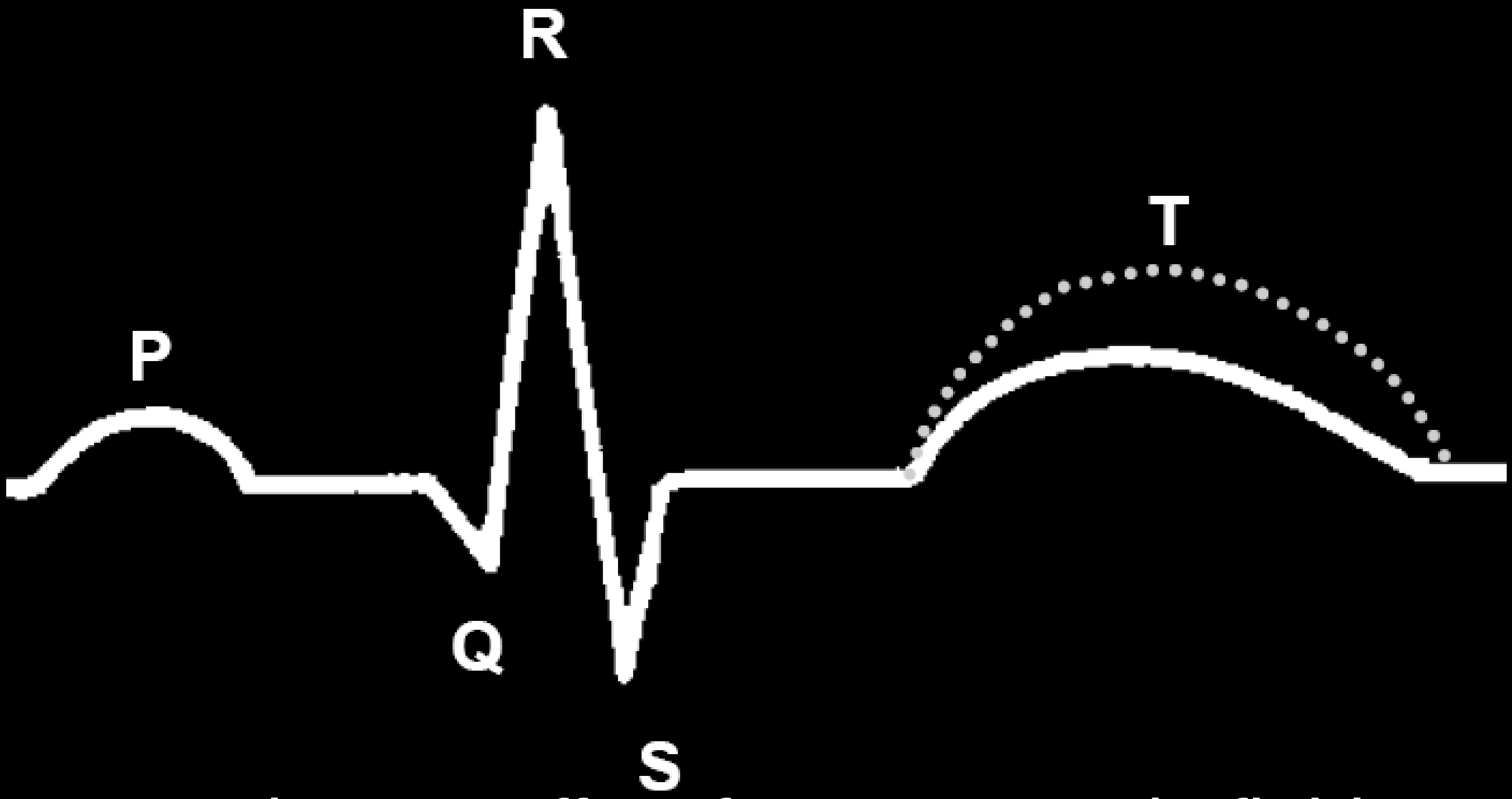
TR and TE



Bioeffects of Main Field

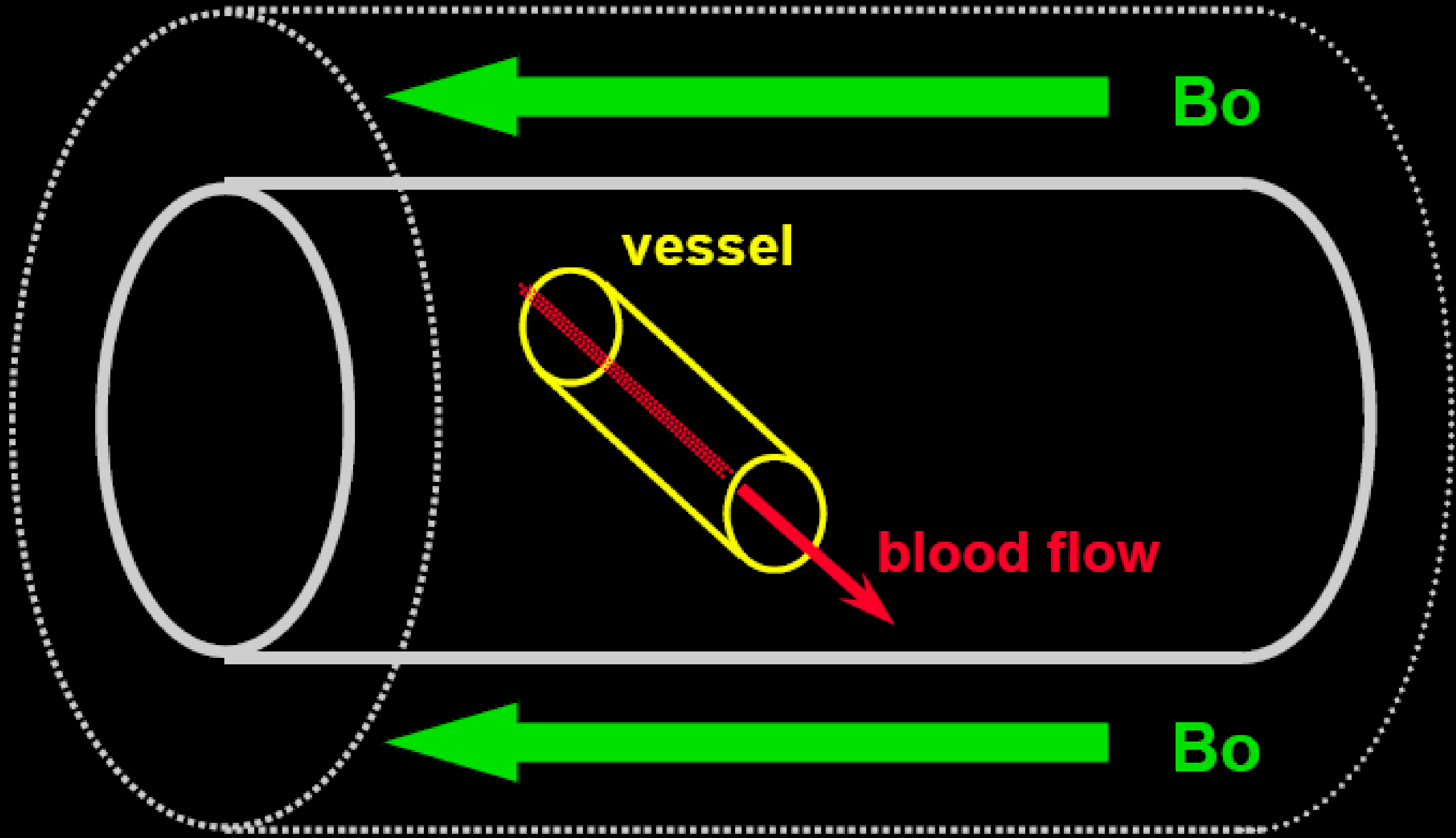
- Enhanced T-wave in ECG
- Magnetohydrodynamic effect
- Blood is electrically conductive
- Electrical induction from moving conductor in magnetic field
- Detected by ECG surface electrodes

Enhanced T-wave in Electrocardiogram



- A known effect from MRI main field

Magnetohydrodynamic Effect



- Electrical induction from moving conductor

RF Bioeffects

- Local temperature increases with too much RF
- FDA: specific absorption rate (SAR) limits (2004):
  - Mean < 3.0 W/Kg in head
  - Mean < 4.0 W/Kg whole-body
  - Mean < 8.0 W/Kg body (軀幹)
  - Mean < 12 W/Kg locally (四肢)
- Automatic detection by MRI system (body weight)
- Related to protocol, e.g. fast spin echo

Heating Effects from RF

- Temperature raise induced by RF
  - ~1ºC
  - Head < 38ºC, body < 39ºC, limbs < 40ºC
- Homeostasis for maintaining body temperature in human
- Blood flow carries away the heat

Gradient Bioeffects

- Magnetophosphene
- Rapid B_0 change on conductive human body
- Electric induction due to fast dB/dt
- Flash-like vision when optic nerves fire action potential

Magnetophosphene

- Smaller effects near MRI isocenter
- Peripheral nerve stimulation
- Response gone after scan stops
- Optic nerves unharmed
- Present in EPI scan only

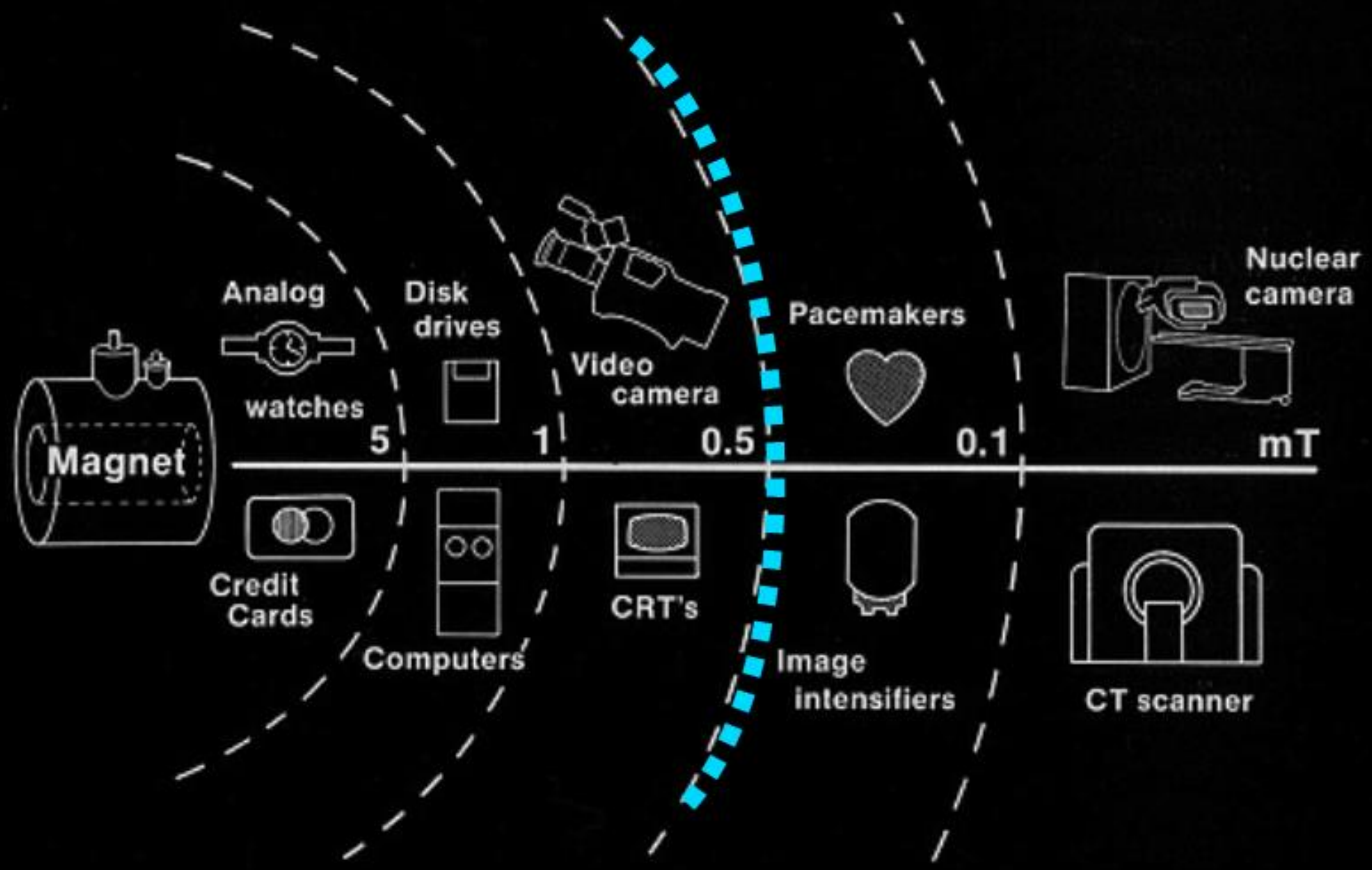
Protection for MRI Safety

- What kind of protection do we need if MRI is so safe?
- No worry under normal operation
- Abnormal operation can be extremely dangerous

The Strong MRI Magnet

- Earth field: 0.5 Gauss
- Toy magnets: ~ 50 Gauss
- MRI magnet: 15,000~117,000 Gauss

Magnetic Effect to Electronic Devices



Danger of Strong B_0

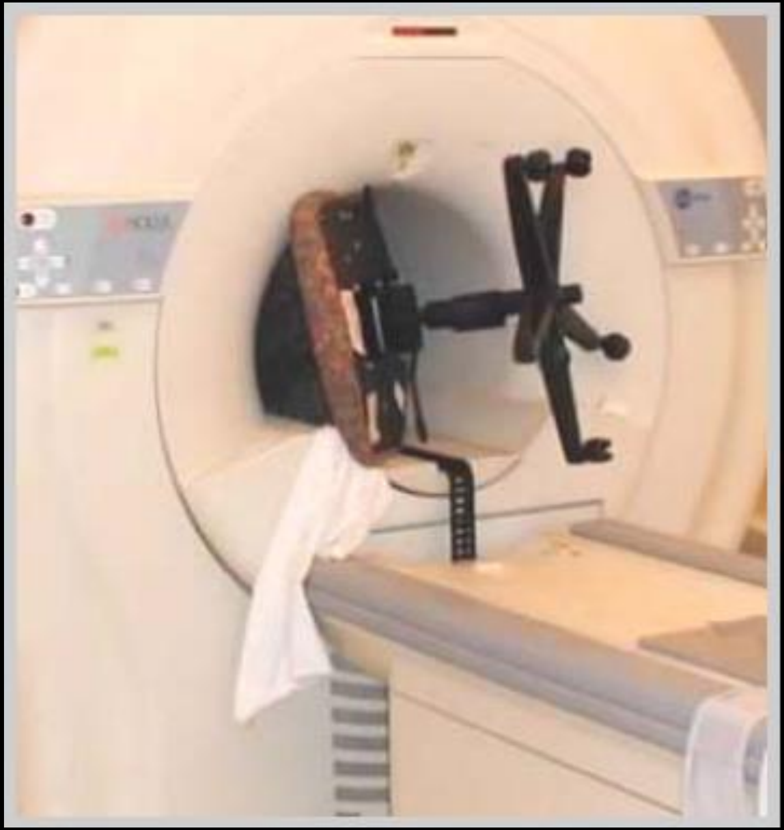
- Huge attractive force for appliance
  - Nail scissors, tweezers
  - Wrench, screwdriver, hammer
  - Computer, chair, oscilloscope

Danger of Ferromagnetic Object in MRI

Power amplifier

De-humidifier

Danger of Ferromagnetic Object in MRI

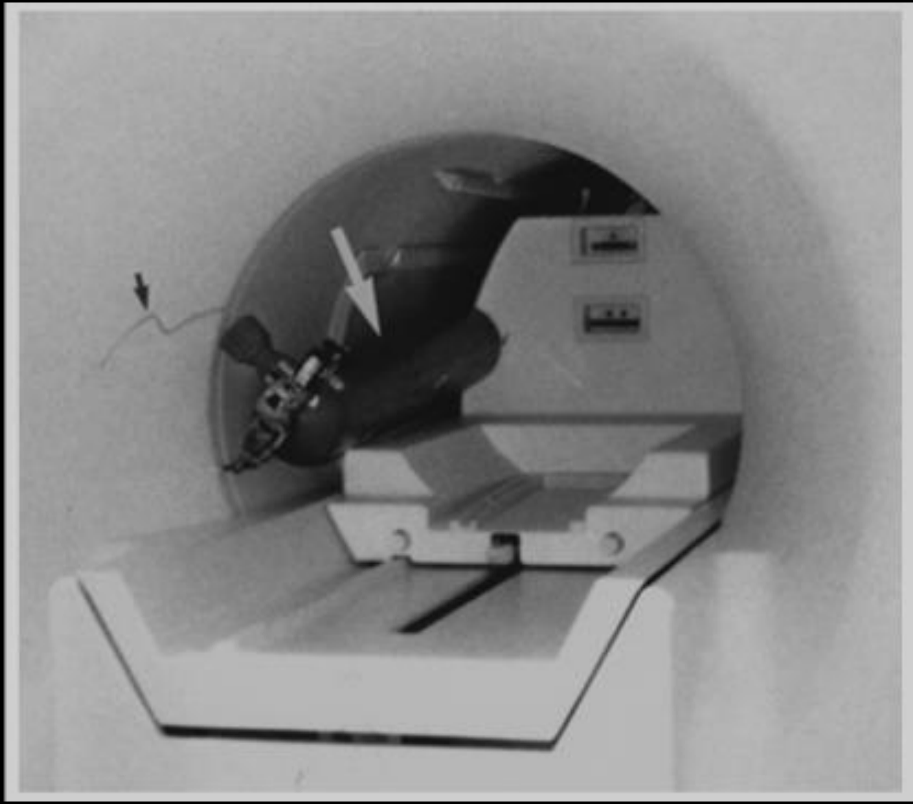


Chair

Buffer

Danger of Ferromagnetic Object in MRI

Nitrous oxide tank



Oxygen cylinder

Danger of Ferromagnetic Object in MRI

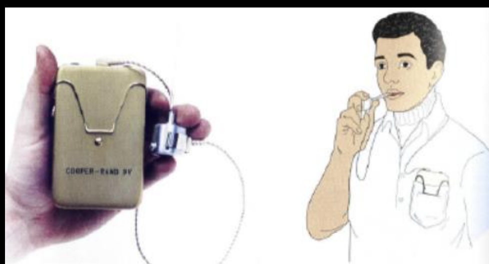
Vacuum cleaner

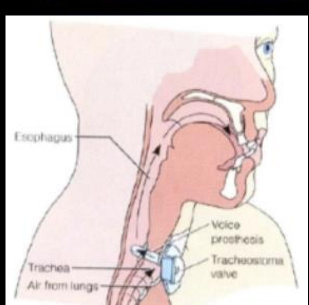
i.v. injector

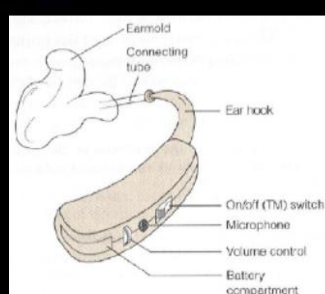
Other "Bad" Things

- Metal or magnetic stuff
  - Implants
    - Surgical clips
    - Cochlear implants
    - Injection pump
    - Prosthesis
  - Carry-on
    - Dental work
    - Leather belt
    - Make-up (eye shadow)
    - Hair pin
- Discomfort or image distortions

Some Known "Bad Things"







Superfunction or Susceptibility Artifact

恭賀 巴登洛德法王「金剛換體禪」開頂成聖

巴登洛德法王 MRI 核磁共振腦斷層，其頭頂大樂輪門處開口近 3 英吋寬，腦髓中開出一個下陷的深凹洞大如鵝蛋。

噶舉派巴登洛德仁波且

巴登洛德仁波且： 喜饒僧格轉世的噶舉瑪倉派法王，是第三世多杰羌佛的弟子。受第三世多杰羌佛灌頂傳境行大法"金剛換體禪"，堅持自行修持開頂，並誓言若不修成，斷臂燃燈供佛，代眾生受苦。虔修三年如願開頂，MRI 核磁共振腦斷層掃描檢測，其頭頂大樂輪門處開口近三英寸寬，腦髓中開出一個下陷的深凹洞大如鵝蛋。2011 年自請七師十證考核證量，在百餘信眾面前入三昧定神識出體，施展聖力轉動金剛杵。更為殊勝的是，當時整個考場內外出現極其祥瑞的聖境，無數曼陀羅瓚城在人群中穿梭，天空白雲降到樹梢上，多杰羌佛藍色莊嚴像出現在眾人頭頂，化為五彩虹光飛向天際。考試結果，十七位聖德考官發重誓擔保巴登洛德仁波且為"金剛換體禪"開頂聖德。

翻拍自「無上珍寶之福音」佛書 34 頁

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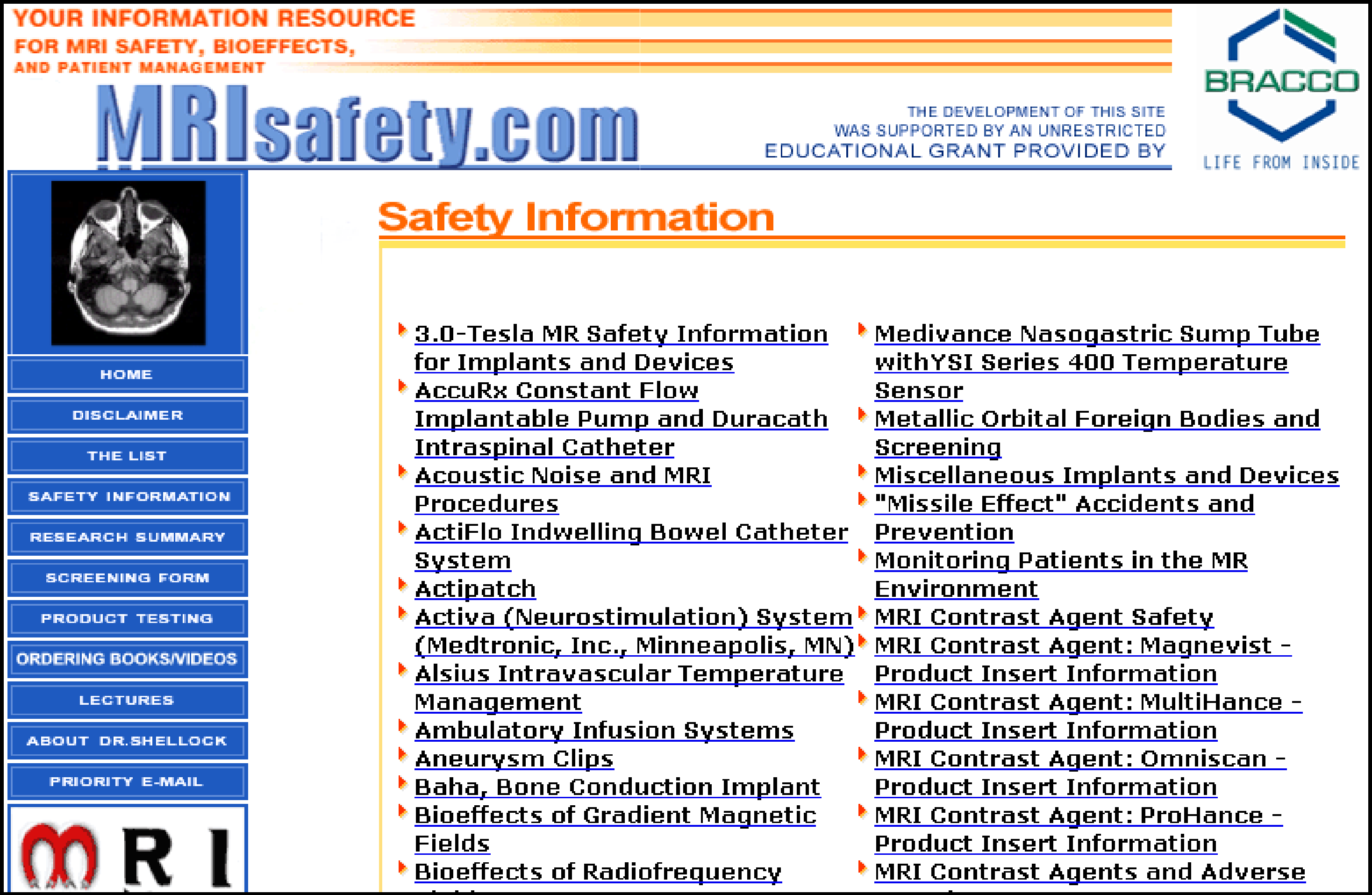
全敬賀

Safety information



- http://www.mrisafety.com/safety_info.asp

Take home message

- Excitation
- Relaxation: T1, T2
- Image contrast: T1WI, T2WI, PDWI
- Scan parameters: TR, TE
- Bioeffect and safety

Thank you for your attention

- May the force be with you