Basic ideas

- **Magnetic**: the signal source (magnetization)
- **Resonance**: signal excitation and detection
- **Imaging**: spatial encoding of signals

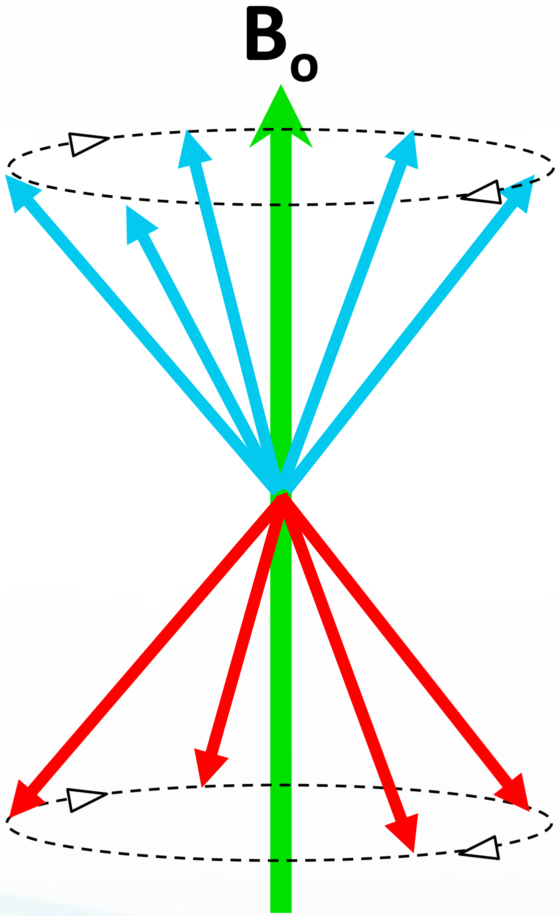
Magnetization has been formed, but…

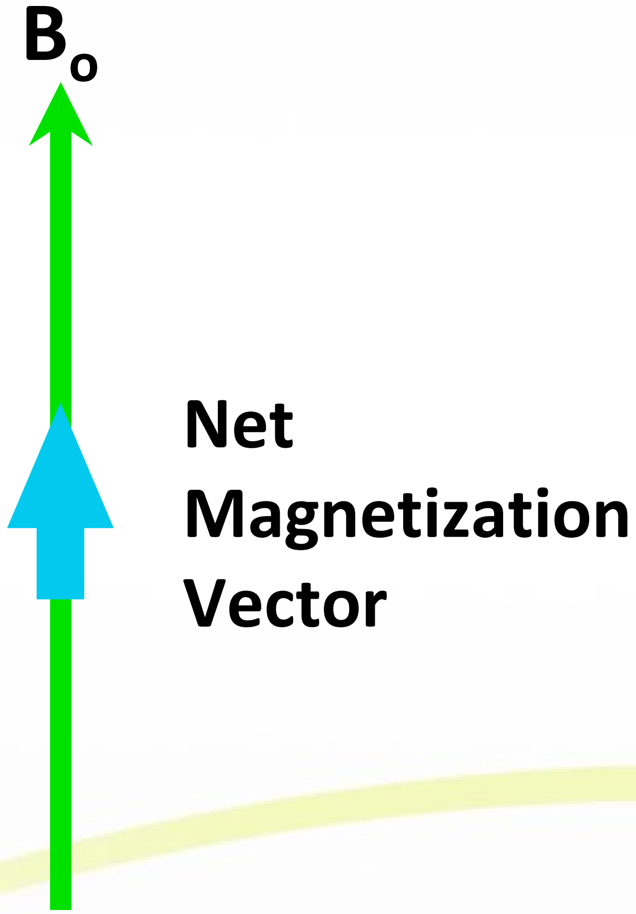
- It aligns with the magnetic field at thermal equilibrium.
- Proper stimulation is required for signal detection.
- Richard Ernst
  - Awarded 1991 Nobel prize for the development of FT NMR spectroscopy

Basic idea of resonance

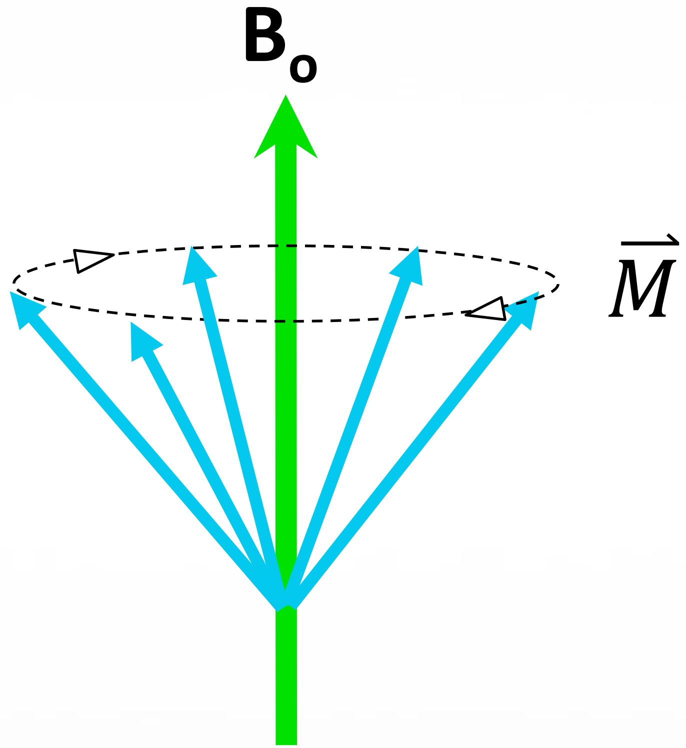
- Motion of magnetization results in time-varying magnetic flux, inducing electrical current.
  - Faraday's law of induction
- Force the motion of $\vec{M}$: excitation
- Evaluate the motion of $\vec{M}$: detection
- Basic tool of MRI: **RF coil**

Nuclear magnetization





If magnetization does not align with B_0



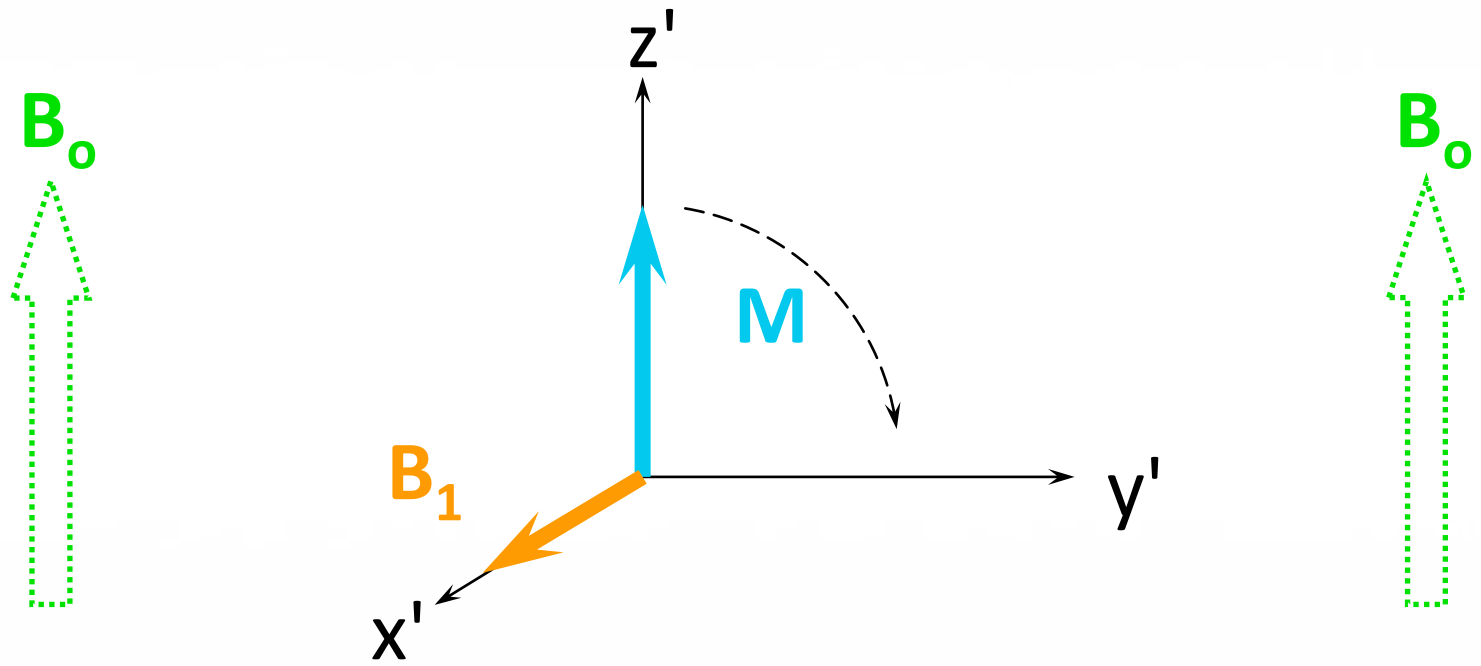
Magnetization will precess along with B_0 (moving now!)

But the main magnetic field is…

- To generate nuclear magnetization
  - Aligned with the magnetic field
- Strong, homogeneous, and static
  - But not able to force the body magnet to move/tilt

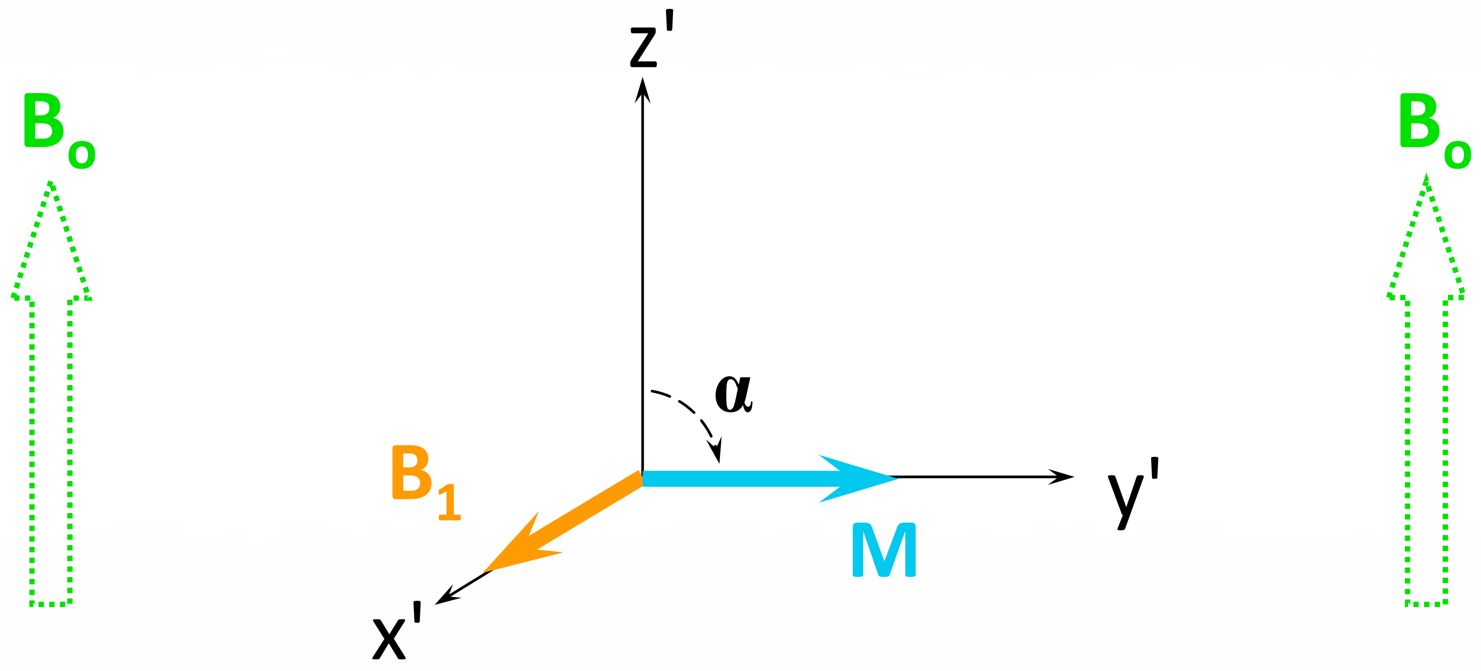
- You need more to make it move! How?

Excitation field (B_1)



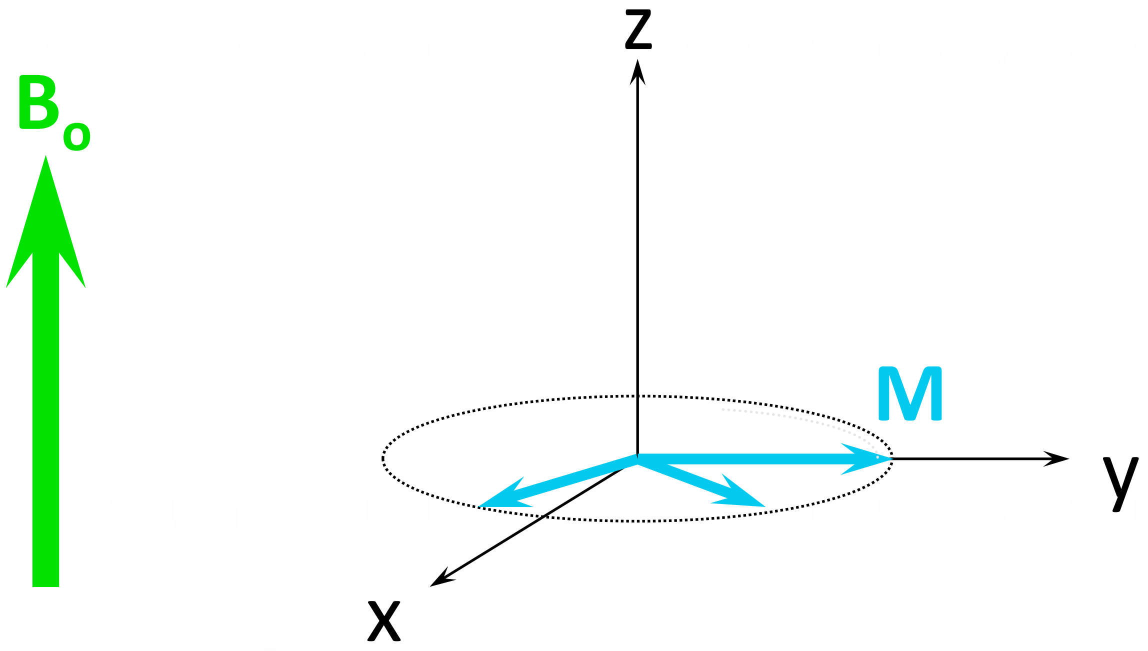
Resonance: the rotating/oscillating frequency of B_1 = Larmor frequency

Excitation field (B_1) and the flip angle (α)



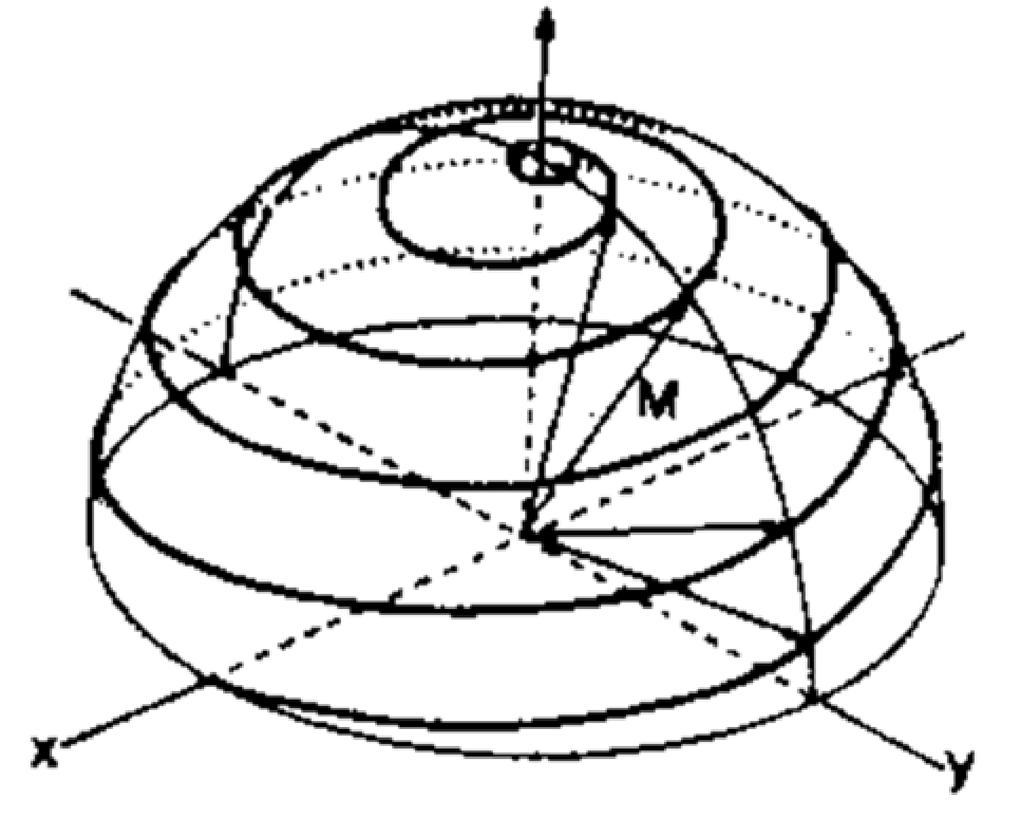
The flip/tilt angle: $\alpha = \gamma B_1 \tau$

After signal excitation (turning B_1 off)



Resonance: Precession of magnetization @Larmor frequency

Trajectory of excitation (laboratory view)

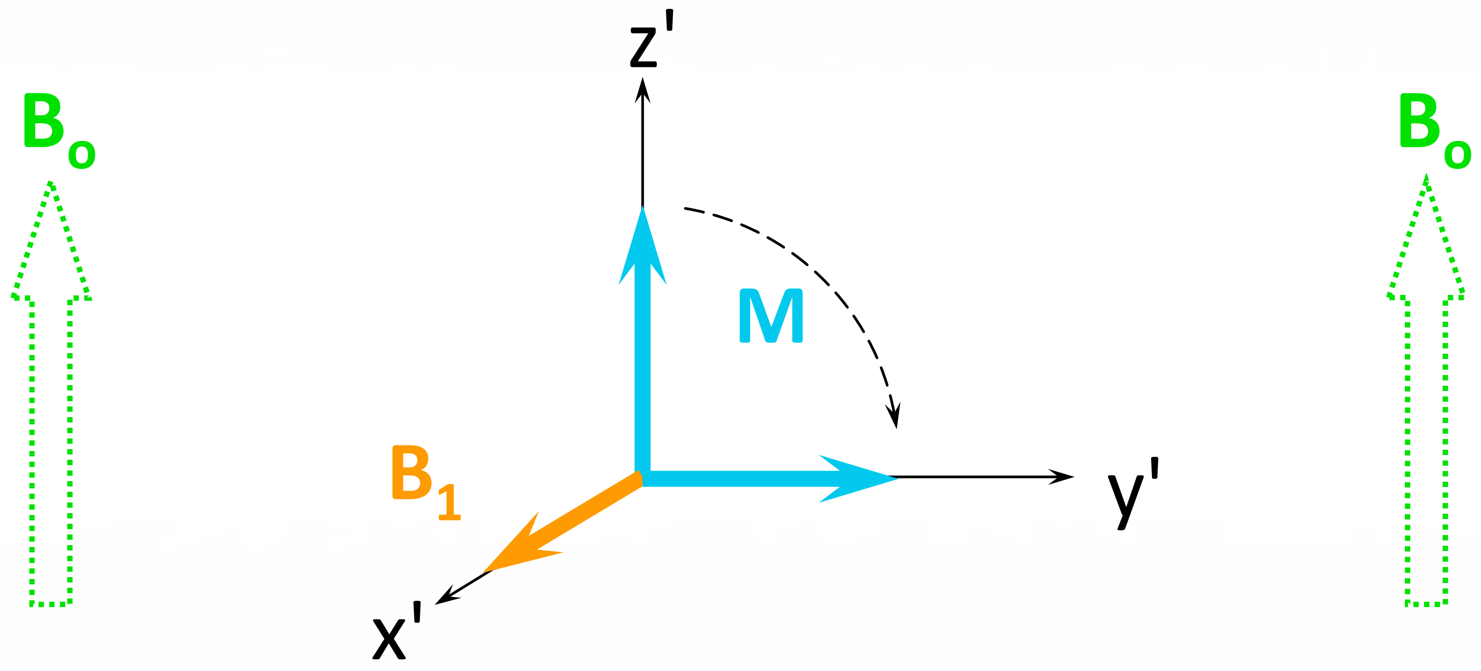


Bloch simulator: http://www.drcmr.dk/BlochSimulator/

Device for RF excitation: RF coil

- To generate a rotating excitation field (B_1) which is perpendicular to the main field (B_0)
  - Oscillating frequency: Larmor freq. (RF waveband)
- Drive the coil with AC at Larmor frequency
  - High efficiency/gain at Larmor freq.
  - Used as an EM-wave transmitter

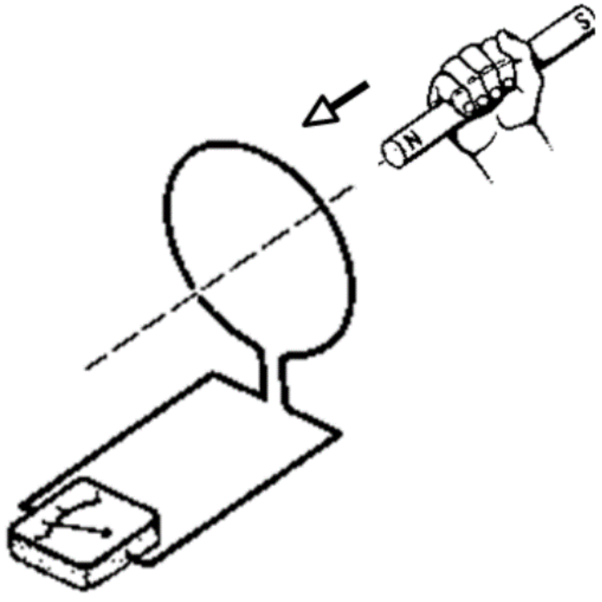
Excitation field (B_1)



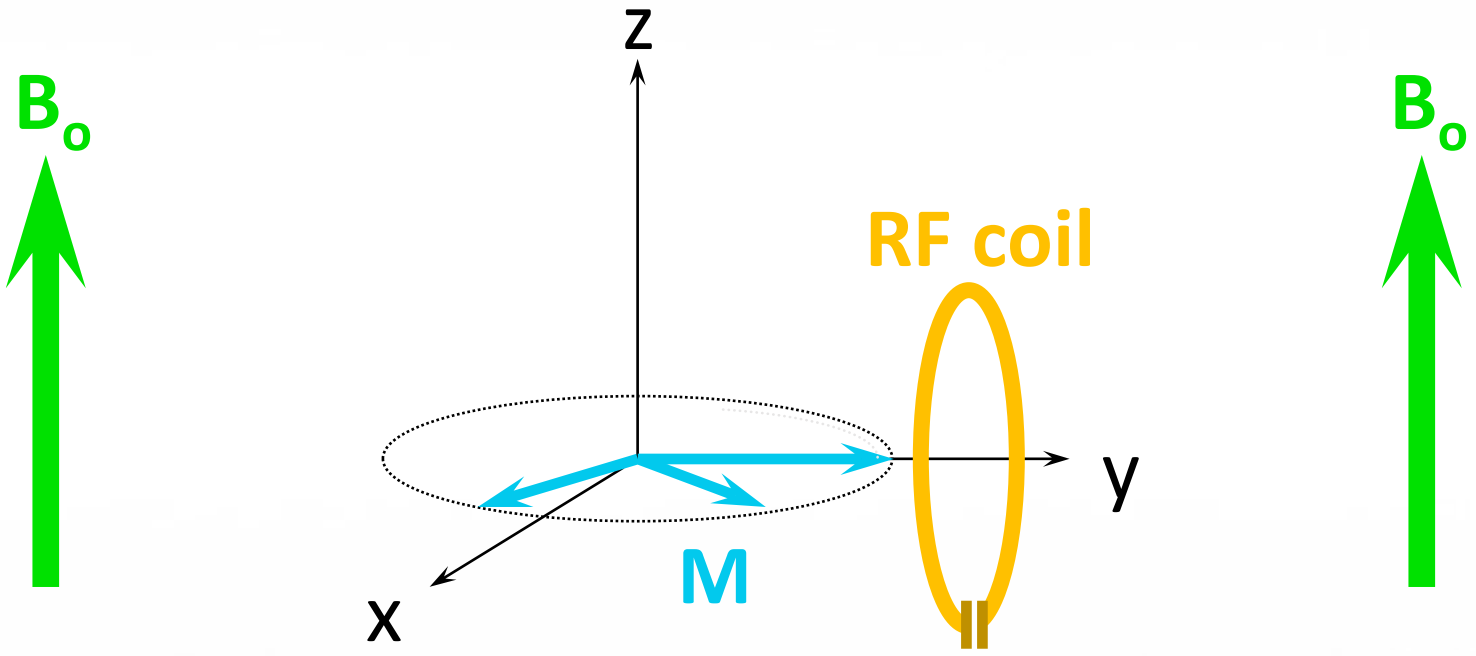
Resonance: the rotating/oscillating frequency of B_1 = Larmor frequency

Detection

- Faraday’s law of induction
- Precession of magnetization induces AC at Larmor frequency.



After turning off the excitation…



Resonance: Precession of magnetization @Larmor frequency

Device for RF reception: RF coil

- To pick up the inductive electrical current
  - Orientation: perpendicular to the main field (B_0)
  - Oscillating frequency: Larmor freq. (RF waveband)
  - Used as an EM-wave receptor

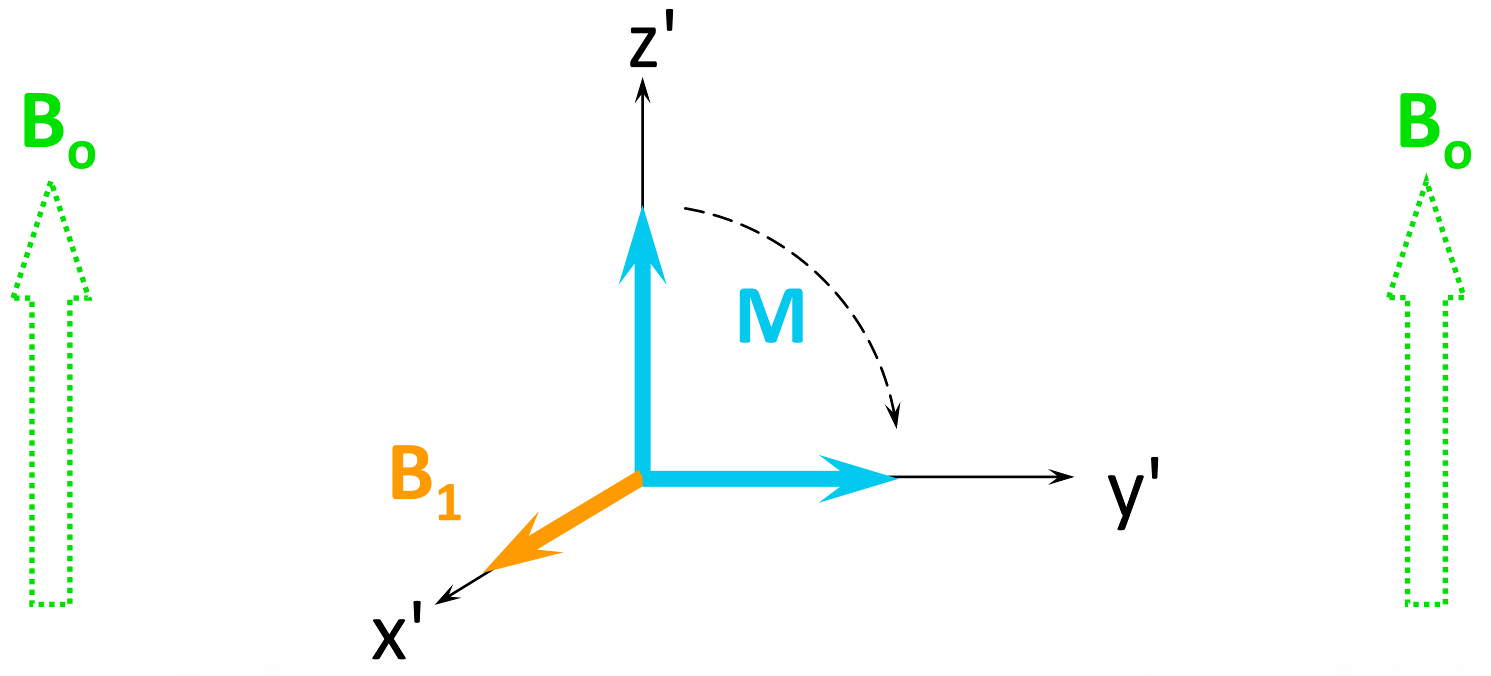
RF excitation and detection

- The requisite for RF excitation and detection is quite similar!
- You can use the same RF coil for both purposes.
- Usually, different coils are used separately to reach
  - Homogeneous excitation
  - Sensitive detection

Relaxation

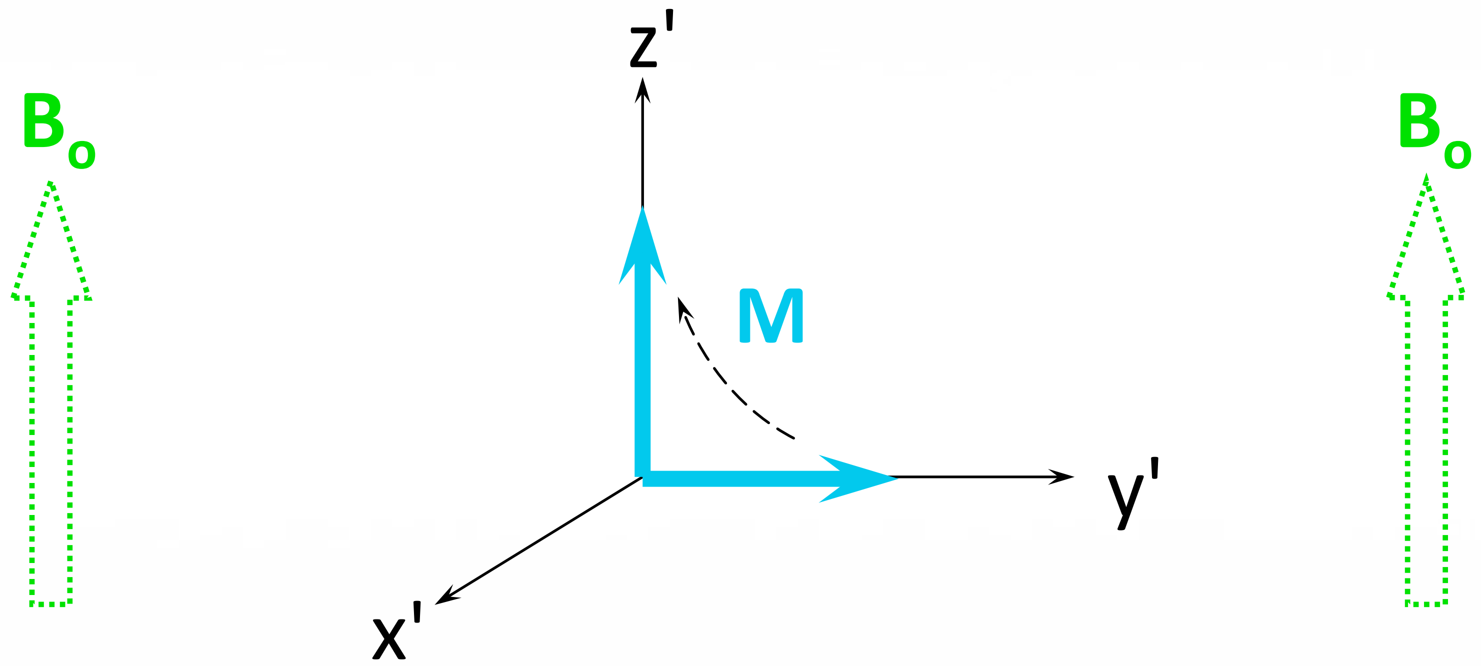
- After excitation, the spins tend to return to its initial state (thermal equilibrium)
  - T1 relaxation: recovery of longitudinal magnetization M_z
  - T2 relaxation: decay of transverse magnetization M_{xy}
- Inherent property of tissue, which is associated with microstructure and biochemistry

Excitation field (B_1)



Excitation of magnetization

Relaxation

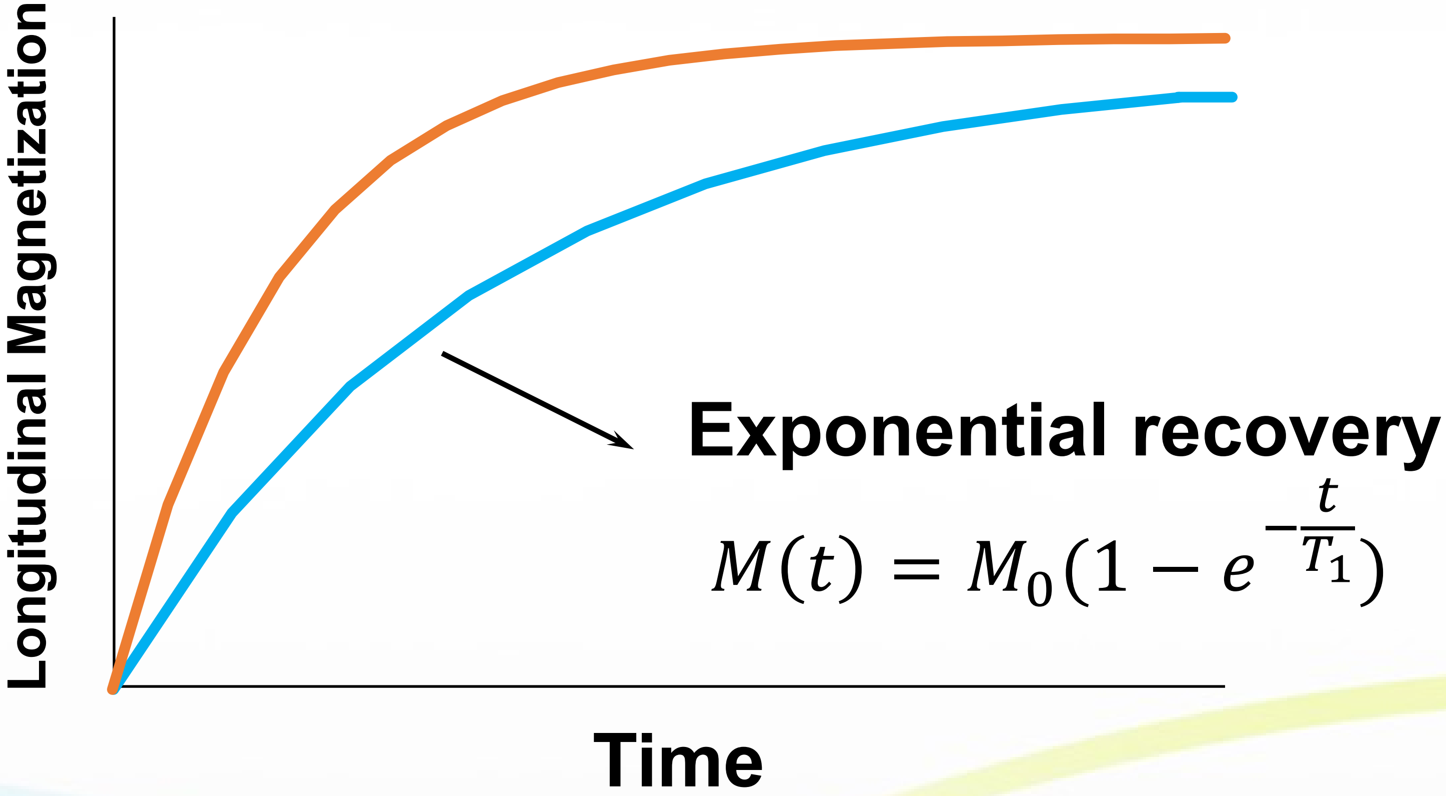


Magnetization always returns to its thermal equilibrium

T1 Relaxation

- Longitudinal return of magnetization
- T1 relaxation time is the time constant of exponential recovery
  - Reaching 63% of its maximum after one T1
- Longer T1 indicates slower recovery

T1 recovery



$$M(t) = M_0(1 - e^{-\frac{t}{T_1}})$$

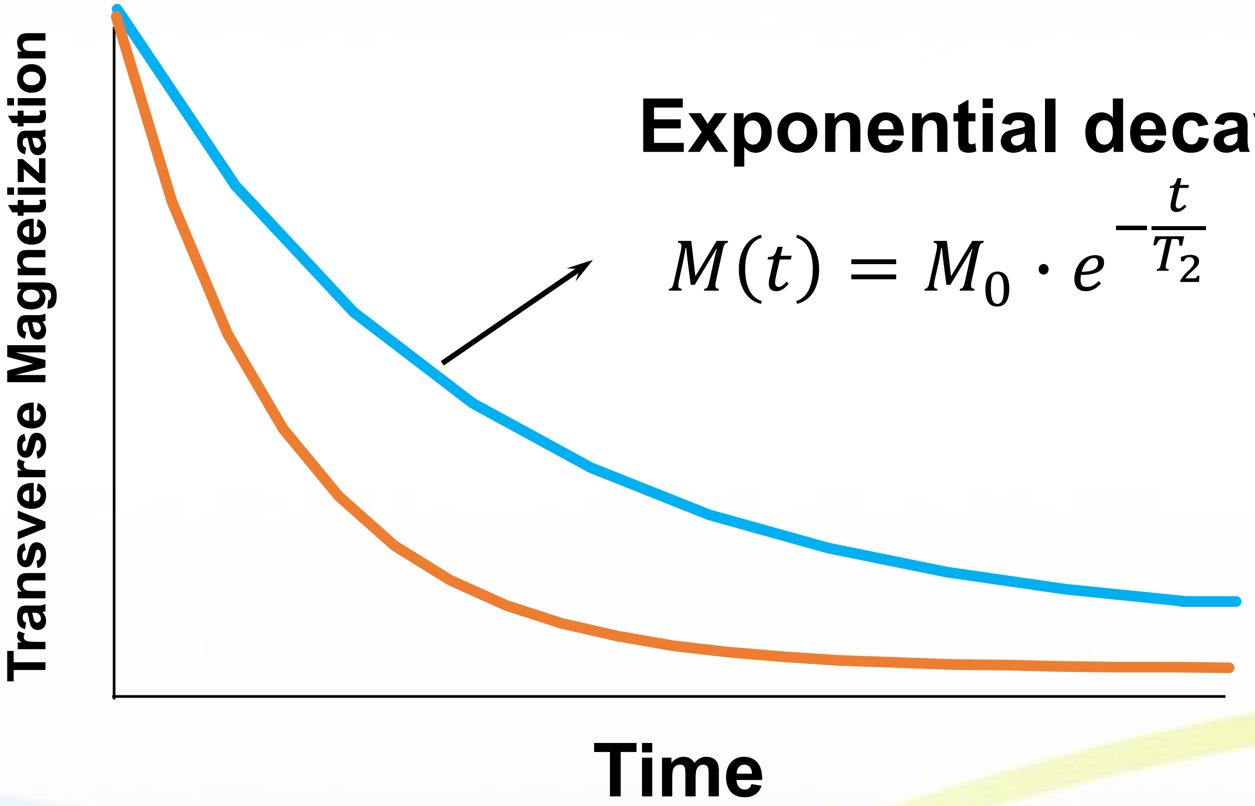
The physical meaning of T1 Relaxation

- During excitation, some of the spins receive RF energy to reach higher energy level
- To return to thermal equilibrium, the release of energy must occur
  - Released to its surroundings (lattice)
- Also termed as spin-lattice relaxation

T2 Relaxation

- Transverse decay of magnetization
- T2 relaxation time is the time constant of exponential decay
  - Reaching 37% of its initial value after one T2
- Longer T2 indicates slower decay

T2 decay

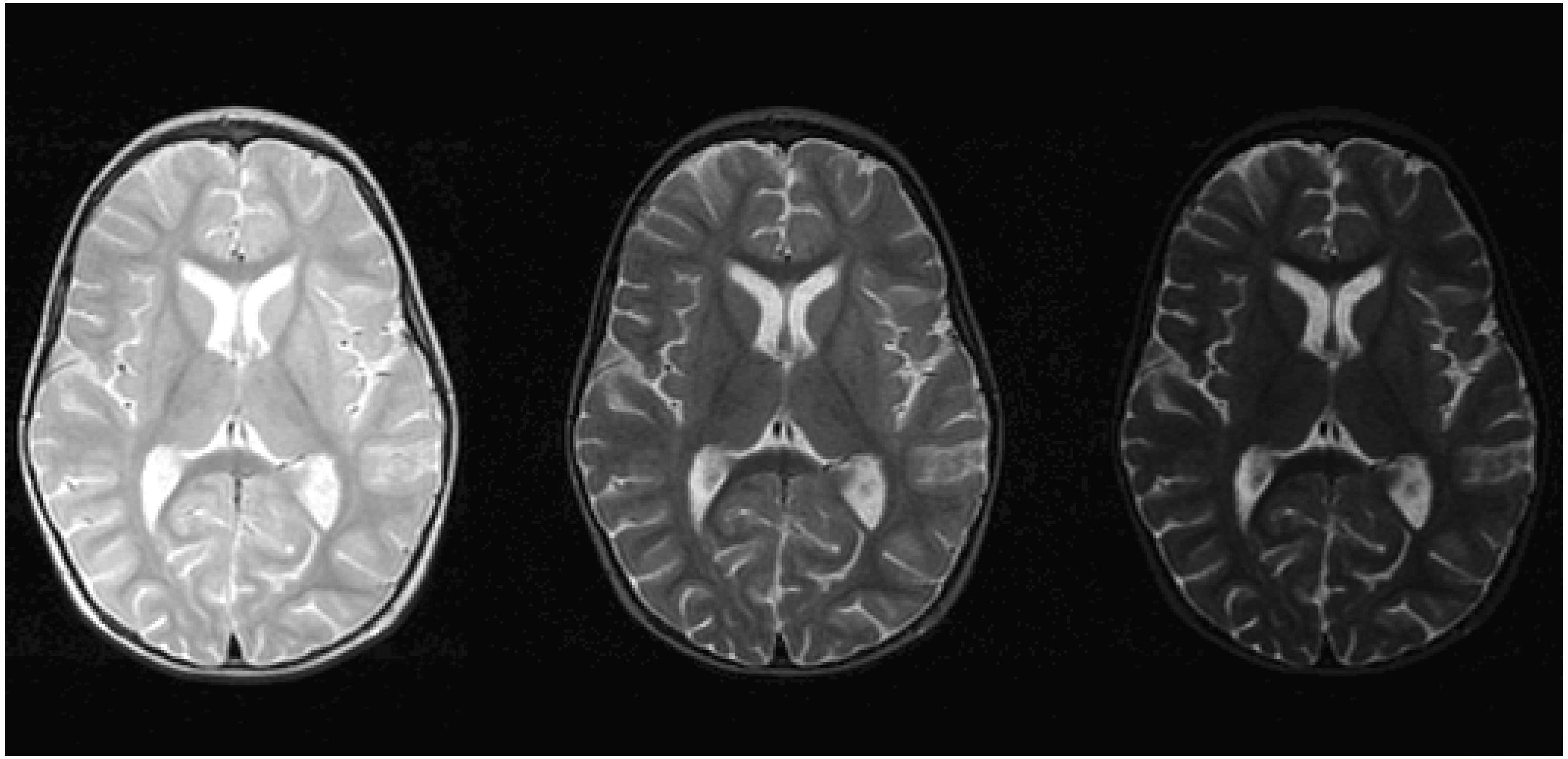


$$M(t) = M_0 \cdot e^{-\frac{t}{T_2}}$$

The physical meaning of T2 Relaxation

- Local field disturbance cause the incoherence of transverse magnetization
  - Magnetic dipoles
  - Rotation and trembling of water molecules
  - Macromolecules (e.g., protein)
- Also termed as spin-spin relaxation

T2 contrast: an effect of TE

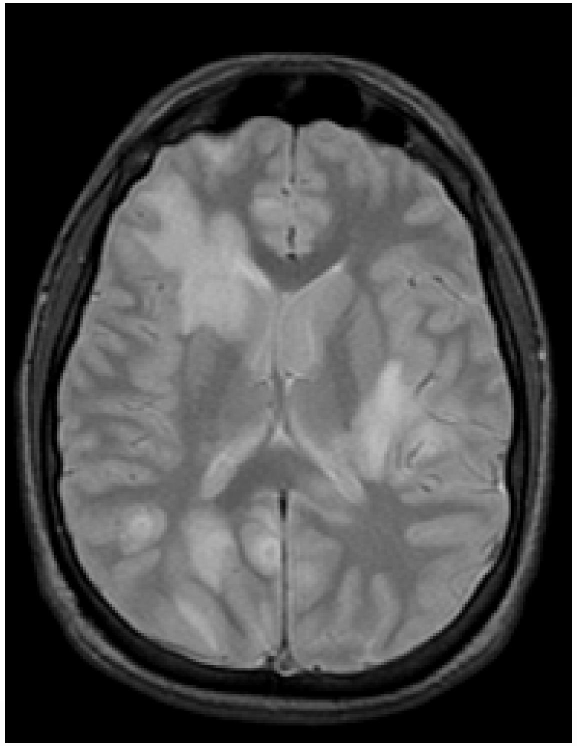


TE = 30 TE = 90 TE = 150

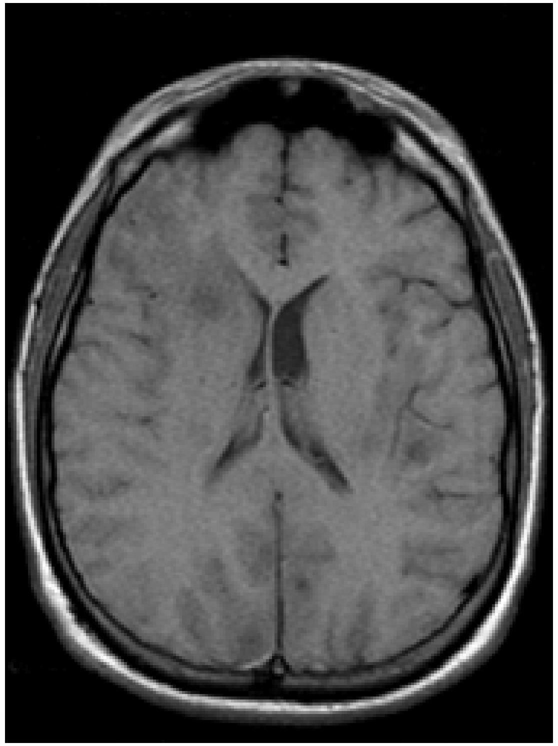
Why relaxation matters?

- Relaxation provides information of tissue change associated with diseases.
- For example, tumor usually has higher T2 than normal tissue.

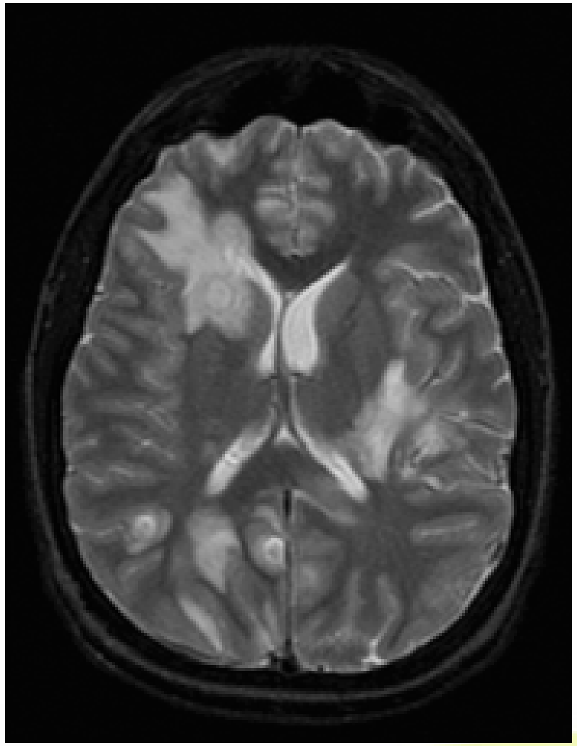
Brain MRI



PDWI



T1WI

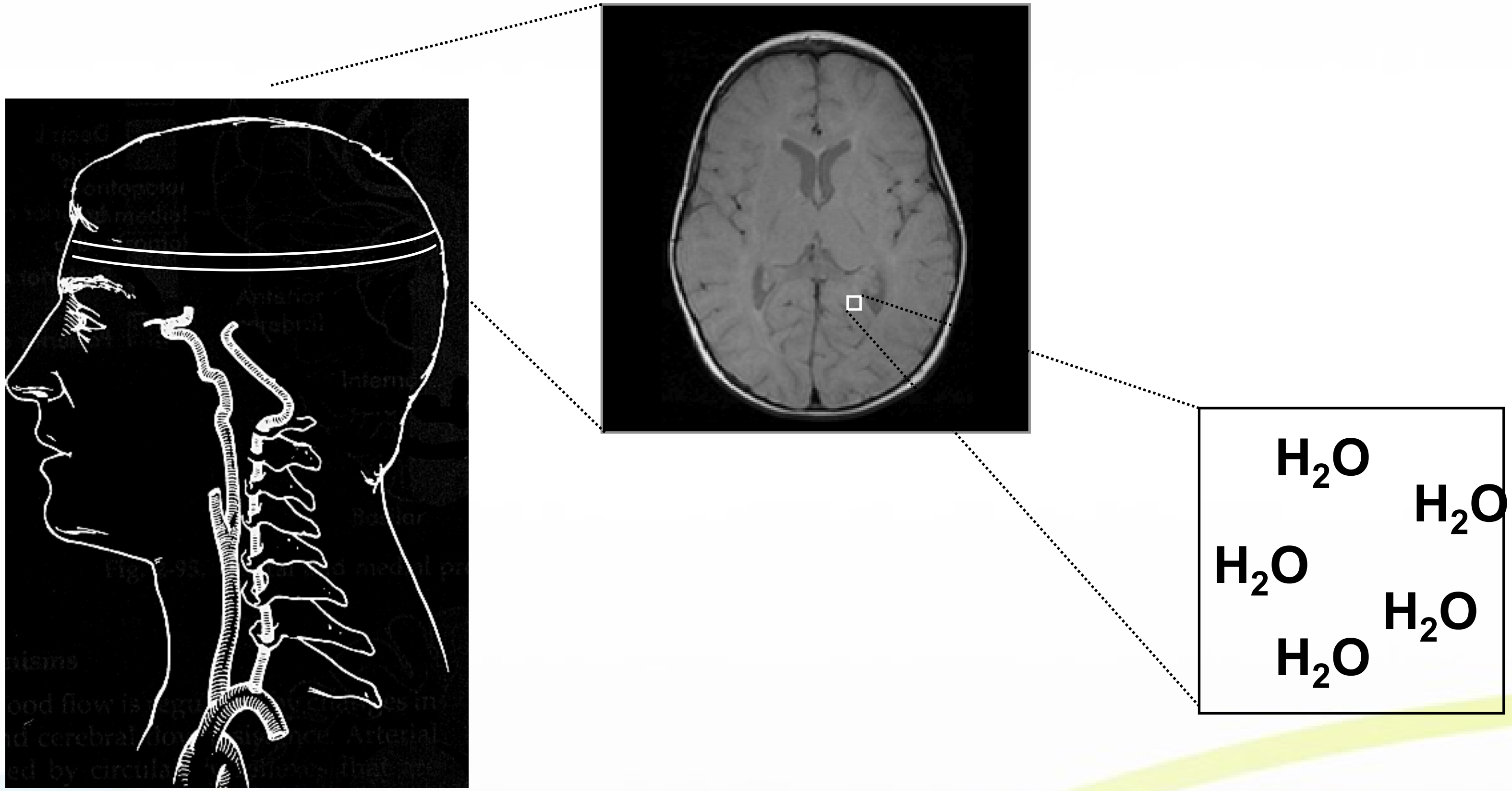


T2WI

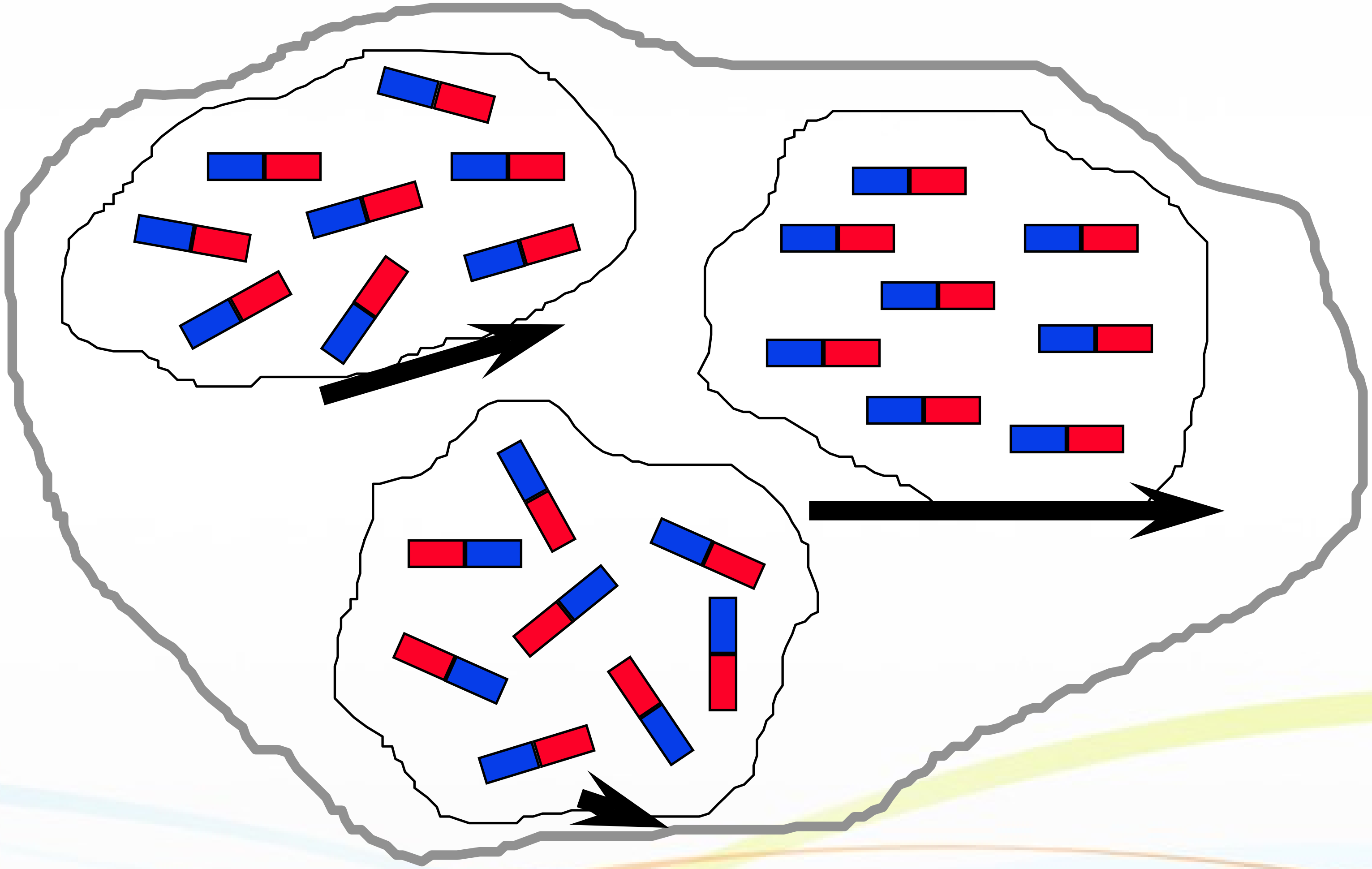
In fact, decay could be faster…

- Inhomogeneity of magnetic field may lead to incoherent precession and intravoxel dephasing.
  - Intrinsic defects of main magnetic field
  - Tissue susceptibility
- T2* relaxation (T2* ≤ T2)

Every voxel contains tons of H nuclei

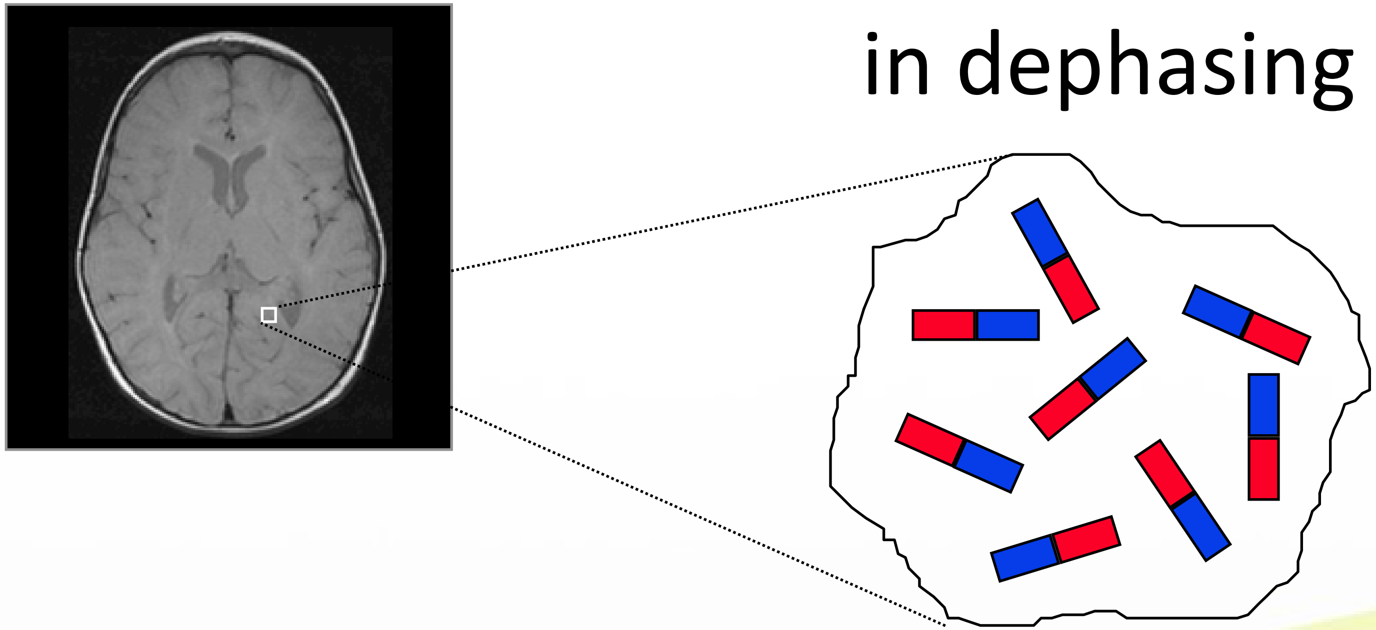


Phase incoherence

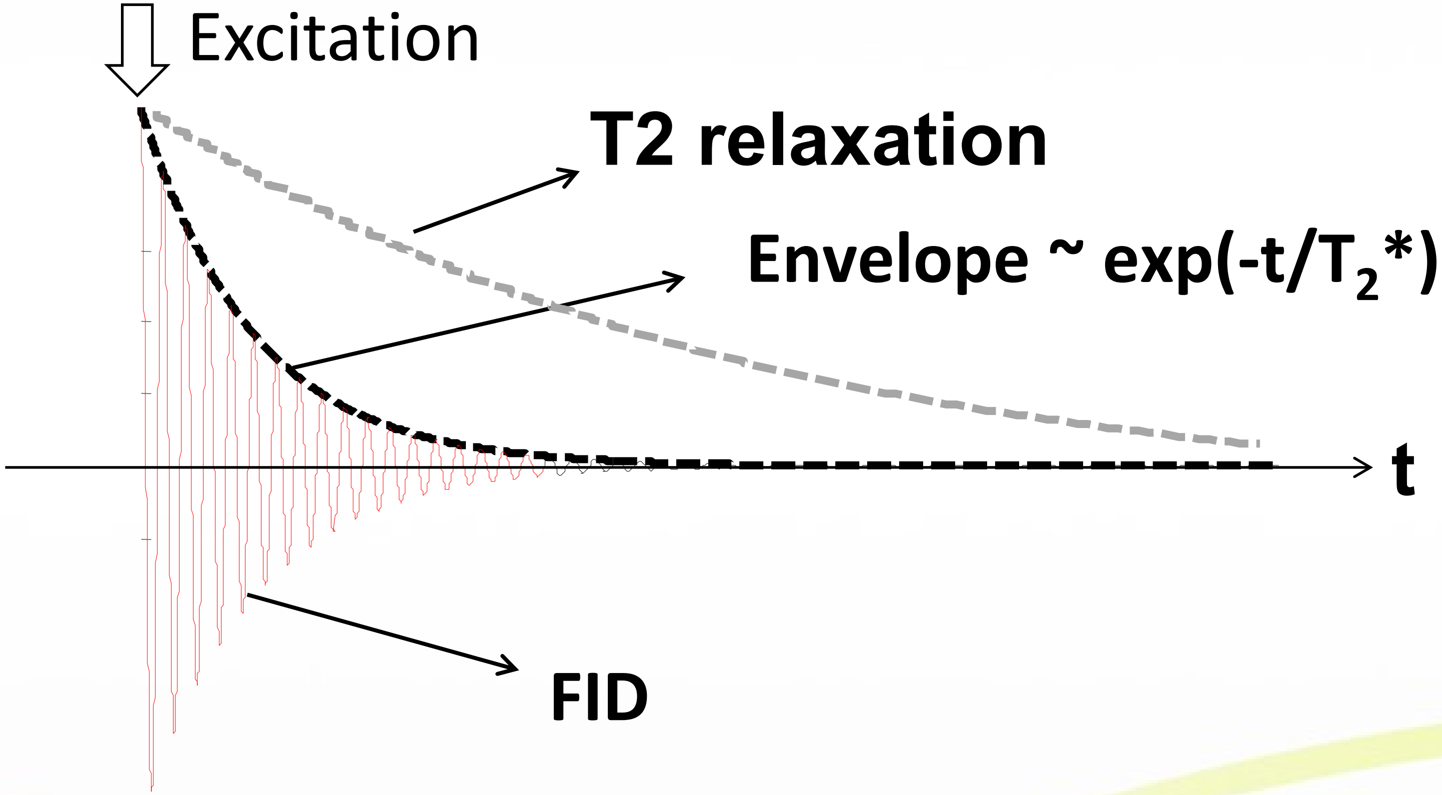


Intravoxel dephasing

Low signal intensity
in dephasing voxels



Free Induction Decay



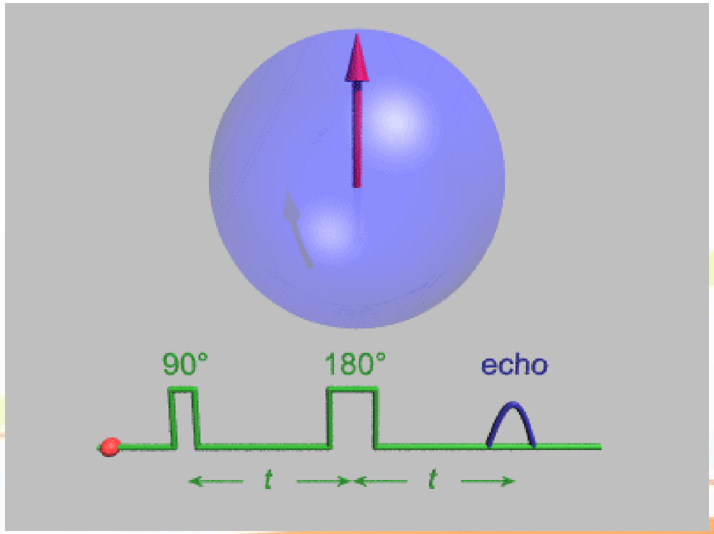
T2 vs T2*

- T2: atomic and molecular level, non-reversible
- T2*: related to instruments/tissues, reversible

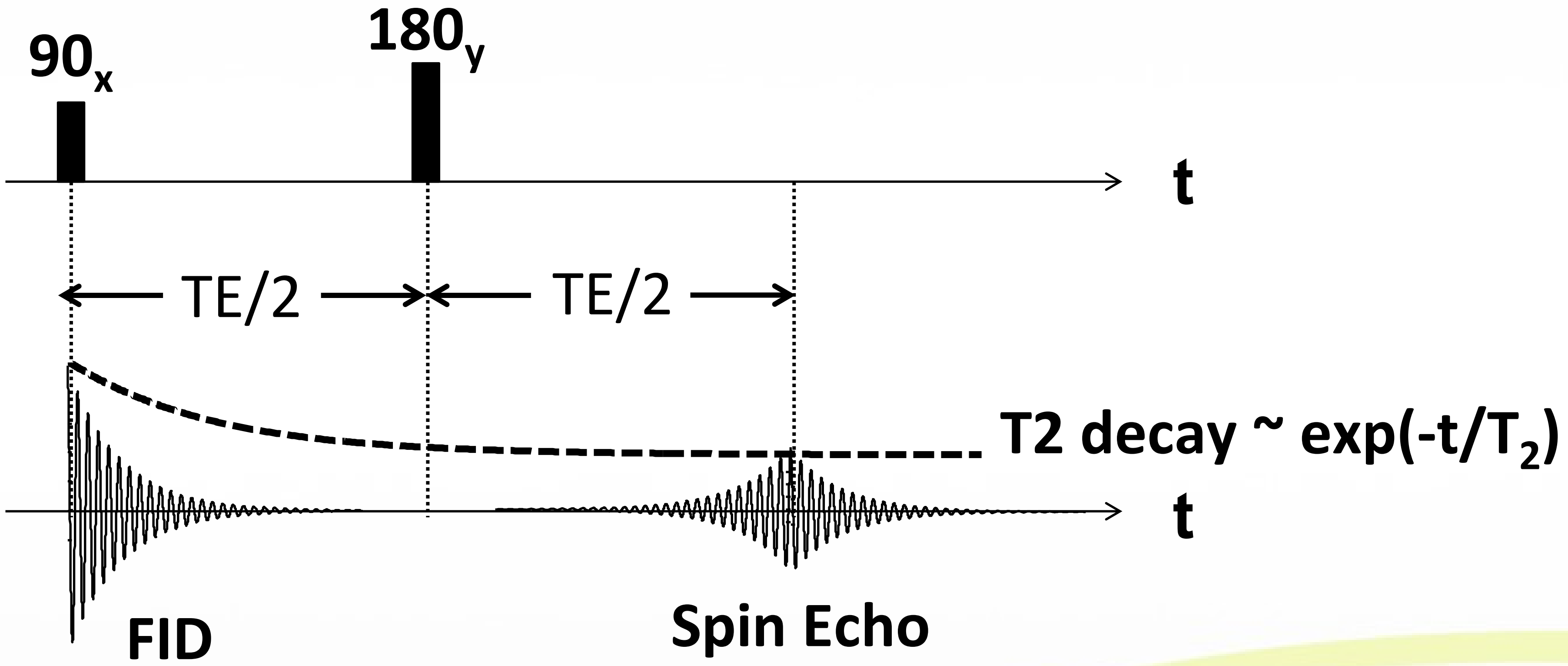
- How to retrieve T2 decay?
  - Pure microscopic information

Concept of spin echo

- Following excitation, use an 180° RF to invert the phase angle
- Spins refocus to form the spin echo after an equal duration
  - T2 relaxation



Spin echo



Measurement of T1/T2 relaxation time

- Concept: sampling on the relaxation curve
- T2: multi-echo spin-echo
- T1: inversion recovery
- Curve fitting with two or more points