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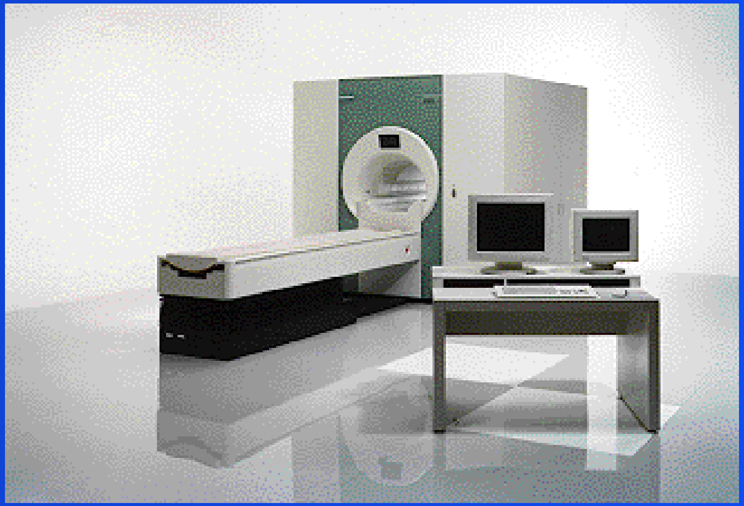
An Introduction to the Basics of Magnetic Resonance Imaging



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1

MR Physics

The Hydrogen Atom and Protons

- The most common element in the body
- Highest sensitivity to magnetic resonance
- Hydrogen ion (proton) is positively charged

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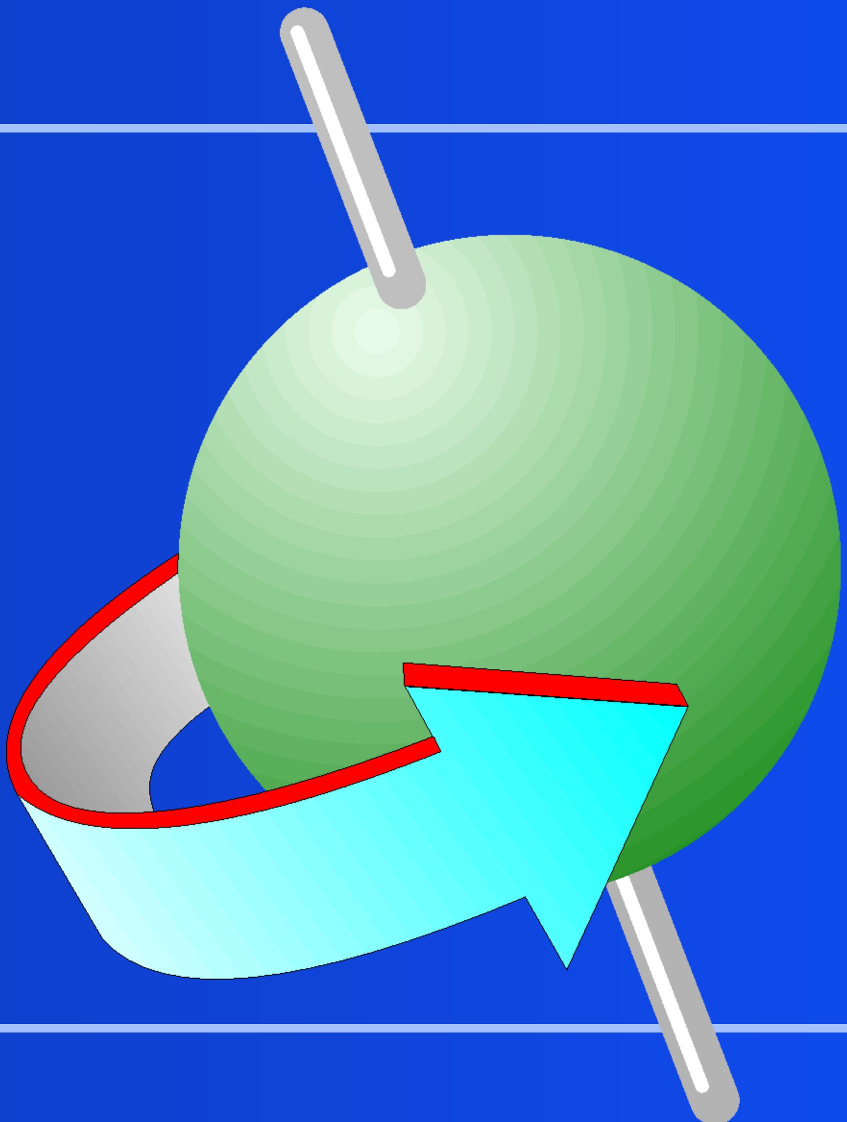

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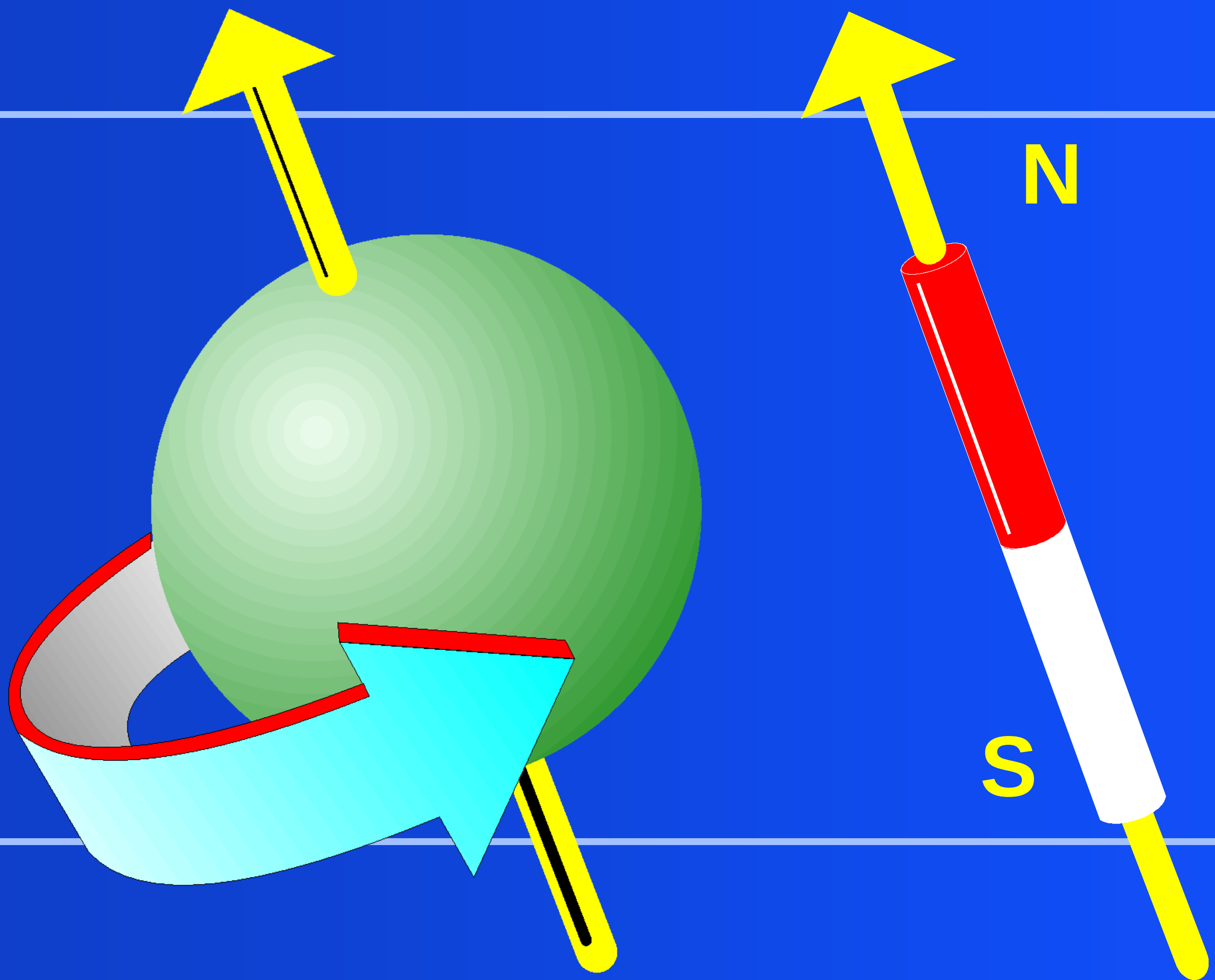
Spin

- A particle rotating upon its own axis
- Electrons, **protons**, and neutrons spin
- Spinning, charged particles have a magnetic moment


N
S

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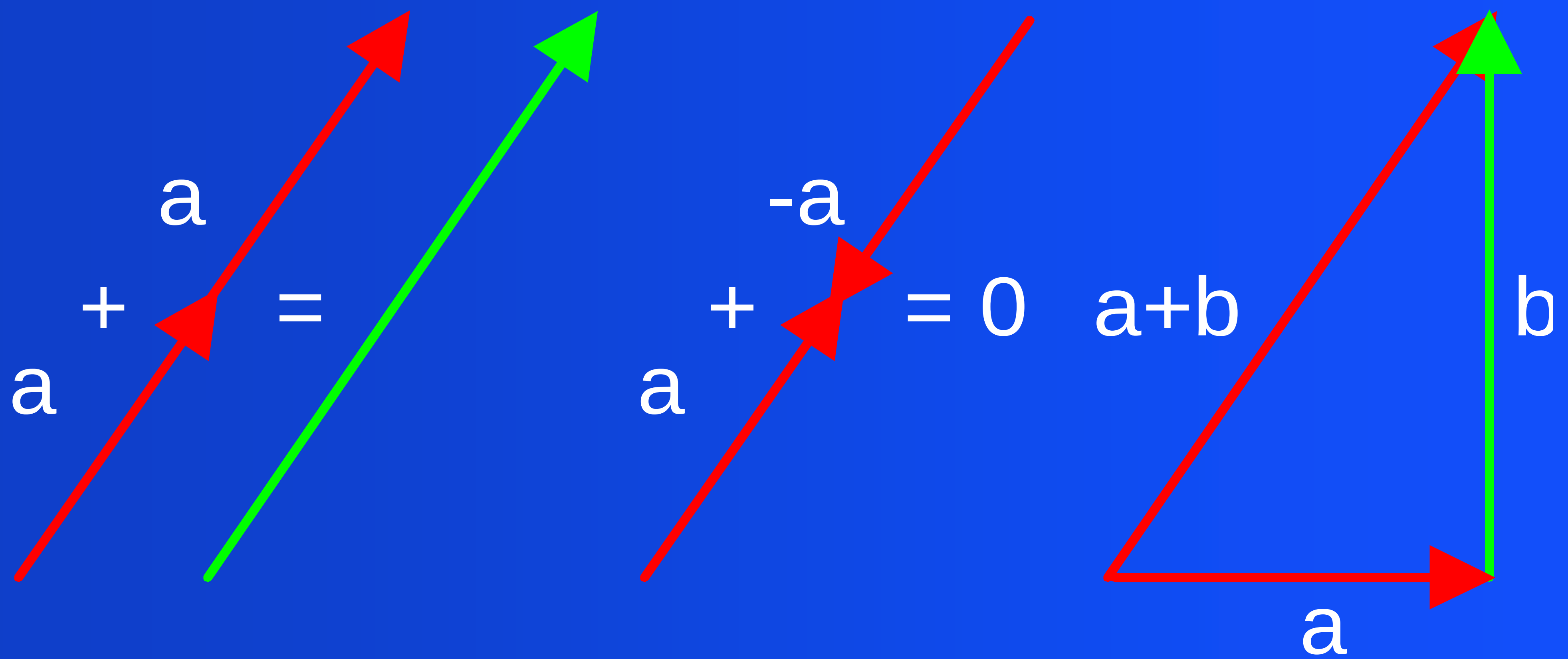
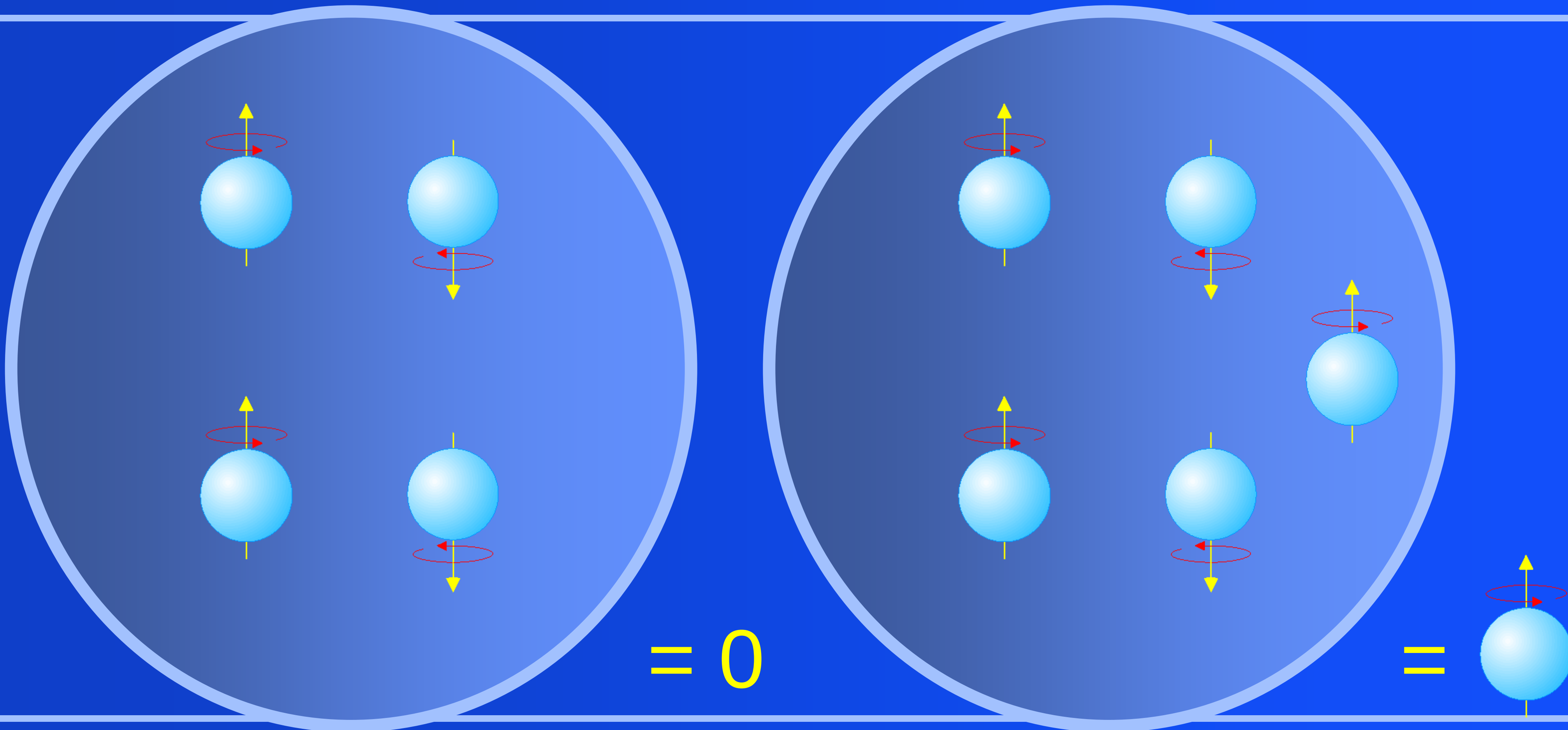
Spin Orientation

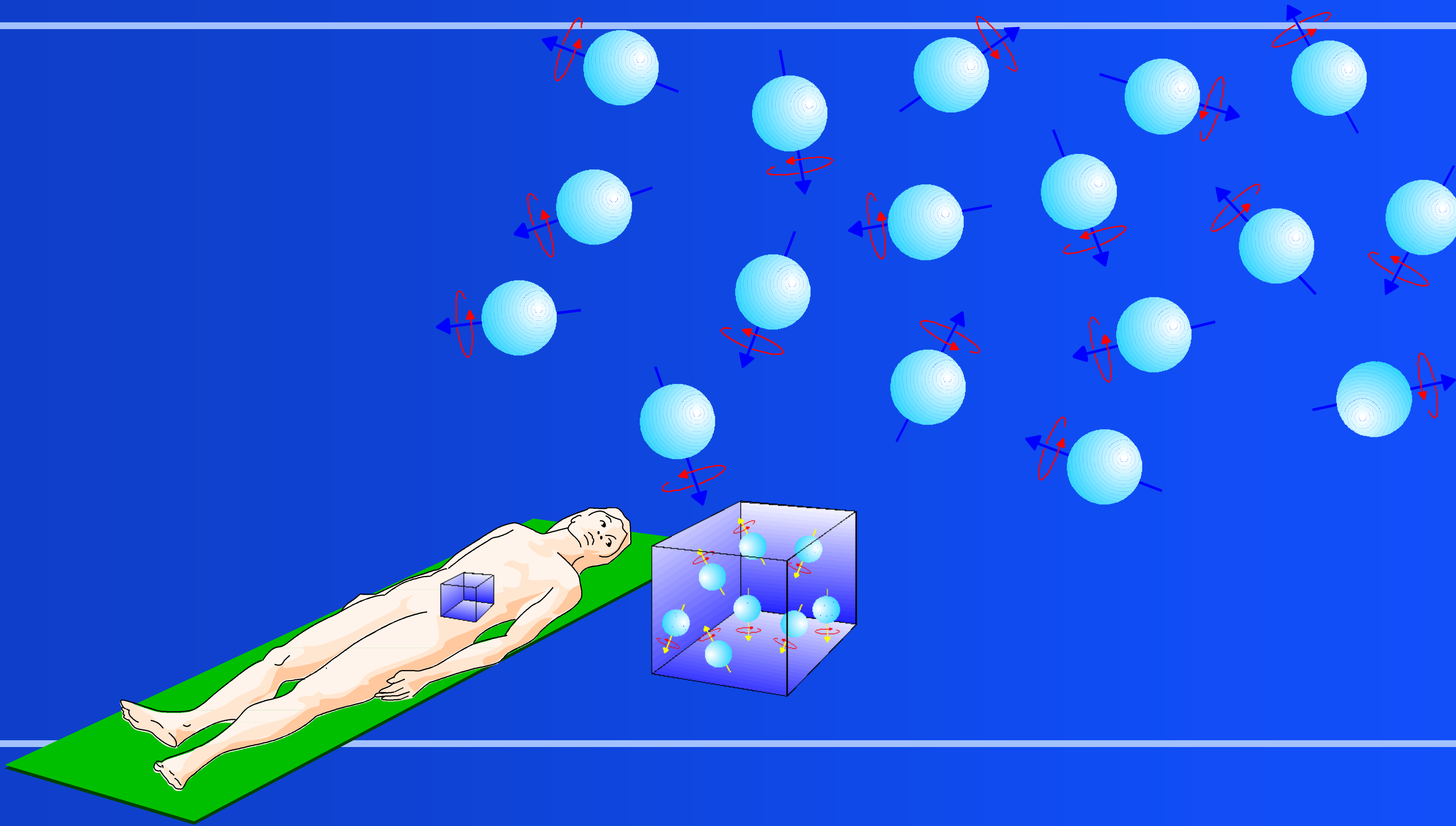
- Represented by a **vector**
- A **vector** is represented by an **arrow**
- The arrow denotes **direction** and **magnitude**


a
+
=
a
-a
+
= 0
a
a+b
b
a

Net Magnetization

- Spins outside a magnetic field = 0
- Spins randomly orientated
- Opposite spins cancel each other


= 0
=



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Up Spin vs Down Spin

- Spins point **up** or **down** parallel to the magnetic field
- There are slightly more spins pointing up
- Up spins are slightly **lower** in energy
- Down spins are slightly **higher** in energy

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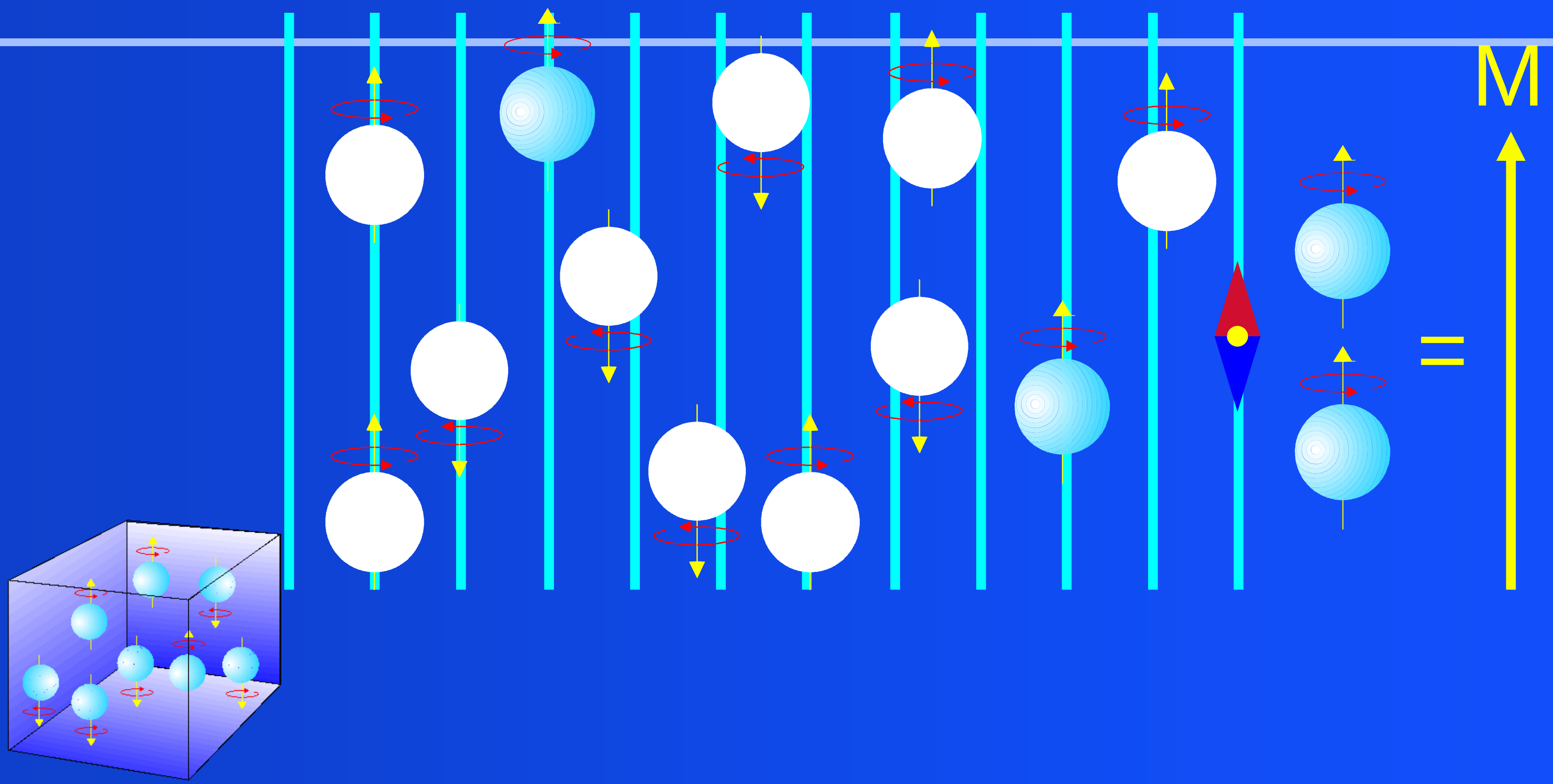

Number of Excess Spins

- **Increases** with the density of protons in the volume measured
- **Increases** dependent on the magnetic field strength
- **Decreases** as temperature increases
- May be expressed in **ppm**

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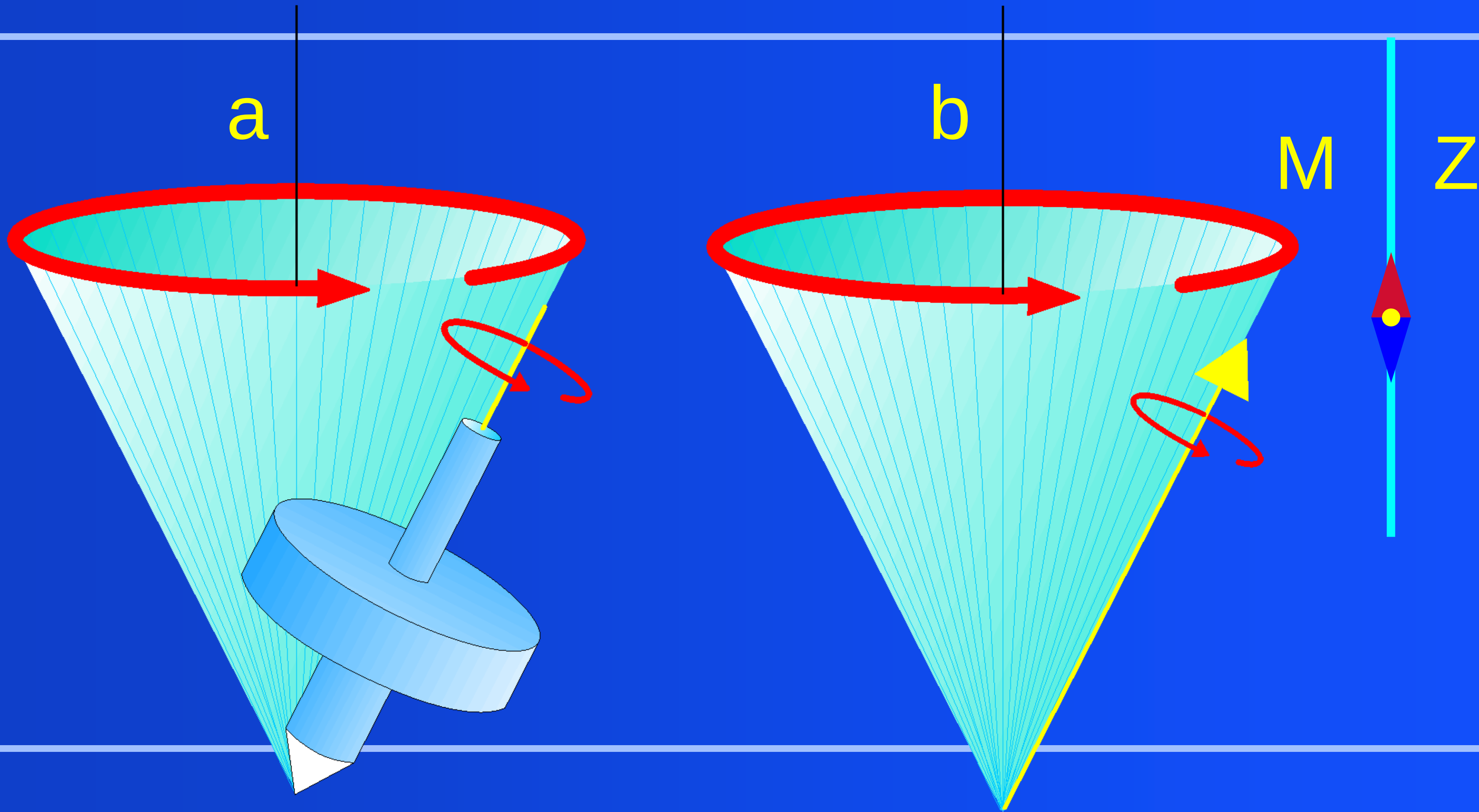
Precession

- A spinning particle rotating upon its axis in the presence of a magnetic field
- Precession occurs about the axis of the magnetic field; **(z axis)**


a
b
M
Z

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Larmor Frequency

- Frequency at which a spin precesses about an external magnetic field

- Dependent on **type of nucleus** and **strength** of the **magnetic field**

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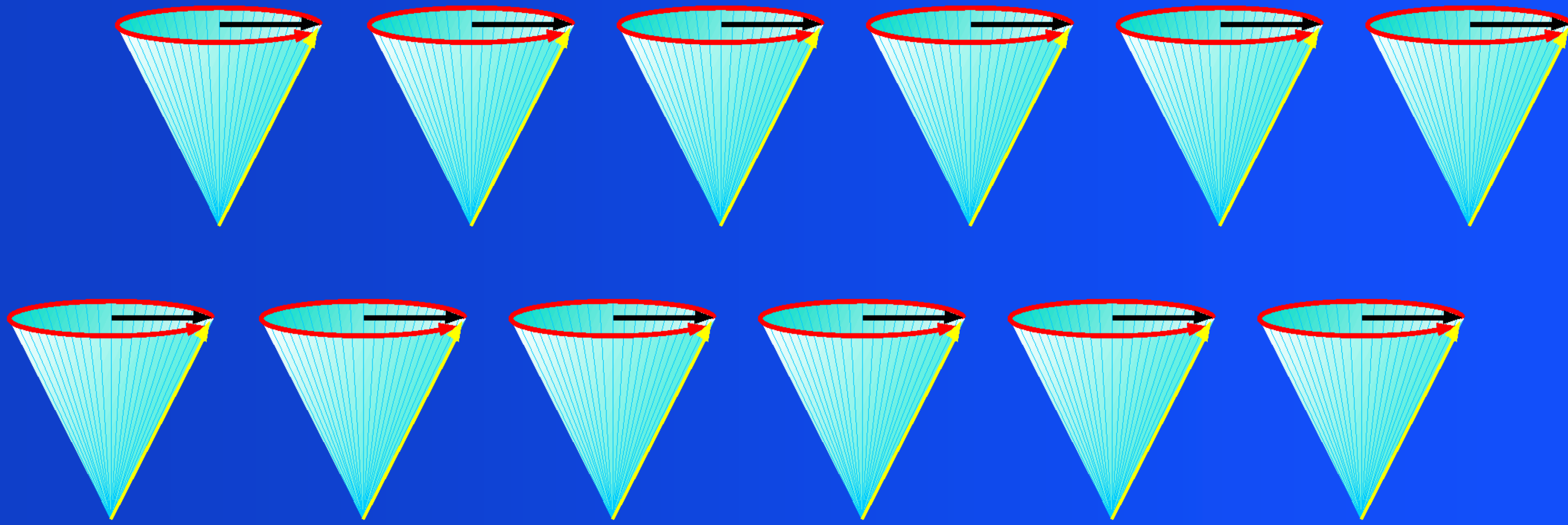
Phase

- **Random phase** =
  net magnetization of zero in the x-y plane
- Relative only to the excess spins

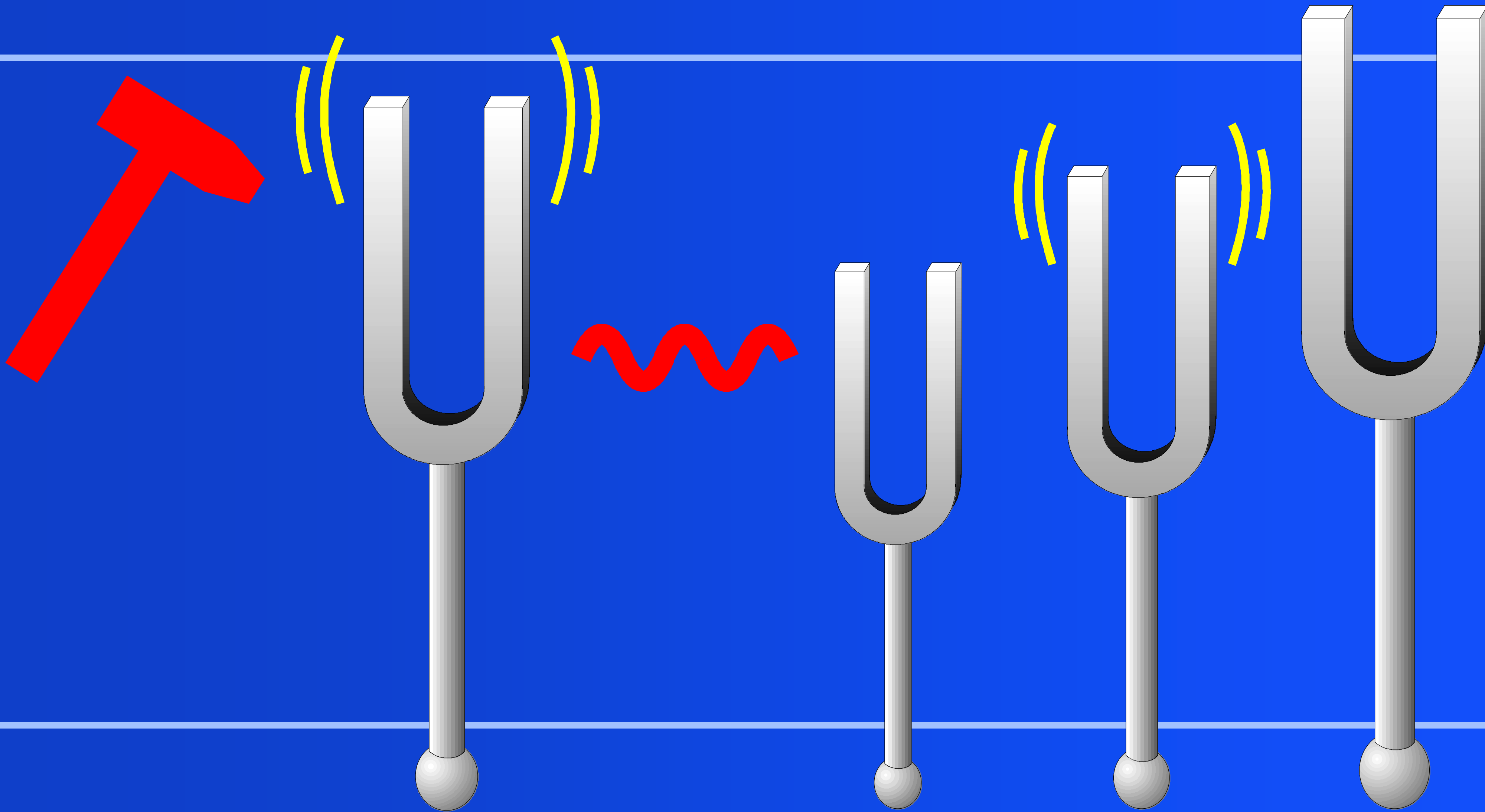
Phase Coherence

- In phase = pointing the same direction
- Phase coherence = in phase
- The sum of the vectors of **in-phase** spins creates net magnetization in the x-y plane



Resonance

- Oscillation at a specific frequency
- In resonance =
  oscillation at the same frequency in acoustic response to the initial oscillation



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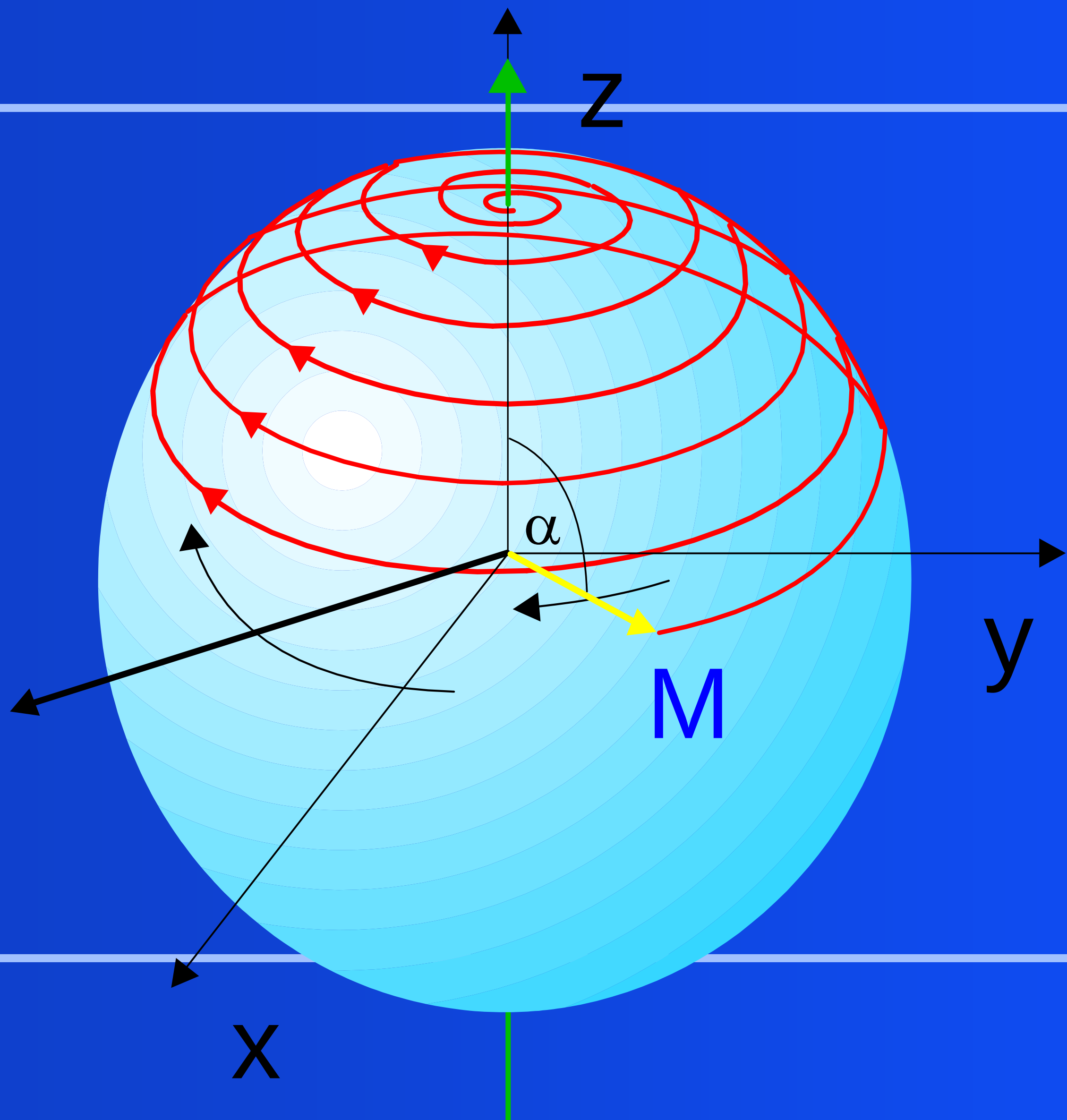
RF Pulse

- Applied to spins within the magnetic field
- Applied at the Larmor frequency
- Will deflect spins from equilibrium

The Spiral

- Your perception of the net magnetization from **outside** the magnetic field


z
α
y
M
x

Merry-go-round

- Your perception of the net magnetization at the **centre** of the magnetic field

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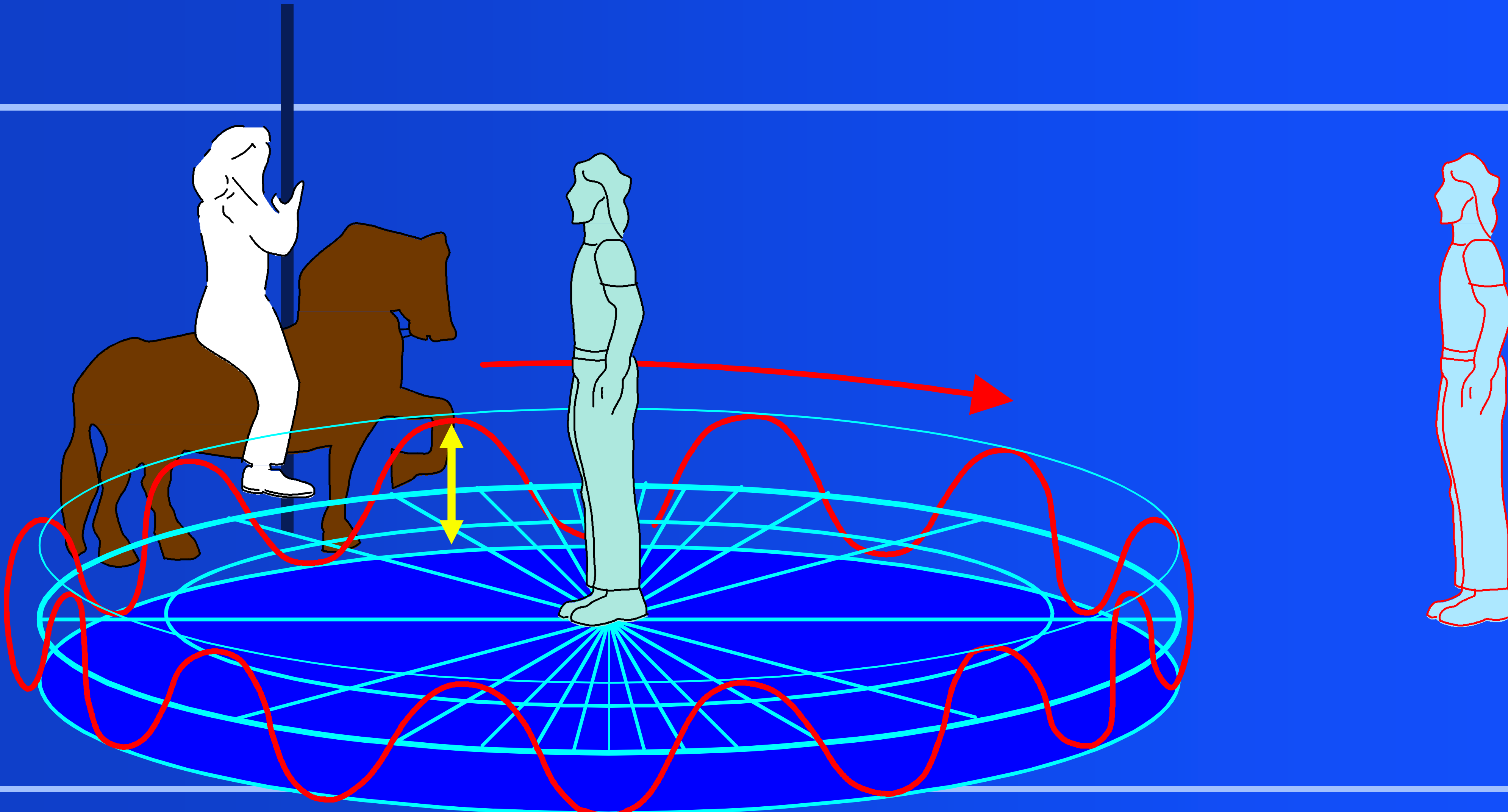
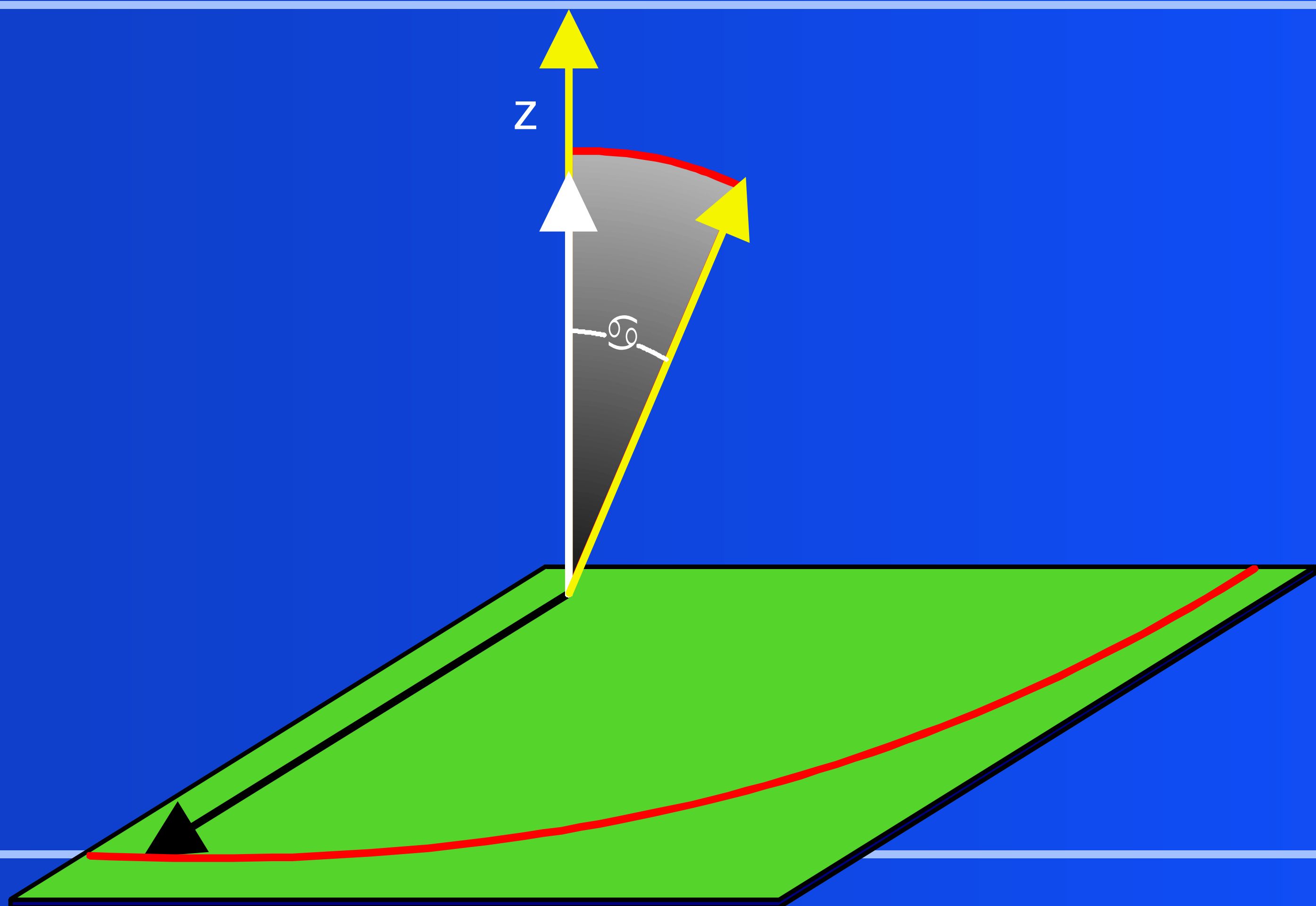
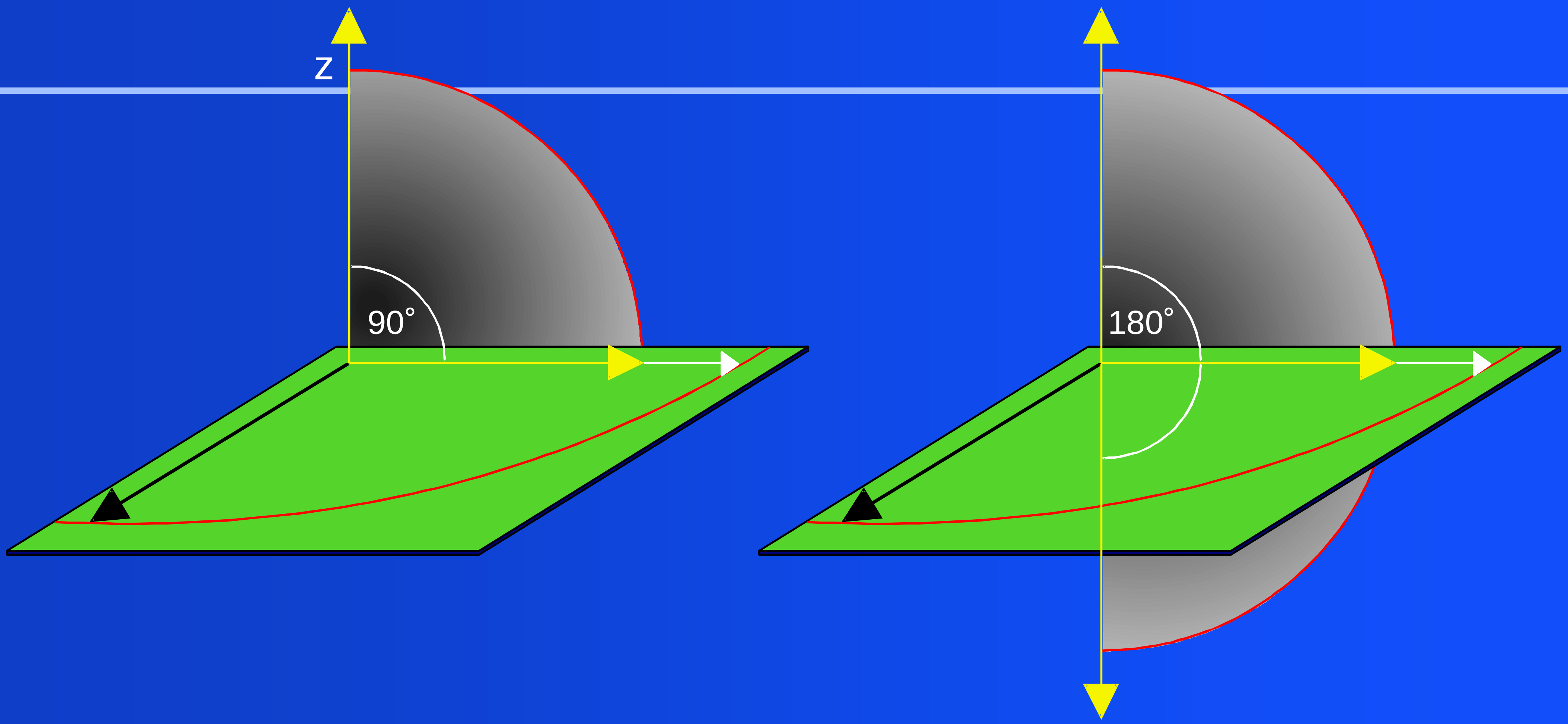


Magnetization and Flip Angles

- Flip Angle (♋) = the total amount of deflection of the magnetization after the end of an applied RF pulse

- The stronger the energy of the applied RF pulse, the greater the flip angle


z



z
90°
180°

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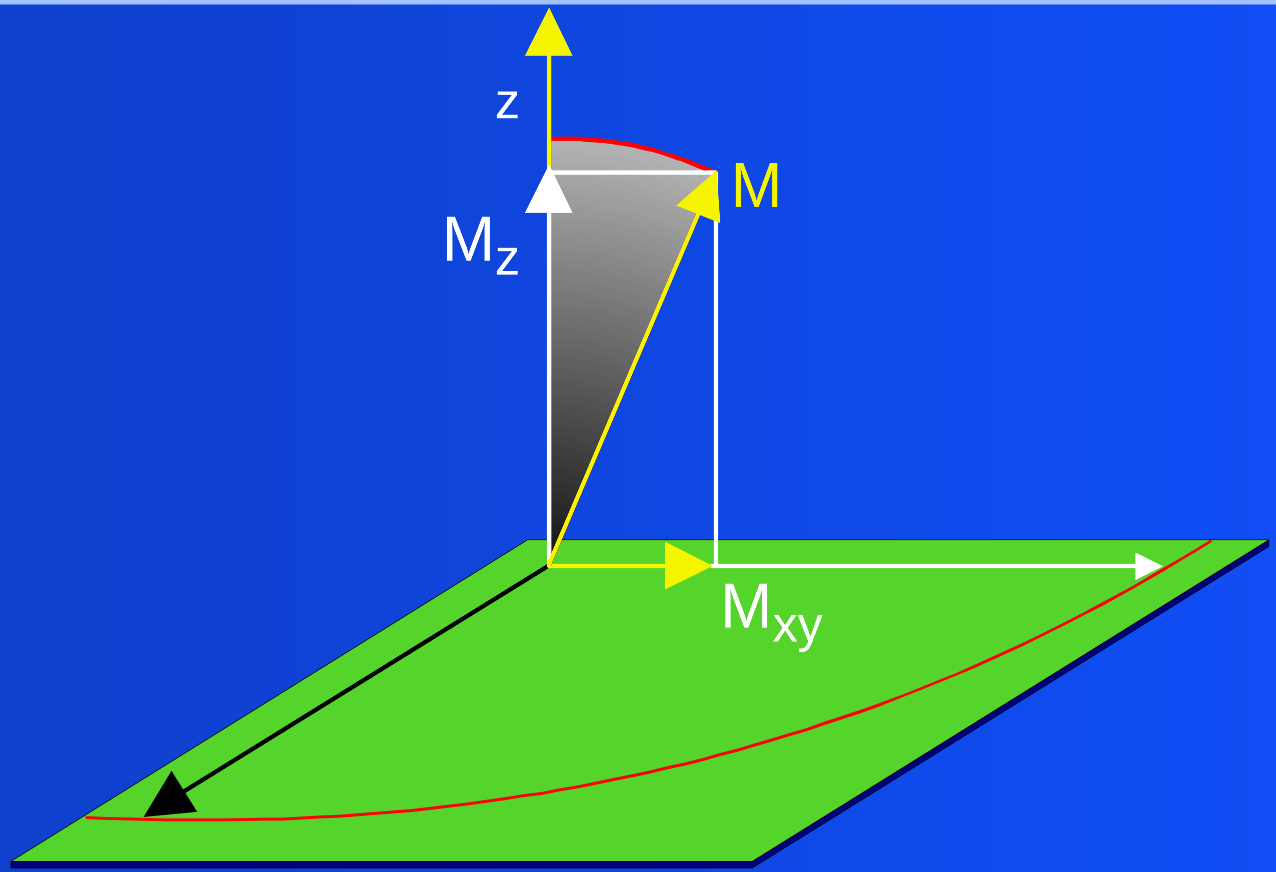
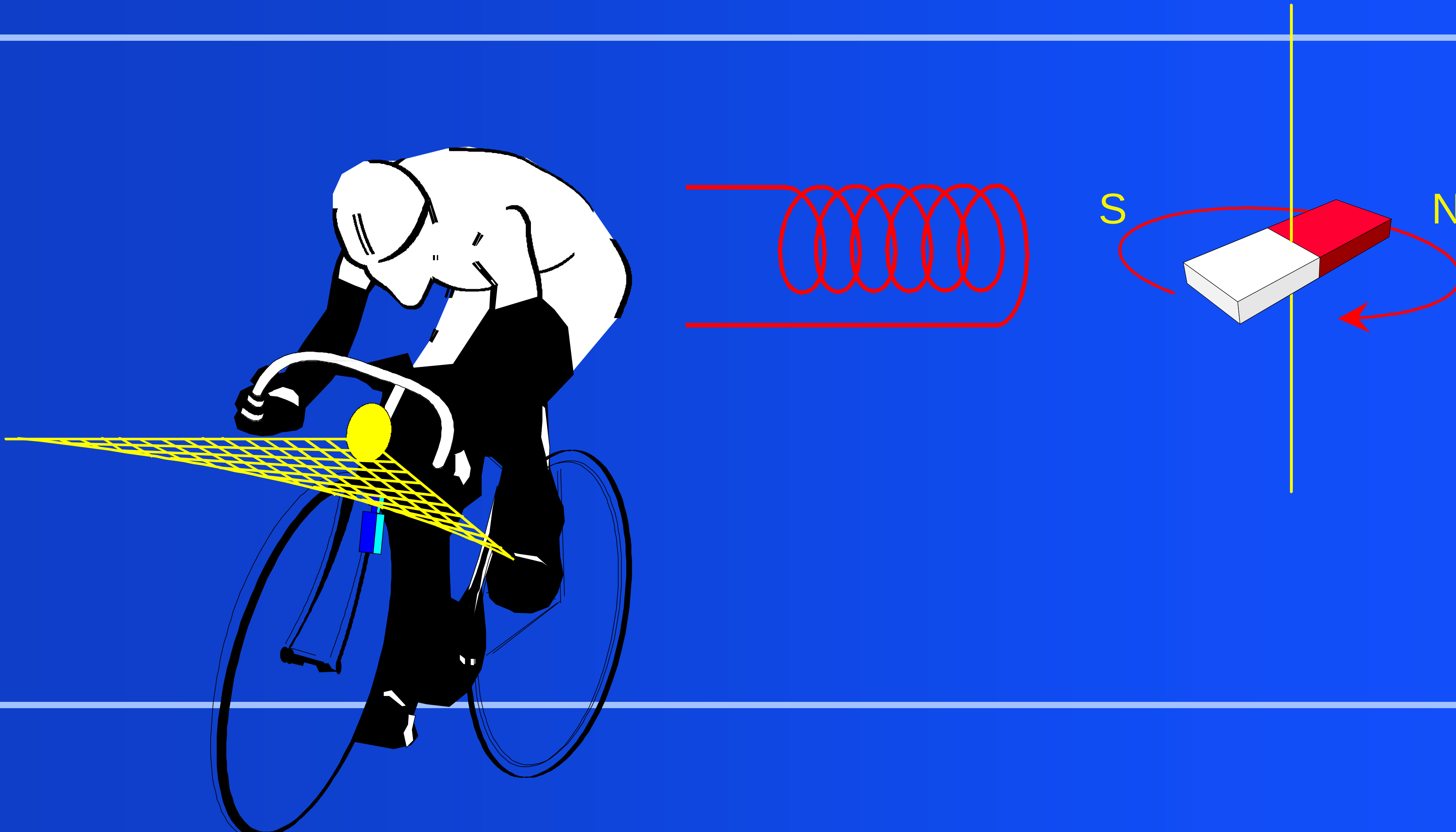


The MR Signal

- Longitudinal magnetization (M_z) is in the z-direction, along the external magnetic field
- Transverse magnetization (M_{xy}) is in the x-y plane, perpendicular to the external magnetic field
- Spins must be in the x-y plane in order for us to receive an MR signal


S
N

Electromagnetic Induction

- The voltage generated in a receiver coil caused by a changing magnetic field

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Decay

- **RF** is turned **off**
- **Loss of phase coherence** causes **transverse decay**
- **FID** = free induction decay
- As transverse magnetization decays longitudinal magnetization recovers

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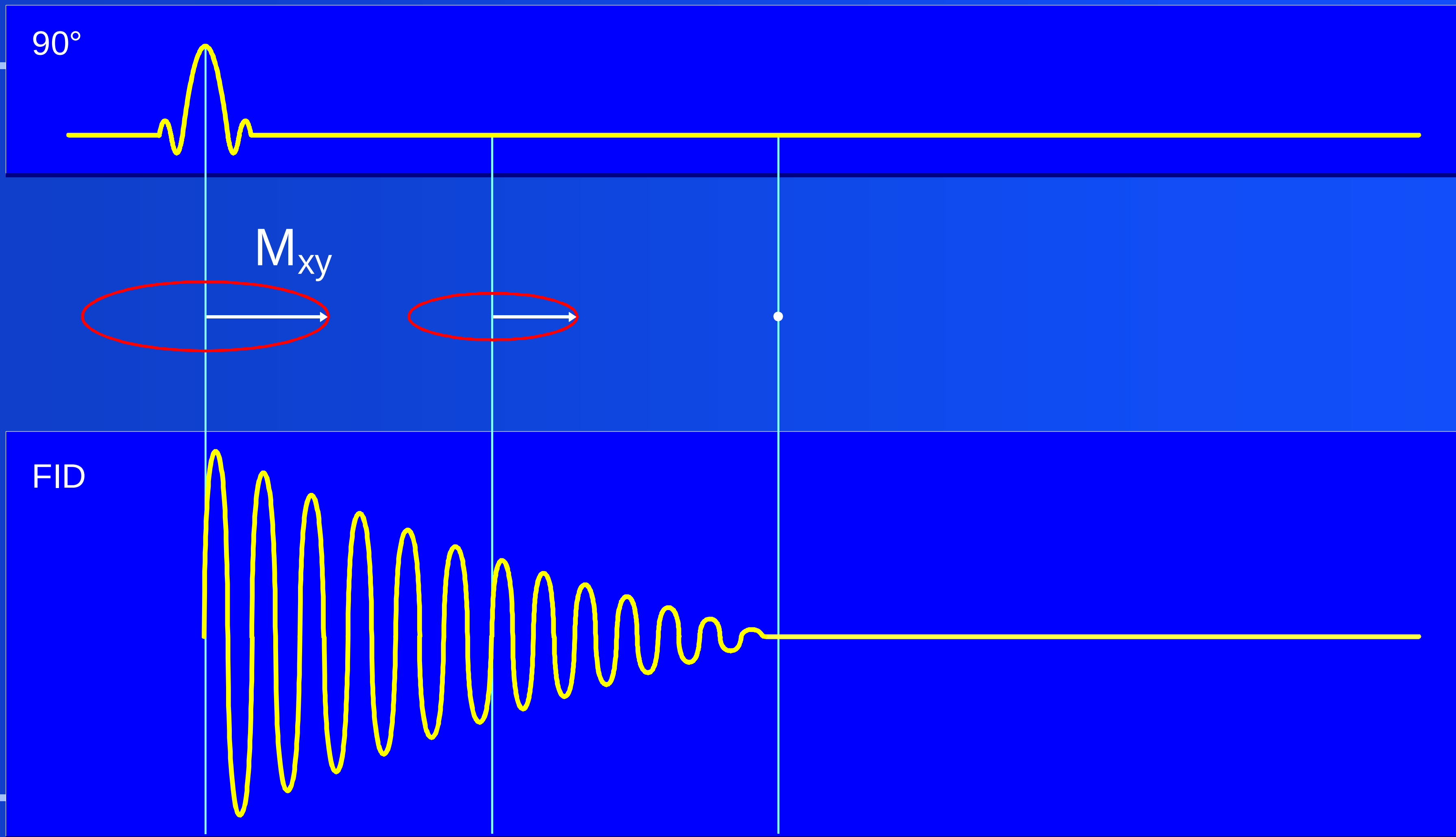

The MR Experiment

- 90° pulse causes deflection of spins
- RF turned off
- Spins precess in the x-y plane and slowly return to equilibrium

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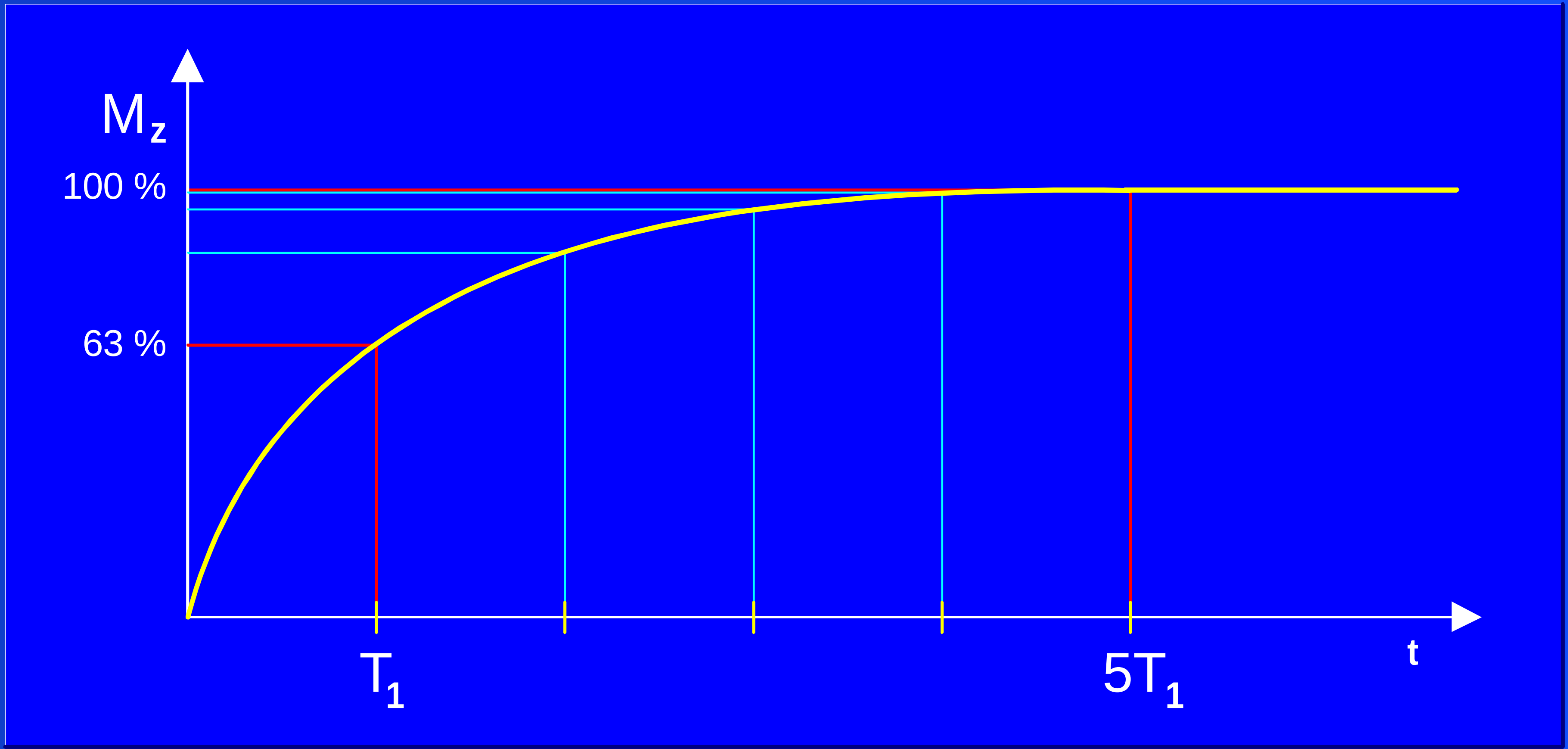
Spin Recovery and Echoes

- Rotation of the transverse magnetization generates MR signal
- Spin coherence decays
- Longitudinal magnetization is recovered

T_1

- **T_1** = the time it takes for 63 % of longitudinal magnetization recovery
- **$5T_1$** = the time it takes for spins to fully recover back to the z axis
- **T_1 is tissue specific**

Longitudinal Relaxation (T_1)




90°
M_{xy}
63 %
~100 %
T_1
$5T_1$

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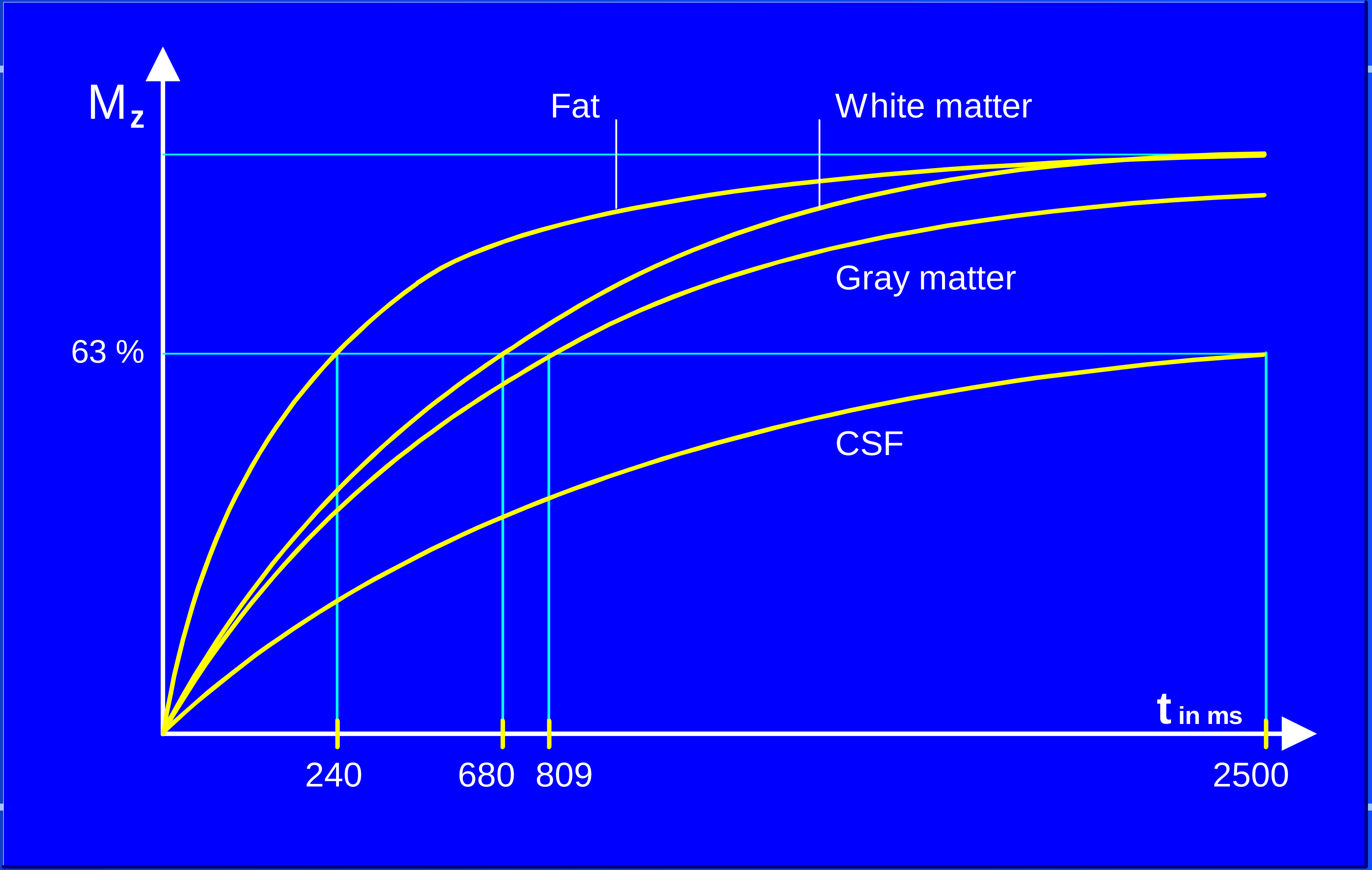
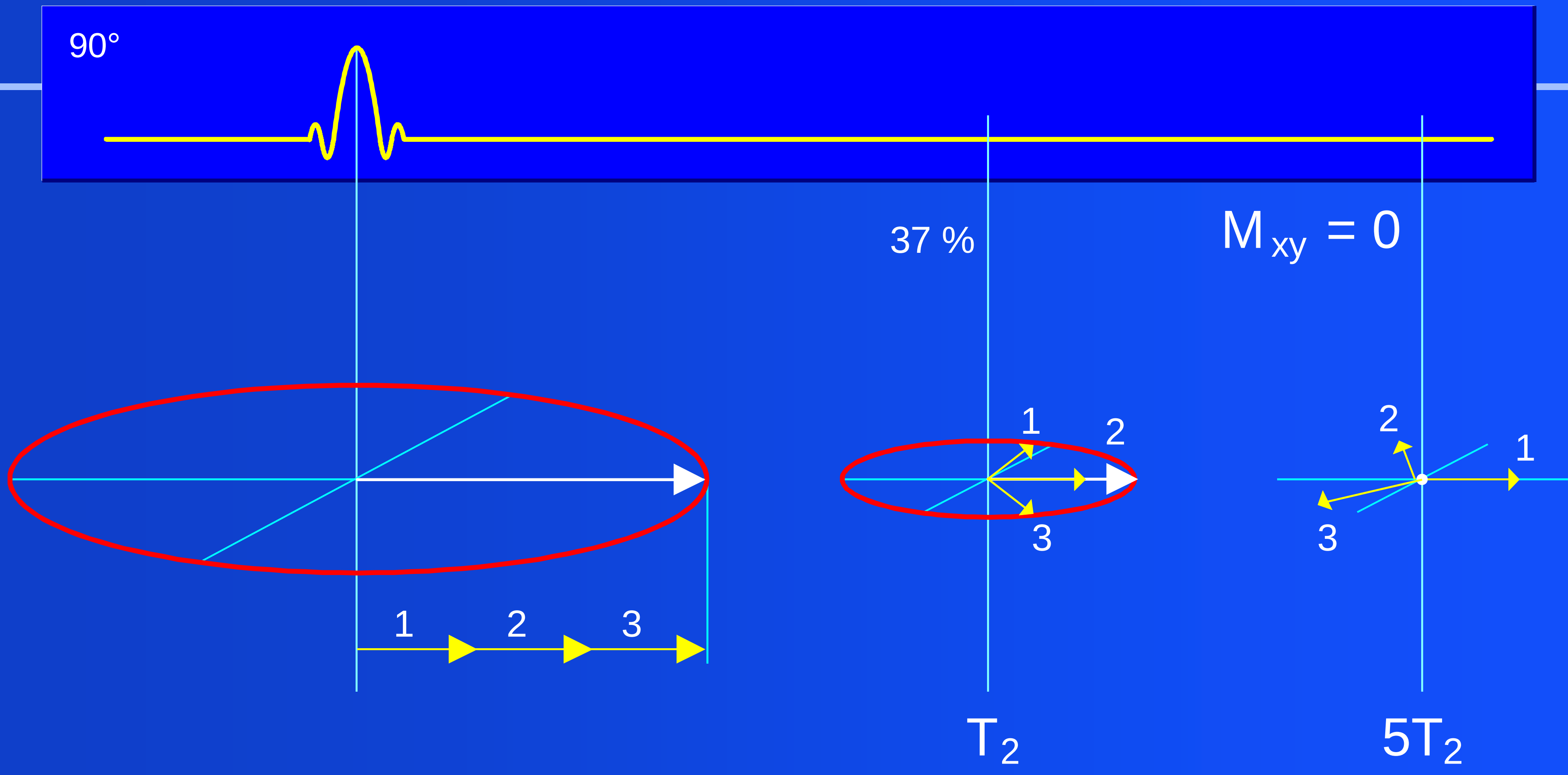


Transverse Relaxation

- Transverse relaxation = loss of phase coherence of spins in the transverse plane (x-y). Non-recoverable!!!


90°
37 %
M xy = 0
1
2
3
1
2
3
2
1
3
T2
5T2

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T_2 Relaxation

- **T_2** relaxation = spin - spin relaxation
- **T_2** is the destroying of transverse magnetization
- **T_2** occurs faster than T_1 relaxation

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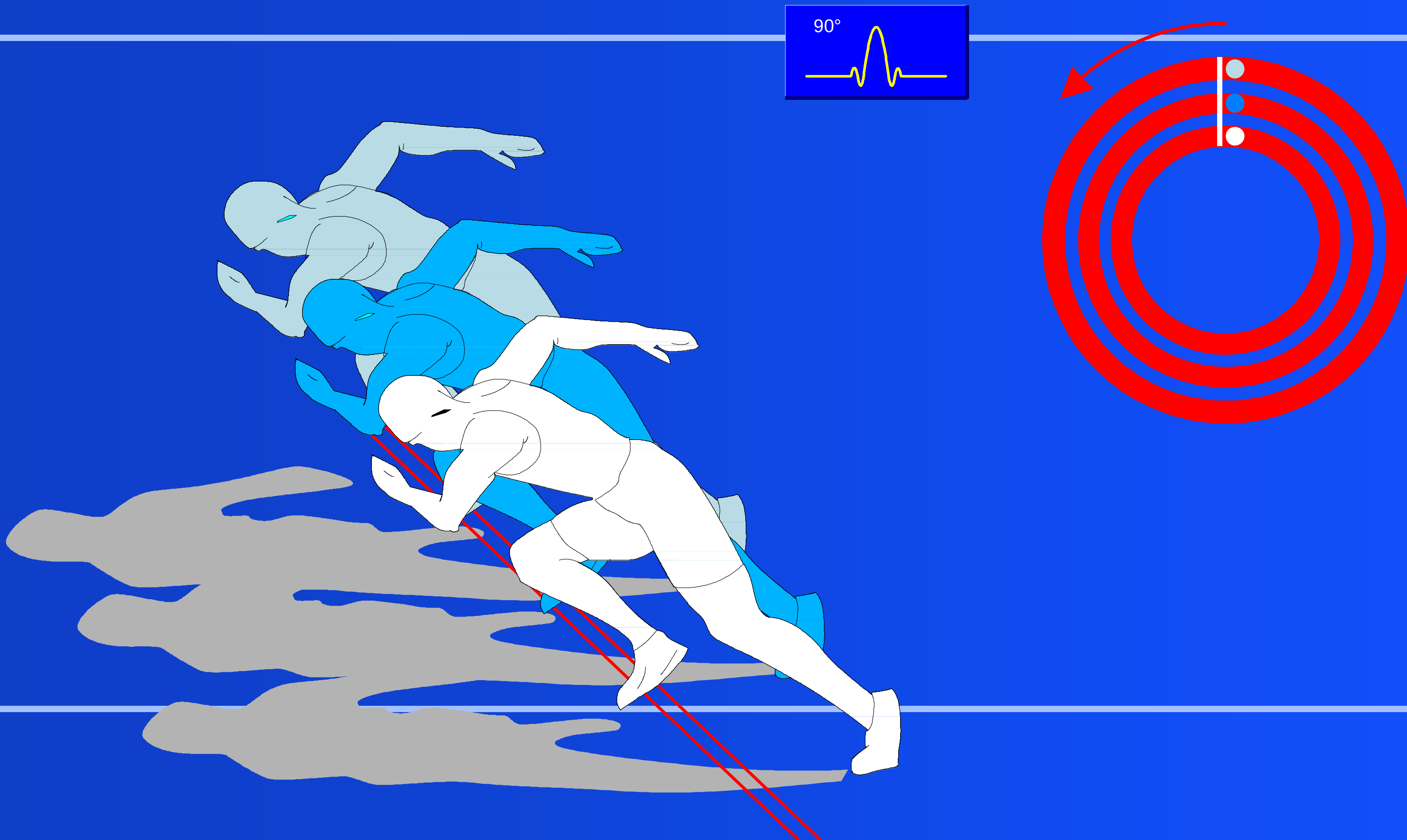

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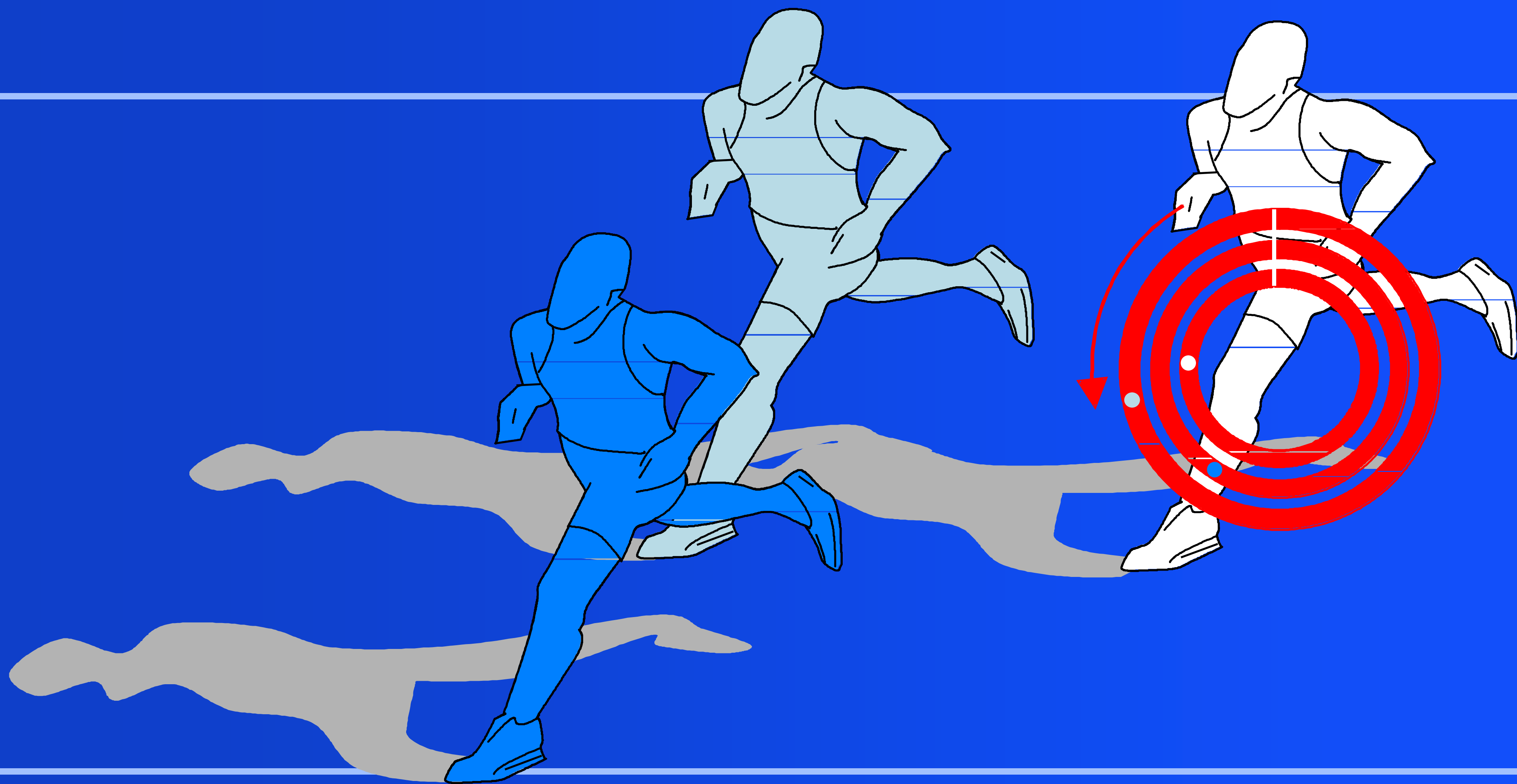
Transverse Phase Coherence

- Runners at the starting line are said to be **phase coherent**
- phase coherent = all at the same point in the transverse plane



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Coherence Loss

- As runners spread out they are said to lose coherence

- Runners are not at the same point in the transverse point in the transverse plane

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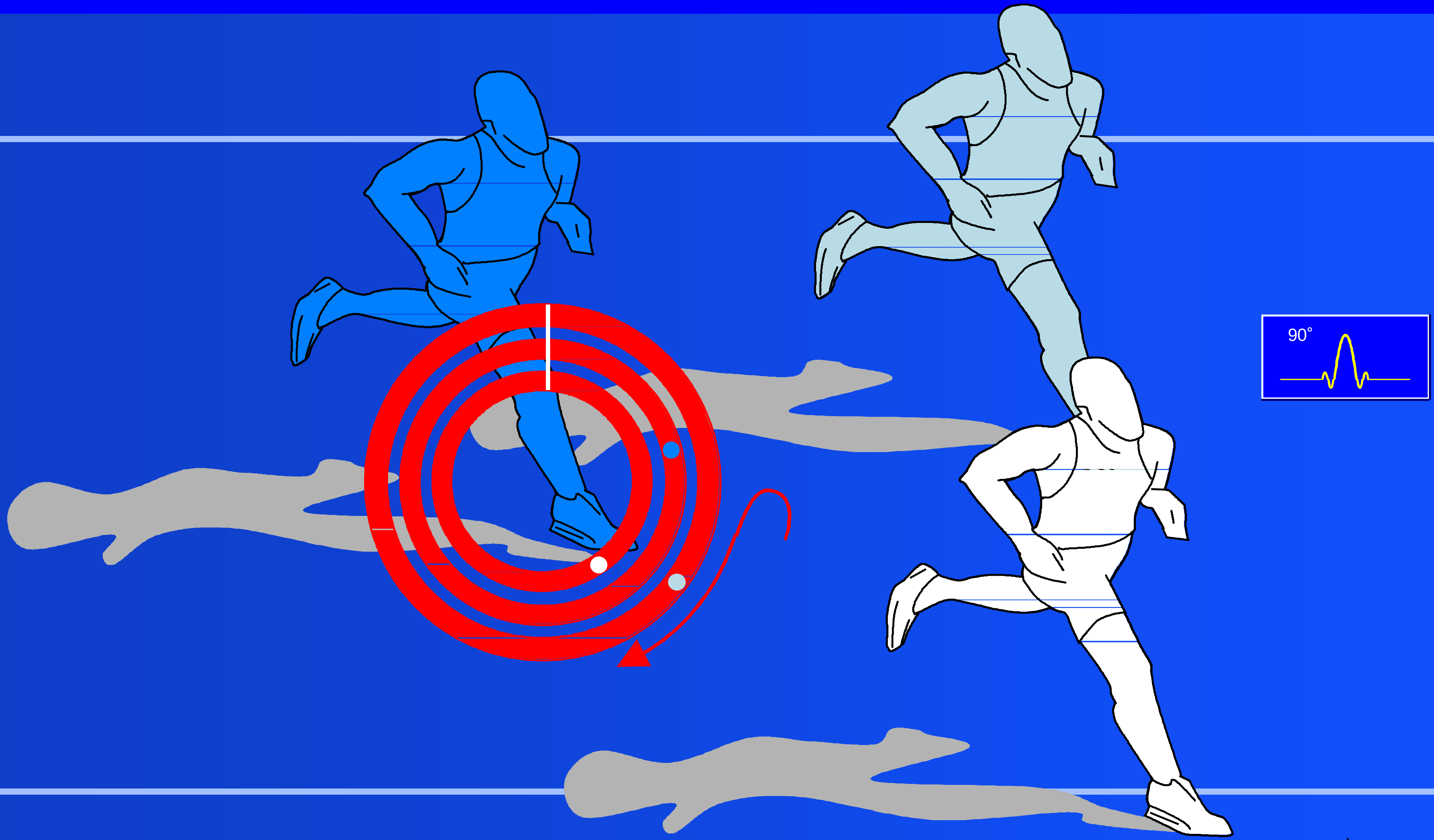

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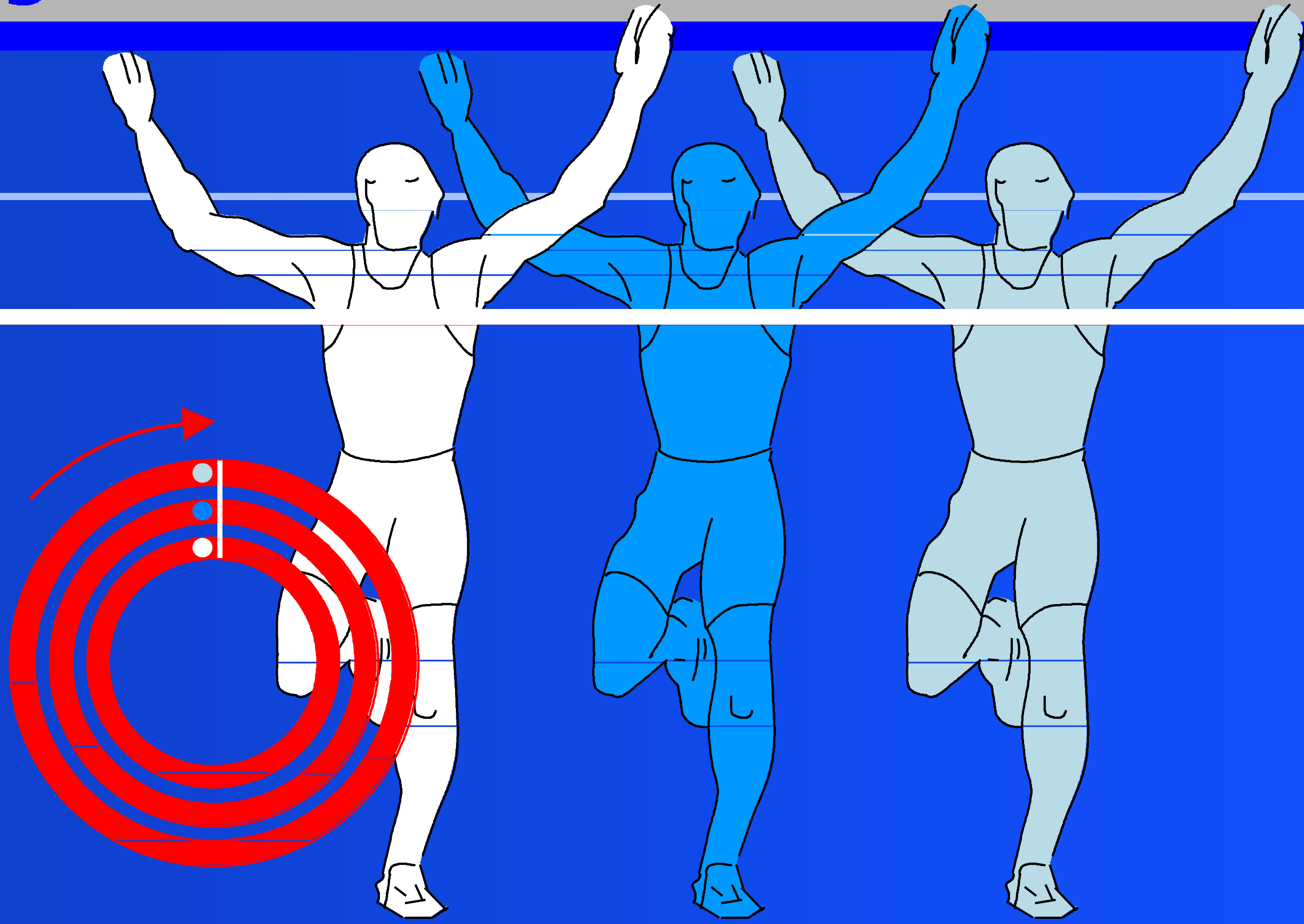

Rephasing

- By turning the runners around 180° , they will catch up to each other at the starting point

- They will regain phase coherence or rephase at that point

T_2^* Relaxation

- **T_2^*:** the *effective* T_2 time constant
- **T_2^*:** accounts for magnetic field inhomogeneity dephasing
- **T_2^*:** is always faster than T_2

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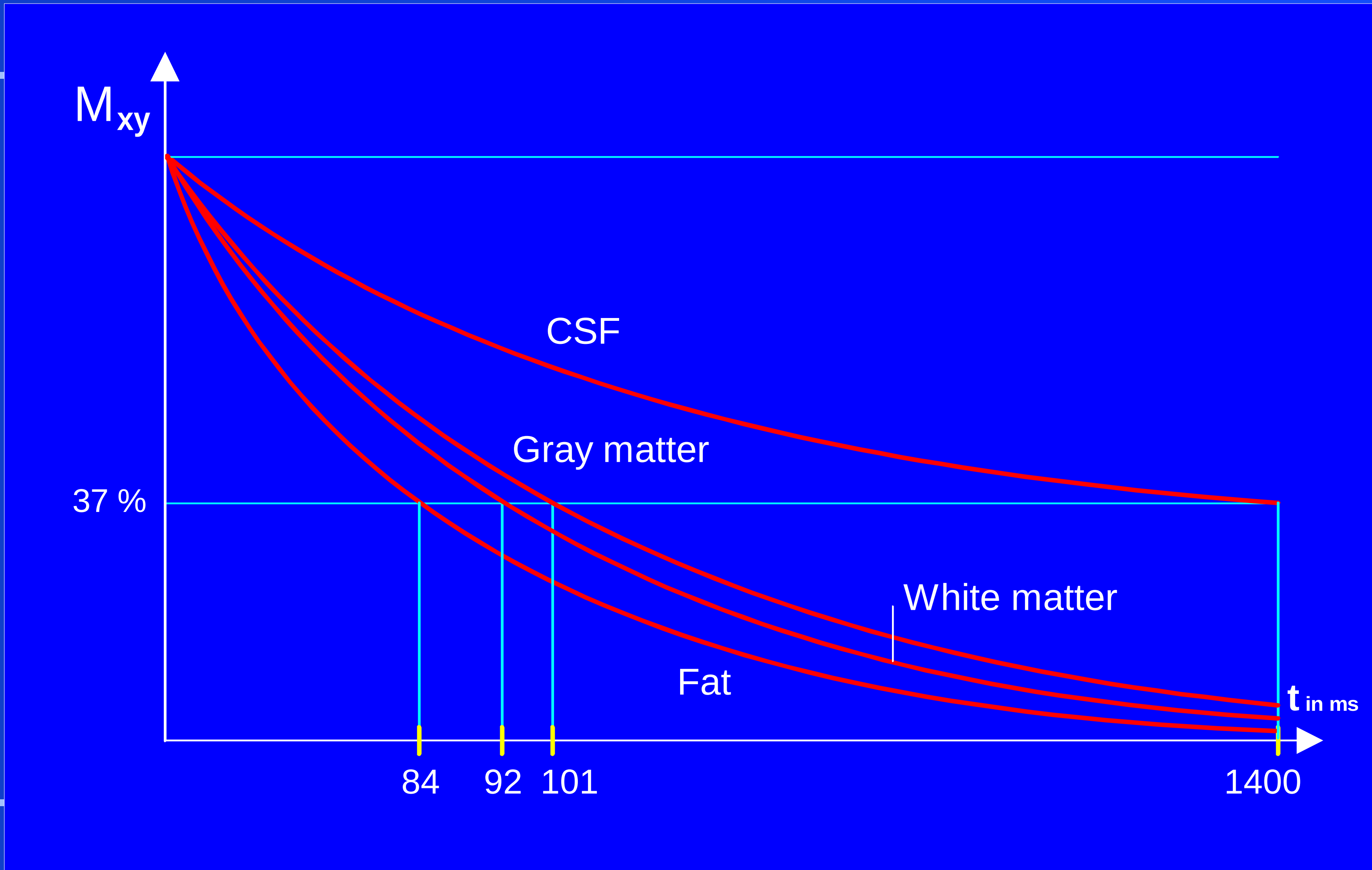

Echo

- Regaining of phase coherence at the starting point is called an **echo**

Spin Echo

- Spin Echo Sequence =
  90° - 180° with a repetition time **TR**

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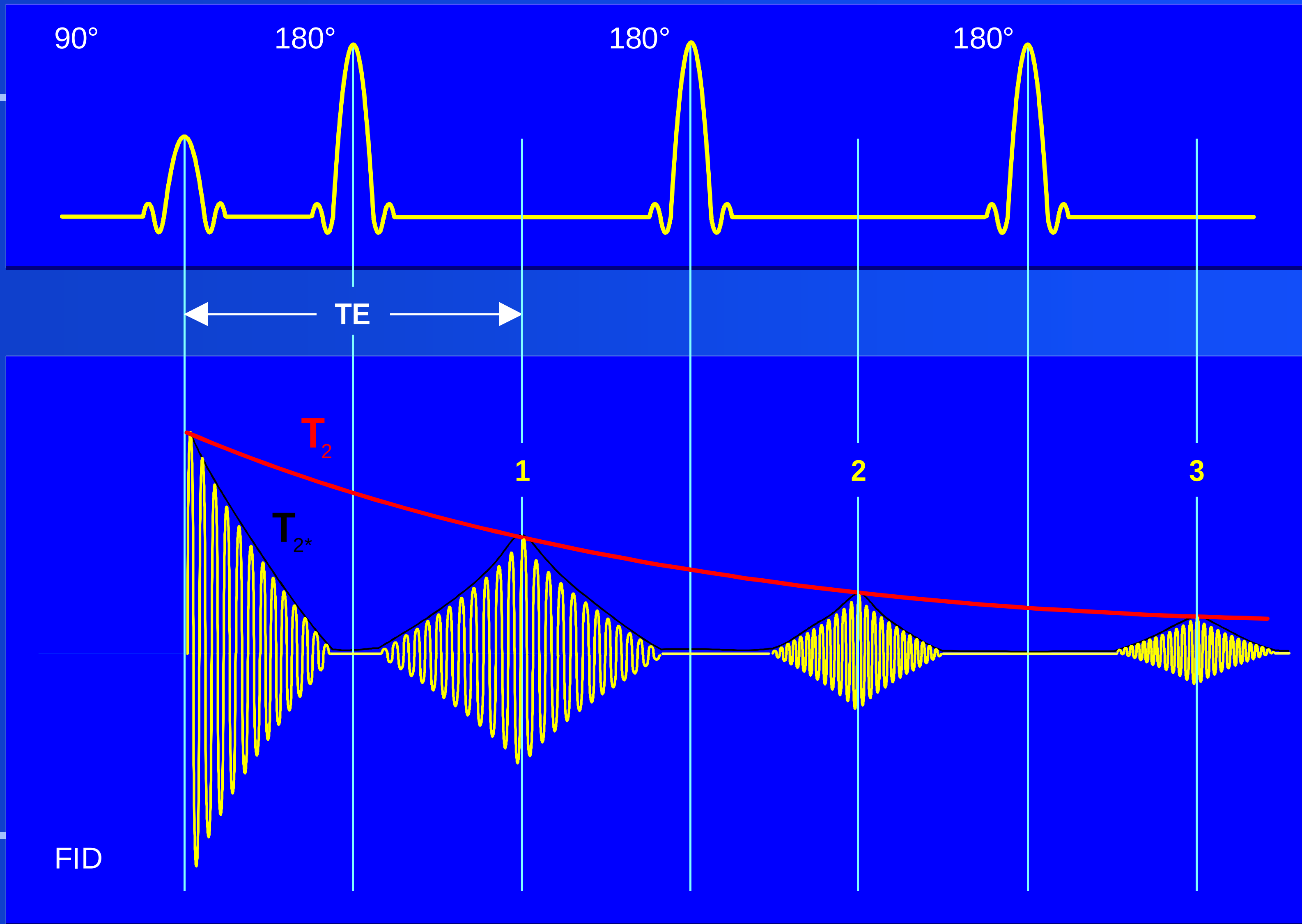

Echoes

- Become smaller over time

- $T2^* < T2 < T1$

3

How Pulse Sequences generate Contrasts

Tissue Contrast

T1: contrast based on different T1 times of different tissues

T2: contrast based on different T2 time of different tissues

Proton Density

contrast based on different proton concentrations of different tissues

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Short TR Short TE	Long TR Short TE	Long TR Long TE
↓	↓	↓
T1	PD	T2

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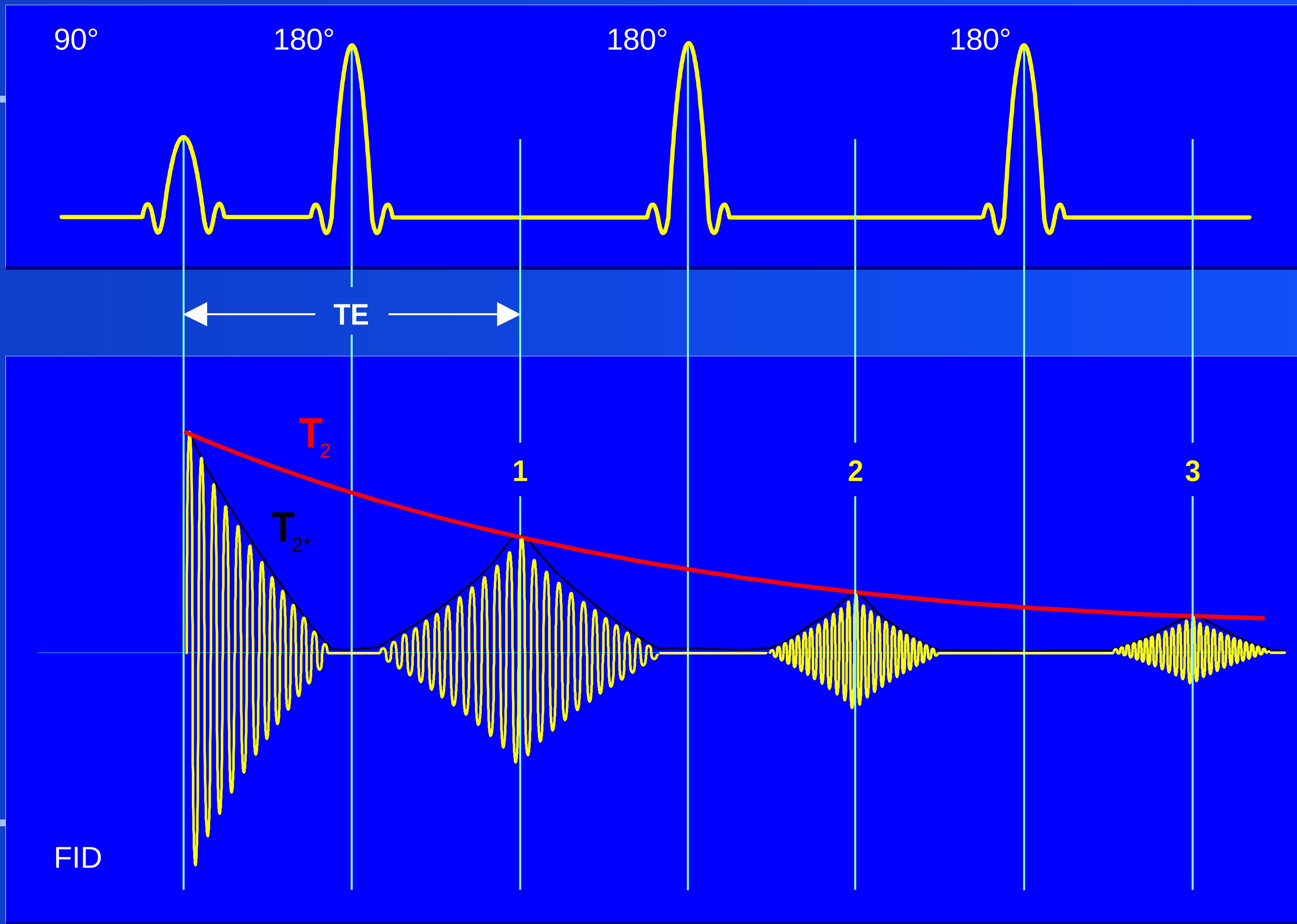

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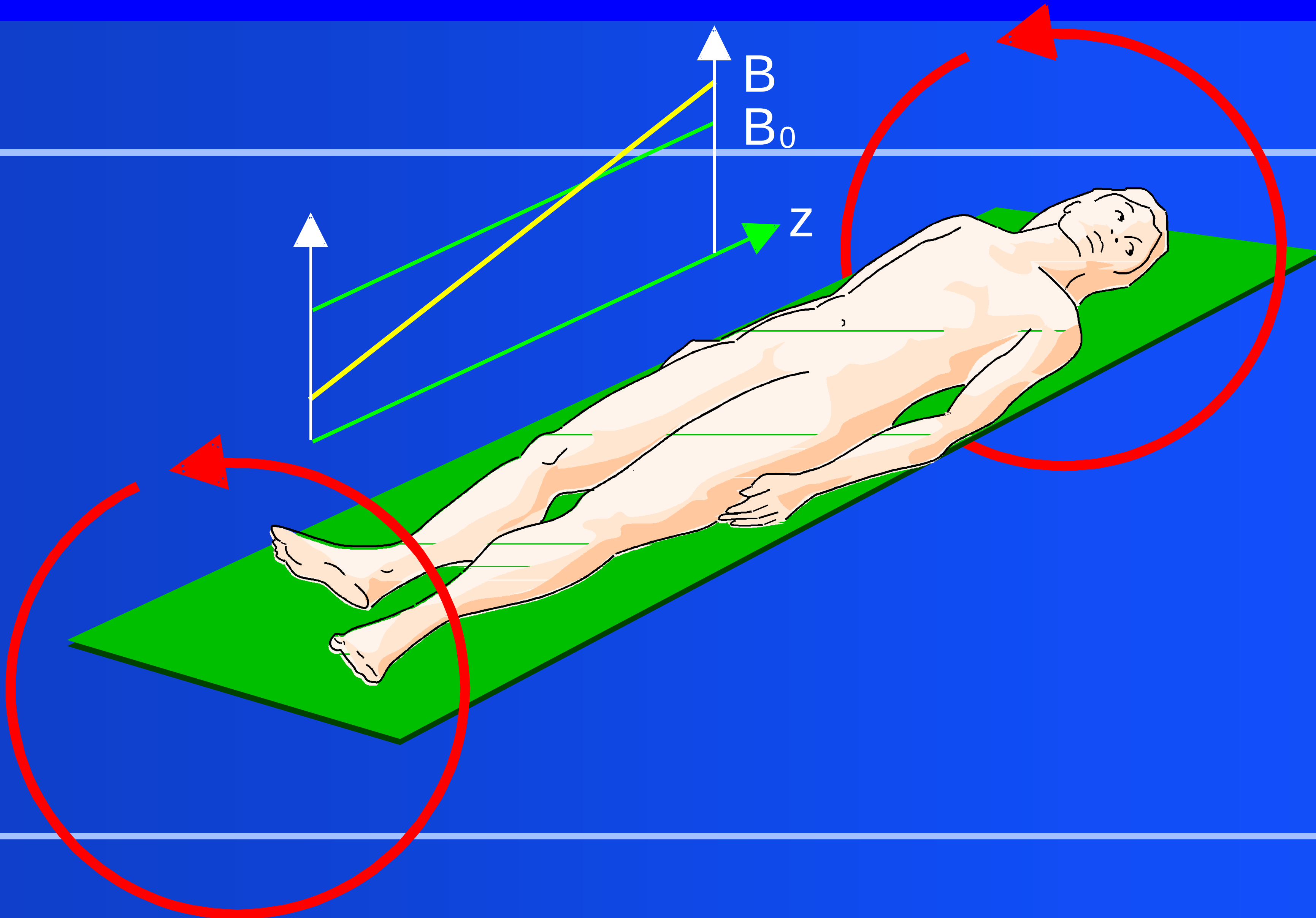
5

Encoding Slices and Images

Spatial Information

- Where inside the magnet did the signal come from?
- **Gradient** = the linear increase or decrease of the magnetic field strength in a given direction


B
B_0
z

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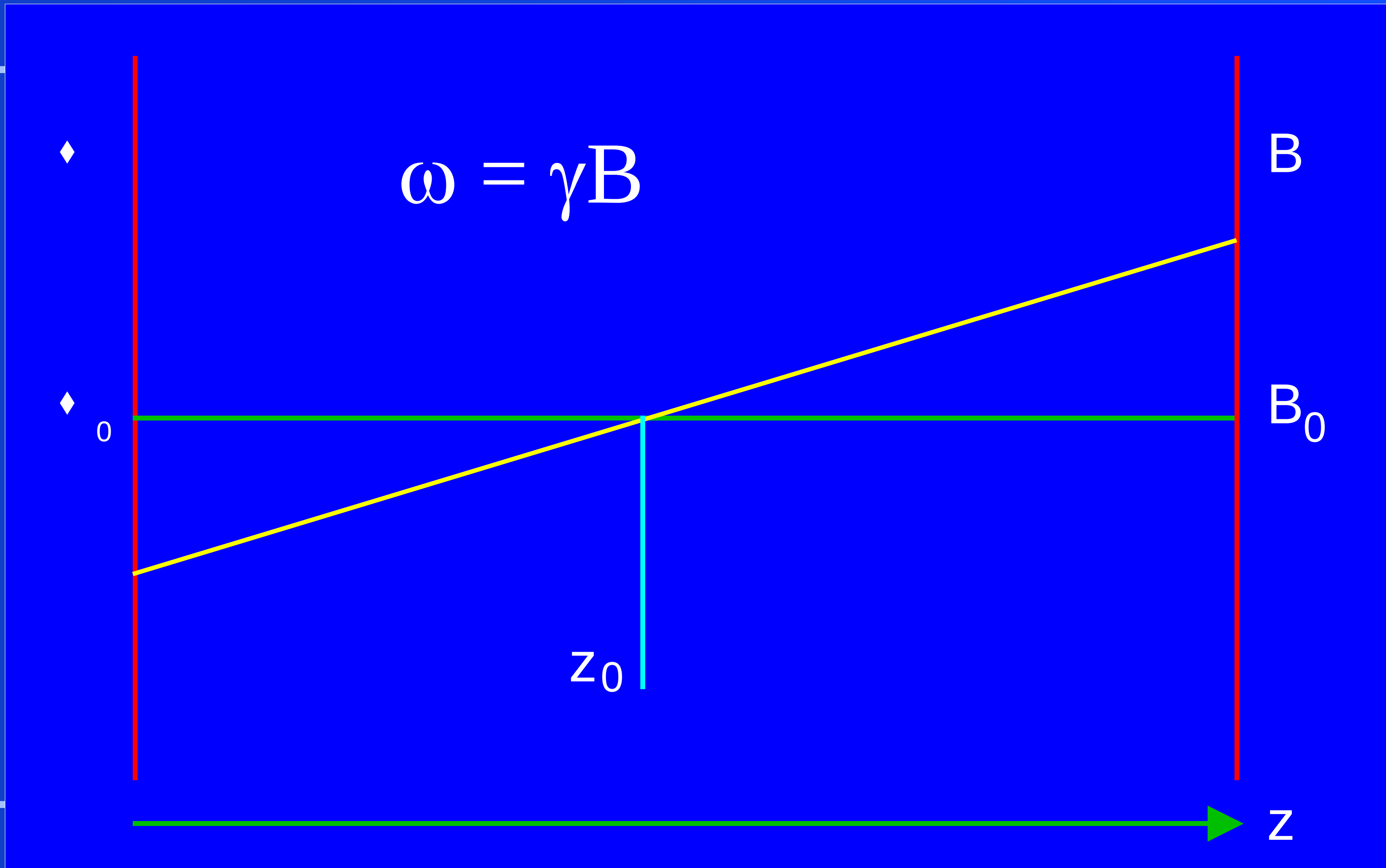
Gradients

- Gradient coils are in pairs
- The pairs are of equal and opposite polarity
- Each either increases or decreases the magnetic field strength by a specific amount
- There are three sets of gradient coils in the magnet: x, y and z



ω = γB
B
B0
0
z0
z

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Slice Selection

- **Inhomogeneity** induced by the gradients cause spins to resonate at different frequencies

- only protons spinning at the **same frequency** as an applied RF pulse will respond

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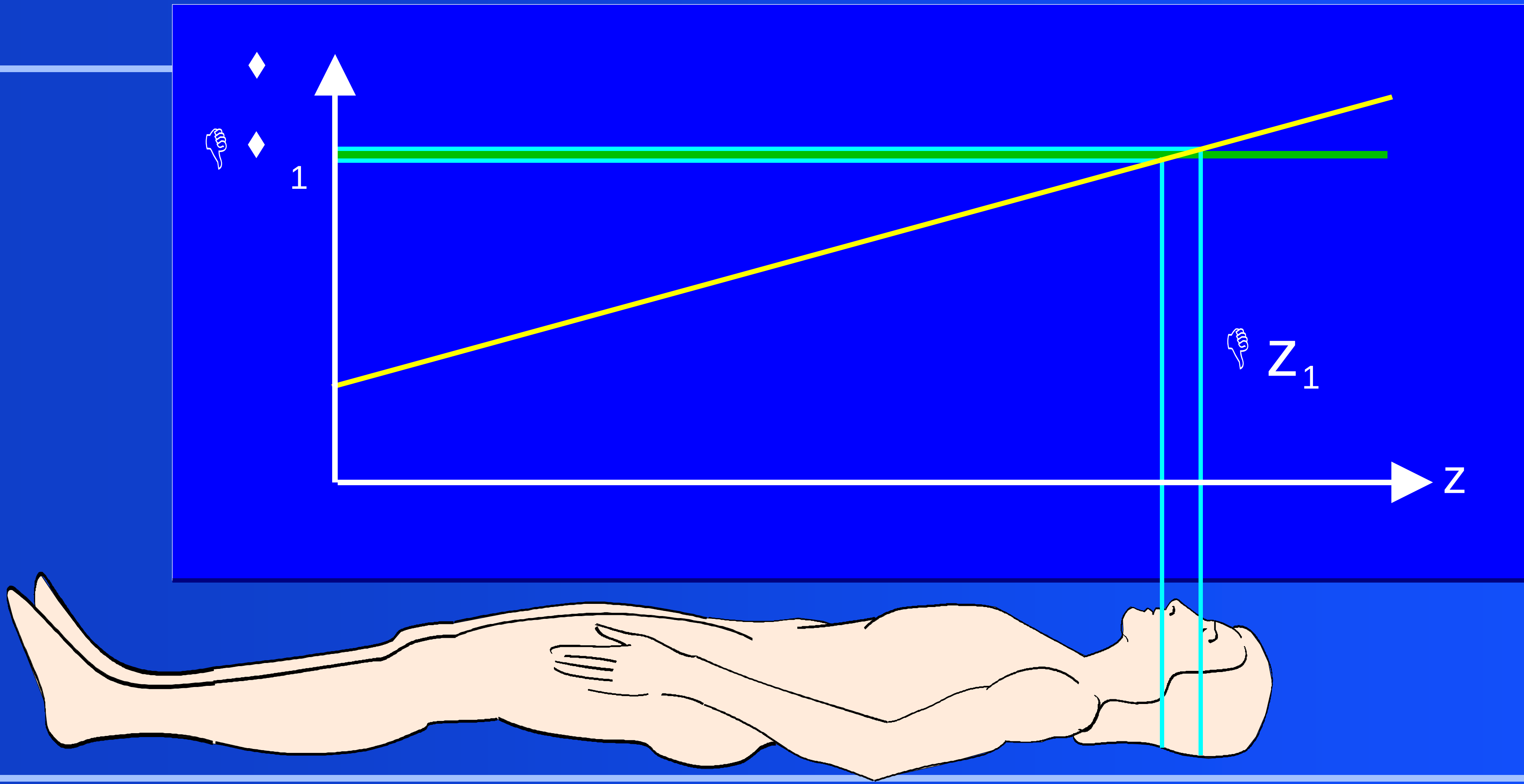

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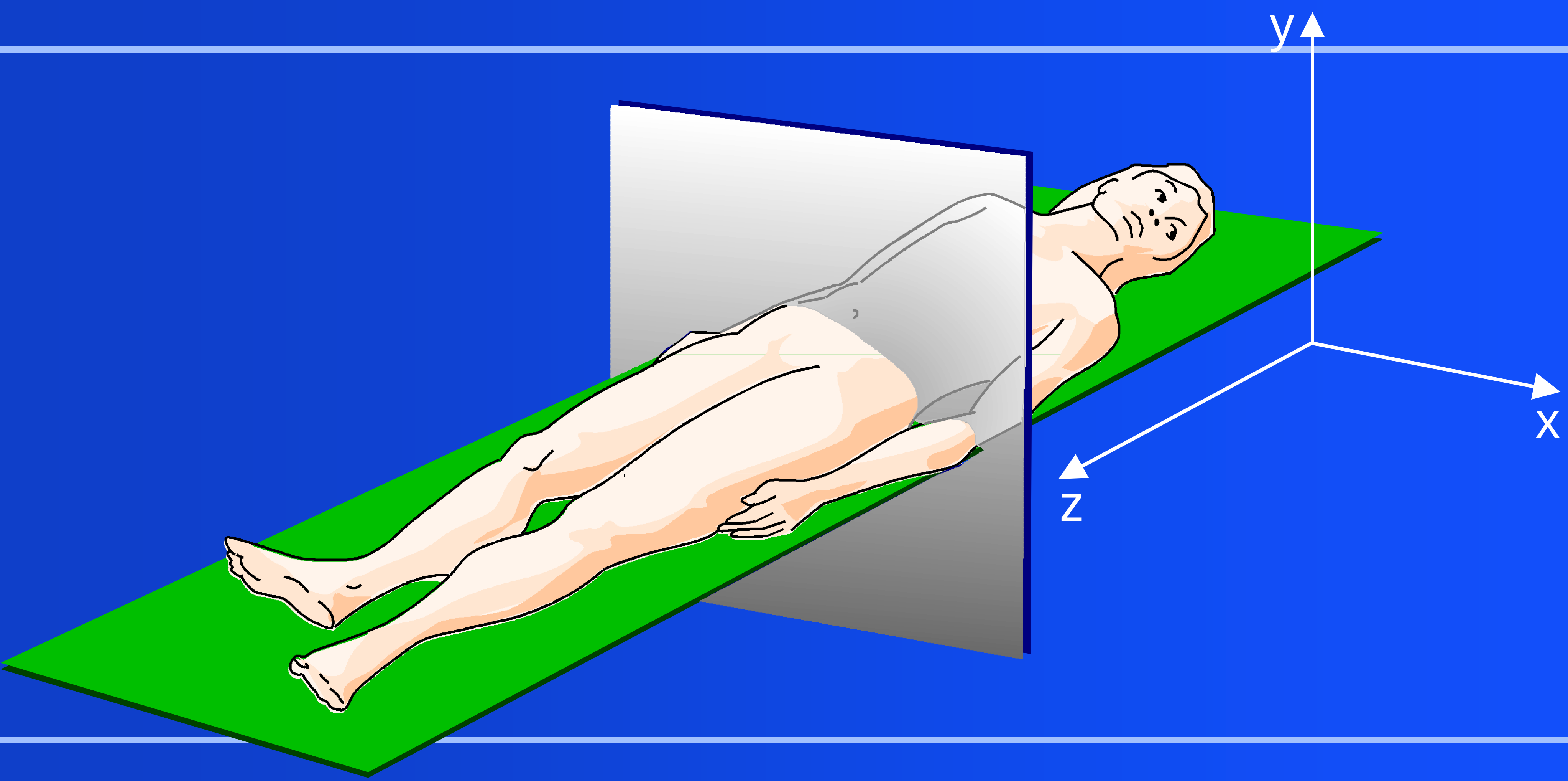
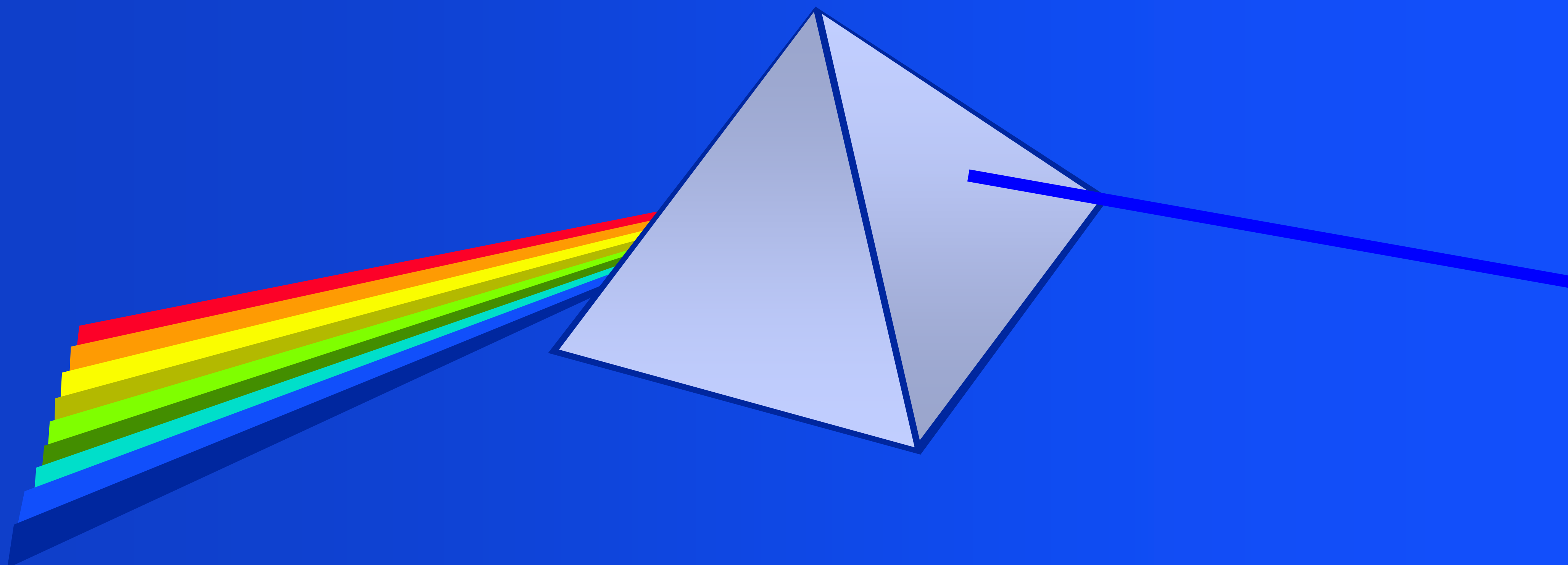


Slice Select Gradient

Slice select:

- x sagittal
- y coronal
- z transverse



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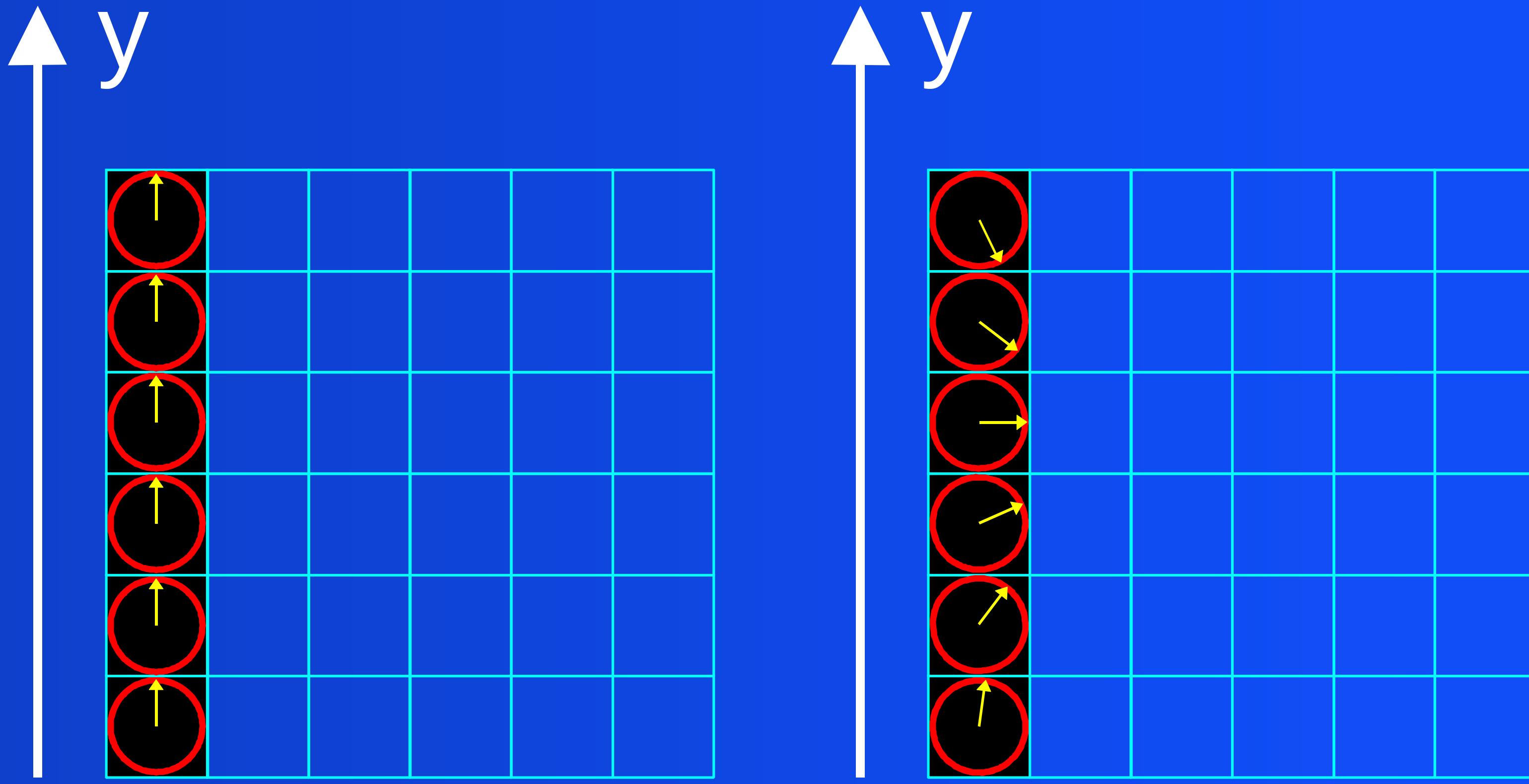
Frequency Encoding

- Fourier transformation = mathematical procedure used to convert measured time-domain signal into frequency components

- Frequency gradient = readout gradient


y
y

Phase Encoding

- Location of spins in a particular row is determined by the **phase shift** of different frequencies
- Phase shift between spins is directly proportional to their location

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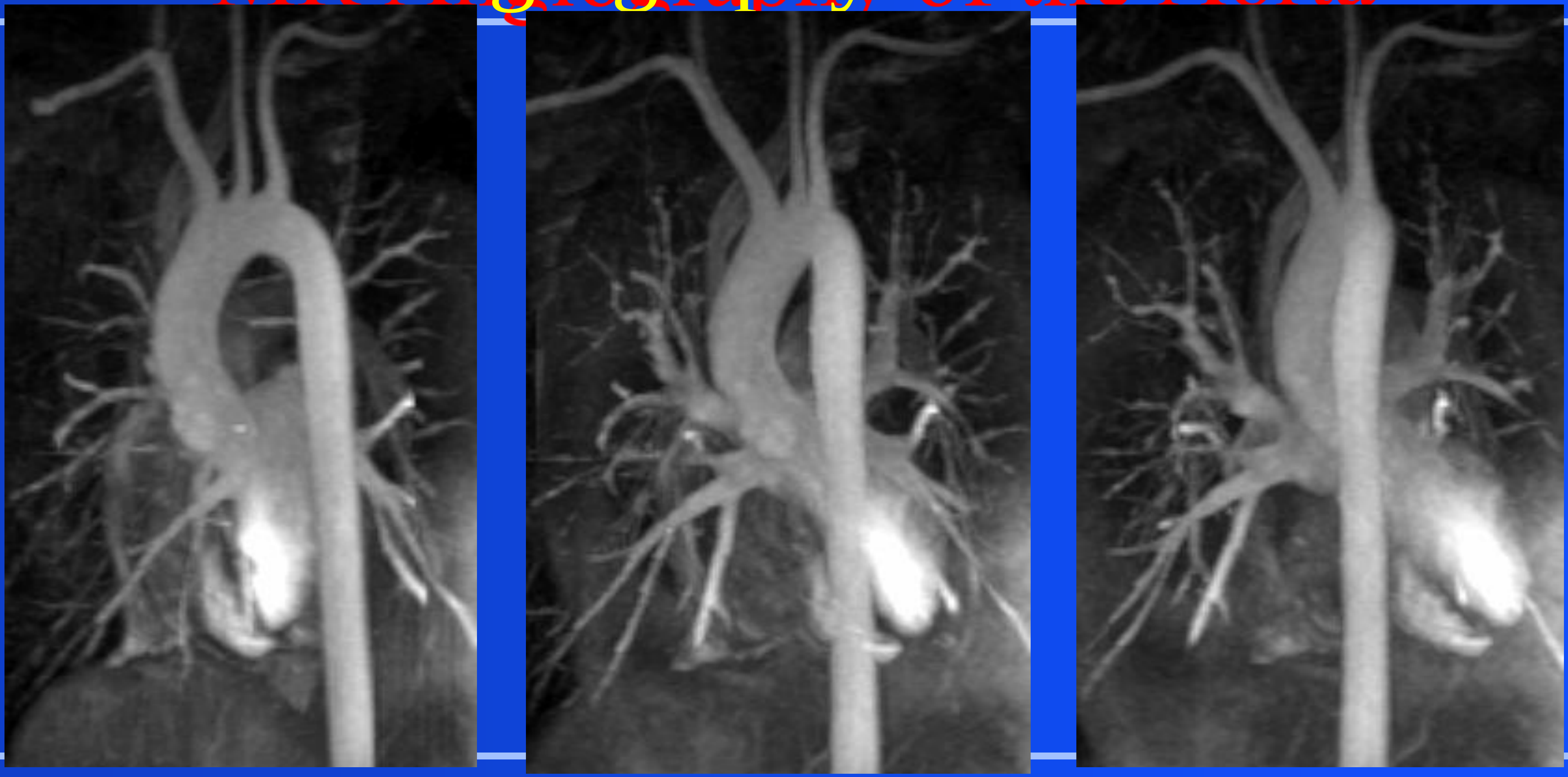
MR Angiography of the Aorta



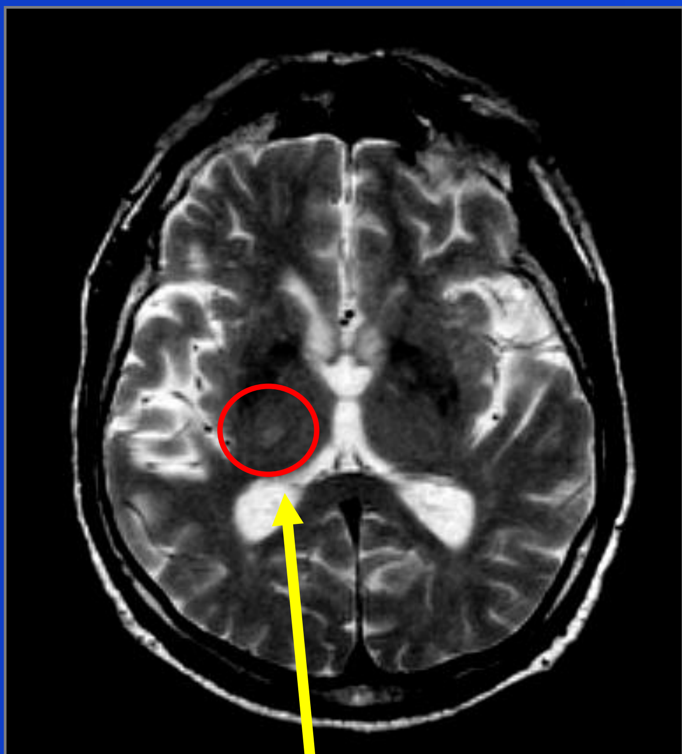
Turbo MRA, TR = 4.2 ms, TE = 1.7 ms, 2.0x1.8x1.4 mm³, TA = 19 sec

courtesy Dr. Wan, Chang Gung Mem. Hospital, Taipei

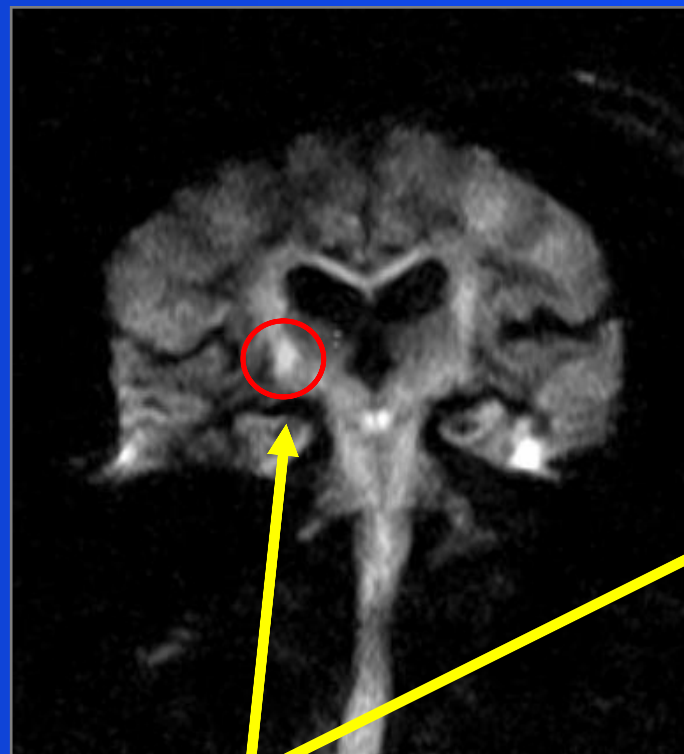
Diffusion

Functional Imaging Pck. & Gradient Overdrive

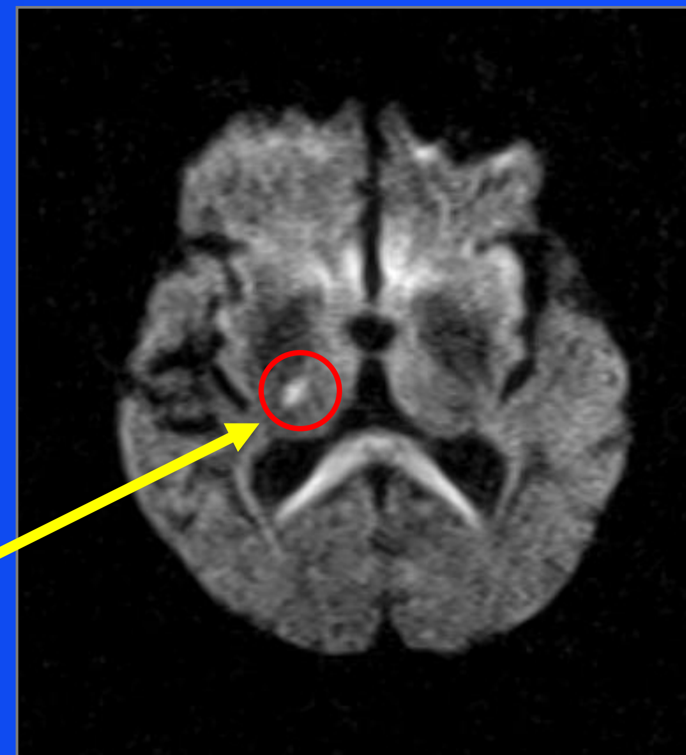
Turbo SE



Diffusion / EPI



Diffusion / EPI



??

Acute stroke (4 h after onset)

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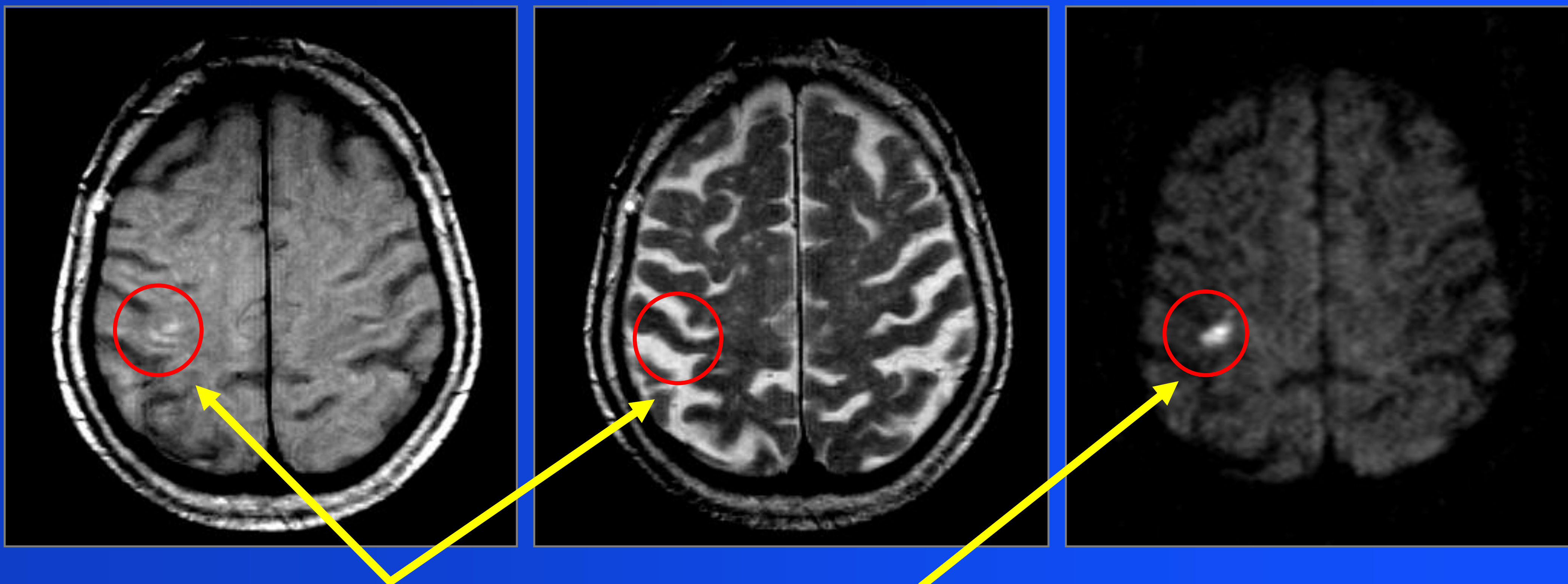
Functional Imaging Pck. & Gradient Overdrive

Diffusion

T_1 - Turbo SE | T_2 - Turbo SE | Diffusion / EPI



??

Acute stroke (24 h after onset)

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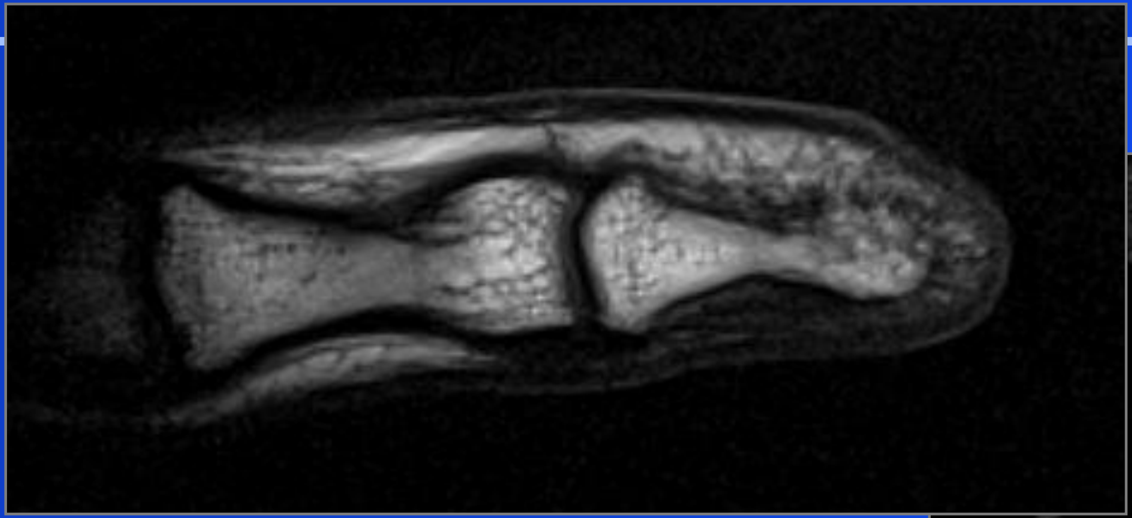
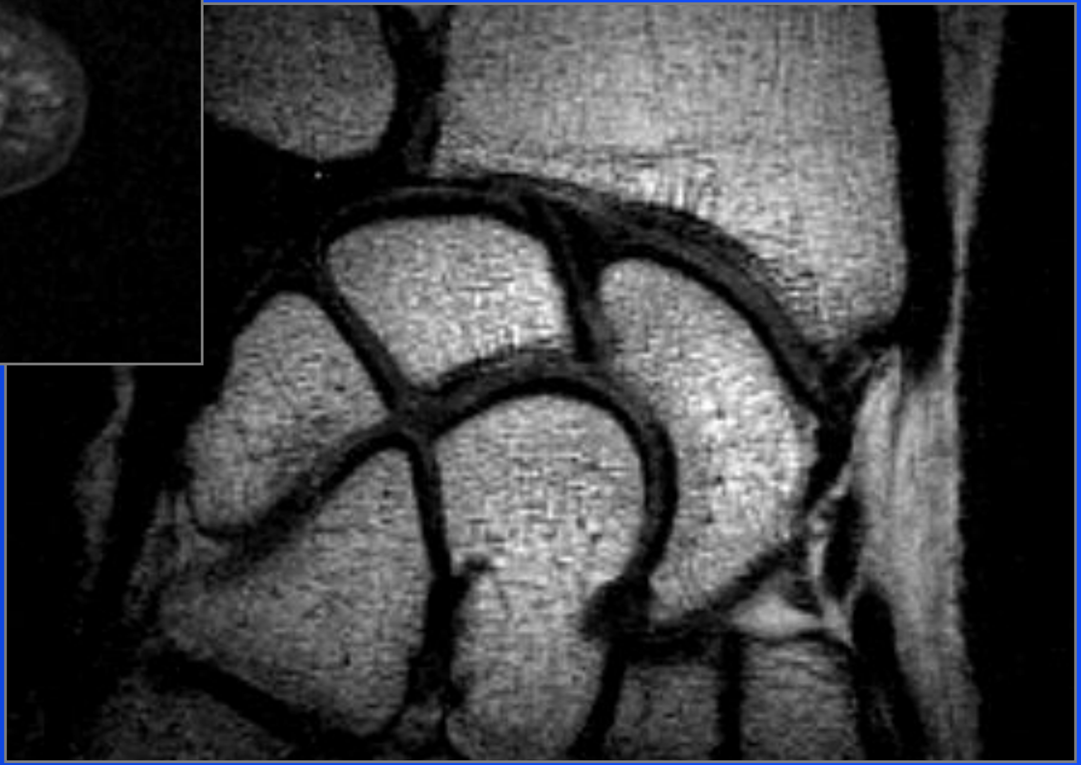
High Resolution Imaging

Clinical Imaging Package





- → Small LP Ring Coil
- → Pixel size: only 0.2 mm

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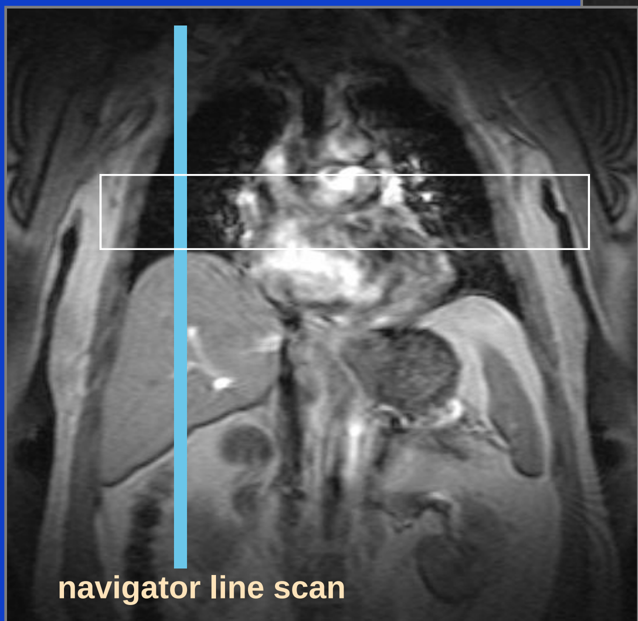
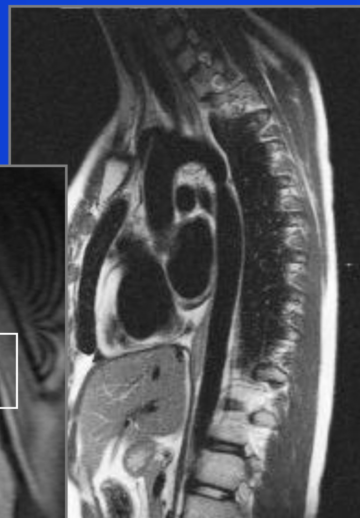
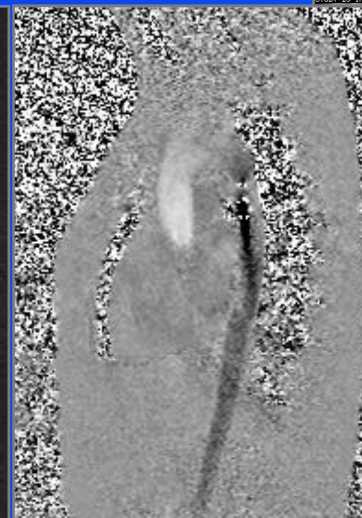
MR Cardio

MR Card Package

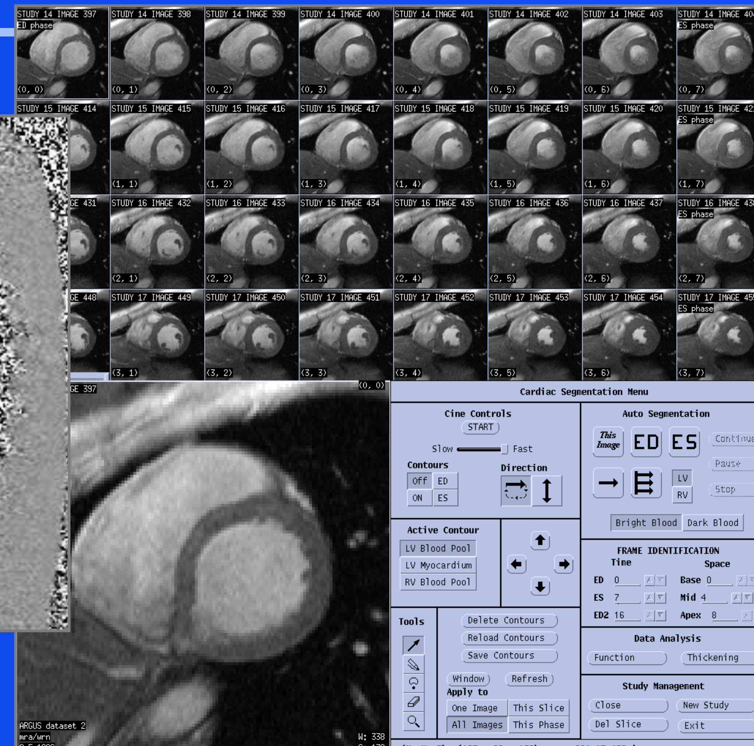


Navigator Scan





Flow Quantification



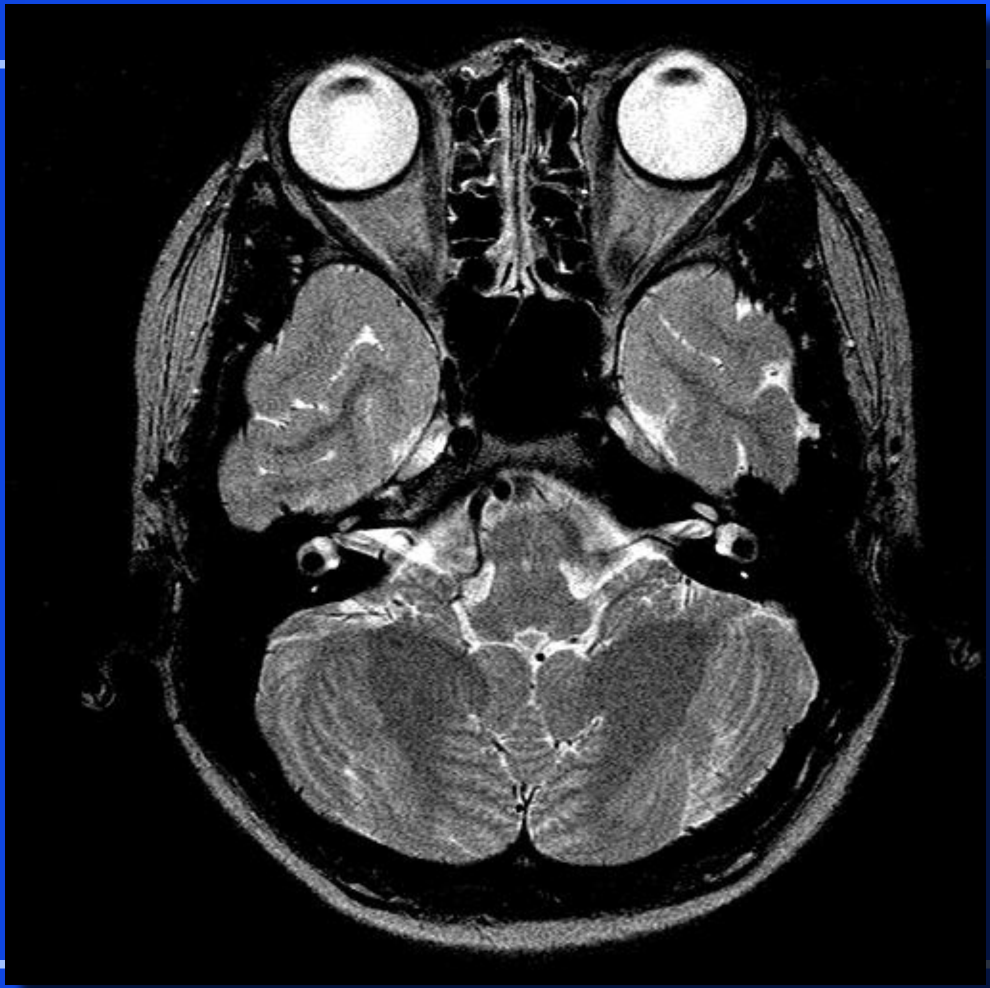
ARGUS Evaluation Package

TSE and clinical applications

Turbo Spin Echo

4500 ms TR
96 ms TEeff
8:12 minutes
1 acq
2 mm
180 mm FoV
378*512 matrix
0.4 mm gap

7 echoes
1.5 T



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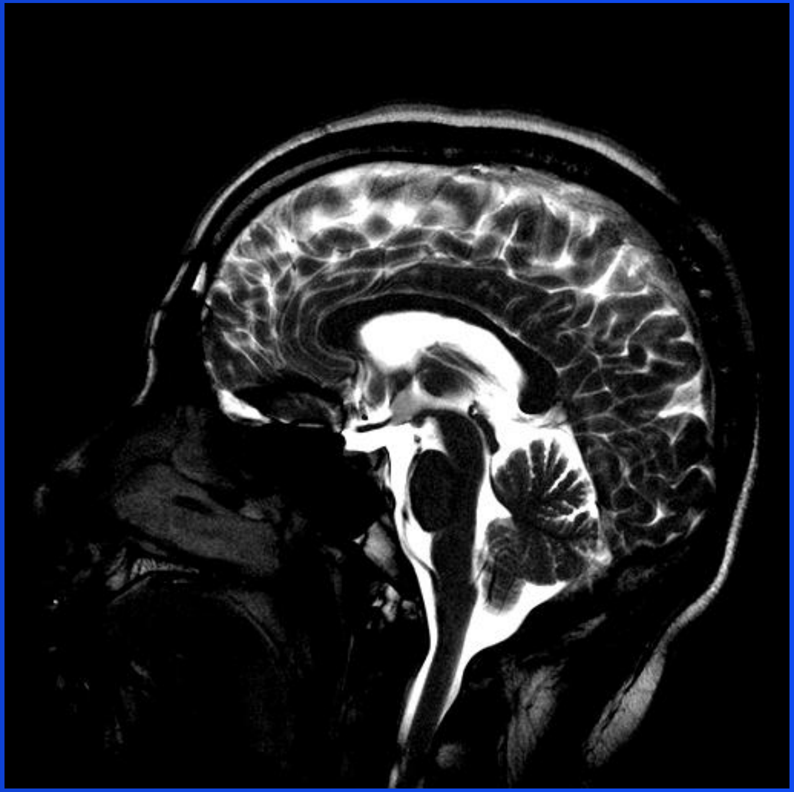
True Fisp: 512 Matrix



measurement time 4 seconds !

true Fast Imaging with Steady Precession