TIMES, OCTOBER 9, 2003

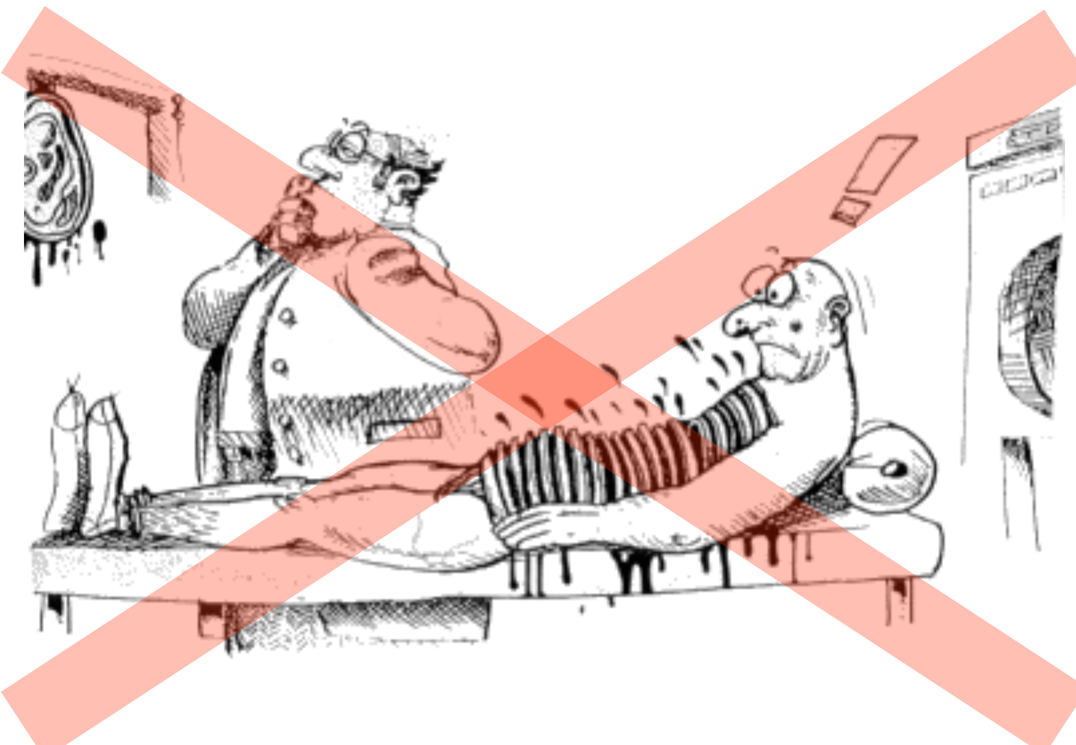
This Year's Nobel Prize in Medicine

The Shameful Wrong That Must Be Righted

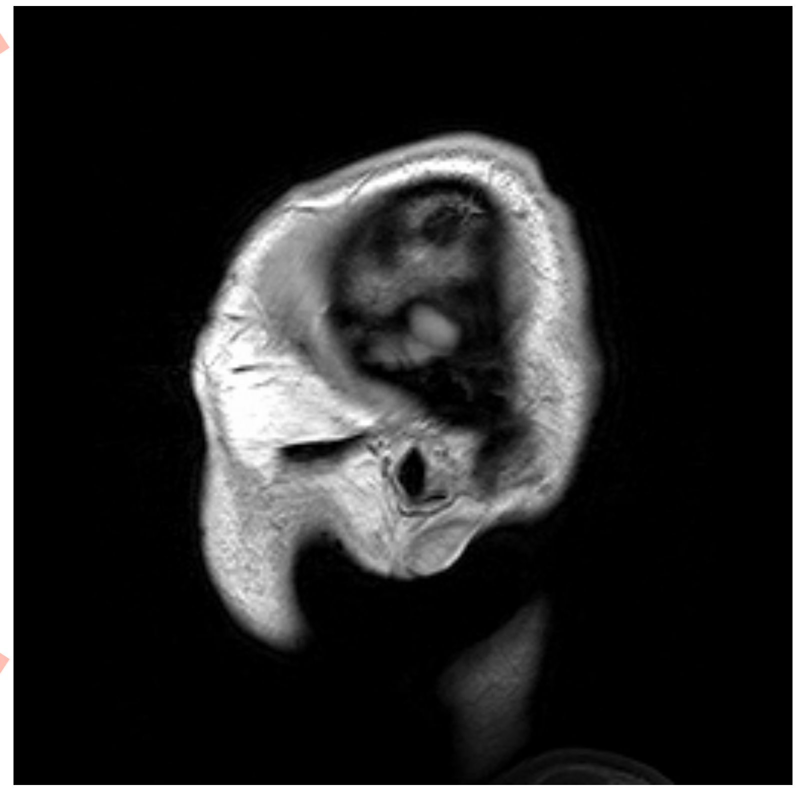
This year the committee that awards The Nobel Prize for Physiology or Medicine did the one thing it has no right to do: it ignored the truth. Eminent scientists, leading medical textbooks and the historical facts are in disagreement with the decision of the committee. So is the U. S. Patent Office. Even Alfred Nobel's will is in disagreement. The committee is attempting to rewrite history.

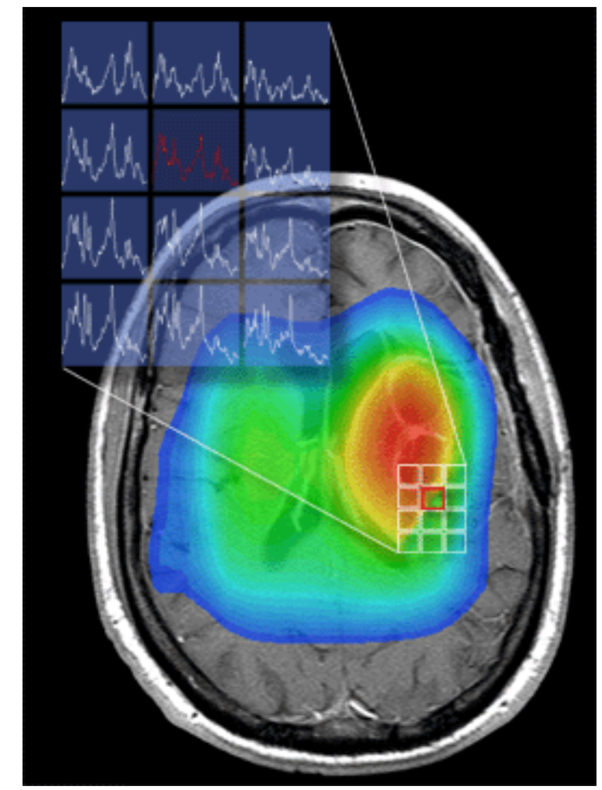
The Nobel Prize Committee to Physiology or Medicine chose to award the prize, not to the medical doctor/research scientist who made the breakthrough discovery on which all MRI technology is based, but to two scientists who later made technological improvements based on his discovery.

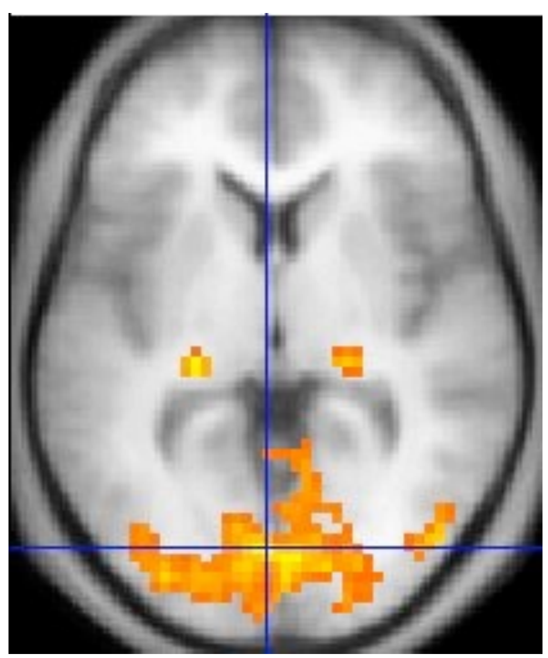
MRI is a revolutionary device

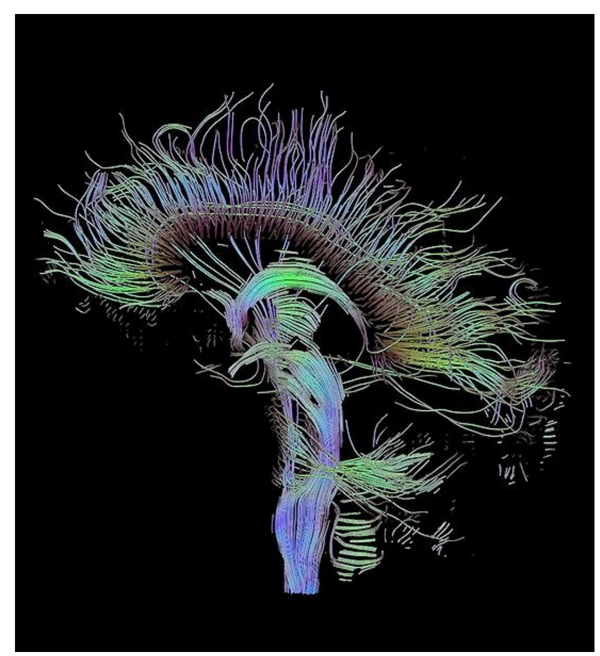


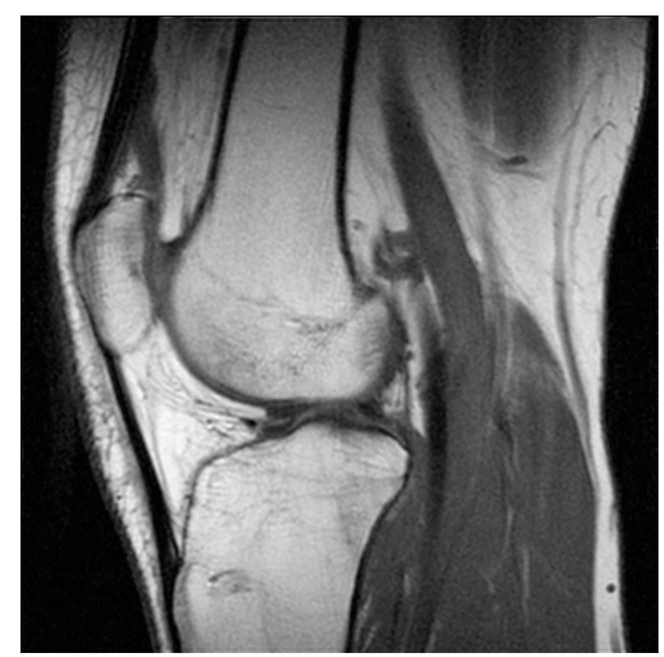
Non-invasive











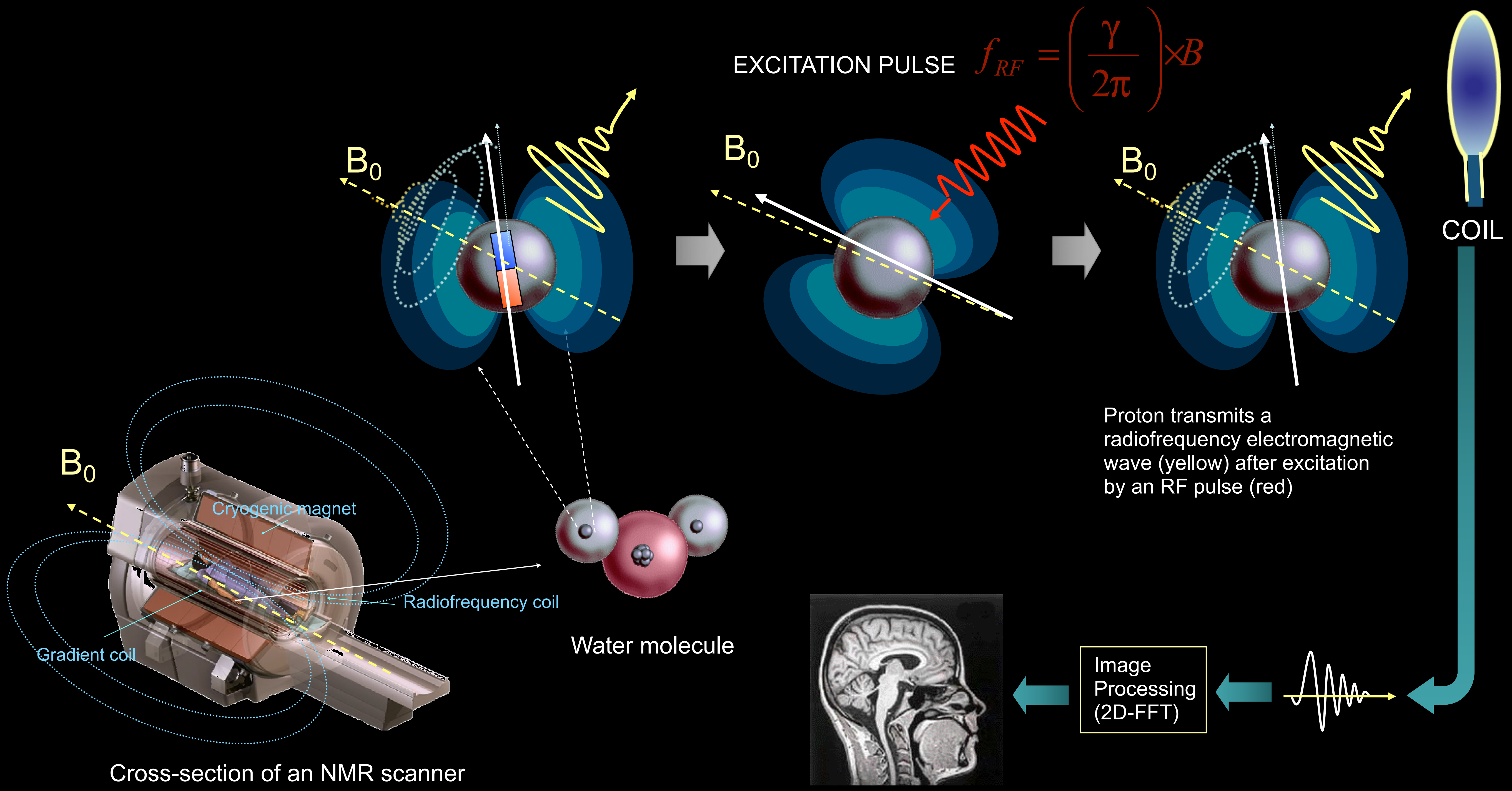
MRI

- History
- Fundamental processes
  (nuclear spin, precession, resonance, excitation-relaxation)
- Imaging
  I. Spatial coding
  II. Image reconstruction
  III. Color contrast
  IV. Scanners
  V. Contrast agents
  VI. Artifacts
  VII. Dangers, contraindications
- Applications, future trends

MRI History

- 1970 - Raymond Damadian: T1 and T2 relaxations of neoplastic and normal tissues are different.
- 1972 - Raymond Damadian: US patent
- 1973 - Paul Lauterbur: 2D MR imaging method
- 1974 - Peter Mansfield: 3D MR imaging method
- 1977 - Raymond Damadian: first MR scanner ("focused field" method)
- 2003 - Nobel-prize: Lauterbur, Mansfield
- NMR: method which has received the most Nobel-prizes (6)
  Otto Stern (1942), Isidor Rabi (1944), Felix Bloch, Edward Purcell (1952), Richard Ernst (1991), Kurt Wüthrich (2002)

Nuclear Magnetic Resonance Imaging: Basic principle

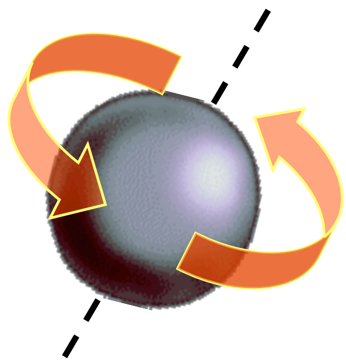


MRI FUNDAMENTALS

I. ATOMIC NUCLEI WITH NUCLEAR SPIN ARE ELEMENTARY MAGNETS

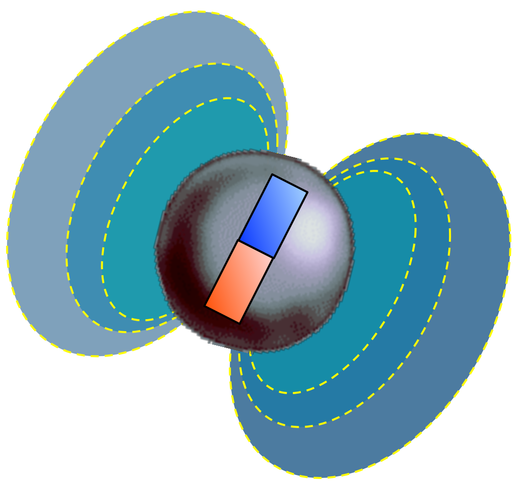
Otto Stern

W. Gerlach



Atomic nuclei have mass:

$$m_{proton} = 1{,}67.10^{-24}\ \text{g}$$



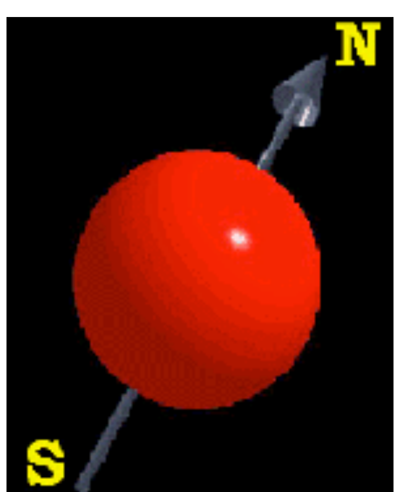
Atomic nuclei carry angular momentum:

$$L = \sqrt{l(l+1)\hbar}$$

l = spin quantum number

Atomic nuclei carry charge:

$$q_{proton} = 1{,}6.10^{-19}\ \text{C}$$



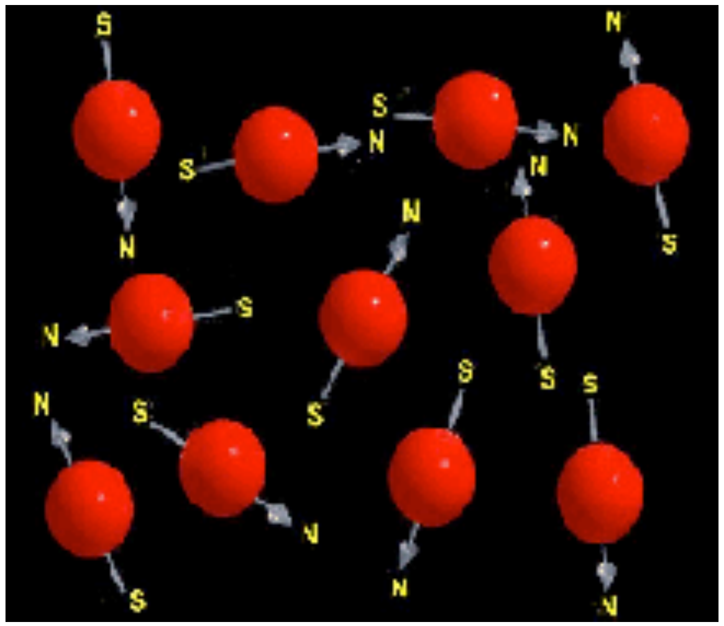
Atomic nuclei possess magnetic moment:

$$\mu_i = \gamma L$$

γ = gyromagnetic ratio
L = angular momentum

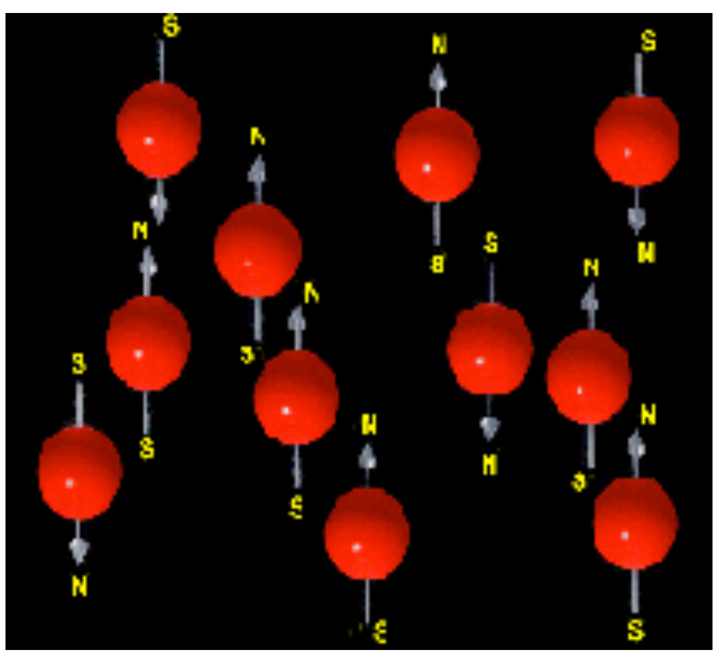
MRI FUNDAMENTALS

II. NUCLEAR SPINS ORIENT IN A MAGNETIC FIELD



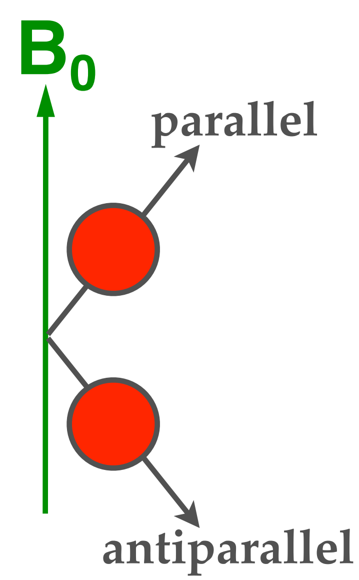
In absence of magnetic field:

random orientation of elementary magnets

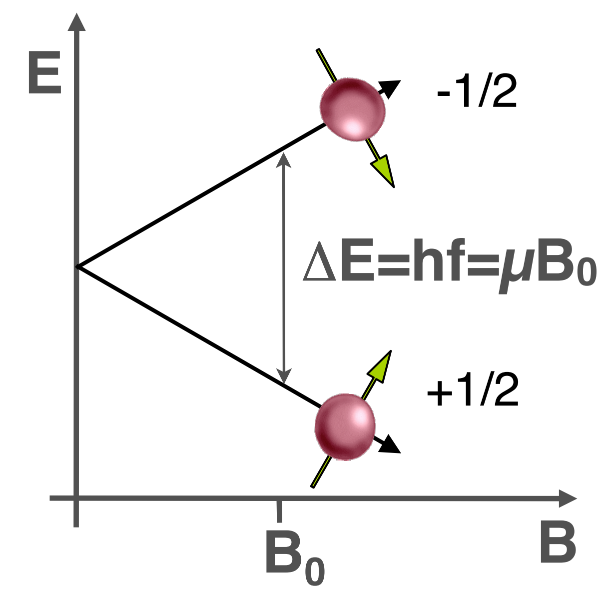


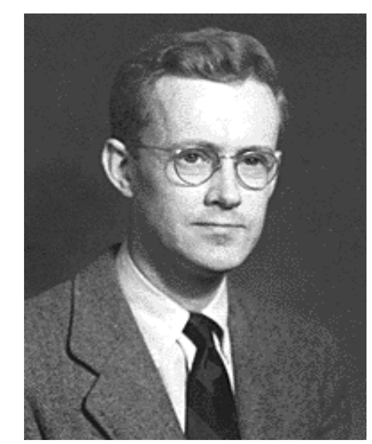
In magnetic field:

elementary magnets orient



energy levels split





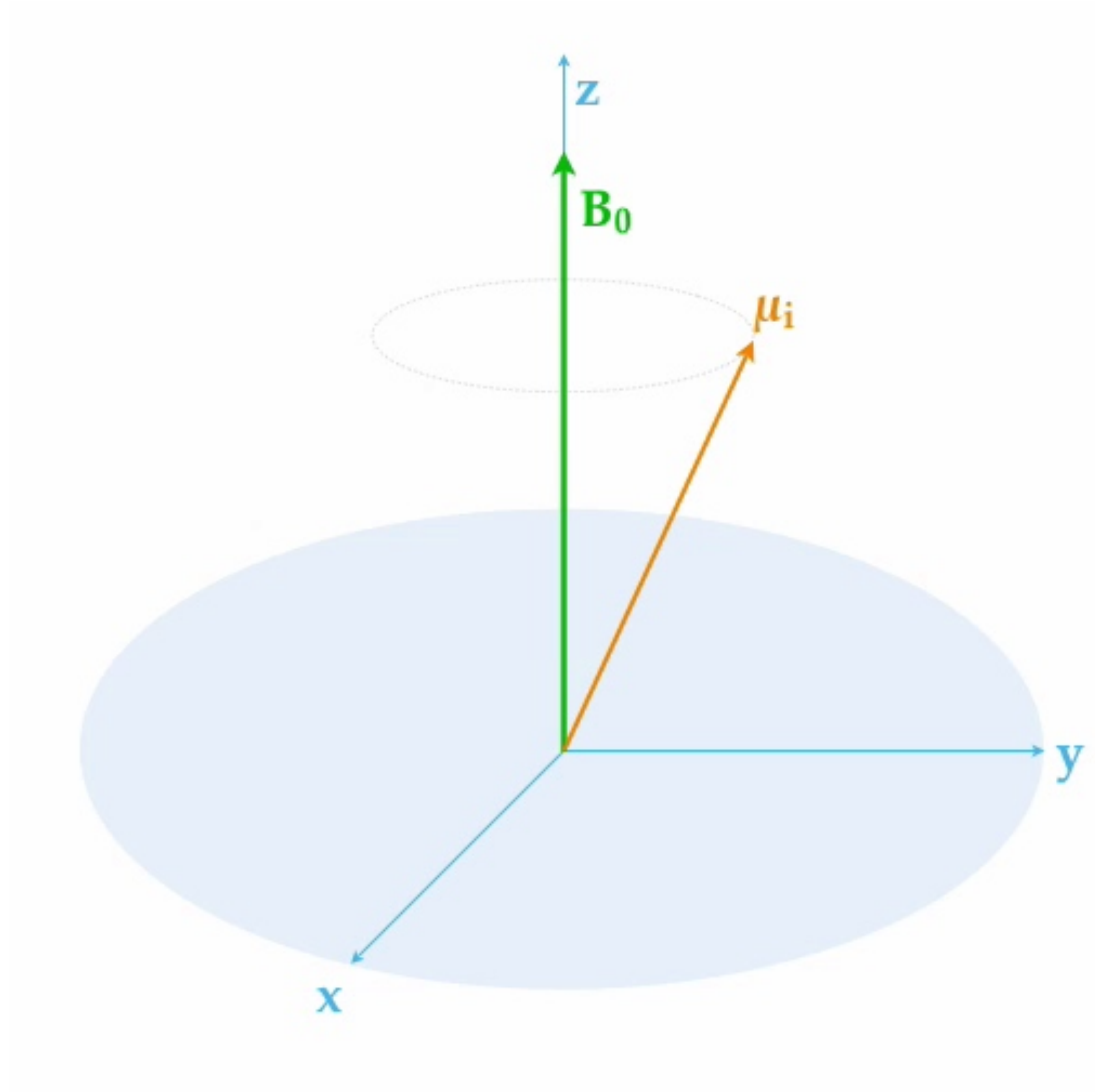
Edward Purcell, 1946

Useful nuclei in MRI: ^{1}H, ^{13}C, ^{19}F, ^{23}N, ^{31}P

MRI FUNDAMENTALS

III. Oriented nuclear spins display precessional motion

Precession of a top



Precession or Larmor frequency:

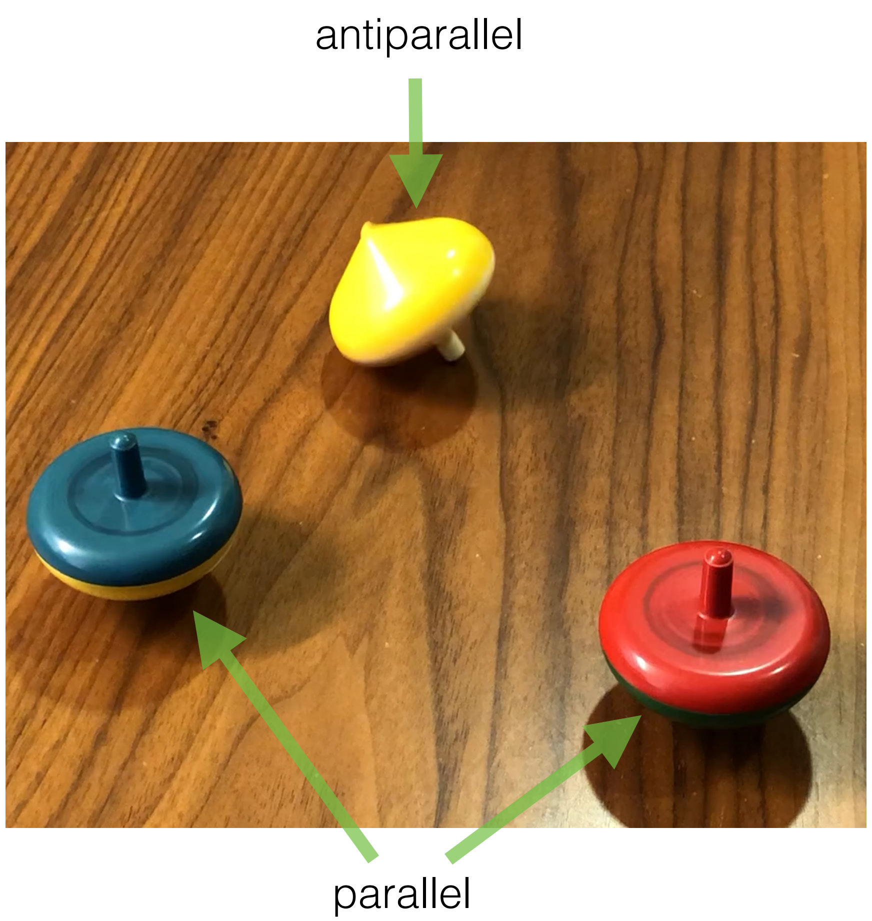
$$\omega_0 = \gamma B_0$$

$$f_{Larmor} = \frac{\gamma}{2\pi} B_0$$

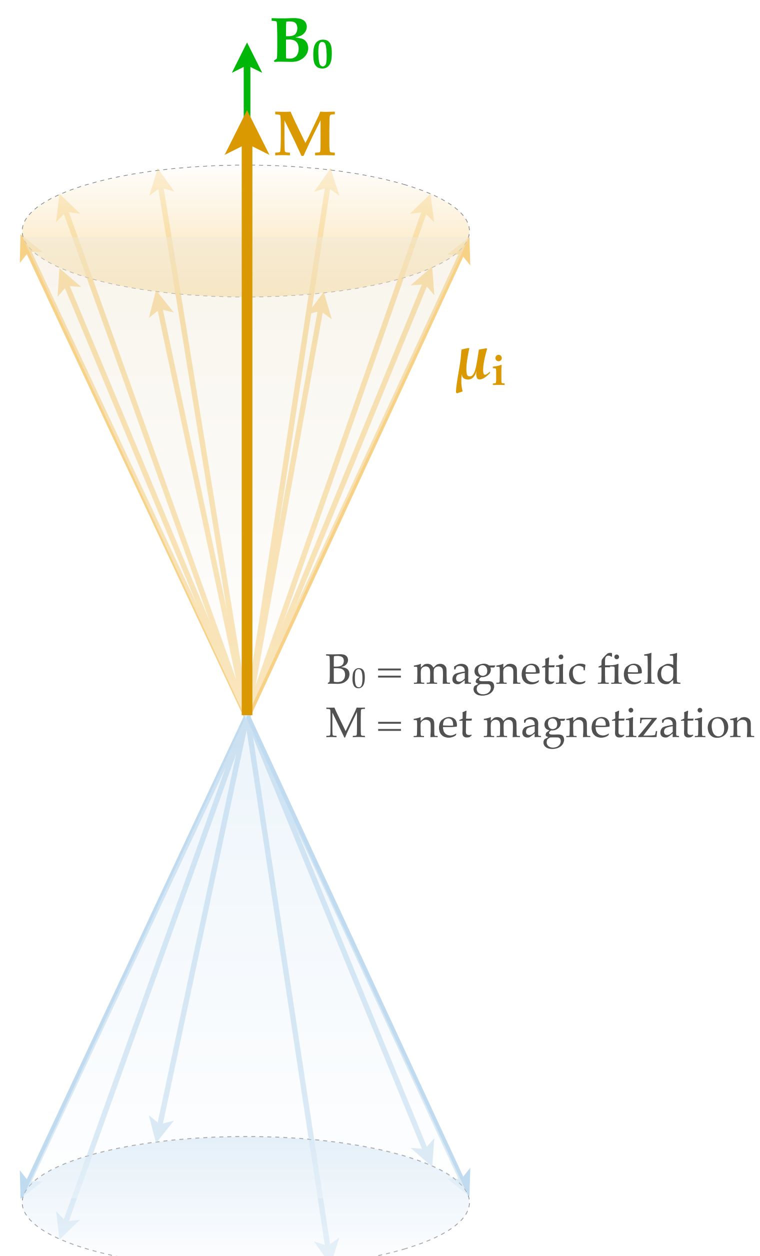
Felix Bloch, 1946

Net magnetization

Due to spin access in different energy states



Low energy state
parallel in case of proton



High energy state
antiparallel in case of proton

Ratio of magnetic spins in high- (antiparallel) and low-energy (parallel) states:

$$\frac{N_{antiparallel}}{N_{parallel}} = e^{-\frac{\Delta E}{k_B T}}$$

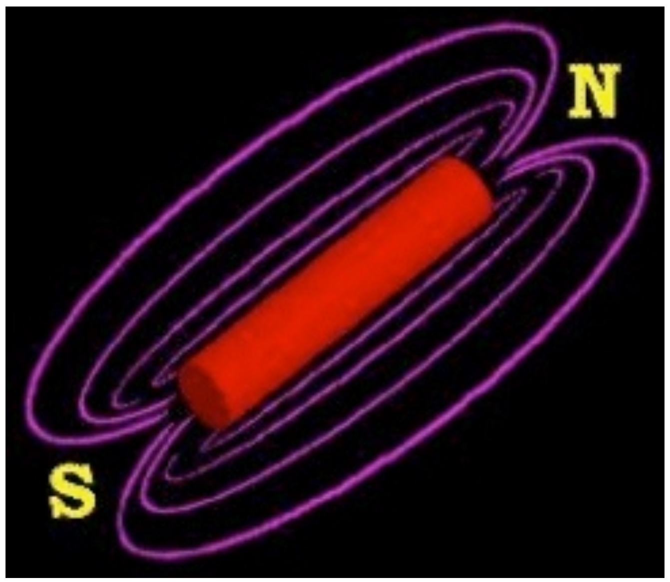
Boltzmann distribution

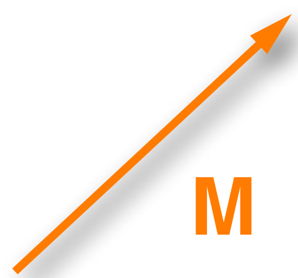
Magnetic field in MRI:
20-50 thousand times that of the Earth’s magnetic field

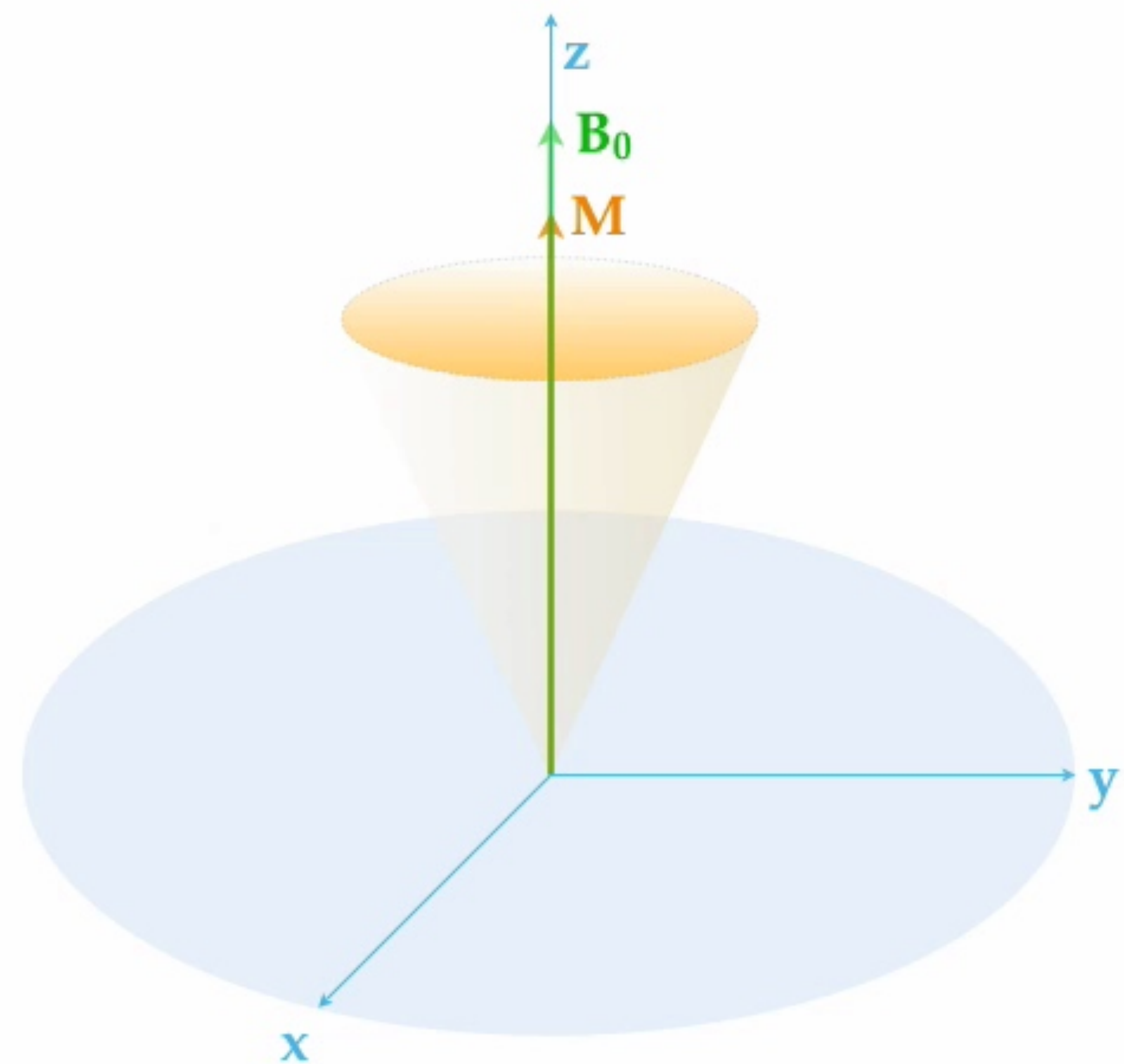
MRI FUNDAMENTALS

IV. The system may be excited with radio frequency radiation

Resonance condition: Larmor frequency





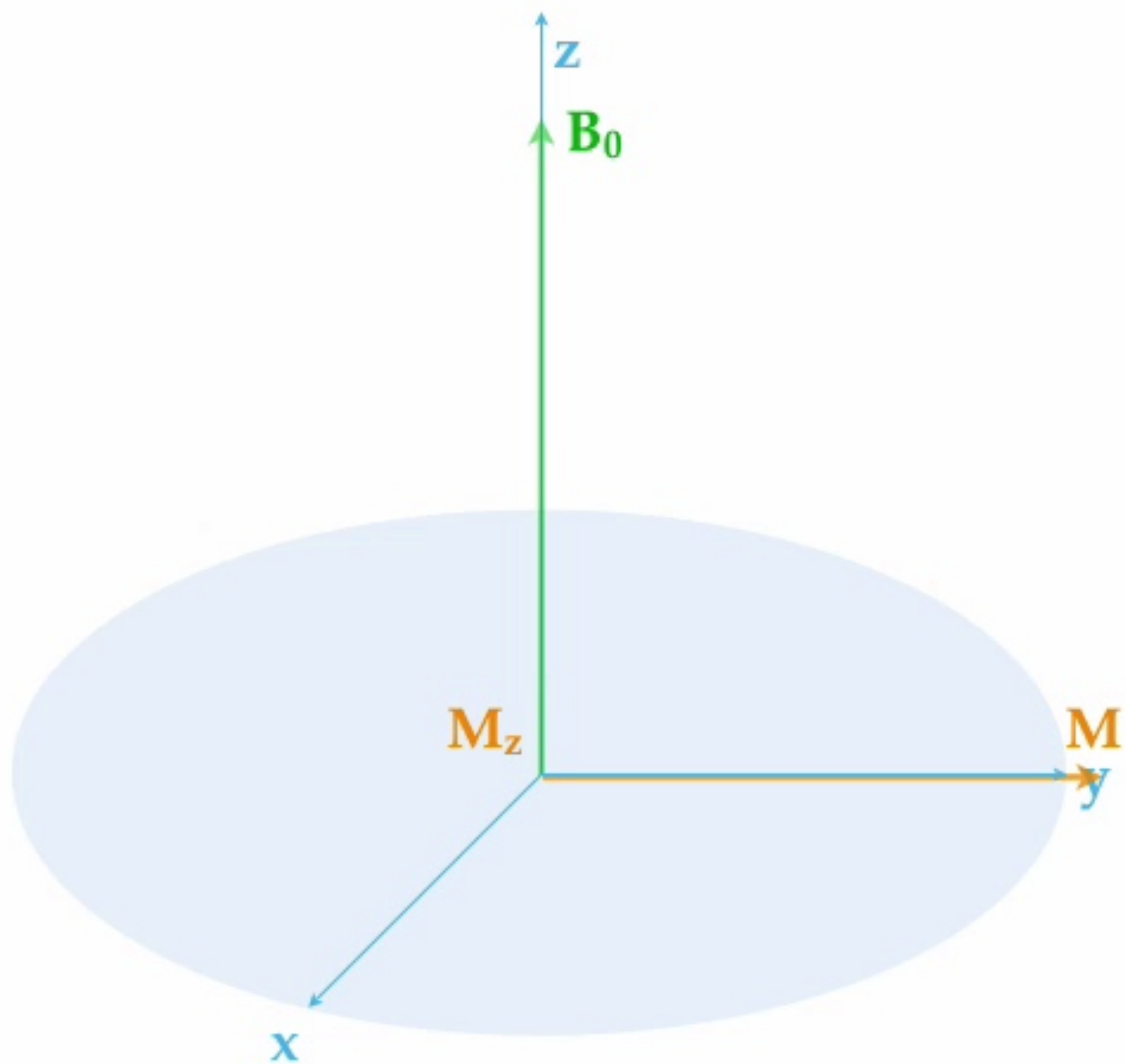


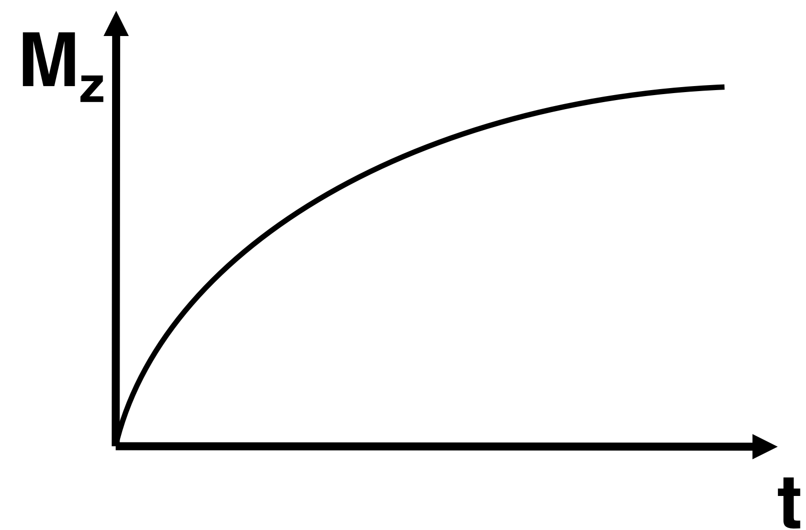
B_0 = magnetic field
M = net magnetization
B_1 = irradiated radio frequency wave

Electromagnetic radiation in MRI:
Radio waves

Spin-lattice relaxation

T1 or longitudinal relaxation

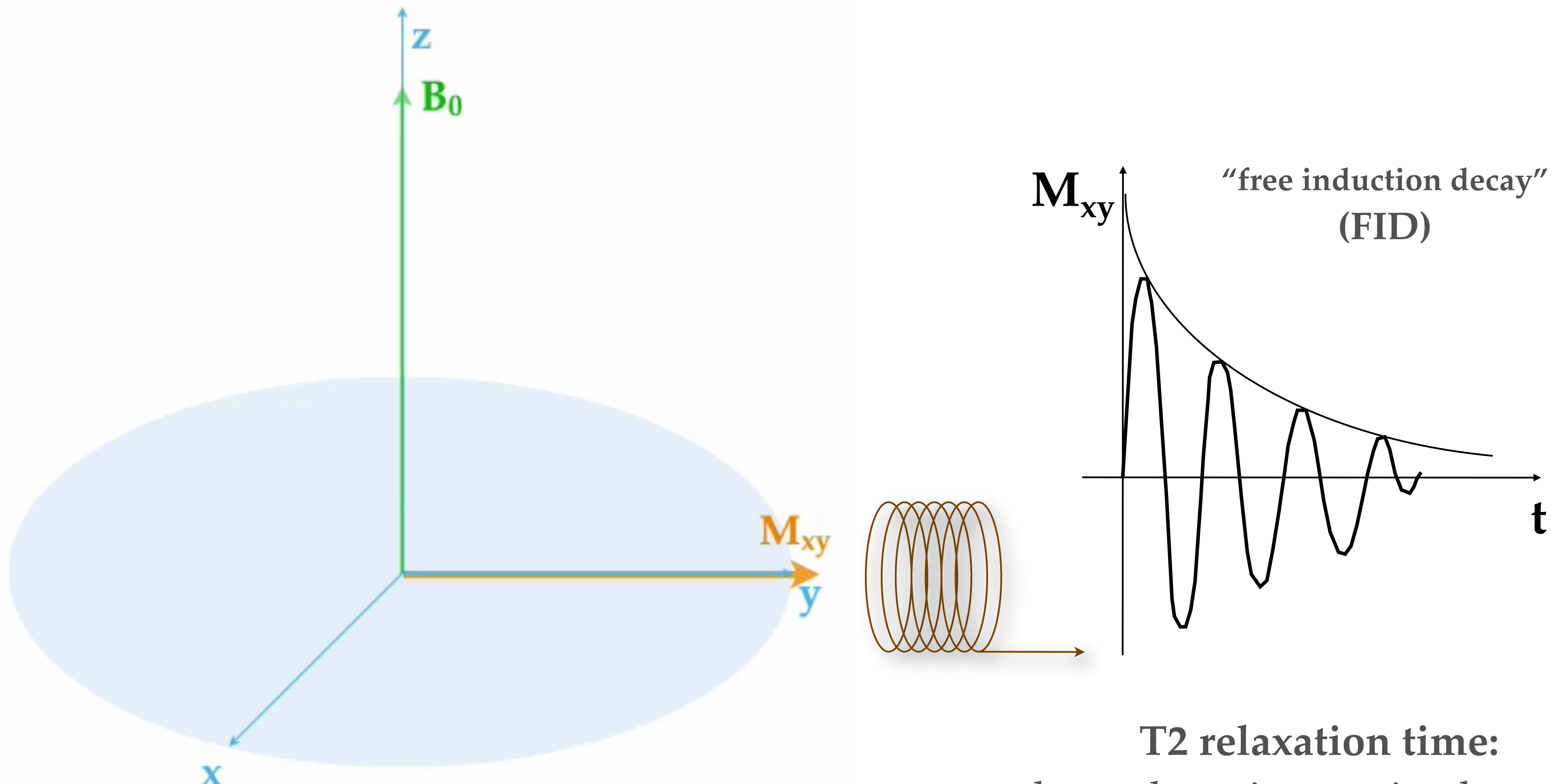




T1 relaxation time:
depends on interaction
between elementary magnet (proton)
and its environment

Spin-spin relaxation

T2 or transverse relaxation

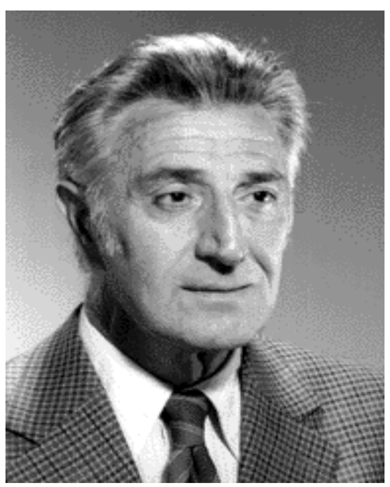


T2 relaxation time:
depends on interaction between elementary magnets (protons)

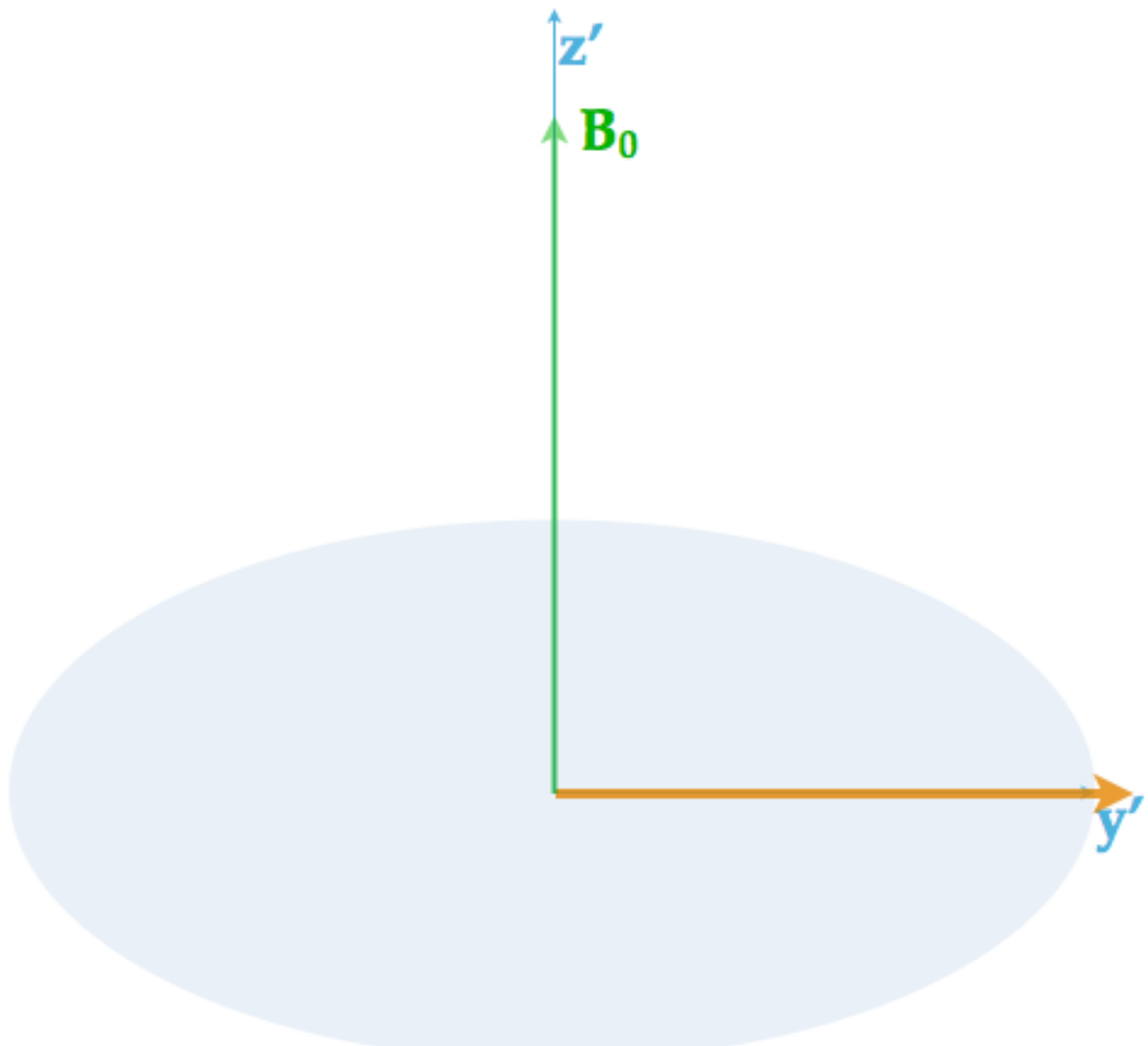
Spin-spin relaxation

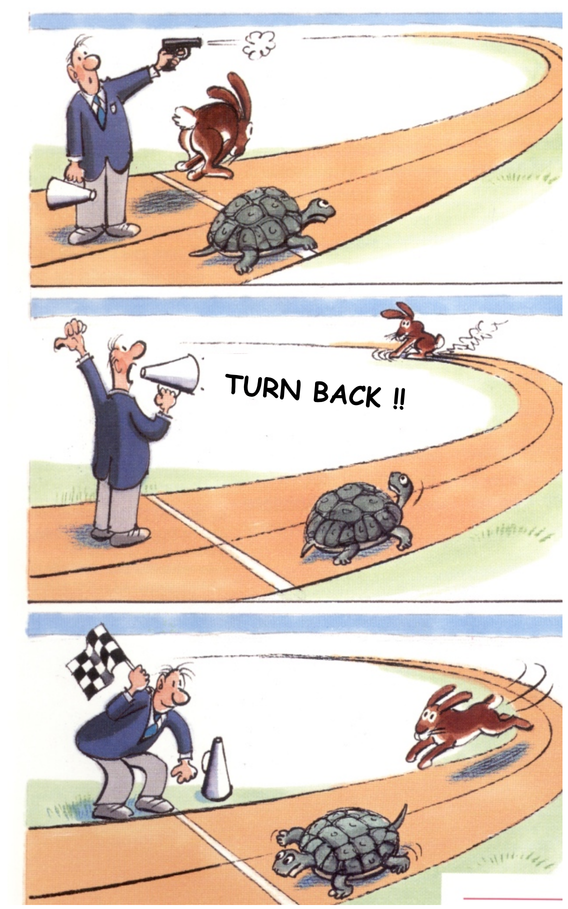
T2 or transverse relaxation

Repetitive pulses of excitation and subsequent relaxation: spin-echo sequence

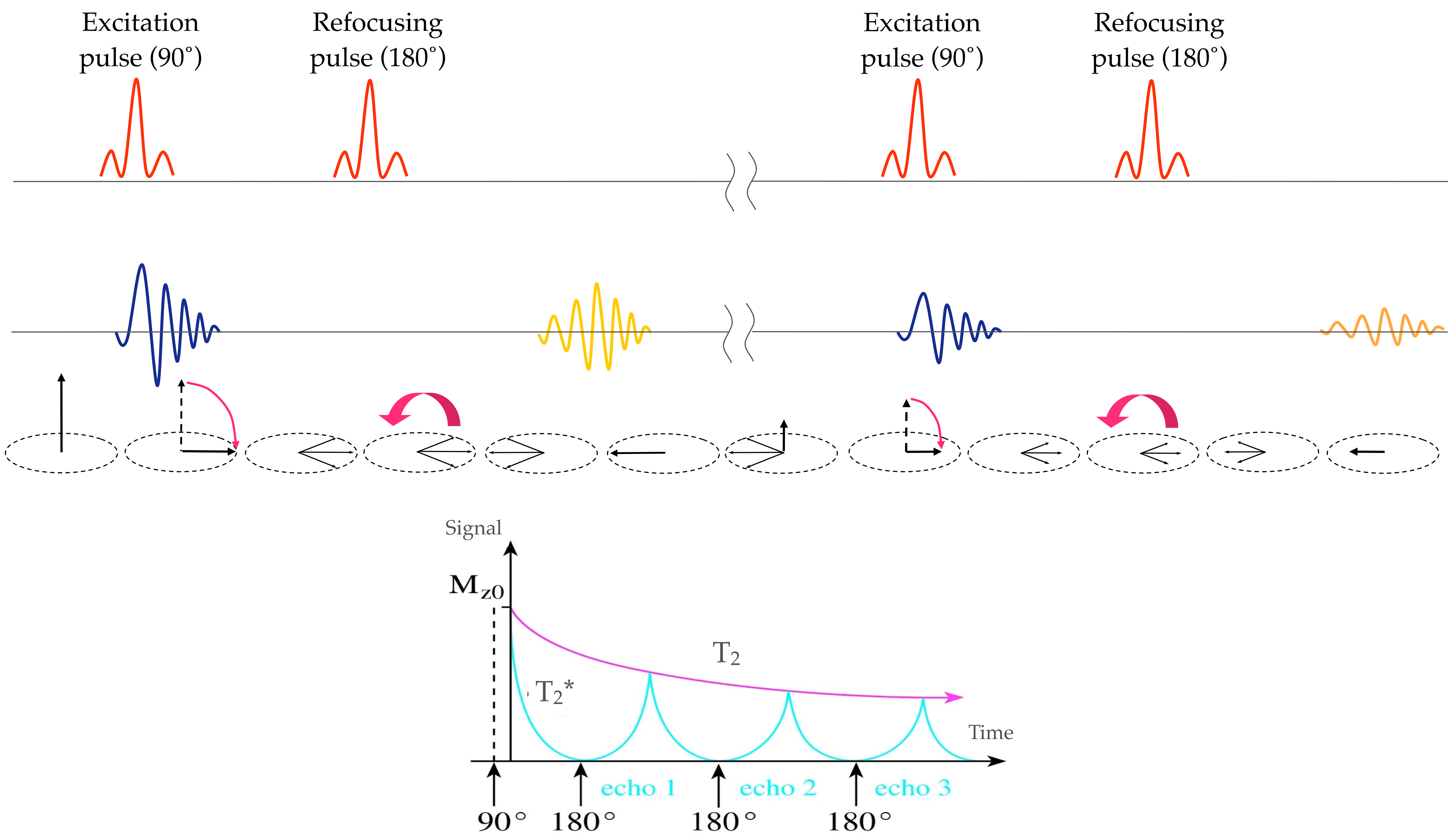


Erwin Hahn, 1949

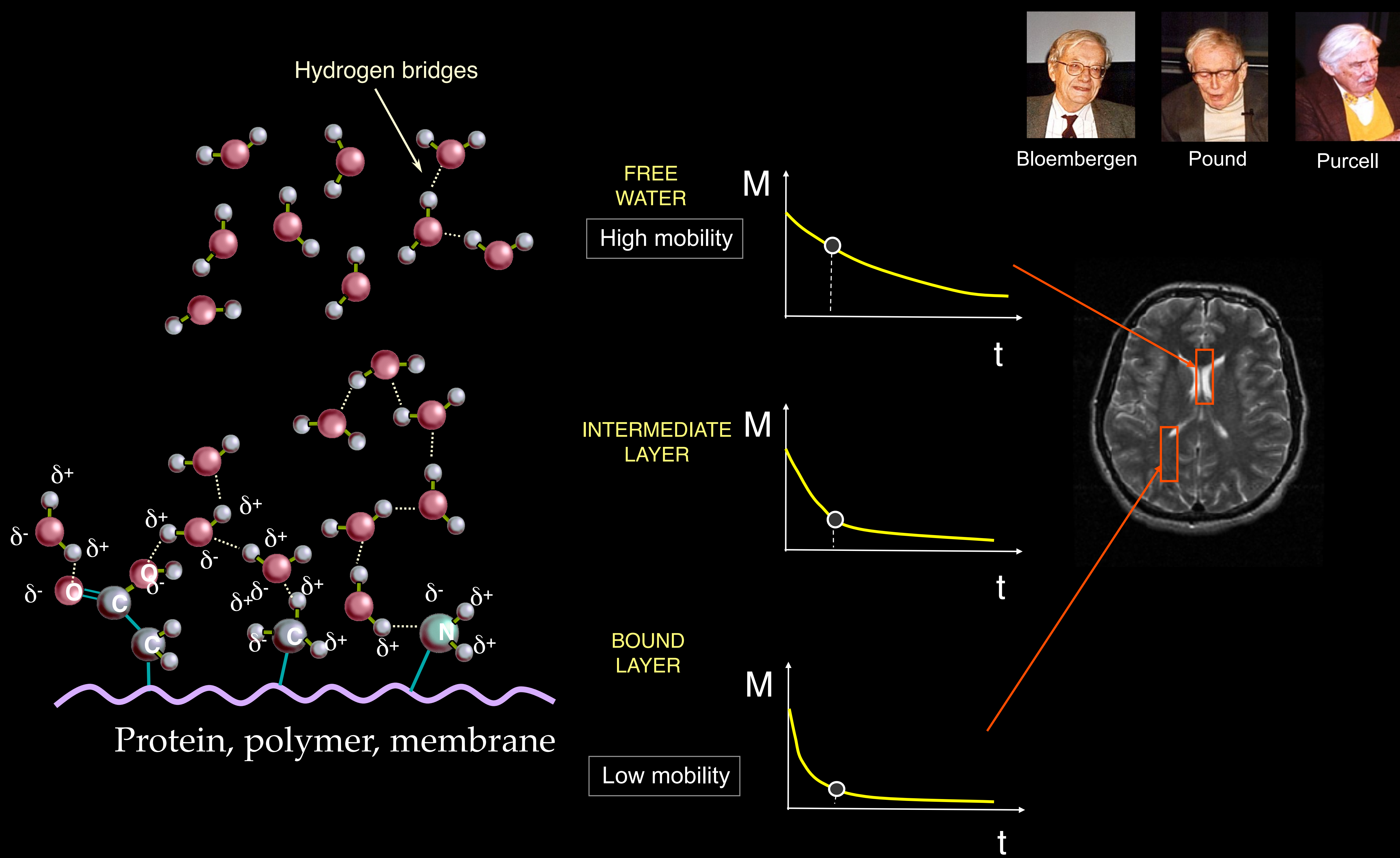




The spin-echo experiment

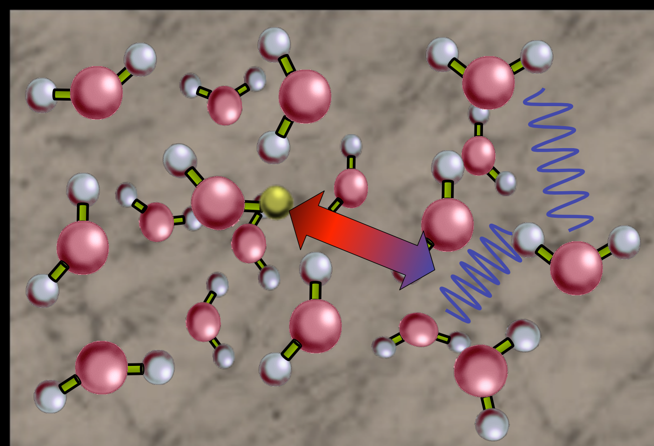


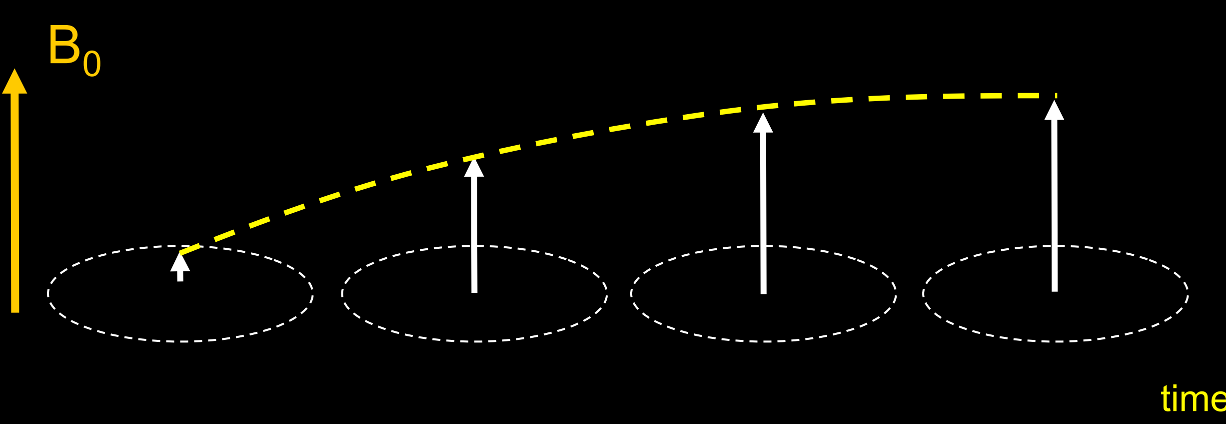
Contrast in MR images is determined by the interaction of spin systems



Nuclear Magnetic Resonance Imaging: Two important relaxation mechanisms

Spin-lattice relaxation T1





Restoration of longitudinal magnetization

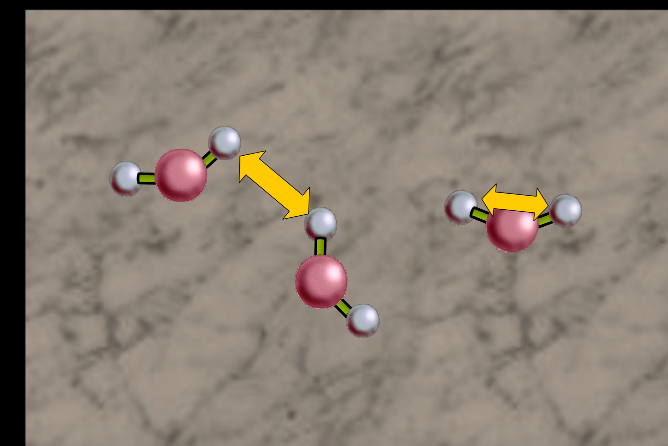
Energy transfered to lattice (phonons)

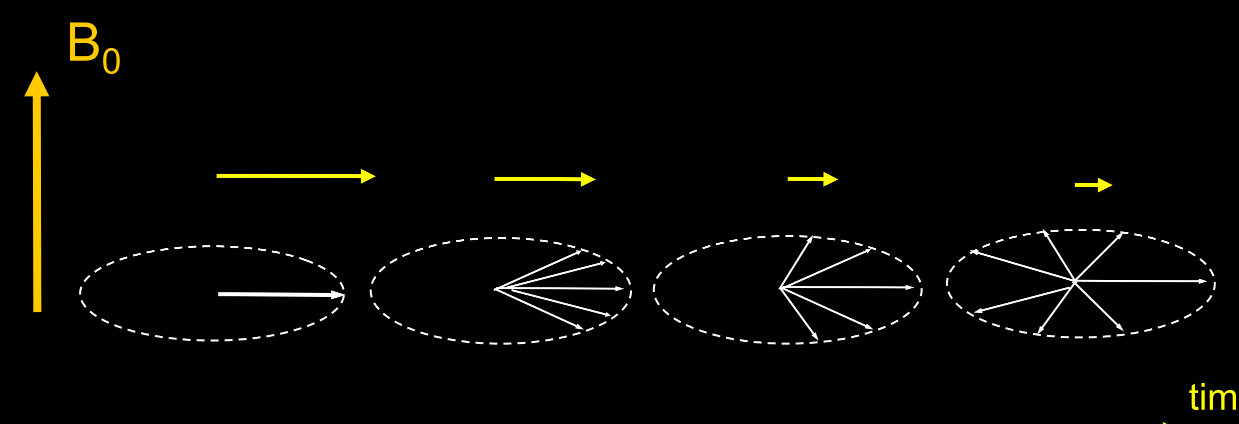
Entropy increases

Repopulation of spins between spin energy levels

Interactions with magnetic field fluctuations at Larmor frequency

Spin-spin relaxation T2





Dephasing of transverse magnetization

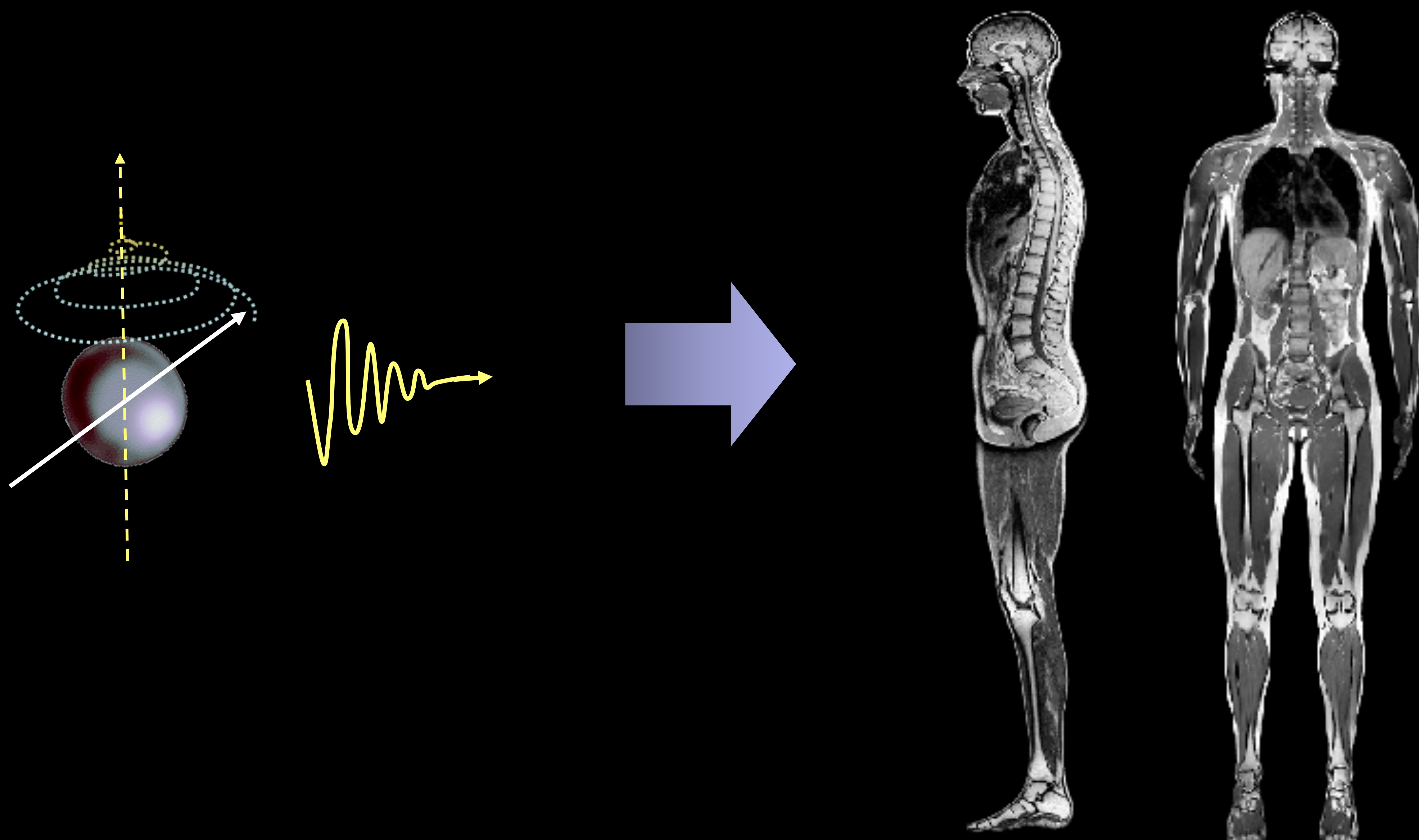
Energy transferred between spins

No entropy change of total spin system

No repopulation of spins between spin energy levels

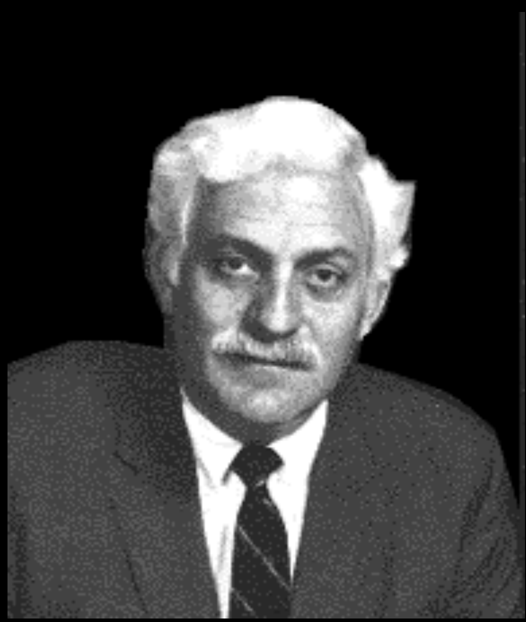
Interactions with magnetic field fluctuations at low frequency

From nuclear magnetic resonance signal to Magnetic Resonance Imaging

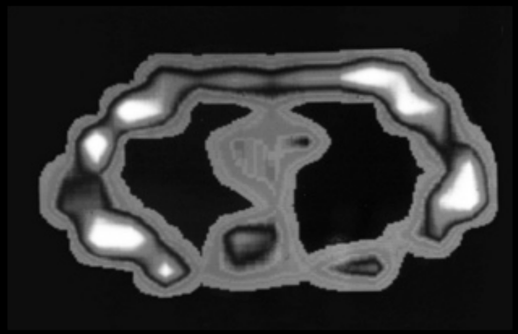


MRI: net magnetization of the human body is generated

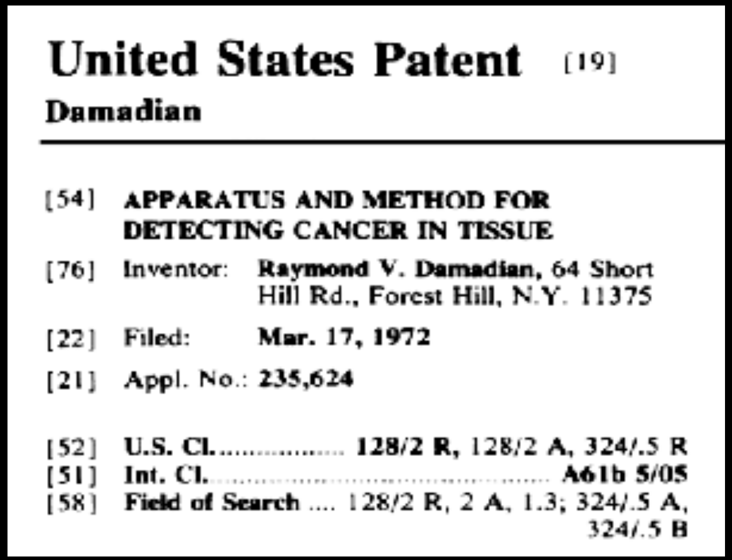
Downstate Medical Center - Brooklyn, 1972



Raymond V. Damadian



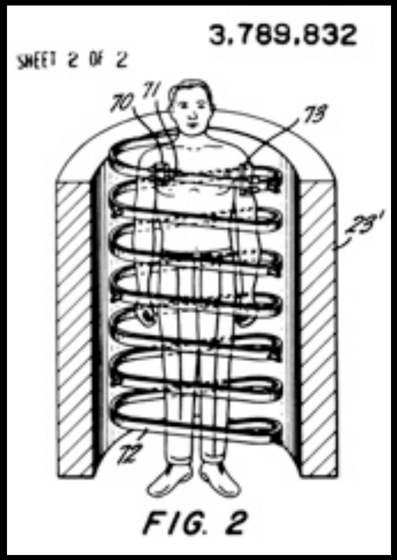
First MRI scan



United States Patent [19]
Damadian

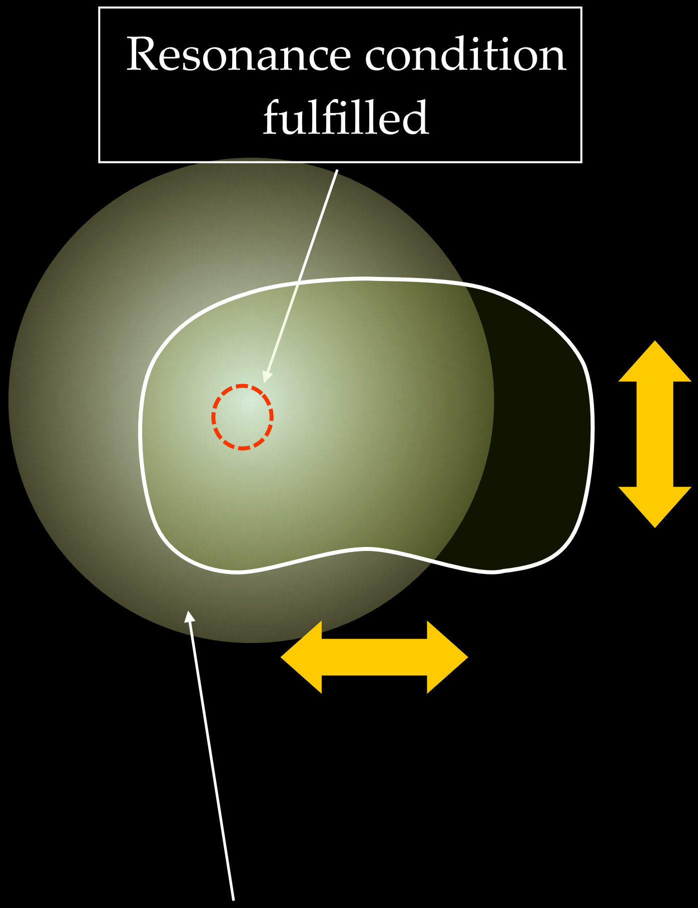
[54] APPARATUS AND METHOD FOR DETECTING CANCER IN TISSUE
[76] Inventor: Raymond V. Damadian, 64 Short Hill Rd., Forest Hill, N.Y. 11375
[22] Filed: Mar. 17, 1972
[21] Appl. No.: 235,624

[52] U.S. Cl. .... 128/2 R, 128/2 A, 324/.5 R
[51] Int. Cl. A61b 5/05
[58] Field of Search .... 128/2 R, 2 A, 1.3; 324/.5 A, 324/.5 B



1970: detection of lengthened relaxation times in cancerous tissues
1972: theoretical development of human in vivo 3D NMR
1977: first human MRI image

$\omega = \gamma B$

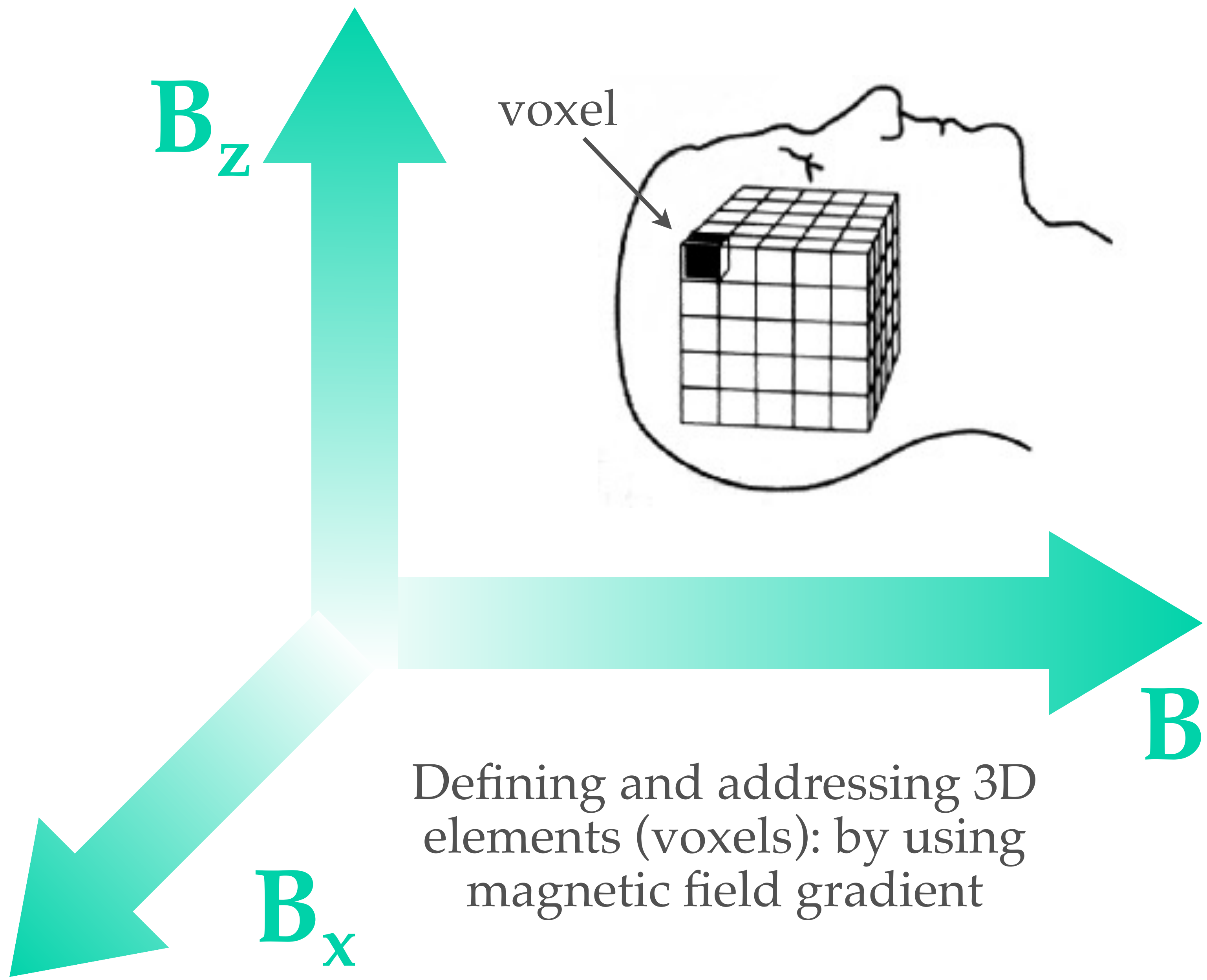


Inhomogeneous magnetic field

MRI Imaging

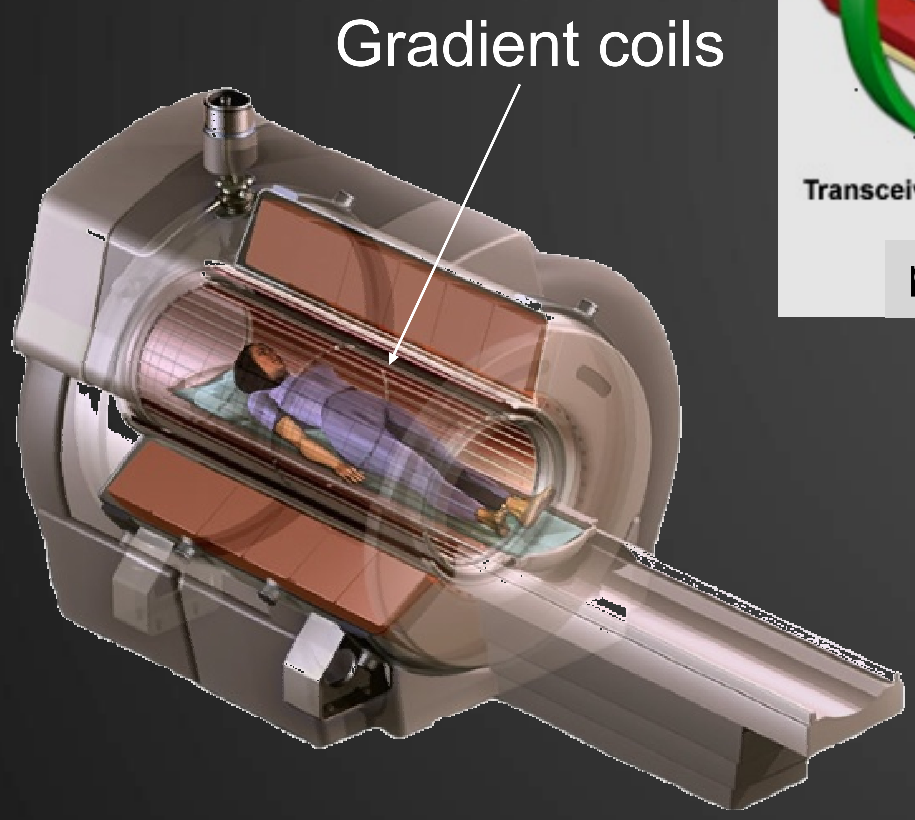
I. Spatial encoding

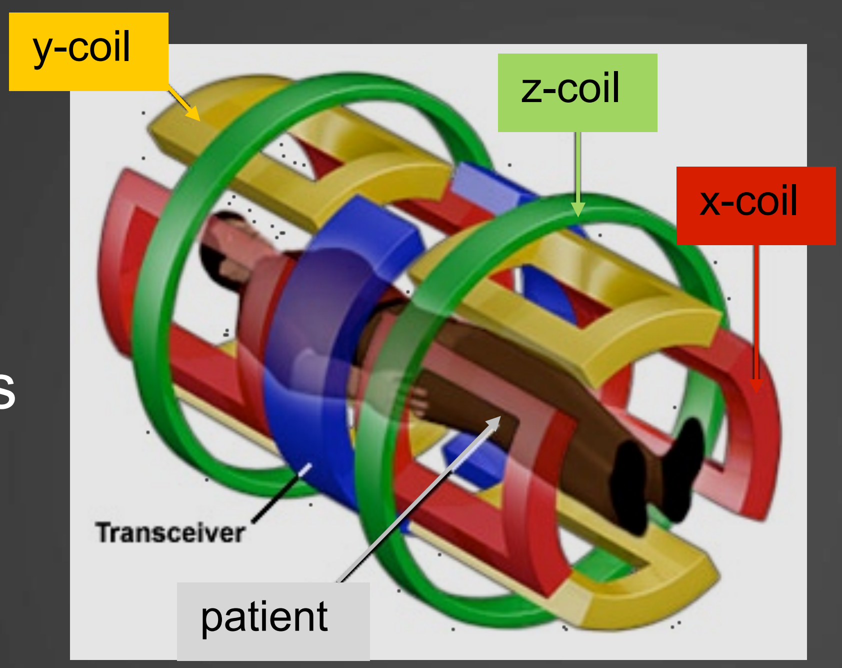
Paul C. Lauterbur (1929-)
Developer of spatially
resolved NMR

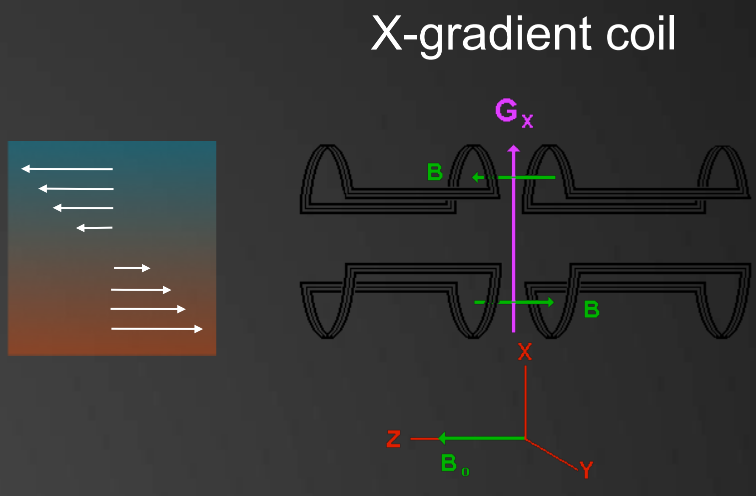


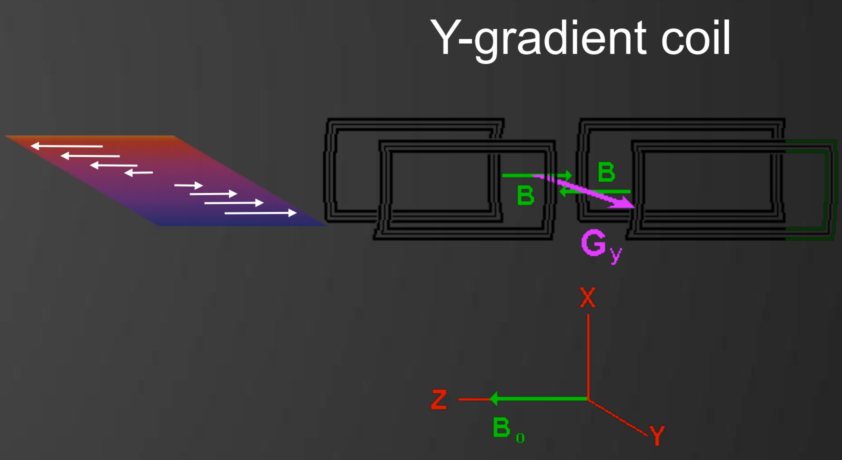
Defining and addressing 3D elements (voxels): by using magnetic field gradient

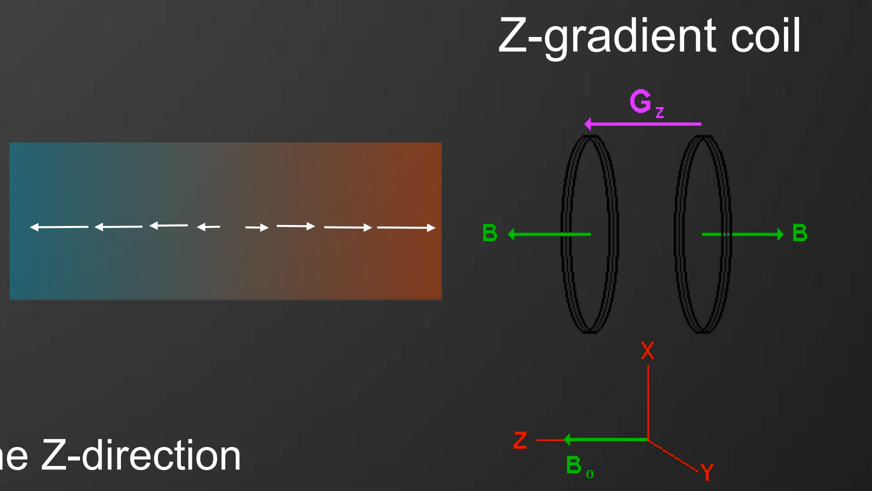
Spatial encoding of the NMR signal: Imaging gradients











IMPORTANT NOTE:
The magnetic field is always in the Z-direction

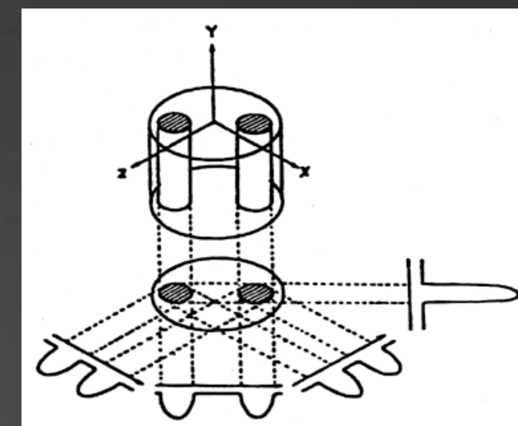
MRI Imaging
II. Image reconstruction

1.“Backprojection”

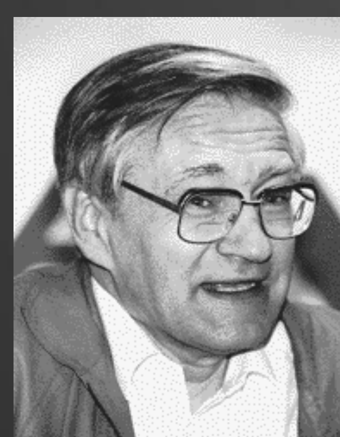
Paul Lauterbur,
1973, Illinois

Peter Mansfield,
1973, Nottingham

Nobel-prize (2003, Physiology or Medicine)



2. 2D Fourier transformation



Richard Ernst,
1974, Zürich

Nobel-prize (1991, chemistry)

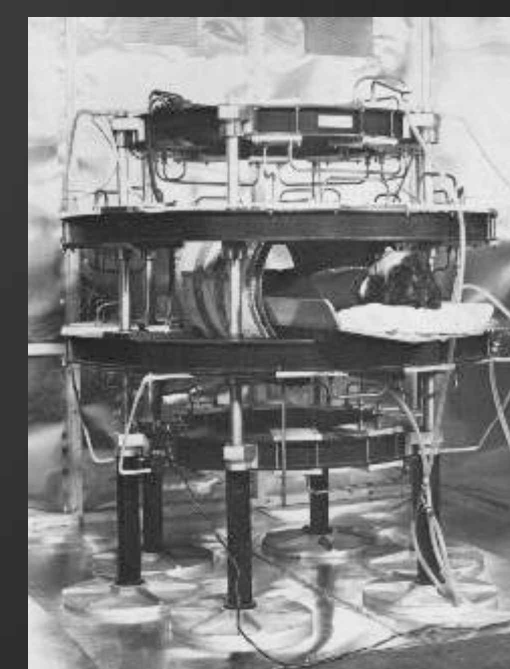
NMR Fourier Zeugmatography

Anil Kumar, Dieter Welti, and Richard R. Ernst

Laboratorium für Physikalische Chemie, Eidgenössische Technische Hochschule, 8006 Zürich, Switzerland

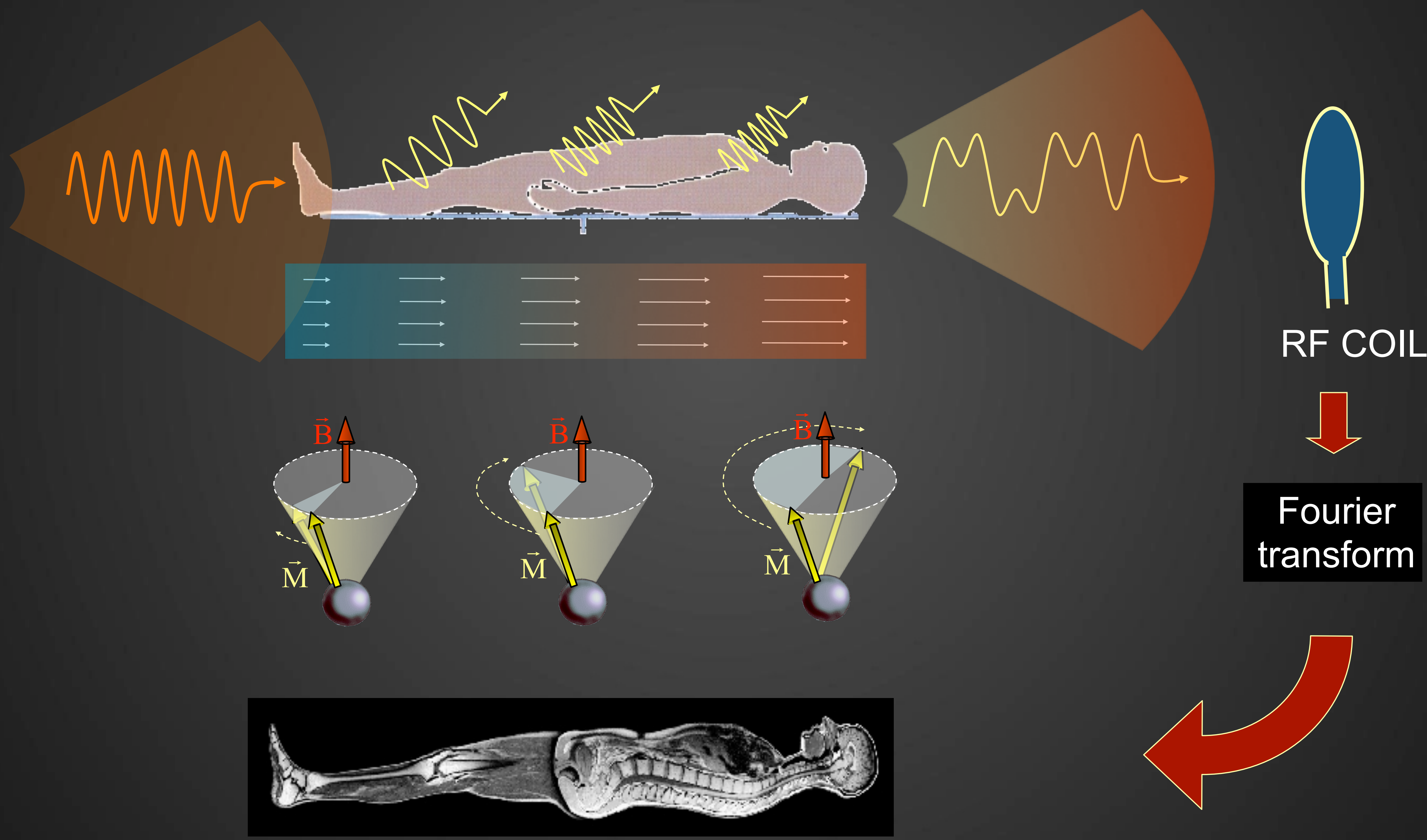
Received August 2, 1974

A new technique of forming two- or three-dimensional images of a macroscopic sample by means of NMR is described. It is based on the application of a sequence of pulsed magnetic field gradients during a series of free induction decays. The image formation can be achieved by a straightforward two- or three-dimensional Fourier transformation. The method has the advantage of high sensitivity combined with experimental and computational simplicity.



MRI: Spatial encoding and image reconstruction

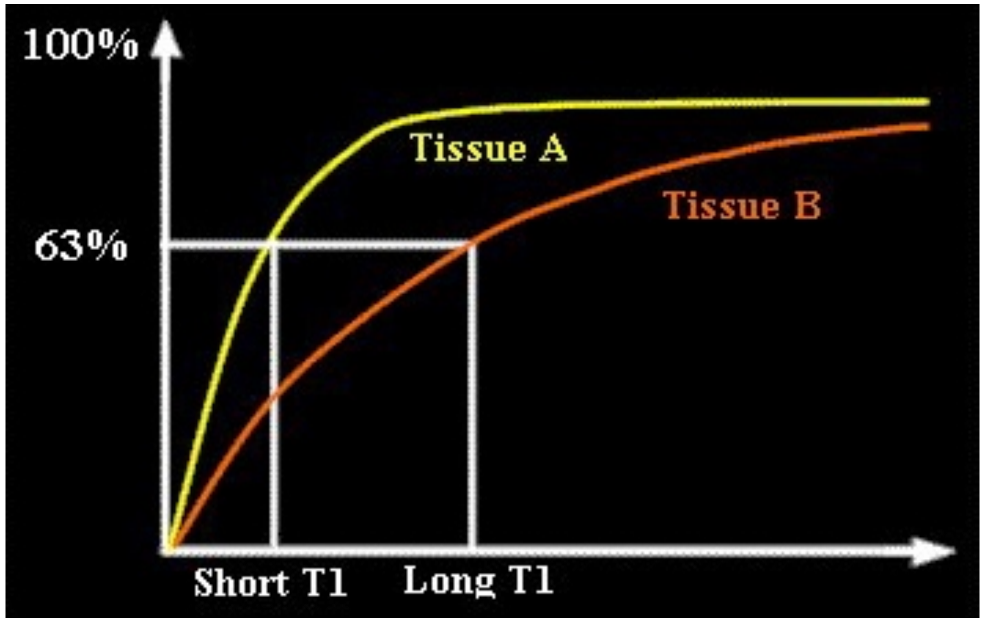
Based on spatially-encoded, frequency-dependent precession

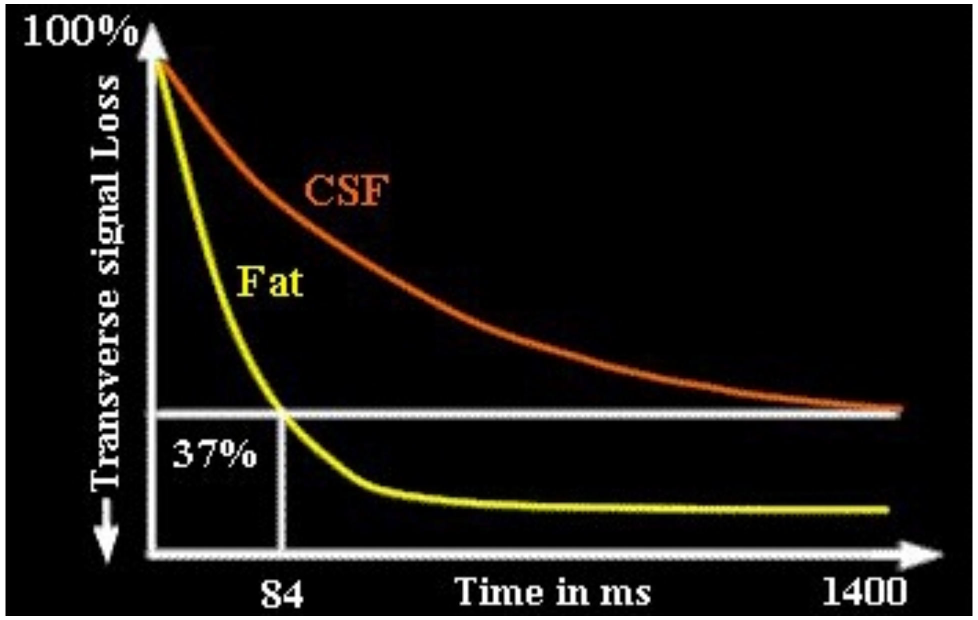


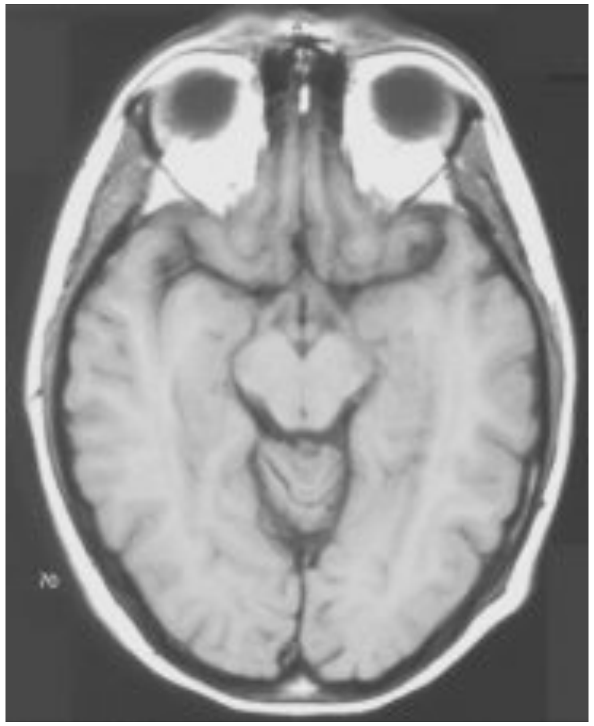
MRI Imaging

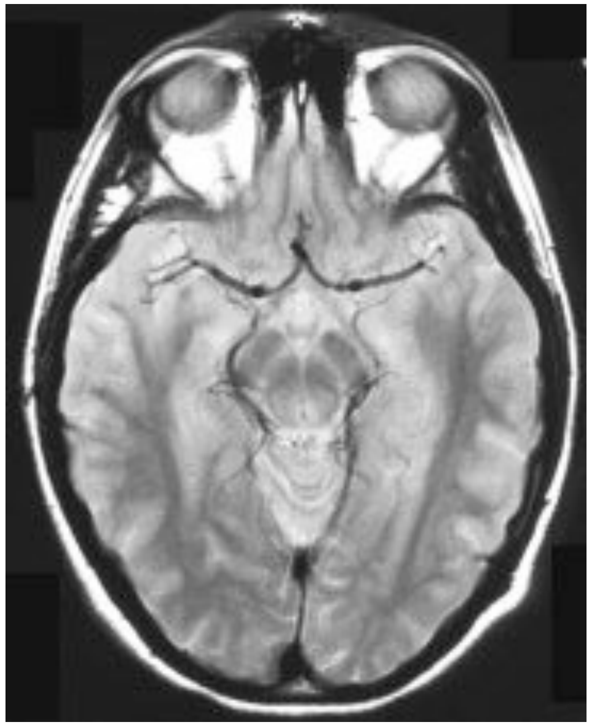
III. Color contrast

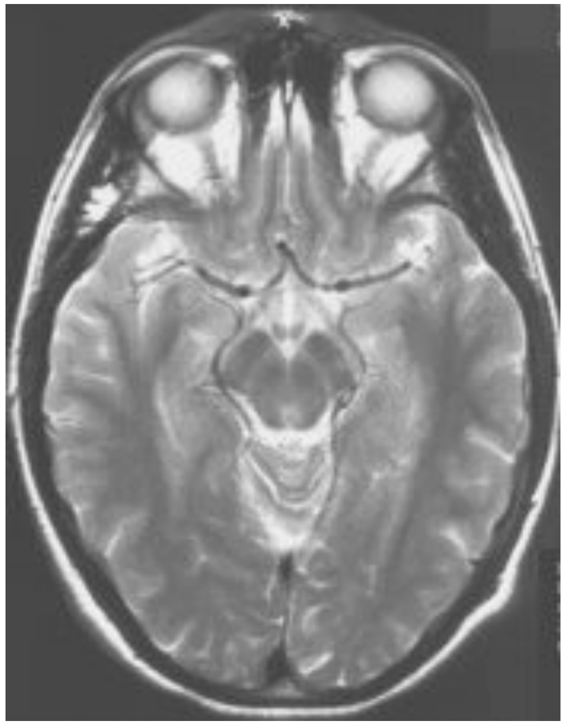
Based on spin density and relaxation times






T1-weighted


Proton density-weighted

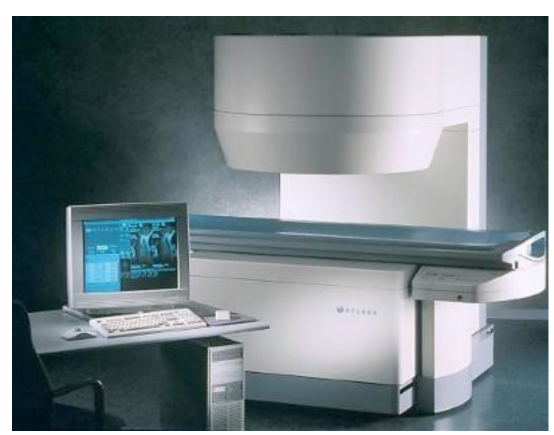

T2-weighted

MRI Imaging:
IV. Scanners

Early times

Present

Interventional MRI unit



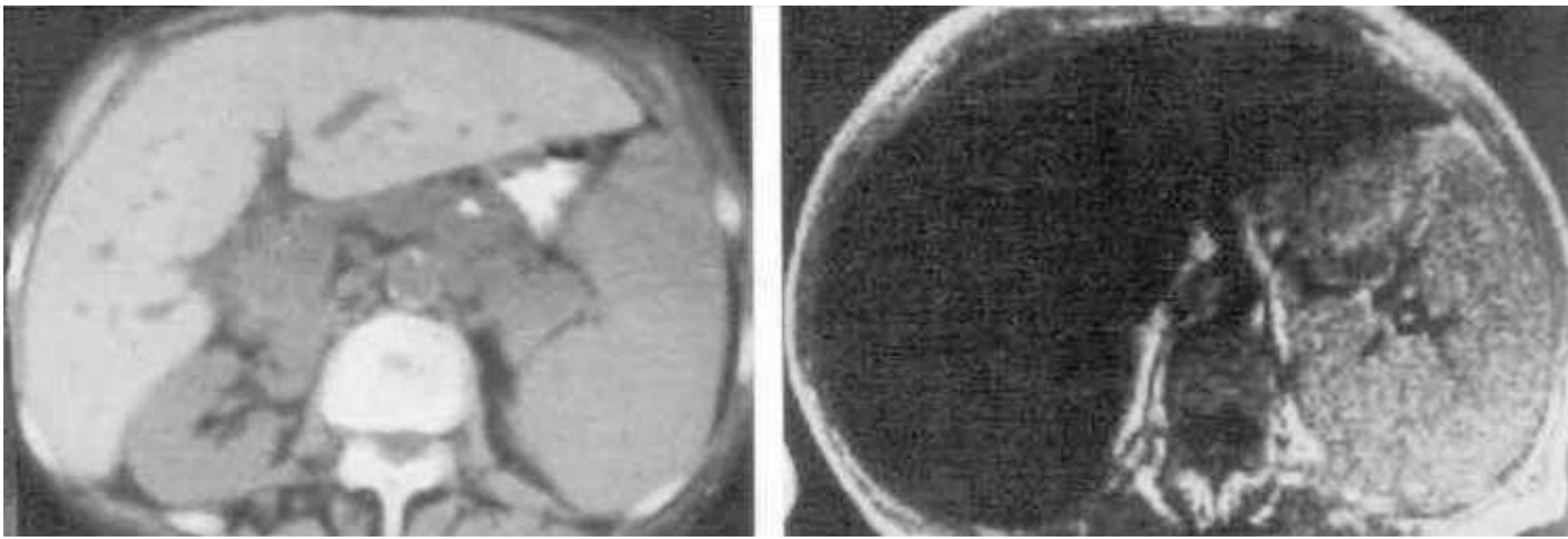
Open MRI unit

Mobile MRI

MRI Imaging:
V. Contrast agents

Positive: paramagnetic elements (T1 contrast): Gd, Mn

Negative: superparamagnetic, ferromagnetic (T2 contrast): FeIII, MnII

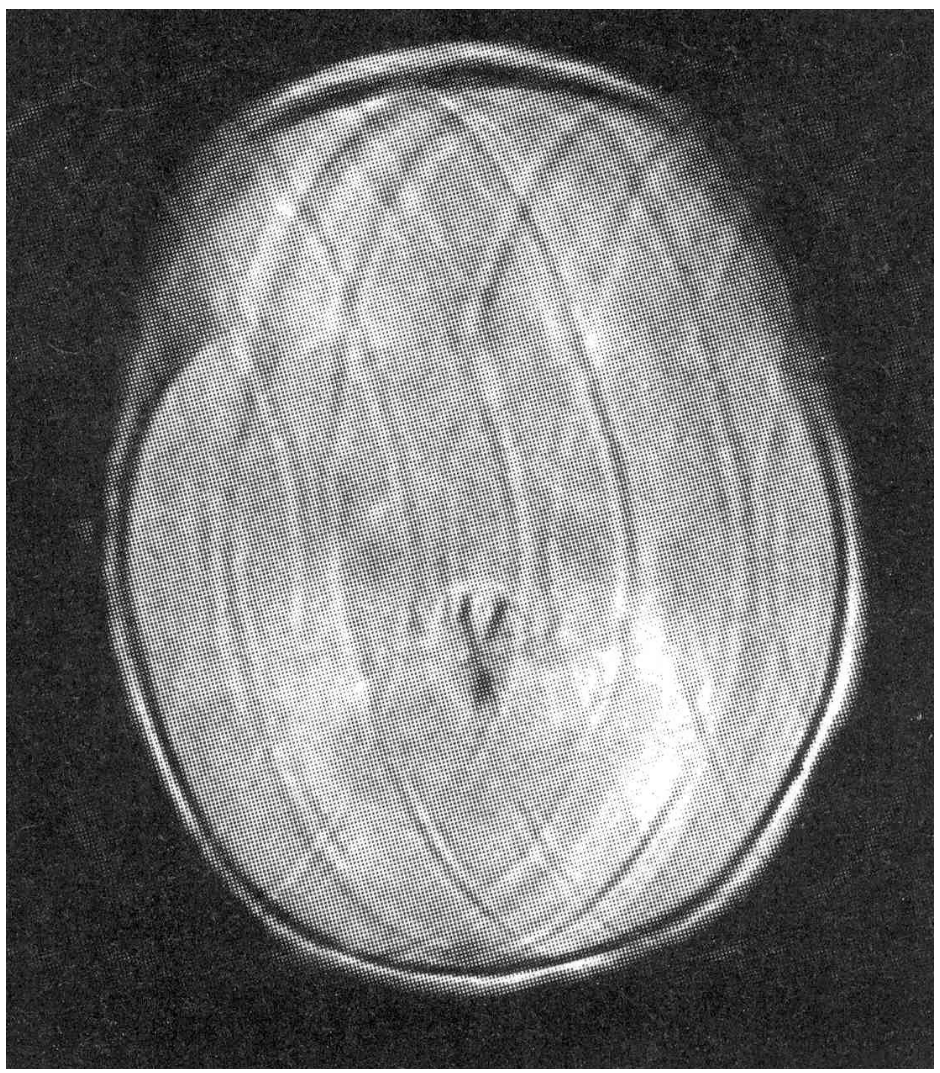


CT MR T2

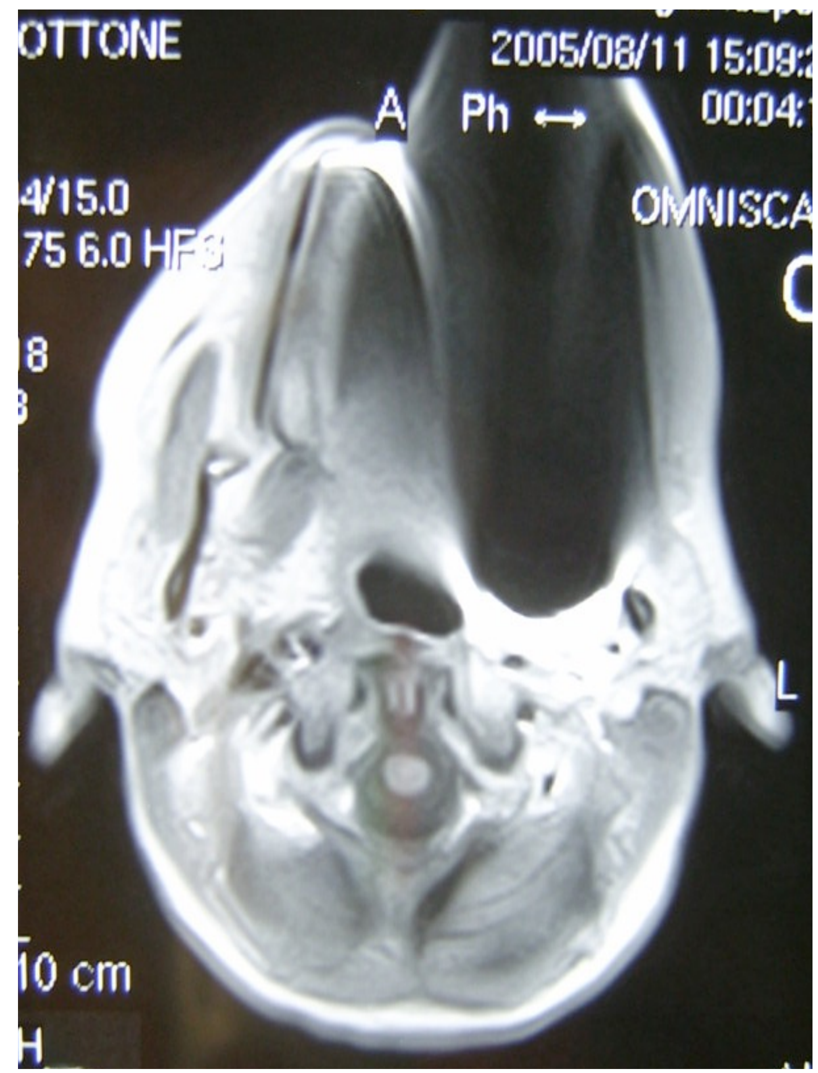
Haemochromatosis hepatis

MRI Imaging:
VI. Artifacts

- Motion
- Metals (implants, injury)



Motion artifact



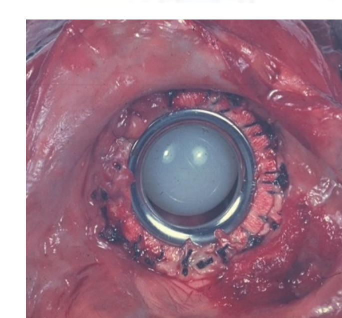
Metal in the orbit of the eye

MRI Imaging:
VII. Dangers, contraindications

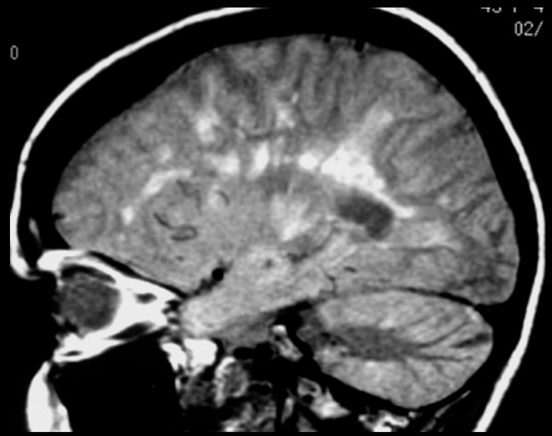
- Static magnetic field - metal objects
  Contraindications: implanted devices (pacemaker, defibrillator, hearing aids, drug delivery devices), neurostimulators, brain aneurysm clamps, early cardiac valve implants
- Gradient field - induced current
- Radio frequency field - thermal effects (lens, testis)



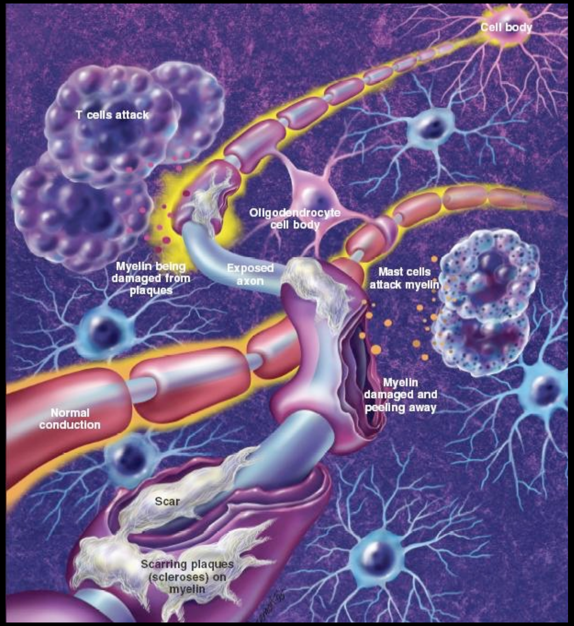




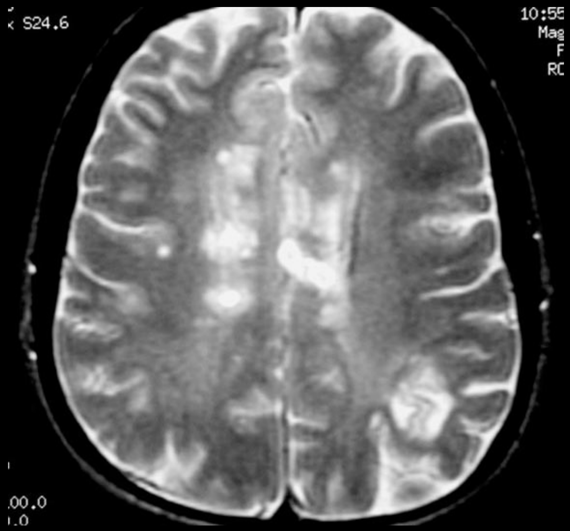
Anatomical imaging: Multiple sclerosis



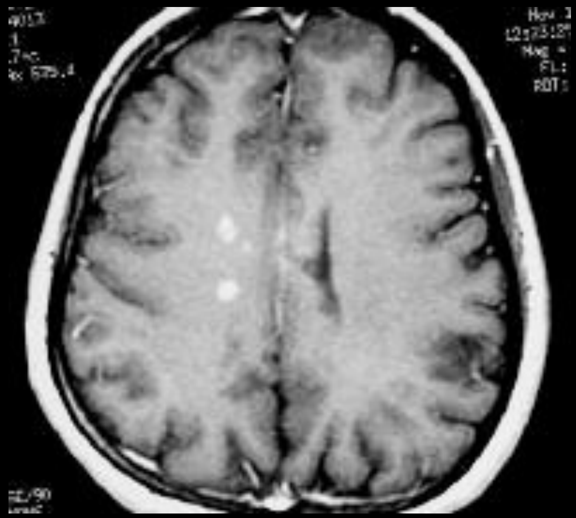
Proton density (sagital)



Proton density (transverse)



T2 weighted (transverse)

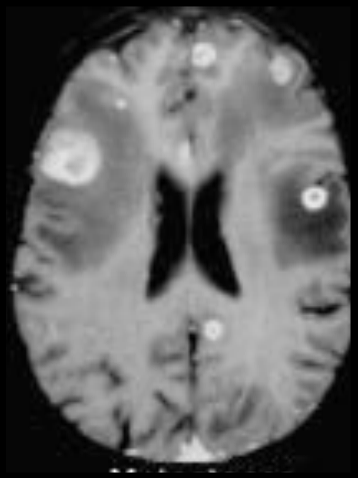


T1 weighted With contrast agent

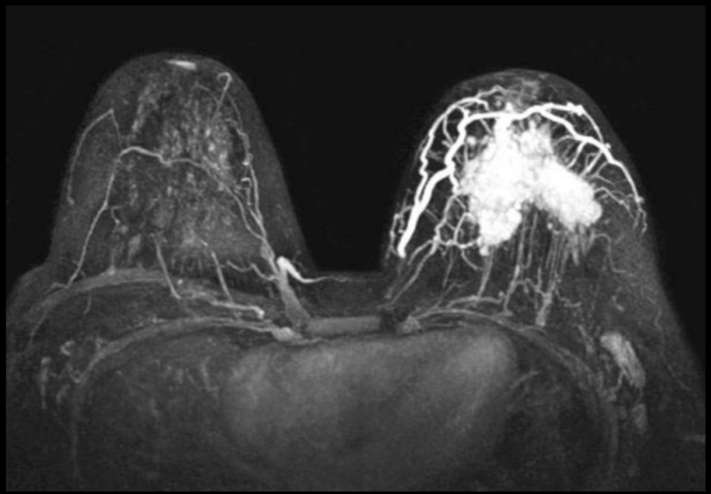
Anatomical imaging: Oncology

T2 weighted
(chondrosarcoma)

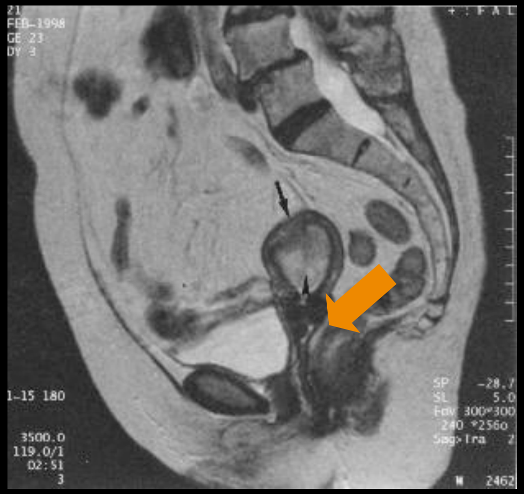
T2 weighted
(cyst)



Protondensity
(Brain metastasis)



T1 weighted with contrastagent
(Breast carcinoma)

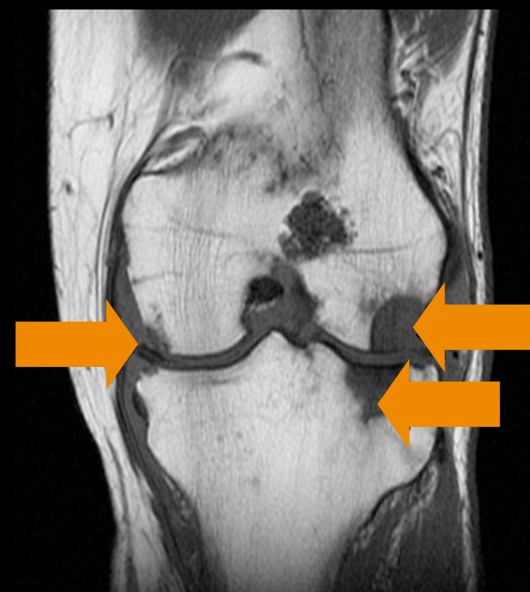


T2 weighted
(cervix carcinoma)

T2 weighted
(prostate tumor)

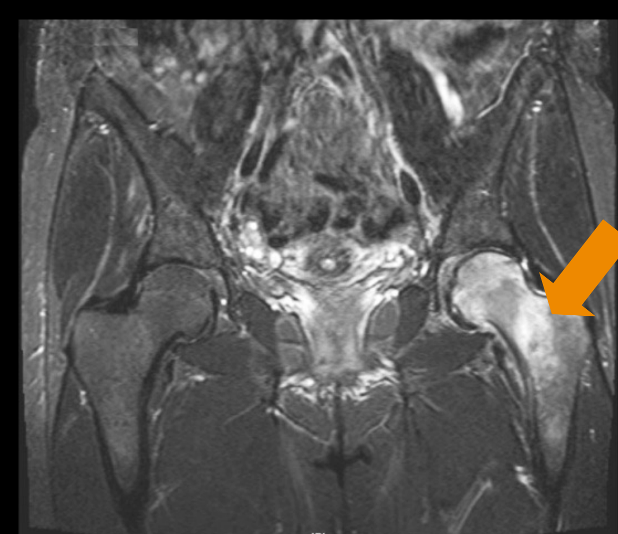
Anatomical imaging
Bone and soft tissue

T2 weighted
(torn ligaments)



Rheumatoid arthritis
knee

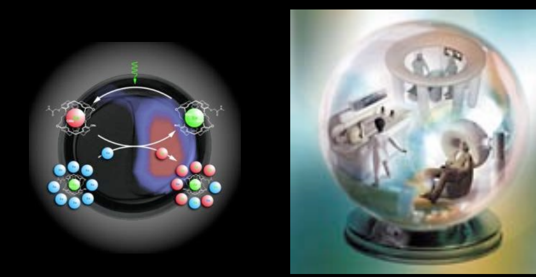
Rheumatoid arthritis
whrist

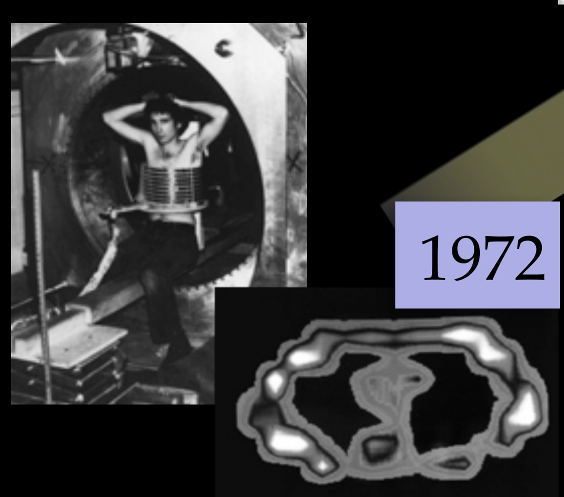


Osteoporosis (femur)

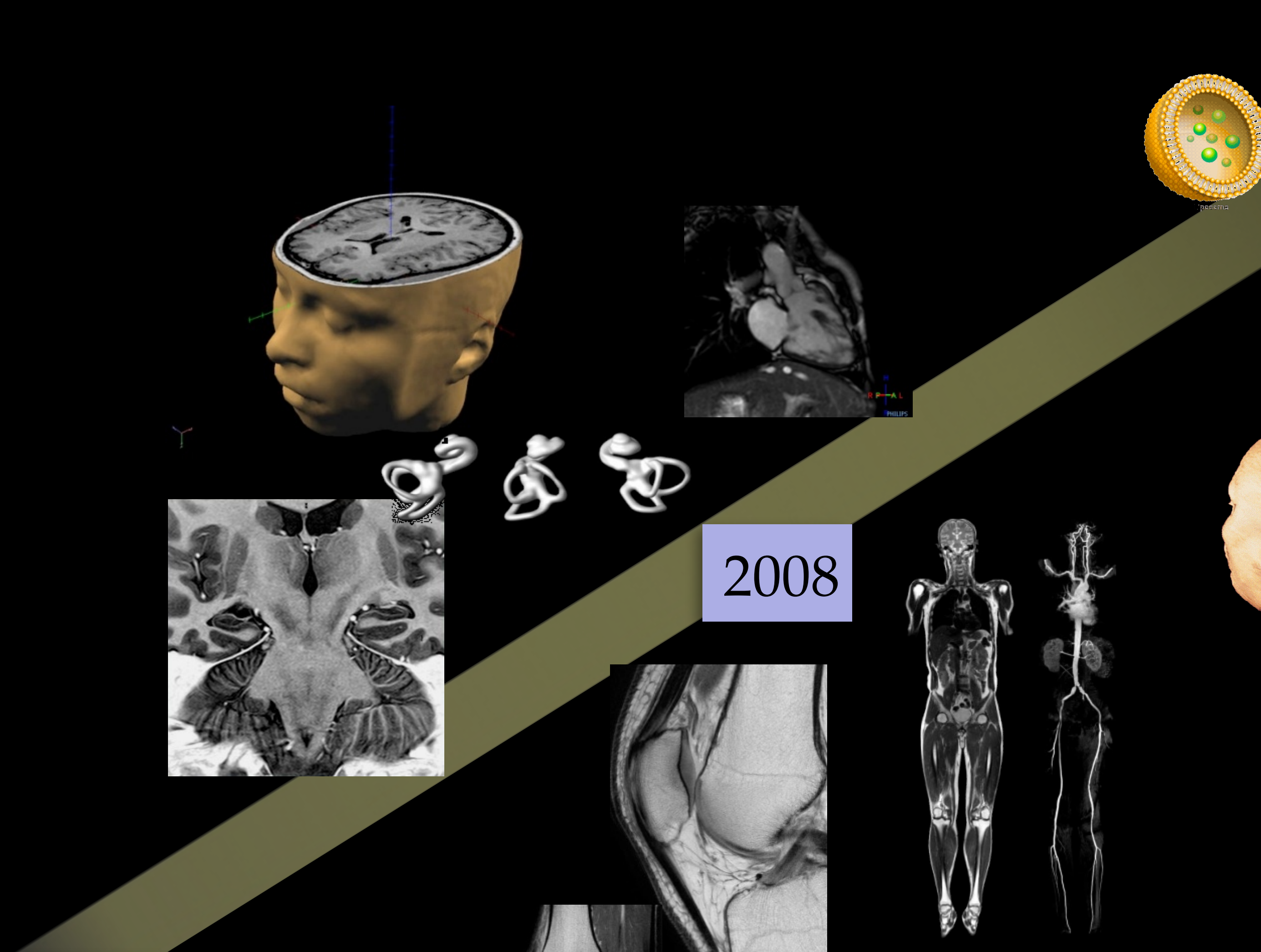
T2 weighted
(hernia)

There is more to MRI than anatomical imaging …



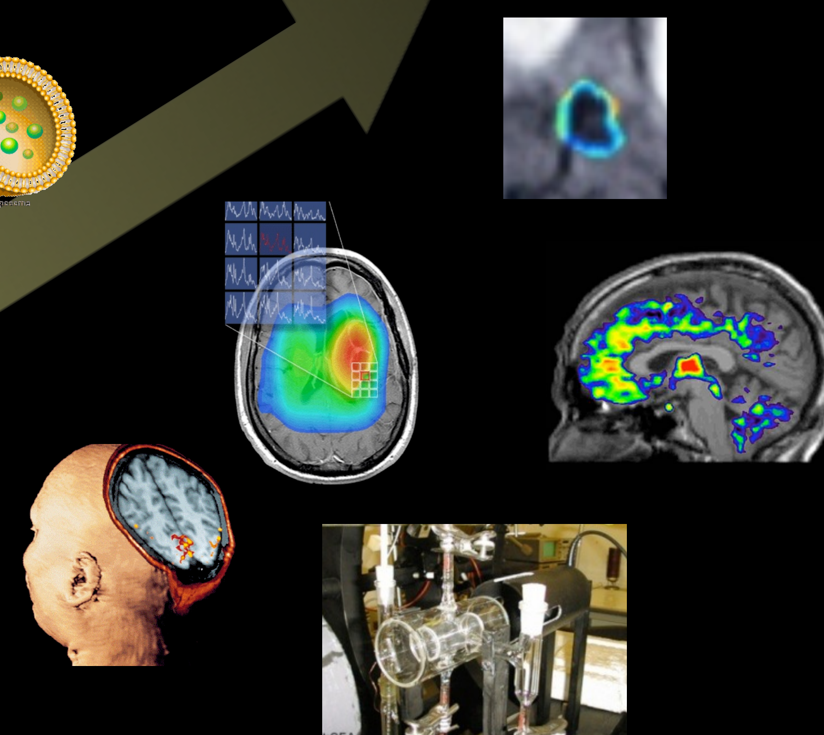


First NMR images



‘State of the art’

- 3D images
- dynamic images
- sharp image resolution

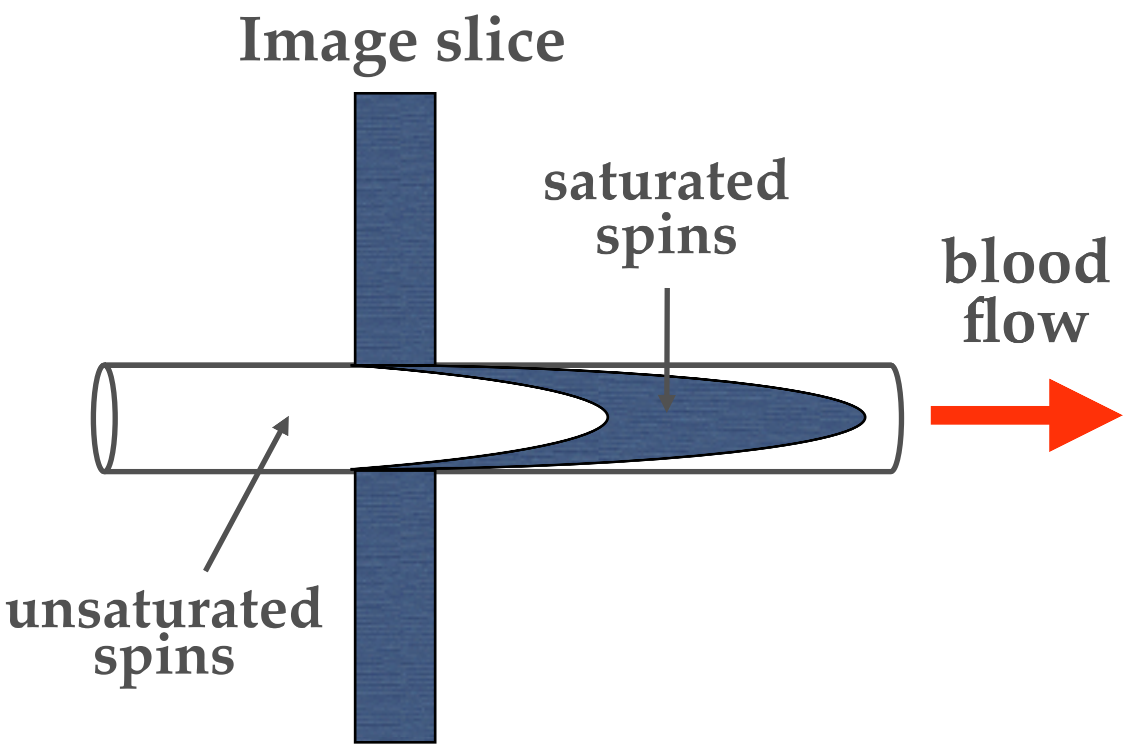


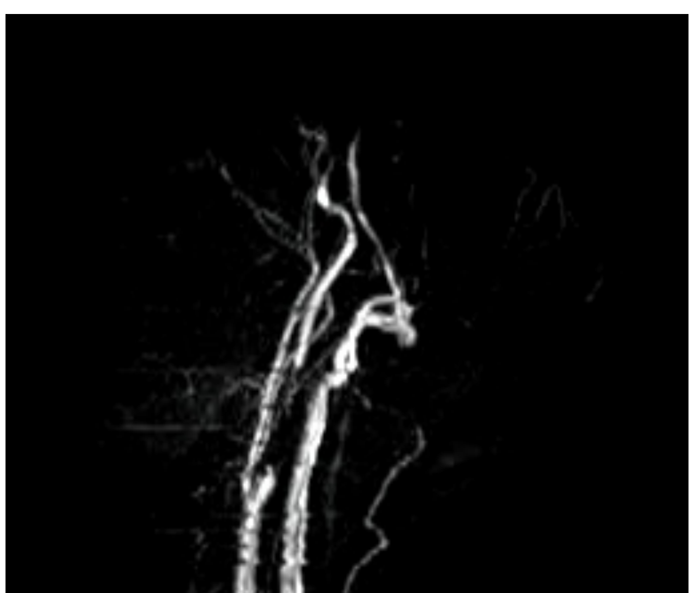
In research phase

- quantitative imaging
- cell-specific contrast agents
- hyperpolarized MRI
- in vivo spectroscopy
- functional imaging
- ‘multimodality’ imaging

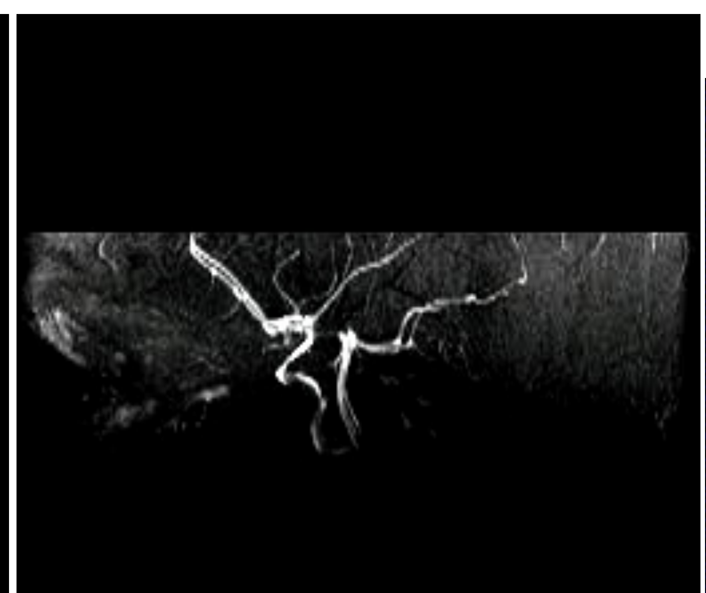
MRI:

Non-invasive angiography

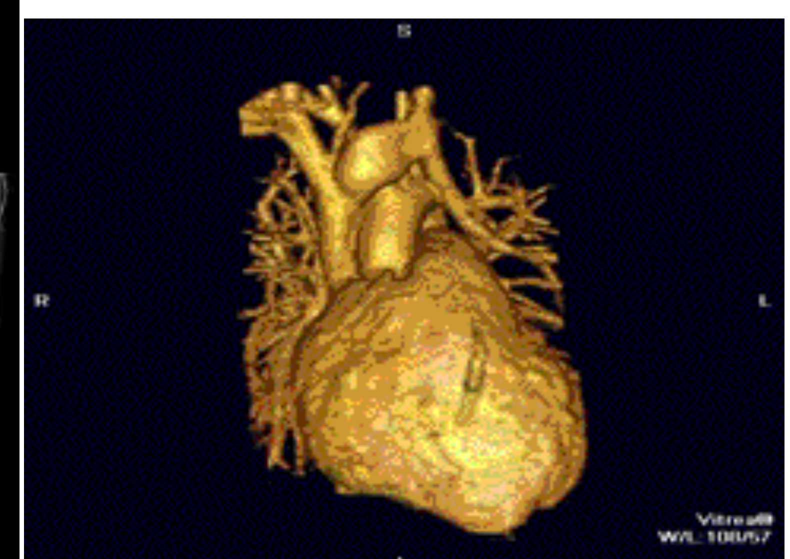




Arteria carotis



Circulus arteriosus Willisii

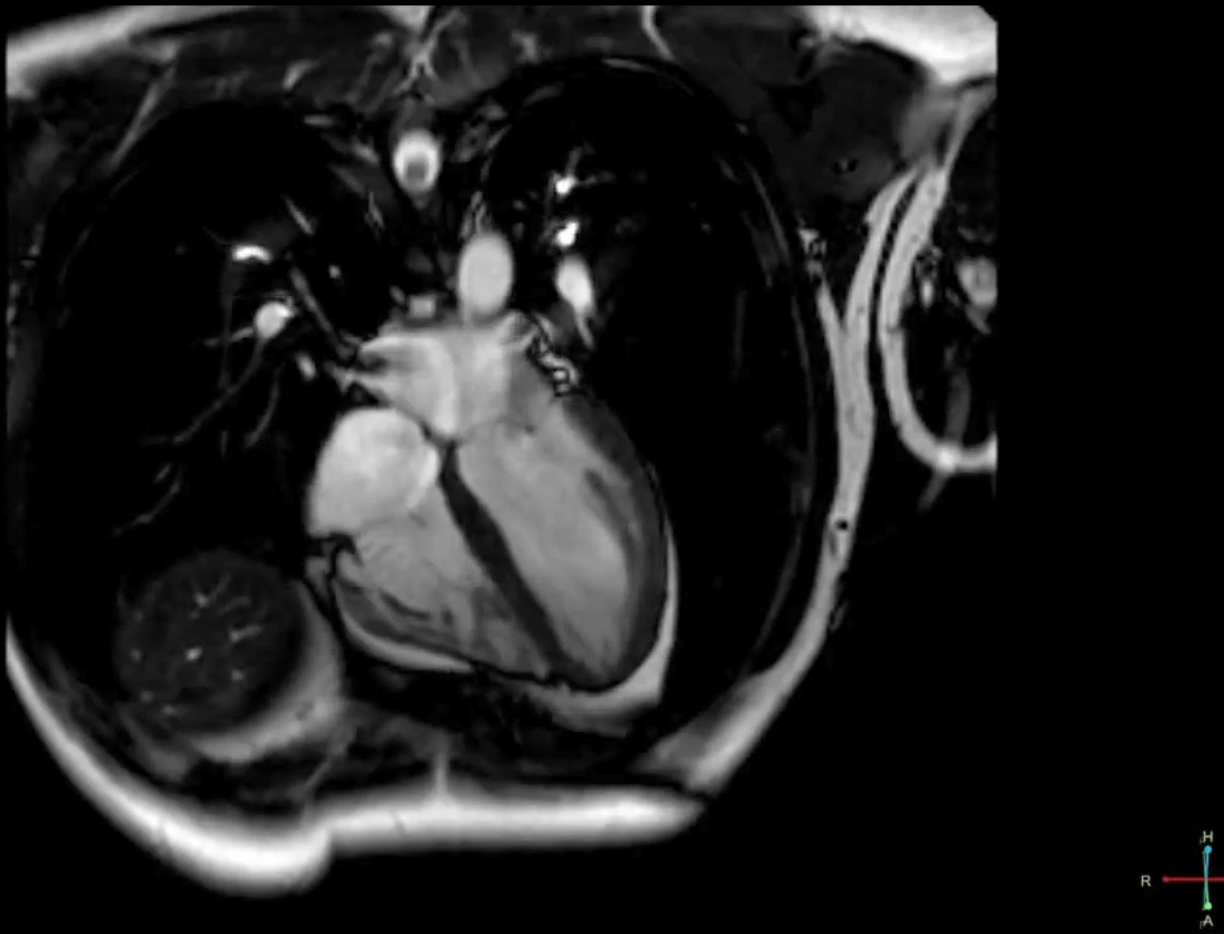


Heart and large vessels

MRI movie

Based on high time resolution images

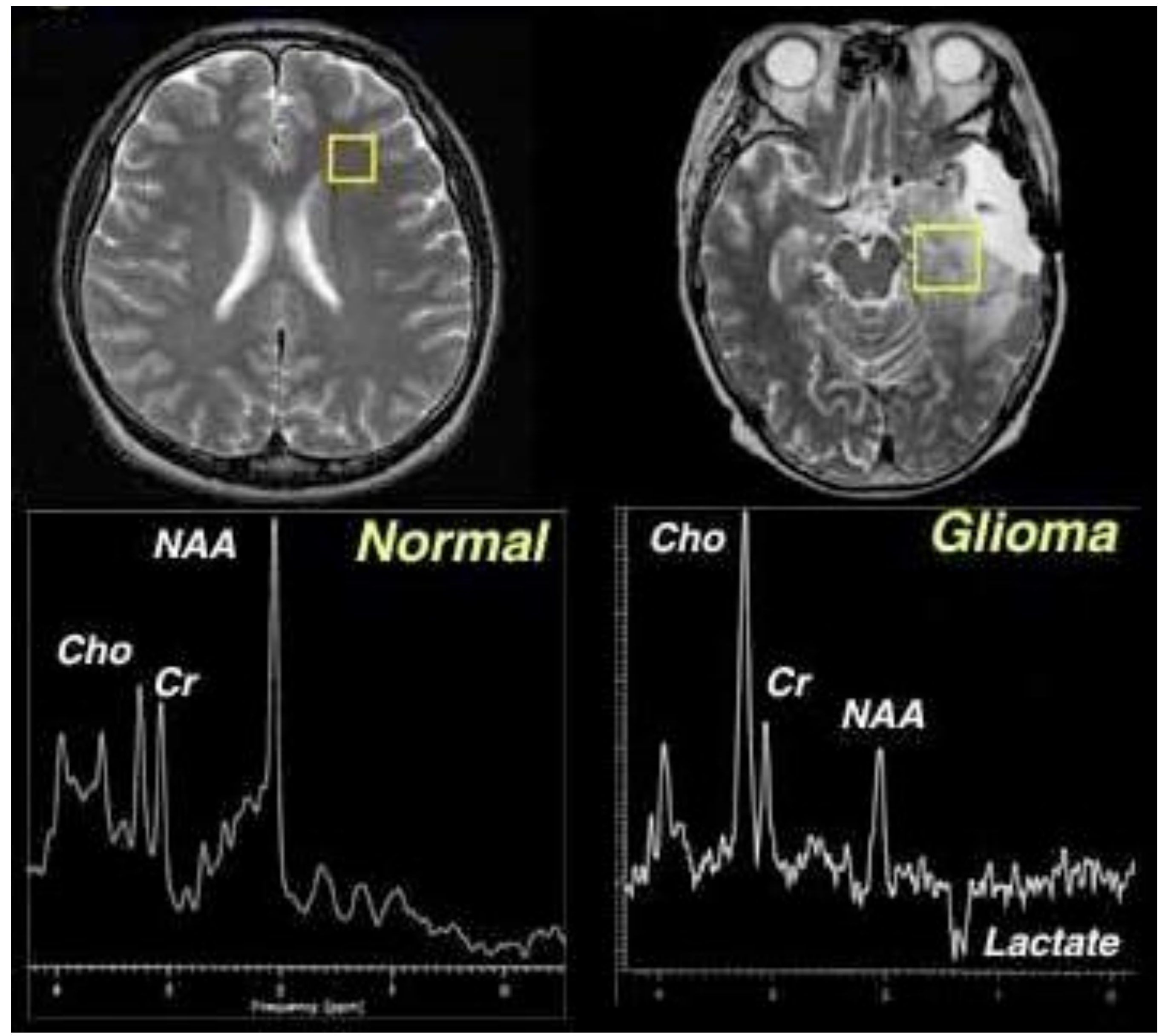
Opening and closing of aorta valve



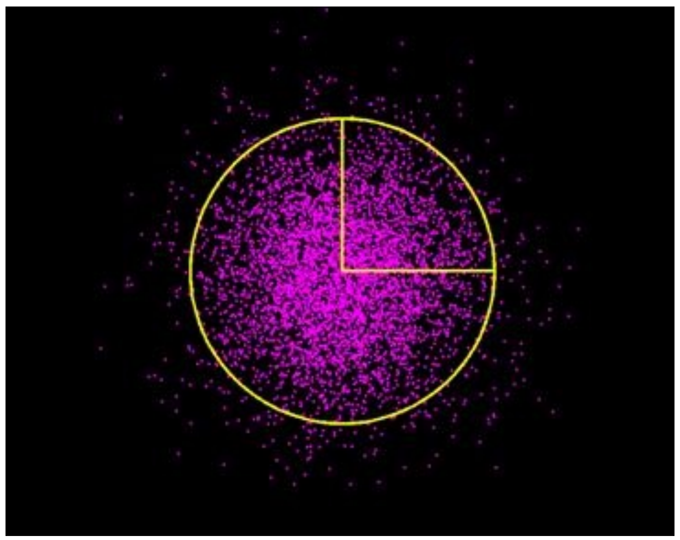
Blod flow in cardiac chambers

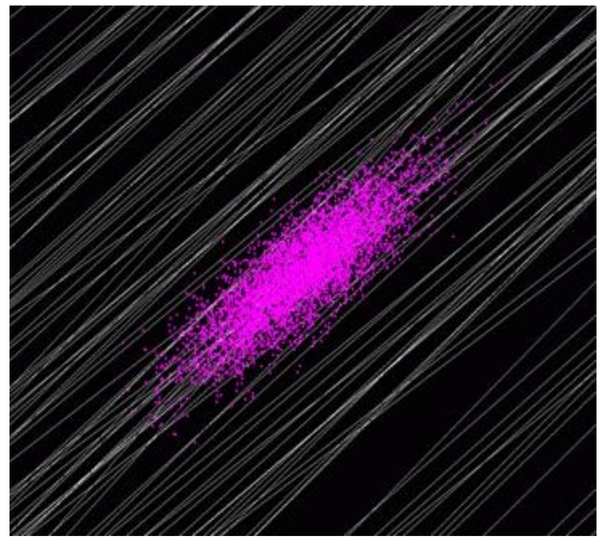
MR Spectroscopy

- Chemical shift
- Identification of metabolited
- Tumor diagnostics

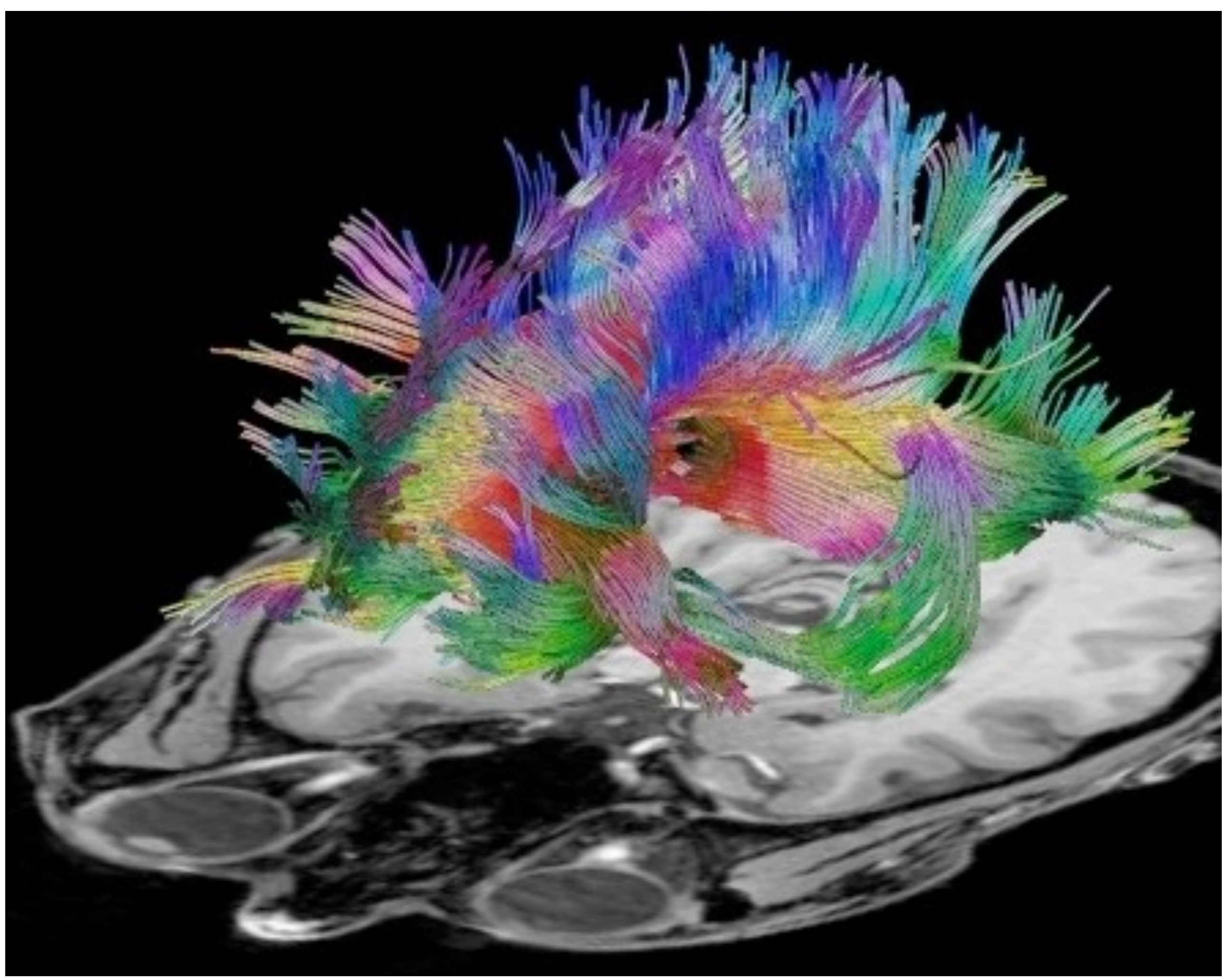


Diffusion imaging





Anisotropic water diffusion: contrast

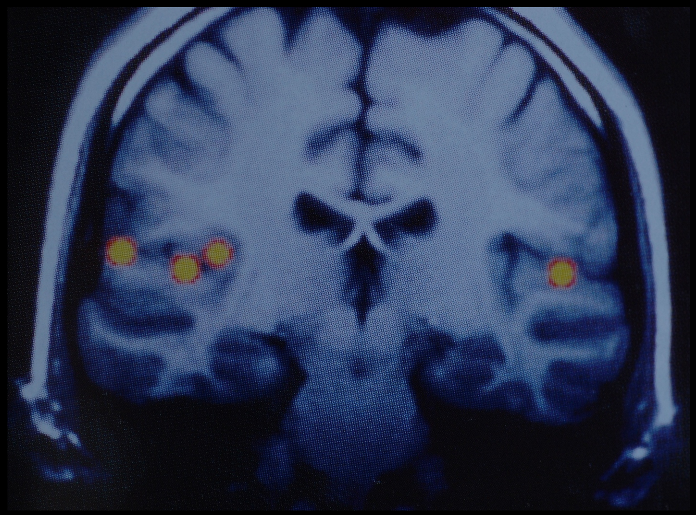


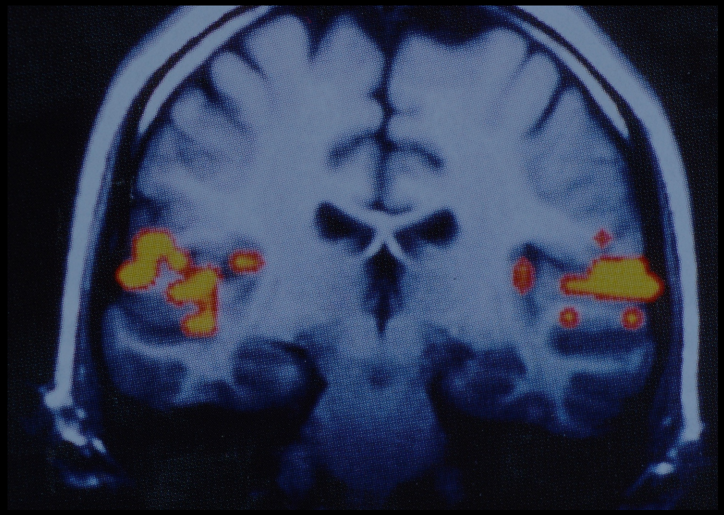
Imaging neural tracts: tractography

Corpus callosum

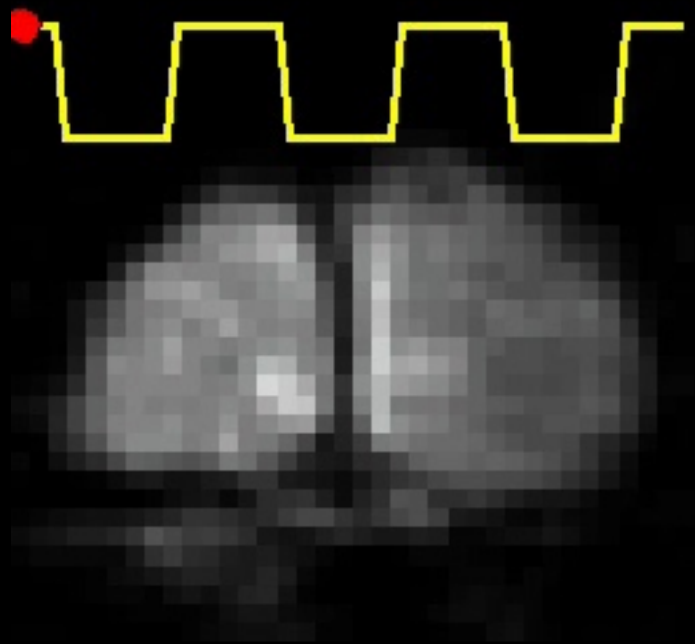
Functional MRI (fMRI)

High time resolution images recorded synchronously with physiological processes





Activation in the acoustic cortex



Effect of light pulses on visual cortex

Superposition of MRI on other information (PET)

Superimposed MRI and PET sequence

PET activity: during eye movement
Volume rendering

Feedback

http://report.semmelweis.hu/linkreport.php?qr=HEI90MLSS8XKJSSW