

TIMES, OCTOBER 9, 2003

**This Year's
Nobel Prize
in Medicine**



The Shameful Wrong That Must Be Righted

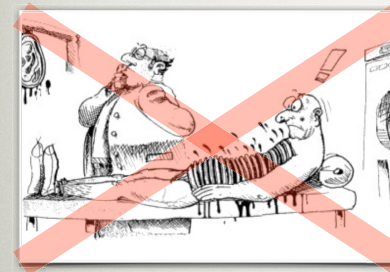
This year the committee that awards The Nobel Prize for Physiology or Medicine did the one thing it has no right to do: it ignored the truth. Eminent scientists, leading medical textbooks and the historical facts are in disagreement with the decision of the committee. So is the U. S. Patent Office. Even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

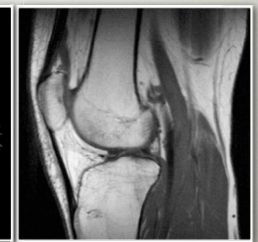
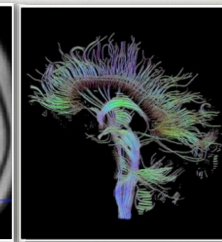
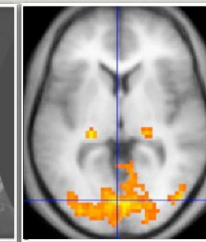
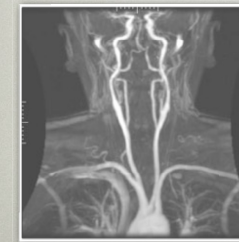
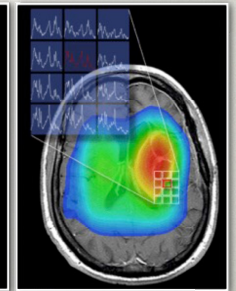
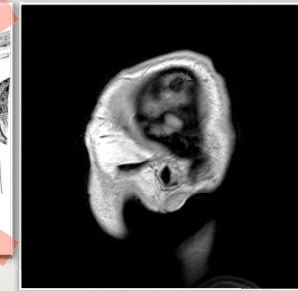
MRI

- 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 IS A REVOLUTIONARY DEVICE



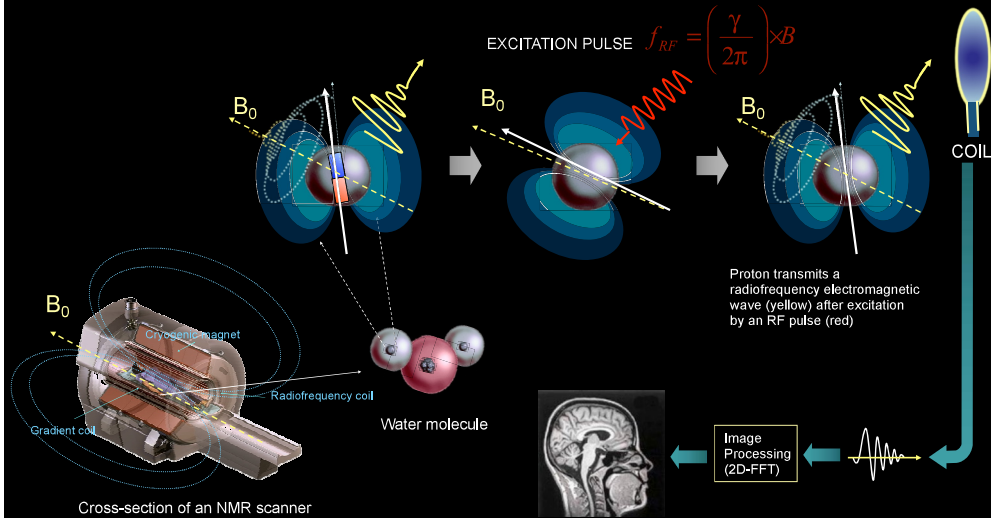
Non-invasive



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

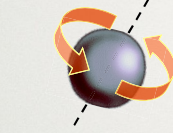
I. ATOMIC NUCLEI WITH NUCLEAR SPIN ARE ELEMENTARY MAGNETS



Otto Stern

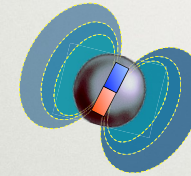


W. Gerlach



Atomic nuclei
have mass:

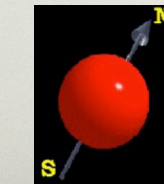
$$m_{\text{proton}} = 1,67.10^{-24} \text{ g}$$



Atomic nuclei carry
angular momentum:

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

l = spin quantum number



Atomic nuclei
carry charge:

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

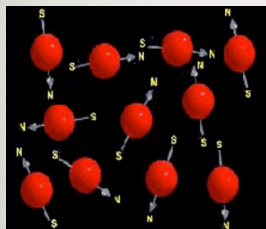
Atomic nuclei possess
magnetic moment:

$$\mu_i = \gamma L$$

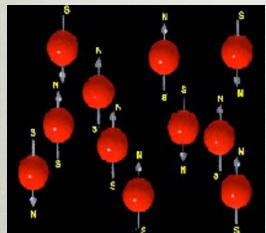
γ = gyromagnetic ratio
 L = angular momentum

MRI FUNDAMENTALS

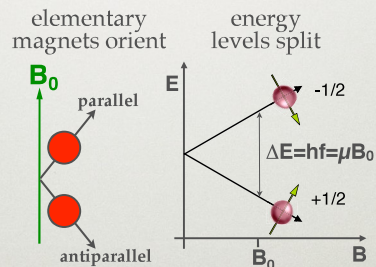
II. NUCLEAR SPINS ORIENT IN A MAGNETIC FIELD



In absence of magnetic field:
random orientation of elementary magnets



In magnetic field:

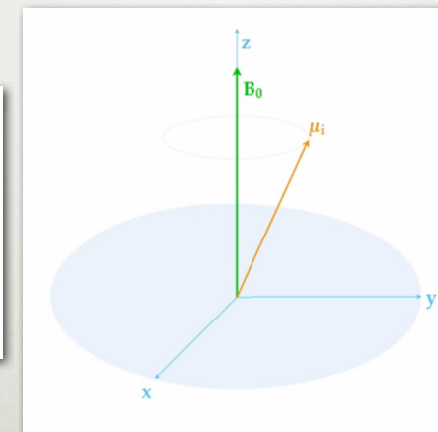
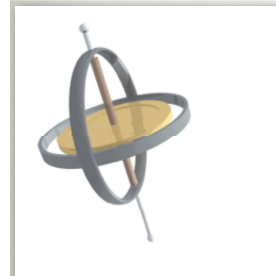


Edward Purcell, 1946

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

MRI FUNDAMENTALS

III. ORIENTED NUCLEAR SPINS DISPLAY PRECESSIONAL MOTION



Precession or
Larmor frequency:

$$\omega_0 = \gamma B_0$$

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

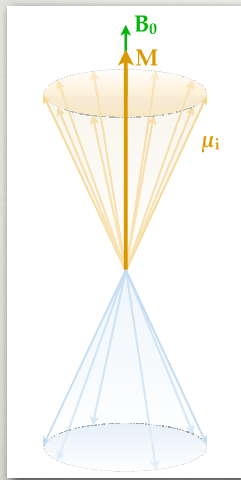


Felix Bloch, 1946

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:

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

Boltzmann distribution

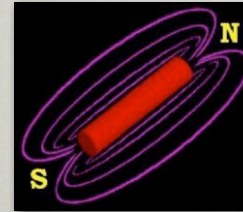
B_0 = magnetic field
 M = net magnetization

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

MRI FUNDAMENTALS

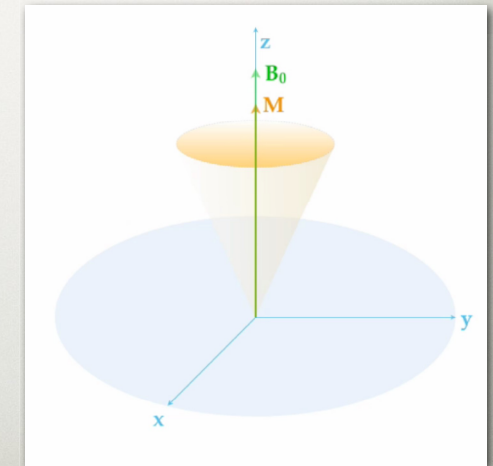
IV. THE SYSTEM MAY BE EXCITED WITH RADIO FREQUENCY RADIATION

Resonance condition: Larmor frequency



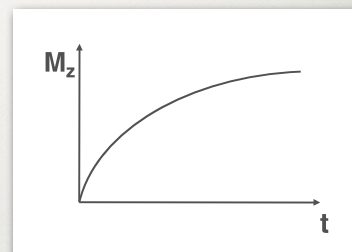
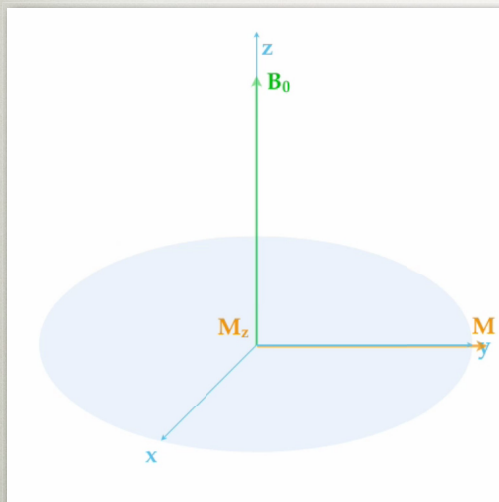
B_0 = magnetic field
 M = net magnetization
 B_1 = irradiated radio frequency wave

**Electromagnetic radiation in
MRI:**
Radio waves



SPIN-LATTICE RELAXATION

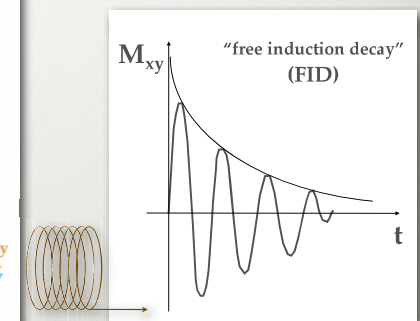
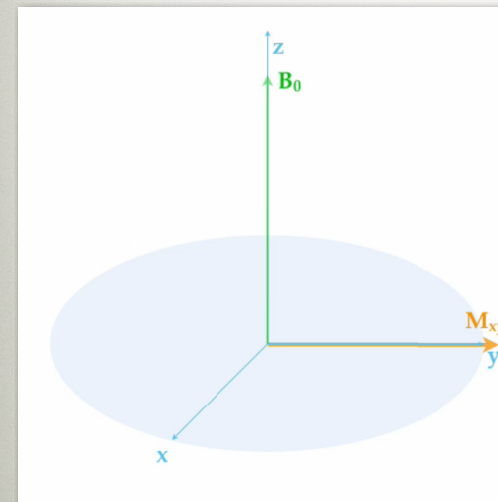
T1 OR LONGITUDINAL RELAXATION



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)

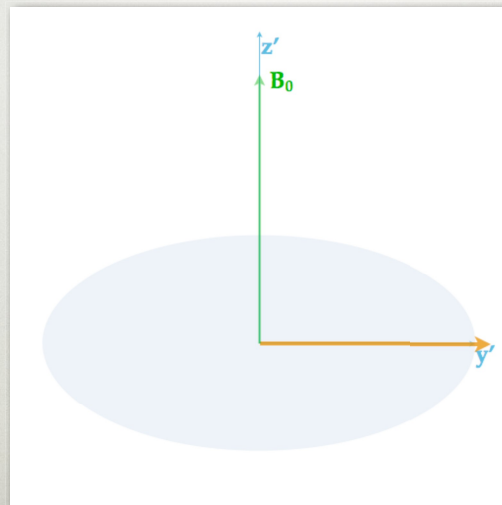
SPIN-SPIN RELAXATION

T2 OR TRANSVERSE RELAXATION

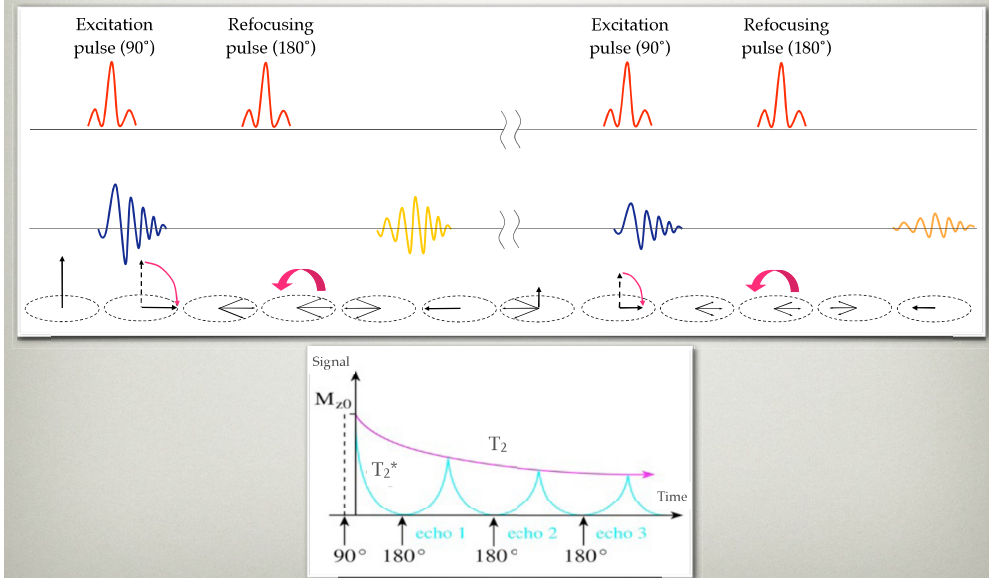
Repetitive pulses of excitation and subsequent relaxation: spin-echo sequence



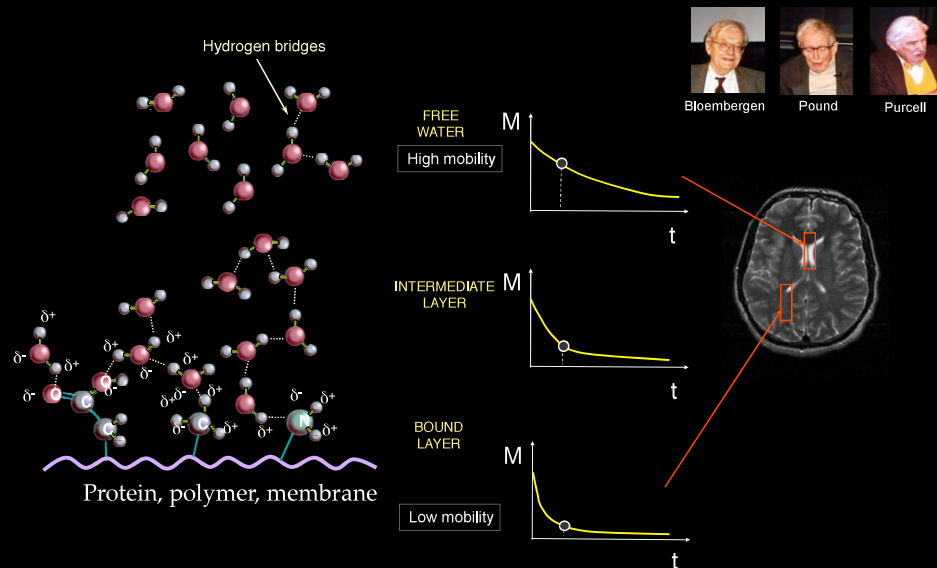
Erwin Hahn, 1949



THE SPIN-ECHO EXPERIMENT



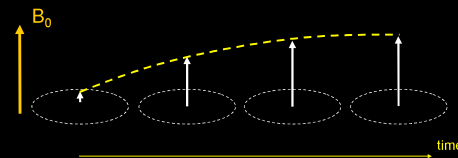
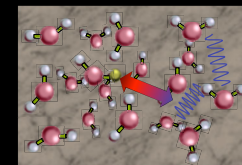
CONTRAST IN MR IMAGES IS DETERMINED BY THE INTERACTION OF SPIN SYSTEMS



NUCLEAR MAGNETIC RESONANCE IMAGING: TWO IMPORTANT RELAXATION MECHANISMS

Spin-lattice relaxation

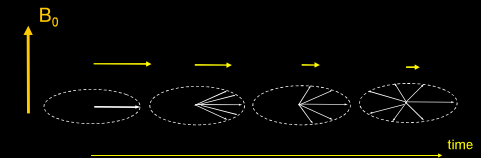
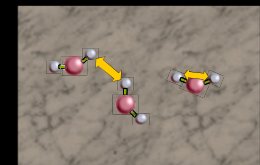
T1



Restoration of longitudinal magnetization
Energy transferred to lattice (phonons)
Entropy increases
Repopulation of spins between spin energy levels
Interactions with magnetic field fluctuations at Larmor frequency

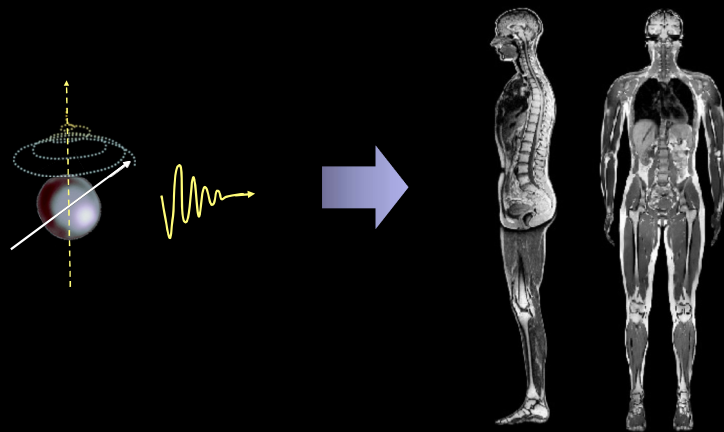
Spin-spin relaxation

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

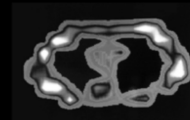


MRI: NET MAGNETIZATION OF THE HUMAN BODY IS GENERATED

Downstate Medical
Center - Brooklyn, 1972



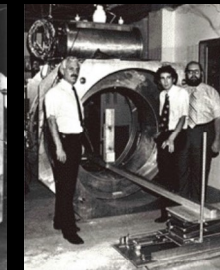
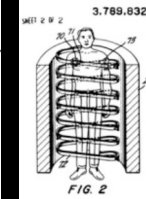
Raymond V. Damadian



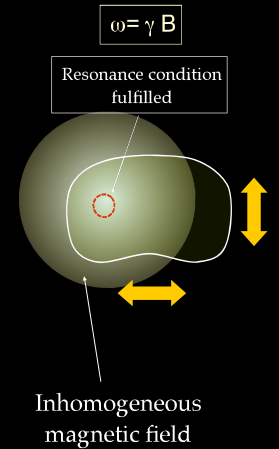
First MRI scan

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.: 235,634
[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



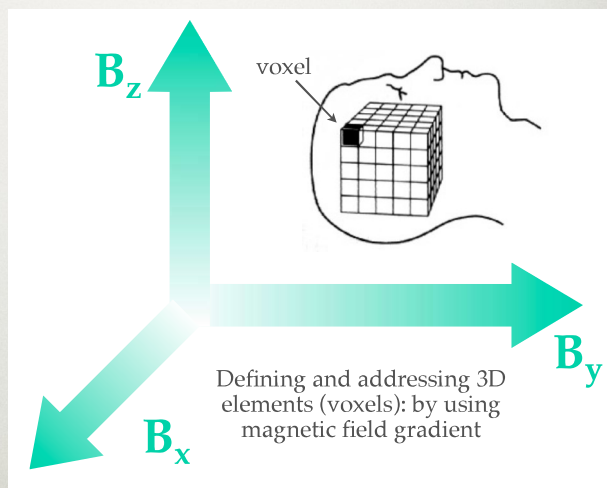
1970: detection of lengthened relaxation times in cancerous tissues
1972: theoretical development of human in vivo 3D NMR
1977: first human MRI image



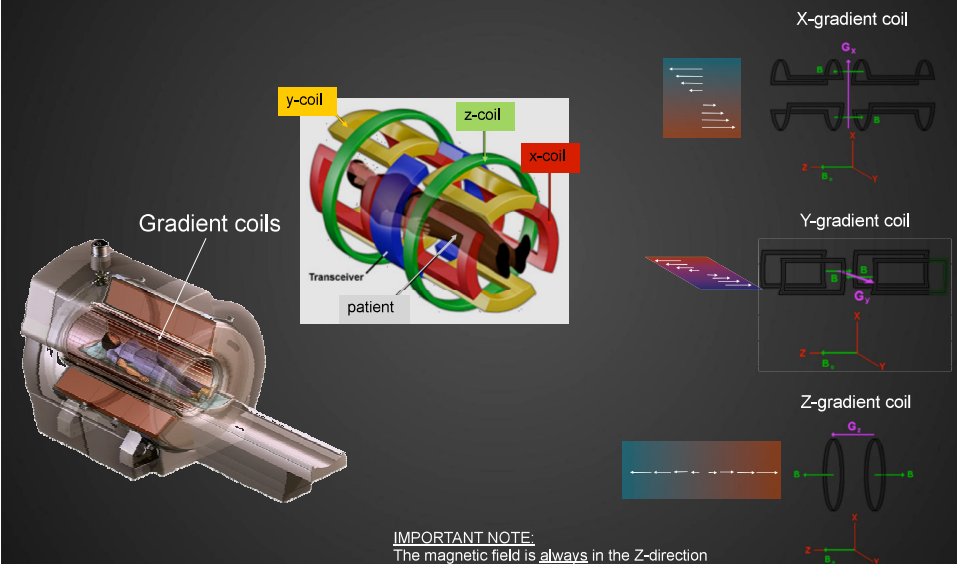
MRI IMAGING I. SPATIAL ENCODING



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



SPATIAL ENCODING OF THE NMR SIGNAL: IMAGING GRADIENTS



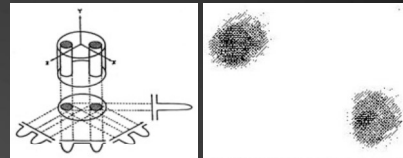
MRI IMAGING

II. IMAGE RECONSTRUCTION

1. "Backprojection"



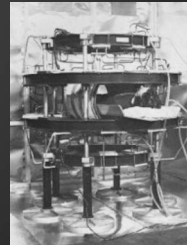
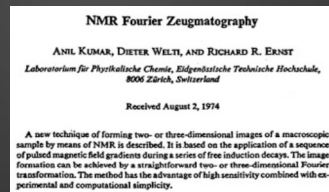
Paul Lauterbur,
1973, Illinois
Peter Mansfield,
1973, Nottingham
Nobel-prize (2003, Physiology or Medicine)



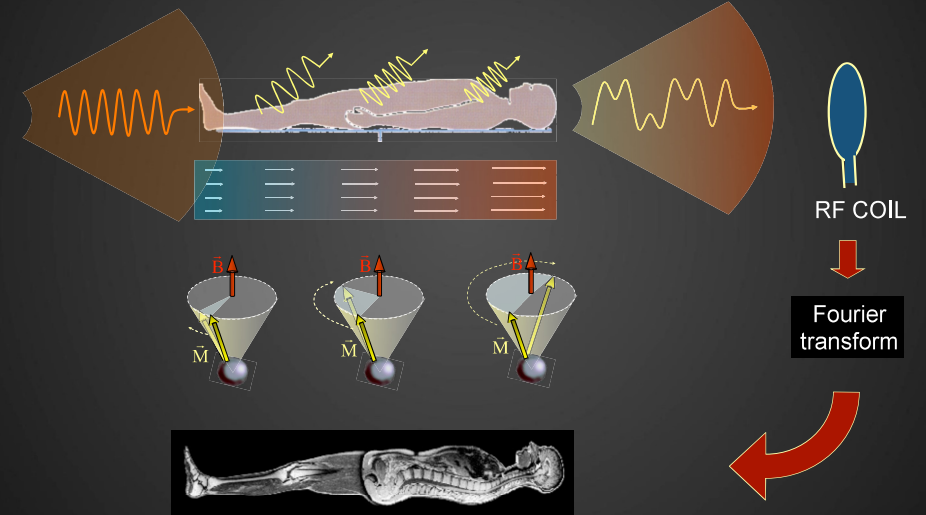
2. 2D Fourier transformation



Richard Ernst,
1974, Zürich
Nobel-prize (1991, chemistry)



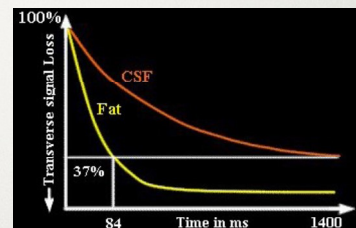
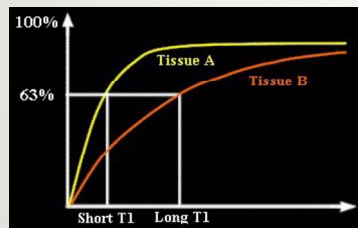
MRI: SPATIAL ENCODING AND IMAGE RECONSTRUCTION BASED ON SPATIALLY-ENCODED, FREQUENCY-DEPENDENT PRECESSION



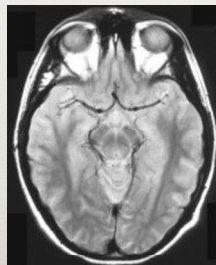
MRI IMAGING

III. COLOR CONTRAST

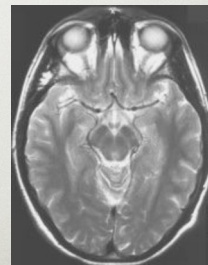
BASED ON SPIN DENSITY AND RELAXATION TIMES



T1-weighted



Proton density-weighted

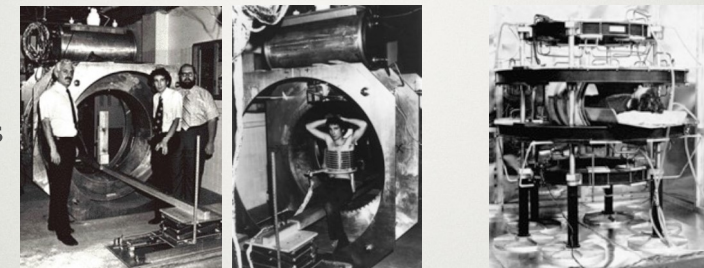


T2-weighted

MRI IMAGING:

IV. SCANNERS

Early times



Present



Interventional MRI unit



Open MRI unit



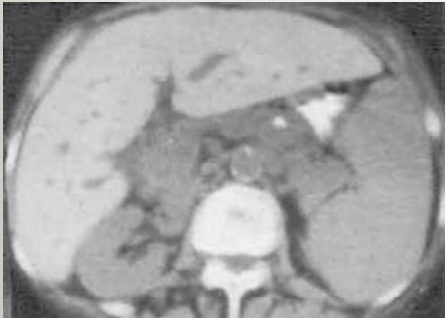
Mobile MRI



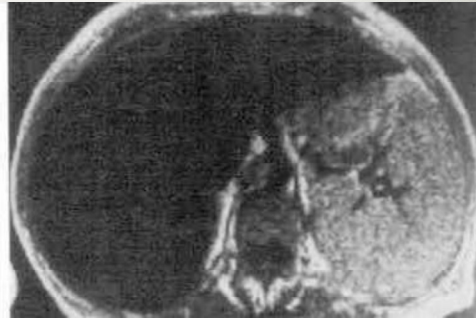
MRI IMAGING: V. CONTRAST AGENTS

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

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



CT

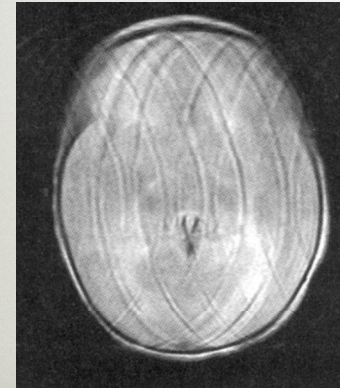


MR T2

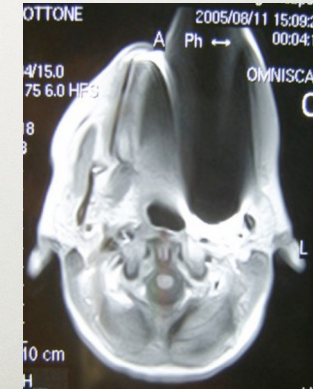
Haemochromatosis hepatis

MRI IMAGING: VI. ARTIFACTS

- Motion
- Metals (implants, injury)



Motion artifact



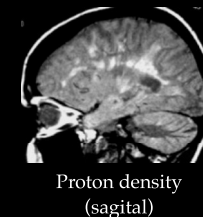
Metal in the orbit of the eye

MRI IMAGING: VII. DANGERS, CONTRAINDICATIONS

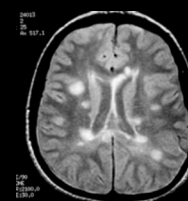
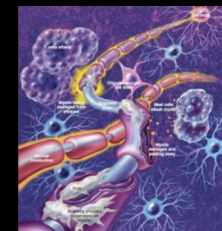
- Static magnetic field - metal objects
Contraindications: implanted devices (pacemaker, defibrillator, hearing aids, drug delivery devices), neurostimulators, brain aneurysm clamps, early cardiac valve implants
- Gradient field - induced current
- Radio frequency field - thermal effects (lens, testis)



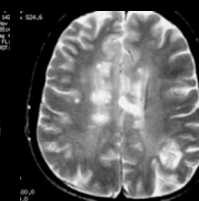
ANATOMICAL IMAGING: MULTIPLE SCLEROSIS



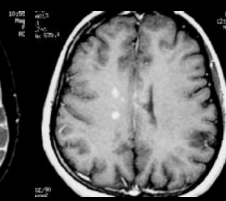
Proton density
(sagittal)



Proton density
(transverse)



T2 weighted
(transverse)

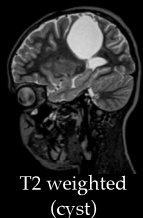


T1 weighted
With contrast agent

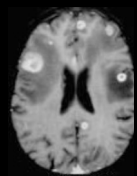
ANATOMICAL IMAGING: ONCOLOGY



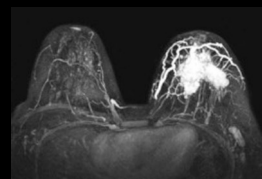
T2 weighted
(chondrosarcoma)



T2 weighted
(cyst)



Proton density
(Brain metastasis)



T1 weighted with contrastagent
(Breast carcinoma)

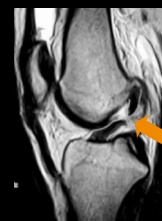


T2 weighted
(cervix carcinoma)

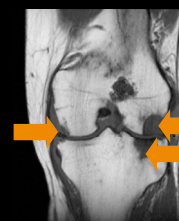


T2 weighted
(prostate tumor)

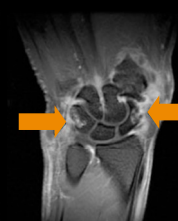
ANATOMICAL IMAGING BONE AND SOFT TISSUE



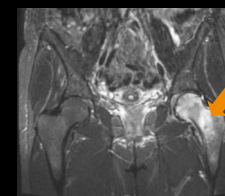
T2 weighted
(torn ligaments)



Rheumatoid arthritis
knee



Rheumatoid arthritis
wrist

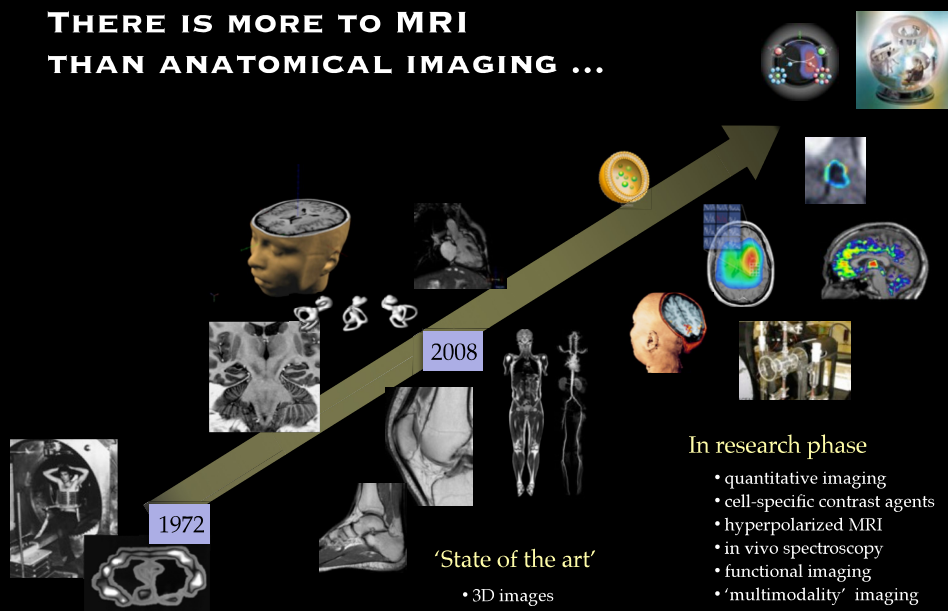


Osteoporosis (femur)



T2 weighted
(hernia)

THERE IS MORE TO MRI THAN ANATOMICAL IMAGING ...



1972

2008

'State of the art'

- 3D images
- dynamic images
- sharp image resolution

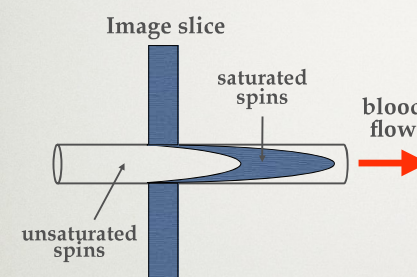
In research phase

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

First NMR images

MRI:

NON-INVASIVE ANGIOGRAPHY



Arteria
carotis

Circulus
arteriosus
Willisii

MRI MOVIE

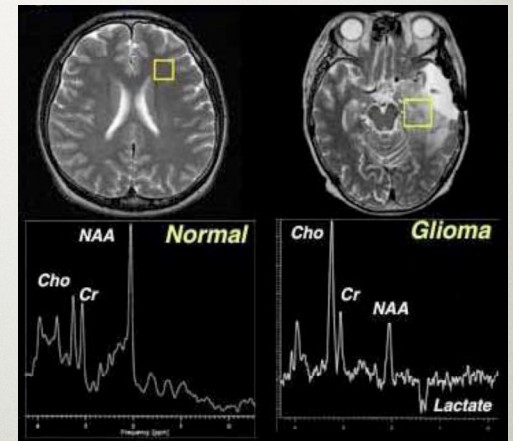
BASED ON HIGH TIME RESOLUTION IMAGES



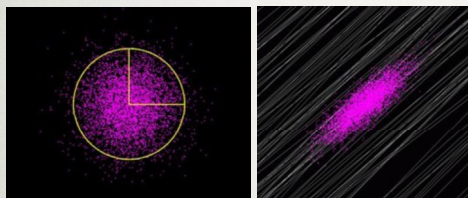
Opening and closing of aorta valve

MR SPECTROSCOPY

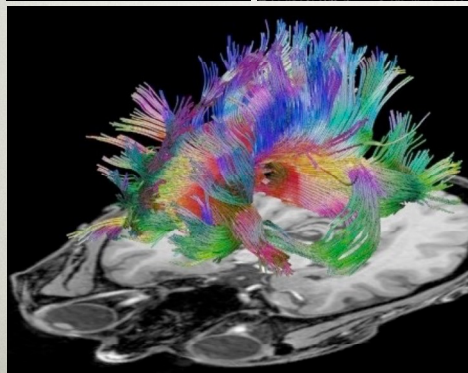
- Chemical shift
- Identification of metabolites
- Tumor diagnostics



DIFFUSION IMAGING



Anisotropic water diffusion: contrast

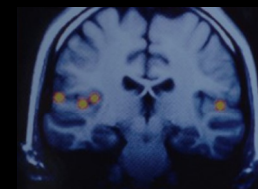


Imaging neural tracts: tractography

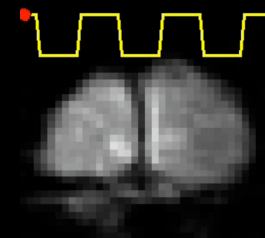
Corpus callosum

FUNCTIONAL MRI (fMRI)

HIGH TIME RESOLUTION IMAGES RECORDED
SYNCHRONOUSLY WITH PHYSIOLOGICAL PROCESSES

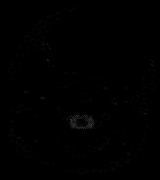


Activation in the acoustic cortex

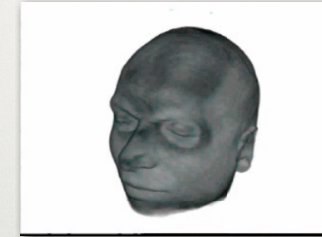


Effect of light pulses on visual cortex

SUPERPOSITION OF MRI ON OTHER INFORMATION (PET)



SUPERIMPOSED MRI AND PET SEQUENCE



PET activity: during eye movement
Volume rendering