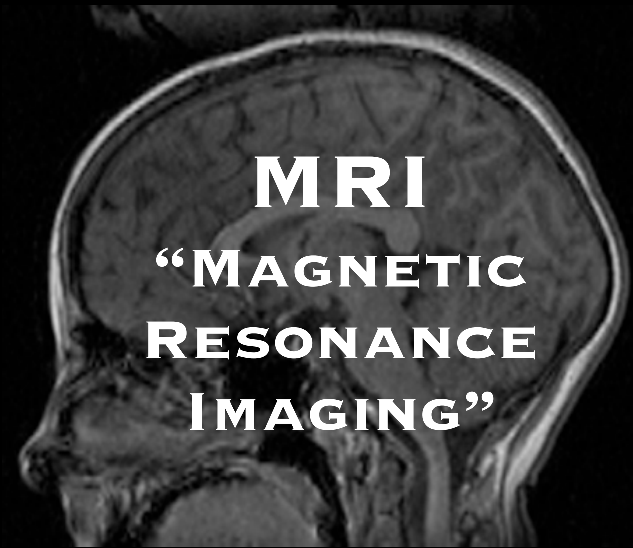
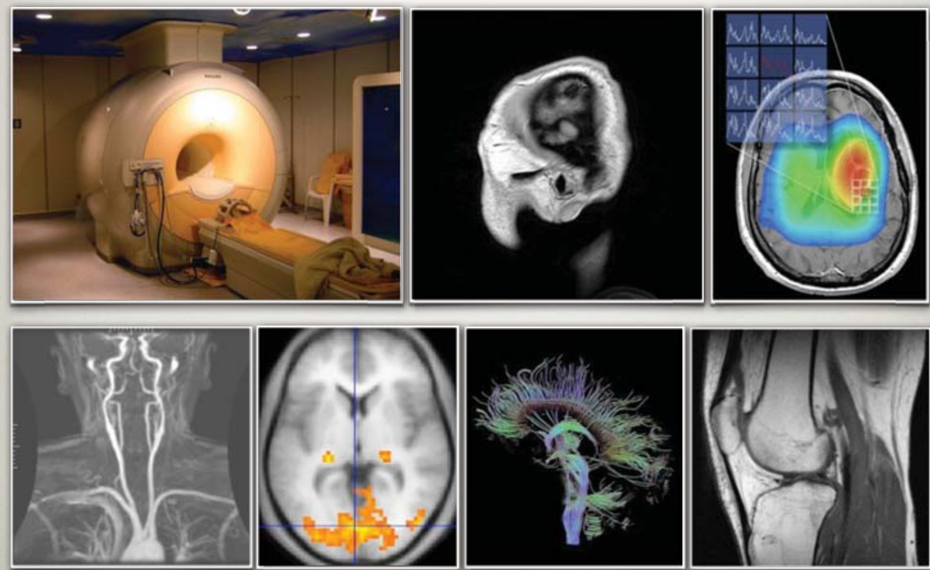


MRI
“Magnetic Resonance Imaging”

MRI is a revolutionary device

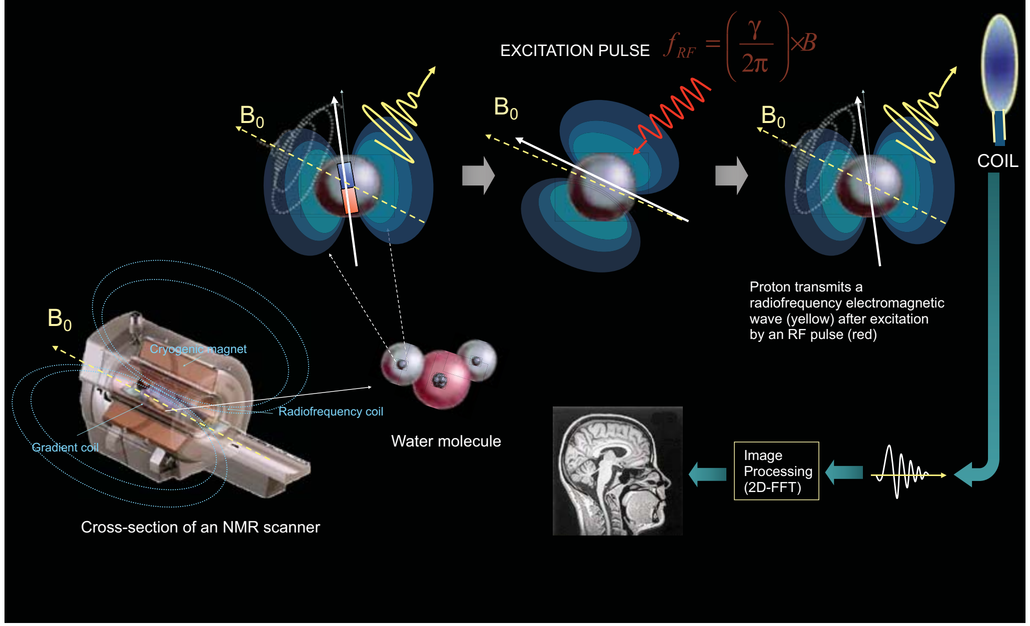


MRI is a non-invasive tomographic method

History of MRI

- 1946 Felix Bloch and Edward Purcell discovered nuclear magnetic resonance
- 1950 1950-1970 NMR matures as physical & chemical technique.
- 1971 Damadian shows tumors appear different than healthy tissue.
- 1973 Lauterbur does MRI on test tubes
- 1975 Ernst suggests frequency and phase gradients and Fourier Transform
- 1980 Edelstein et al. First body MRI
- 1987 Cardiac MRI
- 1992 fMRI
- And Beyond

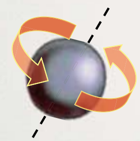
Nuclear Magnetic Resonance Imaging: Basic principle

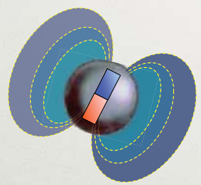


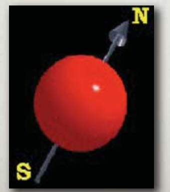
Atomic nuclei with nuclear spin: elementary magnets

Otto Stern

W. Gerlach







Atomic nuclei have mass: $m_{proton} = 1{,}67.10^{-24}$ g

Atomic nuclei carry angular momentum: $L = \sqrt{l(l+1)}\hbar$

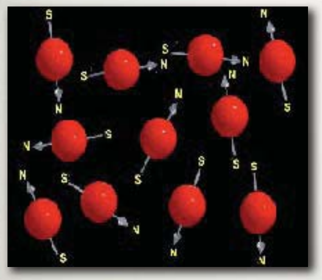
l = spin quantum number

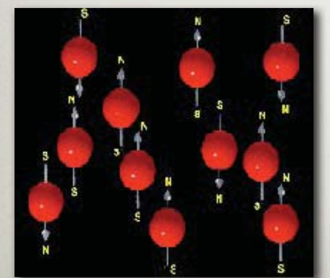
Atomic nuclei carry charge: $q_{proton} = 1{,}6.10^{-19}$ C

Atomic nuclei possess magnetic moment: $\mu_i = \gamma L$

γ = gyromagnetic ratio
L = angular momentum

Nuclear Magnetic Resonance (NMR)

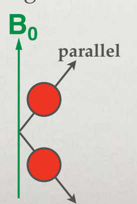




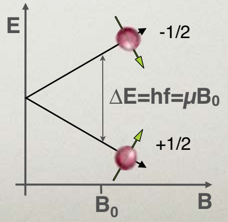
In absence of magnetic field:
random orientation of elementary magnets

In magnetic field:

elementary magnets orient

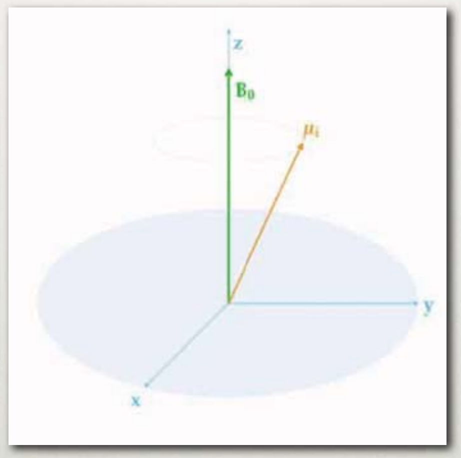


energy levels split



Edward Purcell, 1946

Nuclear Magnetic Resonance: Spin Precession



Precession or Larmor frequency:

$$\omega_0 = \gamma B_0$$

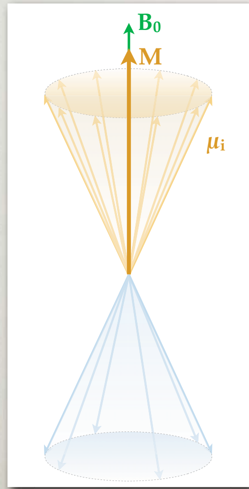
$$f_{Larmor} = \frac{\gamma}{2\pi} B_0$$

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

B_0 = magnetic field
M = net magnetization

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

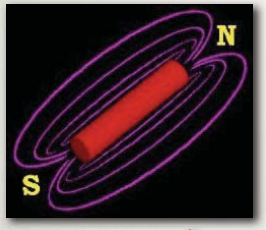
$$\frac{N_{antiparallel}}{N_{parallel}} = e^{-\frac{\Delta E}{k_B T}}$$

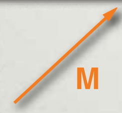
Boltzmann distribution

Excitation

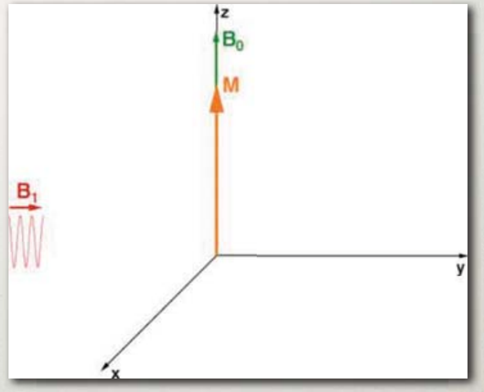
Using radio frequency radiation

Resonance condition: Larmor frequency



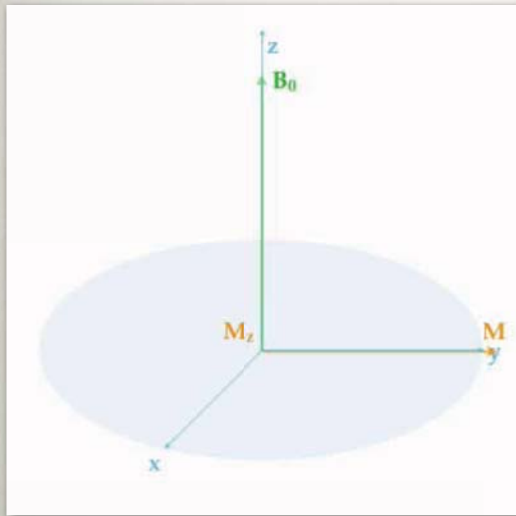


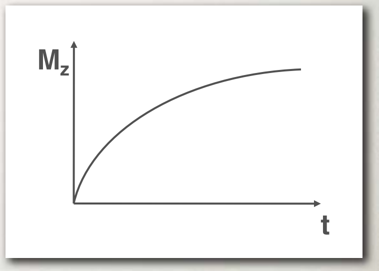
B_0 = magnetic field
M = net magnetization
B_1 = irradiated radio frequency wave



Spin-lattice relaxation

T1 or longitudinal relaxation

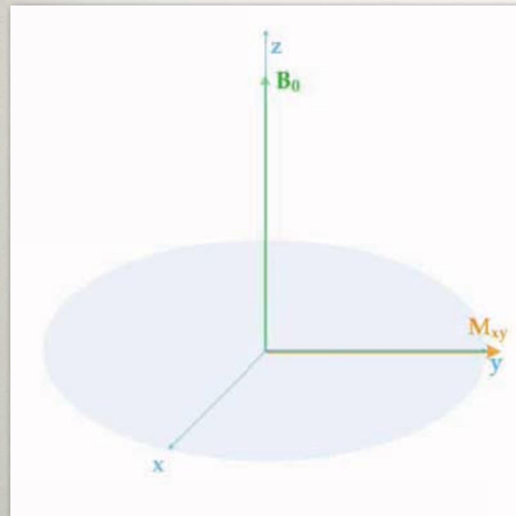


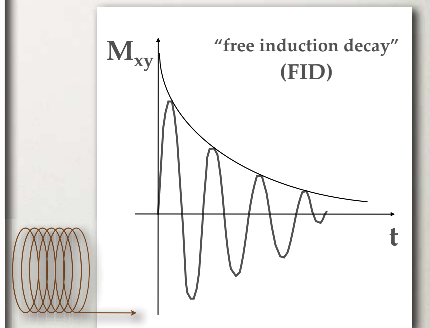


T1 relaxation time:
depends on interaction
between elementary magnet (proton)
and its environment

Spin-spin relaxation

T2 or transverse relaxation



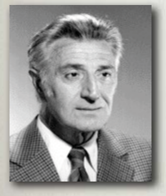


T2 relaxation time:
depends on interaction between
elementary magnets (protons)

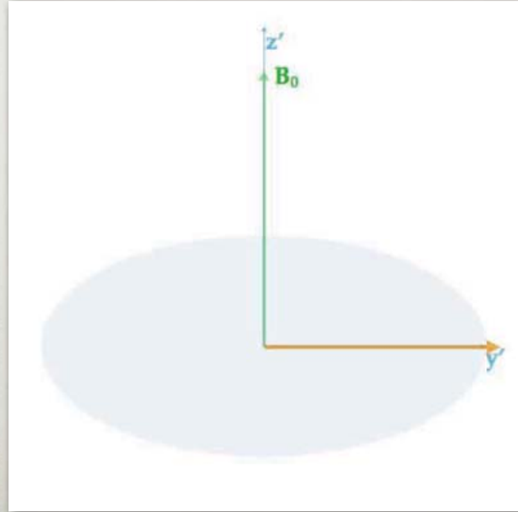
Spin-spin relaxation

T2 or transverse relaxation

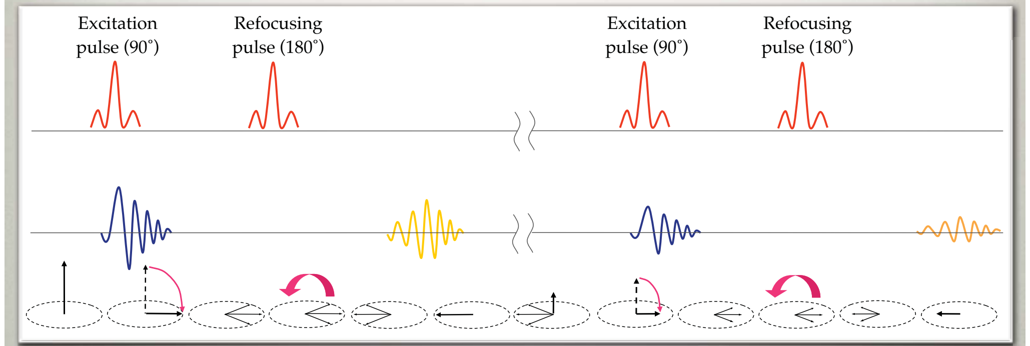
Repetitive pulses of excitation and subsequent relaxation: spin-echo sequence

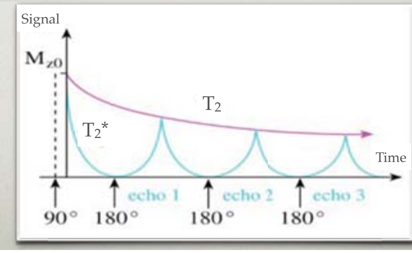


Erwin Hahn, 1949

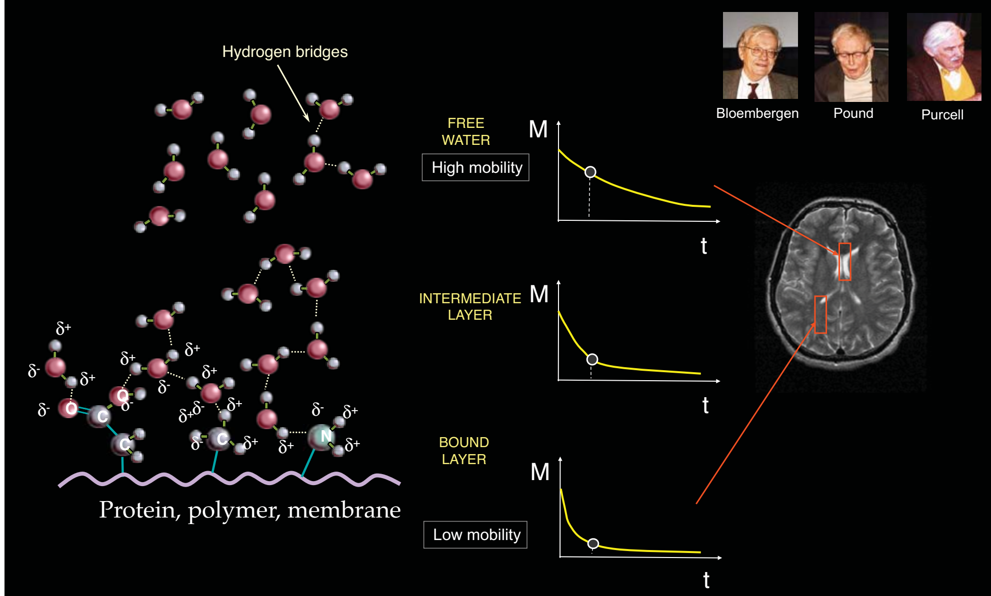


The spin-echo experiment

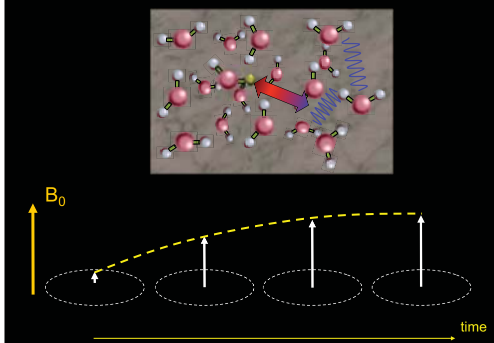
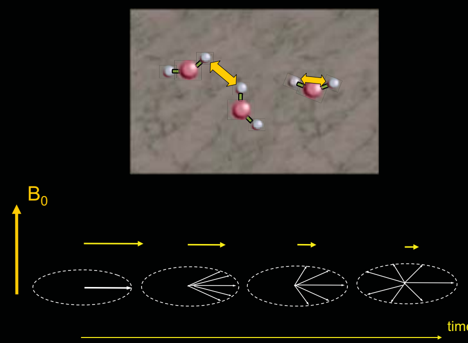




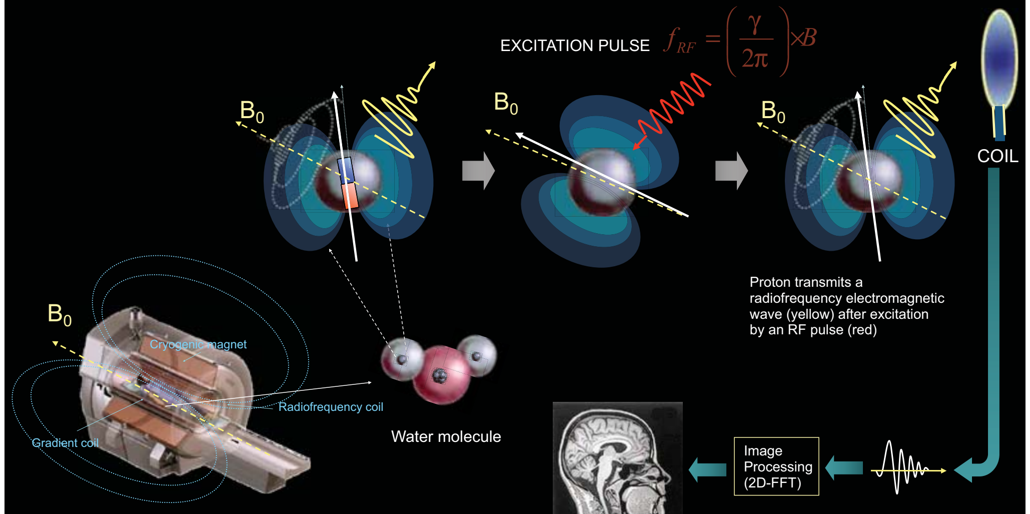
Contrast in MR images is determined by the interaction of spin systems



Nuclear Magnetic Resonance Imaging: Two important relaxation mechanisms

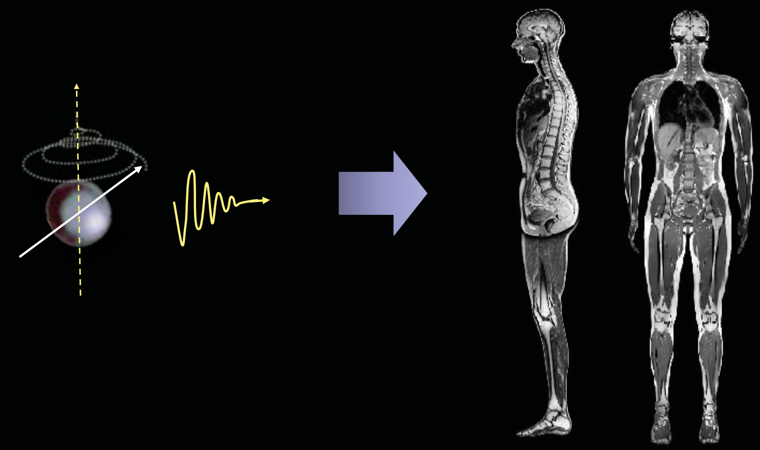
Spin-lattice relaxation T1	Spin-spin relaxation T2
	
Restoration of longitudinal magnetization	Dephasing of transverse magnetization
Energy transfered to lattice (phonons)	Energy transferred between spins
Entropy increases	No entropy change of total spin system
Repopulation of spins between spin energy levels	No repopulation of spins between spin energy levels
Interactions with magnetic field fluctuations at Larmor frequency	Interactions with magnetic field fluctuations at low frequency

Nuclear Magnetic Resonance Imaging: Basic principle



Cross-section of an NMR scanner

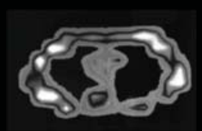
From nuclear magnetic resonance signal to Magnetic Resonance Imaging



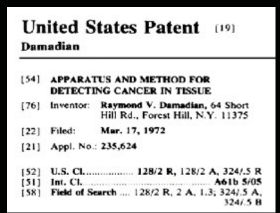
First NMR experiments in vivo

Downstate Medical Center - Brooklyn, 1972

Raymond V. Damadian

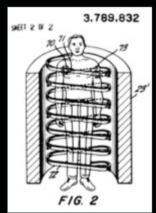


First MRI scan

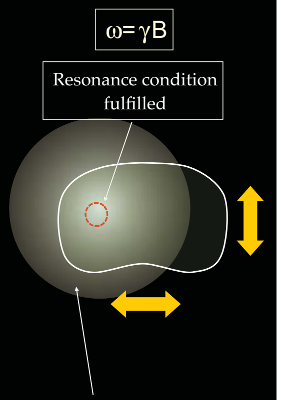


United States Patent [19]
Damadian

[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

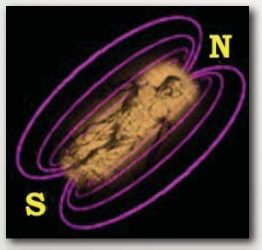


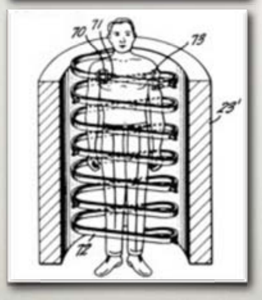
1970: detection of lengthened relaxation times in cancerous tissues
1972: theoretical development of human in vivo 3D NMR
1977: first human MRI image



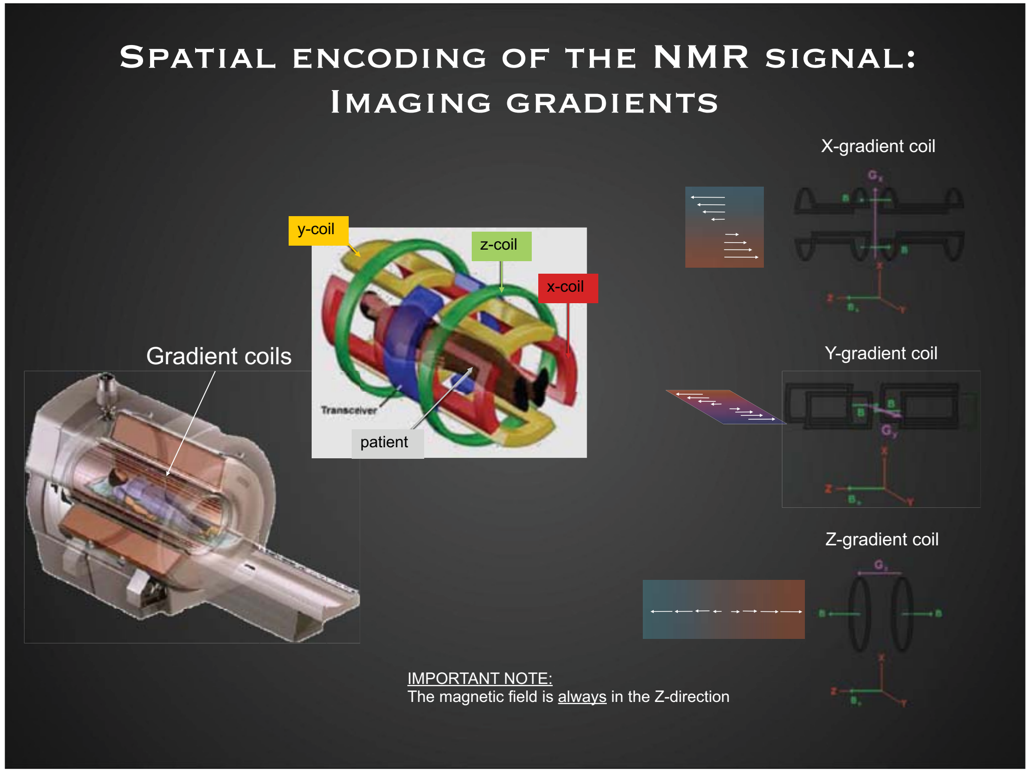
Inhomogeneous magnetic field

MRI:
Net magnetization of the human body is generated

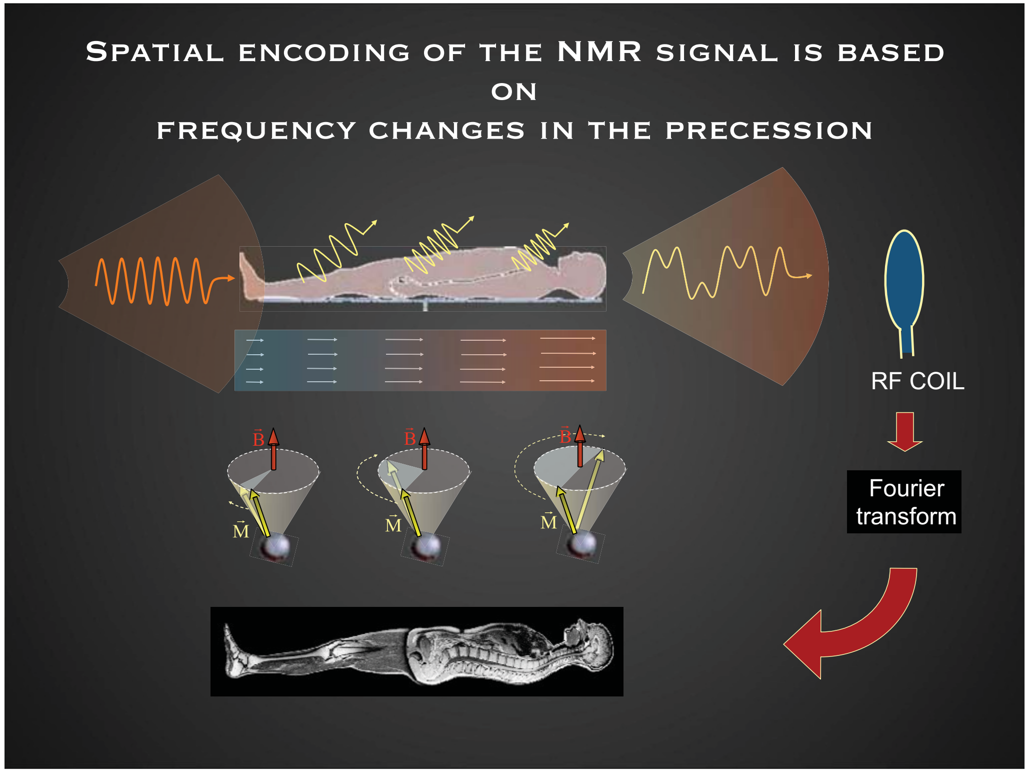




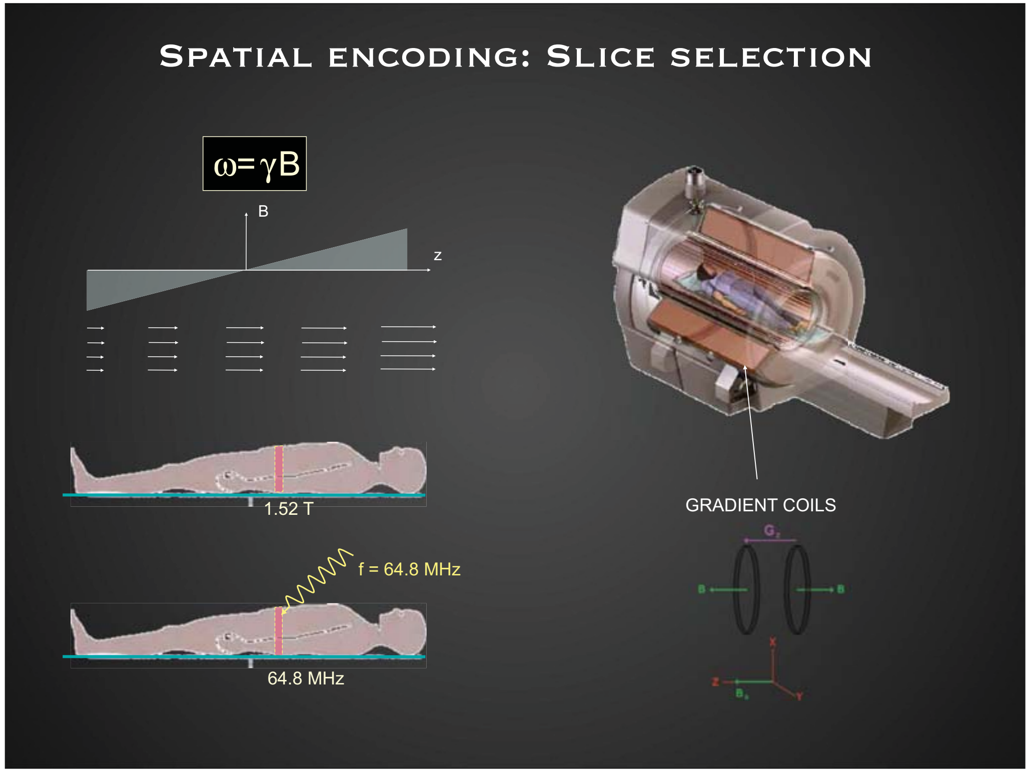
"Indomitable"



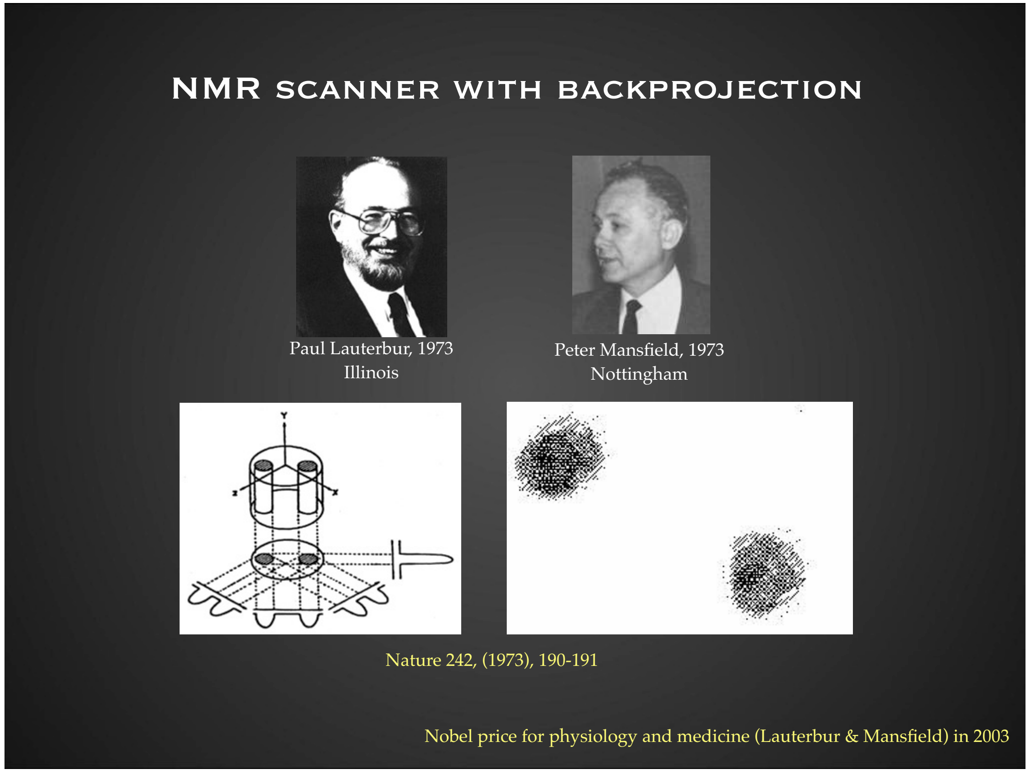
SPATIAL ENCODING OF THE NMR SIGNAL:
IMAGING GRADIENTS
X-gradient coil
y-coil
z-coil
x-coil
Gradient coils
Transceiver
patient
Y-gradient coil
Z-gradient coil
IMPORTANT NOTE:
The magnetic field is always in the Z-direction



SPATIAL ENCODING OF THE NMR SIGNAL IS BASED ON
FREQUENCY CHANGES IN THE PRECESSION
RF COIL
Fourier transform

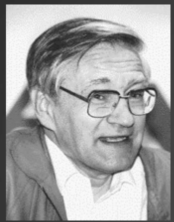


SPATIAL ENCODING: SLICE SELECTION
ω=γB
B
z
1.52 T
f = 64.8 MHz
64.8 MHz
GRADIENT COILS

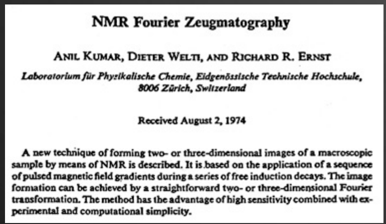


NMR SCANNER WITH BACKPROJECTION
Paul Lauterbur, 1973
Illinois
Peter Mansfield, 1973
Nottingham
Nature 242, (1973), 190-191
Nobel price for physiology and medicine (Lauterbur & Mansfield) in 2003

NMR scanner with 2D Fourier transformation



Richard Ernst, 1974
Zürich



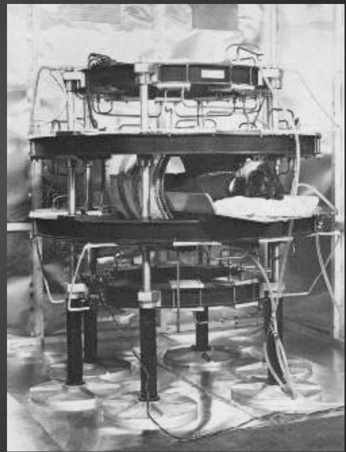
NMR Fourier Zeugmatography

Anil Kumar, Dieter Welti, and Richard R. Ernst

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

Received August 2, 1974

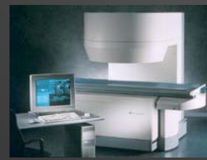
A new technique of forming two- or three-dimensional images of a macroscopic sample by means of NMR is described. It is based on the application of a sequence of pulsed magnetic field gradients during a series of free induction decays. The image formation can be achieved by a straightforward two- or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



Nobel price for chemistry in 1991

The first MRI scanners ...

Interventional MRI unit

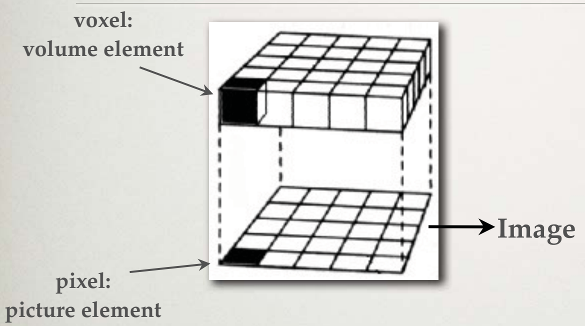


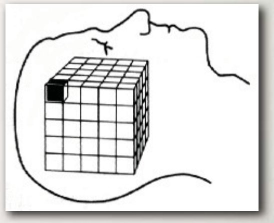
Open MRI unit

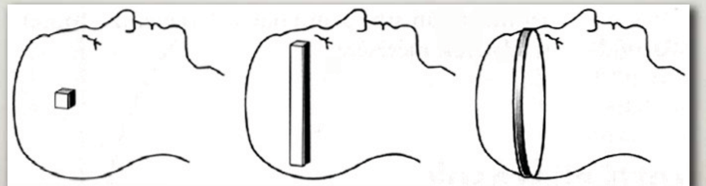
Mobile MRI unit

... and recent ones

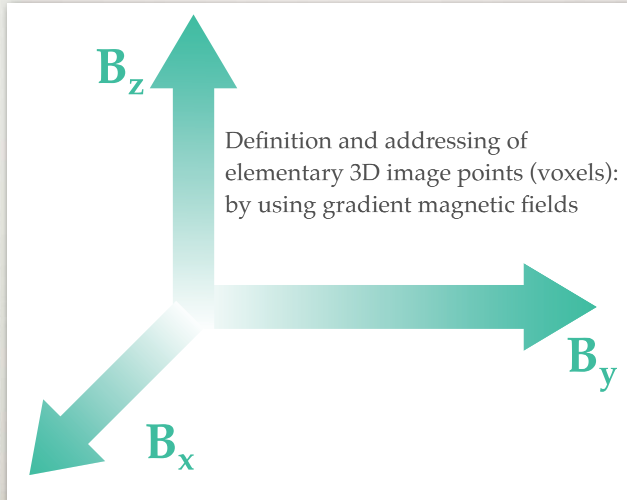
MRI Imaging I:
Spatial resolution



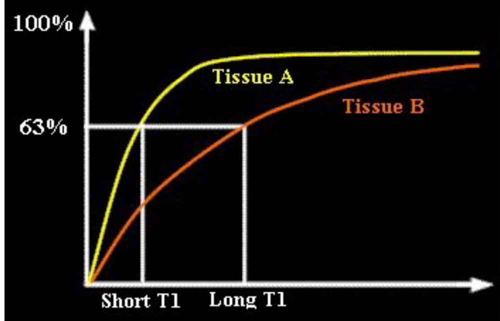


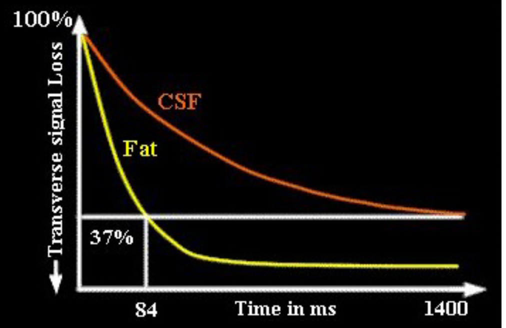


MRI Imaging I:
Spatial resolution

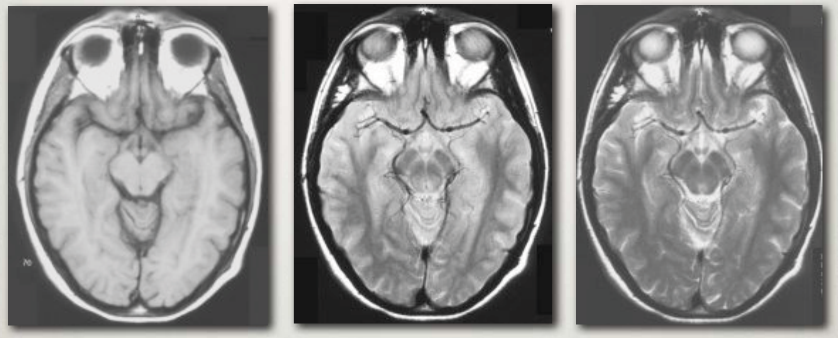


MRI Imaging II:
Color resolution (contrast) based on relaxation times





MRI Imaging II:
Color resolution (contrast)
based on spin density and relaxation times



T1-weighing

Proton density-weighing

T2-weighing

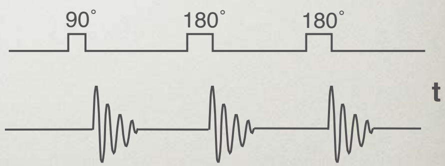
MRI technology

Magnet: superconducting (liquid He)

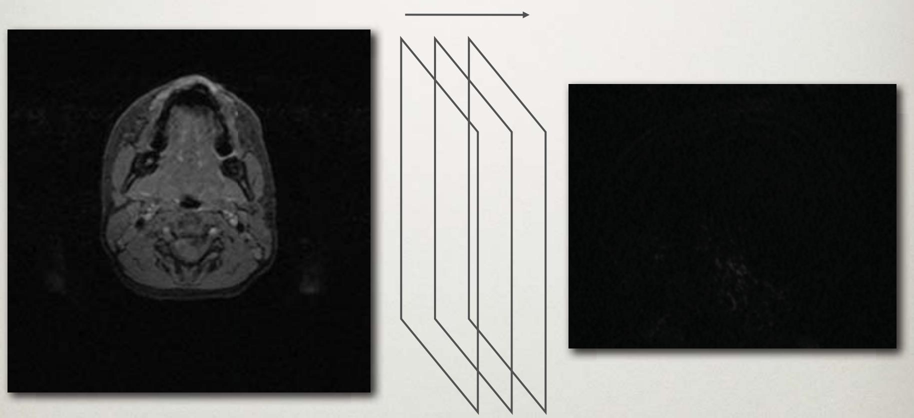
Resolution enhancement: surface RF coils

Excitation with pulse sequences

Detection and analysis:
Fourier transform of temporal signal

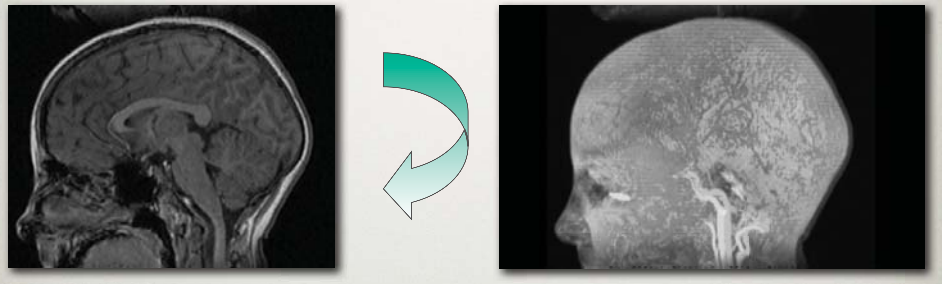


MRI:
Image manipulation I



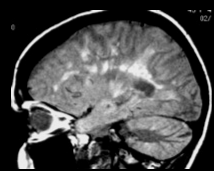
Reslicing in perpendicular plane

MRI:
Image manipulation II

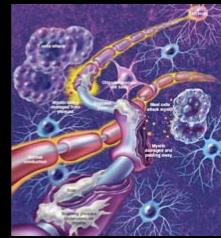


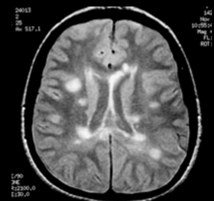
Spatial projection
(„volume rendering”)

Anatomical imaging: Multiple sclerosis

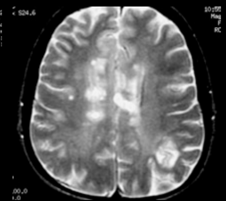


Proton density
(sagital)

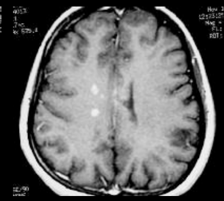




Proton density
(transverse)



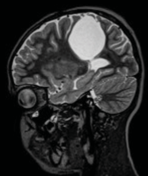
T2 weighted
(transverse)



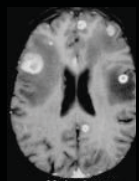
T1 weighted
With contrast agent

Anatomical imaging: Oncology

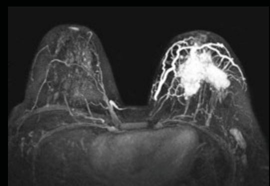
T2 weighted
(chondrosarcoma)



T2 weighted
(cyst)



Protondensity
(Brain metastasis)



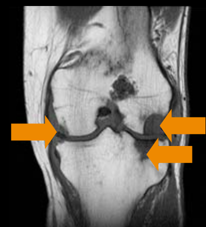
T1 weighted with contrastagent
(Breast carcinoma)

T2 weighted
(cervix carcinoma)

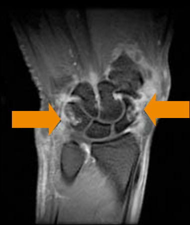
T2 weighted
(prostate tumor)

Anatomical imaging Bone and soft tissue

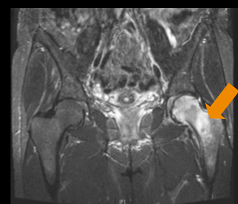
T2 weighted
(torn ligaments)



Rheumatoid arthritis
knee

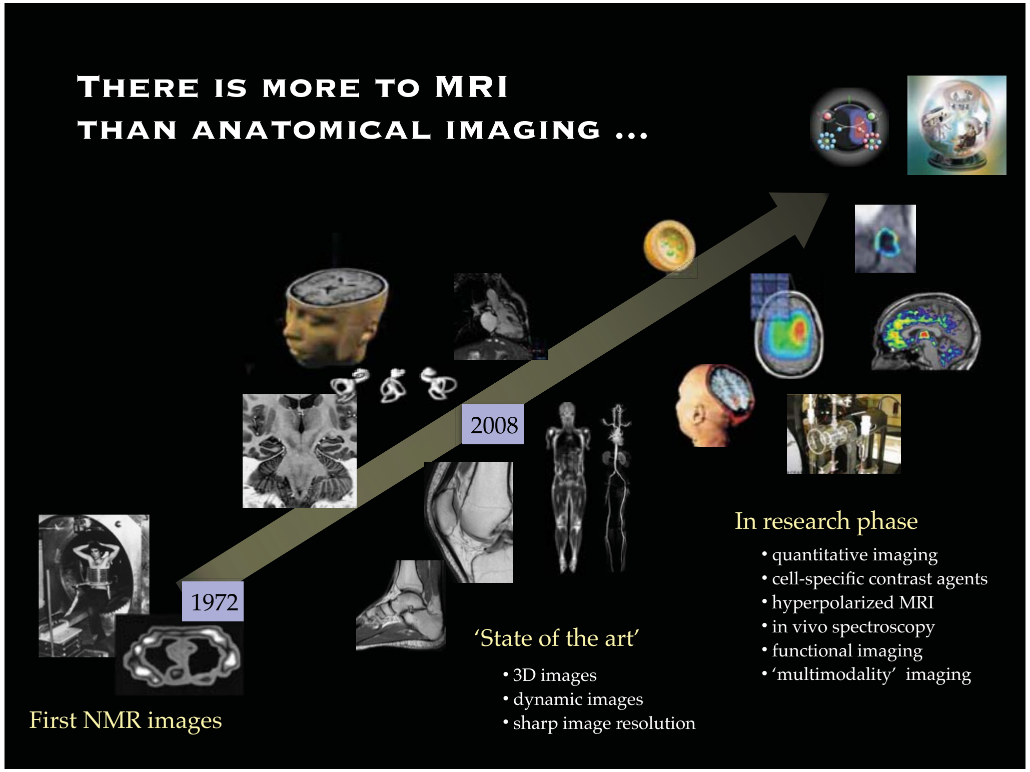


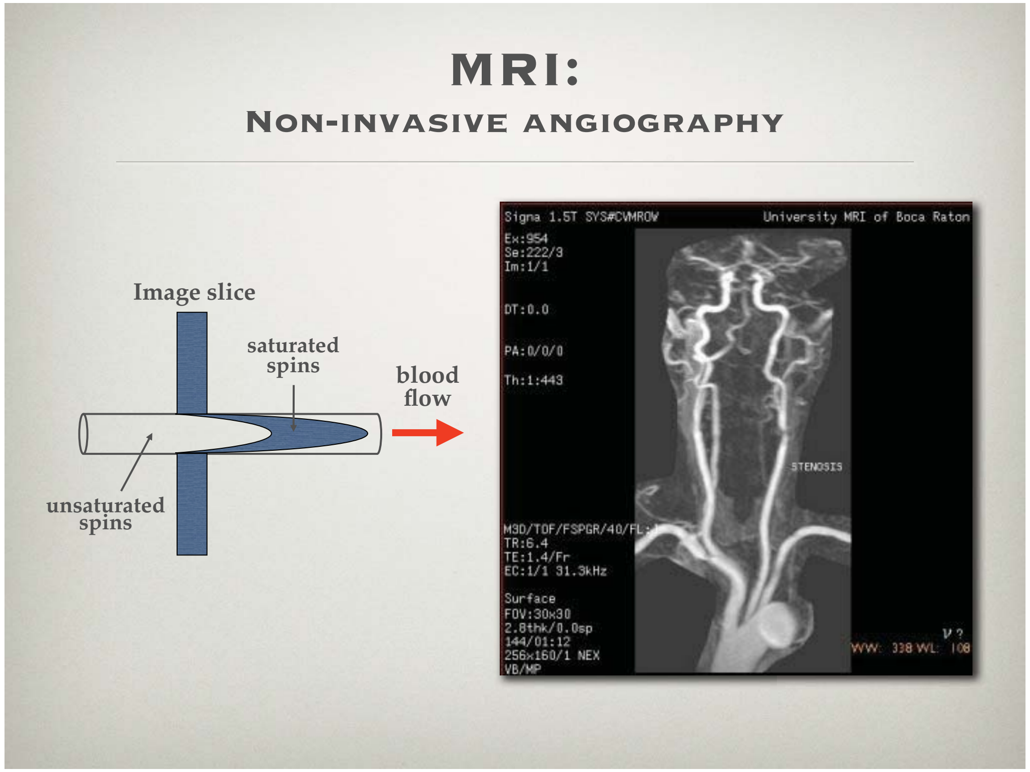
Rheumatoid arthritis
whrist

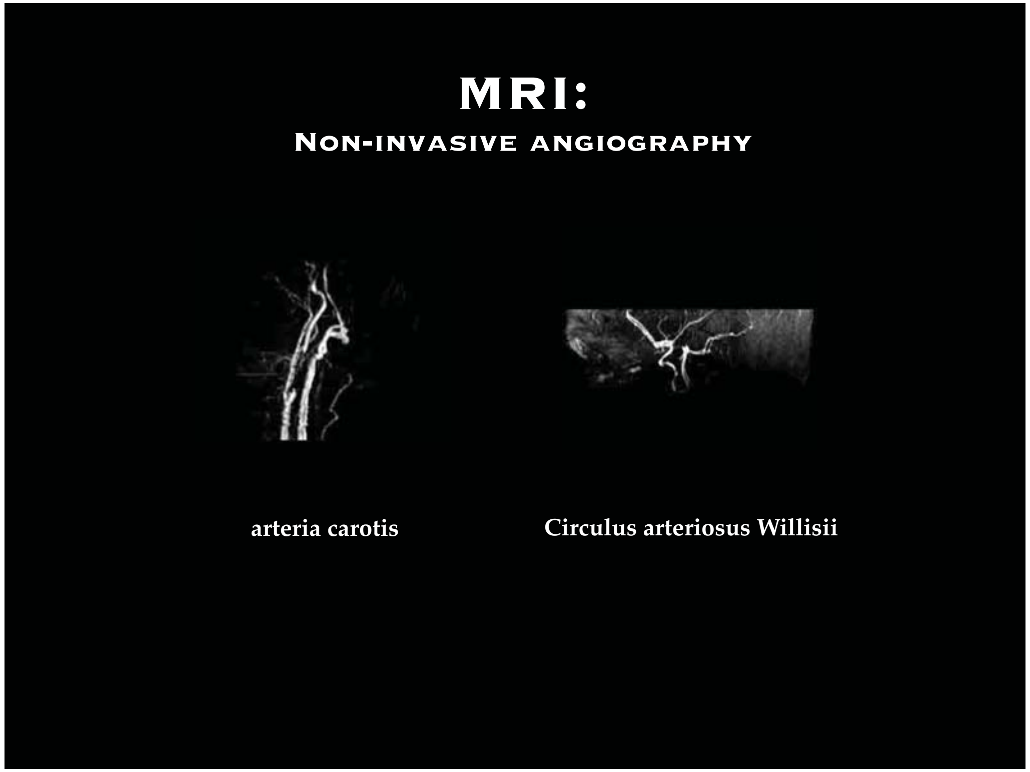


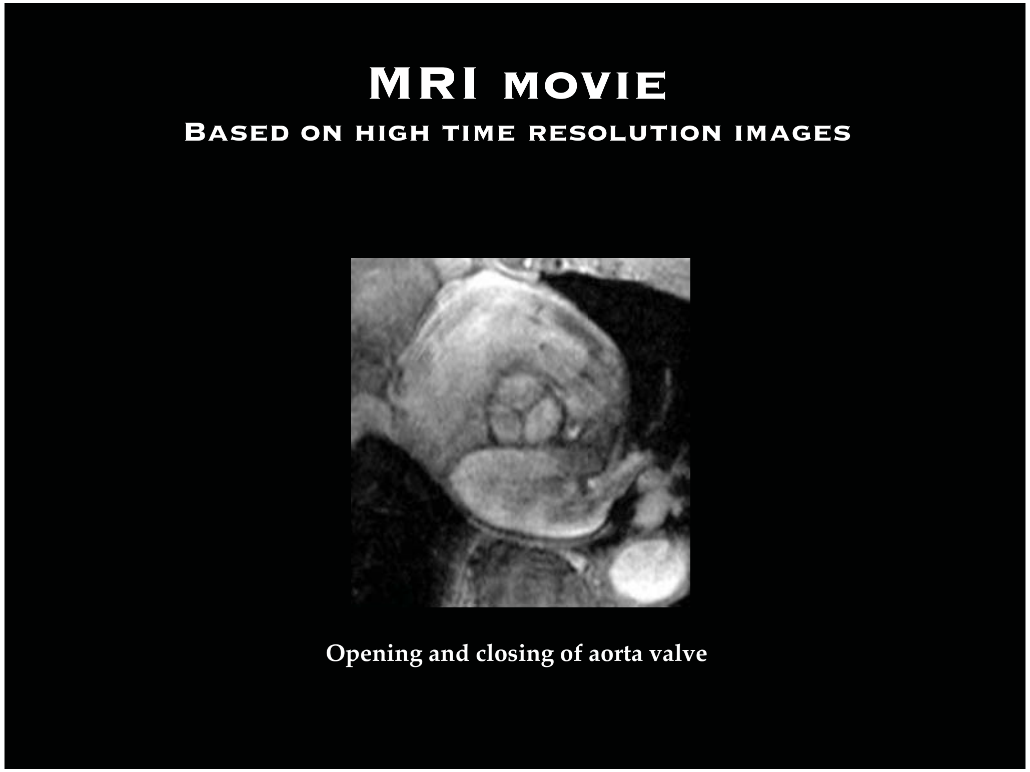
Osteoporosis (femur)

T2 weighted
(hernia)


There is more to MRI
than anatomical imaging …
1972
2008
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

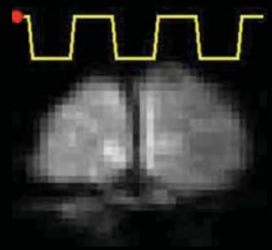

MRI:
Non-invasive angiography
Image slice
saturated spins
blood flow
unsaturated spins
Signa 1.5T SYS#CVMROW
University MRI of Boca Raton
STENOSIS


MRI:
Non-invasive angiography
arteria carotis
Circulus arteriosus Willisii


MRI movie
Based on high time resolution images
Opening and closing of aorta valve

Functional MRI (fMRI)

High time resolution images recorded synchronously with physiological processes



Effect of light pulses on visual cortex

Superposition of MRI on other information (PET)

Superposed MRI and PET sequence

PET activity: during eye movement
Volume rendering