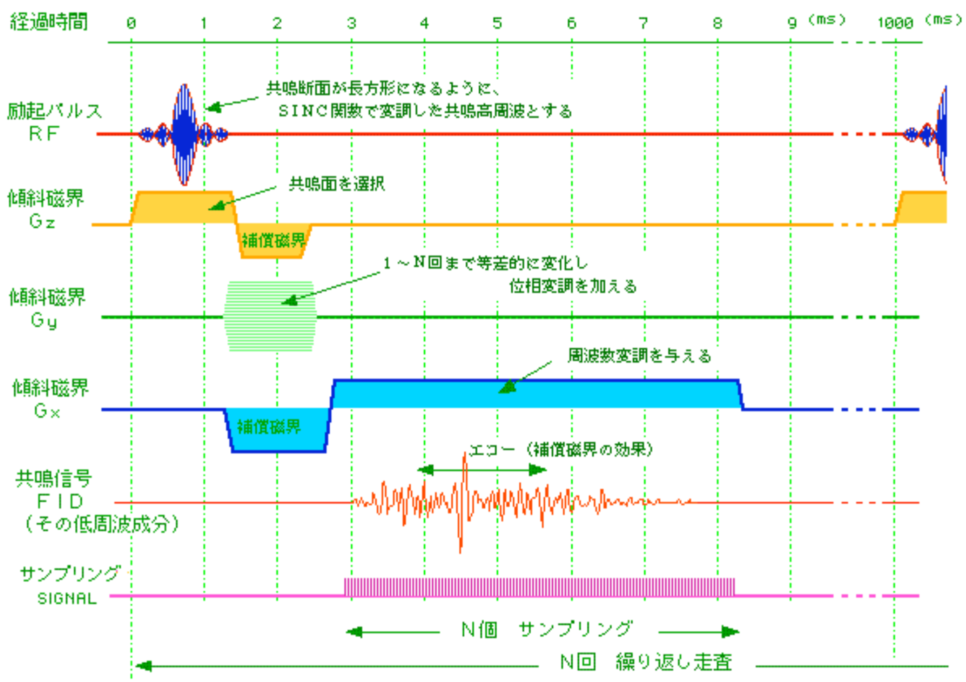
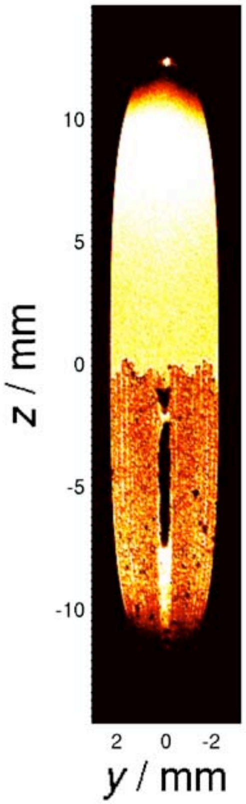
Imaging

- Contrast
- Fourier imaging
- Slice selection



画像測定のための電磁パルス列（フーリエ変換法（スピン・ワープ法））



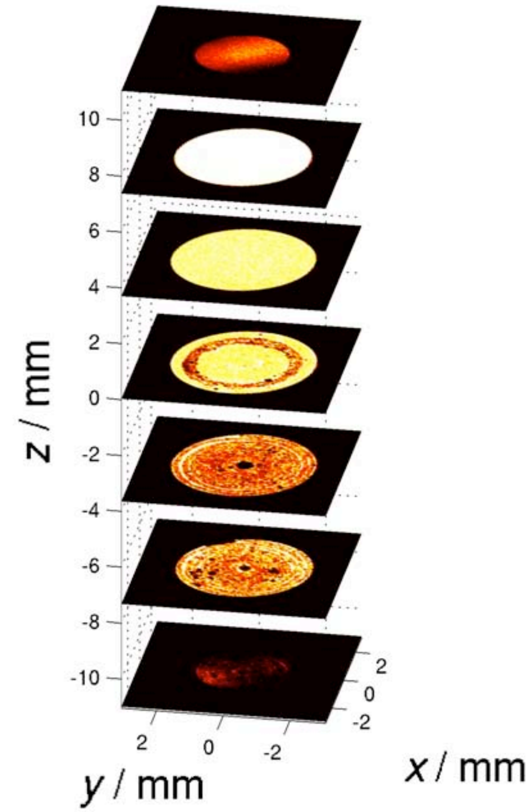
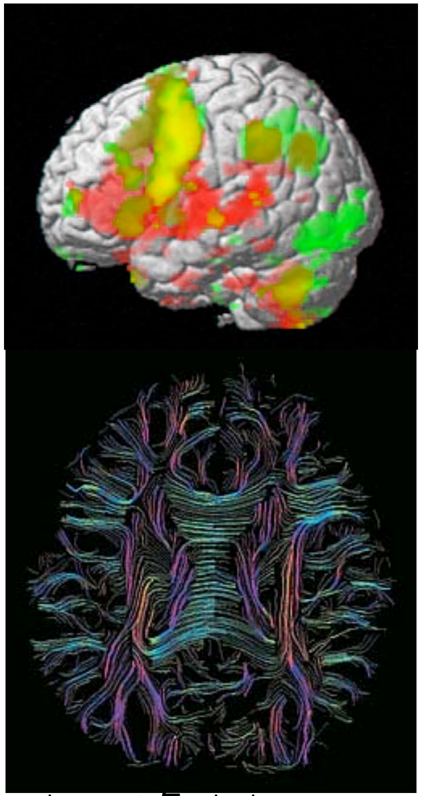


Image intensity in MRI

- Spin density
  - ^{1}H, ^{13}C, ^{31}P, ^{23}Na, …
- Filters
  - relaxation, diffusion, chemical shift, …
- Parameter maps
  - …, diffusion anisotropy, …
- Image analysis
  - blood oxygenation level, fiber tracking

Le Bihan, Nat. Rev. Neurosci. (2003)



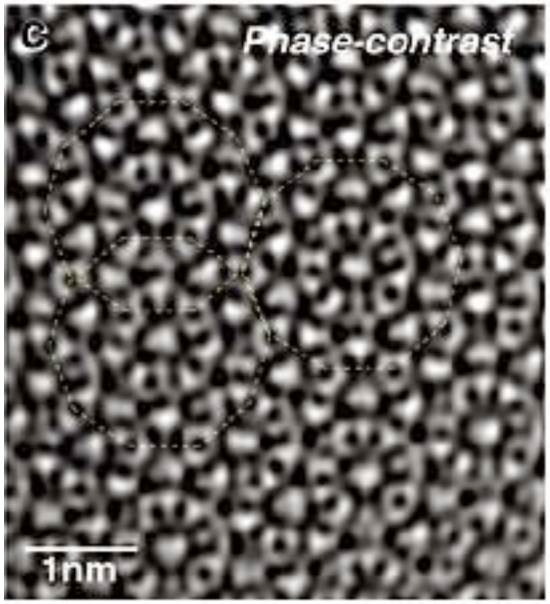
mednews.stanford.edu

Resolution

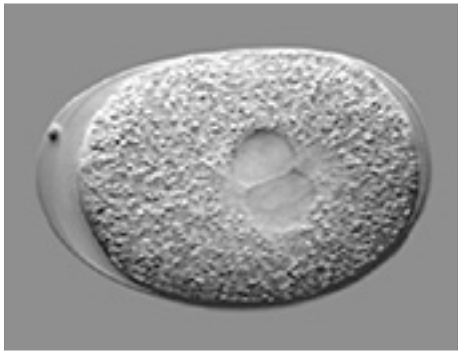
- Clinical MRI: ~1 mm
- Micro MRI: ~10 μm
- Clever use of contrast gives voxel-averaged info about smaller structures

axon diameter 1-10 μm

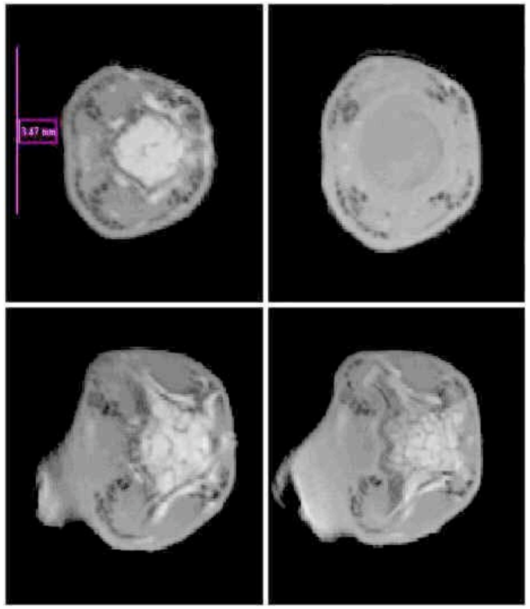
Resolution < wavelength?



electrons
$\lambda = 0.005$ nm
resolution = 0.1 nm



light
$\lambda = 0.5\ \mu$m
resolution = 1 μm



radiowaves
$\lambda = 5$ cm
resolution = 0.1 mm

Resonance condition

$$\omega_0 = -\gamma B_0$$

Contributions from:

- external field
- chemical surroundings
- neighboring spins
- field gradients

$\left.\begin{array}{l}\text{chemical surroundings}\\ \text{neighboring spins}\end{array}\right\}$ spectroscopy

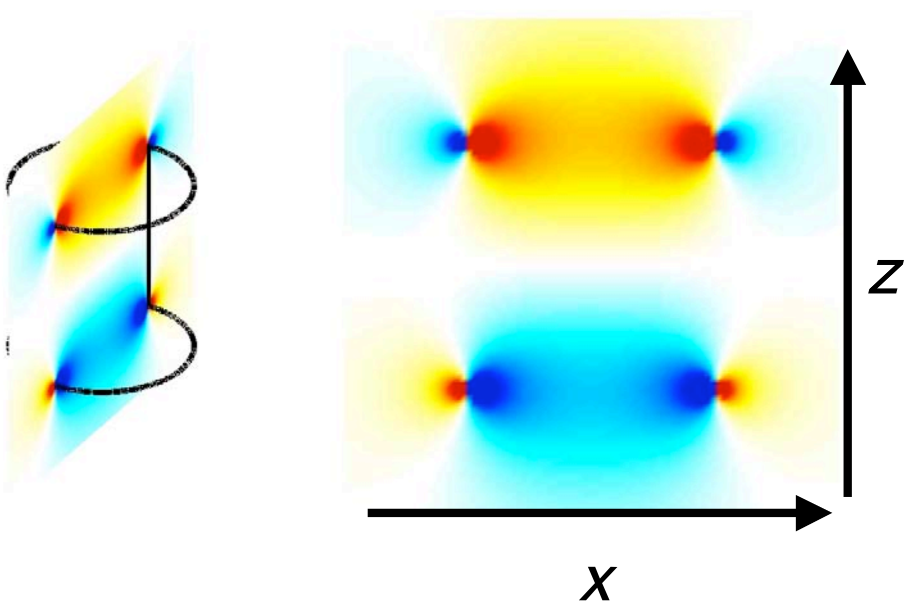
field gradients: imaging

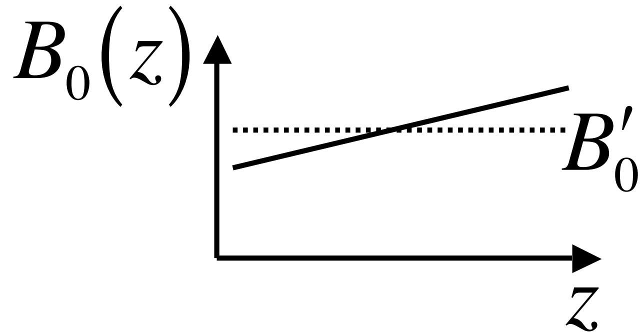
Magnetic field gradients, *G*

position

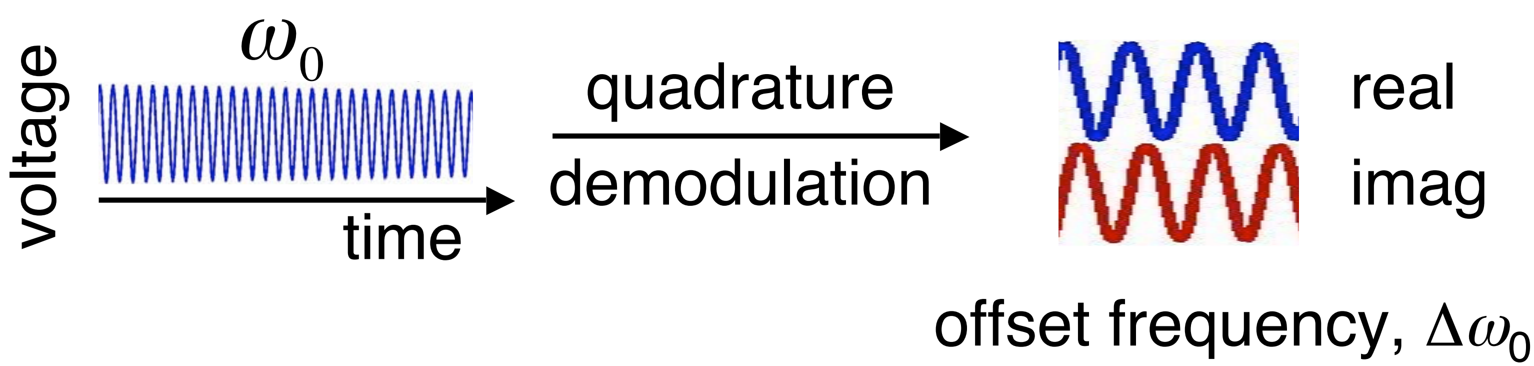
$$B_0(z) = B_0' + Gz$$

homogeneous component





Detection in the rotating frame

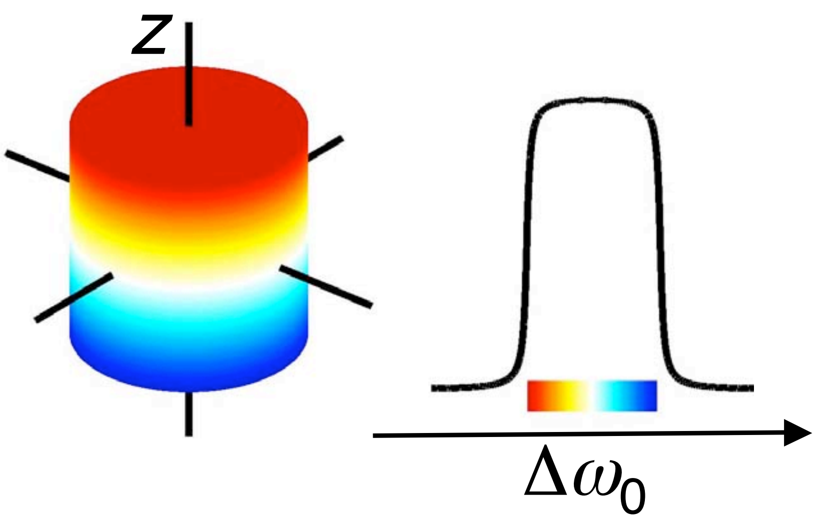


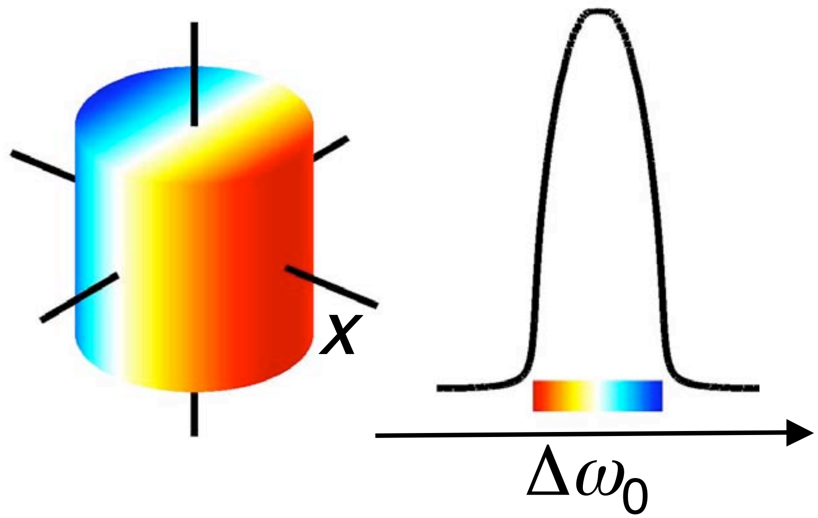
$$
\left.\begin{aligned}
B_0(z) &= B_0' + Gz \\
\omega_0 &= -\gamma B_0 \\
\omega_{\mathrm{RF}} &= -\gamma B_0' \\
\Delta\omega_0 &= \omega_0 - \omega_{\mathrm{RF}}
\end{aligned}\right\} \quad \Delta\omega_0(z) = -\gamma G z
$$

1D profiles

$$\Delta\omega_0(z) = -\gamma G_z z$$

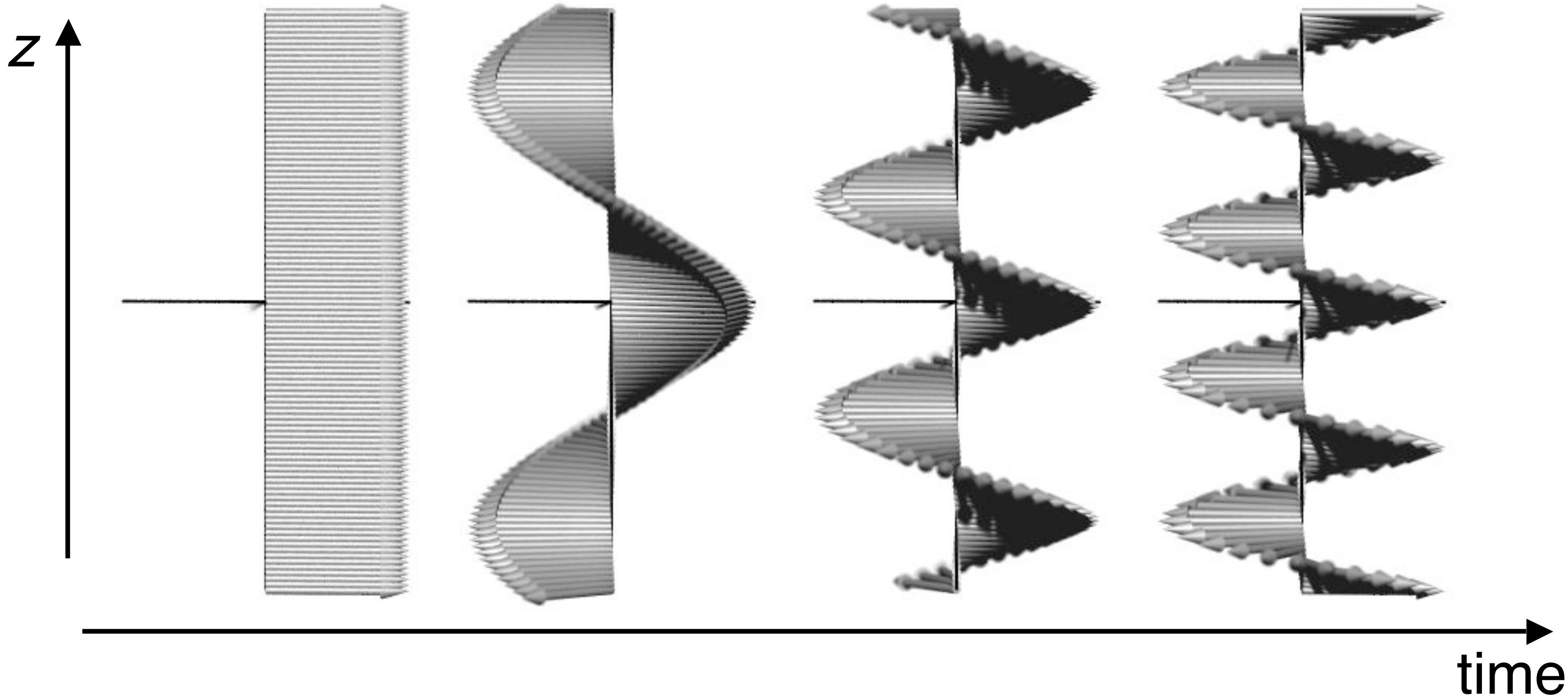
$$\Delta\omega_0(x) = -\gamma G_x x$$





Spin evolution in a gradient

$$\Delta\omega_0(z) = -\gamma G z$$

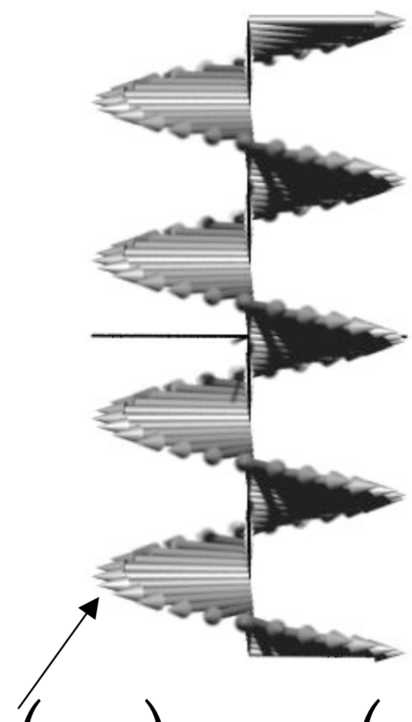


Total signal, *S*

$$S(t) = \int \rho(\mathbf{r}) s(\mathbf{r},t) d\mathbf{r}$$

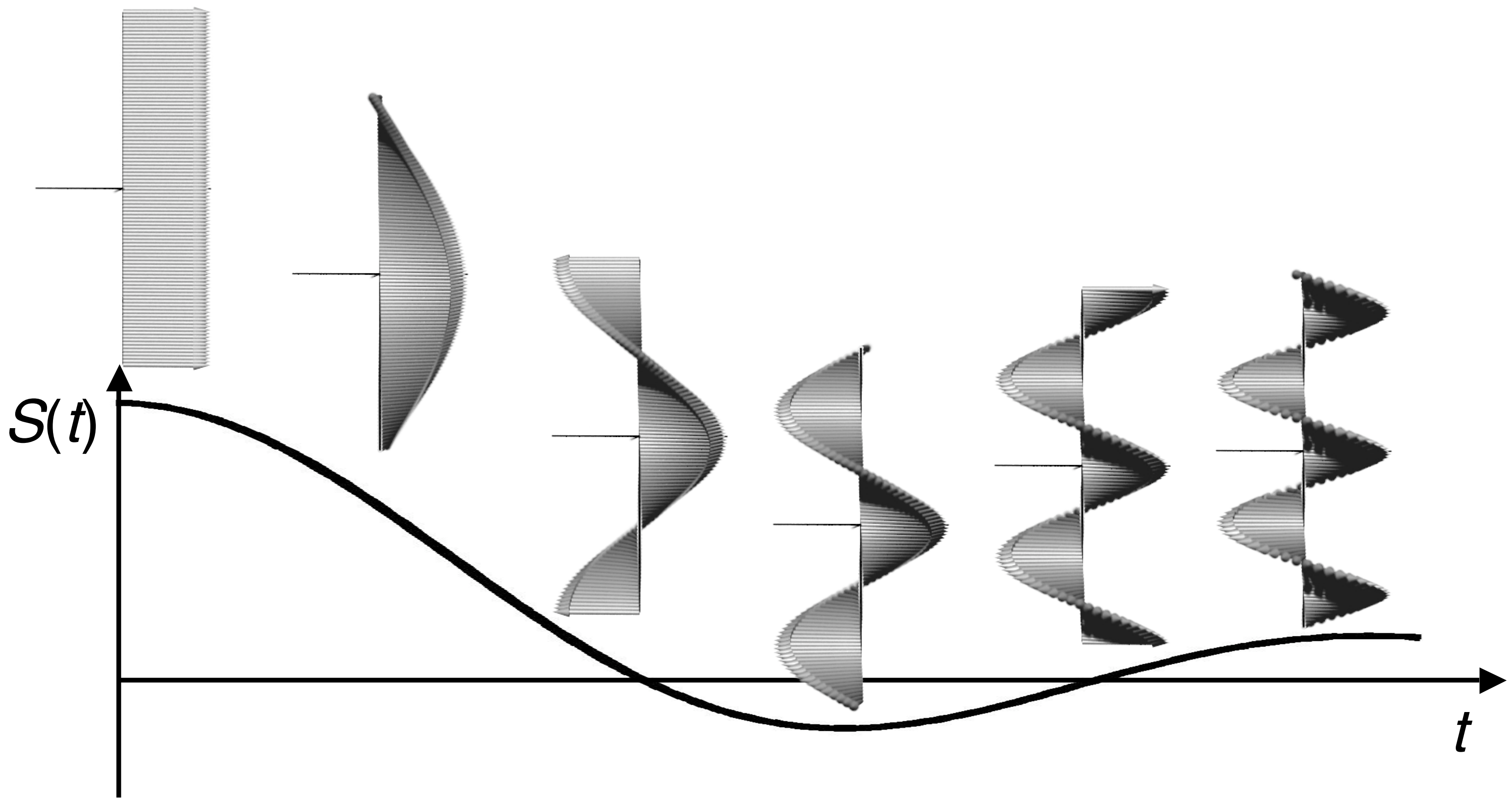
time, *t*
position, **r**
spin density, ρ

integral over entire sample

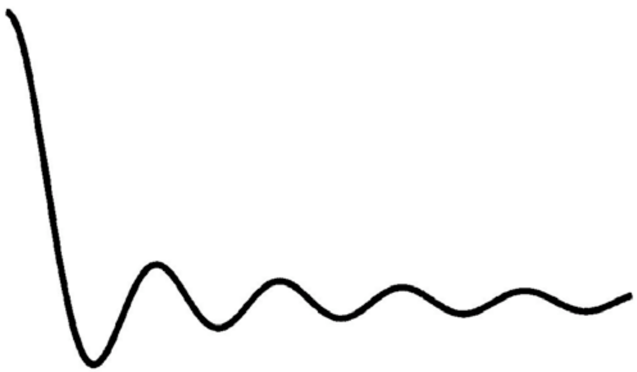


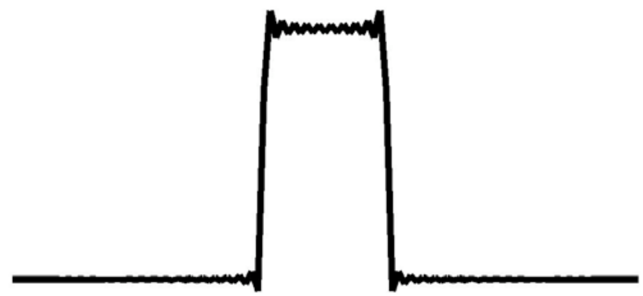
$$s(\mathbf{r},t) \propto m_x(\mathbf{r},t) + i m_y(\mathbf{r},t)$$

Signal, *S*(*t*)



FT => image





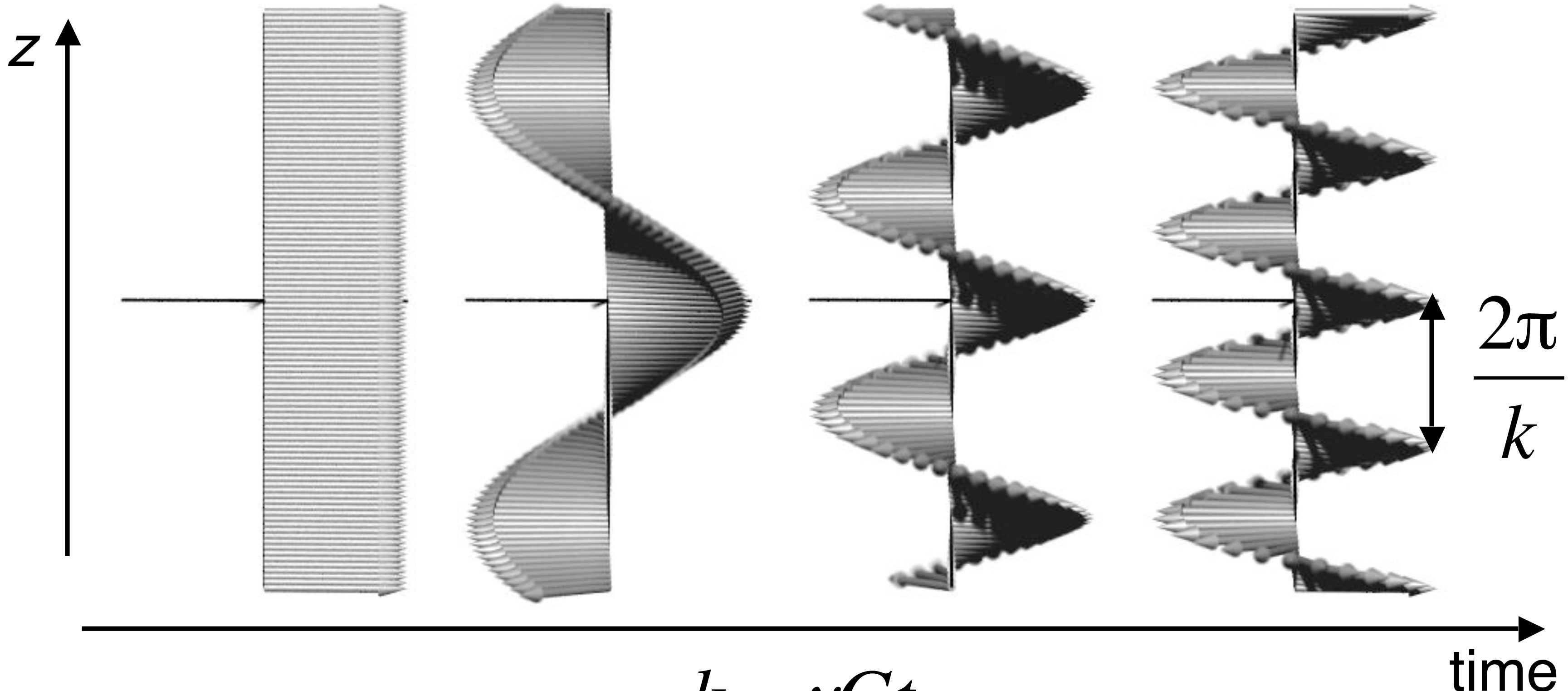
time, t —FT→ offset frequency, $\Delta\omega_0$

? → position, z

$$\Delta\omega_0(z) = -\gamma G z$$

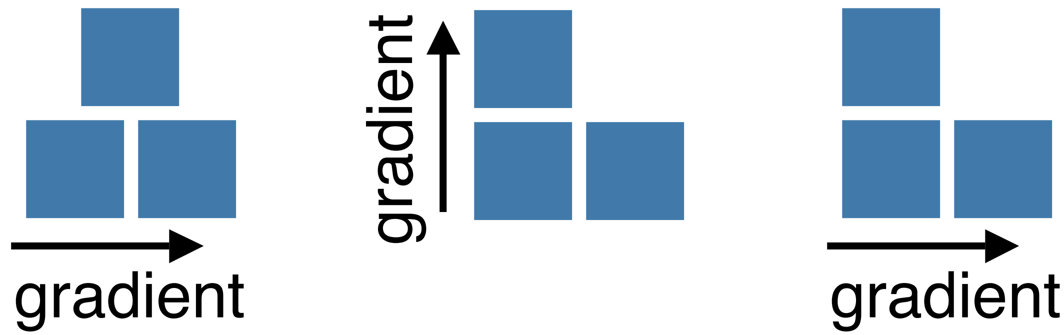
Spatial frequency, *k* [rad/m]

Fourier conjugate to position, *z* [m]

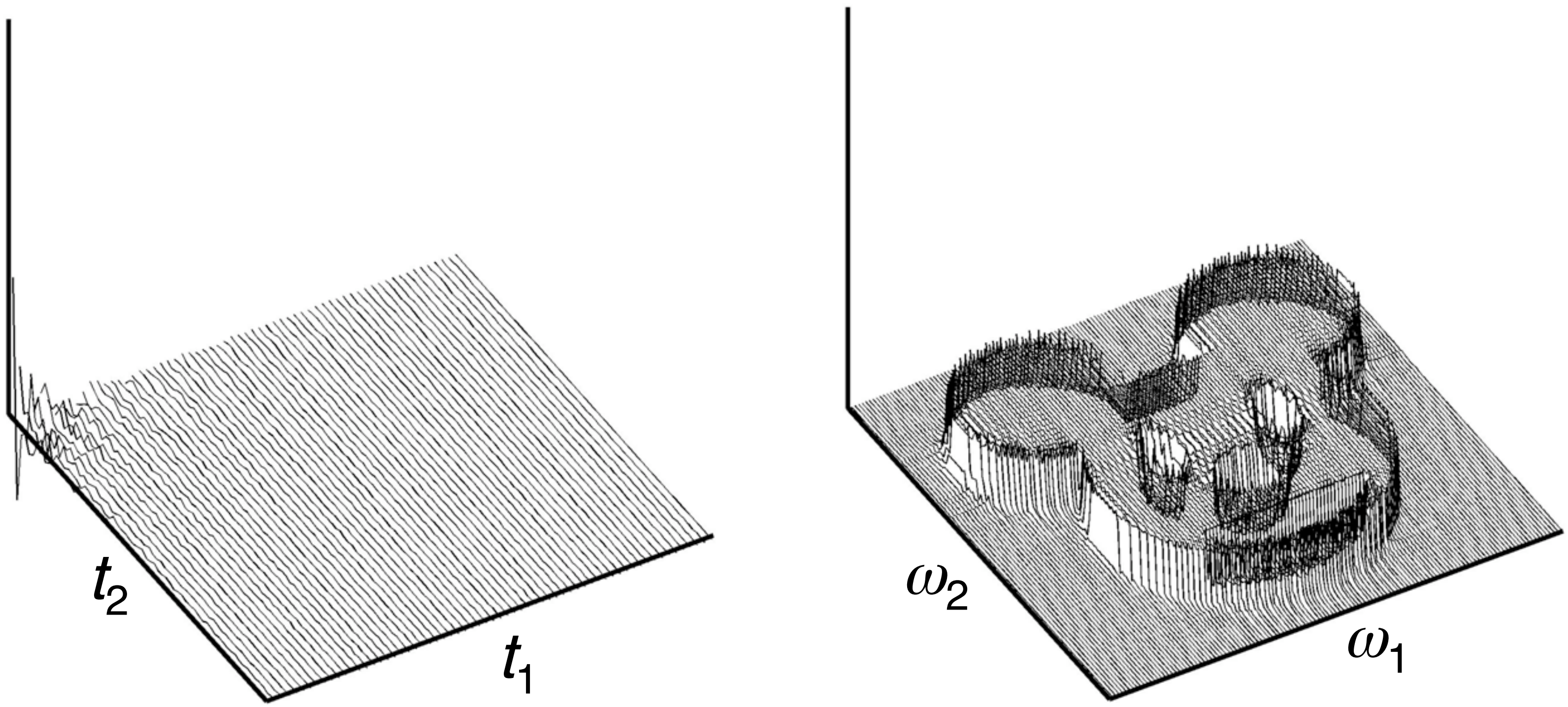


$$k = \gamma G t$$

Draw schematic ^{1}H NMR spectra for water in the following geometries:



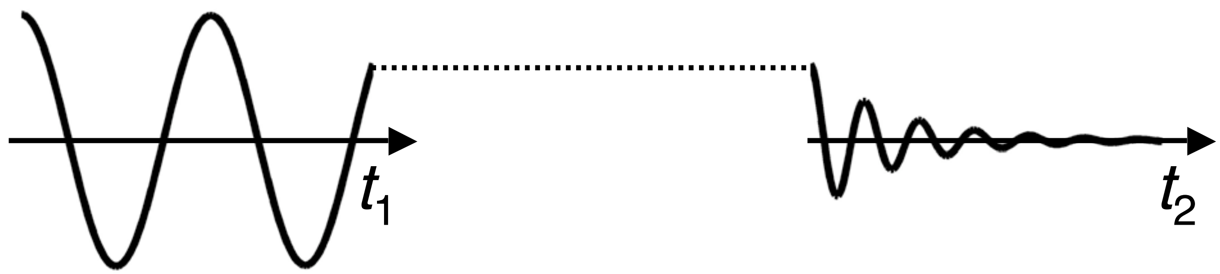
How to get a 2D image?



2D NMR - 2D MRI

G_x on | G_z on

preparation	evolution	mixing	detection

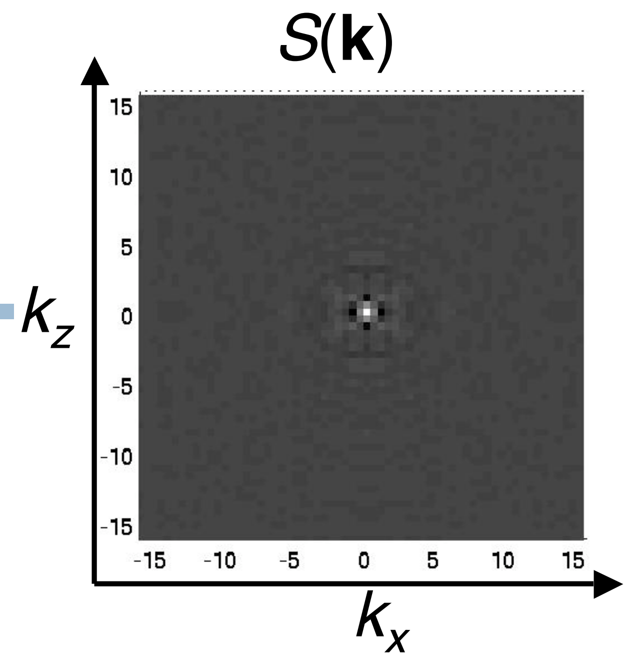


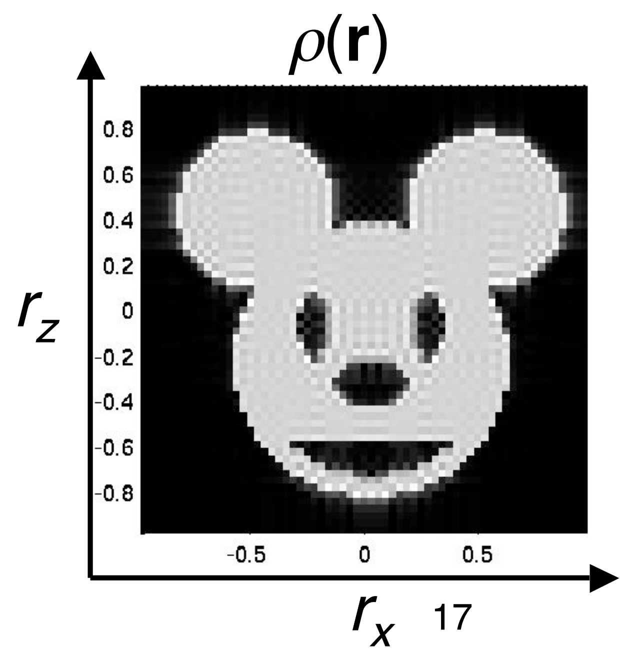
$$k_x = \gamma G_x t_1 \qquad k_z = \gamma G_z t_2$$

Fourier imaging

$$S(\mathbf{k}) = \int \rho(\mathbf{r}) e^{-i\mathbf{k}\cdot\mathbf{r}} d\mathbf{r}$$

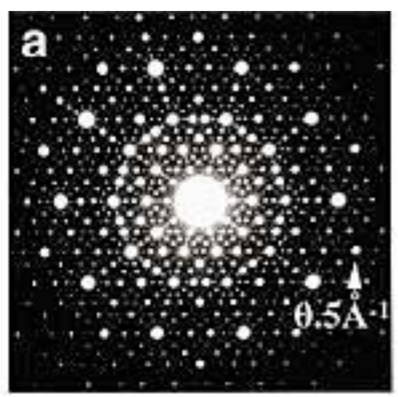
reciprocal-space signal, $S(\mathbf{k})$
real-space spin density, $\rho(\mathbf{r})$
spatial frequency, $\mathbf{k}$
position, $\mathbf{r}$



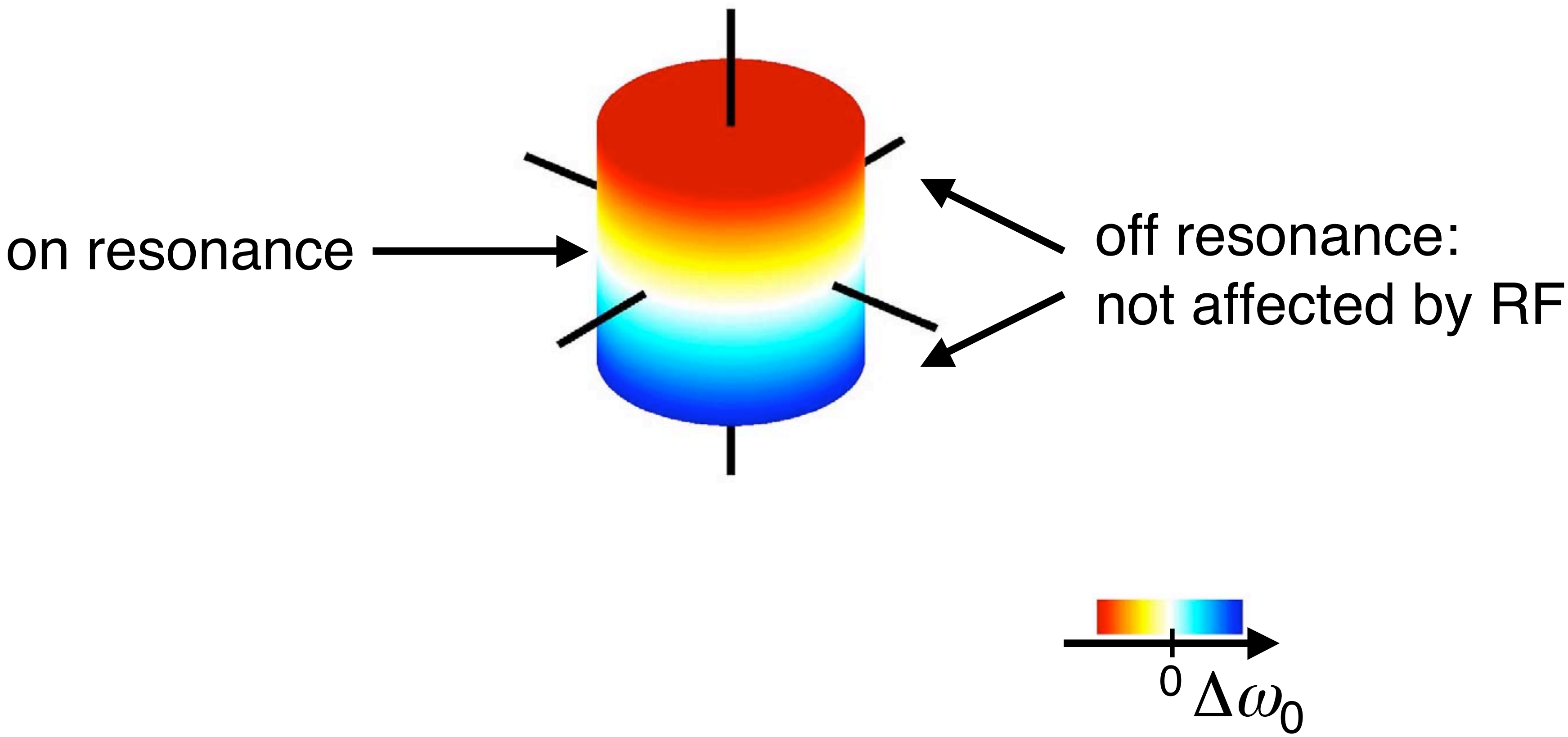


The phase problem

- FT to get an image is not possible if the phase information is missing

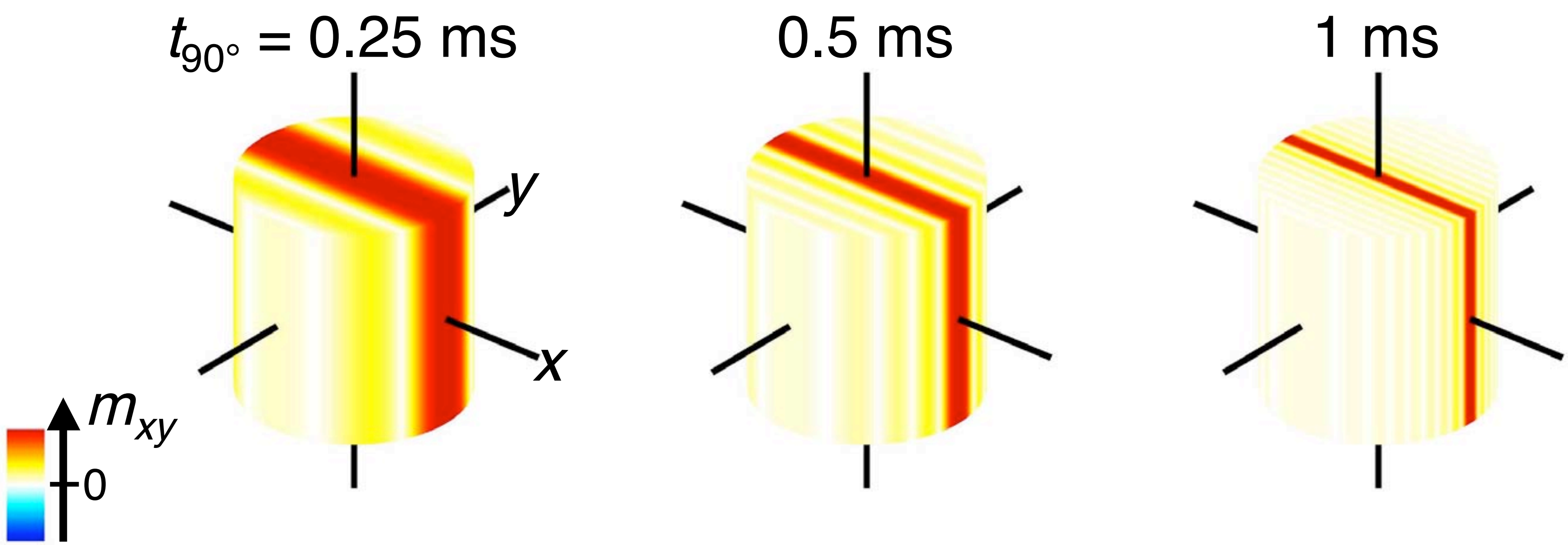


Slice selection



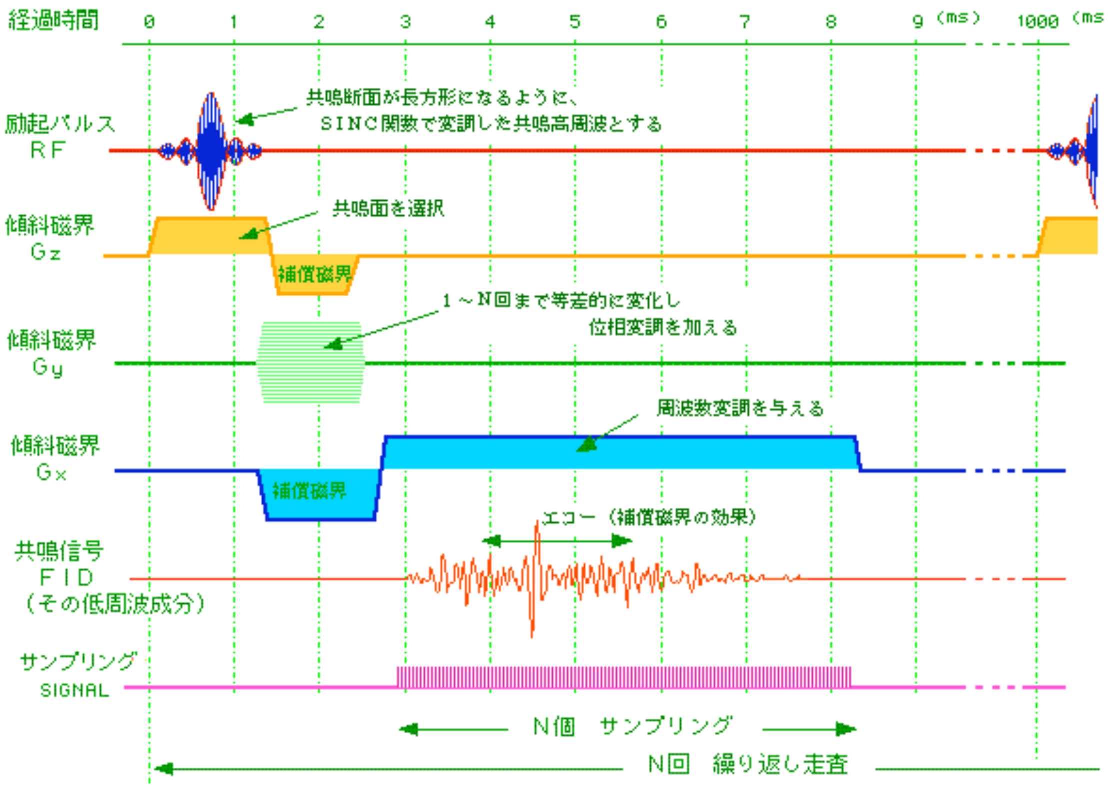
Longer pulse: thinner slice

- Excitation bandwidth ≈ $1/t_{90°}$



G_y = 0.1 T/m
y_{max}-y_{min} = 4 mm

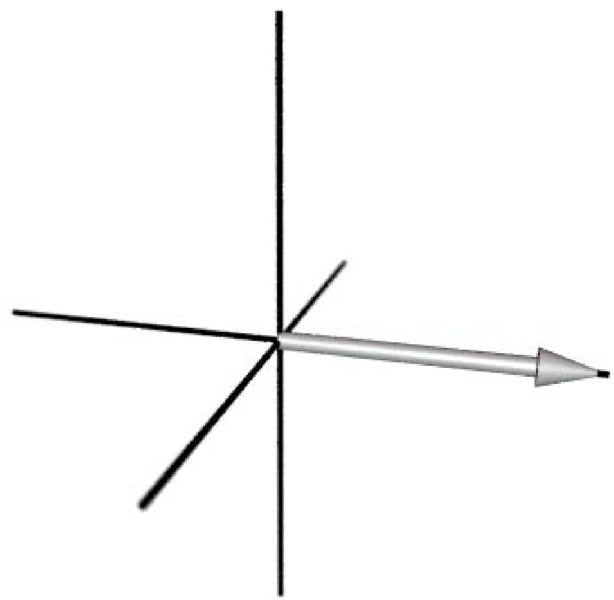
Spin warp



画像測定のための電磁パルス列（フーリエ変換法（スピン・ワープ法））

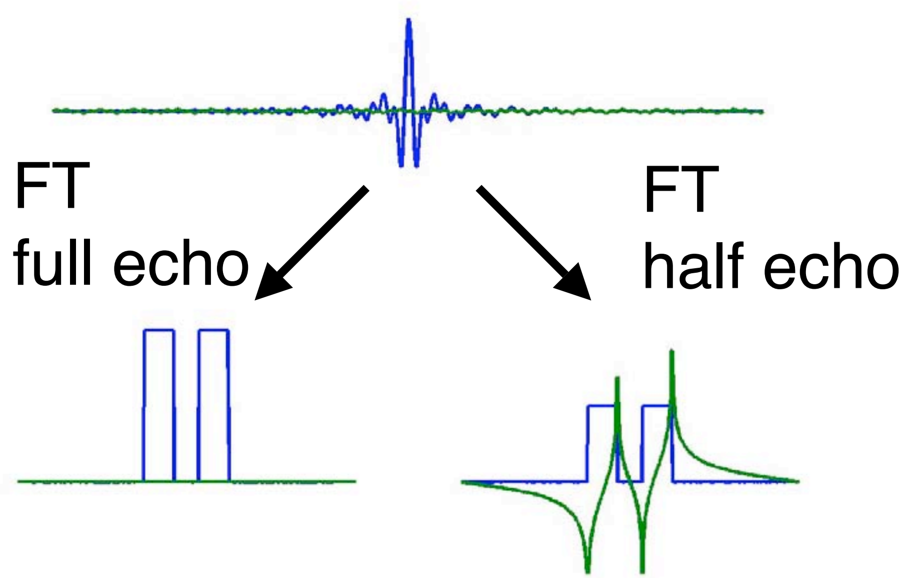
A 0.50 T/m z-gradient is applied to protons in a sample with a height of 20 mm. What is the difference in resonance frequency (in kHz) between the bottom and the top of the sample?

Estimate the slice thickness when a 1.0 ms 90° pulse is applied to protons in a 0.10 T/m gradient. How to modify the parameters to get a slice thickness of 0.10 mm?



Full echo acquisition

- Get rid of imaginary part



Nobel prize in medicine 2003

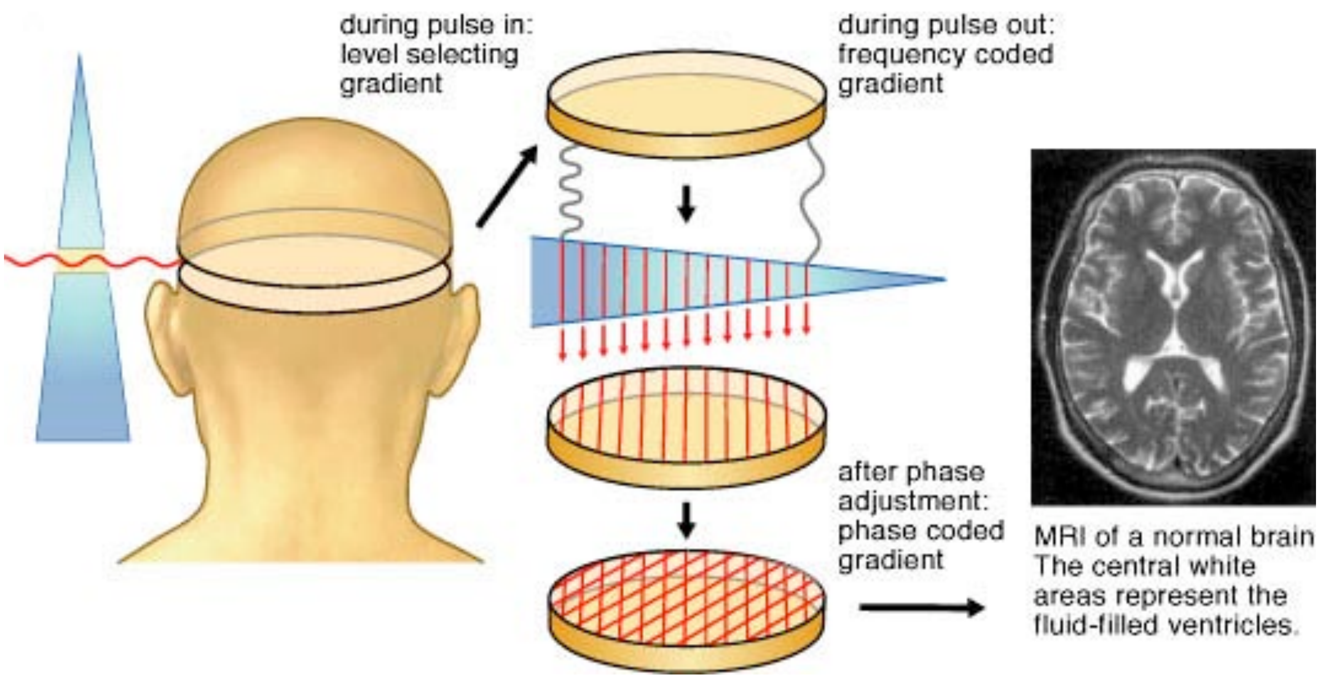
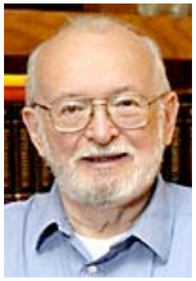


Fig from Nobel website

Mansfield



Lauterbur

T_1 and T_2 in tumors

- 1997: $128,705,766 from General Electric to Damadian

United States Patent [19] [11] **3,789,832**

Damadian [45] **Feb. 5. 1974**

[54] **APPARATUS AND METHOD FOR DETECTING CANCER IN TISSUE**

[76] Inventor: **Raymond V. Damadian,** 64 Short Hill Rd., Forest Hill, N.Y. 11375

1972