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Basics of MRI

Introduction to Magnetic Resonance Imaging

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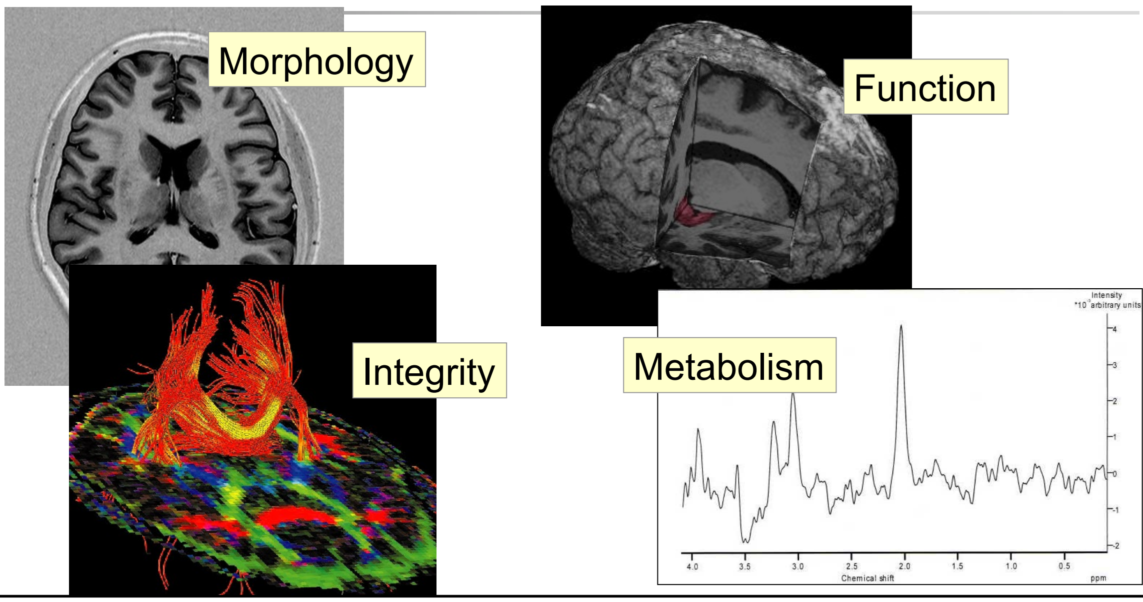
Some Points of MR-views



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MRI System

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Non-ionising radiation

Hugh selection of contrast generation

No permanent effects from interactions of biological systems with magnetic fields

The procedure is considered harmless

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Learning objectives for today

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- What is a MR-Signal and how to create it?
- What do we need to create it?
  - Why three different magntic fields?
  - Some remarks regarding MR-hardware
- What can we do with this signal?
  - Creating images
  - Linking spectral information to Chemistry
- Some basic image weighting
  - T2 weighting
  - T1 weighting
  - Diffusion weigthing
  - …

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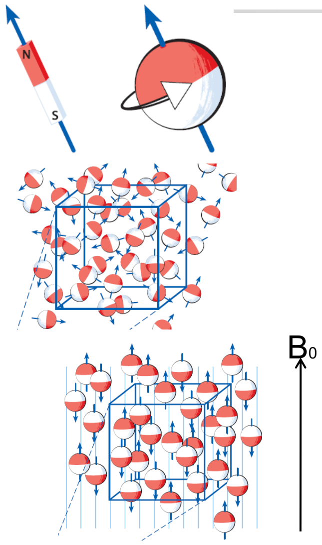
Spin

- Angular momentum in some atoms (^{1}H, ^{13}C, ^{19}F, ^{23}Na, ^{31}P)
- Spin
- Direction of spins is distributed randomly
- Parallel / antiparallel alignment in an external constant magnetic field



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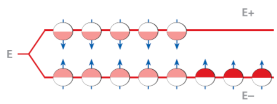
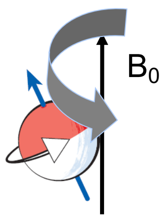
MR-phenomenon

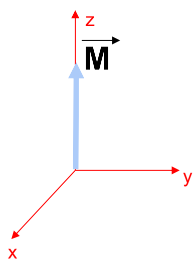
- Boltzmann-statistic for 1.000.000 ^{1}H-nuclei (37°C, B_0 = 3 Tesla):
- N↑ = 500.005
- N↓ = 499.995
- → net magnetization is low (0,001%)



Precession around the B_0 axis



Sum of all spins → net magnetization
rotating coordinate system



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Excitation

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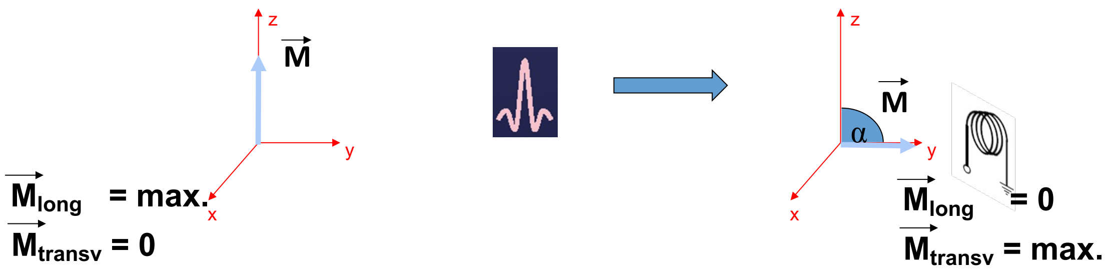
- Resonance frequency ω (3T) = 127,56 MHz → $\omega = \gamma * B_0$

Gyromagnetic ratio γ = 42,52 MHz/T, B_0 static magn. Field [T]

- Excitation (energy absorption) trough electromagnetic wave with resonance frequency, perpendicular to B_0
- Net magnetization flips into the transverse plane (90°-puls)



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What can we measure?

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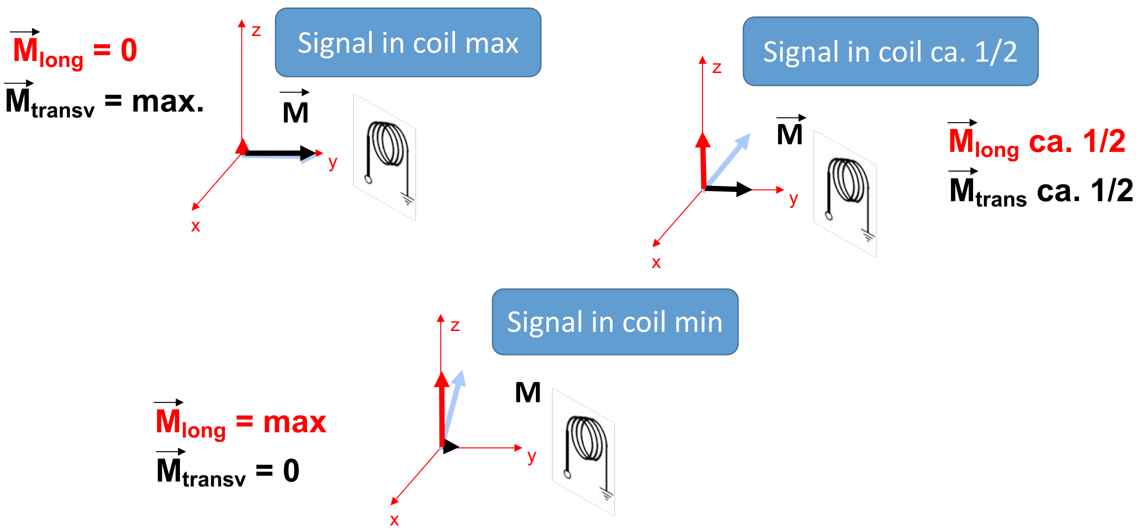

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T1 relaxation

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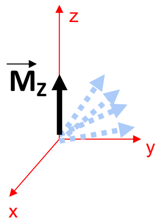
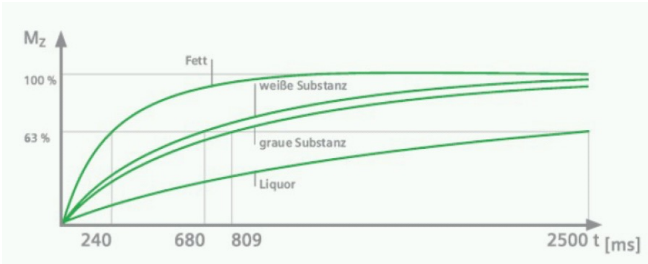
- Increase in longitudinal magnetization (M_Z)





$$M_Z(t) = M_0(1 - e^{-\frac{t}{T_1}})$$

Tissue	T1 (msec)
Water/CSF	4000
Gray matter	900
Muscle	900
Liver	500
Fat	250
Tendon	400
Proteins	250
Ice	5000

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T2 relaxation

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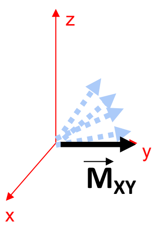
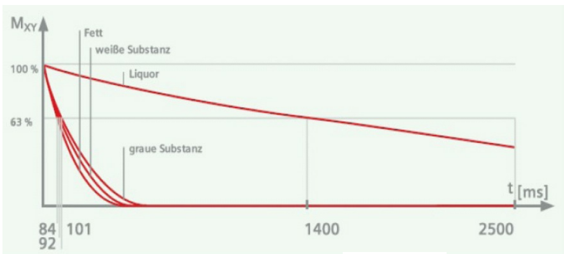
- Decrease in transversal magnetization (M_{XY})
- spin-spin-relaxation





$$M_Z(t) = M_0(e^{-\frac{t}{T_2}})$$

Tissue	T2 (msec)
Water/CSF	2000
Gray matter	90
Muscle	50
Liver	40
Fat	70
Tendon	5
Proteins	0.1- 1.0
Ice	0.001

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T2* relaxation

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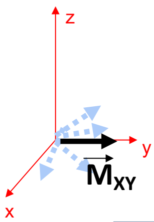
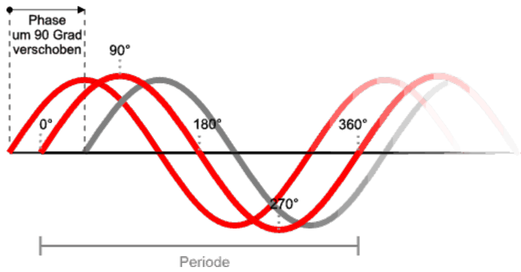
- Decrease in transversal magnetization caused by dephasing





$$\frac{1}{T2^*} = \frac{1}{T2} + \frac{1}{T2_{inh}} = \frac{1}{T2} + \gamma * \Delta B_i$$

ΔB_i : field inhomogeneities
γ: gyromagnetic ratio

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Hardware for B_0

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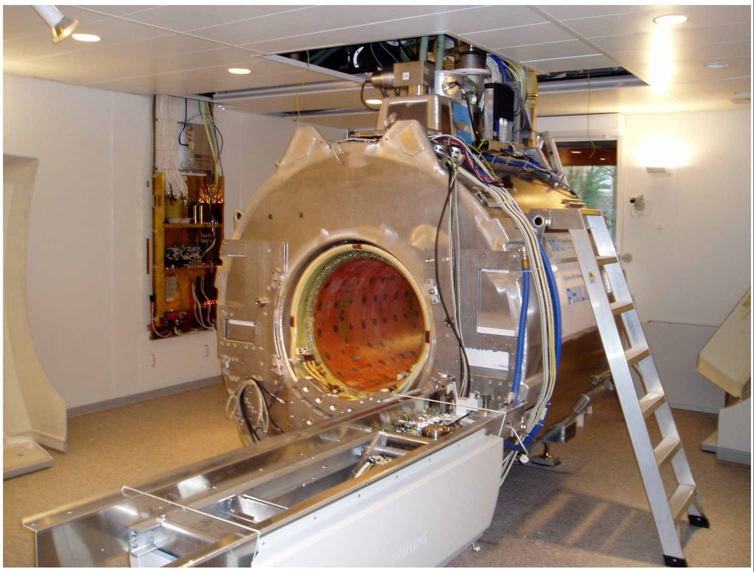
- Static field B_0
- Superconducting coil
- m = 10.000 kg
- Cooling system (cryo system) with liquid He (ca. 1000 l)
- Temp. < 4 K (-269,15° C)
- 3 Tesla



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Hardware for B_1

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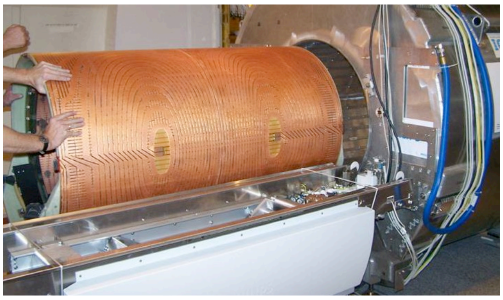
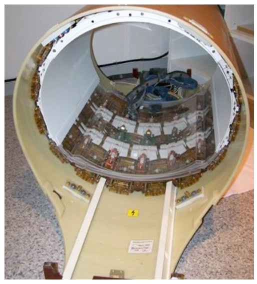
- Excitation coils

Replaceable headcoil

fixed bodycoil





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MR signal –what can we do with it?

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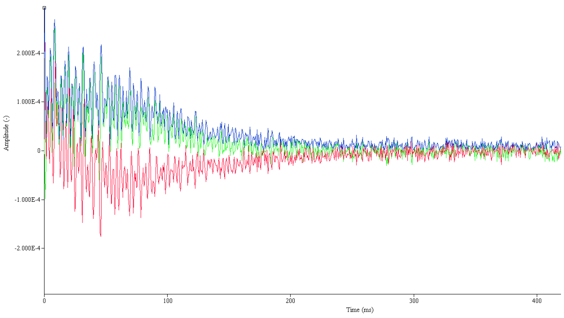
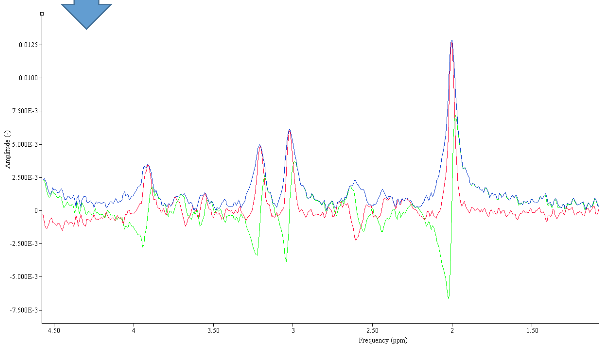


ft



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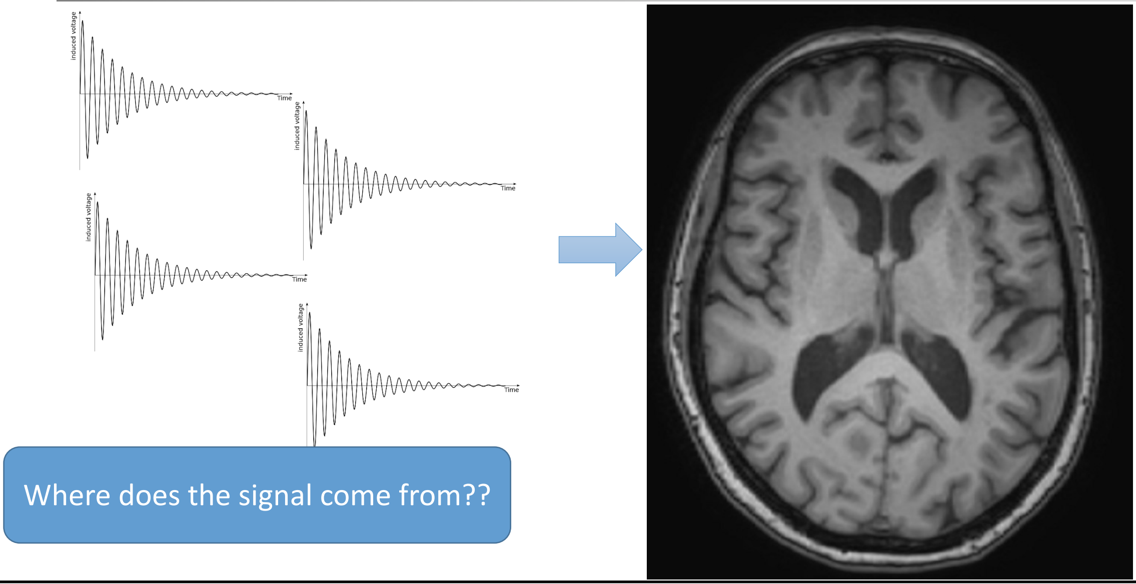
MR signal vs. Image?



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Gradient fields – slice selection

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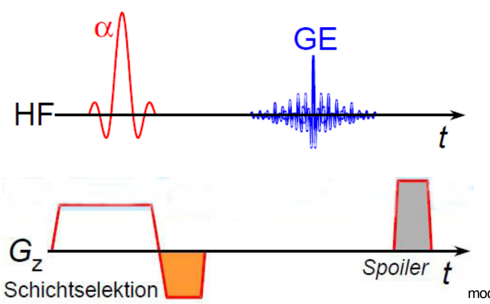
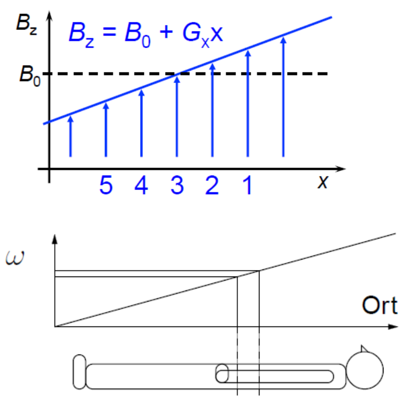
- Superposition of an additional (smaller) location-dependent magnetic field
- Slice selection
- Resonance condition applies only in one slice





mod. nach H.E.Möller (2002)

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Gradient fields – frequency enconding

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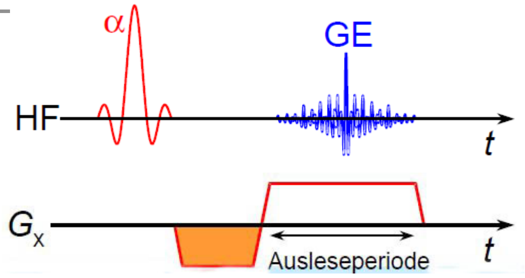
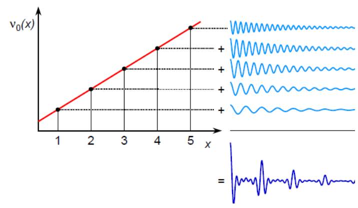
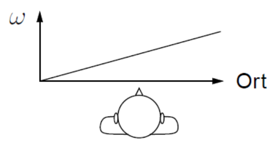


mod. nach H.E.Möller (2002)



The readout gradient / frequency encoding gradient makes the resonance condition dependent from location.



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Gradient fields – phase encoding

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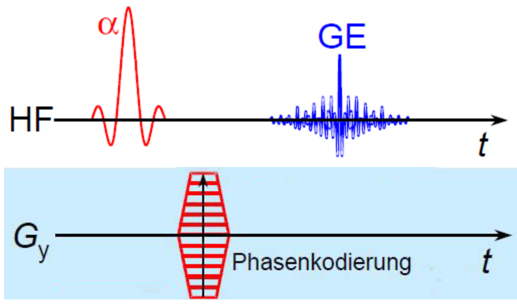
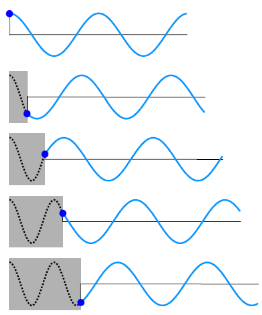
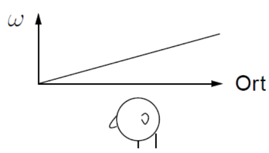


mod. nach H.E.Möller (2002)



The phase encoding gradient makes the phase dependent from location



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Gradient fields

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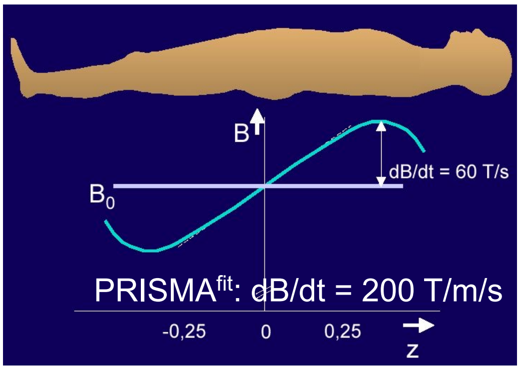

Amplitude:		
1985:	3	mT/m
PRISMA^{fit}:	80	mT/m
Cima.X	200	mT/m
Slew rate:		
1985:	20	T/m/s
PRISMA^{fit} :	200	T/m/s
Cima.X	200	T/m/s

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How does the scanner know the locations of all the MR signals?

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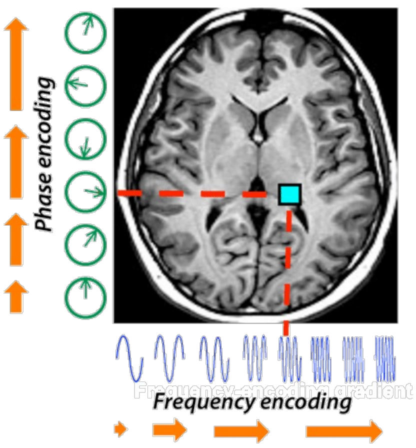
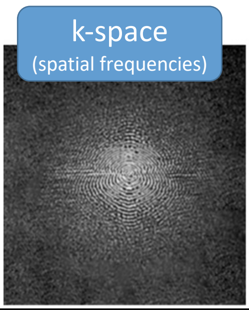
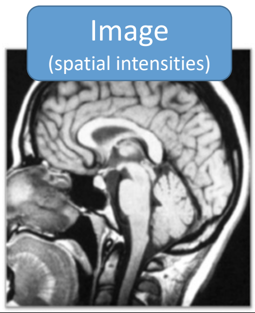


- Slice encoding
- Frequency encoding
- Phase encoding





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Stepwise filling k-space

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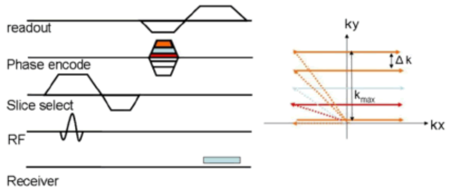
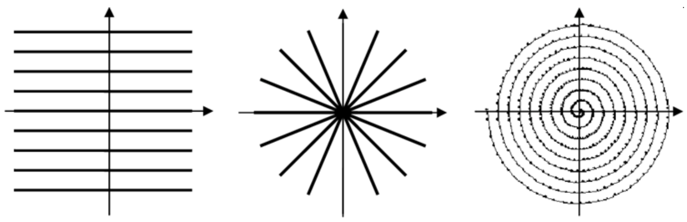


Scan Time=TR*NSA*N_{PE}

N_{PE} : # phase encoding steps
NSA: # signal averages
TR: Repetition time

Other k-space trajectories:



cartesian

radial

spiral

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Repetition time and echo time

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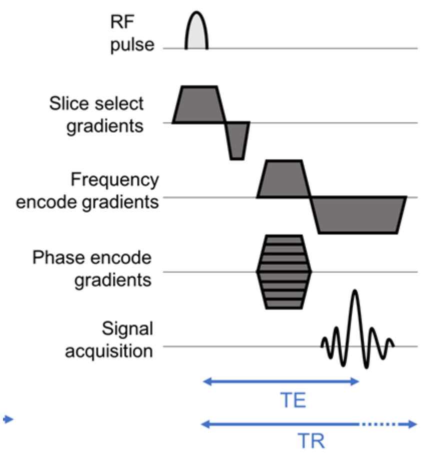
Gradient echo



The echo time (*TE*) represents the time from the center of the RF-pulse to the center of the echo.

The repetition time (*TR*) is the length of time between corresponding consecutive points on a repeating series of pulses and echoes.

TE and TR are the main contrast parameters that determine the image weighting.

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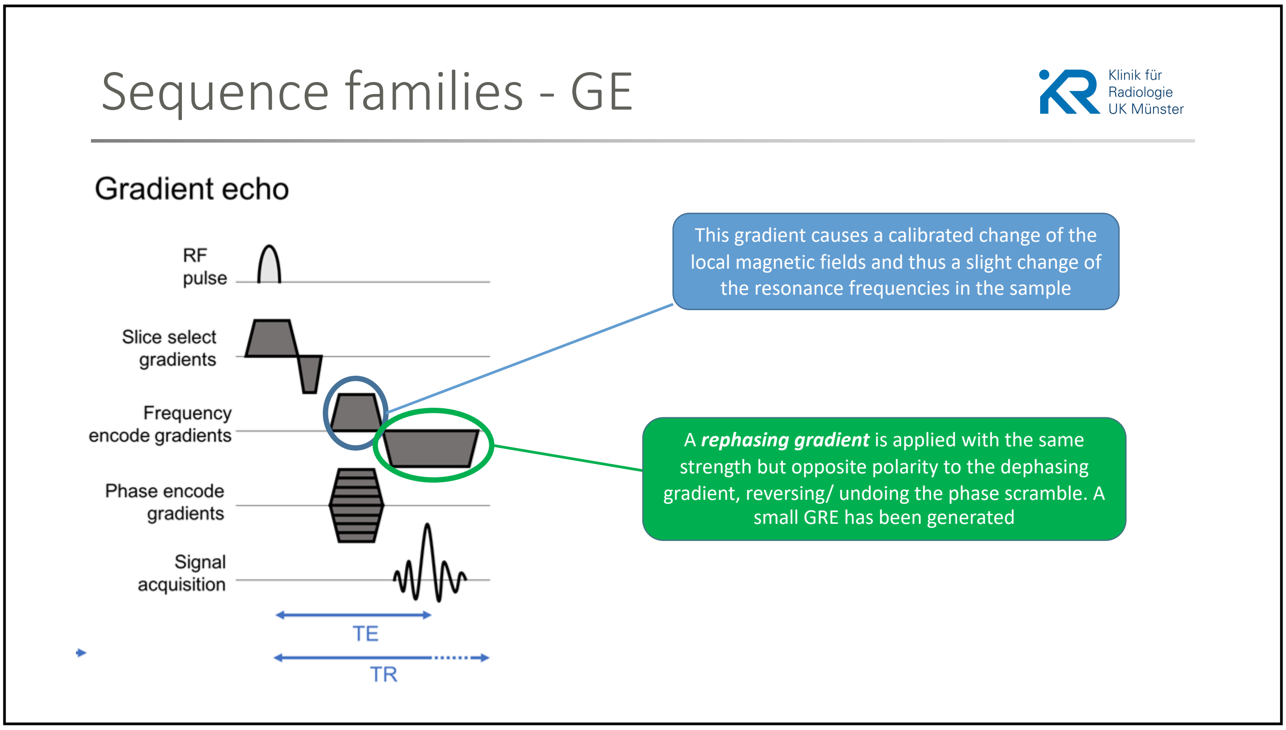
Sequence families - GE
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Gradient echo
RF pulse
Slice select gradients
Frequency encode gradients
Phase encode gradients
Signal acquisition
TE
TR
This gradient causes a calibrated change of the local magnetic fields and thus a slight change of the resonance frequencies in the sample
A ***rephasing gradient*** is applied with the same strength but opposite polarity to the dephasing gradient, reversing/ undoing the phase scramble. A small GRE has been generated

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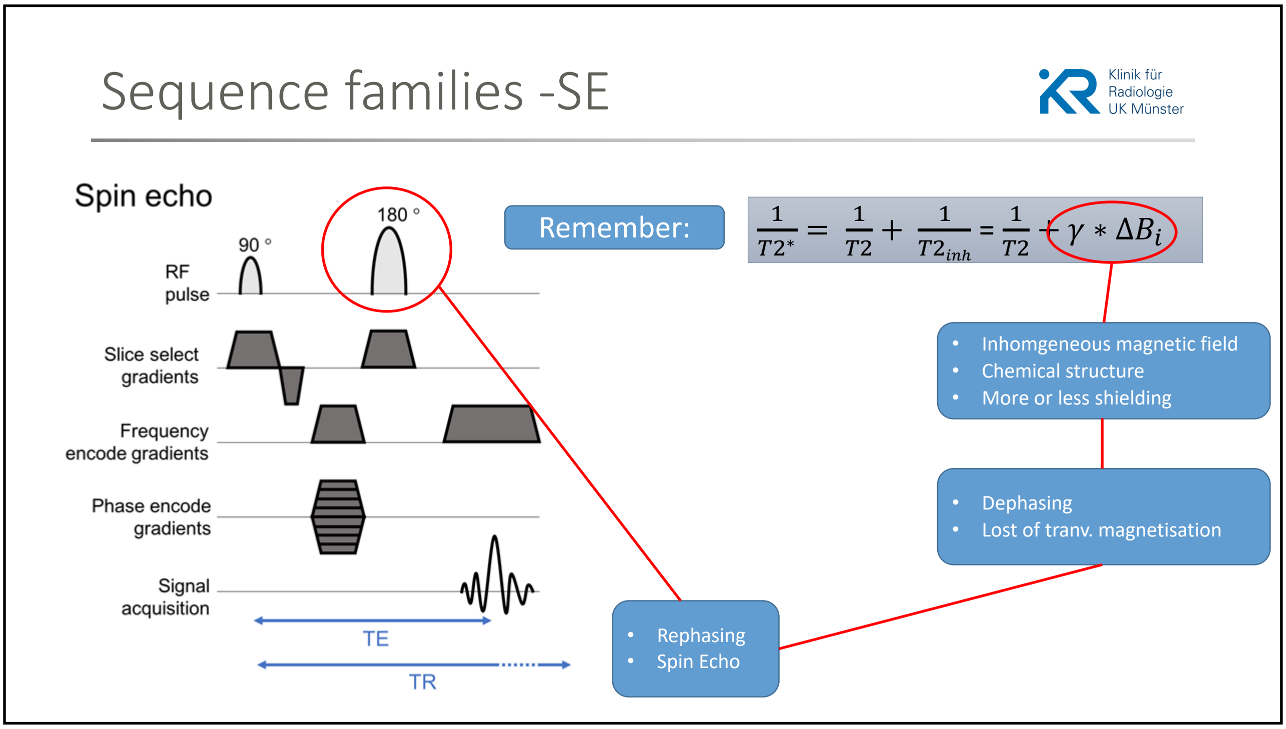
Sequence families -SE
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Spin echo
90 °
180 °
RF pulse
Slice select gradients
Frequency encode gradients
Phase encode gradients
Signal acquisition
TE
TR
Remember:
$\frac{1}{T2^*} = \frac{1}{T2} + \frac{1}{T2_{inh}} = \frac{1}{T2} + \gamma * \Delta B_i$
• Inhomgeneous magnetic field
• Chemical structure
• More or less shielding
• Dephasing
• Lost of tranv. magnetisation
• Rephasing
• Spin Echo

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Contrast generation

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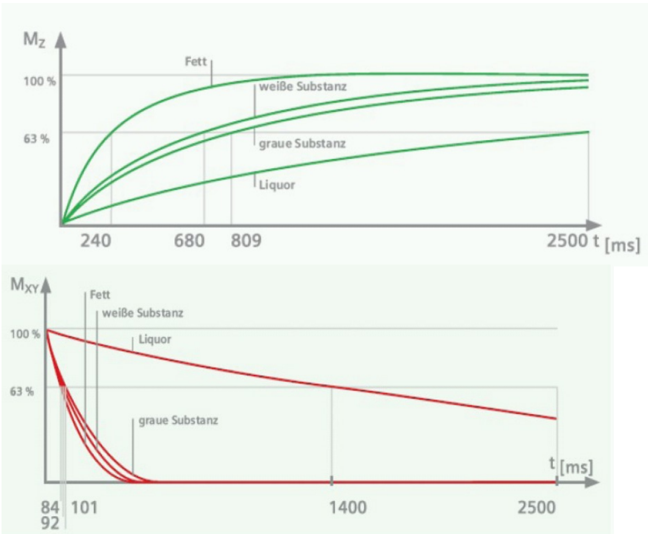
T1 relaxation

T2 relaxation



T2*<T2<T1

Tissue	T1 (msec)	T2 (msec)
Water/CSF	4000	2000
Gray matter	900	90
Muscle	900	50
Liver	500	40
Fat	250	70
Tendon	400	5
Proteins	250	0.1- 1.0
Ice	5000	0.001

Relaxation times depend on velocity of molecular motion

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Weighting

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Signal intensity S

$$S = K \cdot [H] \cdot (1 - e^{-TR/T1}) \cdot e^{-TE/T2}$$

Scaling factor

Proton density

T2 weighting term

T1 weighting term

- TE short (compared to T2)
- TE/T2 ≈ 0
- $e^{-0} = 1$
- T2 effects largely disappear → T1 dominates

- TR short (compared to T1)
- TR/T1 ≈ 0
- $e^{-0} = 1$
- T1 effects largely disappear → T2 dominates

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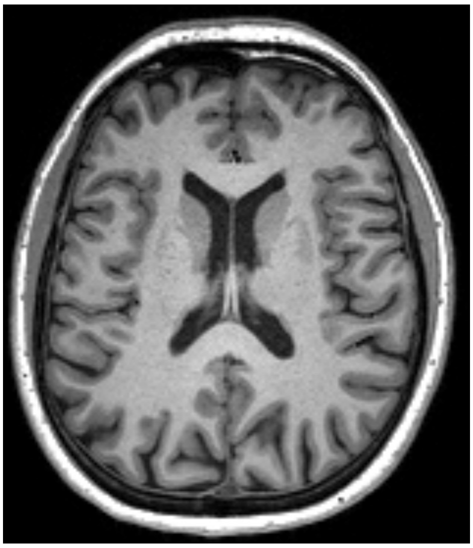
T1 weighting → T1w



Short *TR*	Short *TE*
TR ≤ 500 ms	TE ≤ 20 ms

CSF	very dark
White matter	bright
Gray mater	dark

Let´s have a look on https://virtmri.keks.li/

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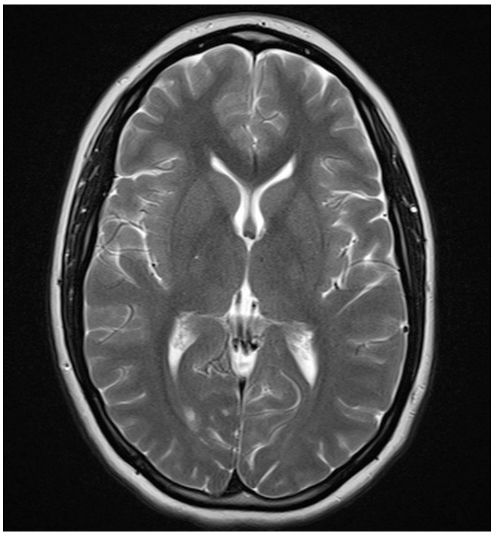
T2 weighting → T2w



Long *TR*	Long *TE*
TR ≥ 1800 ms	TE ≥ 80 ms

CSF	very bright
White matter	dark
Gray mater	bright

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Proton density weighting → PDw

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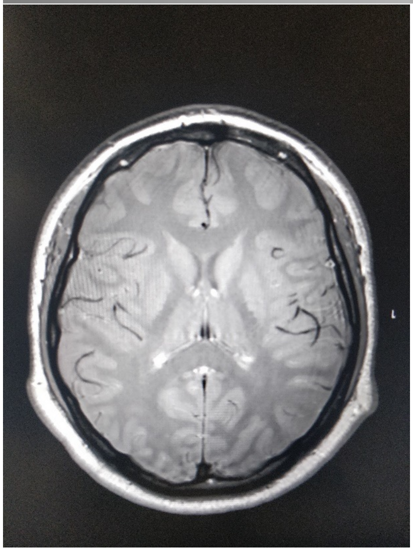

Long *TR*	Short *TE*
TR ≥ 1800 ms	TE ≤ 20 ms

CSF	dark
White matter	dark
Gray mater	bright

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Inversion recovery→ FLAIR

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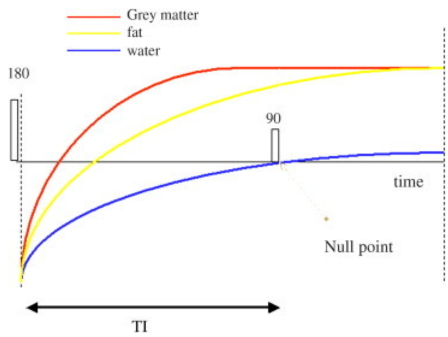

Long *TR*	Short *TE*	*InversionTime TI*
TR ≥ 2500 ms	TE ≥ 100 ms	e.g. TI = 2000 ms

Lesion detection!

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Inversion recovery→ FLAIR

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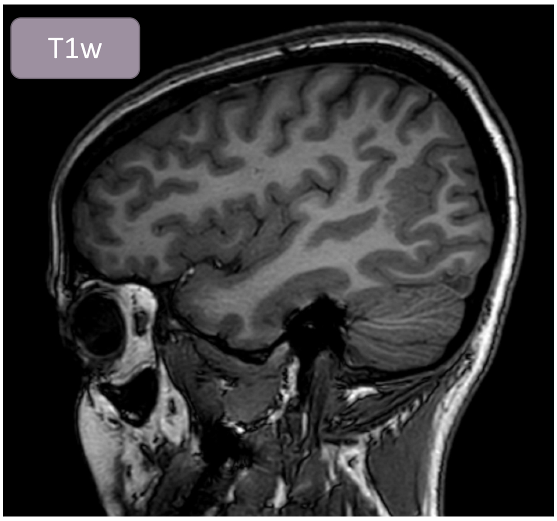

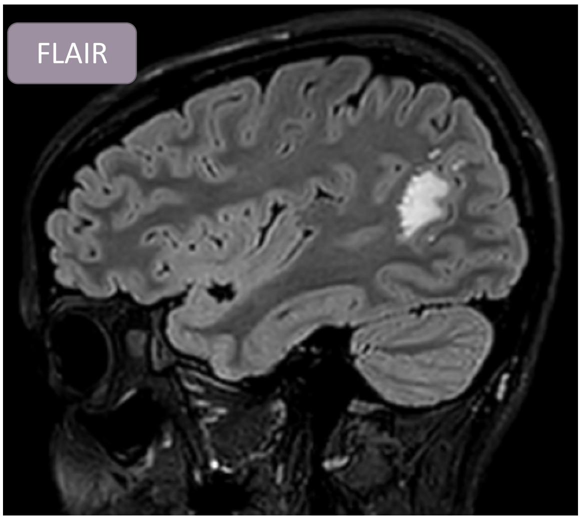

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Suceptibility weighting→ SWI

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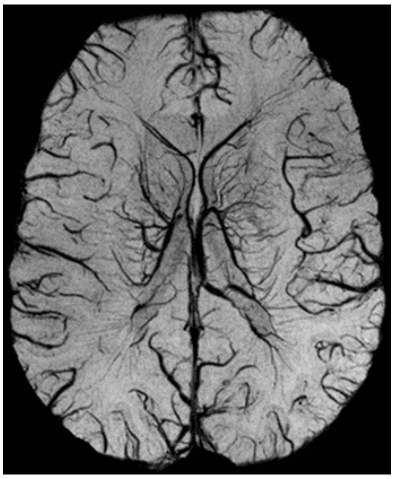

Gradient-Echo-Sequence

T2*-weighting

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SWI + FLAIR = FLAIR*

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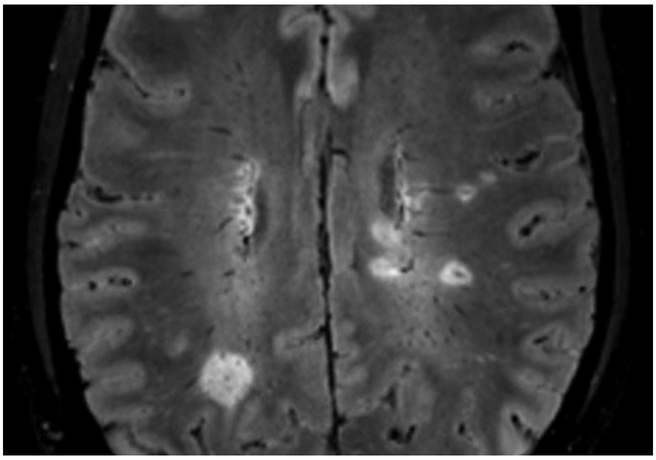
- Central Vein Sign



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Diffusion weighted imaging → DWI

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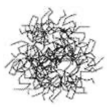
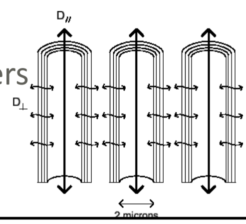
- Brownian motion, or pedesis, is the random motion of particles suspended in a medium



- In fluids isotrop
- In biological tissue it depends on cell size, cell form, cell density …..
  → motion is directed → anisotropic
- In white matter: Diffusion direction is oriented to the nerve fibers



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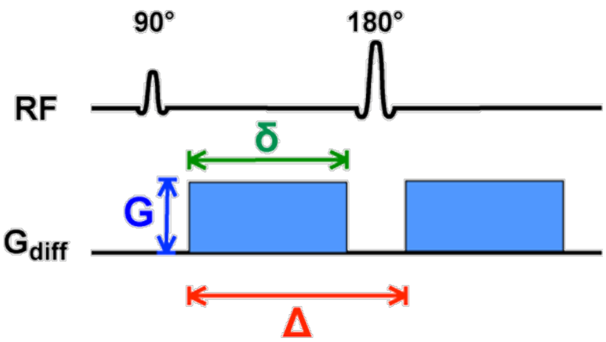
Diffusion weighted imaging → DWI

- Principle: creating a signal decrease in tissues with high directed diffusion using additional diffusion gradients



$b = \gamma^2 G^2 \delta^2 (\Delta - \delta/3)$

magnitude (G), duration (δ) separated by ***time interval (Δ)***.

Stejskal-Tanner 1965

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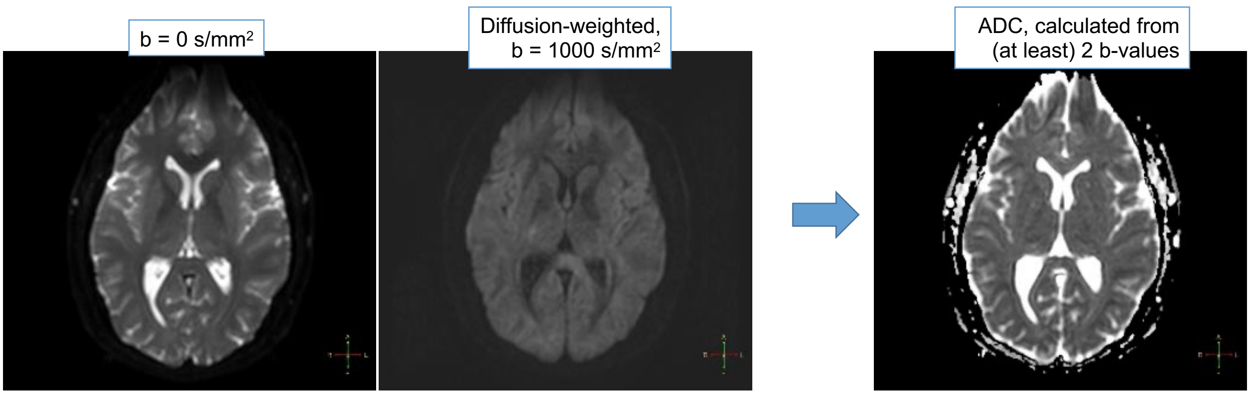
Diffusion weighted imaging → DWI



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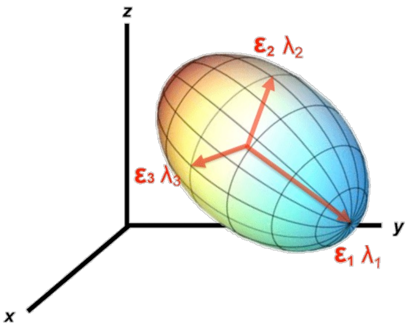
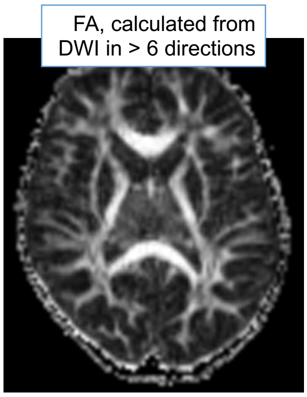
Advanced DWI → DTI

- Giving the diffusiongradients (some or more) directions
- Calculating eigenvectors ε with corresponding lenght λ → Tensors





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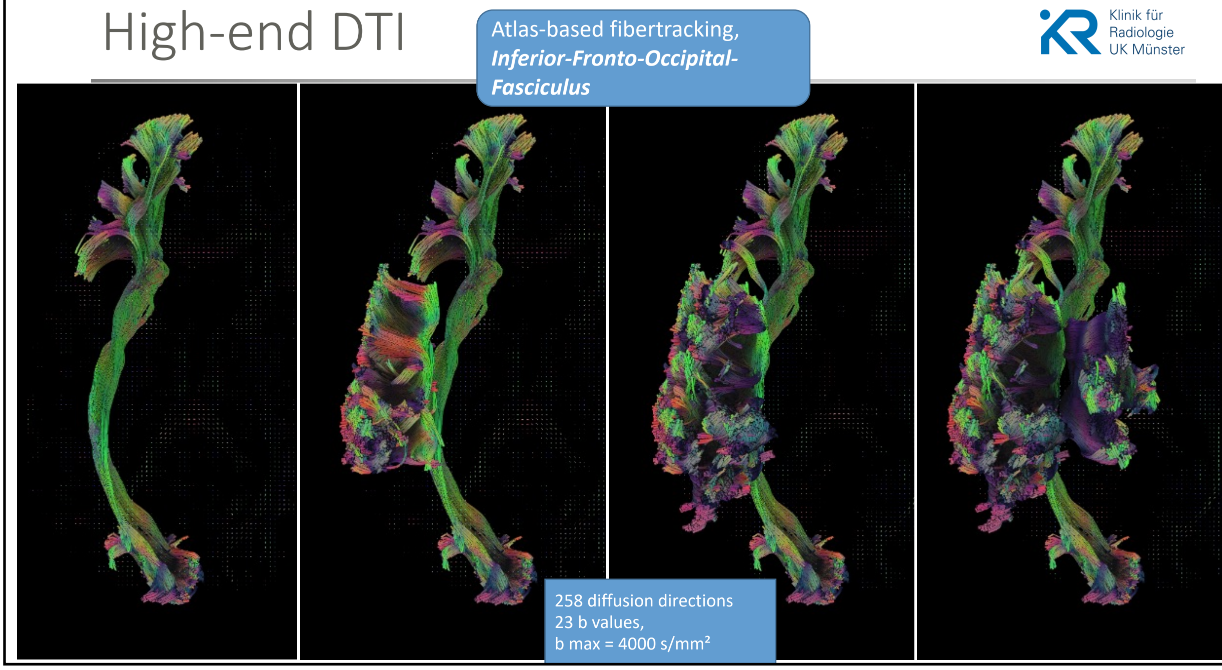
High-end DTI



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Thank you for your attention!

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