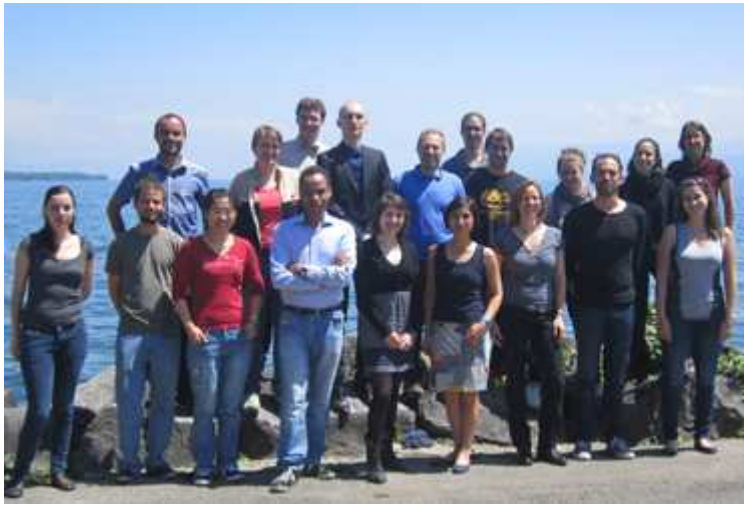

Structural MRI

SPM course - 04/2014

Laboratoire de Recherche En Neuroimagerie (LREN)

Antoine Lutti - antoine.lutti@chuv.ch

Outline

- Principals of image encoding
  - Origin of the signal
  - Image encoding
- Anatomical imaging
  - Image contrast
  - Anatomical imaging - requirements
- Advanced anatomical acquisitions

Outline

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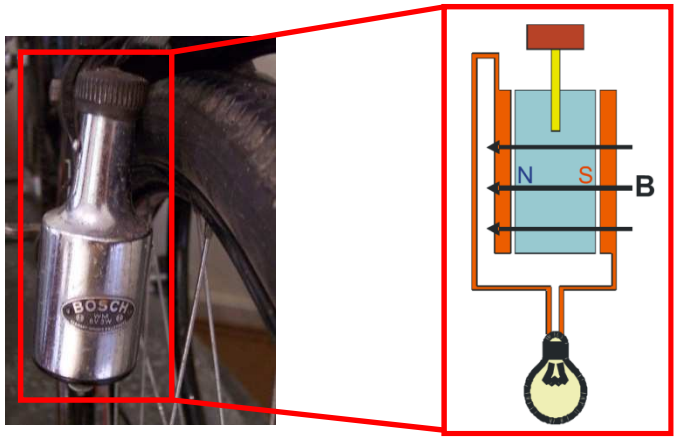
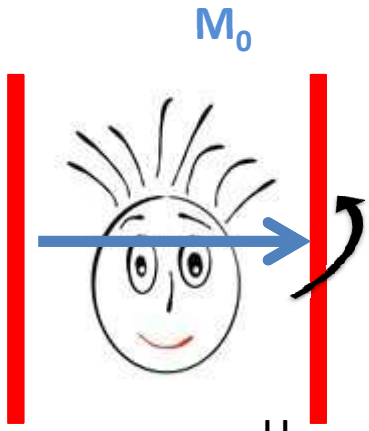
Origin of the signal

Bicycle dynamo

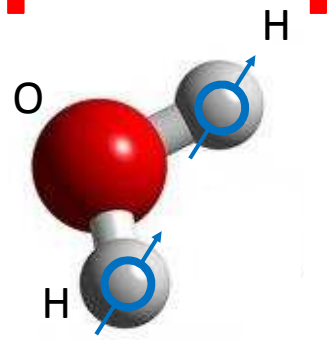


Rotating magnet induces an electric current in the coil.



In MRI: - precessing magnetization $\boldsymbol{M_0}$

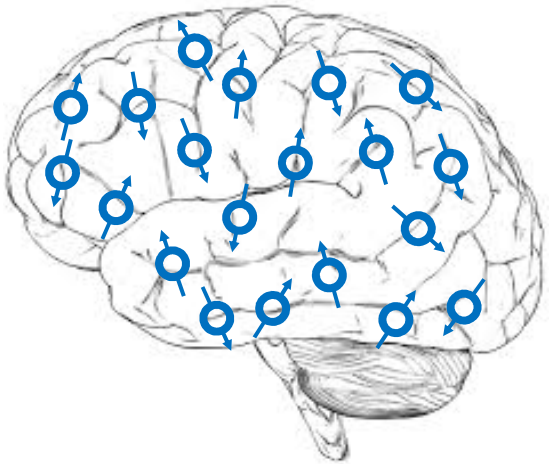
- $\boldsymbol{M_0}$ arises from the spins (↿) of hydrogen nuclei in water molecules



Macroscopic magnetization

: spin of hydrogen nucleus in water molecules

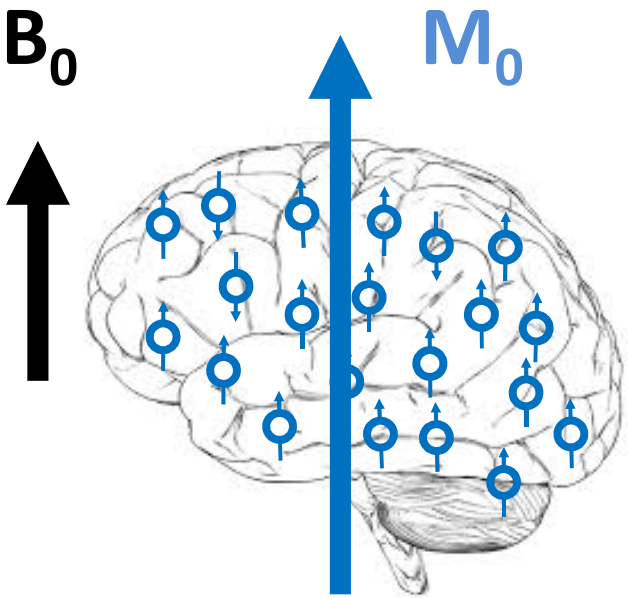
$B_0=0$ $M_0 = 0$



No net magnetization

⇒ **no signal detection**

B_0 M_0

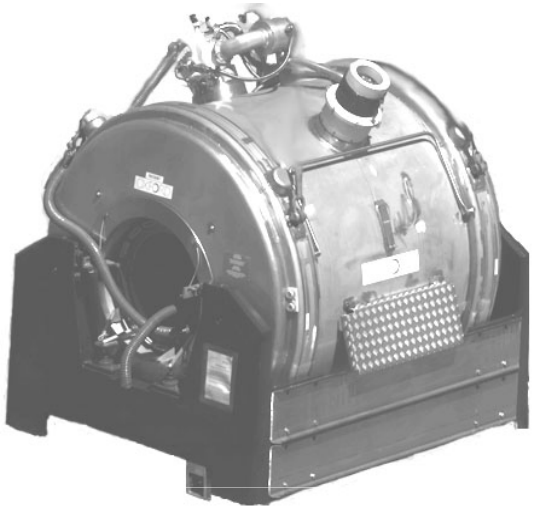


Net magnetization parallel to B_0

⇒**signal detection possible**

M_0: macroscopic magnetization

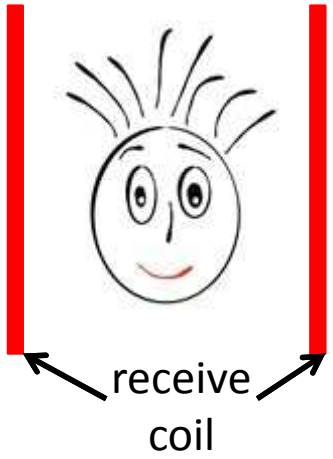
Hardware



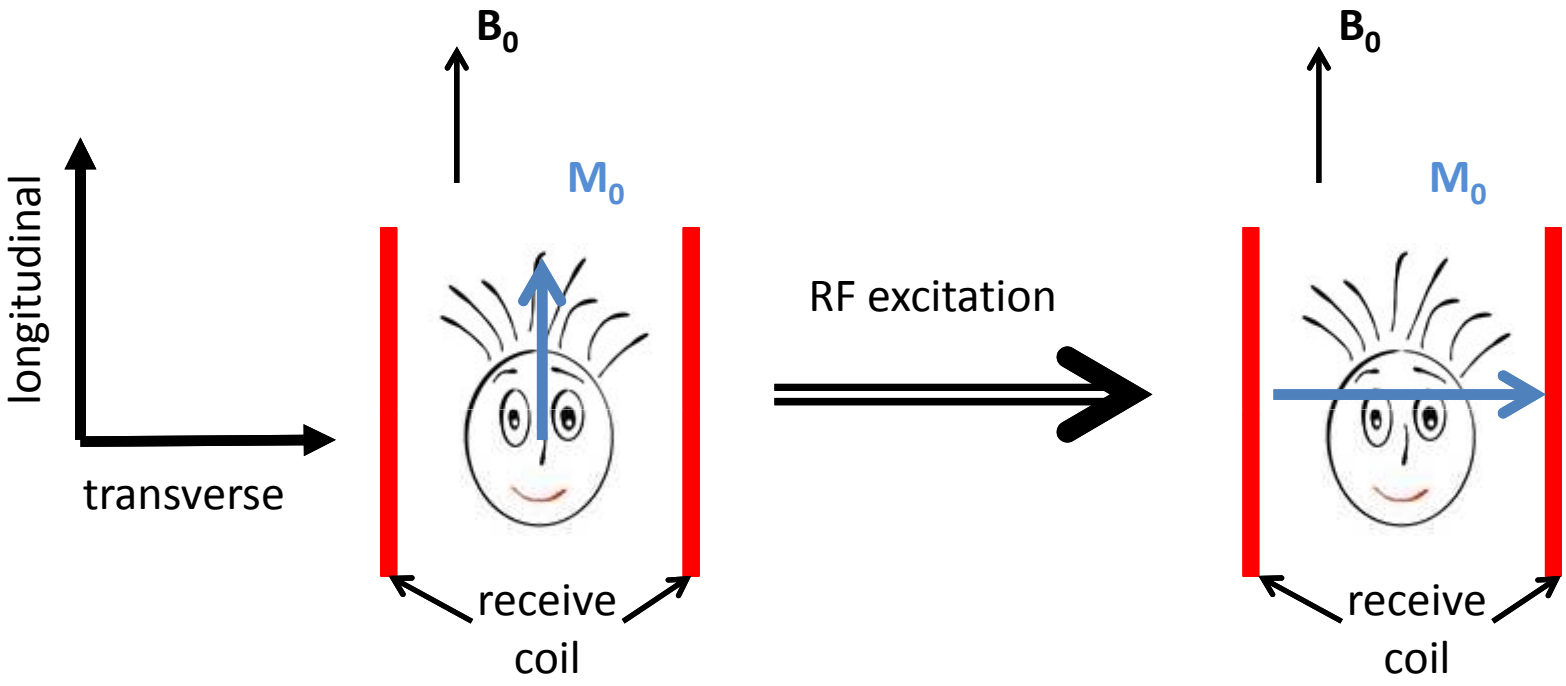
Magnetic field $\mathbf{B_0}$ created by superconducting magnet

$\mathbf{B_0}$ is oriented along the main direction of the bore

The receive coil detects signal arising from the magnetization



RF excitation



At rest:

$\mathbf{M_0}$ is: - along the *longitudinal* direction
- parallel to the receive coil

Signal cannot be detected

After RF excitation:

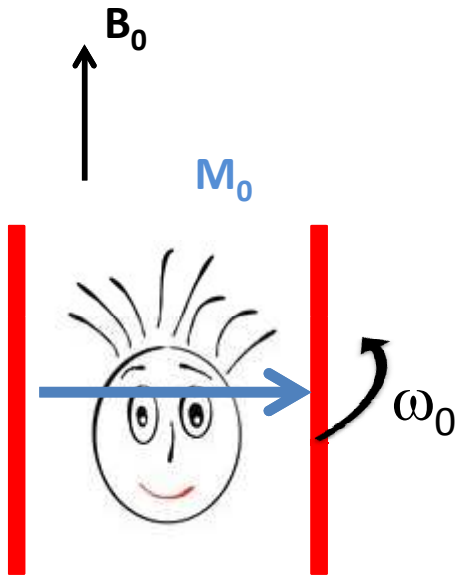
$\mathbf{M_0}$ is: - in the transverse plane
- perpendicular to the receive coil

All MR sequences require RF excitation

Intermediate summary

Following RF excitation **M_0** rotates about **B_0** at :

$$\omega_0 = \gamma B_0$$



In a given B_0:

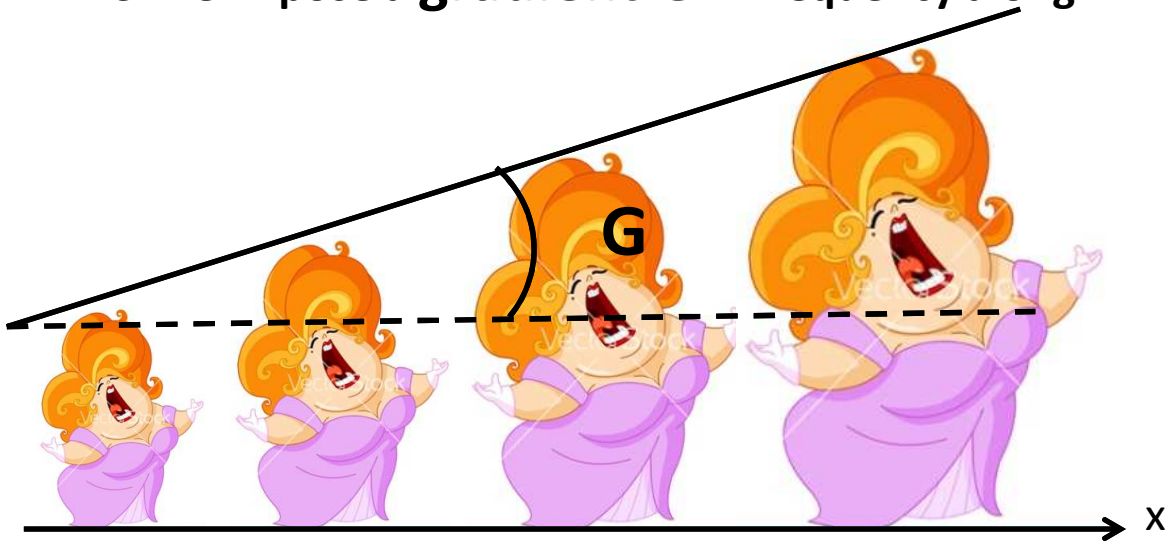
- All hydrogen nuclei (protons) rotate at the **same (*Larmor*) frequency**
- **No spatial information**

How does image encoding work?!

Image encoding – frequency encoding

All singers (*water molecules*) have identical voices (*rotate at the same frequency*)

To obtain an image of the singers, we tune their voices according to their position along x i.e. **we impose a gradient G in frequency along x**:



Relates position and frequency

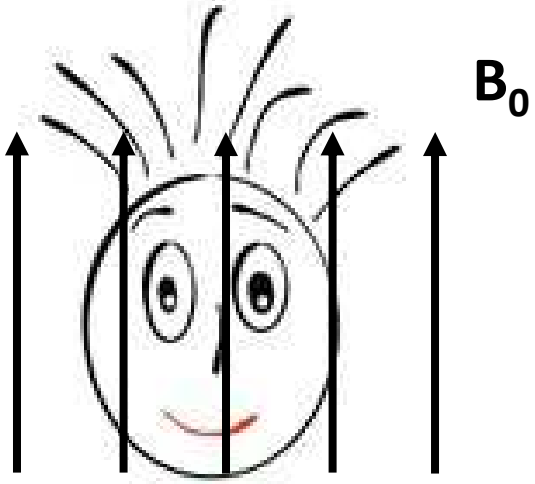
$$\omega(x)=\gamma*(B_0+B(x))$$
$$=\omega_0+\gamma*G*x$$

http://fr.depositphotos.com/4901723/stock-illustration-Opera-singer.html

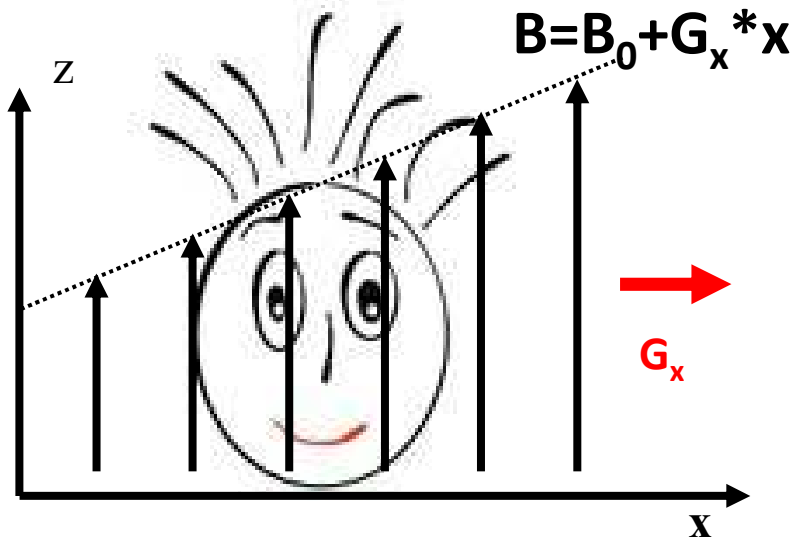
Frequency encoding

Uniform $\mathbf{B_0}$: - precession frequency is uniform

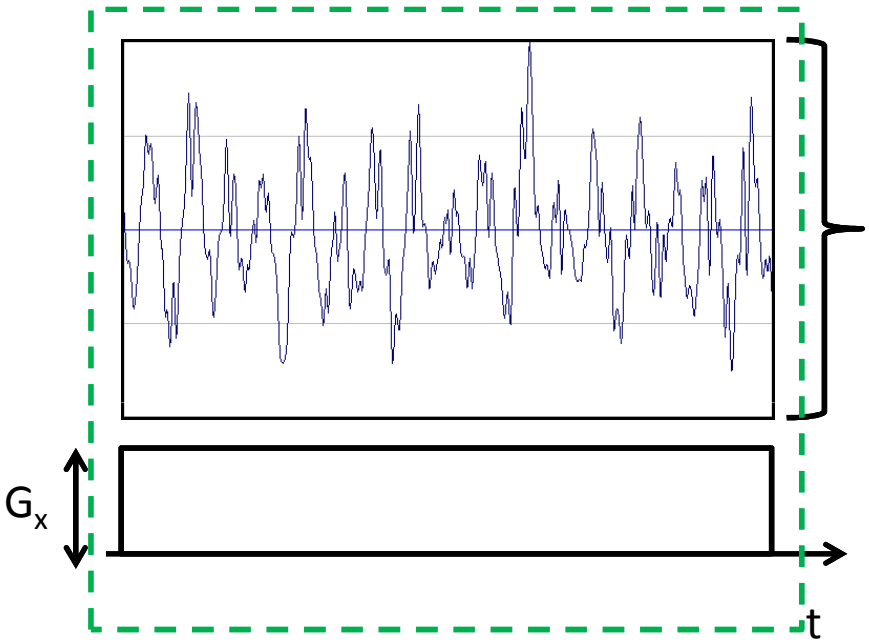
- no information about spatial localization



To spatially encode an image, one uses ***gradients*** of magnetic field

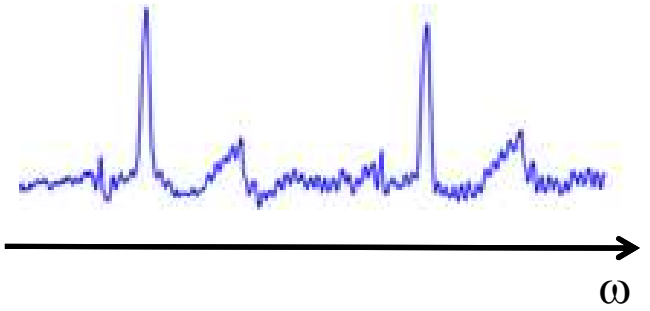


Frequency encoding

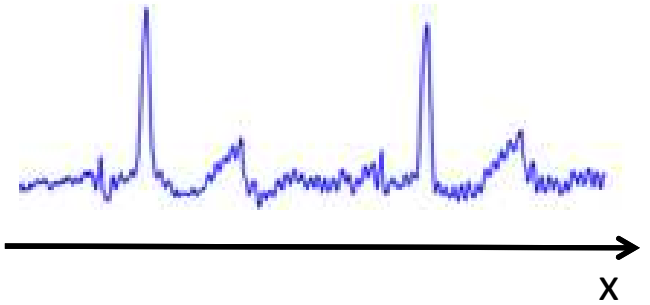


READOUT

FT



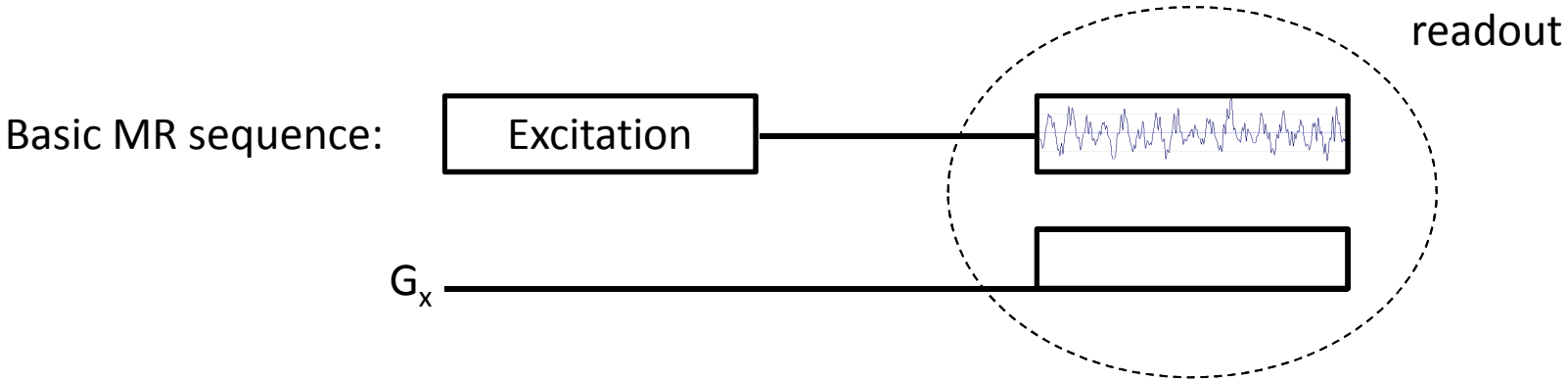
$\omega(x)=\omega_0+\gamma*G*x$



MR IMAGE

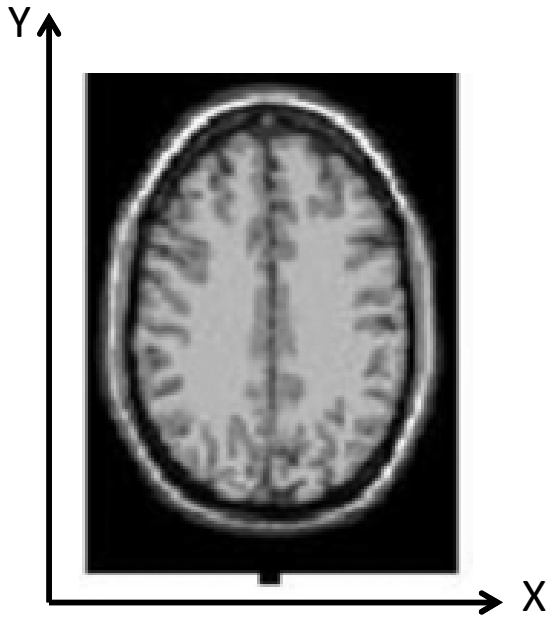
http://dsp.stackexchange.com/questions/4726/what-does-frequency-mean-for-various-kinds-of-signals; http://iopscience.iop.org/0967-3334/33/7/1151/article

Phase encoding

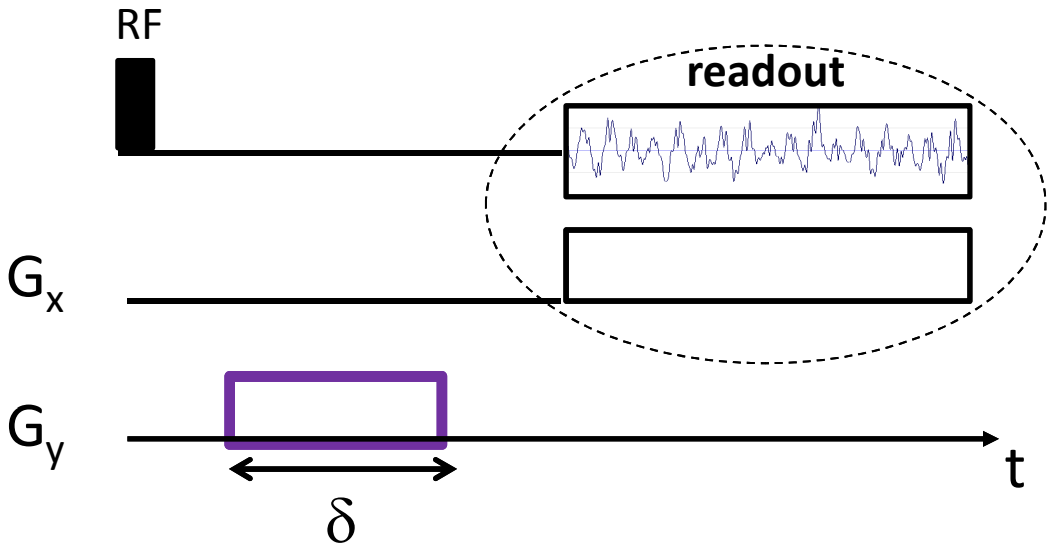


• After one readout, image is encoded along the x-direction only

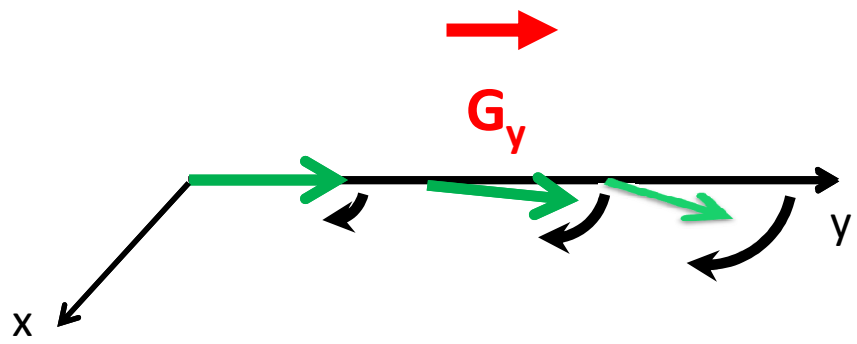
• To get a 2D image, we need to use gradients along the y-direction. This is done by **phase encoding**

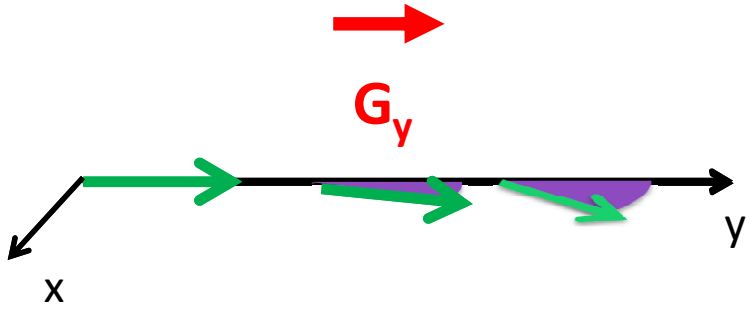


Phase encoding



To spatially encode the image along the y direction, we apply a *gradient of magnetic field* G_y along y prior to readout





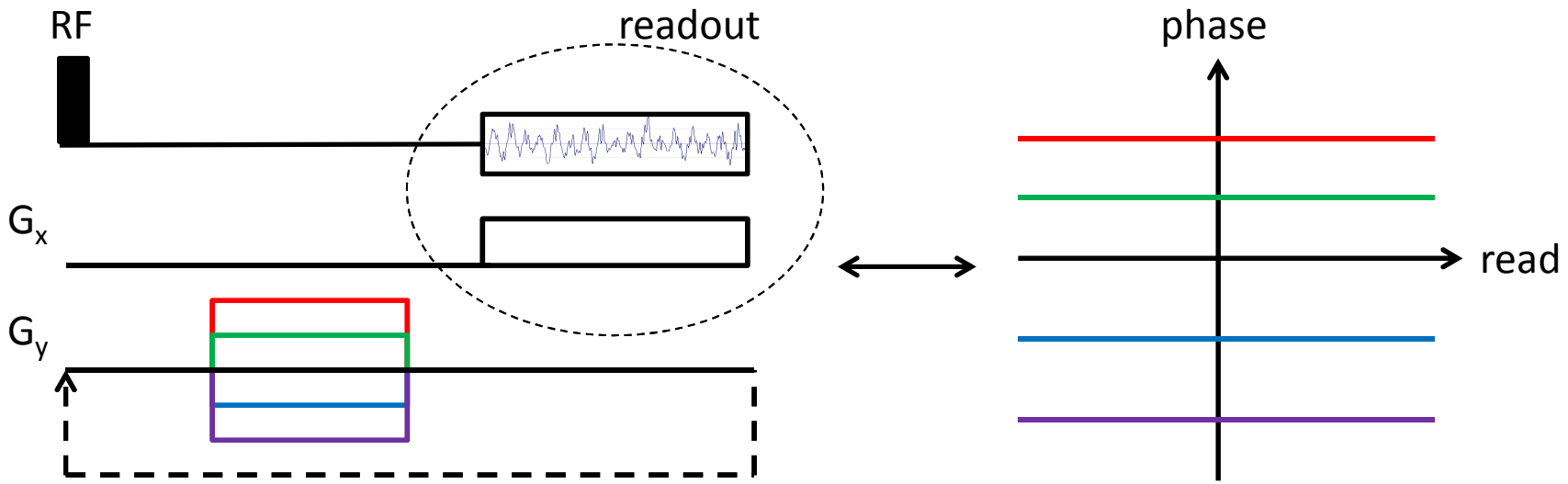
Precession frequency depends on position along y:

$\omega=\omega_0+G_y*y$

After duration δ, y-dependent phase:

$\Phi = \omega*\delta$

2D Image encoding

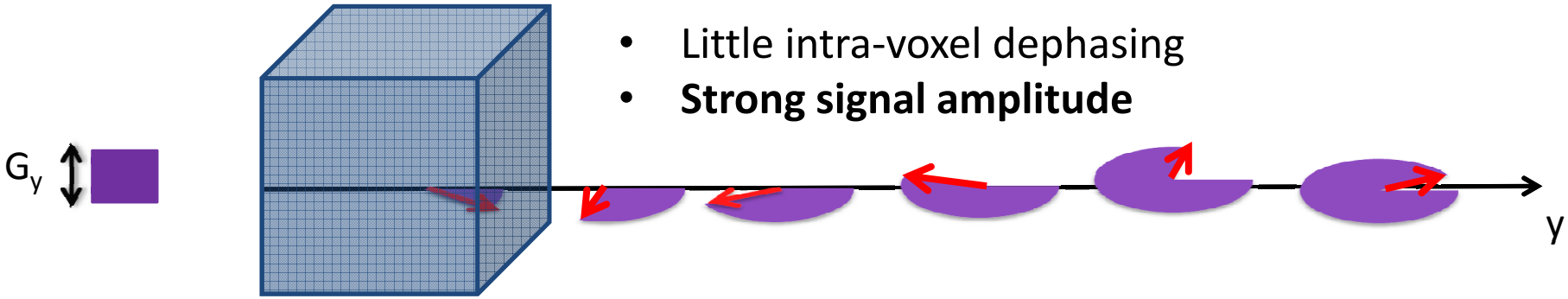


Spatial encoding along y direction:

- Image acquisition repeated with multiple values of the phase-encode gradient
- # of phase-encode steps equals # of voxels along phase direction (e.g. y)

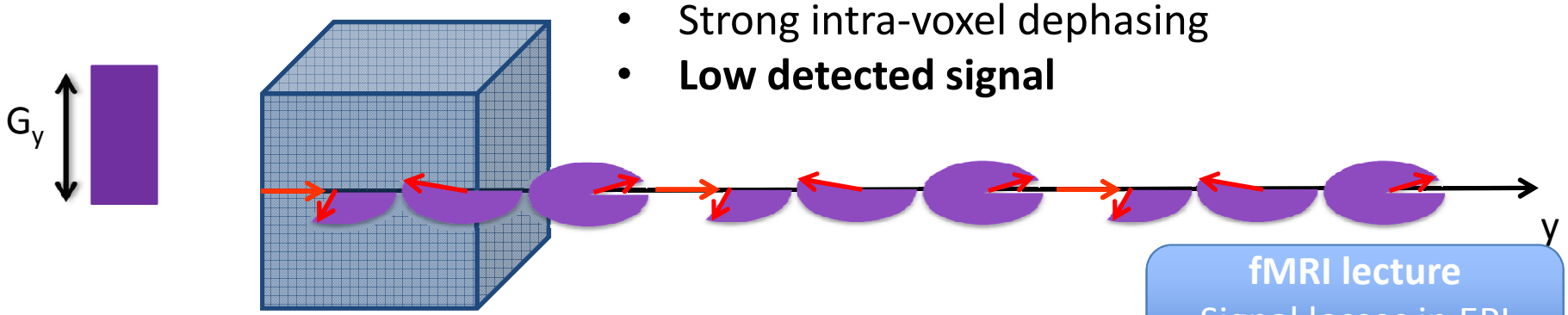
Dephasing and signal amplitude

Weak gradient



- Little intra-voxel dephasing
- **Strong signal amplitude**

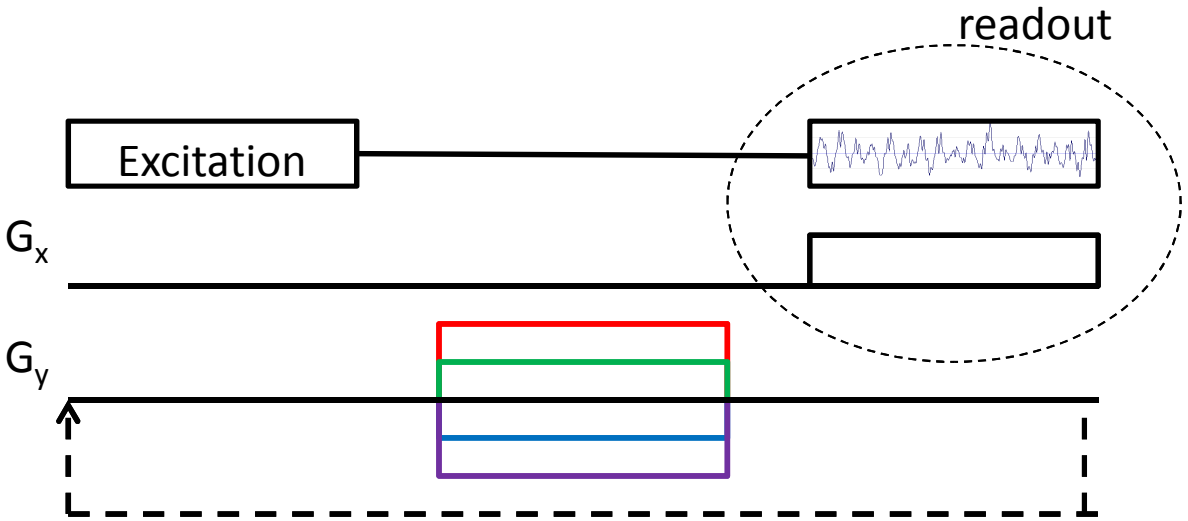
Strong gradient



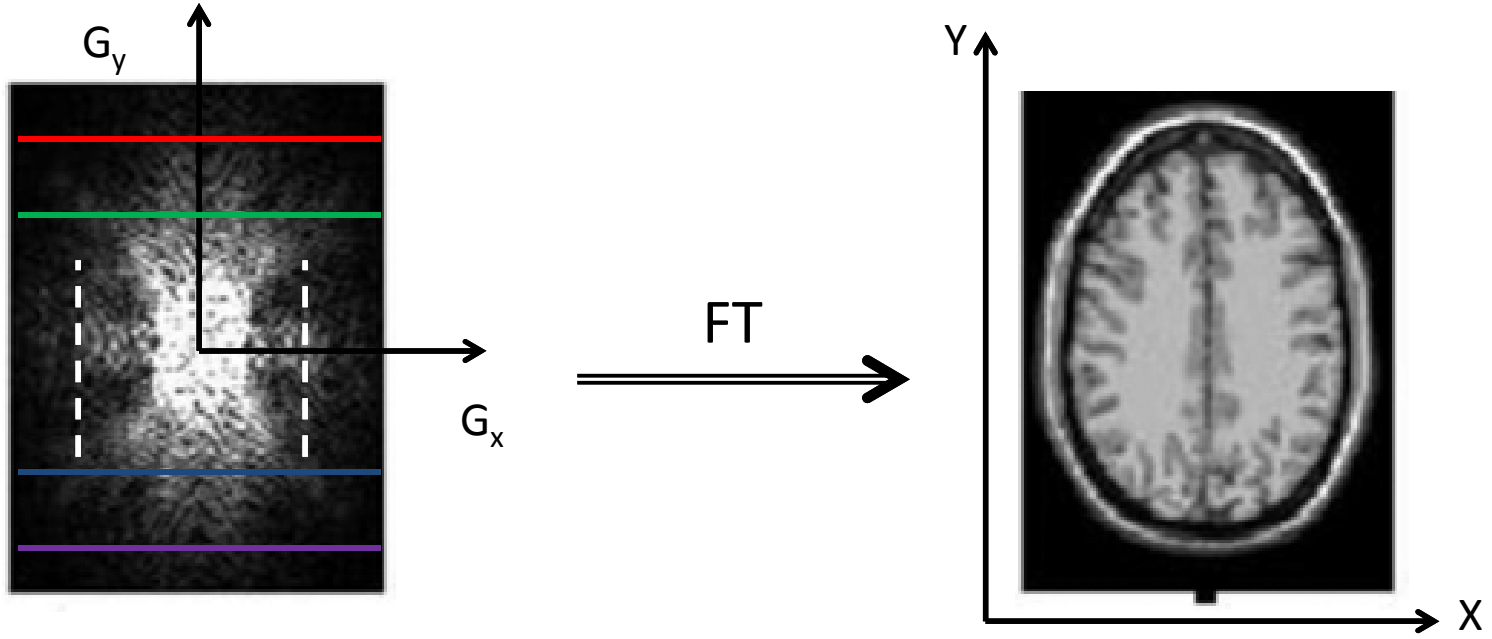
- Strong intra-voxel dephasing
- **Low detected signal**

fMRI lecture
Signal losses in EPI datasets

2D Image encoding



# of phase-encode steps equals # of voxels along phase direction (e.g. y)



Outline

- Principals of image encoding
  - Origin of the signal
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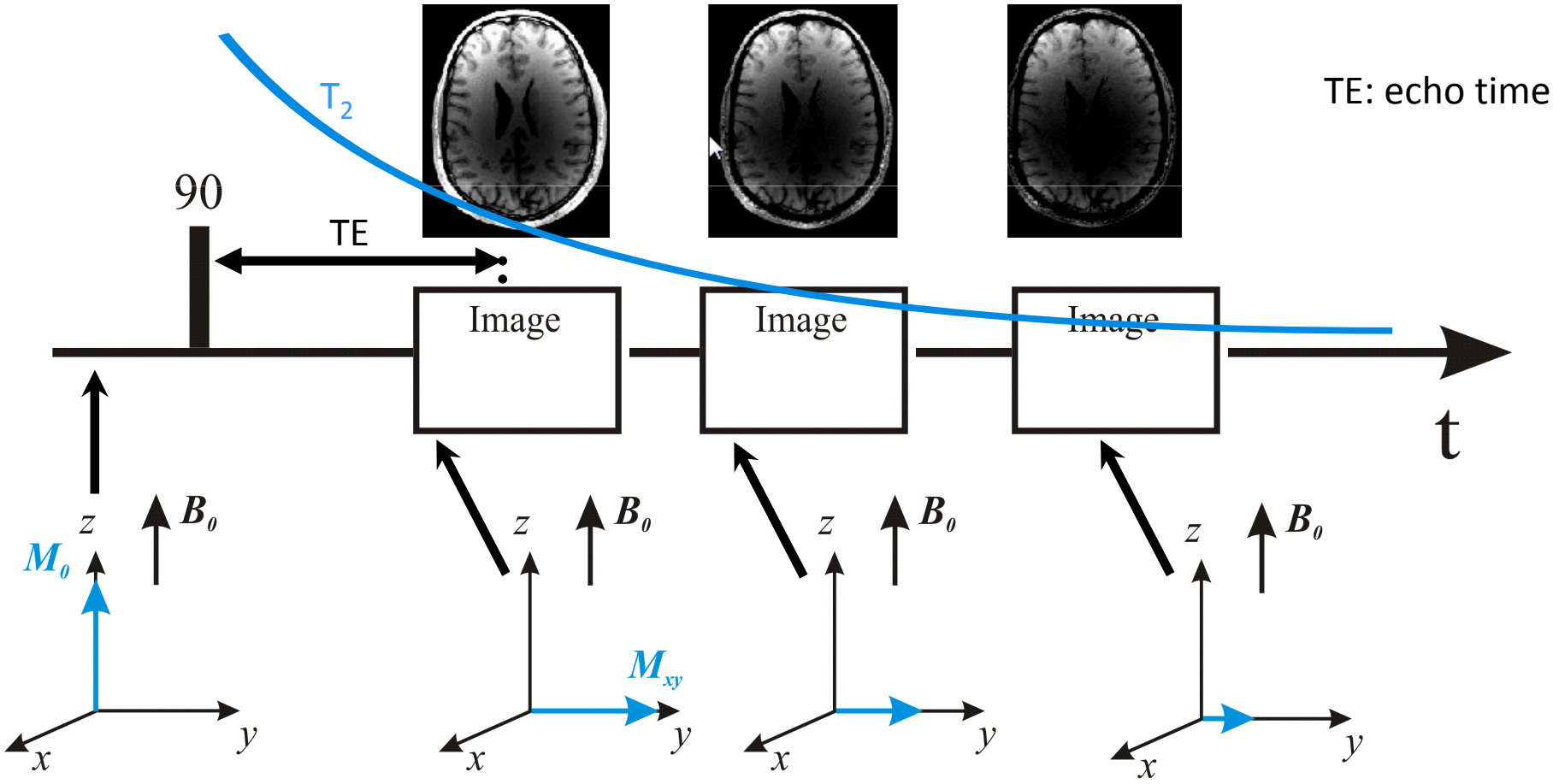
- Anatomical imaging
  - Image contrast
  - Anatomical imaging - requirements
- Advanced anatomical acquisitions

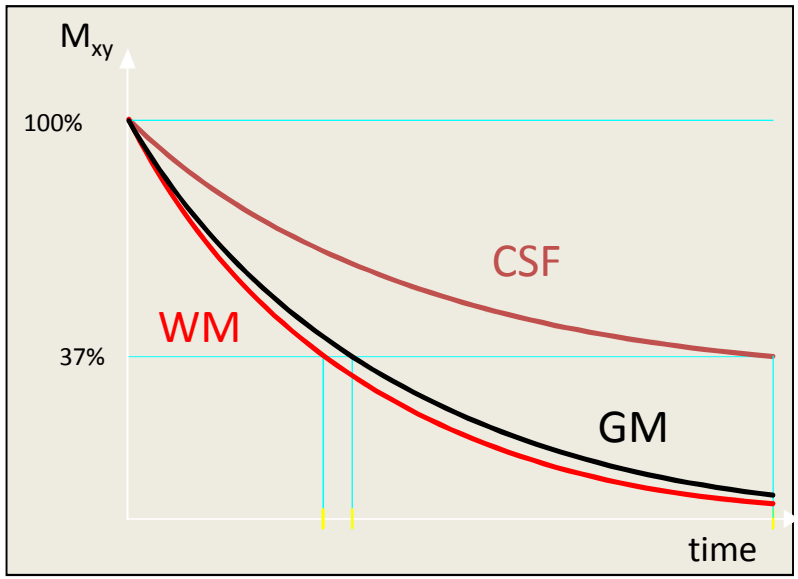
Transverse relaxation

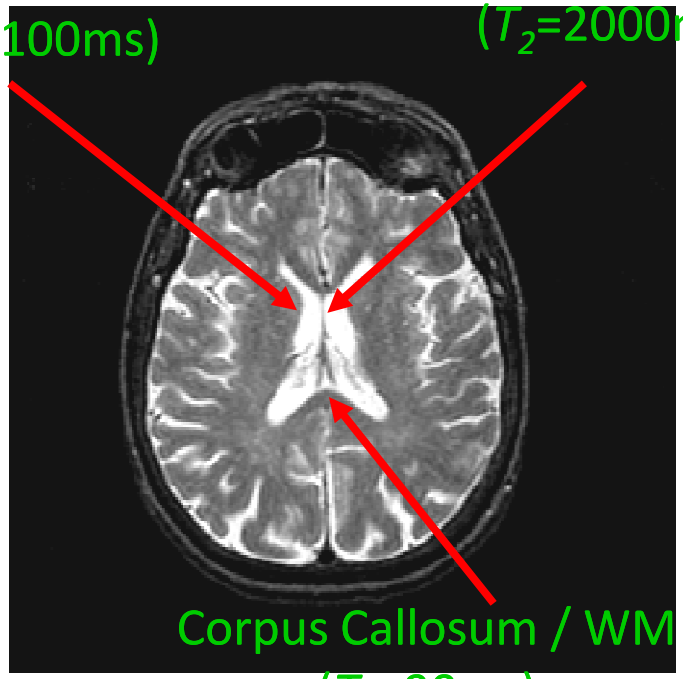
Following RF excitation, *transverse* component of M_0 decays exponentially with a time constant T_2



TE: echo time

T_2 contrast

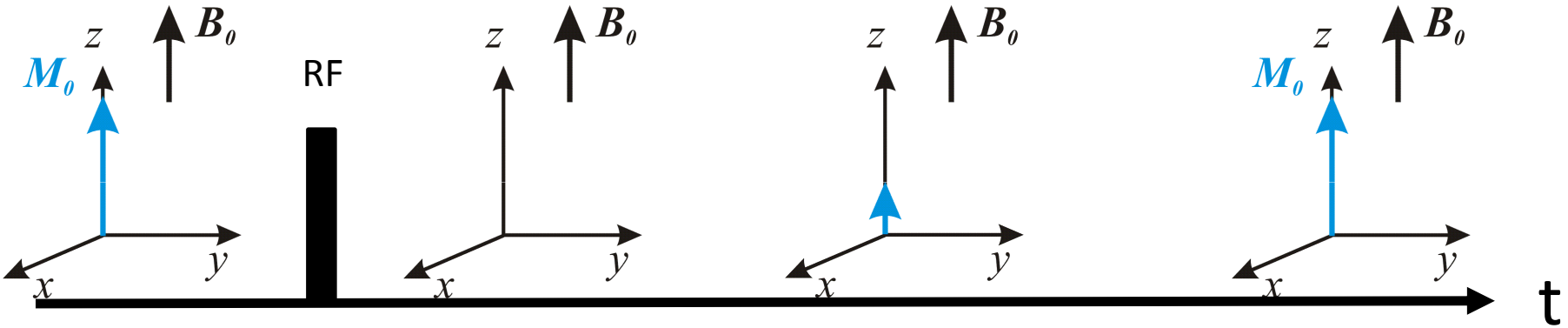


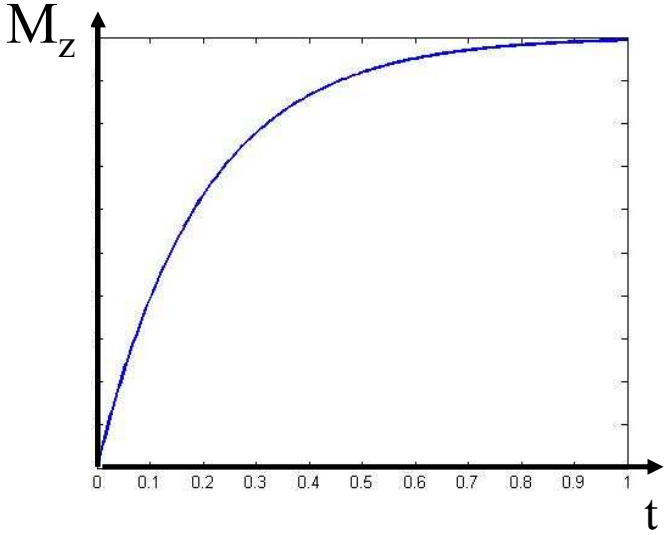


- $T_{2,CSF} > T_{2,GM/WM}$ => On T_2-weighted images, CSF appears bright
- WM and GM have similar T_2 values => low WM/GM contrast in T_2-weighted images

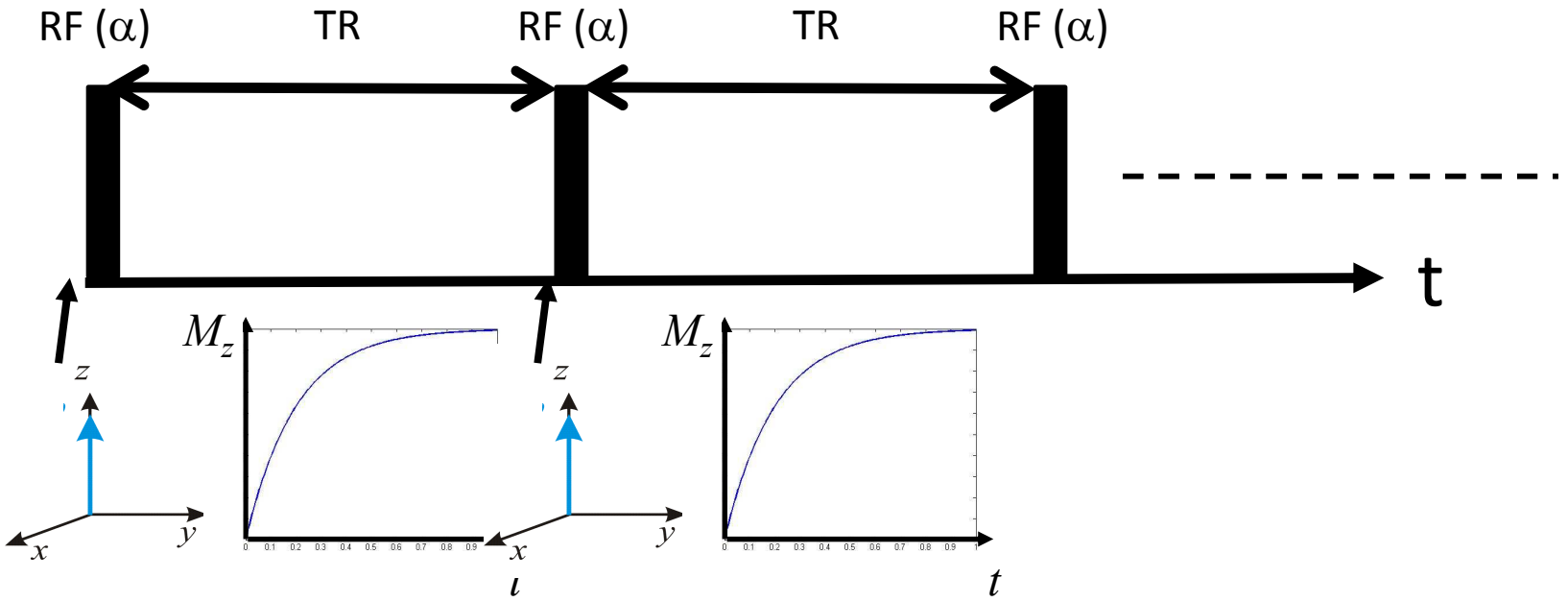
Longitudinal relaxation

After RF excitation, *longitudinal* component of M_0 **returns to equilibrium** over a **time constant T_1**



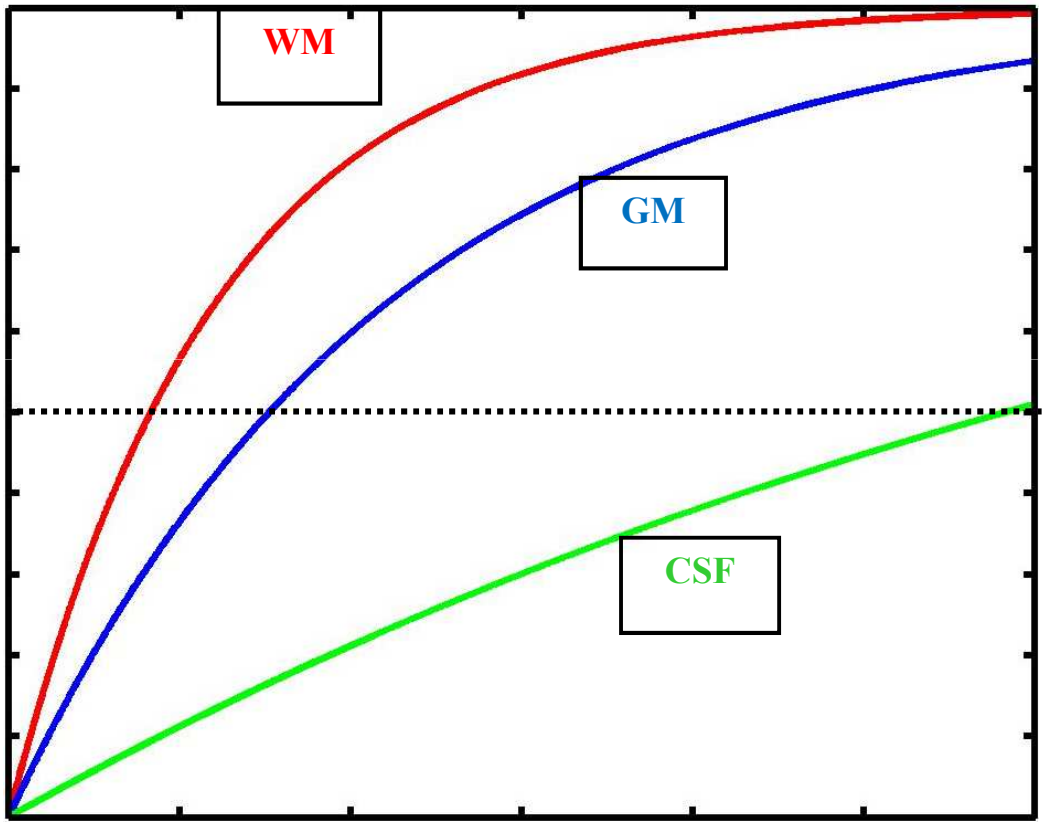


Longitudinal relaxation



T1 relaxation during TR governs amount of magnetization available for next excitation

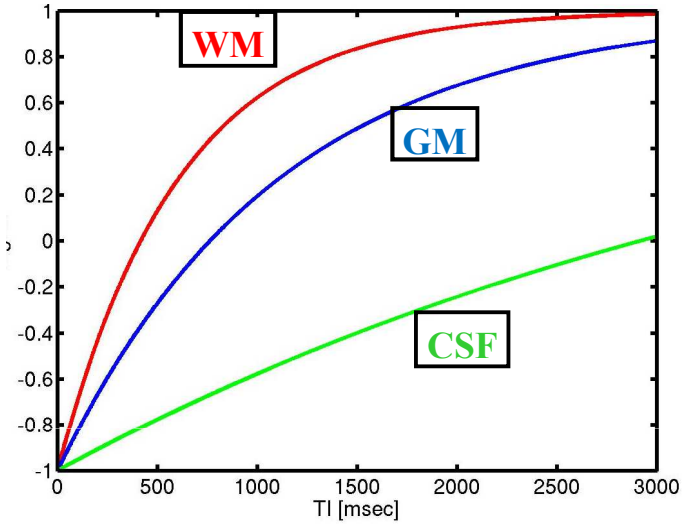
T1 contrast



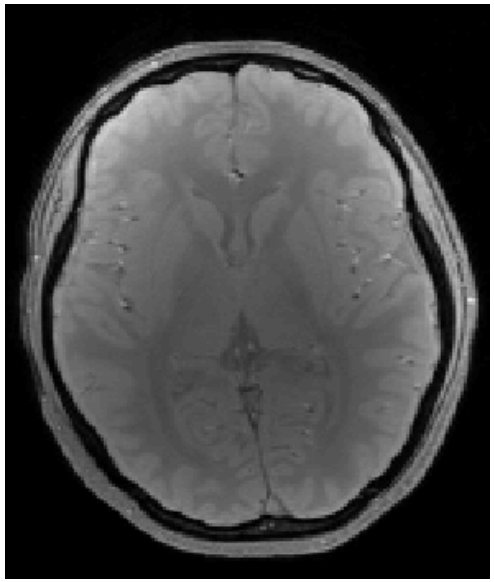
T1 differences between brain tissues yield image contrast in anatomical imaging

PD contrast – long TR

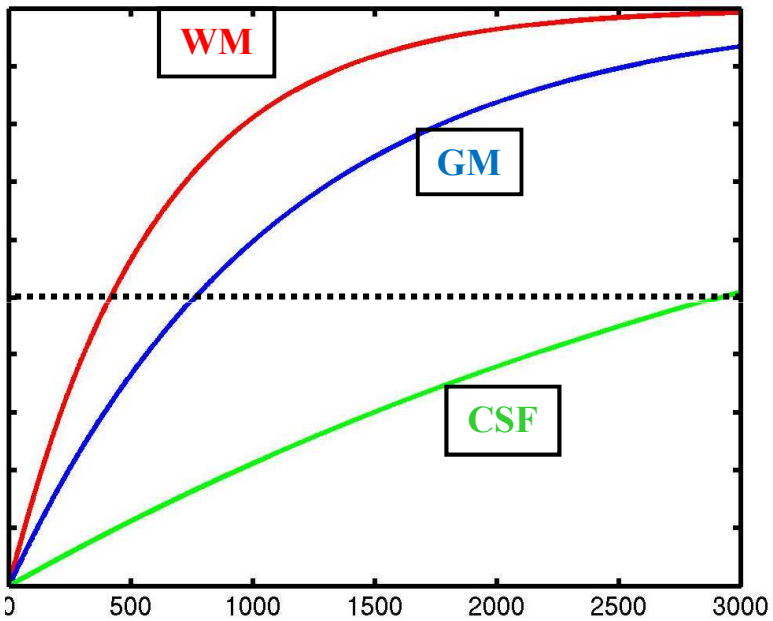
- Long TR (~20s):
  - All tissues fully relax
    → No T1w contrast
  - Image contrast: water density
    → PDw contrast



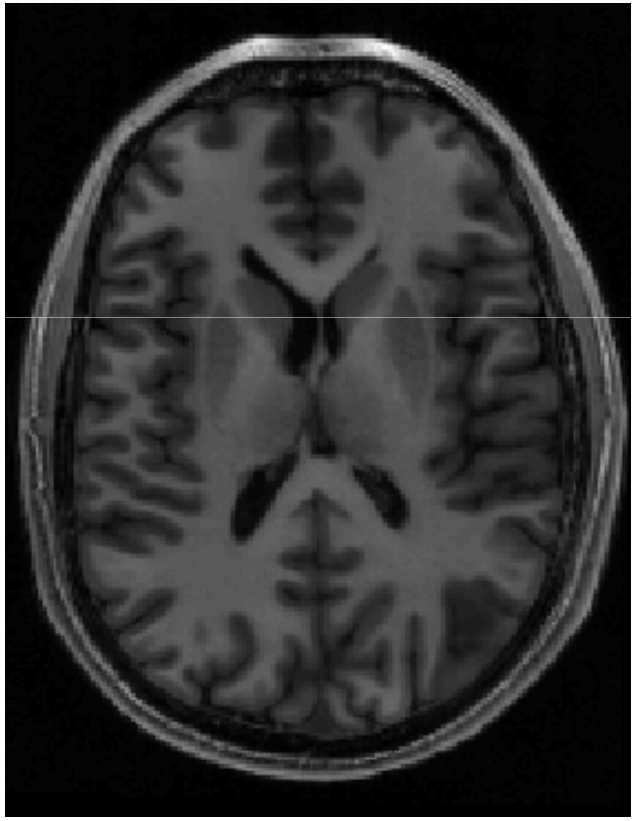
- Inconveniences:
  - Very time consuming
  - Fairly poor GM/WM contrast



T1 contrast – short TR



TR<<T1

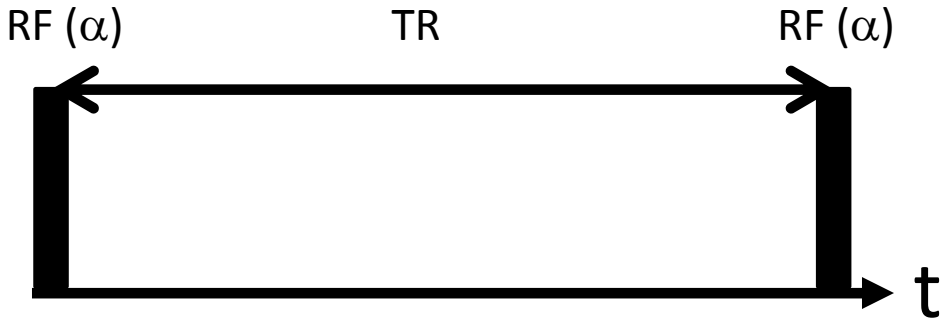


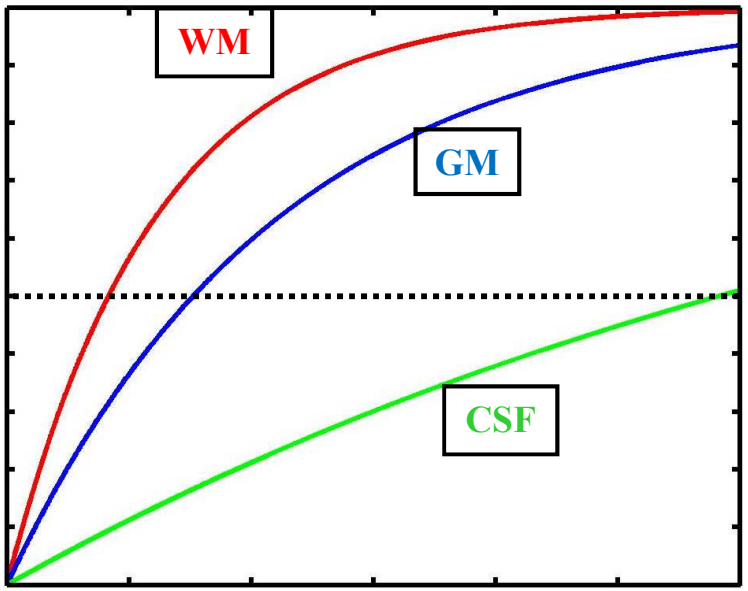
Optimal GM/WM contrast

Generally preferred for anatomical imaging

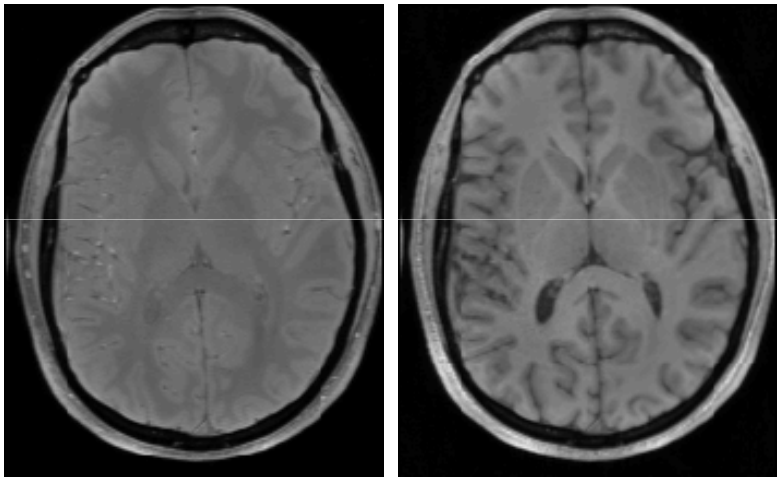
Frahm J. et al. MRM 1986

T1 contrast – short TR





TR=20ms



α=6° PDw

α=20° T1w

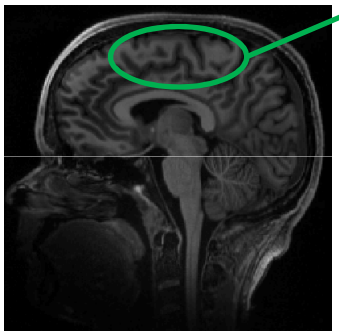
At short TR, image contrast depends on nominal flip angle of RF excitation

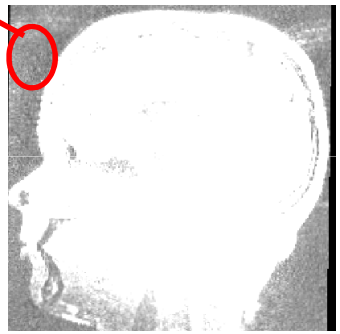
Frahm J. et al. MRM 1986

Anatomical imaging - requirements

- Yield optimal signal-to-noise/contrast-to-noise

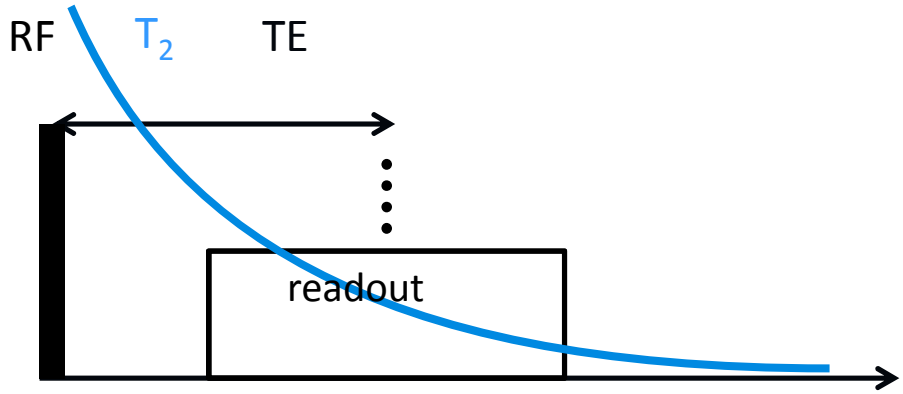
$$CNR = \frac{(S_{WM} - S_{GM})/(S_{WM} + S_{GM})}{\sigma}$$





- Preserve brain morphology
- Minimize acquisition time
- Avoid signal losses

Anatomical imaging – requirements



- Readout time << T2 to **preserve brain morphology**

fMRI lecture
Distortions in EPI images

- TE<<T2 **minimize signal dropouts**

fMRI lecture
Signal losses in EPI datasets

Anatomical imaging – requirements

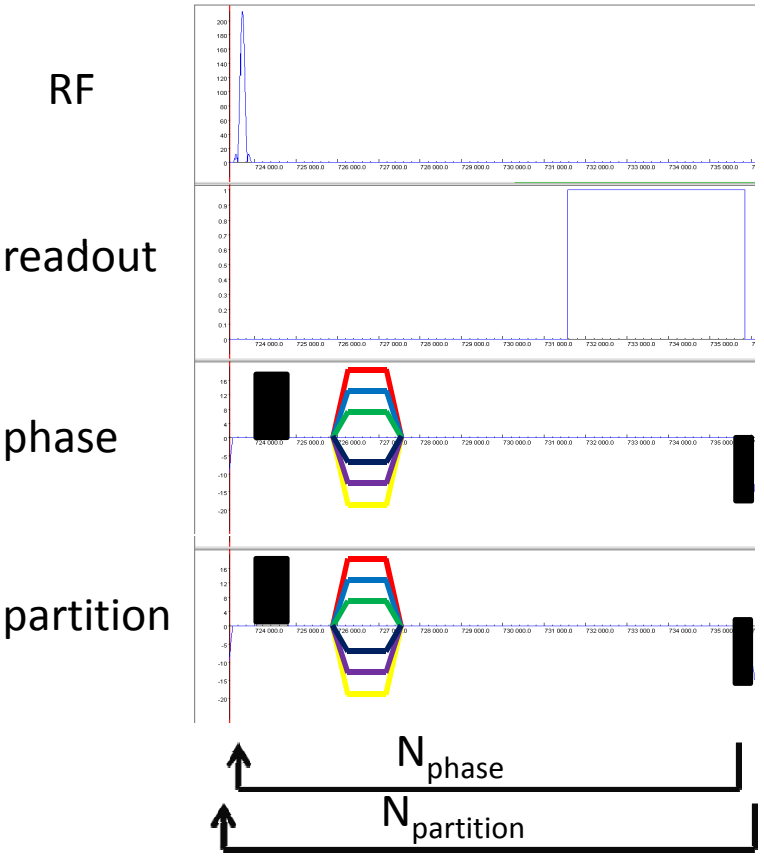
3D image encoding for maximum SNR

- Signal from entire head volume

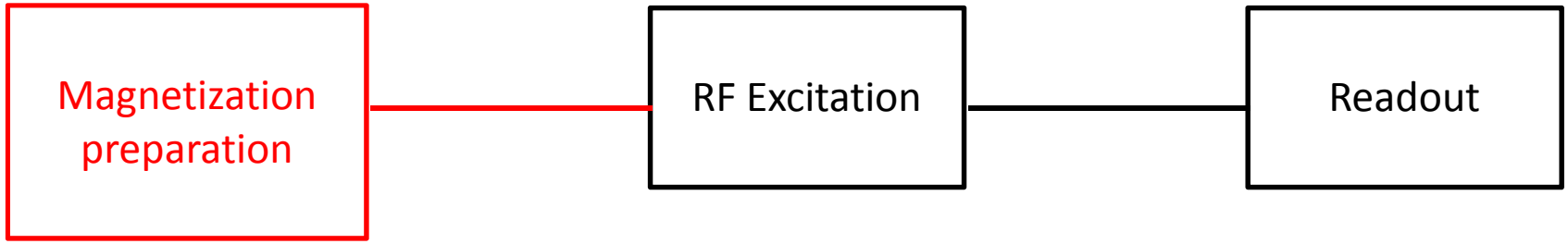
- 3rd direction ('partition') is gradient-encoded.

- $N_{partition} x N_{phase}$ sequence repetitions

!! Image quality sensitive to artefacts during the entire duration of the scan!!



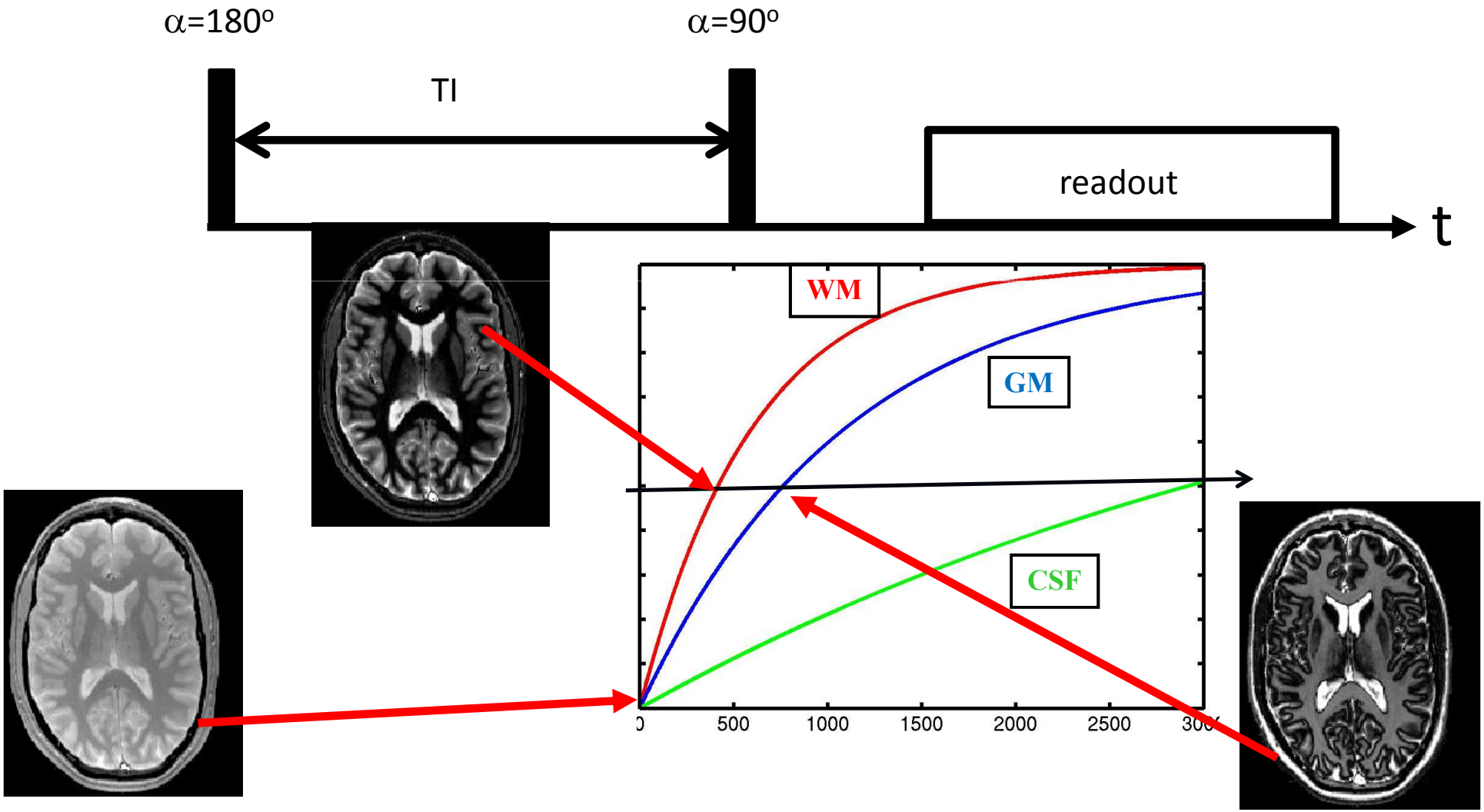
Anatomical imaging – image contrast



- Magnetization preparation enhance image contrast
- Manipulation magnetization prior to excitation/readout

Anatomical imaging – image contrast

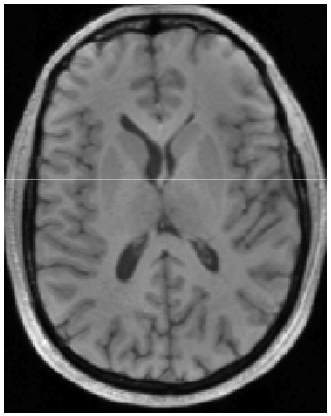
Example: inversion recovery



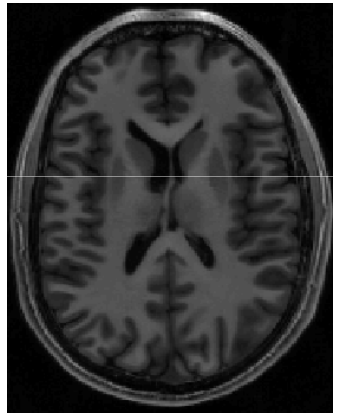
Anatomical imaging – image contrast

FLASH

Frahm J. et al. MRM 1986



MDEFT



- Inversion Recovery (time consuming)

- MPRAGE

Mugler & Brookeman MRM 1990; Mugler & Brookeman JMRI 1991 ; Look D.C., Locker D.R., Rev. Sci. Instrum, 1970 ;

- MDEFT

Deichmann R. et al Neuroimage 2006

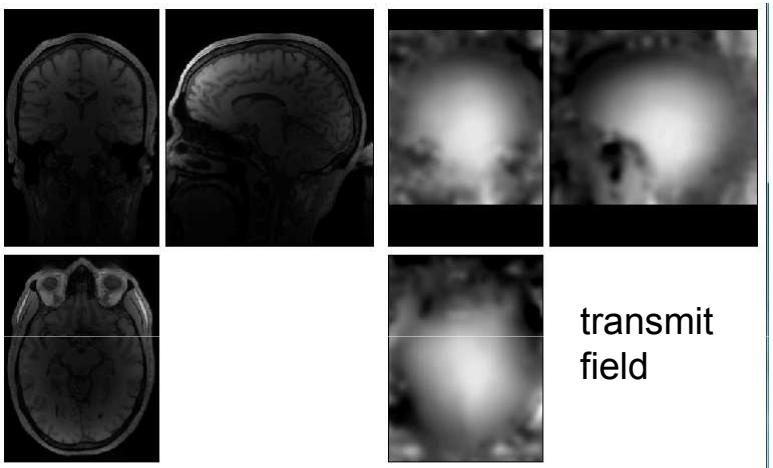
- Magnetization transfer (off-resonance saturation)

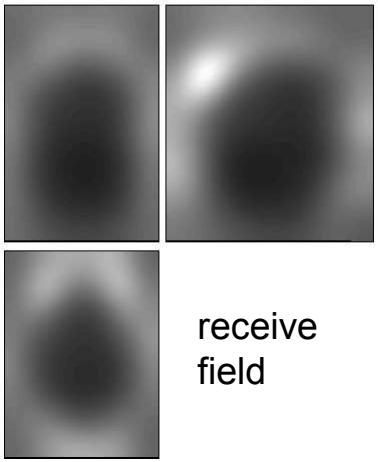
Henkelman R. MRM 1993; Sled J. & Pike G. MRM 2001; Helms G et al 2008

Outline

- Principals of image encoding
  - Origin of the signal
  - Image encoding
- Anatomical imaging
  - Image contrast
  - Anatomical imaging - requirements
- Advanced anatomical acquisitions

Bias in anatomical imaging



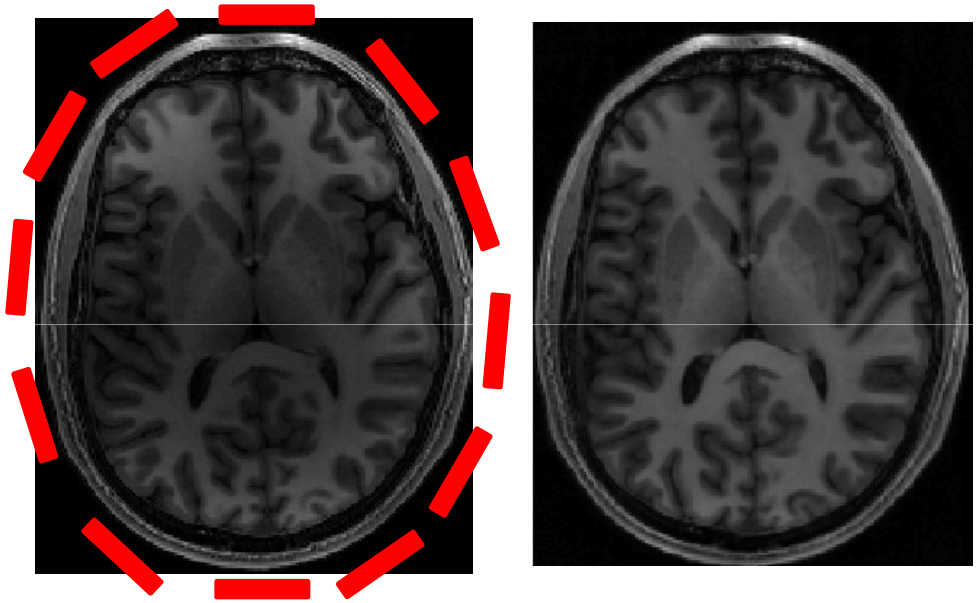


Spatially-varying bias:

- Transmit field B1 used for RF excitation
- Receive field for signal detection

Receive bias

- Receive head coils have spatially varying sensitivities.
- Effect corrected by bias field of SPM 's unified segmentation.

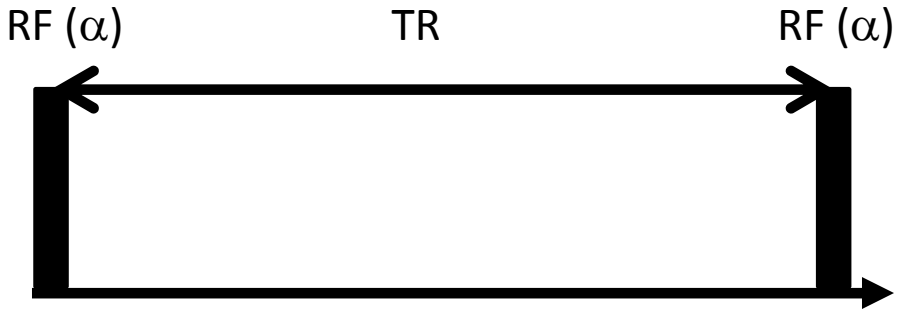


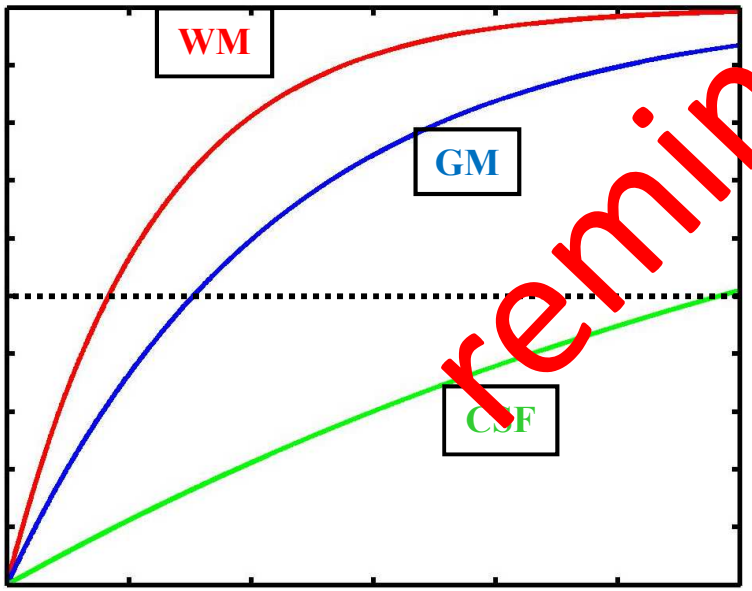
Original image

Bias field corrected image

Ashburner J., Friston K., Neuroimage, 2005

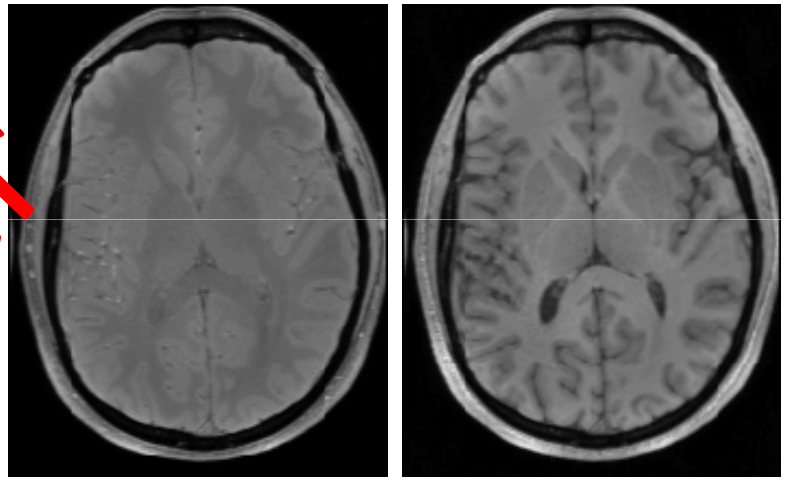
T1 contrast – short TR





reminder

TR=20ms

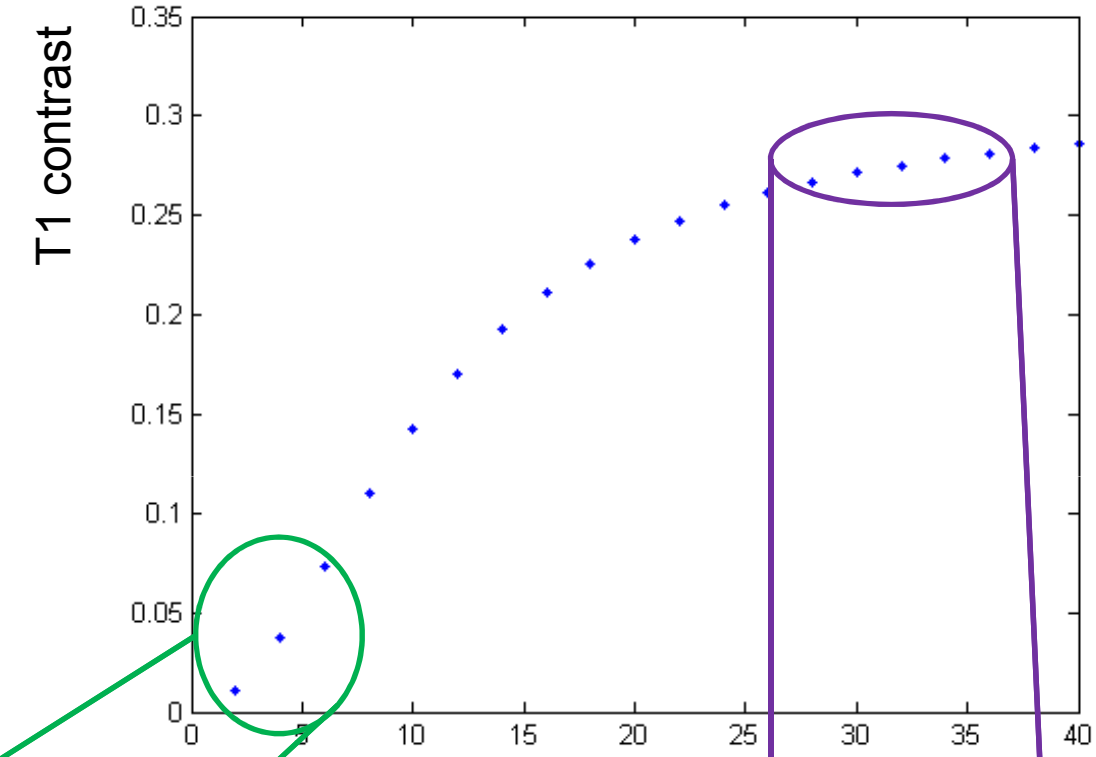


α=6°
PDw

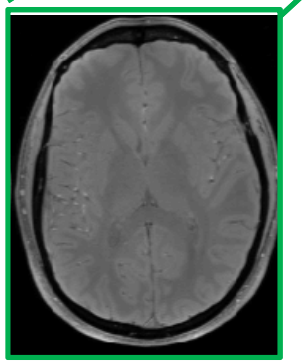
α=20°
T1w

Frahm J. et al. MRM 1986

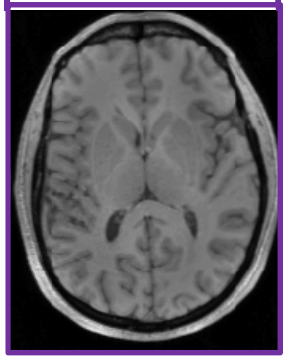
Transmit bias



PDw:



T1w:

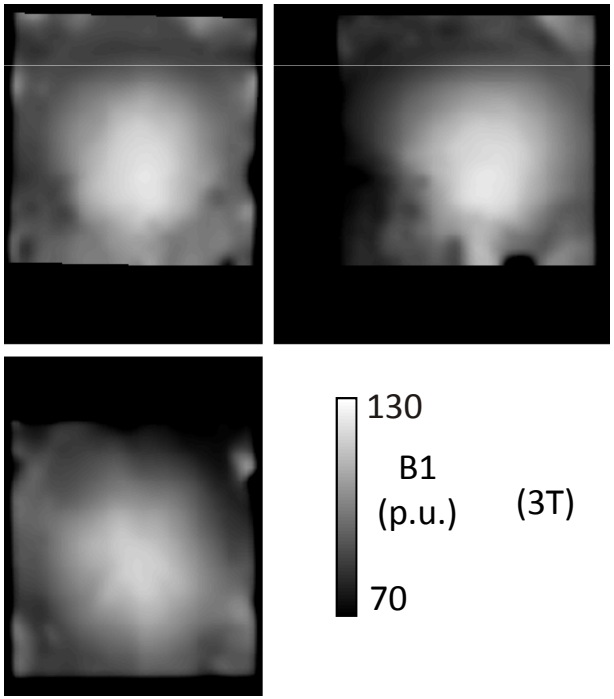


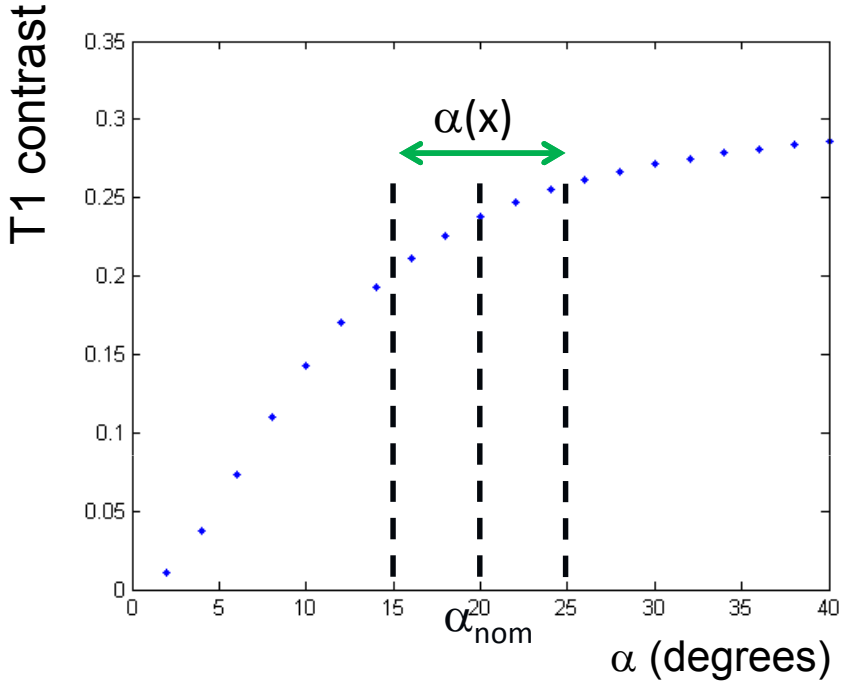
Transmit bias

- Nominal flip angle α_{nom} (e.g. 90º)
- Local flip angles are:

$\alpha(x)=B1\alpha_{nom}$ [B1]=p.u.

B1 map





B1 inhomogeneities:

- **Affect image contrast**
- **Cannot be corrected by SPM bias-field correction**
- **Must be accurately mapped for correction**

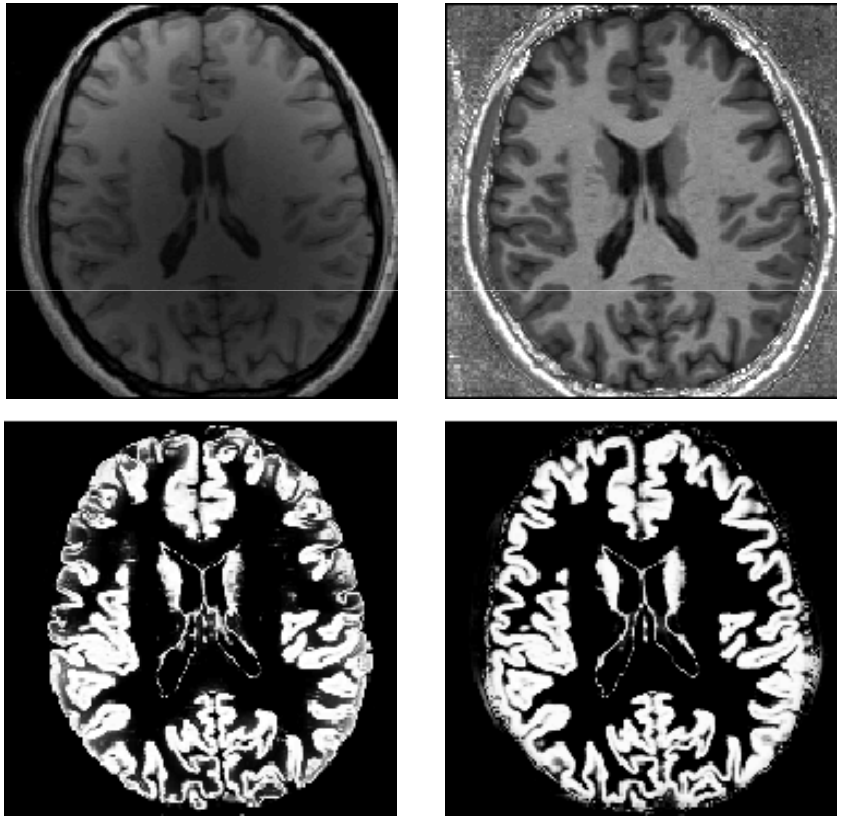
Lutti A. et al MRM 2010, Lutti A. et al PONE 2012;

Morphometry – limits of T1w imaging

Contrast bias affect segmentation results

Standard T1w image

Bias-free image



Ashburner& Friston Neuroimage 2000;
Hutton Neuroimage 2008; Hutton Neuroimage 2009

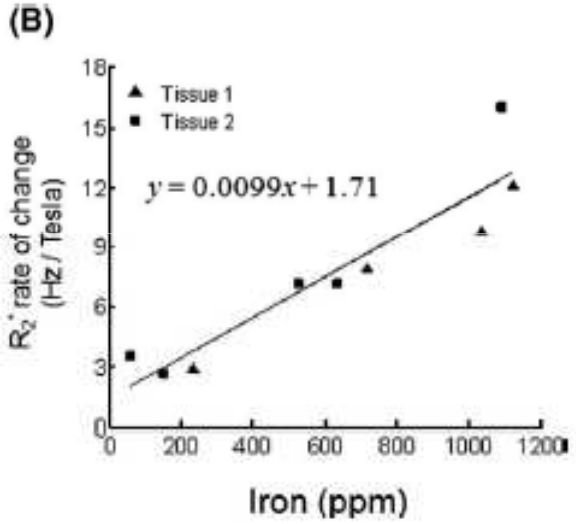
Bias-free anatomical imaging - quantitative mapping

- **Bias-free** measures of MR parameters of tissues
- Measures are **biomarkers of tissue microarchitecture** (concentration of myelin, iron, water,...)
- Data quantitatively **comparable across scanners**
- Reduced variance across multiple scans & imaging centres **Improved sensitivity** in longitudinal and multi-centre studies

Helms G., et al MRM 2008; Helms G., et al MRM 2009; Marques J.P. et al Neuroimage, 2010; Deoni, S.C., JMRI 2007; Glasser M.F., Van Essen D.C., J. Neur, 2011
Weiskopf N. et al Front. Neurosci 2013; Lutti A. et al Neuroimage 2013

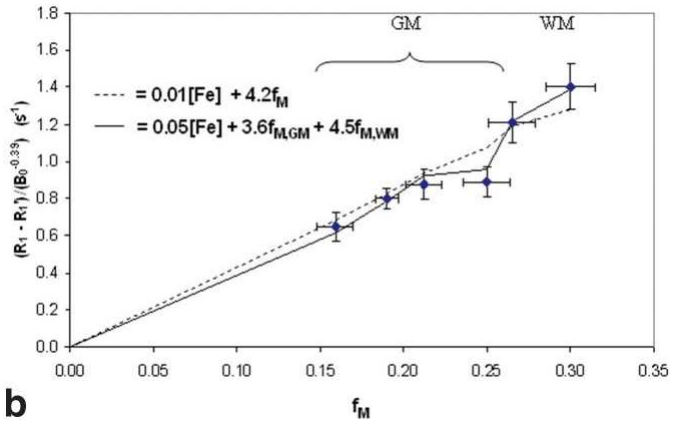
MRI biomarkers of tissue microstructure

R2* vs iron concentration



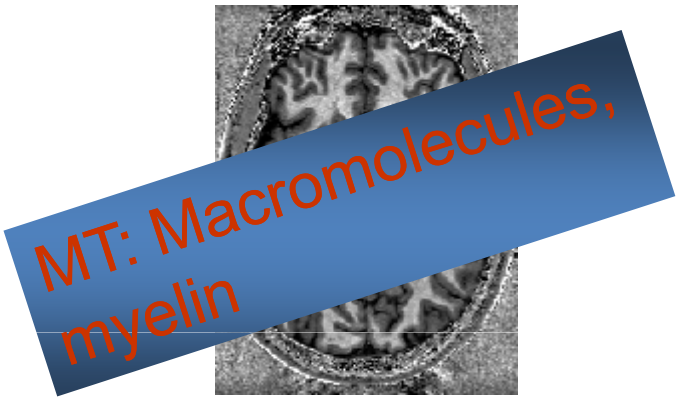
Yao B. et al. NI 2009

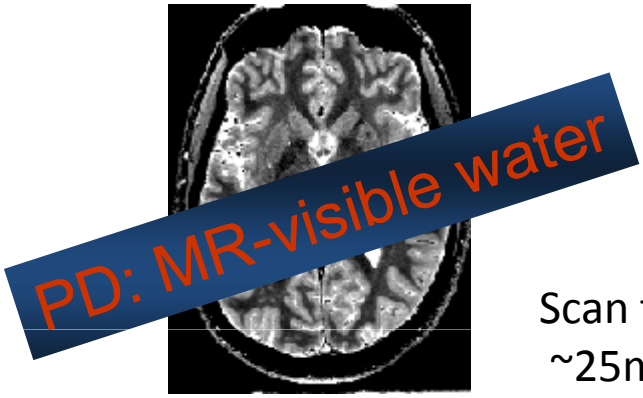
R1 vs myelin concentration



Rooney W.D. et al MRM 2007

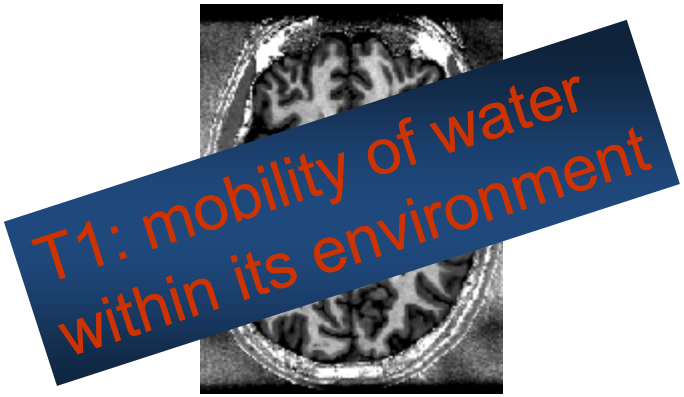
MPM protocol for quantitative mapping

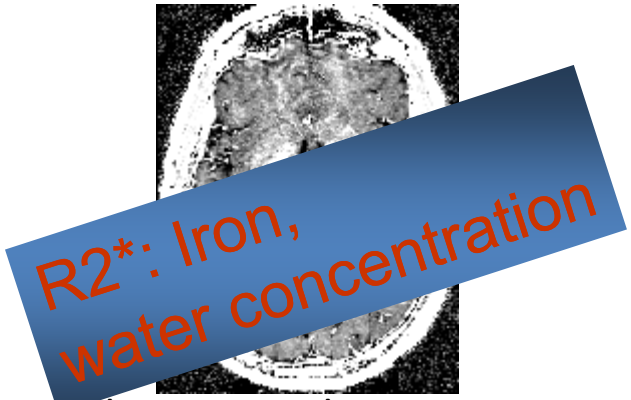




Scan time:
~25min (1mm^3 resolution)

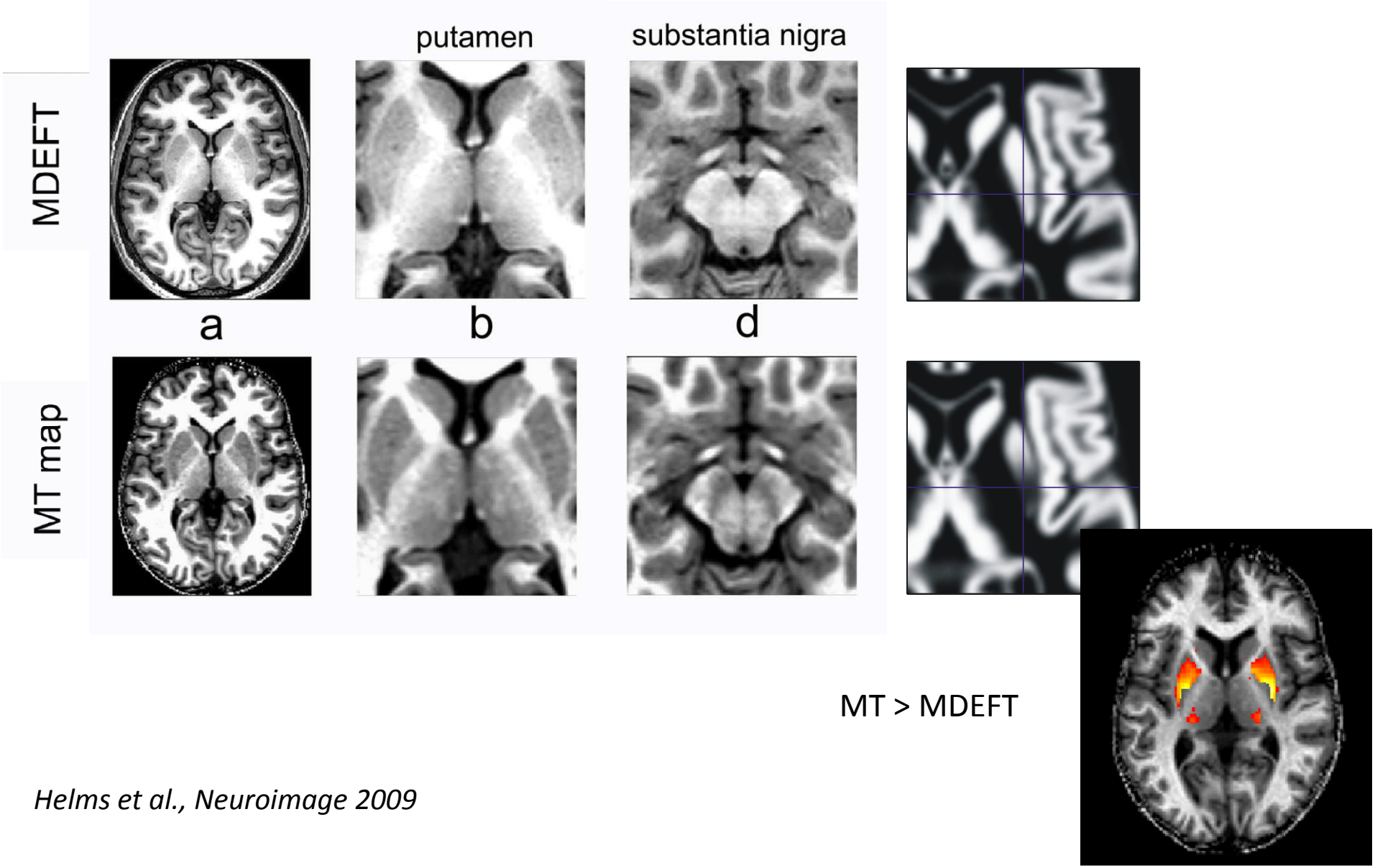
~35min (800um^3 resolution)





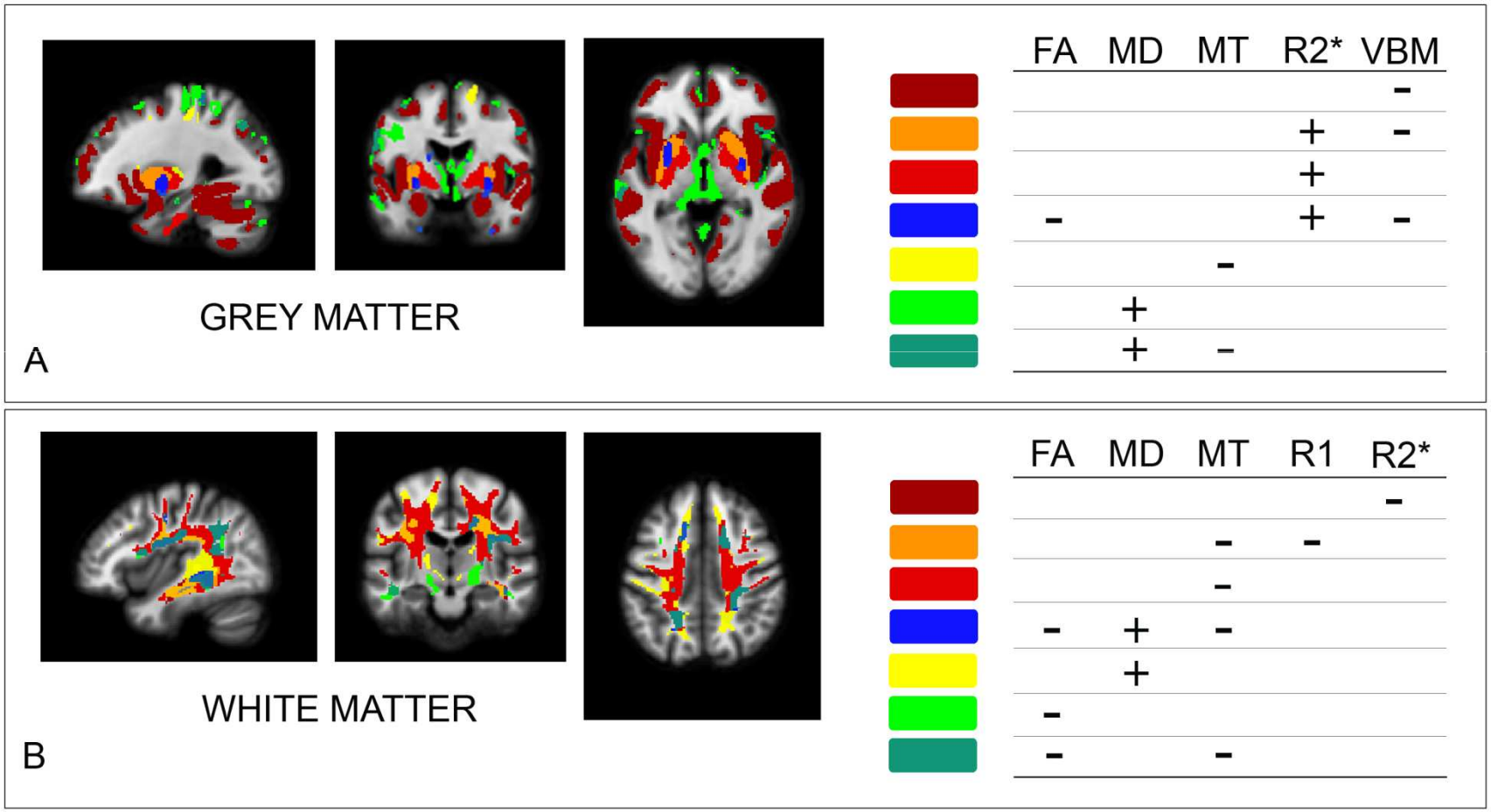
Helms G., et al MRM 2008; Helms G., et al MRM 2009; Lutti A. et al MRM 2010, Lutti A. et al PONE 2012;

Improved morphometry: MT based VBM



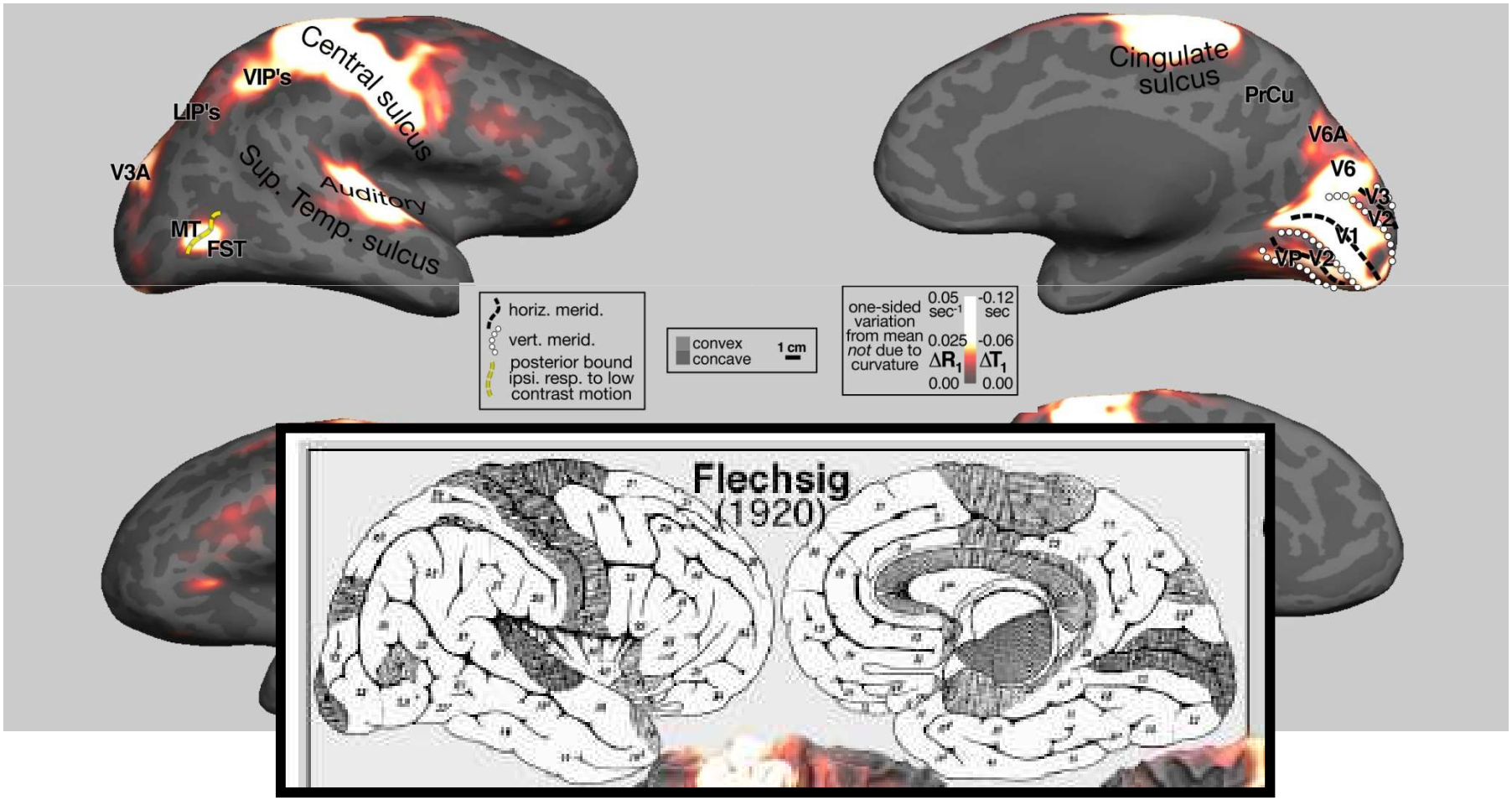
Helms et al., Neuroimage 2009

VBQ: fingerprint of tissue changes in ageing



Draganski et al., Neuroimage 2011

Myelin mapping: towards in-vivo histology



Sereno M.I. et al., Cereb. Cortex 2012

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- Principles of Nuclear Magnetism

  by A. Abragam