

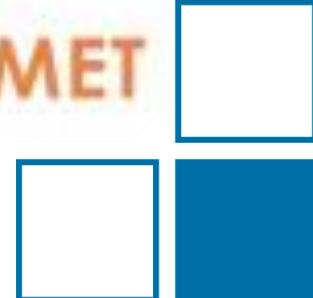
# NeuroMET

## Virtual MR Spectroscopy Workshop

### L1: Basics of MR Spectroscopy

Ariane Fillmer, PhD

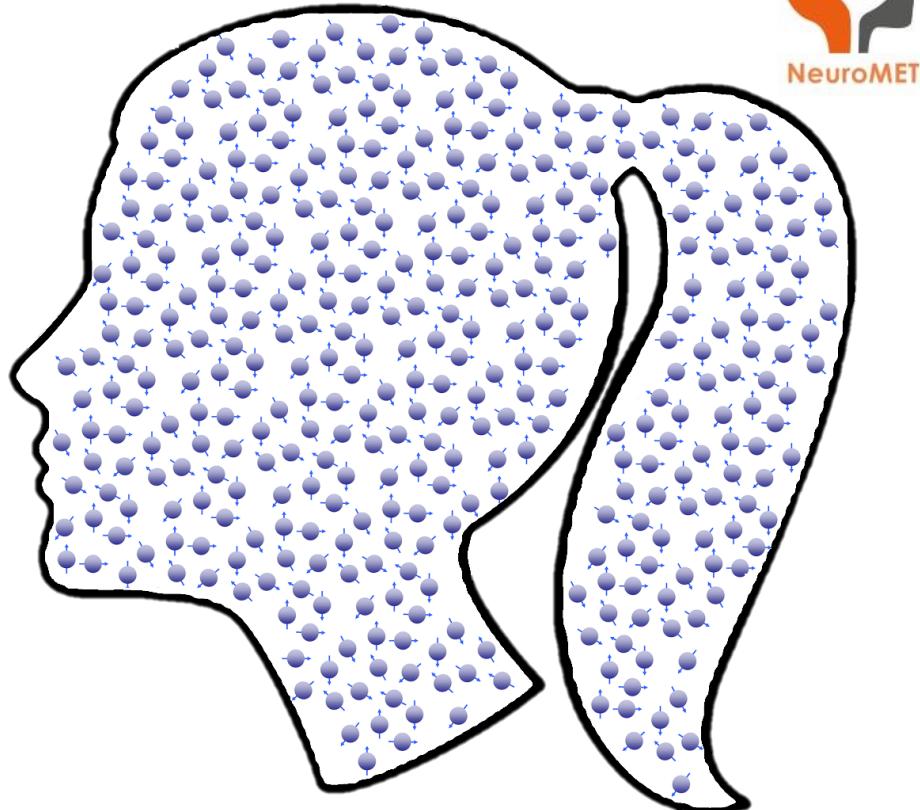
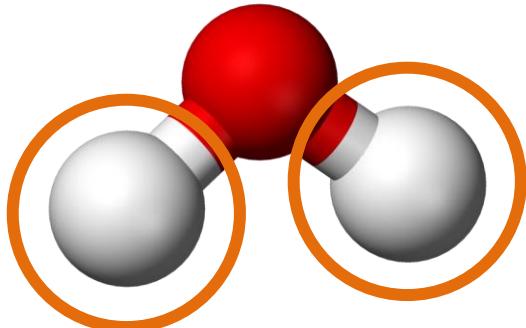
*Physikalisch-Technische Bundesanstalt, AG «In-vivo MRT»*



# MR Signal Generation: Recap

average water content in  
adult humans of both sexes:

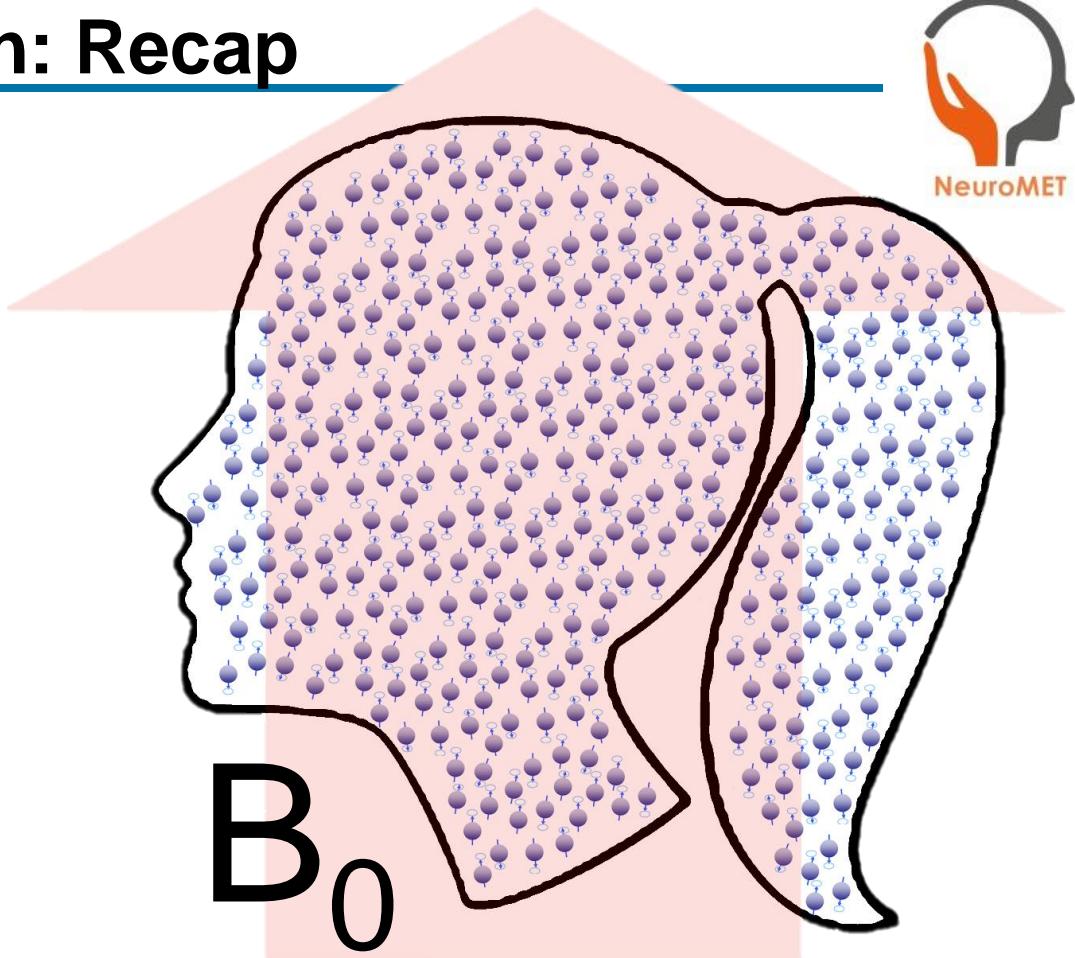
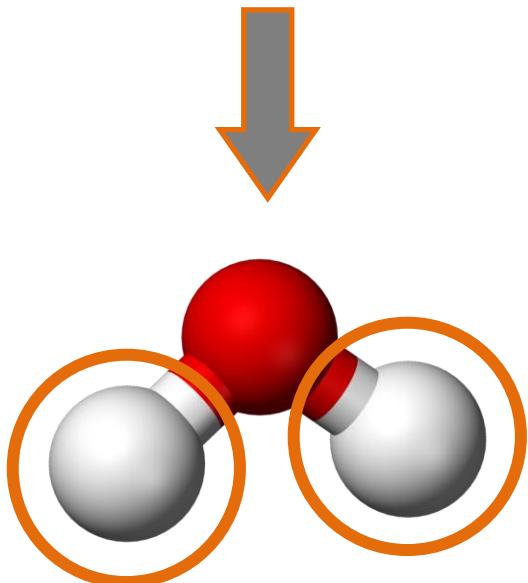
~ 65 %



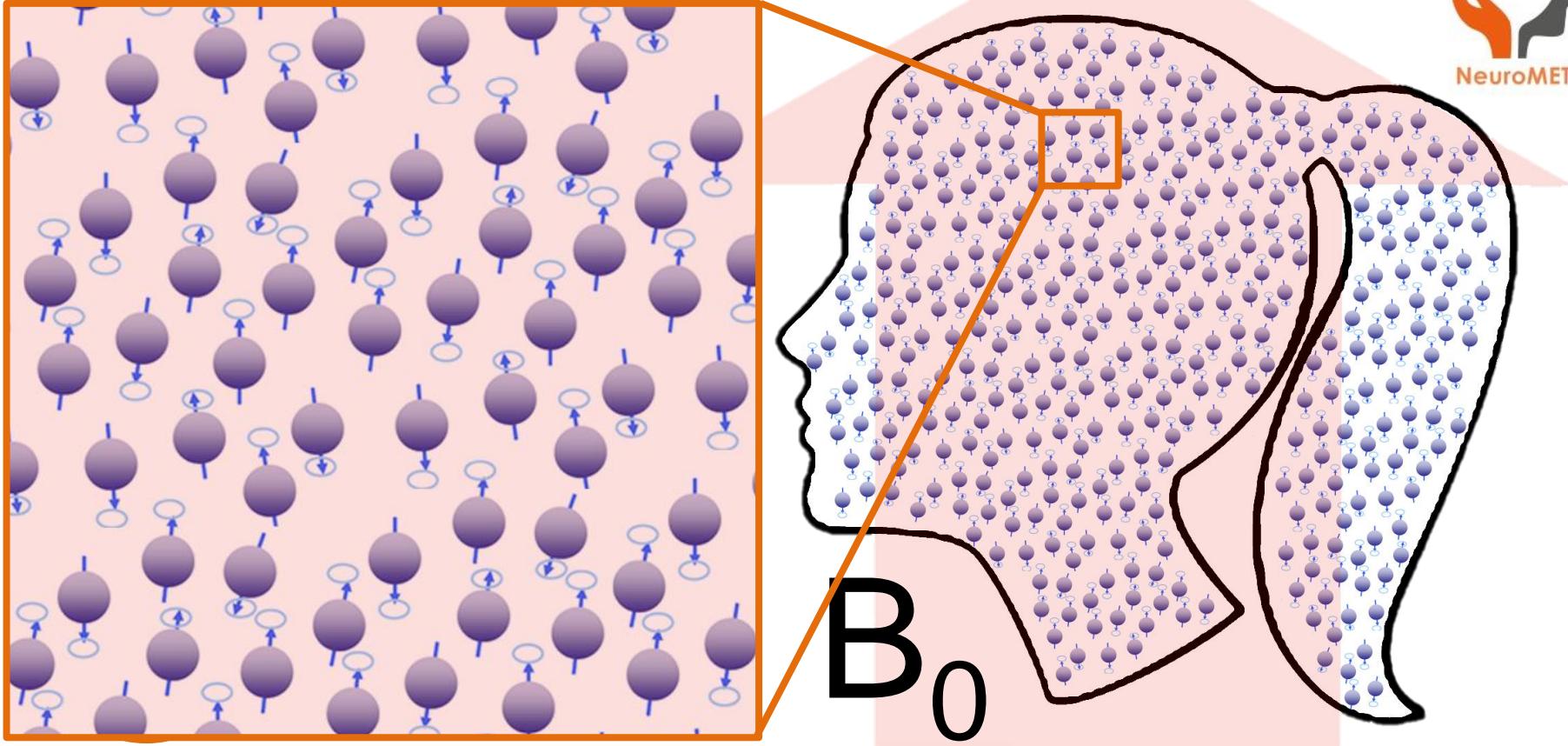
# MR Signal Generation: Recap

average water content in adult humans of both sexes:

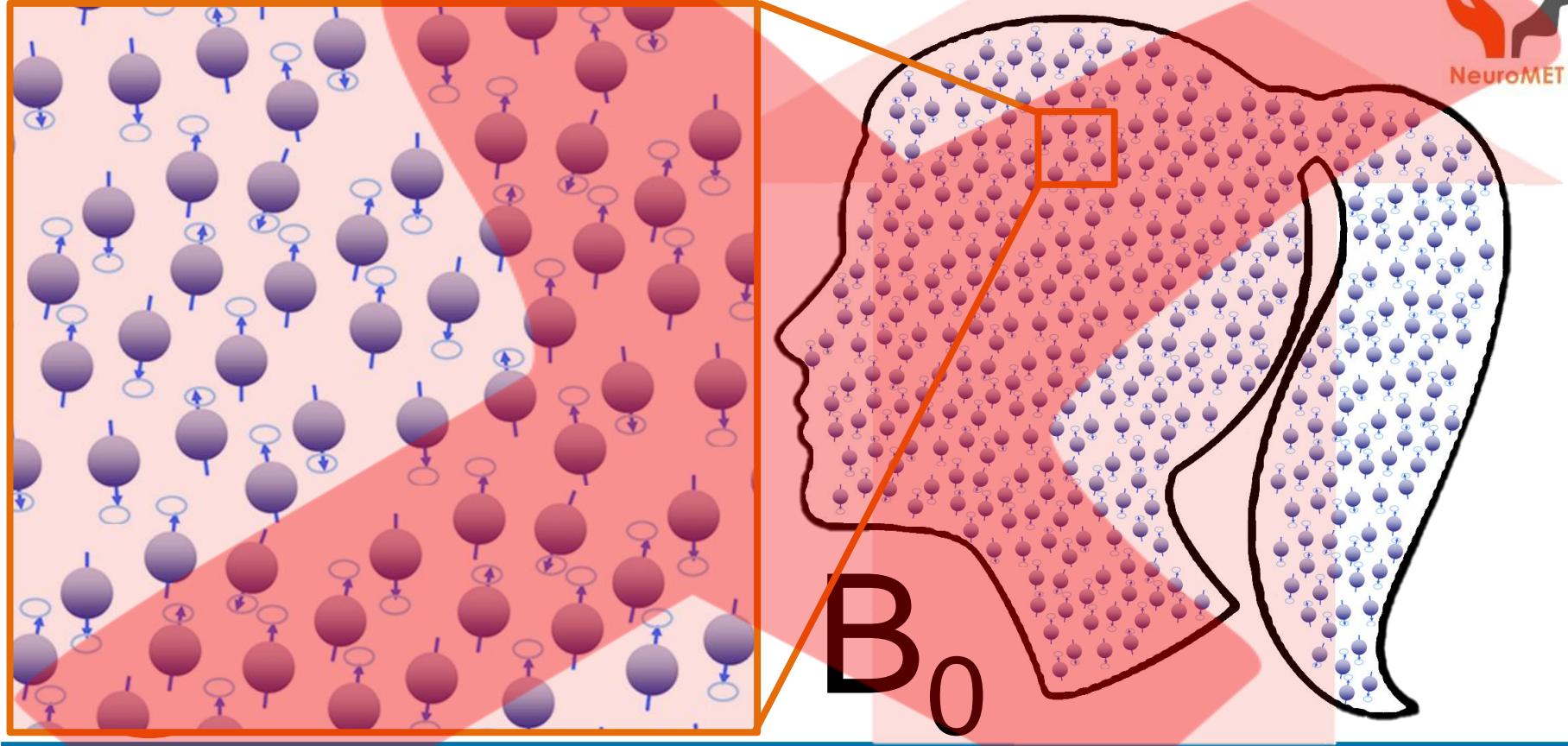
~ 65 %



# MR Signal Generation: Recap



# MR Signal Generation: Recap



# MR Signal Generation: Recap

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## Is Quantum Mechanics Necessary for Understanding Magnetic Resonance?

LARS G. HANSON

*Danish Research Centre for Magnetic Resonance, Copenhagen University Hospital, Hvidovre, Denmark*

**ABSTRACT:** Educational material introducing magnetic resonance (MR) typically contains sections on the underlying principles. Unfortunately the explanations given are often unnecessarily complicated or even wrong. MR is often presented as a phenomenon that necessitates a quantum mechanical explanation whereas it really is a classical effect, i.e. a consequence of the common sense expressed in classical mechanics. This insight is not new, but there have been few attempts to challenge common misleading explanations, so authors and educators are inadvertently keeping myths alive. As a result, new students' first encounters with MR are often obscured by explanations that make the subject difficult to understand. Typical problems are addressed and alternative intuitive explanations are provided. © 2008 Wiley Periodicals, Inc. Concepts Magn Reson Part A 32A: 329–340, 2008.

Hanson, CONCEPT MAGN RESON A: 32A, 329 - 340 (2008)  
<https://www.drcmr.dk/BlochSimulator/>

# MR Signal Generation: Recap

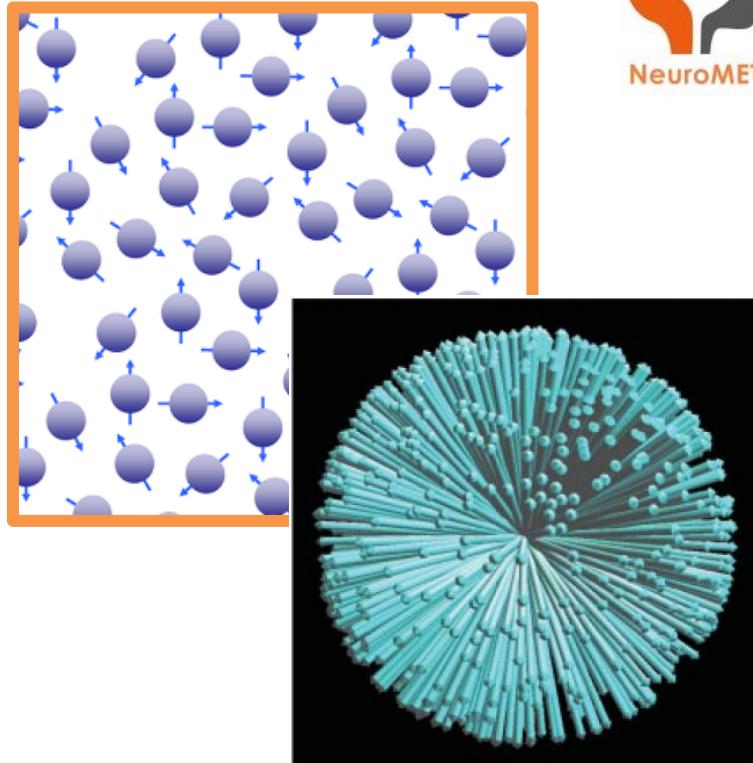


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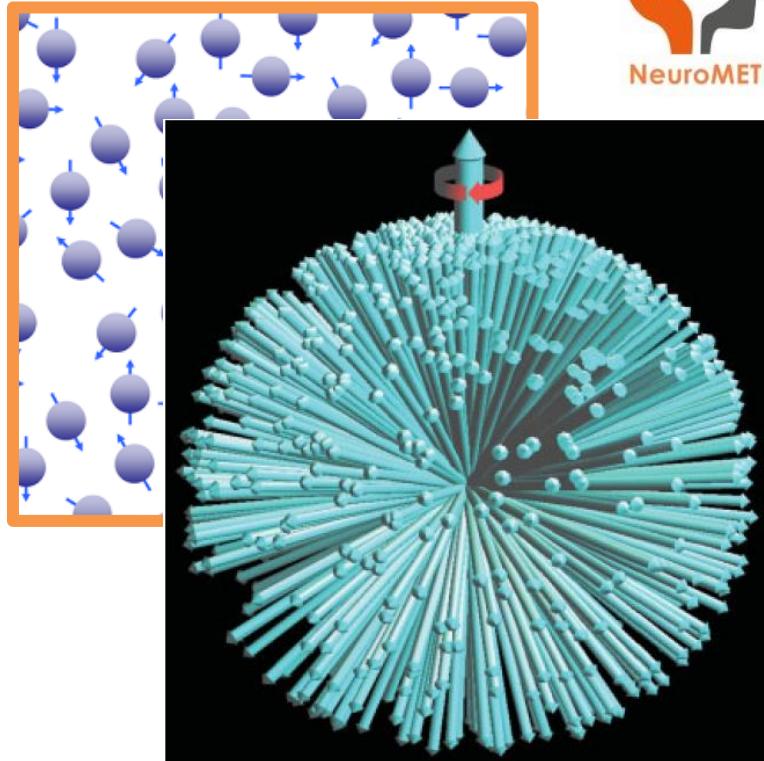


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<https://www.drcmr.dk/BlochSimulator/>

# MR Signal Generation: Recap



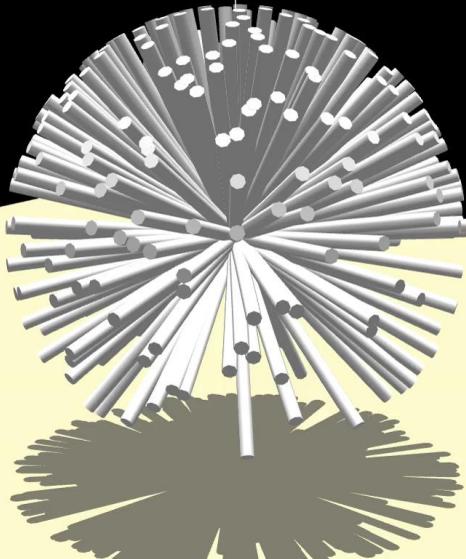
- Bloch Simulator
- Relaxation: Off
- View: Torque,Mx,|Mxy|,Mz
- Fields

B0	1
B1	0
B1freq	1

Gradients: Gx=0, Gy=0

Frame

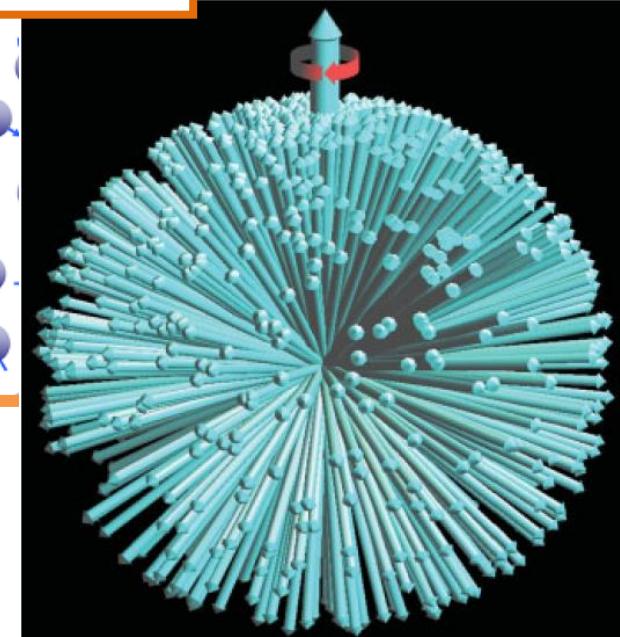
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B0	<input type="checkbox"/>
B1	<input type="checkbox"/>



Ensemble 90° hard 90° soft 180° Spoil Non-rep. exc. ||

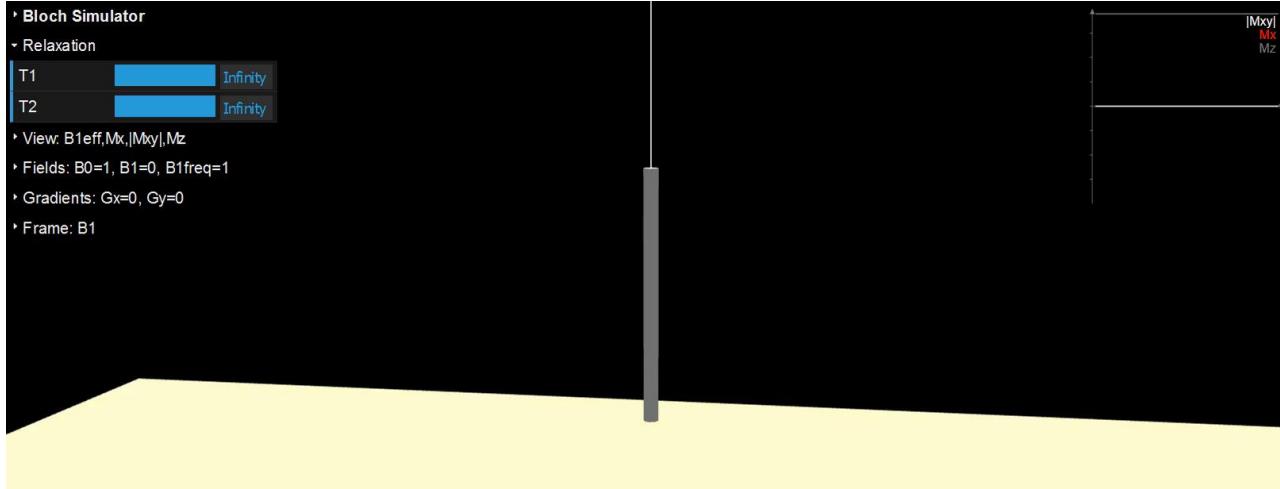
329–340, 2008.

$$\omega_L = -\gamma \cdot B_0$$



Hanson, CONCEPT MAGN RESON A: 32A, 329 - 340 (2008)  
<https://www.drcmr.dk/BlochSimulator/>

# MR Signal Generation: Recap



$$\omega_L = -\gamma \cdot B_0$$

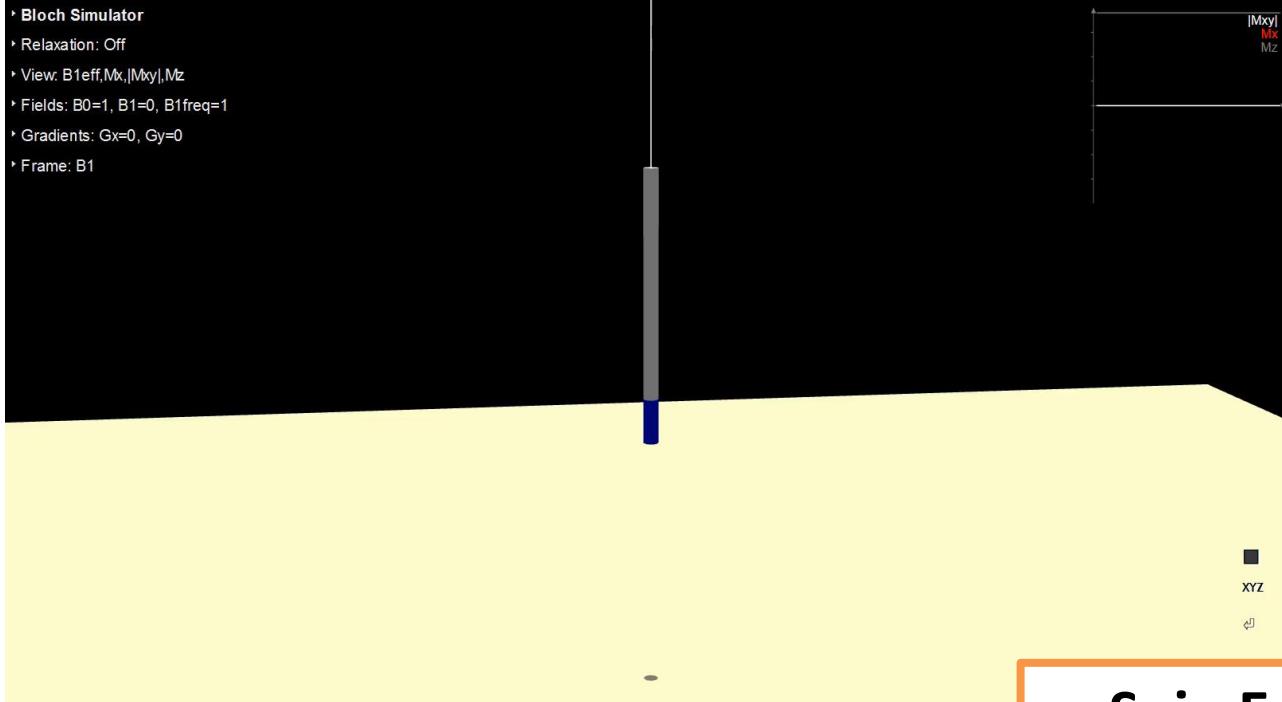
**FID:**  
Free Induction  
Decay

<https://www.drcmri.dk/BlochSimulator/>

# MR Signal Generation: Recap



- › Bloch Simulator
- › Relaxation: Off
- › View: B1eff,Mx,|My|,Mz
- › Fields: B0=1, B1=0, B1freq=1
- › Gradients: Gx=0, Gy=0
- › Frame: B1



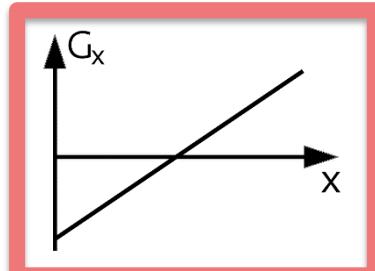
$$\omega_L = -\gamma \cdot B_0$$

Spin Echo

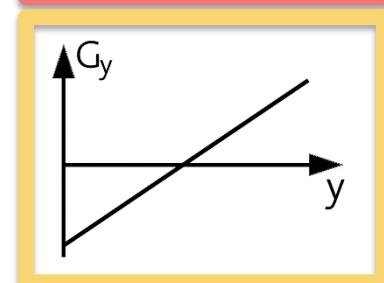
Inhomogeneity ▾ 90° hard ▾ 90° soft ▾ 180° ▾ Spoil ▾ Non-rep. exc. ▾ ||

<https://www.drcmr.dk/BlochSimulator/>

# MR Imaging: Recap



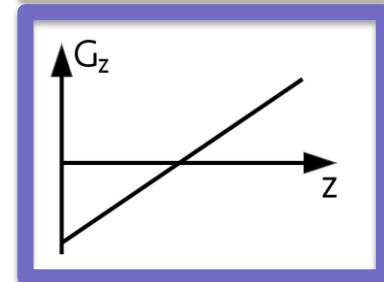
$$\omega_L = -\gamma \cdot B_0$$



$$\omega_L(x, y, z) =$$

$$-\gamma \cdot (B_0(x, y, z)$$

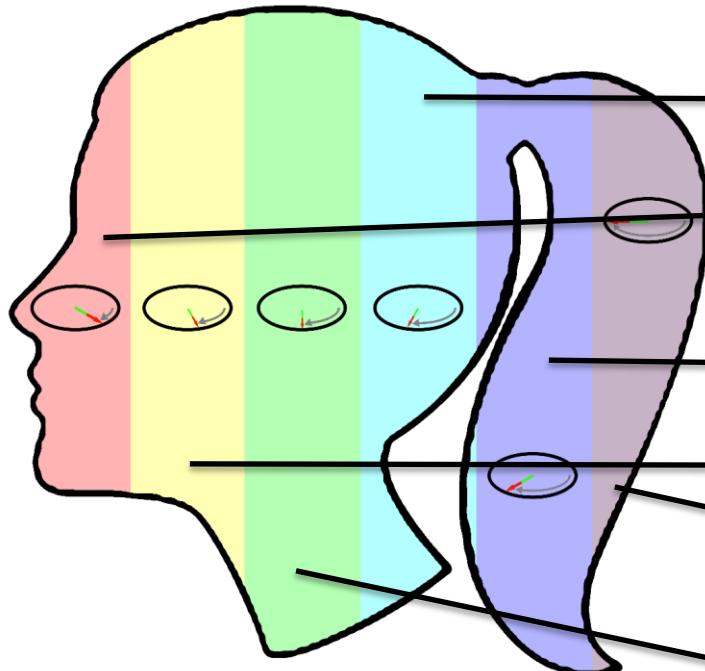
$$+ G_{\textcolor{blue}{x}}(x)$$



$$+ G_{\textcolor{brown}{y}}(y)$$

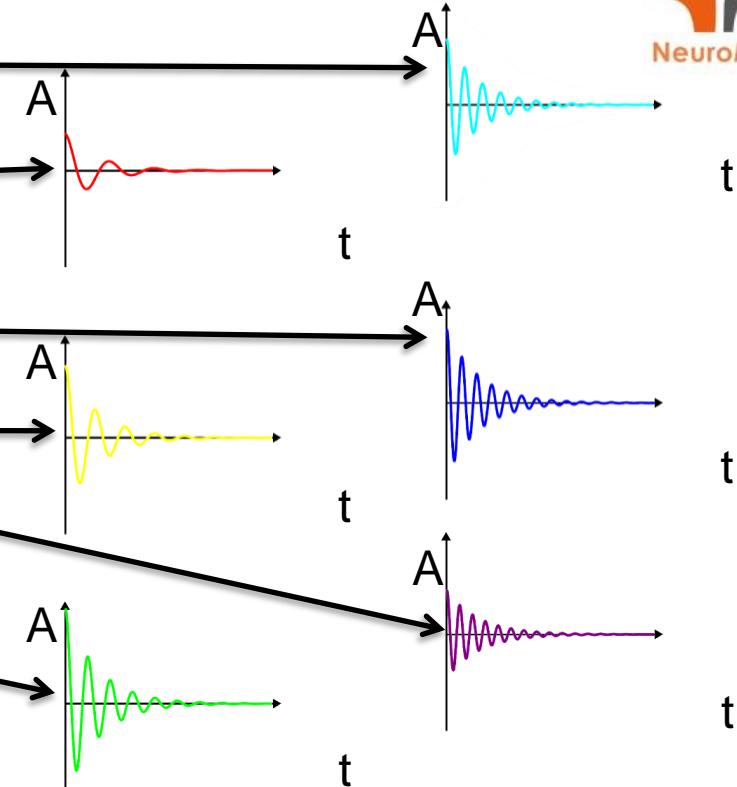
$$+ G_z(z))$$

# MR Imaging: Recap

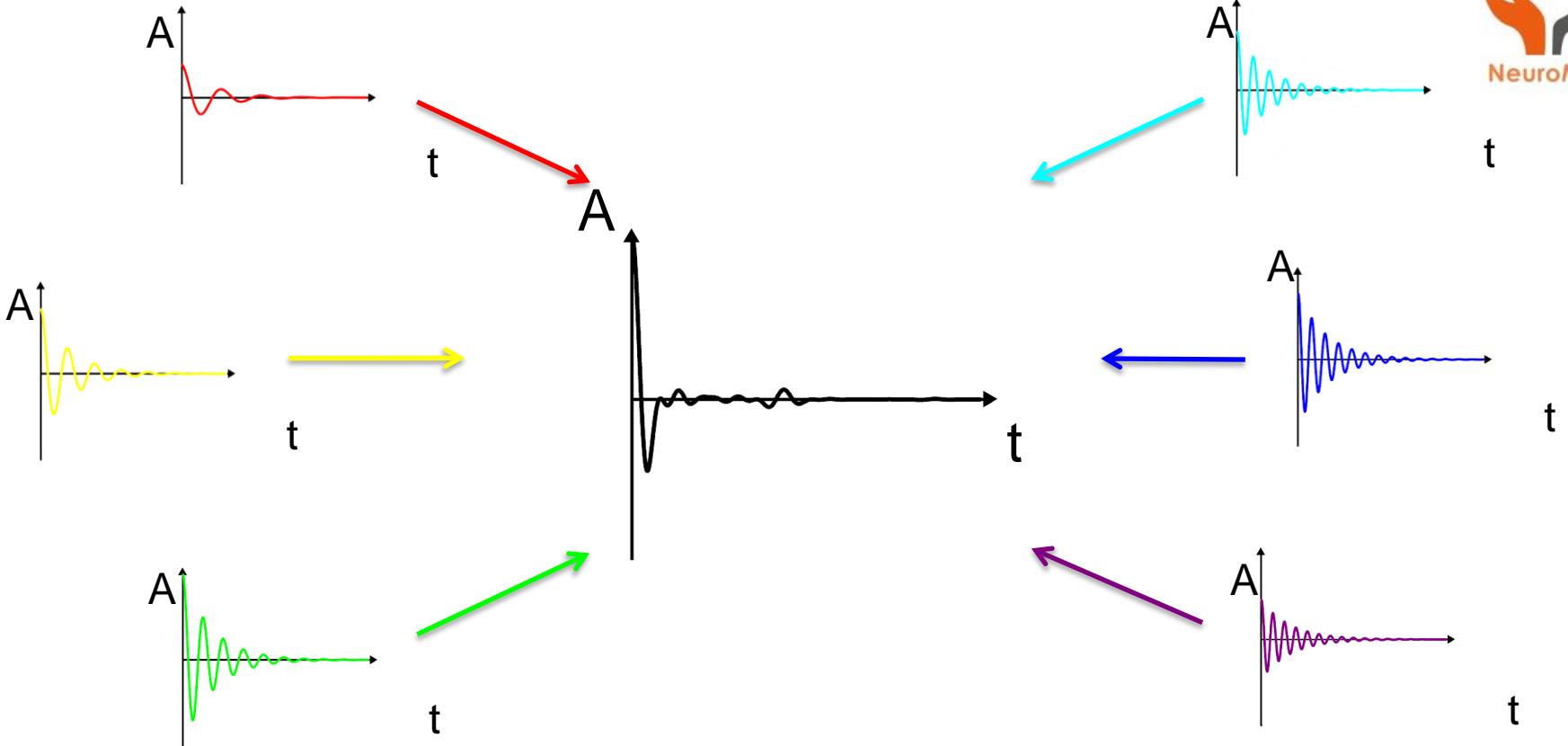


weaker  
magnetic field

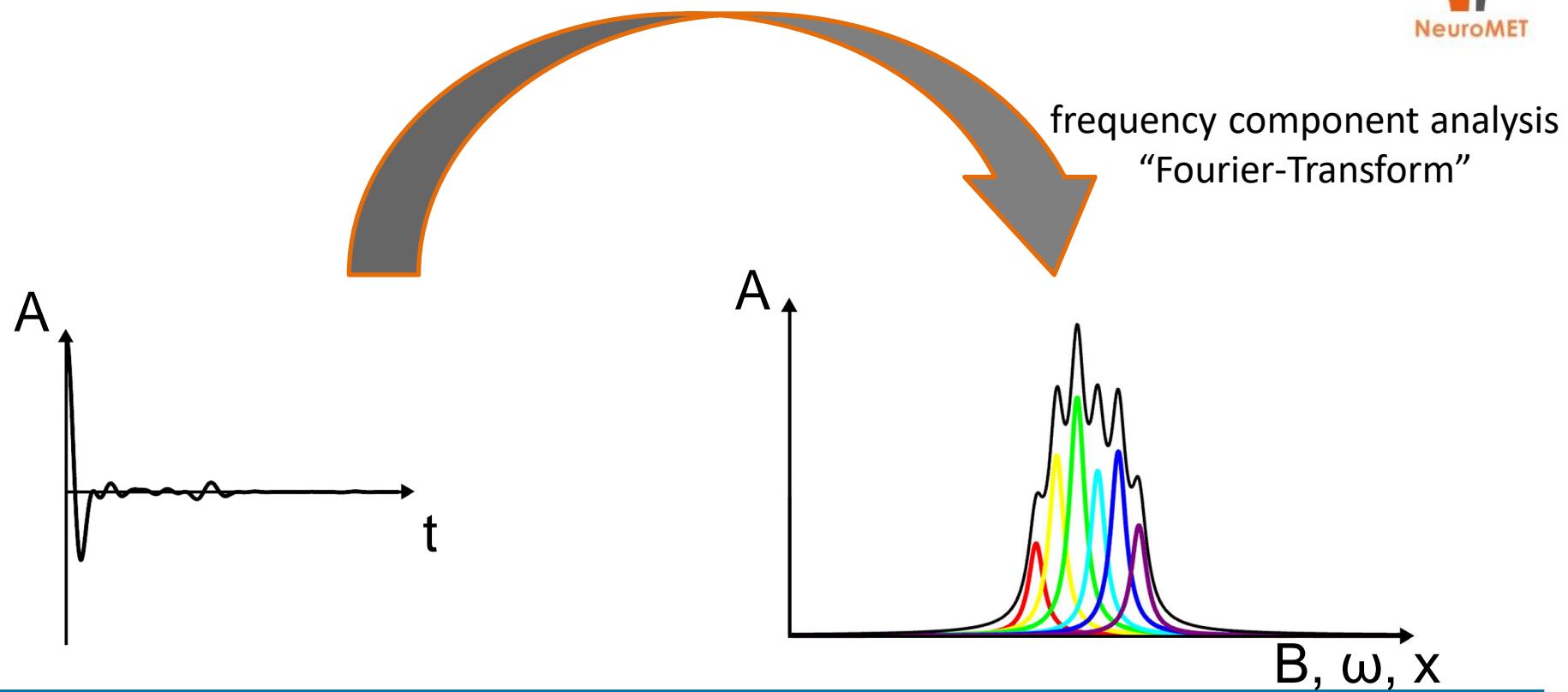
stronger  
magnetic field



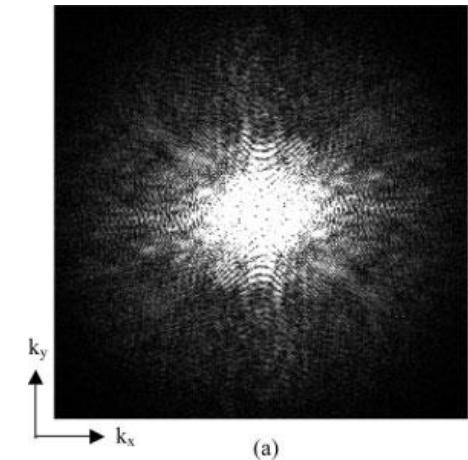
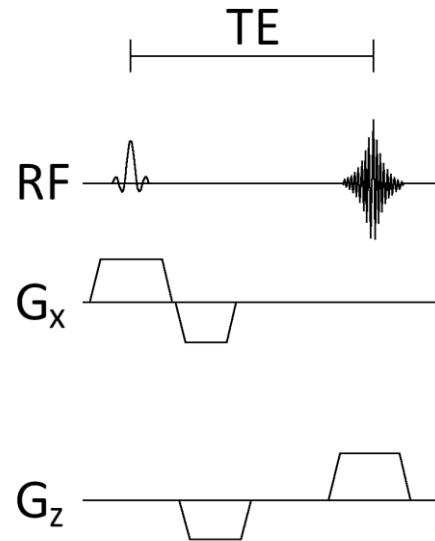
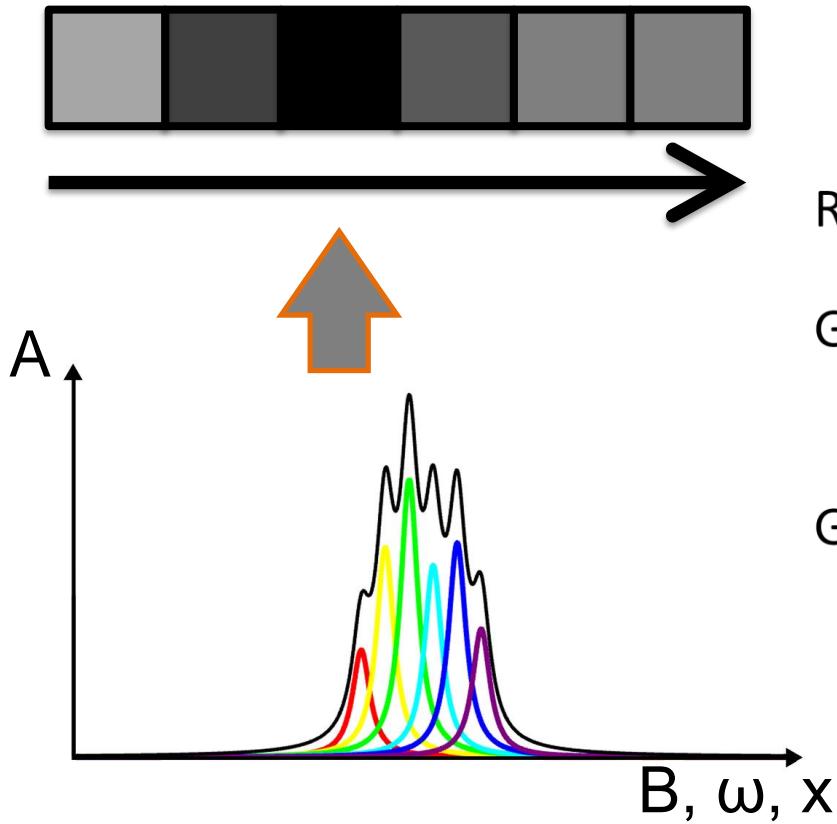
# MR Imaging: Recap



# MR Imaging: Recap

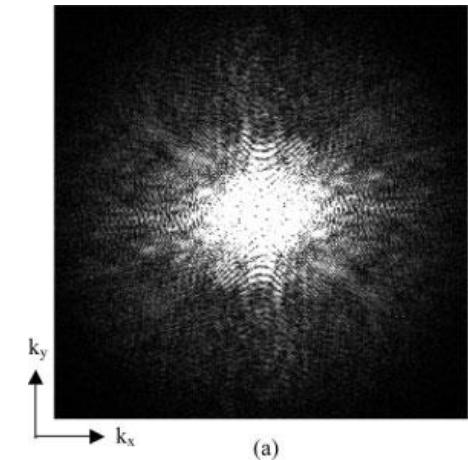
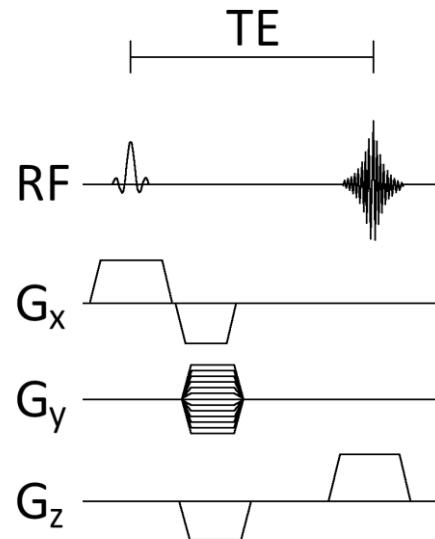
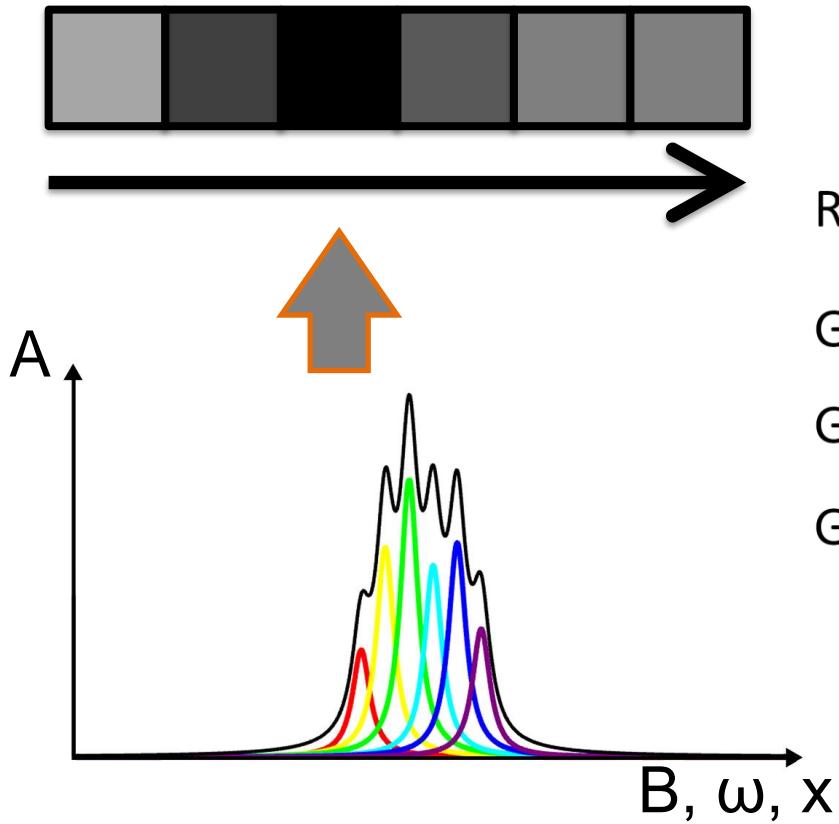


# MR Imaging: Recap



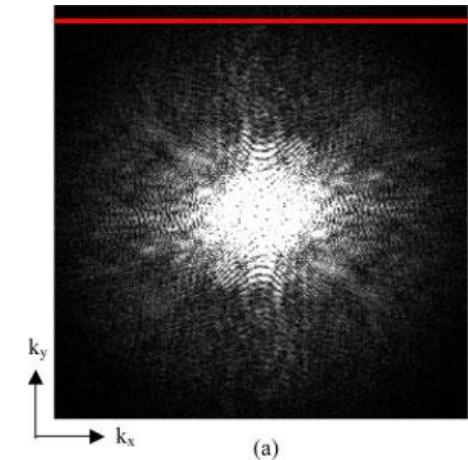
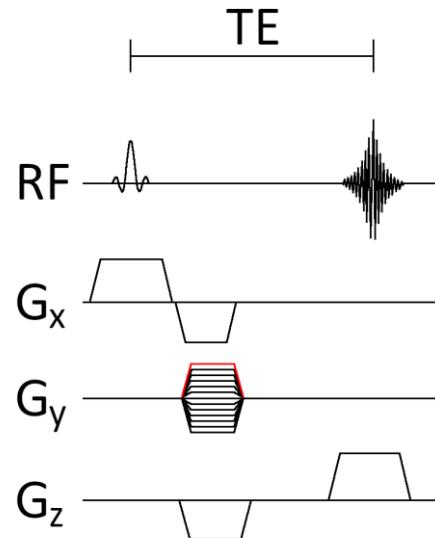
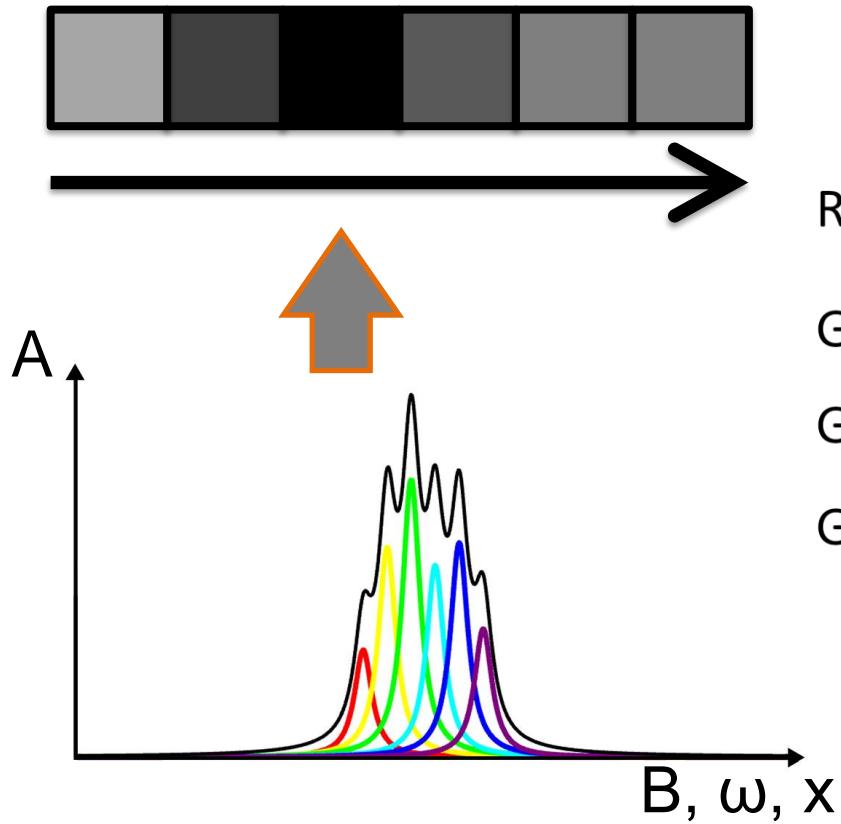
C.Paschal et al., JMRI 19:154-159 (2004)

# MR Imaging: Recap



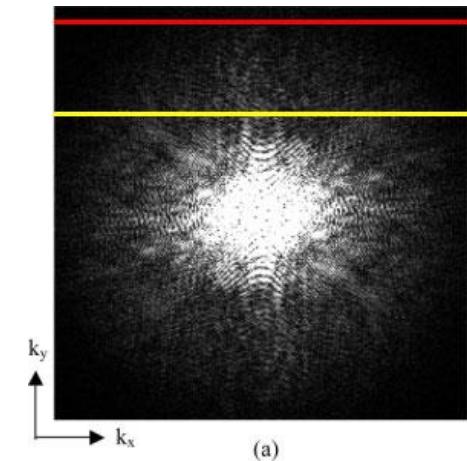
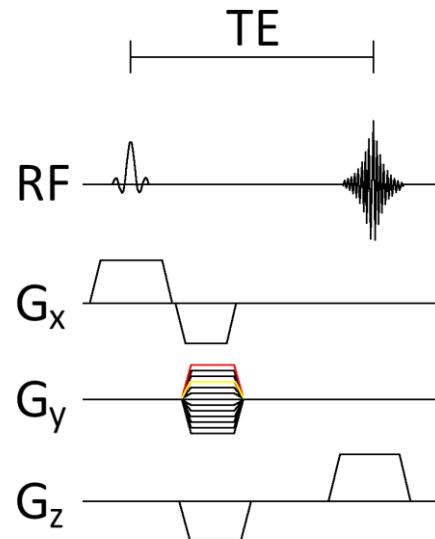
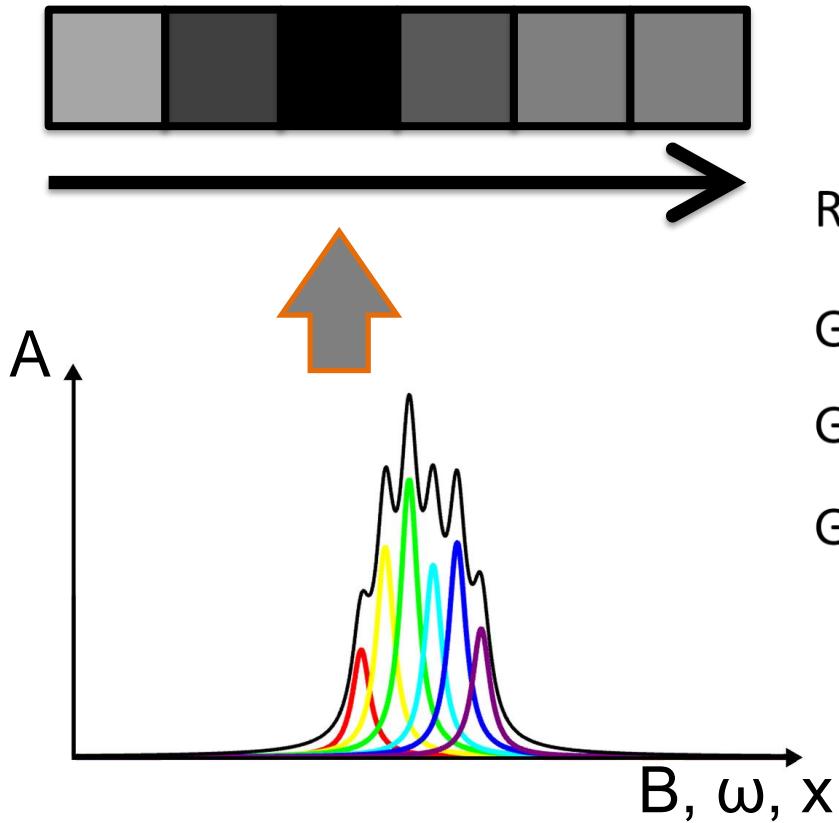
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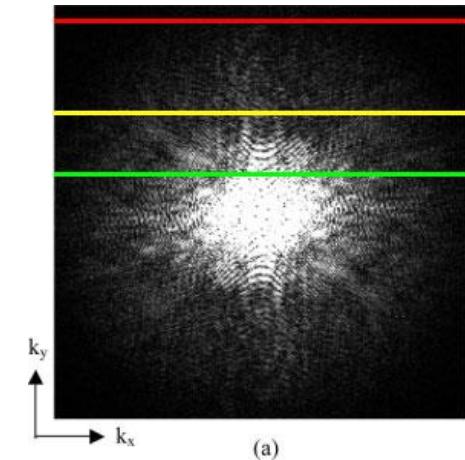
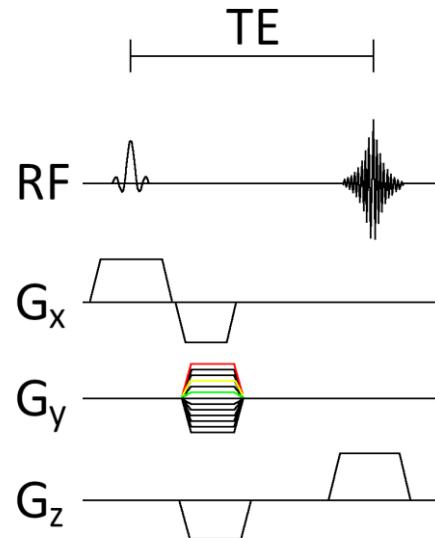
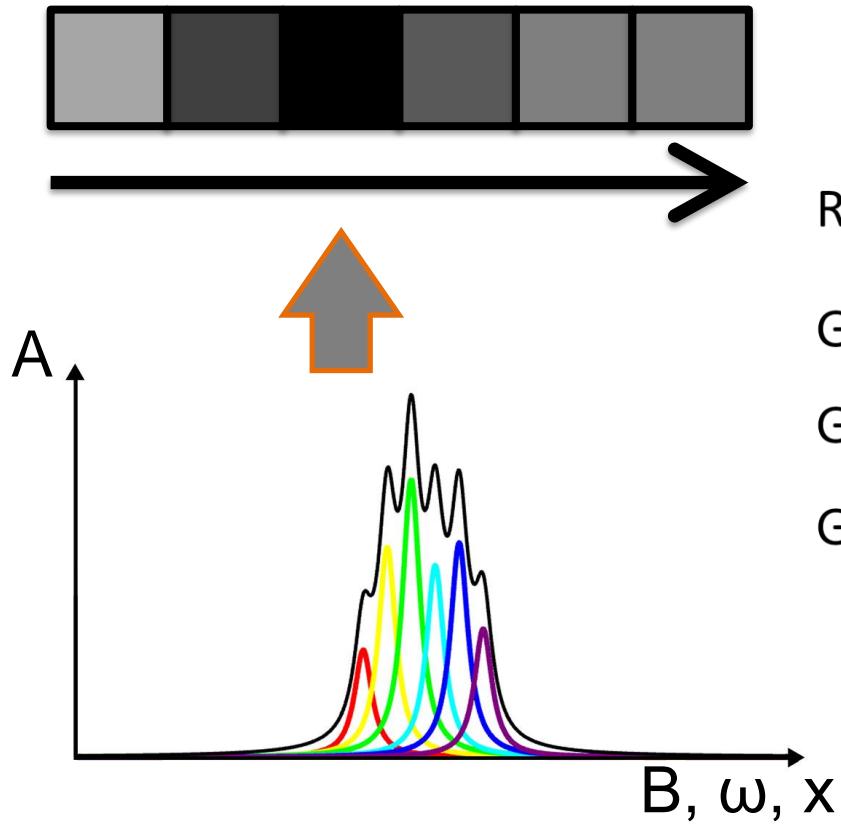
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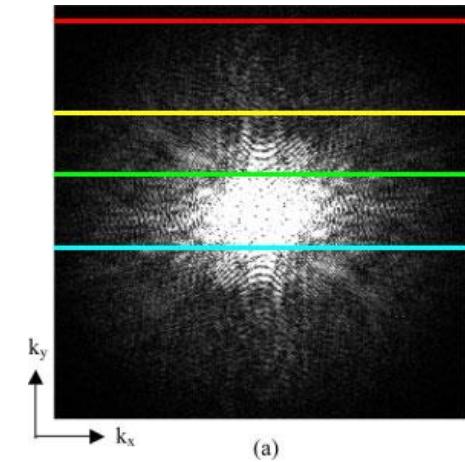
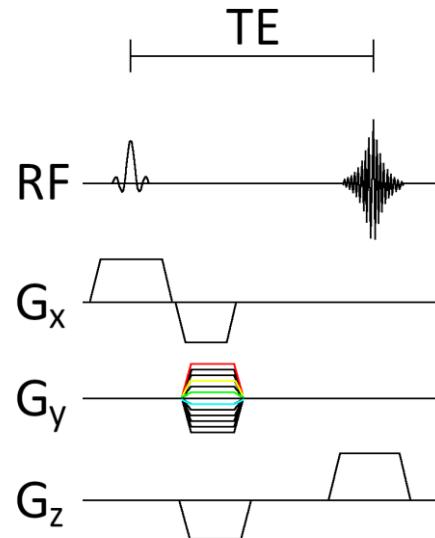
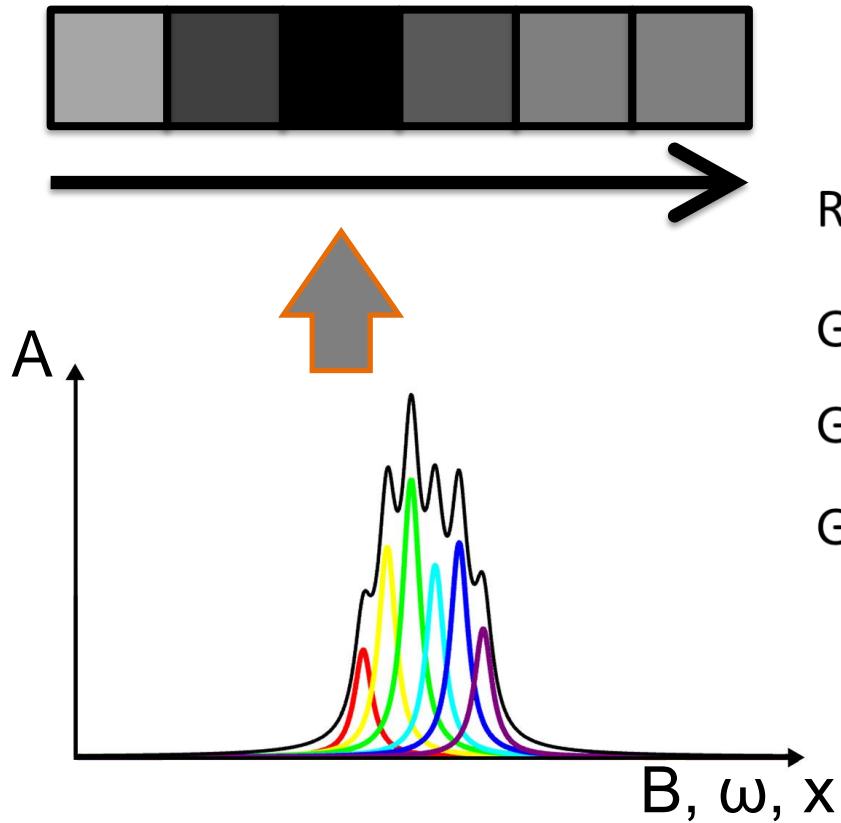
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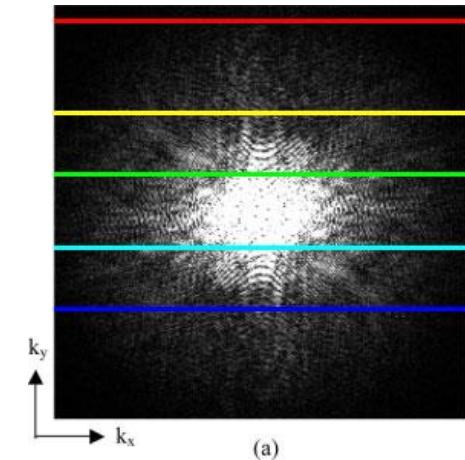
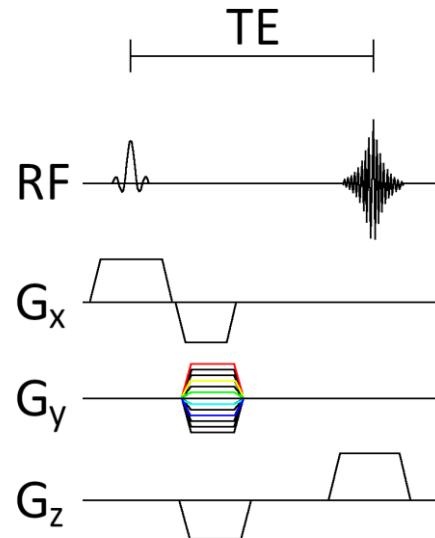
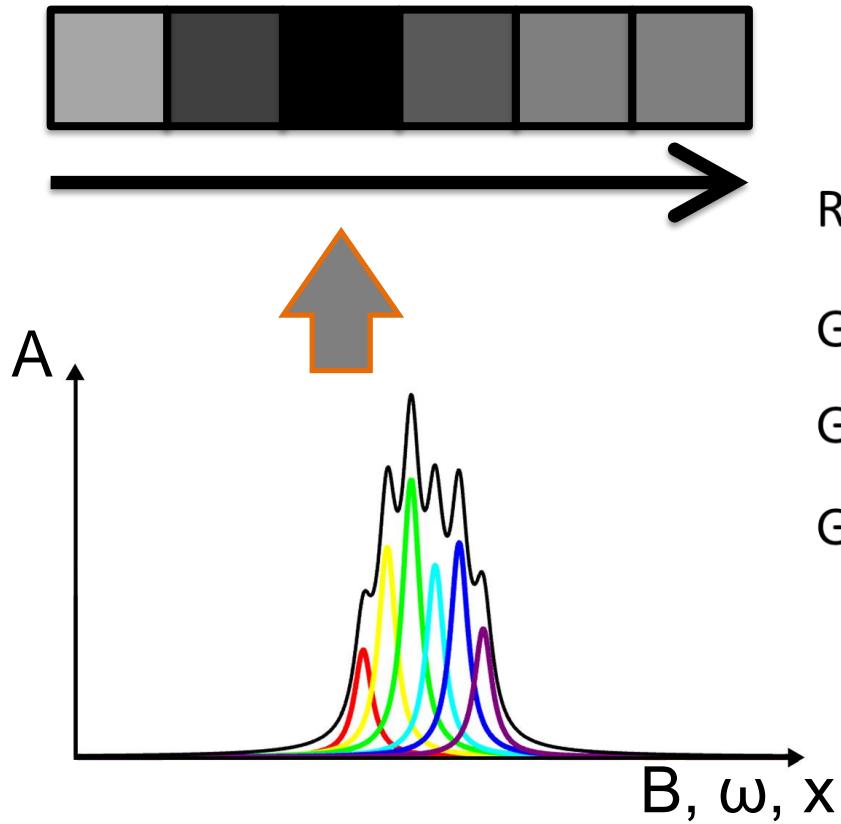
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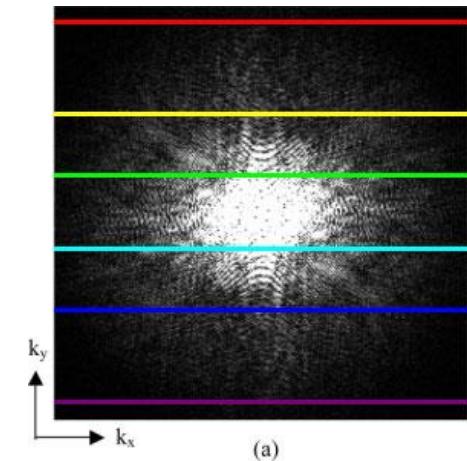
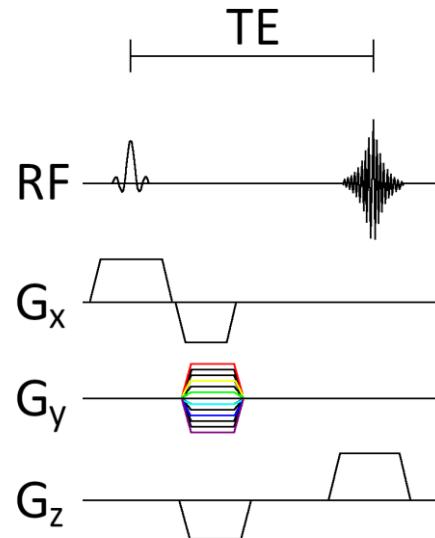
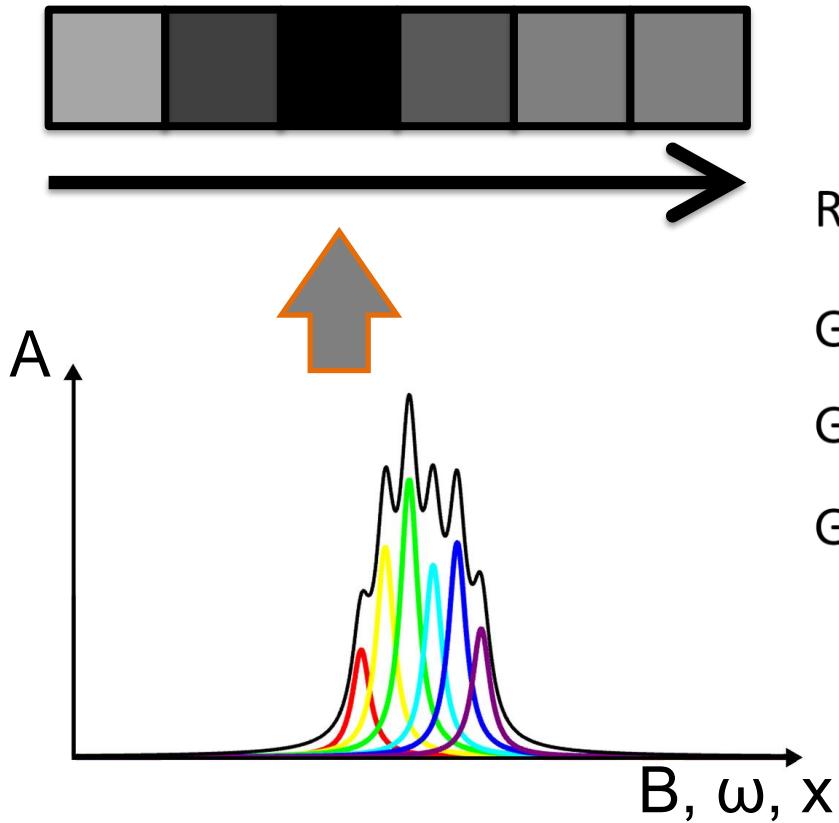
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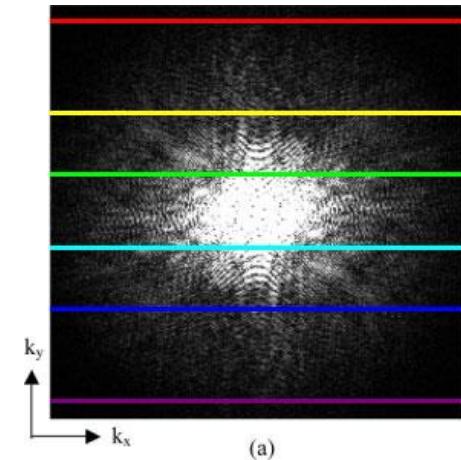
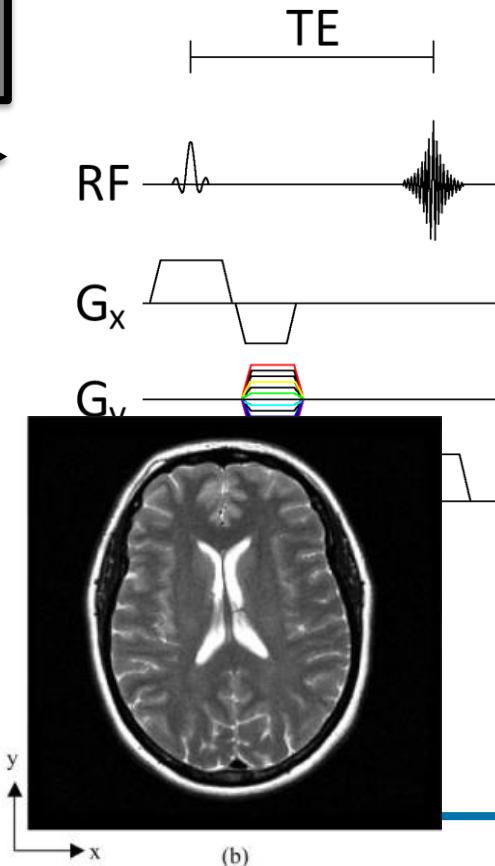
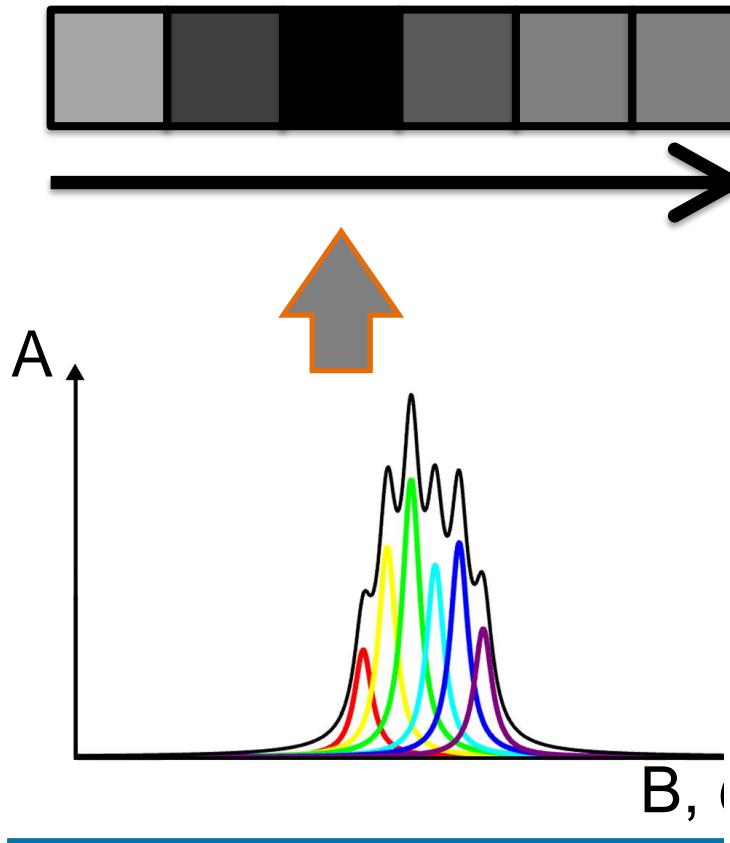
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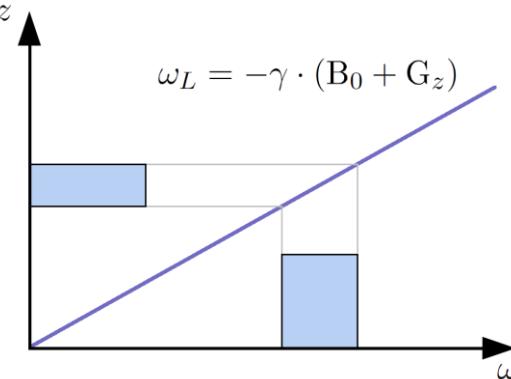
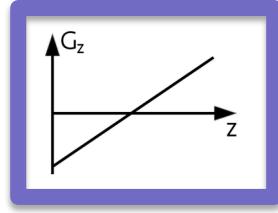
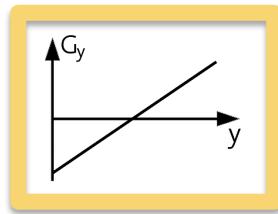
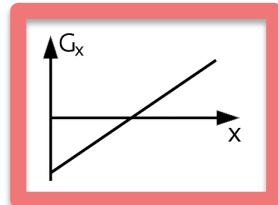
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# Questions?

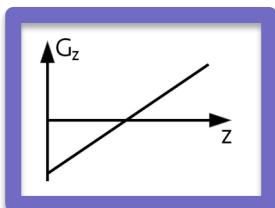
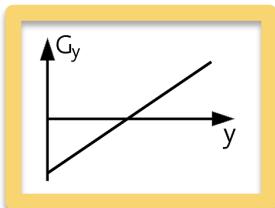
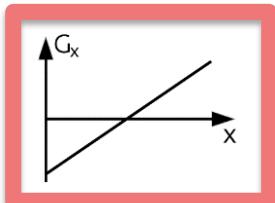
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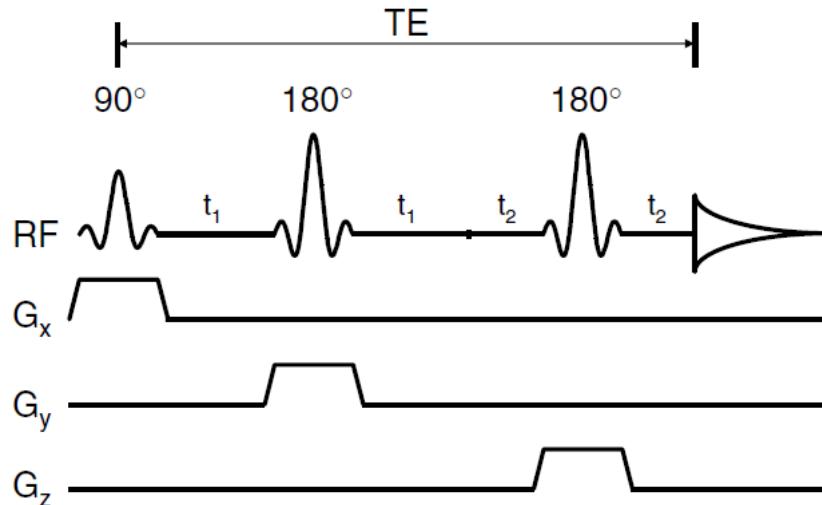
# MR Spectroscopy: Difference from Imaging



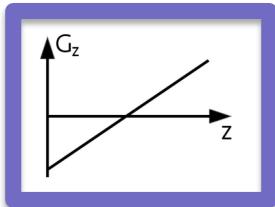
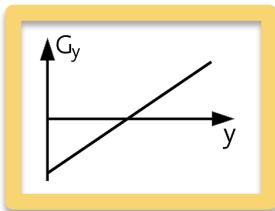
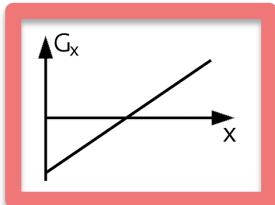
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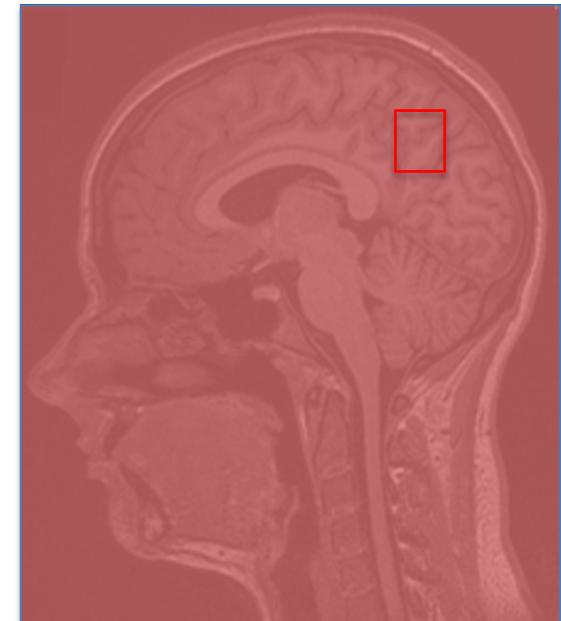
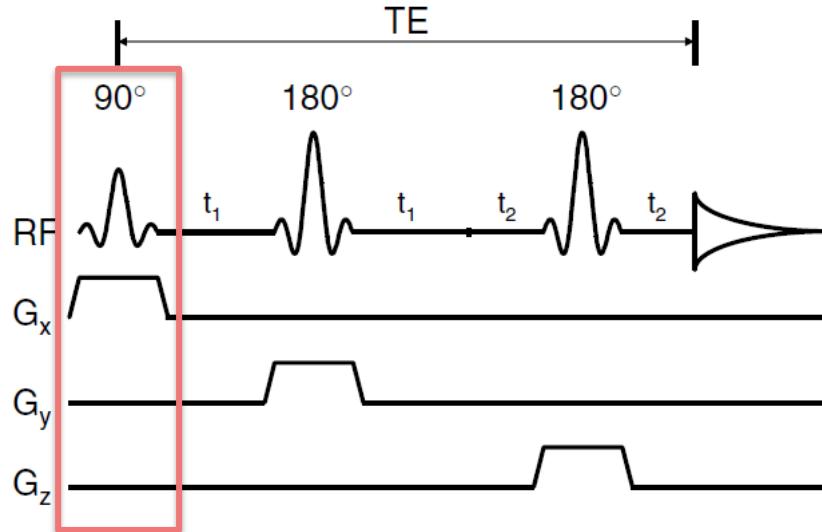
## Point Resolved Spectroscopy (PRESS)



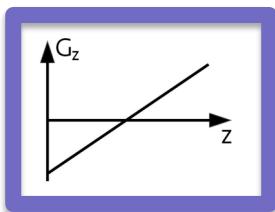
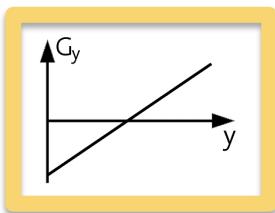
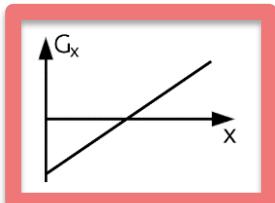
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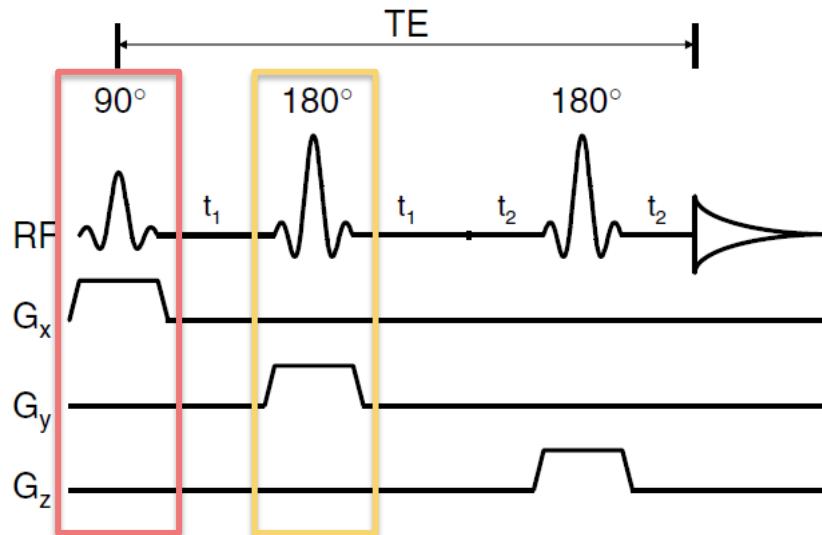
## Point Resolved Spectroscopy (PRESS)



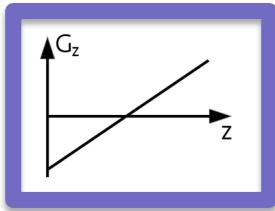
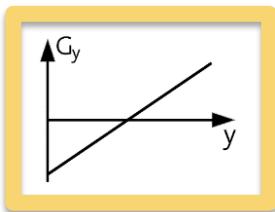
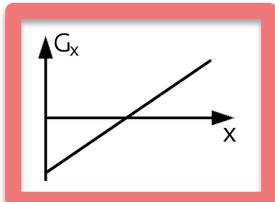
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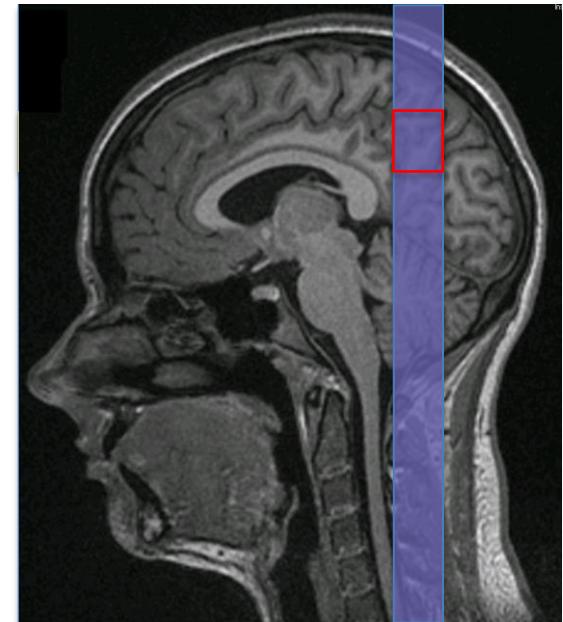
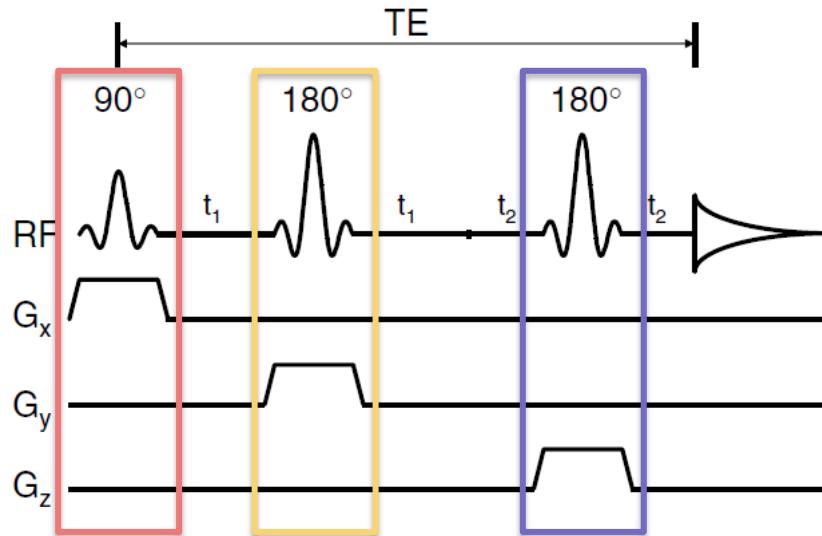
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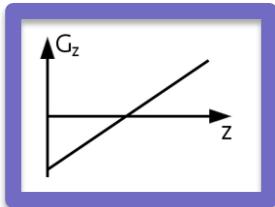
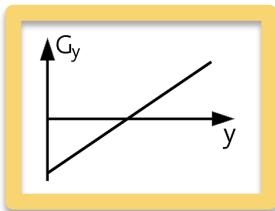
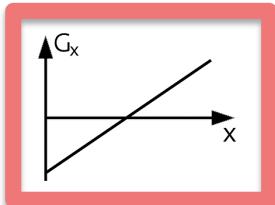
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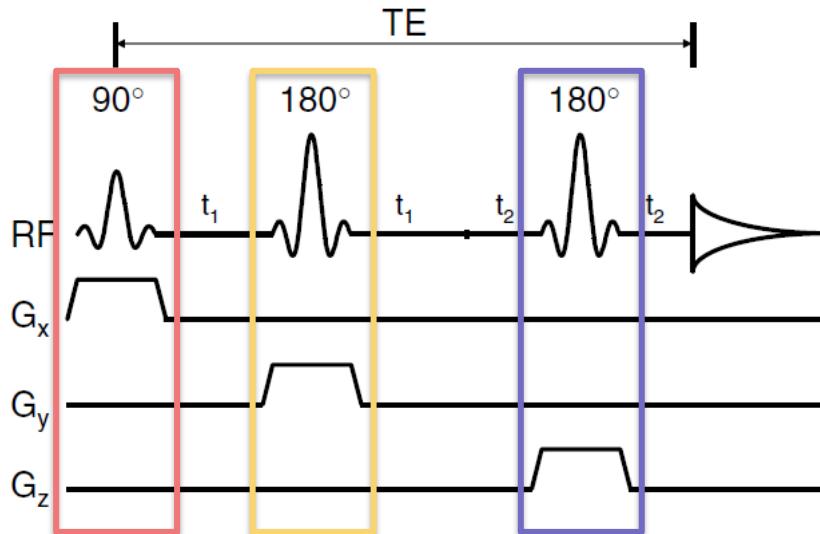
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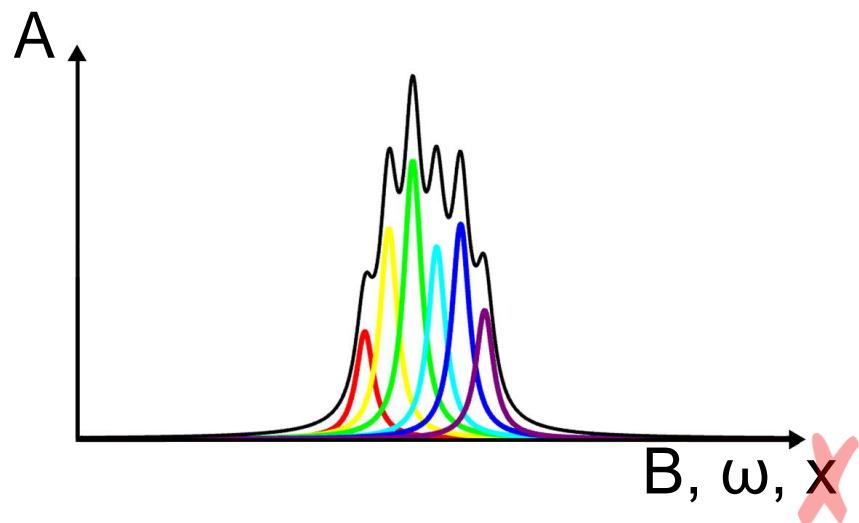
# MR Spectroscopy: Difference from Imaging



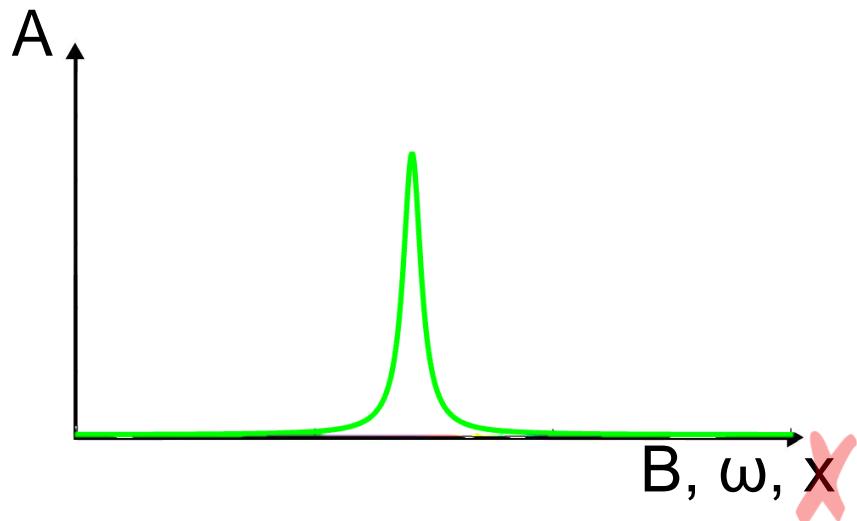
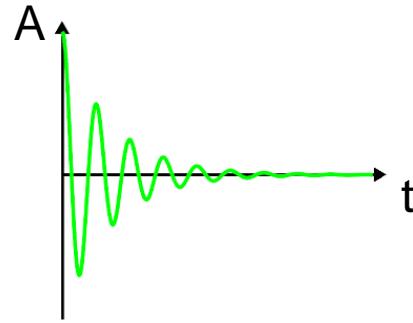
## Point Resolved Spectroscopy (PRESS)



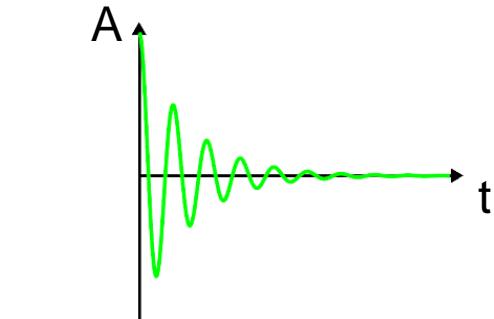
# MR Spectroscopy: Difference from Imaging



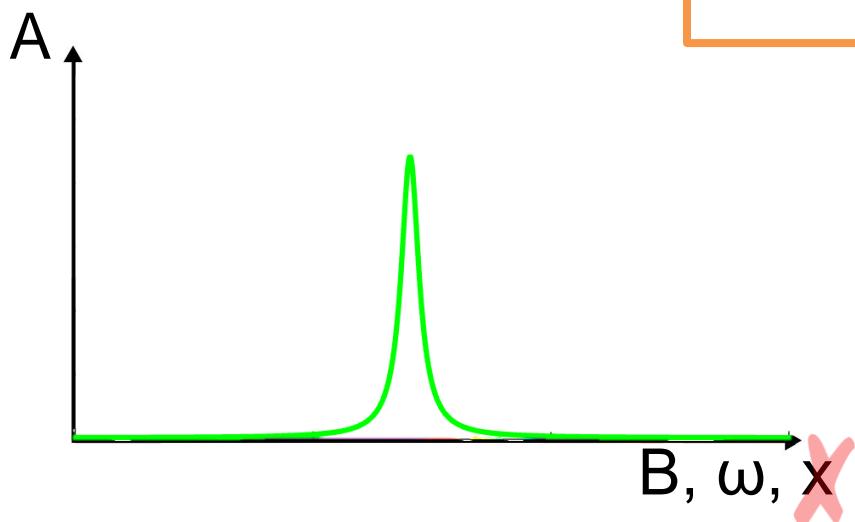
# MR Spectroscopy: Difference from Imaging



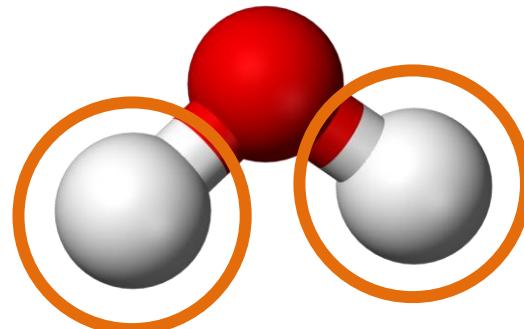
# MR Spectroscopy: Difference from Imaging



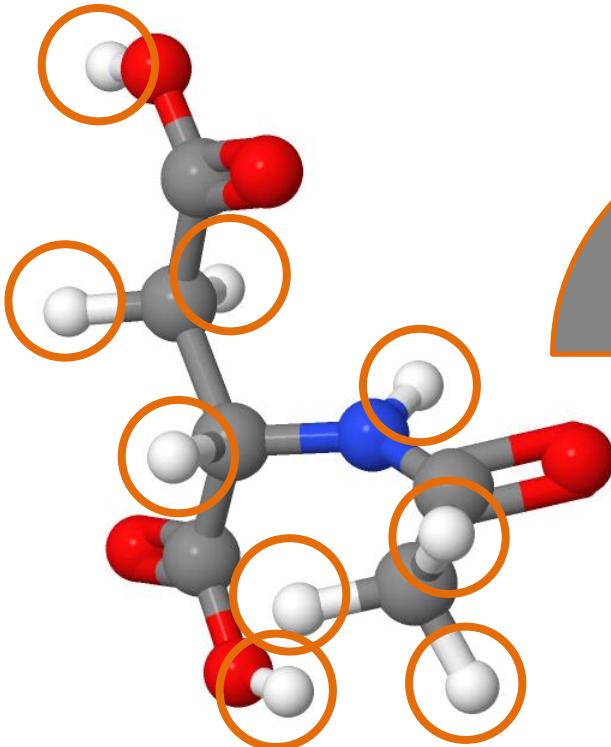
Why do we do this?



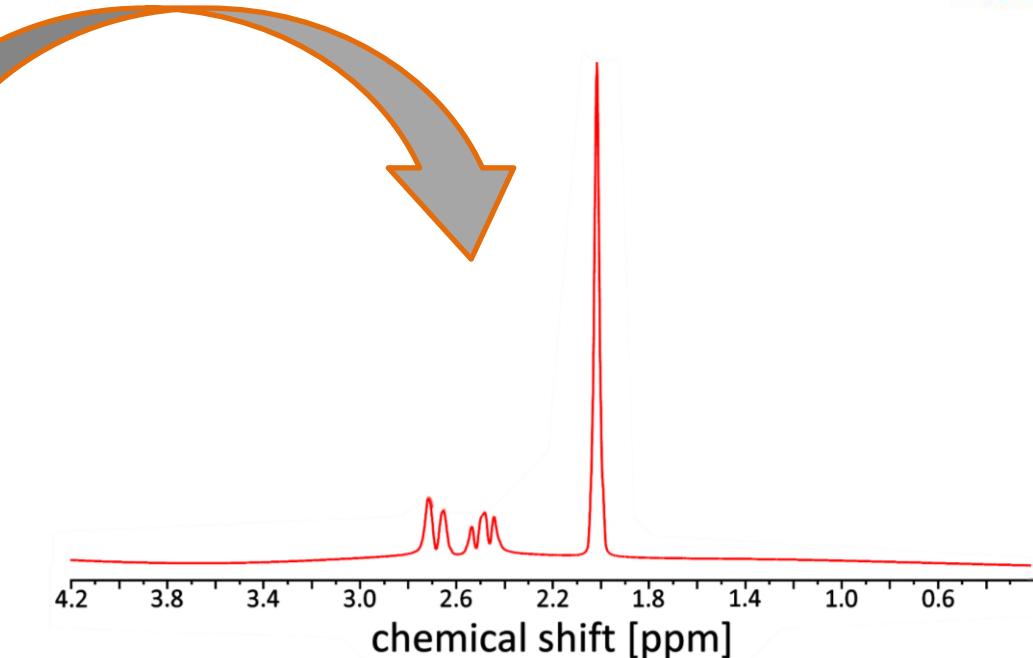
Remember, so far we have only talked about water molecules!



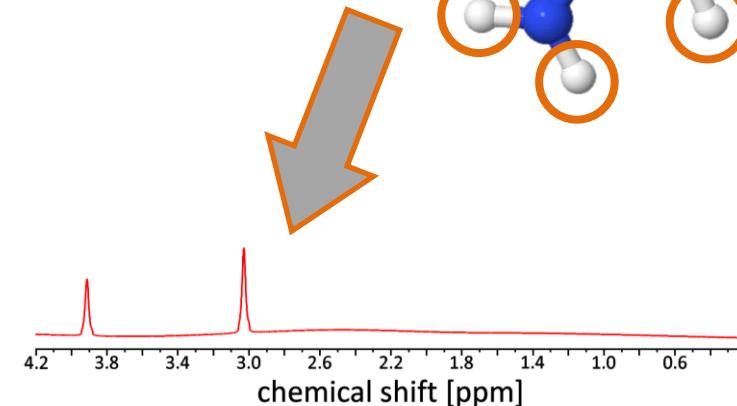
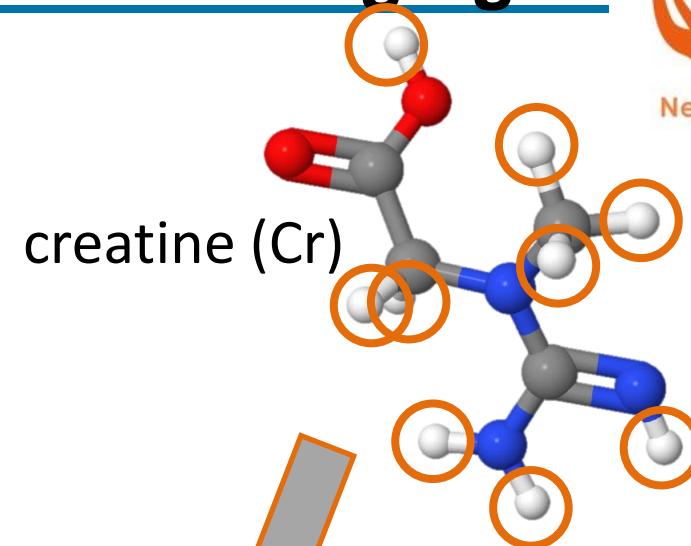
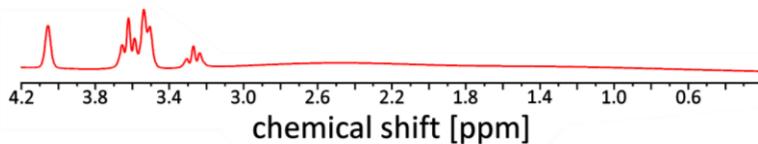
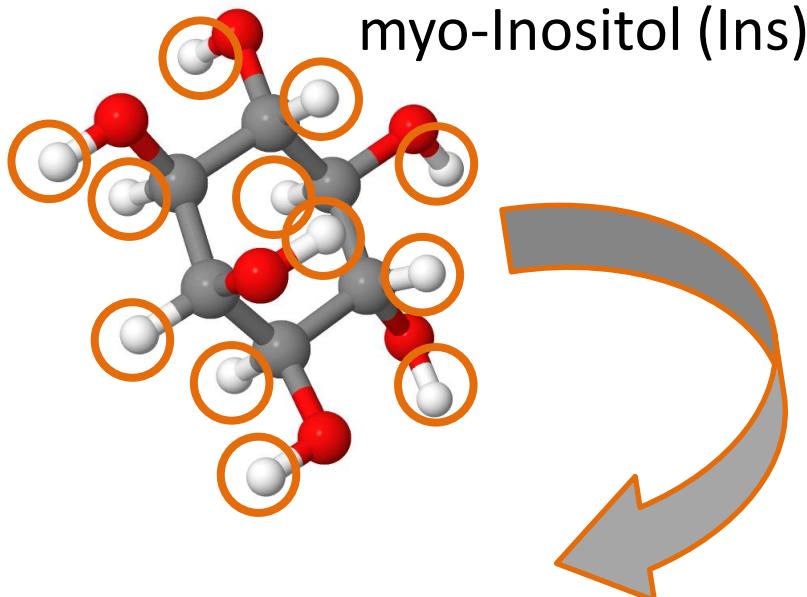
# MR Spectroscopy: Difference from Imaging



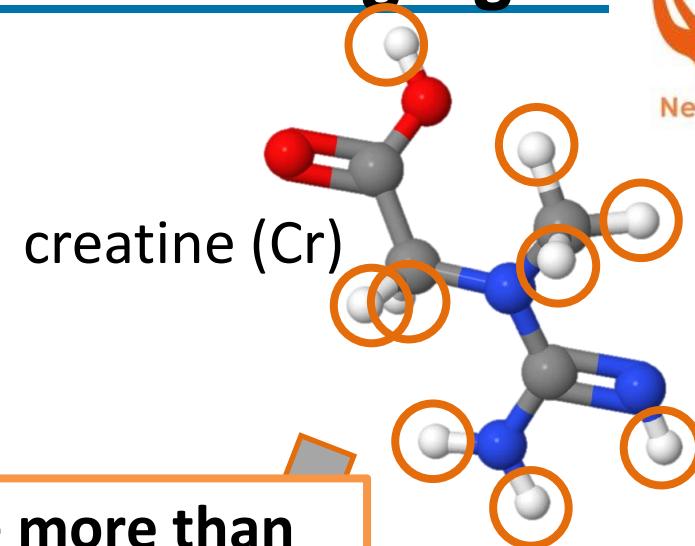
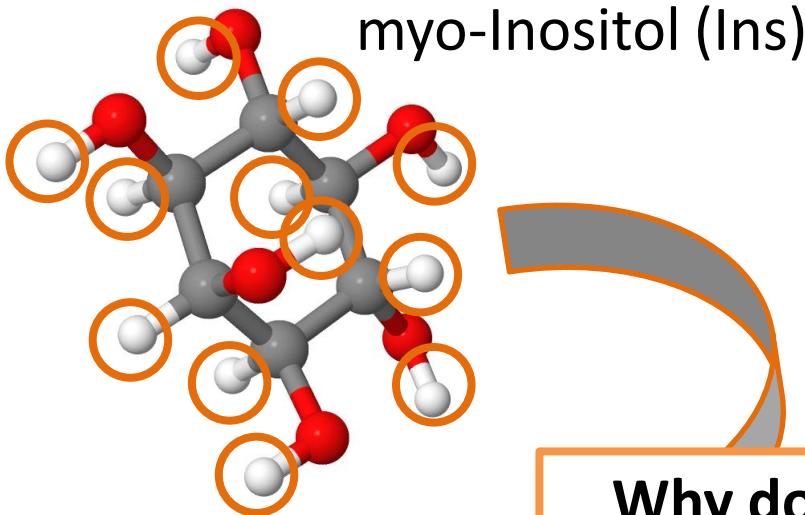
N-acetyl aspartate (NAA)



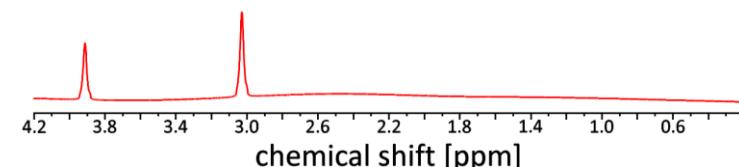
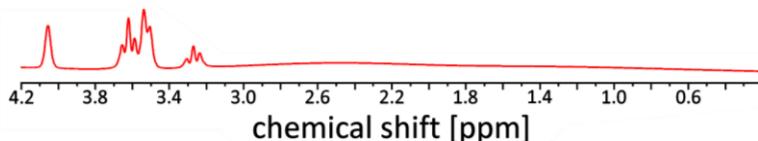
# MR Spectroscopy: Difference from Imaging



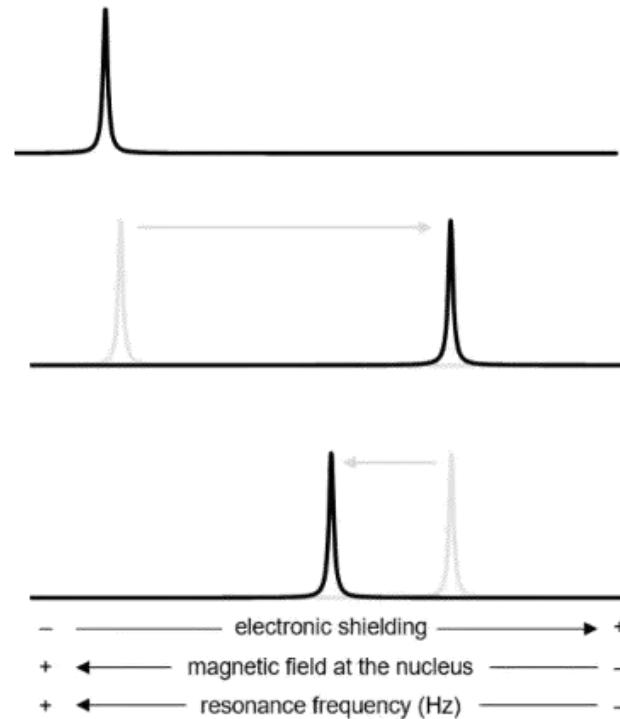
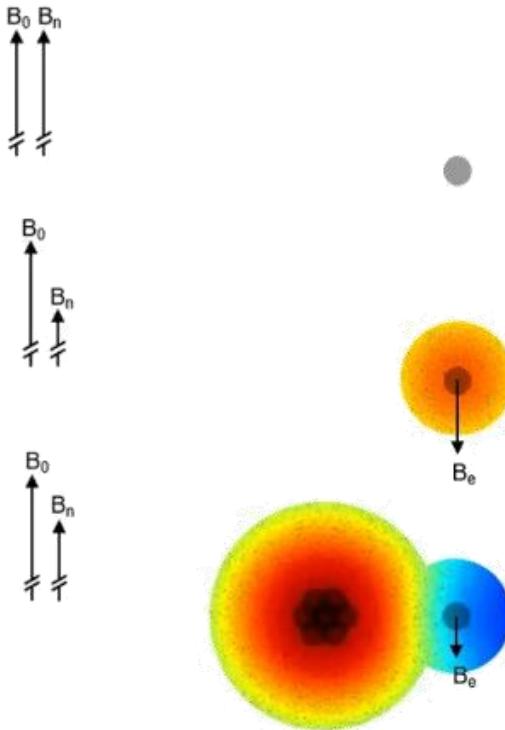
# MR Spectroscopy: Difference from Imaging



Why do we see more than  
one peak?

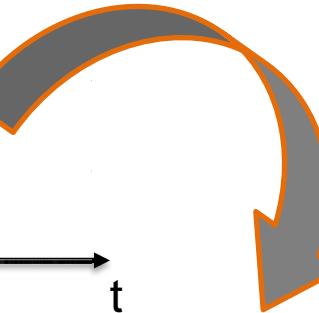
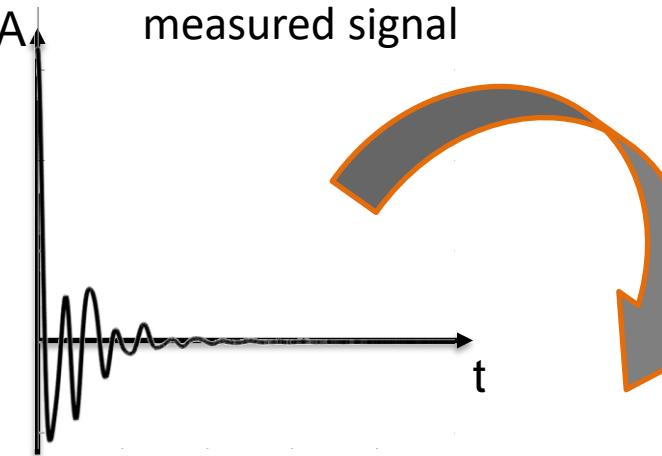
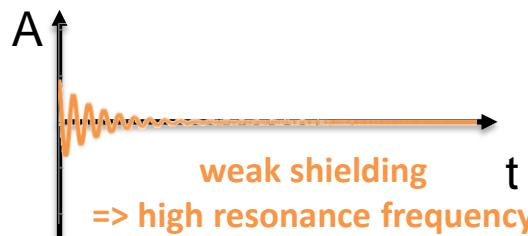
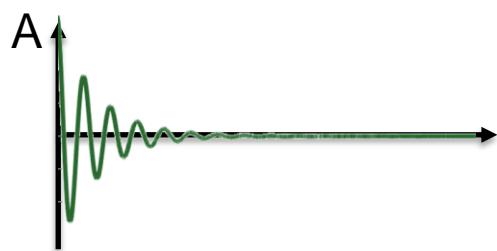
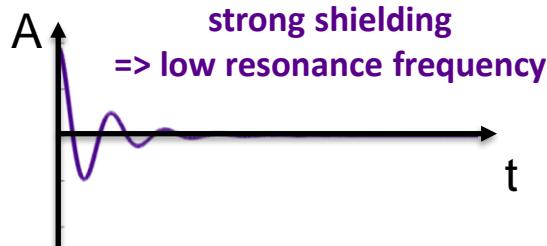


# MR Spectroscopy: Chemical Shift

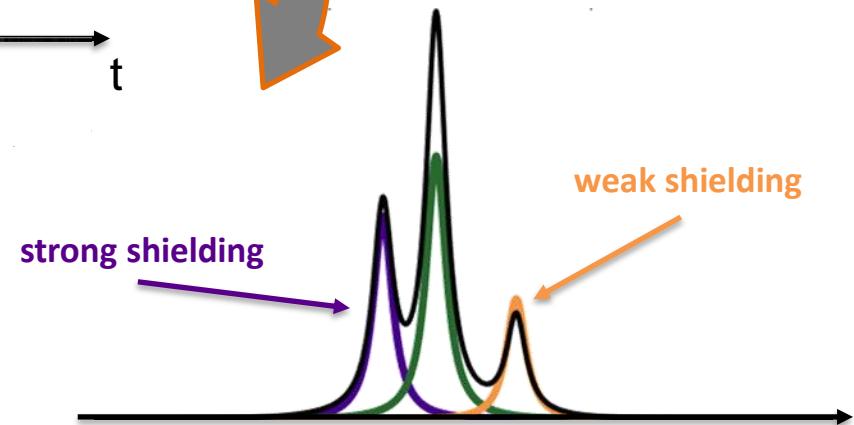


<https://www.youtube.com/watch?v=ImITvTlQeFQ>

# MR Spectroscopy: Chemical Shift



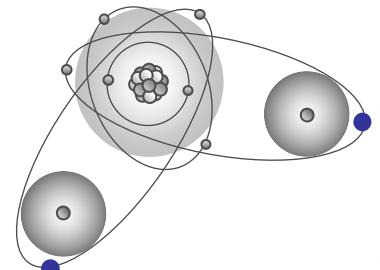
Fourier-Transform



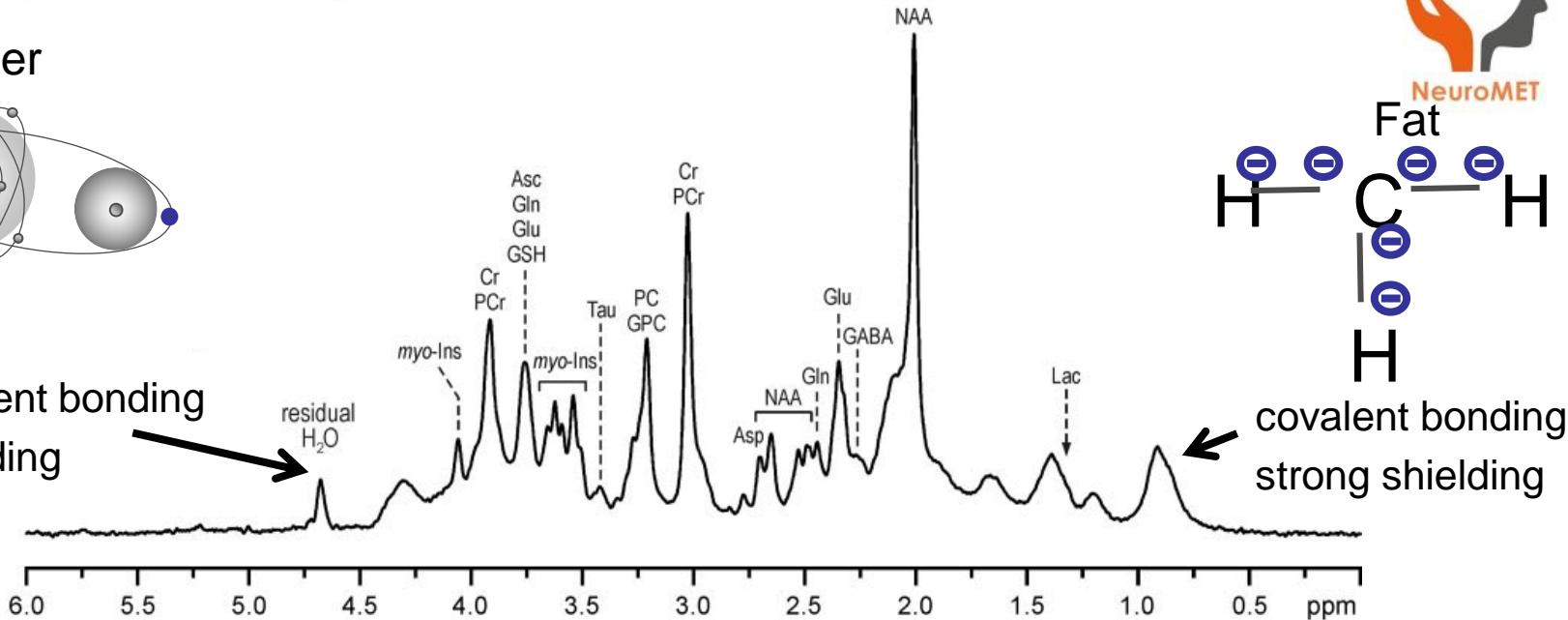
# MR Spectroscopy: Chemical Shift



Water



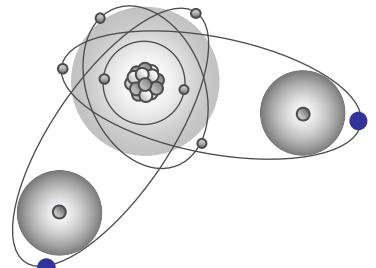
polar covalent bonding  
weak shielding



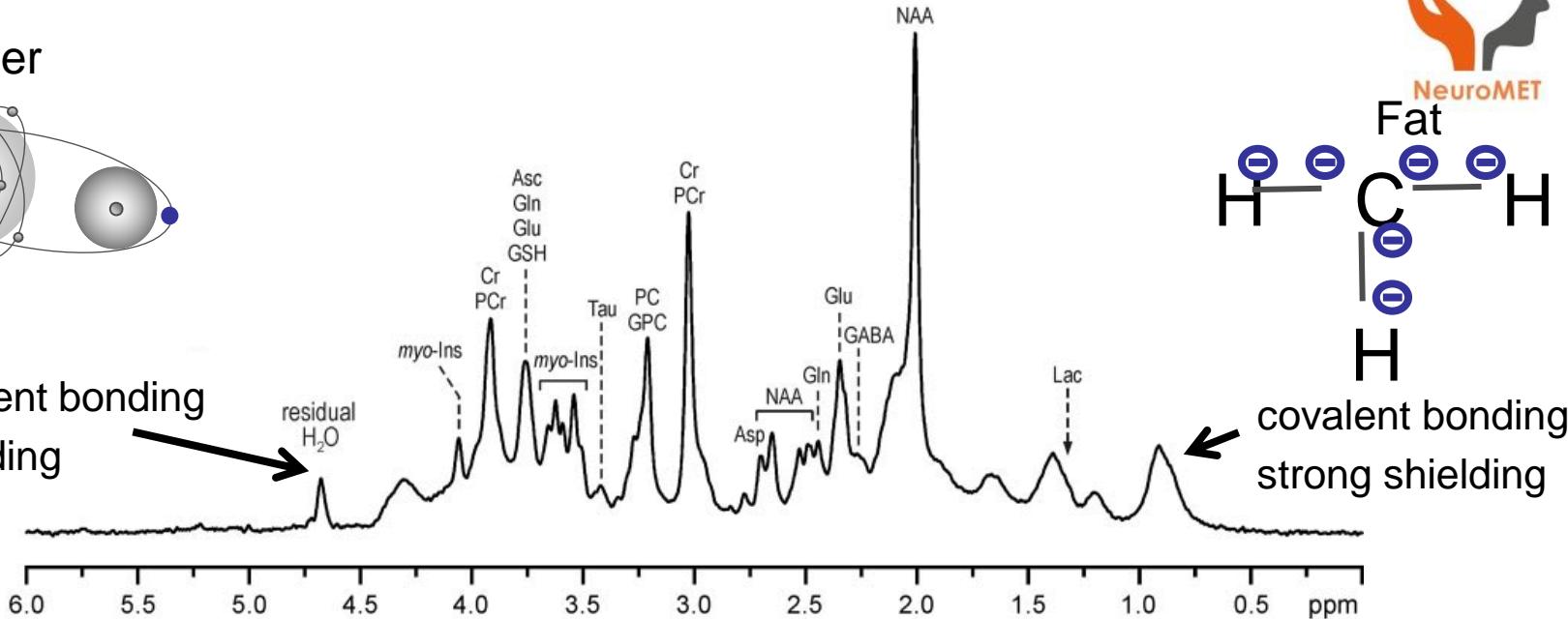
# MR Spectroscopy: Chemical Shift



Water



polar covalent bonding  
weak shielding

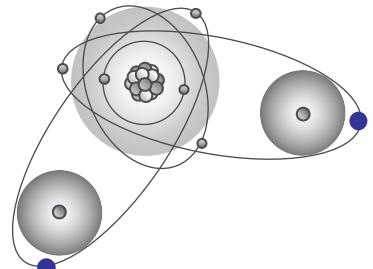


mag. field at nucleus

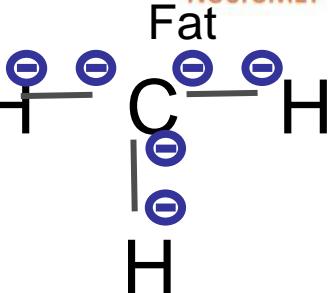
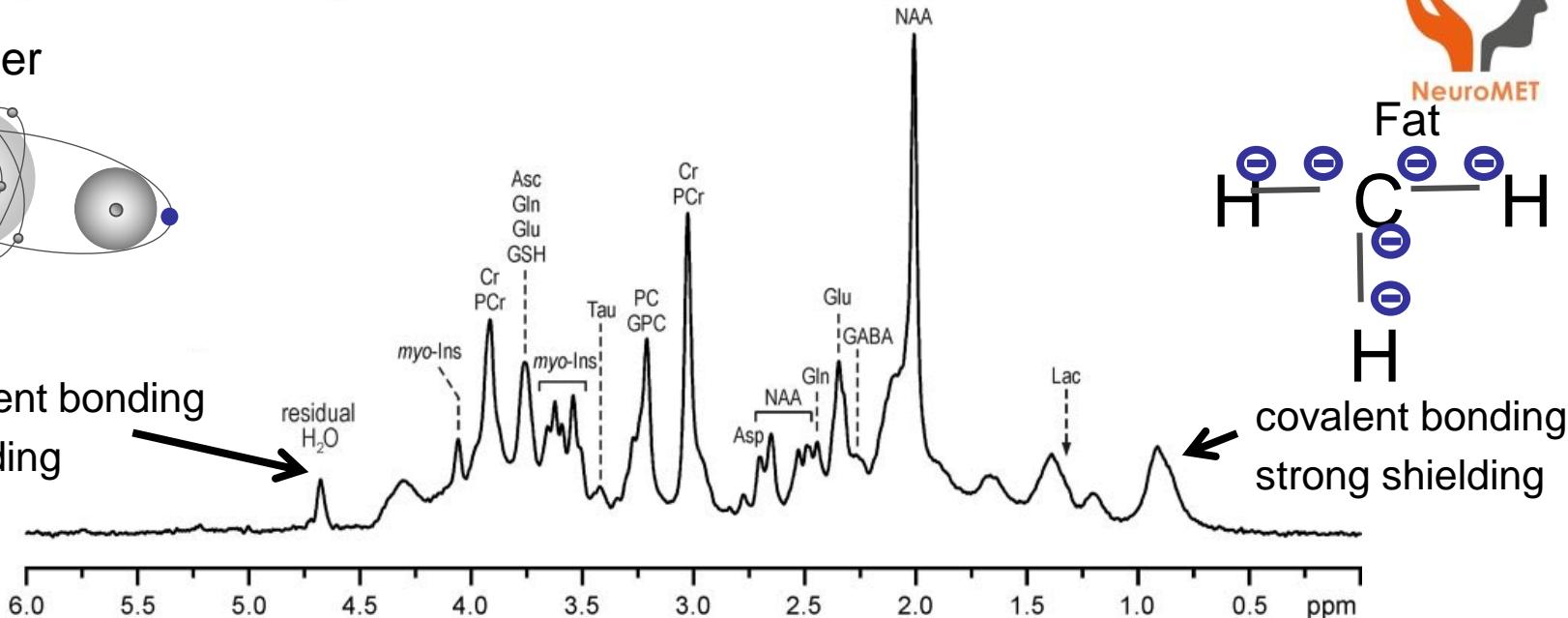
# MR Spectroscopy: Chemical Shift



Water



polar covalent bonding  
weak shielding



Fat

H

C

H

H

H

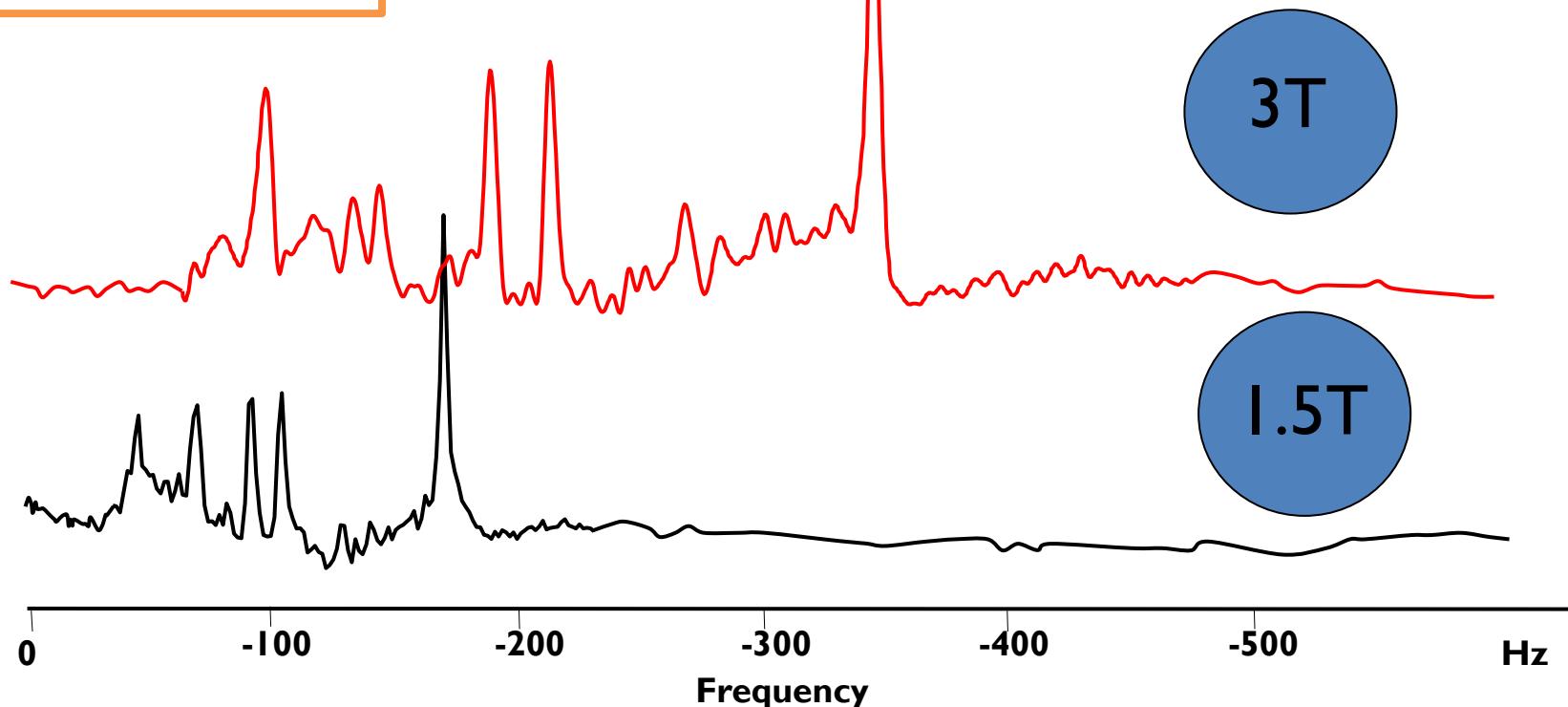
covalent bonding  
strong shielding

resonance frequency (energy)

# MR Spectroscopy: Chemical Shift



Hz Scaling



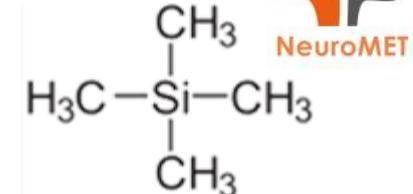
# MR Spectroscopy: Chemical Shift



$$\delta = \frac{\nu - \nu_{ref}}{\nu_{ref}} \cdot 10^6$$

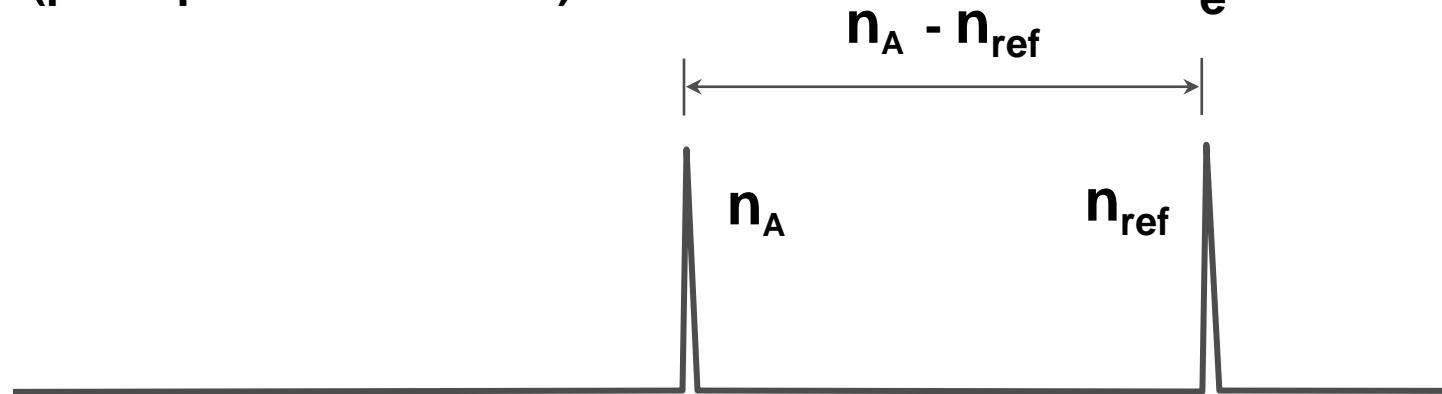
$^1\text{H}$  &  $^{13}\text{C}$ :

$n_{ref} = 0 \text{ ppm} = n_{\text{TMS}}$



unit: ppm (parts per million =  $10^{-6}$ )

TMS:  
tetramethylsilane

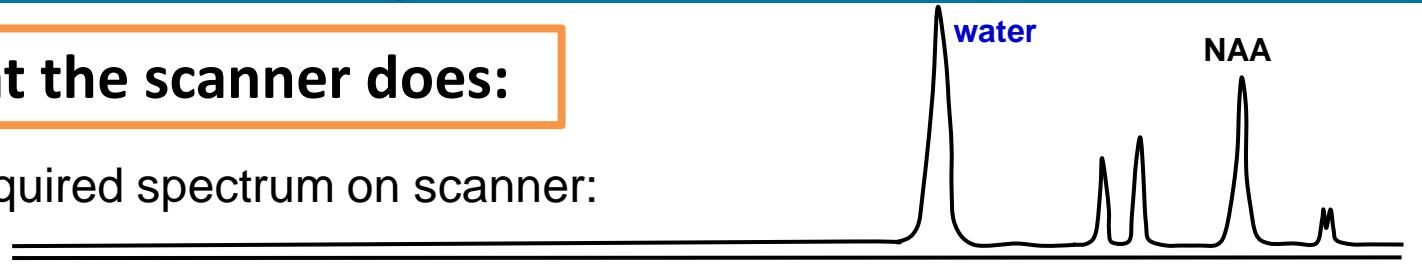


# MR Spectroscopy: Chemical Shift

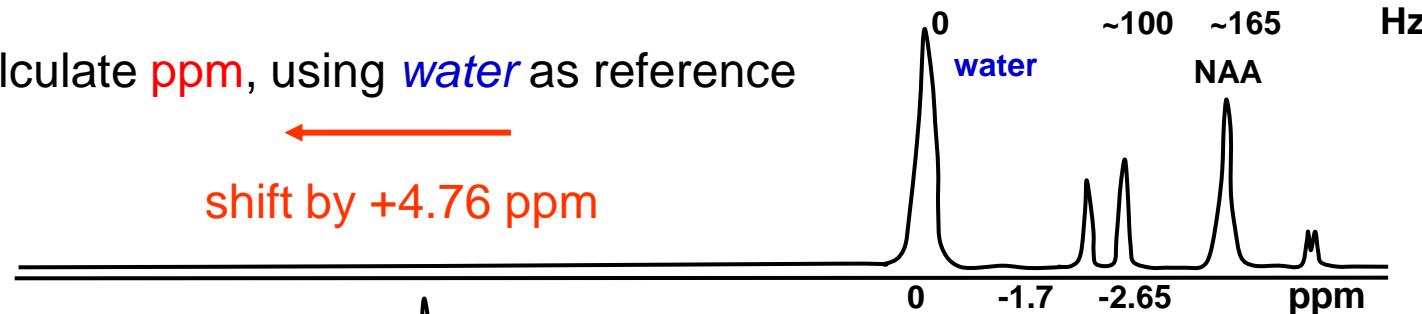


What the scanner does:

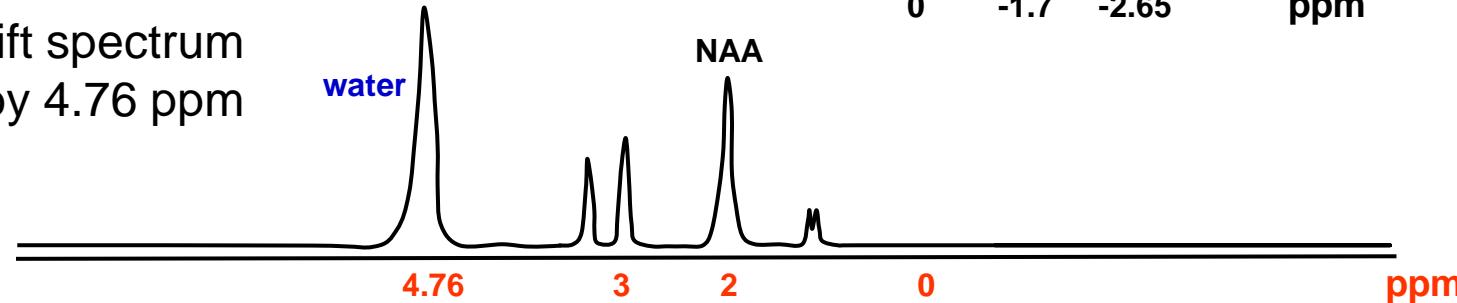
1. Acquired spectrum on scanner:



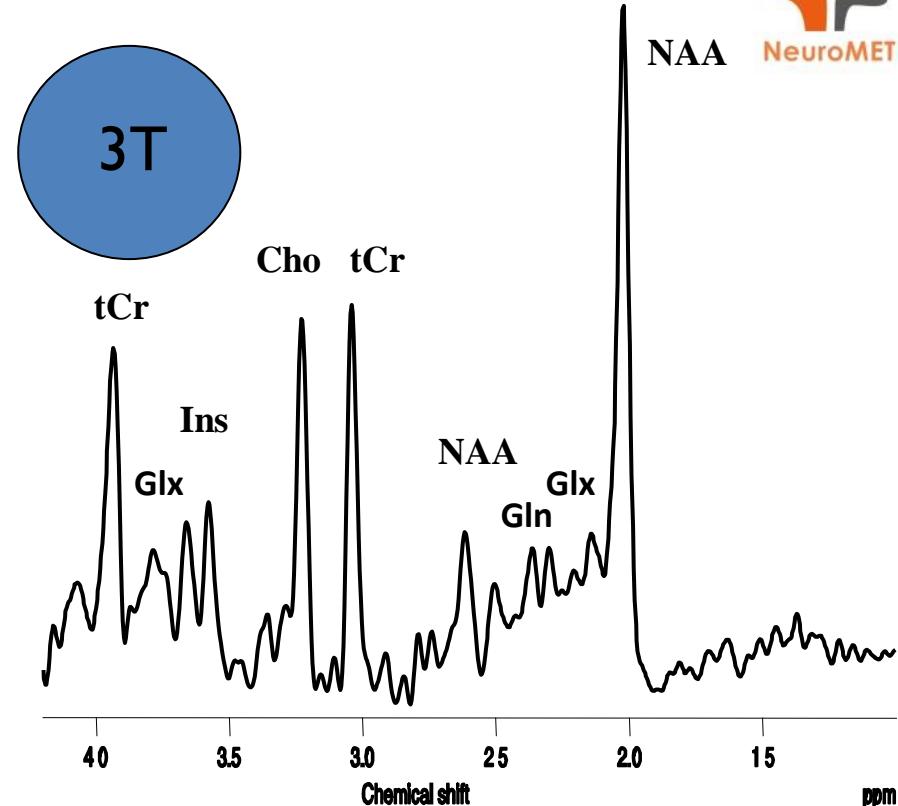
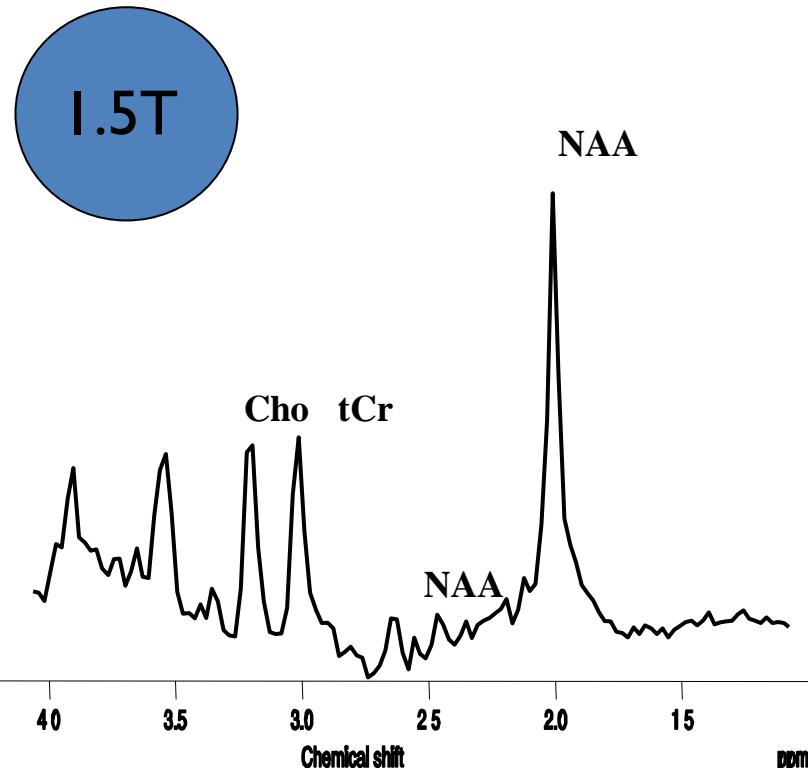
2. Calculate ppm, using water as reference



3. Shift spectrum by 4.76 ppm



# MR Spectroscopy: Chemical Shift



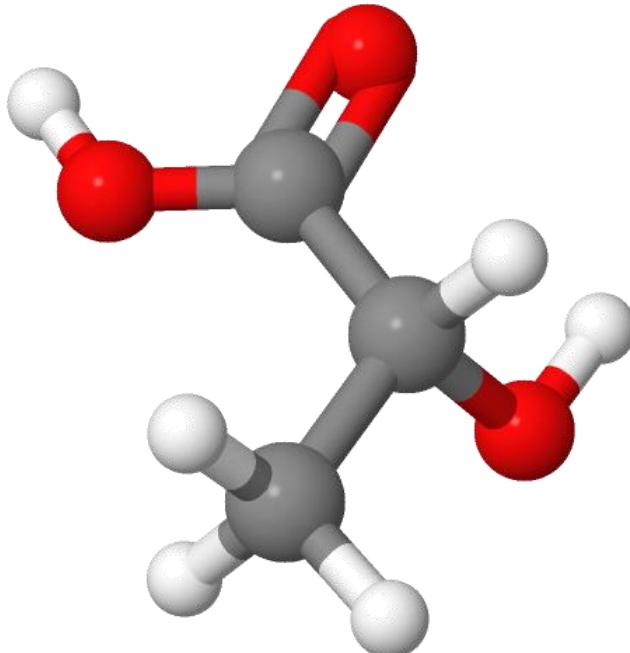
# Questions?

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# J-Coupling

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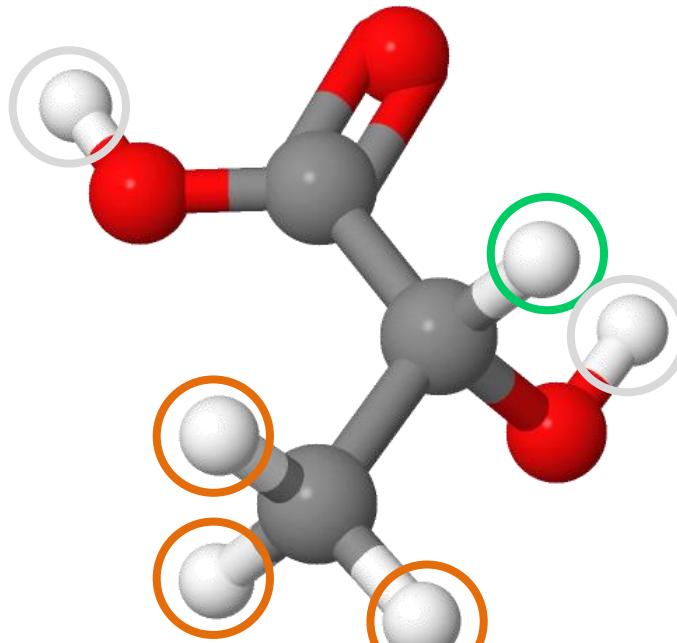


Lactate (Lac)

J-coupling aka  
scalar coupling, spin-spin coupling

- Electron-mediated interaction
- within the same molecule
- typically less than 3 bonds away
- $n+1$  rule predicts number of peaks
- amplitude of peaks predicted by pascal's triangle

# J-Coupling



Lactate (Lac)

J-coupling aka  
scalar coupling, spin-spin coupling

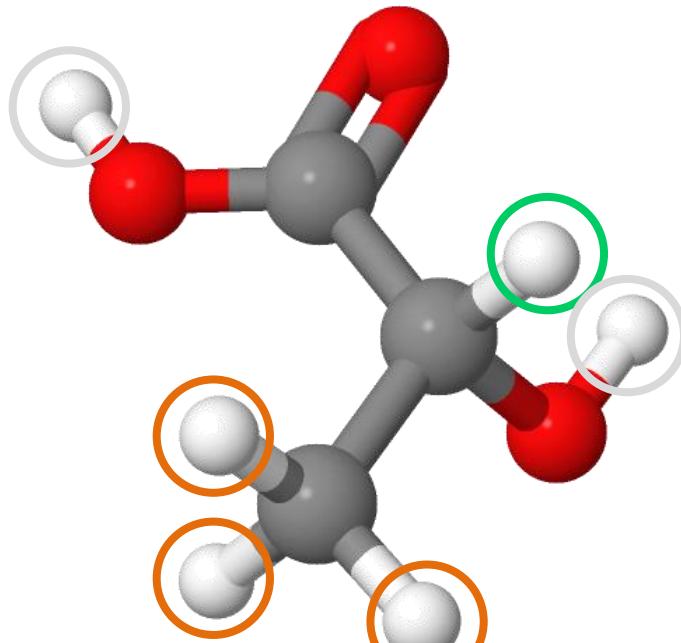
1 proton

1

3 protons

3

# J-Coupling

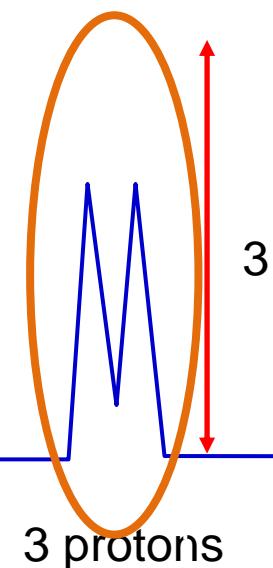


Lactate (Lac)

J-coupling aka  
scalar coupling, spin-spin coupling

1 proton

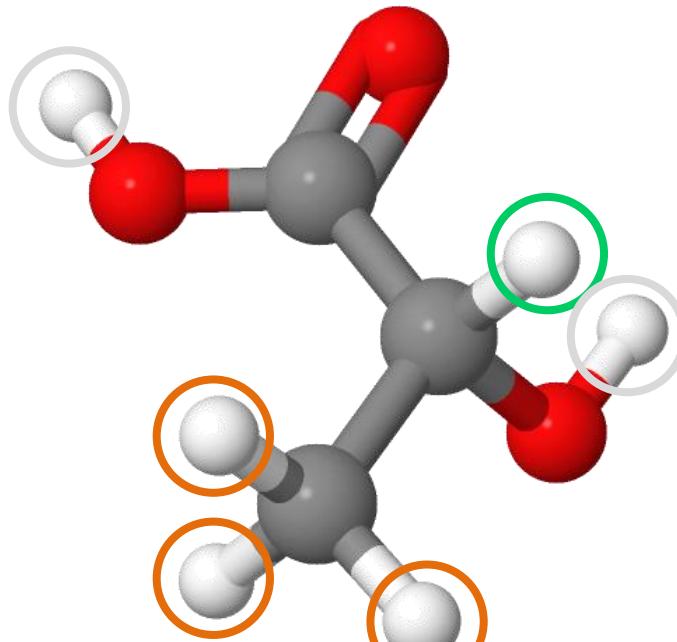
1



3

3 protons

# J-Coupling

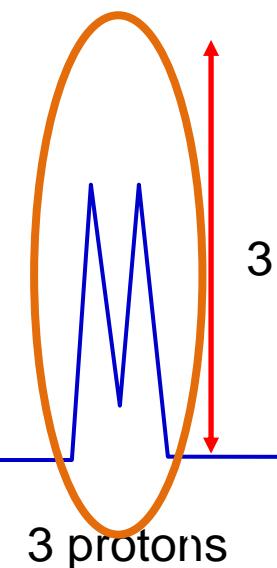


Lactate (Lac)

J-coupling aka  
scalar coupling, spin-spin coupling

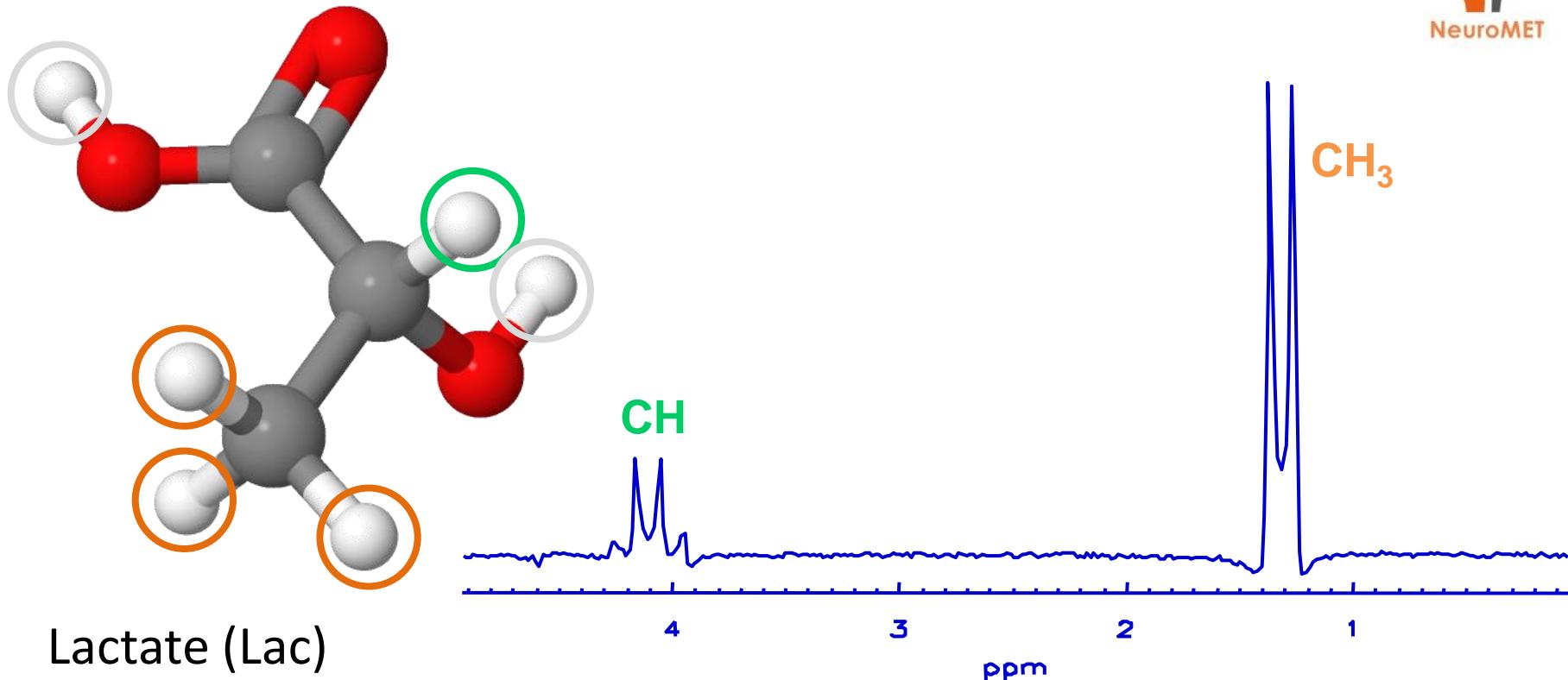
1 proton

1



3 protons

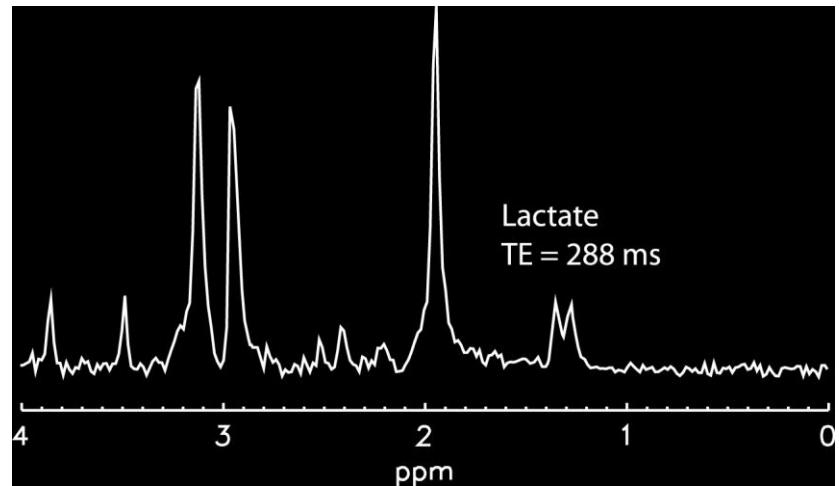
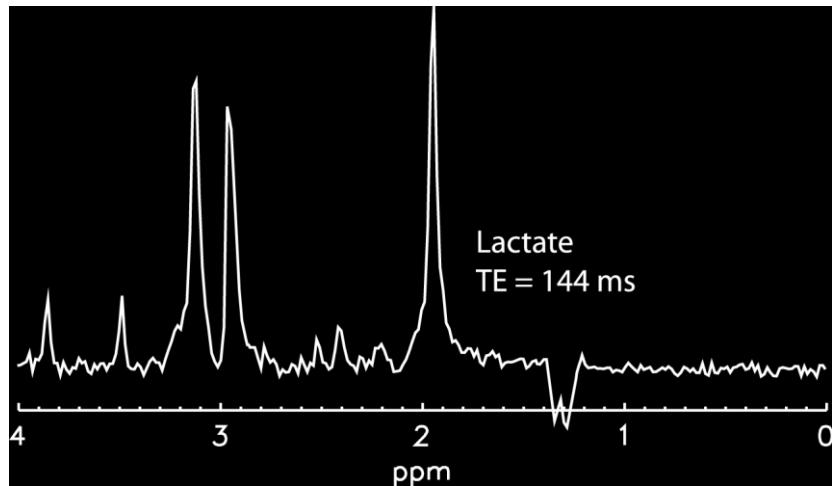
# J-Coupling



# J-coupling evolution



Effect of echo time on evolution of (weakly) coupled spins of lactate



=> up at  $TE = n/J$  with even  $n$   
down at  $TE = n/J$  with odd  $n$

# J-Coupling

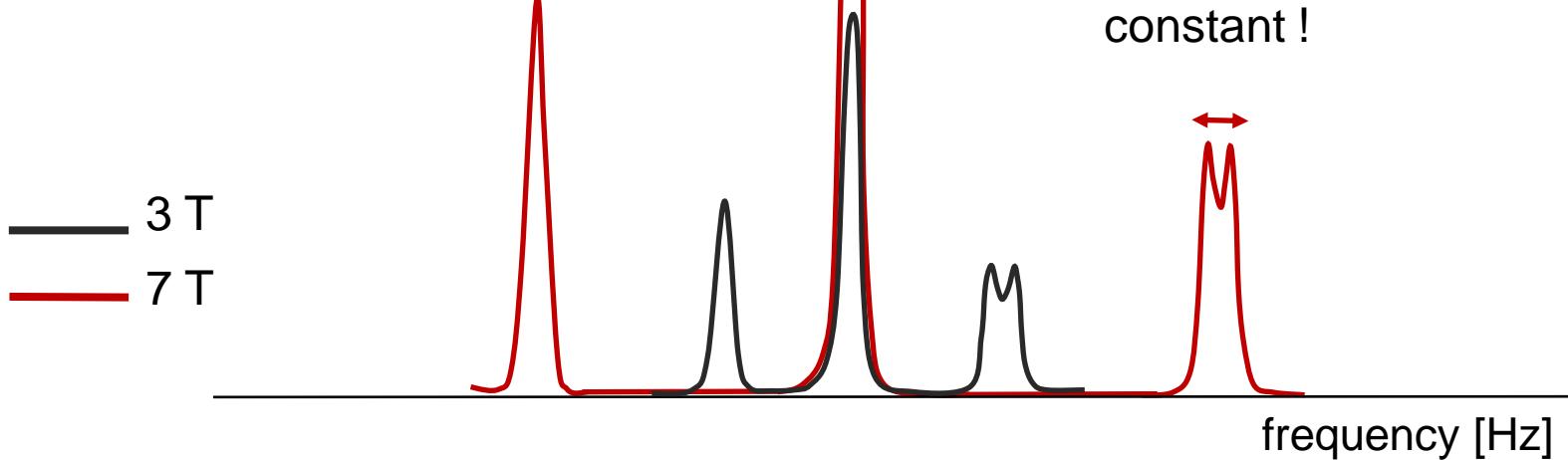


$B_0$  field dependency:

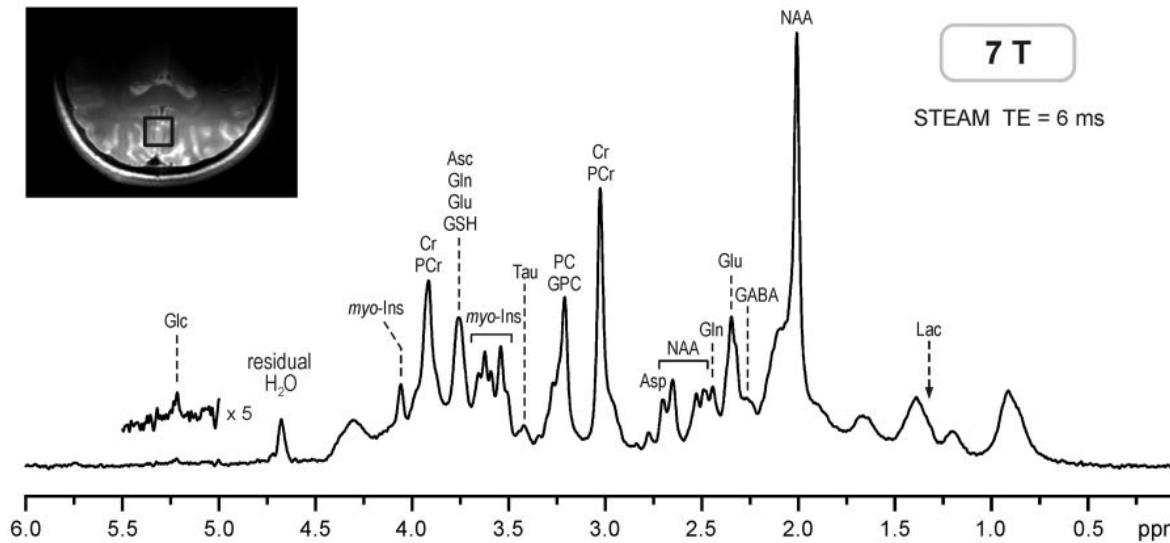
$$CS \propto B_0$$

$$SNR \propto B_0$$

BUT: J-coupling stays constant !



# MR Spectroscopy: Information Content



**Frequency:** identification of metabolite through chemical shift and J-coupling

**Signal intensity (=peak area):** number of protons, concentration

**Signal decay:** tissue properties/magnetic environment

**Signal phase:** spatial encoding (phase-encoding)

I. Tkac et al, MRM 62:868-879 (2009)

# Questions?

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# MRS in Diagnostic



What do all these metabolite concentrations tell us?

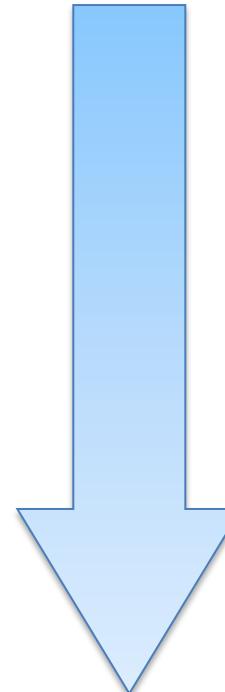
- Axonal loss, neuronal damage => ↓NAA
- Demyelination => ↑tCho, ↑MM, ↑lipids
- Glial proliferation => ↑mlns
- Inflammation => ↑tCho, ↑mlns
- Mitochondrial dysfunction => ↓ tCr, ↓ NAA, ↑Gln/Glu
- Energy metabolism => tCr, glucose, Lac
- Oxidative stress => GSH, ascorbate
- Neurotransmitters and neuromodulators => Glu, GABA, NAAG, Tau
- Osmolytes => Tau, mlns
- Tumor metabolism => Gln, Gly, 2-hydroxyglutarate

# MRS in Diagnostic



## Where is MRS useful?

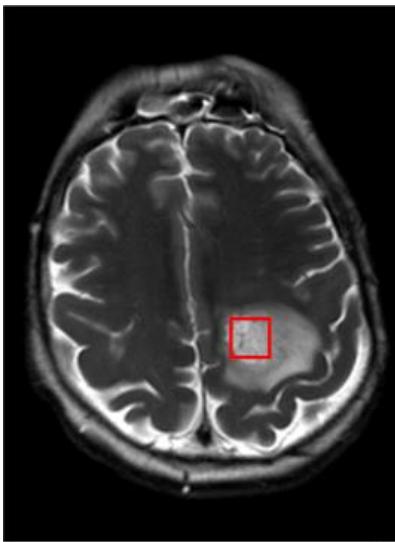
- ⇒ Brain Tumors
- ⇒ Inborn Errors of Metabolism
- ⇒ Infections
- ⇒ Ischemia
- ⇒ Epilepsy
- ⇒ Neurodegenerative Diseases
- ⇒ Psychiatric Disorders



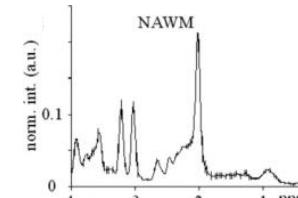
# MRS in Diagnostic



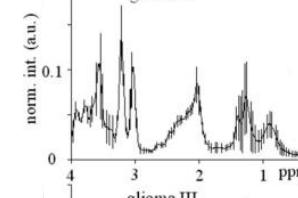
## MRS of Brain Tumors



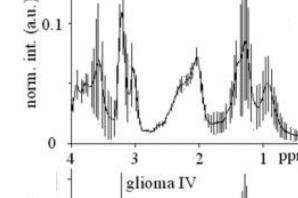
- Normalized PRESS spectra
- TR = 5000 ms, TE = 30 ms
- Mean (black line) and SD (vertical lines)
- 1.5 T Siemens Avanto
- VOIs varied from 4.5 to 5.8 cm<sup>3</sup>



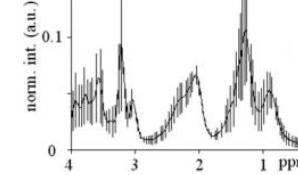
NAWM (n = 10)



Glioma II (n = 6)



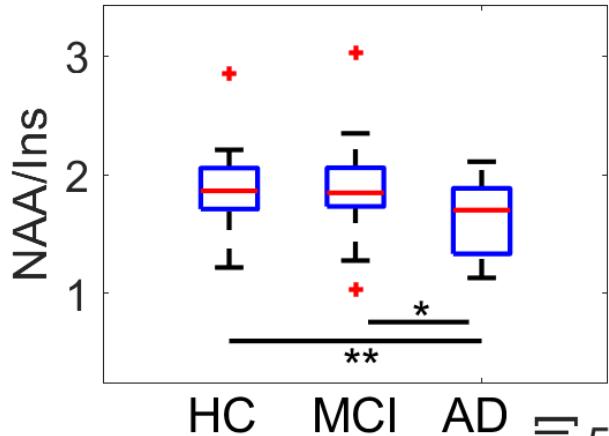
Glioma III (n = 3)



Glioma IV (n = 6)

Weis J. et al, JMRI, 31:39–45 (2010)

# MRS in Diagnostic

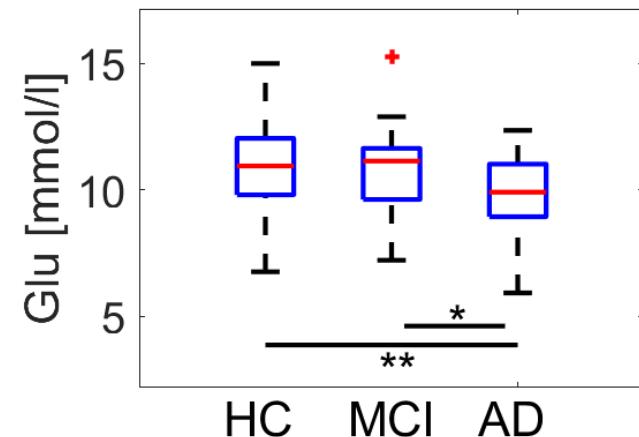
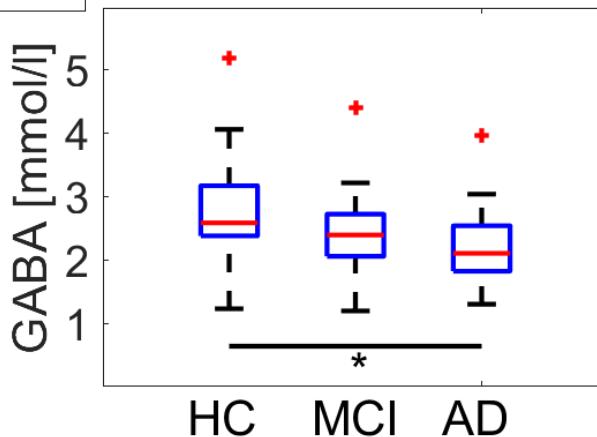


2-sample t-test:

\*:  $p < 0.05$   
\*\*:  $p < 0.01$

36 HC  
22 MCI  
23 AD

Alzheimer's  
Disease



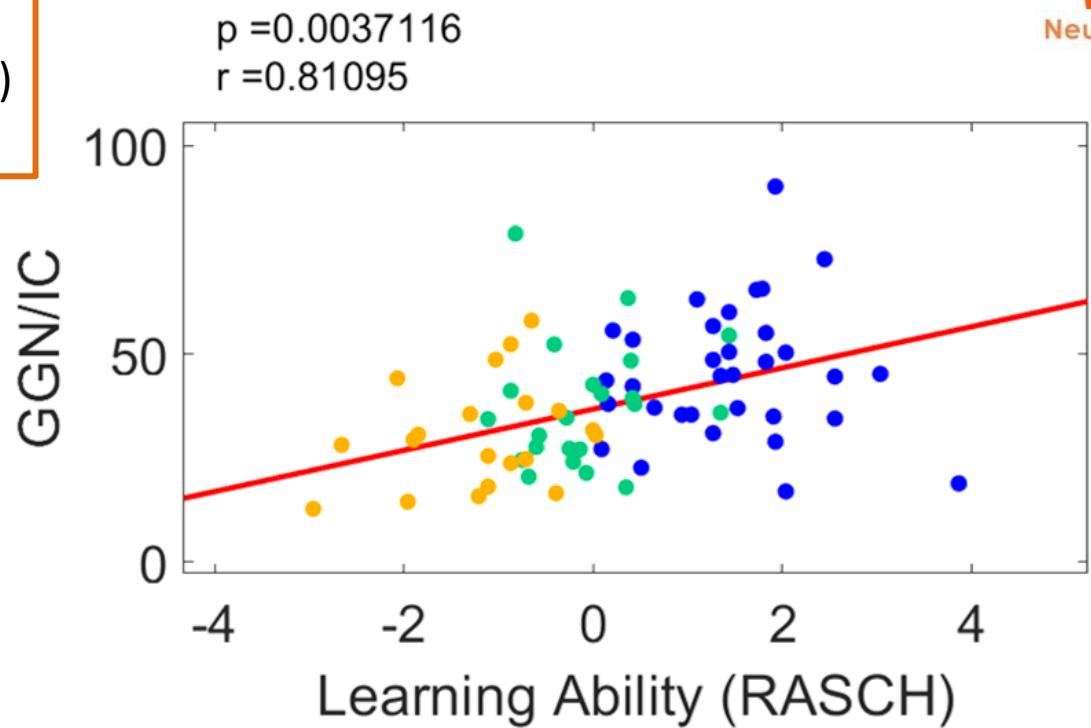
A. Fillmer et al., Proc. Int. Soc. Magn. Reson. Med. 2018: 3903 (2018)

# MRS in Diagnostic

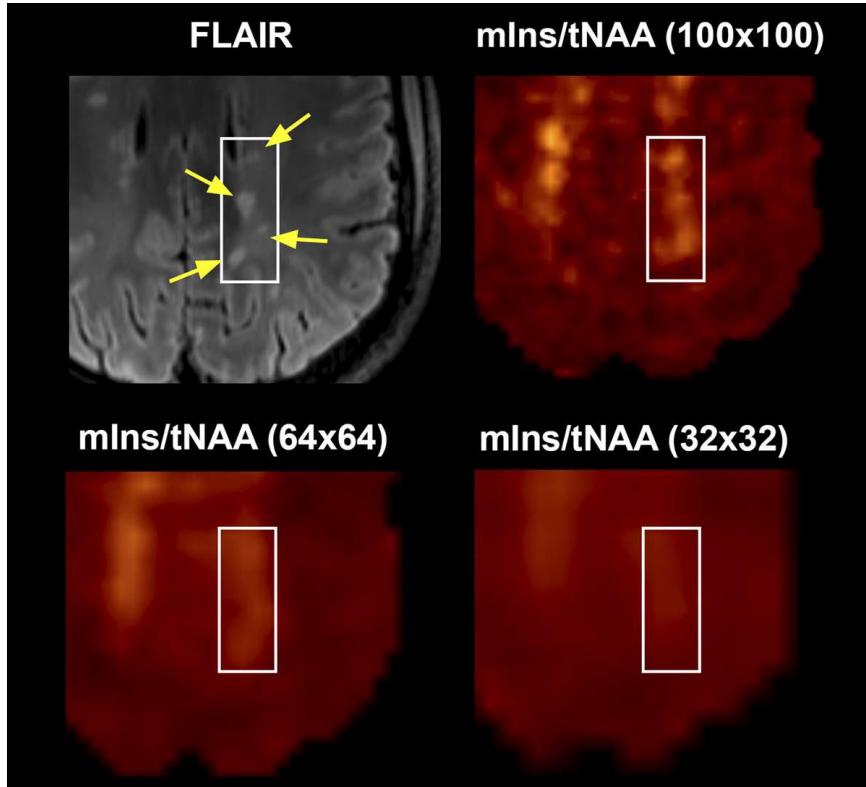


- HC (n = 36)
- MCI (n = 22)
- AD (n = 23)

Alzheimer's  
Disease



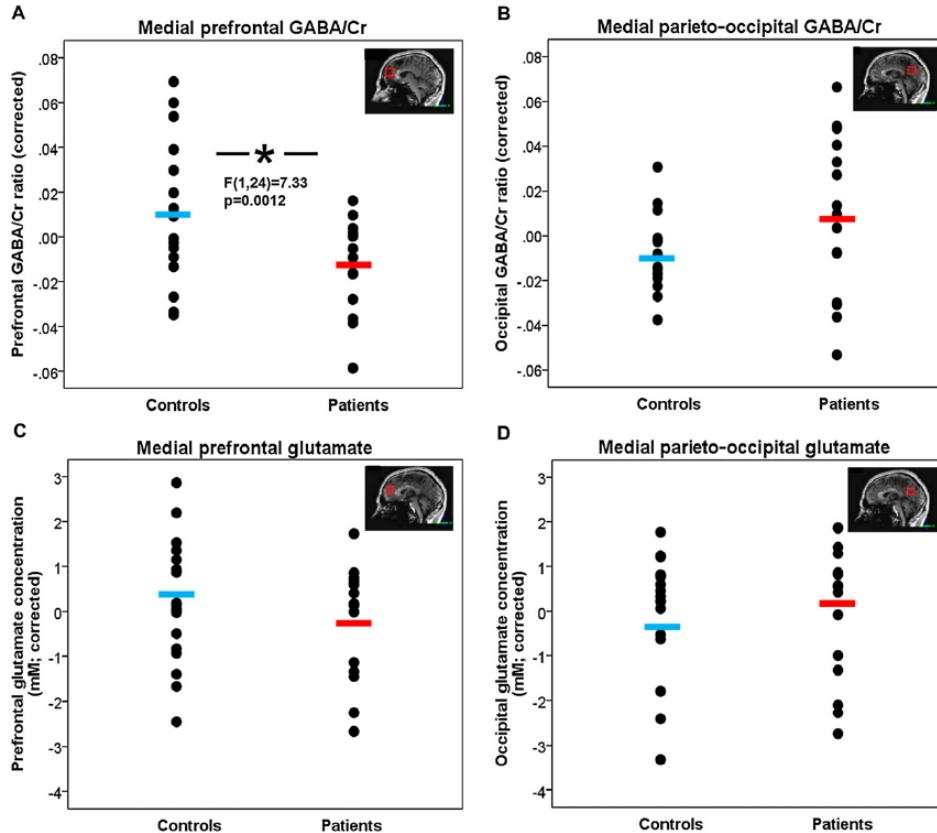
# MRS in Diagnostic



Multiple  
Sclerosis

E. Heckova et al., Invest Radiol. 54:247-254 (2019)

# MRS in Diagnostic



Schizophrenia

A. Marsman et al., NeuroImage: Clinical 6:398-407 (2014)

# Questions?

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