Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

NeuroMET

Virtual MR Spectroscopy Workshop

L2: Localization Methods

Layla Tabea Riemann, M.Sc.

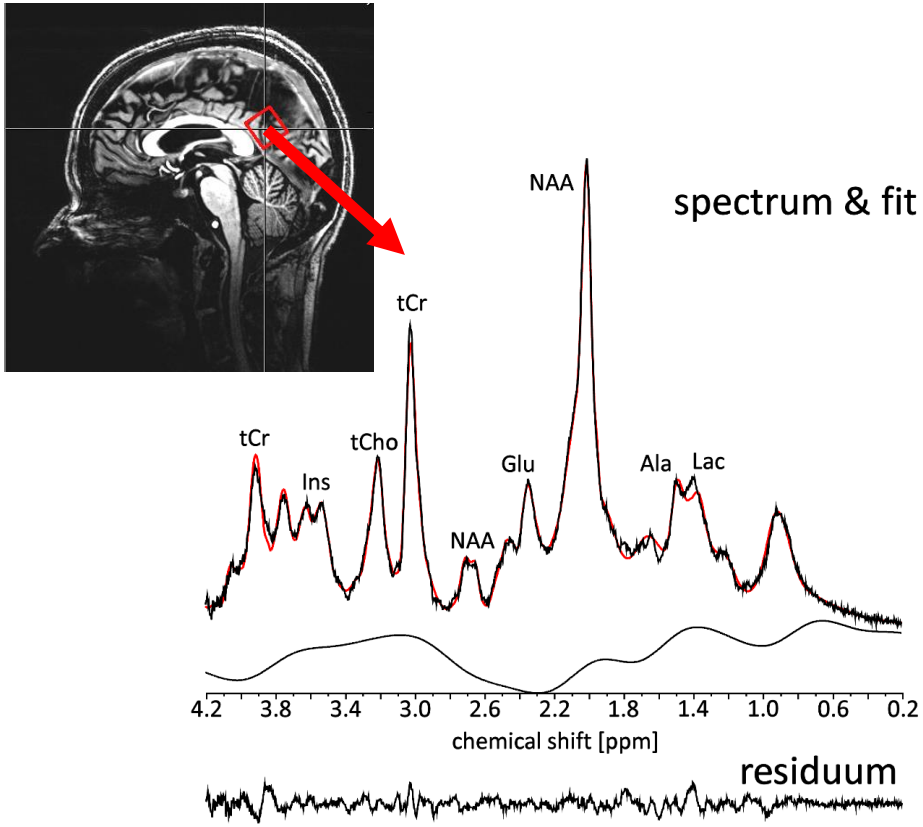
Physikalisch-Technische Bundesanstalt, AG «In-vivo MRT»

NeuroMET

Universitätsmedizin GREIFSWALD

EURAMET

How do we get there?



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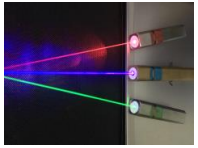
   1.2 STEAM 

   1.3 ISIS → ^{31}P MRS 

   1.4 (s)LASER 

   1.5 SPECIAL 

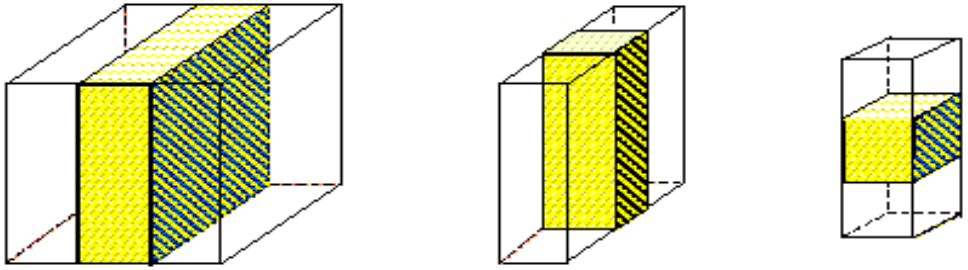
2. Further Methods

   2.1 MEGA 

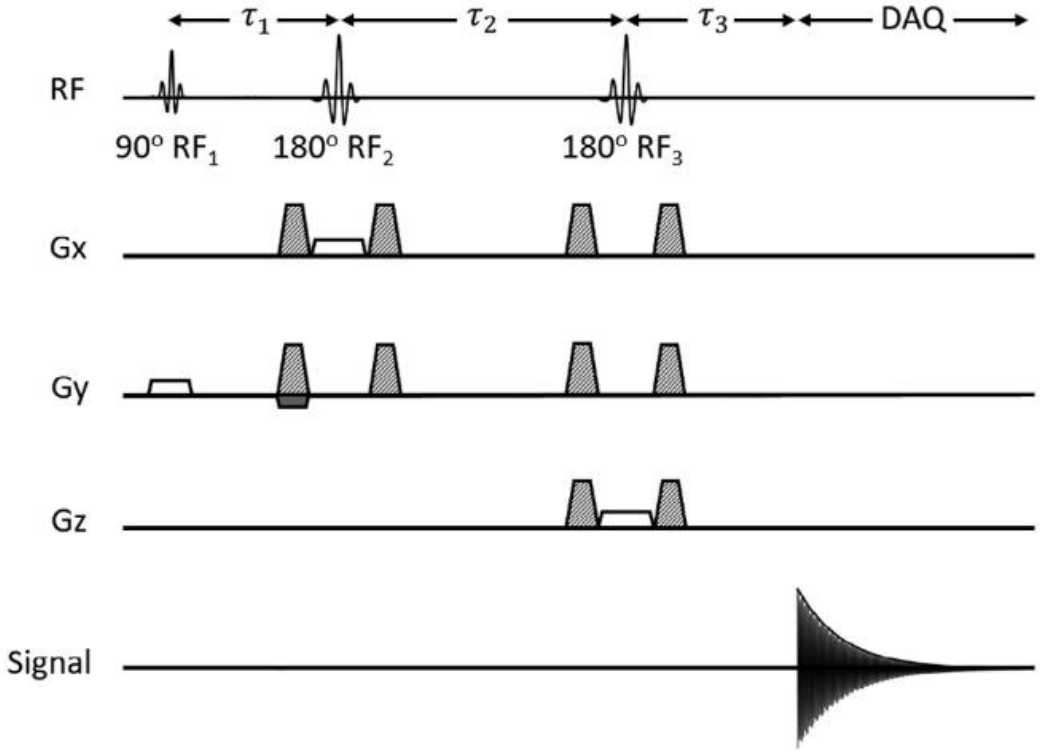
   2.2 MRSI/CSI 

1. Localisation by gradients

in each direction a gradient field defines one slice → the intersection of these slices is the selected volume of interest



1. Sequence diagram



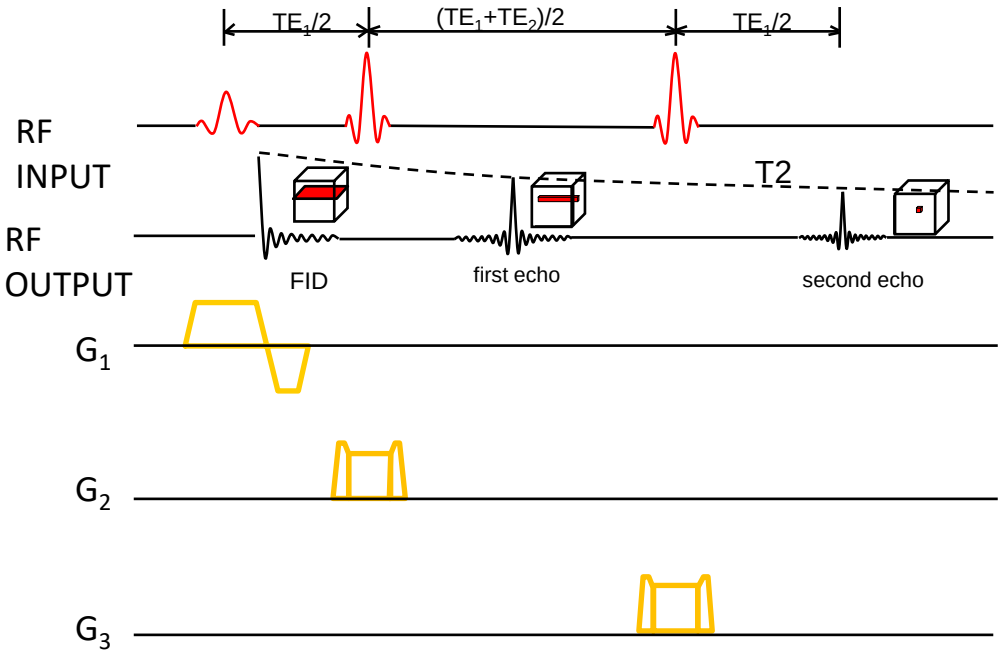
Landheer et al., Journal of MRI, 2019

1.1 Spin Echo Selection

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

1.1 Spin Echo Selection

Method of choice for 1H spectroscopy

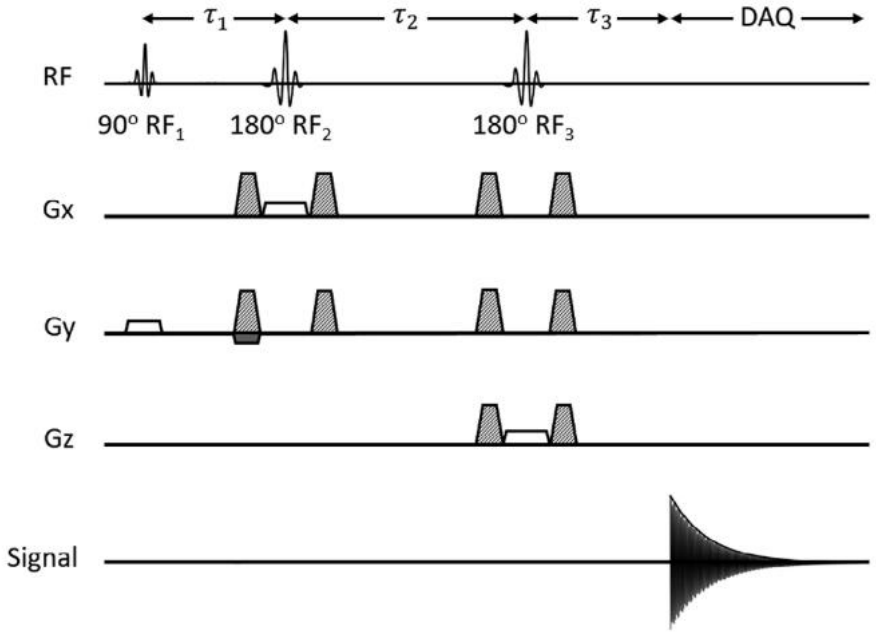


1.1 PRESS

- Point RESolved Spectroscopy

- Double spin echo sequence: 90° - 180° - 180° - echo acquisition

- Spoiler/crusher gradients: eliminate unwanted echo signals from outside the selected volume



Landheer et al., Journal of MRI, 2019

1.1 PRESS

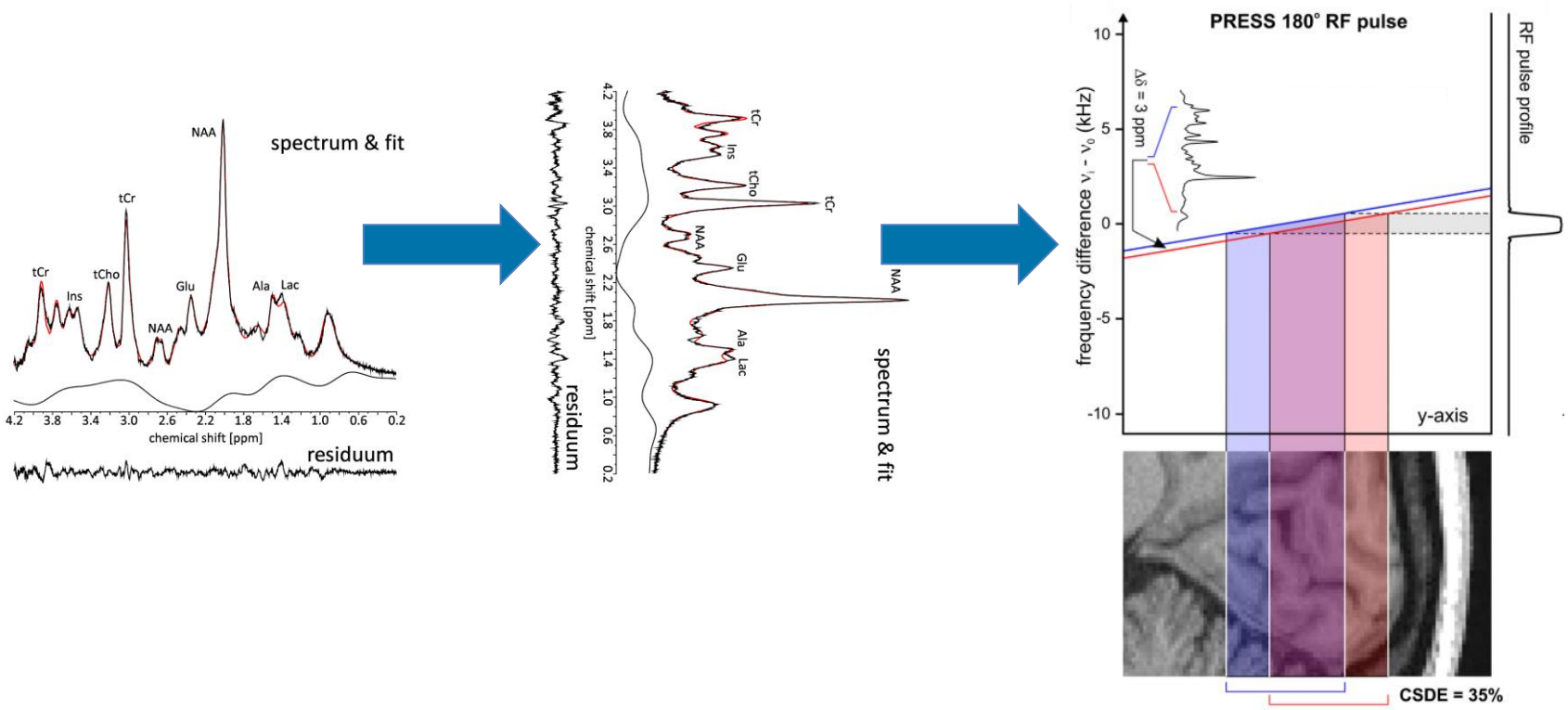
Advantages:

- Good localization and strong suppression of signals outside the selected volume in one measurement → widely used for ^{1}H spectroscopy
- Less motion sensitive than STEAM (in a minute ☺)
- Twice as much signal as with STEAM

Disadvantages:

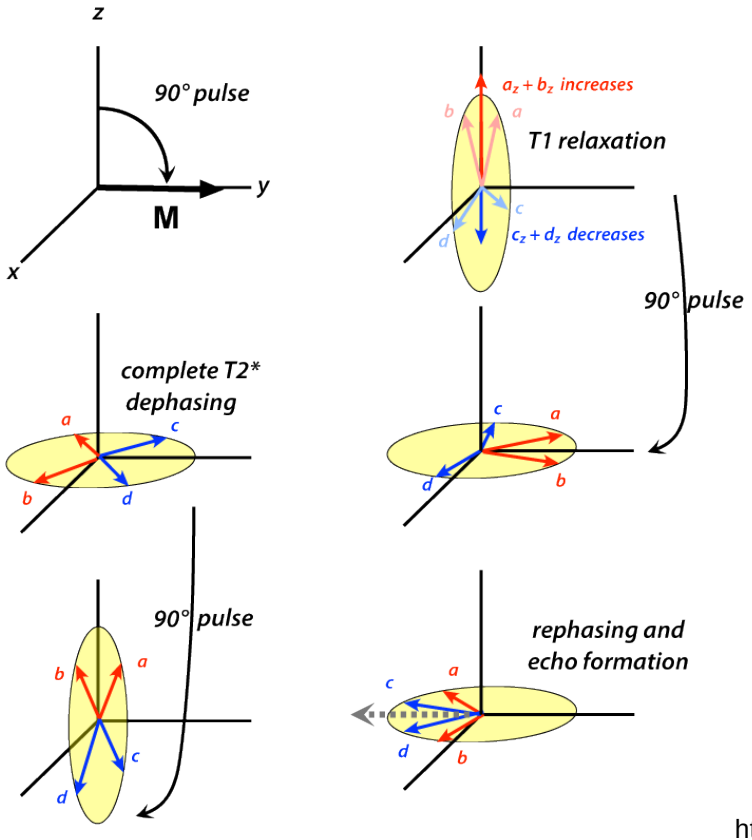
- Minimal echo time: 19 ms (1.5T) / 31 ms (3T)
- 3T, 7T: large chemial shift displacement (CSD)

Chemical Shift Displacement (CSD)



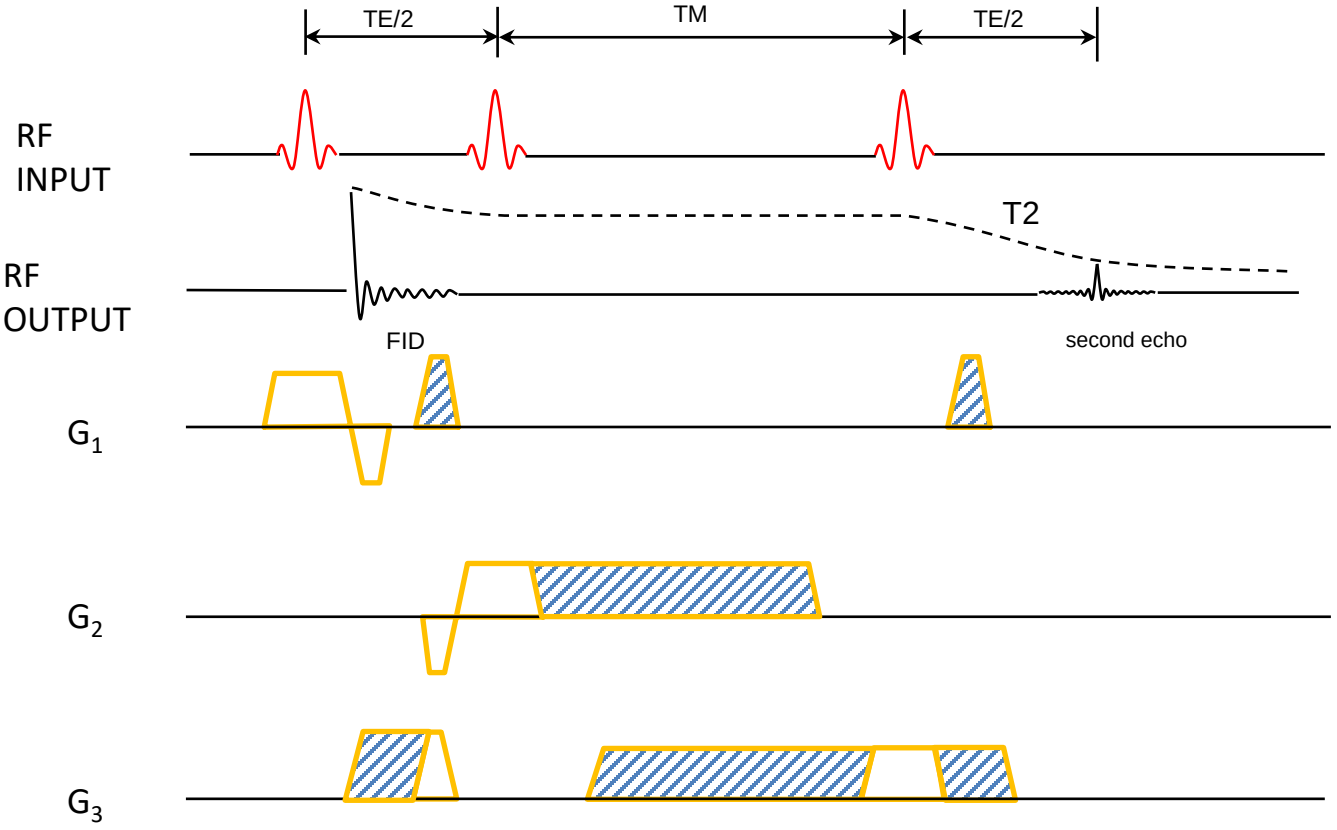
Öz et al., NRM in Biomedicine, 2020

1.2 Stimulated Echo



https://www.mriquestions.com/stimulated-echoes.html

1.2 Stimulated Echo

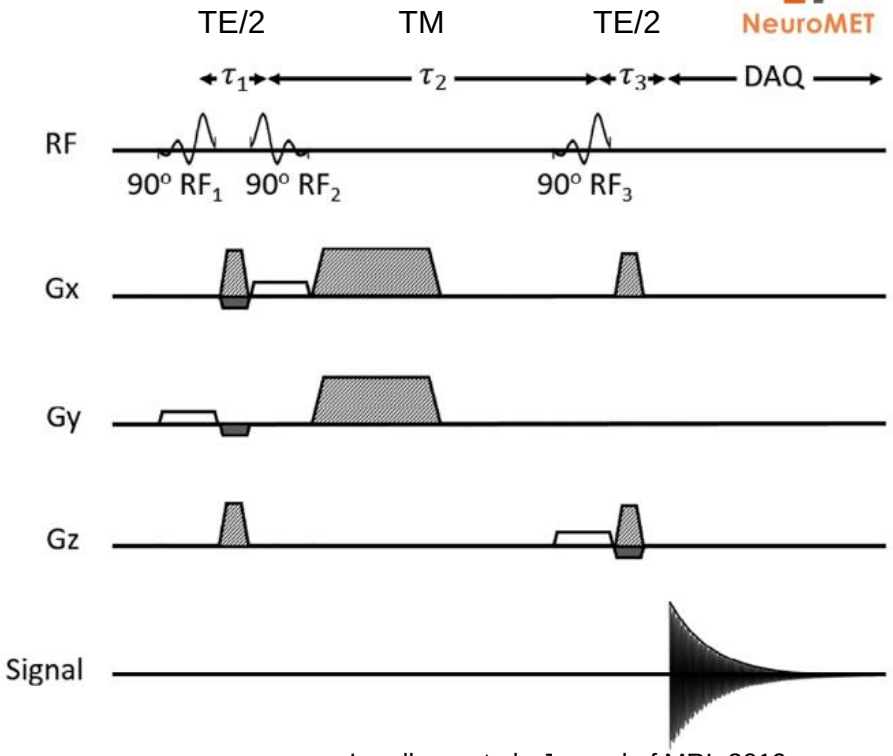


1.2 STEAM

- Stimulated Echo Acquisition Mode

- Selective excitation

- Uses 3 slice selective 90° pulses forming a stimulated echo after TE + TM



Landheer et al., Journal of MRI, 2019

1.2 STEAM

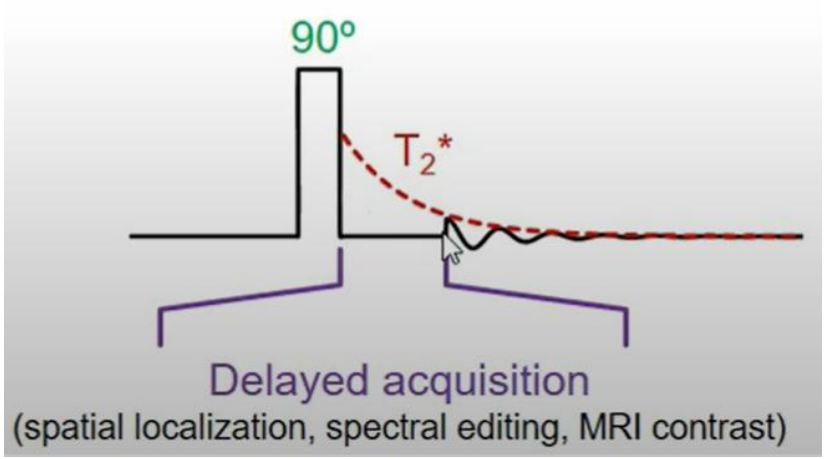
Advantages:

- Allows shorter echo times than PRESS (down to 5 ms)
- Less CSD due to using only 90° pulses

Disadvantages:

- Signal intensities are only **half** of those obtained with PRESS

How do we get a signal if the FID is gone?



- T_2* occurs from macroscopic, reversible loss of phase coherence in addition to T_2 relaxation
- T_2 occurs from microscopic, irreversible loss of phase coherence
- $T_2 >> T_2$*

→ We have to compensate for T2* relaxation

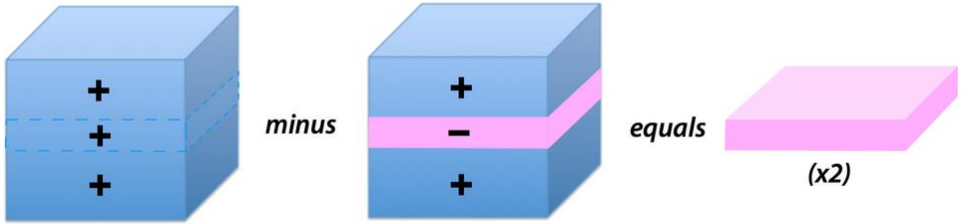
https://www.youtube.com/watch?v=A7Pa-rIVzao&list=PL471uBfQUs9qcODBkQGJTZkcblIKrjKry&index=5

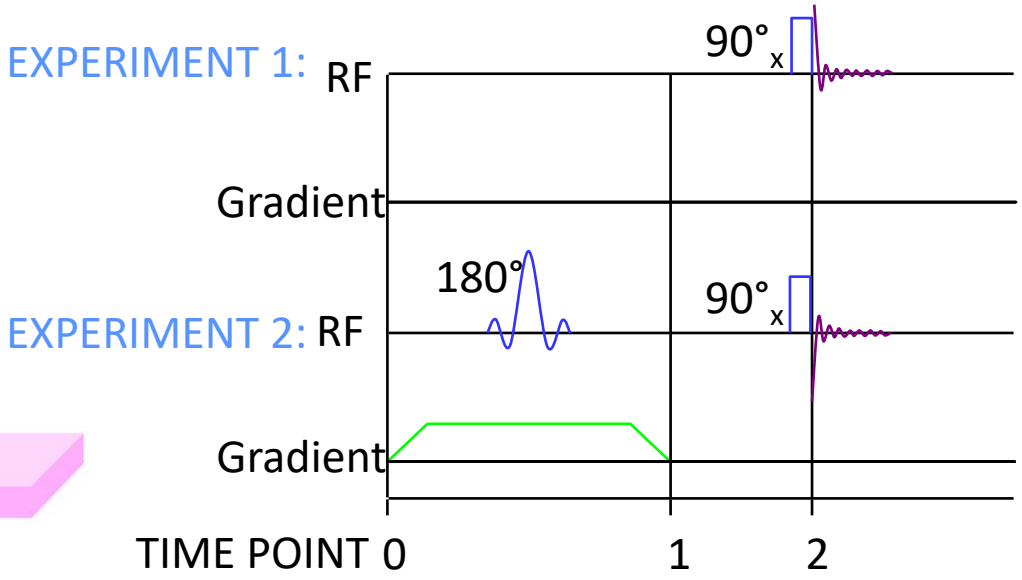
1.3 ISIS

https://www.mriquestions.com/isis.html

NeuroMET

- Image Selected In vivo Spectroscopy (oldest SVS technique)
- Method of choice for ^{31}P, ^{19}F MRS





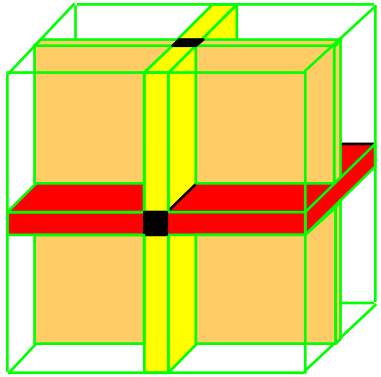
PTB

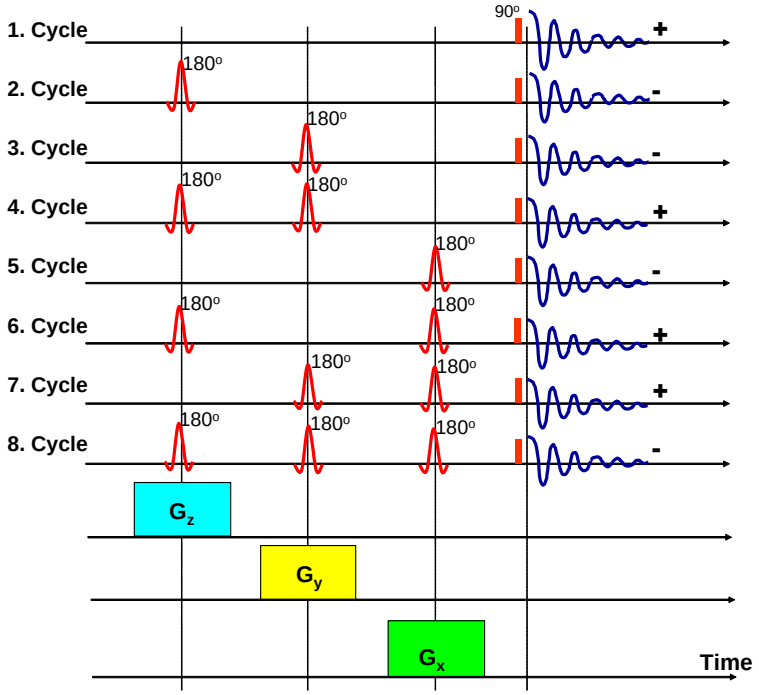
1.3 ISIS

https://www.mriquestions.com/isis.html

NeuroMET

- Image Selected In vivo Spectroscopy (oldest SVS technique)
- Method of choice for ^{31}P, ^{19}F MRS
- 2D needs 4 experiments, 3D needs 8





1.3 ISIS

Advantages:

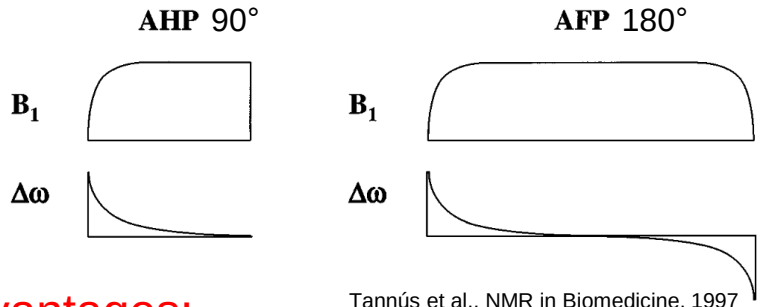
- FID acquisition starts immediately after excitation → no T_2-loss, no J-modulation → primarily used for ^{31}P MRS because of short T_2 relaxation times
- Easily adjustuable for 2 or 4 volumes with linear time increase
- The 8 needed phase cycles hardly increase the measurement time, as *in vivo* ^{31}P spectroscopy needs multiple signal acquisitions

Disadvantages:

- Large signals are subtracted from each other → sensible to instrumental instabilities, motion, T_1 saturation

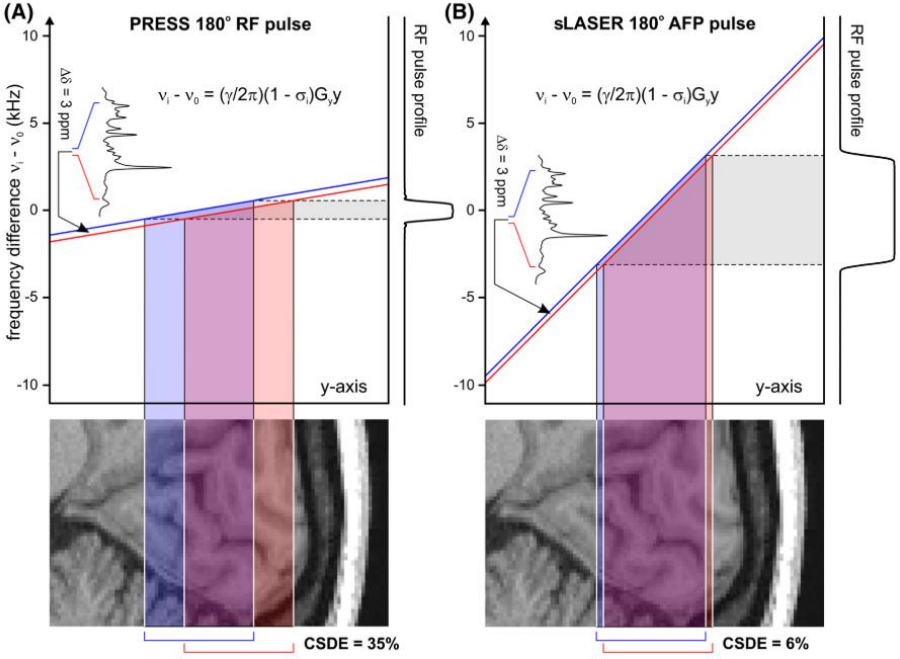
  →Not used for ^{1}H spectroscopy anymore

1.4.1 Adiabatic Pulses



Tannús et al., NMR in Biomedicine, 1997

Youtube: Robin de Graaf, ‚Basics of in vivo NMR‘



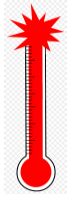
Öz et al., NRM in Biomedicine, 2020

Advantages:

- Insensitive to B_1 inhomogeneities
- Smaller CSD
- Larger bandwidth → insensitive to B_0 inhomogeneities

Disadvantages:

- Increased specific absorption rate (SAR)
- Long pulse duration

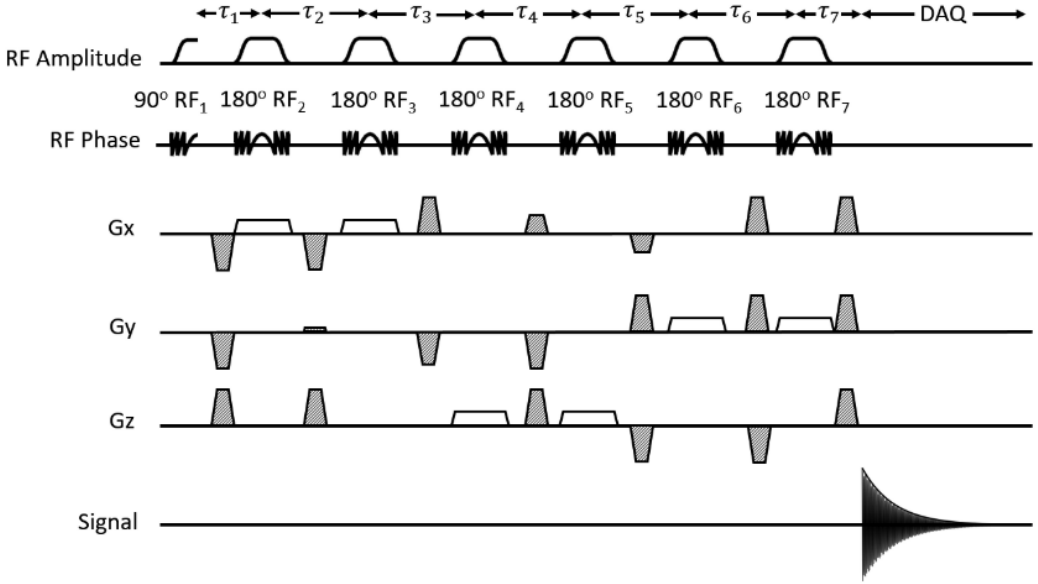


https://www.clipartkey.com/search/thermometer/

1.4.1 LASER

- Localization by Adiabatic Selective Refocusing

- Non-selective excitation
- Uses 3 slice selective 180° pulse pairs for slice selection



Landheer et al., Journal of MRI, 2019

1.4.1 LASER

Advantages:

- Reduced CSD compared to PRESS
- Reduced B_1 sensitivity

Disadvantages:

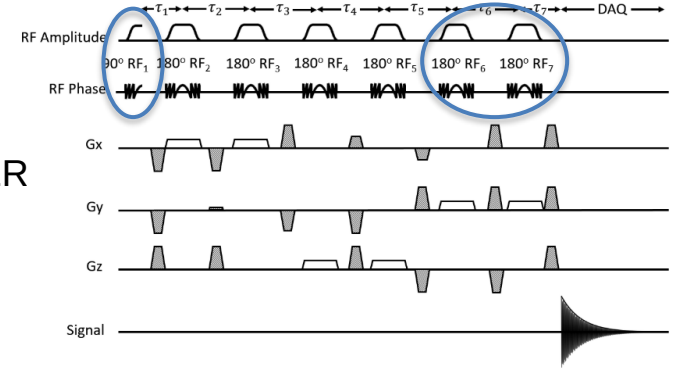
- Nonlinear phase profile of adiabatic pulse → paired pulses → increased TE compared to PRESS
- Higher SAR due to three refocussing pulse pairs

1.4.2 sLASER

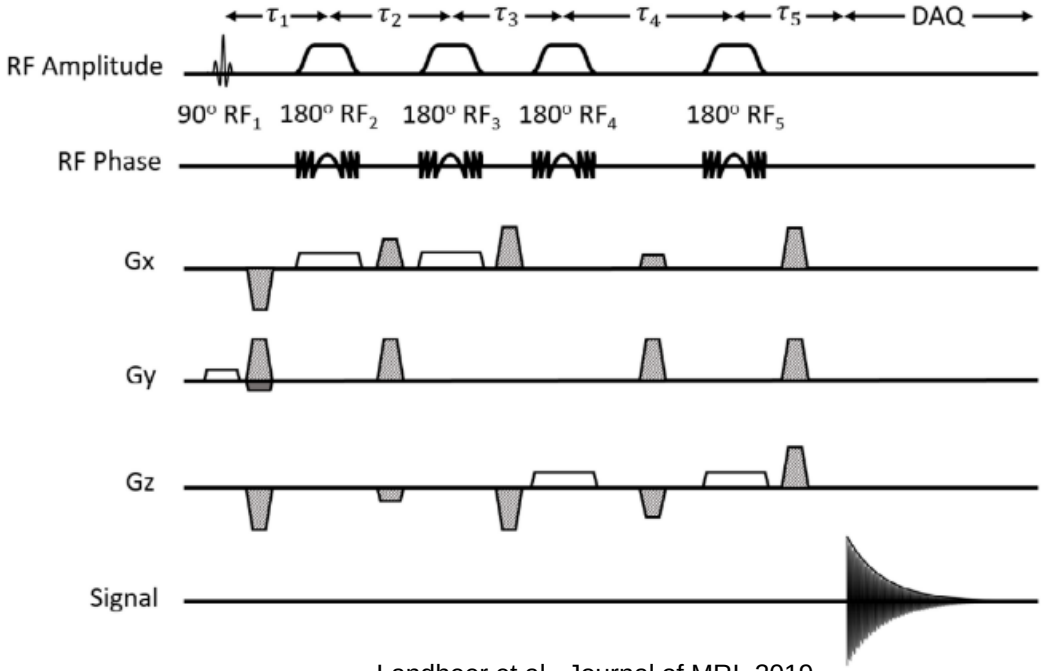
- Semi Localization by Adiabatic Selective Refocusing

- Uses one slice-selective excitation pulse, followed by two pairs of adiabatic refocussing pulses (three pulses replaced from LASER: one non-selective excitation and two slice-selective refocussing)

LASER



sLASER



Landheer et al., Journal of MRI, 2019

1.4.2 sLASER

Advantages:

- Smaller TE than LASER (7 T: 24 ms) → good for editing (section 2…stay thrilled)
- Lower SAR than LASER

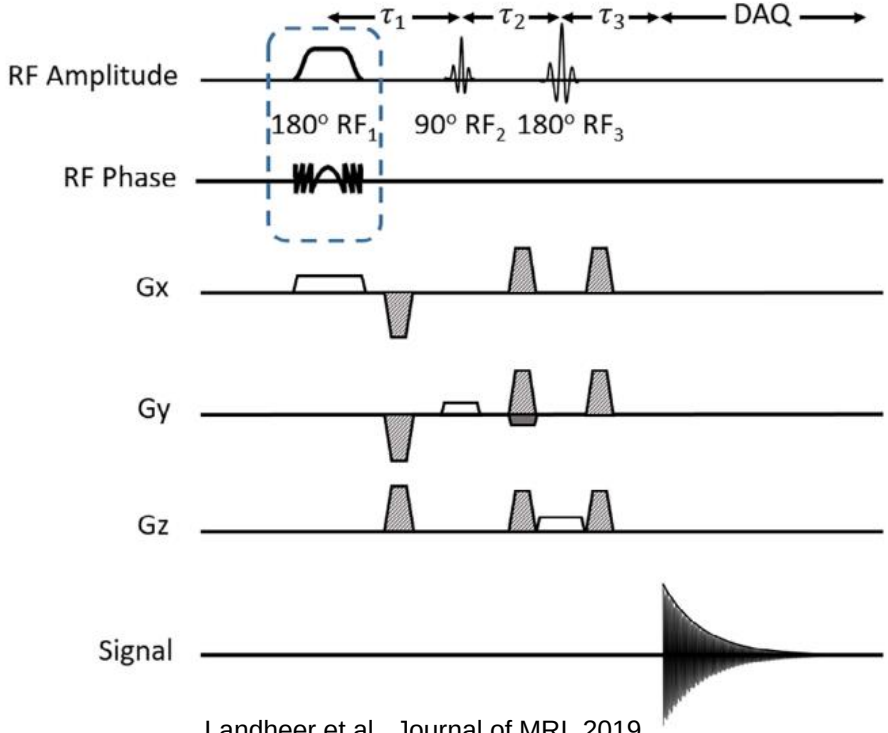
Disadvantages:

- Excitation pulse sensitive to B_1 inhomogeneities and lower bandwidth because no adiabatic pulse

1.5 SPECIAL

NeuroMET

- SPin ECho, full Intensity Acquired Localized
- Combination of  and 
- Uses an on/off selective adiabatic inversion pulse, a 90° excitation and a 180° refocussing pulse



Landheer et al., Journal of MRI, 2019

PTB

1.5 SPECIAL

Advantages:

- Very short TEs (3 T/7 T < 6/10 ms) due to 1D ISIS before excitation

Disadvantages:

- Strong CSD in refocussing dimension → SPECIAL-sLASER
- two-cycle schemes → systematic variations between cycles manifest in their difference spectrum
- strong lipid contamination → lipid suppression techniques necessary

1. Conclusion

1. Conclusion

PRESS
Spin echo → longer TE_{min}
best SNR
more CSD
→ ‘standard’ MRS sequence

STEAM
stimulated echo → shortest TE
only half the signal of PRESS
less CSD

‚classical‘ MRS sequences
→ No adiabatic pulses

ISIS
Historically oldest MRS sequence
Add/Subtract scheme
→ ^{31}P MR spectroscopy

1. Conclusion

LASER
Non-selective excitation with adiabatic refocusing pulses
Lowest CSD

sLASER
Slice-selective excitation + LASER
Smaller SAR and TE than LASER

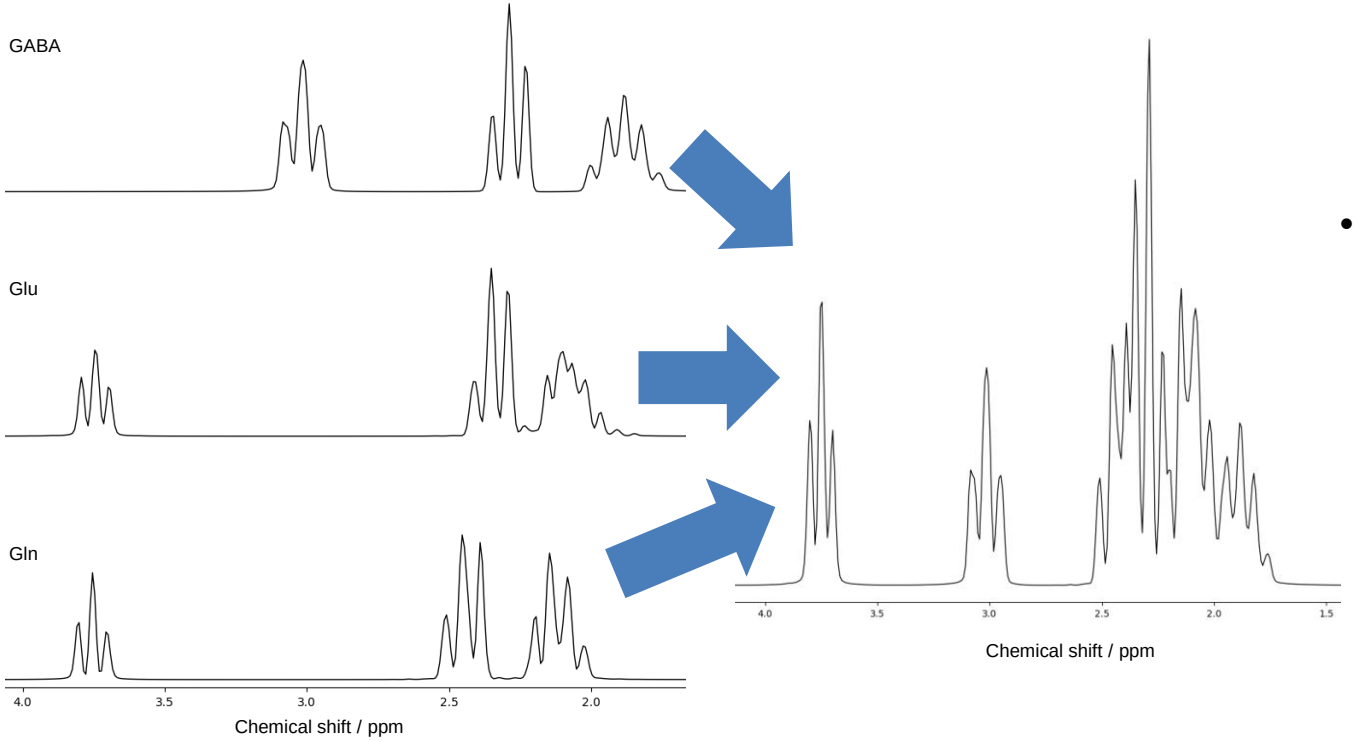
SPECIAL
1D ISIS (adiabatic pulse) + PRESS
Very short TEs
→ $TE_{SPECIAL} < TE_{sLASER} < TE_{LASER}$

most of the latest technical developments

‚modern' MRS sequences
→ adiabatic pulses

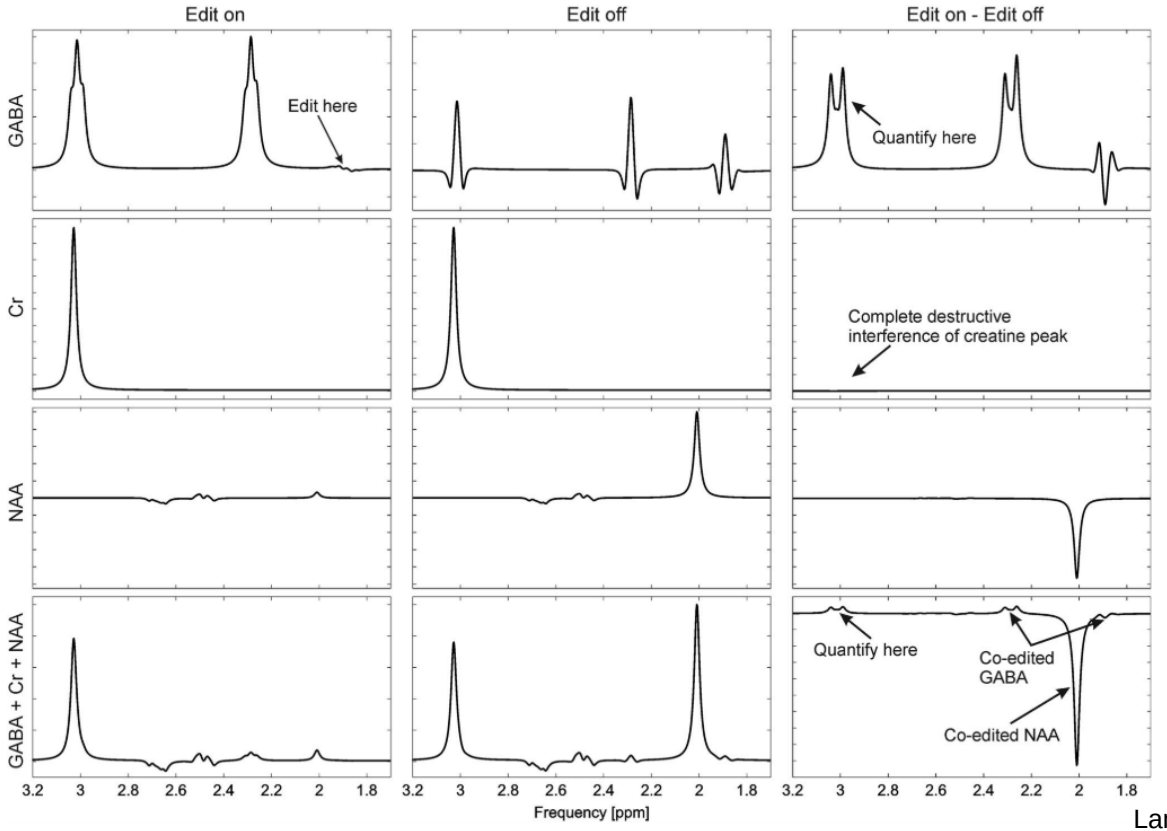
2.1 MEGA

- MEsher and GArwood (first and last author of first publication about this topic)



- Necessary to quantify single metabolites out of overlapping peaks → glutamate, GABA, glutamine

2.1 MEGA

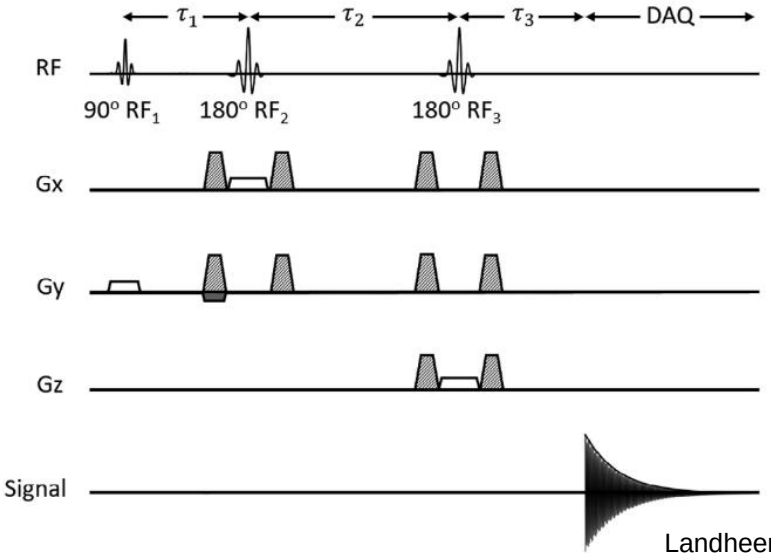


Landheer et al., Journal of MRI, 2019

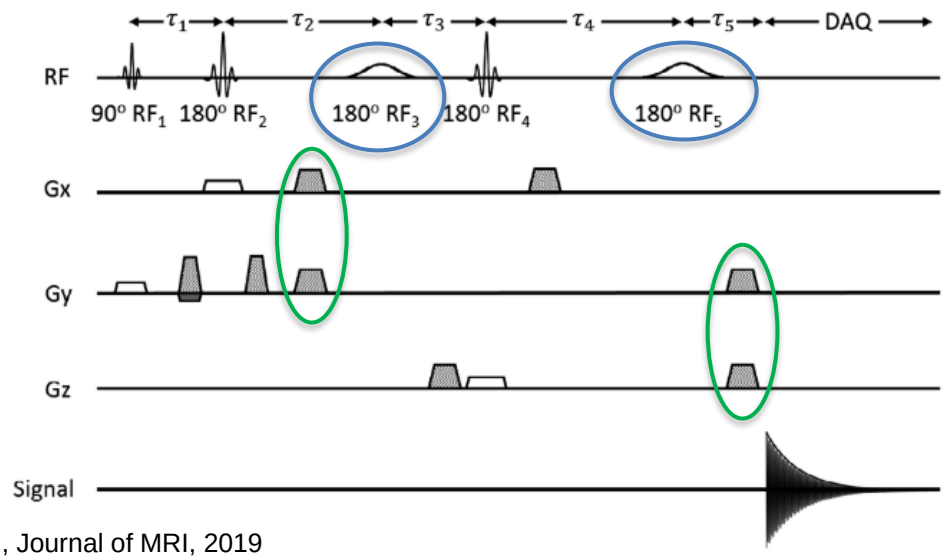
2.1 MEGA

- two frequency-selective pulses designed to invert and, with the use of crushers, dephase unwanted resonances while not affecting desired resonances

PRESS



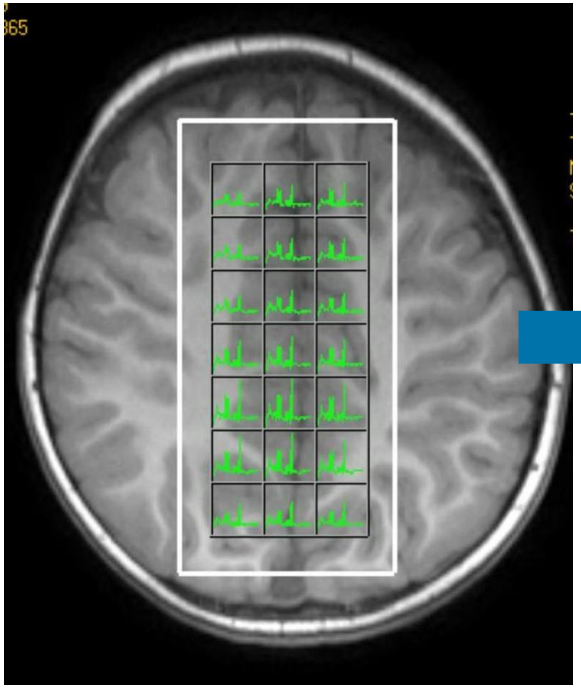
MEGA-PRESS

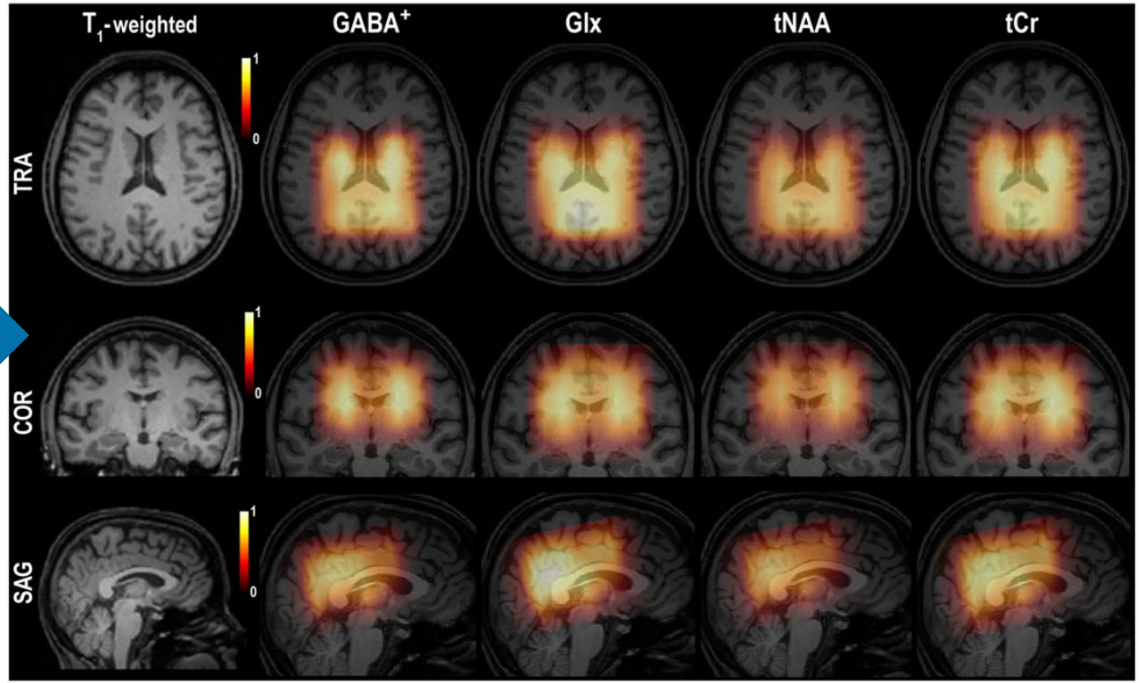


Landheer et al., Journal of MRI, 2019

2.2 MRSI

- Magnetic Resonance Spectroscopic Imaging or Chemical Shift Imaging (CSI, old)

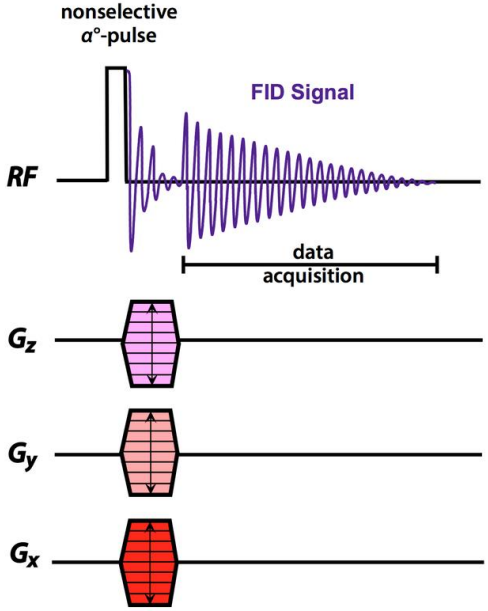




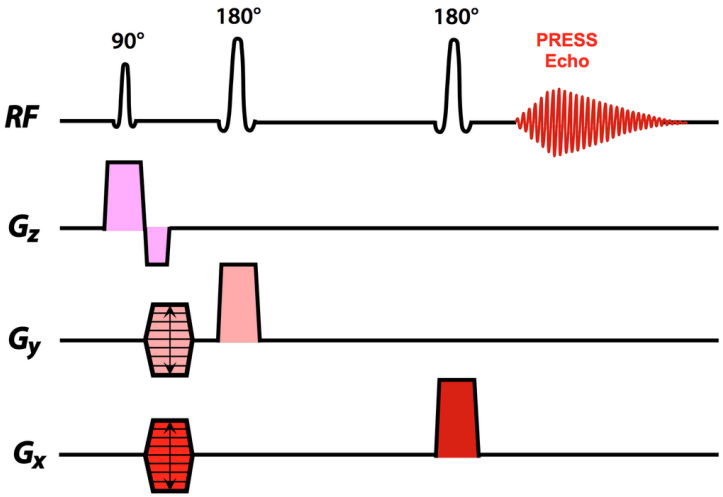
https://www.mriquestions.com/csi.html

Hnilivocá et al., NMR in Biomedicine, 2016

2.2 MRSI



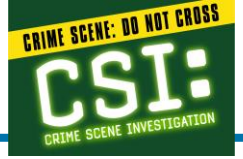
3D MRSI sequence using nonselective volume excitation and stepped phase-encoding gradients along all three axes → ^{31}P



2D-PRESS MRSI sequence with slice-selective excitation pulses in three planes with stepped phase-encoding gradients along 2 axes → ^{1}H brain

https://www.mriquestions.com/csi.html

2.2 MRSI



NeuroMET

Advantages:

- Spatial distribution of measured signal

Disadvantages:

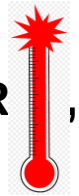
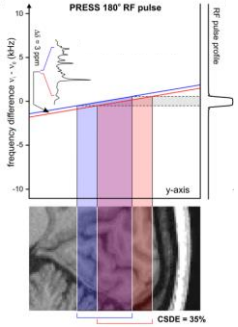
- Larger point spread function → increased signal bleeding
- B_0 Shim not optimized
- Long measurement time

It is QUIZ time

https://www.menti.com/95vrtaxcce

Menti.com, Code: **2800 3789**

Take Home Messages

- ‚classical' SVS MRS sequences without adiabatic pulses
- ‚modern' ones with adiabatic pulses and combination with ‚classical' sequences
- **Trade-off between SAR**  **, CSD** 

and TE/measurement time 
- MEGA technique → increasing metabolic specificity J-Difference editing
- MRSI if spatial distribution of the metabolite signal required, while SVS easier to acquire and easier to correctly quantify

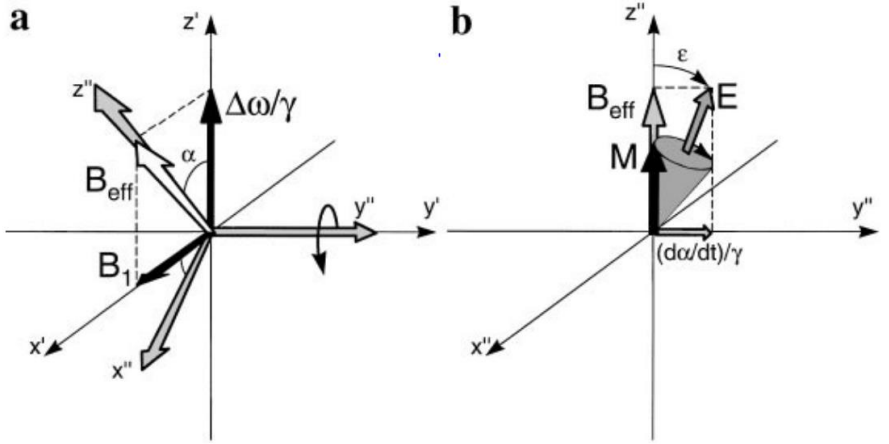
https://www.dreamstime.com/stock-video-footage-wall-clock-cartoon-illustration-hand-drawn-animation-transparent-background-video51546887

Thank you!

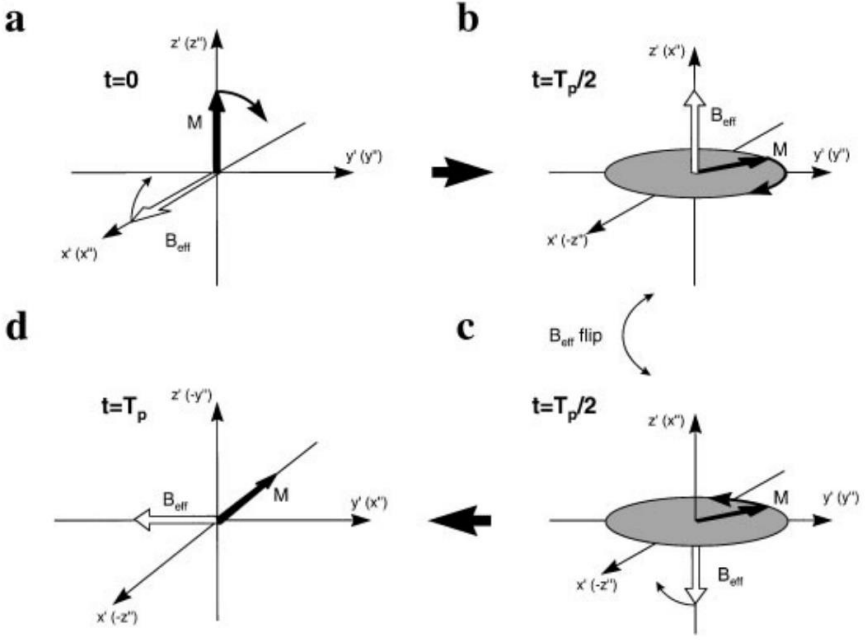
Layla.riemann@ptb.de

https://www.dreamstime.com/illustration/cartoon-questions.html

More adiabatic pulses (yippie ☺)



- Produces a nearly perfect inversion of net magnetization (**M**) that is relatively tolerant to $\mathbf{B_1}$-field inhomogeneities
- Continuous RF-excitation swept over a range of frequencies from far below to far above the resonance frequency
- Provided the $\mathbf{B_1}$-field was strong enough and applied slowly enough (the ***adiabatic condition***), the net magnetization (**M**) could be nutated with a complete inversion by the end of the sweep



A closer look on stimulated echos