FITTING & QUANTIFICATION OF MR SPECTRA

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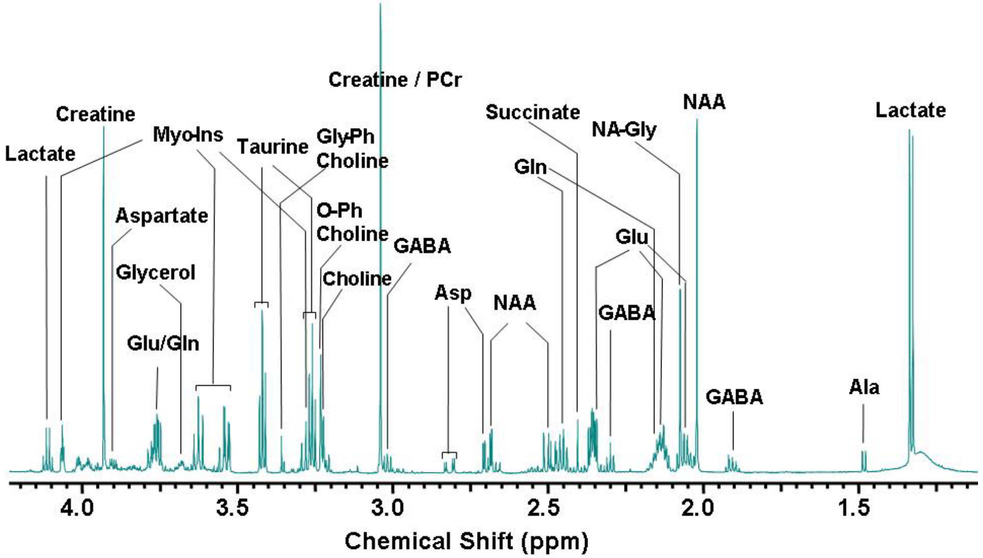
CIBM MRI EPFL AIT

cristina.cudalbu@epfl.ch

CONTEXT

MAGNETIC RESONANCE SPECTROSCOPY

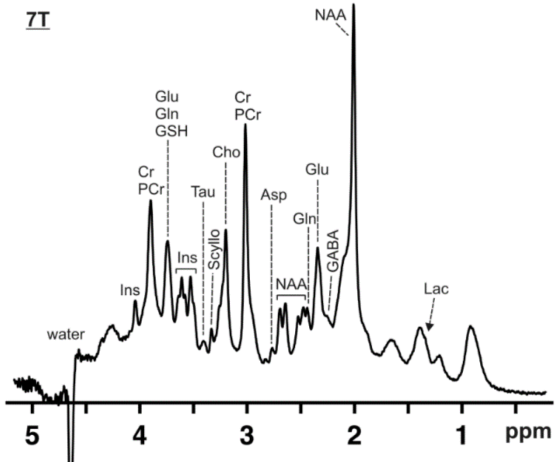
- NMR Spectroscopy

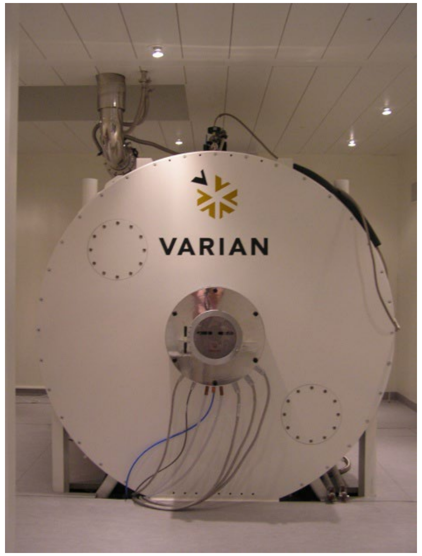


MAGNETIC RESONANCE SPECTROSCOPY

In Vivo MR spectroscopy (MRS)

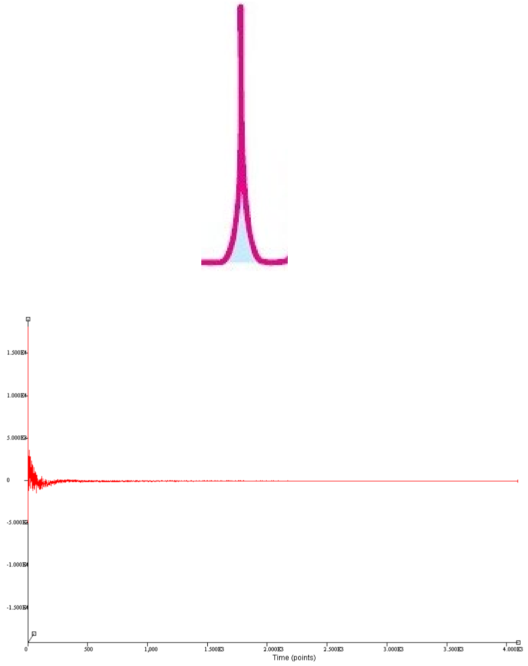
- Measurement of different metabolites- metabolism
- Different organs
- Different nuclei: 1H, 13C, 31P, 15N, ..
- Different magnetic fields
- Different acquisition parameters



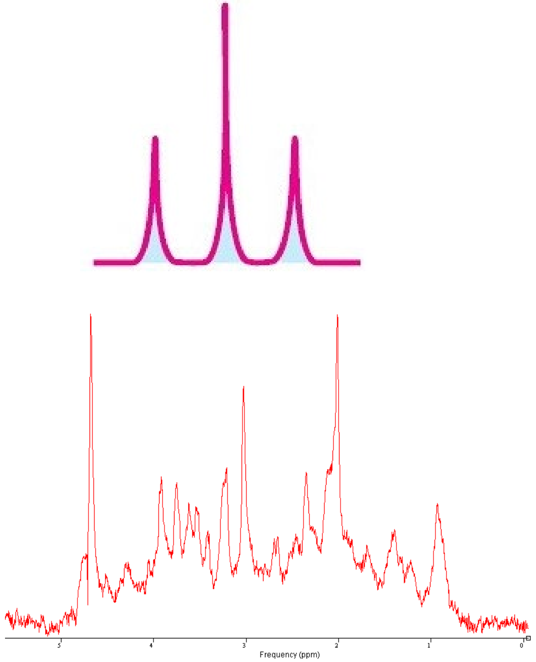


FITTING & QUANTIFICATION

- MRS – principal goal – quantification of changes in concentration of known metabolites



- Frequencies
- Amplitudes
- Damping factor
- Phase
- Beginning time



- Frequencies
- Surface
- Linewidths
- Zero order phase.
- first order phase

WHY IN VIVO 1H MR SPECTROSCOPY ?

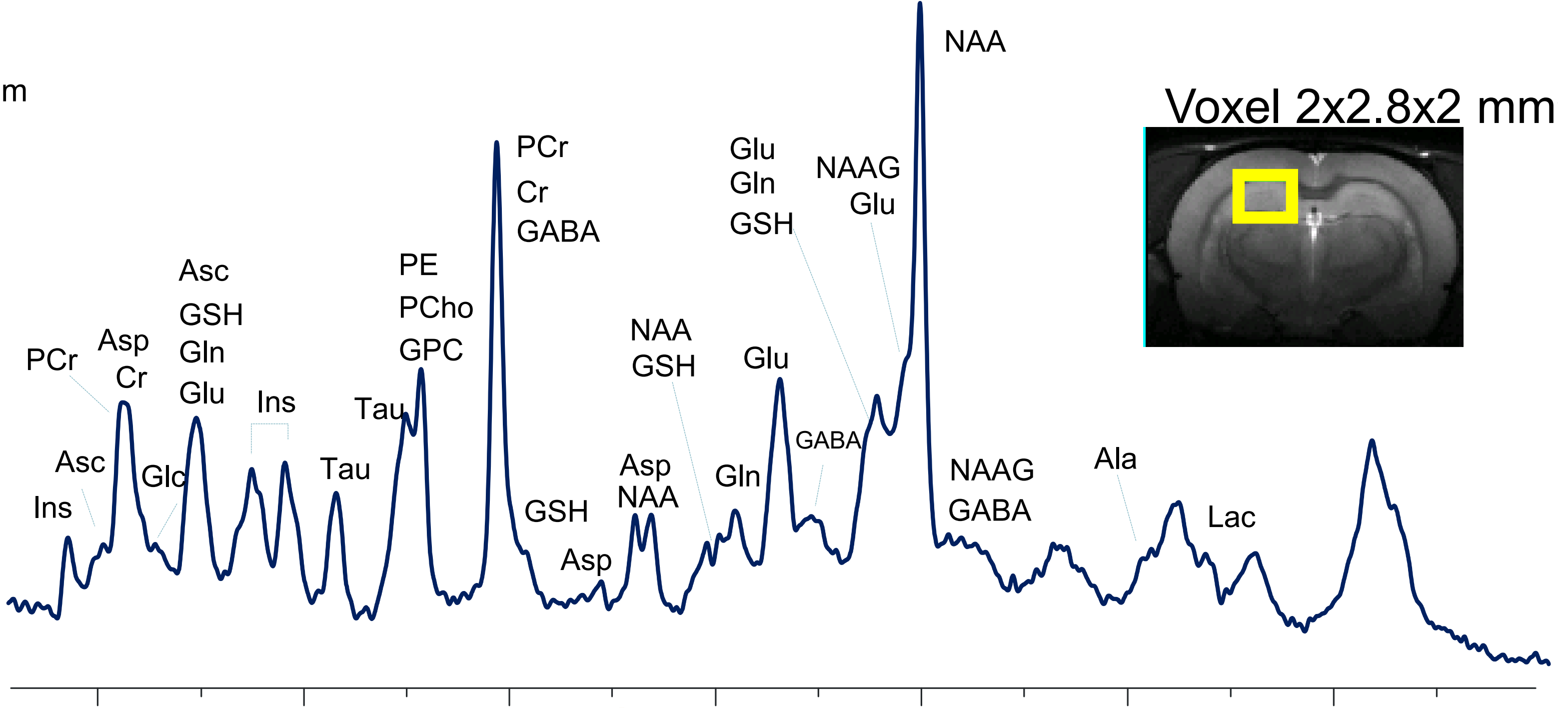
Neurochemical Profile at 9.4T

>18 Markers of :

Myelination/Cell proliferation
Energy metabolism
Osmoregulation
Neurotransmitter metabolism
Antioxidants

- **at high magnetic field (9.4T)**
- **ultra short TE (2.8ms)**

- ***in vivo***
- **non invasively**
- **localized in hippocampus**



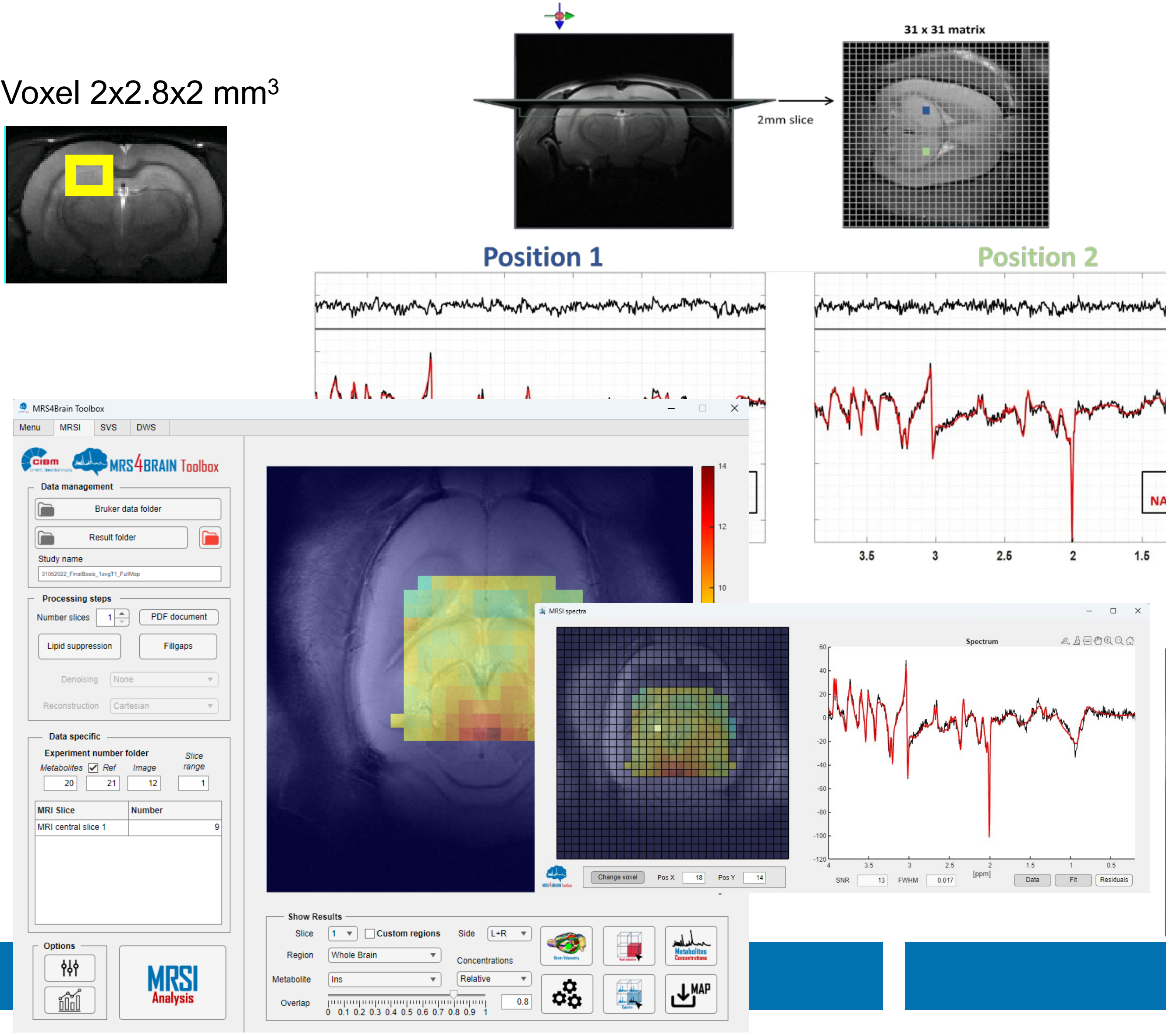
Voxel 2x2.8x2 mm^3

- Maximize the neurochemical information
- Increase precision, accuracy – quantification
- Increase the reliability of obtained concentrations

CD Rae et al, Anal Biochem. 2017; CD Rae .Neurochem Res. 2014; V Račkayová et al 2017; JMN Duarte 2012

METABOLIC MAPPING via MRSI

B Alves



Voxel 2x2.8x2 mm^3

Study name: 31052022_FinalBasis_1avgT1_FullMap

Number slices: 1

Denoising: None

Reconstruction: Cartesian

Metabolites: 20 ☑ Ref: 21 Image: 12 Slice range: 1

MRI Slice	Number
MRI central slice 1	9

Slice: 1 ☐ Custom regions Side: L+R

Region: Whole Brain

Metabolite: Ins Concentrations: Relative

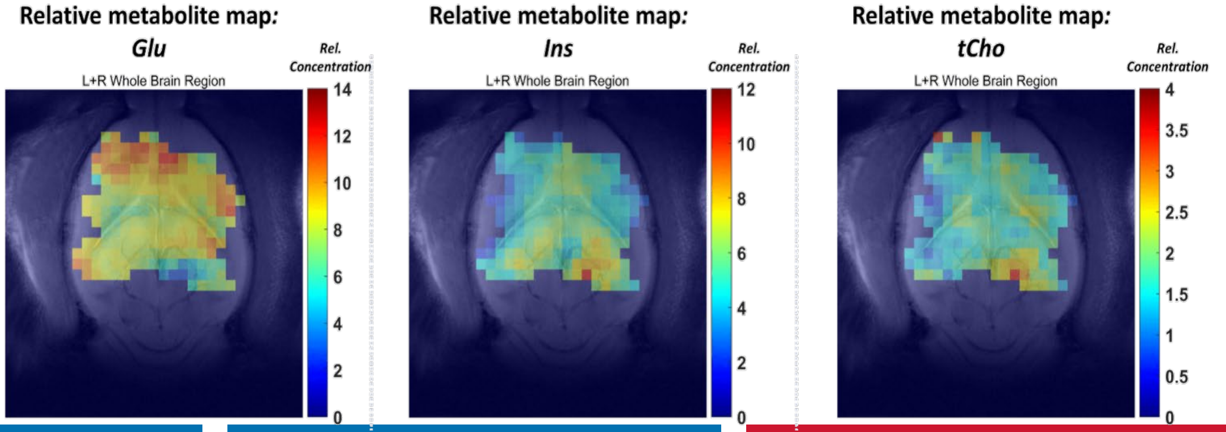
Overlap: 0.8

Pos X: 18 Pos Y: 14

SNR: 13 FWHM: 0.017

FID- MRSI
0.7x0.7x2mm^3
13 min @14.1T

https://www.epfl.ch/labs/mrs4brain/ressources/mrs4brain-toolbox/



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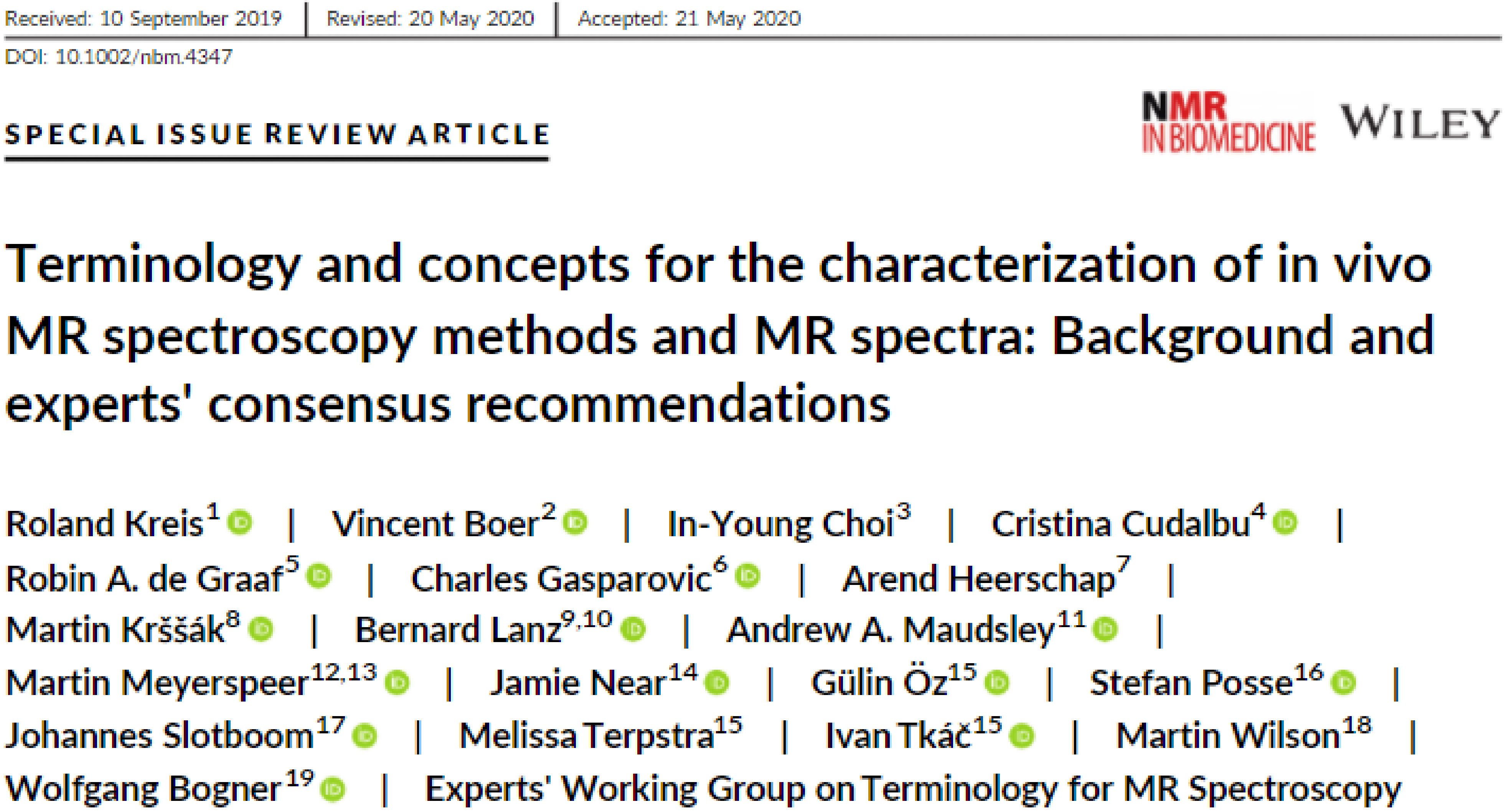
B Alves, et al, NMR Biomed, 2024; D Simicic et al, NMR Biomed 2025



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DOI: 10.1002/nbm.4347

SPECIAL ISSUE REVIEW ARTICLE

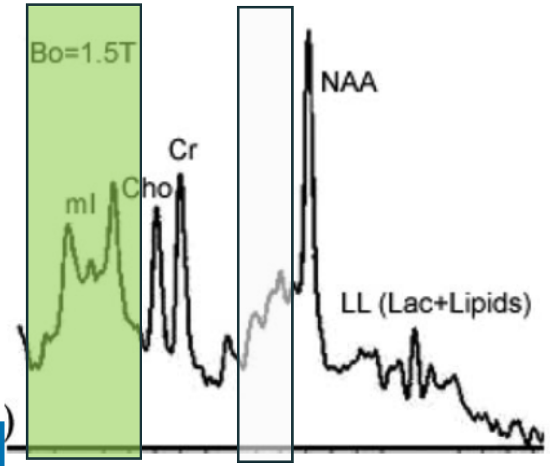
NMR IN BIOMEDICINE WILEY

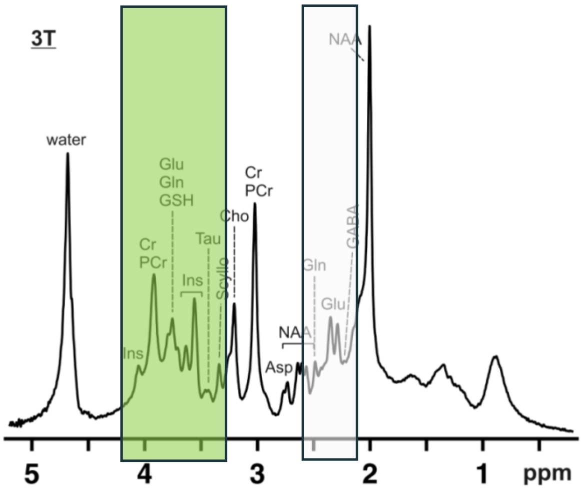
Terminology and concepts for the characterization of in vivo MR spectroscopy methods and MR spectra: Background and experts' consensus recommendations

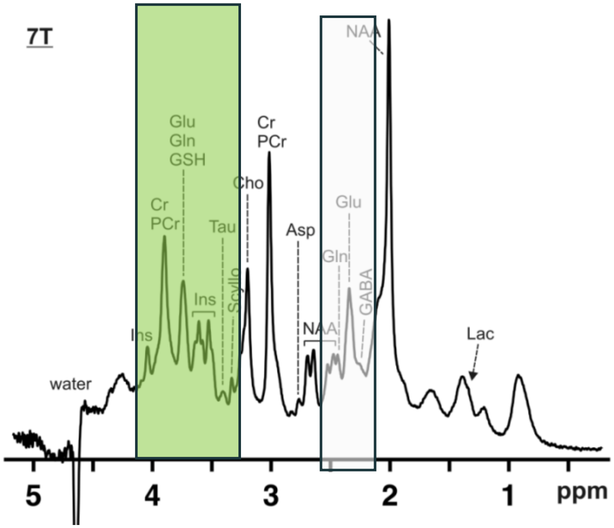
Roland Kreis[1] | Vincent Boer[2] | In-Young Choi[3] | Cristina Cudalbu[4] | Robin A. de Graaf[5] | Charles Gasparovic[6] | Arend Heerschap[7] | Martin Krššák[8] | Bernard Lanz[9,10] | Andrew A. Maudsley[11] | Martin Meyerspeer[12,13] | Jamie Near[14] | Gülin Öz[15] | Stefan Posse[16] | Johannes Slotboom[17] | Melissa Terpstra[15] | Ivan Tkáč[15] | Martin Wilson[18] | Wolfgang Bogner[19] | Experts' Working Group on Terminology for MR Spectroscopy

WHY HIGH MAGNETIC FIELD ?

- More signal
- More spectral resolution
- And more sensitivity



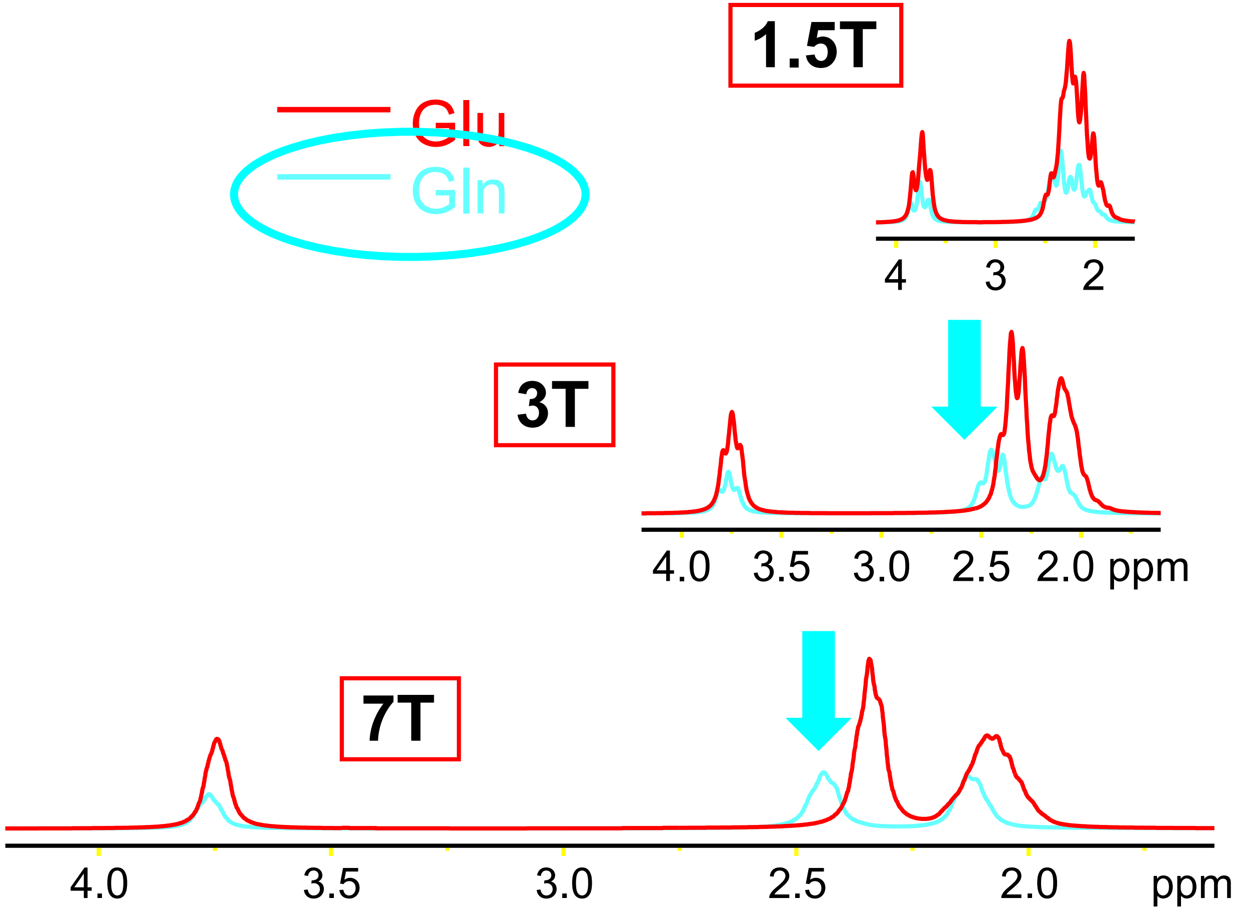




Ralf Mekle et al, (2009) MRM 50: 1279

WHY HIGH B_0?

- Enormous progress
  - ↑ SNR 🙂
  - ↑ chemical shift dispersion – ↑ resolution 🙂
  - decreased strong J-coupling effects
  - Improve quantification precision and accuracy
  - ↓ T_2^* - ↑ spectral lw in Hz ☹

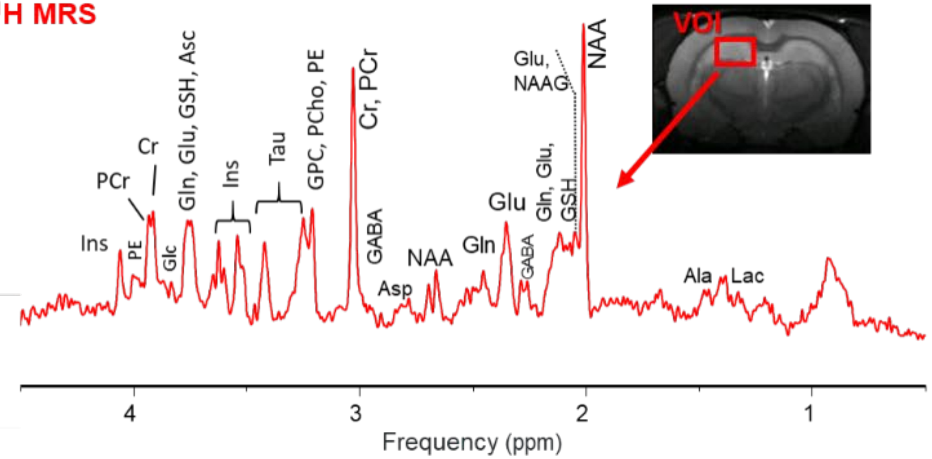


Courtesy of I Tkac

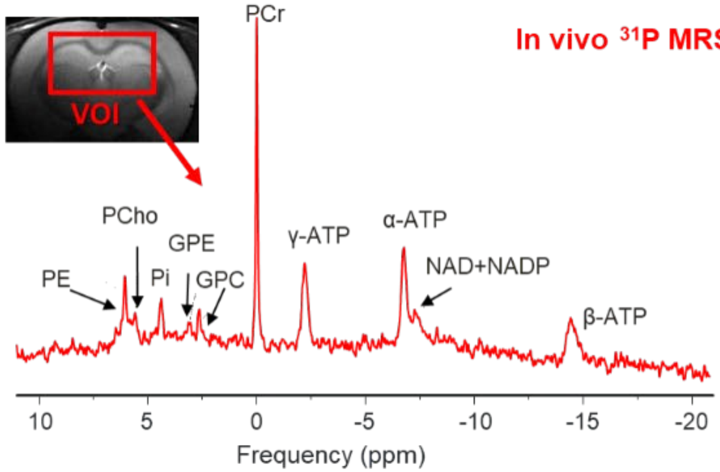
Oz G, et al., Clinical proton MR spectroscopy in central nervous system disorders. Radiology. 2014
Wilson M, et al., Methodological consensus on clinical proton MRS of the brain: Review and recommendations. Magn Reson Med. 2019

X NUCLEI MRS – 9.4T

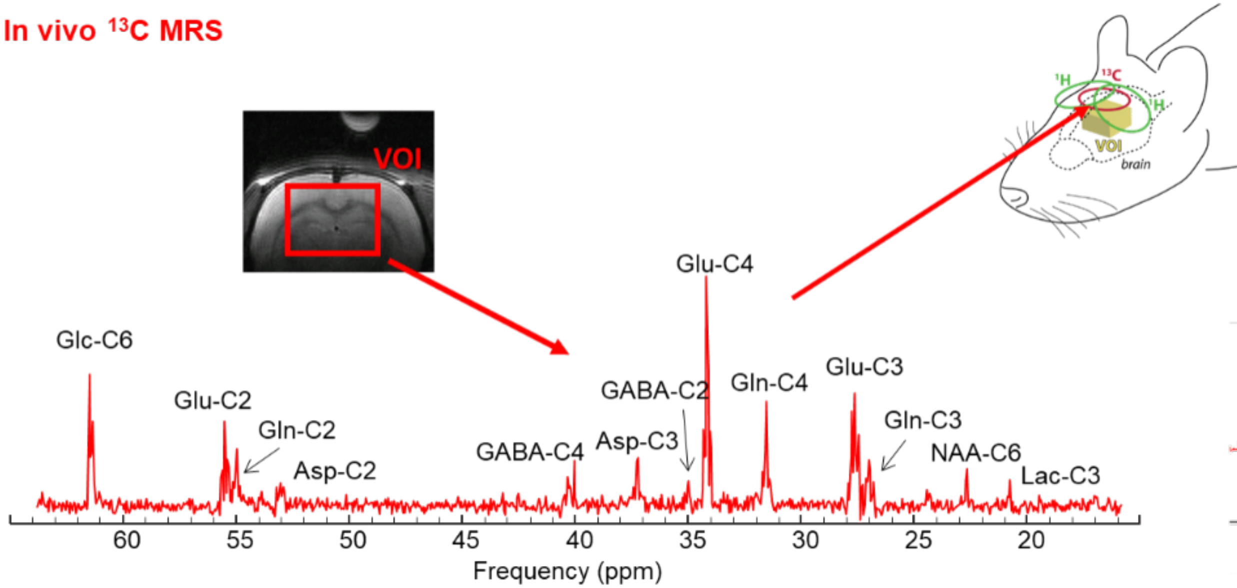
In vivo ^{1}H MRS



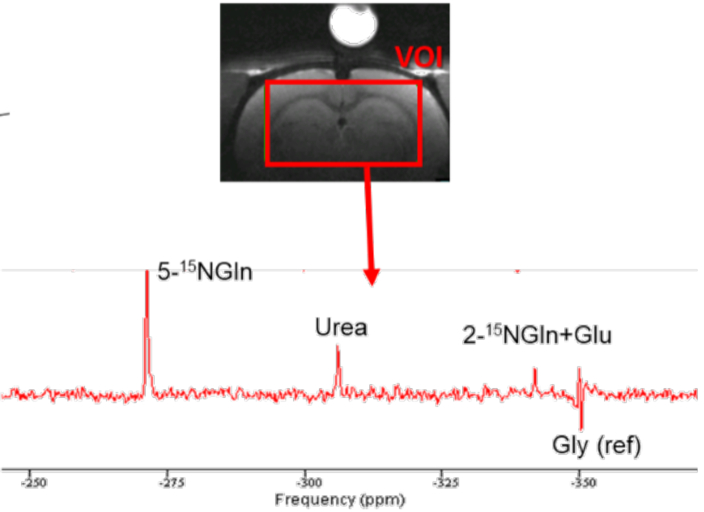
In vivo ^{31}P MRS



In vivo ^{13}C MRS



In vivo ^{15}N MRS



Lanz et al, 2017, 2020; Cudalbu et al 2021;

CLINICAL VS PRECLINICAL DATA

	Preclinical	Clinical
Subjects	Animal (rat/mouse) - anesthesia	Human – no anesthesia
Motion	☺	? ☹
Time for scanning	☺ Shim, WS, OVS, …	☹
@scanner	MRS experts	Not necessary MRS experts
Amount of data	+++	+++++++

(Lots) Data with sometimes artifacts

- Need to be identified
- Corrected or data discarded
- Preprocessed
- Fitted & Quantified

Clinicians

☹ Draw incorrect decisions
☹ Standard quantification software – NO quality check
☹ CRLB …..

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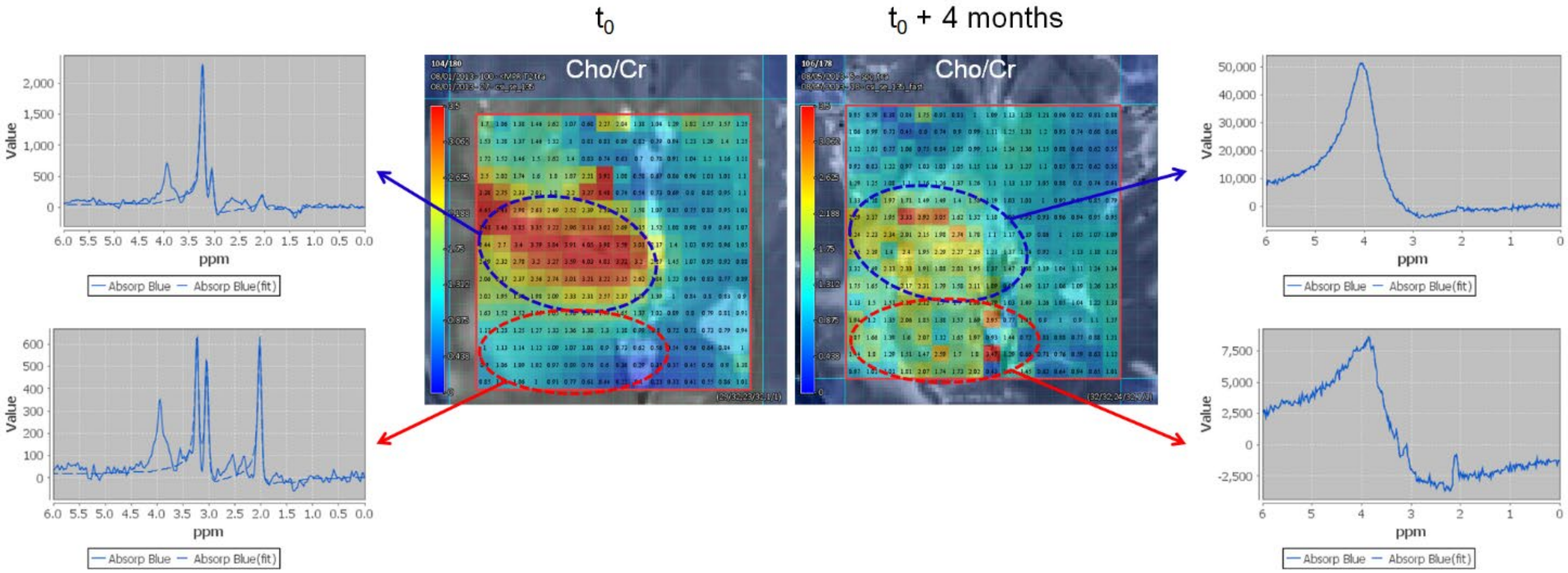
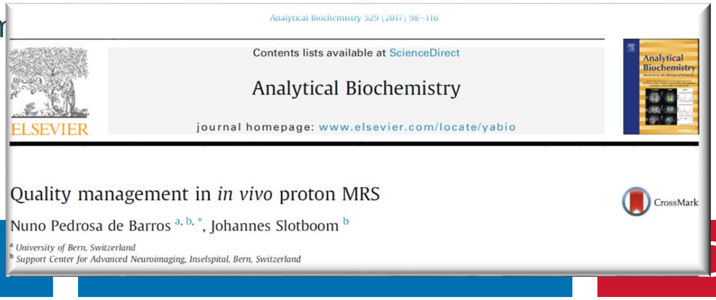
CLINICAL VS PRECLINICAL DATA



Example showing two Cho/Cr maps of a Glioma patient acquired 4 months apart.
Siemens Aera 1.5 T, 2D-PRESS, 12x12 interpolated to 32x32, TE/TR 135/1500m

From N Barros et al, Analytical Biochemistry, 2017



Analytical Biochemistry 529 (2017) 98–116

Contents lists available at ScienceDirect

Analytical Biochemistry

journal homepage: www.elsevier.com/locate/yabio

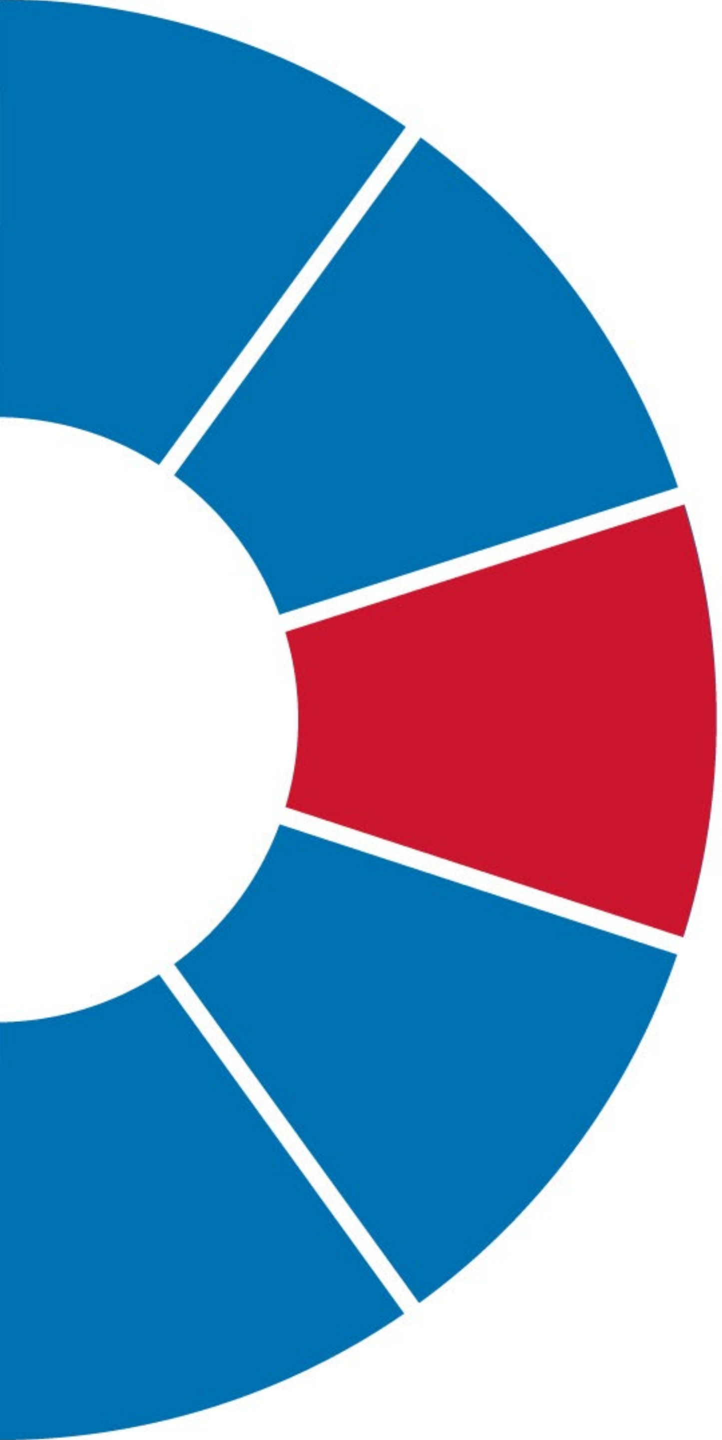
ELSEVIER

Quality management in *in vivo* proton MRS

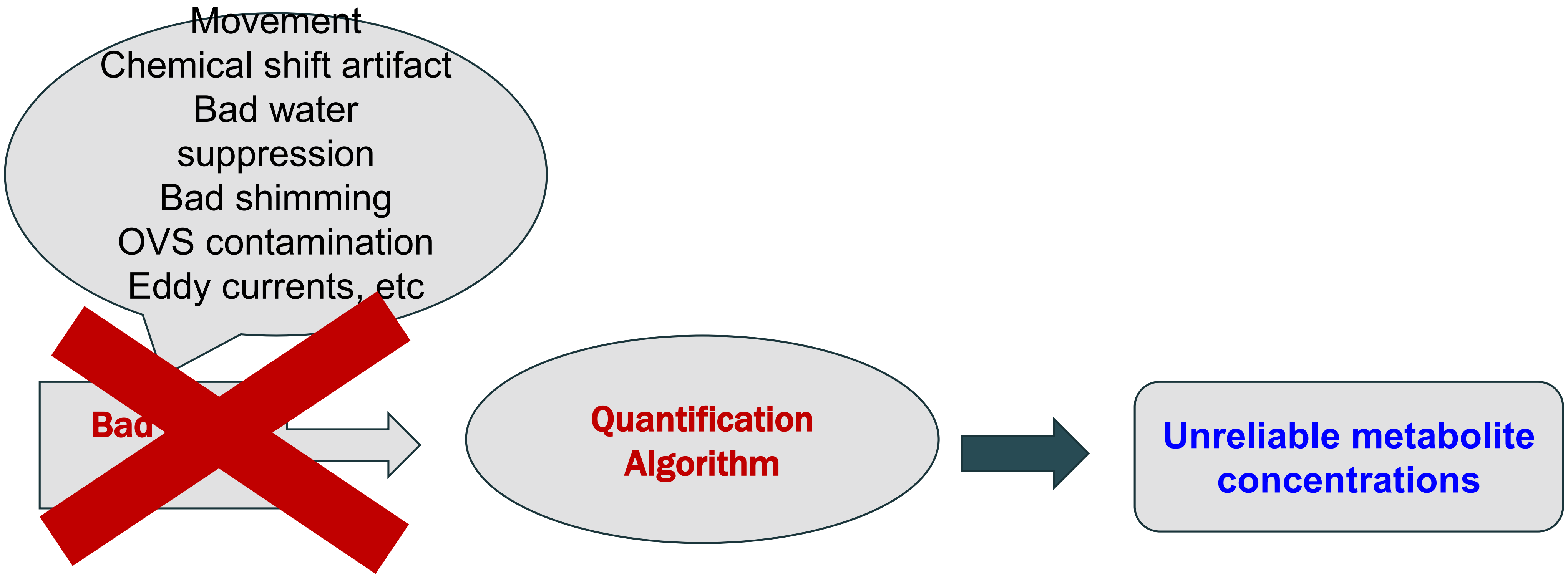
Nuno Pedrosa de Barros [a, b, *], Johannes Slotboom [b]

[a] University of Bern, Switzerland
[b] Support Center for Advanced Neuroimaging, Inselspital, Bern, Switzerland

CrossMark



ARTIFACTS IN 1H MRS


Movement
Chemical shift artifact
Bad water suppression
Bad shimming
OVS contamination
Eddy currents, etc

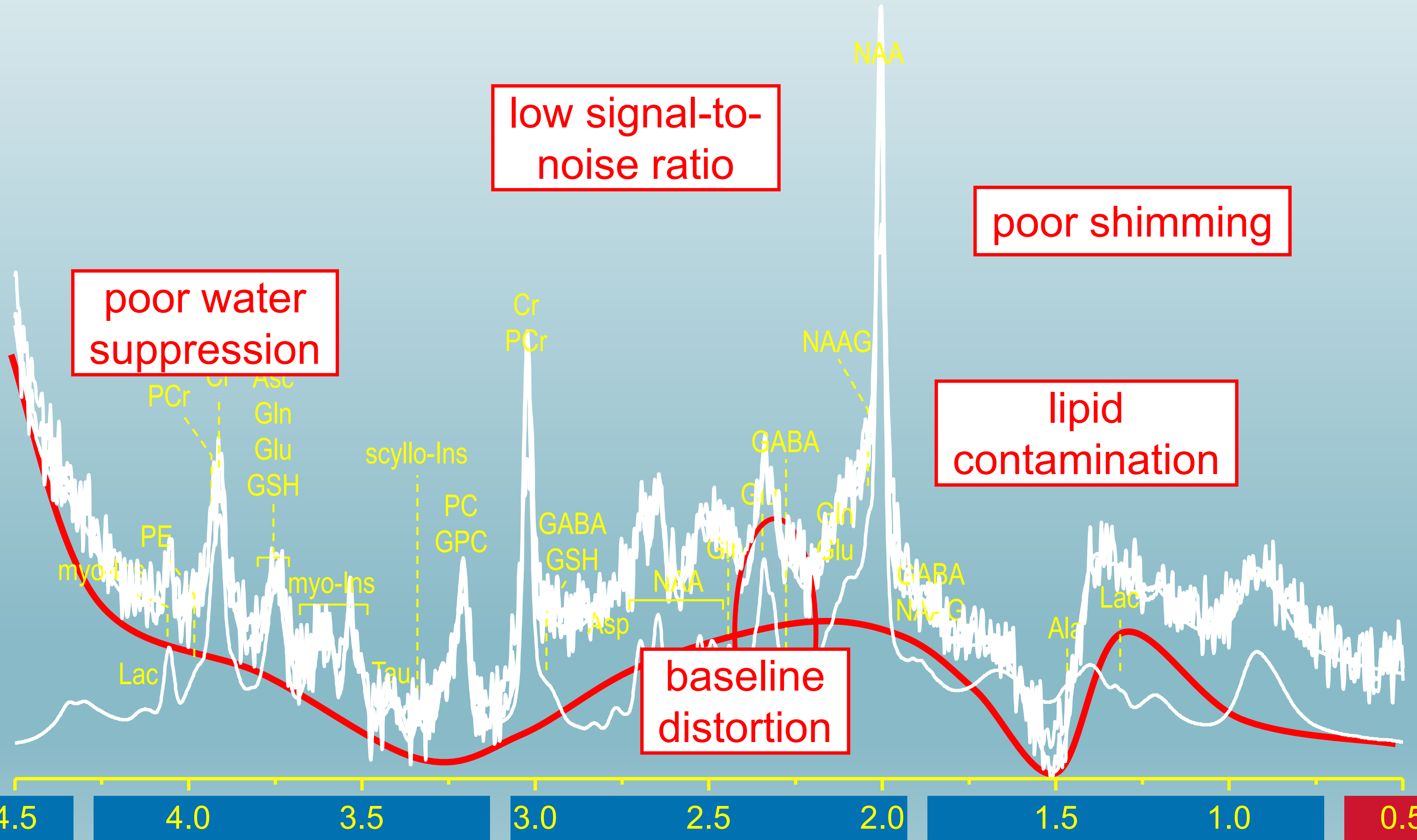
Bad

Quantification Algorithm

Unreliable metabolite concentrations

ISMRM 2010, Potentials and Challenges at High Field MRS
R Kreis, NMR Biomed 2004, 17:361
Tkáč I, et al, Appl Magn Reson. 2005 29:139.

DISTORTIONS OF 1H NMR SPECTRUM OF THE HUMAN BRAIN AT 7T



poor water suppression

low signal-to-noise ratio

poor shimming

lipid contamination

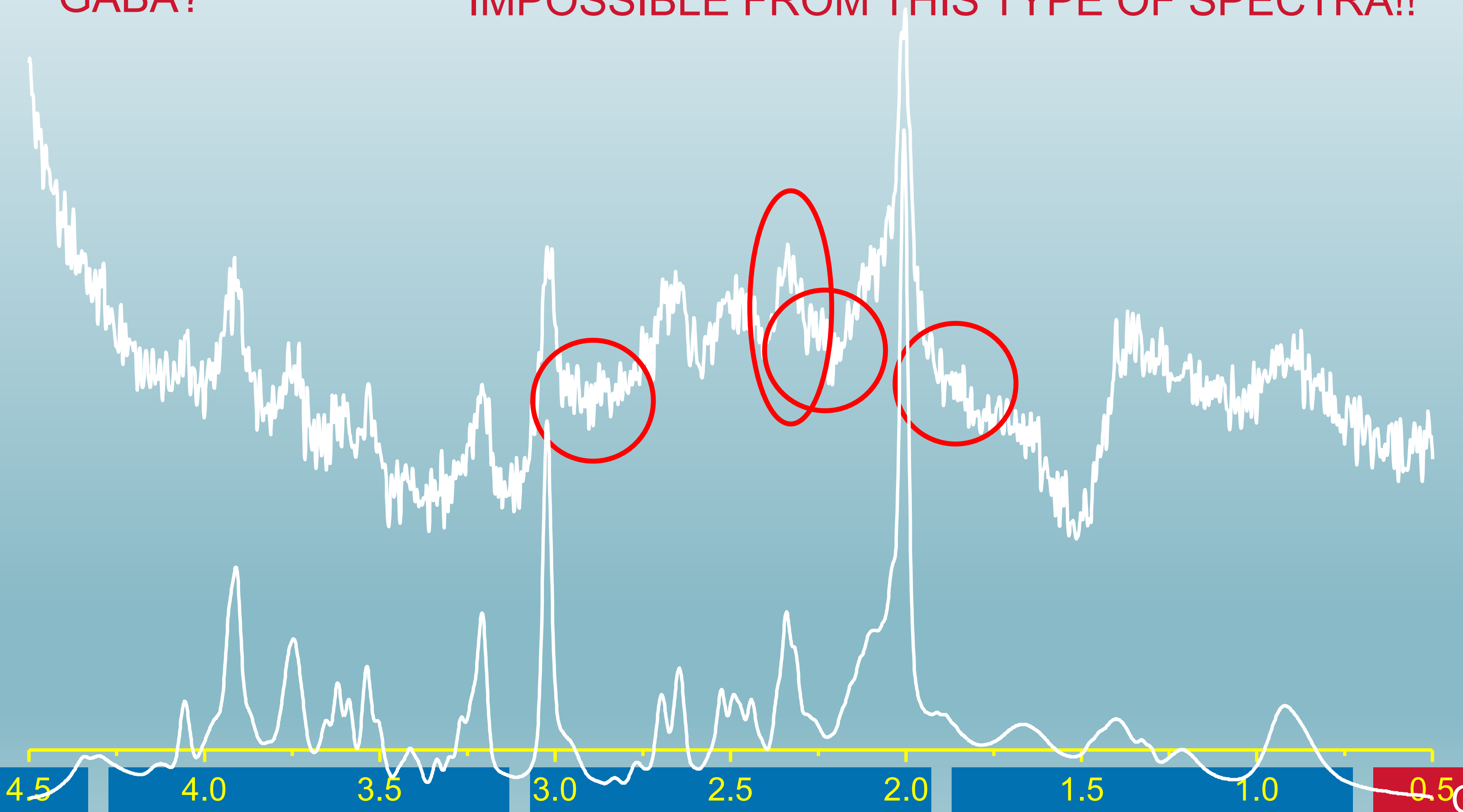
baseline distortion

TKAC, University of Minnesota

IS RELIABLE QUANTIFICATION OF GABA AND GLU POSSIBLE?

GLUTAMATE? DIFFICULT, LIMITED PRECISION

GABA? IMPOSSIBLE FROM THIS TYPE OF SPECTRA!!



C I B M . C H

TKAC, University of Minnesota

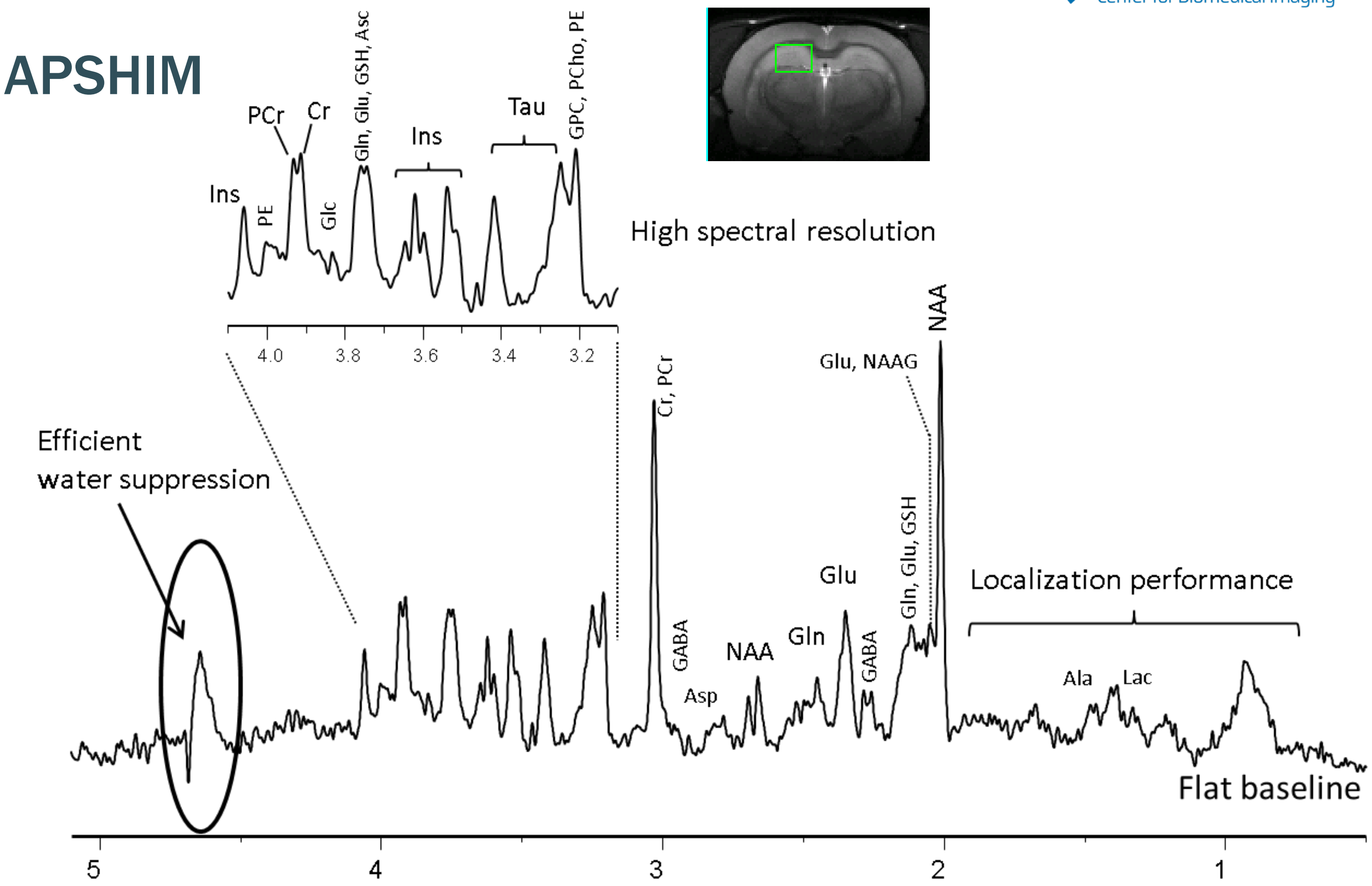
GOOD QUALITY DATA AT SHORT TE

- **Shimming: e.g. FASTMAP, MAPSHIM**
- **Pulse sequence at short TE**

Provide undistorted multiplets and no T_2 weighting

Increased no of metabolites

Improved quantification

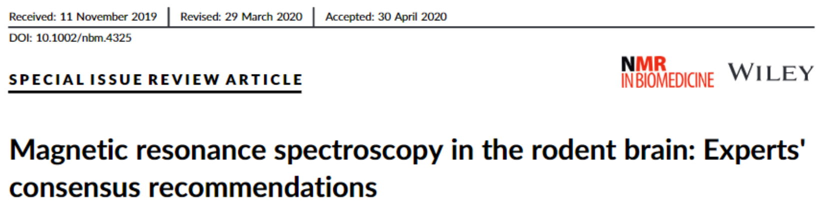


SPECIAL, TE=2.8ms, 10 min

R Kreis 2004; C Cudalbu 2013 (450) Quality of MRS/MRSI – YouTube - I Tkac

ACQUISITION SEQUENCES

- Reduced CSDE
- Good localization :
  - double : OVS+Seq or LASER
- Strong crusher gradients
- Good WS


Received: 11 November 2019 | Revised: 29 March 2020 | Accepted: 30 April 2020
DOI: 10.1002/nbm.4325

SPECIAL ISSUE REVIEW ARTICLE

NMR IN BIOMEDICINE WILEY

Magnetic resonance spectroscopy in the rodent brain: Experts' consensus recommendations

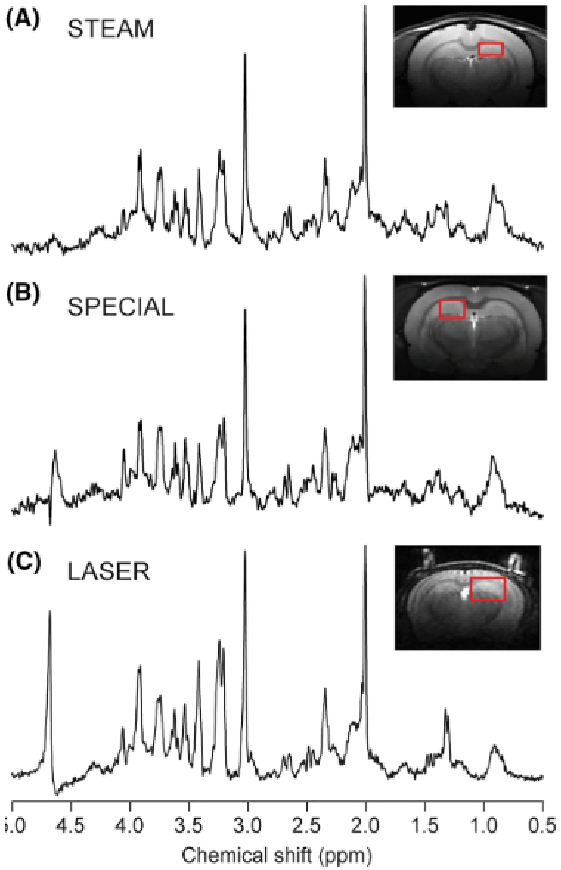
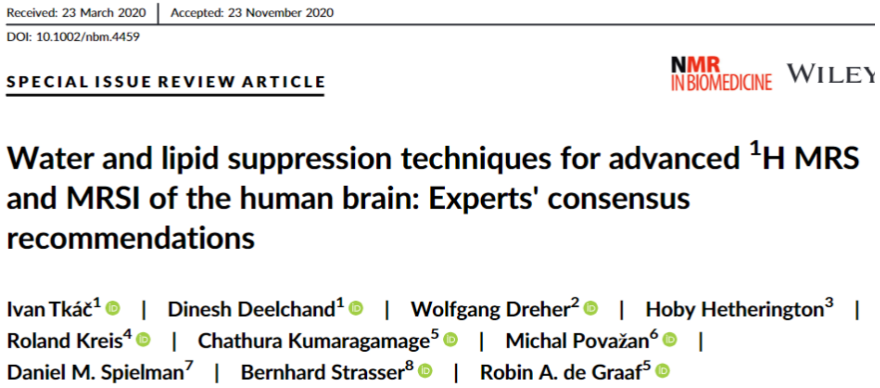


FIGURE 3 Example ^{1}H MR spectra obtained in rodent brains at 9.4 T with STEAM (A), SPECIAL (B) and LASER (C) sequences. A, STEAM spectrum: rat brain, 2.3 × 1.3 × 2.5 mm^3 voxel placed in the hippocampus, TR = 5 s, TE = 2 ms, TM = 20 ms, number of averages = 448. Spectrum is shown with Gaussian factor = 0.15. B, SPECIAL spectrum: rat brain, 2 × 2.8 × 2 mm^3 voxel placed in the hippocampus, TR = 4, TE = 2.8 ms, number of averages = 160. C, LASER spectrum: mouse brain, 1.7 × 2.25 × 2.25 mm^3 voxel placed in hippocampus, TR = 4 s, TE = 27 ms, number of averages = 384. The STEAM spectrum was provided by Ivan Tkáč


Received: 23 March 2020 | Accepted: 23 November 2020
DOI: 10.1002/nbm.4459

SPECIAL ISSUE REVIEW ARTICLE

NMR IN BIOMEDICINE WILEY

Water and lipid suppression techniques for advanced ^{1}H MRS and MRSI of the human brain: Experts' consensus recommendations

Ivan Tkáč[1] | Dinesh Deelchand[1] | Wolfgang Dreher[2] | Hoby Hetherington[3] | Roland Kreis[4] | Chathura Kumaragamage[5] | Michal Považan[6] | Daniel M. Spielman[7] | Bernhard Strasser[8] | Robin A. de Graaf[5]


Received: 15 March 2019 | Revised: 29 October 2019 | Accepted: 7 November 2019
DOI: 10.1002/nbm.4236

SPECIAL ISSUE REVIEW ARTICLE

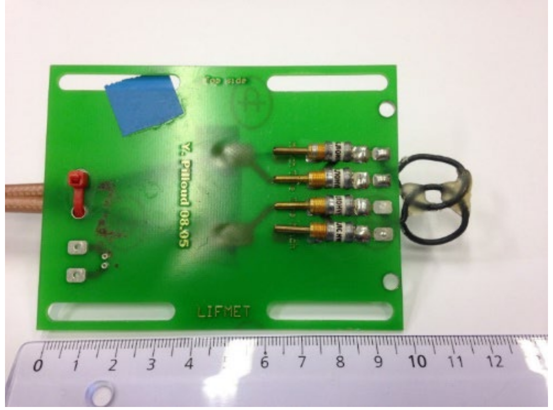
WILEY NMR IN BIOMEDICINE

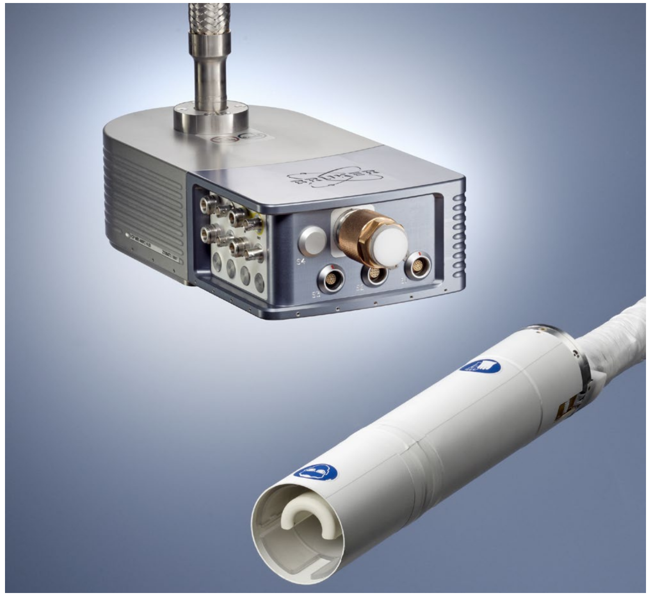
Advanced single voxel ^{1}H magnetic resonance spectroscopy techniques in humans: Experts' consensus recommendations

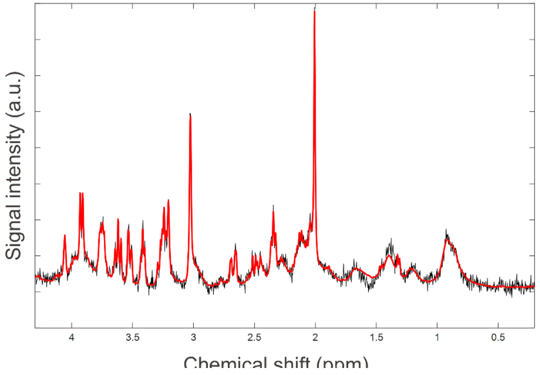
Gülin Öz[1] | Dinesh K. Deelchand[1] | Jannie P. Wijnen[2] | Vladimír Mlynárik[3] | Lijing Xin[4] | Ralf Mekle[5] | Ralph Noeske[6] | Tom W.J. Scheenen[7,8] | Ivan Tkáč[1] | the Experts' Working Group on Advanced Single Voxel ^{1}H MRS

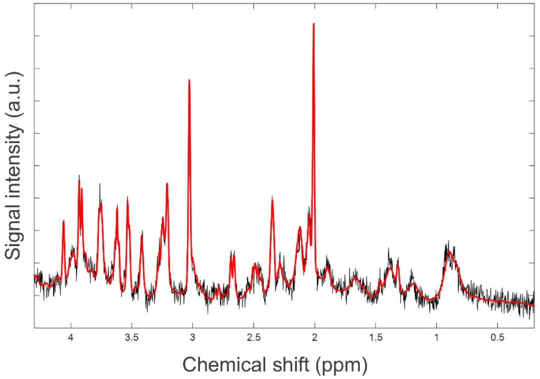
RF COILS

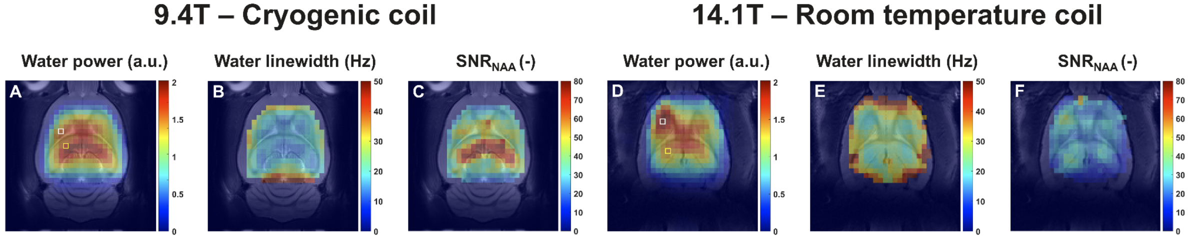
T Le

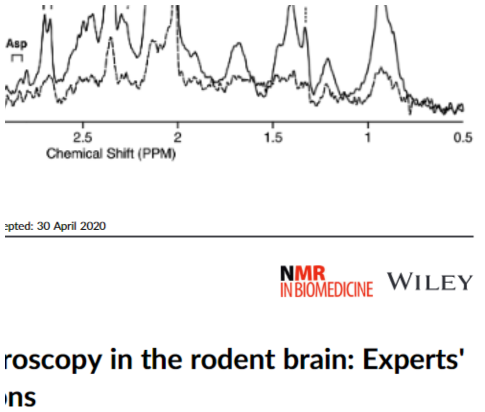








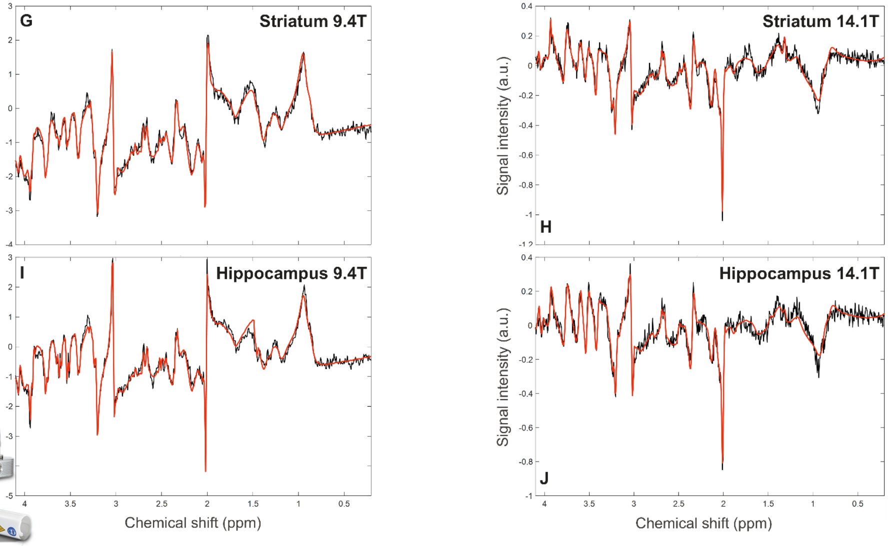


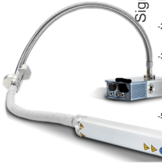


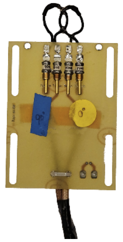
pted: 30 April 2020

NMR IN BIOMEDICINE WILEY

roscopy in the rodent brain: Experts'
ns







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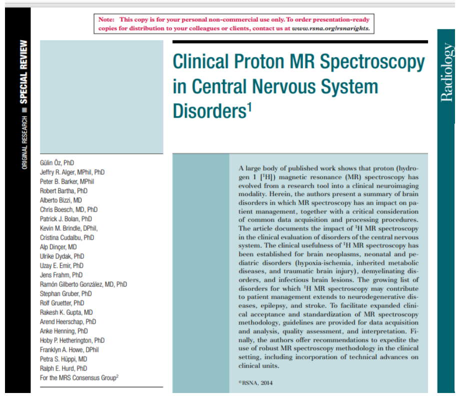
MINIMUM QUALITY CRITERIA



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ORIGINAL RESEARCH ■ SPECIAL REVIEW

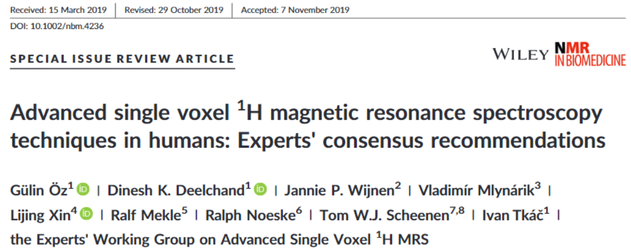
Radiology

Clinical Proton MR Spectroscopy in Central Nervous System Disorders[1]

Gülin Öz, PhD
Jeffry R. Alger, MPhil, PhD
Peter B. Barker, MPhil
Robert Bartha, PhD
Alberto Bizzi, MD
Chris Boesch, MD, PhD
Patrick J. Bolan, PhD
Kevin M. Brindle, DPhil,
Cristina Cudalbu, PhD
Alp Dinçer, MD
Ulrike Dydak, PhD
Uzay E. Emir, PhD
Jens Frahm, PhD
Ramón Gilberto González, MD, PhD
Stephan Gruber, PhD
Rolf Gruetter, PhD
Rakesh K. Gupta, MD
Arend Heerschap, PhD
Anke Henning, PhD
Hoby P. Hetherington, PhD
Franklyn A. Howe, DPhil
Petra S. Hüppi, MD
Ralph E. Hurd, PhD
For the MRS Consensus Group[2]

A large body of published work shows that proton (hydrogen 1 [^{1}H]) magnetic resonance (MR) spectroscopy has evolved from a research tool into a clinical neuroimaging modality. Herein, the authors present a summary of brain disorders in which MR spectroscopy has an impact on patient management, together with a critical consideration of common data acquisition and processing procedures. The article documents the impact of ^{1}H MR spectroscopy in the clinical evaluation of disorders of the central nervous system. The clinical usefulness of ^{1}H MR spectroscopy has been established for brain neoplasms, neonatal and pediatric disorders (hypoxia-ischemia, inherited metabolic diseases, and traumatic brain injury), demyelinating disorders, and infectious brain lesions. The growing list of disorders for which ^{1}H MR spectroscopy may contribute to patient management extends to neurodegenerative diseases, epilepsy, and stroke. To facilitate expanded clinical acceptance and standardization of MR spectroscopy methodology, guidelines are provided for data acquisition and analysis, quality assessment, and interpretation. Finally, the authors offer recommendations to expedite the use of robust MR spectroscopy methodology in the clinical setting, including incorporation of technical advances on clinical units.

©RSNA, 2014



Received: 15 March 2019 | Revised: 29 October 2019 | Accepted: 7 November 2019
DOI: 10.1002/nbm.4236

SPECIAL ISSUE REVIEW ARTICLE

WILEY NMR IN BIOMEDICINE

Advanced single voxel ^{1}H magnetic resonance spectroscopy techniques in humans: Experts' consensus recommendations

Gülin Öz[1] | Dinesh K. Deelchand[1] | Jannie P. Wijnen[2] | Vladimír Mlynárik[3] | Lijing Xin[4] | Ralf Mekle[5] | Ralph Noeske[6] | Tom W.J. Scheenen[7,8] | Ivan Tkáč[1] | the Experts' Working Group on Advanced Single Voxel ^{1}H MRS

- SNR >3 for major resonances
- Linewidth - shimming
- Lineshape – symmetric
- WS
- No lipid contamination
- No other visible artifacts
  - Not so obvious artifacts (Chemical shift artifact, localization inaccuracies, signal cancellation, etc)
- CRBs
- Residuals with unexplained features

Signal

Quantification

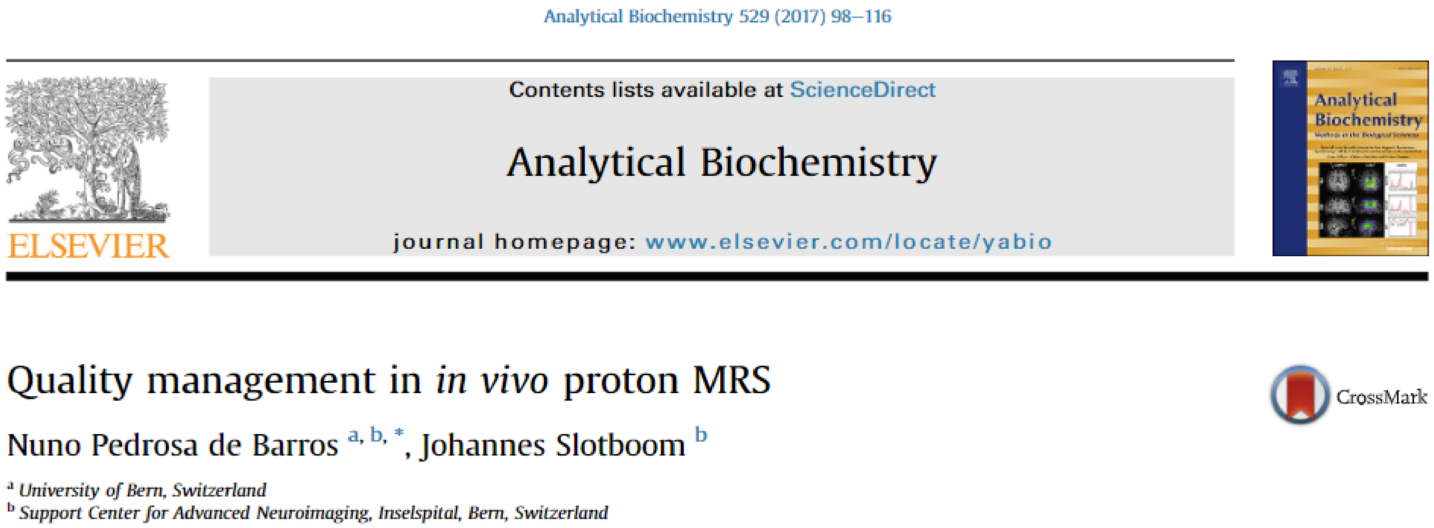
ISMRM 2010, Potentials and Challenges at High Field MRS
R Kreis, NMR Biomed 2004, 17:361
Tkáč I, et al, Appl Magn Reson. 2005 29:139.

http://www.ismrm.org/workshops/Spectroscopy16/program.htm
2nd TRANSACT Workshop, University Bern: Quality Issues in Clinical MRS 2014
The MRS Consensus Group. (2014), Radiology, 270(3):658-79.

QUALITY CONTROL

- **Quality Control – detection of artifacts (rejection or correction)**
  - **Signal Quality Control**
  - **Quantification Quality Control**
  - **Automatic (semi-automatic)**

https://mrs2022.cibm.ch/agenda/



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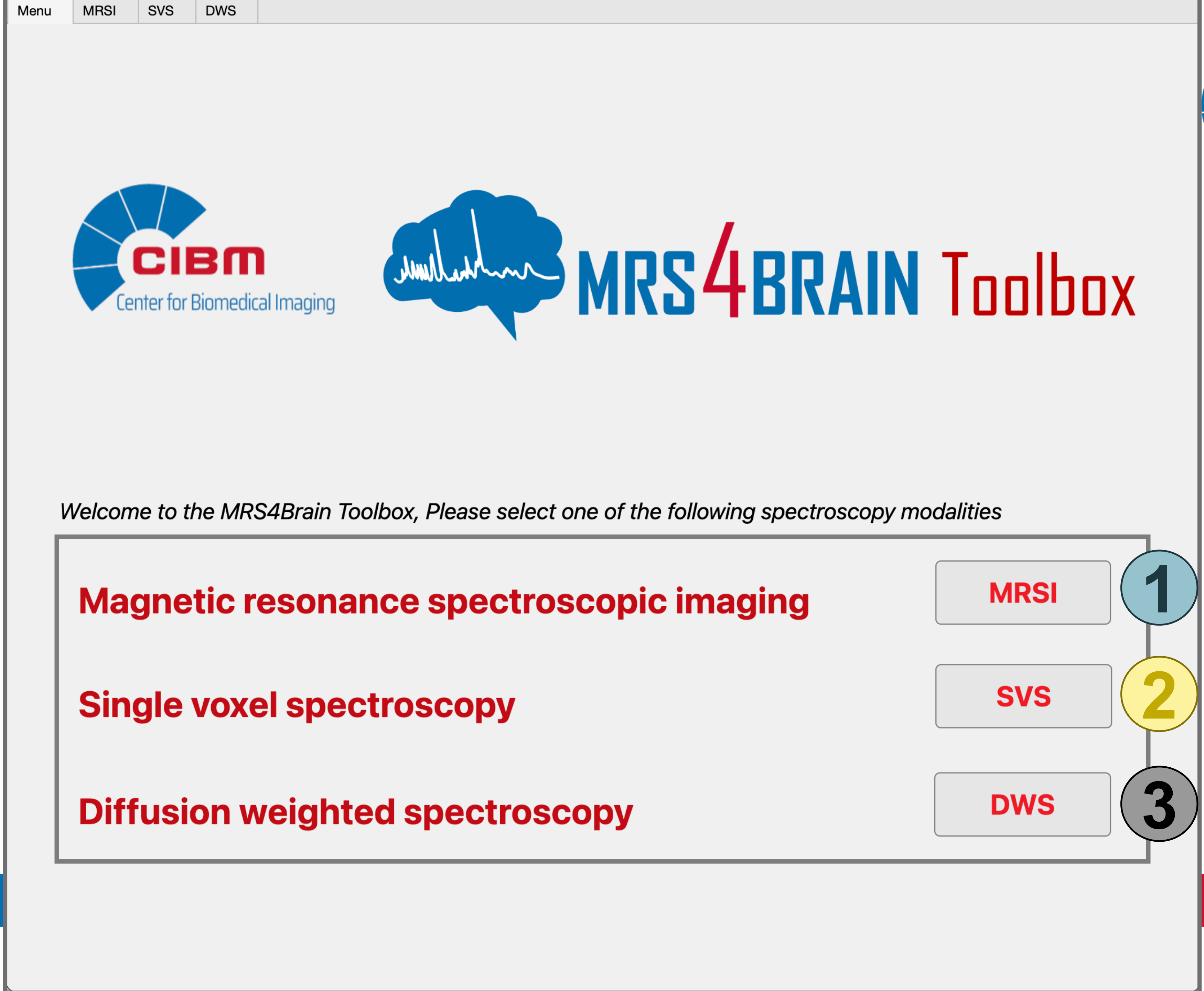
ELSEVIER

Quality management in *in vivo* proton MRS

Nuno Pedrosa de Barros [a, b, *], Johannes Slotboom [b]

[a] *University of Bern, Switzerland*
[b] *Support Center for Advanced Neuroimaging, Inselspital, Bern, Switzerland*

N Barros et al, Analytical Biochemistry, 2017

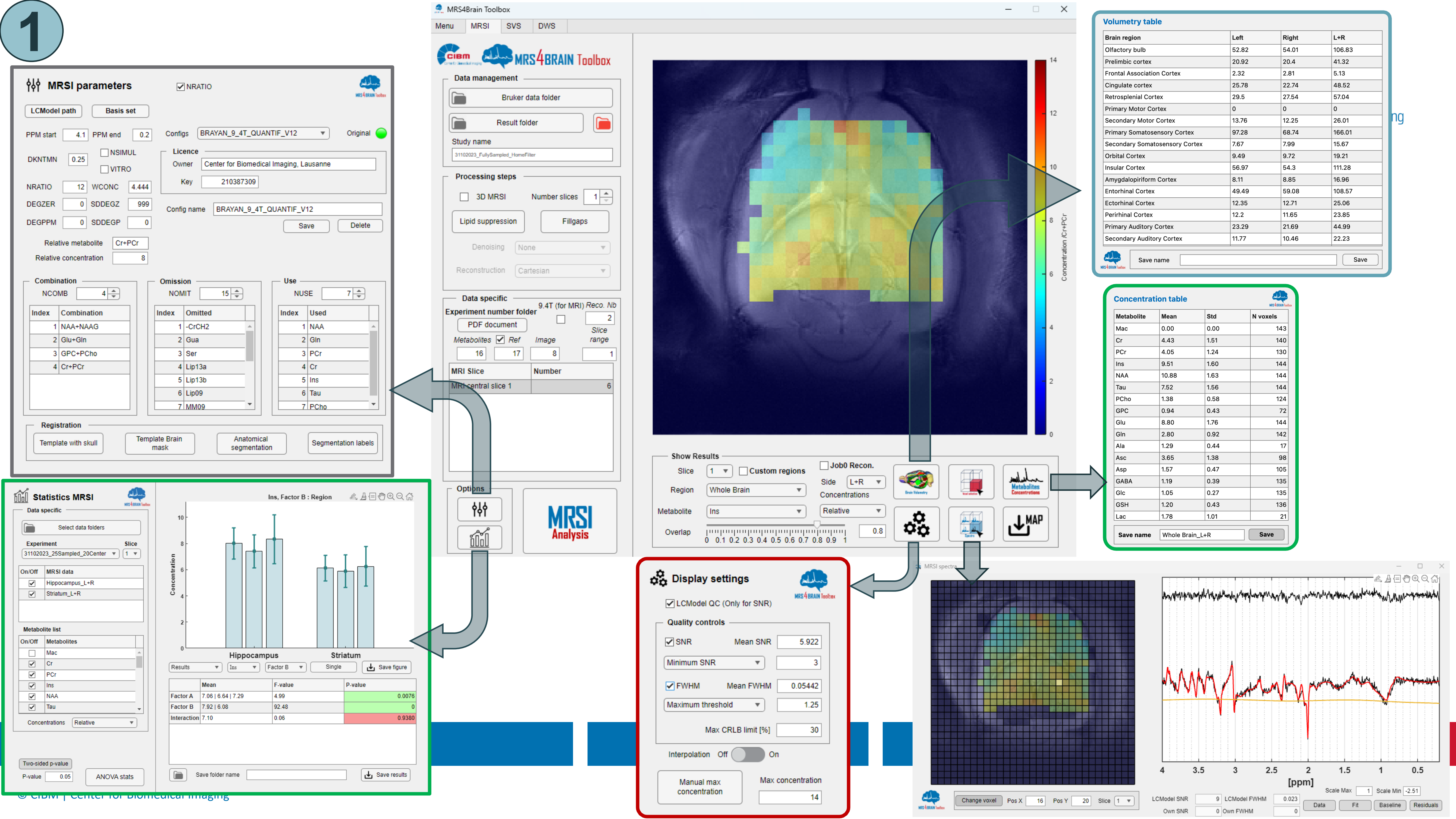


Welcome to the MRS4Brain Toolbox, Please select one of the following spectroscopy modalities

Magnetic resonance spectroscopic imaging MRSI ①

Single voxel spectroscopy SVS ②

Diffusion weighted spectroscopy DWS ③



MRSI parameters

☑ NRATIO

LCModel path | Basis set

PPM start 4.1
PPM end 0.2
Configs BRAYAN_9_4T_QUANTIF_V12
Original
DKNTMN 0.25
☐ NSIMUL
☐ VITRO
NRATIO 12
WCONC 4.444
DEGZER 0
SDDEGZ 999
DEGPPM 0
SDDEGP 0

Licence
Owner Center for Biomedical Imaging, Lausanne
Key 210387309

Config name BRAYAN_9_4T_QUANTIF_V12
Save | Delete

Relative metabolite Cr+PCr
Relative concentration 8

Combination
NCOMB 4

Index	Combination
1	NAA+NAAG
2	Glu+Gln
3	GPC+PCho
4	Cr+PCr

Omission
NOMIT 15

Index	Omitted
1	-CrCH2
2	Gua
3	Ser
4	Lip13a
5	Lip13b
6	Lip09
7	MM09

Use
NUSE 7

Index	Used
1	NAA
2	Gln
3	PCr
4	Cr
5	Ins
6	Tau
7	PCho

Registration
Template with skull | Template Brain mask | Anatomical segmentation | Segmentation labels

Data management
Bruker data folder
Result folder
Study name 31102023_FullySampled_HomeFilter

Processing steps
☐ 3D MRSI
Number slices 1
Lipid suppression | Fillgaps
Denoising None
Reconstruction Cartesian

Data specific
Experiment number folder
9.4T (for MRI) ☐
Reco. Nb 2
PDF document
Metabolites 16
☑ *Ref* 17
Image 8
Slice range 1

MRI Slice	Number
MRI central slice 1	6

Options

Show Results
Slice 1
☐ Custom regions
☐ Job0 Recon.
Region Whole Brain
Side L+R
Concentrations Relative
Metabolite Ins
Overlap 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
0.8

Volumetry table

Brain region	Left	Right	L+R
Olfactory bulb	52.82	54.01	106.83
Prelimbic cortex	20.92	20.4	41.32
Frontal Association Cortex	2.32	2.81	5.13
Cingulate cortex	25.78	22.74	48.52
Retrosplenial Cortex	29.5	27.54	57.04
Primary Motor Cortex	0	0	0
Secondary Motor Cortex	13.76	12.25	26.01
Primary Somatosensory Cortex	97.28	68.74	166.01
Secondary Somatosensory Cortex	7.67	7.99	15.67
Orbital Cortex	9.49	9.72	19.21
Insular Cortex	56.97	54.3	111.28
Amygdalopiriform Cortex	8.11	8.85	16.96
Entorhinal Cortex	49.49	59.08	108.57
Ectorhinal Cortex	12.35	12.71	25.06
Perirhinal Cortex	12.2	11.65	23.85
Primary Auditory Cortex	23.29	21.69	44.99
Secondary Auditory Cortex	11.77	10.46	22.23

Save name
Save

Concentration table

Metabolite	Mean	Std	N voxels
Mac	0.00	0.00	143
Cr	4.43	1.51	140
PCr	4.05	1.24	130
Ins	9.51	1.60	144
NAA	10.88	1.63	144
Tau	7.52	1.56	144
PCho	1.38	0.58	124
GPC	0.94	0.43	72
Glu	8.80	1.76	144
Gln	2.80	0.92	142
Ala	1.29	0.44	17
Asc	3.65	1.38	98
Asp	1.57	0.47	105
GABA	1.19	0.39	135
Glc	1.05	0.27	135
GSH	1.20	0.43	136
Lac	1.78	1.01	21

Save name Whole Brain_L+R
Save

Statistics MRSI

Data specific
Select data folders
Experiment 31102023_25Sampled_20Center
Slice 1

On/Off	MRSI data
☑	Hippocampus_L+R
☑	Striatum_L+R

Metabolite list

On/Off	Metabolites
☐	Mac
☑	Cr
☑	PCr
☑	Ins
☑	NAA
☑	Tau

Concentrations Relative

Two-sided p-value
P-value 0.05
ANOVA stats

Results | Ins | Factor B | Single | Save figure

	Mean	F-value	P-value
Factor A	7.06 | 6.64 | 7.29	4.99	0.0076
Factor B	7.92 | 6.08	92.48	0
Interaction	7.10	0.06	0.9380

Save folder name
Save results

Display settings

☑ LCModel QC (Only for SNR)

Quality controls
☑ SNR
Mean SNR 5.922
Minimum SNR 3
☑ FWHM
Mean FWHM 0.05442
Maximum threshold 1.25
Max CRLB limit [%] 30

Interpolation Off On

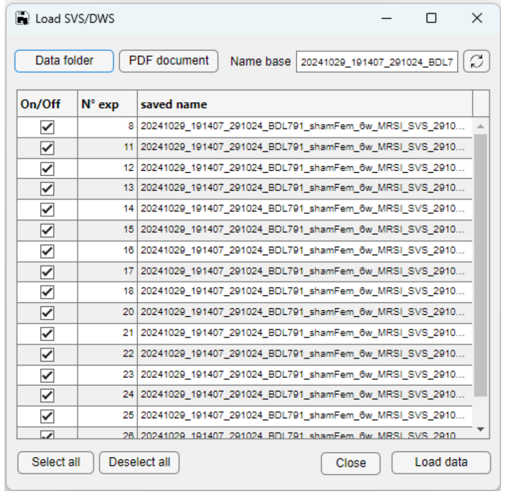
Manual max concentration
Max concentration 14

MRSI spectra

Change voxel
Pos X 16
Pos Y 20
Slice 1

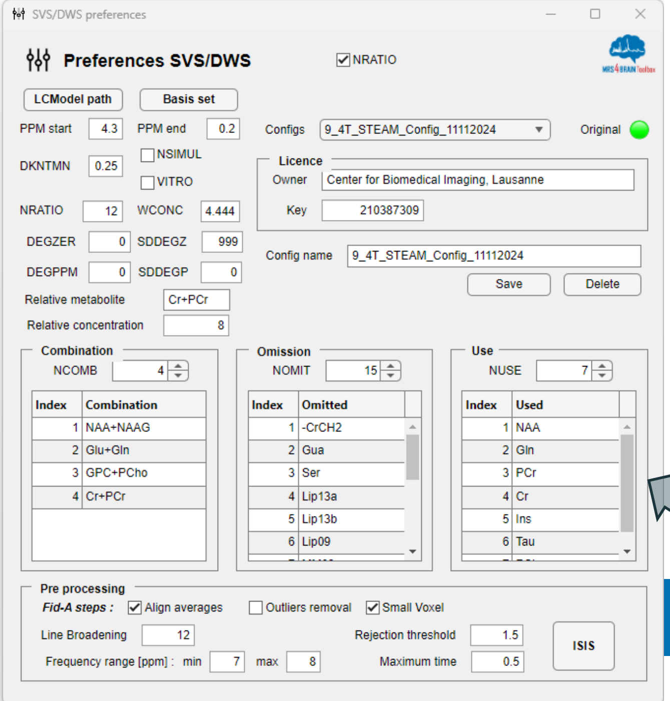
Scale Max 1
Scale Min -2.51
LCModel SNR 9
LCModel FWHM 0.023
Own SNR 0
Own FWHM 0
Data | Fit | Baseline | Residuals

②



Name base: 20241029_191407_291024_BDL7

On/Off	N° exp	saved name
☑	8	20241029_191407_291024_BDL791_shamFem_6w_MRSI_SVS_2910...
☑	11	20241029_191407_291024_BDL791_shamFem_6w_MRSI_SVS_2910...
☑	12	20241029_191407_291024_BDL791_shamFem_6w_MRSI_SVS_2910...
☑	13	20241029_191407_291024_BDL791_shamFem_6w_MRSI_SVS_2910...
☑	14	20241029_191407_291024_BDL791_shamFem_6w_MRSI_SVS_2910...
☑	15	20241029_191407_291024_BDL791_shamFem_6w_MRSI_SVS_2910...
☑	16	20241029_191407_291024_BDL791_shamFem_6w_MRSI_SVS_2910...
☑	17	20241029_191407_291024_BDL791_shamFem_6w_MRSI_SVS_2910...
☑	18	20241029_191407_291024_BDL791_shamFem_6w_MRSI_SVS_2910...
☑	20	20241029_191407_291024_BDL791_shamFem_6w_MRSI_SVS_2910...
☑	21	20241029_191407_291024_BDL791_shamFem_6w_MRSI_SVS_2910...
☑	22	20241029_191407_291024_BDL791_shamFem_6w_MRSI_SVS_2910...
☑	23	20241029_191407_291024_BDL791_shamFem_6w_MRSI_SVS_2910...
☑	24	20241029_191407_291024_BDL791_shamFem_6w_MRSI_SVS_2910...
☑	25	20241029_191407_291024_BDL791_shamFem_6w_MRSI_SVS_2910...
☑	26	20241029_191407_291024_BDL791_shamFem_6w_MRSI_SVS_2910...



Preferences SVS/DWS

☑ NRATIO

PPM start: 4.3
PPM end: 0.2
DKNTMN: 0.25
☐ NSIMUL
☐ VITRO
NRATIO: 12
WCONC: 4.444
DEGZER: 0
SDDEGZ: 999
DEGPPM: 0
SDDEGP: 0
Relative metabolite: Cr+PCr
Relative concentration: 8

Configs: 9_4T_STEAM_Config_11112024
Original ●

Licence
Owner: Center for Biomedical Imaging, Lausanne
Key: 210387309

Config name: 9_4T_STEAM_Config_11112024

Combination
NCOMB: 4

Index	Combination
1	NAA+NAAG
2	Glu+Gln
3	GPC+PCho
4	Cr+PCr

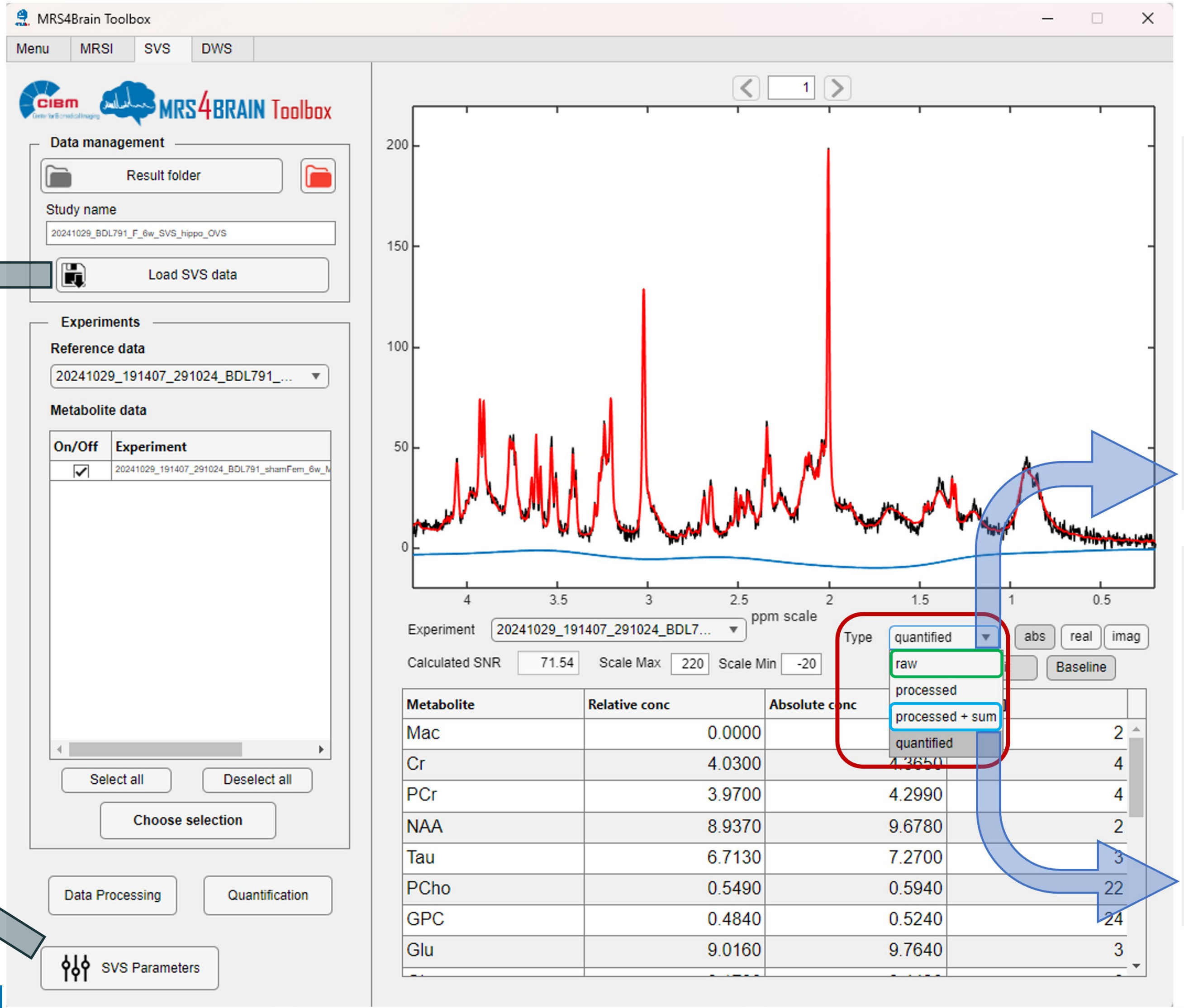
Omission
NOMIT: 15

Index	Omitted
1	-CrCH2
2	Gua
3	Ser
4	Lip13a
5	Lip13b
6	Lip09

Use
NUSE: 7

Index	Used
1	NAA
2	Gln
3	PCr
4	Cr
5	Ins
6	Tau

Pre processing
Fid-A steps : ☑ Align averages ☐ Outliers removal ☑ Small Voxel
Line Broadening: 12
Rejection threshold: 1.5
Frequency range [ppm] : min 7 max 8
Maximum time: 0.5



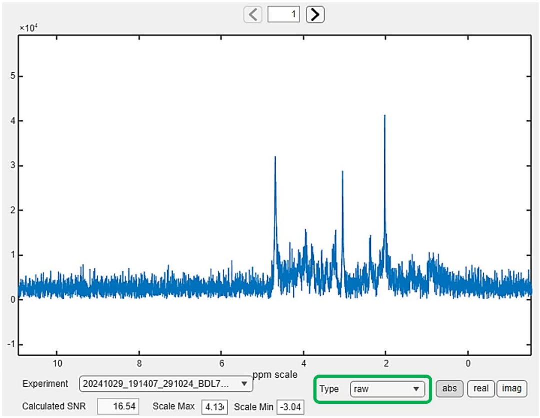
Data management
Study name: 20241029_BDL791_F_6w_SVS_hippo_OVS

Experiments
Reference data: 20241029_191407_291024_BDL791_...
Metabolite data

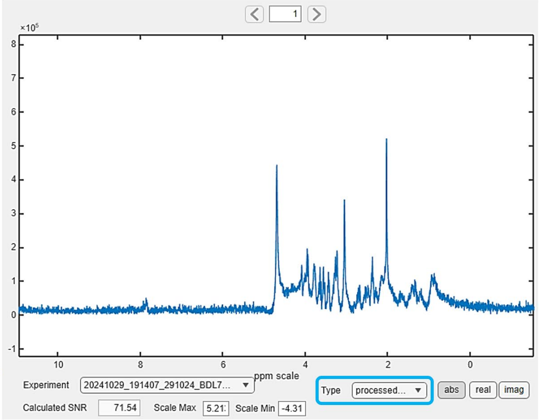
On/Off	Experiment
☑	20241029_191407_291024_BDL791_shamFem_6w_M

Experiment: 20241029_191407_291024_BDL7...
Calculated SNR: 71.54
Scale Max: 220
Scale Min: -20
Type: quantified
- raw
- processed
- processed + sum
- quantified

Metabolite	Relative conc	Absolute conc	
Mac	0.0000		2
Cr	4.0300	4.3650	4
PCr	3.9700	4.2990	4
NAA	8.9370	9.6780	2
Tau	6.7130	7.2700	3
PCho	0.5490	0.5940	22
GPC	0.4840	0.5240	24
Glu	9.0160	9.7640	3

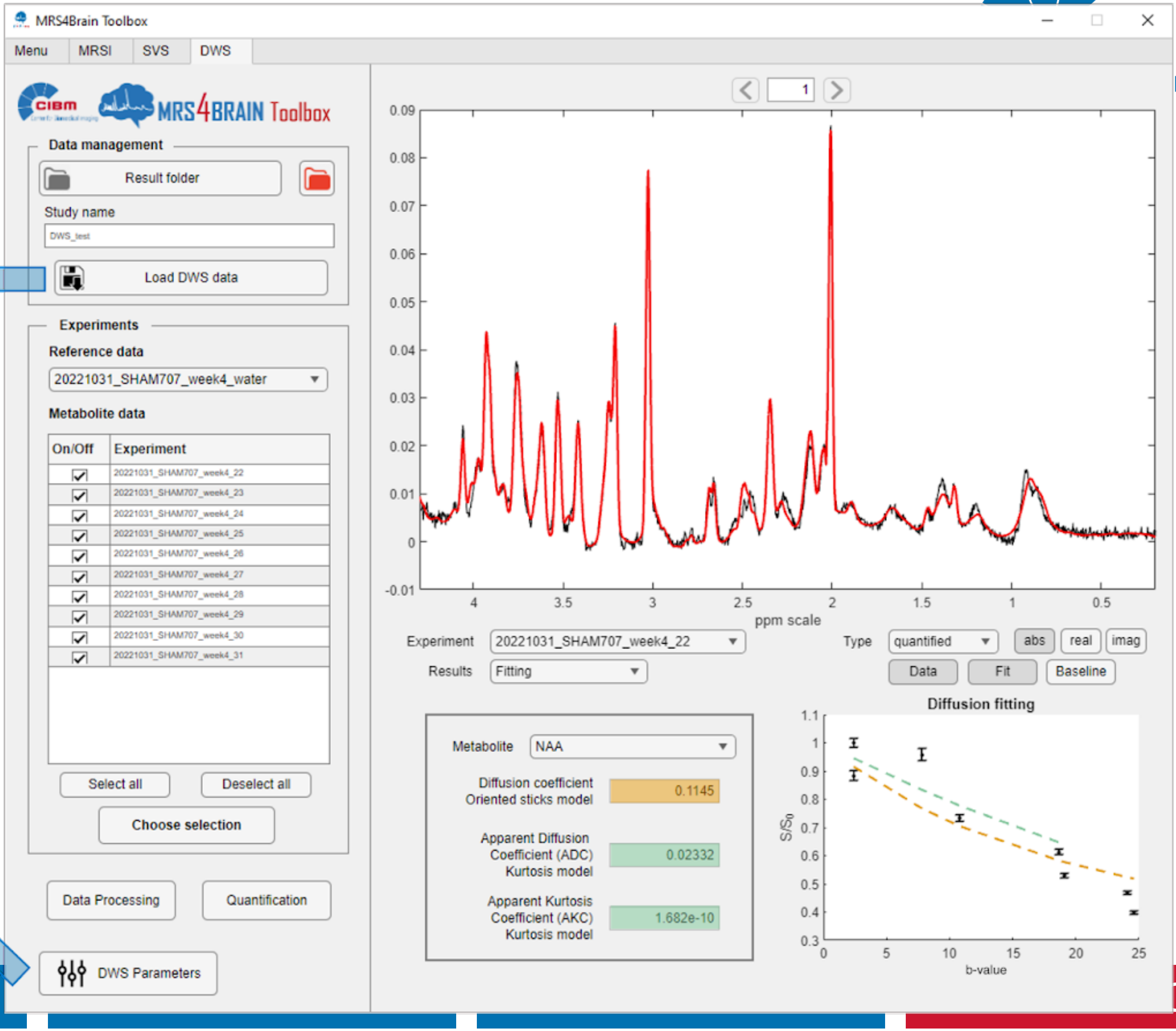


Experiment: 20241029_191407_291024_BDL7...
Type: raw
Calculated SNR: 16.54
Scale Max: 4.13
Scale Min: -3.04



Experiment: 20241029_191407_291024_BDL7...
Type: processed...
Calculated SNR: 71.54
Scale Max: 5.21
Scale Min: -4.31

③



Data management

Study name: DWS_test

Experiments

Reference data: 20221031_SHAM707_week4_water

Metabolite data

On/Off	Experiment
☑	20221031_SHAM707_week4_22
☑	20221031_SHAM707_week4_23
☑	20221031_SHAM707_week4_24
☑	20221031_SHAM707_week4_25
☑	20221031_SHAM707_week4_26
☑	20221031_SHAM707_week4_27
☑	20221031_SHAM707_week4_28
☑	20221031_SHAM707_week4_29
☑	20221031_SHAM707_week4_30
☑	20221031_SHAM707_week4_31

Experiment: 20221031_SHAM707_week4_22

Results: Fitting

Type: quantified

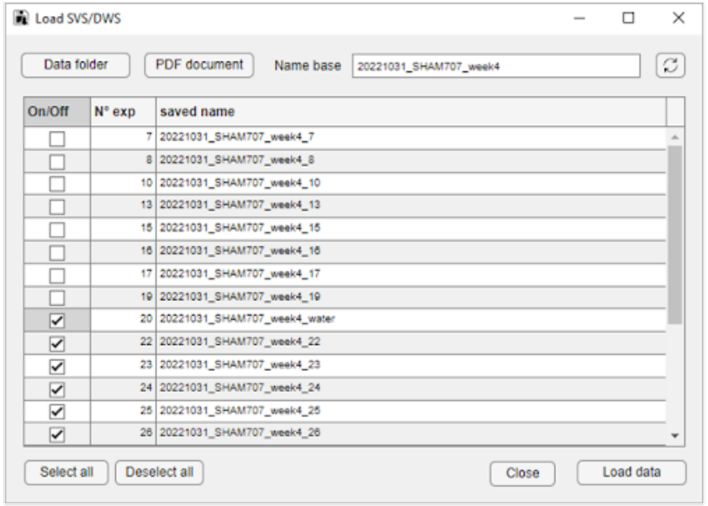
Page: 1

Metabolite: NAA

Diffusion coefficient Oriented sticks model: 0.1145

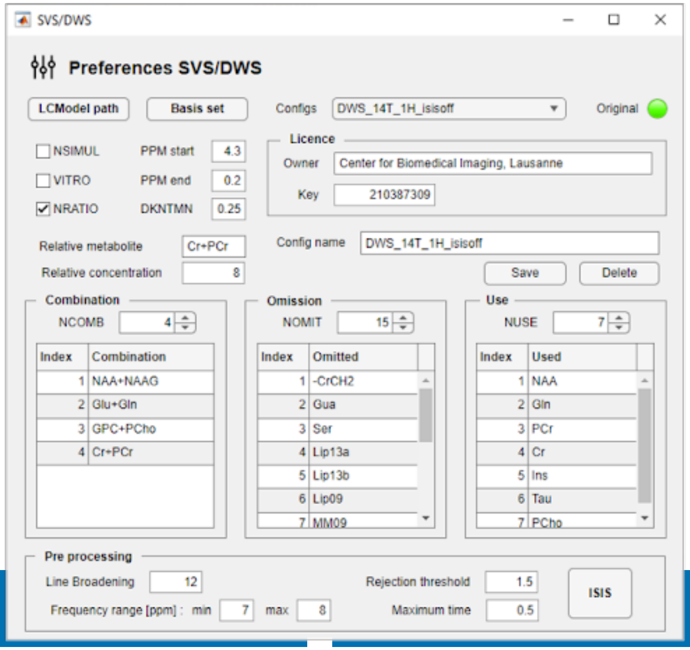
Apparent Diffusion Coefficient (ADC) Kurtosis model: 0.02332

Apparent Kurtosis Coefficient (AKC) Kurtosis model: 1.682e-10



Name base: 20221031_SHAM707_week4

On/Off	N° exp	saved name
☐	7	20221031_SHAM707_week4_7
☐	8	20221031_SHAM707_week4_8
☐	10	20221031_SHAM707_week4_10
☐	13	20221031_SHAM707_week4_13
☐	15	20221031_SHAM707_week4_15
☐	16	20221031_SHAM707_week4_16
☐	17	20221031_SHAM707_week4_17
☐	19	20221031_SHAM707_week4_19
☑	20	20221031_SHAM707_week4_water
☑	22	20221031_SHAM707_week4_22
☑	23	20221031_SHAM707_week4_23
☑	24	20221031_SHAM707_week4_24
☑	25	20221031_SHAM707_week4_25
☑	26	20221031_SHAM707_week4_26



Preferences SVS/DWS

Configs: DWS_14T_1H_isisoff

Original ●

☐ NSIMUL PPM start 4.3

☐ VITRO PPM end 0.2

☑ NRATIO DKNTMN 0.25

Relative metabolite: Cr+PCr

Relative concentration: 8

Licence

Owner: Center for Biomedical Imaging, Lausanne

Key: 210387309

Config name: DWS_14T_1H_isisoff

Combination

NCOMB: 4

Index	Combination
1	NAA+NAAG
2	Glu+Gln
3	GPC+PCho
4	Cr+PCr

Omission

NOMIT: 15

Index	Omitted
1	-CrCH2
2	Gua
3	Ser
4	Lip13a
5	Lip13b
6	Lip09
7	MM09

Use

NUSE: 7

Index	Used
1	NAA
2	Gln
3	PCr
4	Cr
5	Ins
6	Tau
7	PCho

Pre processing

Line Broadening: 12

Frequency range [ppm] : min 7 max 8

Rejection threshold: 1.5

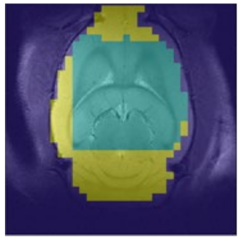
Maximum time: 0.5

MRS4BRAIN Toolbox

https://github.com/AlvBrayan/MRS4Brain-toolbox
https://www.epfl.ch/labs/mrs4brain/ressources/mrs4brain-toolbox/

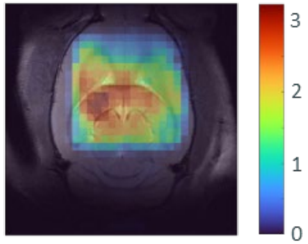
CIBM Center for Biomedical Imaging

1. **Read the Bruker MRSI data format**
2. **Brain mask** – Water power mask
3. **HSVD water removal**
4. **Lipid suppression**
5. Quick data assessment maps
   - → linewidth and ΔB_0 map (water signal)
   - → SNR map (NAA peak hight / σ noise)
6. **LCmodel (Version 6.3-1N)**
7. **Quality selection criteria**
   - → SNR (75% of $\overline{SNR}$), FWHM (125% of $\overline{FWHM}$) and CRLBs (<40%)
8. **Metabolic maps and atlas based automatic segmentation (SIGMA atlas)**

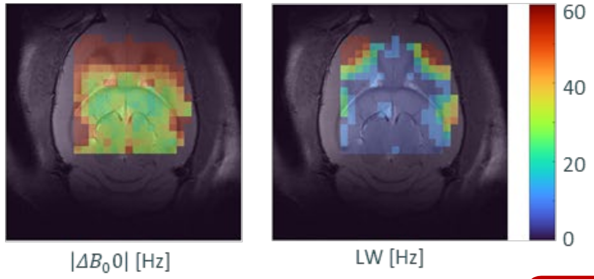


$$Power_{x,y} = \sum_{i=1}^{1024} |spectral\ point|$$

$$0 < Power_{x,y} - \overline{Power} \leftarrow Selection$$



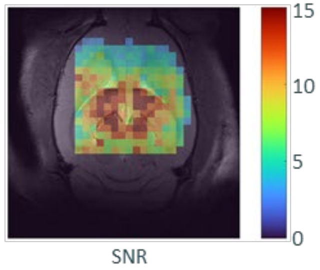
→ ΔB_0 and linewidth map (water signal)



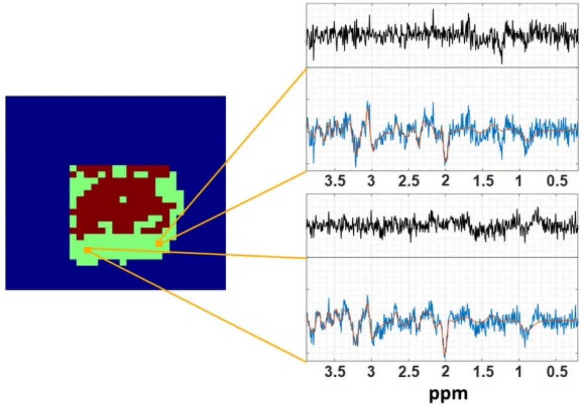
$|\Delta B_0|$ [Hz]

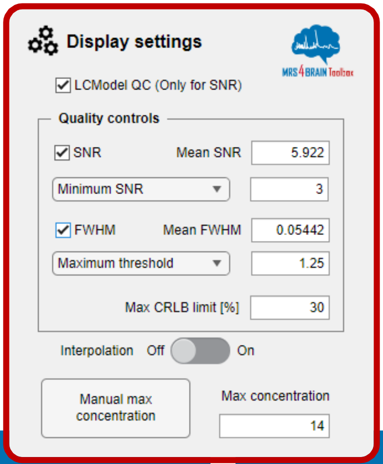
LW [Hz]

→ SNR map (NAA peak hight / σ noise)



SNR





Display settings

☑ LCModel QC (Only for SNR)

Quality controls

☑ SNR Mean SNR 5.922

Minimum SNR ▾ 3

☑ FWHM Mean FWHM 0.05442

Maximum threshold ▾ 1.25

Max CRLB limit [%] 30

Interpolation Off On

Manual max concentration

Max concentration 14

B Alves & G Briand

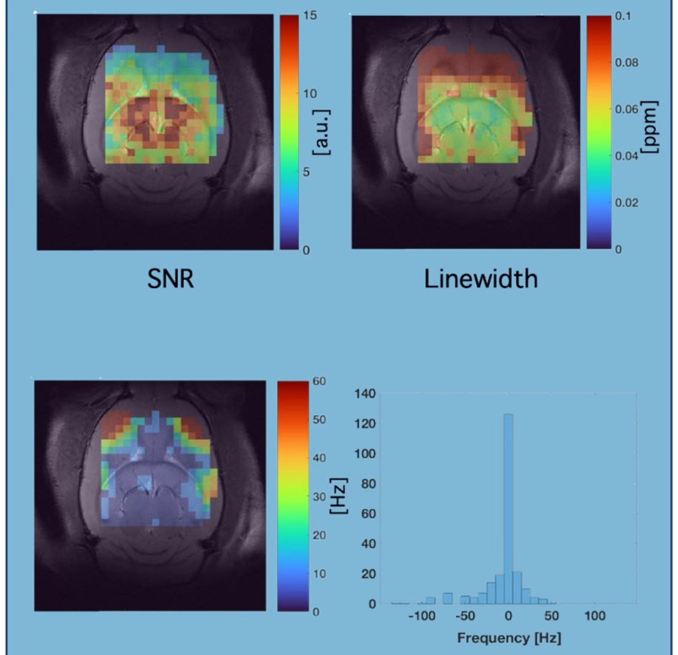
CIBM.CH

cristina.cudalbu@epfl.ch

MRS4BRAIN TOOLBOX : MRSI (QUALITY CONTROL)

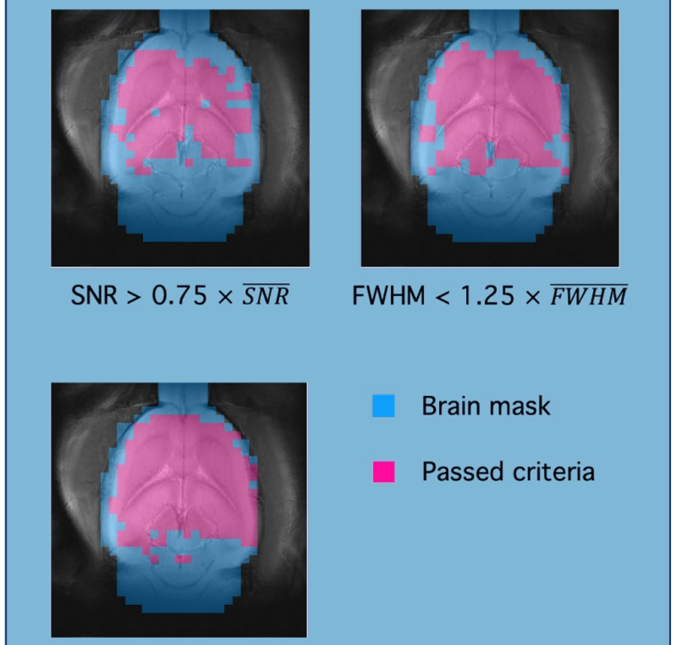
CIBM
Center for Biomedical Imaging

Quality check *(before fitting)*



B0 map and histogram

Quality control *(after fitting)*



SNR > 0.75 × $\overline{SNR}$

FWHM < 1.25 × $\overline{FWHM}$

CRLB < 30 %

- 4 Quality Metrics reported : Signal-to-noise ratio (SNR), linewidth (lw or FWHM), B_0 shift & Cramer Rao lower bound (CRLB)
- Quality check before fitting (no masking)
- Quality control after fitting (masking of unwanted data)

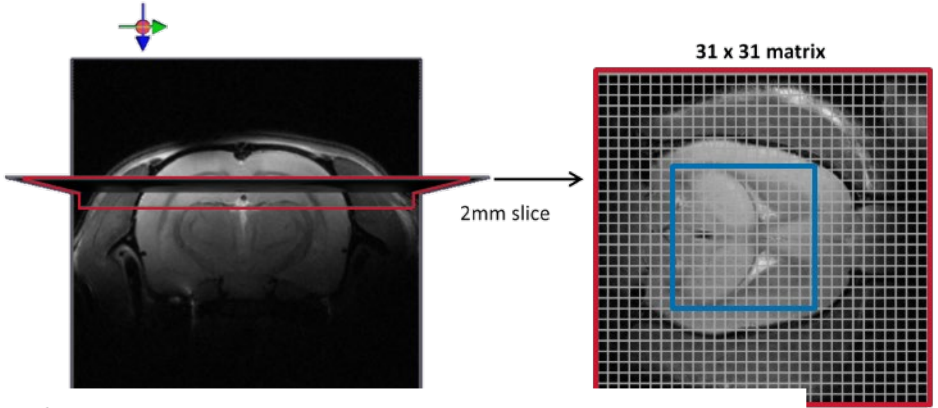
https://www.epfl.ch/labs/mrs4brain/ressources/mrs4brain-toolbox/

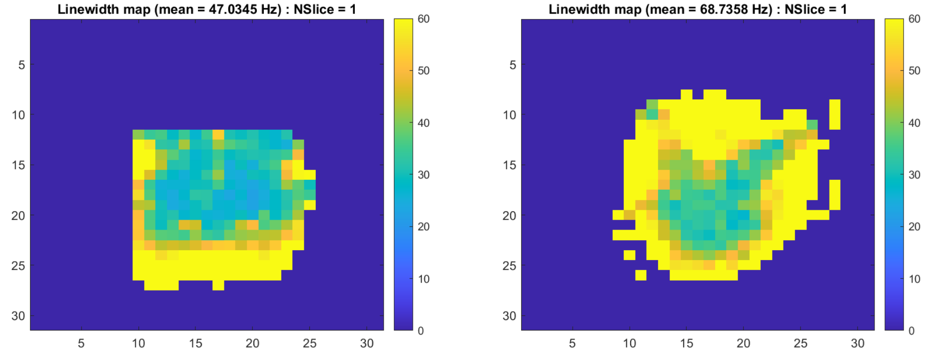
MRS4BRAIN Toolbox

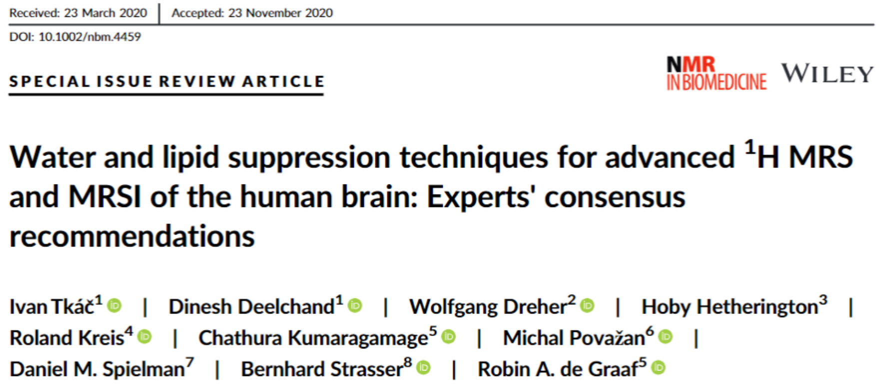
MRSI – quality control

B Alves

- Bo shimming – shim larger regions – significant Bo inhomogeneities







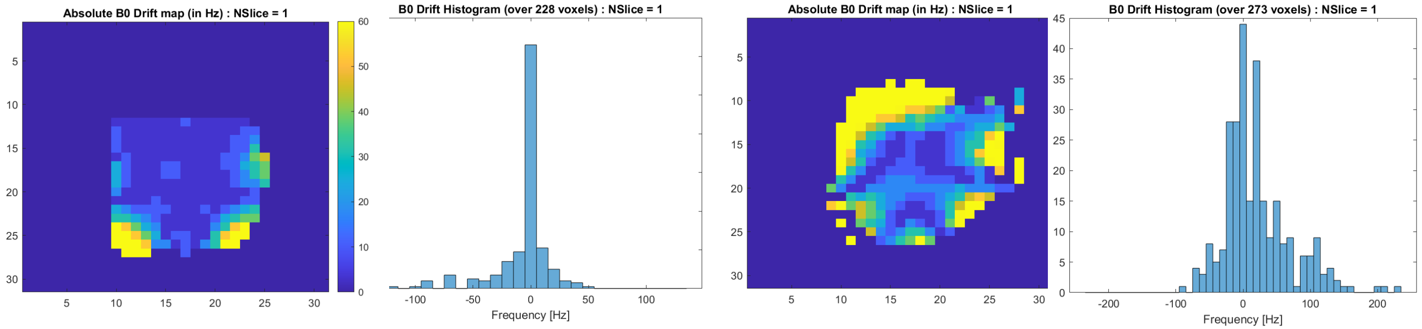
Received: 23 March 2020 | Accepted: 23 November 2020
DOI: 10.1002/nbm.4459

SPECIAL ISSUE REVIEW ARTICLE

NMR IN BIOMEDICINE WILEY

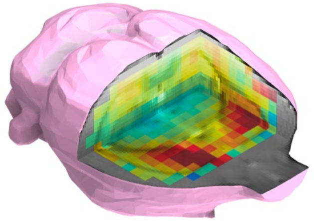
Water and lipid suppression techniques for advanced ^{1}H MRS and MRSI of the human brain: Experts' consensus recommendations

Ivan Tkáč[1] | Dinesh Deelchand[1] | Wolfgang Dreher[2] | Hoby Hetherington[3] | Roland Kreis[4] | Chathura Kumaragamage[5] | Michal Považan[6] | Daniel M. Spielman[7] | Bernhard Strasser[8] | Robin A. de Graaf[5]



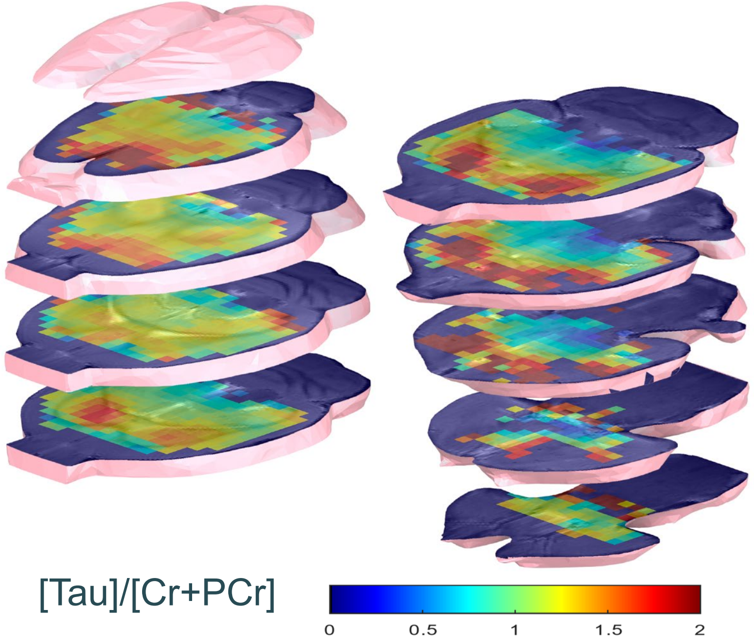
https://www.epfl.ch/labs/mrs4brain/ressources/live-demos/

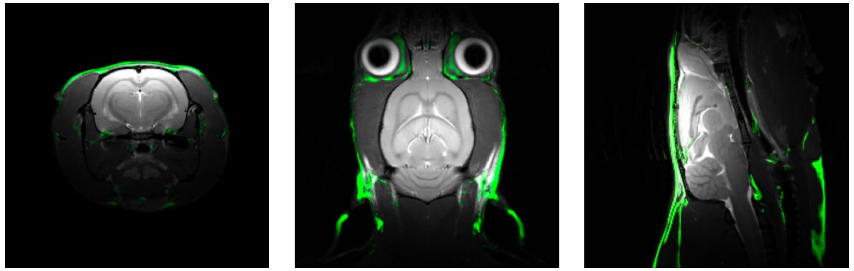
3D METABOLIC MAP

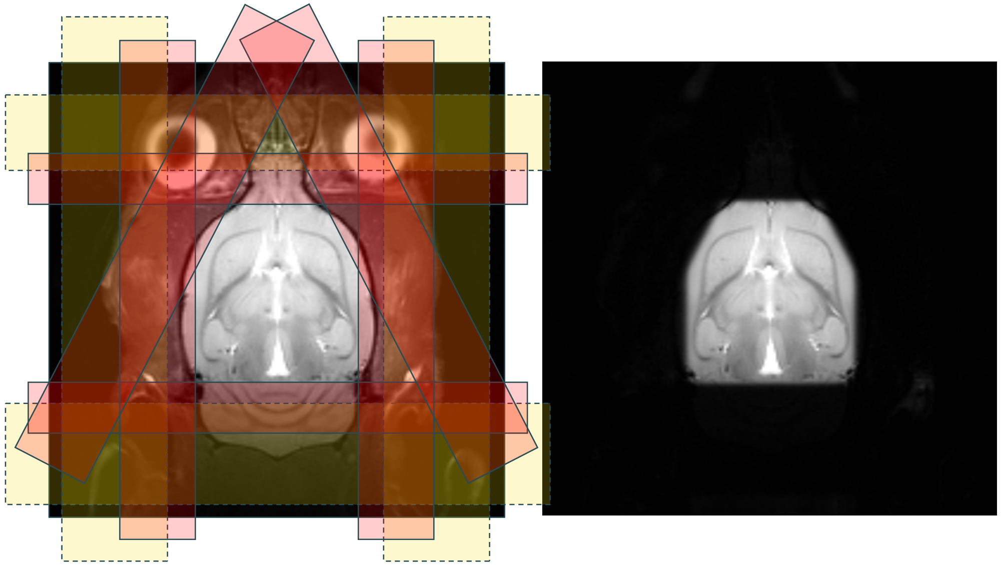


B Alves

T Le

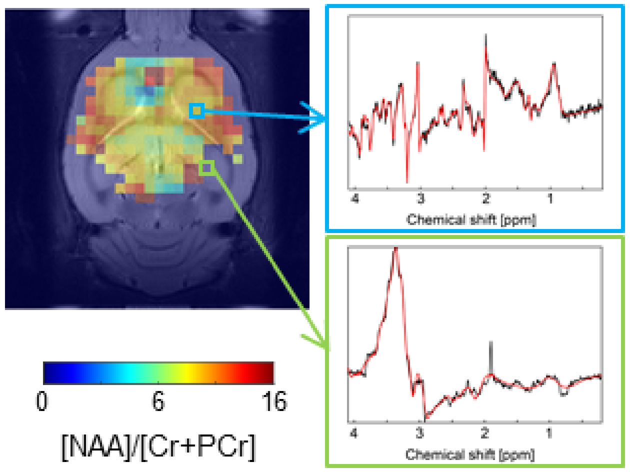




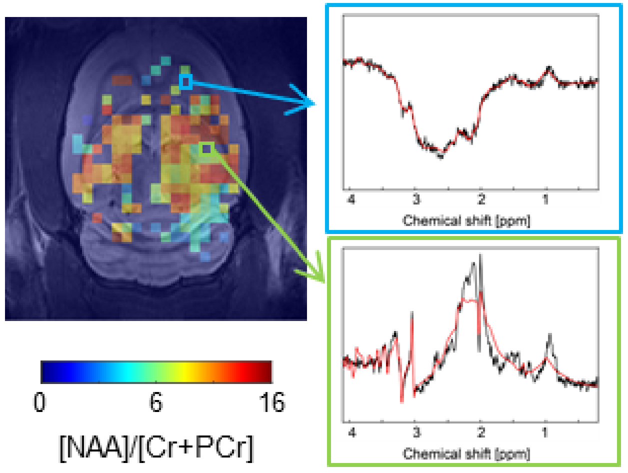


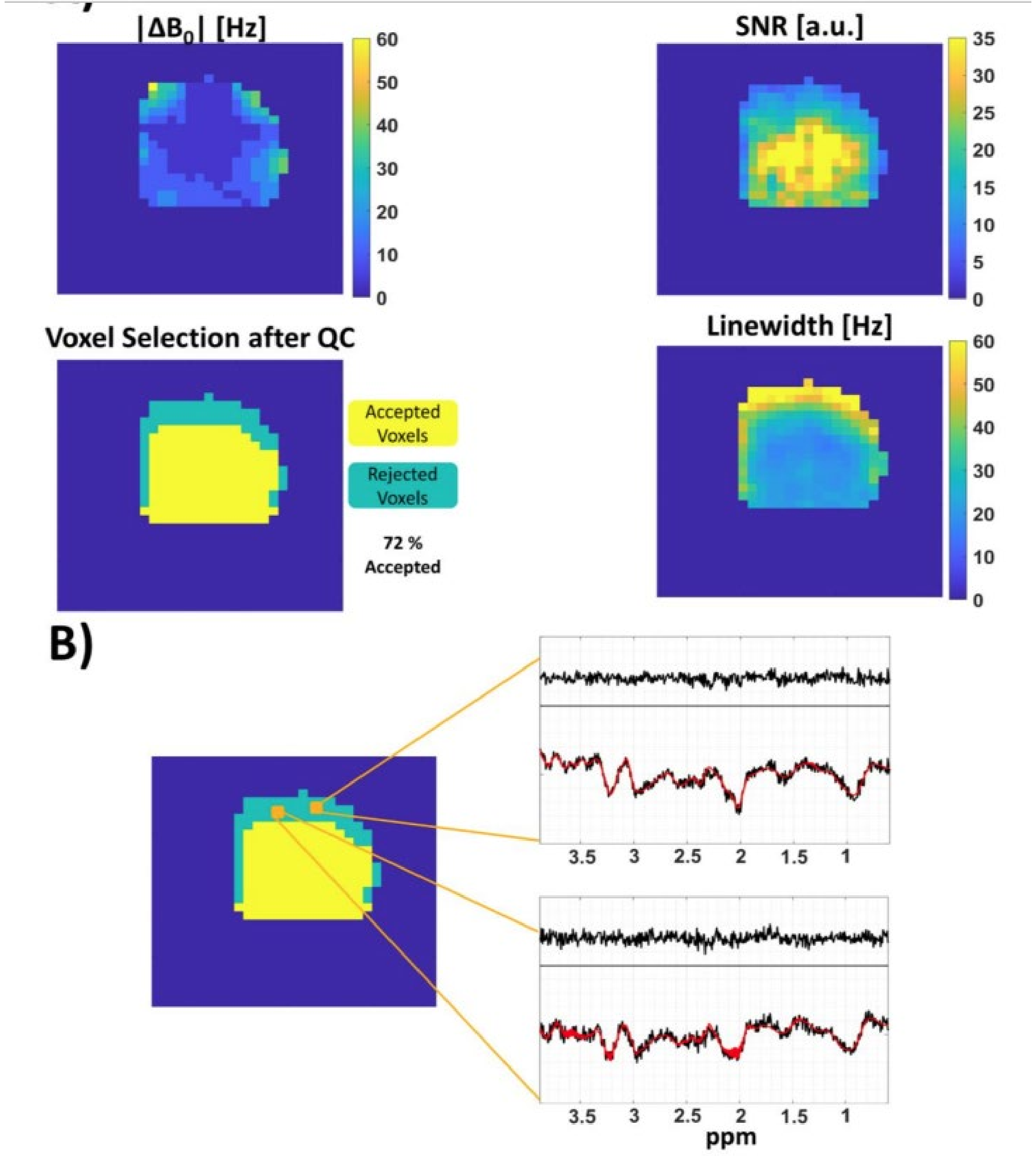
- Time – CS (AF=4, 119min→28min), 1.19 µL to 0.59 µL
- PSF & Resolution
- Lipid contamination -- Saturation bands
- Post processing
- …

(B) Mildly lipid-contaminated map



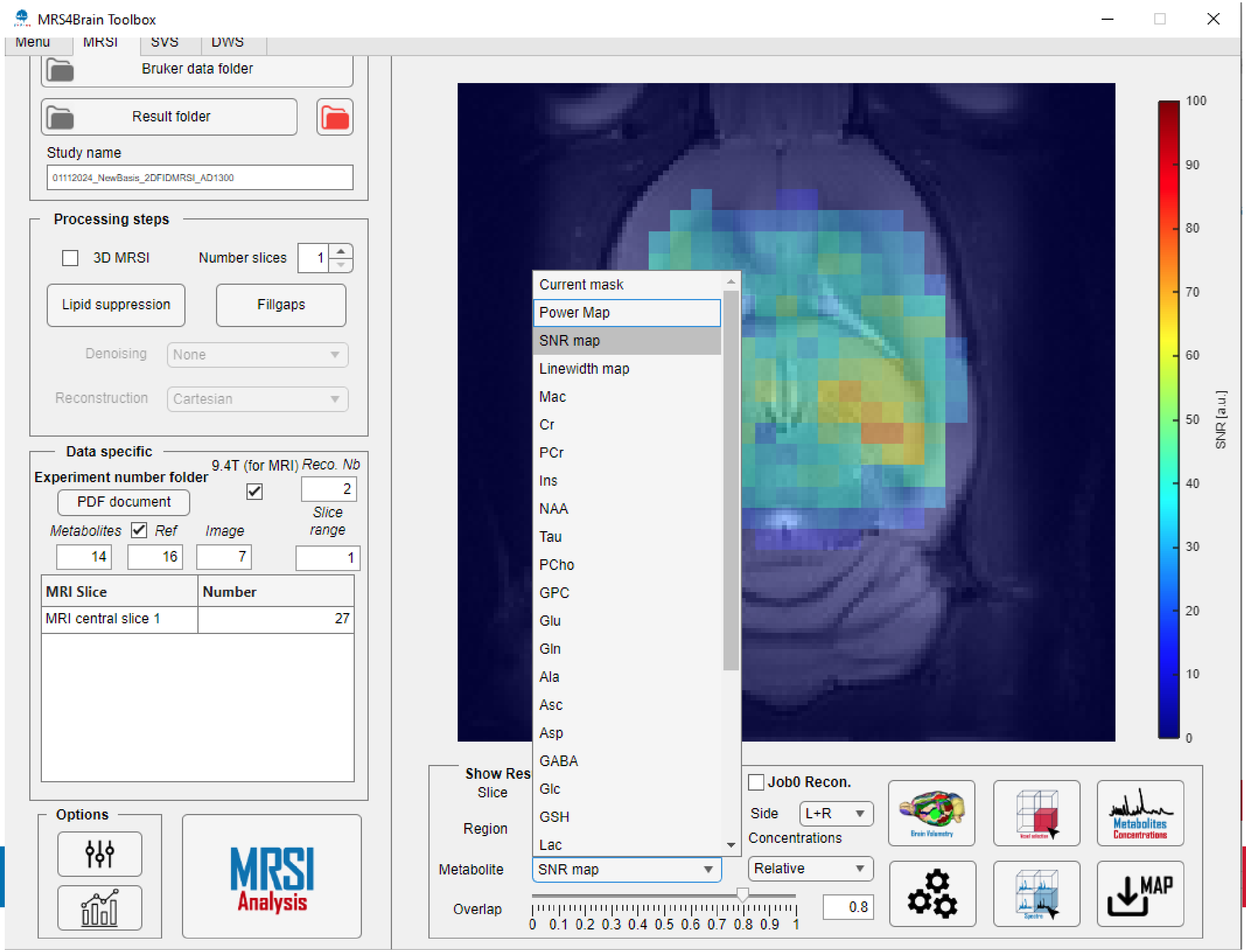
(C) Severely lipid-contaminated map





QUALITY CONTROL IN MRS4BRAIN TOOLBOX

https://www.epfl.ch/labs/mrs4brain/ressources/mrs4brain-toolbox/



Study name: 01112024_NewBasis_2DFIDMRSI_AD1300

☐ 3D MRSI Number slices: 1

Denoising: None

Reconstruction: Cartesian

Experiment number folder

9.4T (for MRI) ☑ *Reco. Nb*: 2

Metabolites: 14 ☑ *Ref*: 16 *Image*: 7 *Slice range*: 1

MRI Slice	Number
MRI central slice 1	27

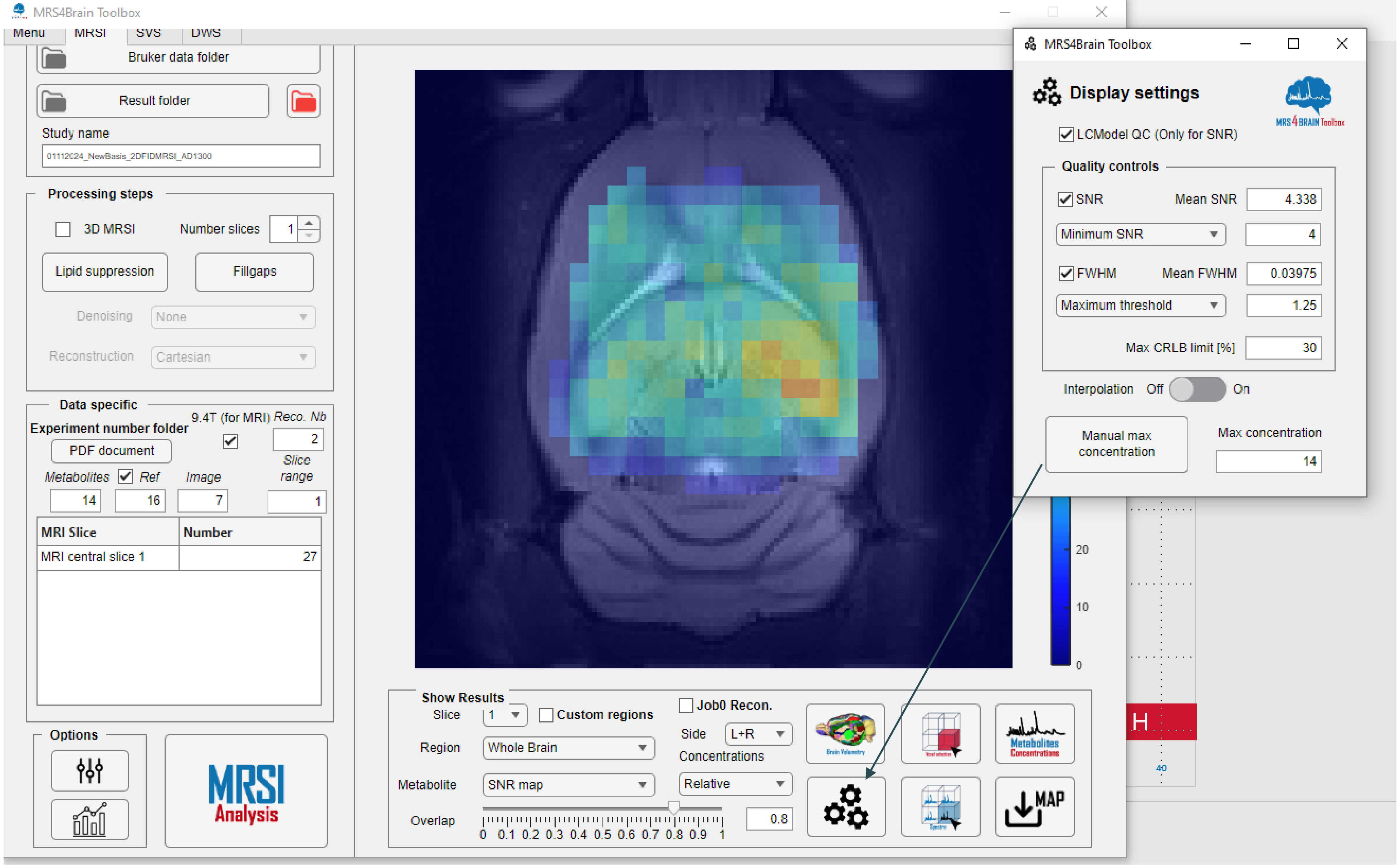
☐ Job0 Recon.

Side: L+R

Concentrations: Relative

Metabolite: SNR map

Overlap: 0.8



Study name: 01112024_NewBasis_2DFIDMRSI_AD1300

☐ 3D MRSI
Number slices: 1
Denoising: None
Reconstruction: Cartesian

Experiment number folder
9.4T (for MRI) ☑
Reco. Nb: 2
Metabolites: 14
☑ Ref: 16
Image: 7
Slice range: 1

MRI Slice	Number
MRI central slice 1	27

Slice: 1
☐ Custom regions
☐ Job0 Recon.
Region: Whole Brain
Side: L+R
Concentrations: Relative
Metabolite: SNR map
Overlap: 0.8

☑ LCModel QC (Only for SNR)

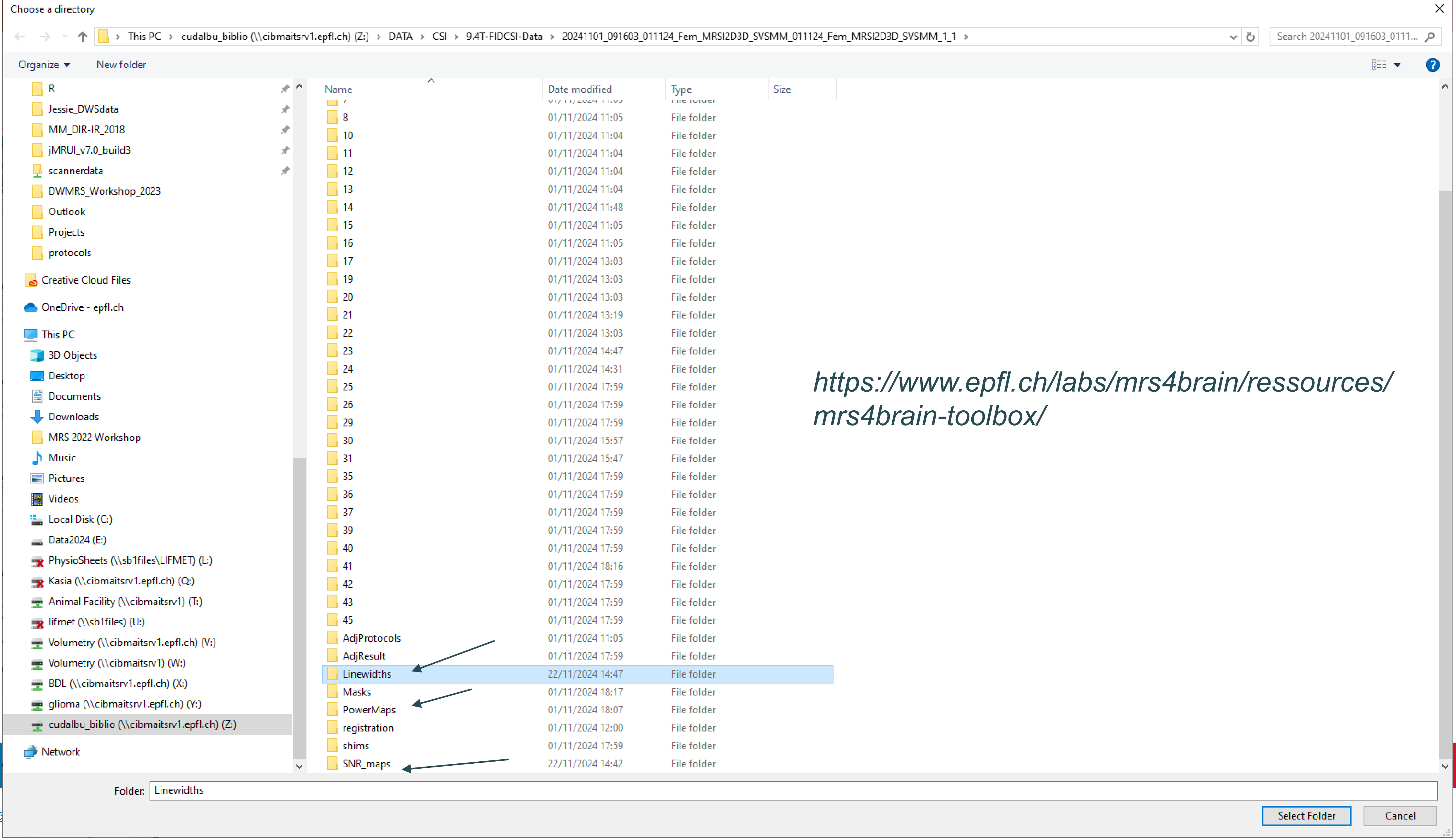
Quality controls

☑ SNR
Mean SNR: 4.338
Minimum SNR: 4
☑ FWHM
Mean FWHM: 0.03975
Maximum threshold: 1.25
Max CRLB limit [%]: 30

Interpolation Off ○ On

Max concentration: 14

https://www.epfl.ch/labs/mrs4brain/ressources/mrs4brain-toolbox/



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16	01/11/2024 11:05	File folder	
17	01/11/2024 13:03	File folder	
19	01/11/2024 13:03	File folder	
20	01/11/2024 13:03	File folder	
21	01/11/2024 13:19	File folder	
22	01/11/2024 13:03	File folder	
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25	01/11/2024 17:59	File folder	
26	01/11/2024 17:59	File folder	
29	01/11/2024 17:59	File folder	
30	01/11/2024 15:57	File folder	
31	01/11/2024 15:47	File folder	
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AdjResult	01/11/2024 17:59	File folder	
Linewidths	22/11/2024 14:47	File folder	
Masks	01/11/2024 18:17	File folder	
PowerMaps	01/11/2024 18:07	File folder	
registration	01/11/2024 12:00	File folder	
shims	01/11/2024 17:59	File folder	
SNR_maps	22/11/2024 14:42	File folder	

Folder: Linewidths

https://www.epfl.ch/labs/mrs4brain/ressources/mrs4brain-toolbox/

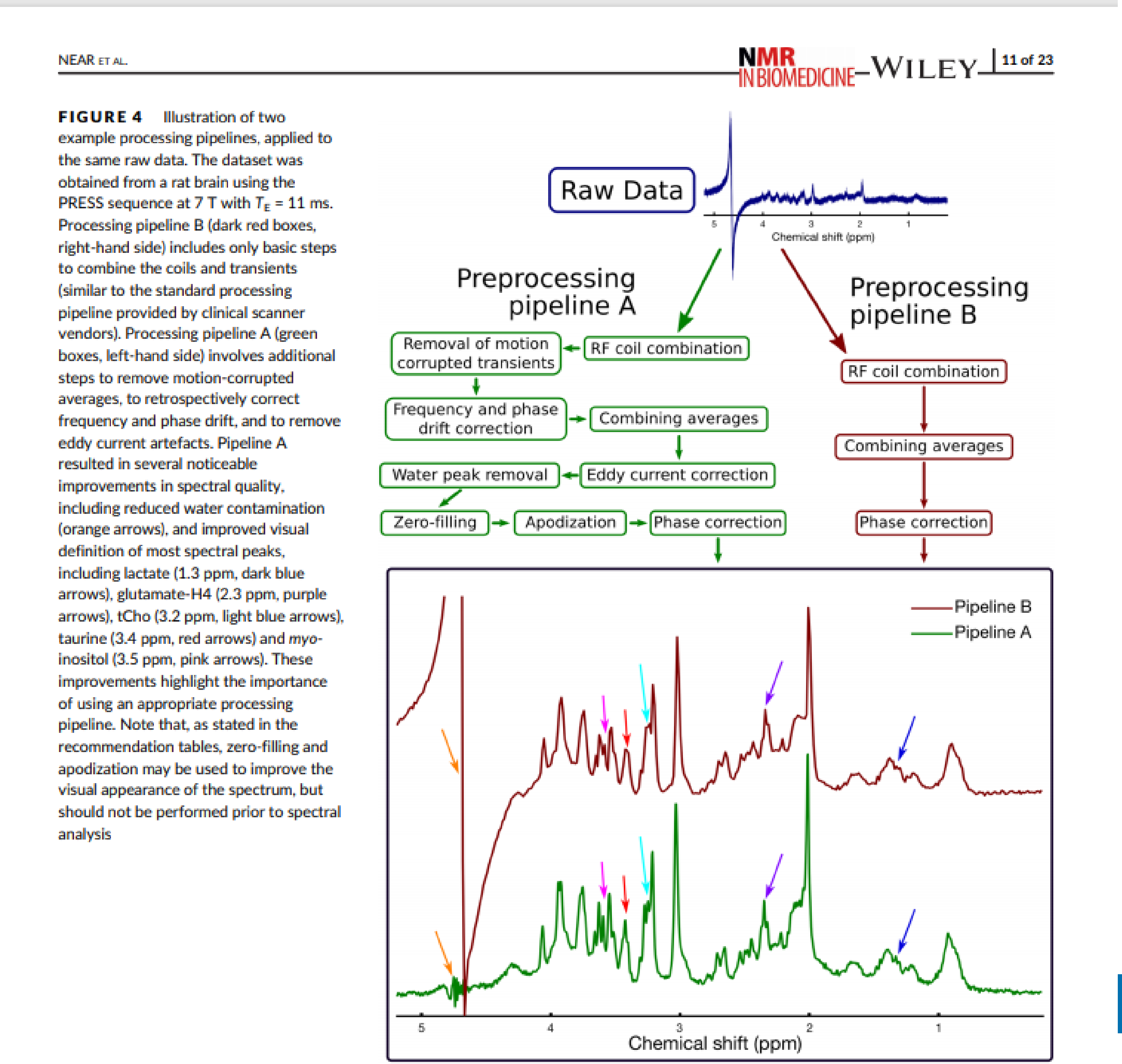
PREPROCESSING STEPS

- Phase offsets (0 and 1st order)
- Subject motion
- Scanner drift
- Eddy currents
- Alignment of spectra that need to be added/subtracted
- Water contamination
- …..

PREPROCESSING STEPS

- Why ?
  - quantification algorithms do not account for all of them
  - Lead to errors in the quantification process

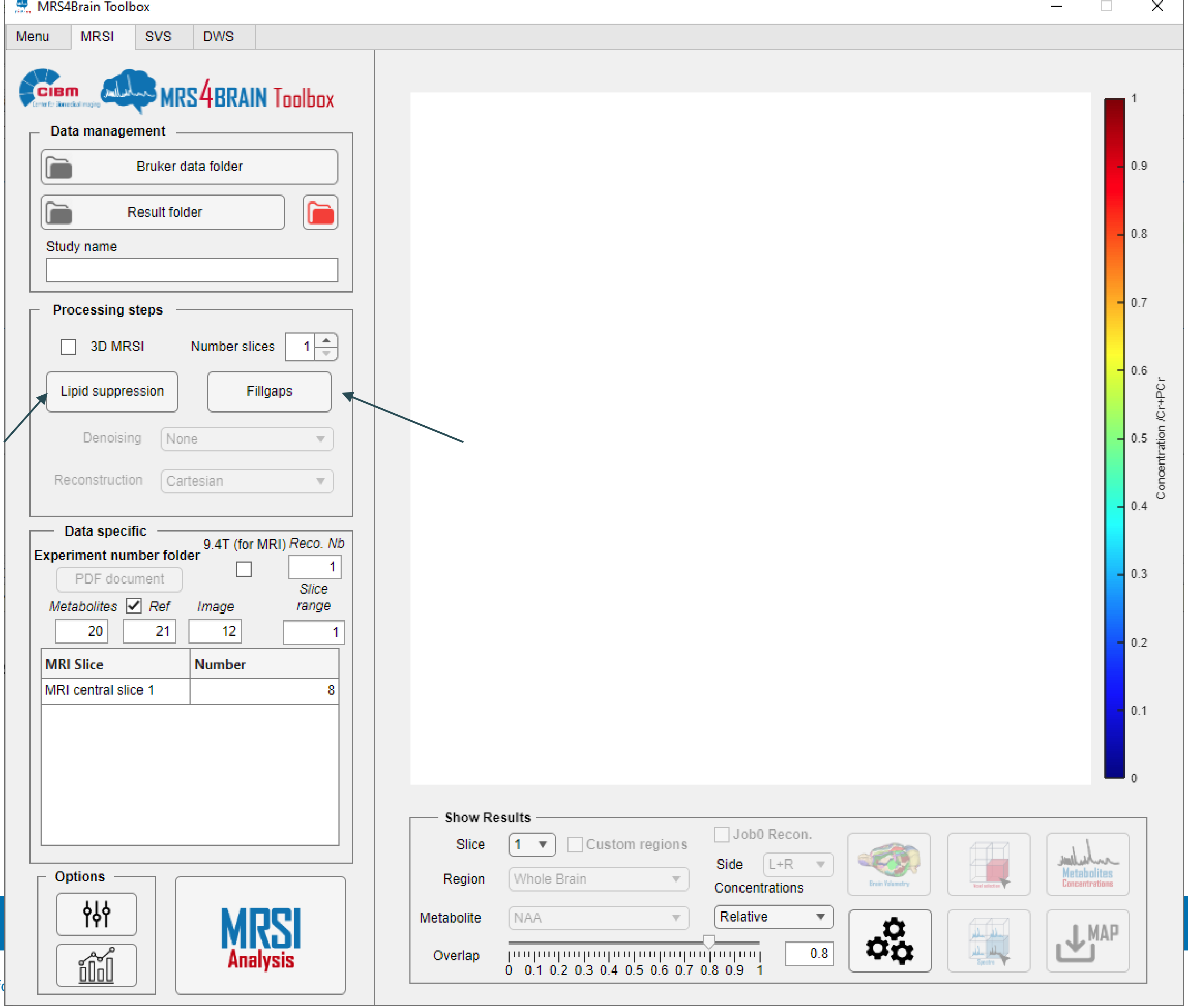
- Requirements:
  - Automated methods
  - Included in the quantification software



NEAR ET AL.

NMR IN BIOMEDICINE –WILEY | 11 of 23

FIGURE 4 Illustration of two example processing pipelines, applied to the same raw data. The dataset was obtained from a rat brain using the PRESS sequence at 7 T with T_E = 11 ms. Processing pipeline B (dark red boxes, right-hand side) includes only basic steps to combine the coils and transients (similar to the standard processing pipeline provided by clinical scanner vendors). Processing pipeline A (green boxes, left-hand side) involves additional steps to remove motion-corrupted averages, to retrospectively correct frequency and phase drift, and to remove eddy current artefacts. Pipeline A resulted in several noticeable improvements in spectral quality, including reduced water contamination (orange arrows), and improved visual definition of most spectral peaks, including lactate (1.3 ppm, dark blue arrows), glutamate-H4 (2.3 ppm, purple arrows), tCho (3.2 ppm, light blue arrows), taurine (3.4 ppm, red arrows) and *myo*-inositol (3.5 ppm, pink arrows). These improvements highlight the importance of using an appropriate processing pipeline. Note that, as stated in the recommendation tables, zero-filling and apodization may be used to improve the visual appearance of the spectrum, but should not be performed prior to spectral analysis



Study name:

☐ 3D MRSI   Number slices: 1

Denoising: None

Reconstruction: Cartesian

9.4T (for MRI) ☐   Reco. Nb: 1

Metabolites: 20   ☑ Ref: 21   Image: 12   Slice range: 1

MRI Slice	Number
MRI central slice 1	8

Slice: 1   ☐ Custom regions   ☐ Job0 Recon.

Side: L+R

Region: Whole Brain

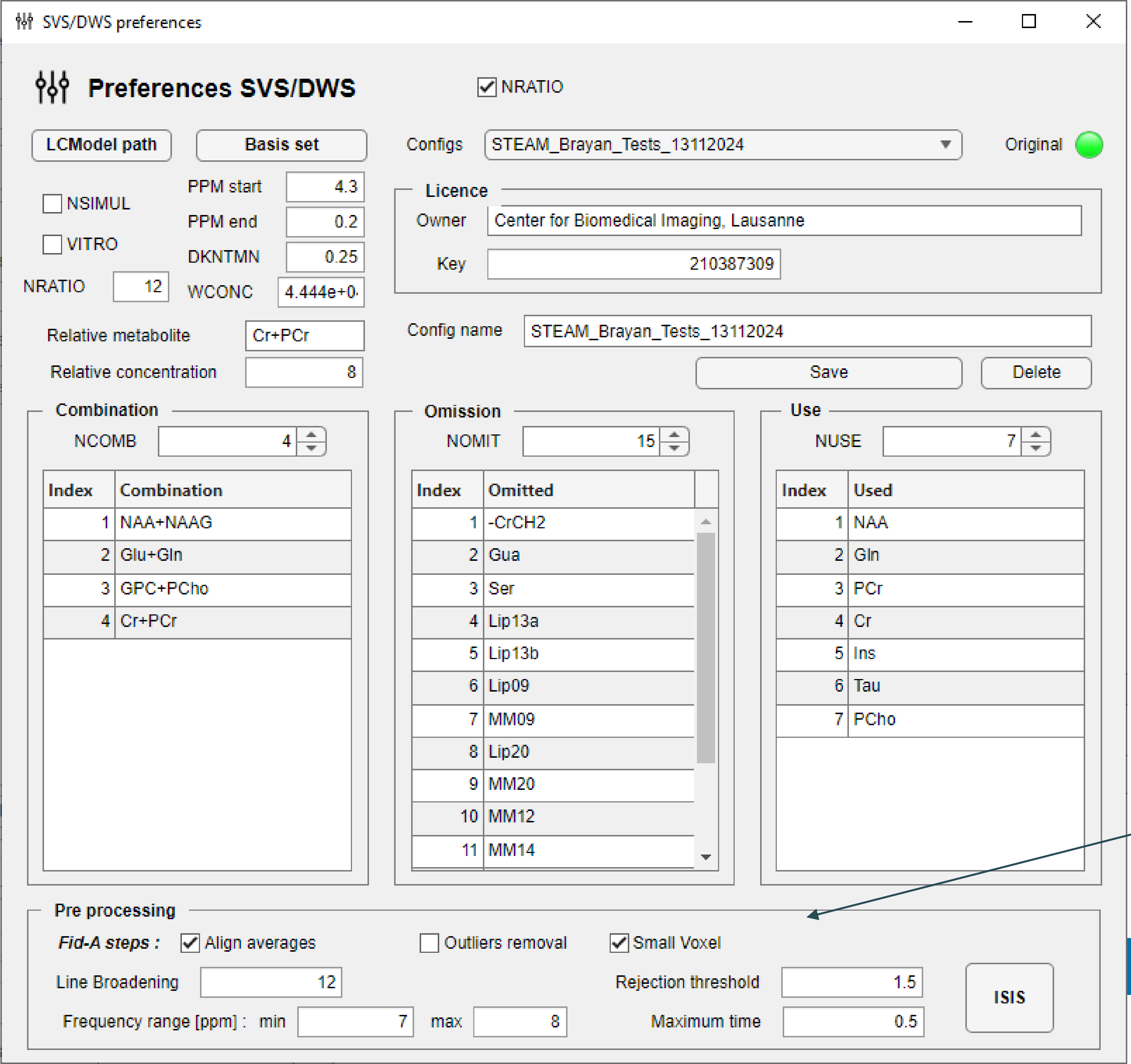
Concentrations: Relative

Metabolite: NAA

Overlap: 0.8

https://www.epfl.ch/labs/mrs4brain/ressources/mrs4brain-toolbox/

CIBM.CH



Preferences SVS/DWS

☑ NRATIO

Configs: STEAM_Brayan_Tests_13112024

Original ●

☐ NSIMUL
☐ VITRO

PPM start: 4.3
PPM end: 0.2
DKNTMN: 0.25
NRATIO: 12
WCONC: 4.444e+0

Licence
Owner: Center for Biomedical Imaging, Lausanne
Key: 210387309

Relative metabolite: Cr+PCr
Relative concentration: 8

Config name: STEAM_Brayan_Tests_13112024

Combination
NCOMB: 4

Index	Combination
1	NAA+NAAG
2	Glu+Gln
3	GPC+PCho
4	Cr+PCr

Omission
NOMIT: 15

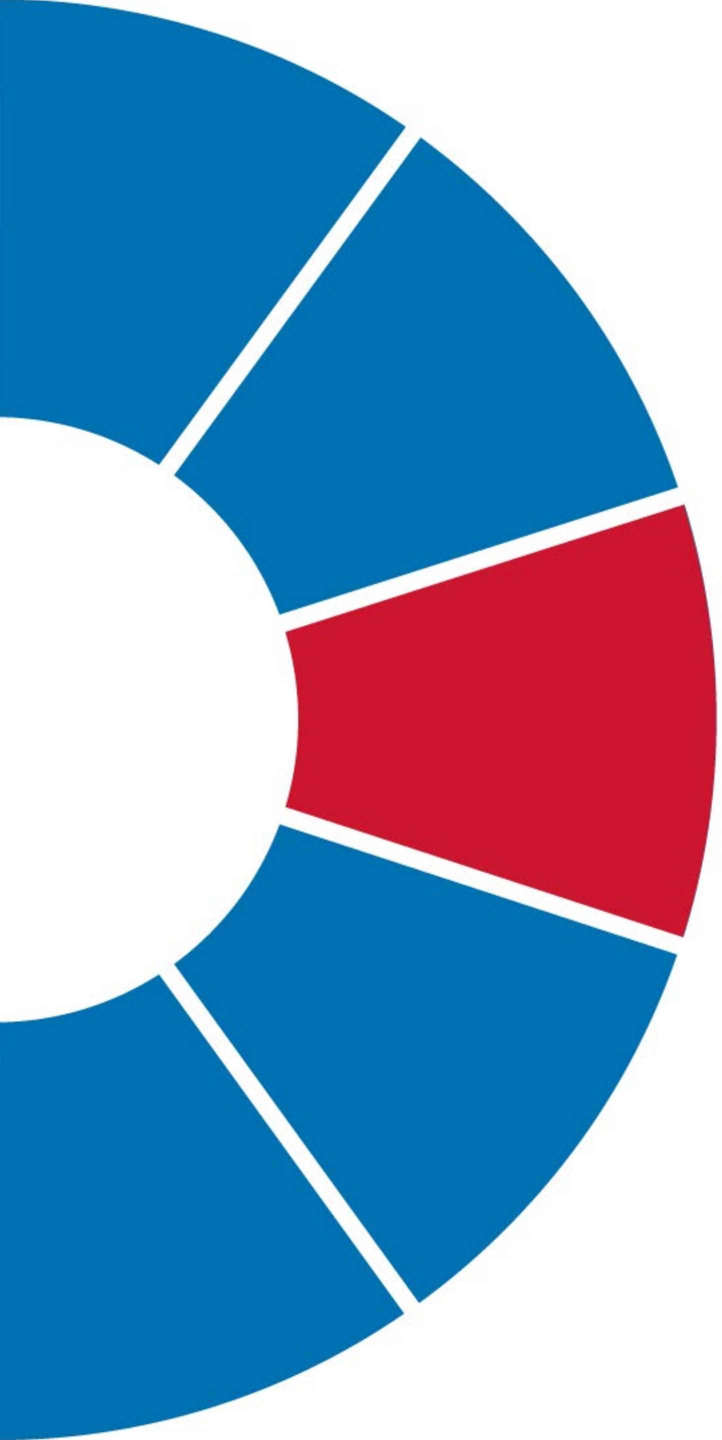
Index	Omitted
1	-CrCH2
2	Gua
3	Ser
4	Lip13a
5	Lip13b
6	Lip09
7	MM09
8	Lip20
9	MM20
10	MM12
11	MM14

Use
NUSE: 7

Index	Used
1	NAA
2	Gln
3	PCr
4	Cr
5	Ins
6	Tau
7	PCho

Pre processing
Fid-A steps : ☑ Align averages ☐ Outliers removal ☑ Small Voxel
Line Broadening: 12
Rejection threshold: 1.5
Frequency range [ppm] : min 7 max 8
Maximum time: 0.5

https://www.epfl.ch/labs/mrs4brain/resources/mrs4brain-toolbox/

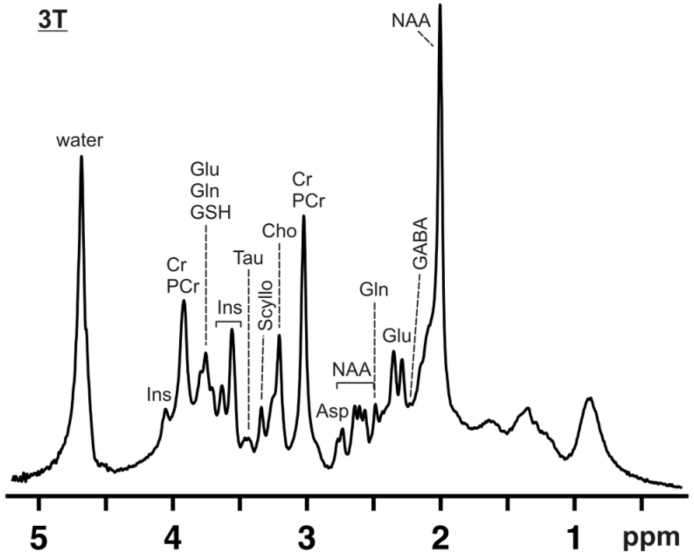


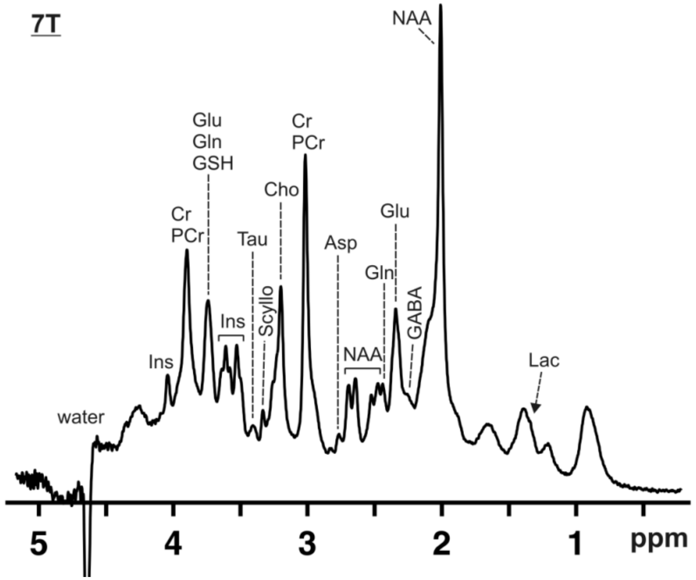
FITTING SOFTWARE

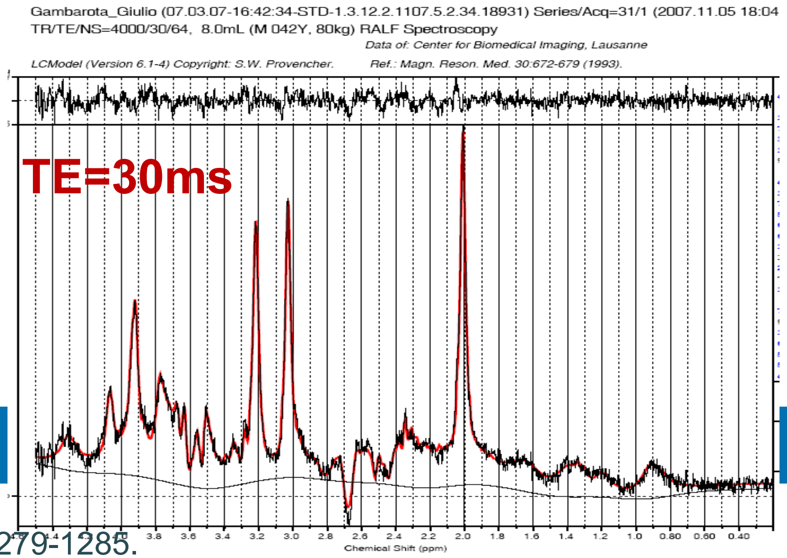
QUANTIFICATION

- MRS – principal goal – quantification of changes in concentration of known metabolites
- Accurate and precise quantification:
  - Signal quality
    - Hardware performance
    - Pulse sequence design & adjustment
  - Data (pre)processing (estimate the signal amplitude or peak area)
  - Quantification strategies (→ tissue content)
- Final Goal:
  - Maximize the neurochemical information
  - Increase the precision and accuracy of quantification
  - Maximize the reliability of neurochemical data

QUANTIFICATION







Gambarota_Giulio (07.03.07-16:42:34-STD-1.3.12.2.1107.5.2.34.18931) Series/Acq=31/1 (2007.11.05 18:04
TR/TE/NS=4000/30/64, 8.0mL (M 042Y, 80kg) RALF Spectroscopy

Data of: Center for Biomedical Imaging, Lausanne

LCModel (Version 6.1-4) Copyright: S.W. Provencher. *Ref.: Magn. Reson. Med. 30:672-679 (1993).*

Mekle R, et al. Magn Reson Med 61, 1279-1285.

QUANTIFICATION

Signals are different (acq param, Bo, nucleus, etc)

– quantification is also different

THE ALGORITHMS ARE AUTOMATIC
BUT NOT FULLY PUSH-BUTTON
NEED TO BE ADAPTED

QUANTIFICATION

In vivo spectra - high B_0 → Increased - sensitivity

- spectral resolution

- short TE

is difficult:

- Complexity of the spectra:
  - many resonances
  - peak overlap
  - contribution of macromolecules and residual water
- Unpredictable lineshape :
  - residual eddy currents
  - field inhomogeneity
- Unpredictable baseline:
  - macromolecules
  - lipid signals
  - partially suppressed water

QUANTIFICATION

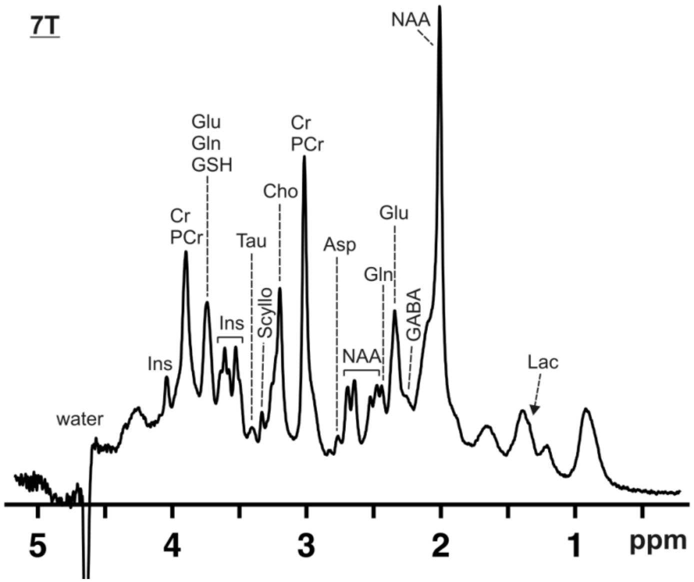
In vivo spectra - high B_0

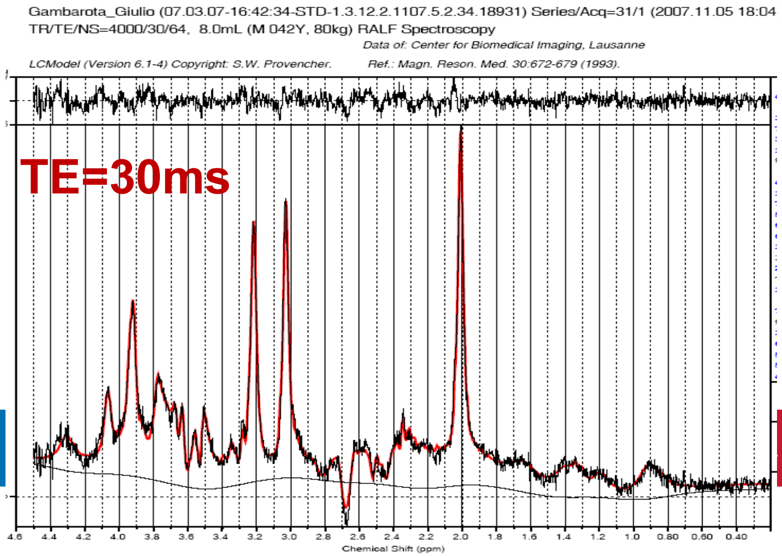
- short TE

→

Increased - sensitivity

- spectral resolution




Gambarota_Giulio (07.03.07-16:42:34-STD-1.3.12.2.1107.5.2.34.18931) Series/Acq=31/1 (2007.11.05 18:04
TR/TE/NS=4000/30/64, 8.0mL (M 042Y, 80kg) RALF Spectroscopy
Data of: Center for Biomedical Imaging, Lausanne
LCModel (Version 6.1-4) Copyright: S.W. Provencher. *Ref.: Magn. Reson. Med. 30:672-679 (1993).*

Ralf Mekle & Giulio Gambarota

QUANTIFICATION

☹Vendors software - visualization of spectra

☹Peak fitting - !!!! Overlapping peaks ☹

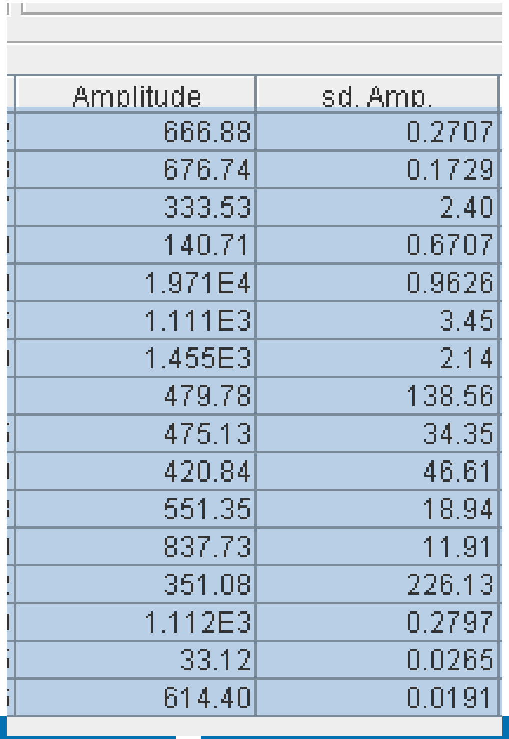
☺X nuclei

☺"Basis-set" fitting – In vivo MRS spectrum is modelled as a linear combination of individual metabolite basis spectra

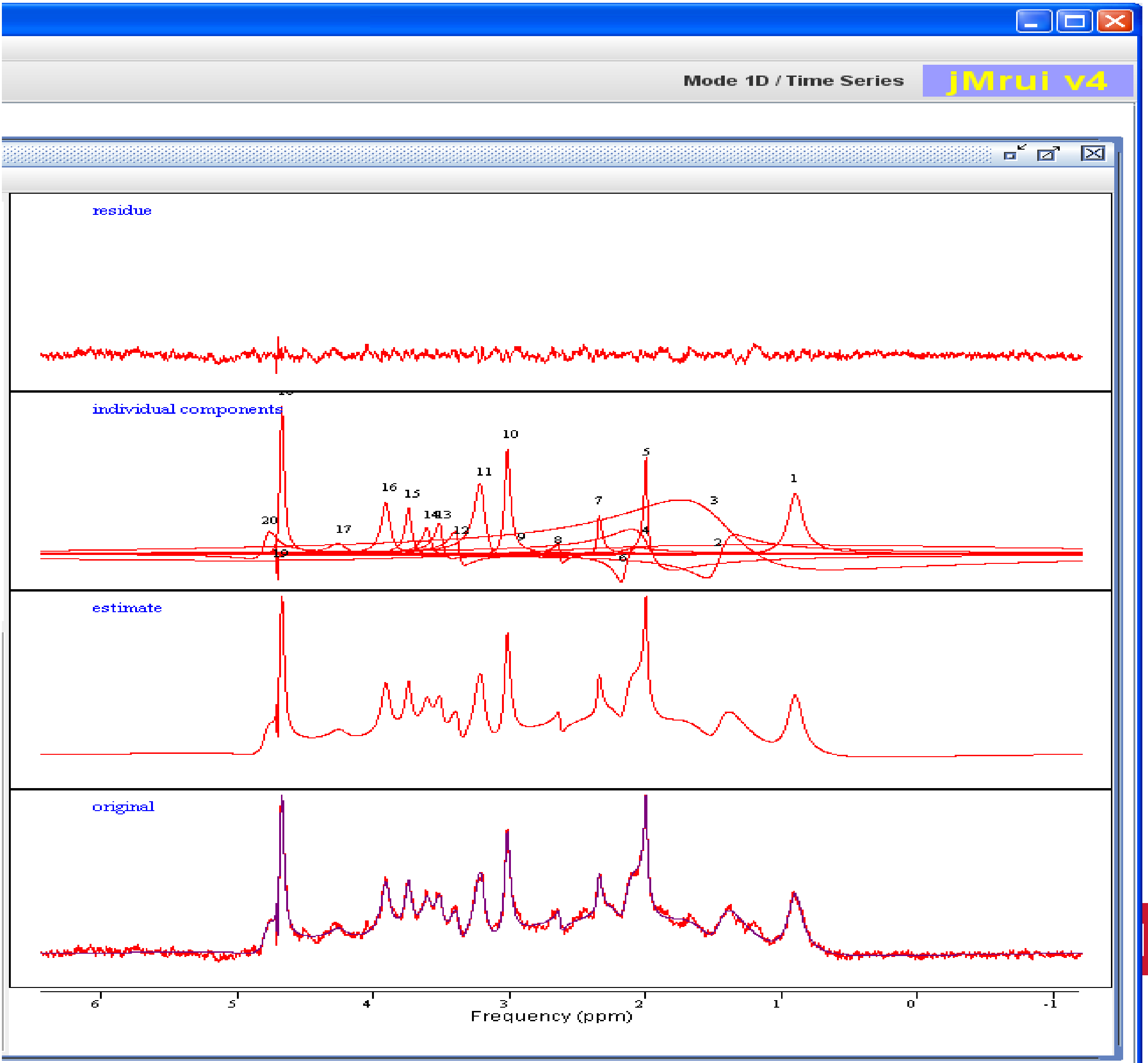
- Experimentally
- Simulated
  - User-friendly software packages: NMRScopeB, Vespa, GAMMA, GAVA, ….
- Macromolecules contribution
- Lipids contribution (i.e. malignant brain tumors)

SHORT DESCRIPTION OF THE ALGORITHMS

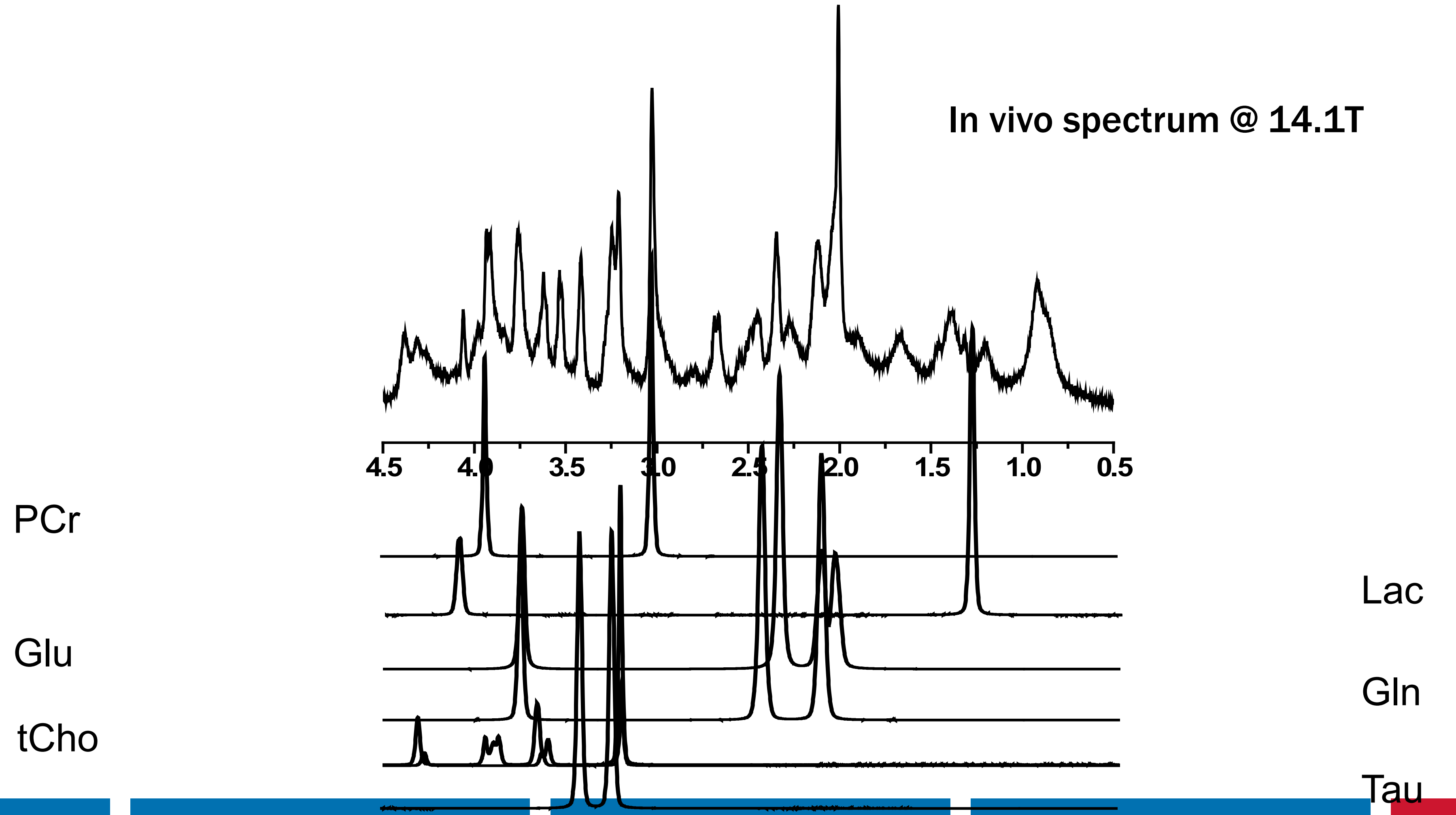
HLSVD quantification



Amplitude	sd. Amp.
666.88	0.2707
676.74	0.1729
333.53	2.40
140.71	0.6707
1.971E4	0.9626
1.111E3	3.45
1.455E3	2.14
479.78	138.56
475.13	34.35
420.84	46.61
551.35	18.94
837.73	11.91
351.08	226.13
1.112E3	0.2797
33.12	0.0265
614.40	0.0191

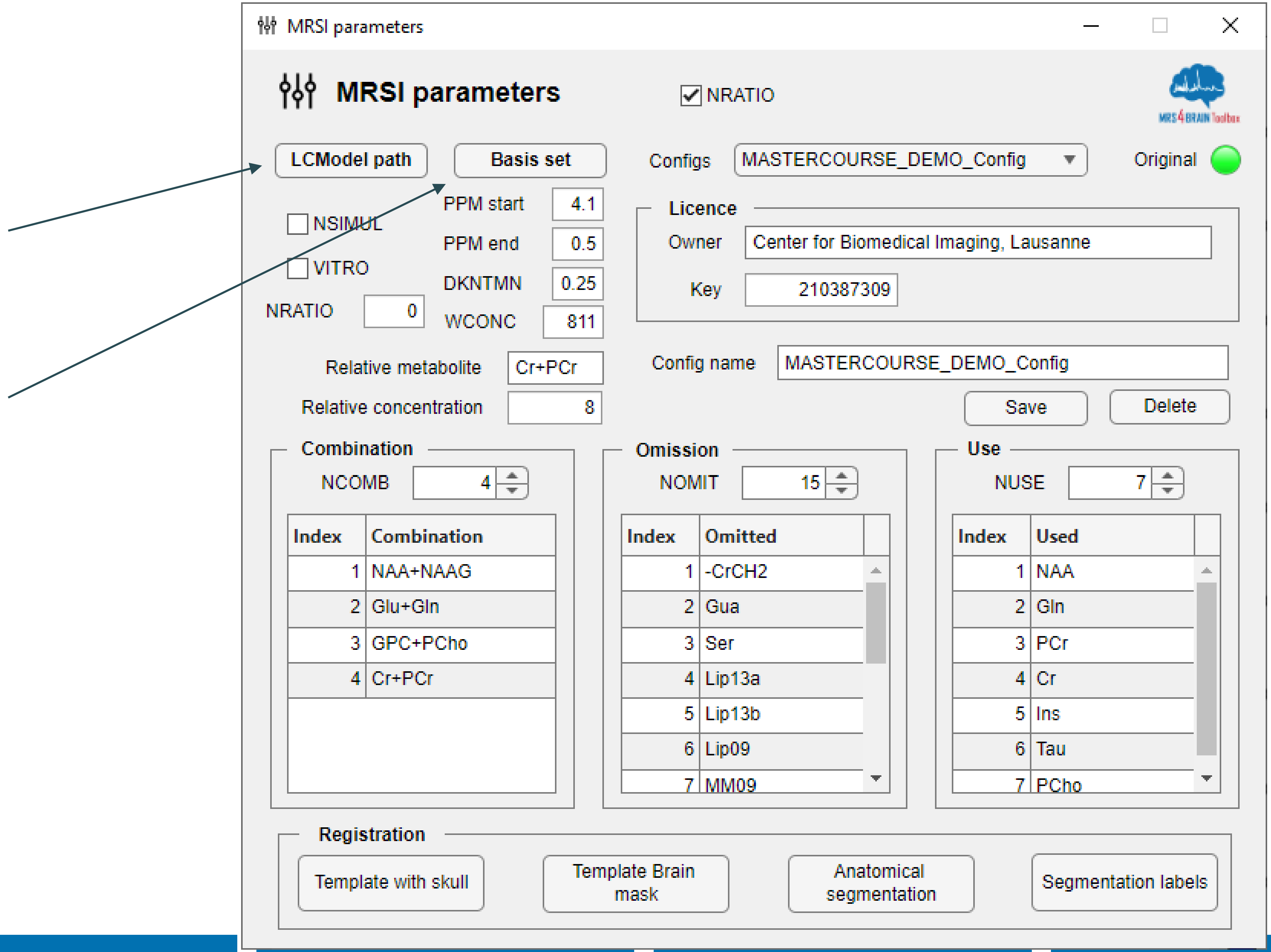


QUANTIFICATION WITH A BASIS SET



■ ■ ■ ■

CIBM Center for Biomedical Imaging



MRSI parameters

MRSI parameters

☑ NRATIO

Configs: MASTERCOURSE_DEMO_Config ▼

Original ●

☐ NSIMUL

☐ VITRO

NRATIO: 0

PPM start: 4.1

PPM end: 0.5

DKNTMN: 0.25

WCONC: 811

Relative metabolite: Cr+PCr

Relative concentration: 8

Licence

Owner: Center for Biomedical Imaging, Lausanne

Key: 210387309

Config name: MASTERCOURSE_DEMO_Config

Combination

NCOMB: 4

Index	Combination
1	NAA+NAAG
2	Glu+Gln
3	GPC+PCho
4	Cr+PCr

Omission

NOMIT: 15

Index	Omitted
1	-CrCH2
2	Gua
3	Ser
4	Lip13a
5	Lip13b
6	Lip09
7	MM09

Use

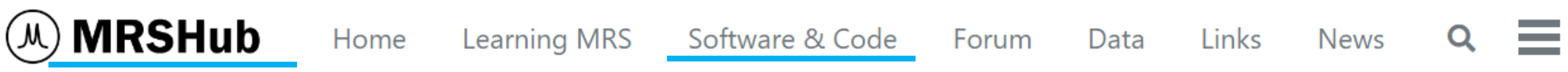
NUSE: 7

Index	Used
1	NAA
2	Gln
3	PCr
4	Cr
5	Ins
6	Tau
7	PCho

Registration

https://www.epfl.ch/labs/mrs4brain/resources/mrs4brain-toolbox/

QUANTIFICATION SOFTWARE

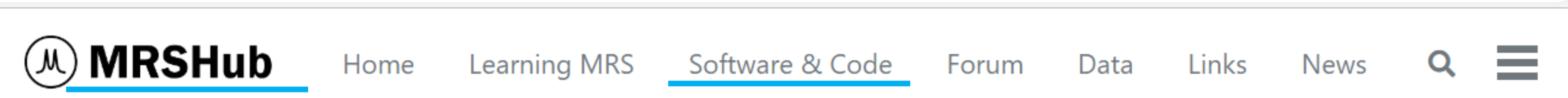


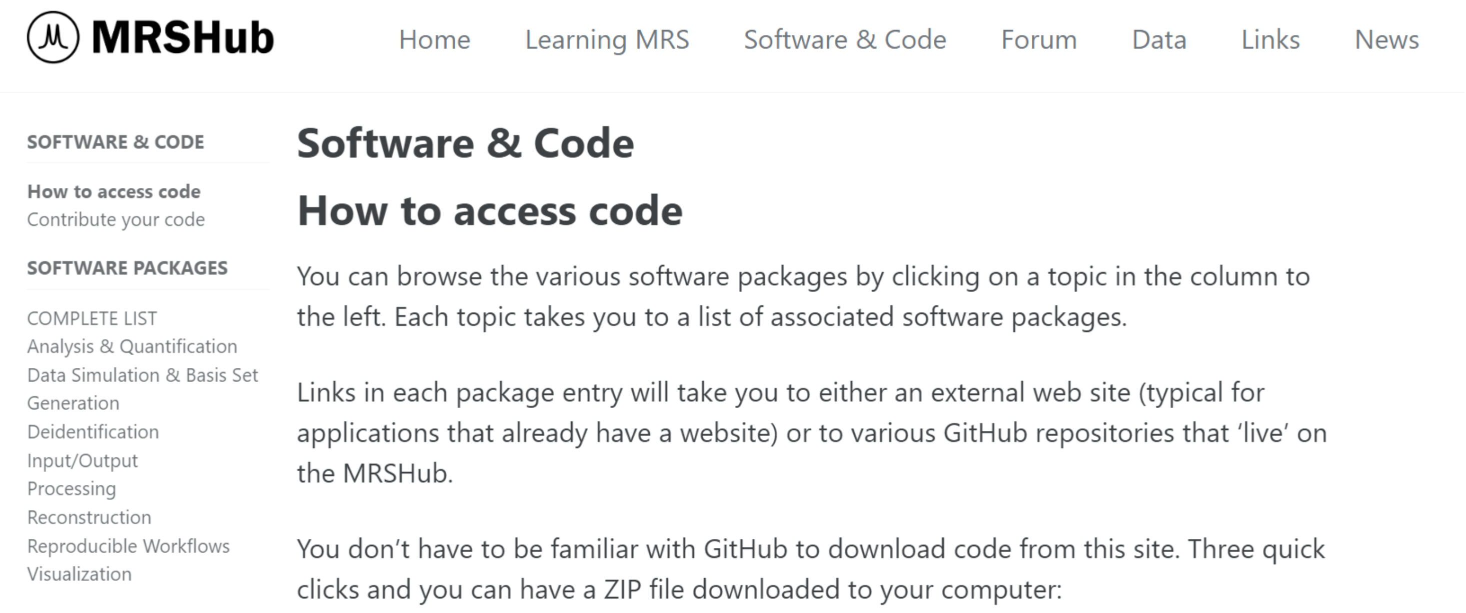
	Cost	Type of data	Preprocessing	Simulations	Lineshape model	MM
Vespa	free	all	yes	yes	yes	yes
TARQUIN	free	all	yes	Yes – basic	Voigt	Baseline –TD Add
jMRUI	free	all	yes	yes	Lorentzian	Add TD
LCModel	Yes	all	yes	No Basis sets	estimated	Splines

Anke Henning. eMagRes, 2016, Vol 5: 981–994. DOI 10.1002/9780470034590.emrstm1472
Dirk van Ormondt, et al, eMagRes, 2015, Vol 4: 651–662. DOI 10.1002/9780470034590.emrstm1427
Jamie Near, Magnetic Resonance Spectrscopy Elsevier 2014
Jamie Near, et al, NMR Biomed, 2020 **https://doi.org/10.1002/nbm.4257**

https://mrs2022.cibm.ch/agenda/

FURTHER READING





Software & Code

How to access code

You can browse the various software packages by clicking on a topic in the column to the left. Each topic takes you to a list of associated software packages.

Links in each package entry will take you to either an external web site (typical for applications that already have a website) or to various GitHub repositories that 'live' on the MRSHub.

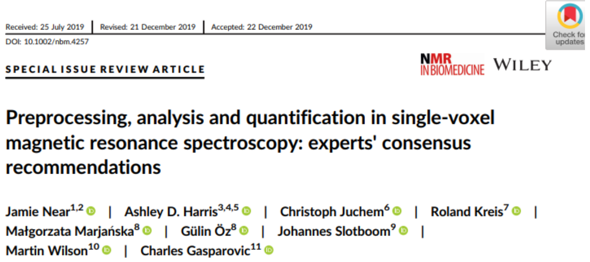
You don't have to be familiar with GitHub to download code from this site. Three quick clicks and you can have a ZIP file downloaded to your computer:

QUANTIFICATION (ABSOLUTE)

Signal amplitudes
Peak area

Concentrations
$mmol/kg_{ww}$

- External concentration reference
- Internal concentration reference
  - Ratios to tCr or NAA or Cho - They might change – disease
  - Water internal reference
    - Corrections for T1, T2 and water content
    - Very short TE – T2 correction could be neglected
    - Fully relaxed signals – long TR – T1 neglected
    - MT



Received: 25 July 2019 | Revised: 21 December 2019 | Accepted: 22 December 2019
DOI: 10.1002/nbm.4257

SPECIAL ISSUE REVIEW ARTICLE

NMR IN BIOMEDICINE WILEY

Preprocessing, analysis and quantification in single-voxel magnetic resonance spectroscopy: experts' consensus recommendations

Jamie Near[1,2] | Ashley D. Harris[3,4,5] | Christoph Juchem[6] | Roland Kreis[7] | Małgorzata Marjańska[8] | Gülin Öz[8] | Johannes Slotboom[9] | Martin Wilson[10] | Charles Gasparovic[11]

http://www.ismrm.org/workshops/Spectroscopy16/program.htm
2nd TRANSACT Workshop, University Bern: Quality Issues in Clinical MRS 2014
The MRS Consensus Group. (2014), Radiology, 270(3):658-79.

QUANTIFICATION QUALITY CONTROL

- CRLB – theoretical estimation
  - Assumes that the model is perfect
  - R Kreis, MRM 75, 2016 – CRLB % !!! – low conc metabolites
    - CRLB vs mean CRLB in normal cohort

- Fit residuals

QUANTIFICATION: RESULTS DISPLAY

Patient name : anonymous
Date of Birth :
Patient sex : M
Patient ID :

Accession number : 2699671
Study description : Kopf_12_Kanal
Study date : 20110630

Series description : svs_se_135_ws
Series number : 12
Series time : 155149.015000

Scanner type : Verio
Echo time TE : 135000
Repetition time TR : 1500000
Voxel dimension : [15, 15, 15]

Metabolite Name	Concentrations (2 comp) [mmol/kg ww]	Normal (2 comp) [mmol/kg ww]
Choline (Cho)	8.8 ± 0.1	1.5 ± 0.1
Creatine (Cr)	7.7 ± 0.2	5.2 ± 0.1
Glutamate (Glu)	6.6 ± 0.4	3.7 ± 0.2
Glutamine (Gln)	4.4 ± 0.3	2.2 ± 0.1
Lactate (Lac)	1.2 ± 0.2	0.3 ± 0.1
Myo-inositol (m-Ins)	20.7 ± 1.2	7.8 ± 0.4
N-Acetyl Aspartate (NAA)	4.9 ± 0.2	7.5 ± 0.2

For scientific purposes only!
Report created with jMRUI.

Olivier Scheidegger et al, MRM 70:25–32 (2013)

SUMMARY & ACKNOWLEDGMENTS

MRS & MRSI is incredibly rich & versatile ☺

Thank you for listening! Questions?

For any question yon might have later on, please write me an email:

cristina.cudalbu@epfl.ch

ACKNOWLEDGEMENTS

And ALL our collaborators

<u>Fast MRSI</u>

- **A Klauser,** *Siemens*
- **W Bogner, B Strasser,** *University of Vienna*

<u>SVS</u>

- **I Tkac,** *CMRR*
- **V Mlynarik,** *University of Vienna*
- **J Near,** *University of Toronto*

<u>dMRS/dMRI</u>

- **R Kreis,** *University of Bern*
- **I Jelescu,** *CHUV*
- **J Valette,** *CEA*
- **M Palombo,** *University of Cardiff*
- **E Fischi,** *SP CHUV-EPFL*

<u>HE</u>

- **VA McLin,** *HUG-UNIGE*
- **O Braissant,** *CHUV-UNIL*
- **JC Leroux,** *ETHZ*
- **C Sandi, J Grosse,** *EPFL*

H2020-MSCA-ITN-2018, no 813120

310030_201218 & 207935 & 173222
& 10000465
**Swiss National
Science Foundation**

C I B M . C H

cristina.cudalbu@epfl.ch

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Center for Biomedical Imaging

THANK YOU FOR YOUR ATTENTION

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