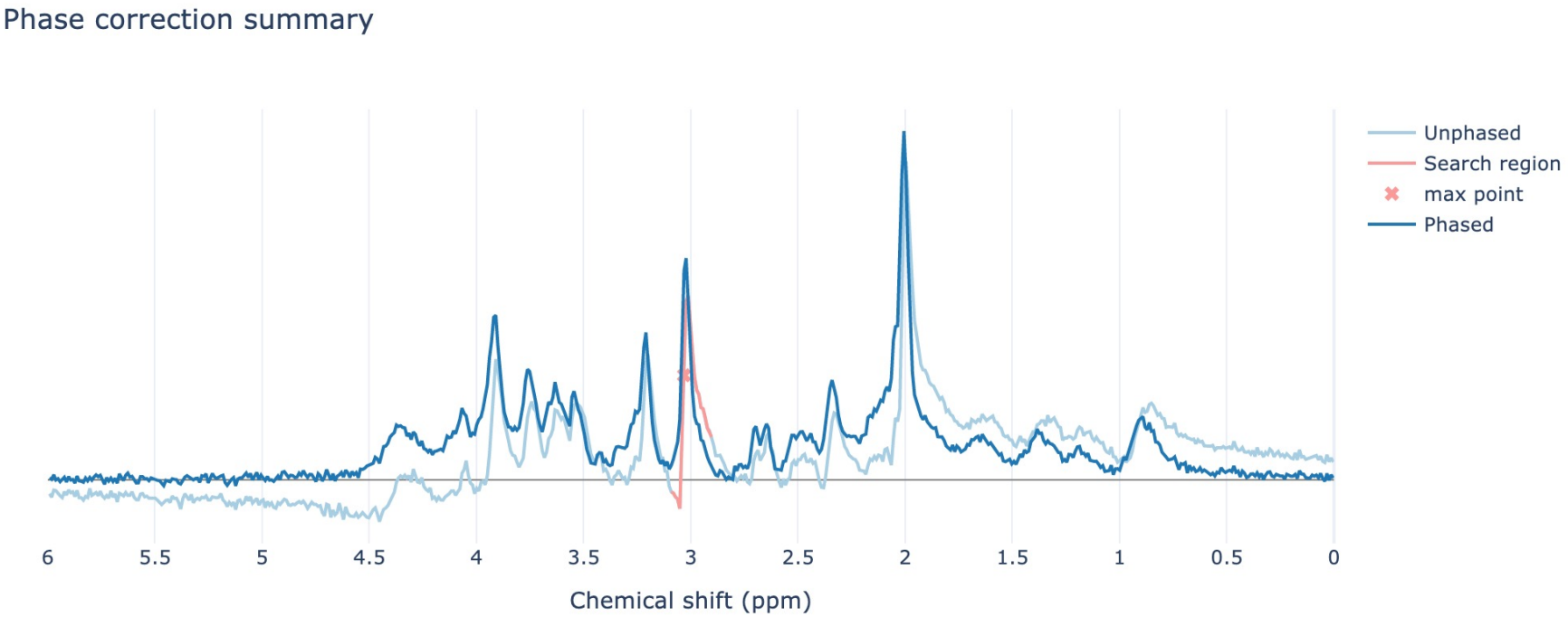
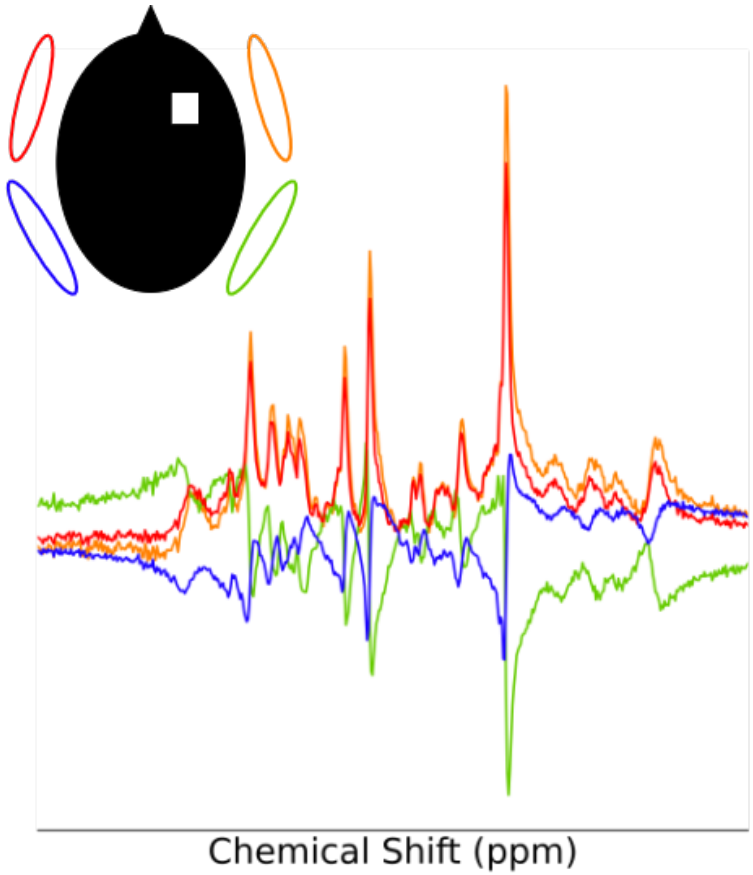
FSL-MRS – Tools for Magnetic Resonance Spectroscopy



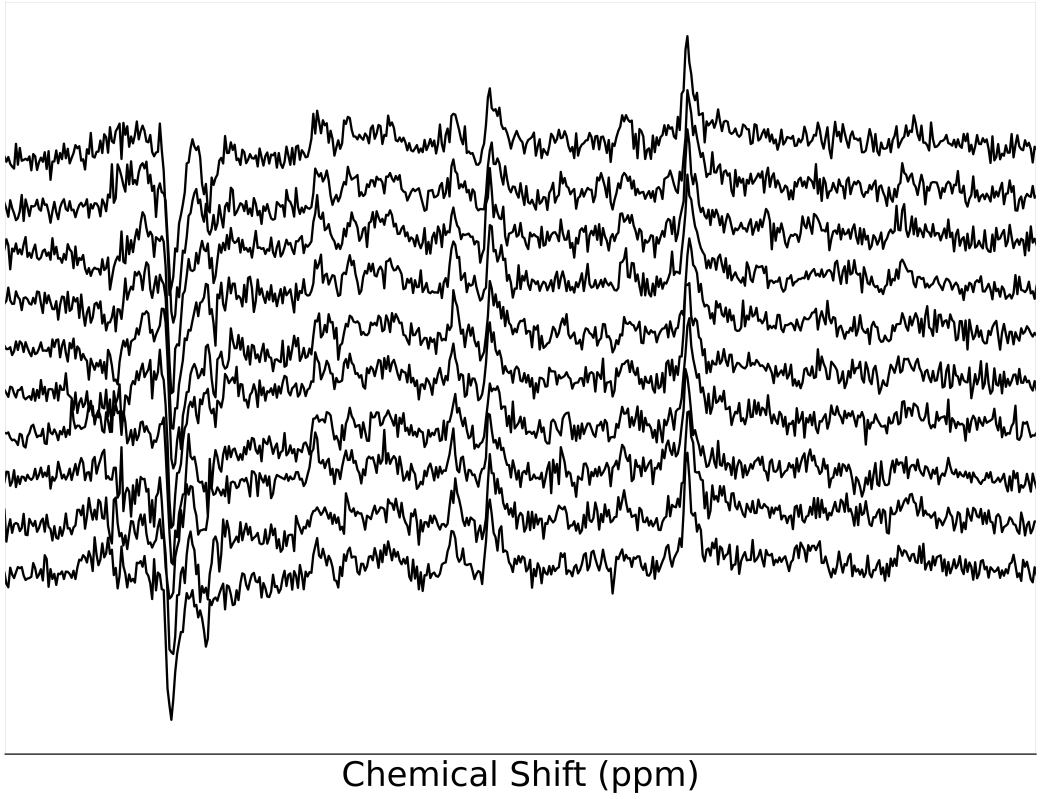
MRS pre-processing

SVS: before pre-processing

Uncombined coils

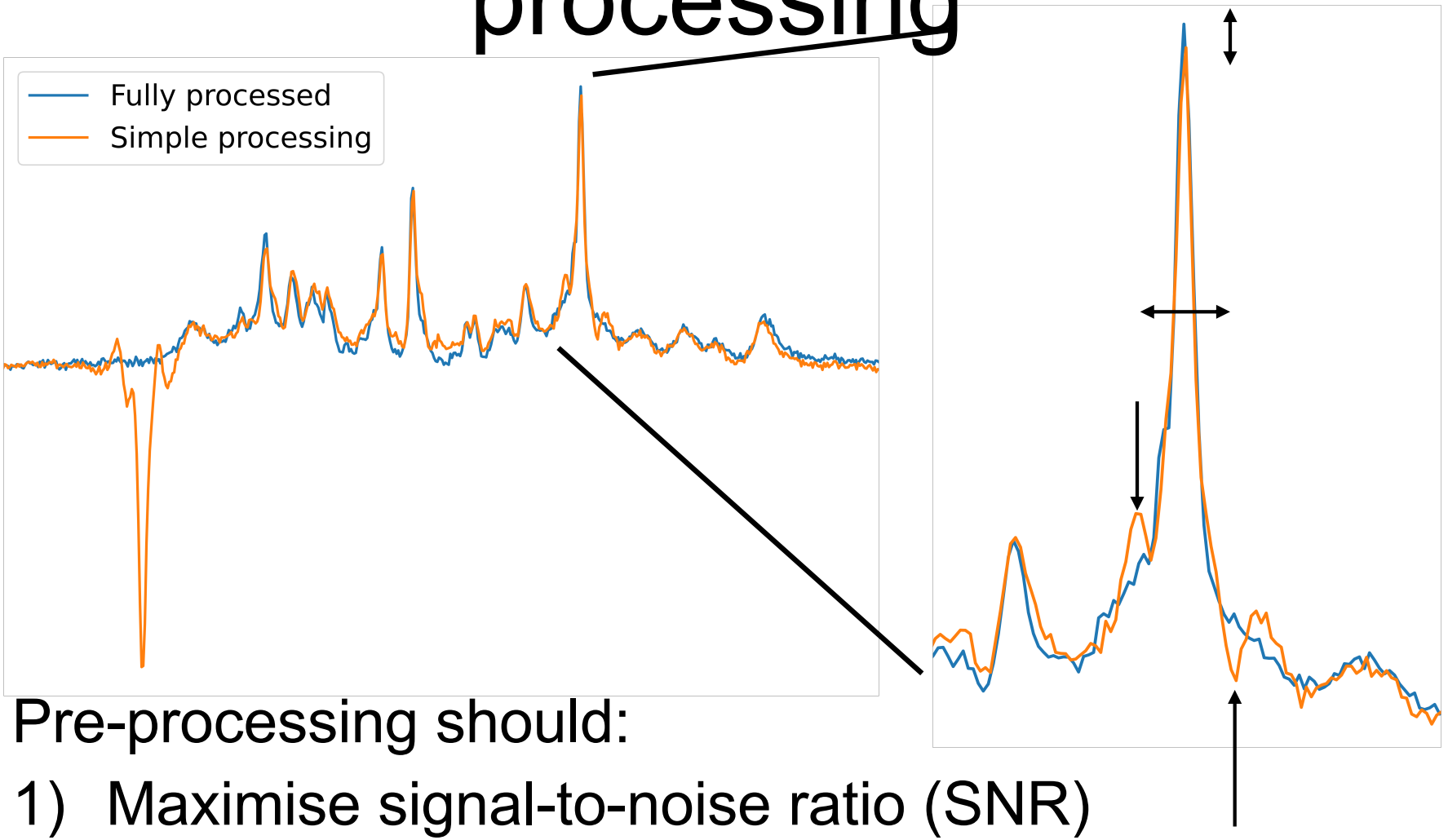


Un-averaged repeats



Data shape - $N_{Time\ Points} \times N_{Averages} \times N_{Coils}$

SVS: after pre-processing



Pre-processing should:

1) Maximise signal-to-noise ratio (SNR)
2) Minimise peak linewidths
3) Reduce baseline and line shape distortion

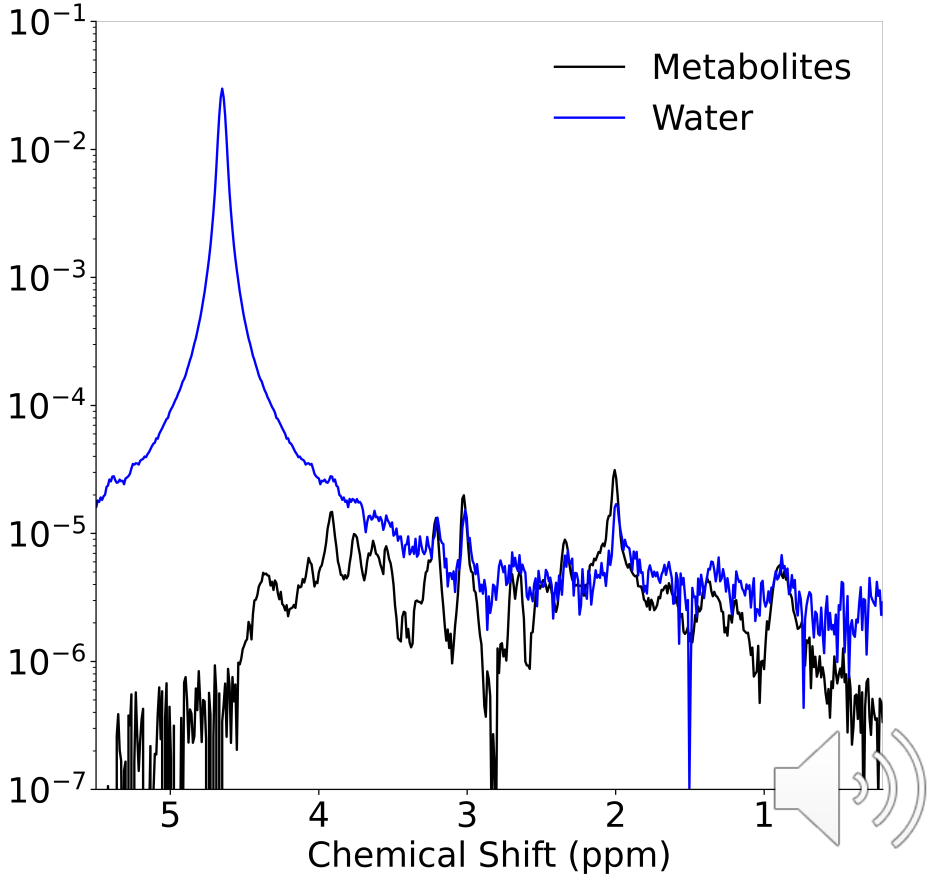
The water-reference

- Very high SNR water signal
- Water signal experiences (almost) the same acquisition conditions.

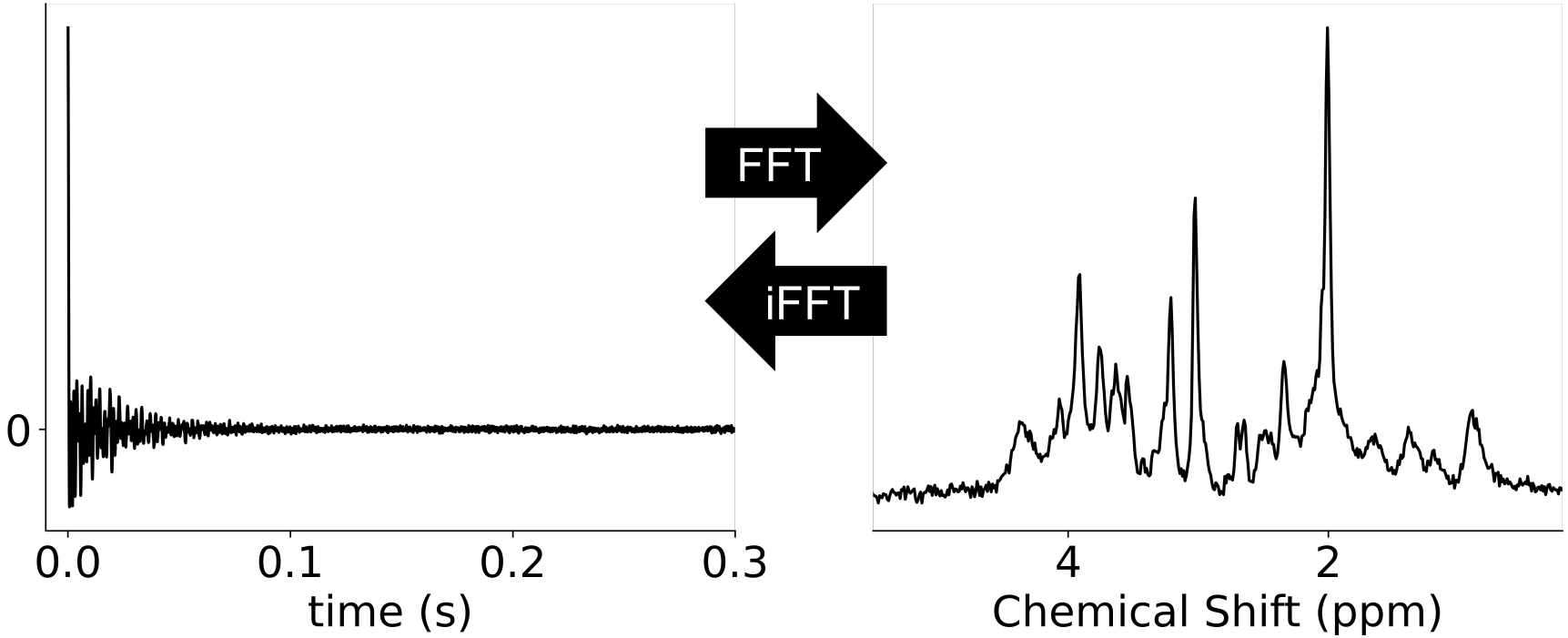
Used for:

- coil combination,
- eddy current correction,
- (sometimes) phase and frequency correction,
- (sometimes) motion correction.

Also must be identically processed to preserve scaling



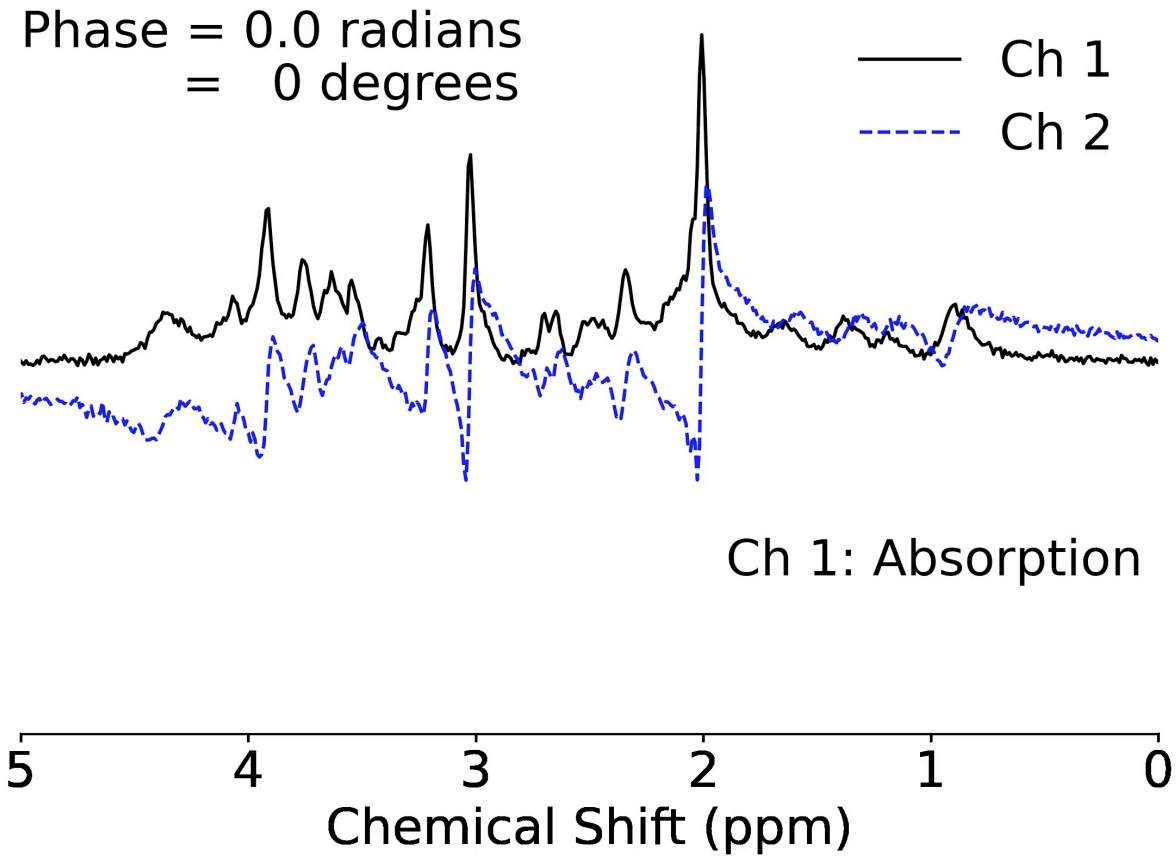
Time domain & frequency domain



MRS data has time domain and frequency domain representation.

Conversion via (inverse) Fast Fourier Transform.

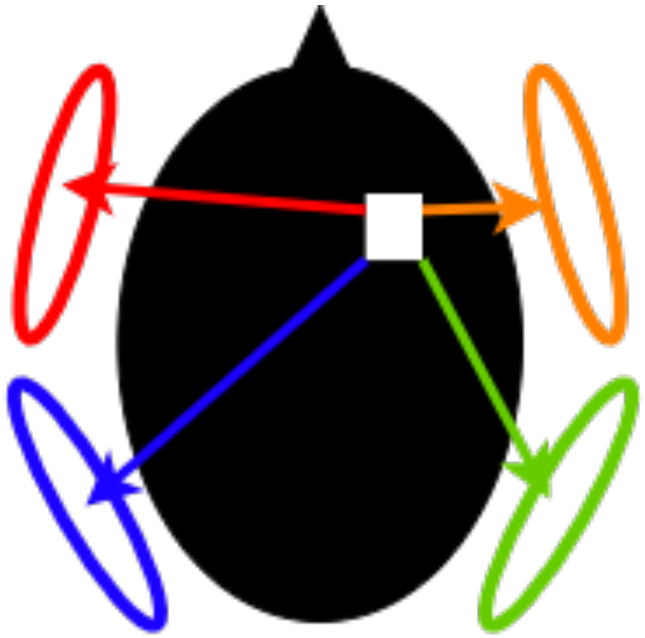
Complex MRS Data



MRS data has two channels:

- Stored as complex data,
- Quadrature relationship (90-degree phase offset).

Coil combination



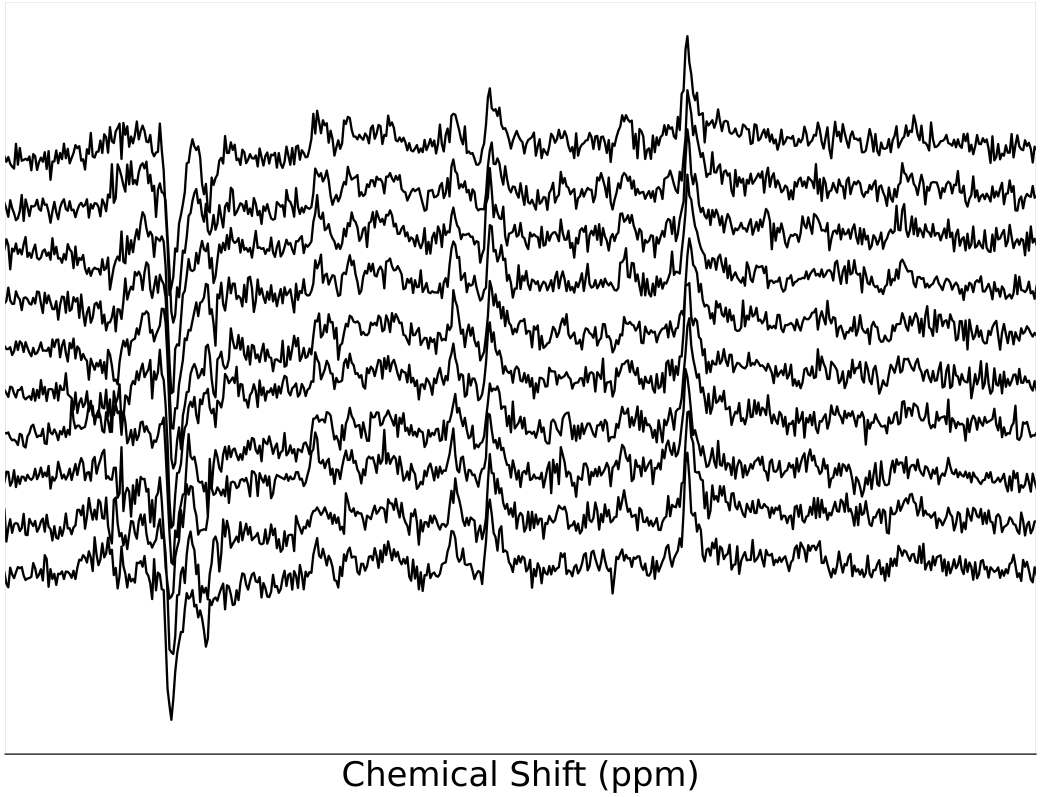
Combine signals with unknown complex (amplitude + phase) weighting. Two approaches:

1. Use ‘fit’ to water reference to derive complex weights.
2. Explicit rank = 1 problem, take first principal component of stacked multi-coil data.

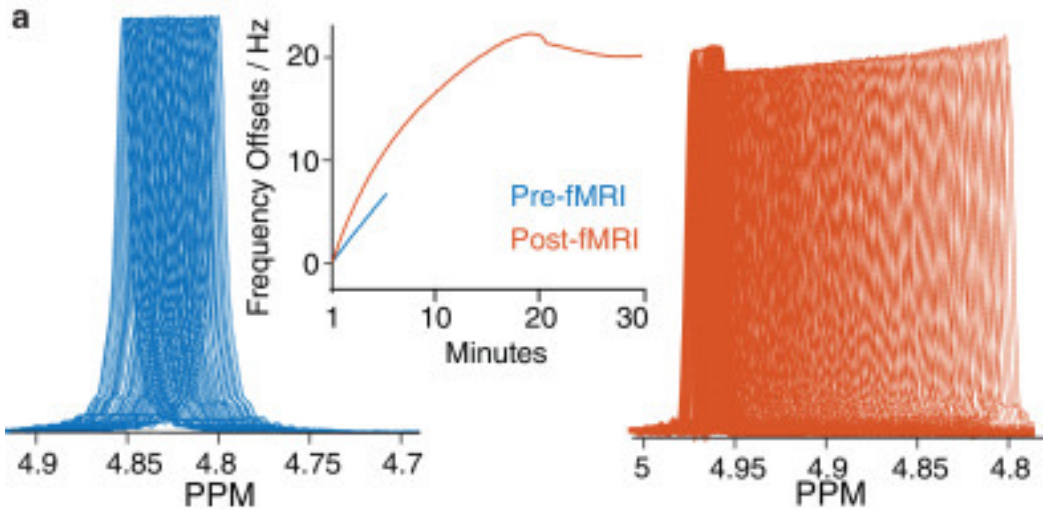
Combining repeated scans

10s to 100s of scans must be combined for sufficient SNR.

<u>BUT</u> hardware drift and physiological motion will cause frequency and phase shifts.



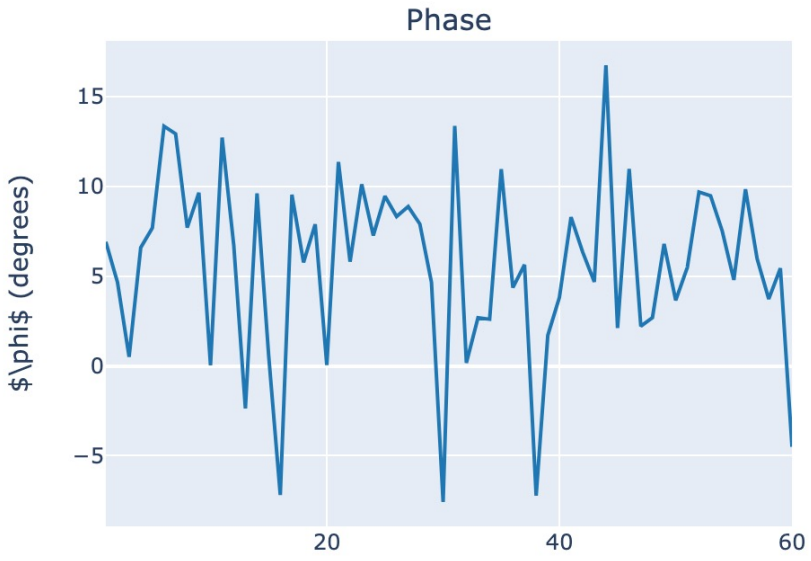
Combining repeated scans: alignment

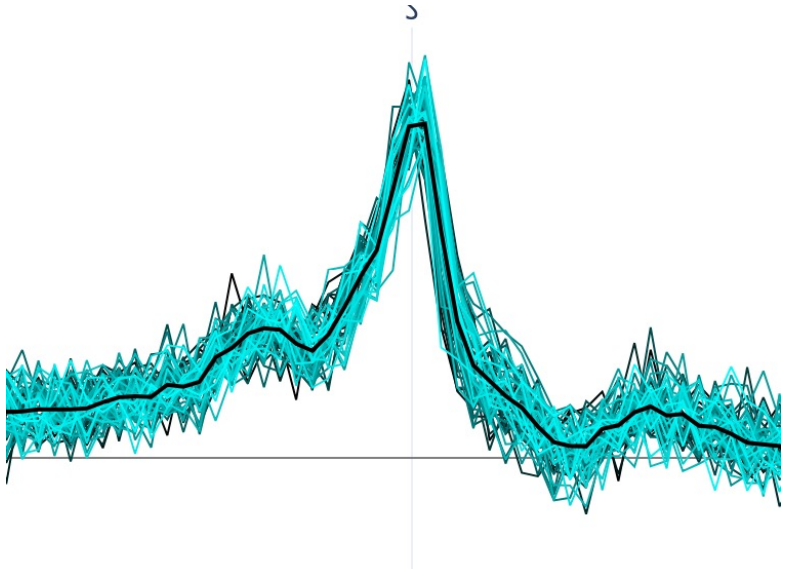


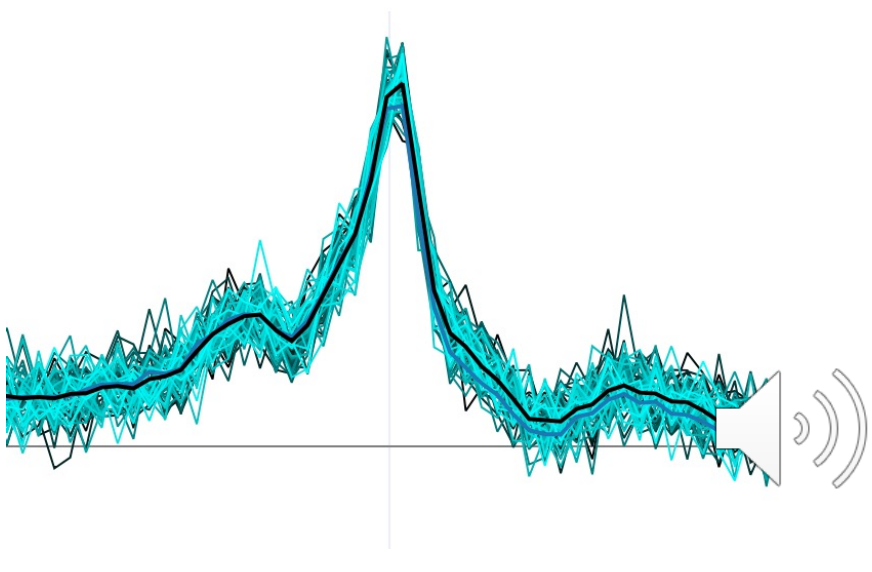
Hui et al. NeuroImage. 241, November 2021, 118430.

Small frequency shifts can be “first order” corrected by shifting and phasing individual spectra

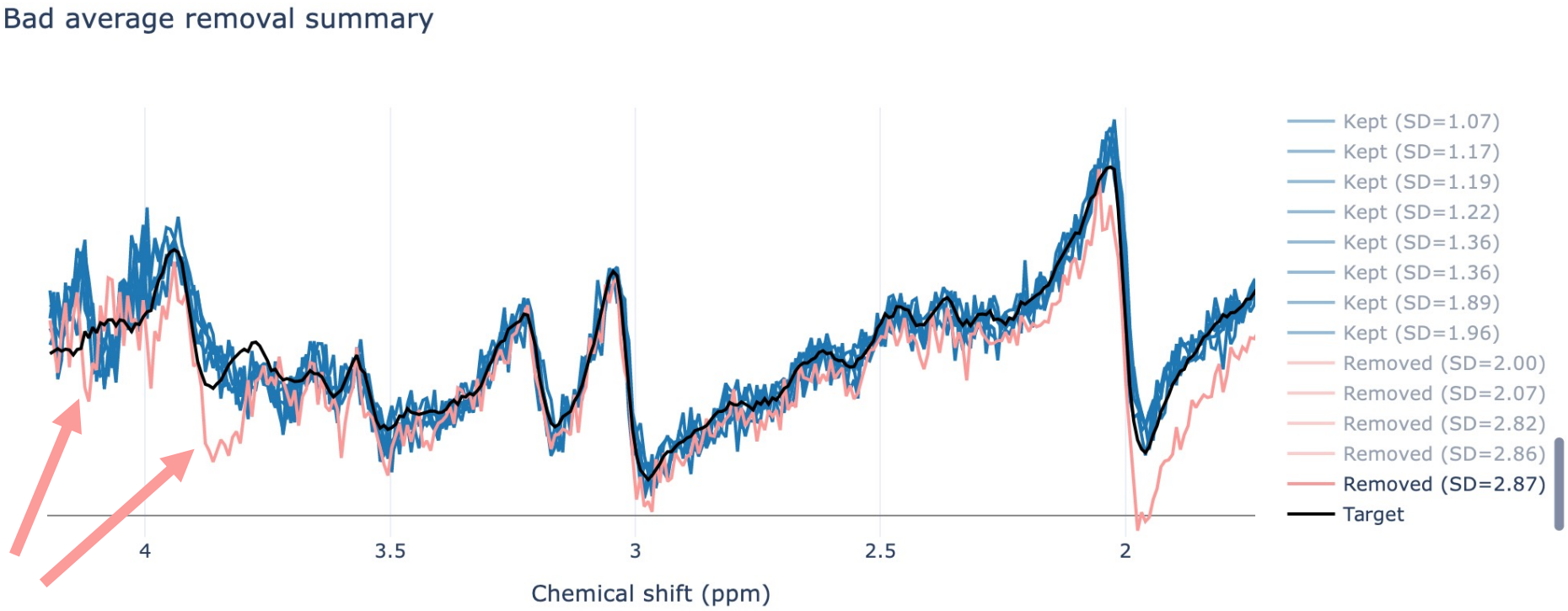
Combining repeated scans: alignment







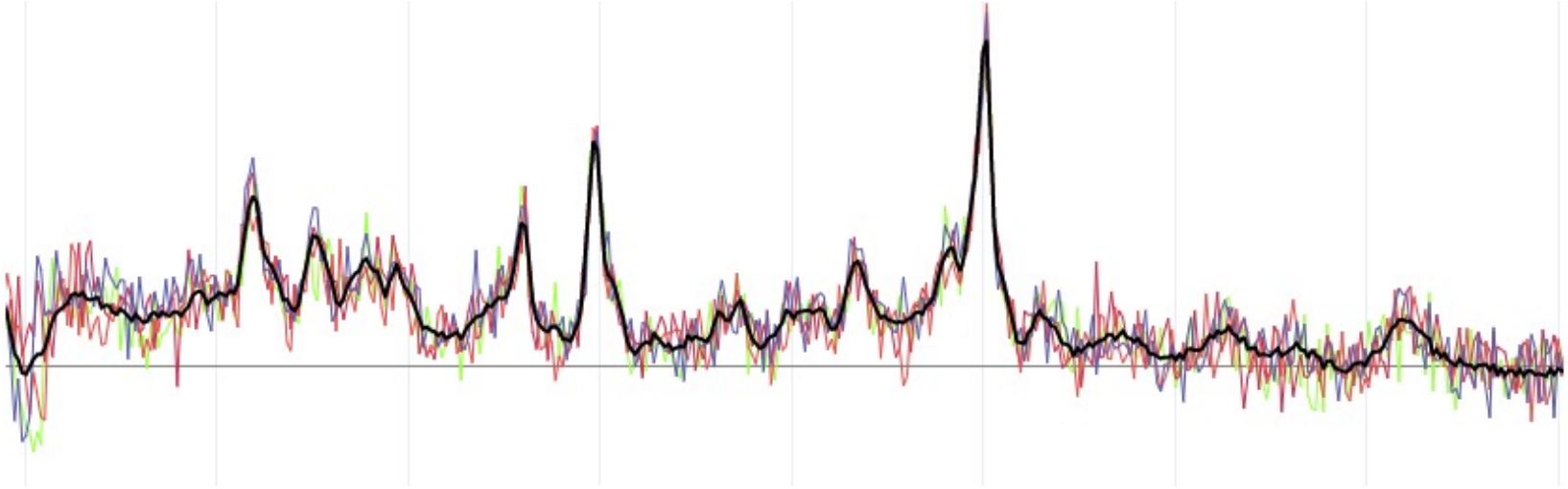
Combining repeated scans: outlier removal



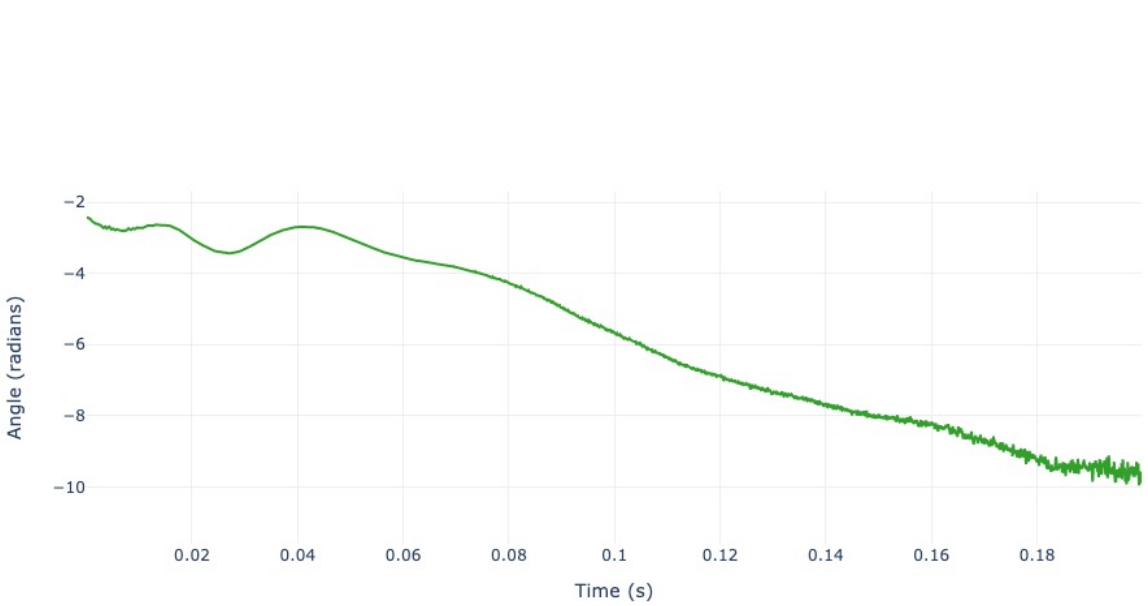
Gross subject motion leads to an incorrectly positioned voxel, severely degraded shim, or both. Corrupted scans should be excluded.

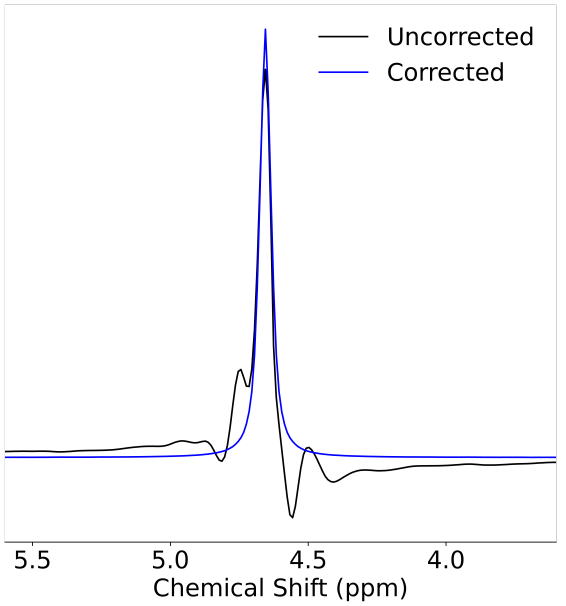
Combining repeated scans: averaging

After alignment and outlier rejection individual scans are combined by taking the mean.



Eddy current artefacts



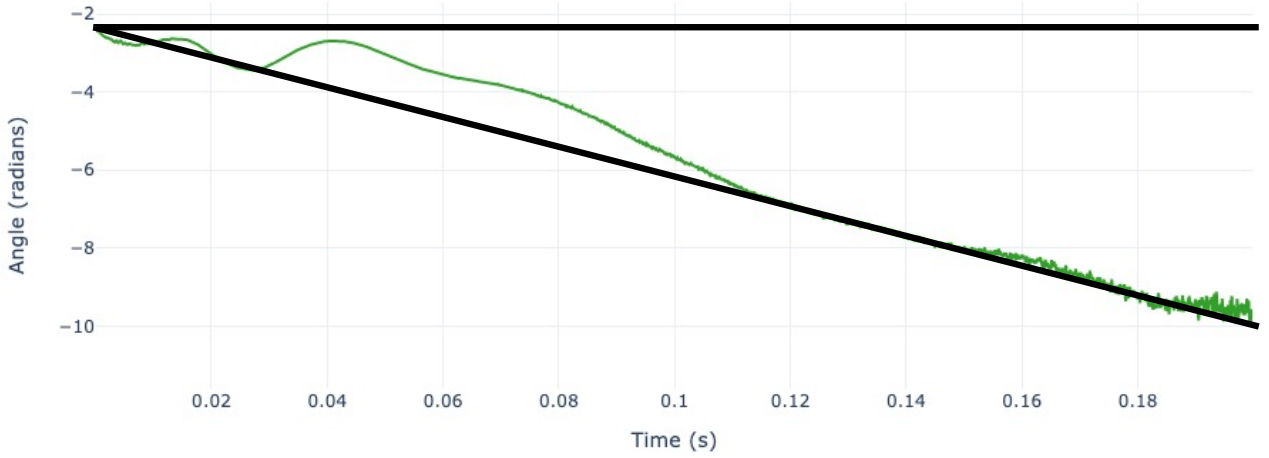


Eddy currents create time dependent magnetic field during FID collection.

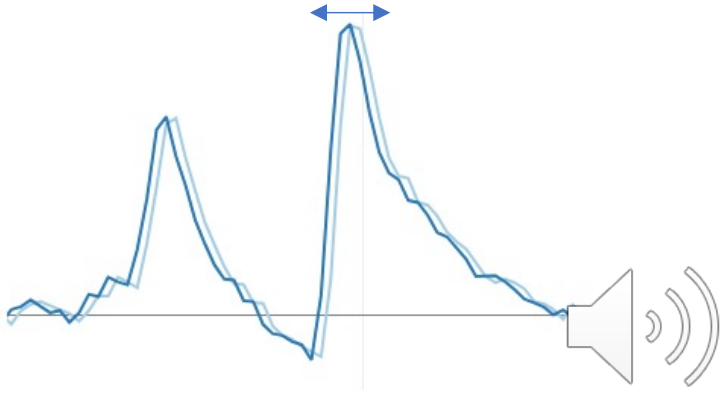
- Easily seen in phase of FID.
- Produces anti-symmetric side peaks in spectrum.
- Corrected by subtracting water reference phase

Dealing with global frequency shifts

Fitting analysis relies on fitting ‘fingerprints’ with known frequency shits. Therefore, desirable to eliminate large global shifts.



ECC or incorrect identification of water frequency on scanner can introduce shifts.



Residual water removal

A large residual water peak can distort baseline.

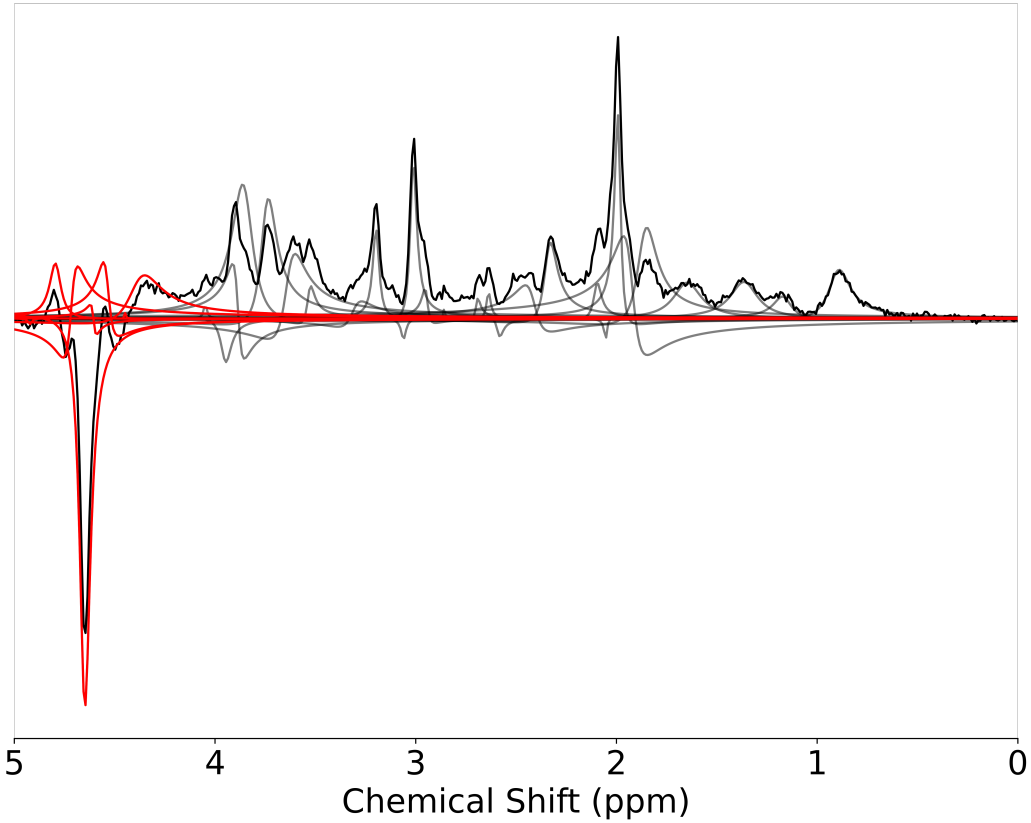
Data-driven fitting approach used to identify and remove residual peak.

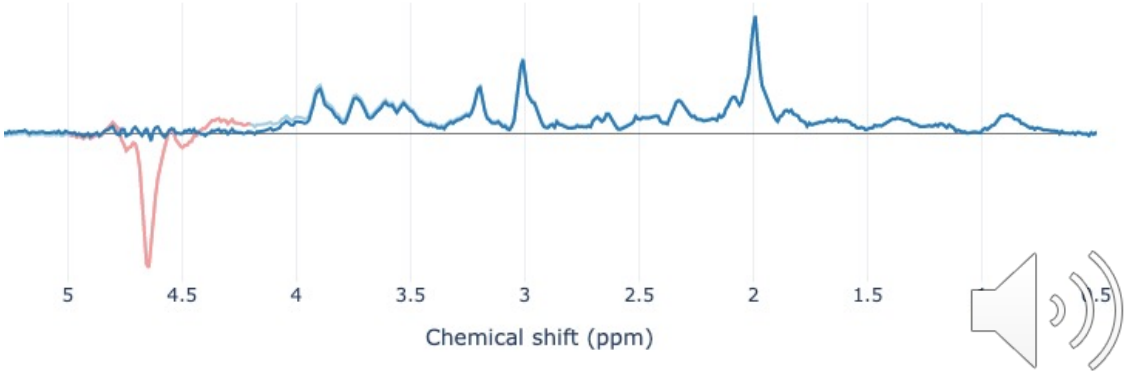
FID formed into Hankel matrix representation.

$$H = \begin{bmatrix} s[1] & \cdots & s[K] \\ s[2] & \cdots & s[K+1] \\ \cdots & \cdots & \cdots \\ s[M-K+1] & \cdots & s[M] \end{bmatrix}.$$

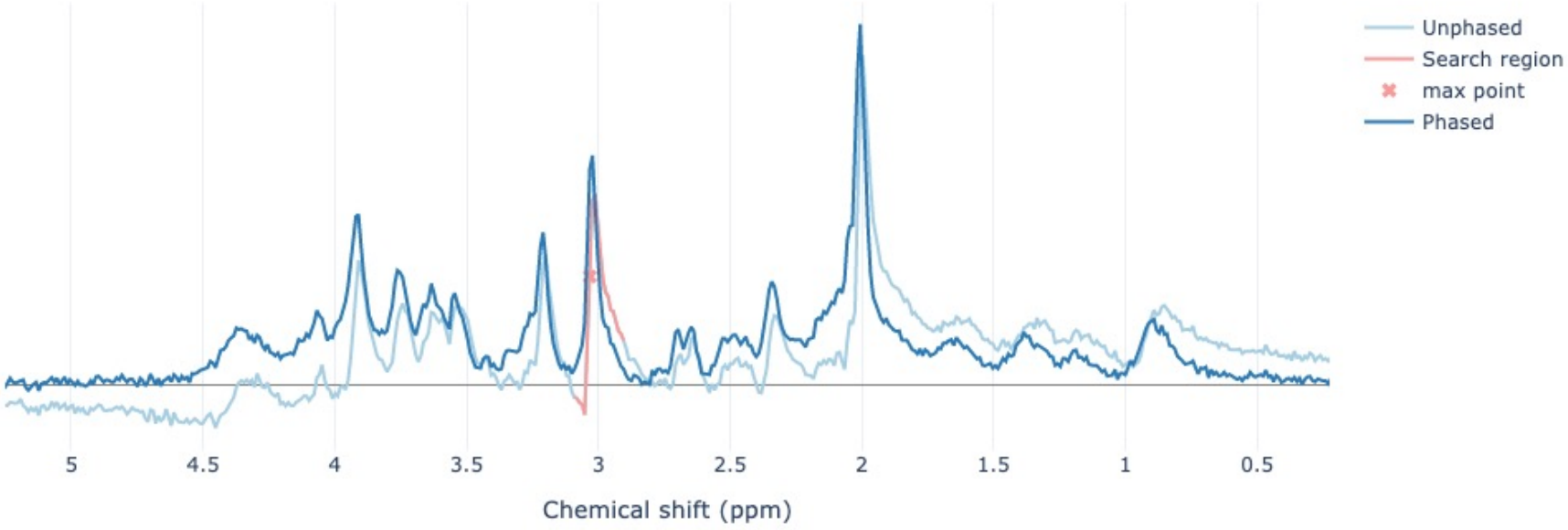
Then SVD used to identify peak components.

Peaks in water frequency range removed.





Phase correction: 0^{th} order



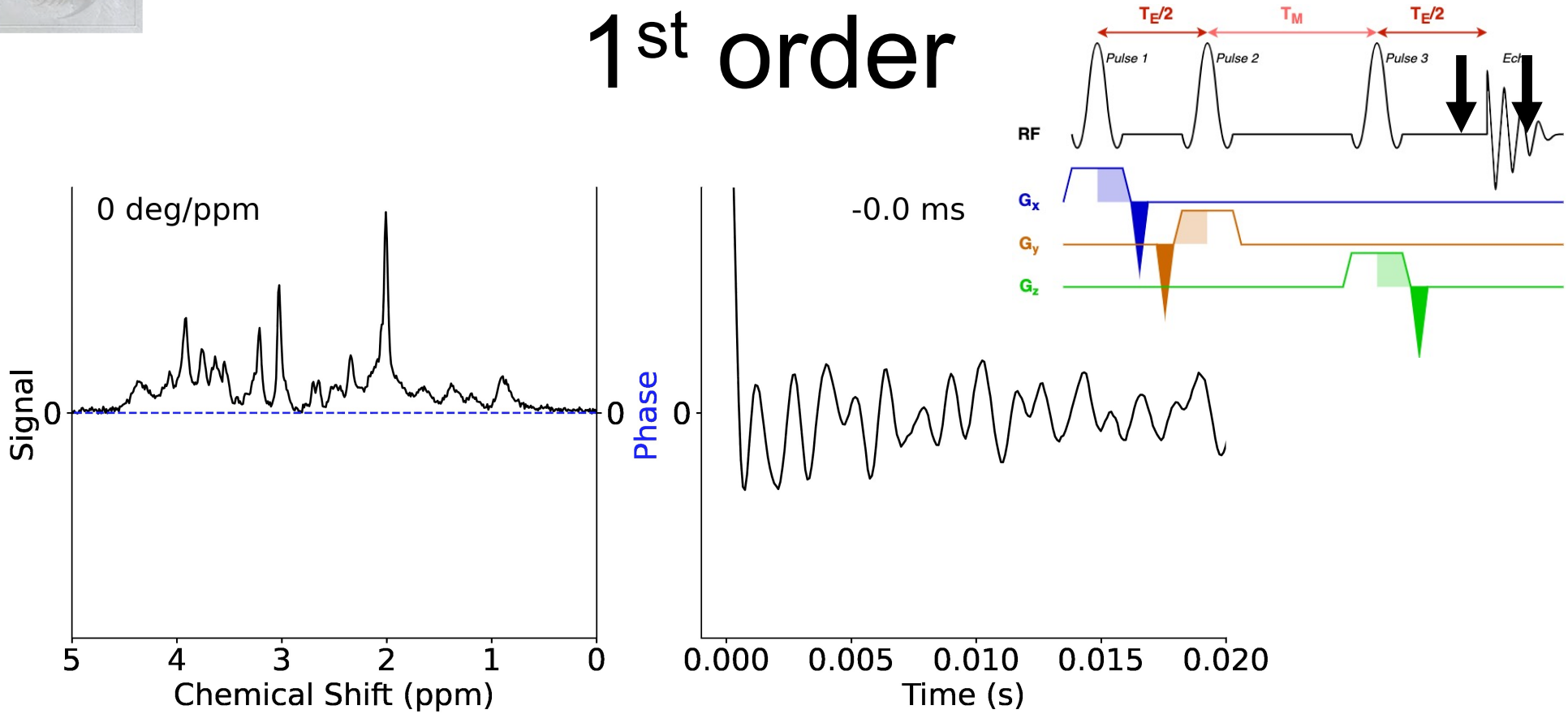
Zero-order phase - uniform phase term

Correction applies complex scalar term $e^{j\phi_0}$

Target a purely absorption spectrum for:

1) visualisation and 2) fitting initialisation

Phase correction: 1st order

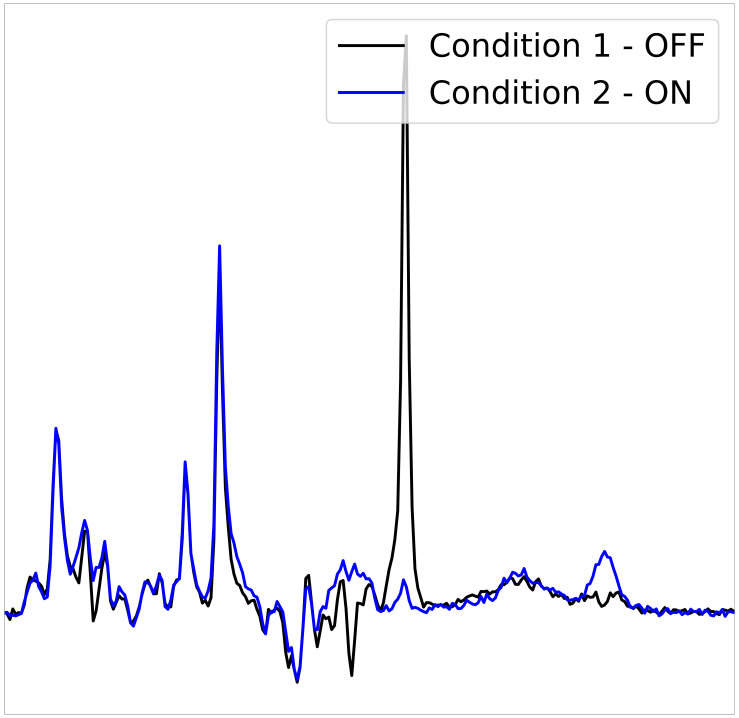


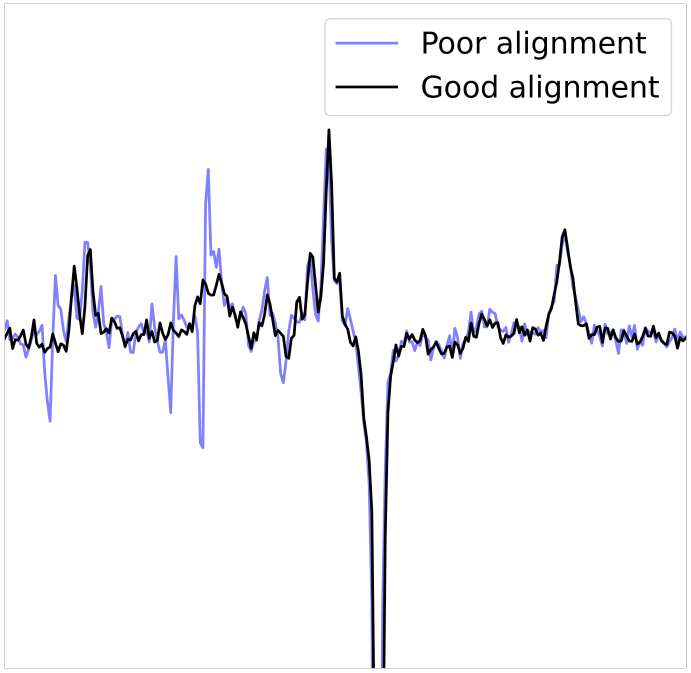
First-order phase - phase term linear with frequency

Correction applies complex vector $e^{2\pi j\omega\phi_1}$

Equivalent to time shift in time domain.

Alignment of edited spectra





Spectral editing dynamically alters acquisition parameters.

Combined with differencing to observe obscured metabolites.

Must align two different spectra based on partial similarity.

MRSI Pre-processing

FSL-MRS has limited tools for MRSI pre-processing. All pre-processing tools can be applied per voxel.

Planned features:

- Lipid removal
- Phase correction
- Motion correction