Module 18: Magnetic Resonance Spectroscopy

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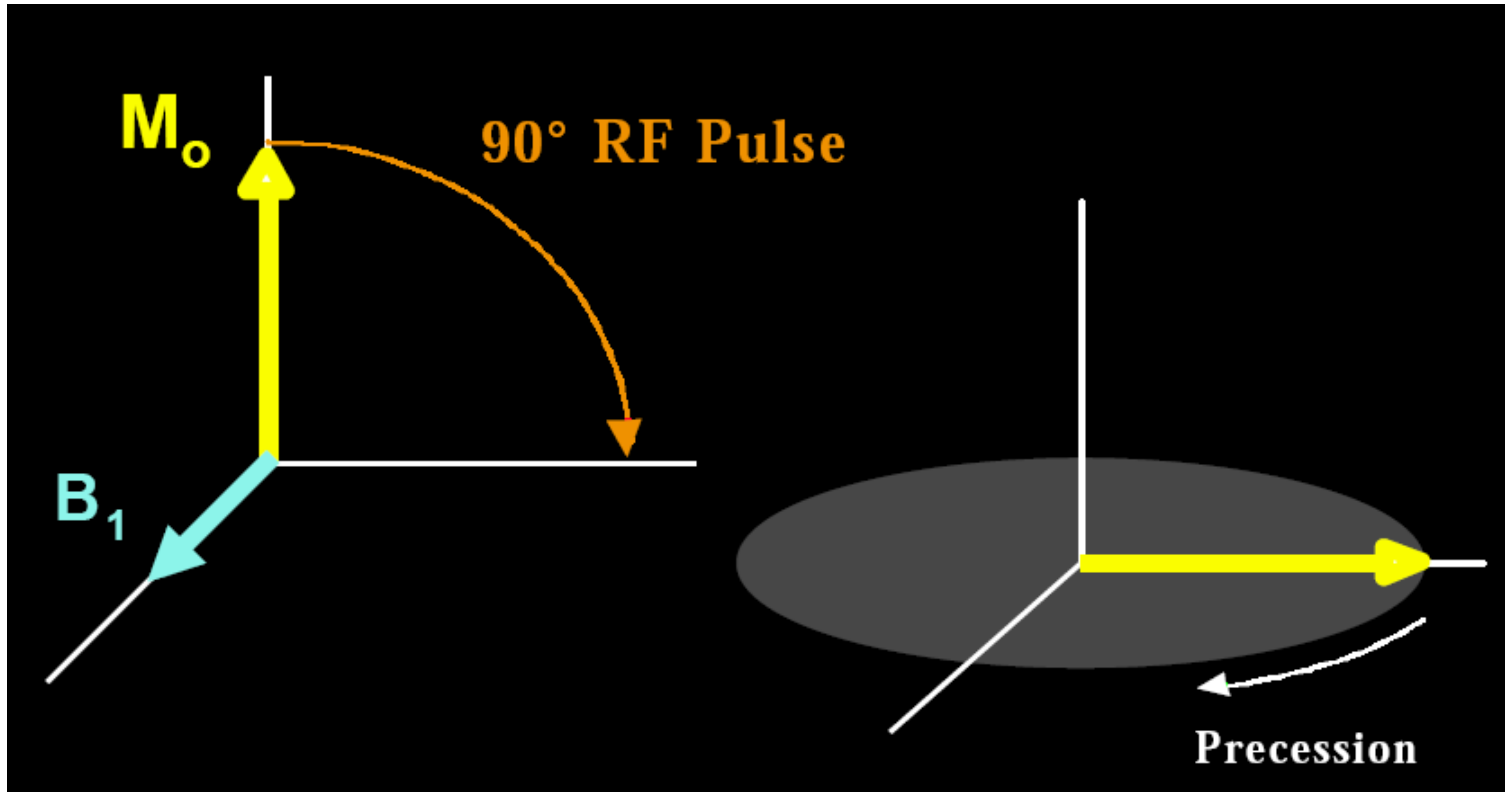
Magnetic Resonance Spectroscopy

- Precession or spins are in low energy parallel or high energy anti-parallel state.
- To change to a a spin from a low energy state to a high energy state electromagnetic energy is needed
- Frequency needed is known as the ***Larmor Frequency:***



$$\omega_0 = \gamma B_0$$

Larmor Frequency in Mhz

Gyromagnetic ratio

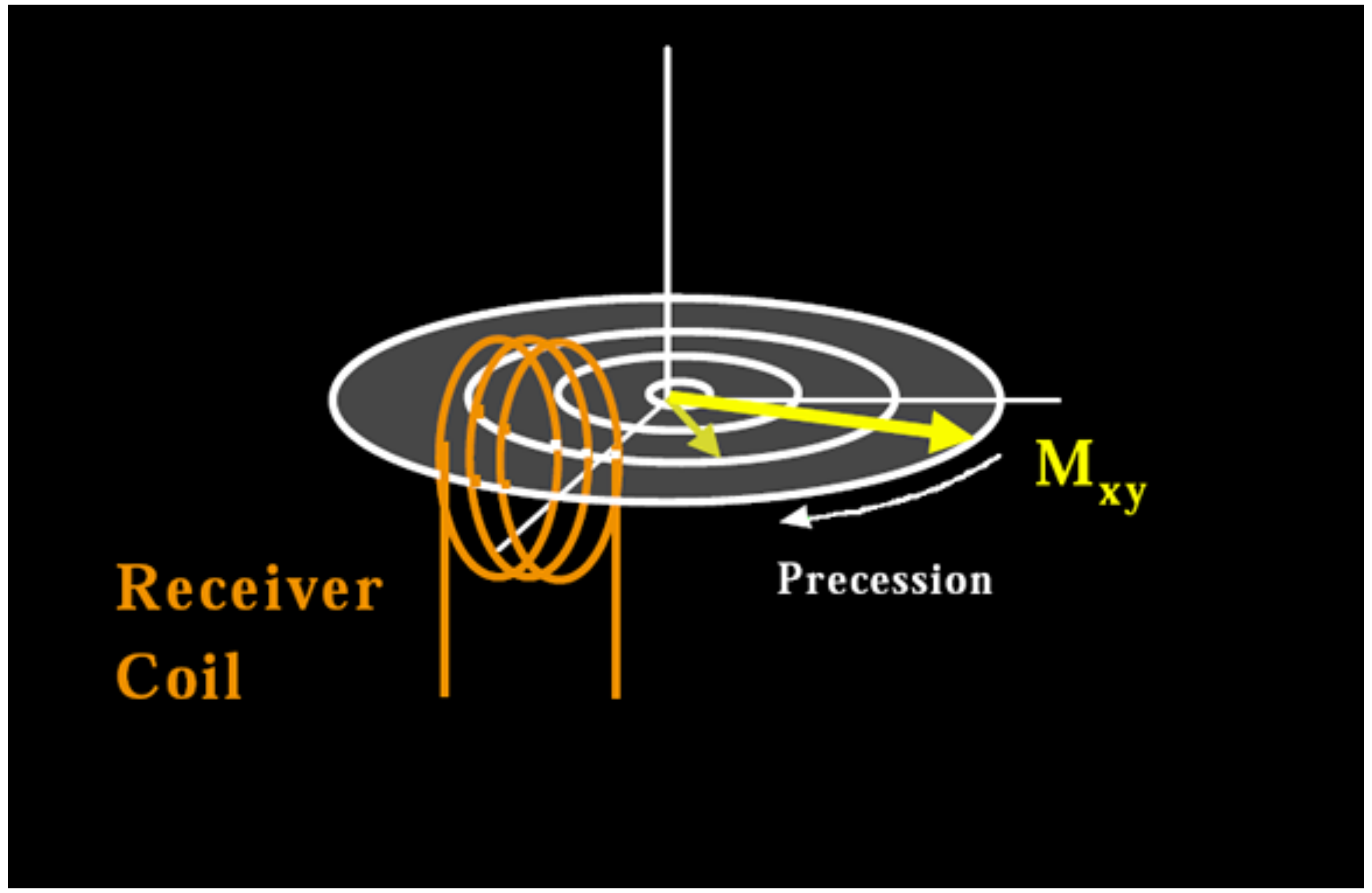
Strength Mag. Field

Nucleus or Particle	Gyromagnetic Ratio (γ) in MHz/Tesla
^{1}H	42.58
^{3}He	-32.43
^{13}C	10.71
^{19}F	40.05
^{23}Na	11.26
^{31}P	17.24
electron	-27,204

Magnetic Resonance Spectroscopy

- Precessions in high energy state cause small local magnetic field at the nucleus in the opposite direction of the static magnetic field

- This changes the local effective magnetic field and causes the signal frequency of the nuclear spin to shift

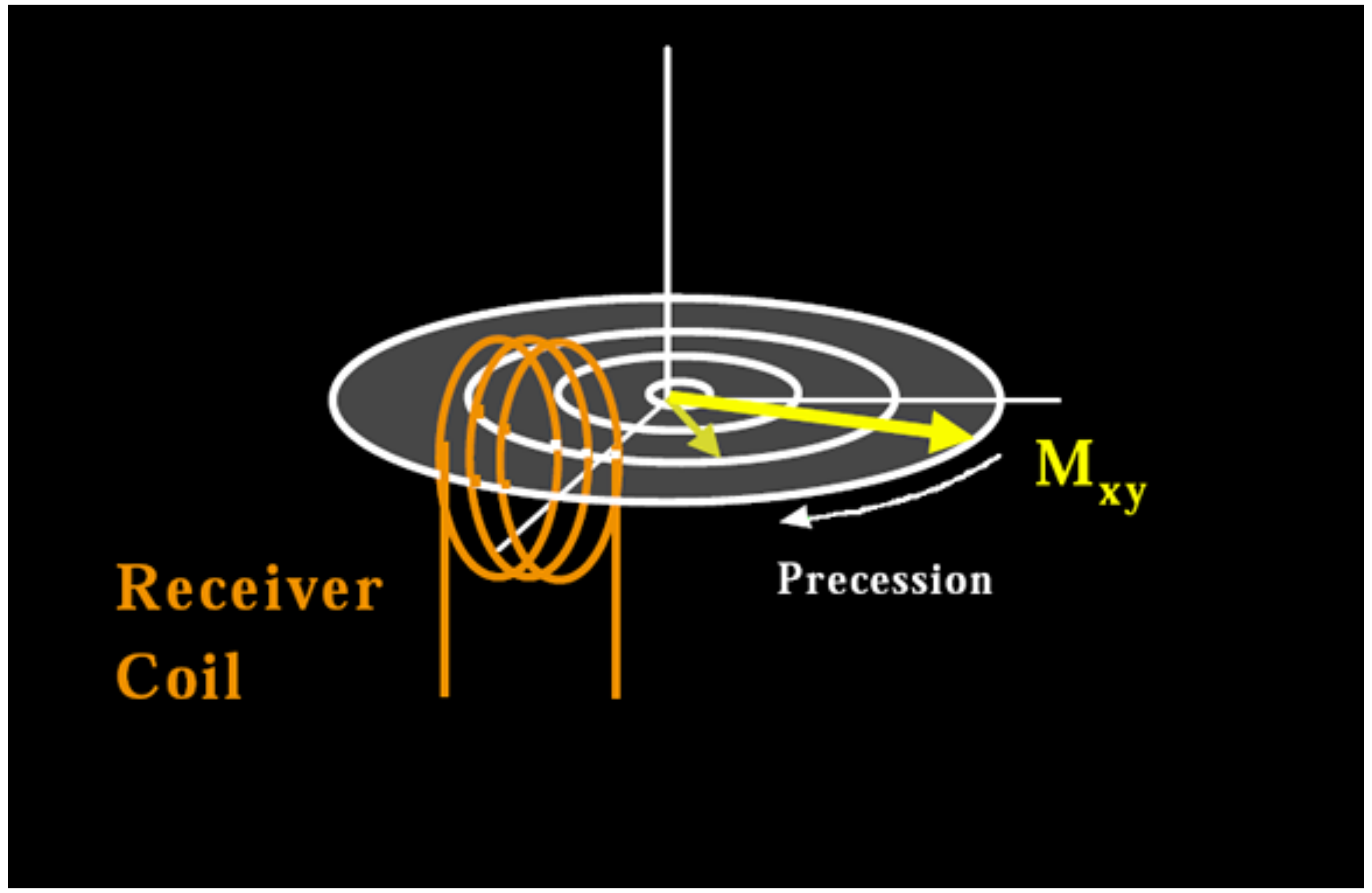


$$\underbrace{\omega_0}_{\text{Larmor Frequency in Mhz}} = \underbrace{\gamma}_{\text{Gyromagnetic ratio}} \underbrace{B_0}_{\text{Strength Mag. Field}}$$

Magnetic Resonance Spectroscopy

Chemical shift:

- Change in the resonant frequency that results from a small change in the local magnetic field
- The value of the difference of the resonance frequencies gives information about the molecular group which the nucleus is part of
- Magnetic Resonance Spectroscopy imaging aims to quantify local presence of certain chemical compounds



$$\omega_0 = \gamma B_0$$

Larmor Frequency in Mhz

Gyromagnetic ratio

Strength Mag. Field

Magnetic Resonance Spectroscopy

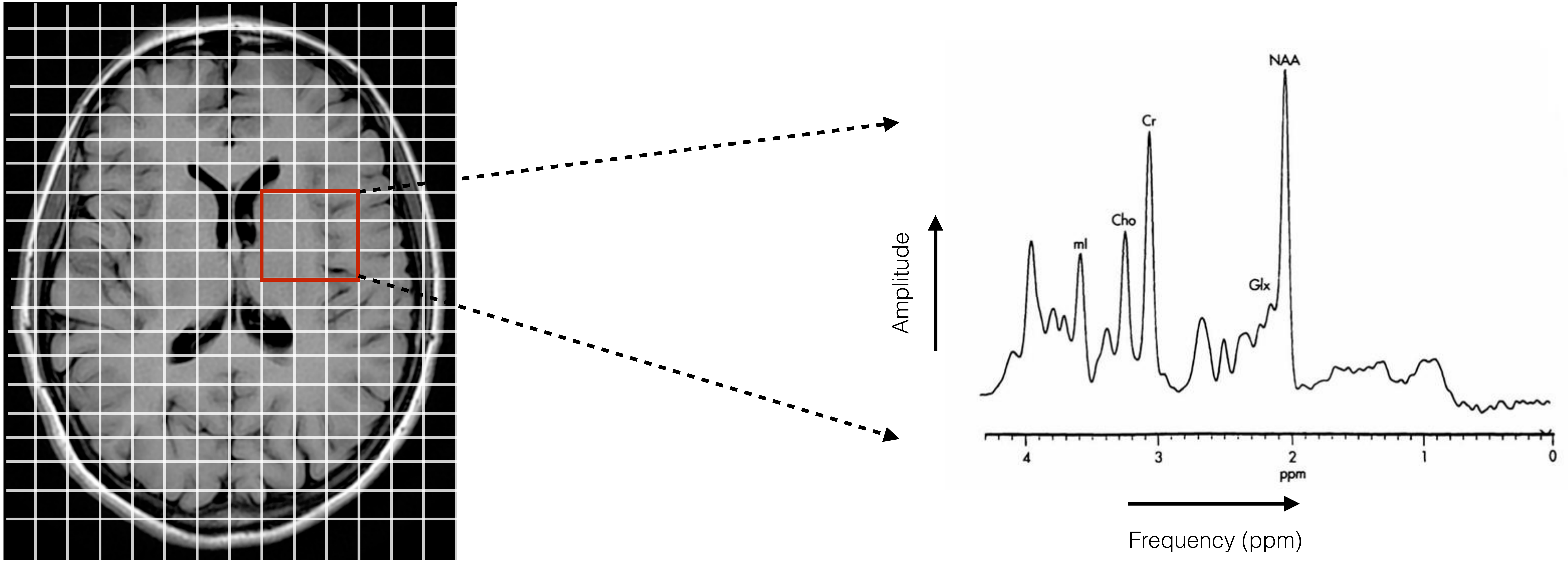
Chemical shift expressed in Parts per Million

$$\underbrace{\omega_0}_{\text{Larmor Frequency in Mhz}} = \underbrace{\gamma}_{\text{Gyromagnetic ratio}} \underbrace{B_0}_{\text{Strength Mag. Field}}$$

$$\text{Chemical shift (ppm)} = \frac{\text{Change in resonance frequency in Hz}}{\text{Spectrometer frequency in Mhz}}$$

Magnetic Resonance Spectroscopy

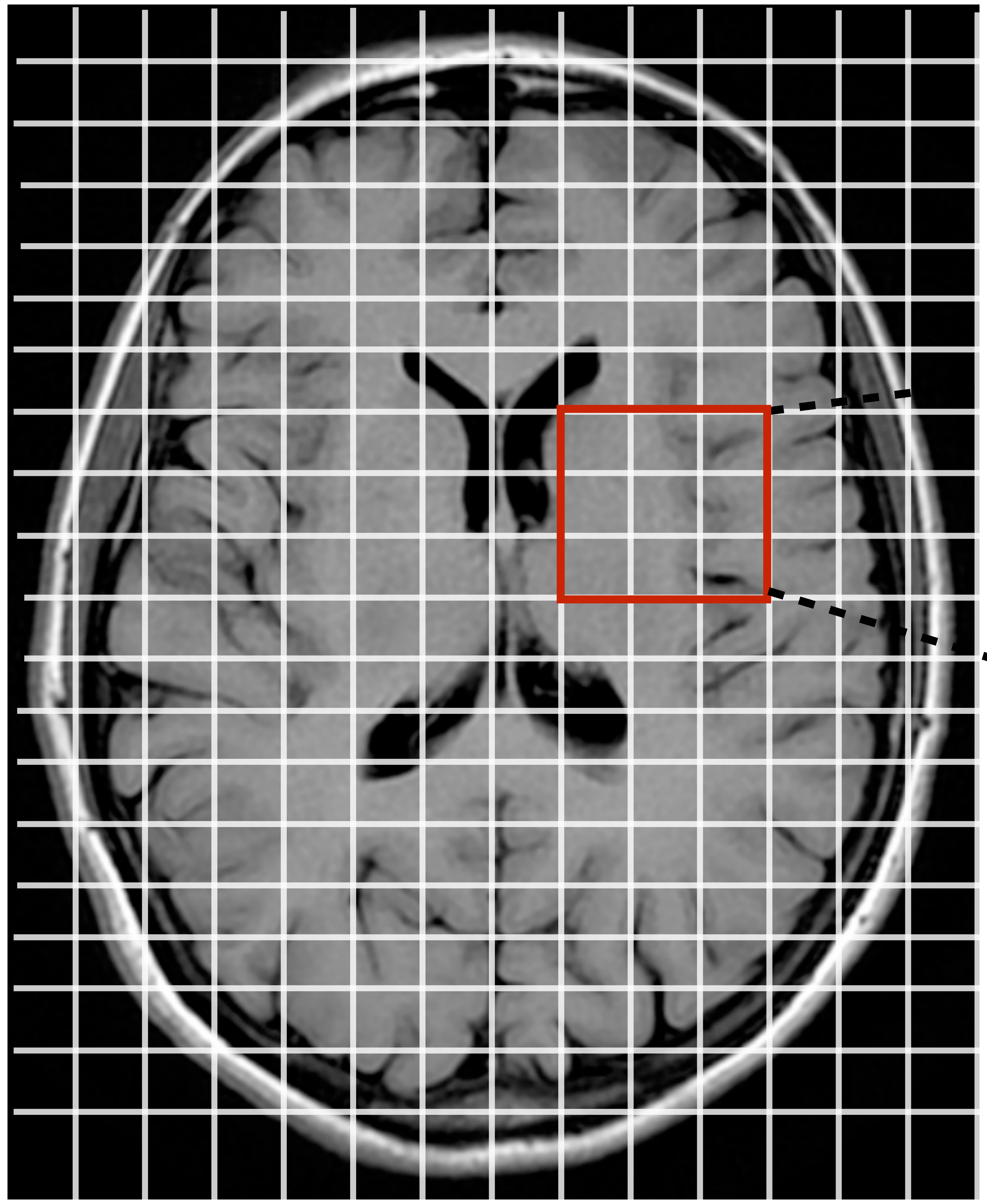
Chemical shift imaging

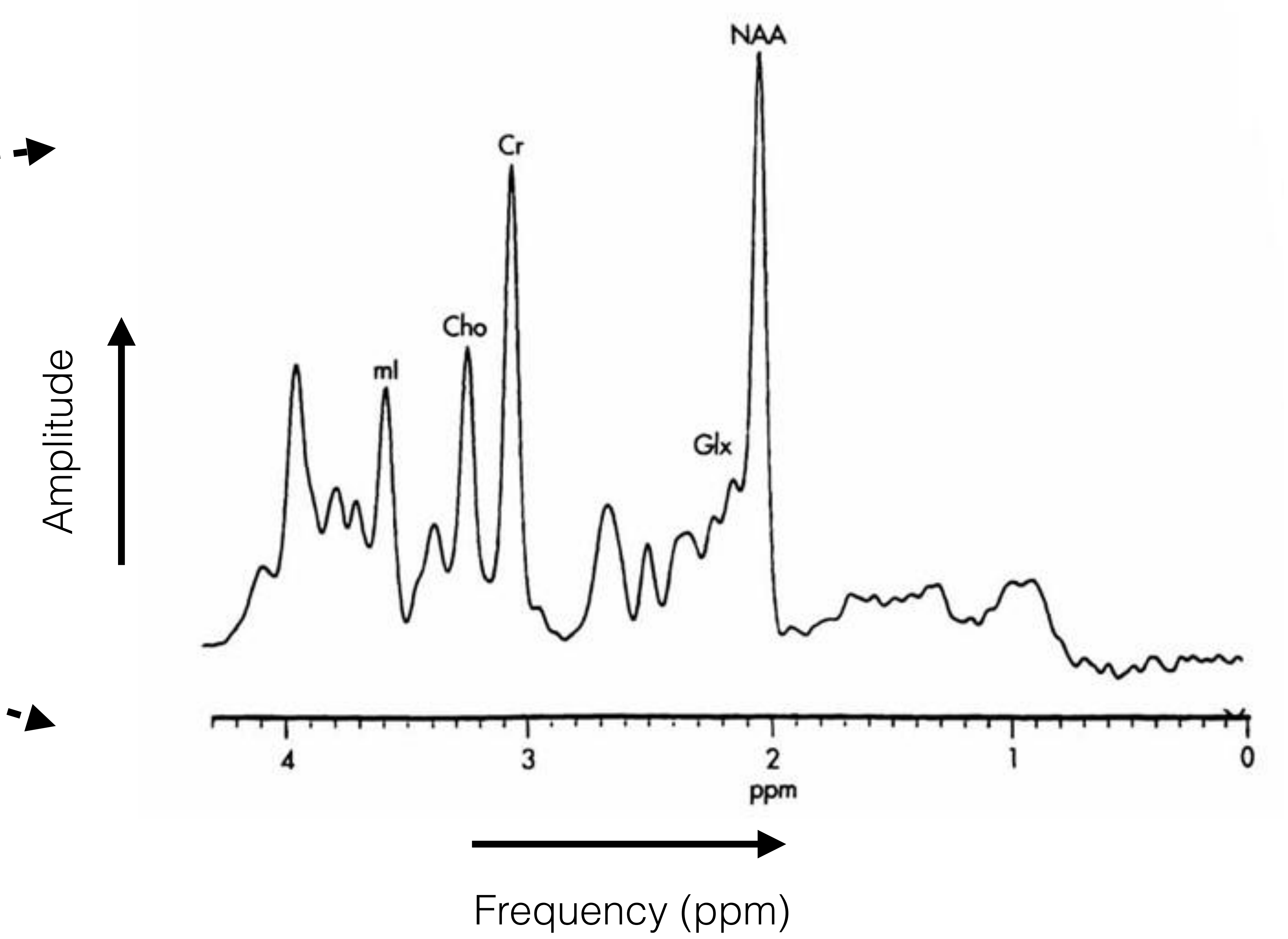


The value of the difference of the resonance frequencies gives information about the molecular group which the nucleus is part of

Magnetic Resonance Spectroscopy

Chemical shift imaging

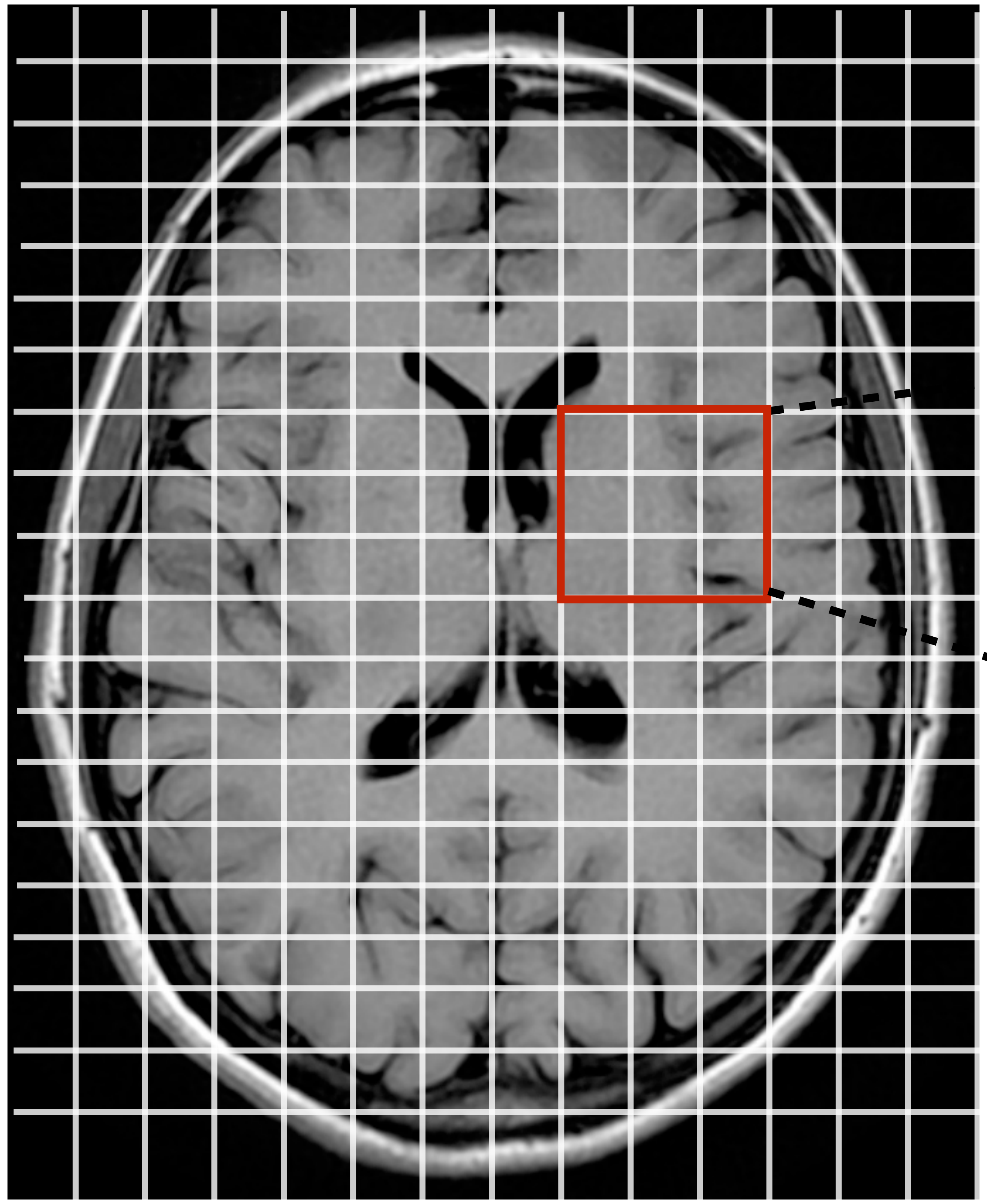


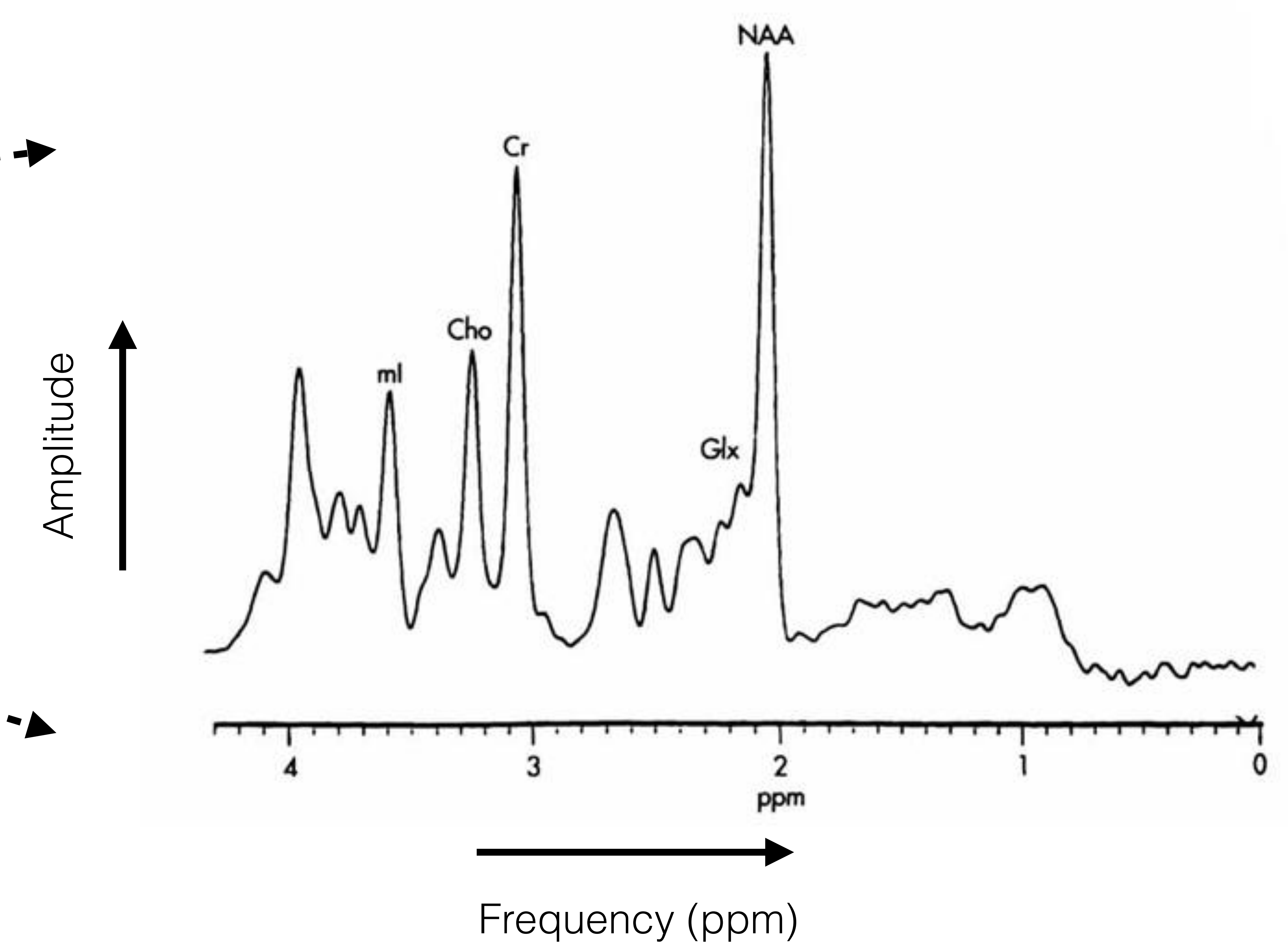


$$\text{Chemical shift (ppm)} = \frac{\text{Frequency in sample - Frequency in Tetramethylsilane (TMS)}}{\text{Spectrometer frequency in Mhz}}$$

Magnetic Resonance Spectroscopy

Chemical shift imaging



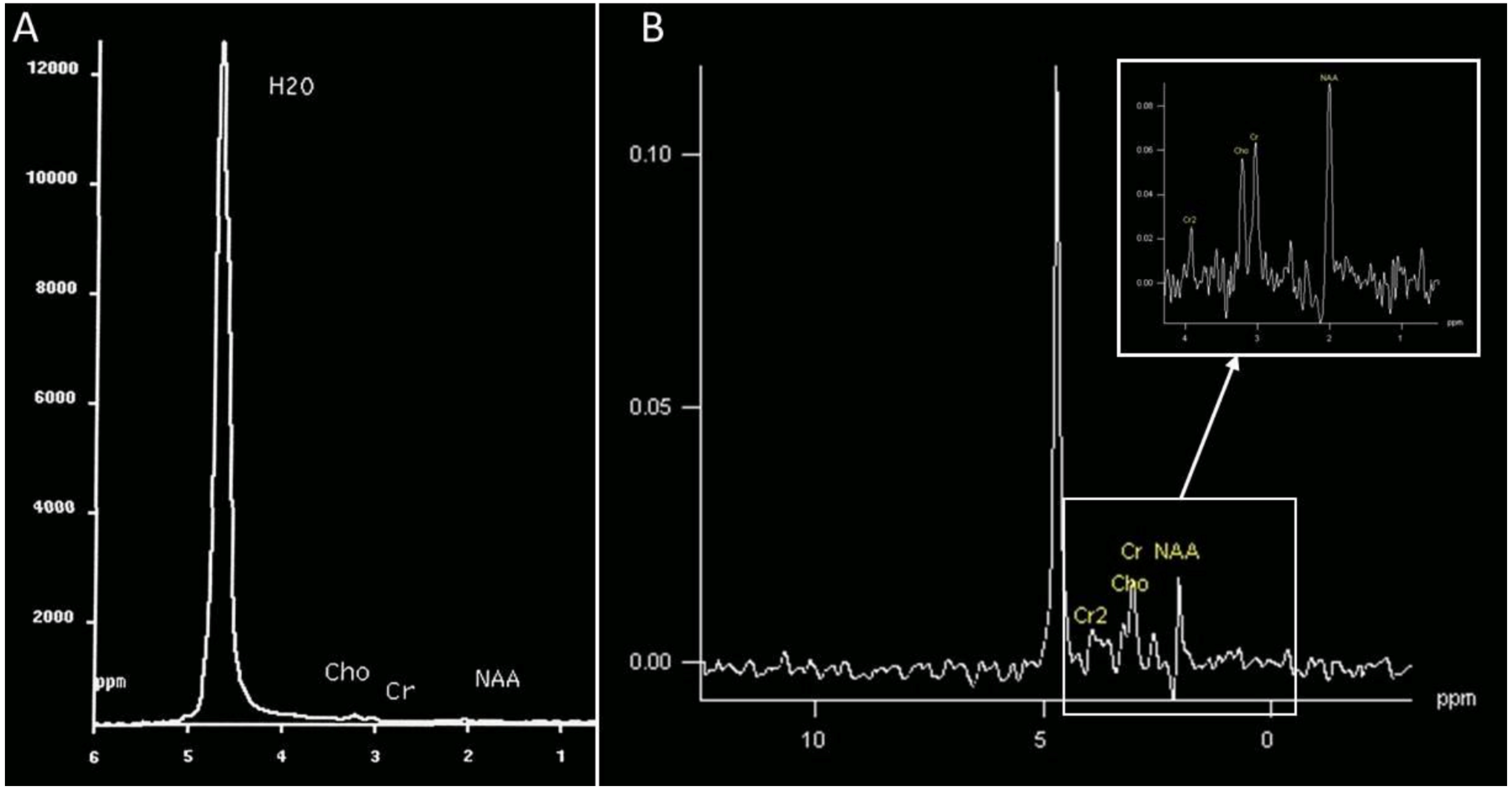


Spectra can be obtained from different nuclei. Protons (^1H) are most commonly used due to high sensitivity and abundance

Magnetic Resonance Spectroscopy

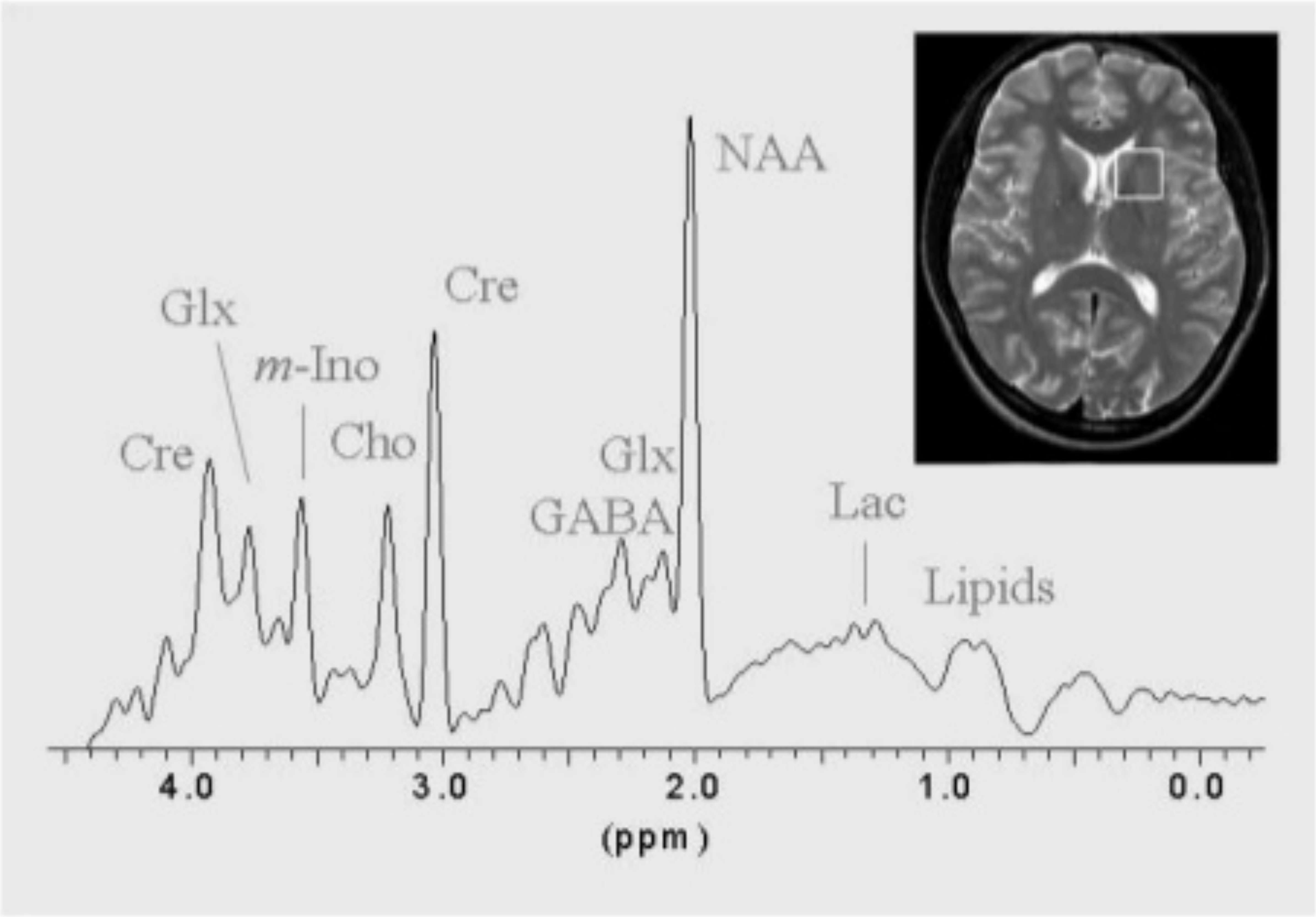
- Molecules of interest have low concentration in brain
- Water is abundant thus water signal is much greater than other material
- Water signal must be suppressed
- Chemical Shift Selective (CHESS) suppression pre-saturates water signal using specific pulse frequency

Water suppression



Magnetic Resonance Spectroscopy

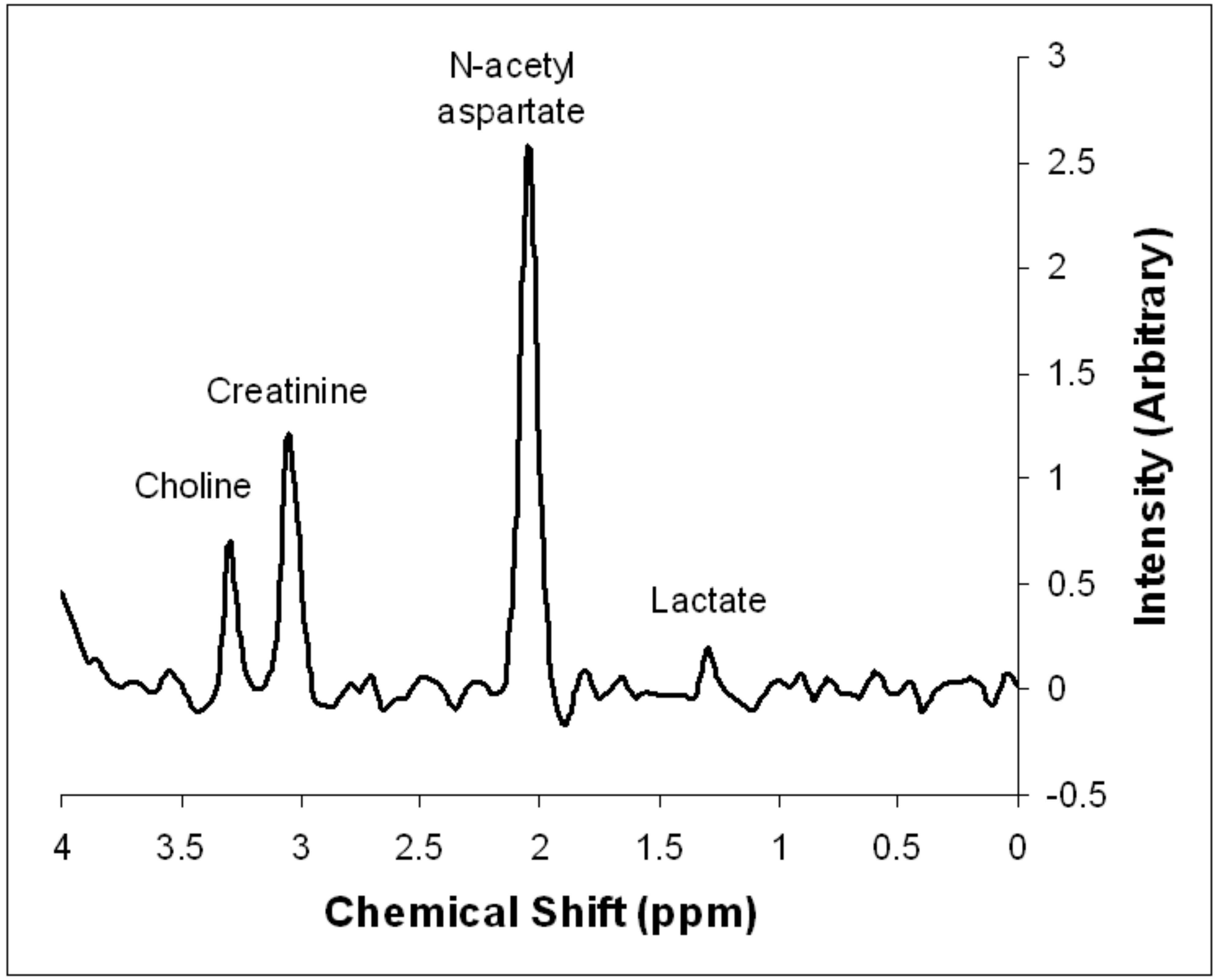
- Spectra provides detection of brain metabolites
- Area under the curve provides metabolite concentration in brain
- Certain sequences are more sensitive to certain metabolites
- Higher field strength results in greater detection
- Changes in metabolites often precede structural brain changes



Magnetic Resonance Spectroscopy

Common metabolites

N-acetylaspartate (NAA):

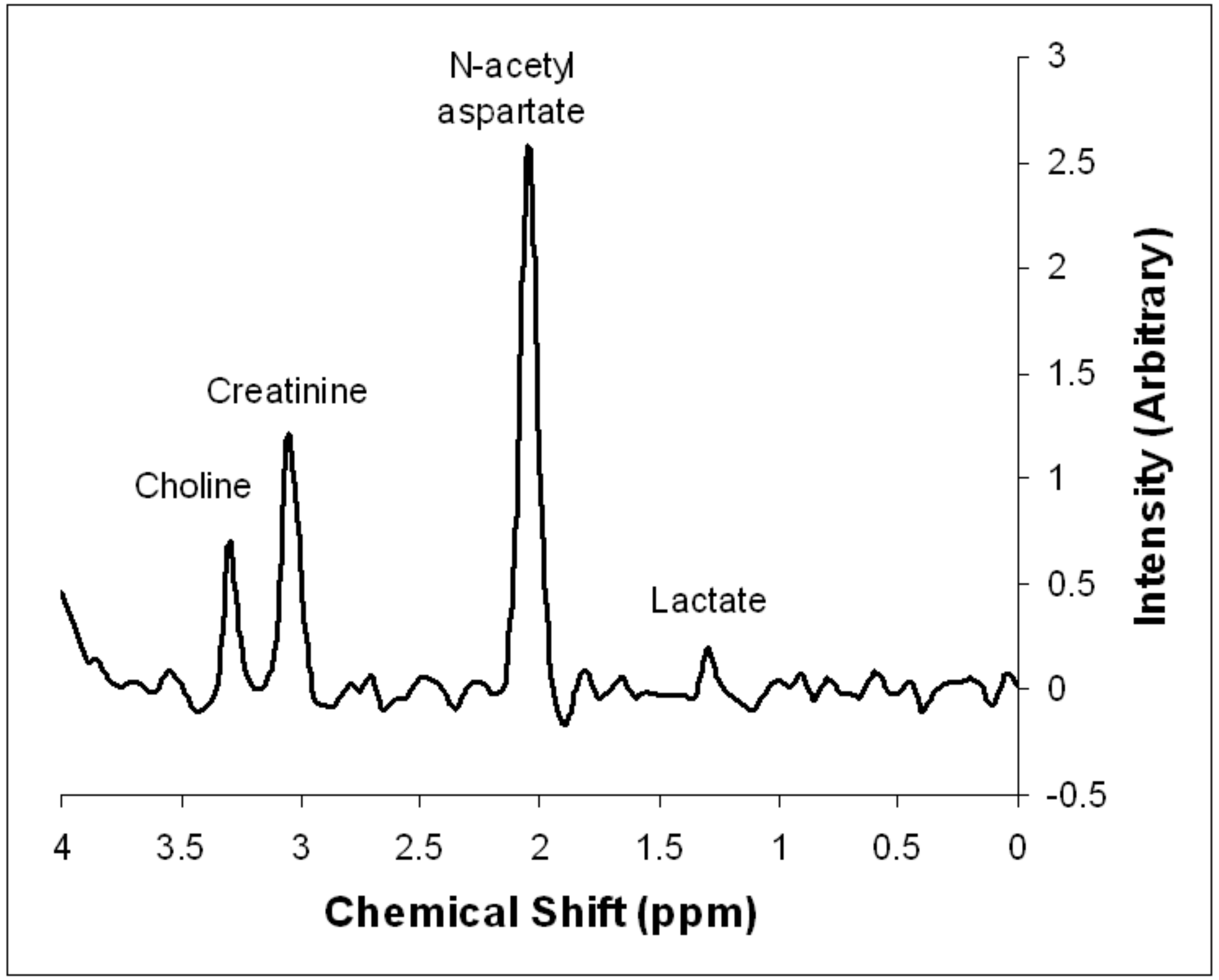


- Highest peak in normal brain
- Marker of neuronal and axonal viability and density
- Decreased concentration is associated with white matter disease, malignant neoplasms

Magnetic Resonance Spectroscopy

Common metabolites

Creatine (Cr):



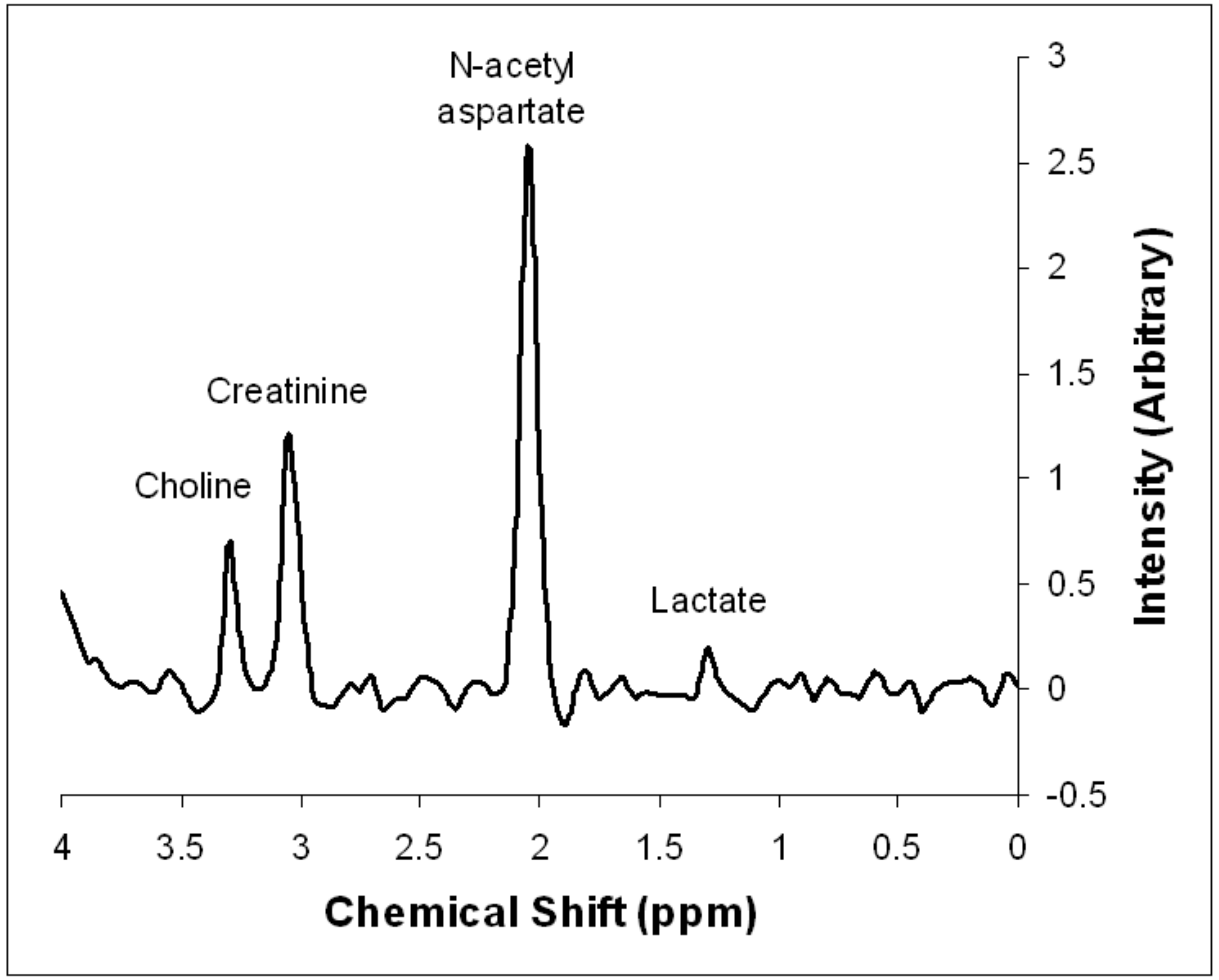
- Represents molecules that contain creatine and phosphocreatine
- Marker of energetic systems and intracellular metabolism
- Reduced Cr signal observed in brain tumors

Magnetic Resonance Spectroscopy

Common metabolites

Choline (Cho):

- Represents choline and choline containing compounds
- Marker of cellular membrane turnover reflecting cellular proliferation
- Increased Cho seen in infarction or inflammation
- Somewhat non-specific

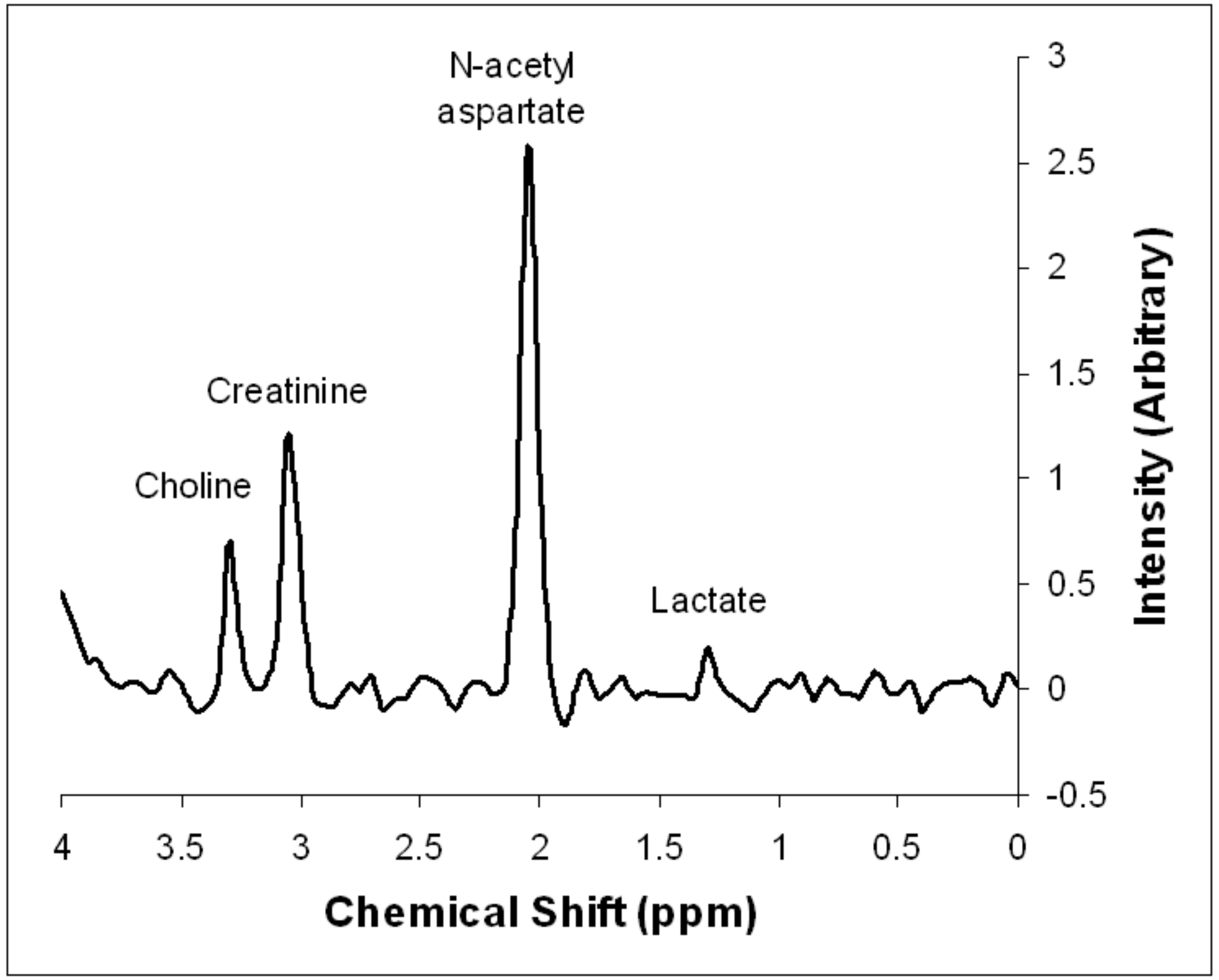


Magnetic Resonance Spectroscopy

Common metabolites

Lactate (Lac):

- Low peak in normal brain
- Marker of anaerobic metabolism such as cerebral hypoxia, ischemia, seizures, metabolic disorders
- Occurs in cysts, normal pressure hydrocephalus and certain tumors



Magnetic Resonance Spectroscopy

Common metabolites

Lipids (Lip):

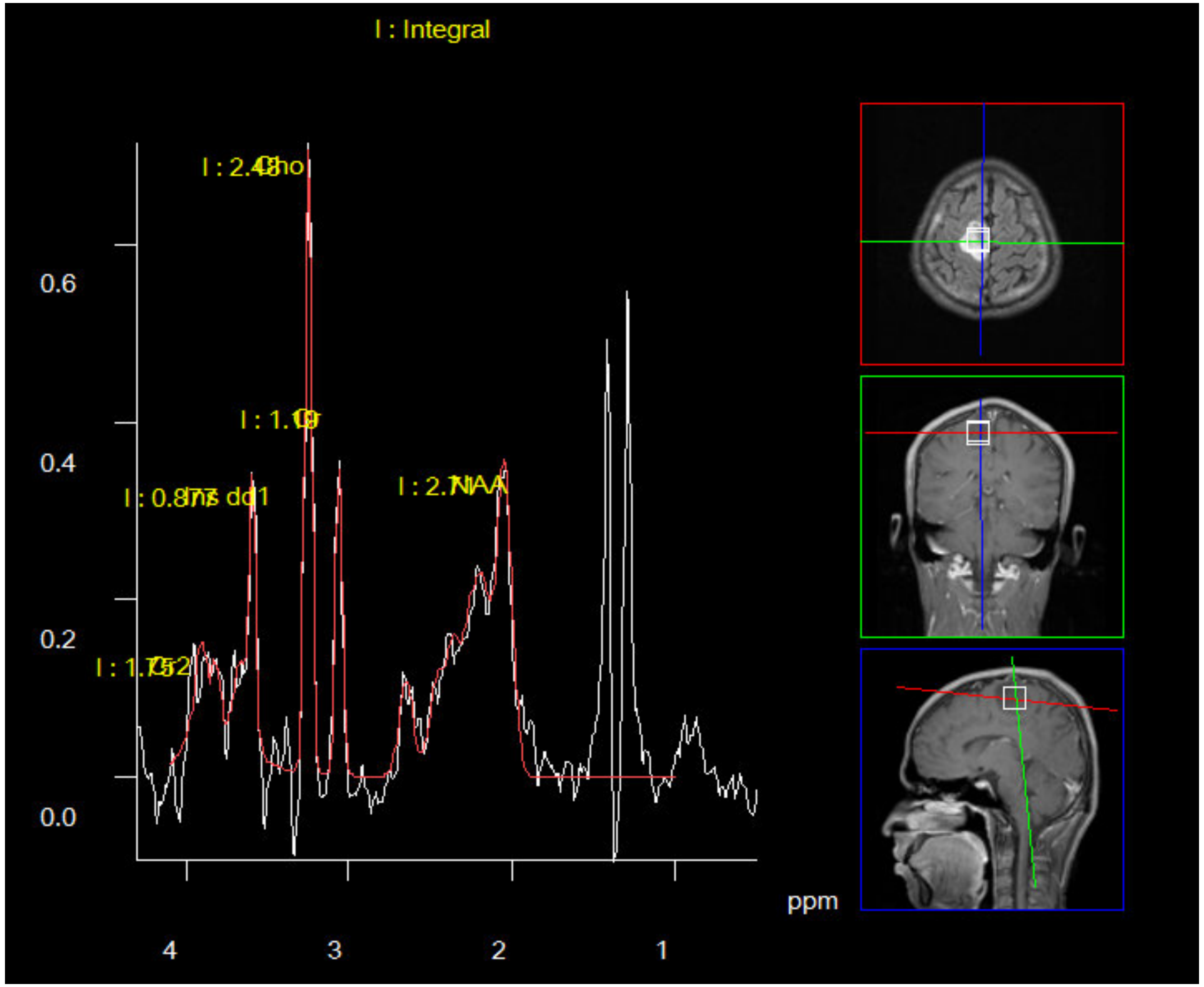
- More difficult to detect. Typically two peaks of Lip
- Marker of cellular membrane breakdown or necrosis as in metastases or malignant tumors

Observable Proton Metabolites

ppm	Metabolite	Properties
0.9-1.4	Lipids	Products of brain destruction
1.3	Lactate	Product of anaerobic glycolysis
2.0	NAA	Neuronal marker
2.2-2.4	Glutamine/GABA	Neurotransmitters
3.0	Creatine	Energy metabolism
3.2	Choline	Cell membrane marker
3.5	*myo*-inositol	Glial cell marker, osmolyte hormone receptor mechanisms
1.2	Ethanol	Triplet
1.48	Alanine	Present in meningiomas
3.4&3.8	Glucose	Increased in diabetes
3.8	Mannitol	Rx for increased ICP

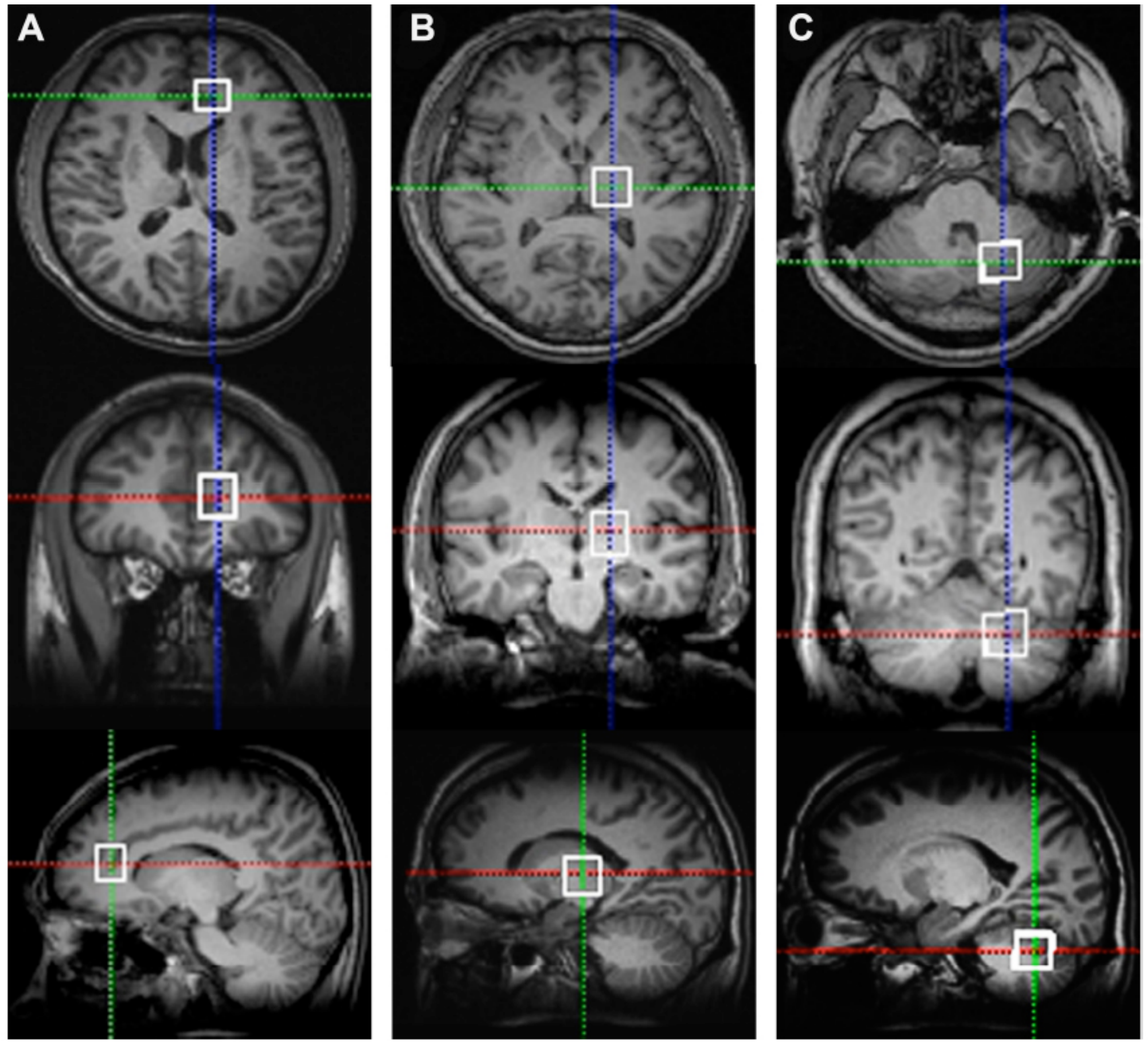
Magnetic Resonance Spectroscopy

Spectroscopy clinically used in brain tumors and metabolic disorders



Magnetic Resonance Spectroscopy

Spectroscopy used in in research



A case-control proton magnetic resonance spectroscopy study confirms cerebellar dysfunction in benign adult familial myoclonic epilepsy

Table 2 ^{1}H-MRS data in BAFME patients and healthy controls

^{1}H-MRS ratios of VOIs	^{1}H-MRS ratios (Mean ± SD)		Mann–Whitney *U*-test *P*-value
	Patients (n=12)	Controls (n=12)	
Frontal cortex			
NAA/Cr	1.421±0.195	1.400±0.246	1.000
NAA/Cho	1.215±0.139	1.267±0.249	0.435
Cho/Cr	1.175±0.171	1.115±0.163	0.817
NAA/(Cr+Cho)	0.642±0.074	0.658±0.114	0.582
Thalamus			
NAA/Cr	1.821±0.263	1.821±0.283	0.862
NAA/Cho	1.911±0.180	1.909±0.396	0.624
Cho/Cr	0.954±0.127	0.988±0.219	0.340
NAA/(Cr+Cho)	0.933±0.097	0.910±0.188	0.977
Cerebellum			
NAA/Cr	1.073±0.138	1.105±0.153	0.386
NAA/Cho	1.165±0.123	1.259±0.198	0.026*
Cho/Cr	0.925±0.109	0.885±0.105	0.083
NAA/(Cr+Cho)	0.559±0.061	0.640±0.121	0.094

Note: * $P<0.05$ versus controls.
Abbreviations: BAFME, benign adult familial myoclonic epilepsy; ^{1}H-MRS, proton magnetic resonance spectroscopy; Cho, choline; Cr, creatine; NAA, N-acetylaspartate; SD, standard deviation; VOIs, volumes of interest.

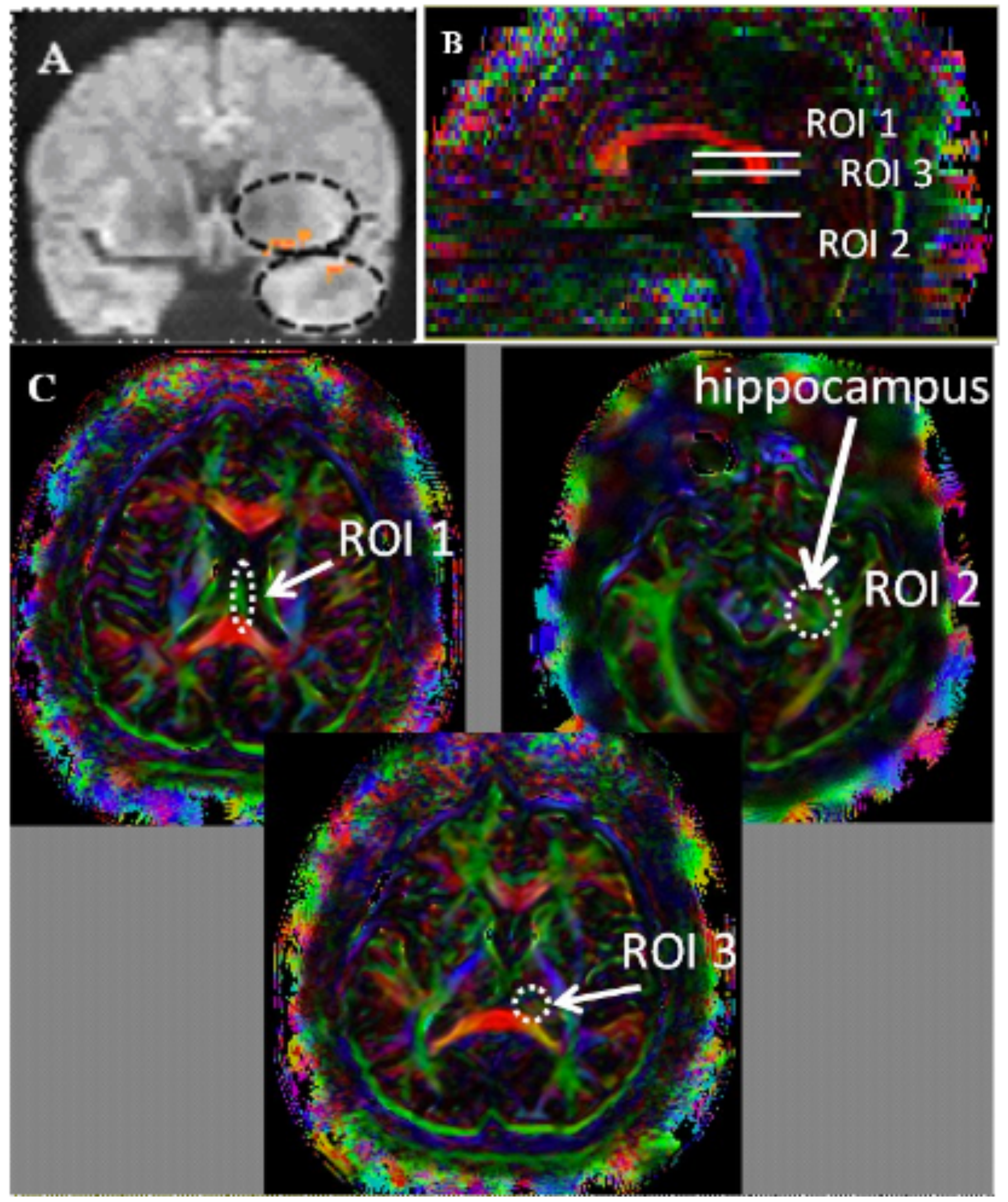
Magnetic Resonance Spectroscopy

Spectroscopy used in in research

- Comparison between patient and control groups
- Correlation with structural volume or growth of tumor
- Correlation with white matter integrity
- Correlation with functional state

Correlation between Diffusion Tensor Tractography and proton MR spectroscopy in normal controls*

T. Sato, N. Maruyama, T. Hoshida, K. Minato



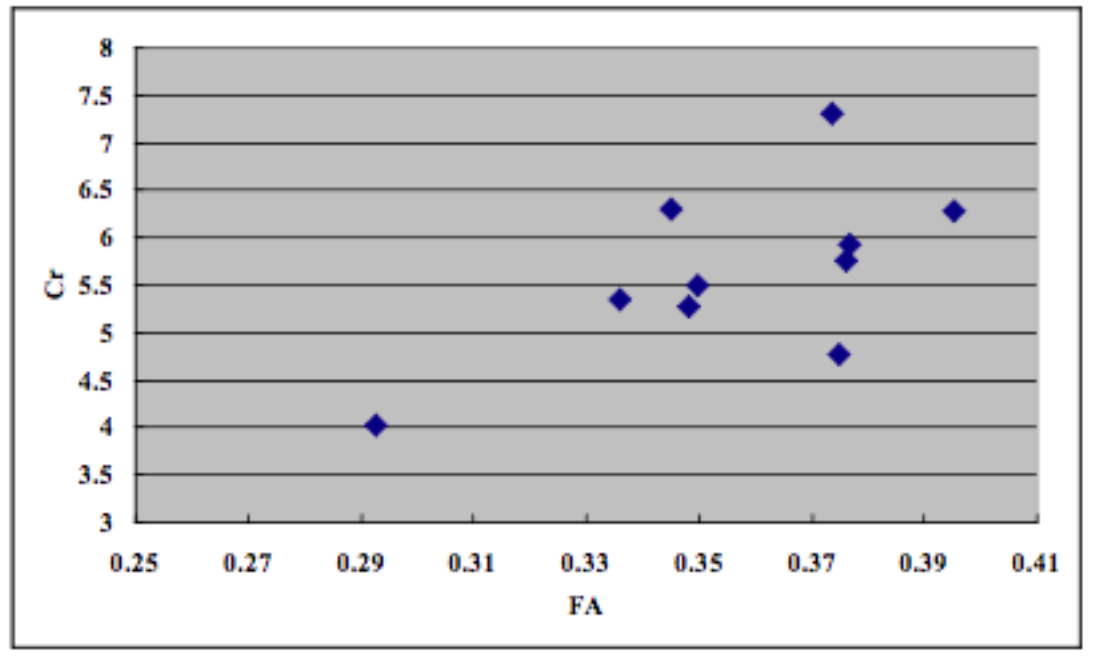


Figure 3. Correlations between FA in the right uncinate fasciculus and Cr in the right temporal stem.