

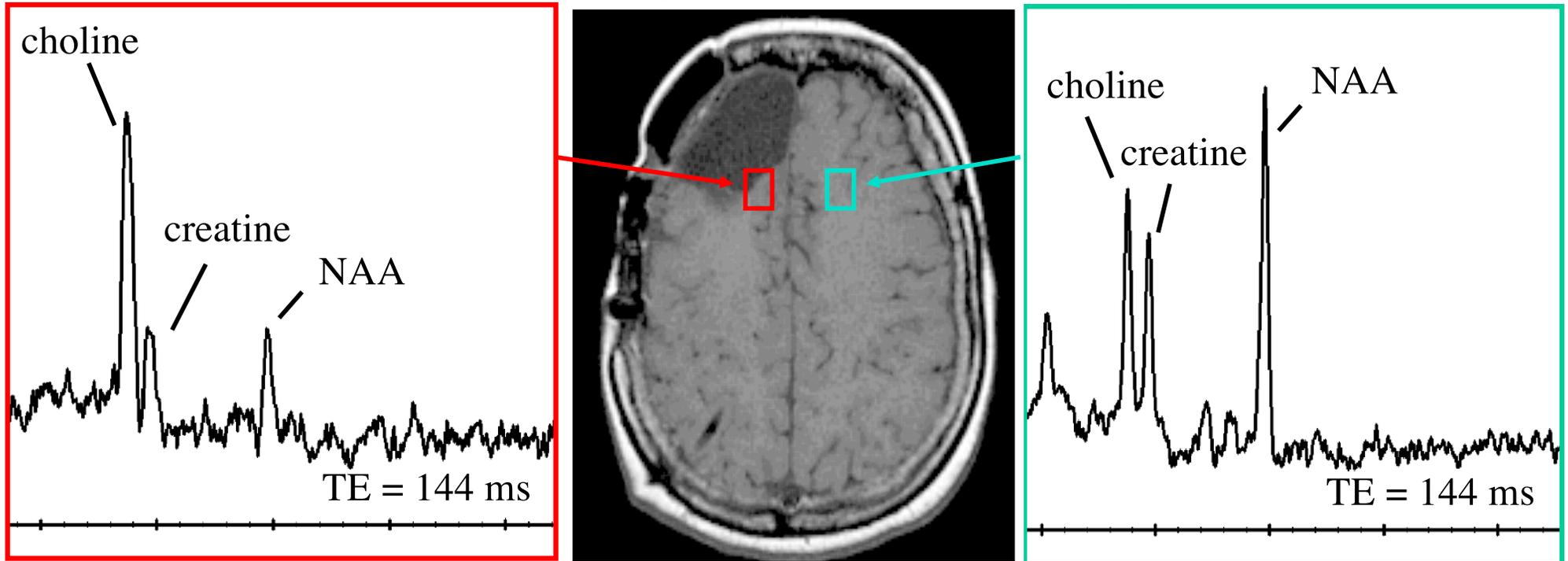
# Lecture #15

## $^1\text{H}$ MRS: Single-voxel and Spectroscopic Imaging Studies

- Single-voxel  $^1\text{H}$  MRS
  - Technical considerations
  - Applications and Research
- $^1\text{H}$  MRSI
  - Technical considerations
  - Applications and Research
- Readings and Handouts
  - de Graaf, Chapters 6, 7, and 9.

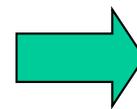
# MRI and MRS

## Anatomy + Biochemistry



Technical requirements

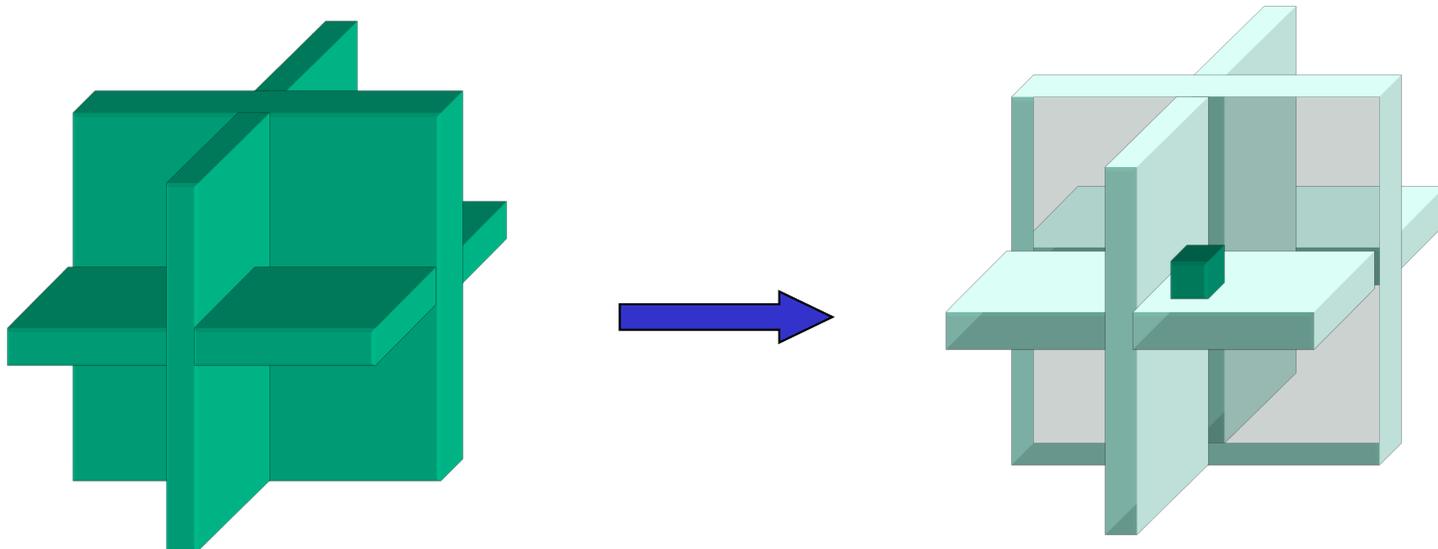
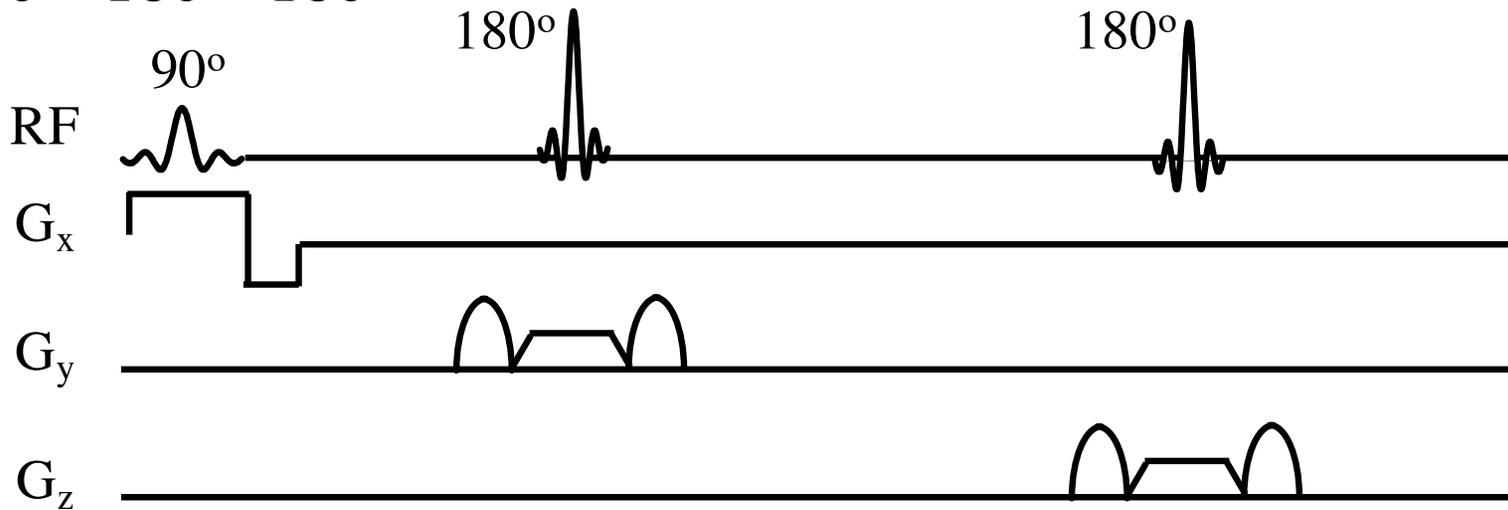
- Spatial localization
- Water suppression
- Lipid suppression
- $B_0$  homogeneity



Spectral quantitation

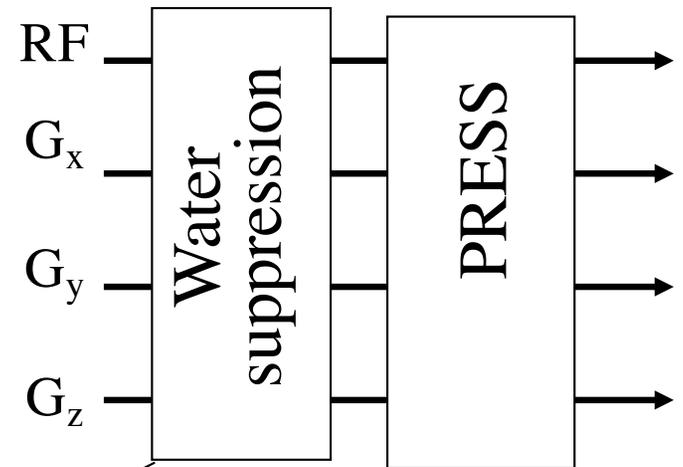
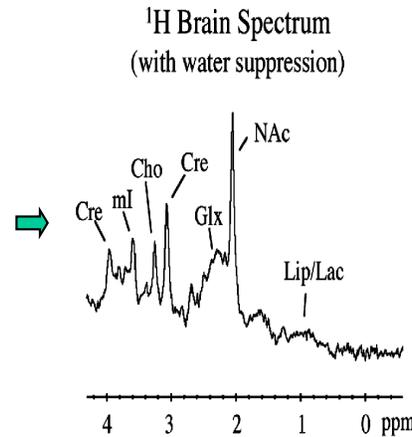
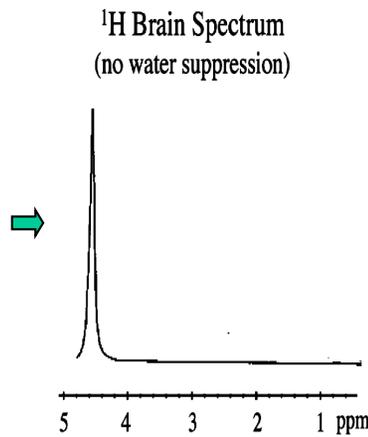
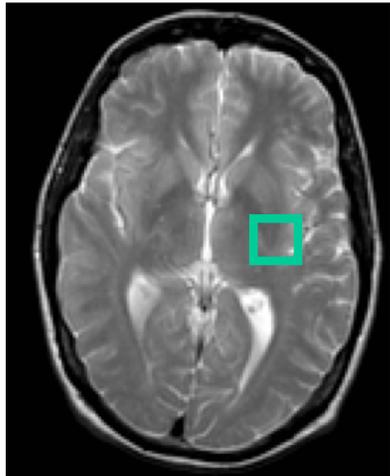
# Position Resolved Spectroscopy (PRESS)

- $90^\circ$ -  $180^\circ$ -  $180^\circ$

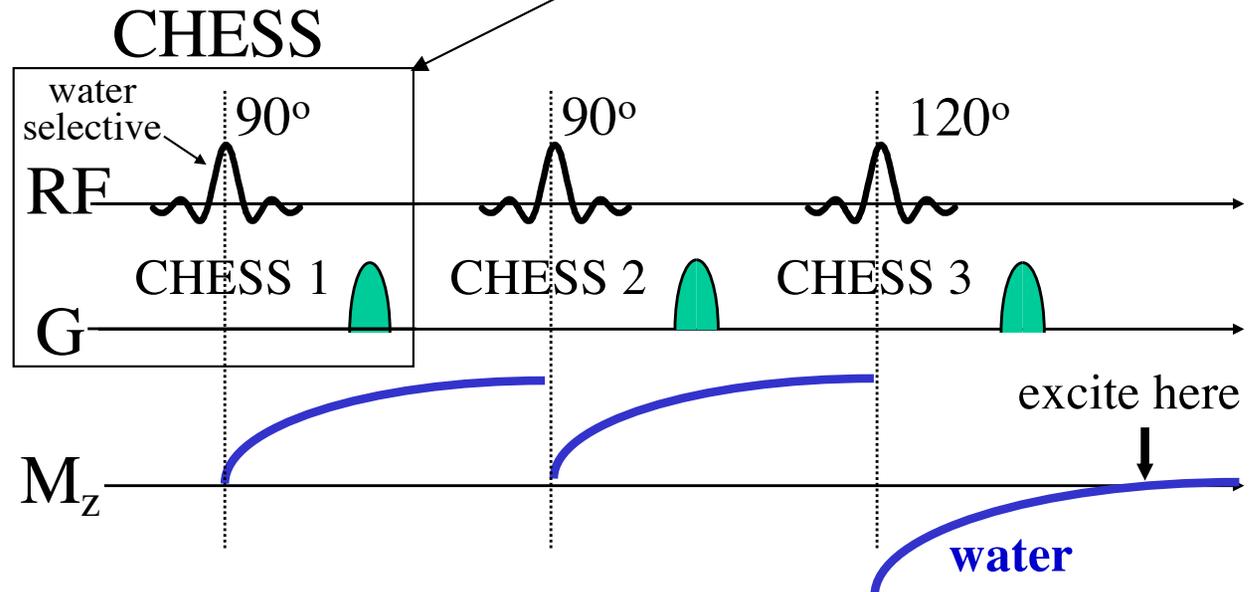


- STEAM: alternative sequence using three  $90^\circ$  to localize via a stimulated echo (1/2 the signal but shorter minimum TE)

# Water Suppression



Flip angle on last  
CHESS pulse  
adjusted to minimize  
water signal:  
typically 110°-120°

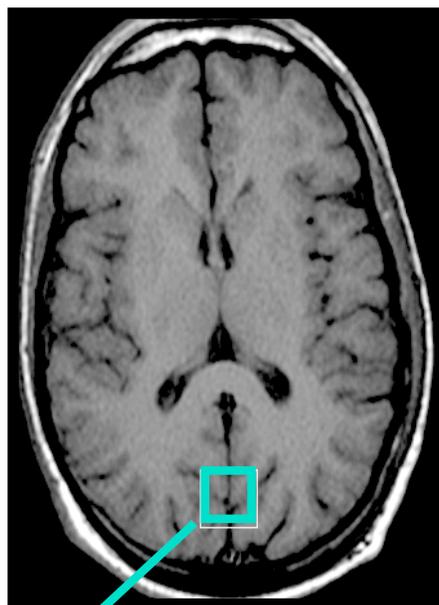
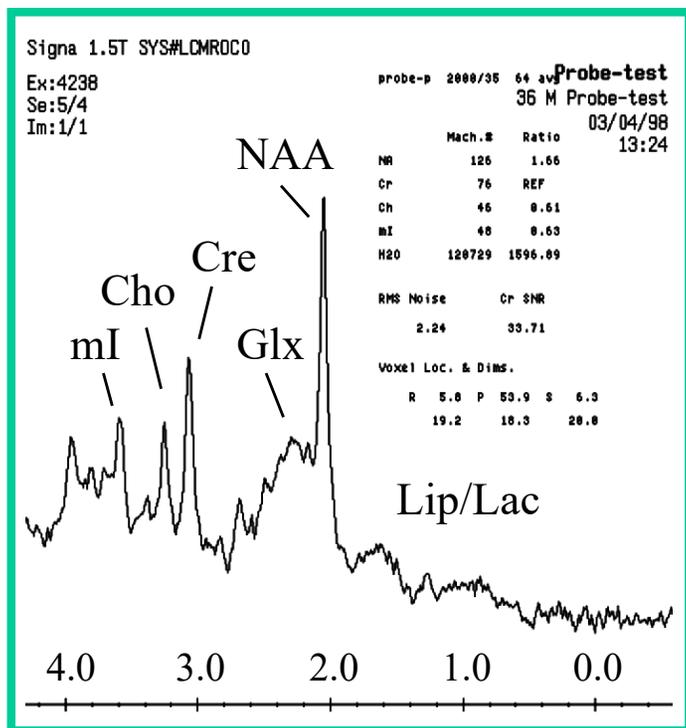


# Single Voxel $^1\text{H}$ MRS

Excite rectangular volume of tissue (PRESS or STEAM)

Widely available, fully automated. Typical Protocol:

- Graphically prescribe ROI
- Shimming (often automated)
- Data collection: 2-5 min, 3-8 cc voxels

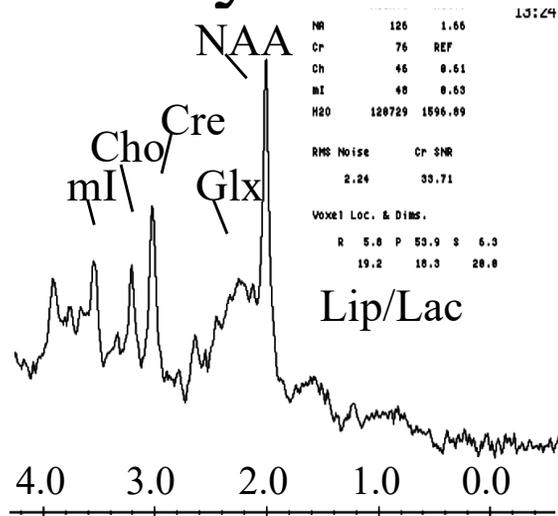


TR/TE=2000/35 ms  
64 averages  
PRESS

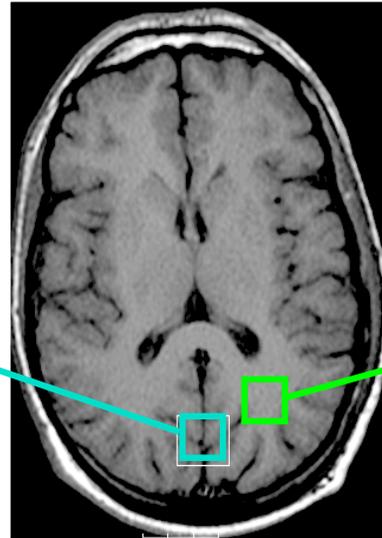
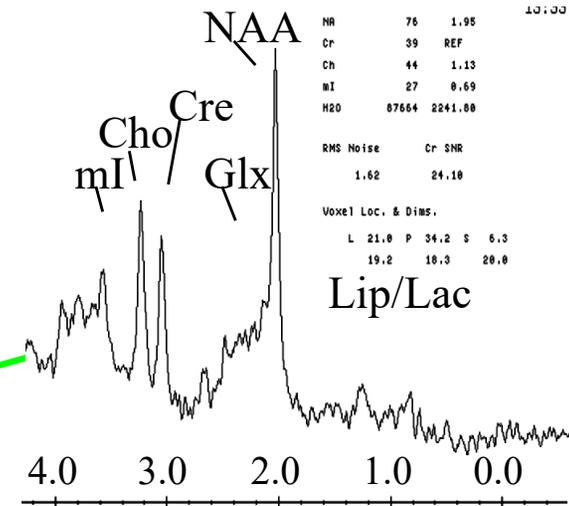
- Applications:
  - focal ROIs
  - diffuse diseases
- Reliability high, but still some technical challenges:
  - homogeneity
  - SNR

# Tissue Composition

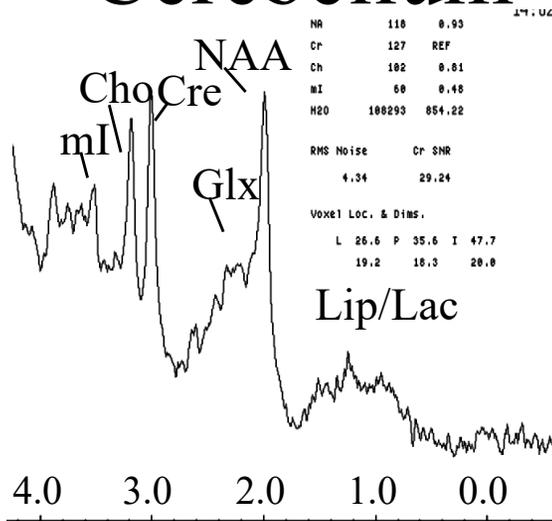
## Gray Matter



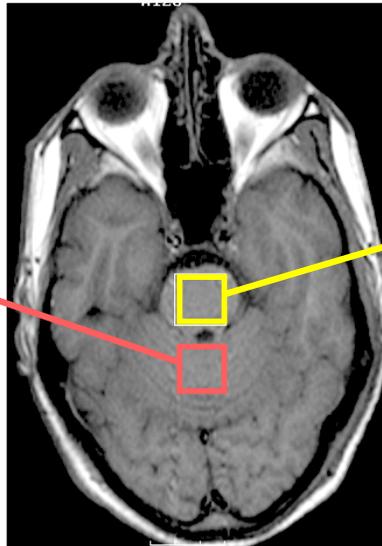
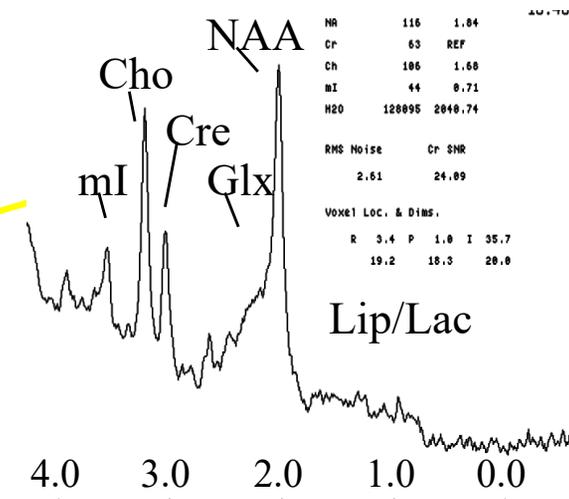
## White Matter



## Cerebellum

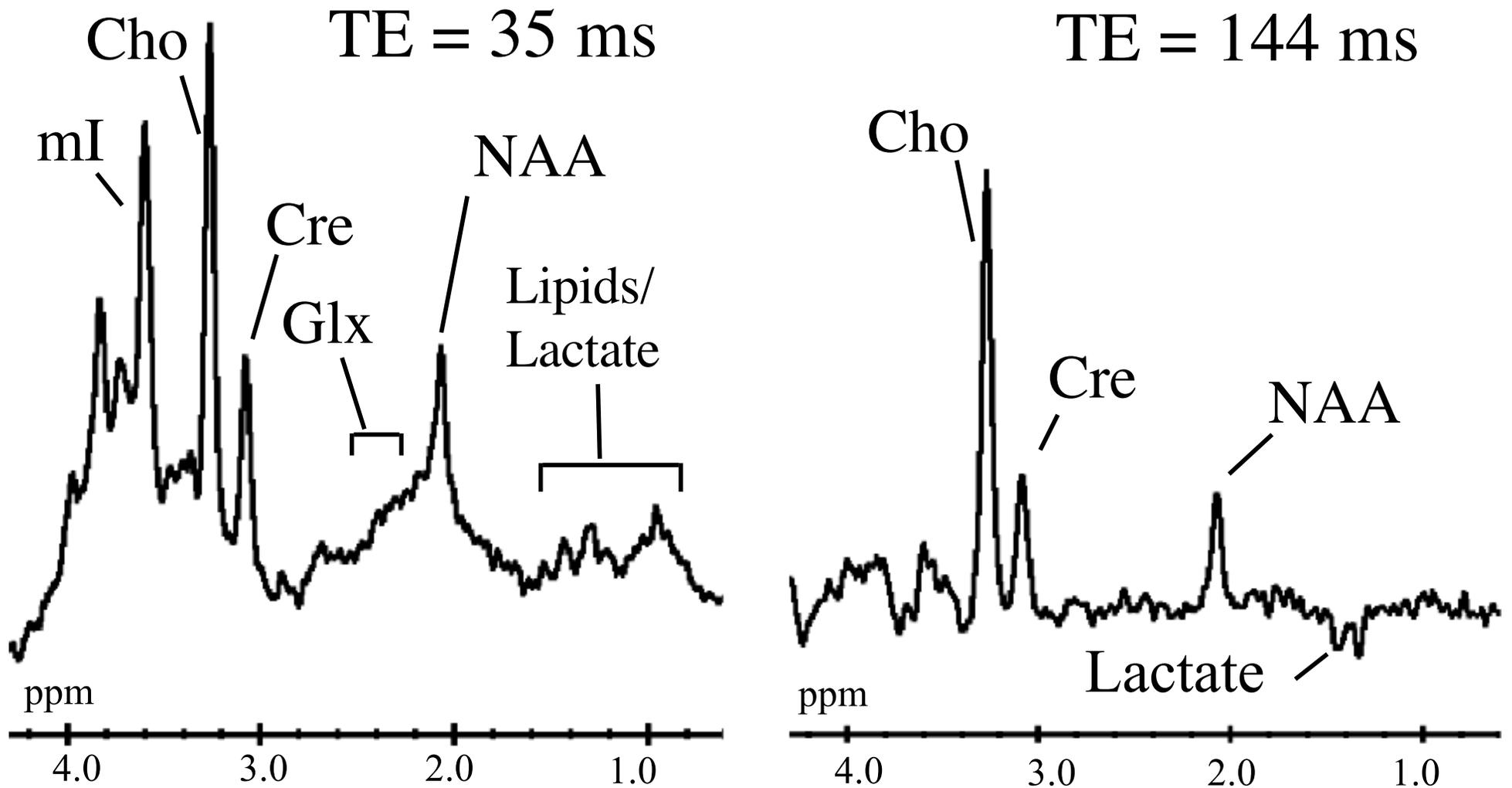


## Pons

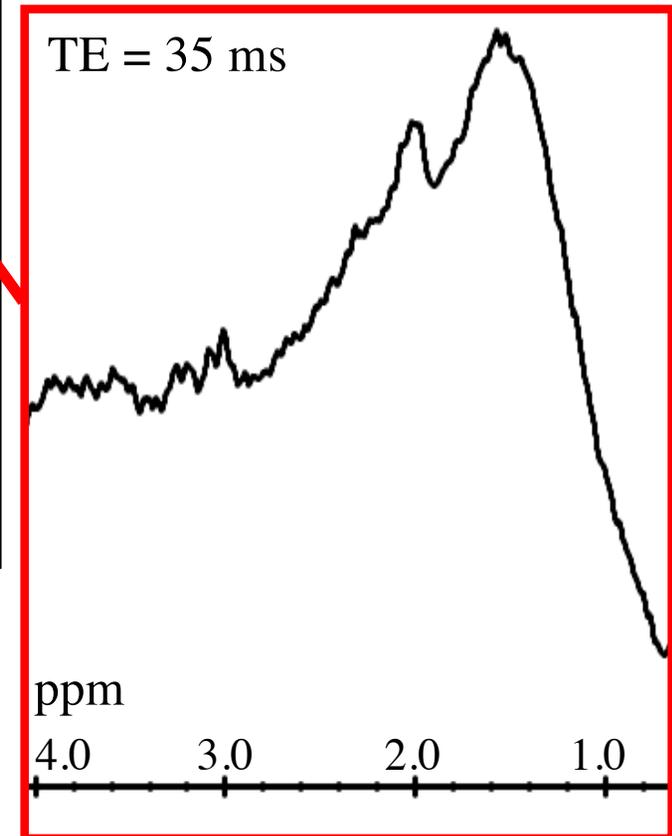
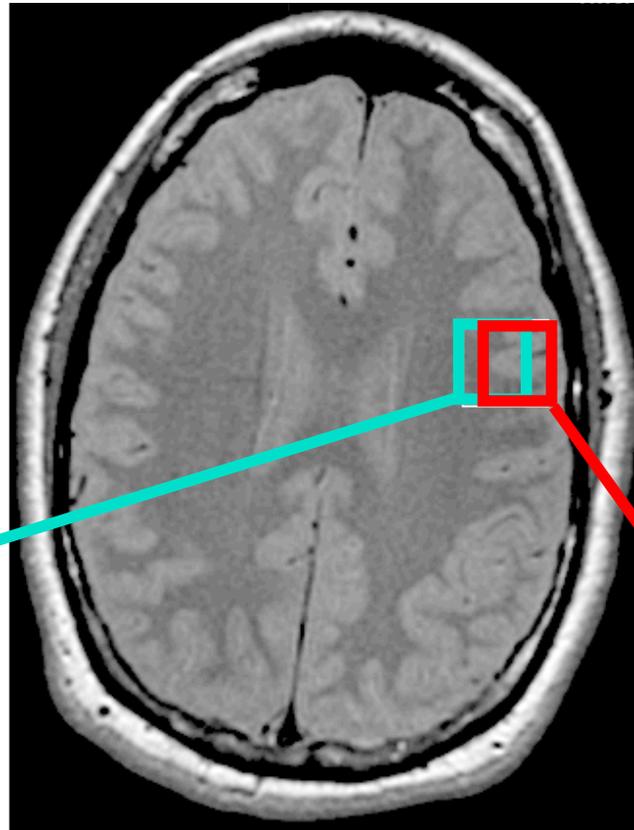
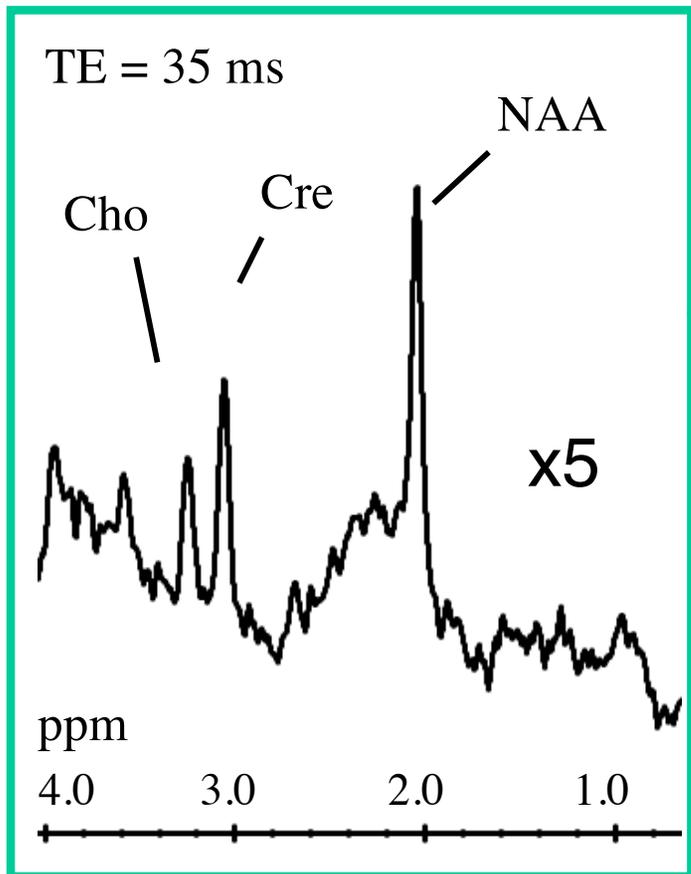


# Echo Time Considerations

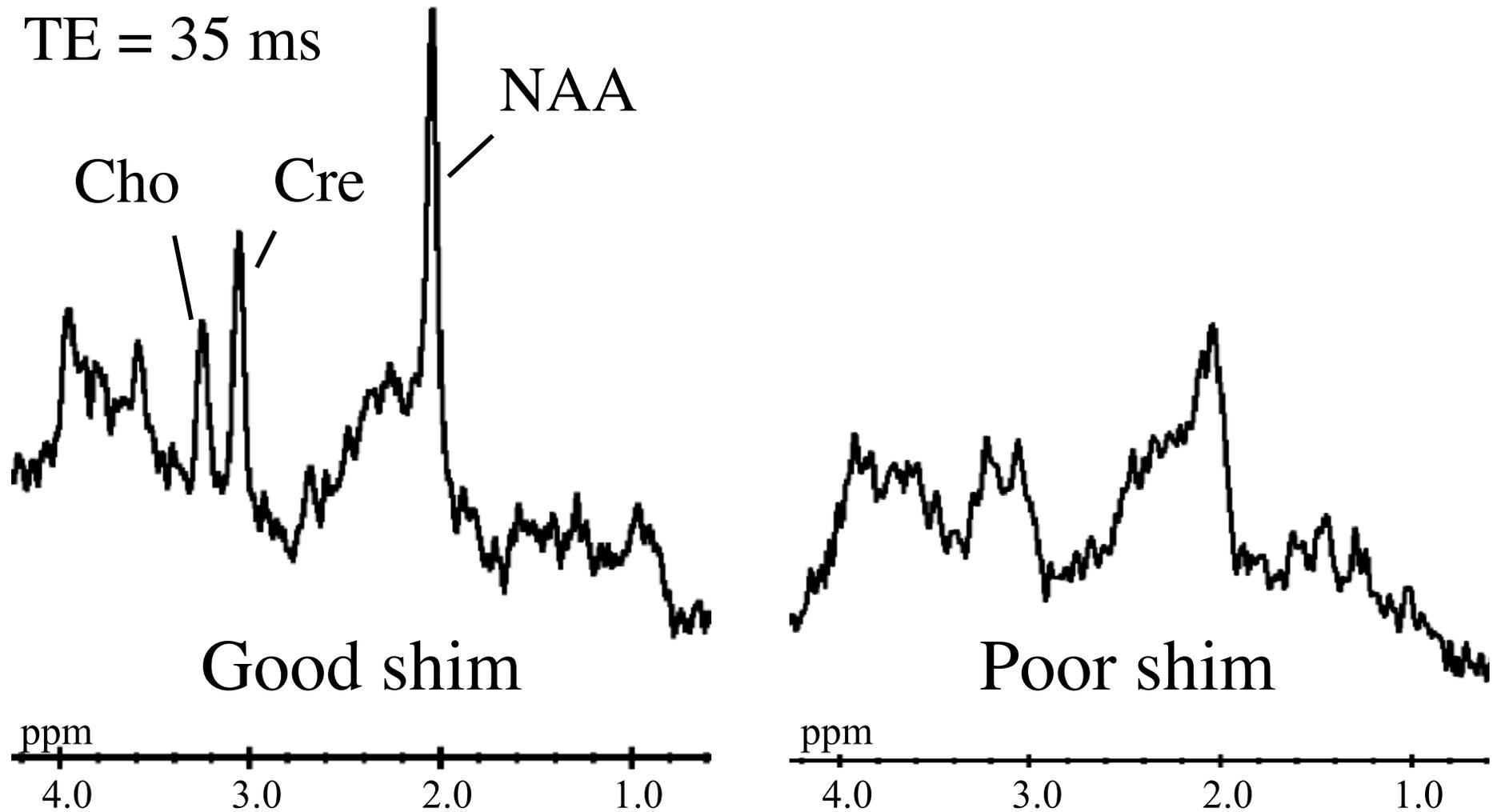
## 1 month old infant



# Difficulties: Lipid Contamination

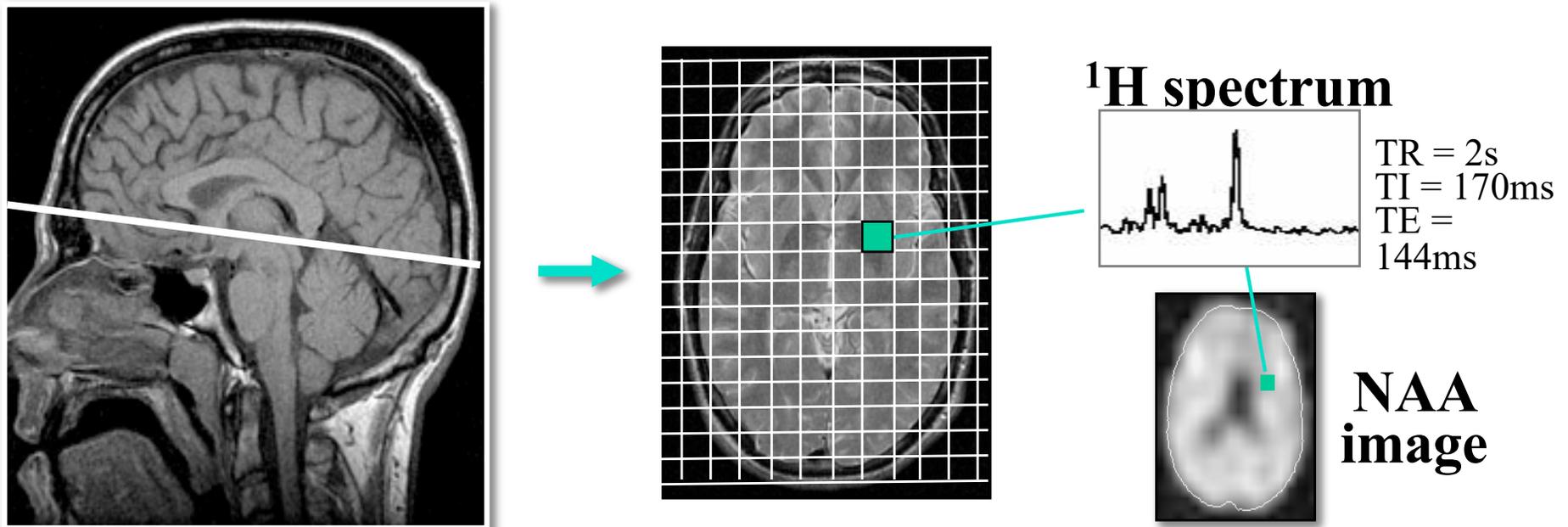


# Difficulties: $B_0$ Inhomogeneity

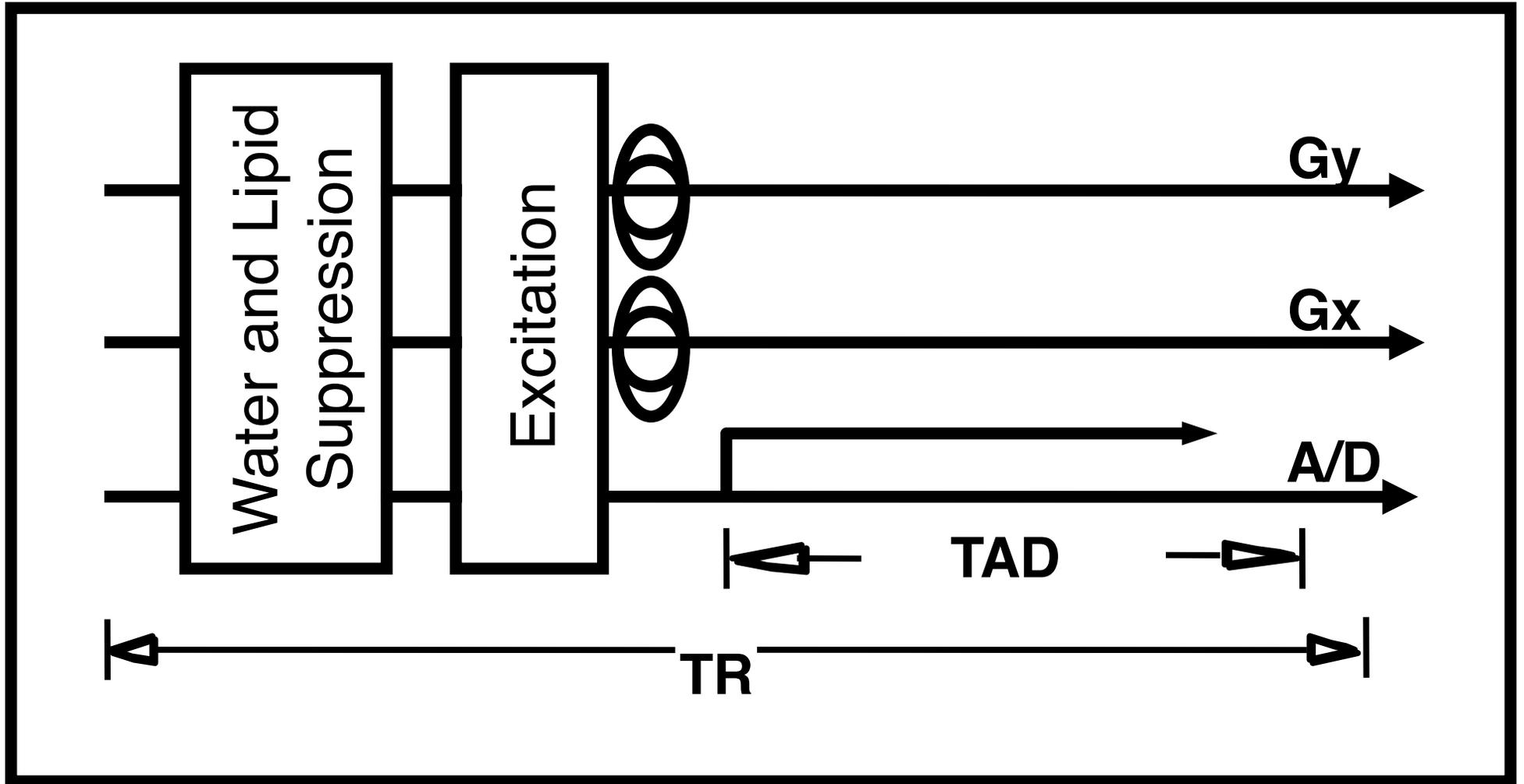


# Spectroscopic Imaging

- Excite a large volume of tissue, then use gradients for spatial encoding
- Typically 5-15 min acq, 1-3 cc voxels

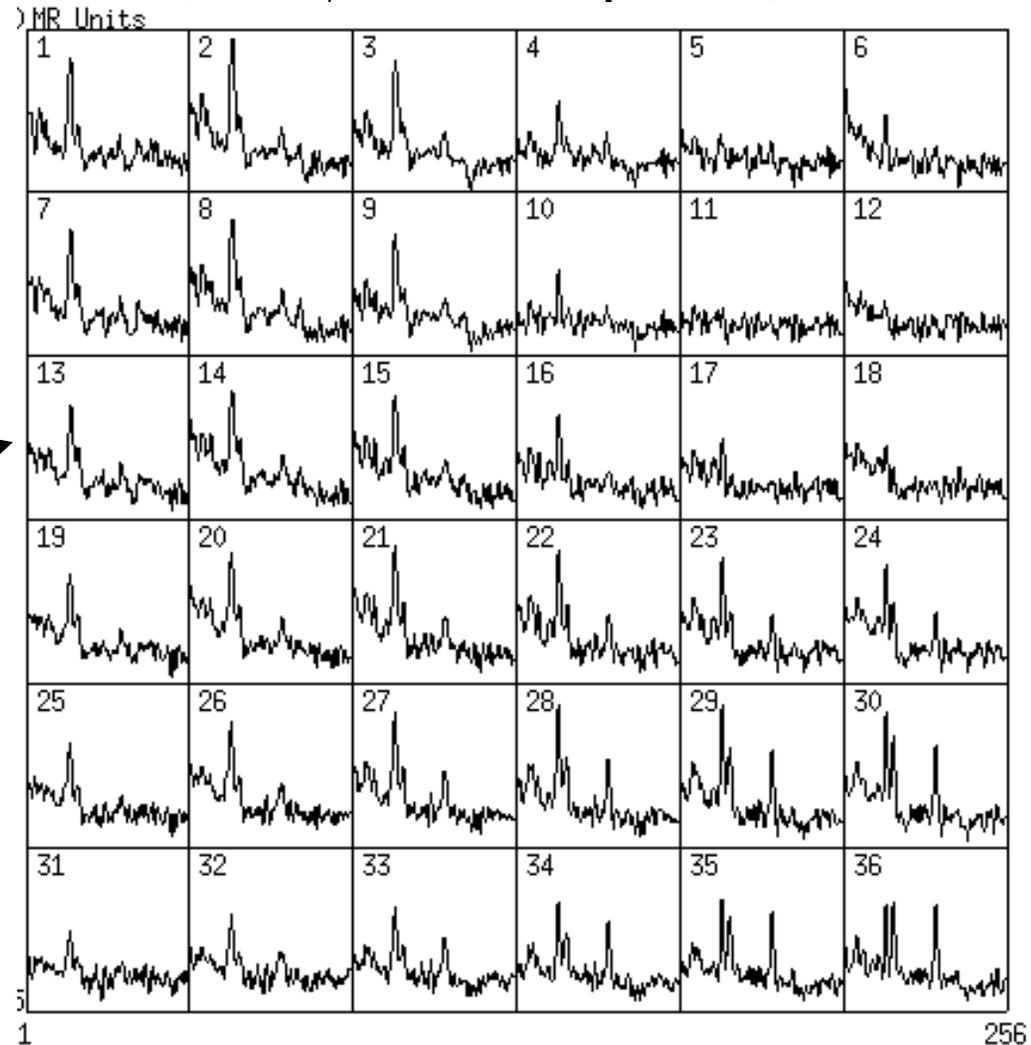
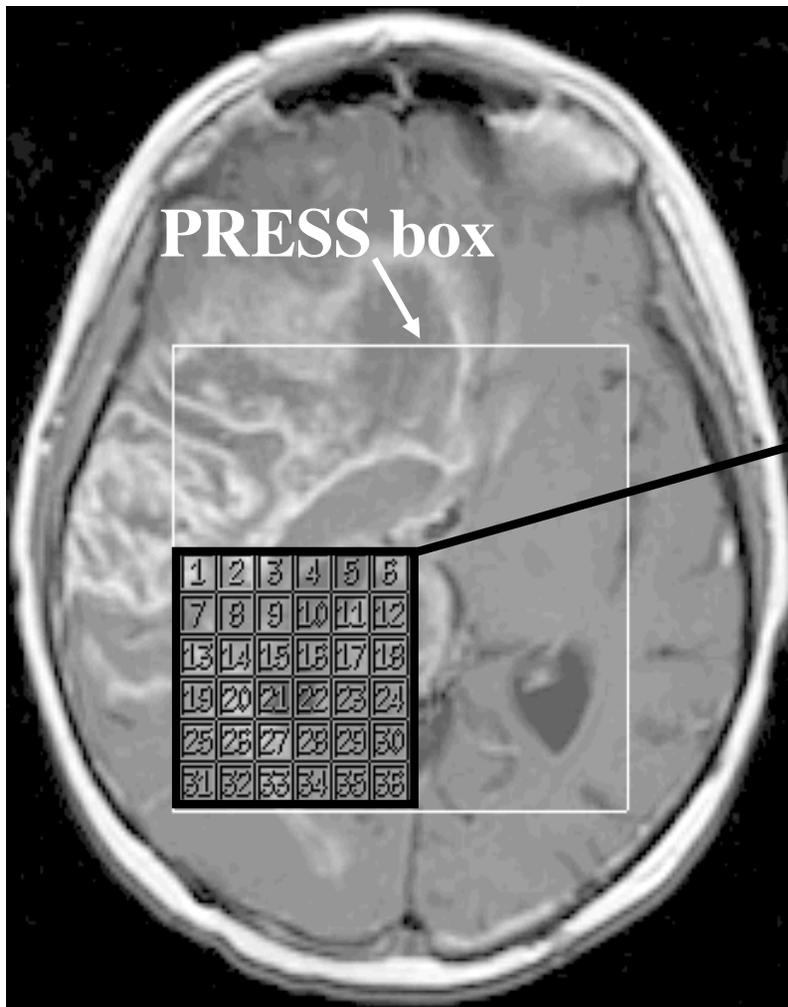


# Traditional $^1\text{H}$ CSI



# PRESS MRSI Example

Typical clinical parameters: TR/TE=1000/144 ms, 16x16 matrix, 1.5 cm slice, 24 cm FOV, 3.4 cc voxels, 4 min acquisition.



Pros: robust, automated

Cons: limited coverage

FOV/resolution/imaging time not independent e.g. 16x16x16 voxels requires 2.3 hrs (TR = 2s)<sup>12</sup>

# Research Topics

- Technical developments:
  - Volumetric spectroscopic imaging
  - Robust measurement of additional metabolites such as mI, Glu, Gln, GABA, etc
  - Spectral quantification
  - $^1\text{H}$  MRS in non-brain tissues (primary problems due to motion and lipids)
- Biological/medical questions: better understanding of the roles of these metabolites under normal and pathological conditions.

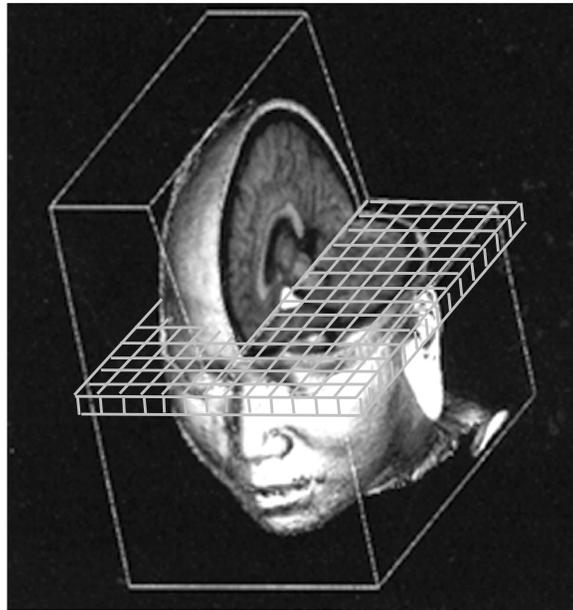
# Motivation for MRSI

SNR considerations should dominate, and SNR is independent of the number of voxels.

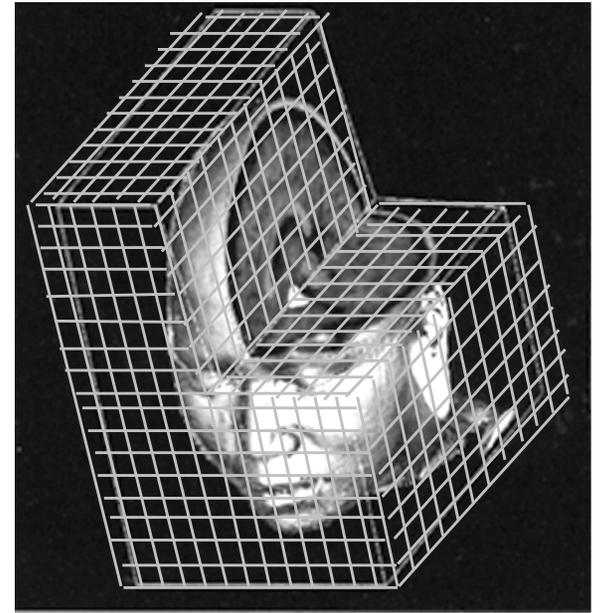
$$\text{SNR} \propto V\sqrt{T_{AD}}$$



single voxel



single slice



volumetric

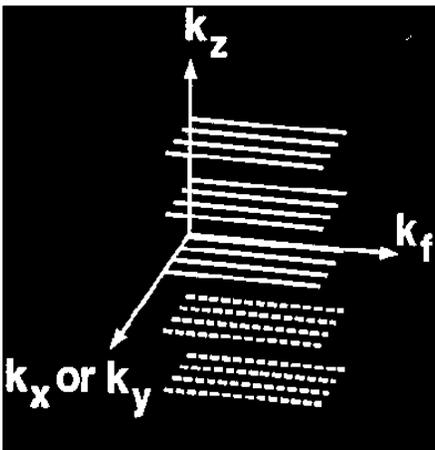


# k-space view of MRSI

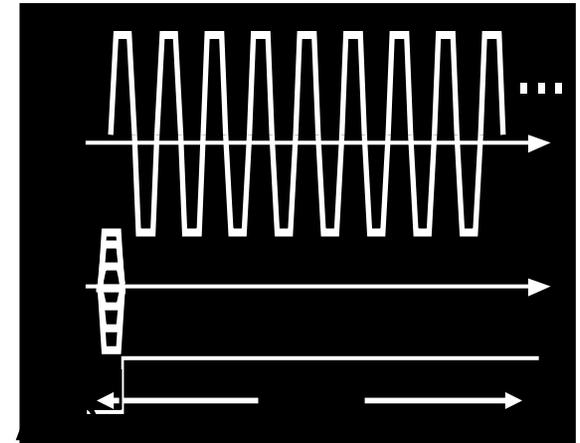
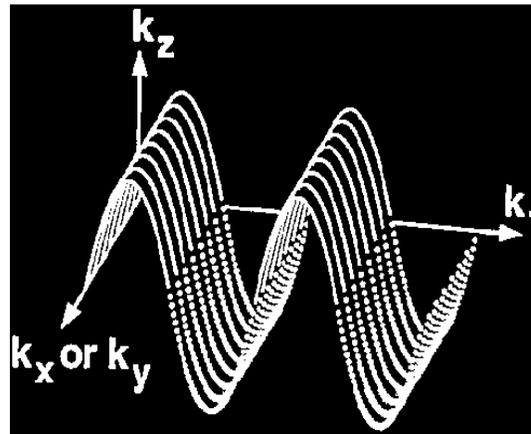
- Gradients allow arbitrary movement along  $k_x$ ,  $k_y$ , and  $k_z$  (subject to amplitude and slew rate constraints)
- Must move linearly along  $k_f = t$

3DFT

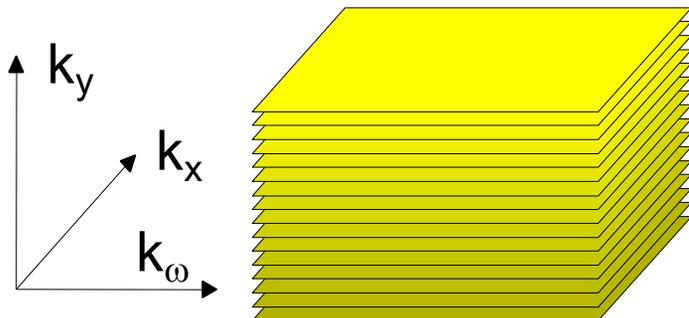
MRSI with an oscillating readout gradient



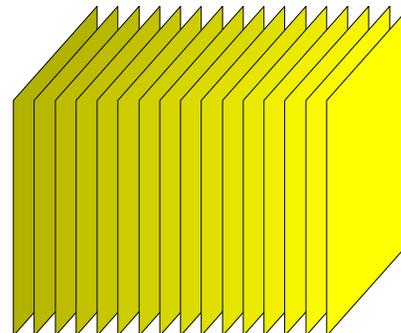
VS



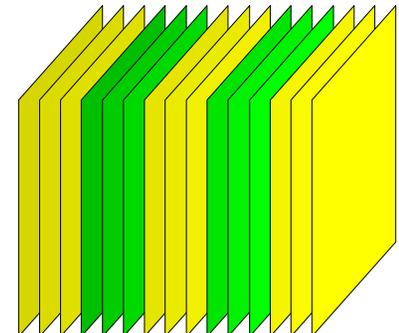
Echo Planar CSI



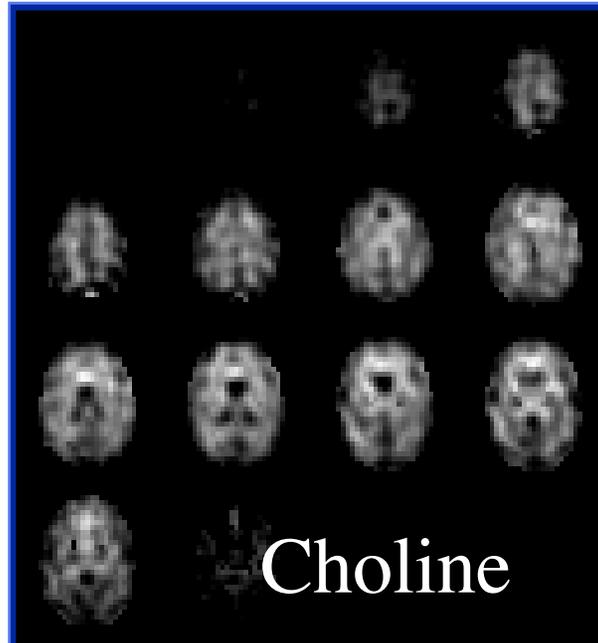
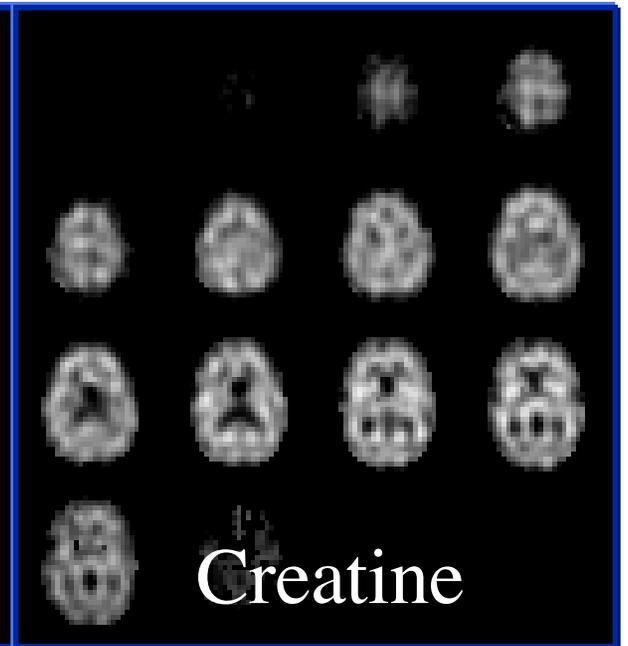
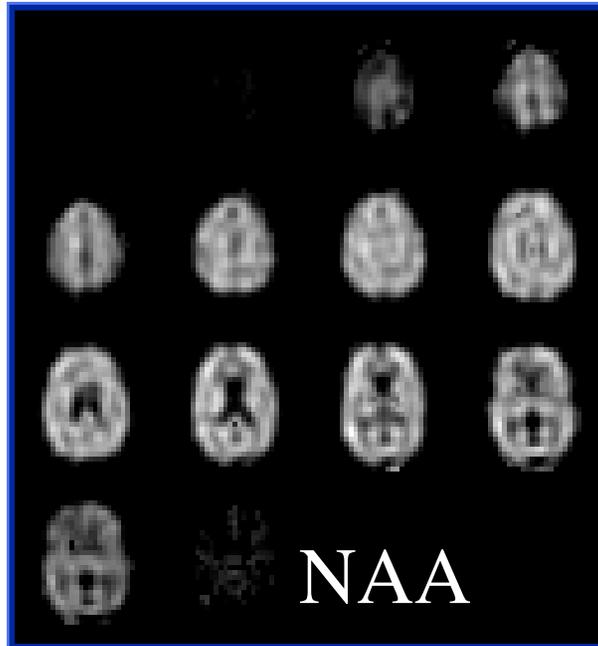
Spectroscopic U-FLARE  
(Dreher, MRM 44:668-72 [2000])



Spectroscopic GRASE  
(Dreher, MRI 17:611-21 [1999])



# Volumetric Echo-Planar MRSI



16 slices

1.1 cc voxels

TR/TI/TE = 2000/170/144 ms

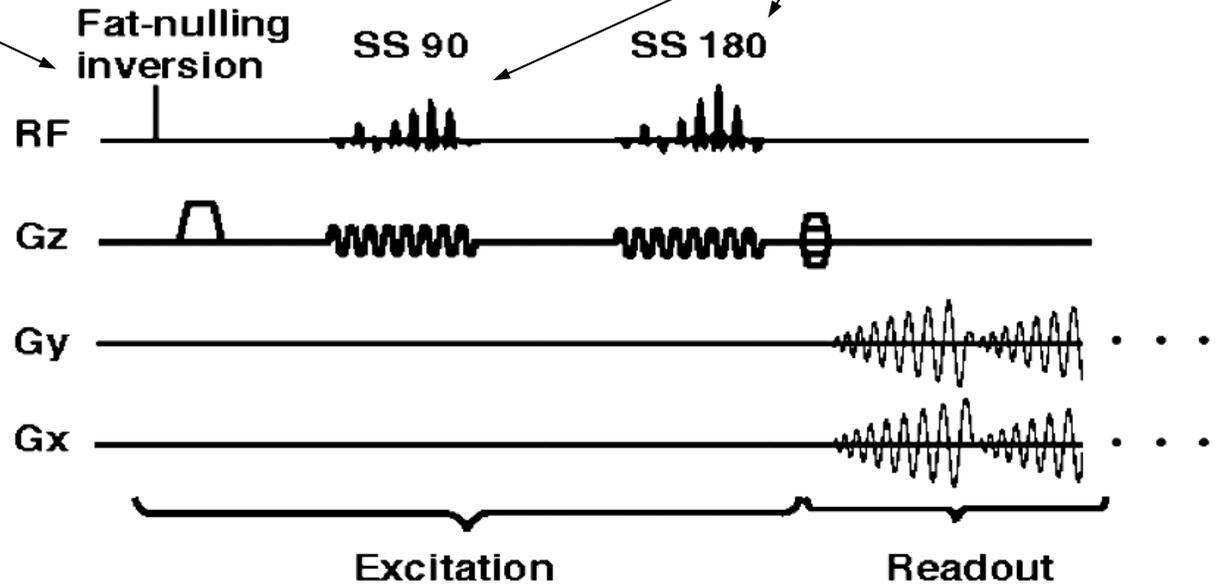
17 min acquisition

Gridding reconstruction

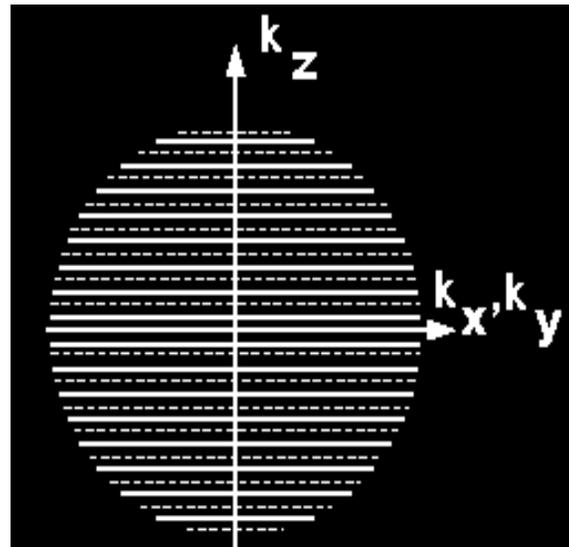
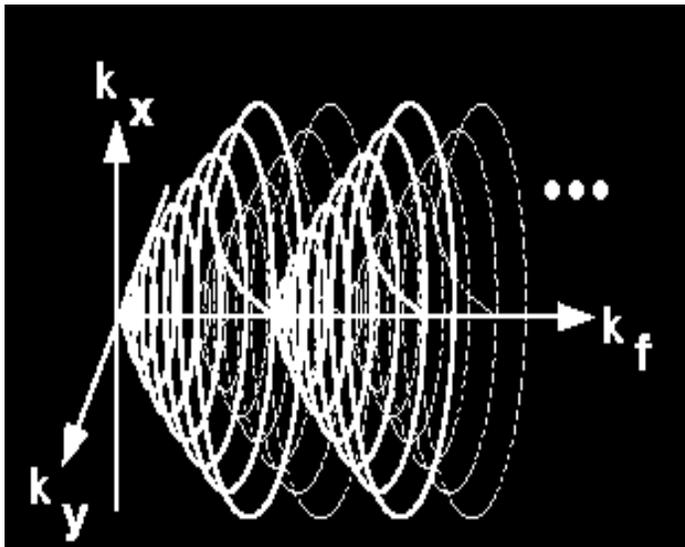
# Spiral MRSI

lipid suppression

water suppression



- Oscillate along two gradient axes



## Typical Protocol

- 16 slices, 18 x 18 pixels each
- FOV = 24 x 24 x 10 cm
- TR/TI/TE = 2000/170/144 ms
- $FOV_f = 400$  Hz,  $Res_f = 5$  Hz
- 46 TRs to cover 4D k-space
- 17 min acq

spherical coverage in  $k_x, k_y, k_z$

# Fast MRSI

Given that SNR constraints require significant averaging, why bother scanning rapidly (e.g. spiral CSI)?

Answer: increased flexibility!

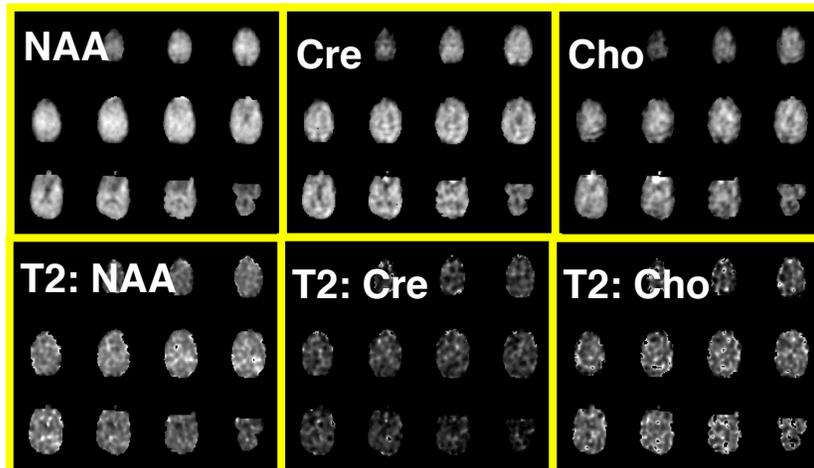
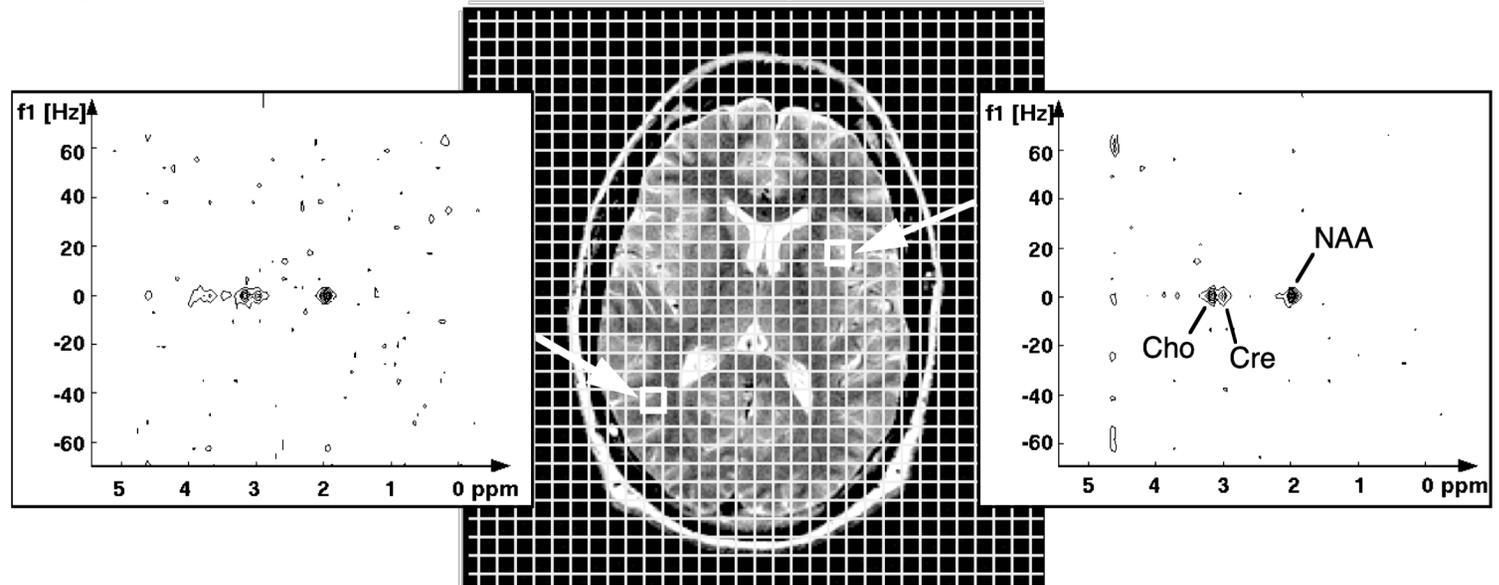
## Spiral MRSI

- Allows “independent” selection of imaging time, voxel size, and FOV
- Allows “smart” averaging
  - Interleaving to increase FOV and/or spectral bandwidth
  - RF phase cycling
- Other applications
  - Water referencing
  - Spatially-resolved 2D NMR
  - $k$ -space filtering

# Spatially Resolved 2-D Spectroscopy

- Spiral gradients allow collection of 2 spectral and up to 3 spatial axes
- Suitable for variety of 2D MRS methods: e.g J-resolved, COSY.

Example:  
J-Resolved  
Spiral MRSI  
(1.5 T)

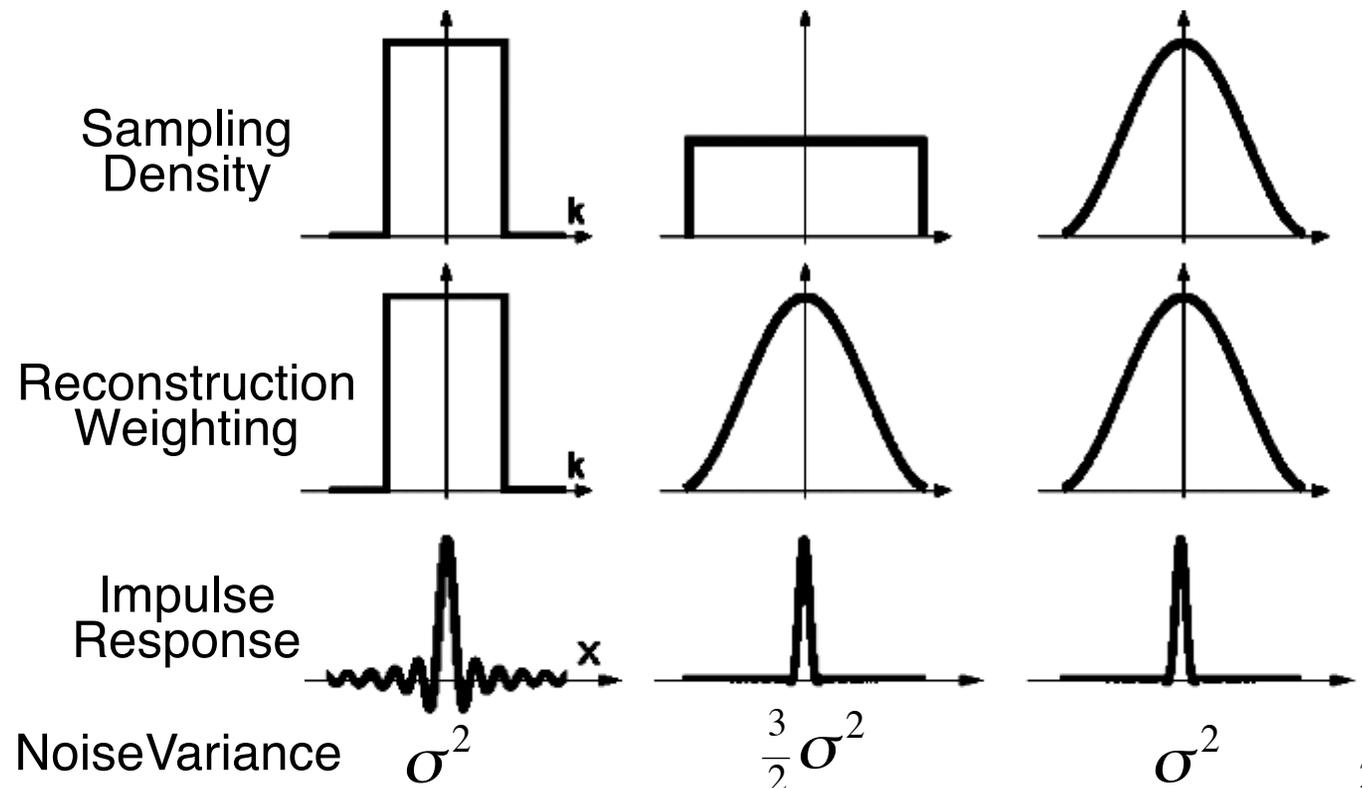


Spiral readout  
 $18 \times 18 \times 128 \times 256$   
( $k_x, k_y, t_1, t_2$ ) data set  
1 cc voxels  
17 min acquisition

# Variable-Density Sampling

- Problem: MRSI suffers from significant Gibbs ringing. Increased k-space coverage can reduce ringing, however post-acquisition windowing reduces SNR (see Problem Set 1).
- Solution: use a k-space sampling density proportional to desired window (Mareci 84, Parker 87, Star-Lack 95, Boada 97)

Examples: Fixed  
Voxel Size &  
Imaging Time

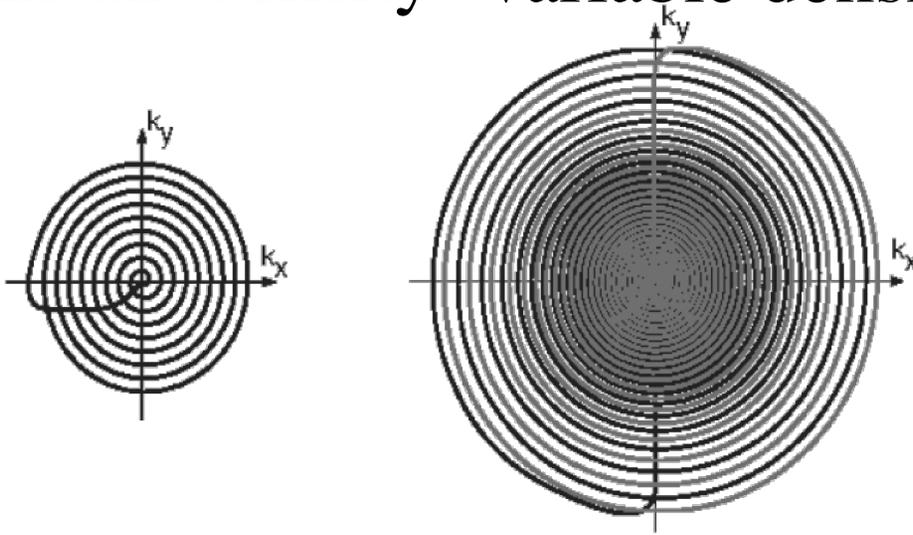


# Variable-Density Spiral MRI

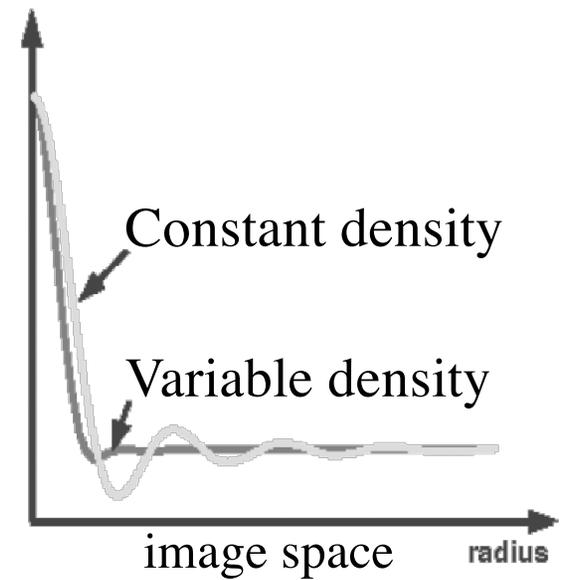
## k-space Coverage

## Impulse Response

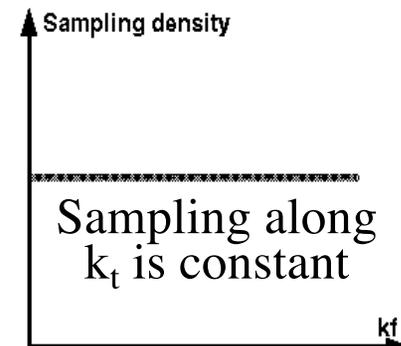
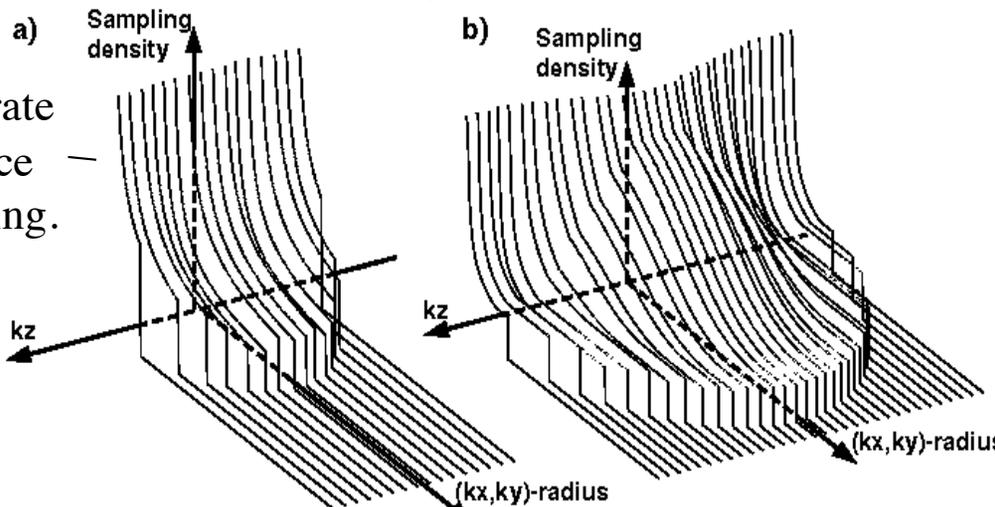
Constant density    Variable density



Fixed nominal voxel size and FOV

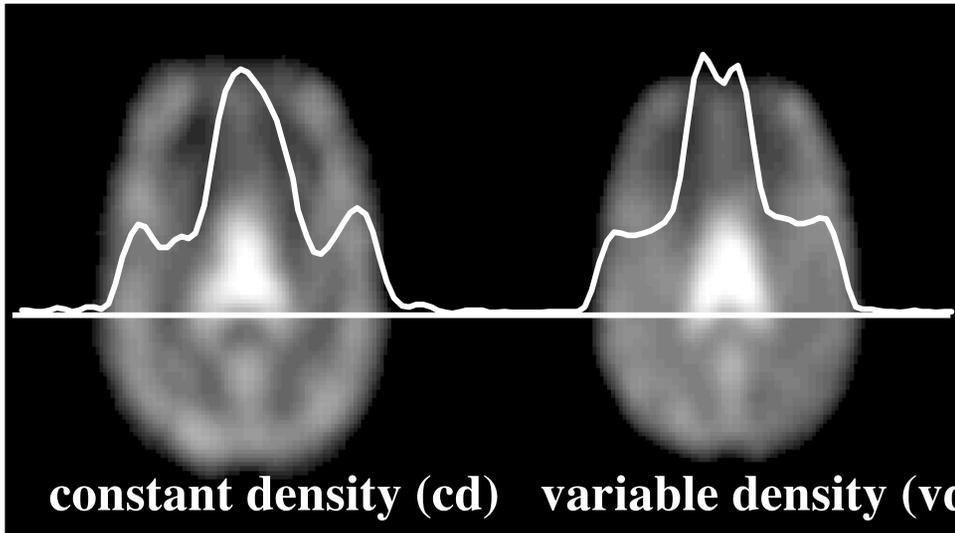


In practice, slew rate constraints produce additional weighting.

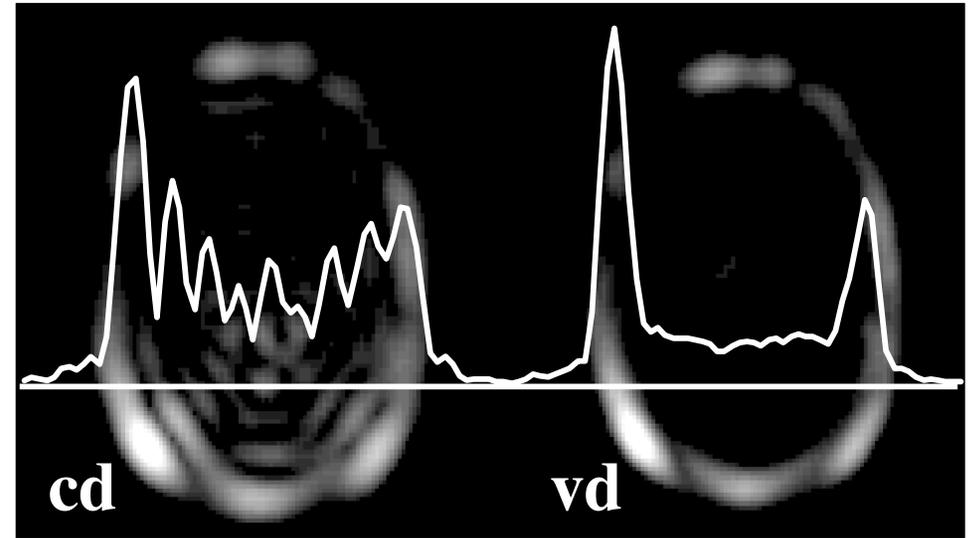


# Variable-Density Spiral MRSI

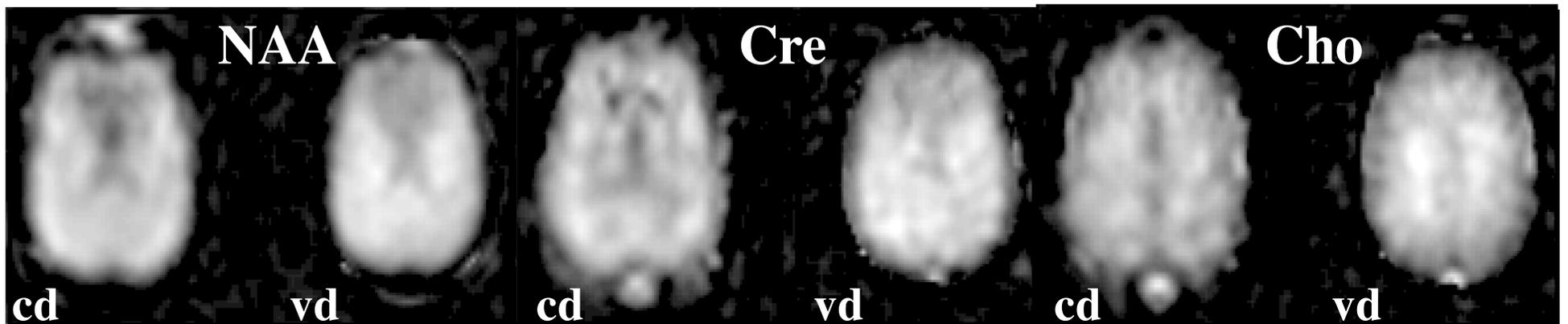
Water Reference



Lipids

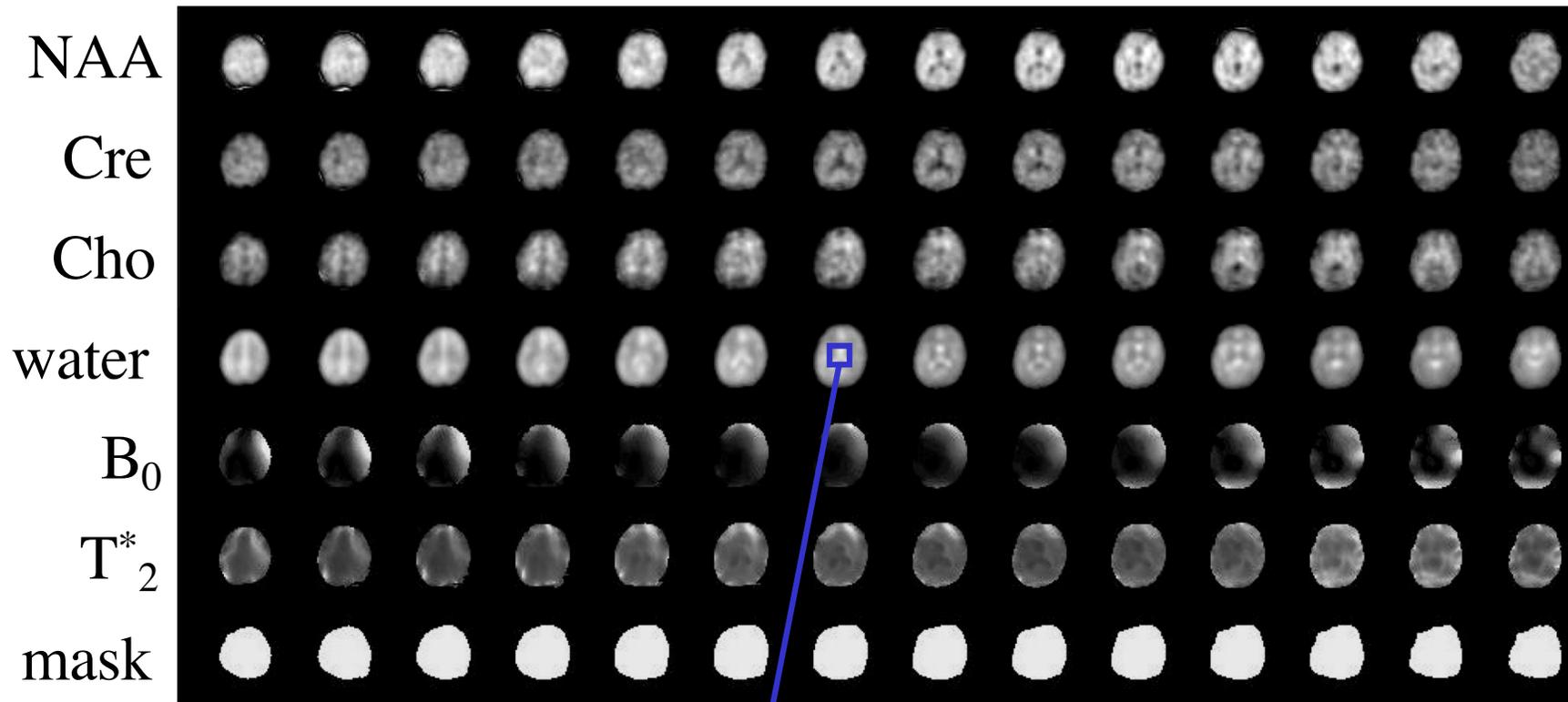


Metabolites

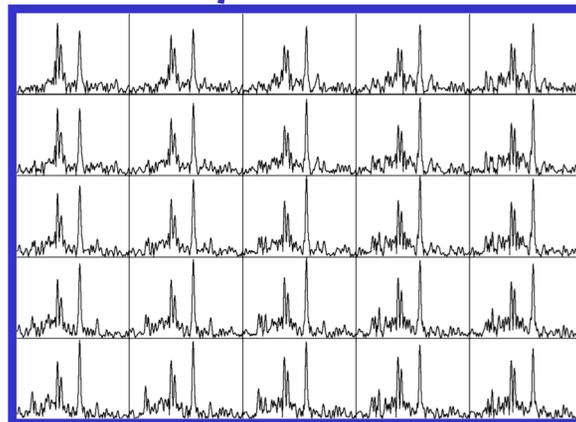


# $^1\text{H}$ volumetric vd-spiral MRSI

1.5 T, 7 yo male, TE=144ms, 1 cc voxels, 15 min acq.



Pro: lots of  
data!



Con: lots of  
data!  
(also poorer shim  
vs single voxel)

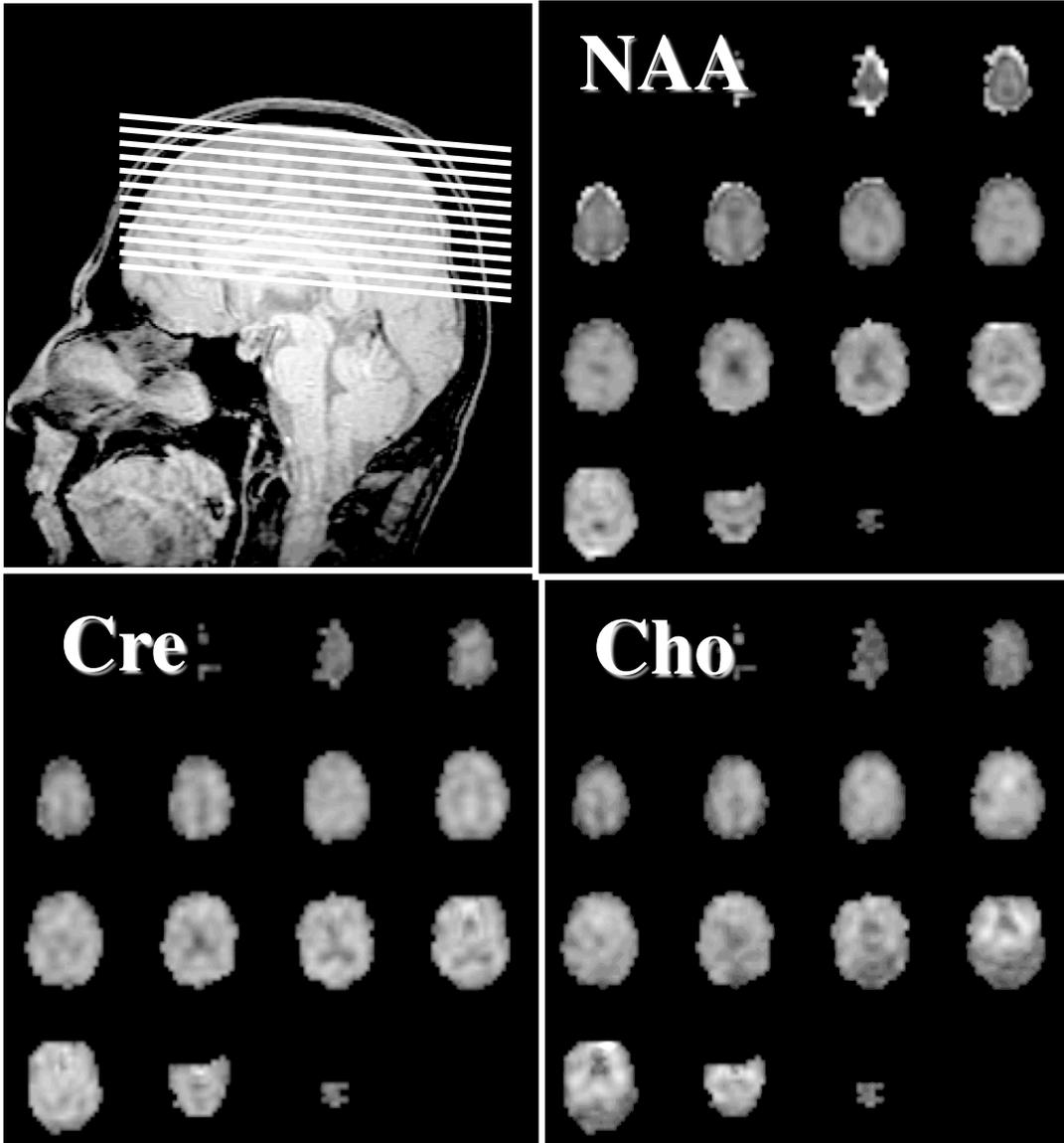
# Fast $^1\text{H}$ MRSI at 3T

Spiral MRSI

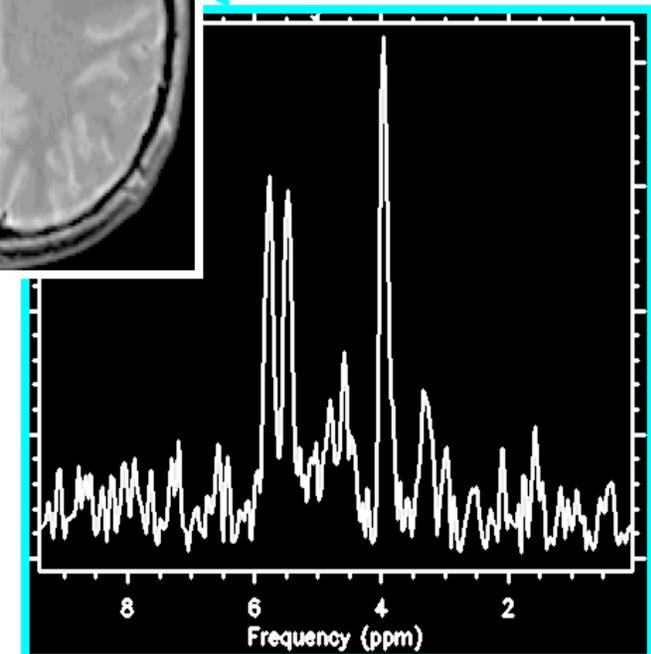
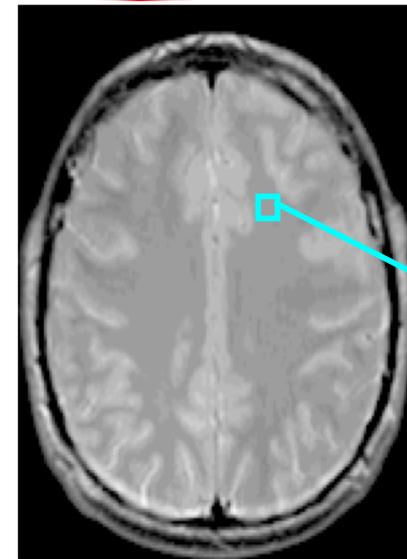
TR/TI/TE=2000/180/144 ms

1.2 cc voxels

3.6 min acquisition



Metabolite maps



Representative spectrum

# In Vivo MRI/MRS

- Three: most important factors for a successful in vivo MRSI exam:
  - Homogeneity, homogeneity, and homogeneity (SNR should probably be somewhere in this list)
- Hence, shimming is extremely important.
- MRI scanners typically compensated with passive and supercon shims to very high orders (e.g. 14th order zonal shims).
  - Typical homogeneity = 1ppm over 30 cm sphere.
- Magnets also equipped with linear gradients for shimming as well as higher order resistive shims such as  $z^2$ ,  $xy$ , etc

Question: If supercon shims already adjusted to maximize field uniformity, why do we need additional resistive shims?

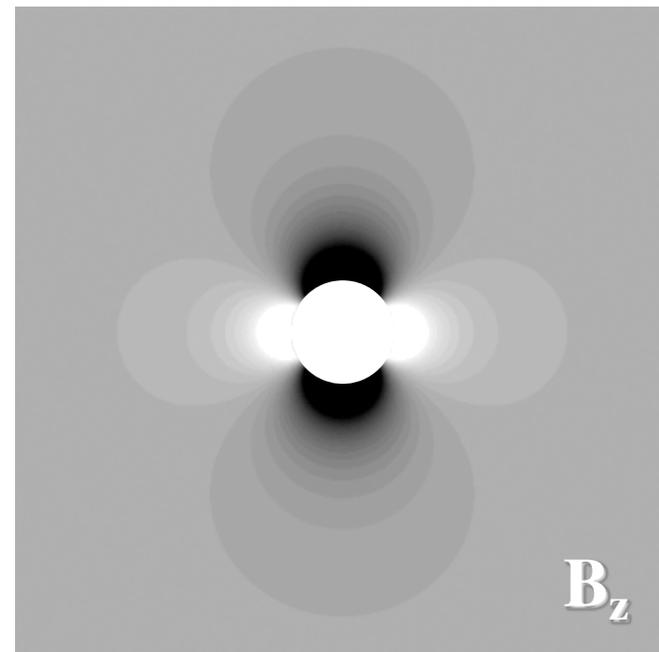
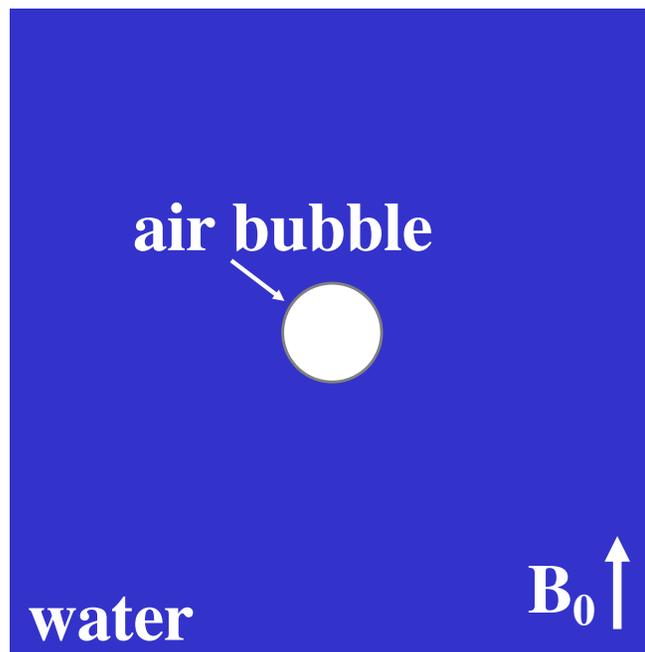
Answer: Any object placed within the main magnet changes the magnetic field!

# Magnetic Susceptibility

- All materials are magnetized to some degree.

$$B = \mu_0(1 + \chi_m)H$$

↑  
magnetic susceptibility



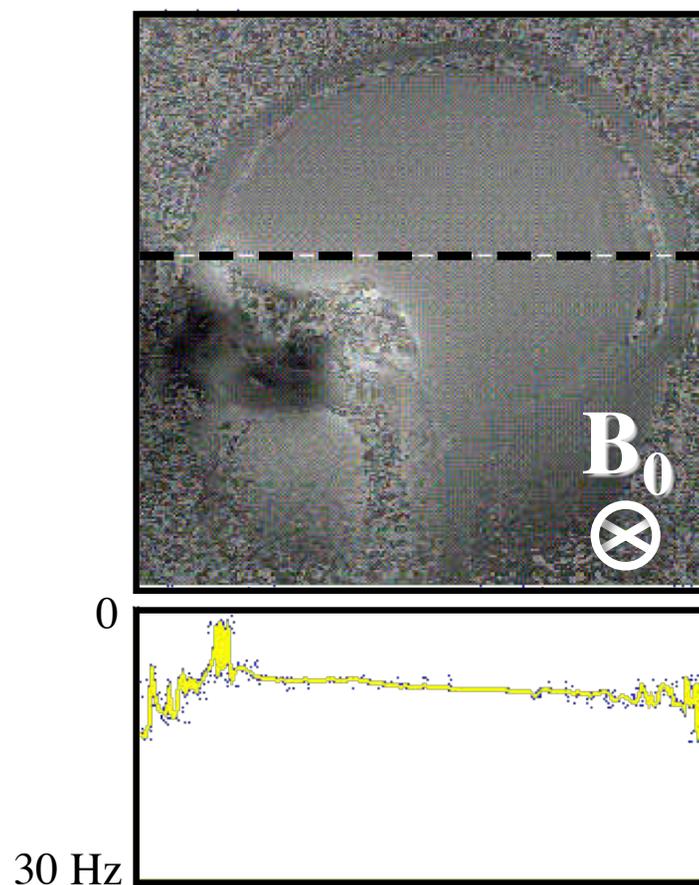
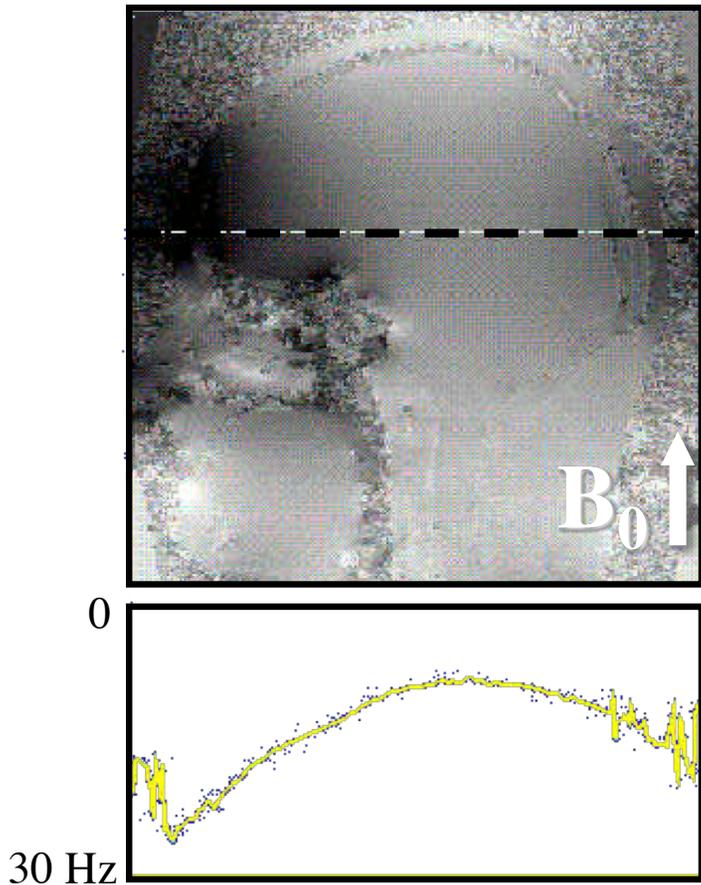
Susceptibility: air = 0.000004  
water = -0.000002

max shift about  $\pm 10$  ppm

# Susceptibility and $B_0$ orientation

Parallel (0.5T)

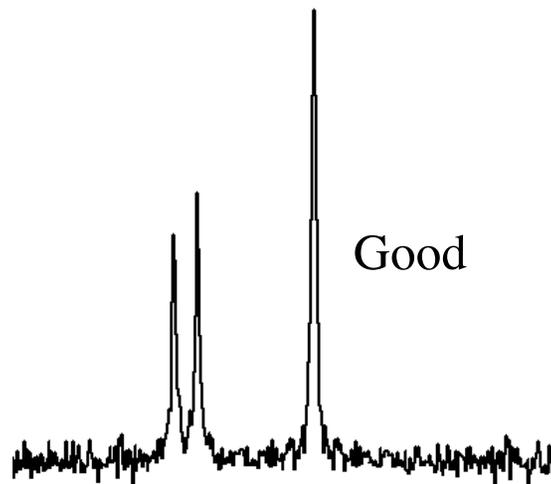
Orthogonal (0.5T)



# High Field Magnets ( $\geq 3\text{T}$ )

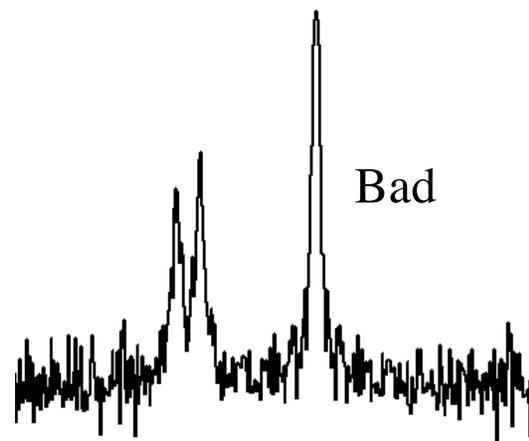
- Pros
  - SNR linear with  $B_0$
  - Spectral separation increases
- Cons
  - Susceptibility scales with  $B_0$
  - If linewidths dominated by  $T_2^*$ , SNR goes only as  $\text{sqrt}(B_0)$

Example:



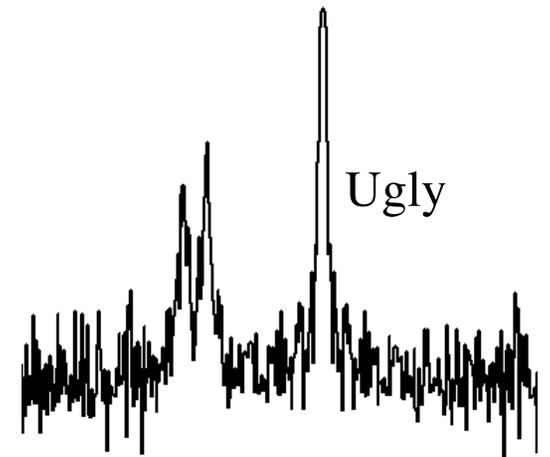
Good

3T  $T_2$  dominated



Bad

3T  $T_2^*$  dominated



Ugly

1.5T

# Summary

- $^1\text{H}$  MRS is best viewed as an adjunct to MRI, currently in widespread clinical use.
- Technical difficulties addressed with large voxels, water/lipid suppression, in vivo shimming
- Clinical neuro applications available today, body applications under development.
- Ongoing technical development:
  - Improved Shimming: homogeneity is key to a successful study!!
  - Automated processing and quantification
  - Phased-array coils, SENSE/SMASH
  - Motion-insensitive sequences
  - High field MRSI: other nuclei, improved spectral editing

Next Lecture: Clinical MRS I