BOLD fMRI:

signal source, data acquisition, and interpretation

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‘Lecture’ series

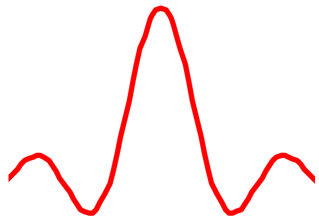
- Week 1: Biological basis: where’s the signal coming from?
- Week 2: Physical basis: what is the signal, how is it measured?
- **Week 3: Imaging basics: image formation, noise, and artifacts.**
- Week 4: The specific case of BOLD fMRI.
- Week 5: BOLD analysis: what’s significant and what’s not?
- Week 6: Spikes vs. BOLD: neural activity in visual areas

Imaging

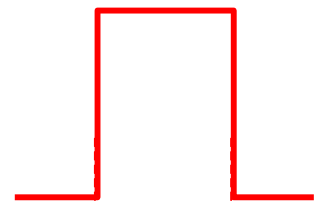
- Sequence
  - Gradients: slice selection, frequency encoding, phase encoding
  - k-space
  - T1, T2 weighted; regular and fast acquisition
- Noise
  - Physiological vs. MR
- Artifacts (no slides …)
  - Folding, segmentation, Nyquist ghosts
  - Distortion vs. blurring (discussion postponed)
  - Motion artifacts

Slice selection

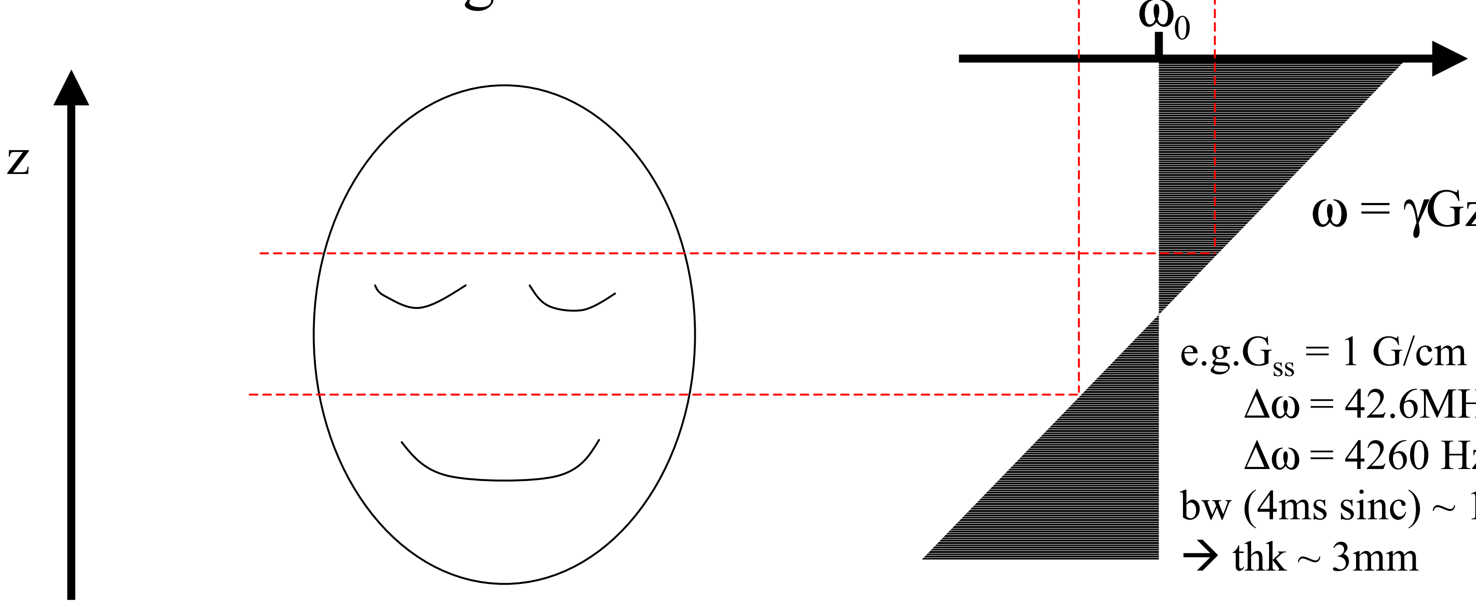
RF pulse: sinc in time



boxcar in frequency



With a slice-select gradient…



e.g. G_{ss} = 1 G/cm

$\Delta\omega$ = 42.6MHz/T* 10^{-4} T/cm

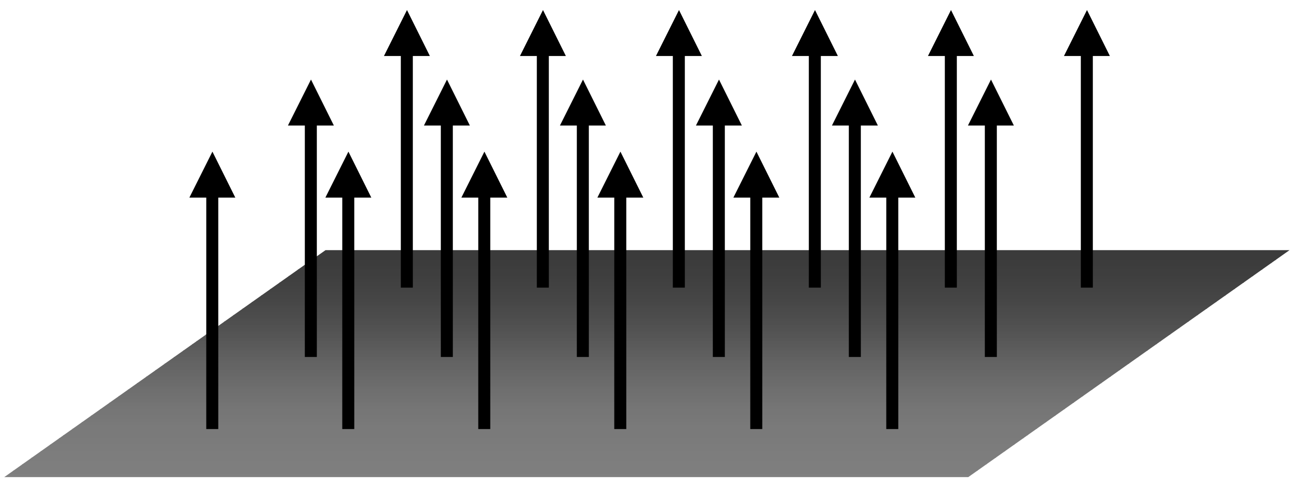
$\Delta\omega$ = 4260 Hz/cm

bw (4ms sinc) ~ 1.2kHz

→ thk ~ 3mm

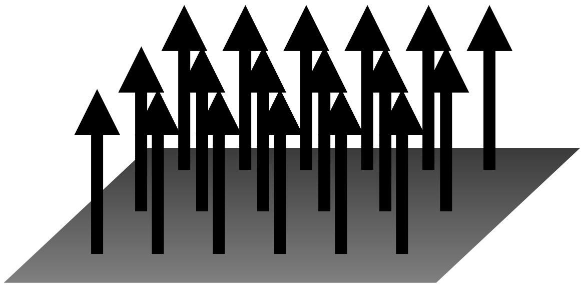
…only a slab of spins are excited

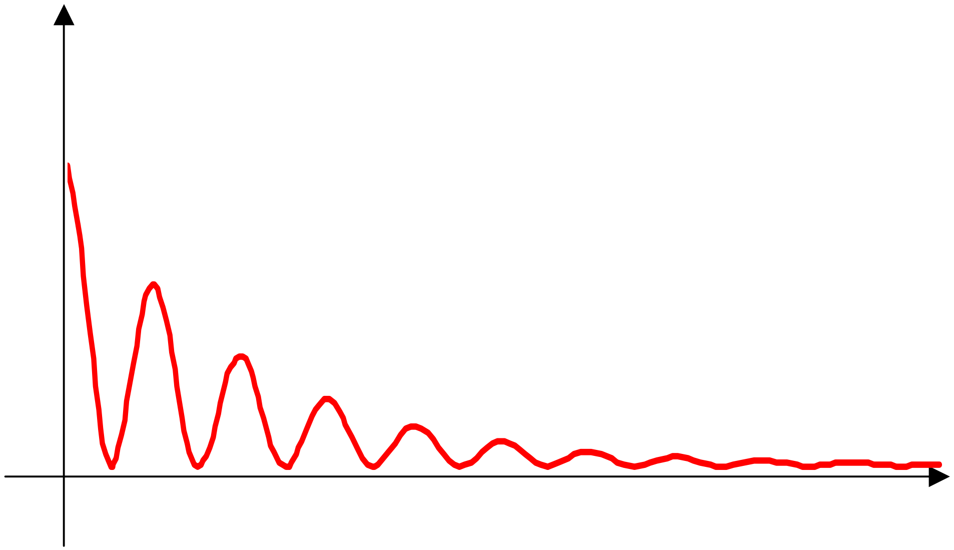
Frequency encoding within the selected slice



No gradients; all the protons precess at the same rate

Acquired signal without gradients

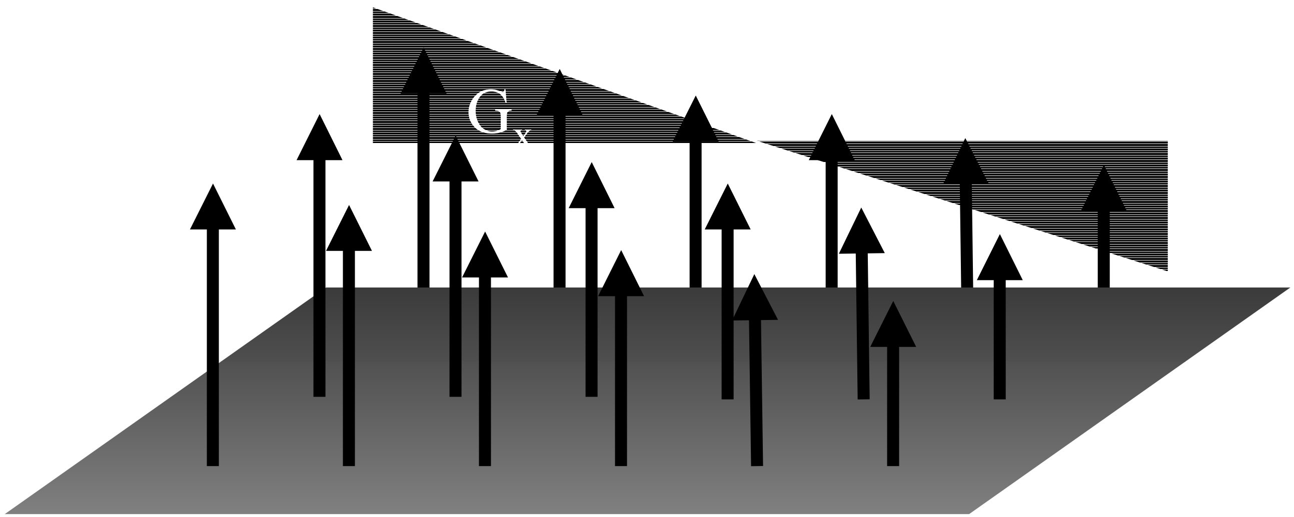




$S(t) = \int dx\ \rho(x)\ e^{i\Omega(t)}\ e^{-t/T2^*}$

Signal looks like homogeneous FID

Within the selected slice …



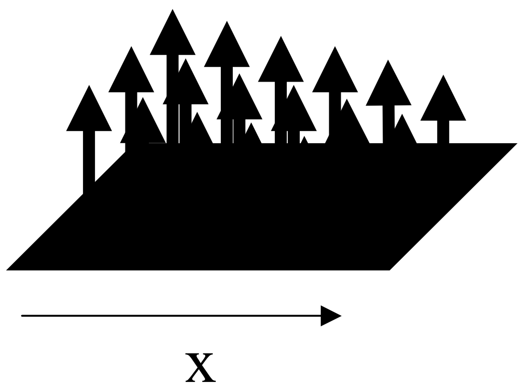
Linear gradient in X; protons precess at different rates

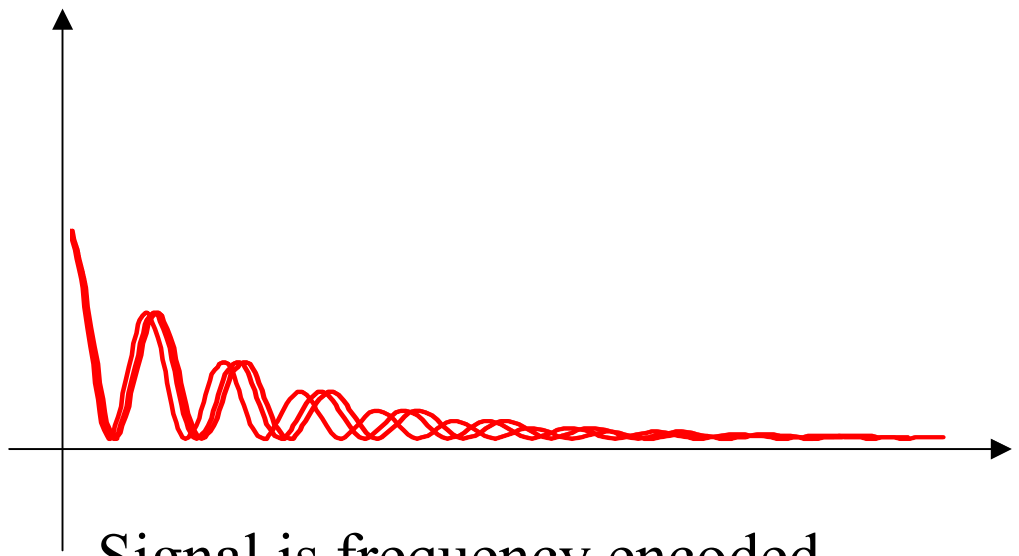
Typical G_r value: 3 G/cm

3 T field (30000 G), 3 G/cm gradient; 20 cm field of view

→ ±30/30000 = ±.1% change over FOV

Acquired signal with gradients





Signal is frequency encoded along one dimension

$$S(t) = \int dx\, \rho(x)\, e^{i(\Omega(t)+\phi(x,t))}\, e^{-t/T2^*}$$
$$= \int dx\, \rho(x)\, e^{i\phi(x,t)}\, e^{-t/T2^*}$$

Getting to k-space

(ignoring T_2^*-induced decay and magnetization history)

$$S(t) = \int dx\ \rho(x)\ e^{i(\Omega(t)+\phi(x,t))} = \int dx\ \rho(x)\ e^{i\phi(x,t)}$$

$$\phi_G(x,t) = - \int dt\ \omega_G(x,t) = -\gamma x \int dt\ G(t)$$

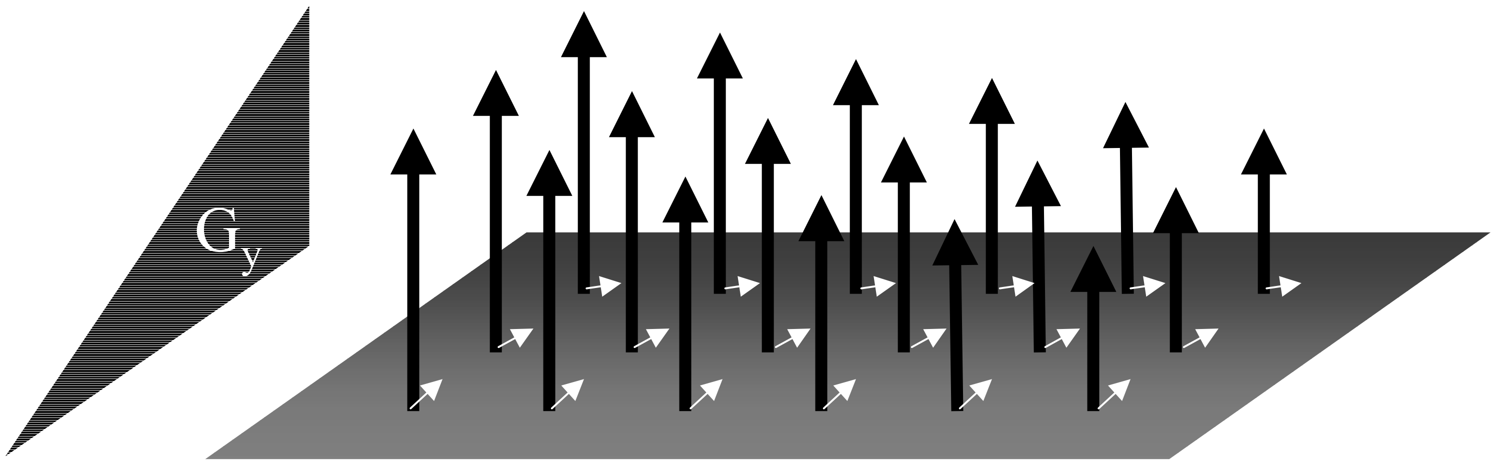
$$\mathbf{k \equiv \phi / 2\pi x}$$

$S(k) = \int dx\ \rho(x)\ e^{i2\pi kx}$, an obvious inverse Fourier transform,

so

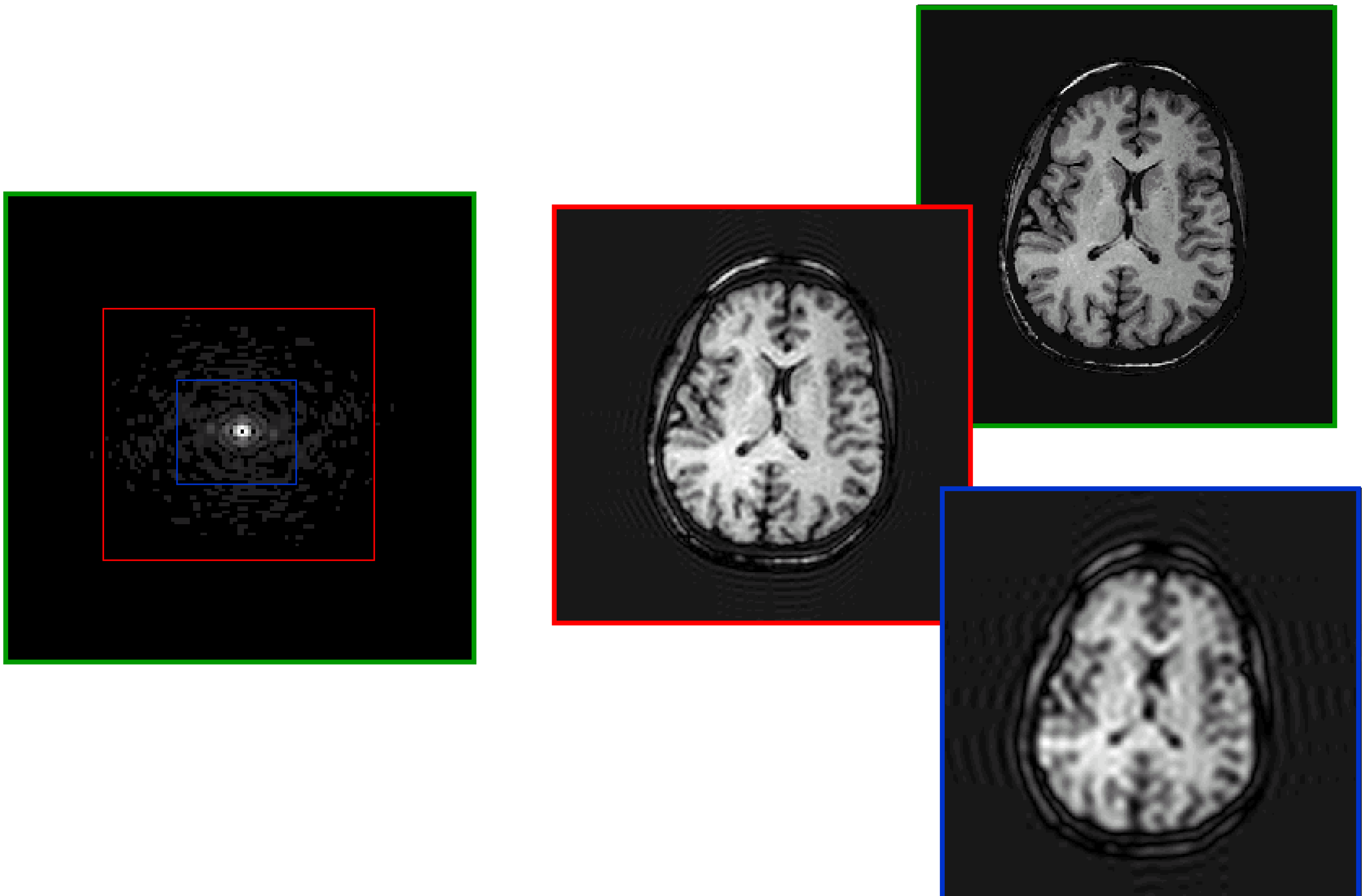
$$\rho(x) = \int dk\ S(k)\ e^{-i2\pi kx}$$

How do you encode the 2nd dimension?

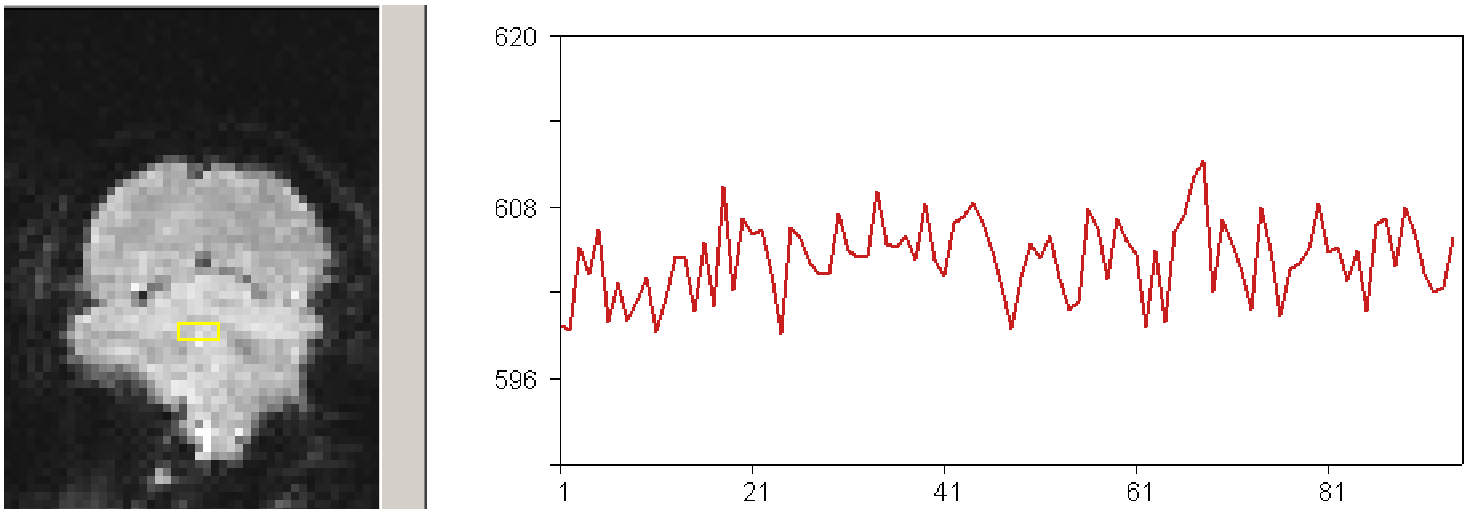


A brief gradient along the y direction lends a different phase to spins with different y positions

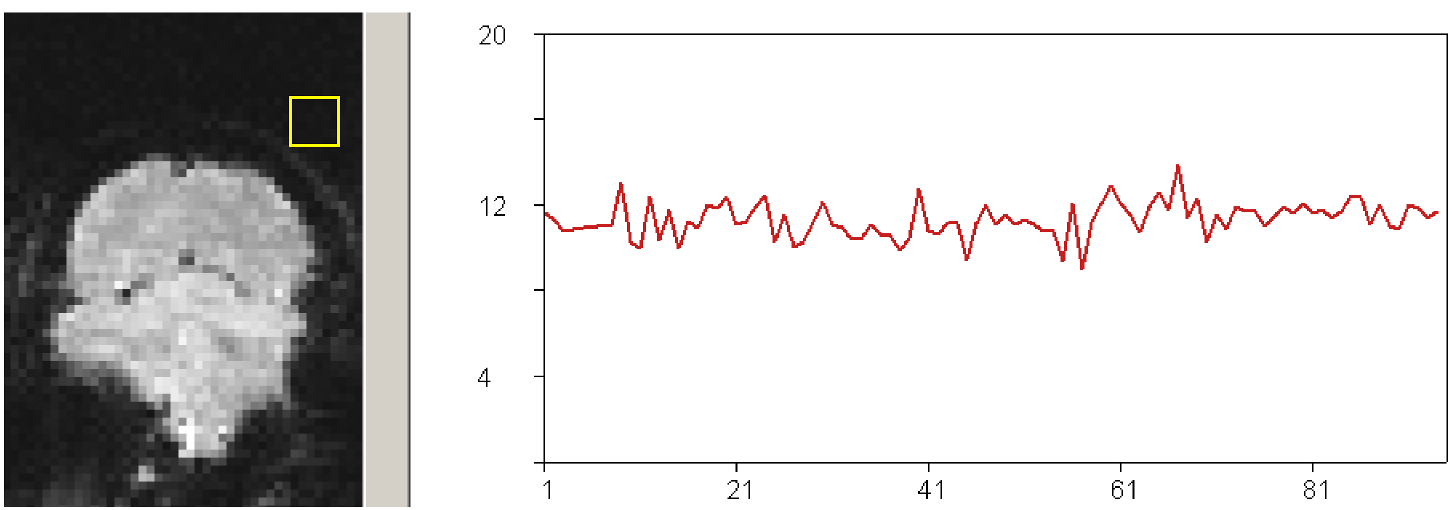
k-space



Noise – physiological vs. RF

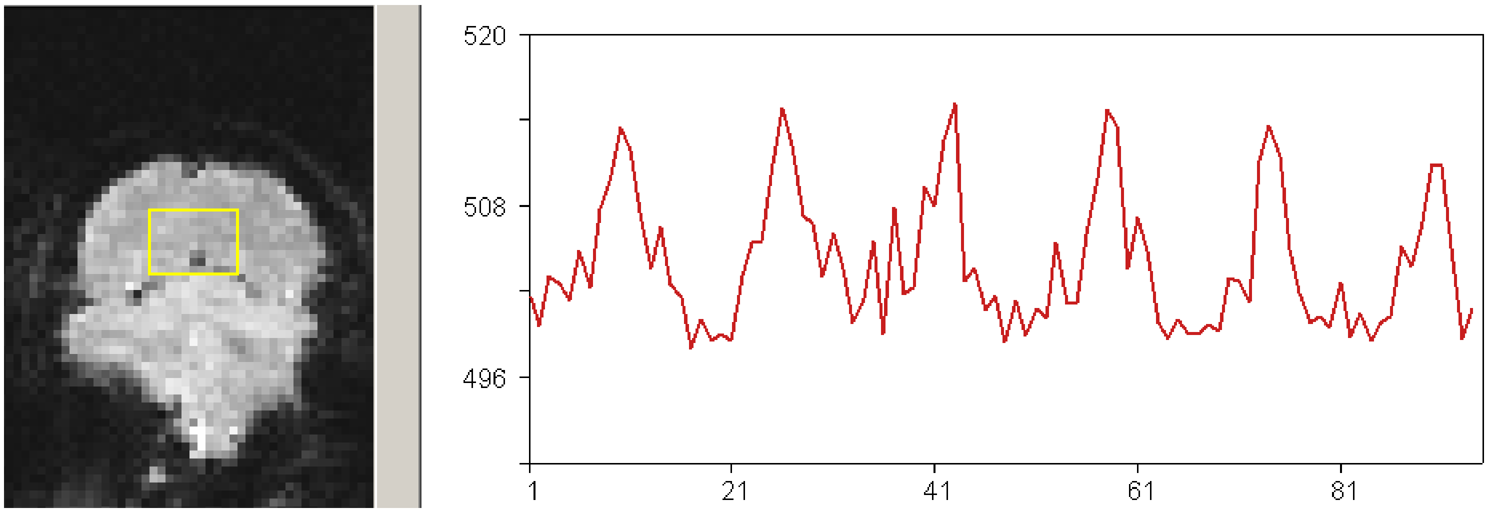


avg signal ~ 600
RMS(signal) ~ 10
SNR ~ 60

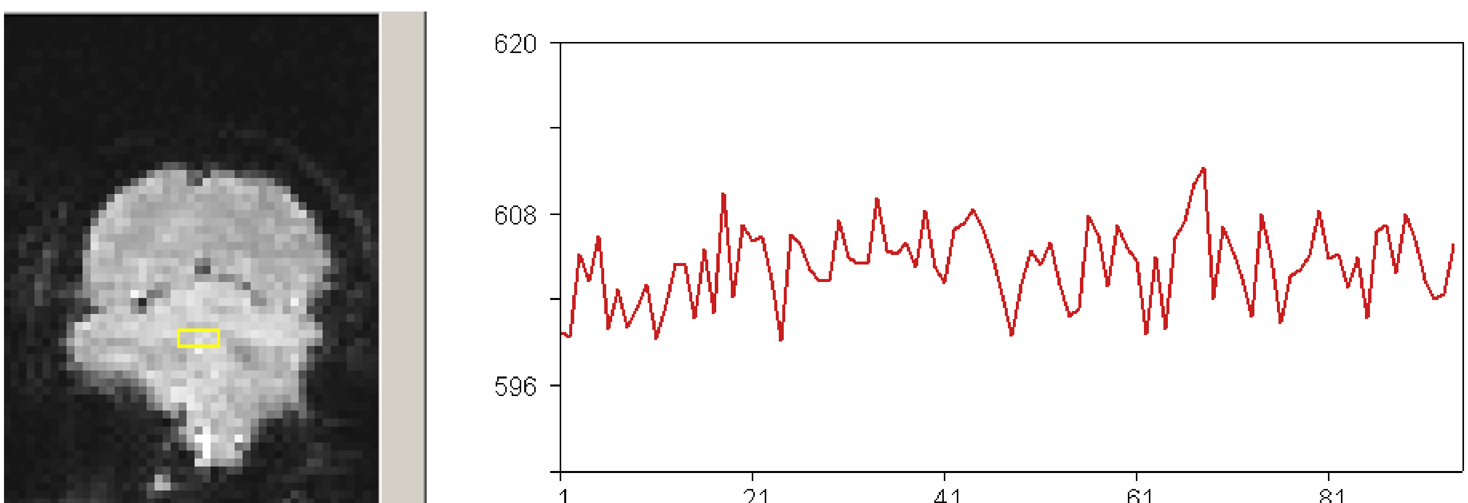


avg signal ~ 600
avg noise ~ 10
SNR ~ 60

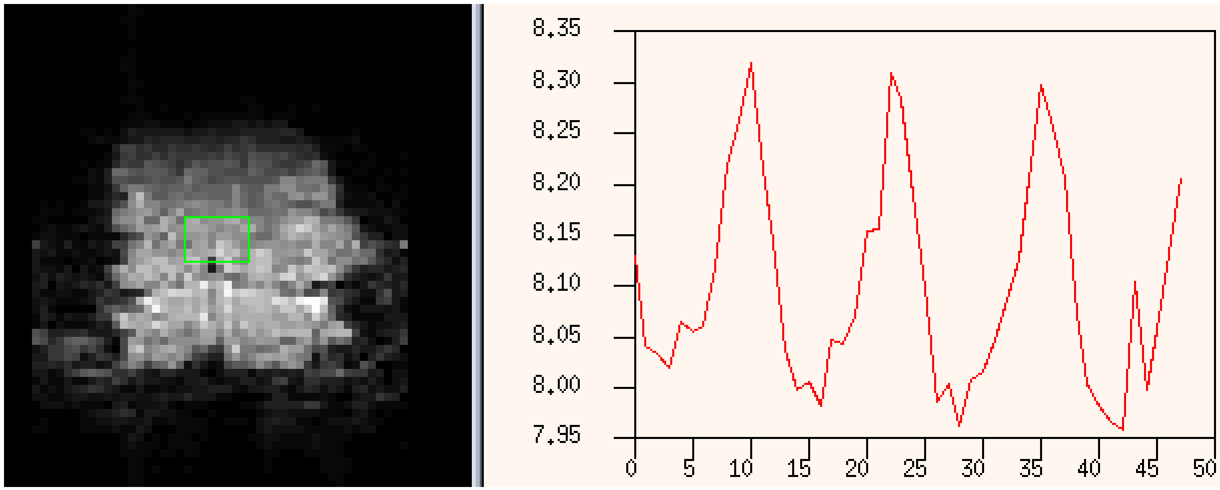
SNR vs. CNR

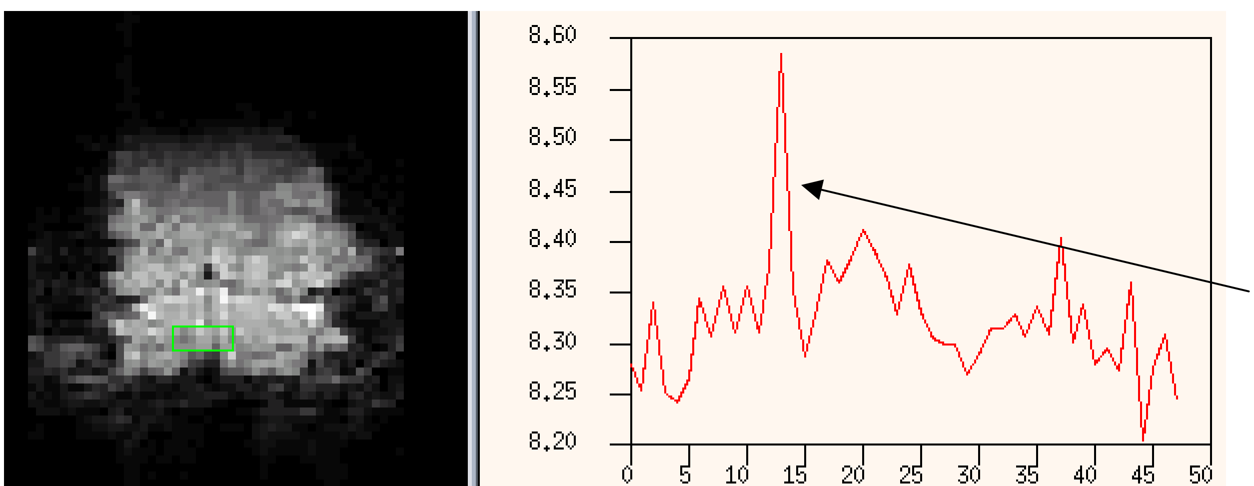


Contrast ~ 15
Noise ~ 10
CNR ~ 1.5



SNR vs. CNR at 7T





Contrast ~ .3
Noise ~ .1
CNR ~ 3

(motion during segmented acquisition)