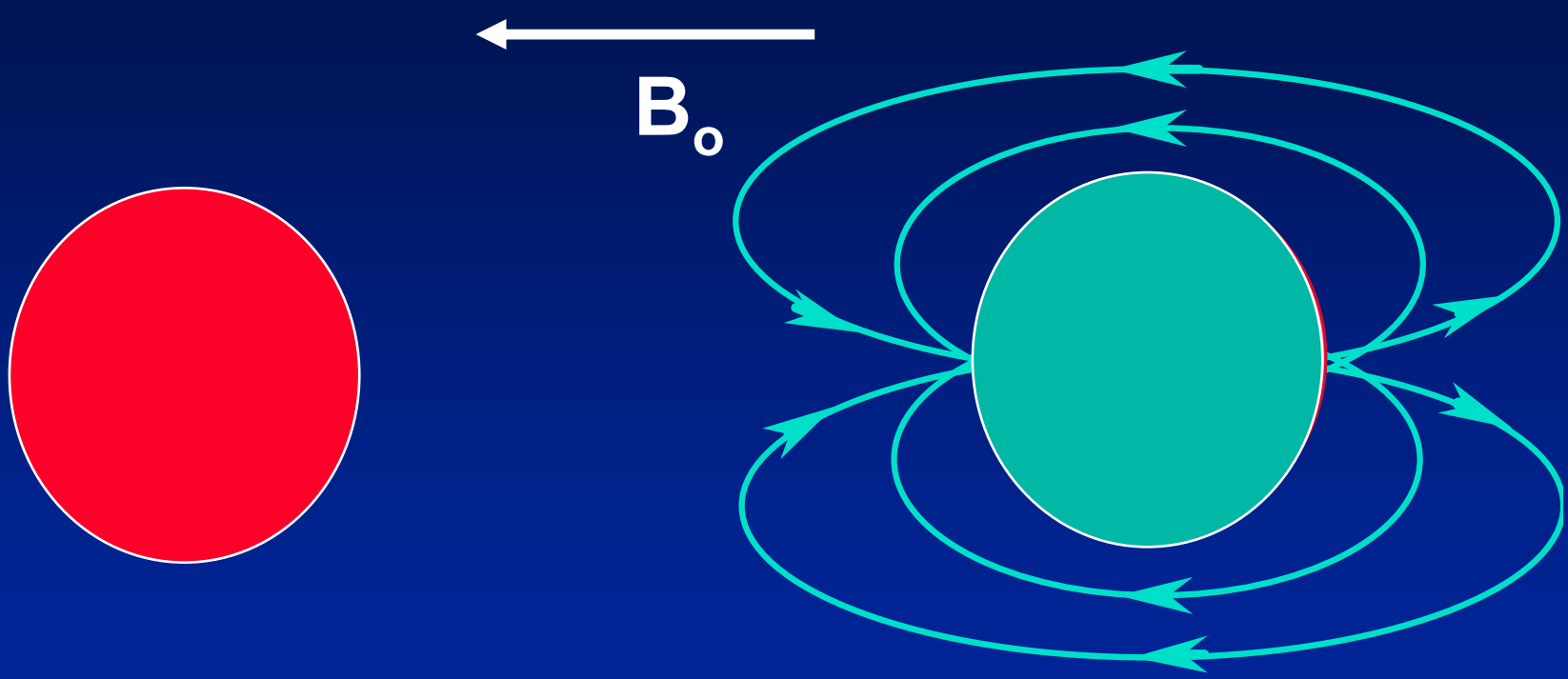
Noise in fMRI

MGH-NMR Center

1) Brief review of BOLD

2) Noise sources in the BOLD experiment

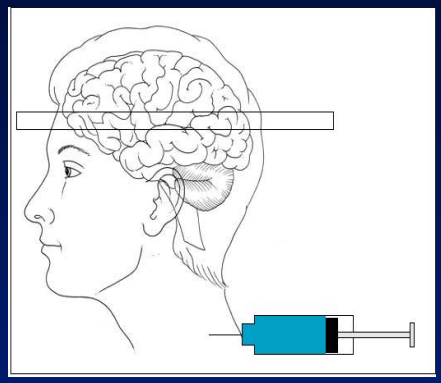
Field Homogeneity and Oxygen State

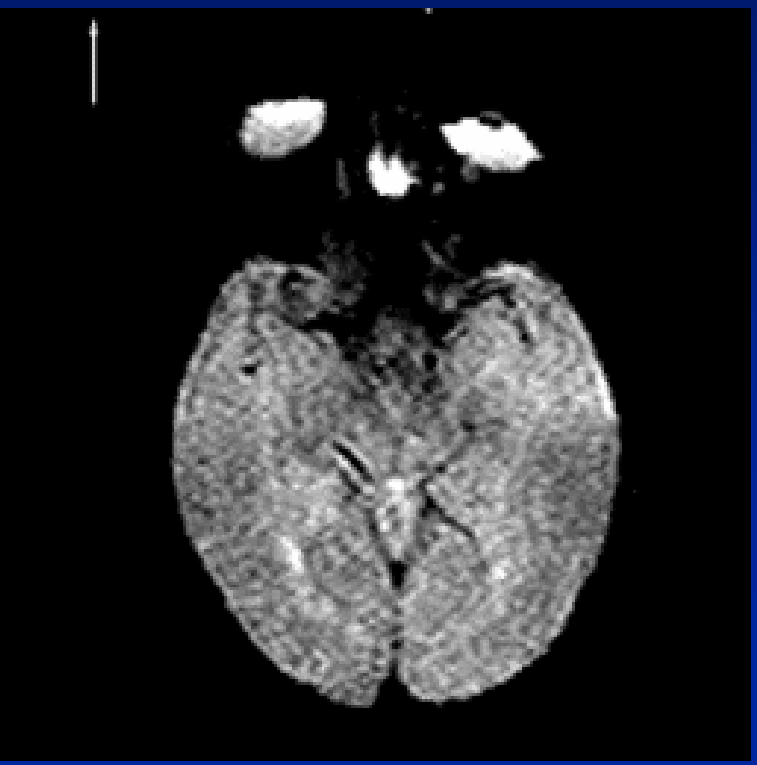


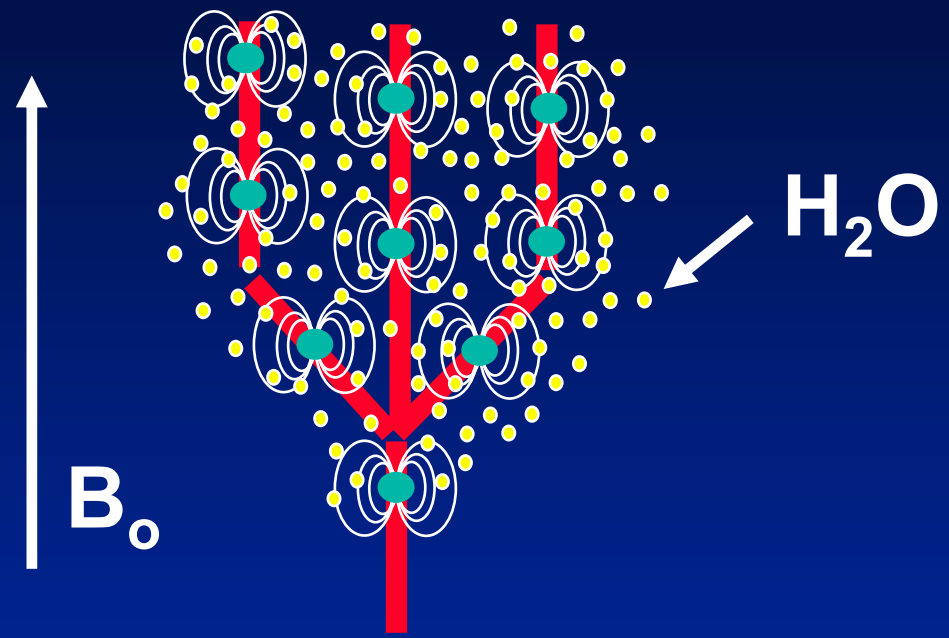
Oxygenated Red Cell

de-Oxygenated Red Cell

Addition of paramagnetic compound to blood







Signal from water is dephased by local fields (T2* shortens), S goes down on EPI

Magnetic stuff ↑ MR signal↓

Basis of BOLD fMRI

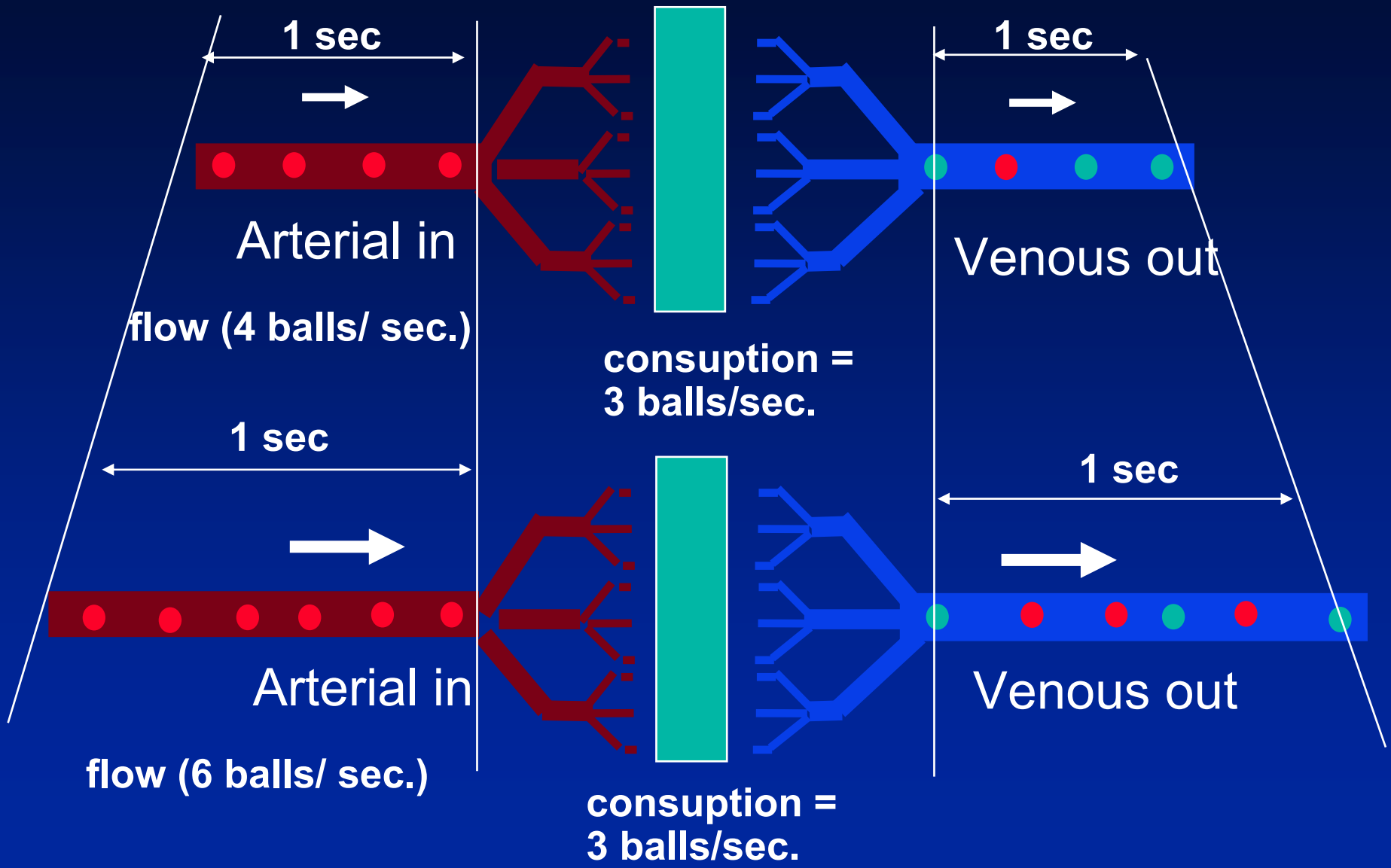
During activation…

Flow ↑ but $CMRO_2$ only goes up a little

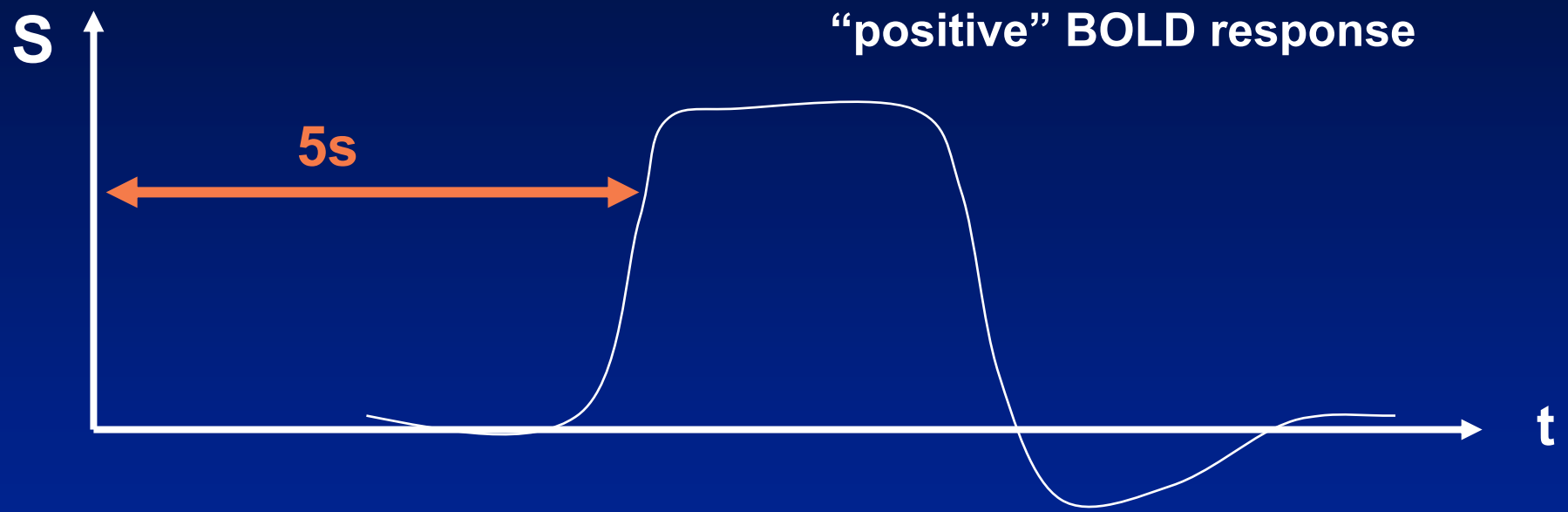
DeOxy Hb in veins ↓

As magnetic stuff ↓ T2* weighted MR signal ↑

decrease in deoxygenated red cell concentration



Time response of BOLD



Important BOLD considerations

- In 50ms, water diffuses 25um on average

  thus moves ~4x diameter of capillary…

- Water diffuses readily in and out of RBC.
- Water does not exchange between vascular and tissue pools.
- 20x more water in tissue space, nonetheless, 2/3 of BOLD signal is intravascular at 1.5T.

Important BOLD considerations

- Diffusion in and around RBC shortens intravascular T2 esp. at high field making intravascular water contribute less to spin echo.

- B-W model shows that spin echo (T2) is more localized to small vessels than grad echo (T2*).

BOLD effect modulates signal where does the noise come from?

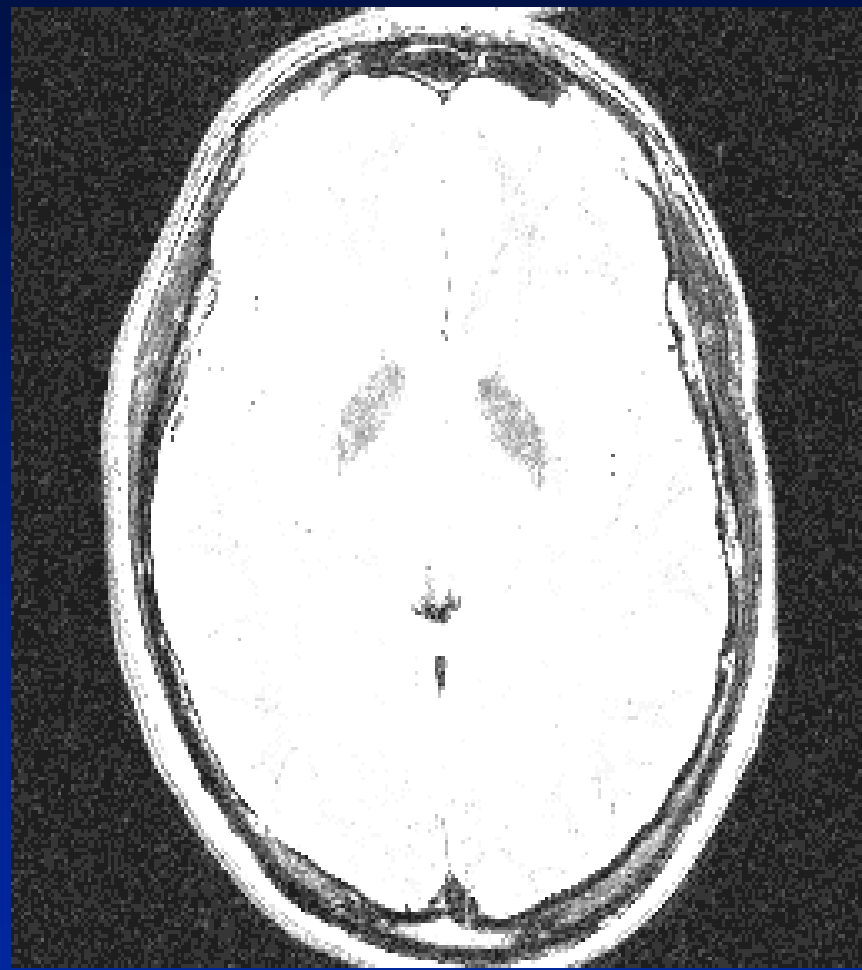
Thermal Noise in MRI

Thermal white noise in a resistor:

$P_{noise} = 4kTRB$

Noise is flat across freq and is not encoded by gradients.

>> noise voltage due to resistive losses is Gaussian, temporally and spatially uncorrelated.



Thermal Noise in MRI

Resistive losses from

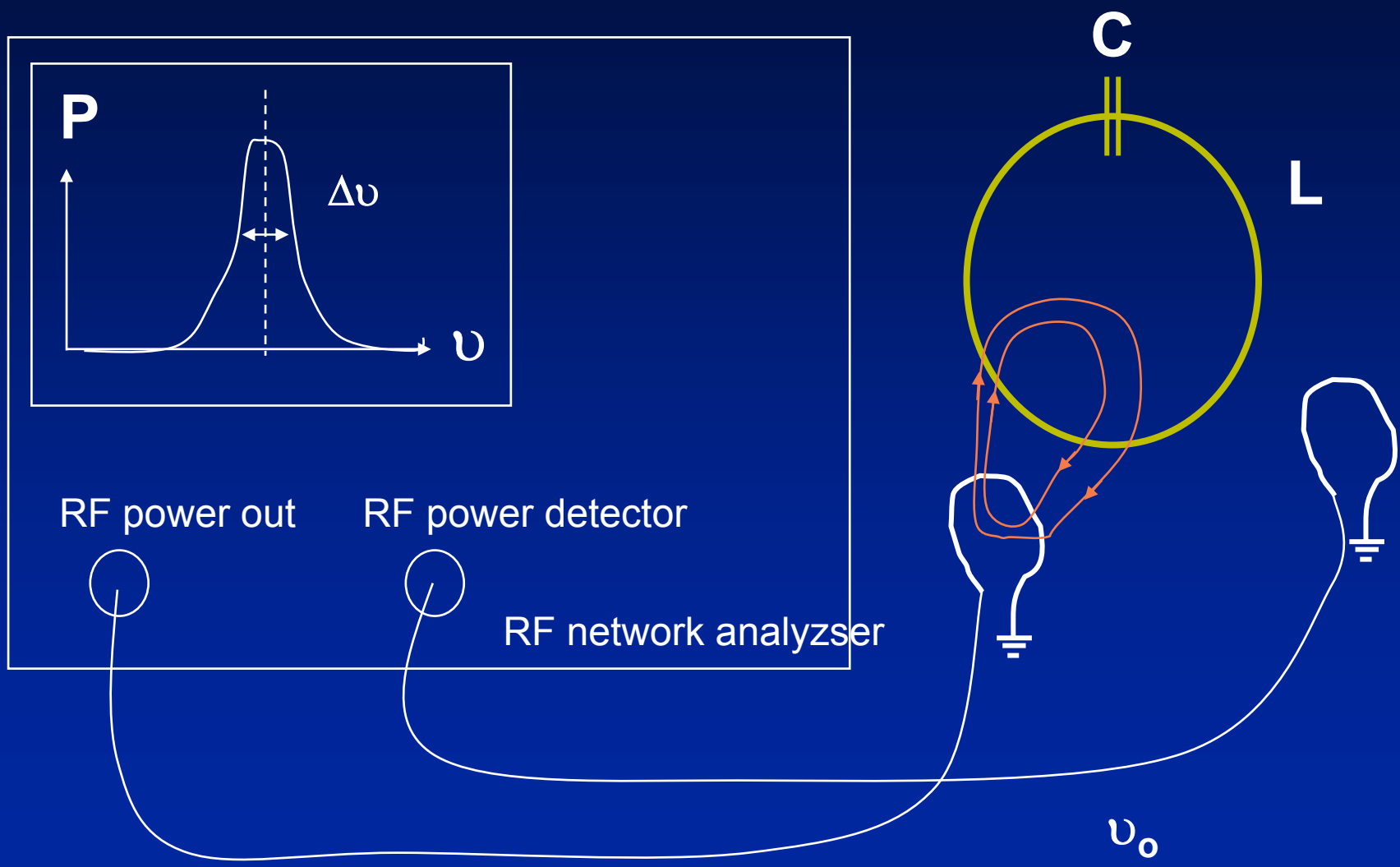
a) wires and components in coil.

b) Driving ionic RF eddy currents in body.

Body losses are generally 5x larger (or more)…

$P_{noise} \alpha R$ means noise scales with volume of tissue in coil

Measuring loss in a coil



Thermal Noise in MRI

$P_{noise} = 4k\ T\ R\ B$

Bandwidth is set by filter determined by Nyquist condition:

B α 1 / dwell time

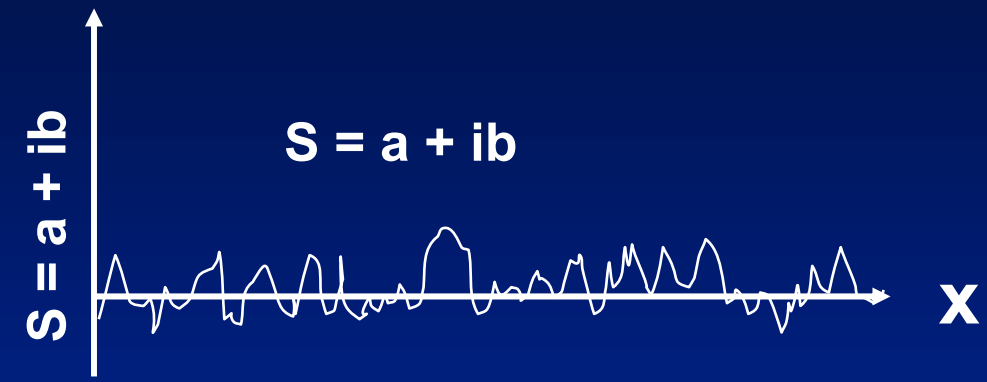
Temporal uncorrelated means:

SNR = 1 / SQRT(averaging time)

$$SNR = \frac{mean(SignalROI)}{\sigma(noiseROI)}$$

(Quick and dirty method)

Noise in the magnitude image is no longer Gaussian



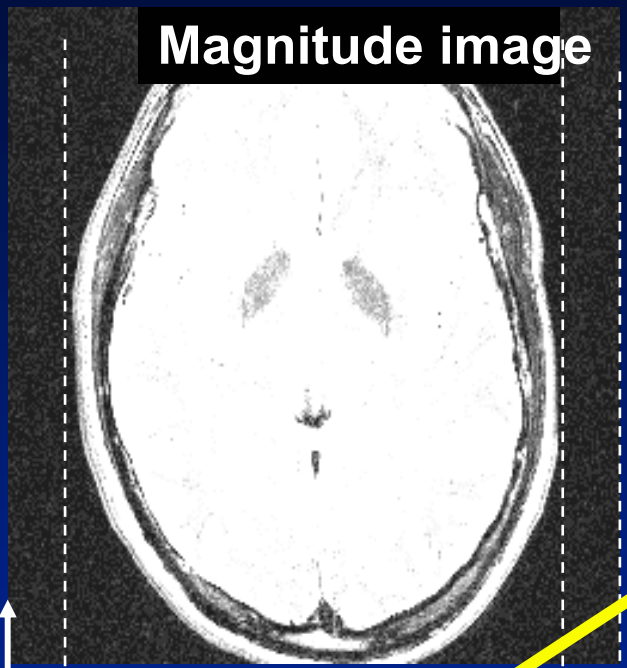
Gaussian prob. distribution

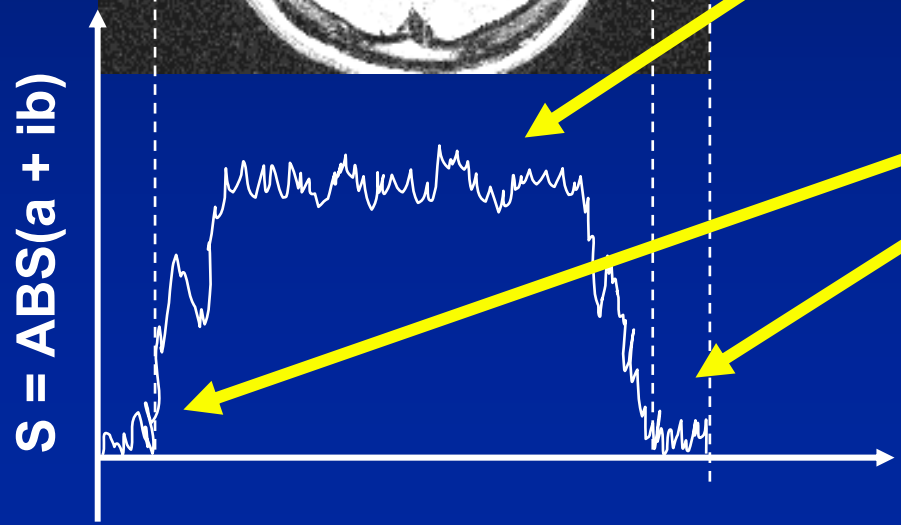
$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left[-\frac{(x-u)^2}{2\sigma^2} \right]$$

Rayleigh prob. distribution

$$f(z) = \frac{z}{\sigma^2} \exp\left(-\frac{z^2}{2\sigma^2} \right)$$

In regions of high SNR, dist. Is Gaussian





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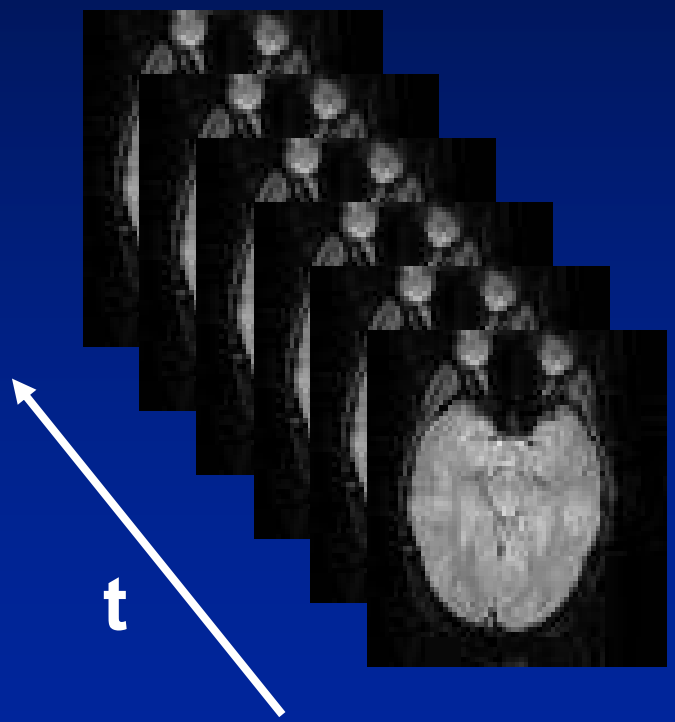
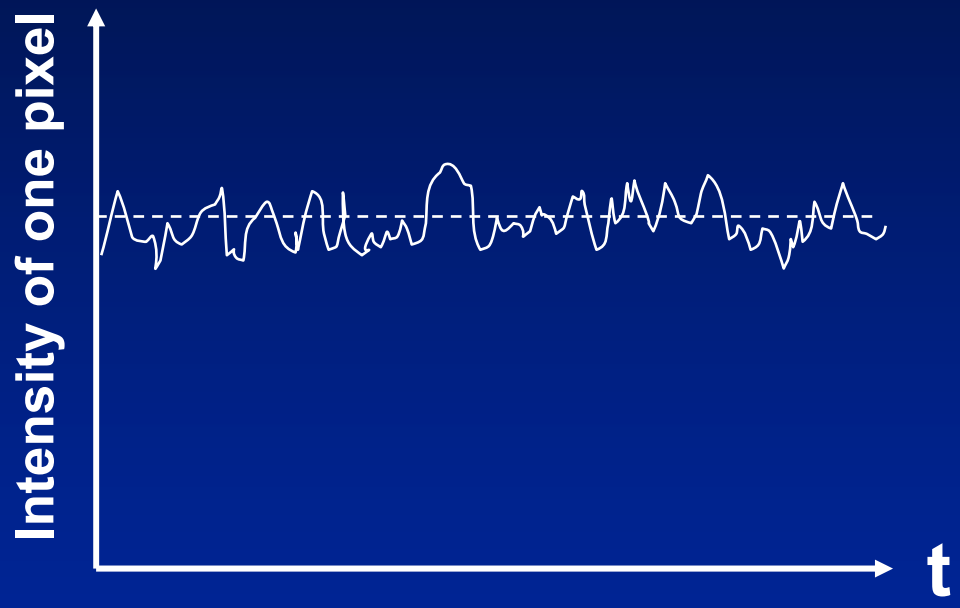
fMRI noise means noise in the time series





Gaussian noise characterized by mean and SD (σ)

Noise sources in fMRI

- Thermal noise from coil and body σ_T
- Drift and instabilities in scanner

  $\sigma_{scanner}$
- Physiologic modulation of MR signal due to non-bold effects σ_{NB}
- Physiologic noise from flux. In basal cerebral CBV, CBF, $CMRO_2$ σ_B

Noise sources in fMRI

- Total system thermal nois $\sigma_o^2 = \sigma_T^2 + \sigma_{scanner}^2$

- Non-BOLD physiologic noise is modulation of signal from:

  $\sigma_{NB} \propto S$

  respiration

  cardiac motion

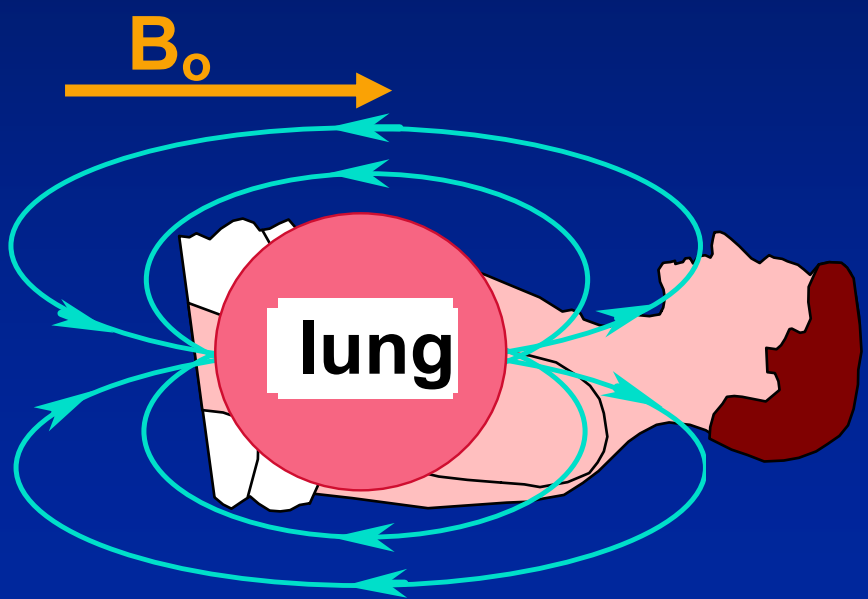
  subject movement

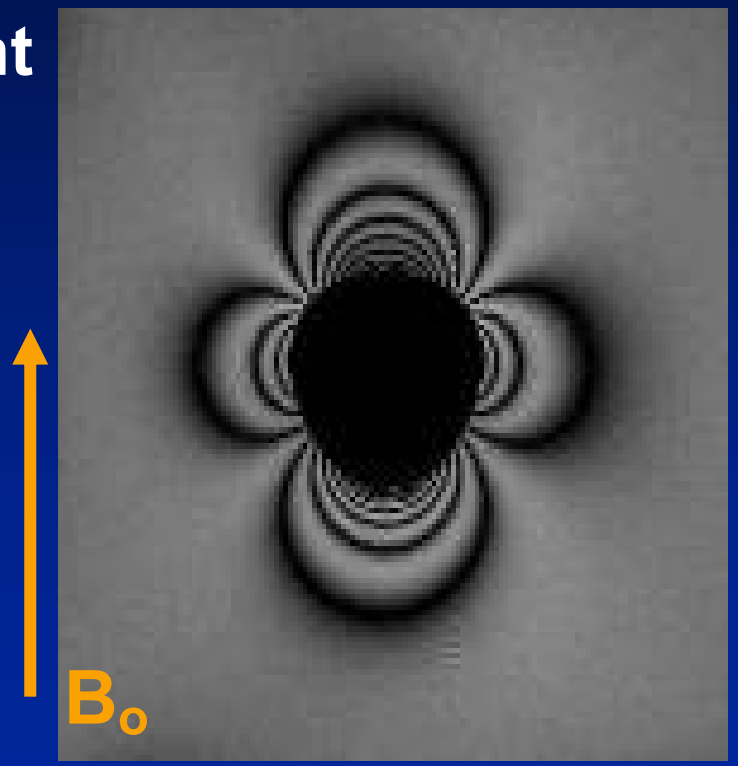
  other?

Respiration: Non-BOLD physiologic noise

(Van de Moortele MRM 47:888 2002)

Inflating lung produces z gradient



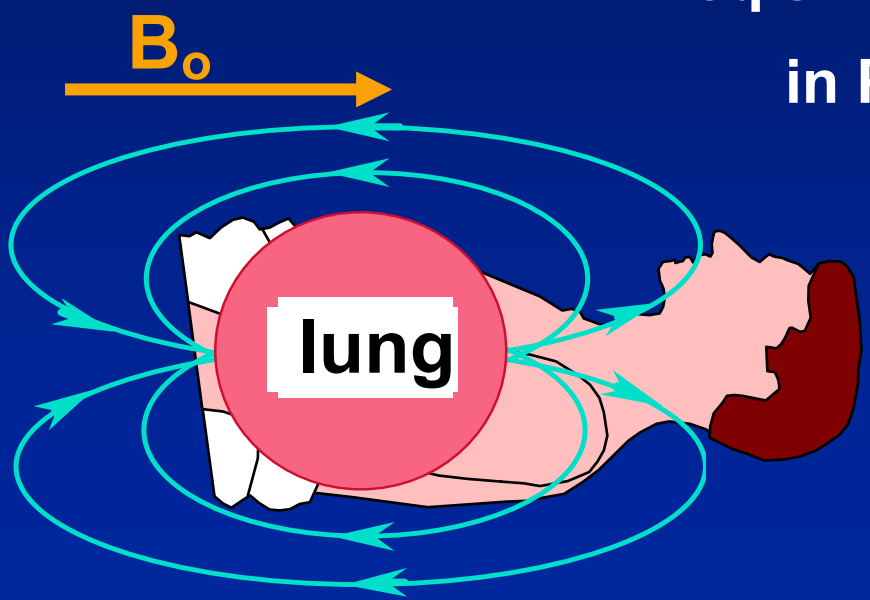


B_o near Ping pong ball in water

Respiration: Non-BOLD physiologic noise

(Van de Moortele MRM 47:888 2002)

- Inflating lung produces z gradient
- Z grad gives each axial slice a different ω.
- Freq shift causes displacement of object in PE direction



Frequency change is as much as 5 Hz.
Shift of 0.25 pixels

Noise sources in fMRI

BOLD noise σ_B Signal modulation from Δ in CBV, CBF, $CMRO_2$ is TE and S dependant.

$$S = S_o \exp\left(-TE \cdot R_2^*\right)$$

$$dS/dR_2^* = -TE \cdot S_o \cdot \exp\left(-TE \cdot R_2^*\right)$$

$$\sigma_B = c_1 \cdot S \cdot \Delta R_2^* \cdot TE$$

Noise sources in fMRI

(Kuger and Glover MRM 46 p631 2001)

Estimate σ_o , σ_B , σ_{NB}

σ_B can be measured by modulating TE

σ_{NB} can be measured by modulating S by changing flip angle

σ_o is the noise independent of TE and flip angle

Noise sources in fMRI

(Kuger and Glover MRM 46 p631 2001)

Relative magnitudes of σ_o , σ_B , σ_{NB}

	gray matter	white matter	phantom
S	3500	3350	1137
σ_{TOTAL}	0.63	0.37	0.19
σ_o	0.21	0.22	0.14
σ_B	0.53	0.25	0.08
σ_{NB}	0.21	0.11	0.08

Noise sources in fMRI

(Kuger and Glover MRM 46 p631 2001)

σ_B is maximum for TE = T2*

Functional SNR: in gray matter = 84

in white matter = 143

Dominant noise sources α S

>> Increasing image SNR thru improved coils and big magnets doesn't help functional SNR after a point…

Elimination of respiration improves fSNR by 10%