Principles of MRI

EE225E / BIO265

Lecture 17

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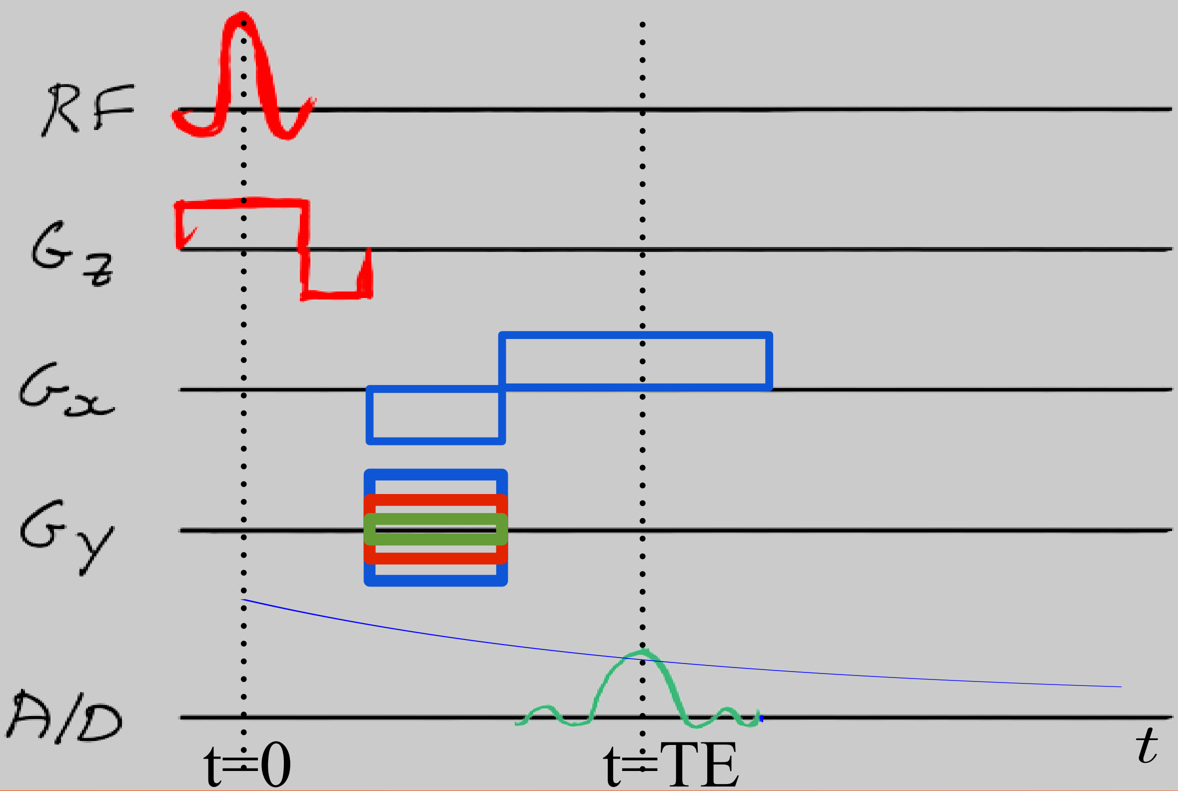
Next:

- Practical Issues in MRI
- T_2 decay
  - Map decay to k-space
  - result in artifacts
    - Image weighting
    - blurring in the readout
- Off-resonance

Effect of T2 Decay on Imaging

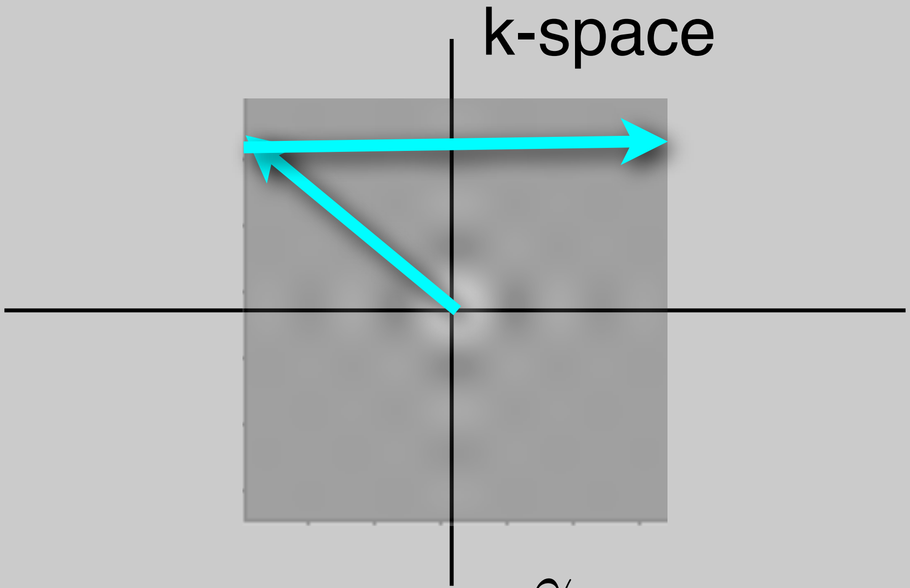
$$s(t) = \int_{\vec{R}} M_{xy}(\vec{r},0) e^{-\frac{t}{T_2}} e^{-i2\pi \vec{k}(t)\cdot\vec{r}} d\vec{r}$$

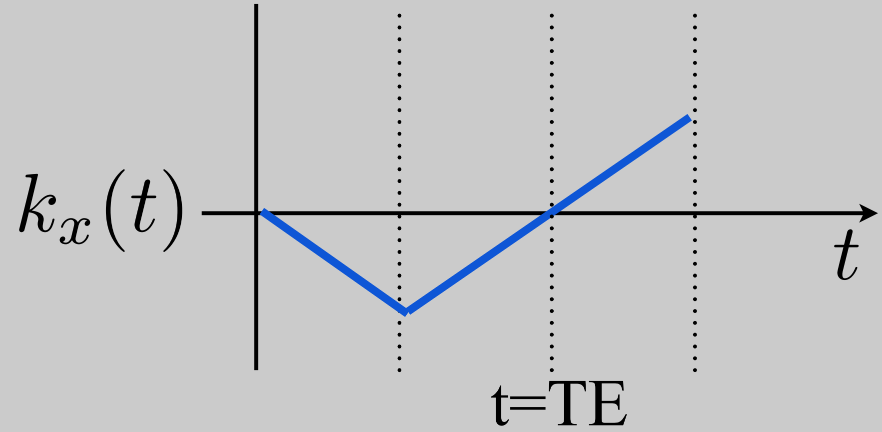
- Signal decays along k-space trajectory



Approximation:
Mxy created mid-RF
Decays with T_2 after

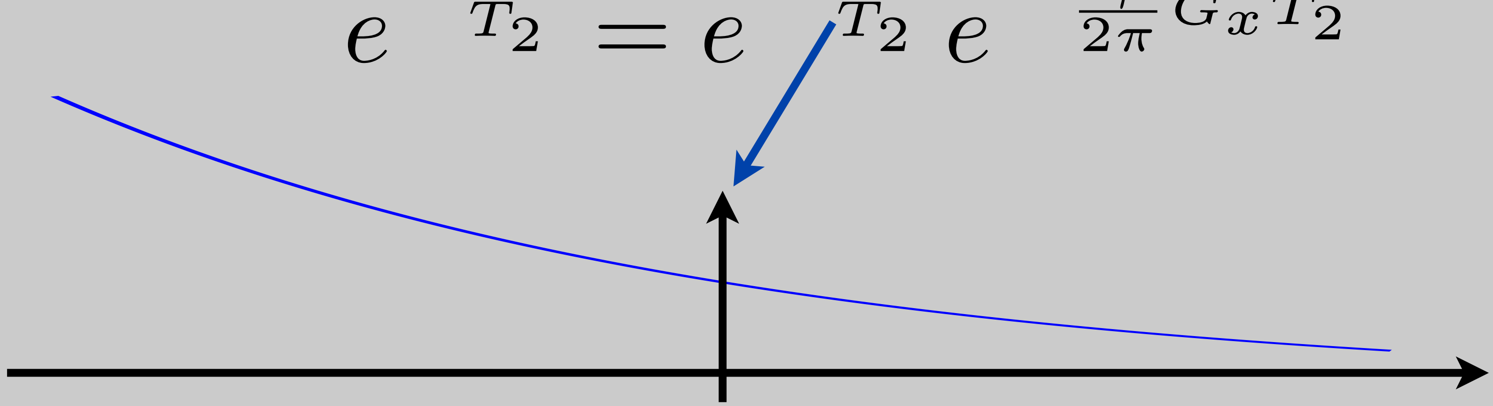
Effect of T2 Decay on Imaging





$$k_x = \frac{\gamma}{2\pi} G_x (t - TE) \Rightarrow t = \frac{k_x}{\frac{\gamma}{2\pi} G_x} + TE$$

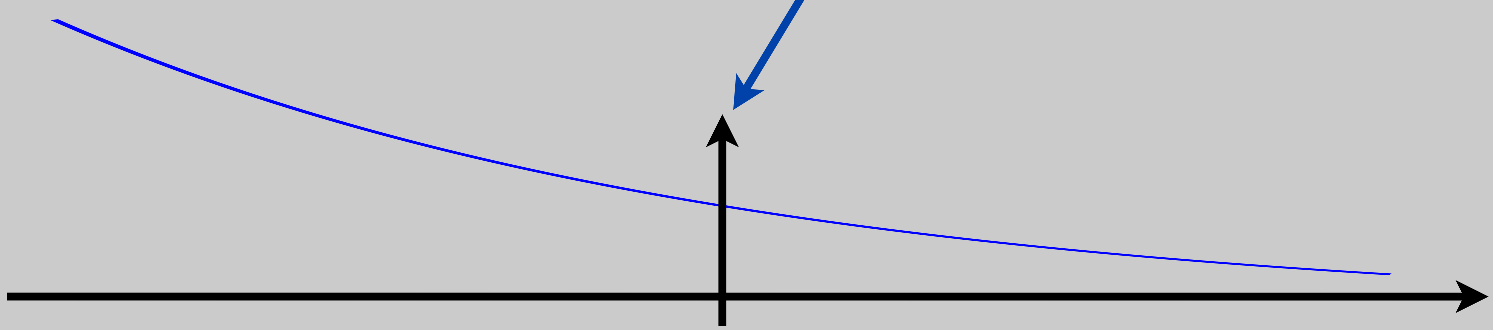
$$e^{-\frac{t}{T_2}} = e^{-\frac{TE}{T_2}} e^{-\frac{k_x}{\frac{\gamma}{2\pi} G_x T_2}}$$



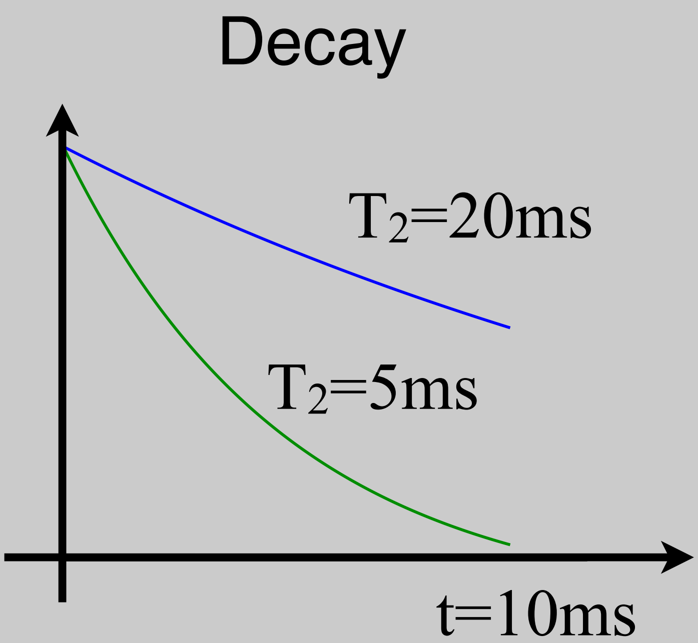
Effect of T2 Decay on Imaging

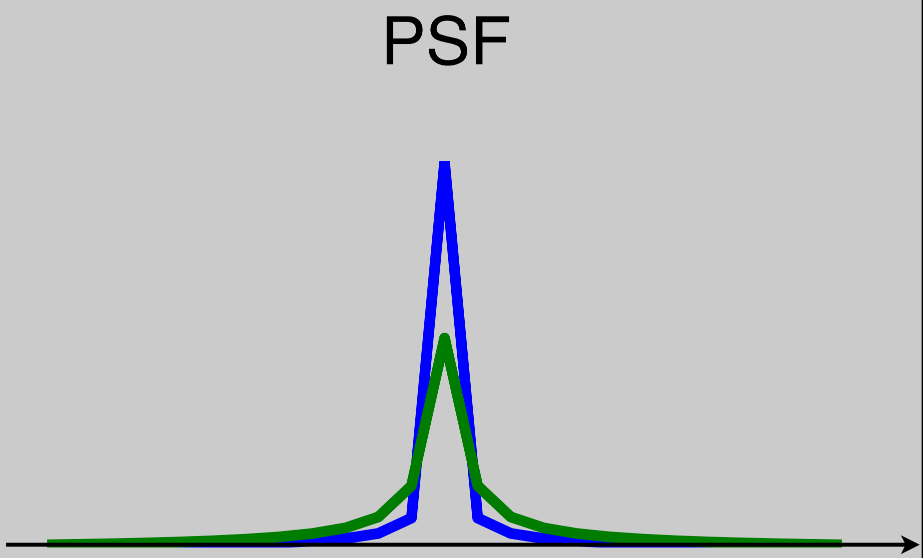
- Two Effects:
  - Signal Loss by $e^{-TE/T2}$ (T_2 Weighting)
  - Apodization by $e^{-\frac{k_x}{\frac{\gamma}{2\pi}G_x T_2}}$
    - Blurring in Image Domain (readout direction)
    - Usually minor effect
    - Reduced by increasing G_x

$$e^{-\frac{t}{T_2}} = e^{-\frac{TE}{T_2}} e^{-\frac{k_x}{\frac{\gamma}{2\pi}G_x T_2}}$$

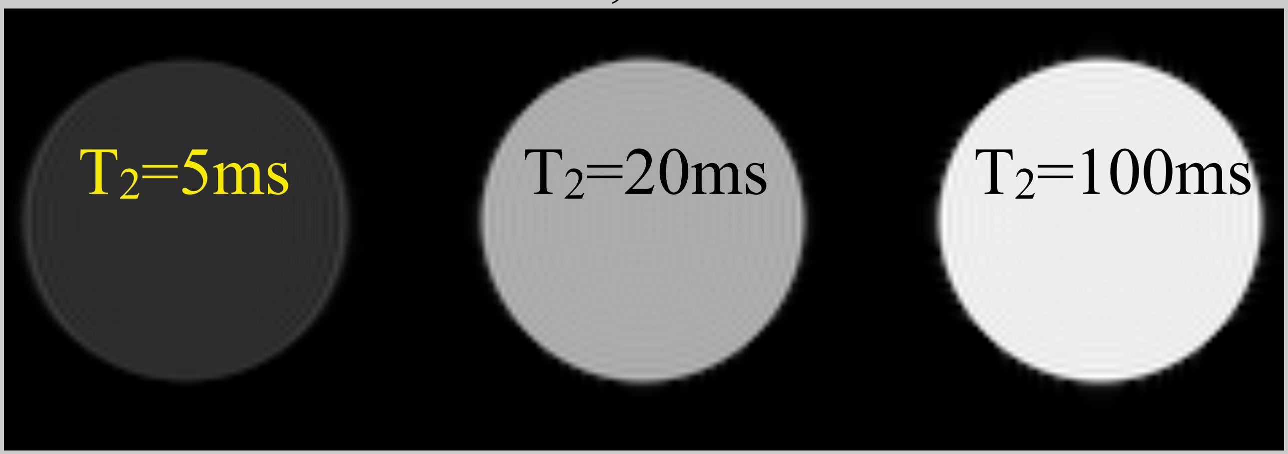


Point Spread Function





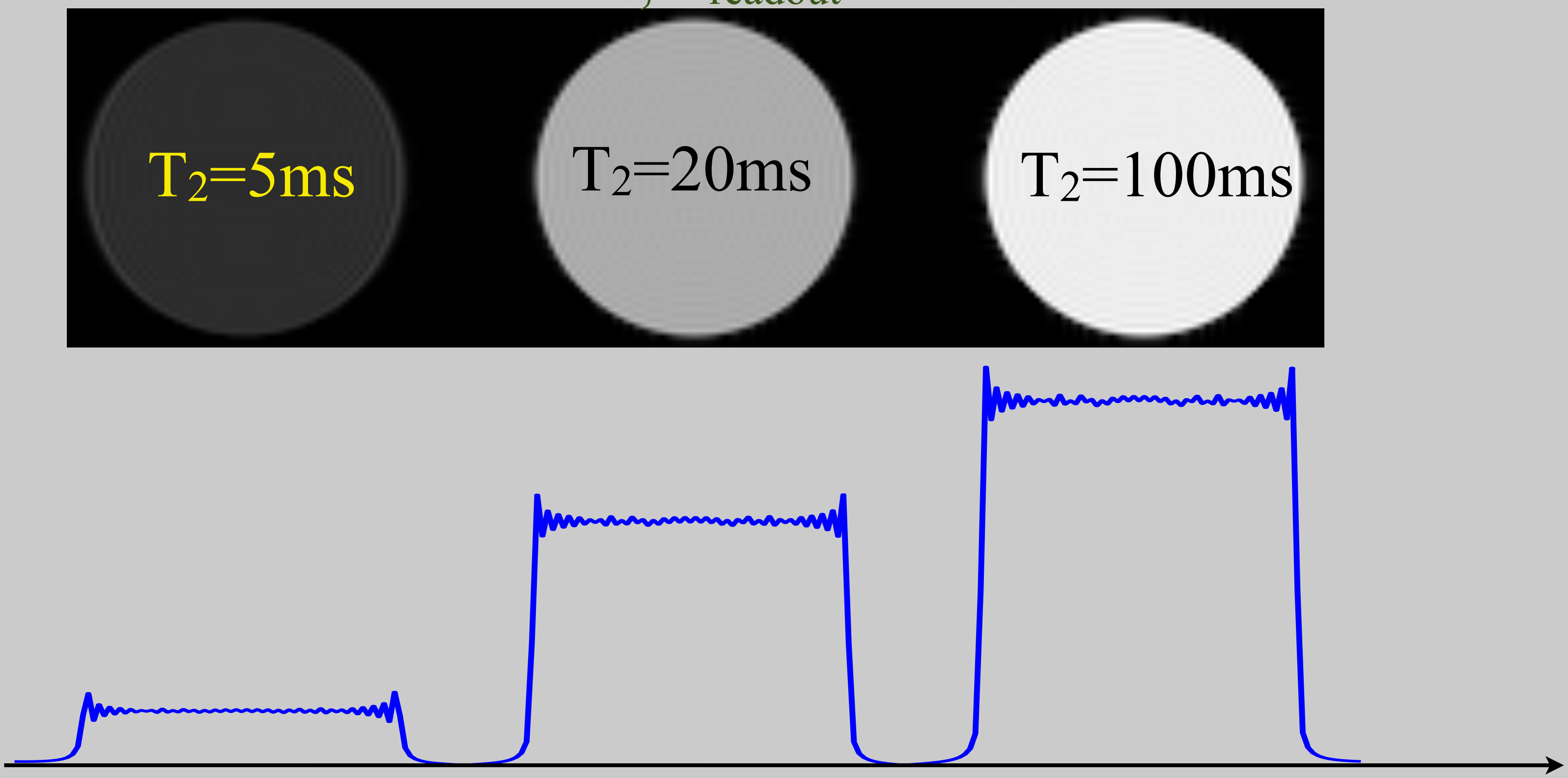
TE=10ms, $T_{readout}$=20ms



Effect of T2 Decay on Imaging

- Two effects:
  - Signal loss by $\exp(-TE/T_2)$ (T2 weighting)
  - Apodization - causes blurring in readout

TE=10ms, $T_{readout}$=20ms



Off - Resonance

- So far, assumed B_0 constant. But B_0 varies due to:
  - Main field inhomogeneity (~ 1ppm)
  - Object magnetic susceptibility
  - Chemical shift

Main Field Inhomogeneity

- Magnet is designed to be homogeneous over a (spherical) volume
- Typical numbers:
  - Bare magnet ~10-100 ppm
  - Shimmed magnet ~1 ppm
    @3T 1ppm is 127Hz

- Generally, main magnet inhomogeneity is <u>not</u> a limitation

Object Susceptibility

- Most biological objects perturb the field

$$\Delta B_{z,\mathrm{tissue}} \approx \chi B_{0,\mathrm{freespace}}$$

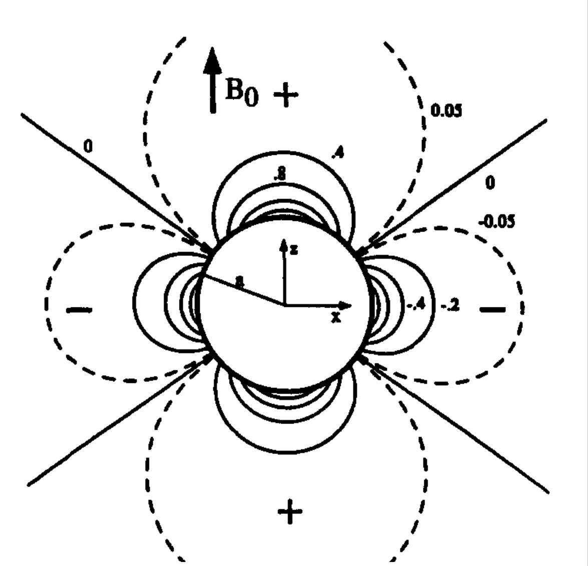
- χ is the magnetic susceptibility
- Larmor frequency lower in tissue than air

  χ_{water} = -9.05ppm w.r.t free-space

  χ_{air} = 0.36 ppm w.r.t free-space

for a sphere:

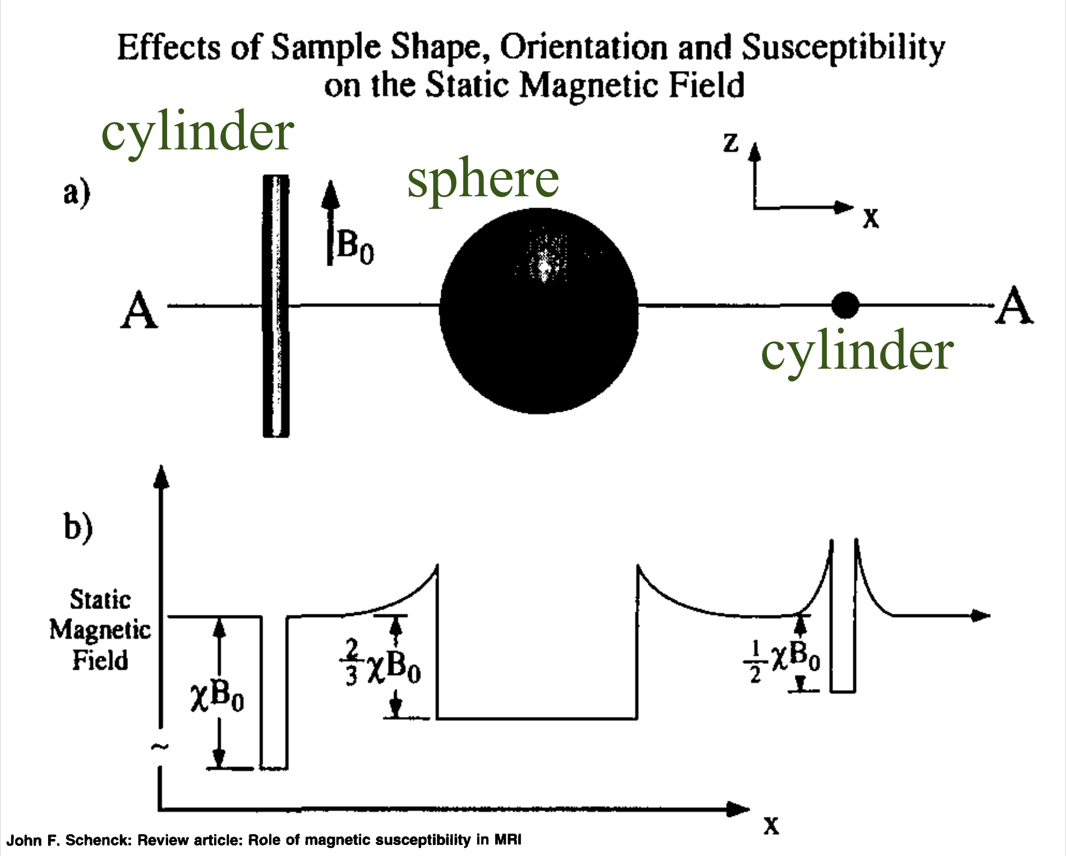
$$\Delta B_z = \frac{\Delta \chi B_0}{3}\left(\frac{a}{r}\right)^3 (3\cos^2\theta - 1)$$



John F. Schenck: Review article: Role of magnetic susceptibility in MRI

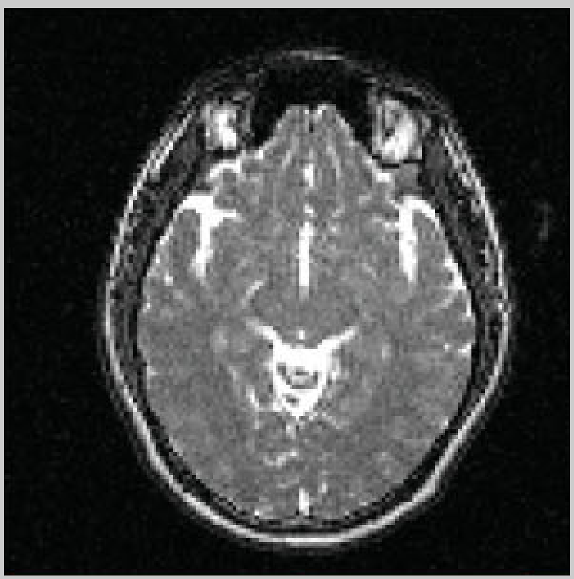
Object Susceptibility

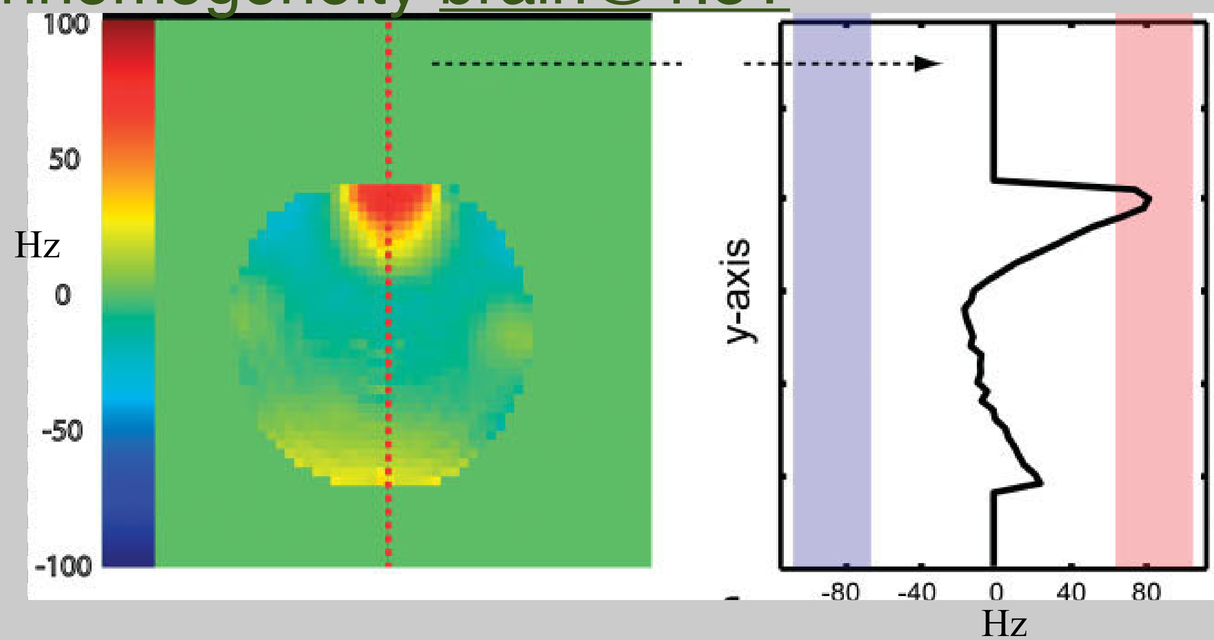
- Complex behavior at boundaries.
  - Depends on $\Delta\chi$ and geometry
  - Typical $\Delta B0 \pm 3$ ppm $(-12 < \chi < -6)$



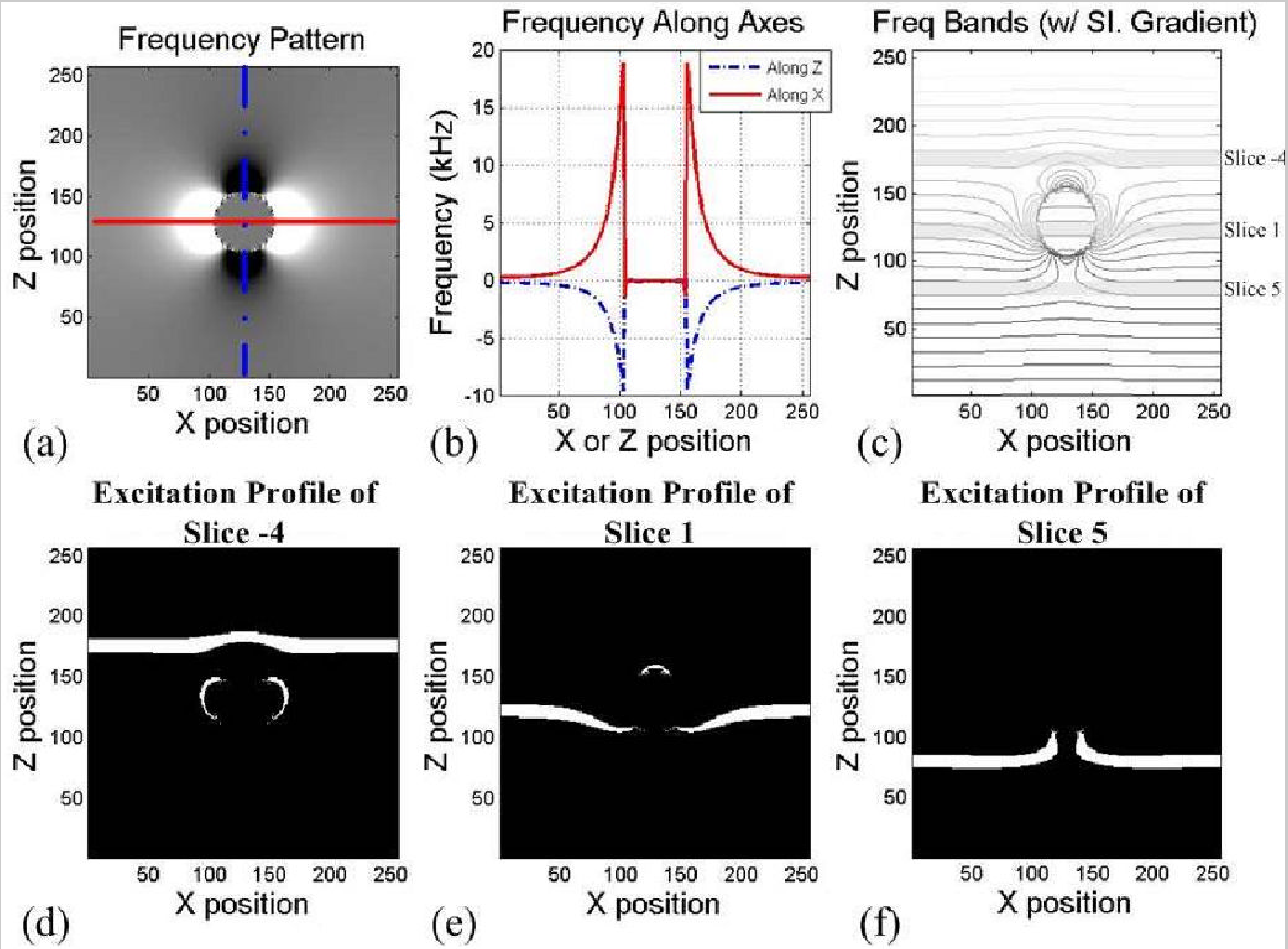
- Problem areas:
  - Brain above sinuses, auditory canals
  - Heart surrounded by lungs
  - Abdomen

Field inhomogeneity brain@1.5T





Macroscopic Effects - Metal Artifacts



Magn Reson Med. 2009 July ; 62(1): 66–76. doi:10.1002/mrm.21967.

Macroscopic Effects - Metal Artifacts

metal artifact

corrected (SEMAC)

- $\chi_{titanium} = 182$

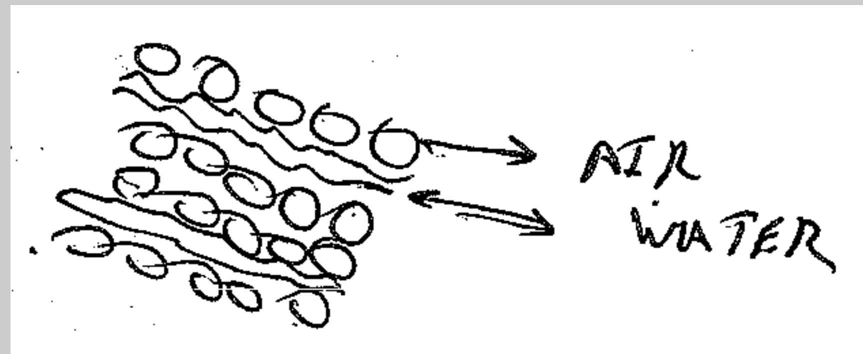
could be a project...

- $\chi_{stainless\ steal}$ (nonmagnetic) = 3520-6700

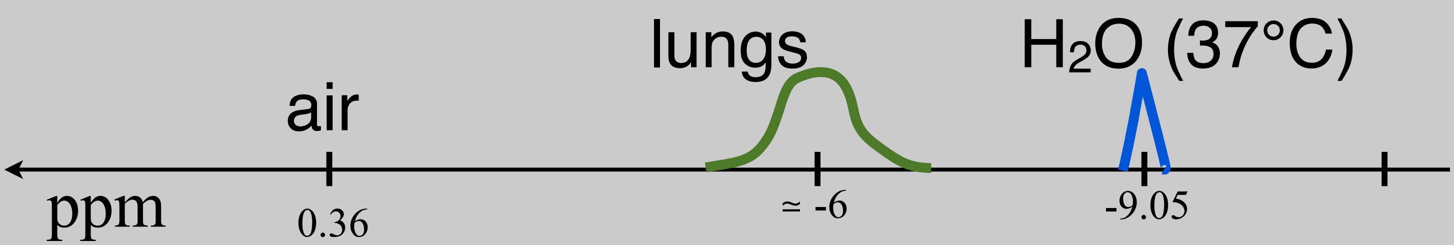
Magn Reson Med. 2009 July ; 62(1): 66–76. doi:10.1002/mrm.21967.

Microscopic Effects

- Lungs:
  - –Approx: 1/6 tissue, 5/6 air



- Result:
  - – Distribution of field/frequencies



  - –Tells a lot about microstructure of tissue

Blood

- +Water χ=-9.05
- +Hemoglobin molecule (deoxy) χ=0.15
- +Red Blood cells (deoxy) χ=-6.52
- *Deoxy blood χ=-8.77
- *Oxy blood χ=-9.05

*Magnetic Resonance in Medicine 68:863–867 (2012)

+ John F. Schenck: Review article: Role of magnetic susceptibility in MRI

Chemical Shift

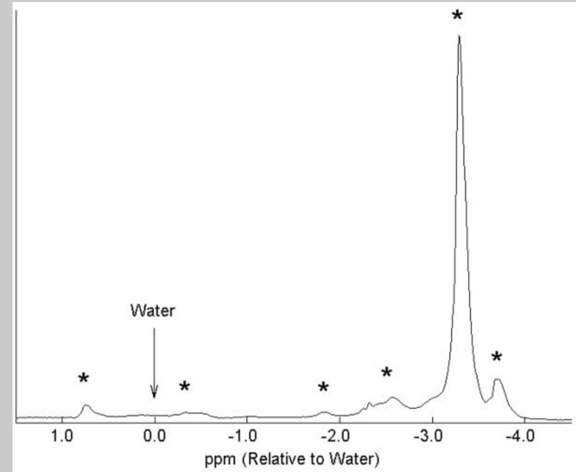
- Protons in complex molecules are “shimmed” by adjacent spins and electrons

$$B_{\mathrm{cs}} = B_0(1 - \sigma)$$

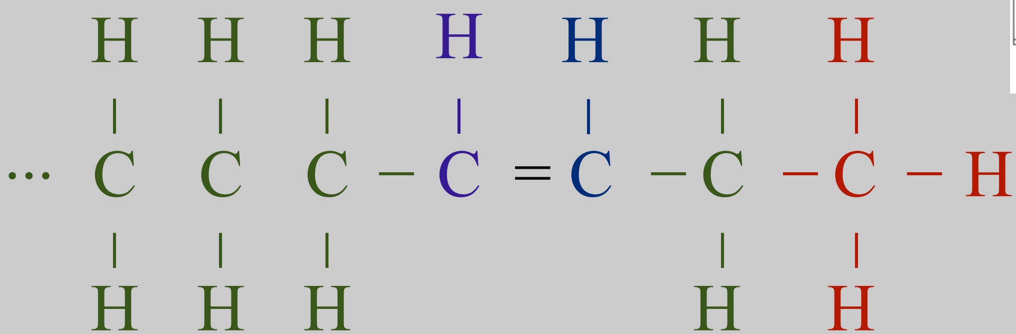
- σ is a shielding constant - depends on molecular structure
- Example: Lipids

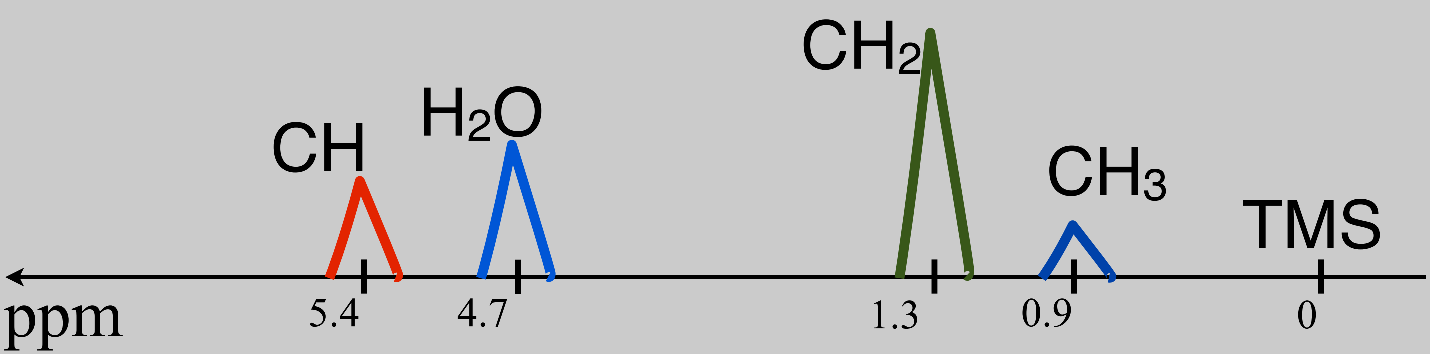
Chemical Shift

- Example: Lipids



J Magn Reson Imaging. 2009 June; 29(6): 1332–1339.





Lipids from CH2 is 3.4ppm below water
@3T ≈ 440 Hz

Heterogeneous Tissue

- Tissue is a combination of
  - Chemical shift
  - Susceptibility
  - Geometry
- Results are complex
  - Interesting cases:
    - Blood (fMRI)
    - Lungs
    - Trabecular bone
    - Iron in brain / liver

Effect on Imaging

- Magnitude
- Phase
- Geometric
- Blurring

- All depend on spatial scale we look at and acquisition strategy