Artifacts, ghosts, and phantoms:
An archaeological tour of MR Imaging

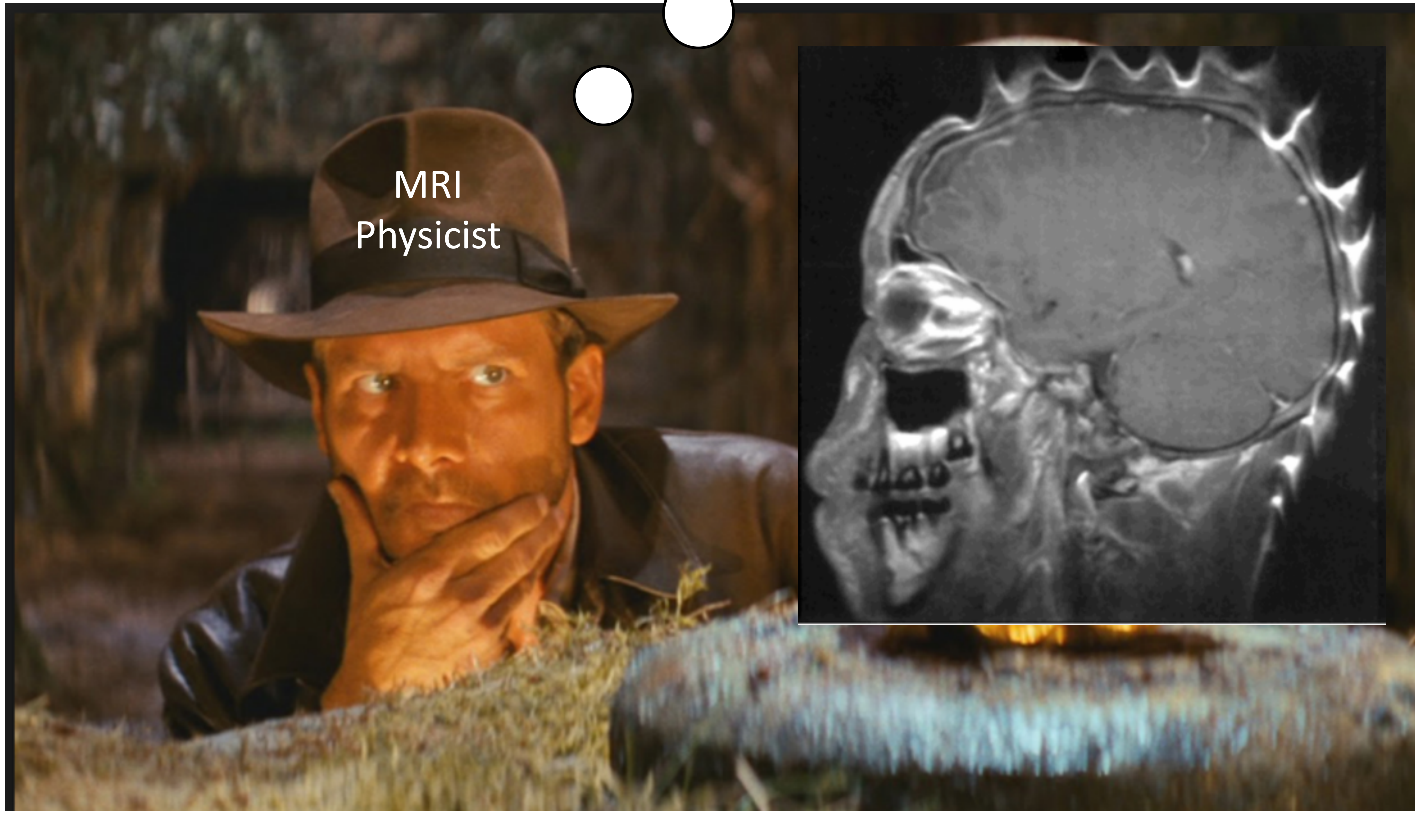
Jason Stockmann

Why N How

Oct. 31, 2019

MRI physicist =
Professional artifact hunter

Interesting…
What kind of artifact is this…?
Where does it come from…?
How was it made…?



Acknowledgements

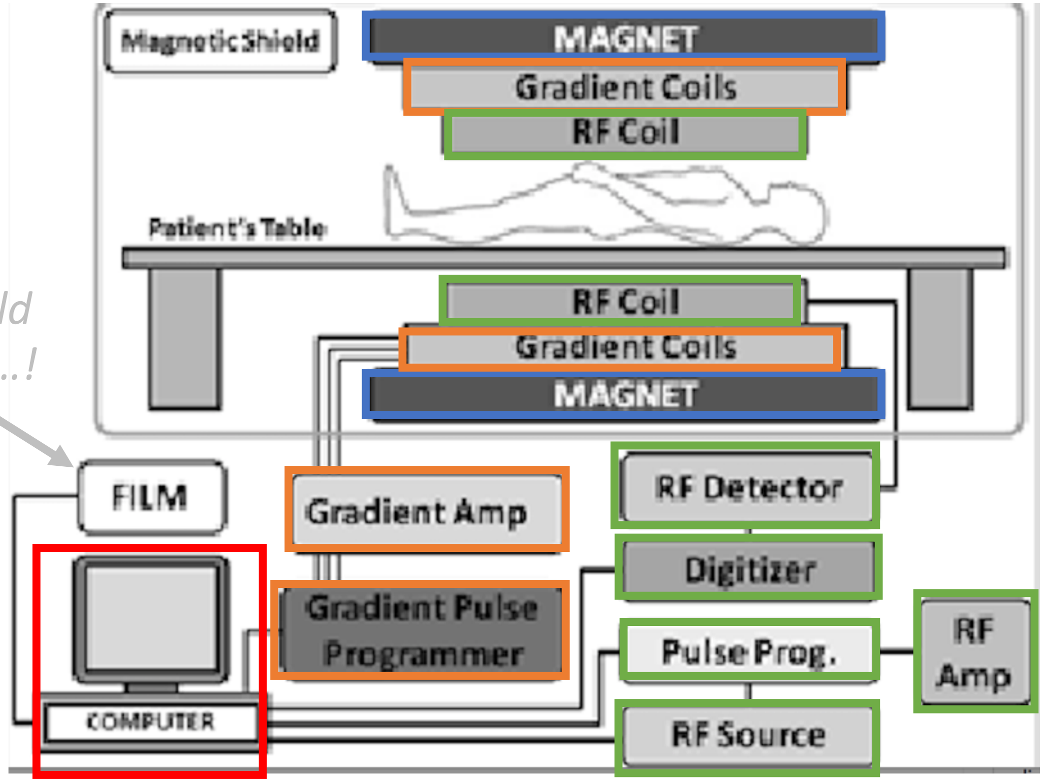
- Most of the slides borrowed from the lecture notes and presentations of Lawrence Wald, Todd Constable, Jon Polimeni, and Doug Noll

Why does MRI have such a wide variety of image artifacts?

- MRI requires seamless integration and interplay of **magnet**, **gradient coil system**, **RF system**, and **pulse sequence computer**, each of which is a complicated subsystem.

- ***Human body*** also moves and interacts with RF and B_0 magnetic fields → both static and dynamic (physiological) effects

Very old figure…!



Learn how to pinpoint where the source of your artifact is hidden in the “k-space domain”… *You need to know where to look!*

Understanding artifacts

- Data is acquired in **k-space domain** → 2D or 3D Fourier transform of the image
- Learn to think about what's going wrong with data collection in k-space → use p**roperties of Fourier transform** to see what effect these errors will create in **image domain**

Fourier Transform

Jean-Baptiste Joseph Fourier
(1768-1830)

- Shows you the spatial frequencies that are present in the image (or audio signal, etc.).

Steps:

(1) Multiply input function (image) by *spatial harmonic (sinusoid)* with a given frequency
(2) Integrate over the whole space (1D, 2D, or 3D) → Gives you one point in k-space
(3) Change spatial frequency (*k*) and repeat steps (1) and (2) until you have populated all of k-space

- One k-space point tells you how much of the corresponding spatial harmonic is needed to build the image. When you add all the harmonics together, the complex-valued functions interfere constructively and destructively in a way that forms the image features.

$$S(k_x) = \int_x M_0(x) e^{-2\pi j k_x x} dx$$

Measured signal is Fourier integral of the projection image!

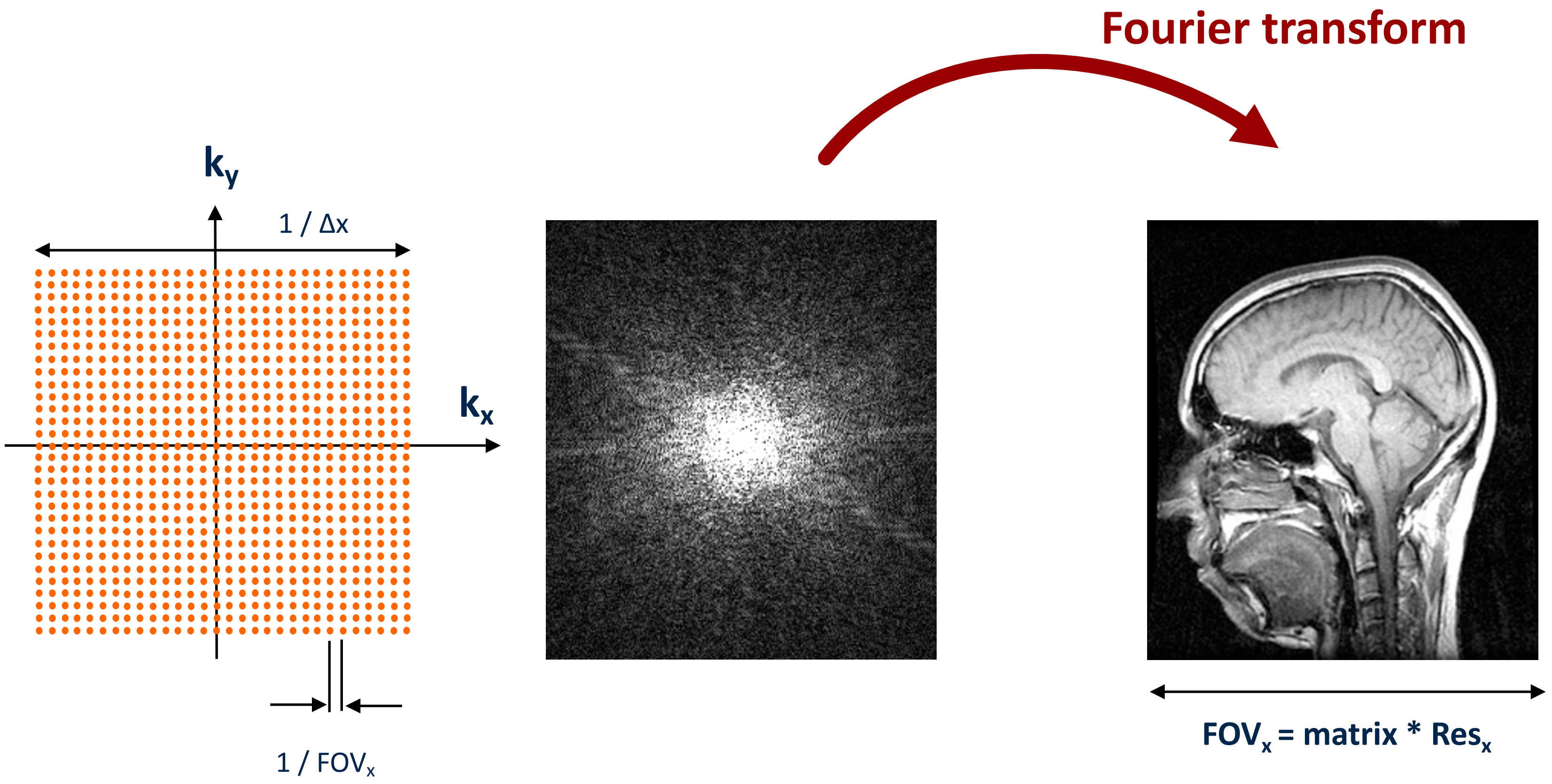
1D Fourier transform along *x*

M_0 is the object

k_x is spatial frequency (k-space coordinate)

In practice we use the discretized version of this formula.
Number of k-space points depends on size of image grid

You've measured:
intensity at a spatial frequency...



Slide courtesy of Lawrence Wald, A. A. Martinos Center, MGH

Planning your image…

Figure out
what you want

FOV_x = matrix * Res_x

Figure out your
kspace params

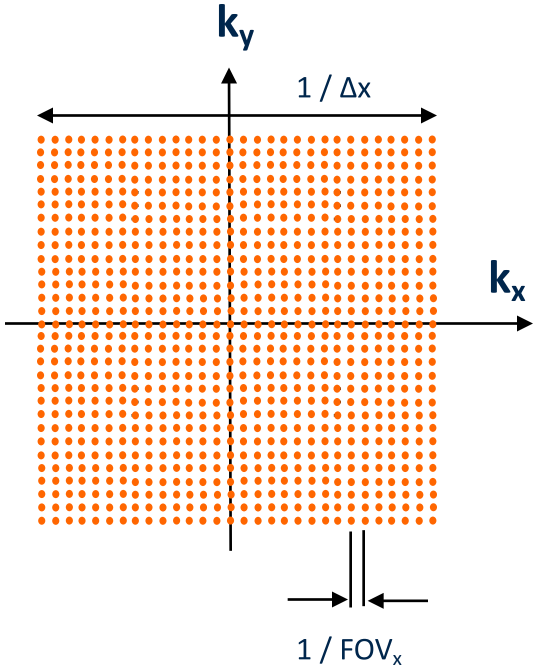
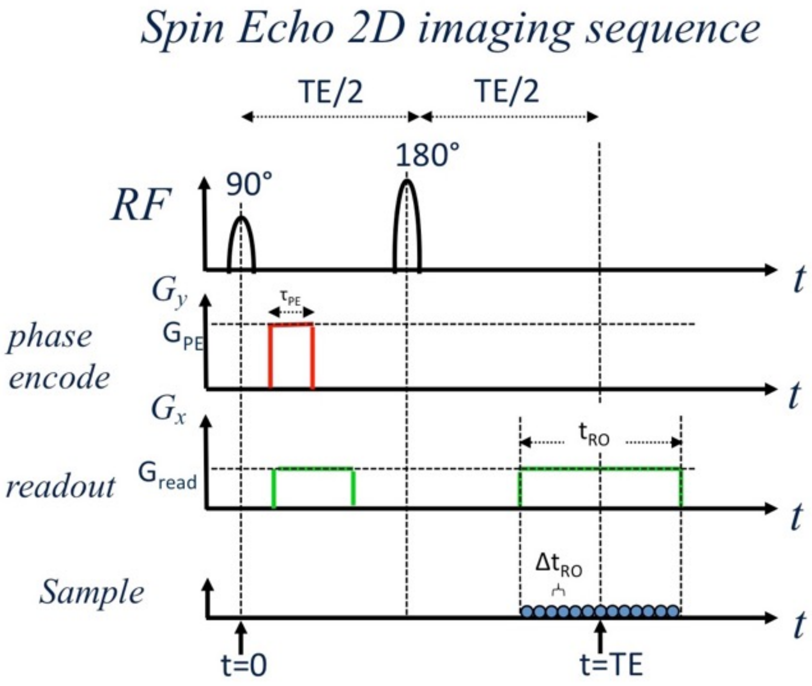
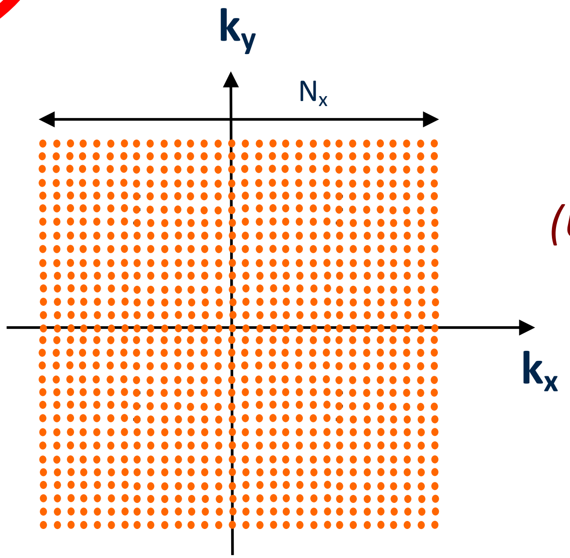


Figure out your gradient
params



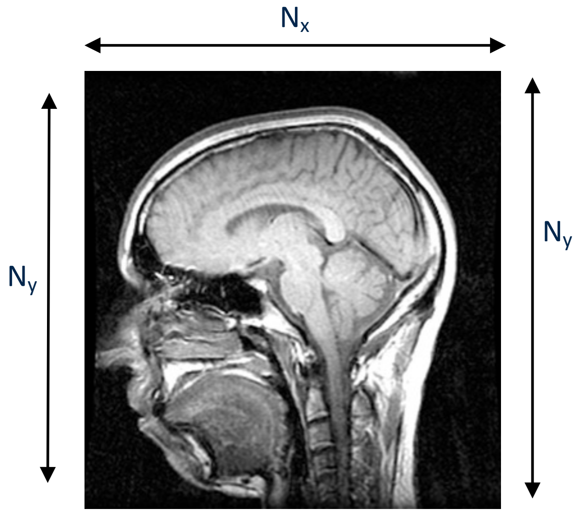
Planning your image…

Data lands in integer indexed matrix



Matlab fft2
(Unitary, reversible operator)

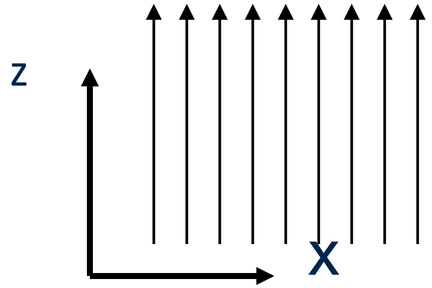
Ta Da!



Slide courtesy of Lawrence Wald, A. A. Martinos Center, MGH

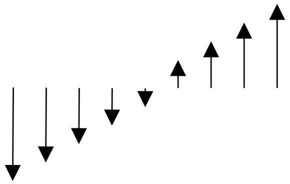
Gradient: Basics of image encoding

B_o



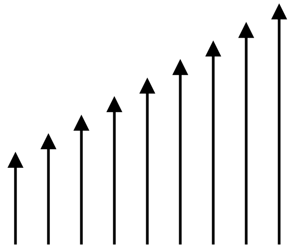
Uniform magnet

$G_x\,x$



Field from gradient coils

$B_o + G_x\,x$



Total field

$$G_x = \partial B_z / \partial x$$

$$\vec{B}(x) = (B_0 + G_x x)\ \hat{z}$$

$$\vec{B}(x,y,z) = (B_0 + \vec{G}\cdot\vec{r})\hat{z}$$

$$\omega(x) = \gamma(B_0 + G_x x)$$

$$\varphi(x) = \int_0^{\tau} \omega(\tau)\,d\tau$$

Slide courtesy of Lawrence Wald, A. A. Martinos Center, MGH

Recasting the signal equation

Science/engineering principle #1: cast your problem into the form of a problem with a known solution…

Change variables:

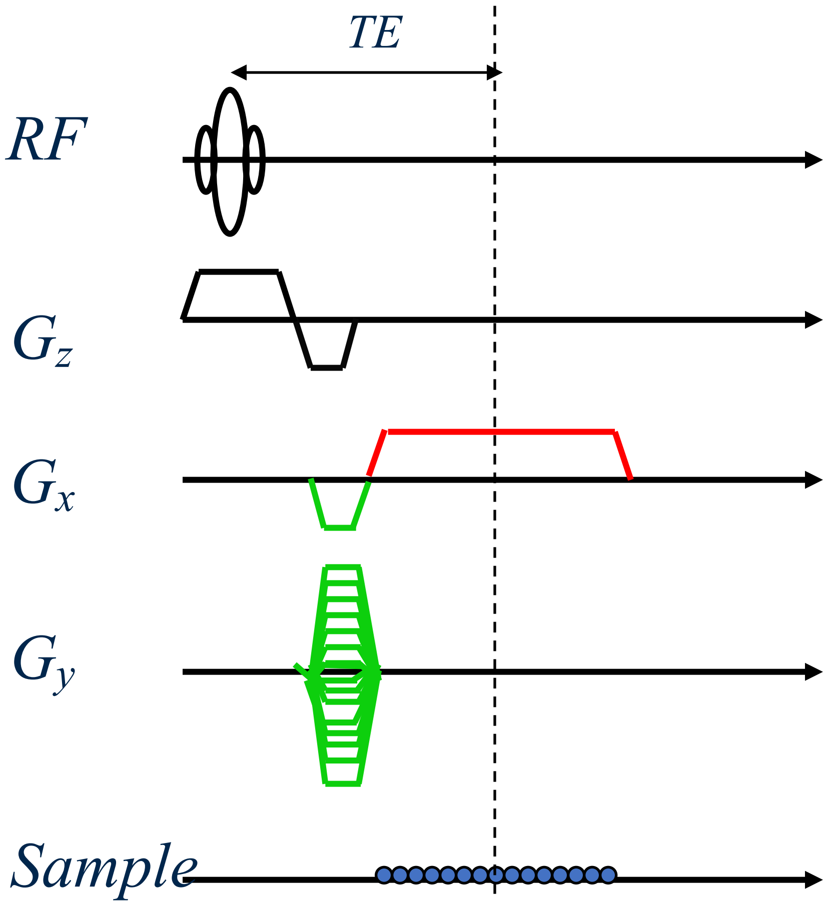
$$k_x(t) \equiv \frac{1}{2\pi}\gamma\int_0^t G_x(\tau)\,d\tau$$

$$S(k_x) = \int_x M_0(x) e^{-2\pi j k_x x}\,dx$$

Measured signal is Fourier integral of the projection image!

Slide courtesy of Lawrence Wald, A. A. Martinos Center, MGH

$$k_x(t) \equiv \frac{1}{2\pi}\gamma \int_0^t G_x(\tau)\,d\tau \qquad k_y(t) \equiv \frac{1}{2\pi}\gamma \int_0^t G_y(\tau)\,d\tau$$



One shot per readout line…

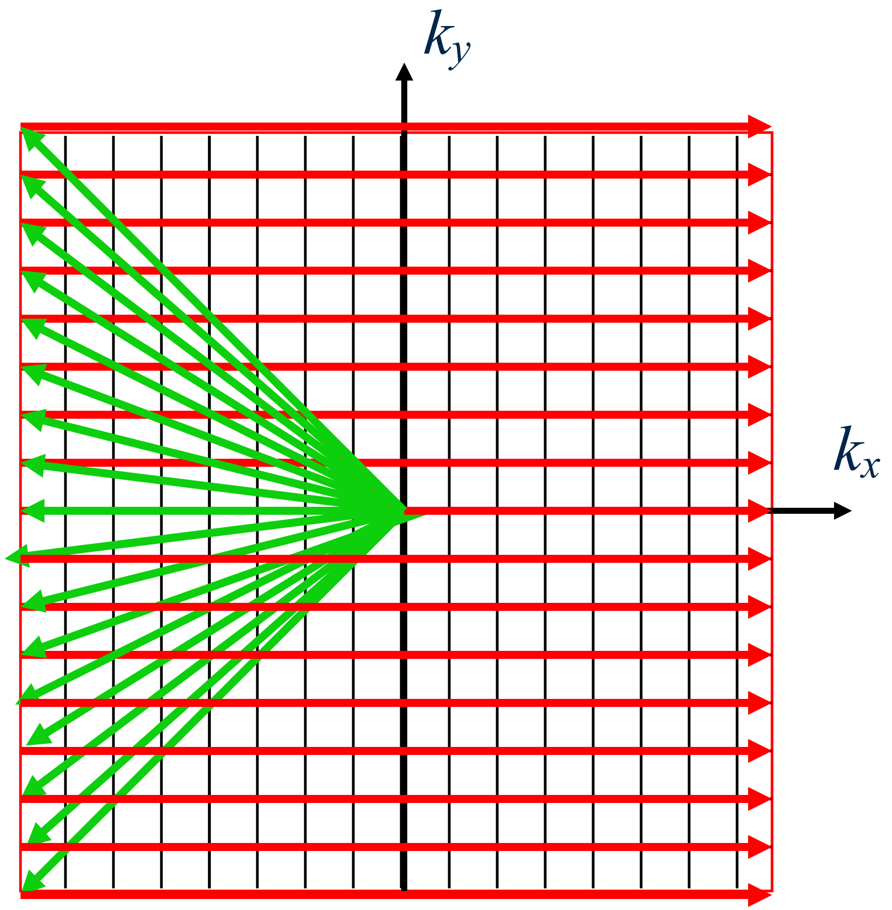
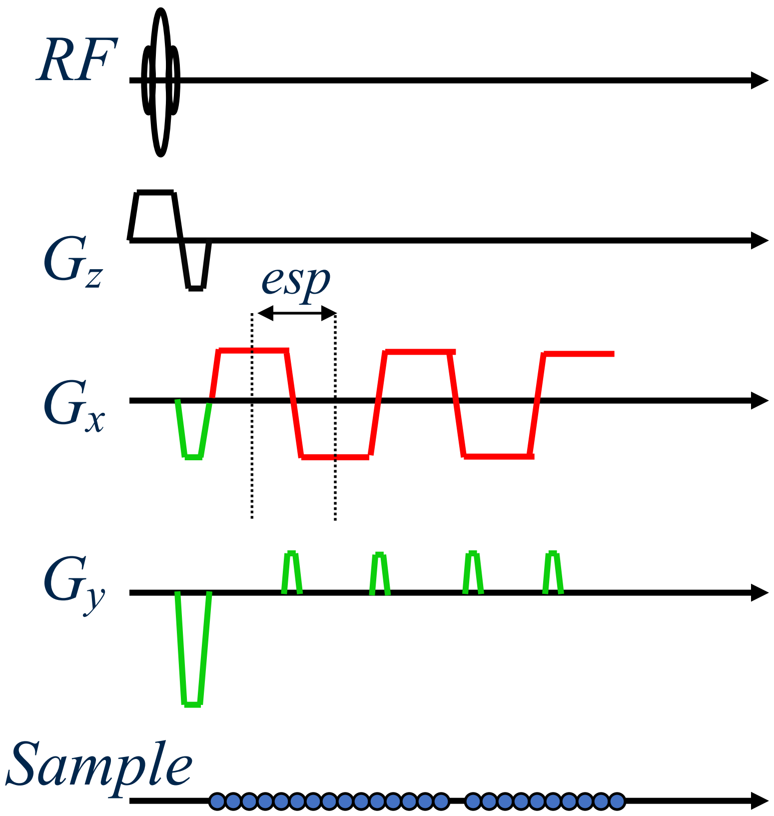
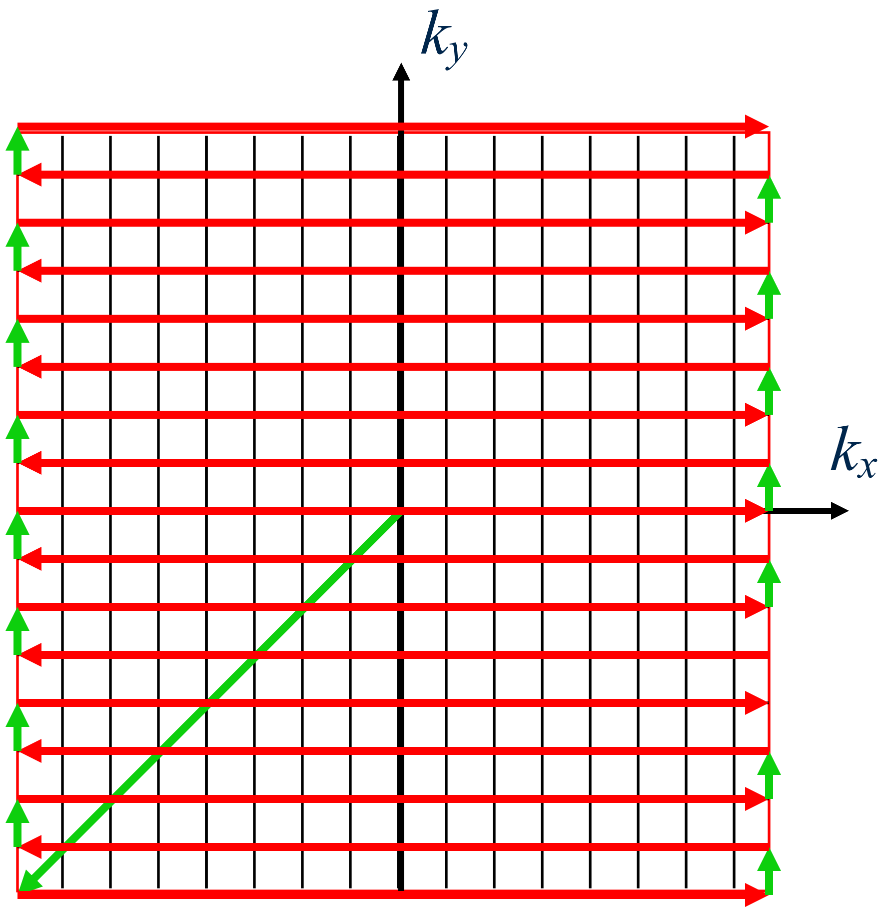


Image encoding strategies:
Echo Planar Imaging



All lines in one shot…

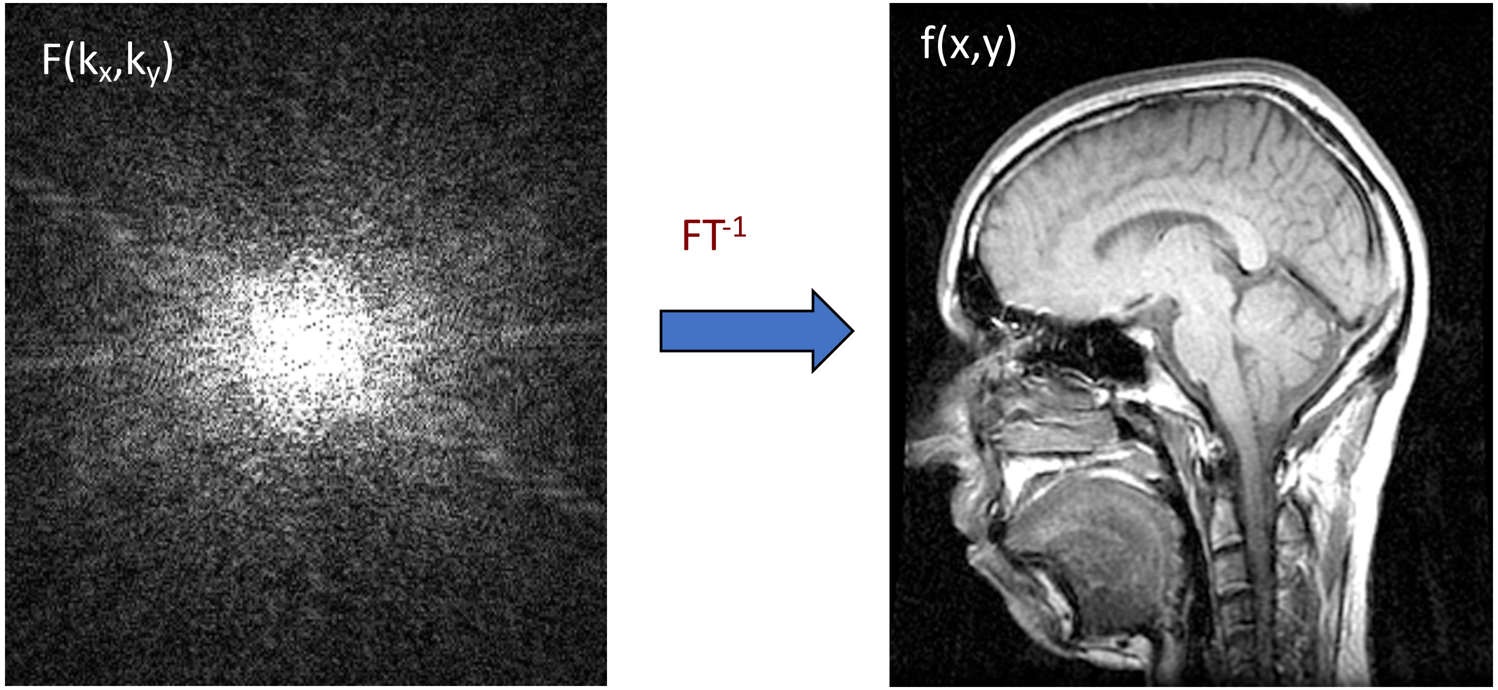


Slide courtesy of Lawrence Wald, A. A. Martinos Center, MGH

Top 5 features of Fourier transform

1) Information content is equal in the two domains.

(inverse FT recovers the periodic function)



256 x 256 complex #s

256 x 256 complex #s

Slide courtesy of Lawrence Wald, A. A. Martinos Center, MGH

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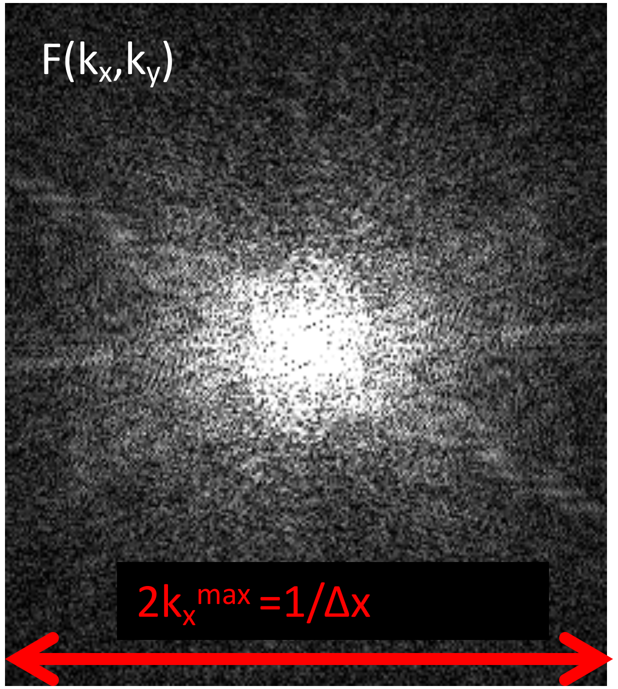
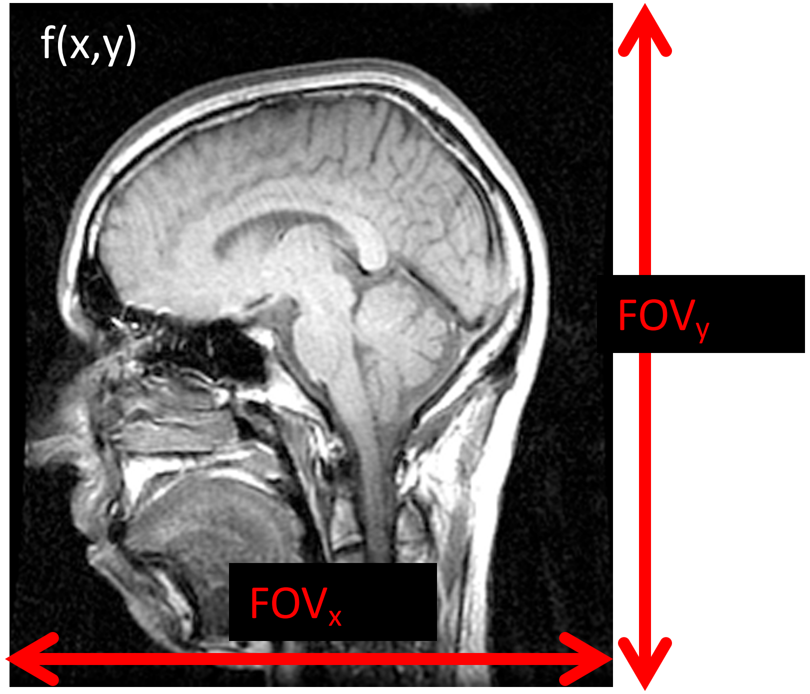


FT^{-1}



256 x 256 complex #s

$\Delta k_x = 1/FOV_x$

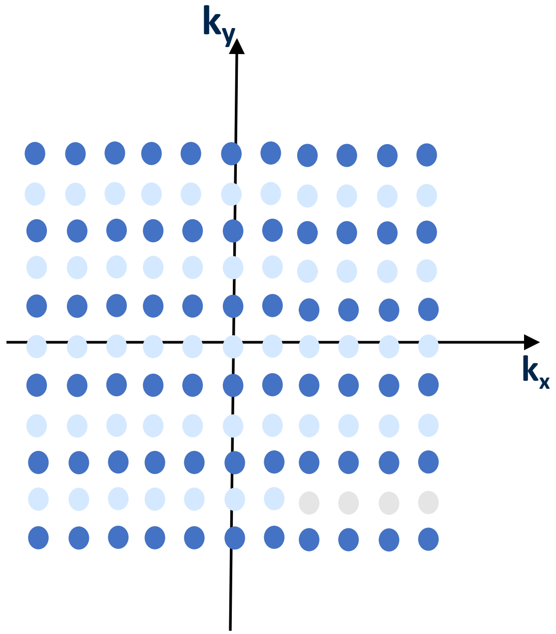
256 x 256 complex #s

Δx= pixel size

Slide courtesy of Lawrence Wald, A. A. Martinos Center, MGH

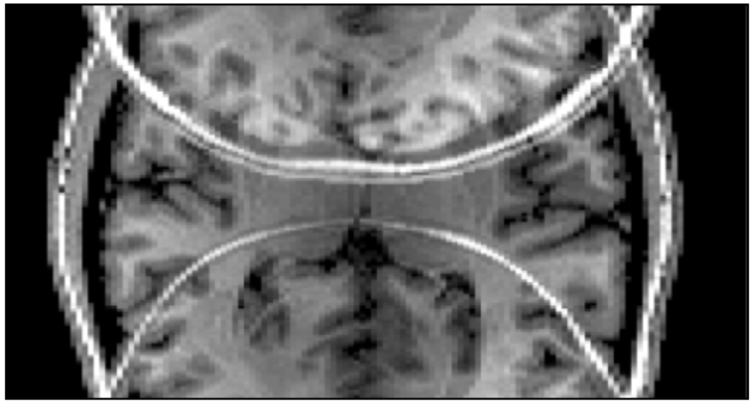
Top 6 features of Fourier transform

If you make FOV too small (Δk to big), you will get aliasing (image wrap).



FT^{-1}

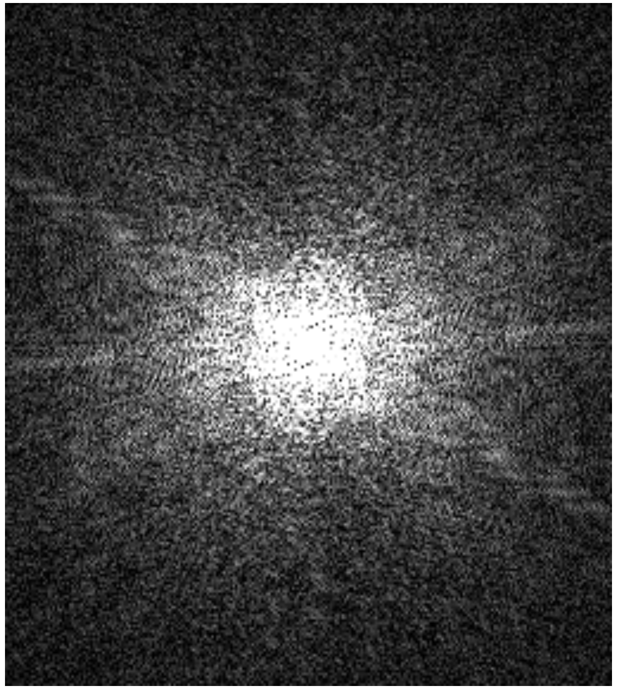
Only green samples



Slide courtesy of Lawrence Wald, A. A. Martinos Center, MGH

Top 5 features of Fourier transform

2) Even though a real object has 0 phase, phase is incredibly important in k-space.



256 x 256 complex #s

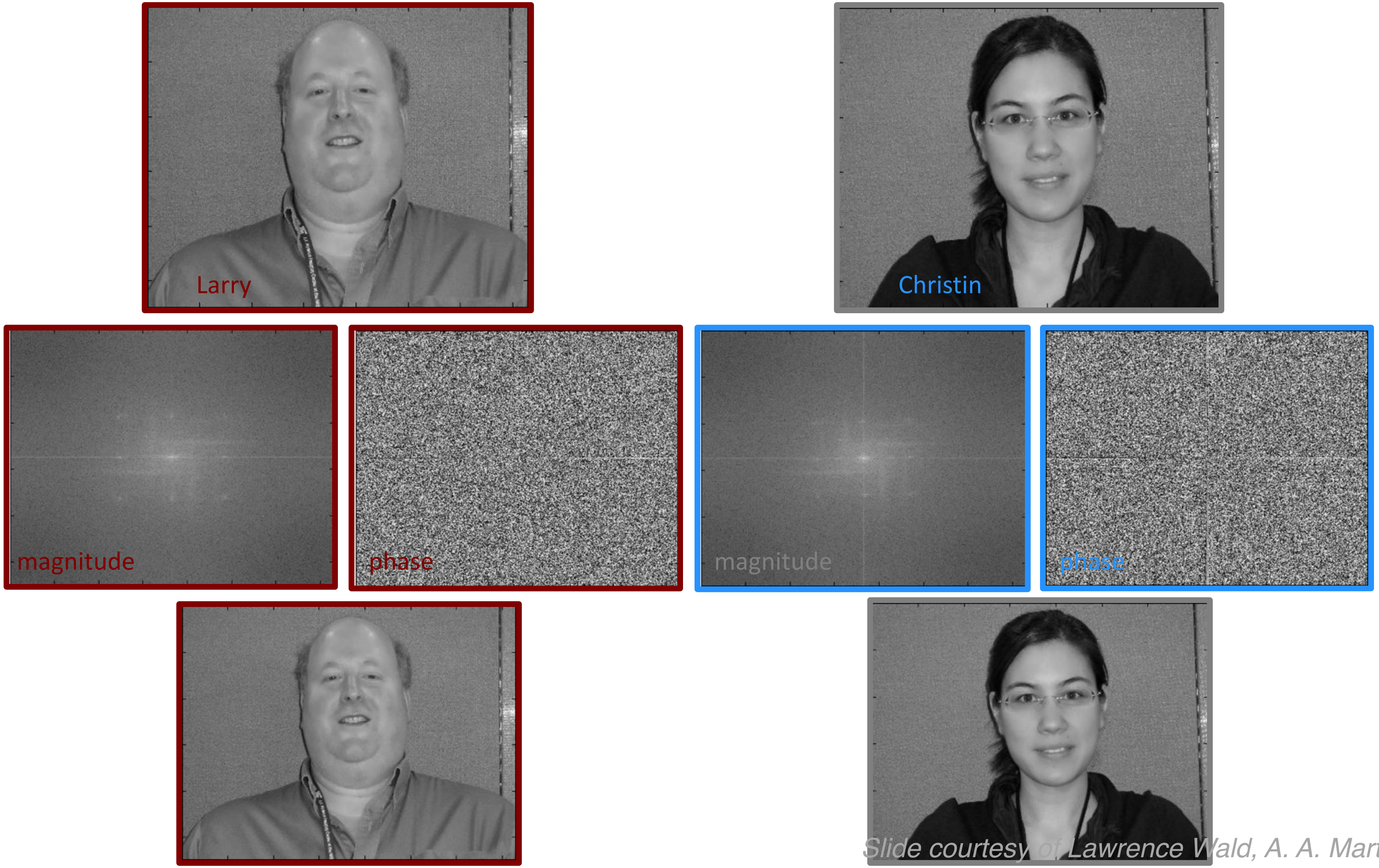
256 x 256 complex #s

Slide courtesy of Lawrence Wald, A. A. Martinos Center, MGH

Where is the majority of the information?

magnitude or phase?

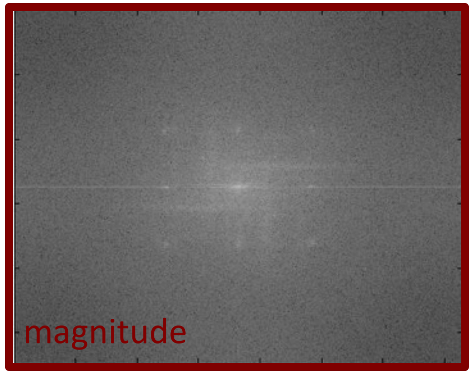
K-space:

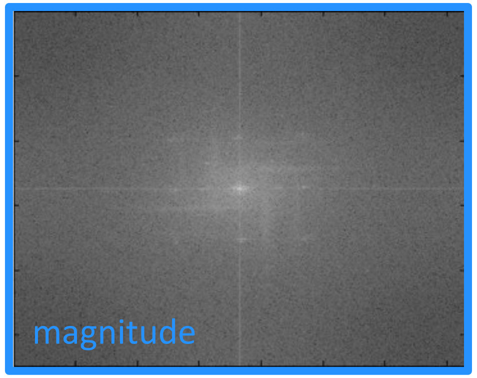


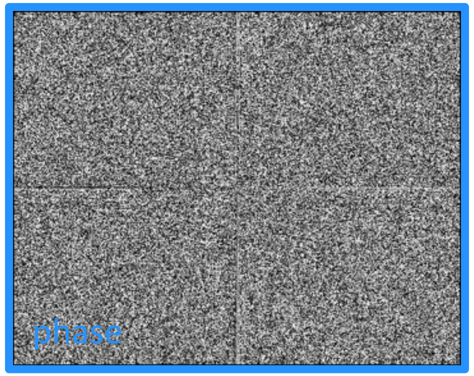
Slide courtesy of Lawrence Wald, A. A. Martinos Center, MGH

Where is the majority of the information?

magnitude or phase?







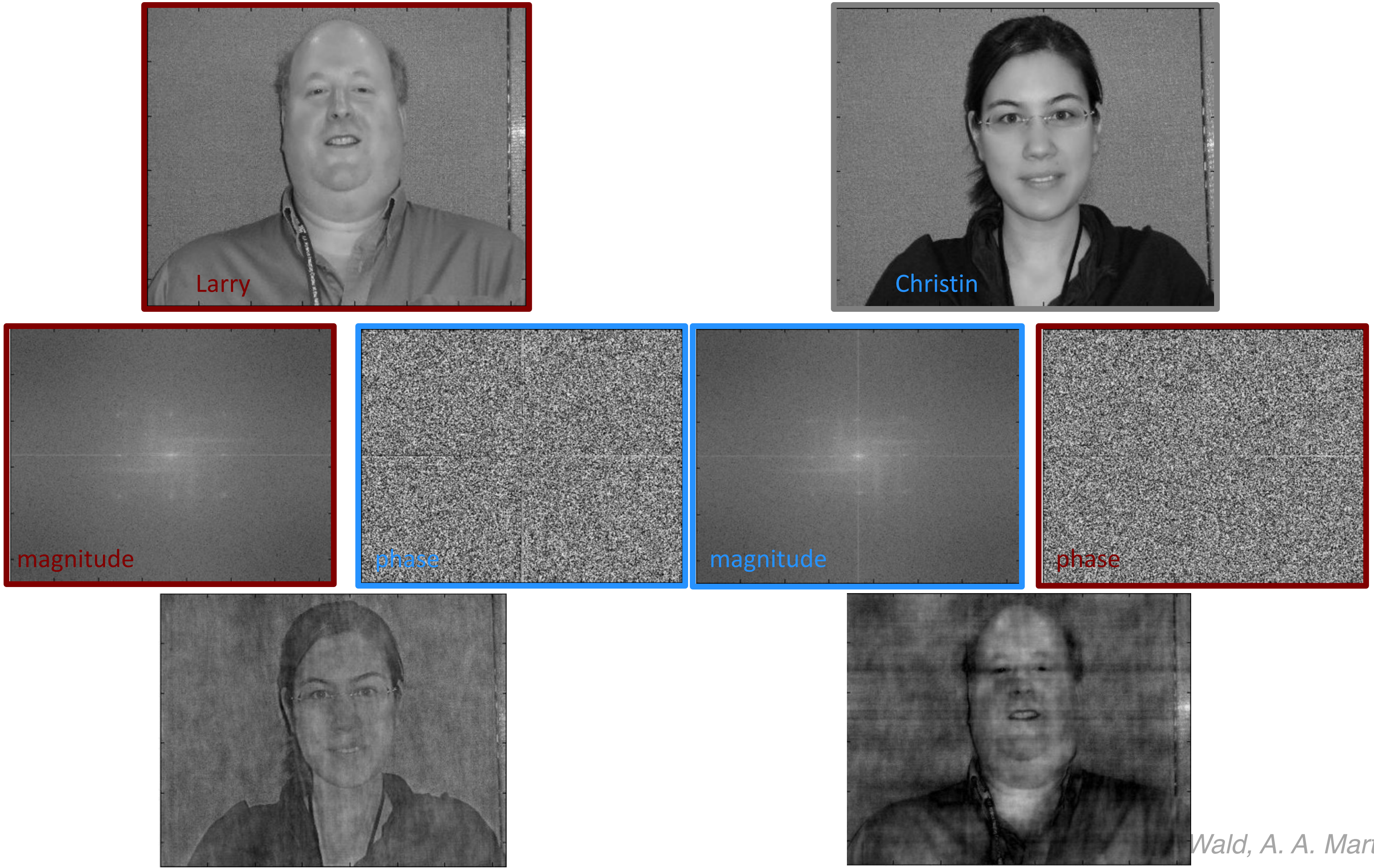
?? ??

1) Larry (mag. dominate) Christin
2) Christin (phase dominate) Larry
3) Mutant monster (both critical) Mutant monster

Slide courtesy of Lawrence Wald, A. A. Martinos Center, MGH

Where is the majority of the information?

magnitude or phase?

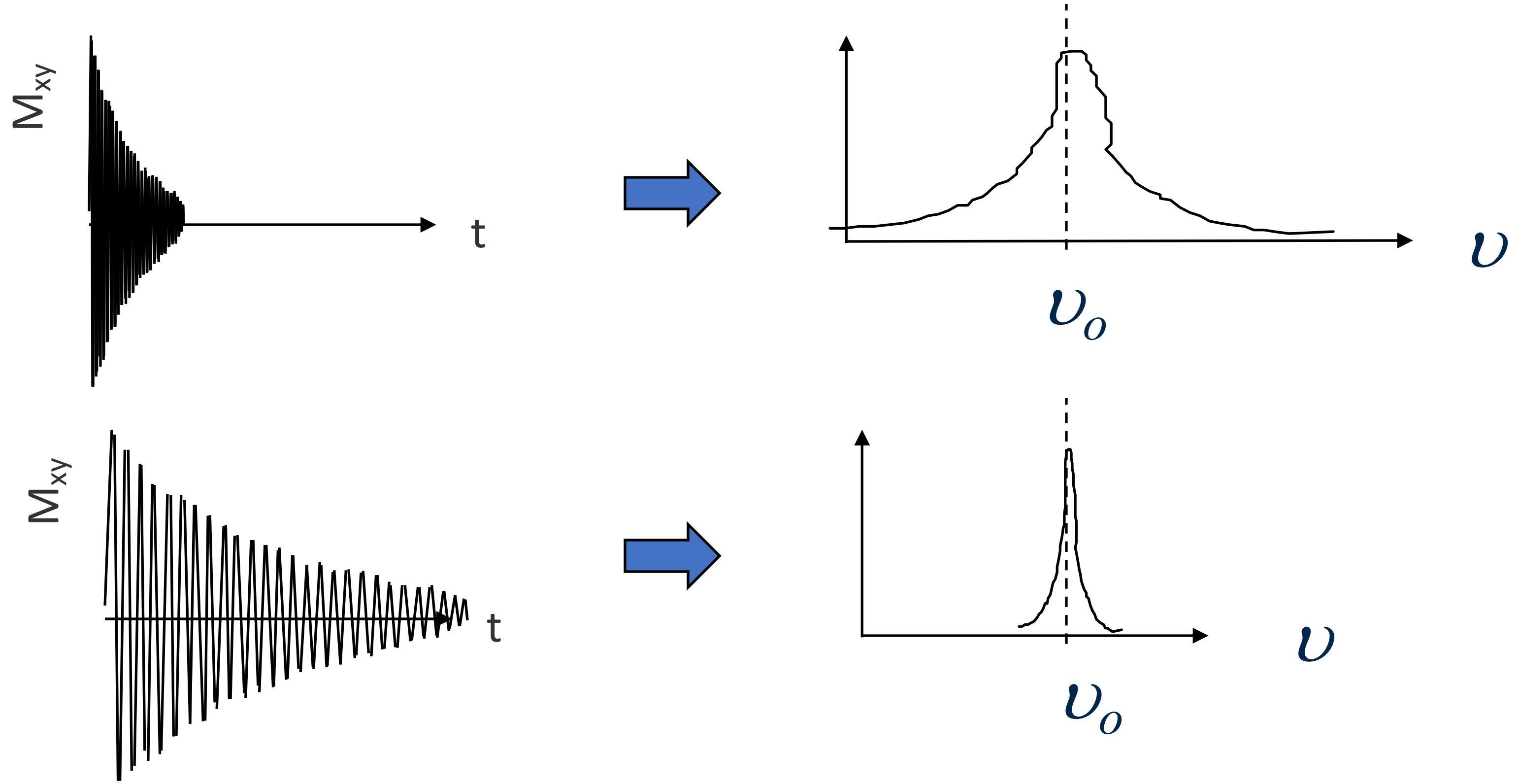


Wald, A. A. Martinos Center, MGH

Top 5 features of Fourier transform

3) Narrow in one domain is wide in the other.

Time/frequency domains



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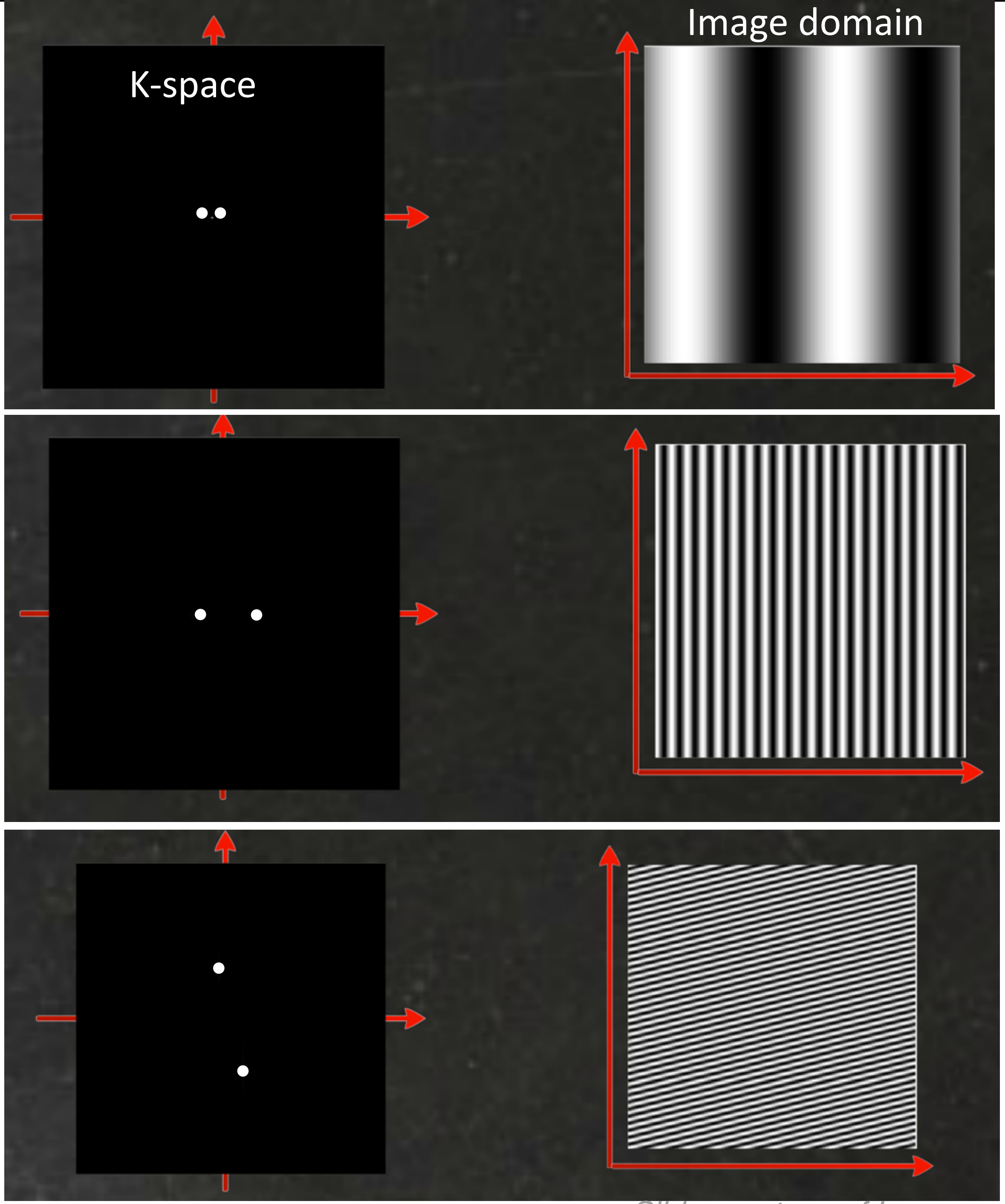
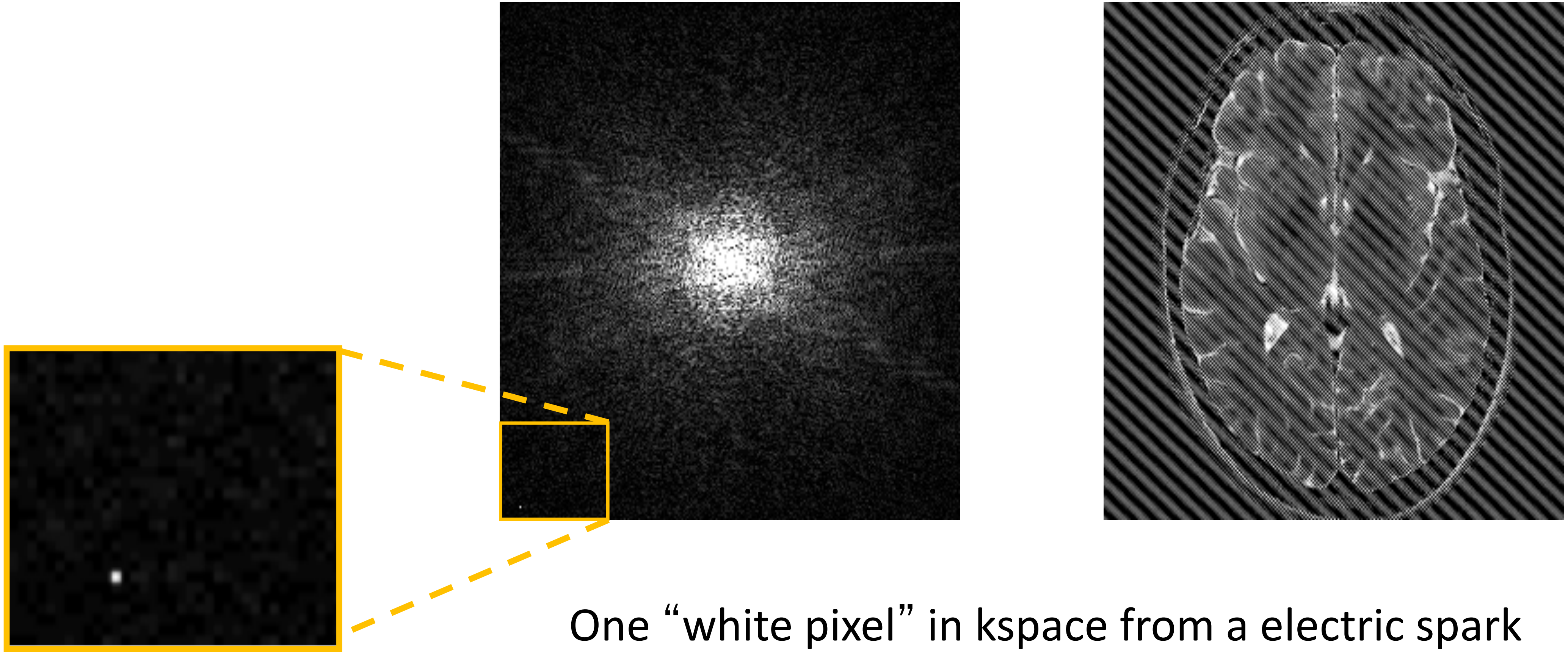


Slide courtesy of Lawrence Wald, A. A. Martinos Center, MGH

Top 5 features of Fourier transform

3) Narrow in one domain is wide in the other.

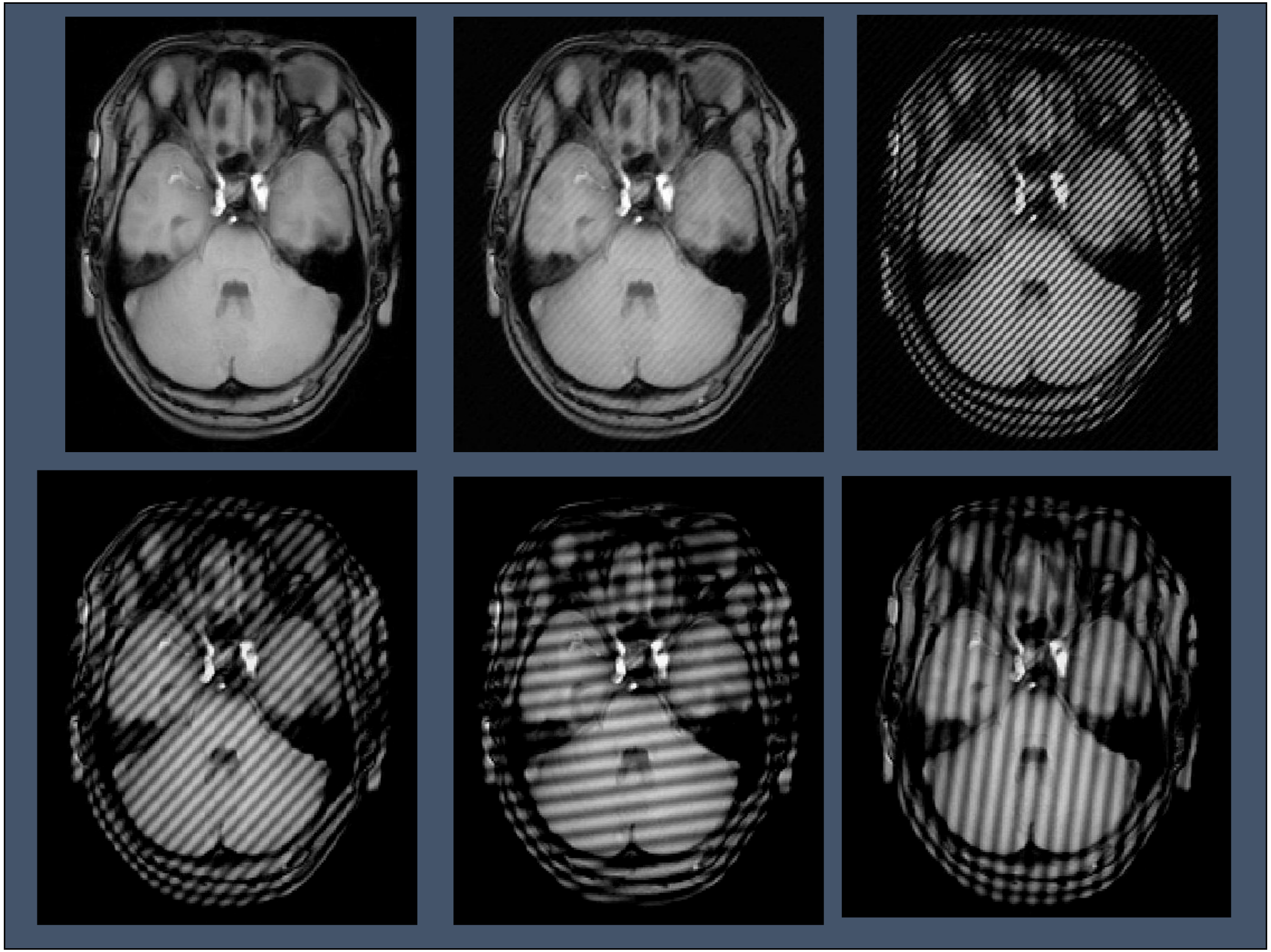
Kspace/space domains



One “white pixel” in kspace from a electric spark

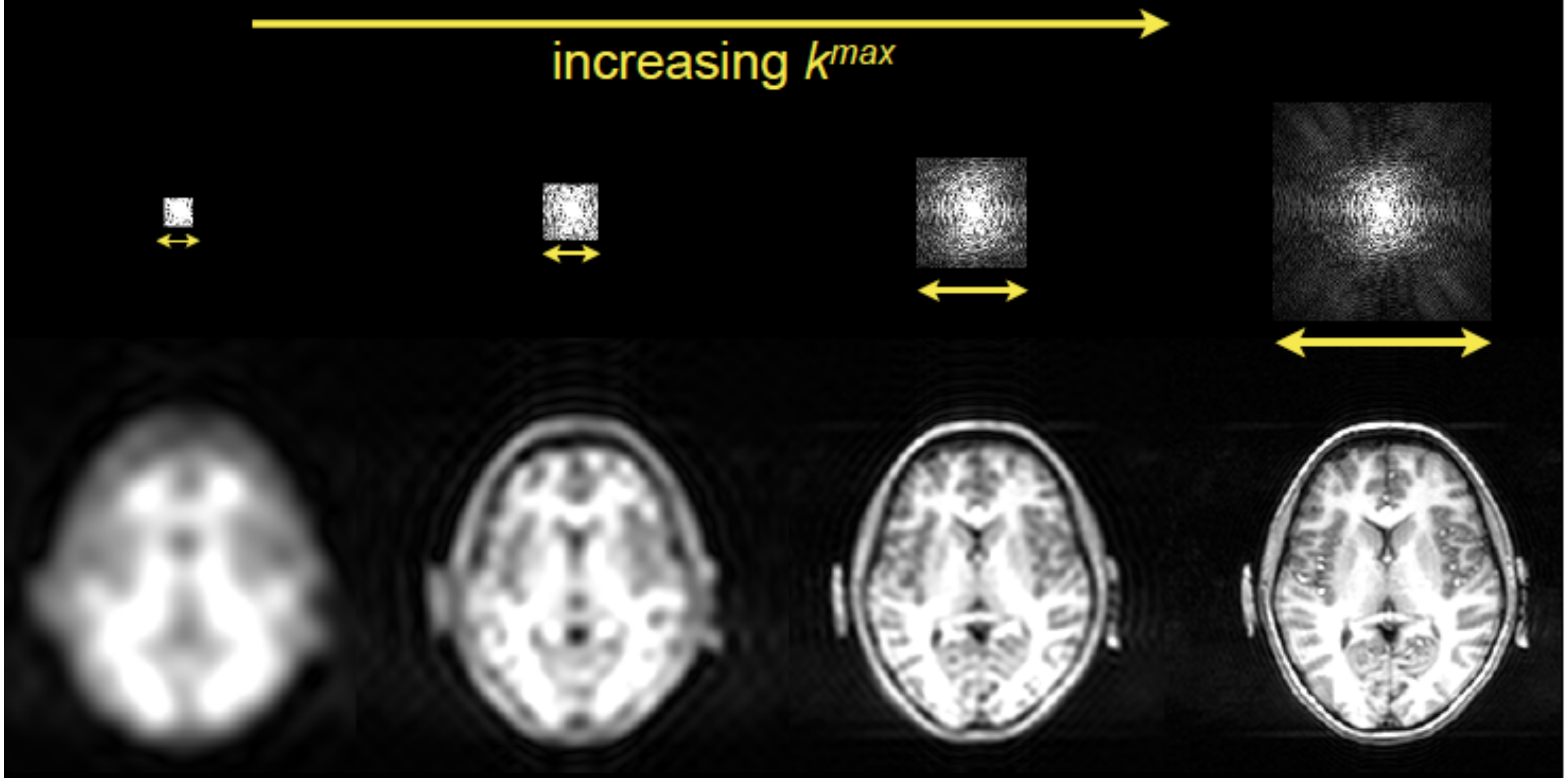
Slide courtesy of Lawrence Wald, A. A. Martinos Center, MGH

Single Spike in Raw Data: Only Location and Amp of Spike is Changing



Slide courtesy of Todd Constable, Yale Univ.

Maximum frequency in k-space

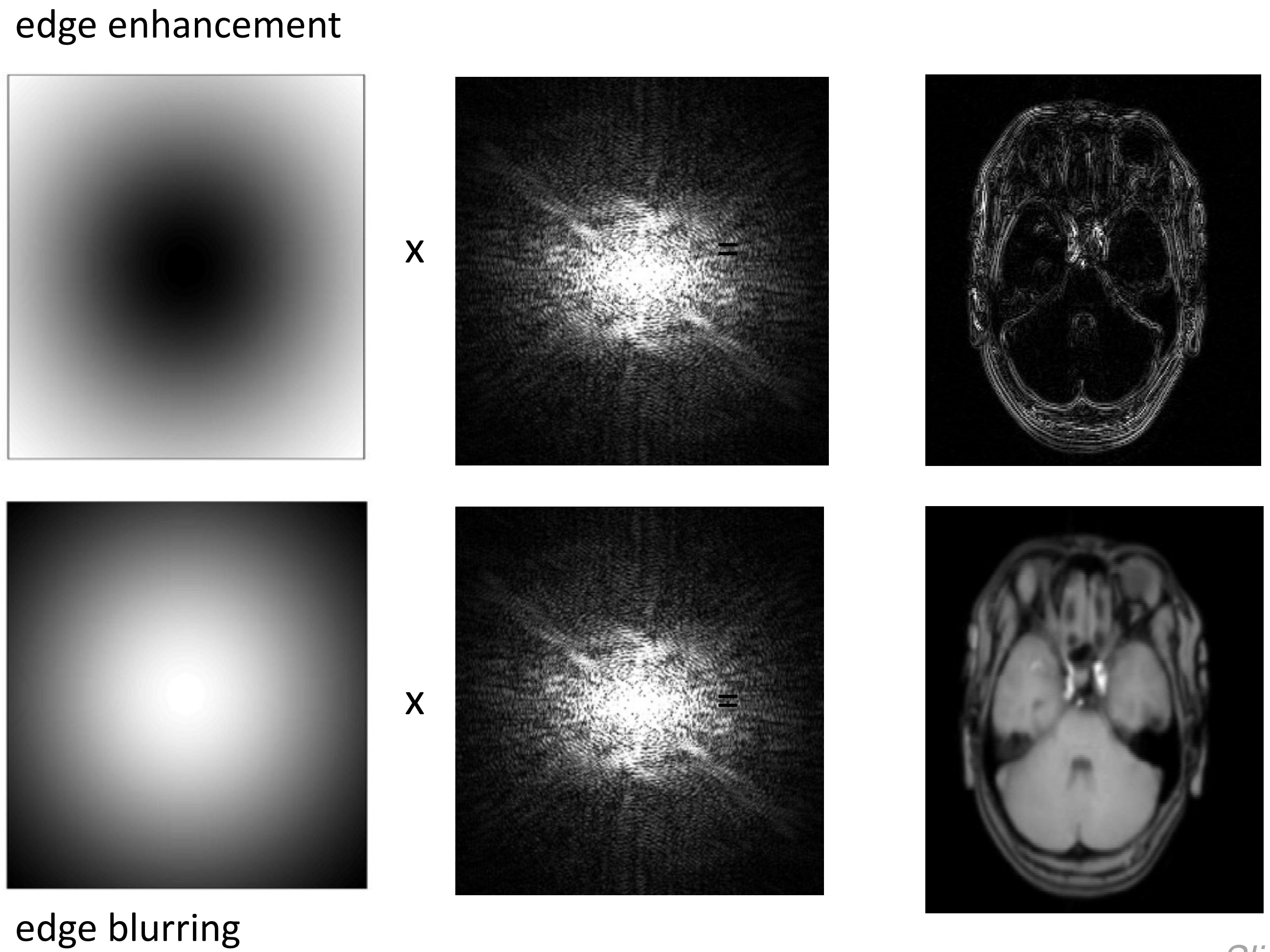


k^{max} determines image resolution

Large k^{max} means high resolution !

Slide courtesy of Lawrence Wald, A. A. Martinos Center, MGH

Filtering and k-space



Slide courtesy of Todd Constable, Yale Univ.

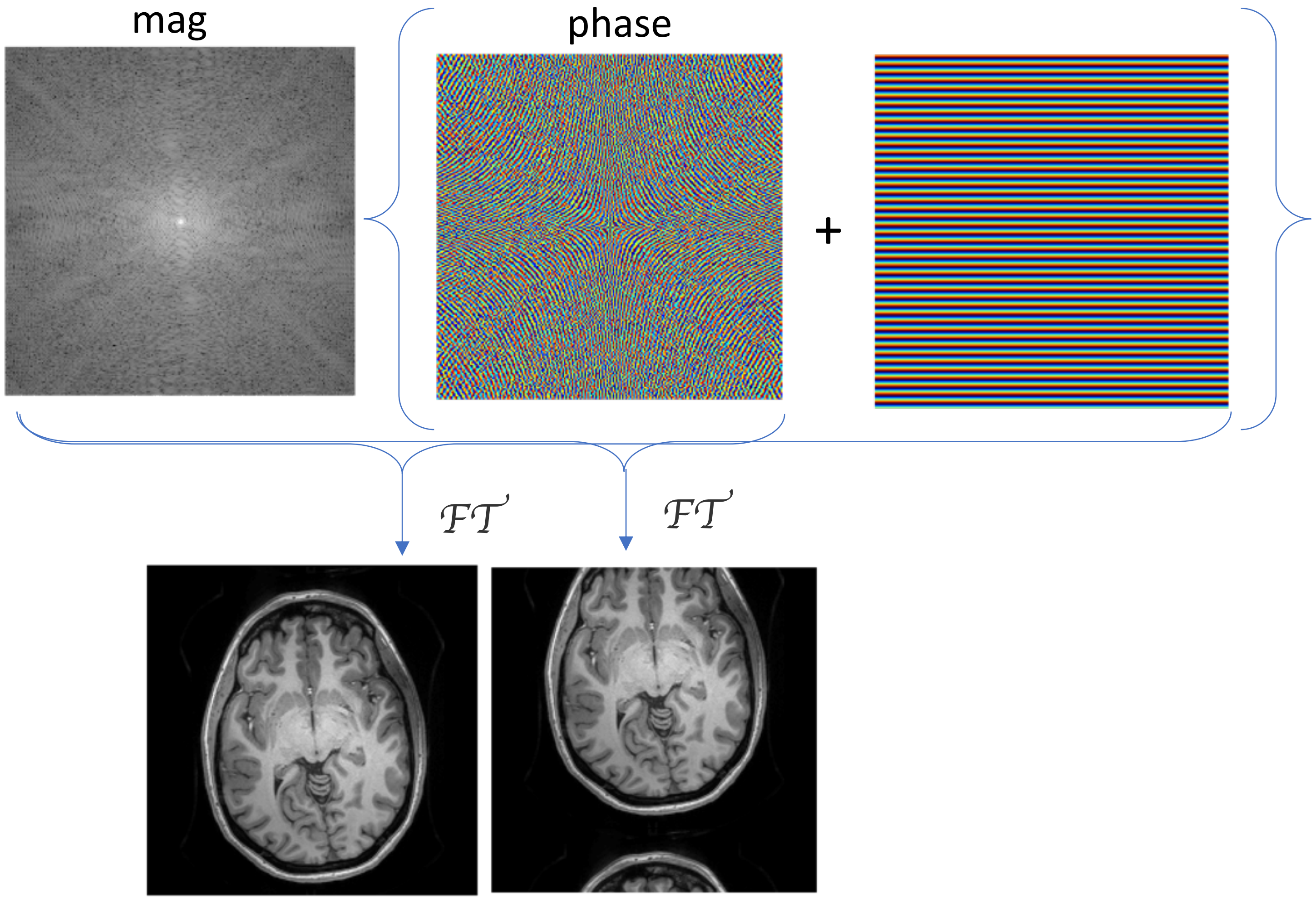
Top 5 features of Fourier transform

4) Shift Theorem

Translation in space is a linear phase roll in kspace

Let $F(k) = \mathcal{FT}\{ f(x) \}$

$$\mathcal{FT}\{ f(x-a) \} = F(k)\, e^{-2\pi jak}$$



Adapted from slide provided by Lawrence Wald, A. A. Martinos Center, MGH

Top 5 features of Fourier transform

5) Convolution Theorem

Multiplication of 2 different kspaces is a FT of a convolution in space

Let: $F(k) = \mathcal{FT}\{ f(x) \}$ $R(k) = \mathcal{FT}\{ r(x) \}$

Convolution: $$f(x) * r(x) \equiv \int_{-\infty}^{\infty} g(x) r(x - x_0)\, dx_0$$

$$\mathcal{FT}\{ f(x) * r(x)\} = F(k)\, R(k)$$

"FT of a convolution
Is the product of the FTs"

....leads to Gibbs ringing

Slide courtesy of Lawrence Wald, A. A. Martinos Center, MGH

Artifacts (a partial list)

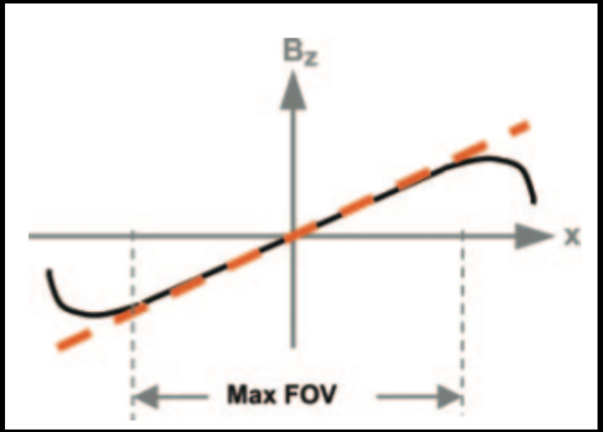
Hardware/Acquisition

- Gradient nonlinearity
- Magnet drift
- Eddy currents
- RF (zipper)
- RF interference (zipper)
- Truncation
- Aliasing
- Ghosting
- Sequence-specific (streaking in radial trajectories, blurring in spiral)
- Susceptibility (rare)
- Receiver dynamic range clipping (rare)

Human body, physiology, implants

- Susceptibility: distortion
- Susceptibility: dropout/dephasing & implants
- RF field inhomogeneity (coil bias)
- Motion
- Flow
- Chemical shift

Subject-specific and generally harder to fix!



asymmetry in *z* leads to some ***gradient nonlinearity***

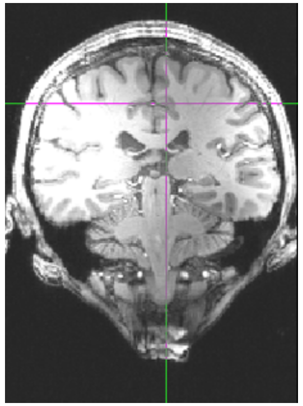
correctable

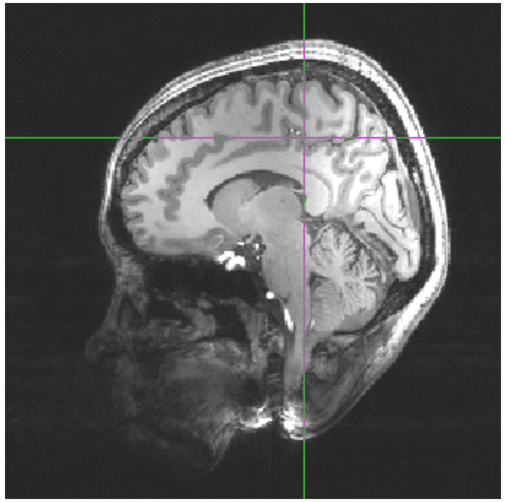
- geometric distortion
- intensity bias
- spatially nonuniform voxel size

Slide courtesy of Jon Polimeni, MGH

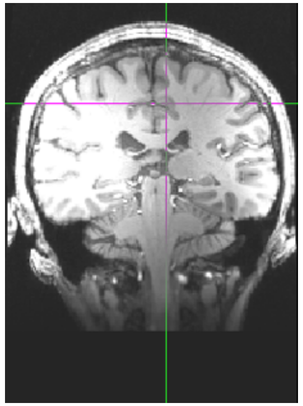
gradient nonlinearity distortion

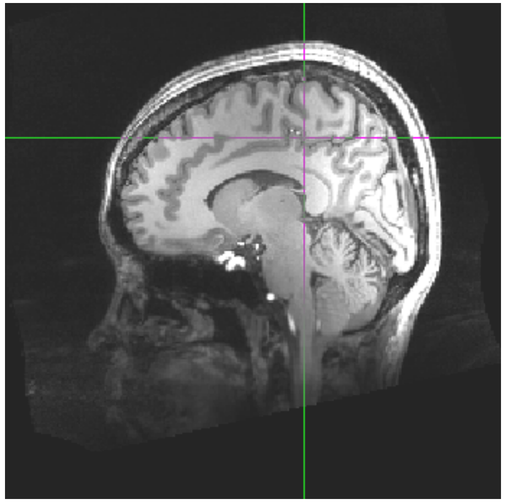
original, acquired





online correction



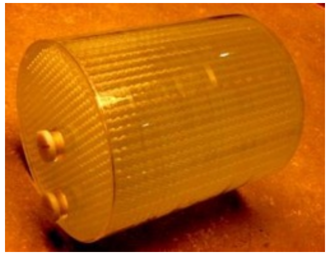


distortion is same for any object, pulse sequence—

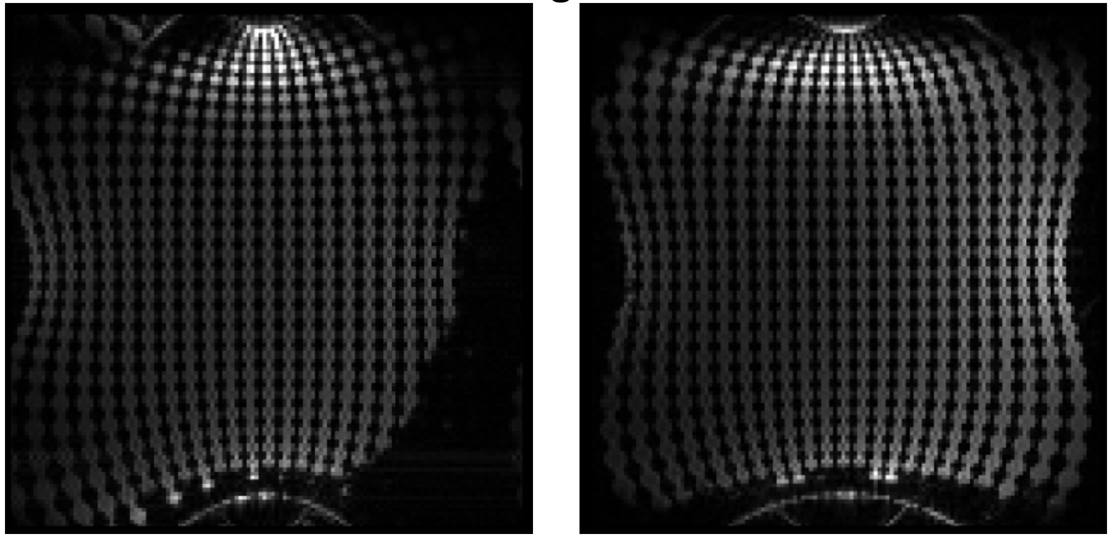
depends only on gradient coil

Slide courtesy of Jon Polimeni, MGH

“ball-grid” validation phantom



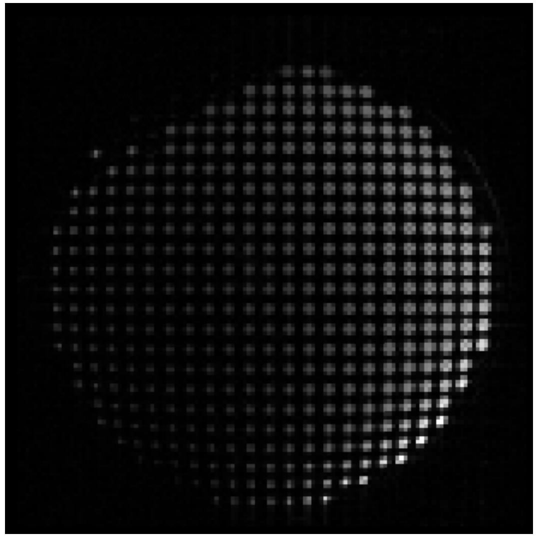
AC84 head gradient coil



250 mm length × 220 mm dia.
(too large for most RF coils)

water-filled beads, 3 mm dia.

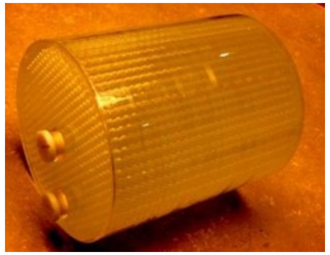
spaced at 10 +/− 0.05 mm



Slide courtesy of Sebastian Littin, Univ. of Freiburg

http://www.birncommunity.org/resources/supplements/brain-morphometry-multi-site-studies/brain-morphometry-mri-phantom/

“ball-grid” validation phantom



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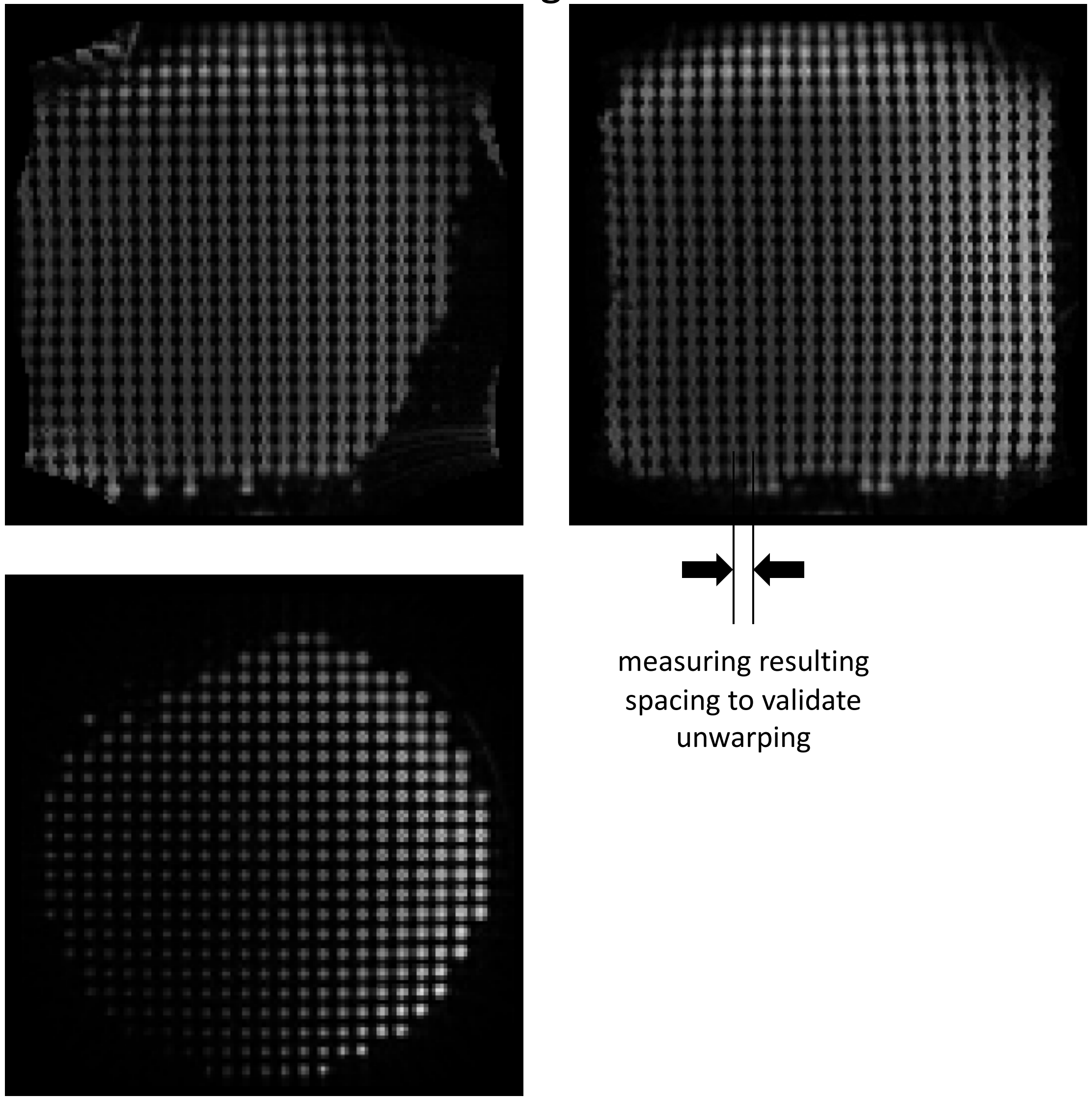

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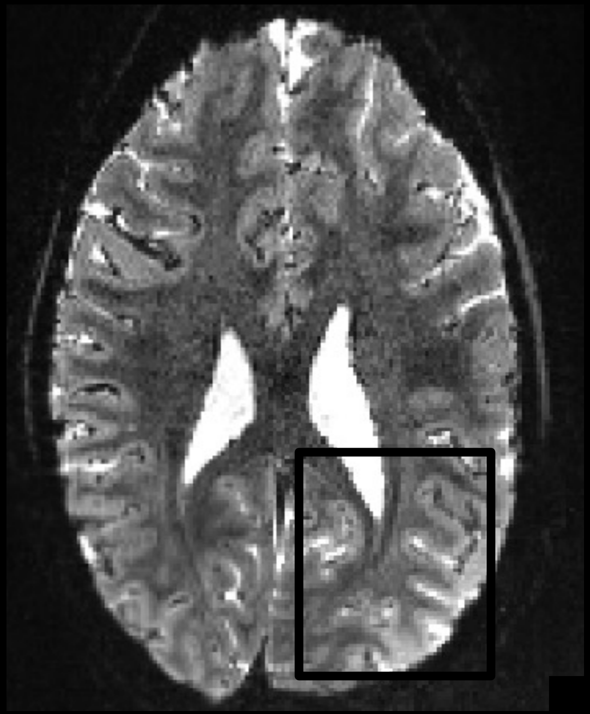
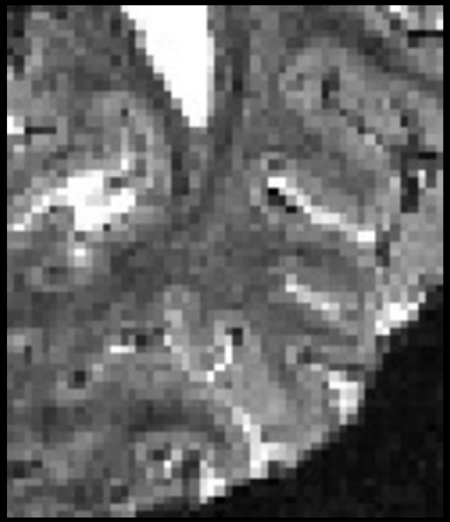
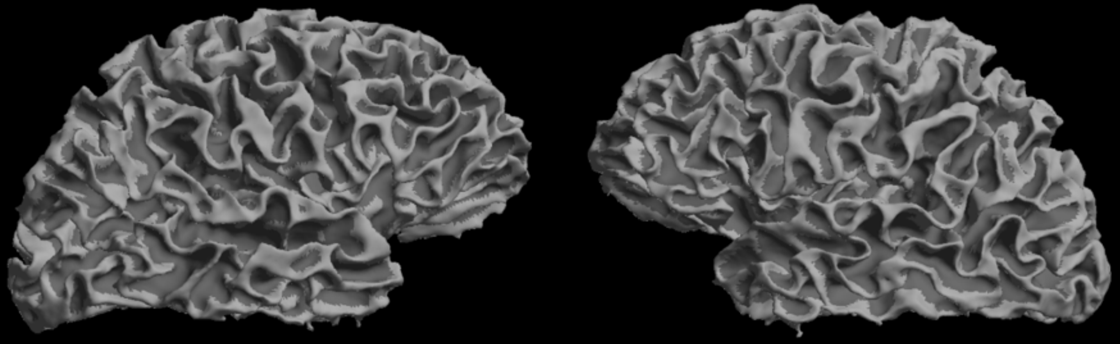
http://www.birncommunity.org/resources/supplements/brain-morphometry-multi-site-studies/brain-morphometry-mri-phantom/

surface-based grad. nonlin. correction



distorted *corrected*





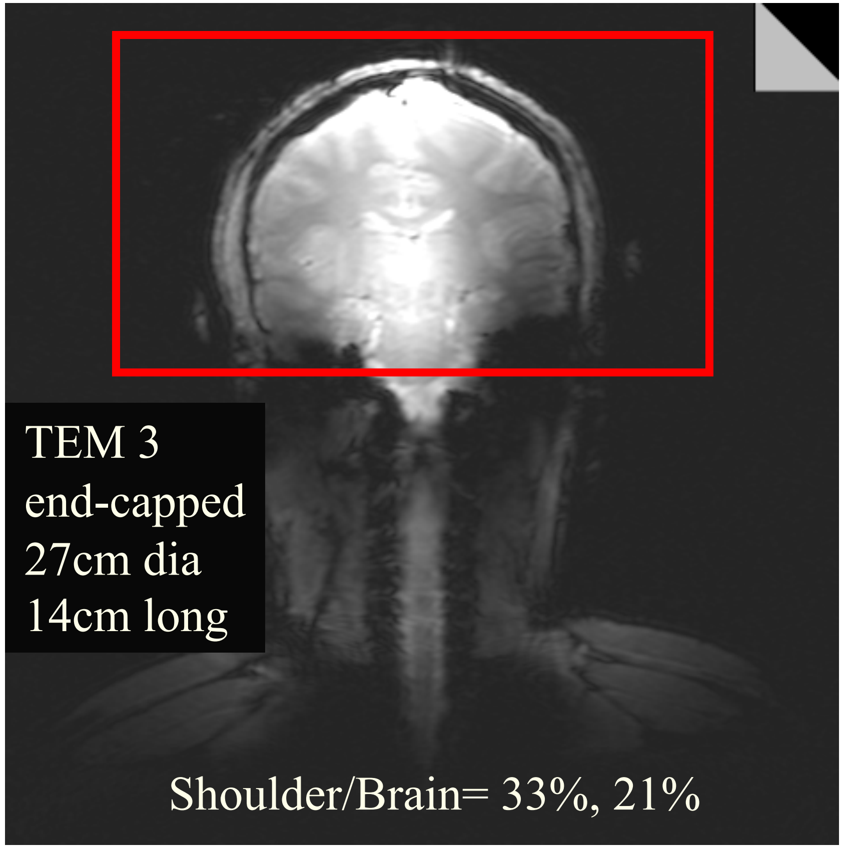
resampling requires
interpolation,
blurs image

avoid blurring by deforming <u>surfaces</u>

Slide courtesy of Jon Polimeni, MGH

7T head gradient in-fold artifact

Coil picks up signal from shoulders…



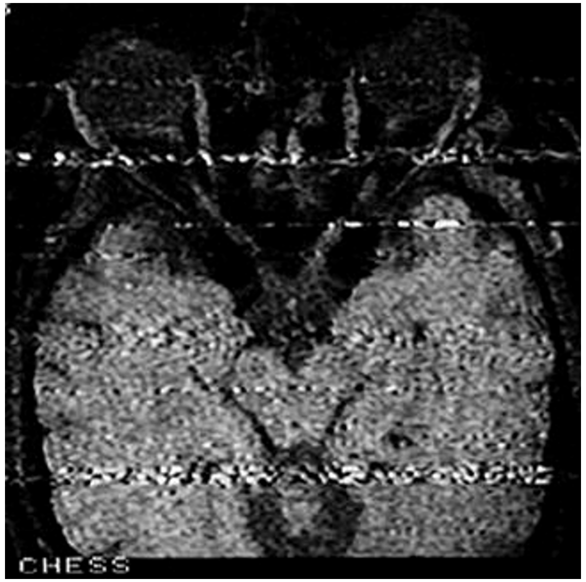
Body gradients

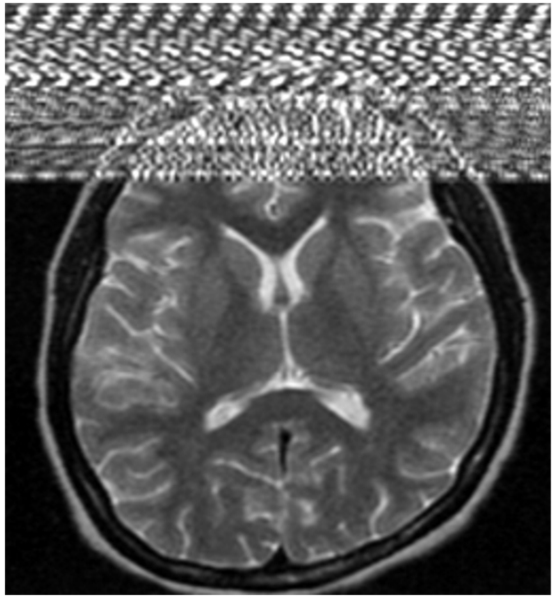
Head gradients

Wald, Boston
June, 2004

Zipper Artifacts

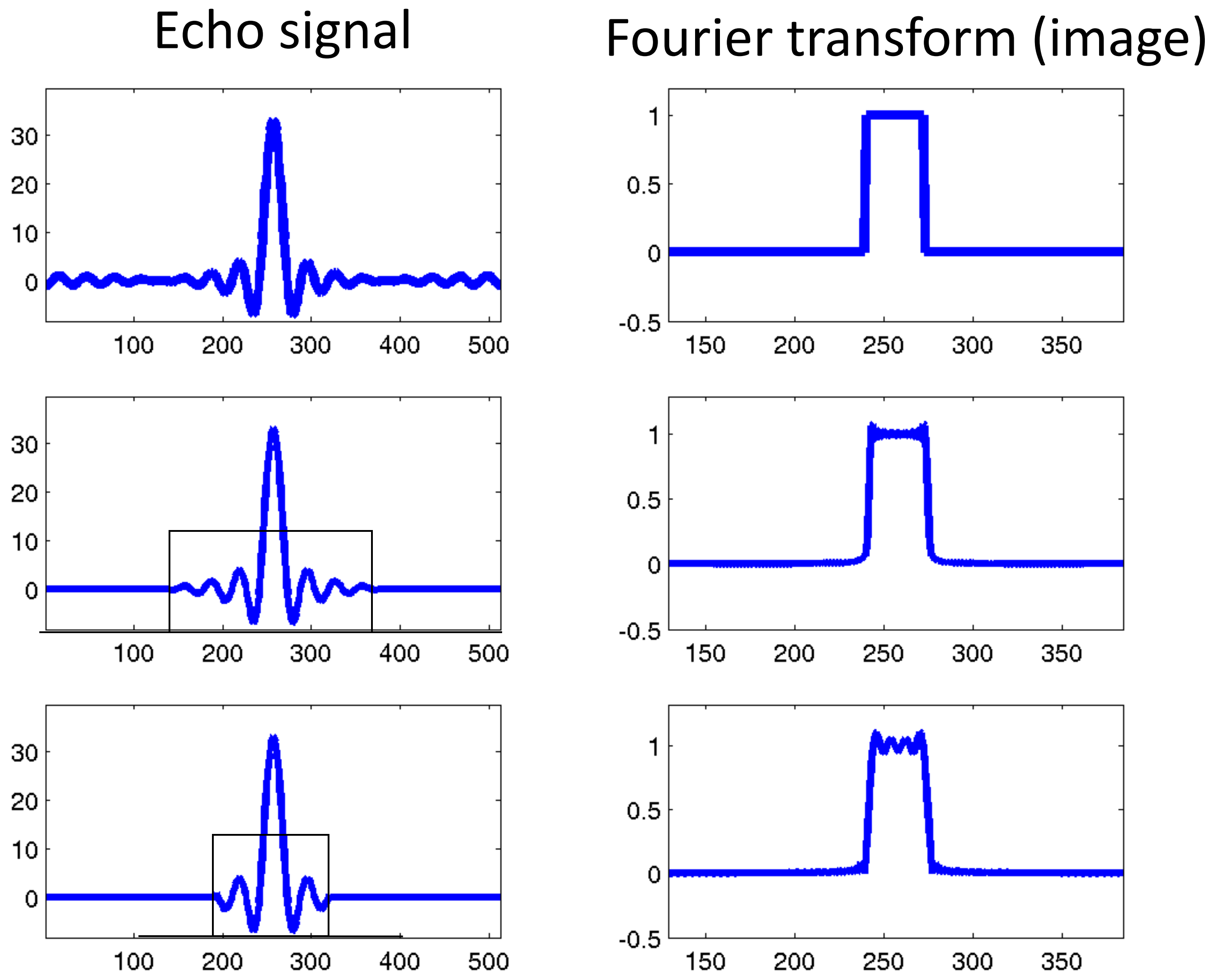
- RF interference → usually shows up as lines along phase-encode direction
- Room not properly shielded
- RF source may be in room - electronic devices





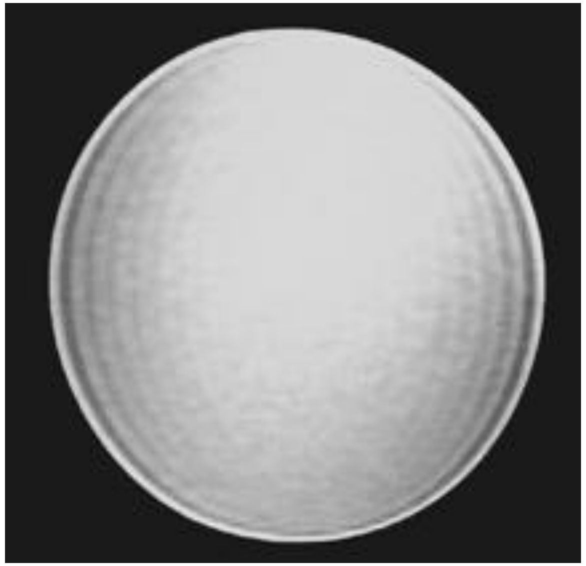
Slide courtesy of Todd Constable, Yale Univ.

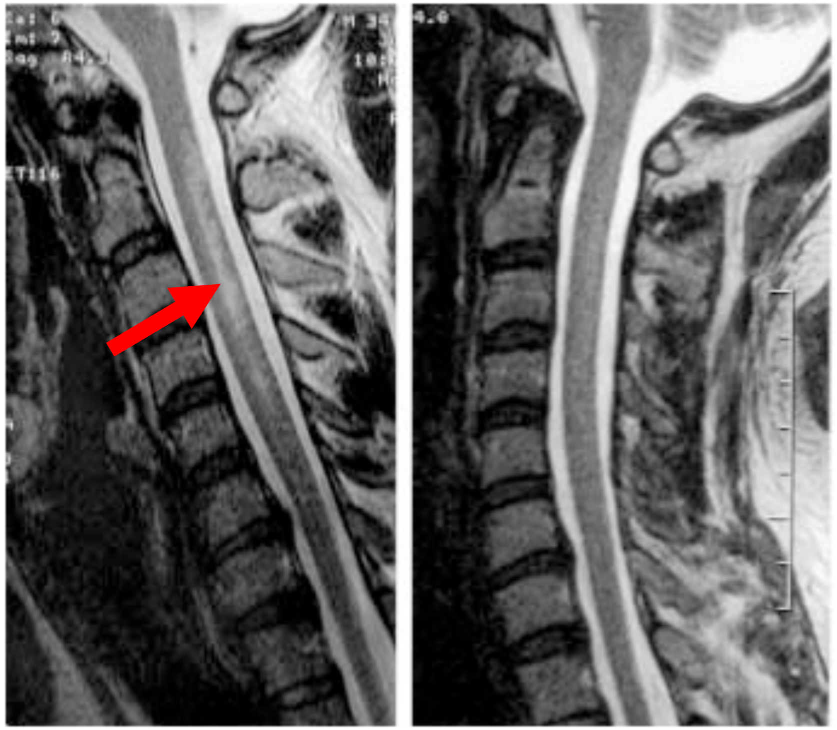
Truncation Artifacts: Consequence of Convolution rule



Slide courtesy of Todd Constable, Yale Univ.

Truncation Artifacts (Gibbs ringing)





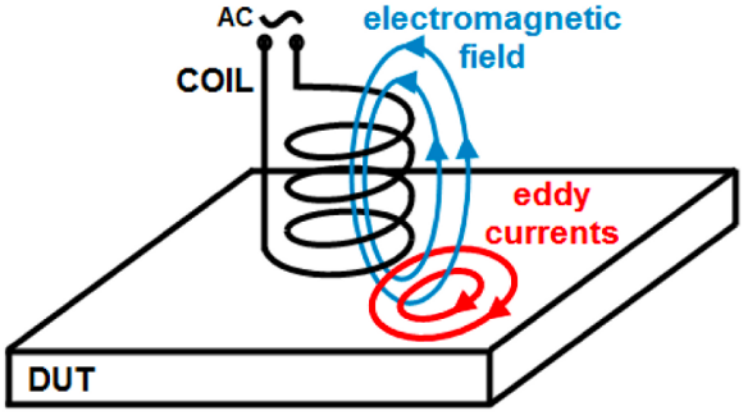
Truncation artifacts can mimic disease - case of true syringomyelia above left, treated and resolved on the right. Looks like a truncation artifact but in this case is not.

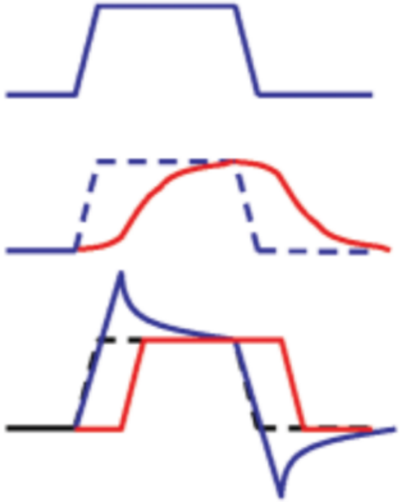
Mayo Clin Proc. 2002;77:291–294 © 2002 Mayo Foundation for Medical Education and Research

Slide courtesy of Todd Constable, Yale Univ.

Eddy currents

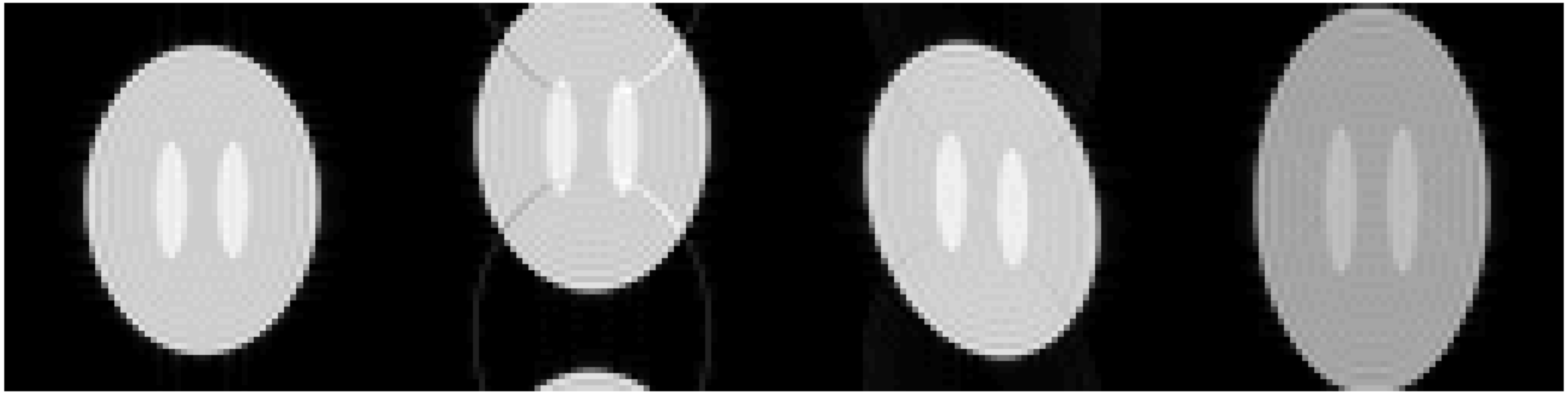
- Switching magnetic field creates unwanted currents in other nearby conductors in the bore *(Lenz's law)*
- *Resists* the desired change in gradient field amplitude





Distortions: Eddy currents

- Cause: Fast switching of diffusion-encoding gradients induces eddy currents in conducting components
- The shifts are **direction-dependent**, *i.e.,* different for each DW image
- Result: Geometric shifts/distortions

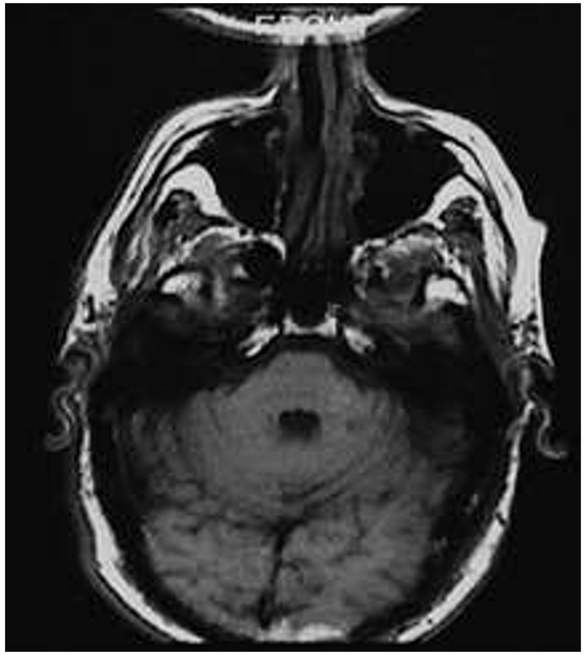


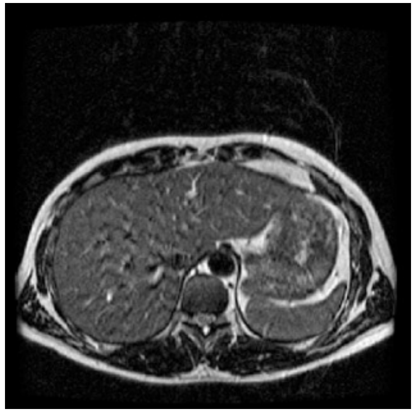
original | z or B0 effect | x effect *(readout)* | y effect *(phase encode)*

Figure courtesy of Douglas Noll, Univ. Michigan

Aliasing: FOV wrap

- K-space samples are too far apart (results in FOV too small)
- Image is wrapped around





FOV_y=40cm

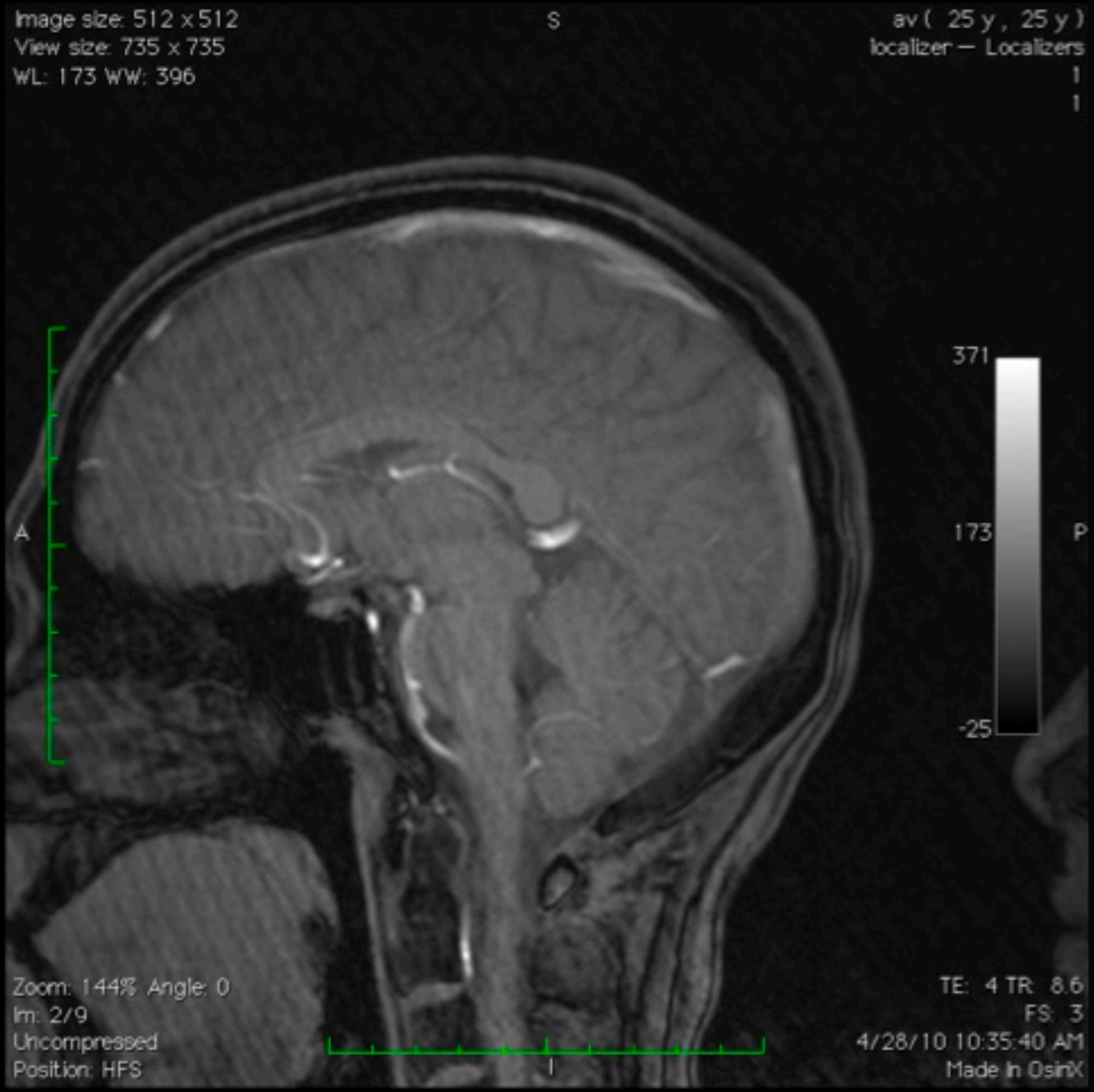
FOV_y=20cm

If resolution is to be maintained between above 2 acquisitions, imaging time will double

In many sequences, you can save time if you skip k-space lines and allow aliasing…
Parallel imaging using multiple RF receive coils “unwraps” aliased image (“iPAT”, “GRAPPA”)

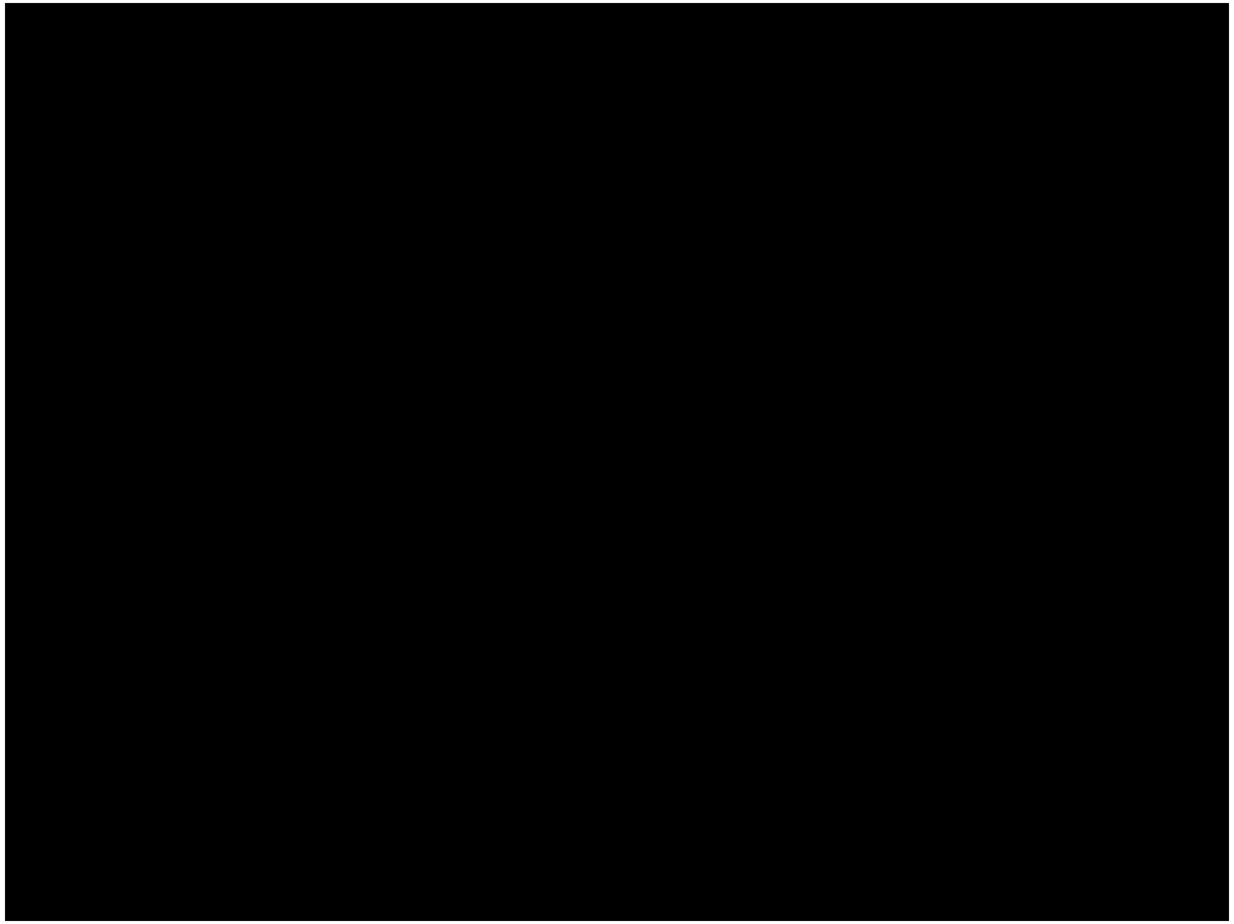
Slide courtesy of Todd Constable, Yale Univ.

Spiking → actively powered components, usually RF coil (PIN diode lines) or gradient coil

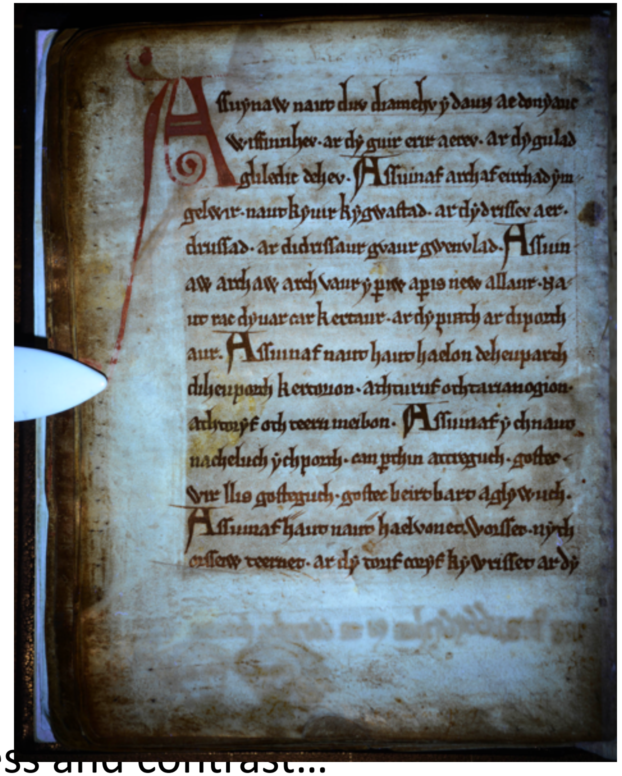


Spiking in EPI time series → comes and goes over time

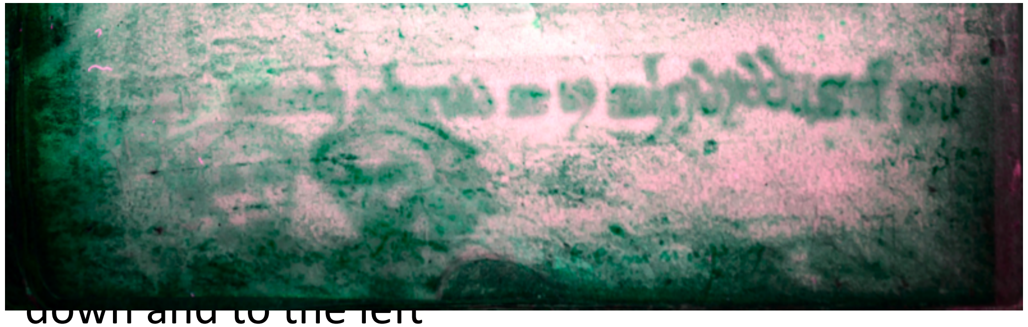
Usually a problem with “active” powered components like gradient coil or RF coil → small arc of electric current generates spike



13th century Welsh medieval manuscript of Arthurian legends under UV light

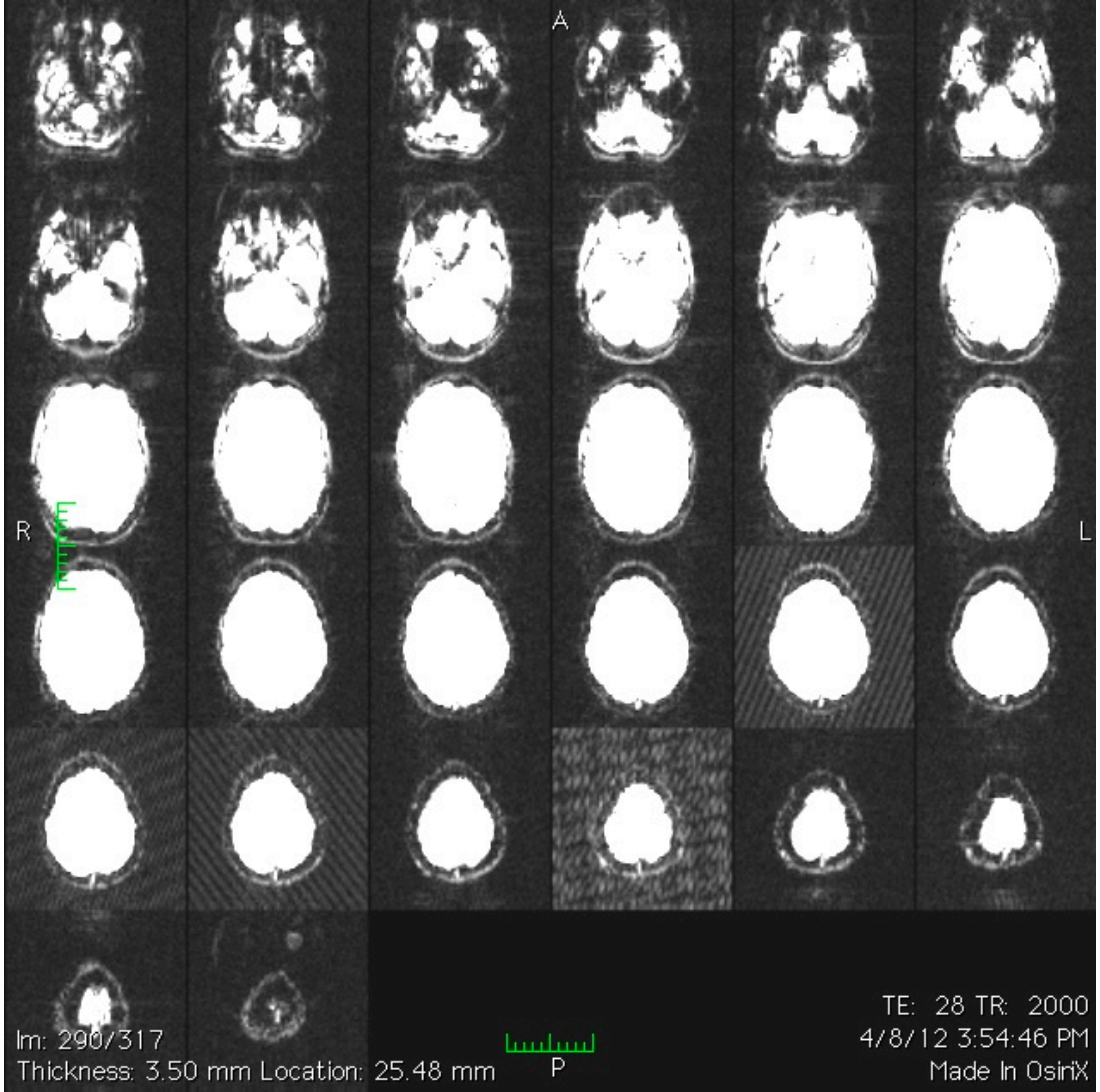


Adjust brightness and contrast…

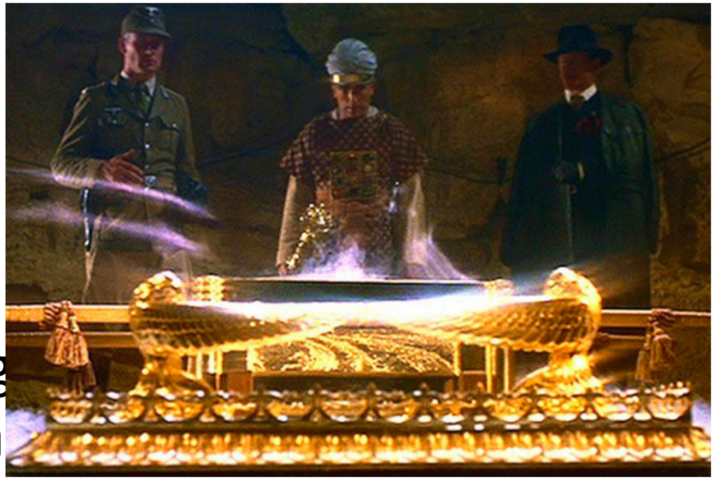


down and to the left

Then the spikes emerge…



Ghosts!



- Bipolar readout g
  lines of k-space a
- Creates image shifted by half a field of view ("N/2 ghost")
- Phase in k-space causes translation of some of the energy in image doman
- "Navigators" used to fix ghost
- But EPI is very sensitive to hardware instability that can gause ghosting

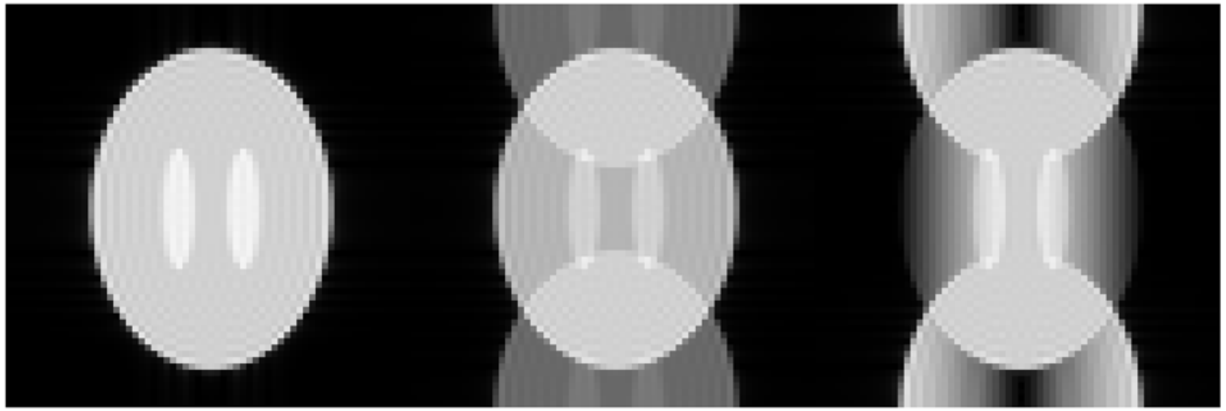
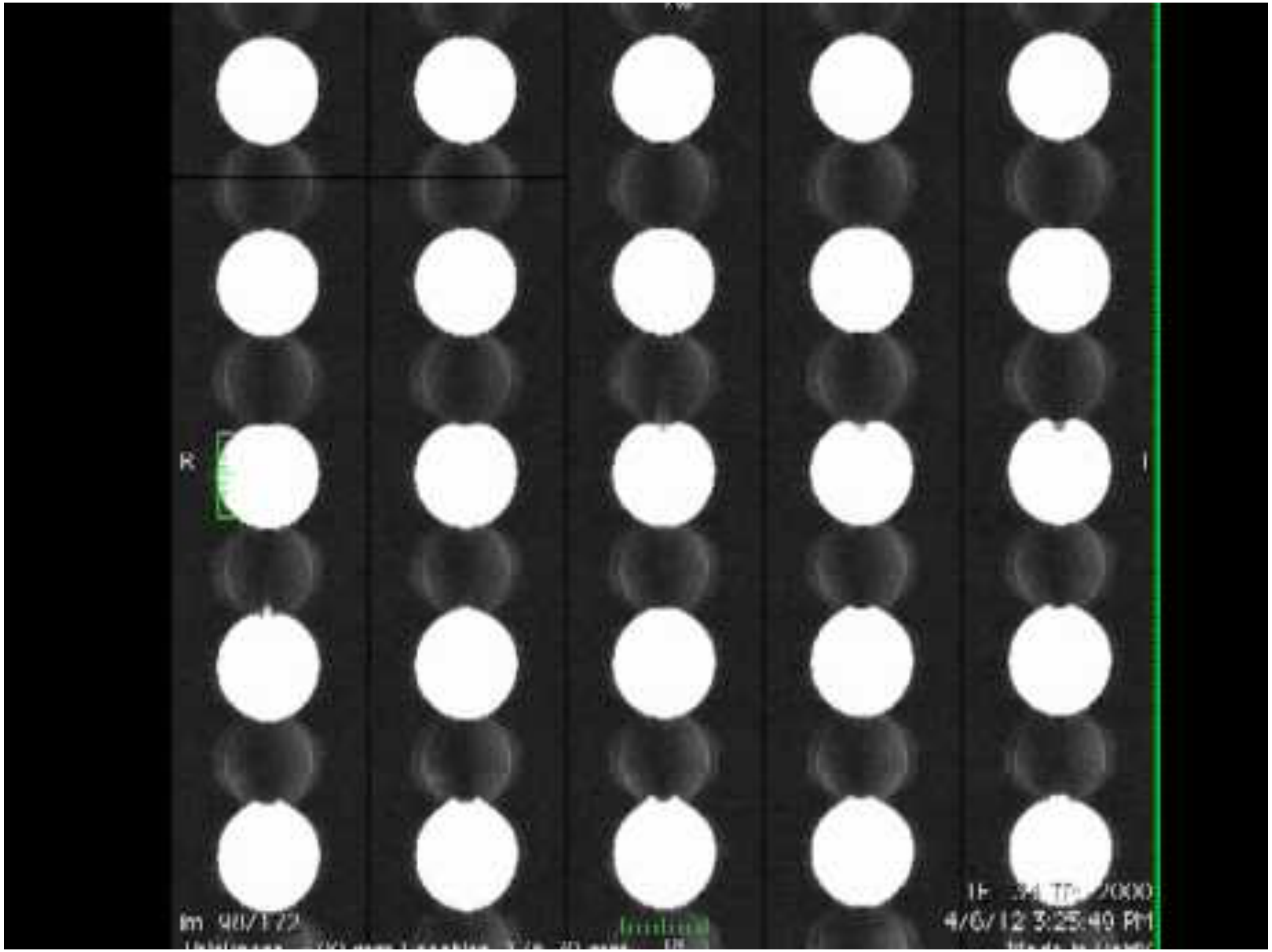


Figure courtesy of Douglas Noll, Univ. Michigan

Ghost flickering from hardware instability → *not the same as "spiking"*



Ghost flickering from hardware instability → *not the same as "spiking"*

Insidious, evil artifact, especially at 7T…. Can bias EPI time series analysis

<u>Possible causes</u>:

- RF power amplifier
- RF Tx or Rx coil
- Too few references lines for training GRAPPA kernel
- GRAPPA factor is too high for the coil array → GRAPPA starts to fail
- Using a "forbidden" echo spacing → gradient coil acoustic resonance!
- Subject motion during ACS lines for GRAPPA

Artifacts

Hardware/Acquisition

- Gradient nonlinearity
- Magnet drift
- Eddy currents
- RF (zipper)
- RF interference (zipper)
- Truncation
- Aliasing
- Ghosting
- Sequence-specific (streaking in radial trajectories, blurring in spiral)
- Susceptibility (rare)
- Receiver dynamic range clipping (rare)

Human body, physiology, implants

- Susceptibility: distortion
- Susceptibility: dropout/dephasing & implants
- RF field inhomogeneity (coil bias)
- Motion
- Flow
- Chemical shift

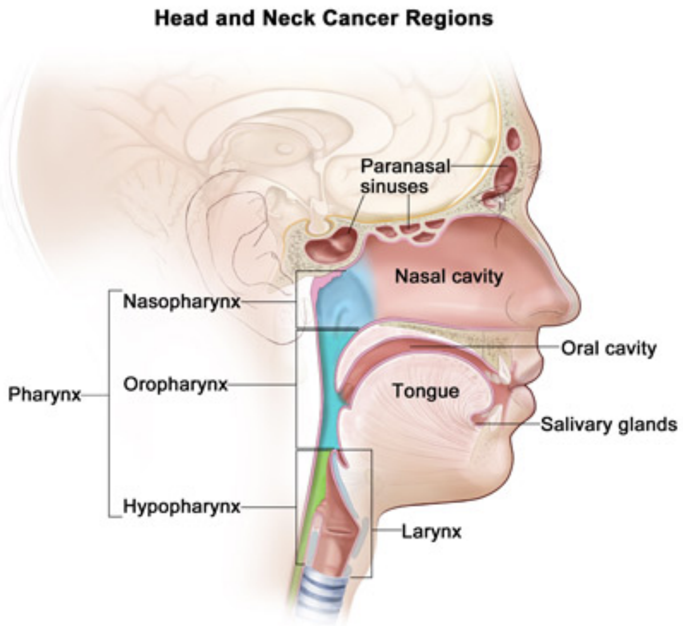
Subject-specific and typically harder to fix!!!

Source of *in vivo* ΔB_0 inhomogeneity

- Empty magnet is shimmed very well accurately
- Air-tissue interfaces in body perturb B_0 field by up to ~1ppm
  - Tissue: *diamagnetic*
  - Air: *paramagnetic*

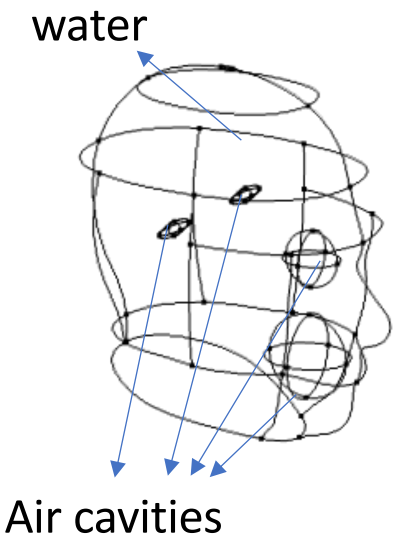
$$\Delta M = \left(\frac{\chi_{\text{tissue}}}{\mu_0}\right) B_0 - \left(\frac{\chi_{\text{air}}}{\mu_0}\right) B_0 = \left(\frac{\Delta\chi}{\mu_0}\right) B_0$$

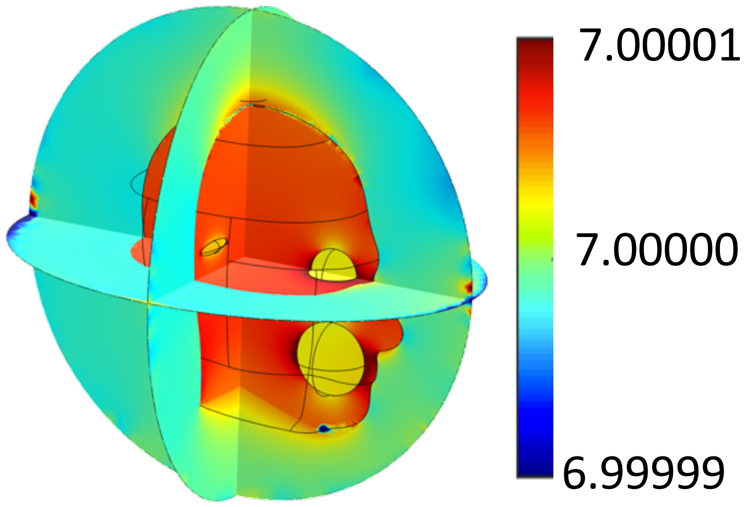
$$\Delta B_z(r) = \Delta\chi \frac{B_0}{4\pi} \frac{3z^2 - r^2}{r^5} \Delta V$$



Source: NIH National Cancer Institute.
http://www.cancer.gov

- Static ΔB_0:
  - Sinus and oral cavities
  - Ear canals
- Dynamic ΔB_0:
  - Chest motion in respiration
  - Other physiological processes





Slide courtesy of Jiazheng Zhou

Static ΔB_0 shimming at UHF

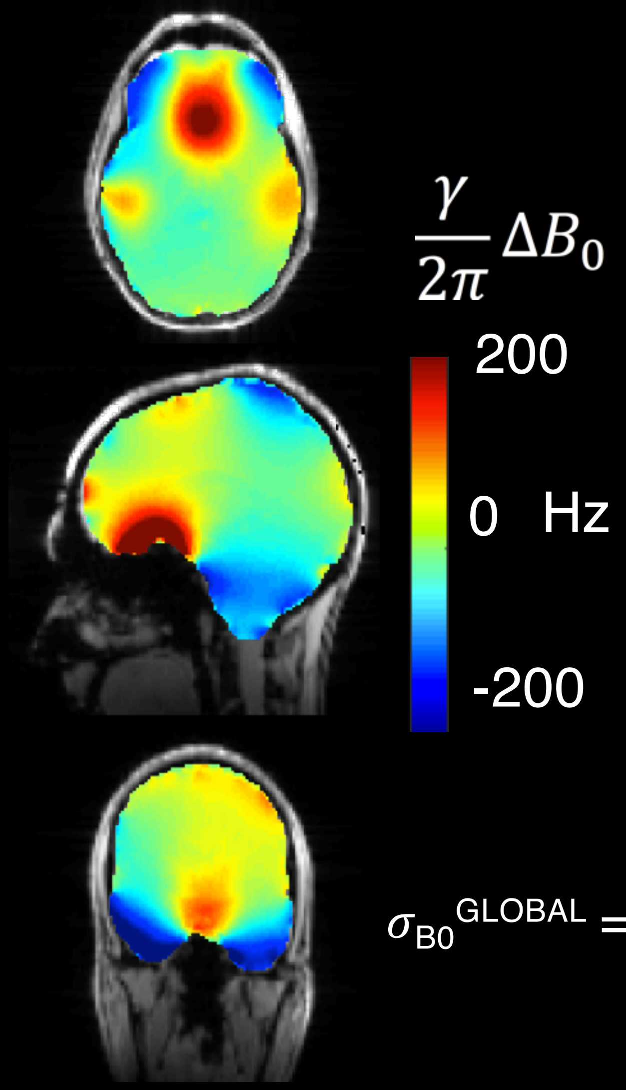
- Susceptibility-contrast (T2*) methods such as blood-oxygen level dependent (BOLD) fMRI and high-res. Susceptibility-weighted imaging (SWI)

- Interested in <u>microscopic</u> T2* of tissue

- Confounded by <u>macroscopic</u> T2* due to ΔB_0
  - grows with B_0

- Scanner tries to "shim" out these field perturbations, but only up to 2nd order spatial components can be removed…

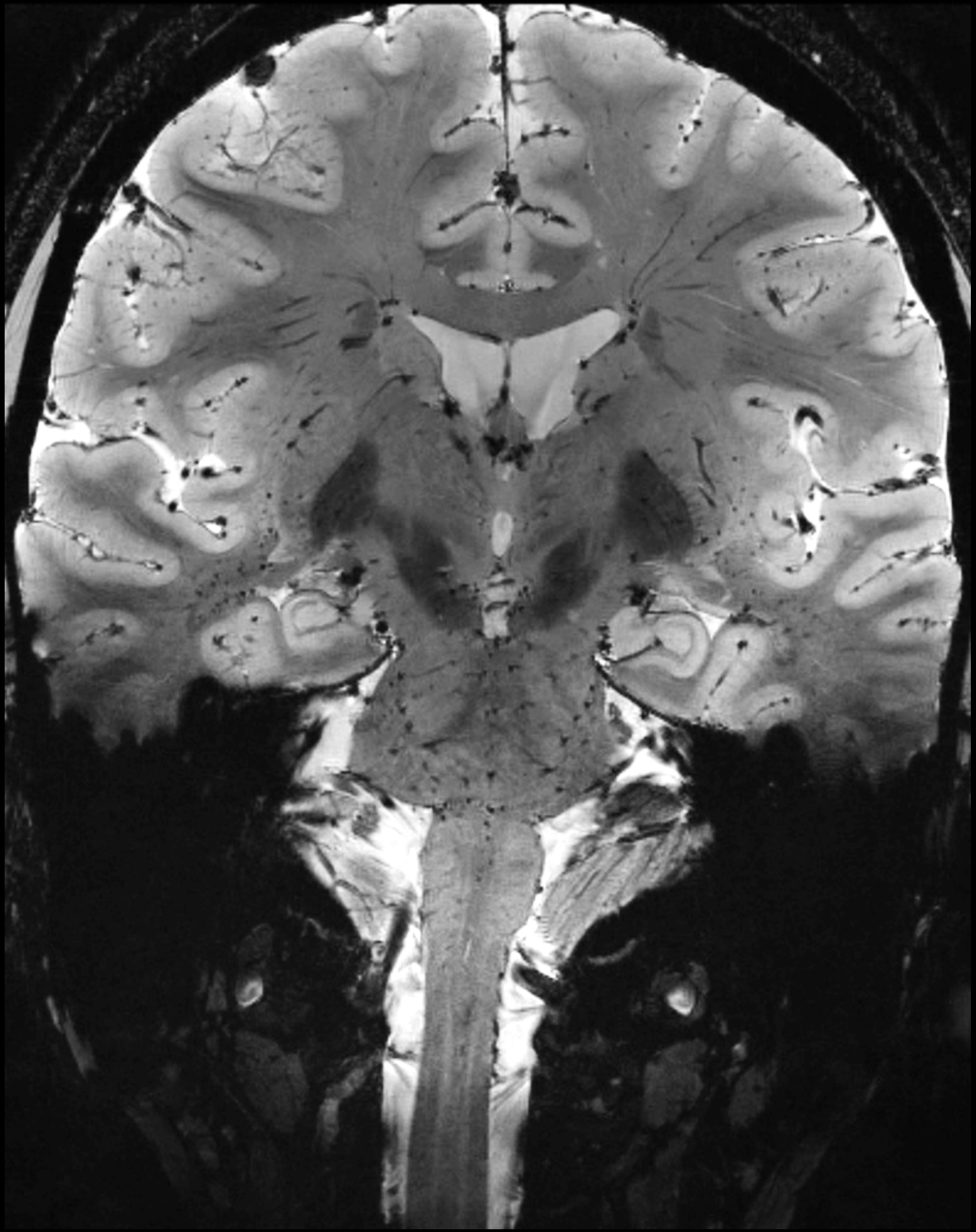
7T ΔB_0 field map
shimmed to 2nd order

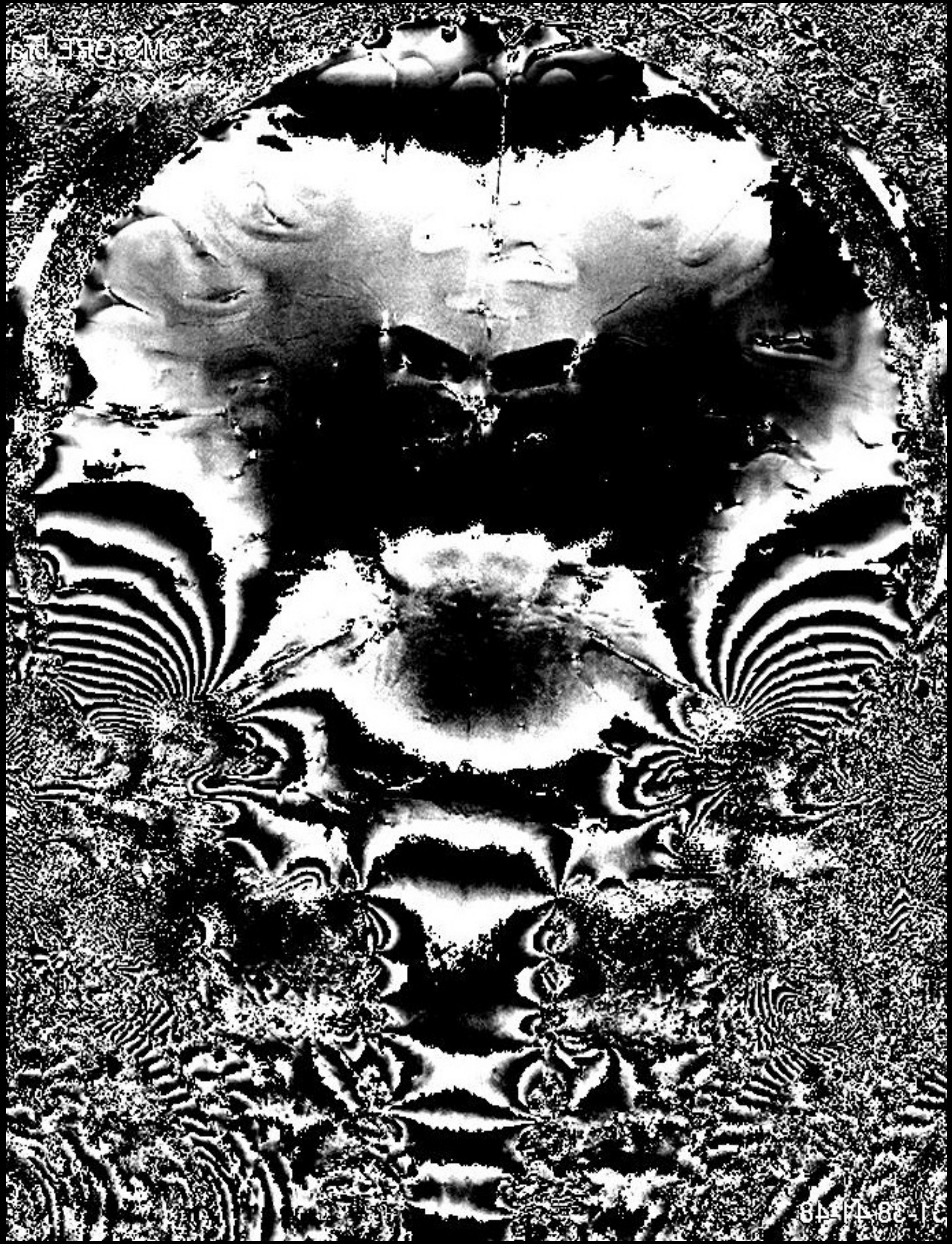


σ_{B0}^{GLOBAL} = 52 Hz

Stockmann JP, NeuroImage, 2017

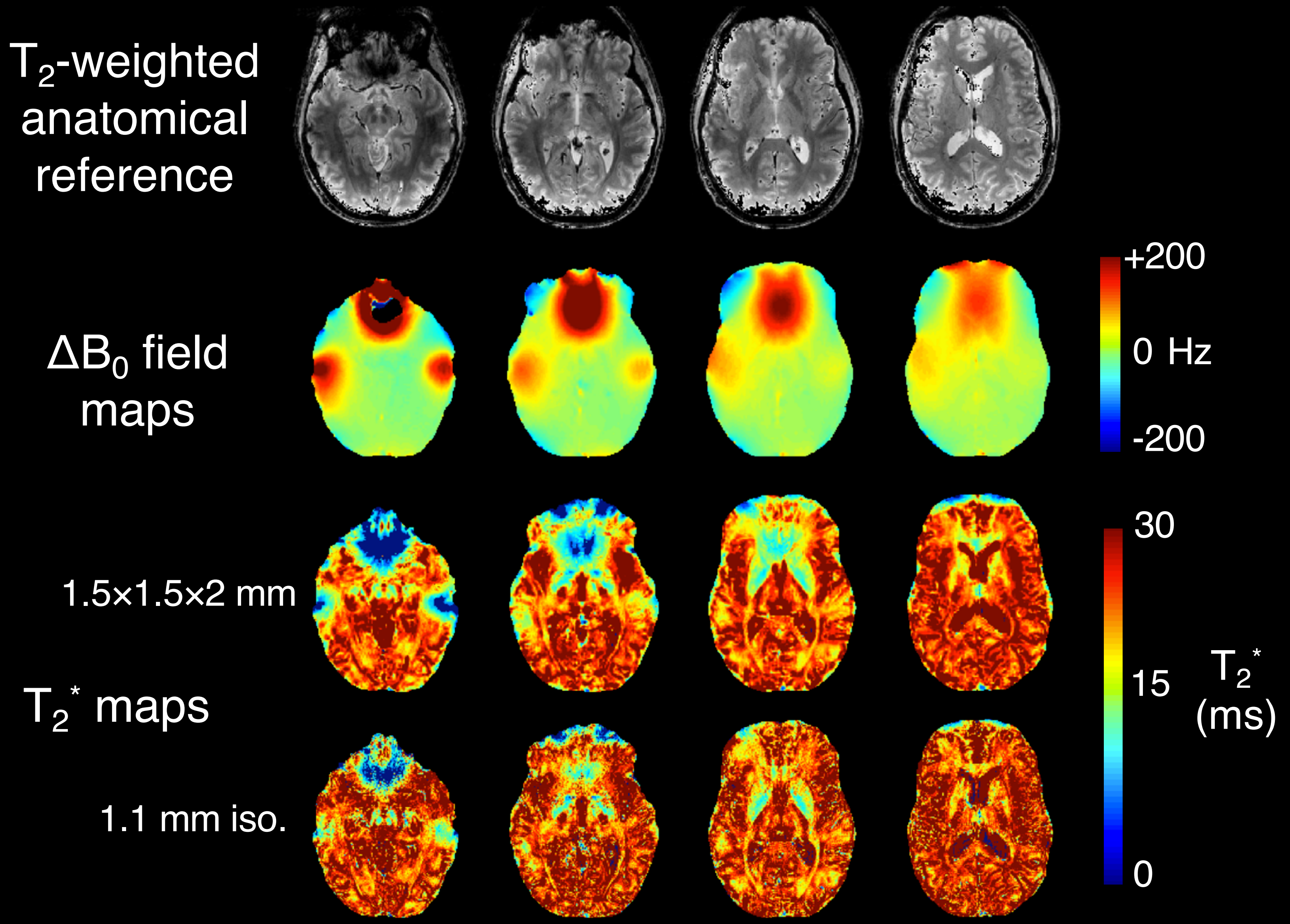
7T gradient echo mag. and phase images, 300 μm in-plane, cardiac-gated





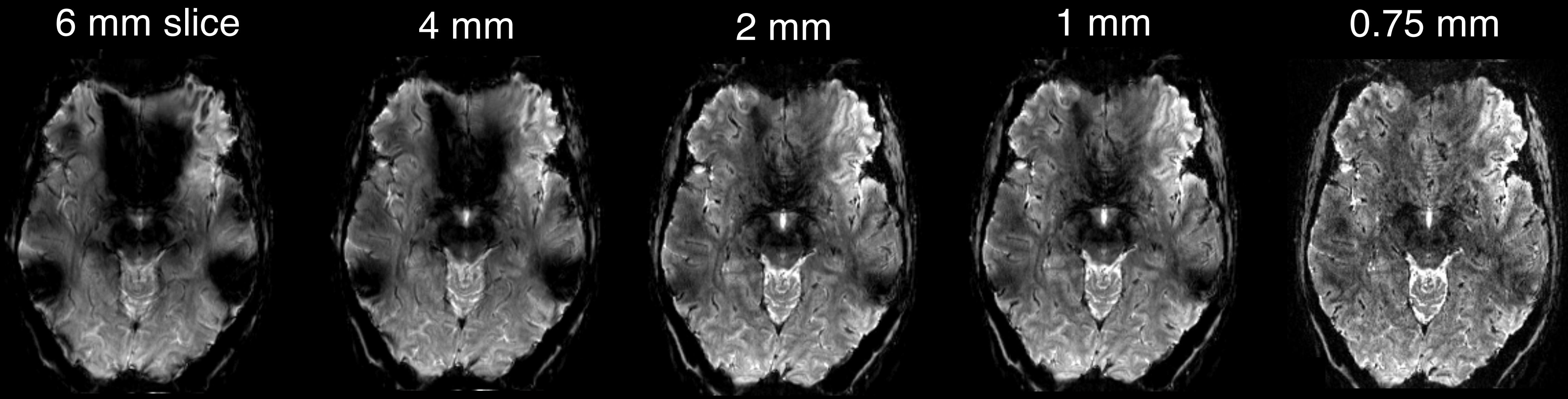
Images courtesy of Jon Polimeni, MGH

Impact of static ΔB_0 on macroscopic T_2^* at 7T



Stockmann JP, NeuroImage, 2017

Through-slice dropout in 7T *gradient-echo* EPI slices



Intravoxel dephasing scales with voxel size

Also gets worse with longer TEs

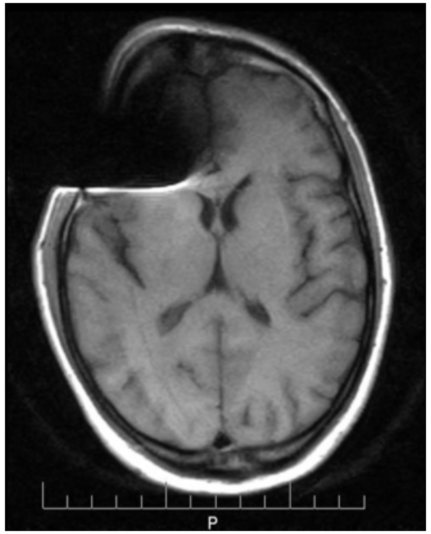
Images courtesy of Jon Polimeni, MGH

Metal implants

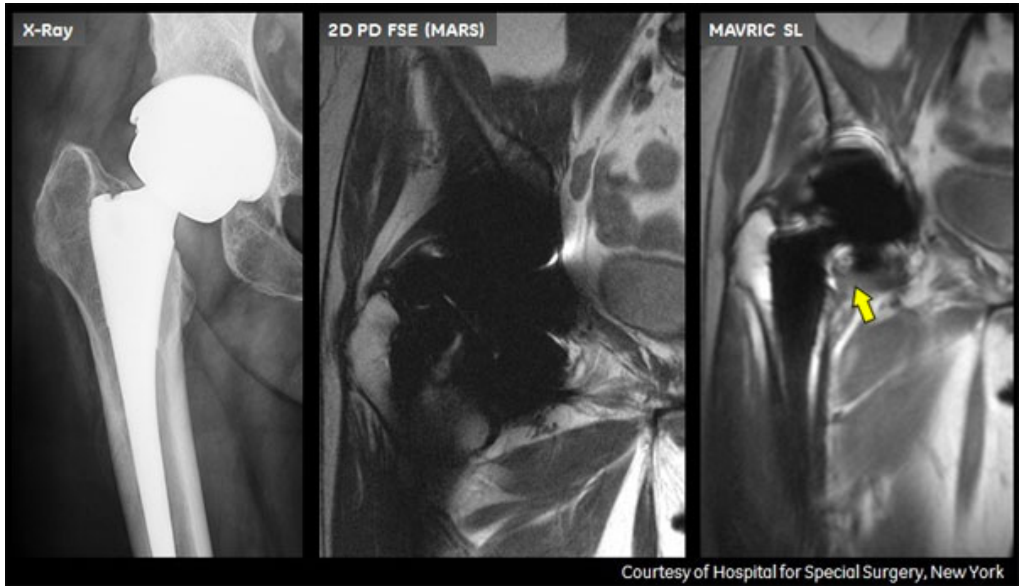
- Severely short T2* near metal in the body
  - Dephasing / signal loss in gradient echo
  - Warping / distortion
  - RF excitation and refocusing pulses don't work properly

Dental metal

Metal in scalp



Hip implant

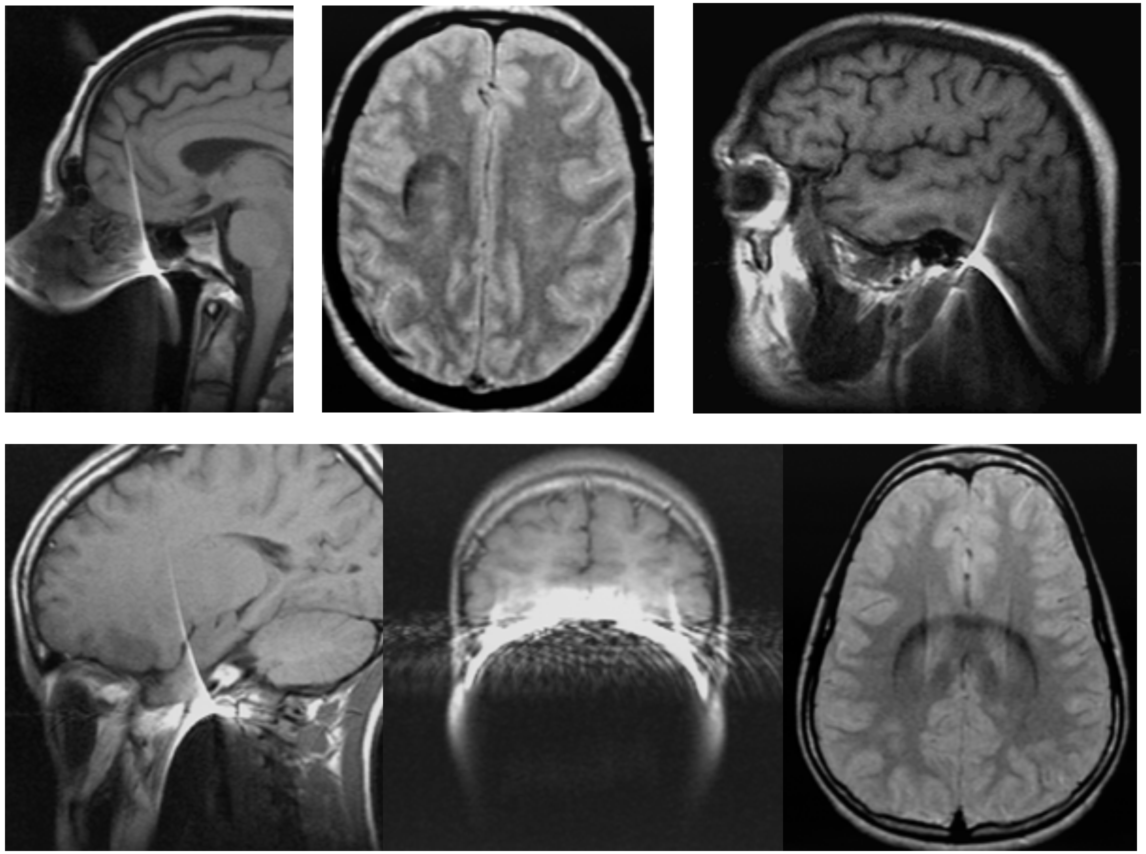


Slide courtesy of Todd Constable, Yale Univ.

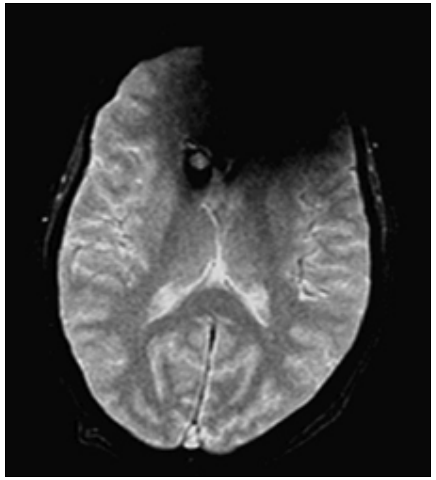
Metal Implants

Ferromagnetic Dental Work & a Hair Band, Piercings, Tattoos, Colored Contact Lens

Spin echo



Gradient echo

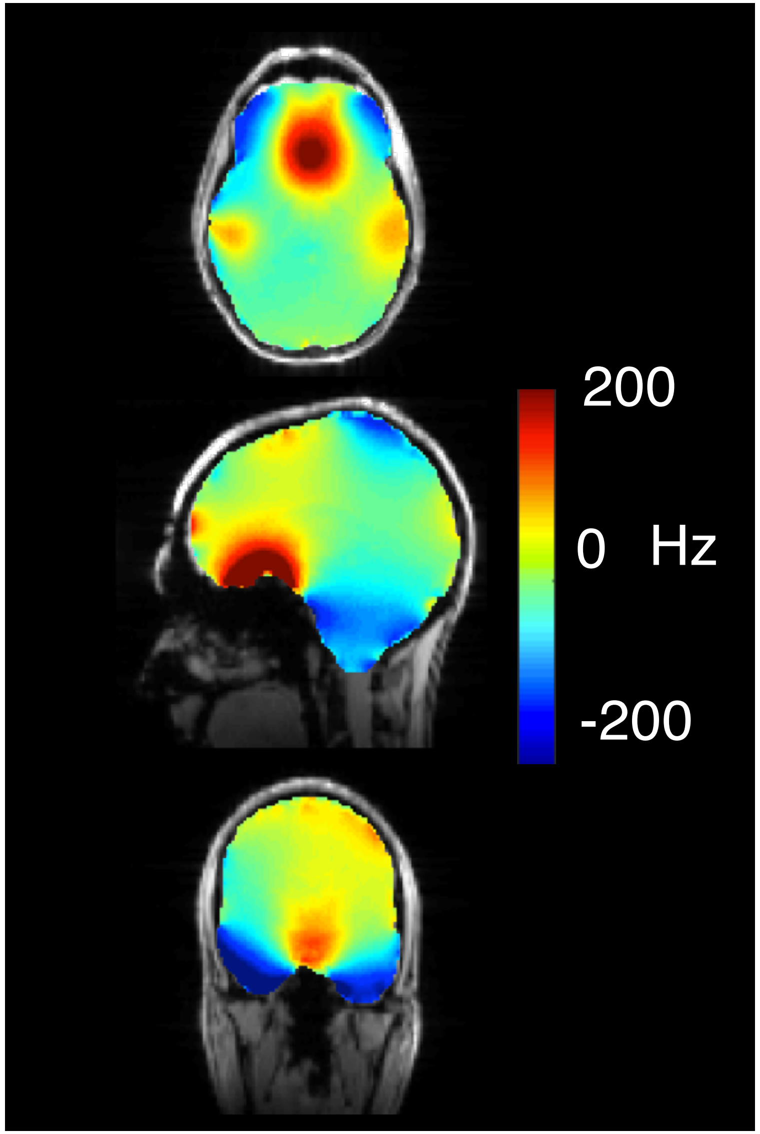


Slide courtesy of Todd Constable, Yale Univ.

Geometric distortion in EPI

- Depends on B_0 off-resonance frequency and the sequence's phase encoding bandwidth
- Linear phase ramp evolves during echo train (along k-space phase encode direction)
  - Causes voxel shift along phase encode direction
- Phase encode bandwidth is 1/echo_spacing
- So for 1ms echo spacing, and image with 100 pixels in PE direction, 100 Hz off-resonance gives you a 10 pixel shift!
- Bigger off-resonance → larger shifts
- *GRAPPA (R_y) reduces distortion! Reduces effective echo spacing*

$$\left(distortion[mm]/_{\Delta B_0}\right) = \frac{\gamma}{2\pi} esp_{eff} \cdot FOV_y[mm] = \frac{\gamma}{2\pi} \frac{esp \cdot FOV_y[mm]}{R_y}$$



Reference: Wald LL, The future of acquisition speed, coverage, sensitivity, and resolution. Neuroimage, 2012.

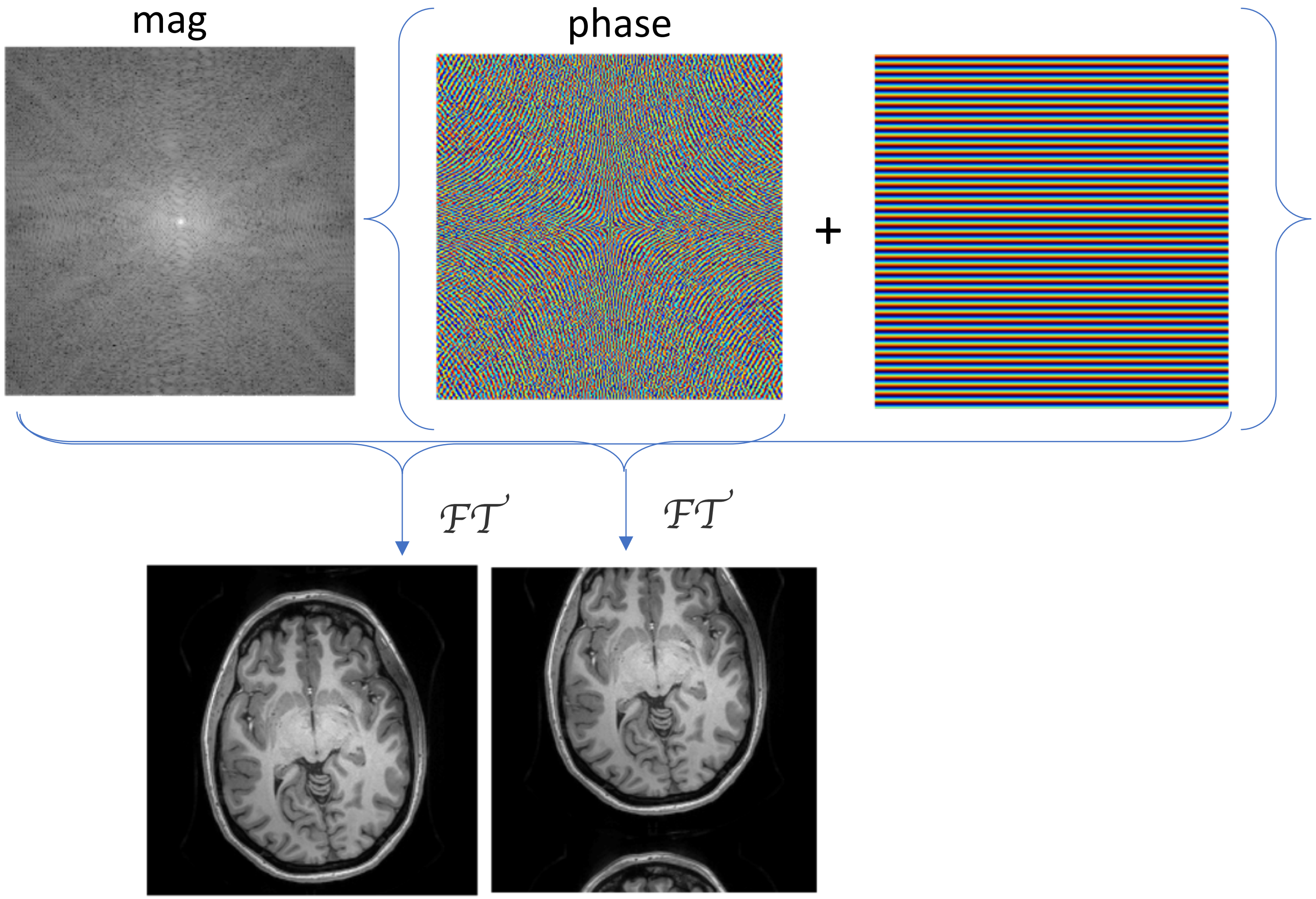
Reminder!

5) Shift Theorem

Translation in space is a linear phase roll in kspace

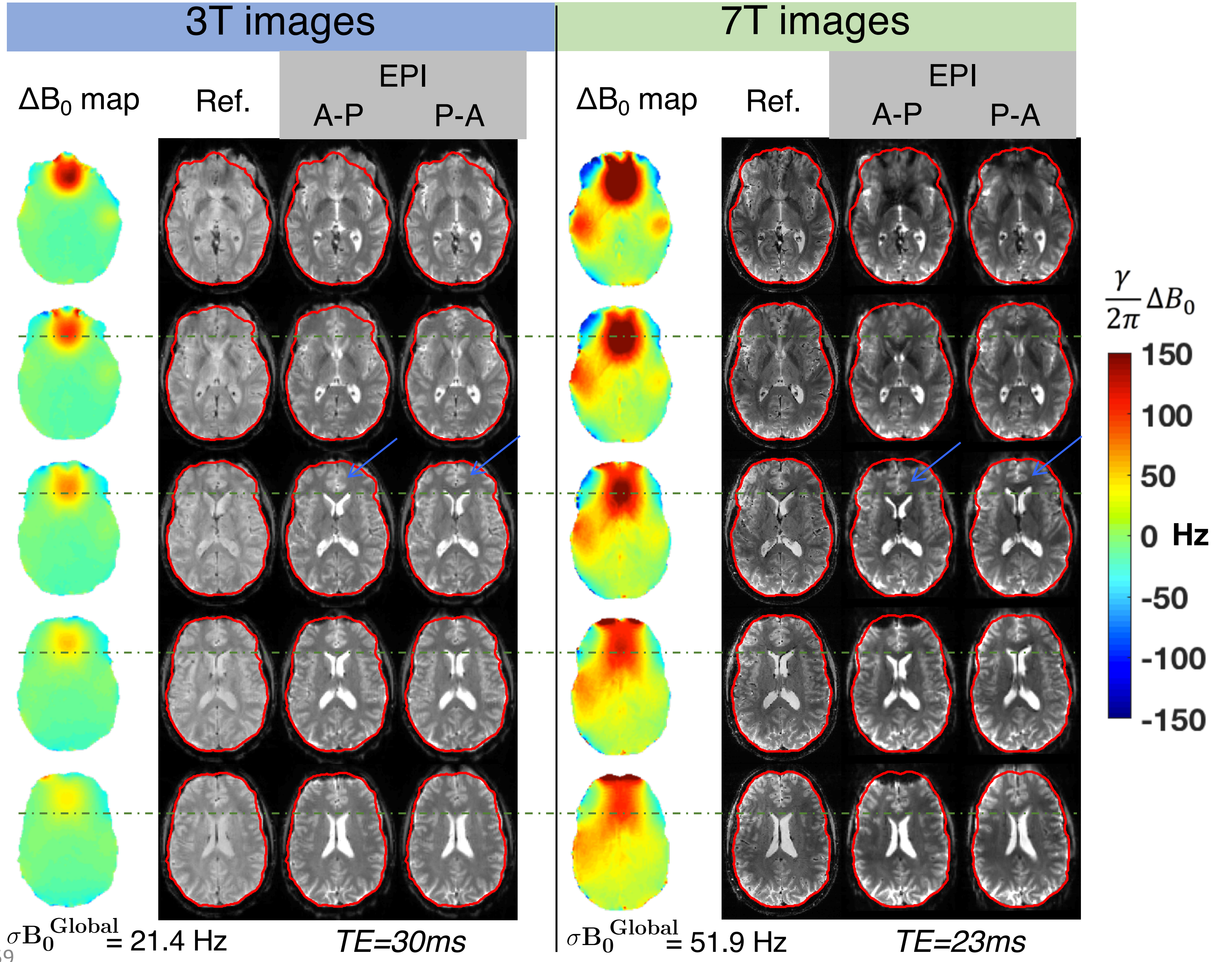
Let $F(k) = \mathcal{FT}\{ f(x) \}$

$$\mathcal{FT}\{ f(x-a) \} = F(k)\, e^{-2\pi jak}$$



Adapted from slide provided by Lawrence Wald, A. A. Martinos Center, MGH

Geometric distortion in EPI



Post-processing unwarping algorithms like TOPUP[1] help, but are not perfect

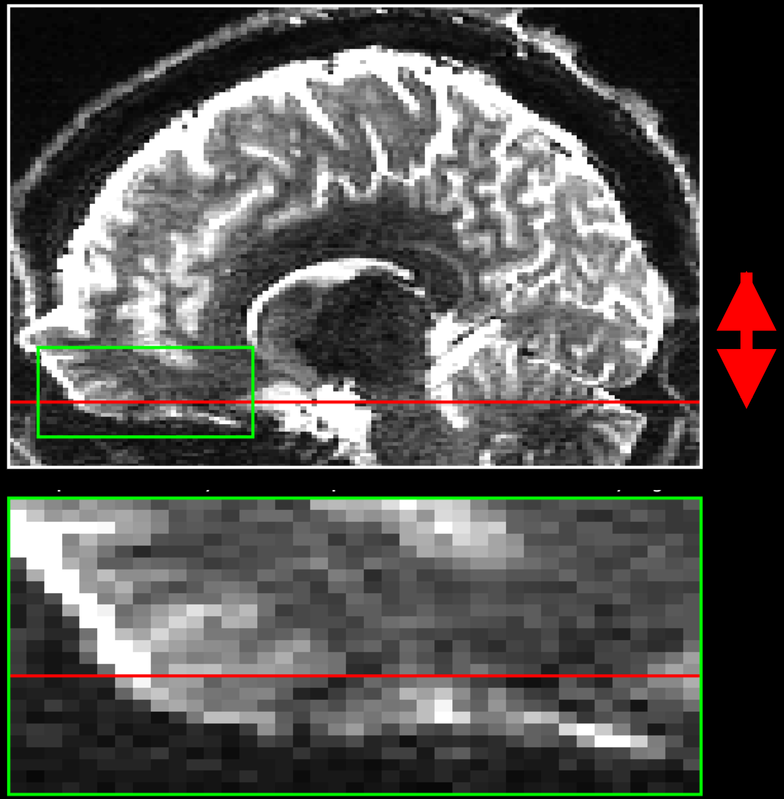
Most common mitigation: **parallel imaging**[2] acceleration → reduce effective echo spacing

Less common: Increase gradient strength and slew rate

[1] *Andersson JLR, Neuroimage, 2003*
[2] *Griswold M, Mag. Res. Med., 2002*

Stockmann JP, NeuroImage, 2017

EPI with alternating slice-encoding gradients: *over-easy*



7T

1.1 mm iso.

axial acquisition

A⟶P phase encode

alternating
<u>slice-select</u>
gradient
polarity

"over-easy" EPI

Slide courtesy of Jon Poliemeni

[Błażejewska *et al.*, 2017 *ISMRM*]

Dynamic ΔB_0 caused by physiology

- Ghosting and ringing in <u>structural</u> images
  - K-space phase modulation due to B_0 fluctuations → ghosts
  - phase stabilization navigators help…

- Stability of EPI time-series <u>functional</u> images
  - Respiration explains ~65% of variance in phase time-series

$Phase_{EPI}(x,y,z,t)$

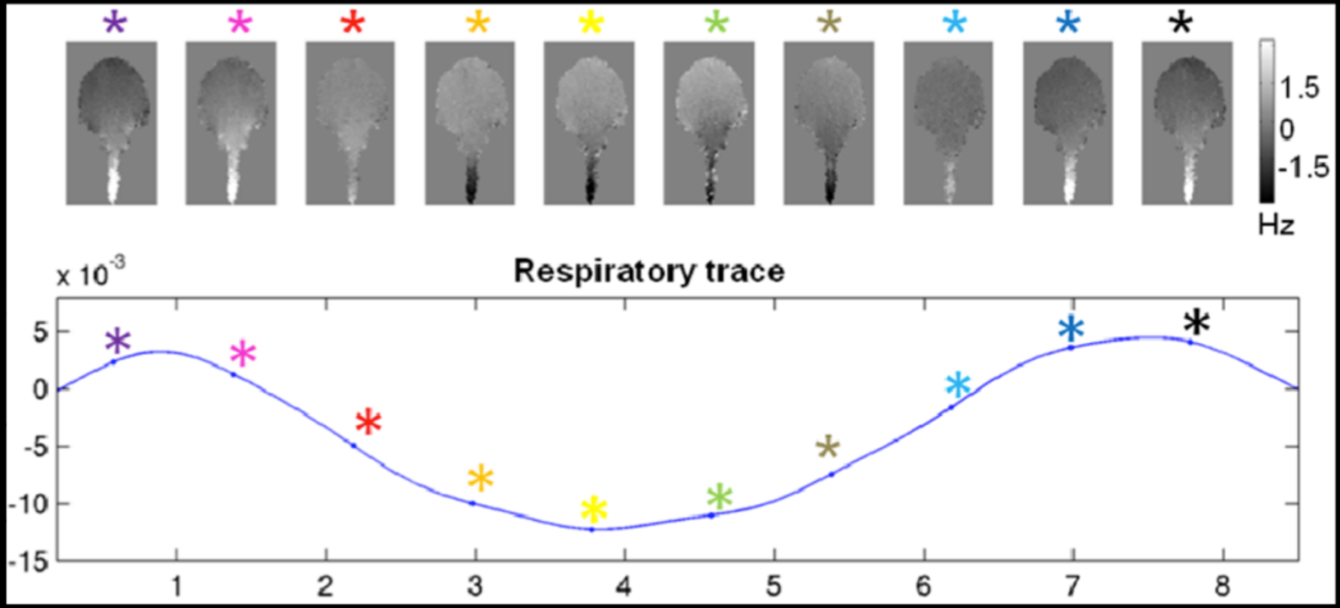
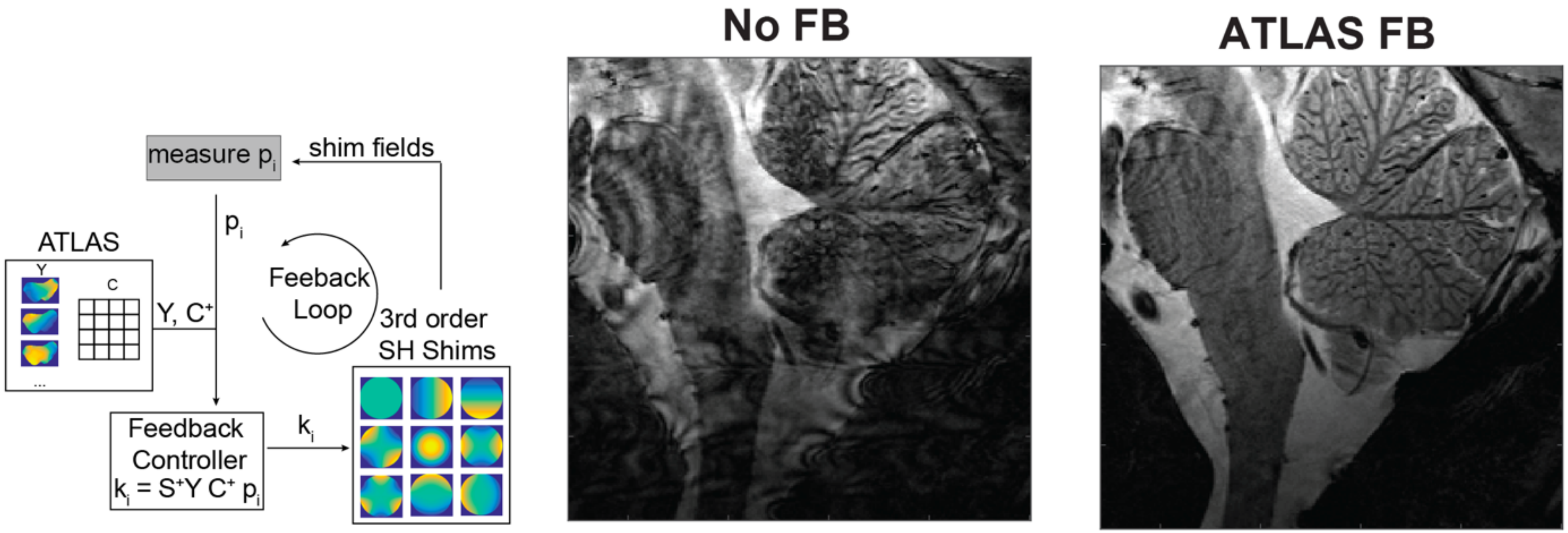


Figure courtesy of Marta Bianciardi, MGH

Regress out in post-processing

Spatiotemporal B_0 fluctuations are worse at 7T, especially in deep brain

<u>Emerging method</u>: Use real-time field monitoring and B_0 shimming to reduce artifacts in structural images

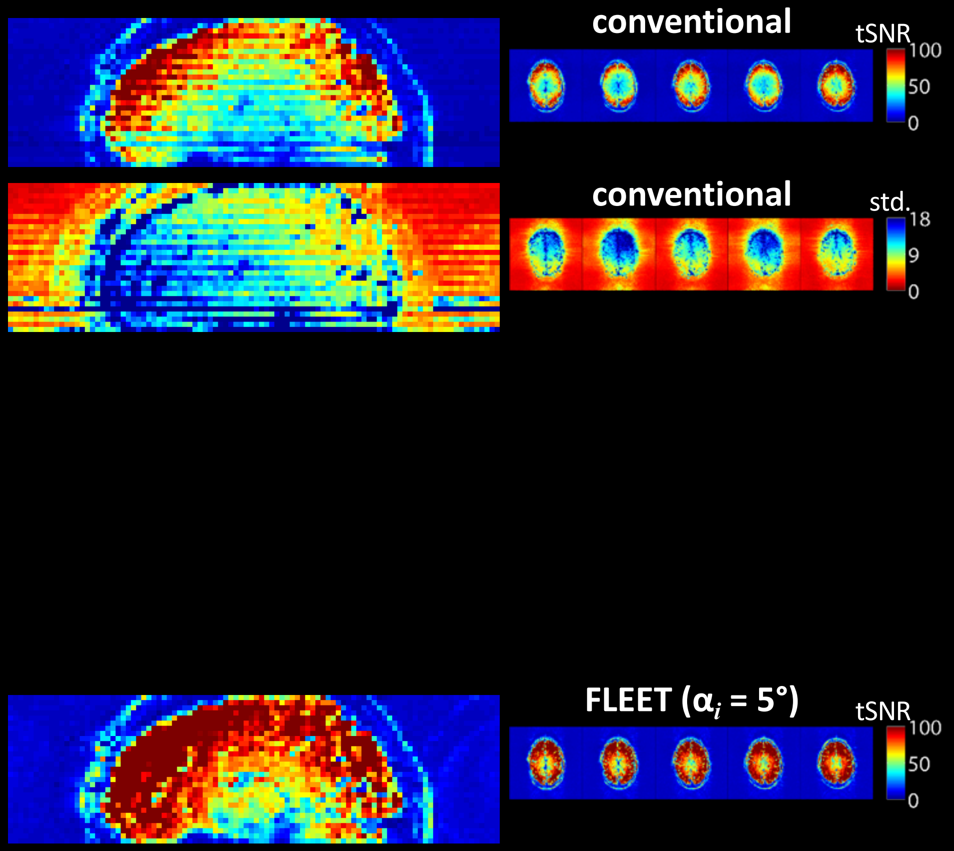


Gross et al., ISMRM 2016

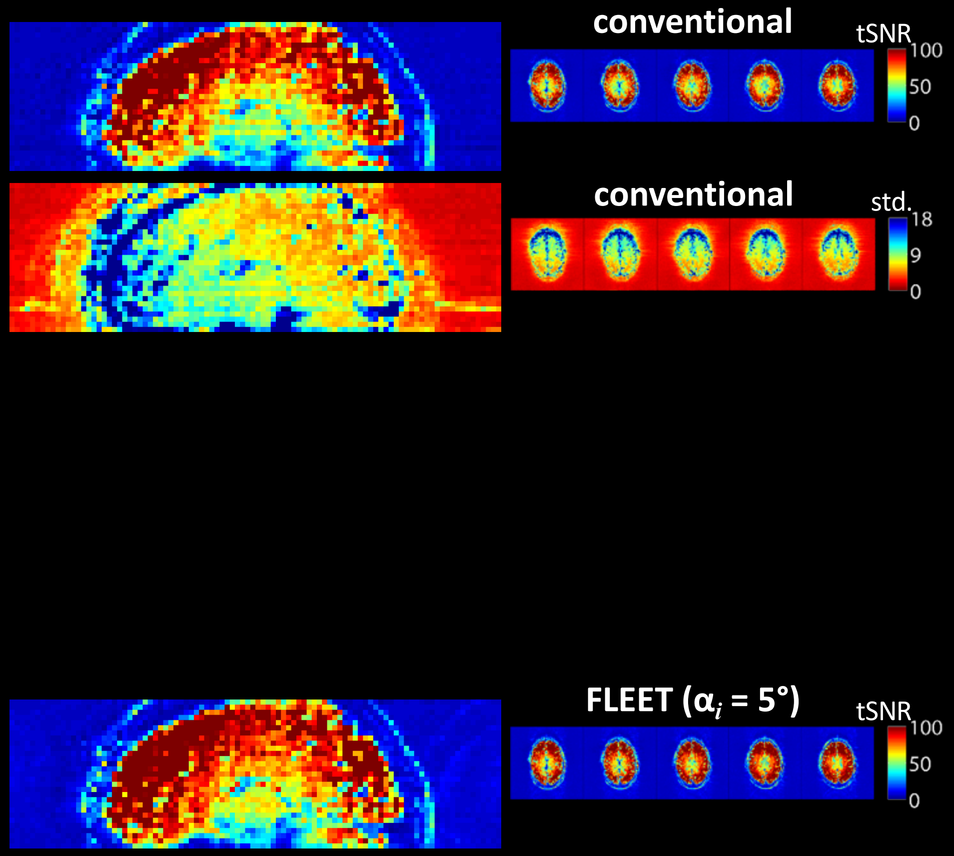
Feedback-controlled dynamic B_0 shim updating could help….

tSNR discontinuity in accel. EPI: *chest motion during respiration*

free breathing during ACS acquisition



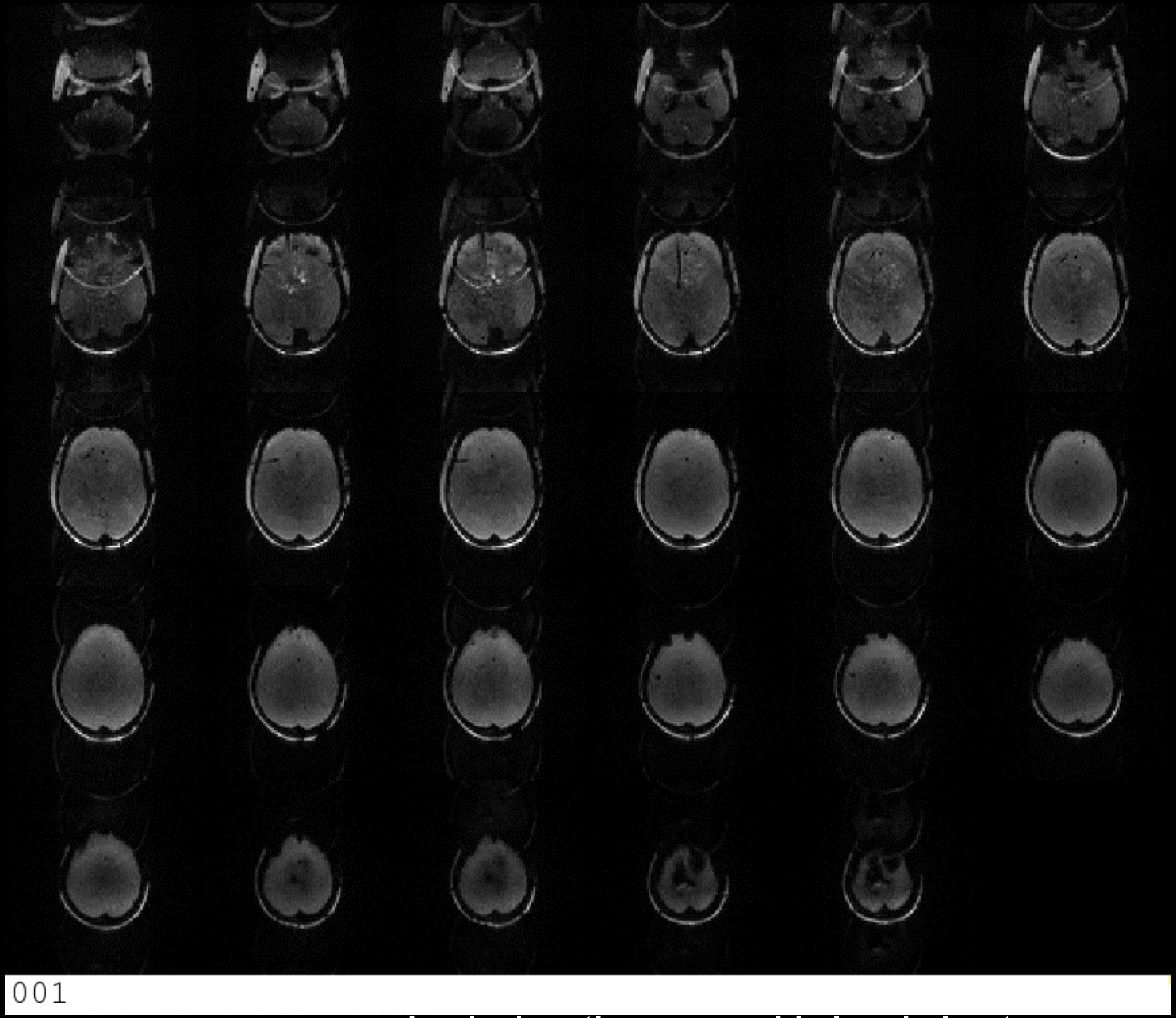
breath-hold during ACS acquisition



FLEET prevents phase errors between shots caused by dynamic B_0 changes

Slide courtesy of Jon Polimeni, MGH

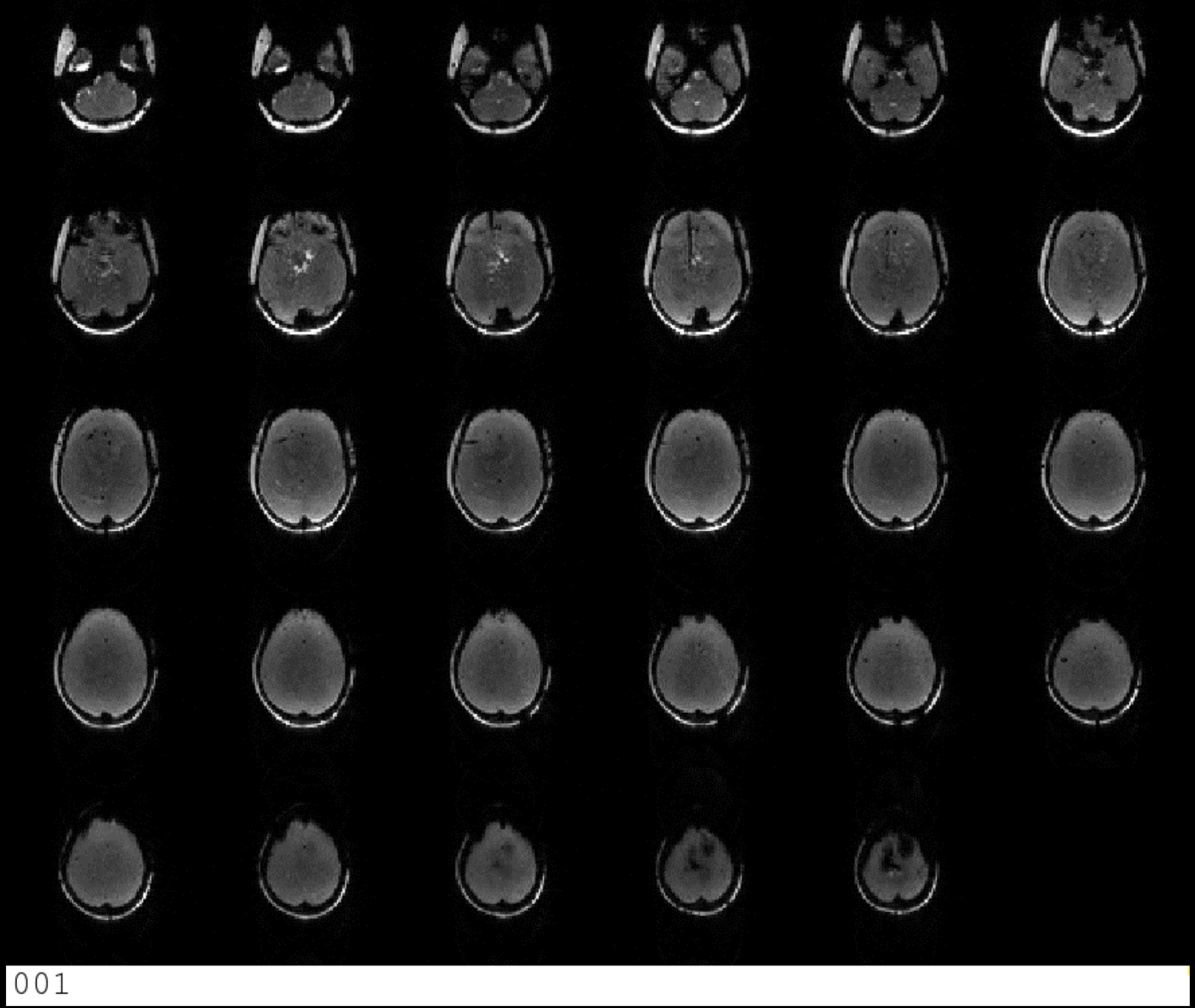
effects of motion: conventional ACS



Slide courtesy of
Jon Polimeni, MGH

vulnerability to motion assessed with a **mechanical, anthropomorphic head phantom** rocking 5°every 15 s

effects of motion: *FLEET* ACS

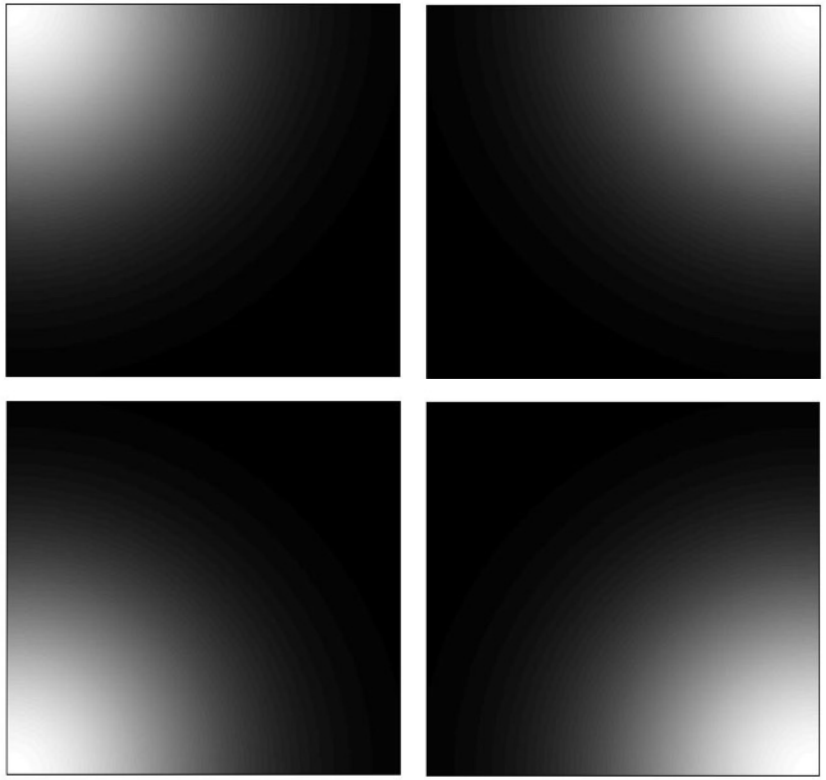


Slide courtesy of
Jon Polimeni, MGH

vulnerability to motion assessed with a **mechanical, anthropomorphic head phantom** rocking 5°every 15 s

Surface Coil B_1^- Sensitivity Profile Effects

coil 1 **coil 2**



coil 3 **coil 4**

4 surface coils and their sensitivity profiles

image 1 **image 2**

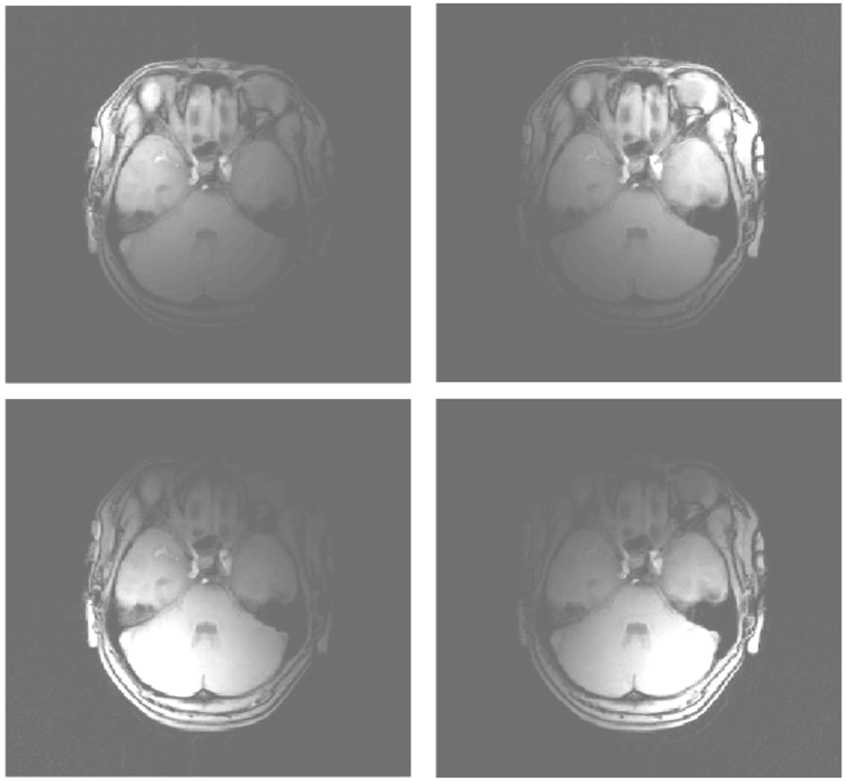


image 3 **image 4**

resultant magnitude images

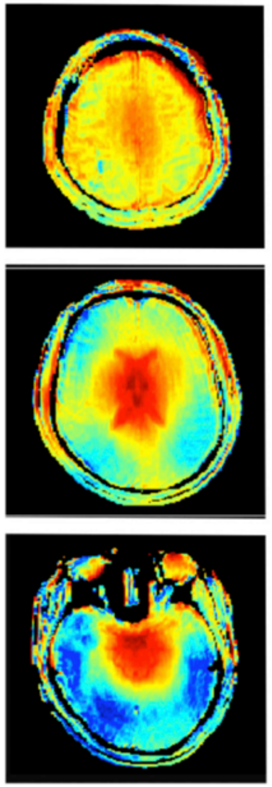
Combined is brighter where Rx coils are more sensitive

Slide courtesy of Todd Constable, Yale Univ.

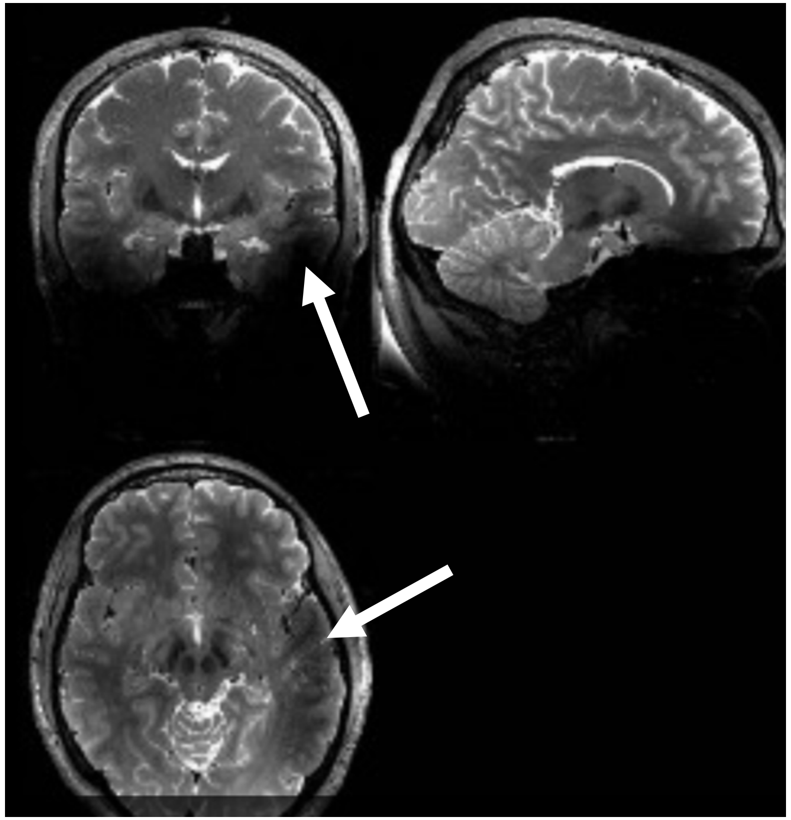
RF B_1^+ inhomogeneity at ultra-high field (7T)

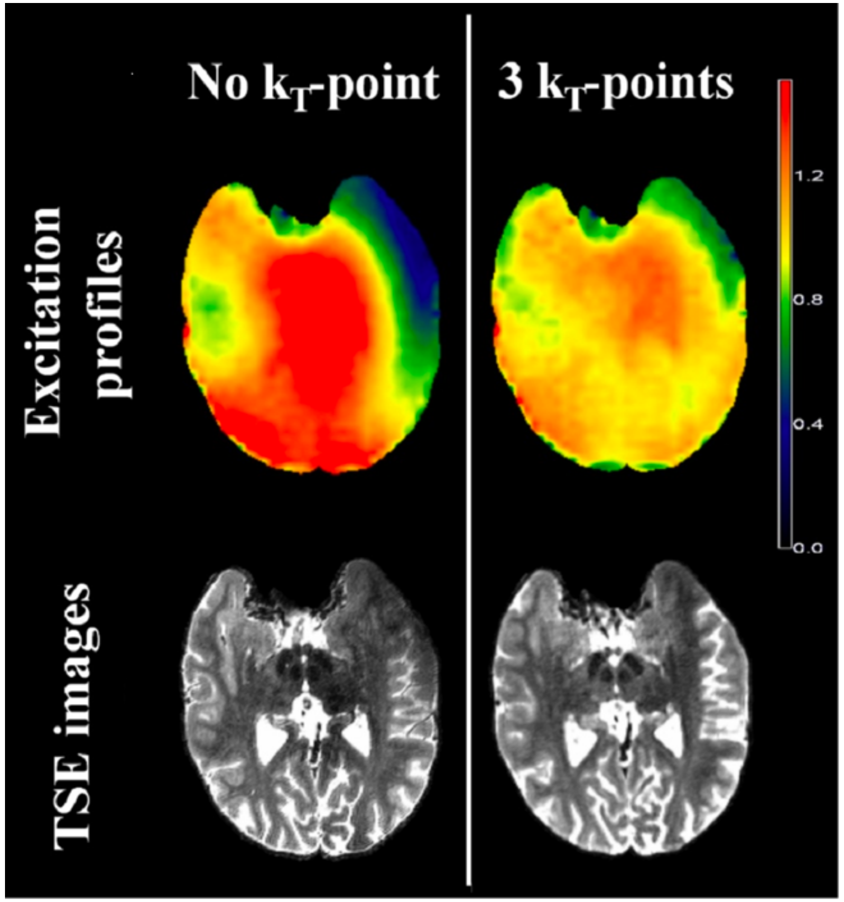
- Interaction of transmit RF field with body tissue (dielectric permittivity and conductivity)
- Dark shading in images, loss of contrast

B_1^+ field amplitude



7T brain images

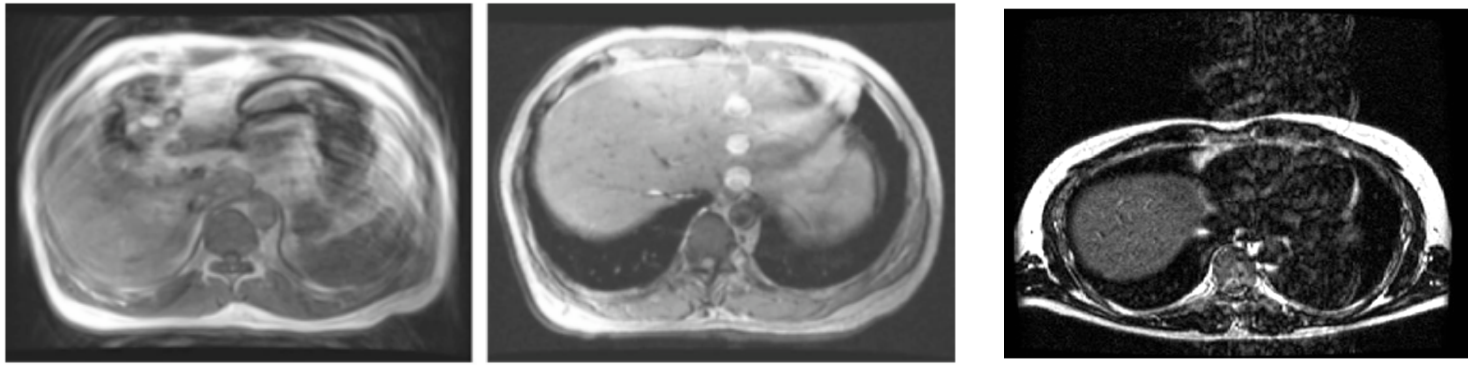




Ugurbil K, NeuroImage, 2017.

Motion Artifacts

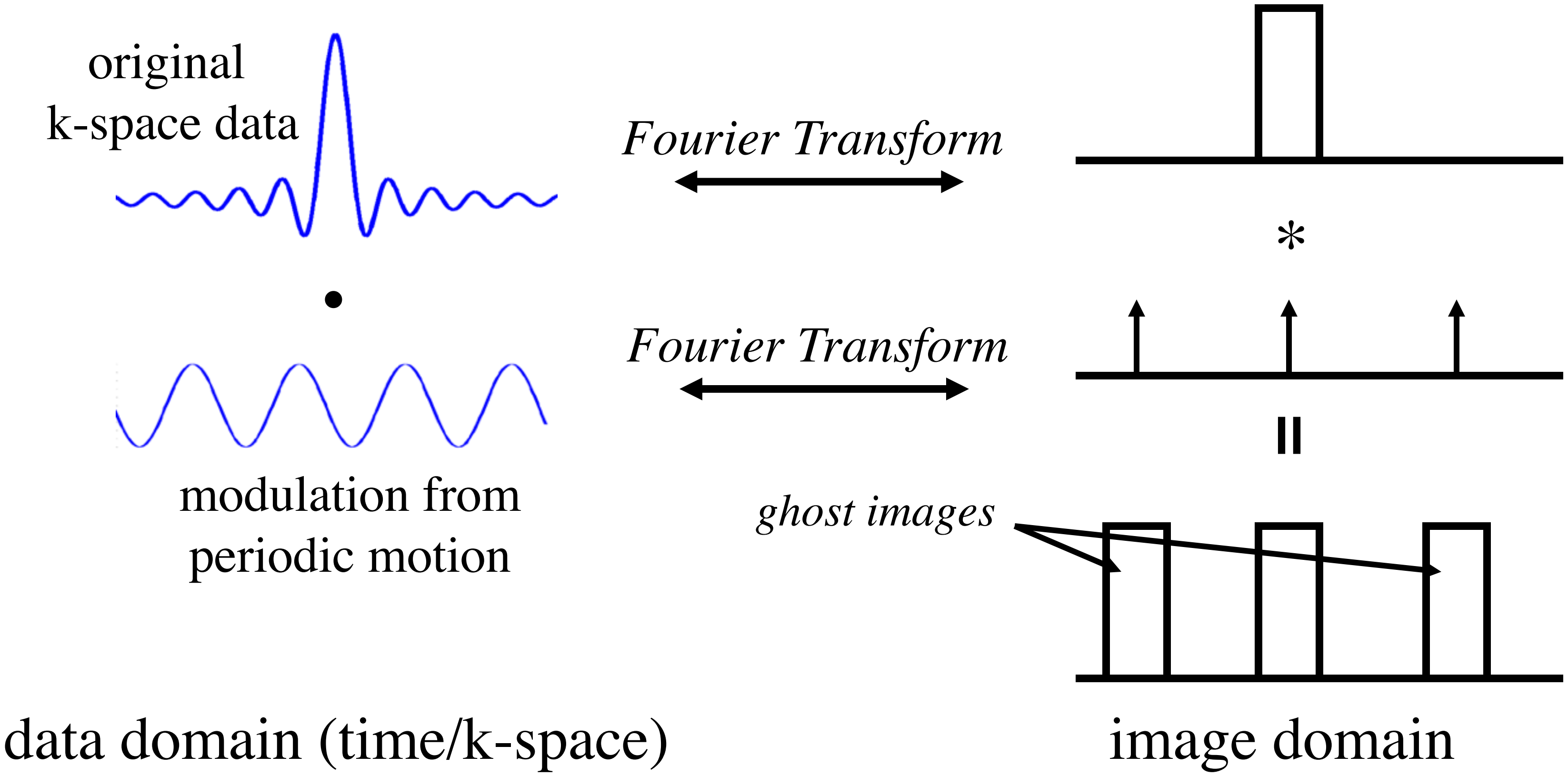
- Motion causes to phase errors in the data which leads to mis-registration in the phase encode (y) direction
- periodic motion leads to ghosting (shifted images that can constructively or destructively interfere with the primary image)
- Remedies:
  - correct for motion induced phase errors
  - fast imaging to freeze motion
  - follow motion



Slide courtesy of Todd Constable, Yale Univ.

1D Example: Motion Present

- consider a 1D image consisting of a box
  - periodic motion



Slide courtesy of Todd Constable, Yale Univ.

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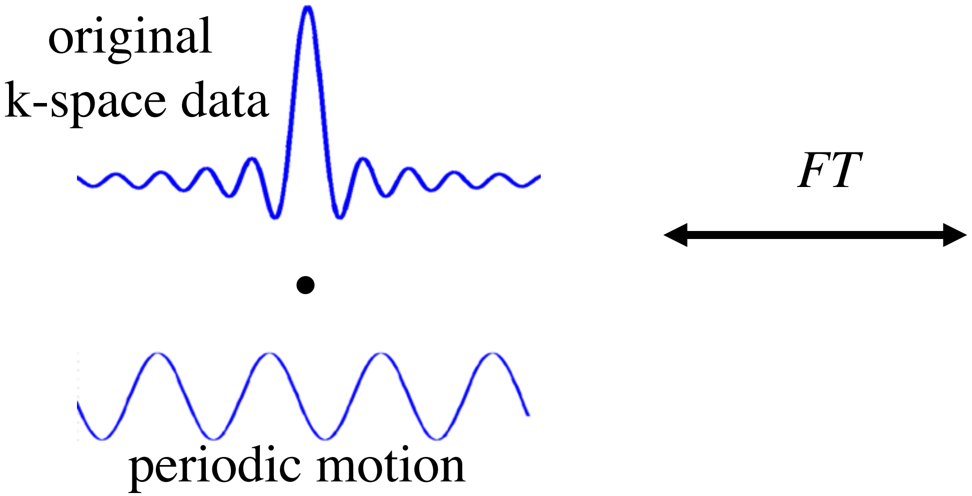
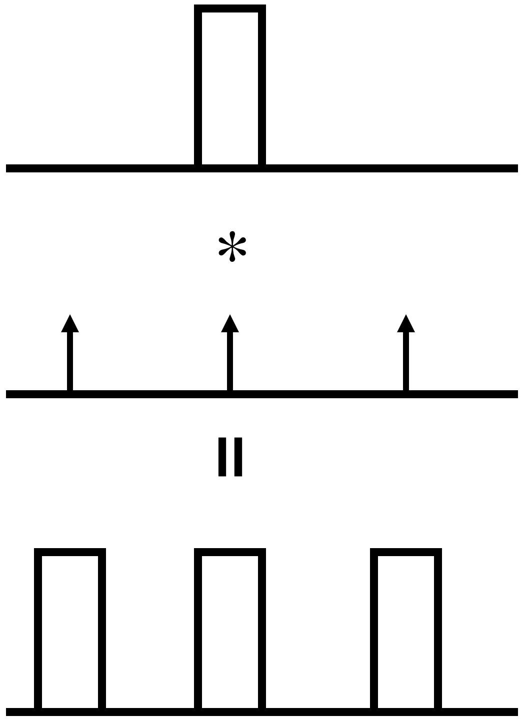


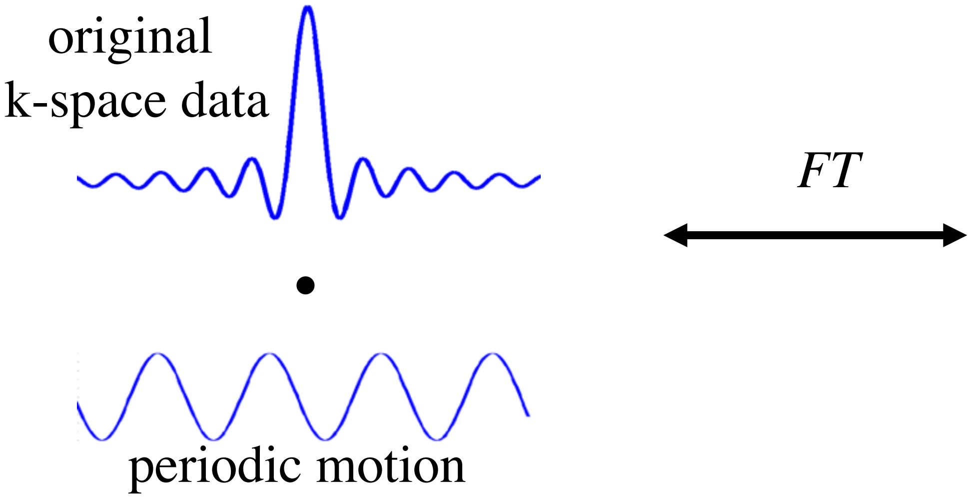


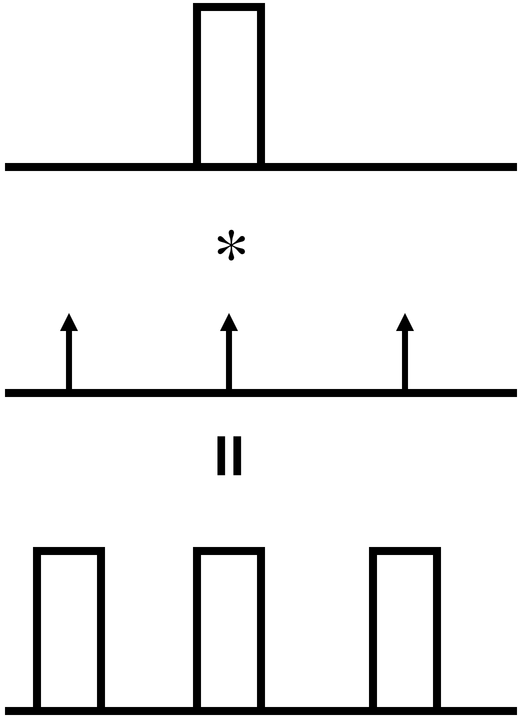
modulation of original data by periodic phase errors leads to discrete ghost images

Slide courtesy of Todd Constable, Yale Univ.

1D Example: Motion Present

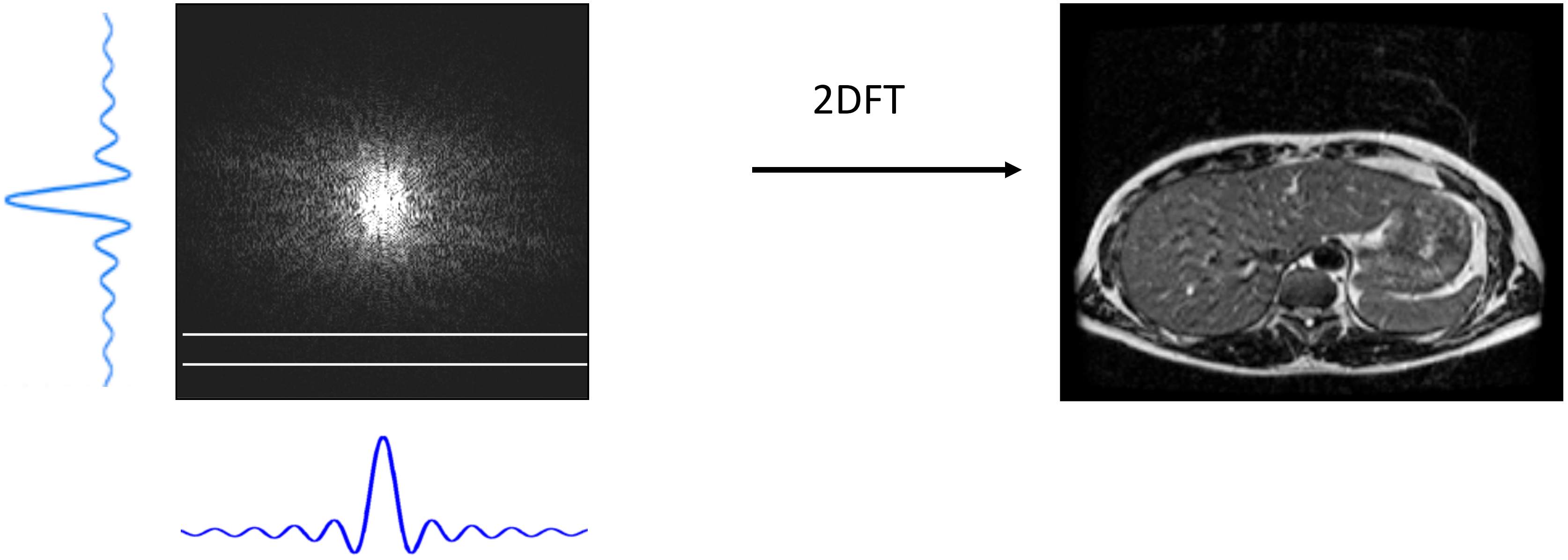
- consider a 1D image consisting of a box
  - periodic motion





- ghosts separated in this example
- usually overlap in practice

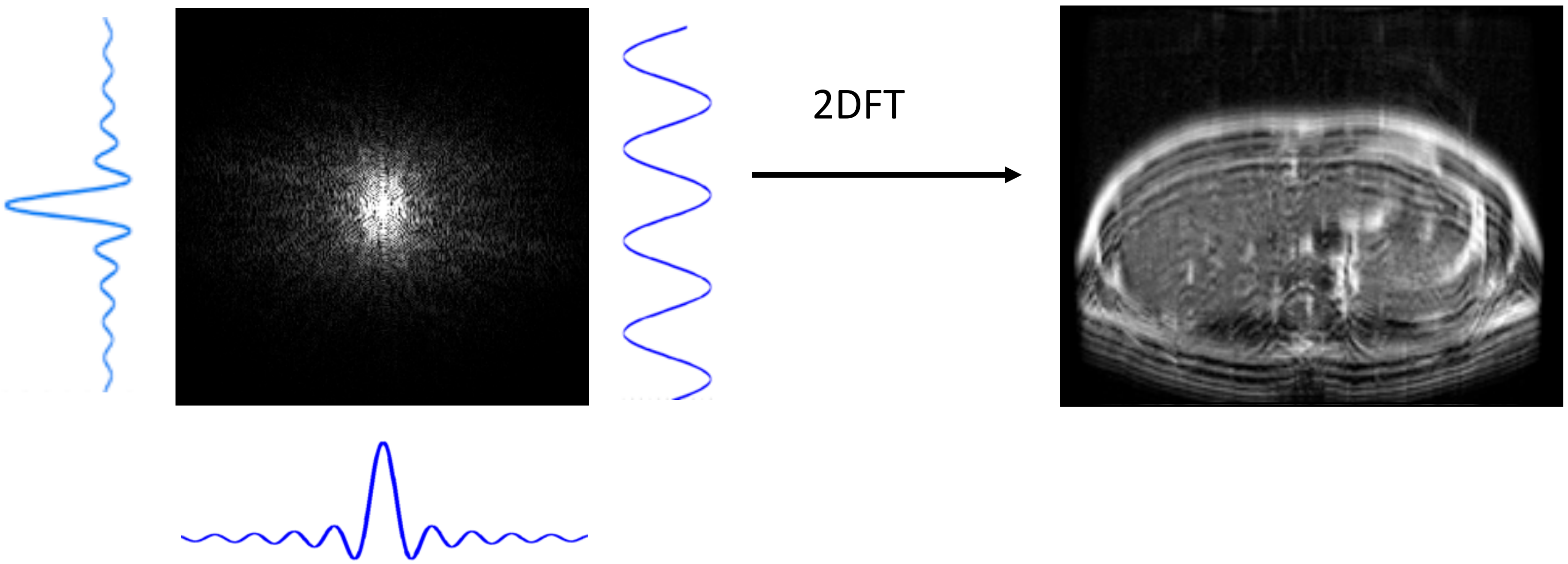
Motion Artifacts in 2D:
Conventional Data Acquisition



data acquired 1 line at a time with a delay = TR between each line

Slide courtesy of Todd Constable, Yale Univ.

Motion Artifacts in 2D:
Conventional Data Acquisition

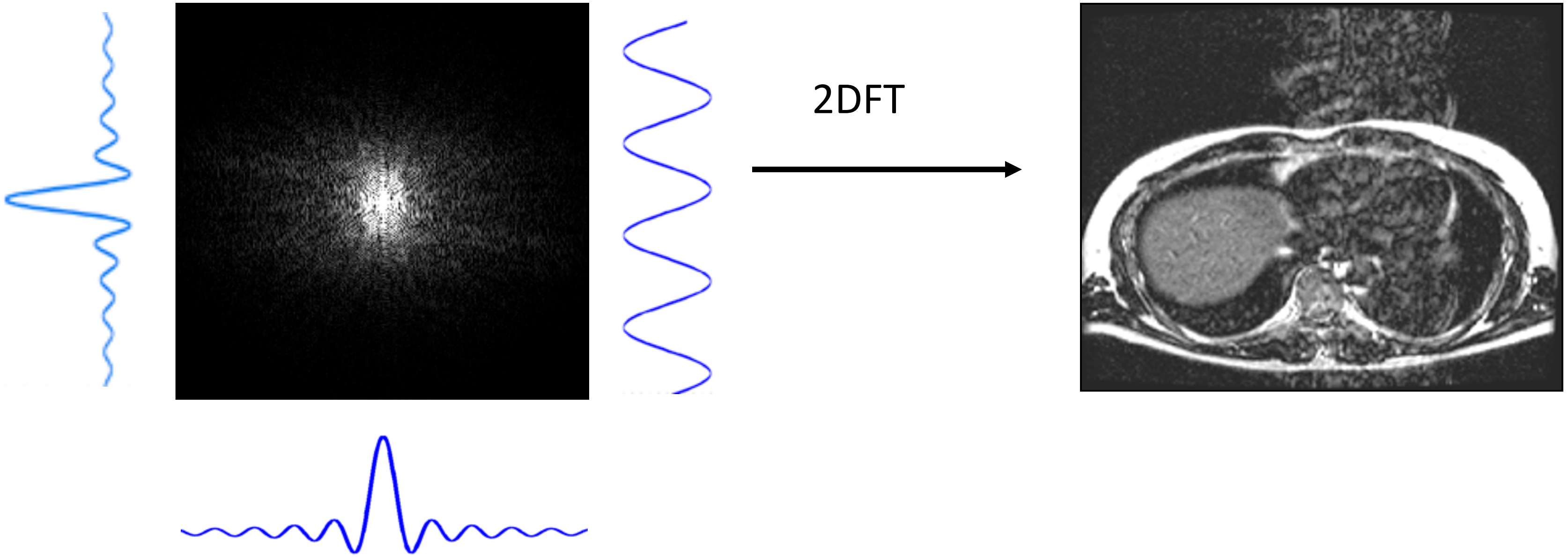


periodic motion introducing a phase error in the phase encode (vertical) direction results in misplacement of tissue in phase encode direction

Slide courtesy of Todd Constable, Yale Univ.

Motion Artifacts in 2D:

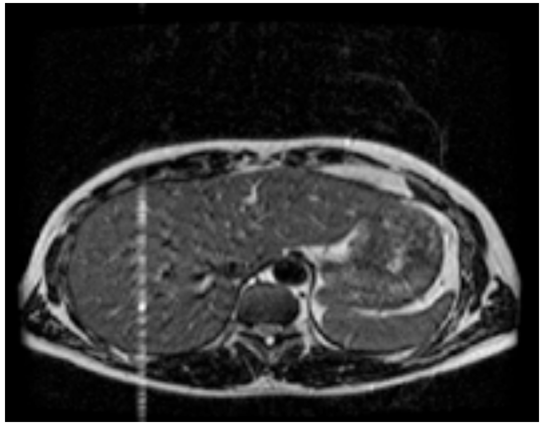
Conventional Data Acquisition



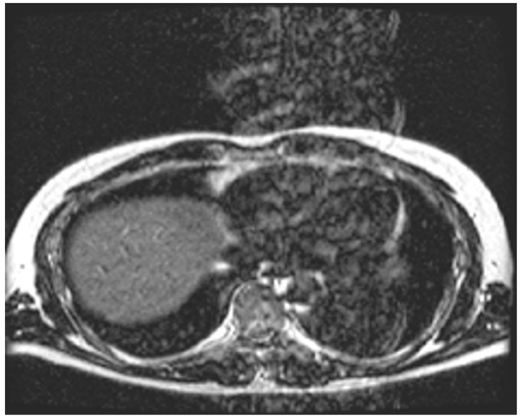
phase errors may occur over the datasets for only certain voxels - not all voxels
(e.g. only the moving ones)

Slide courtesy of Todd Constable, Yale Univ.

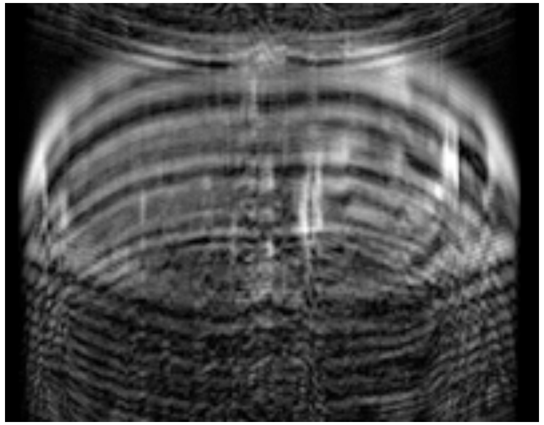
Motion Artifacts in 2D:
Different severity/extent of artifacts



- Motion artifact from flowing blood in vessel
- periodic due to pulsatile nature of flow



- Motion artifact primarily from beating heart



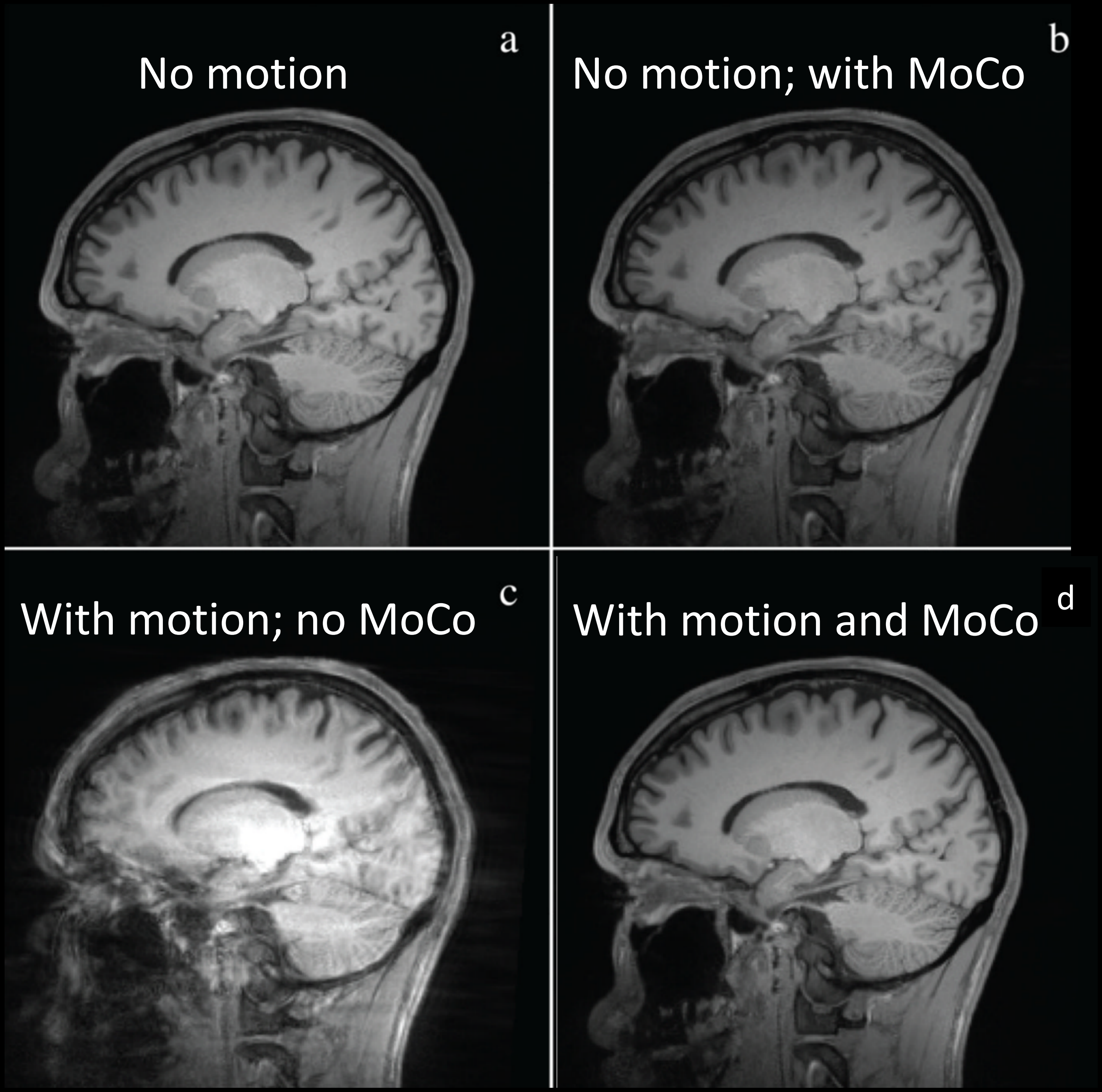
- In this case motion included entire object
- Often limited to anterior wall, or specific organs/structures

Slide courtesy of Todd Constable, Yale Univ.

Head motion

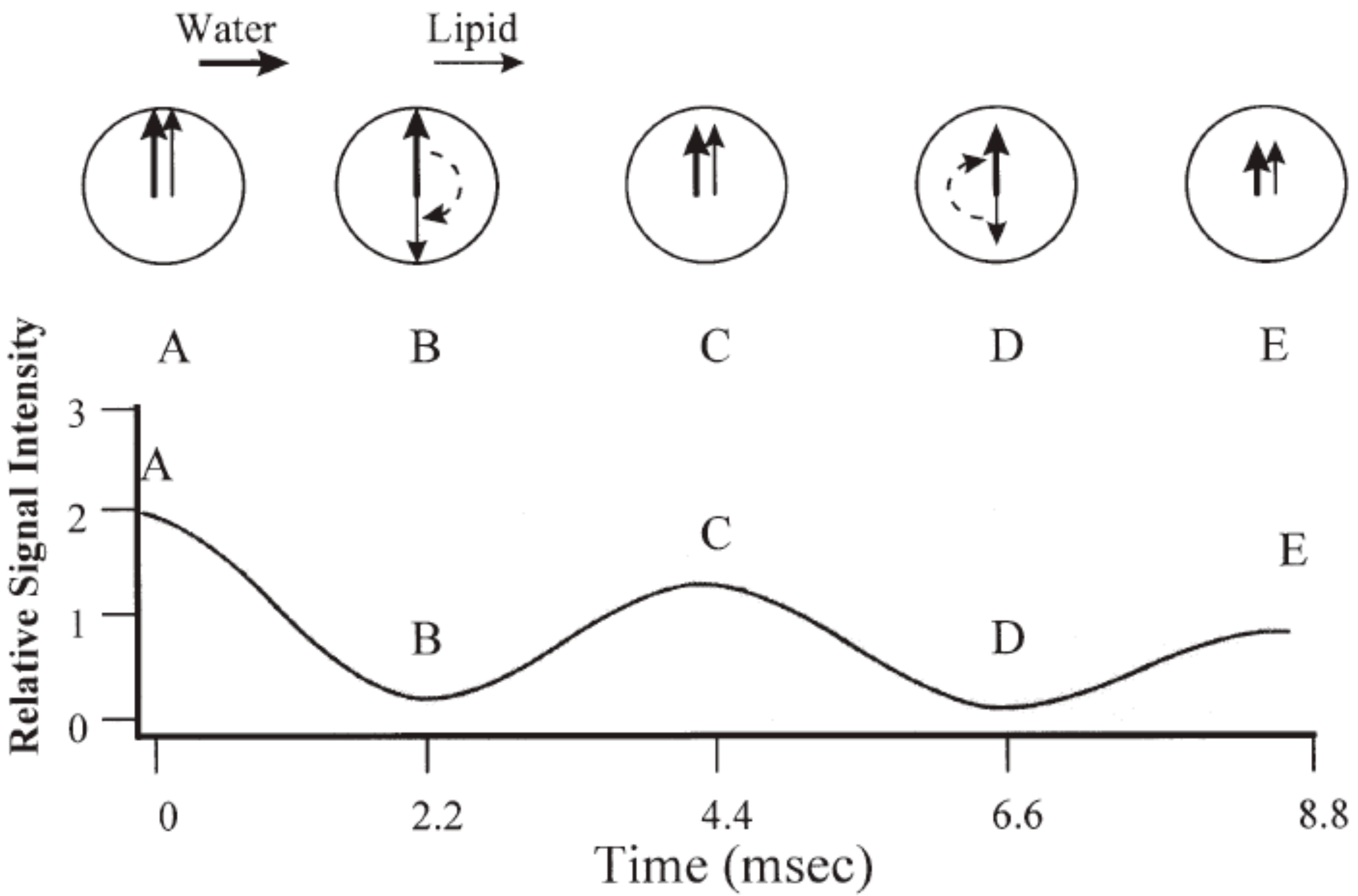
3D acquisition example:

T1-weighted MPRAGE



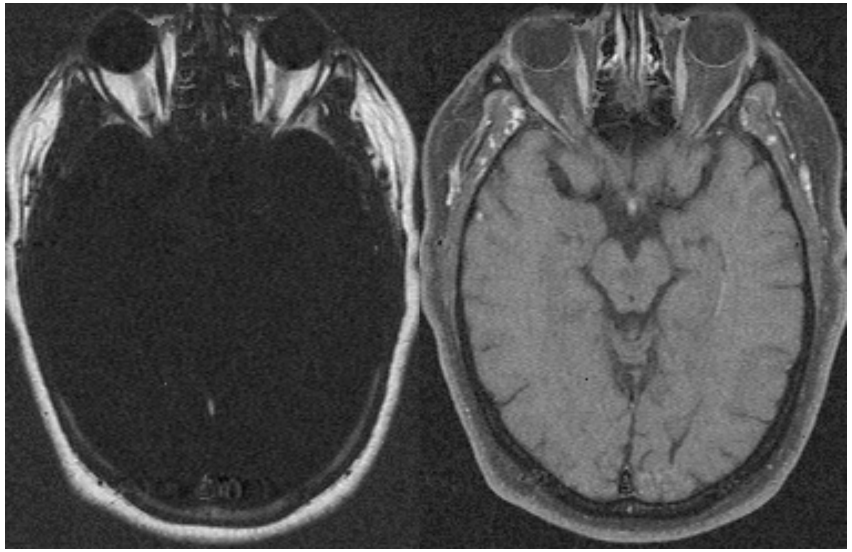
Fat and Water Resonances Move in and out of phase over time

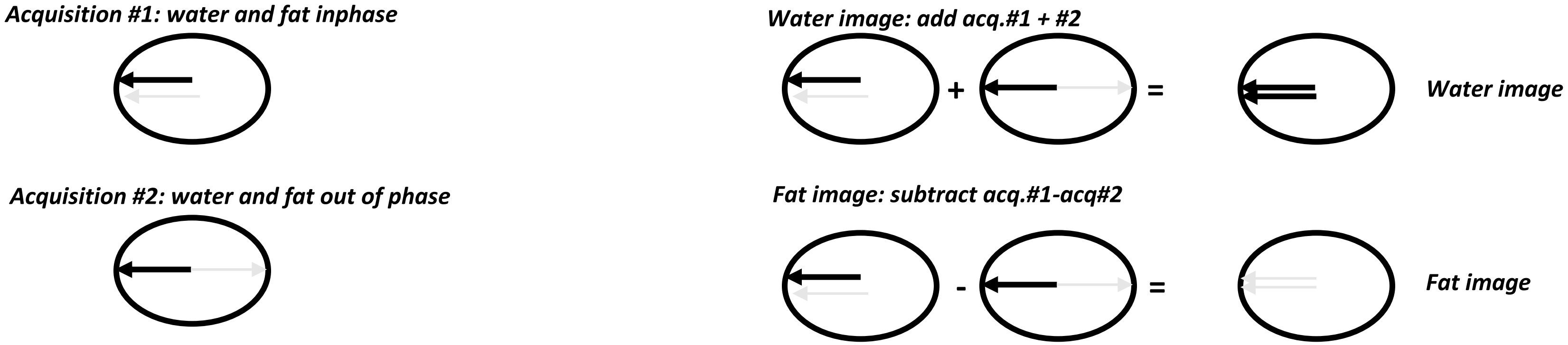
Water precesses approx. 3.5ppm faster than fat



Slide courtesy of Todd Constable, Yale Univ.

Chemical Shift can be Exploited to Produce Fat (left) or Water (right) <u>only</u> Images

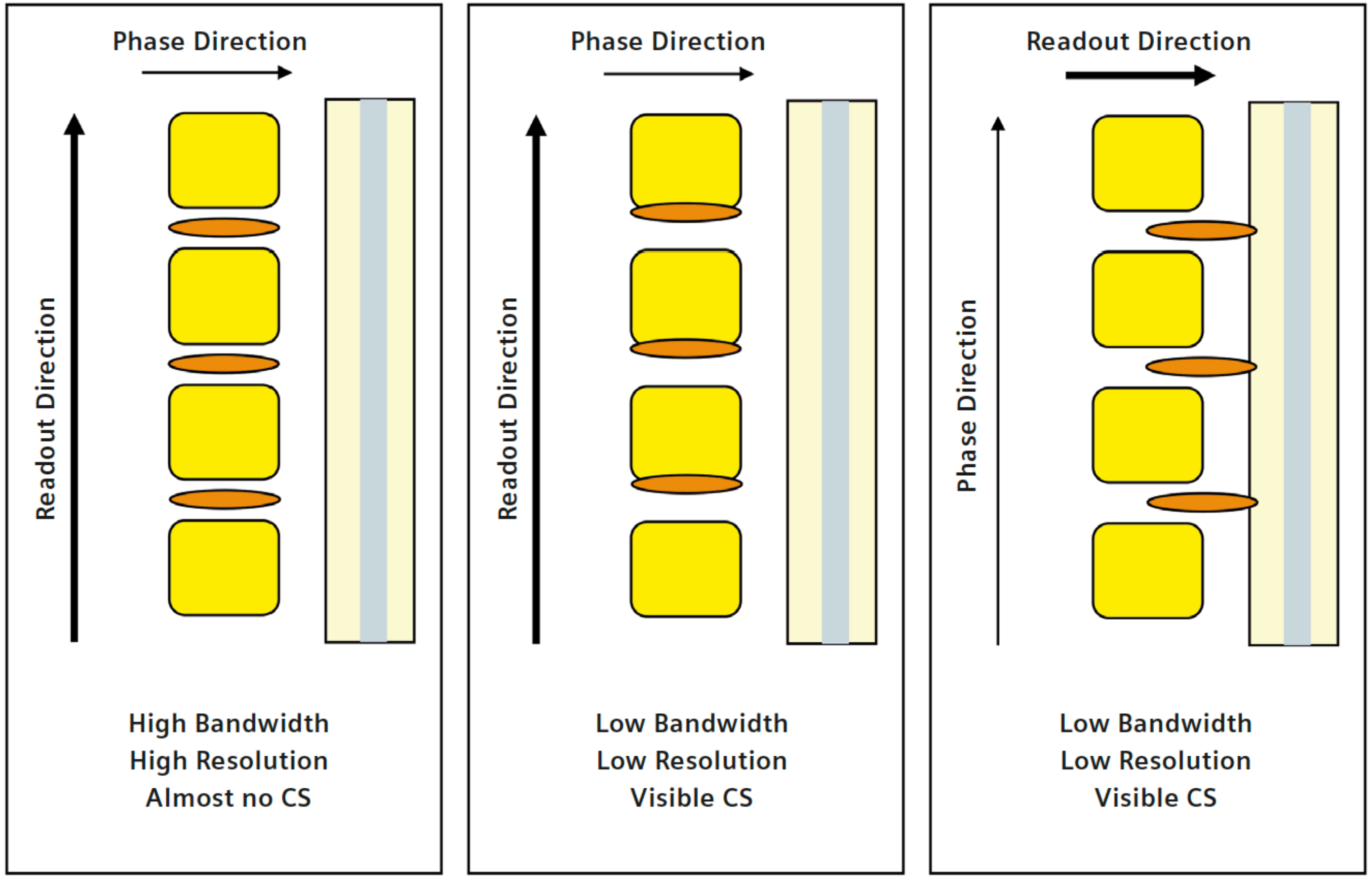


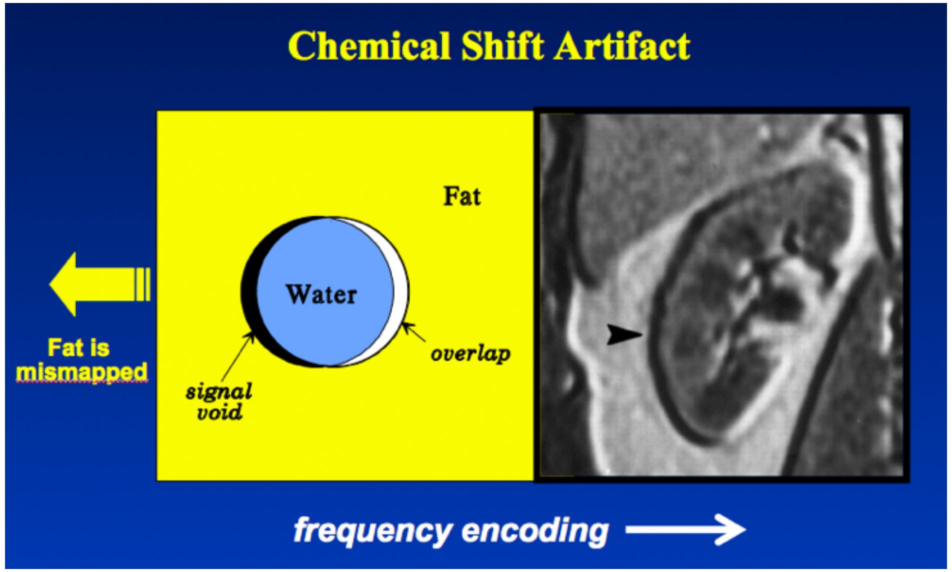


Called the 2-point Dixon method after the guy who developed it.

Slide courtesy of Todd Constable, Yale Univ.

Fat/Water Chemical Shift Effects

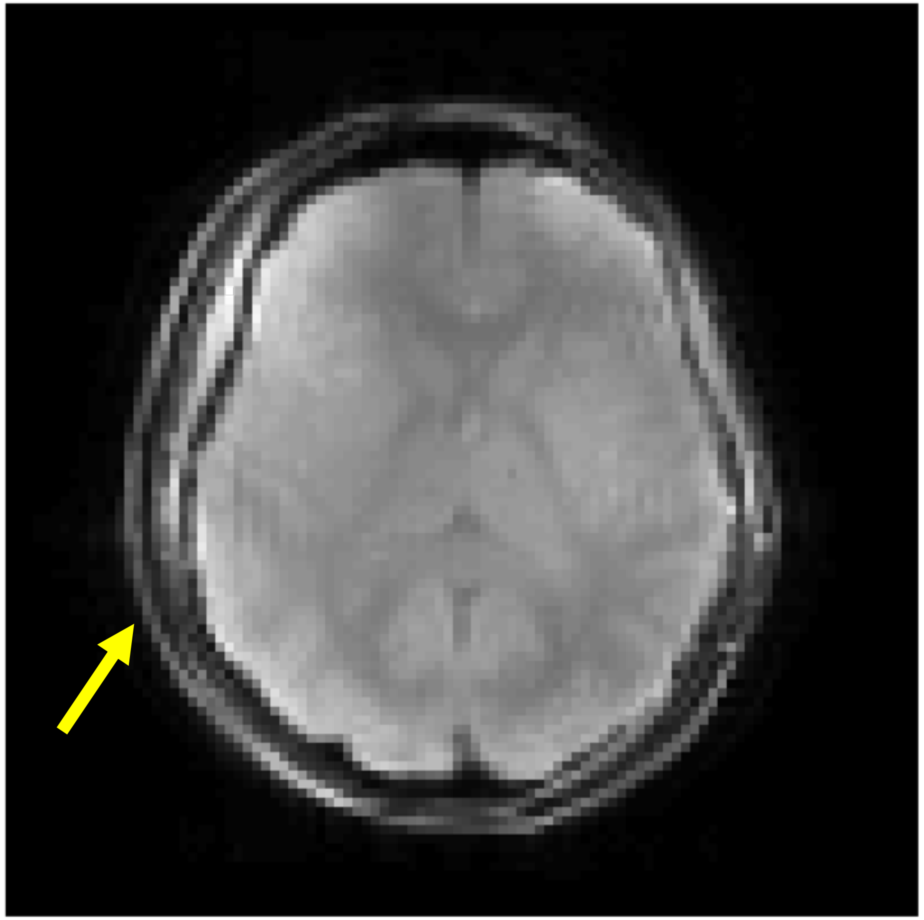




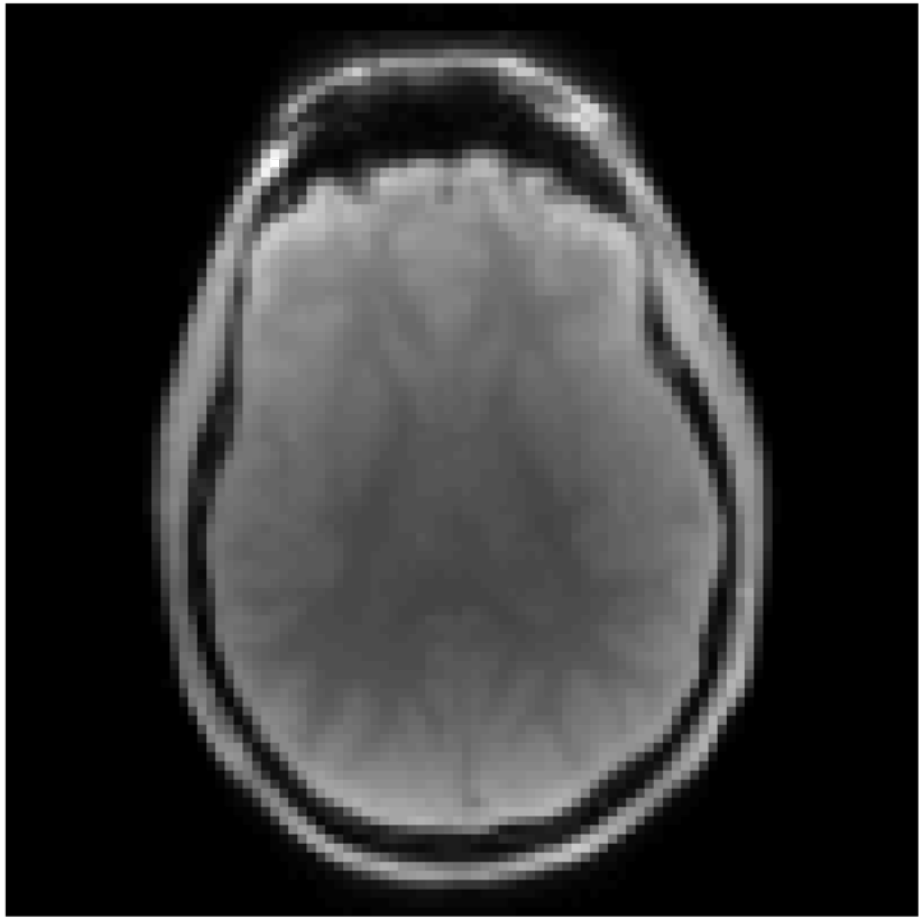
http://mriquestions.com/chemical-shift-artifact.html

Slide courtesy of Todd Constable, Yale Univ.

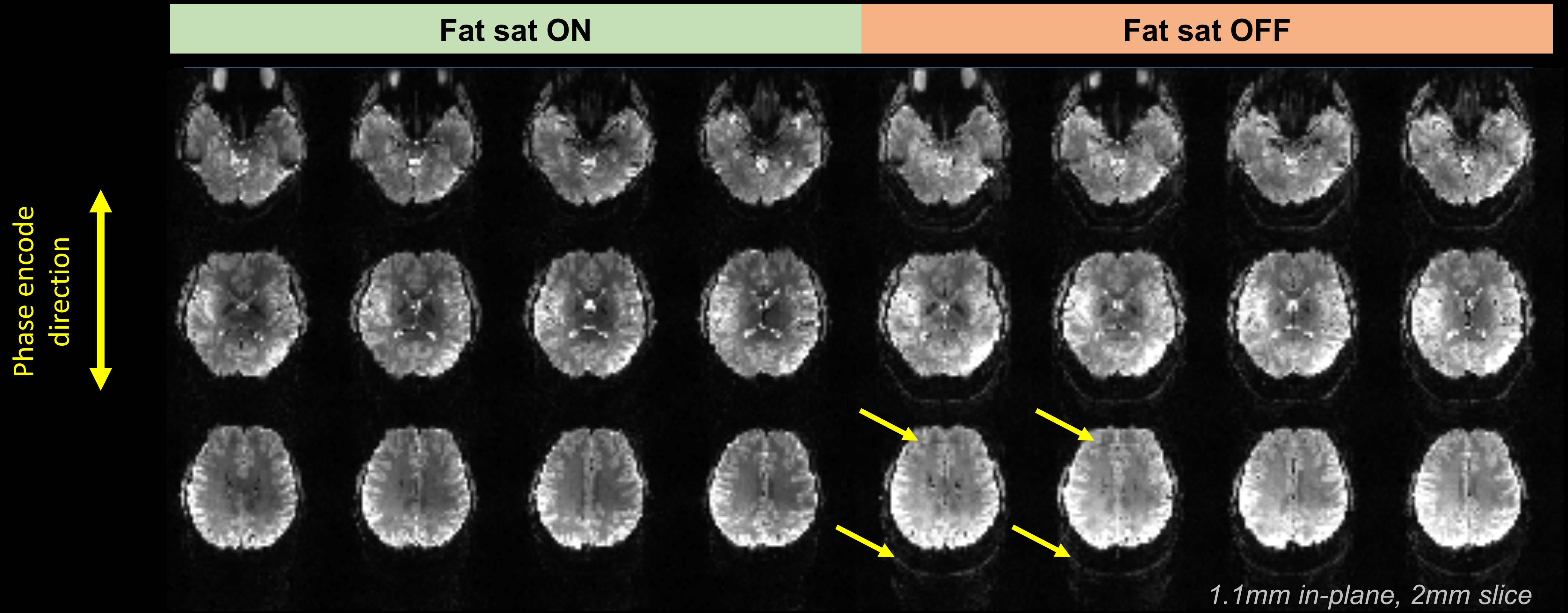
Low readout bandwidth



High readout bandwidth:
No chemical shift artifact



Fat saturation in EPI



Number of voxels shifted depends on fat-water shift and PE bandwidth (Hz/pix)

3.5 ppm x 300 MHz = 1050 Hz fat-water shift

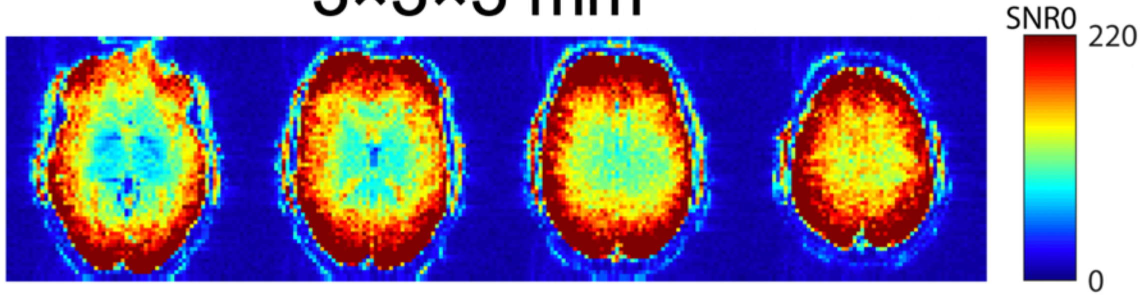
Echo spacing = 0.81ms with R=4 acceleration → 1/.20ms = 5 KHz for 180 pix → 27 Hz/pix
→ 3.5ppm x 297 MHz/(27 Hz/pix) = *38 pix shift*

Physiological noise in EPI time series: Impact on *temporal SNR (μ/σ)*

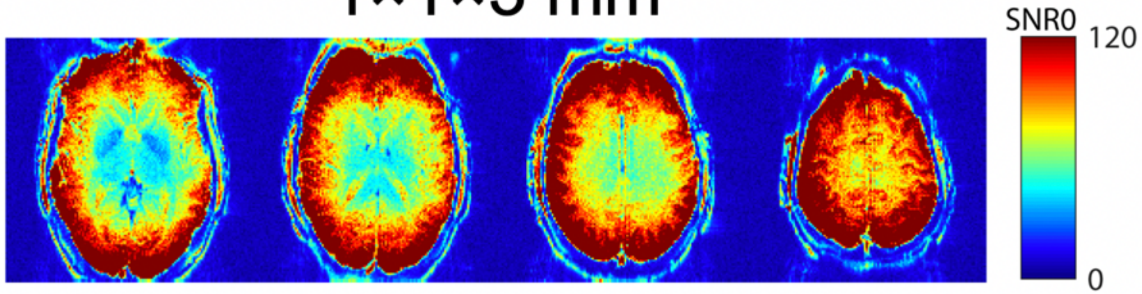
9x smaller volume!!!

SNR$_0$

$3 \times 3 \times 3$ mm^3



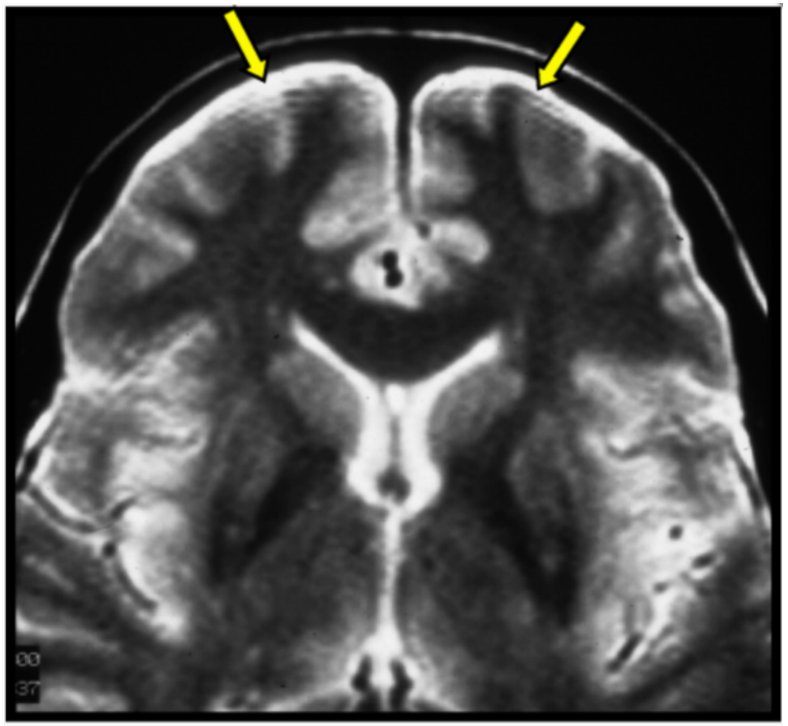
$1 \times 1 \times 3$ mm^3



References: Triantafyllou C, et al., NeuroImage 2011
Polimeni J and Wald LL, NeuroImage, 2017

Quiz!!!

Quiz



(1) Incomplete fat suppression (chemical shift artifact)

(2) “Zipper” artifact from RF noise contamination

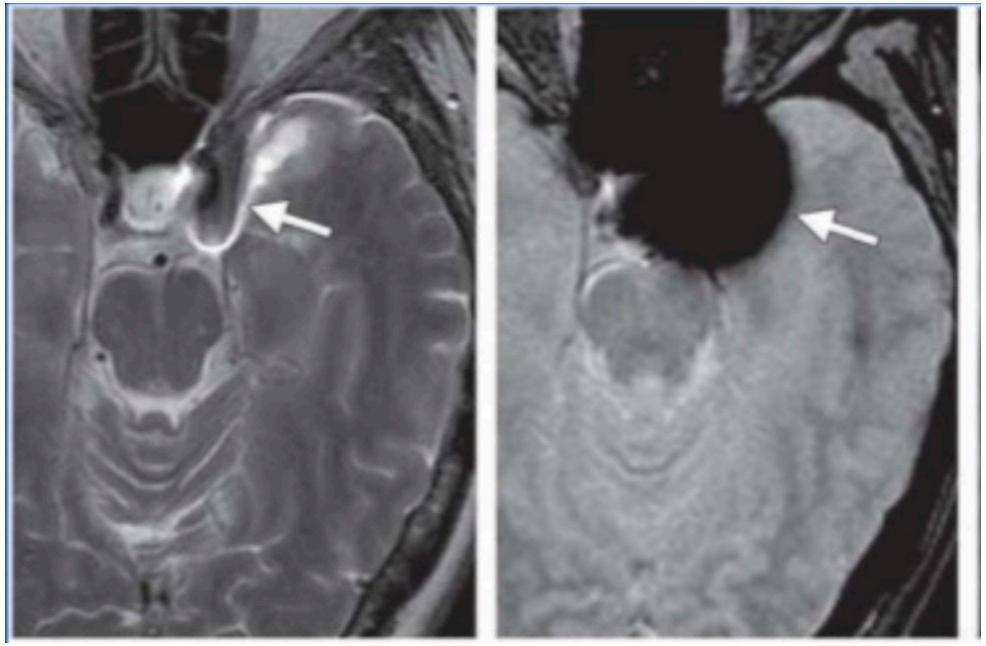
(3) Gibbs ringing from k-space truncation

(4) Head motion artifact

<u>Solution</u>: Can soften with a little filtering/windowing in frequency domain → causes slight blur

Quiz

Spin echo Gradient echo



(1) Blood flow artifact from hematoma

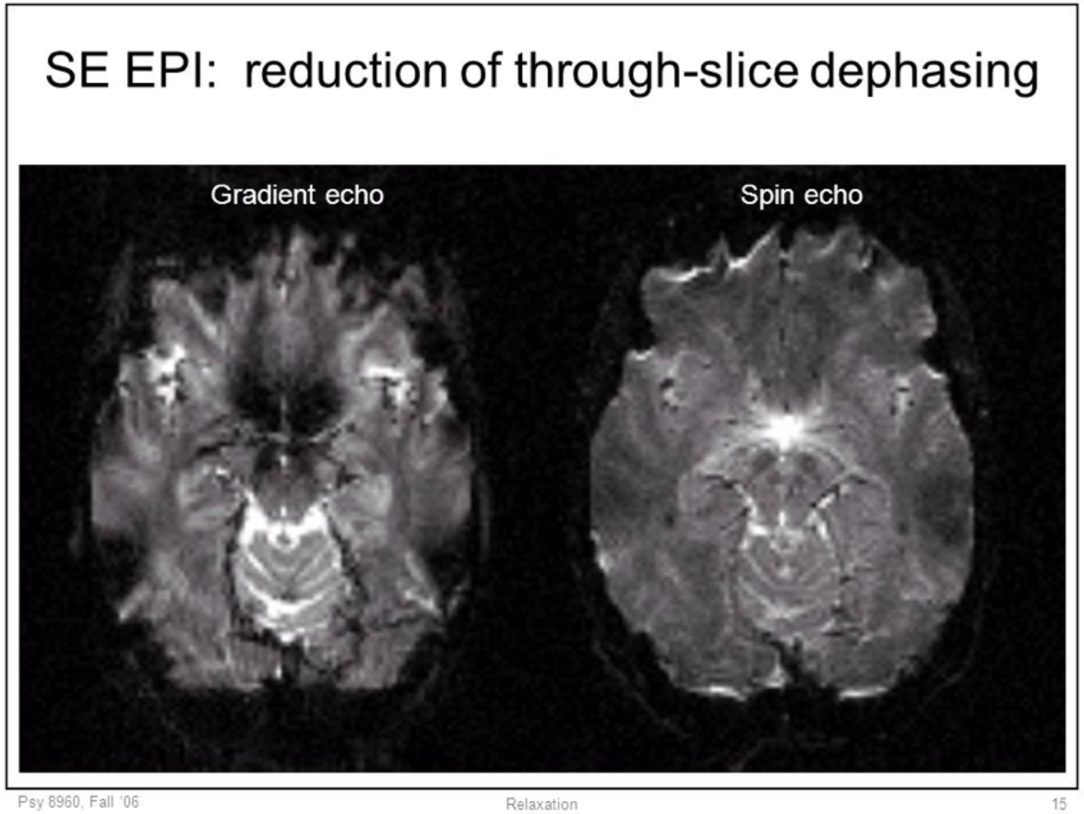
(2) T2* dephasing from metal object (susceptibility)

(3) RF coil transmit field inhomogeneity

(4) T2* dephasing from sinus cavity air-tissue susceptibility interface

<u>Solution</u>: No easy solution….

Quiz



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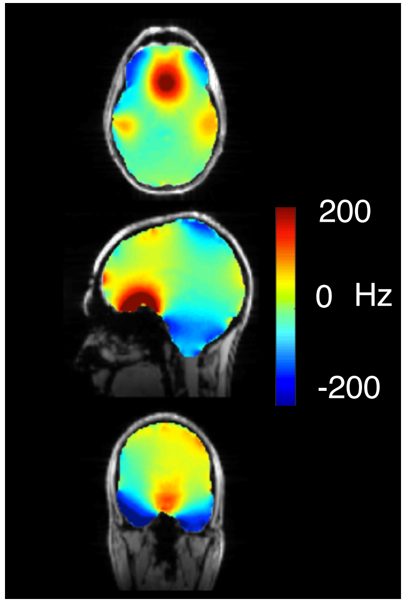
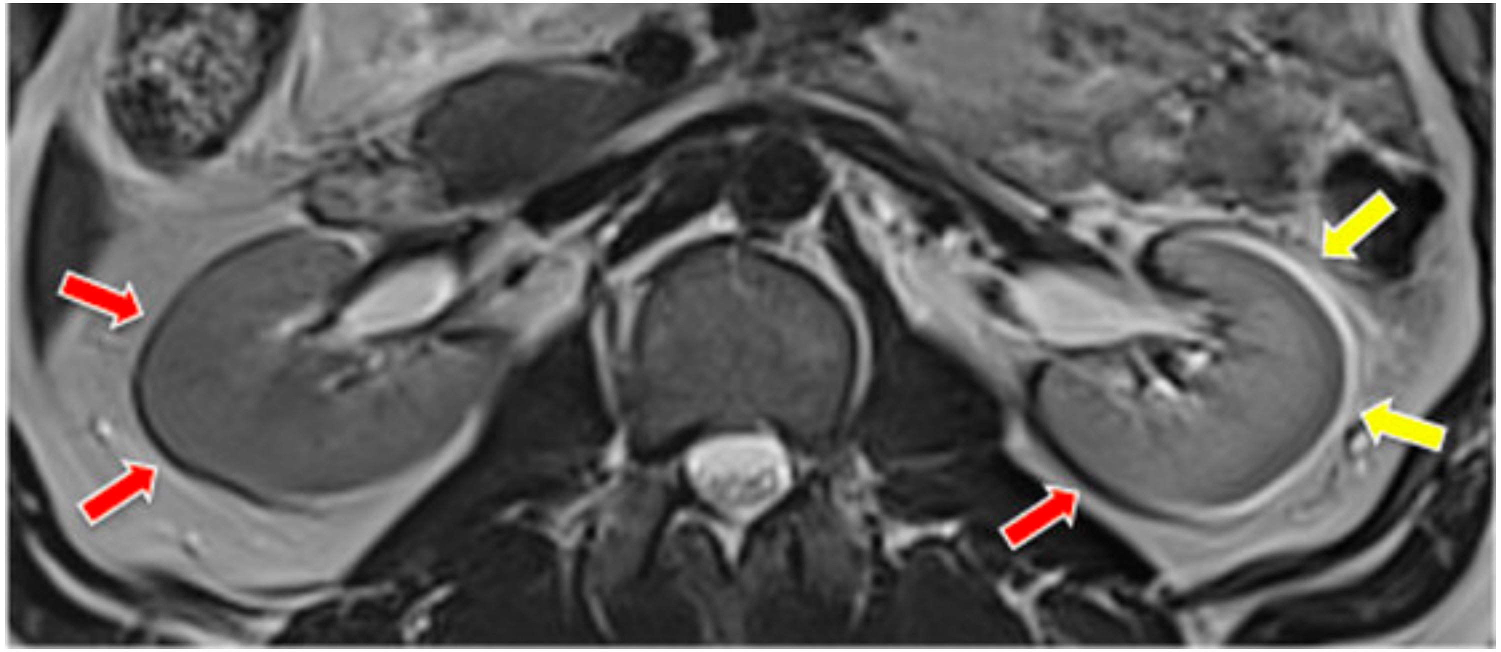


Solution: Use thinner slices or better B_0 shimming



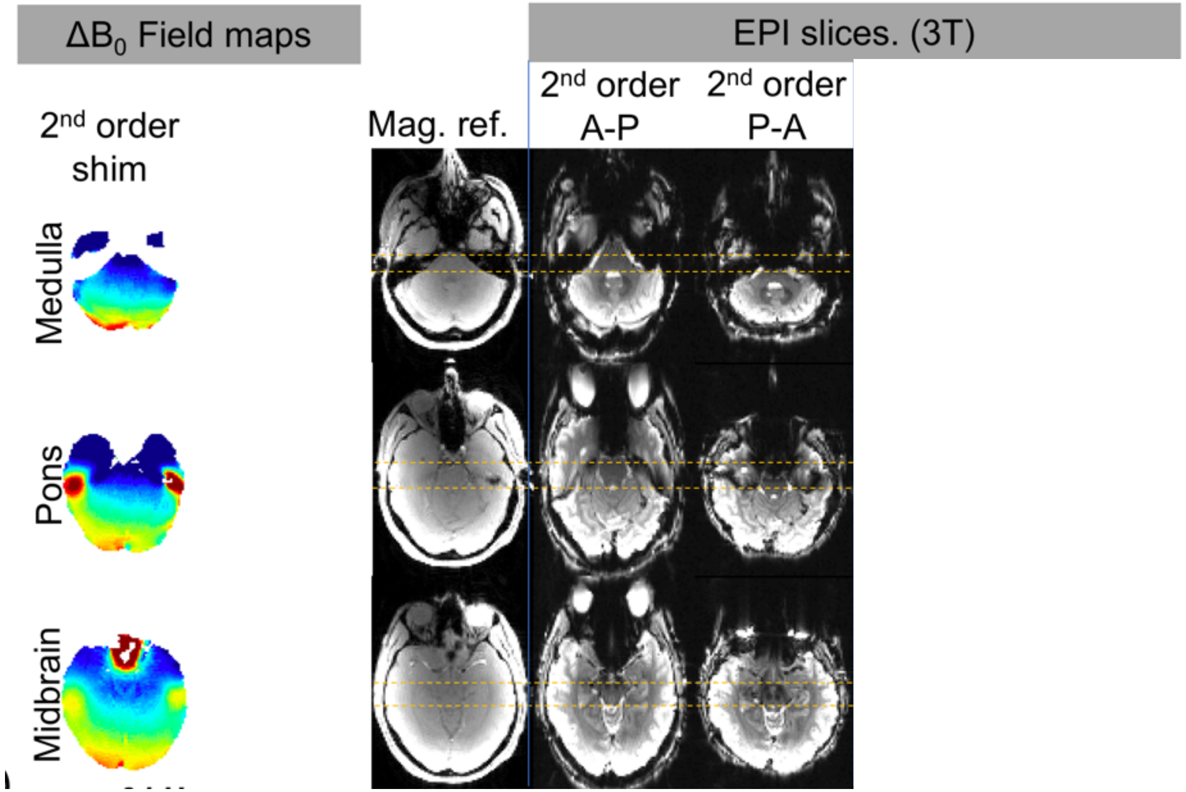
(1) Geometric stretching from phase encode gradient eddy currents

(2) Motion artifact

(3) Fat-water shift along readout direction

(4) No artifact – image shows real anatomical details

Quiz



(1) Gradient nonlinearity

(2) Geometric distortion from gradient eddy currents

(3) Motion artifact

(4) Geometric distortion due to B_0 offset in body

Solution: Reduce echo spacing time, increase iPAT GRAPPA factor, improve B_0 shimming

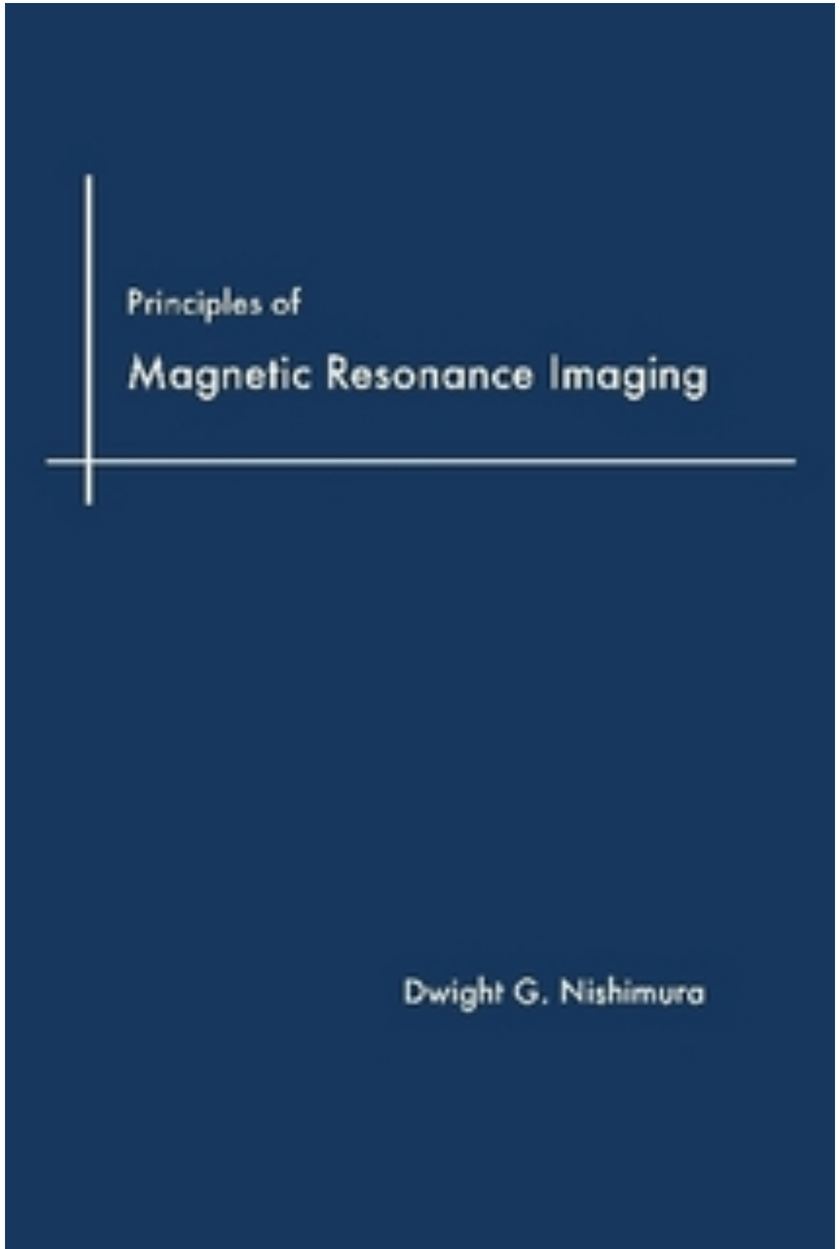

HAPPY
HALLOWEEN

McKinstry RC et al., AJR, 2004

<u>*Cause*</u>: Iron oxide suspended in beeswax hair product

"I think you'll get a kick out of our 'haunted' MRI, Mrs. Hanratty."

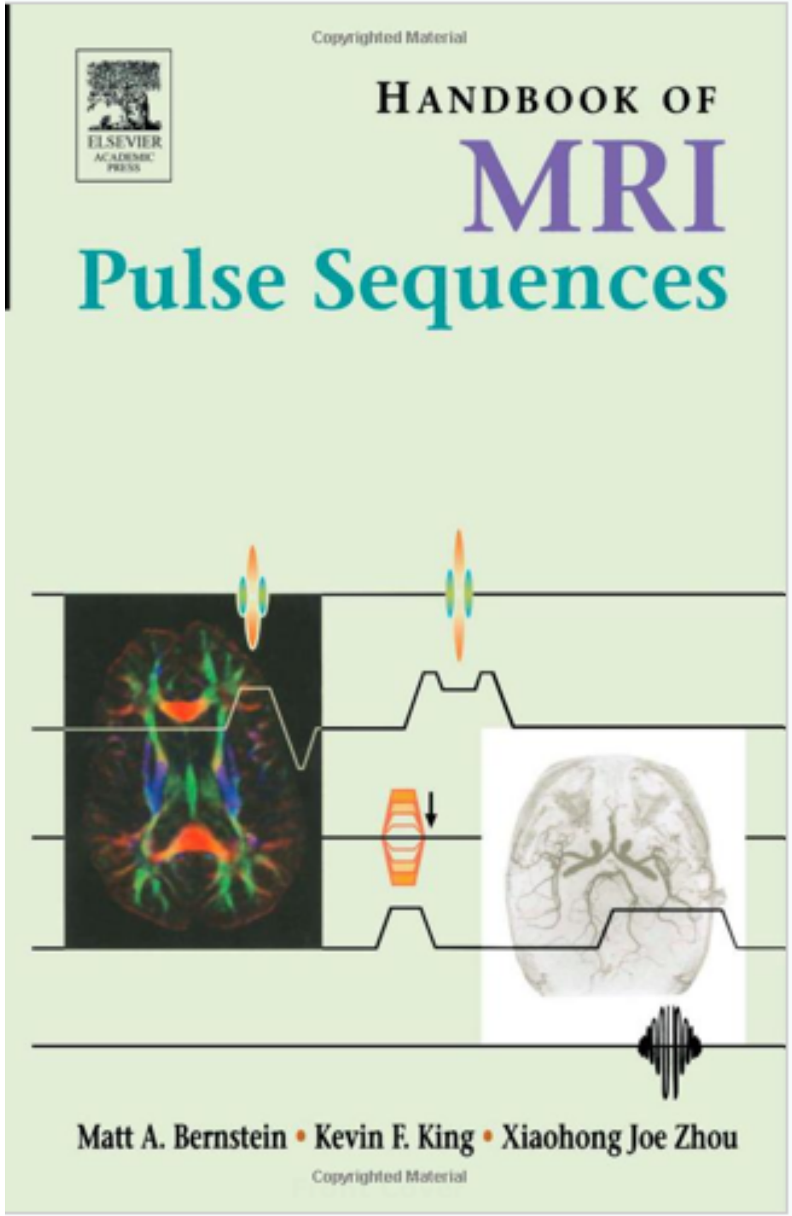
Book recommendations



$35.00 www.lulu.com
(also availible on amazon for 2x this price…)

Very terse, very signal processing oriented. Certainly worth the price.

Book recommendations



$151.00 www.amazon.com

Covers everything about different MRI pulse sequences at a nice level…