MRI Acquisition Basics for the Non-Physicist

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Outline

- Source of the MRI signal
  - Inter-play with the acronym
    - Magnetic …
    - Resonance …
    - Imaging …
- The source contrast in MR images
- Considerations for your experiment

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Magnets in atomic nuclei

- Certain nuclei (odd number of protons and/or neutrons) have magnetic properties (i.e. magnetic moment - 1952 Nobel Prize in Physics, to Bloch and Purcell).
- Include ^{13}C, ^{23}Na, ^{31}P, ^{129}Xe, and …

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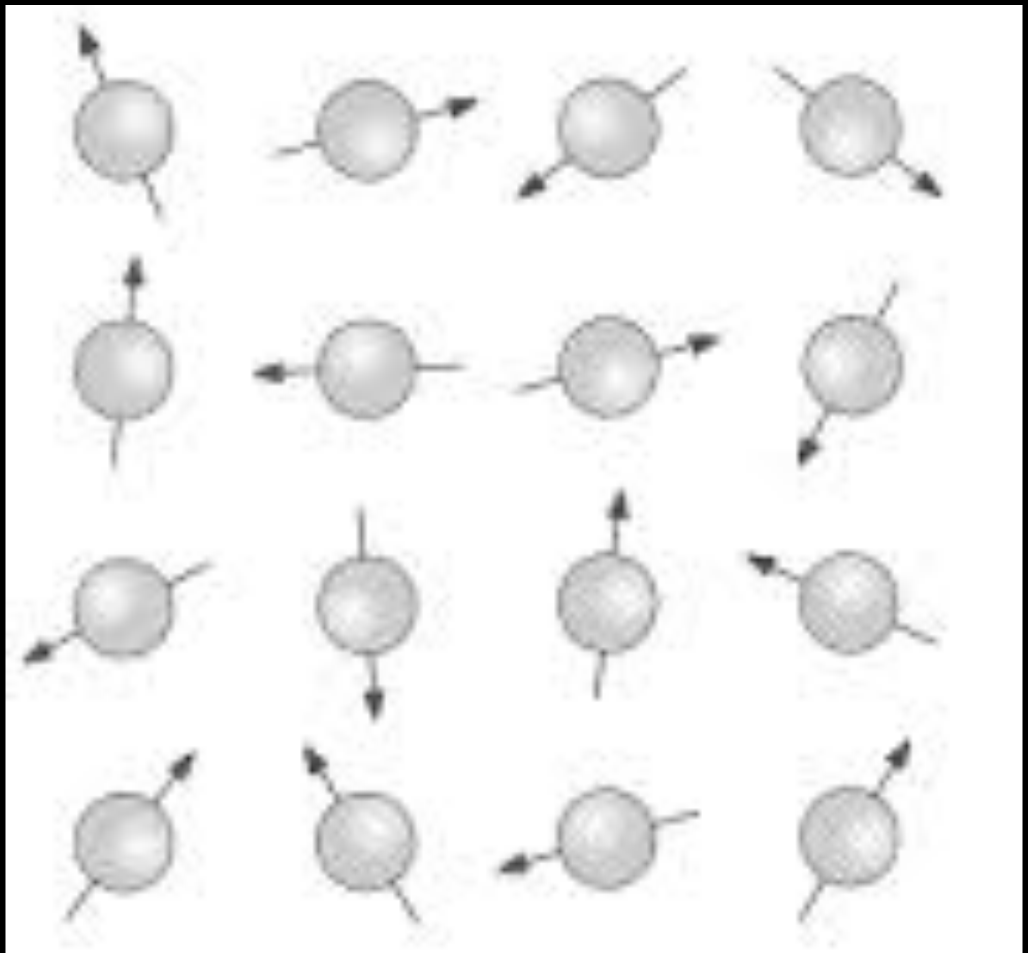
- Include ^{13}C, ^{23}Na, ^{31}P, ^{129}Xe, and …
- ^{1}H !

Magnets

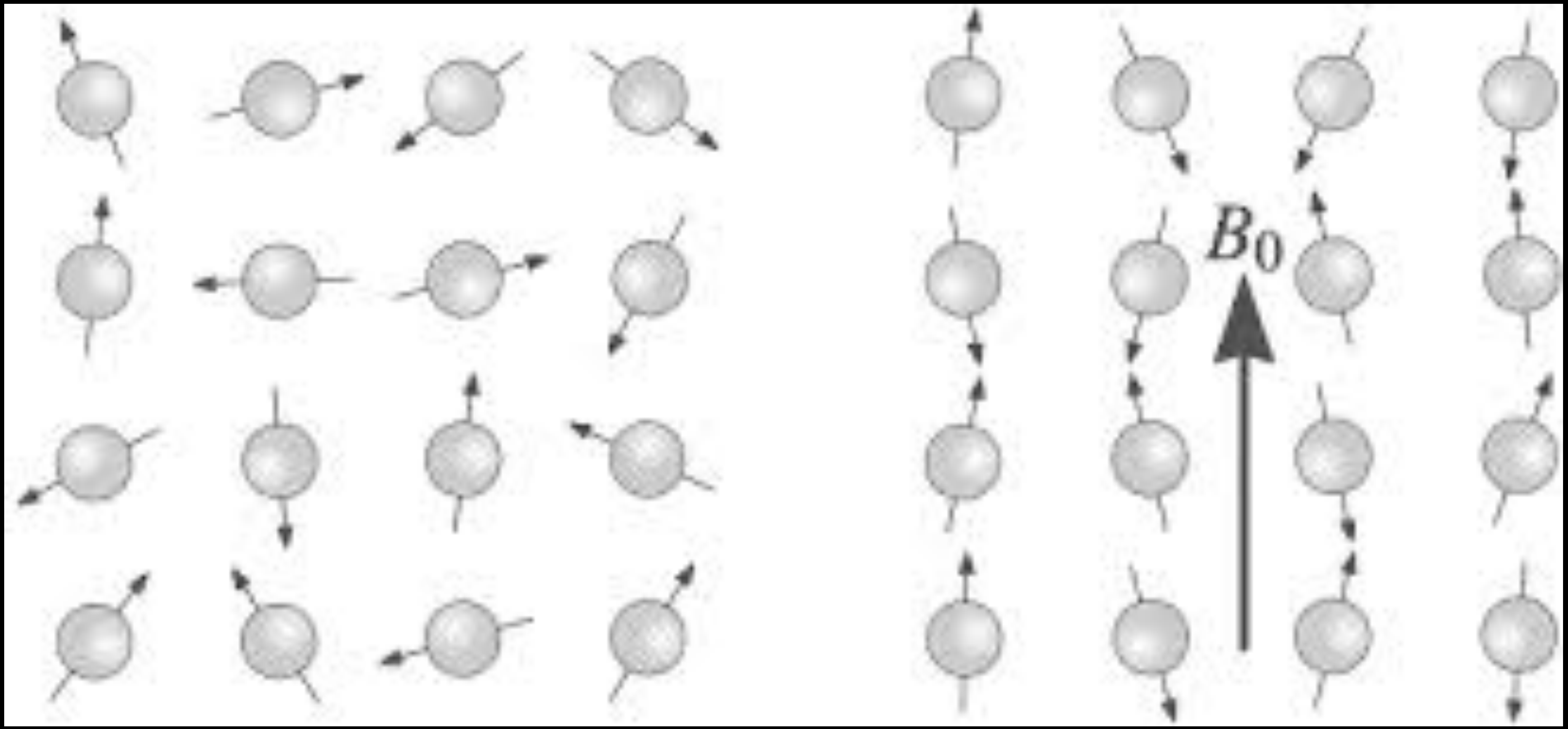
- Protons randomly aligned naturally
- Magnetic poles line up when exposed to strong magnets

Magnets



http://wikidoc.org/index.php/Basic_MRI_Physics

Magnets



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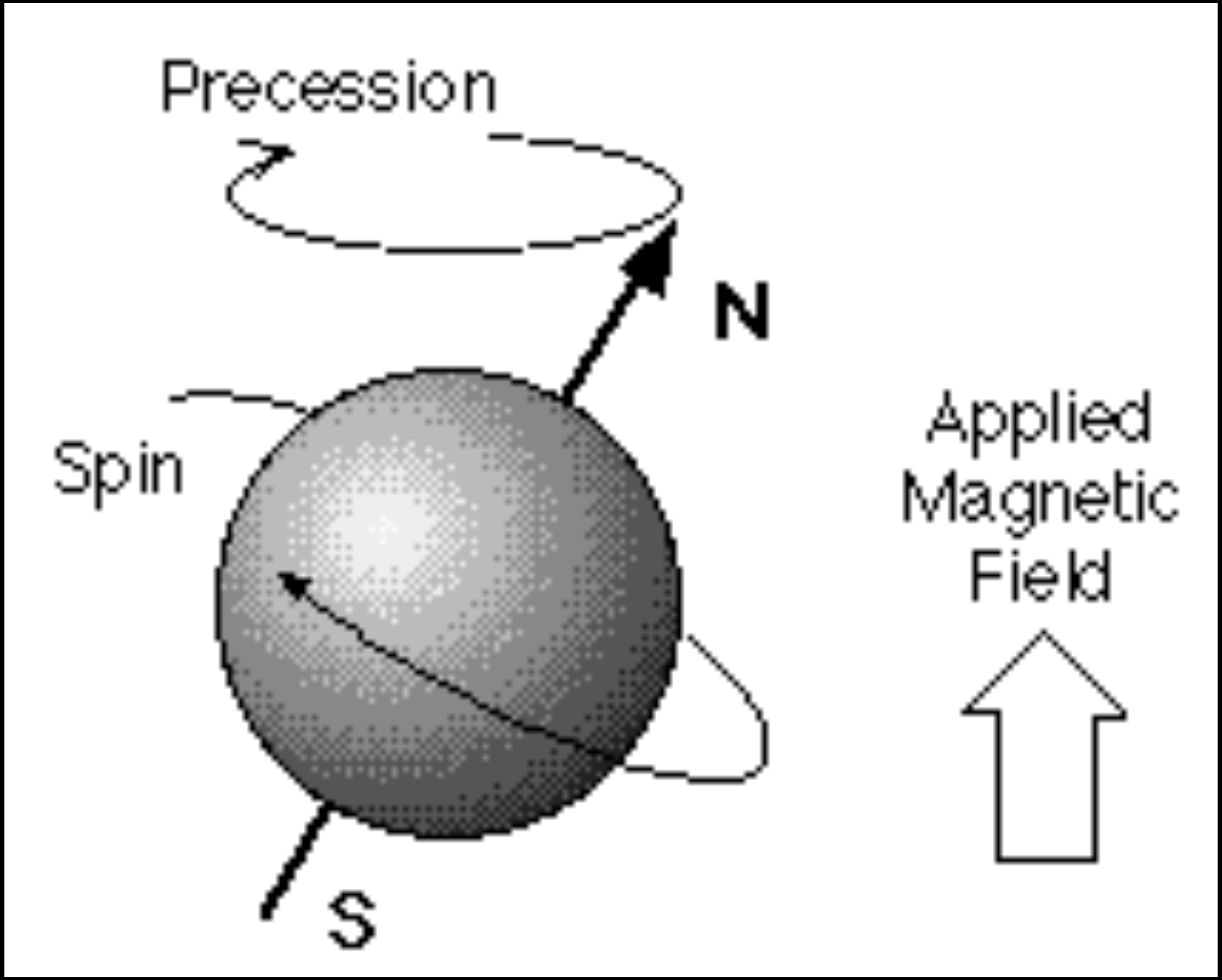
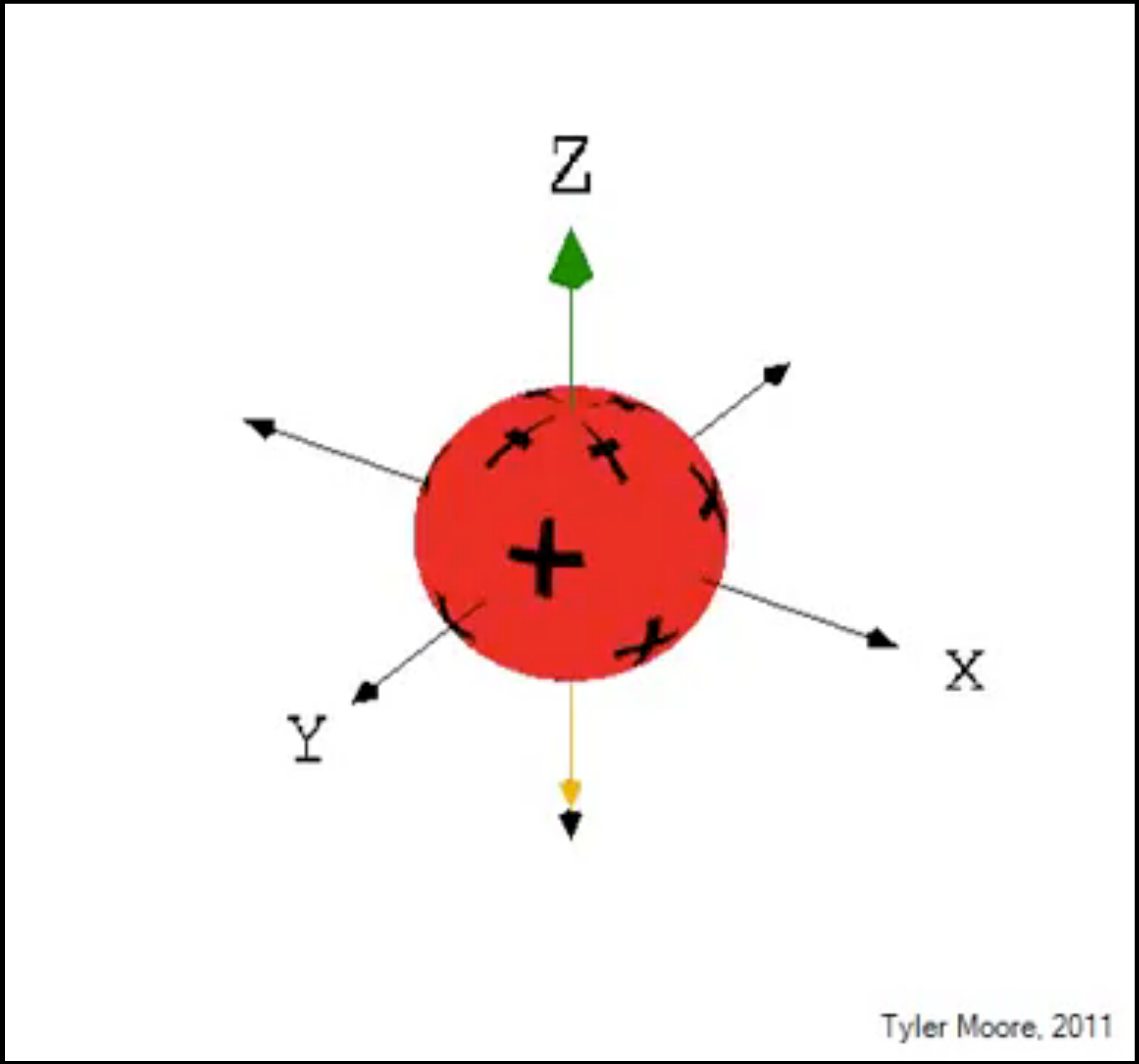
Resonance



http://ccn.ucla.edu/BMCweb/SharedCode/TINS/FMRI-TINS.html

Resonance



https://www.youtube.com/playlist?list=PLAE12114468910462

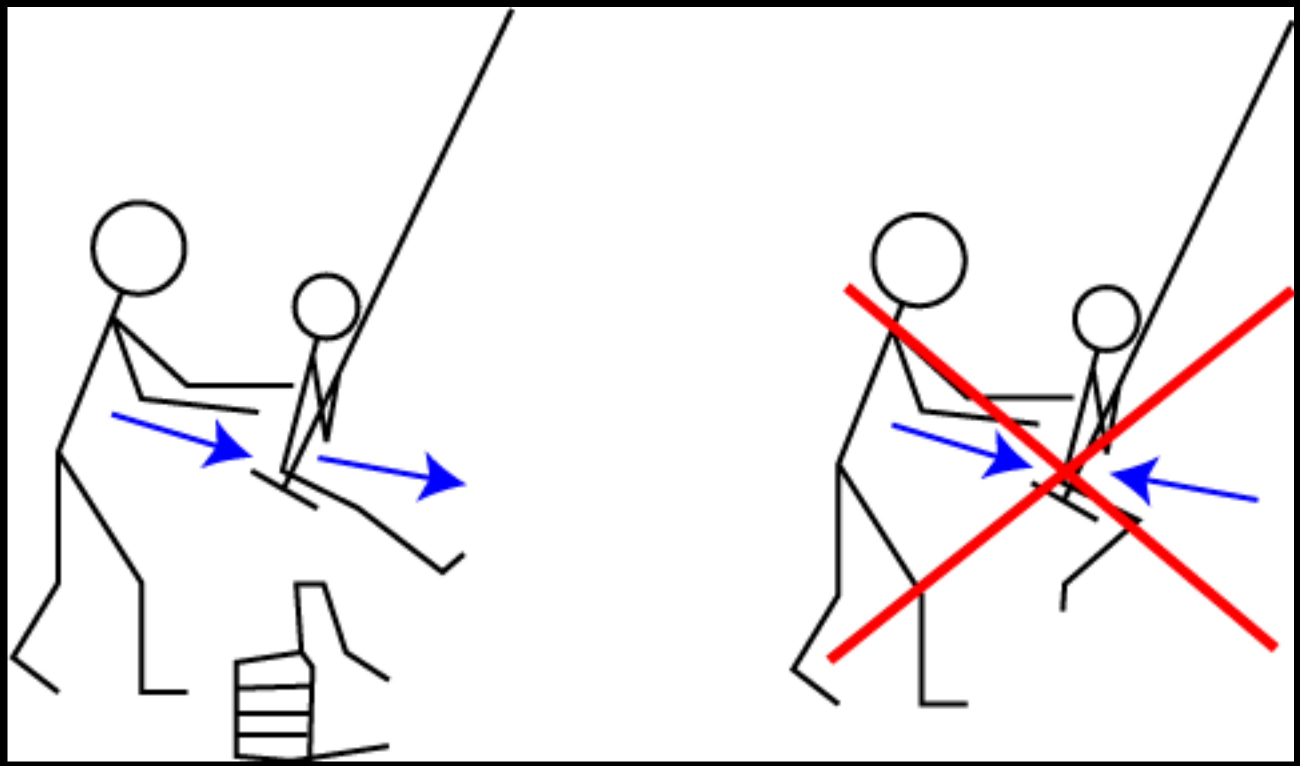
Resonance

$$\omega_0 = \gamma \ B_0$$

Resonance

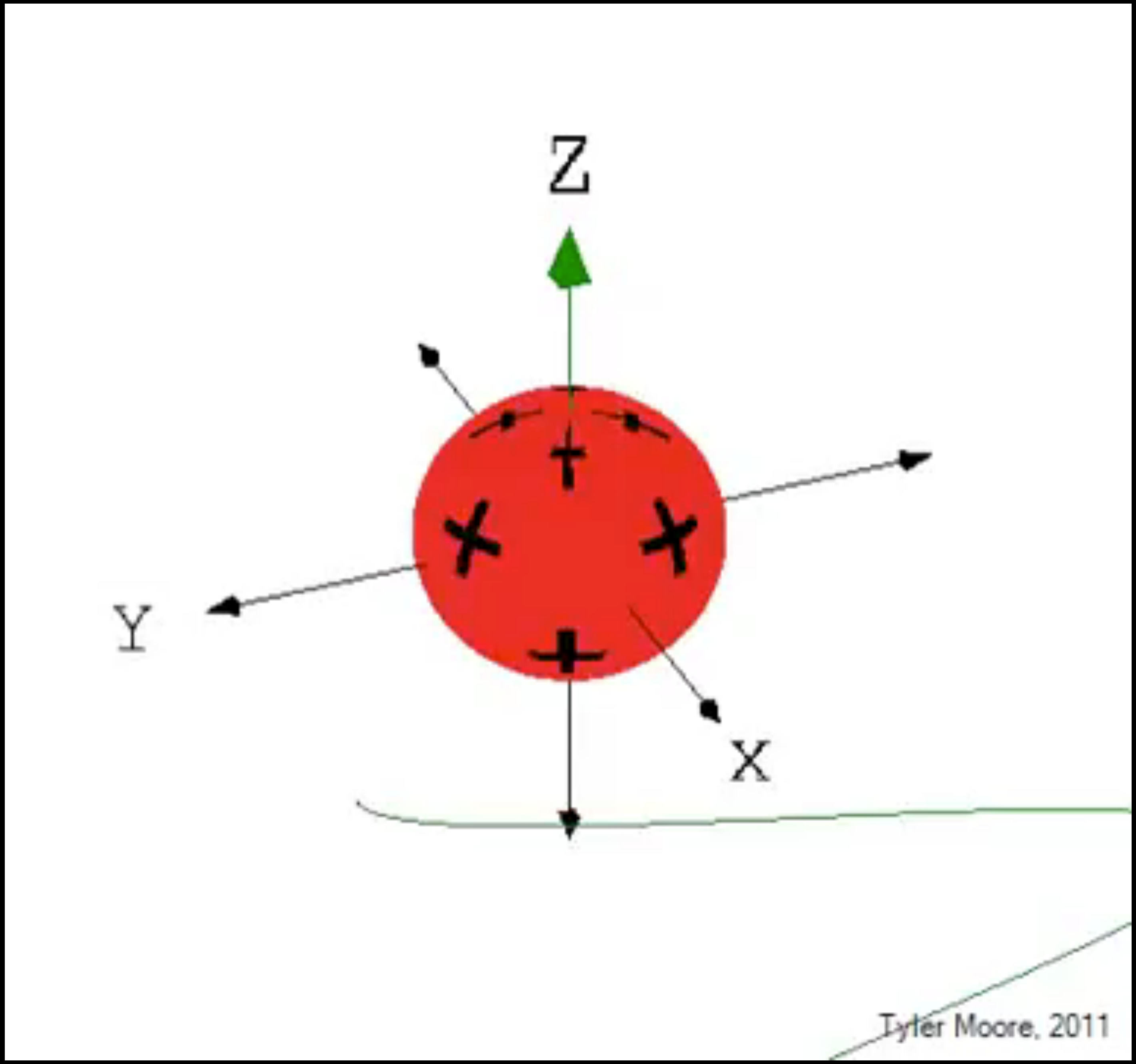
- Protons aligned with main magnetic field (B_0) are not visible / detectable in MR imaging
- “Flip” / excite into visibility by applying energy at the same frequency as precession …
- == Resonance !

Resonance



https://shapeofdata.wordpress.com/2013/12/03/case-study-4-resonance-and-robots/

Resonance



https://www.youtube.com/playlist?list=PLAE12114468910462

Resonance

- Perpendicular protons (partially or completely) are visible in typical MR experiment.
- RF must be “on resonance” for efficient excitation
- Off resonance - power deposited in sample / no signal → high SAR.
- Uniform B_0 → uniform signal. Need additional info to localize signal to generate image.

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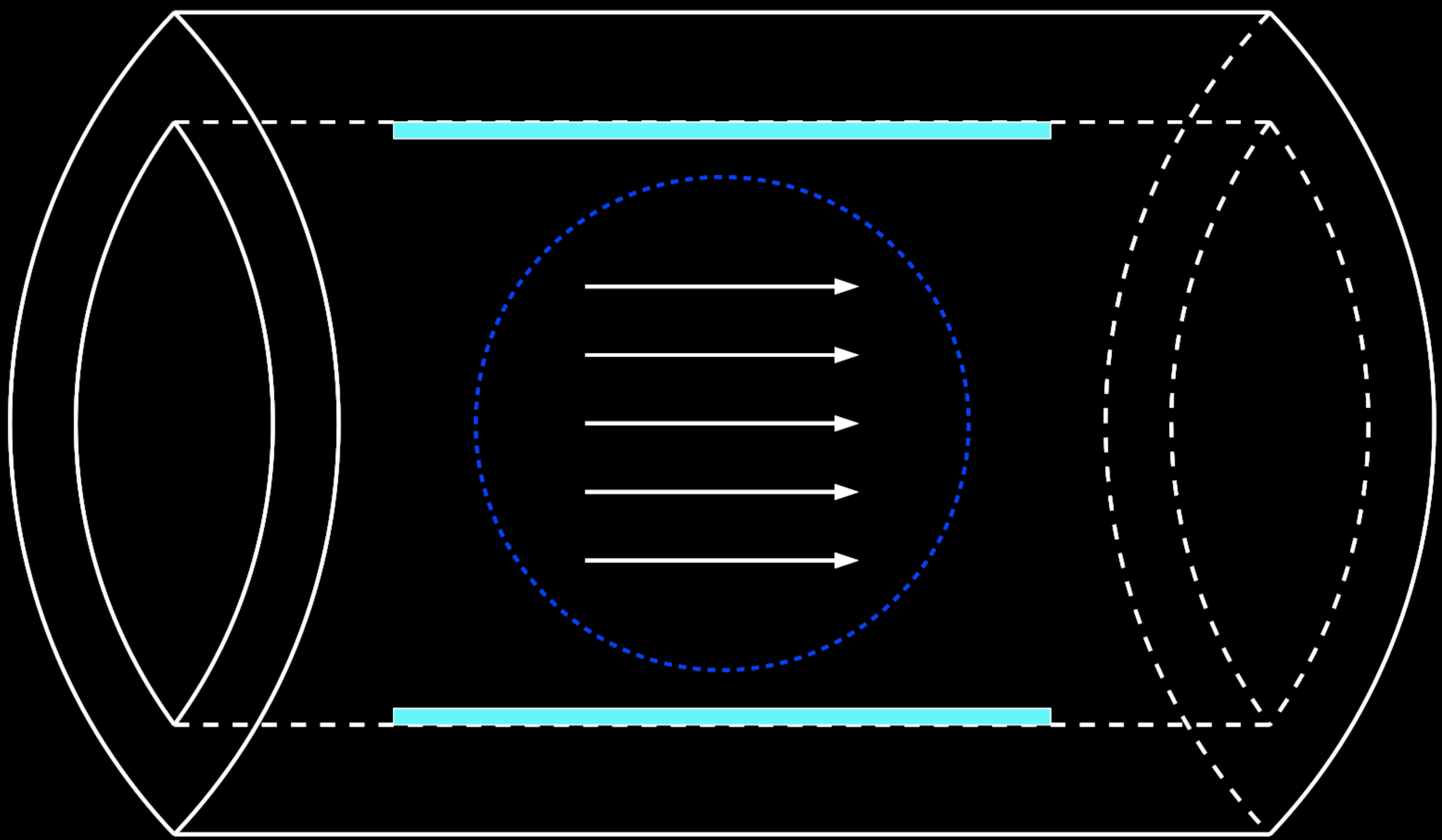
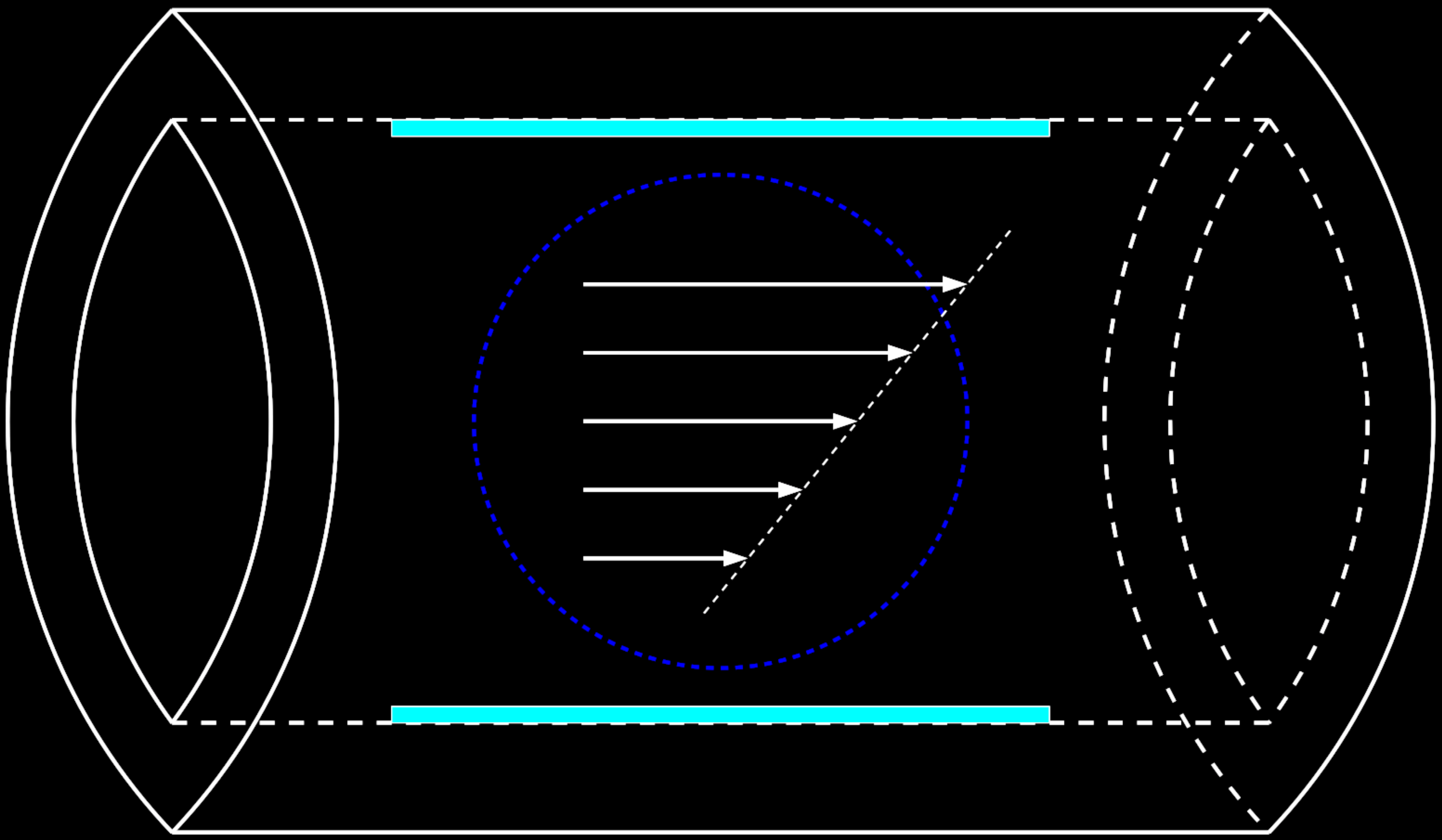
Imaging

- Uniform B_0 → uniform signal - cannot localize … so how to image?



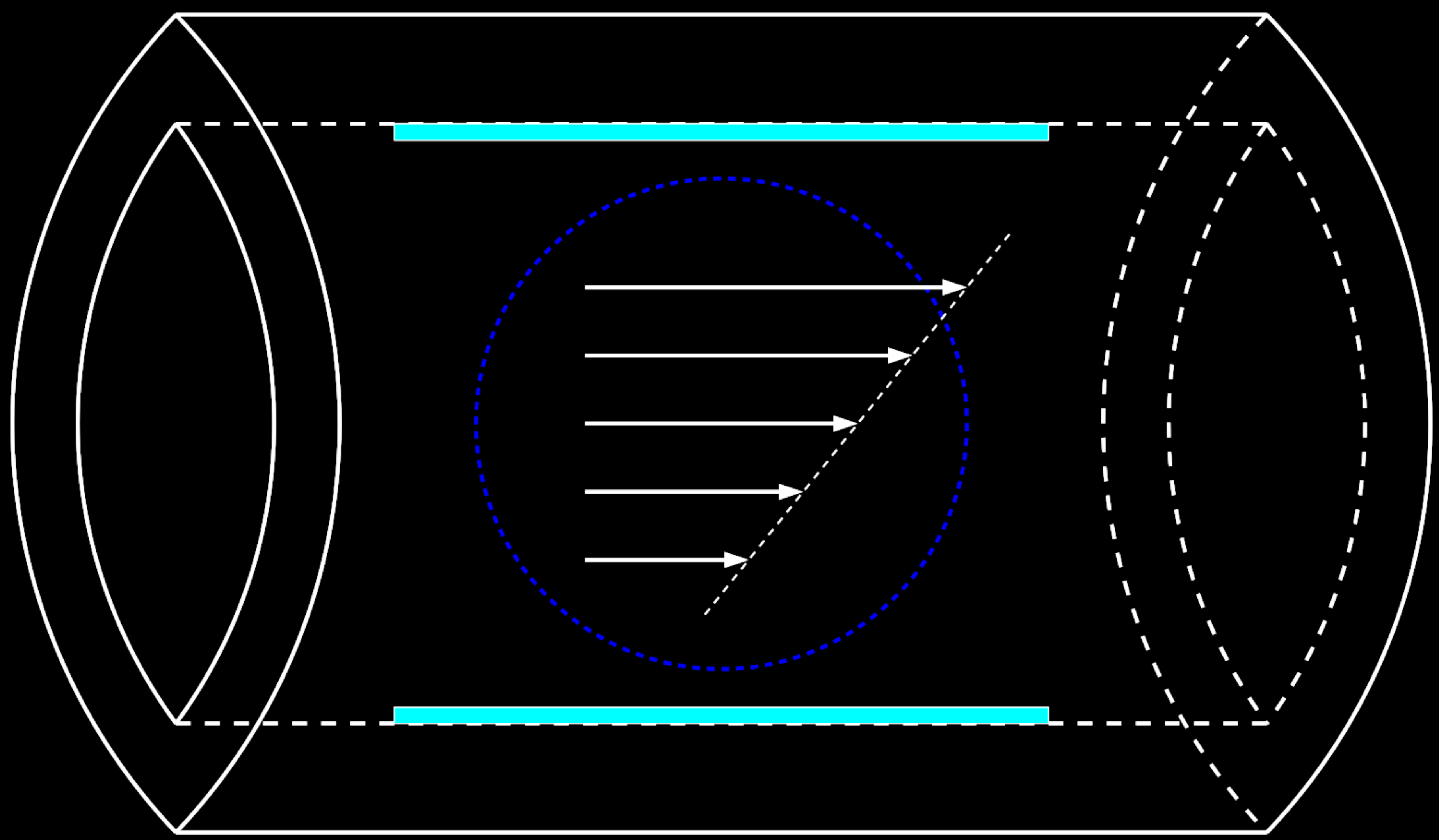
Imaging

- Apply controlled distortion to B_0



Imaging

- Apply controlled distortion to B_0 → → → Spatially varying frequency



Imaging

$$\omega_0 = \gamma\ B_0$$

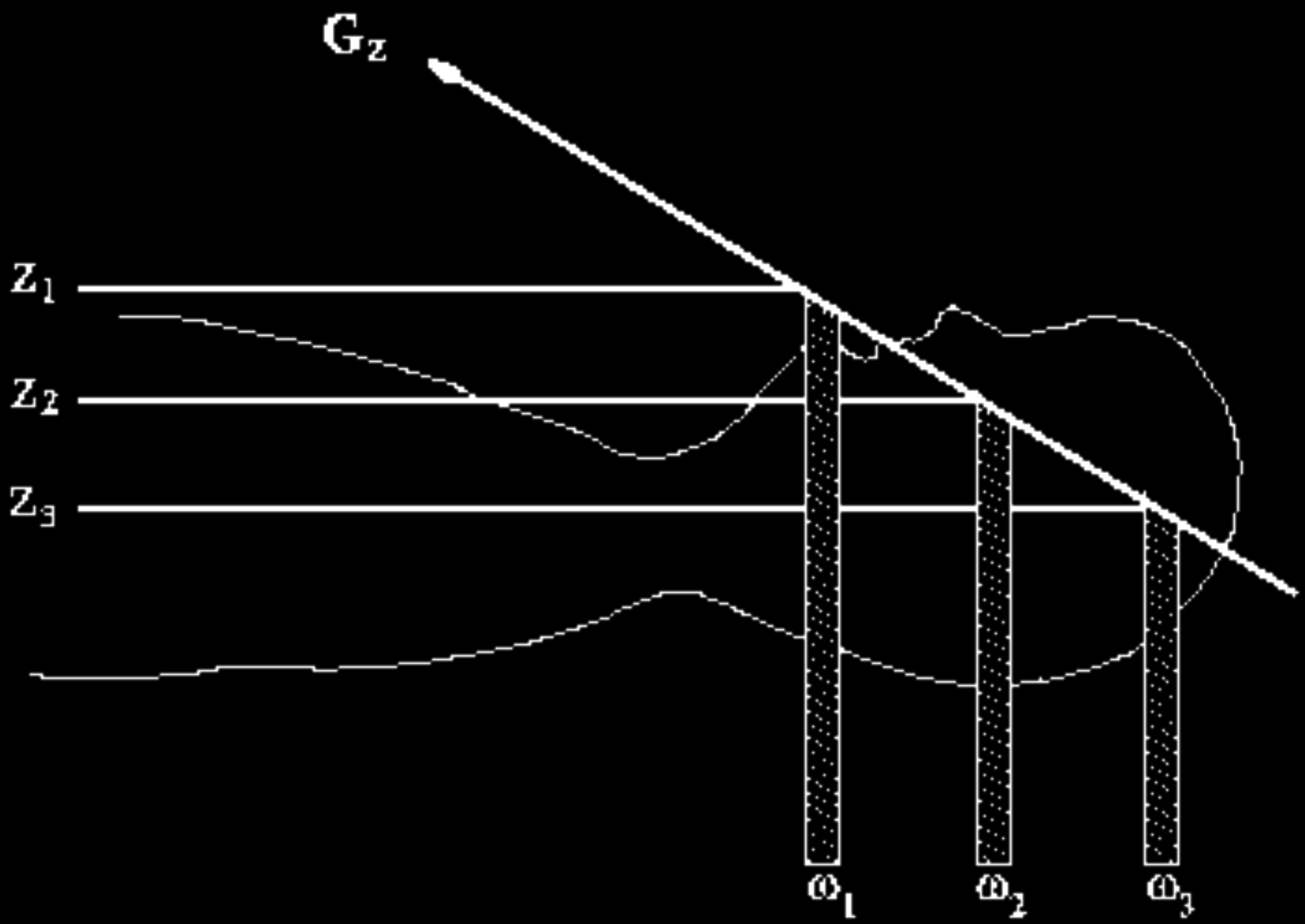
Imaging

$$\omega_x = \gamma \; B_x$$

Imaging

$$\omega_x = \gamma \; (B_0 + G_x)$$

Imaging

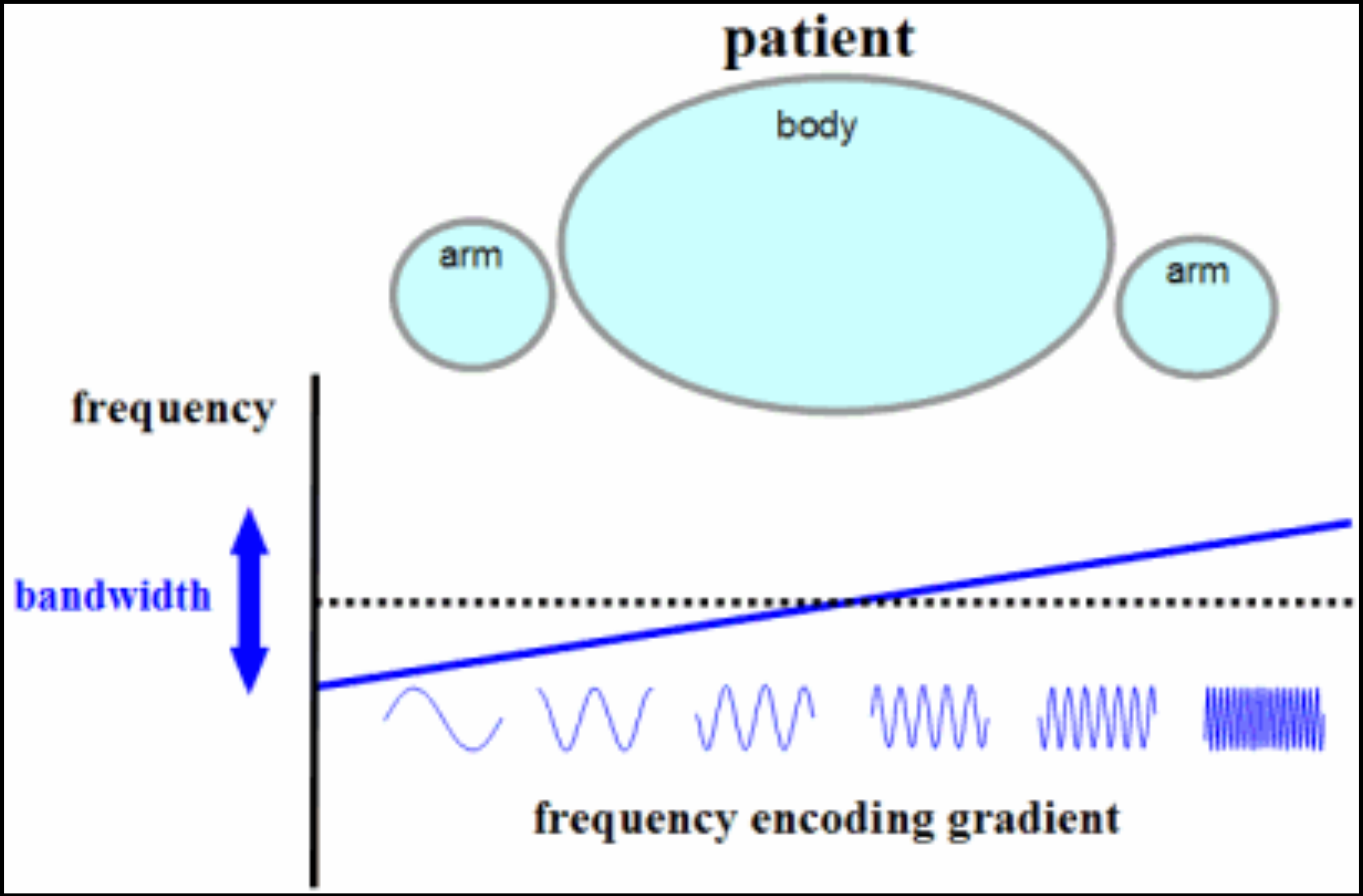


http://sfb649.wiwi.hu-berlin.de/fedc_homepage/xplore/ebooks/html/csa/node255.html

Imaging

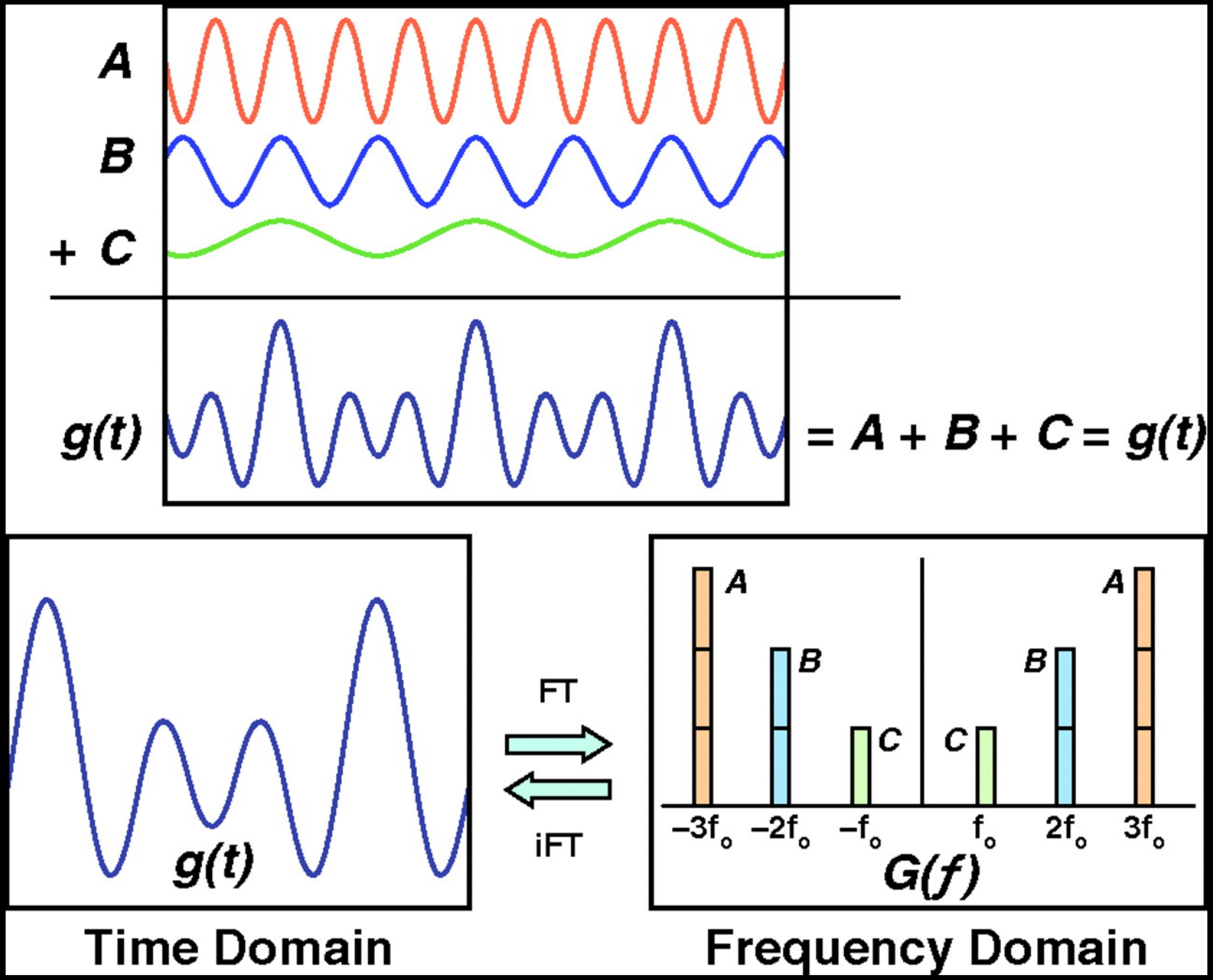
- Extend frequency change to other dimensions (x, y) for image encoding.
- 1st dimension → frequency encoding
- 2nd dimension → phase encoding

Imaging



http://www.revisemri.com/questions/creating_an_image/frequency_encoding_gradient

Imaging

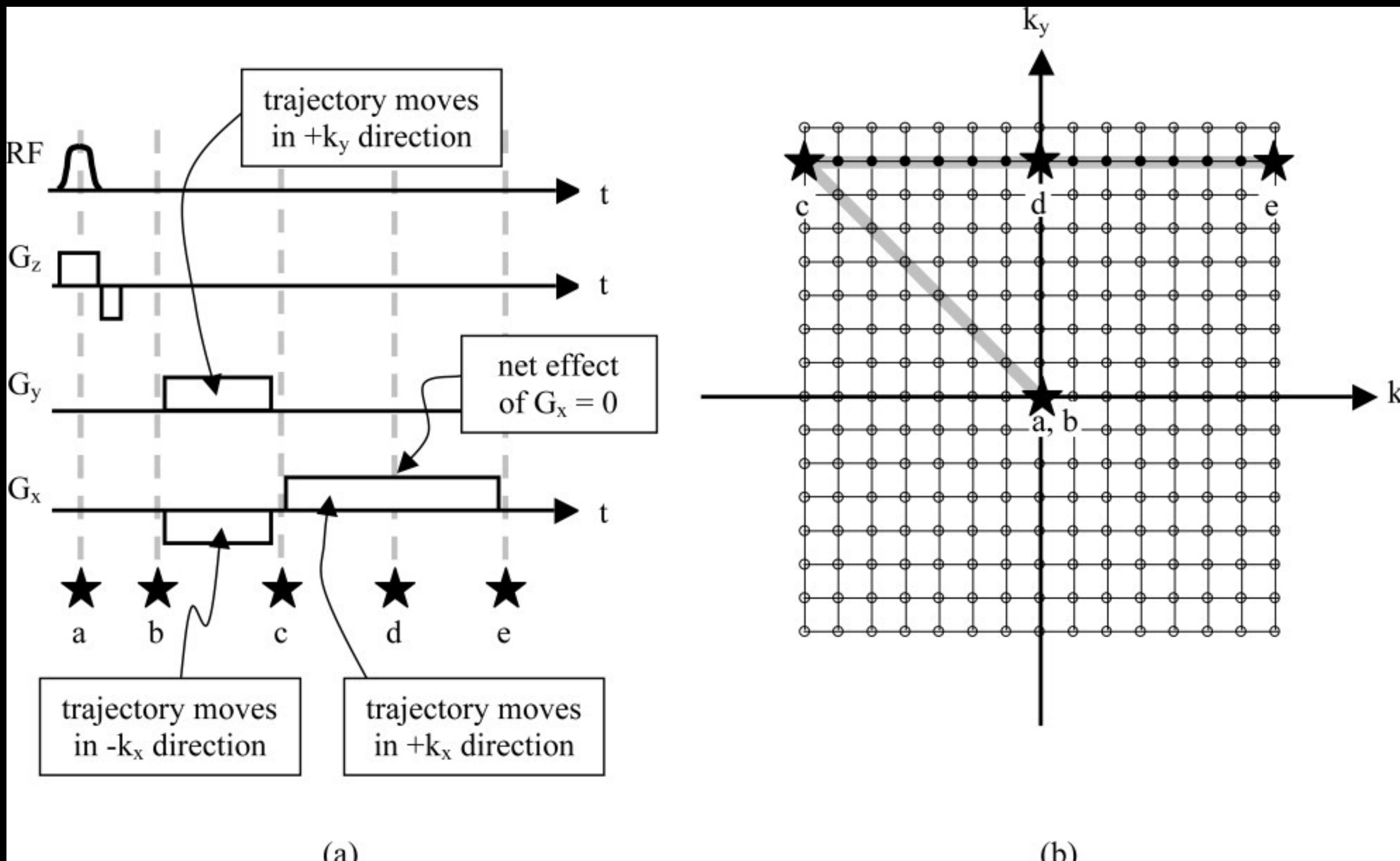


Gallagher, DOI:10.2214/AJR.07.2874

Imaging

- Extend frequency change to other dimensions (x, y) for image encoding.
- 1st dimension → frequency encoding
- 2nd dimension → phase encoding
- Effects of gradients encodes “*k*-space”

Imaging



Paschal and Morris, DOI: 10.1002/jmri.10451

Imaging

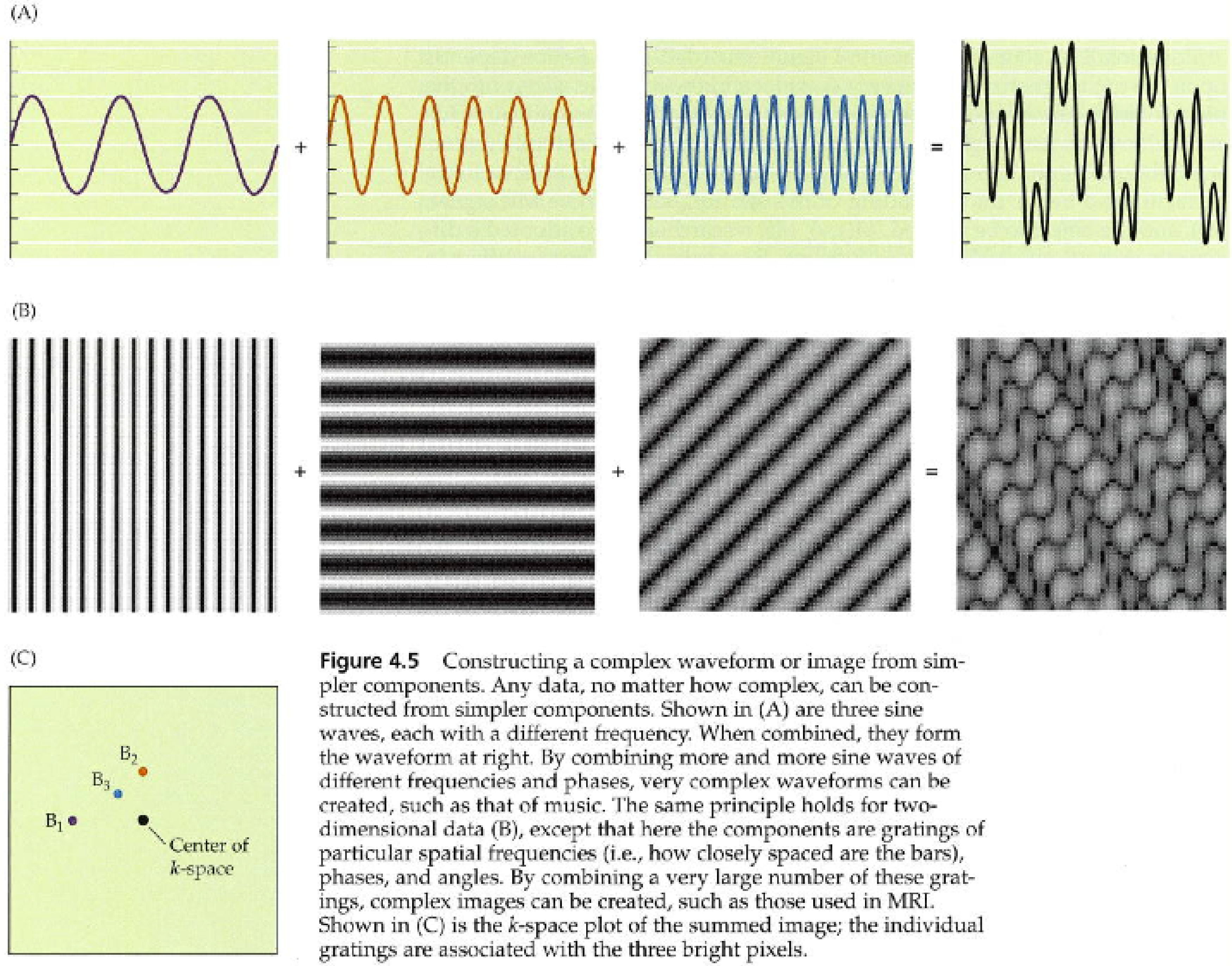


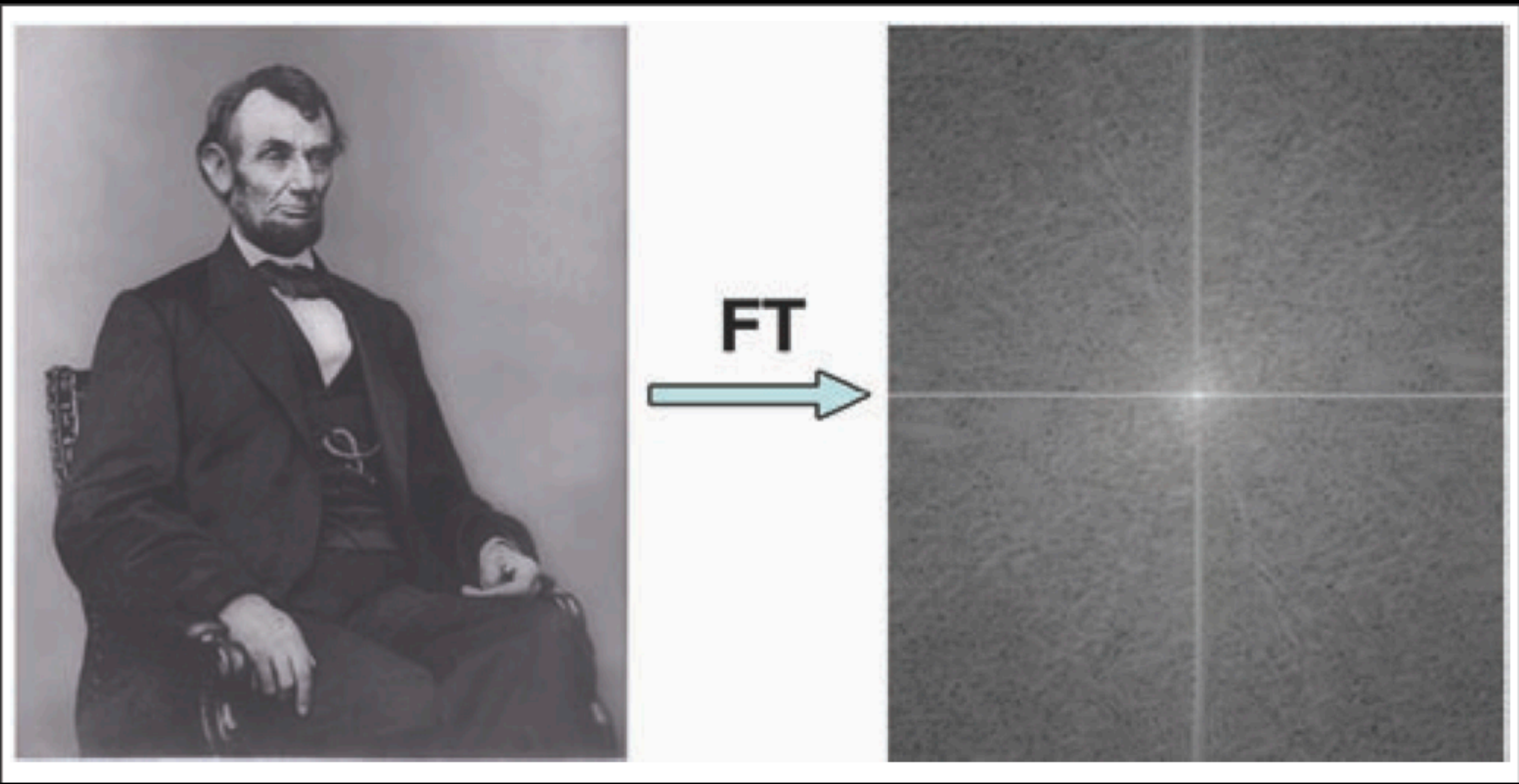
Figure 4.5 Constructing a complex waveform or image from simpler components. Any data, no matter how complex, can be constructed from simpler components. Shown in (A) are three sine waves, each with a different frequency. When combined, they form the waveform at right. By combining more and more sine waves of different frequencies and phases, very complex waveforms can be created, such as that of music. The same principle holds for two-dimensional data (B), except that here the components are gratings of particular spatial frequencies (i.e., how closely spaced are the bars), phases, and angles. By combining a very large number of these gratings, complex images can be created, such as those used in MRI. Shown in (C) is the *k*-space plot of the summed image; the individual gratings are associated with the three bright pixels.

Huettel - Functional Magnetic Resonance Imaging

Signal (Fourier Transform) Equation in MRI

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

Imaging



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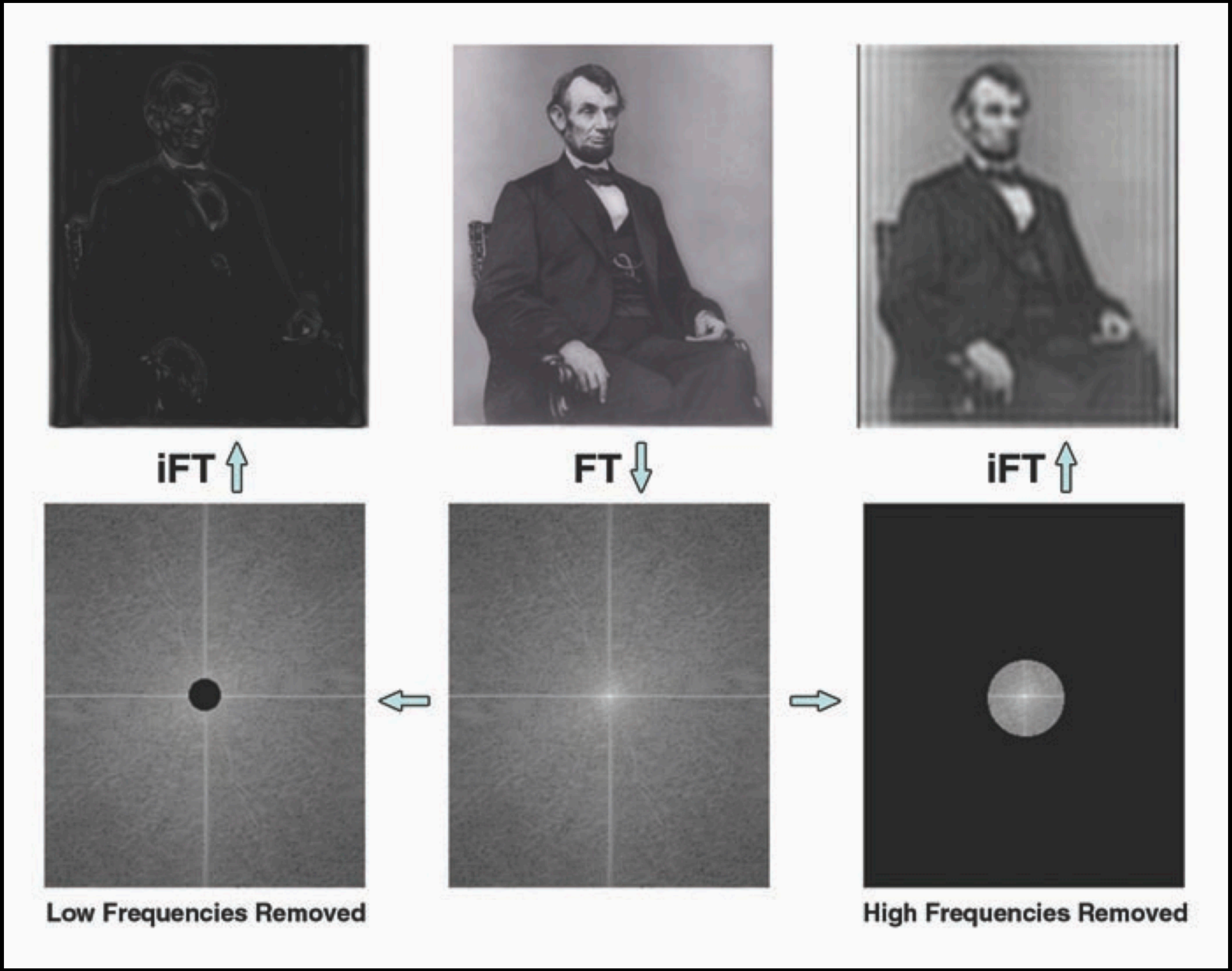
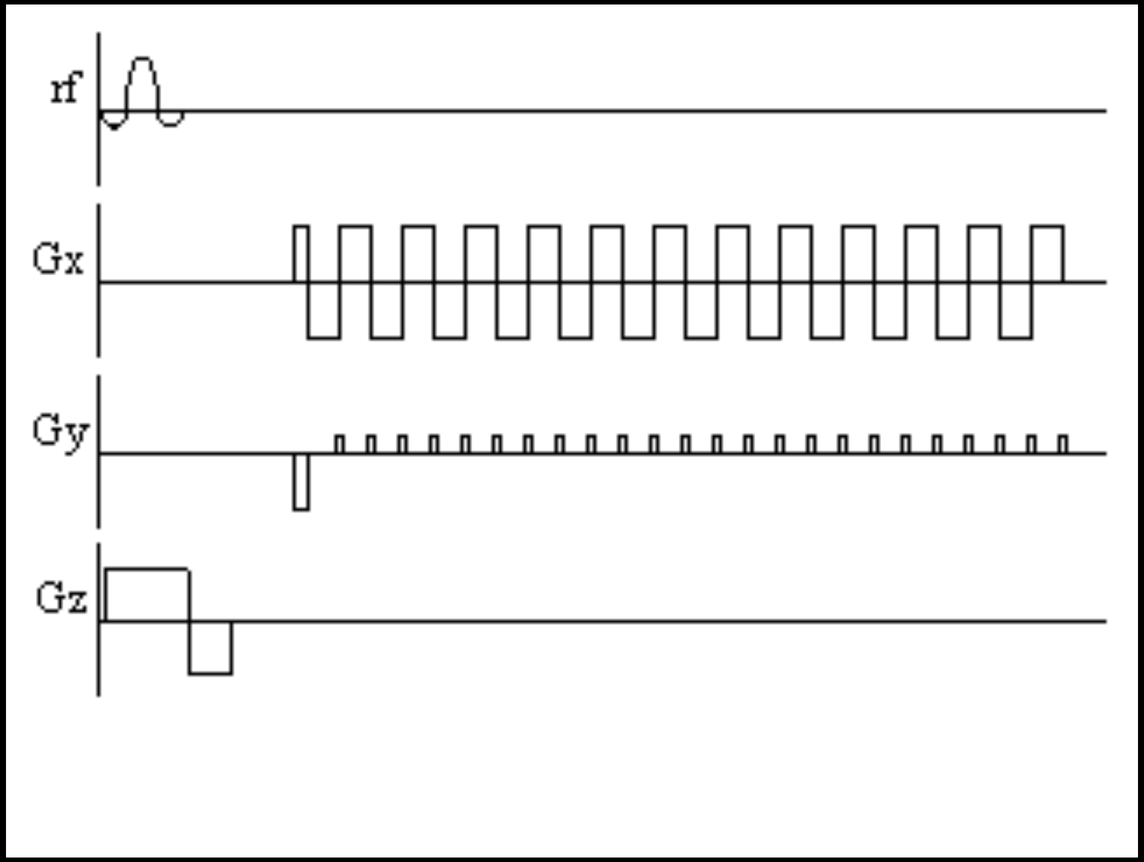
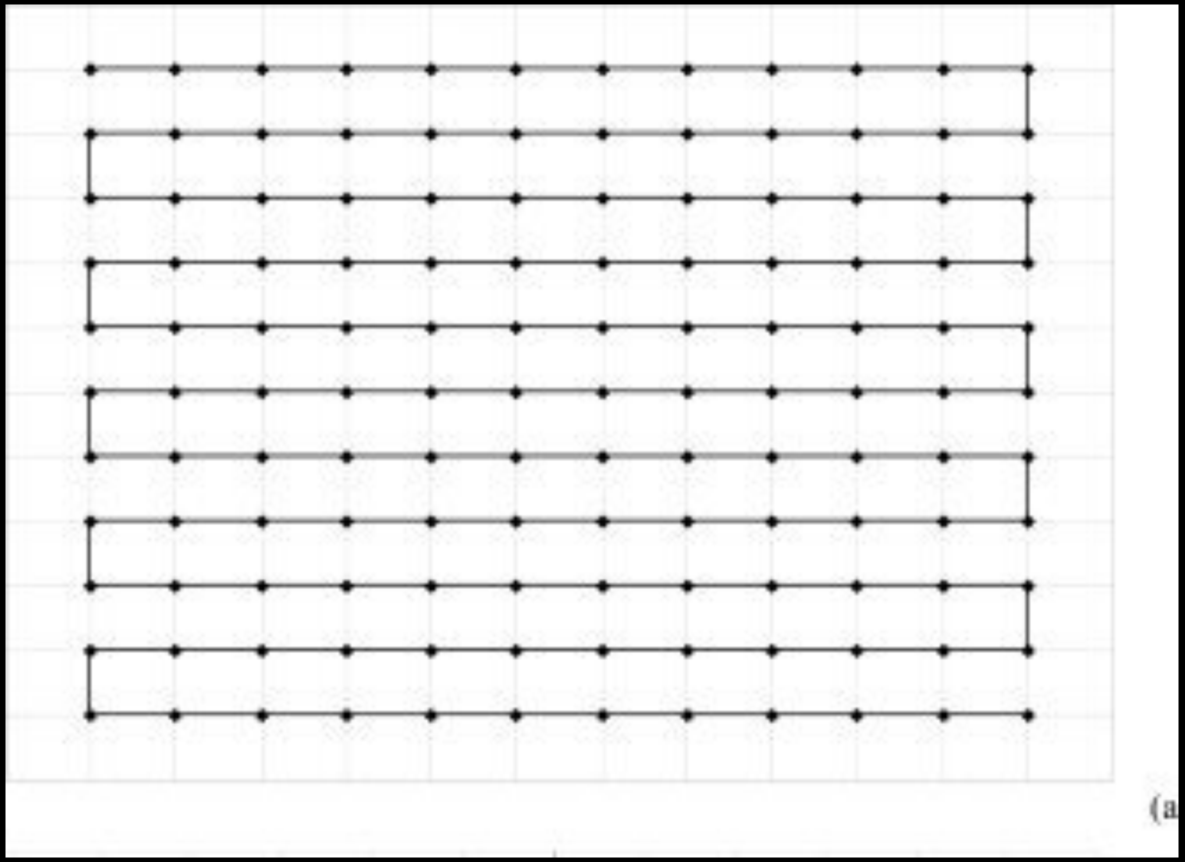
Imaging



Gallagher, DOI:10.2214/AJR.07.2874

Imaging

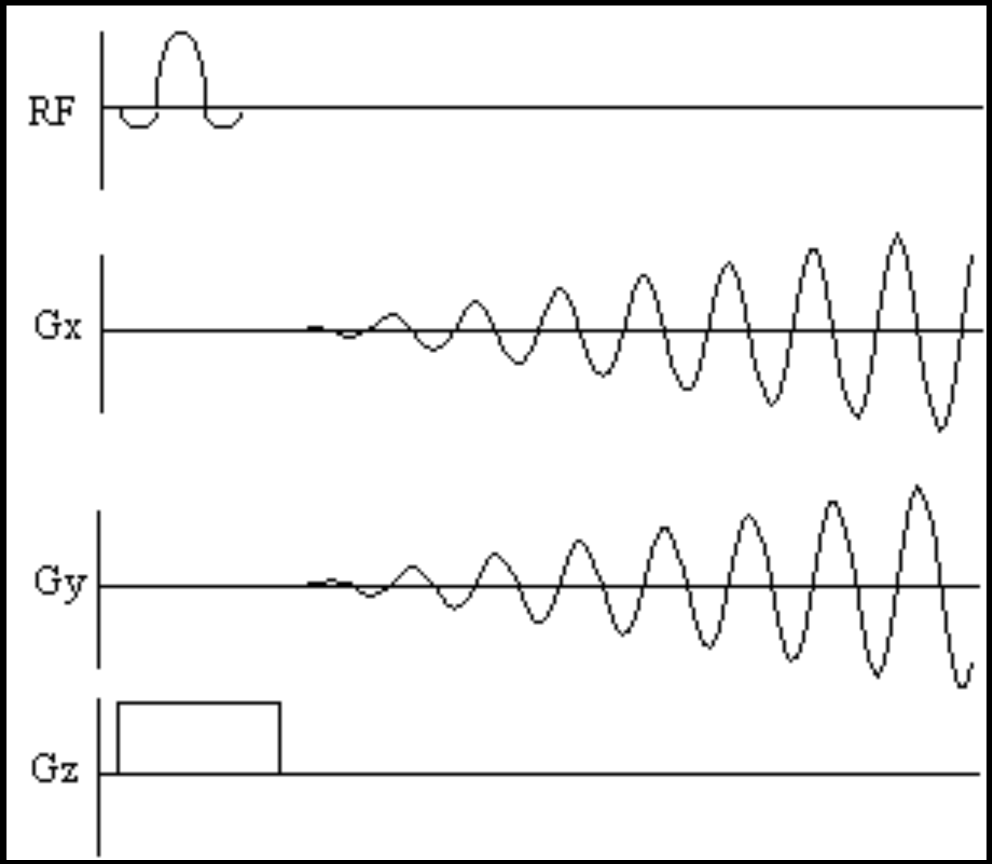


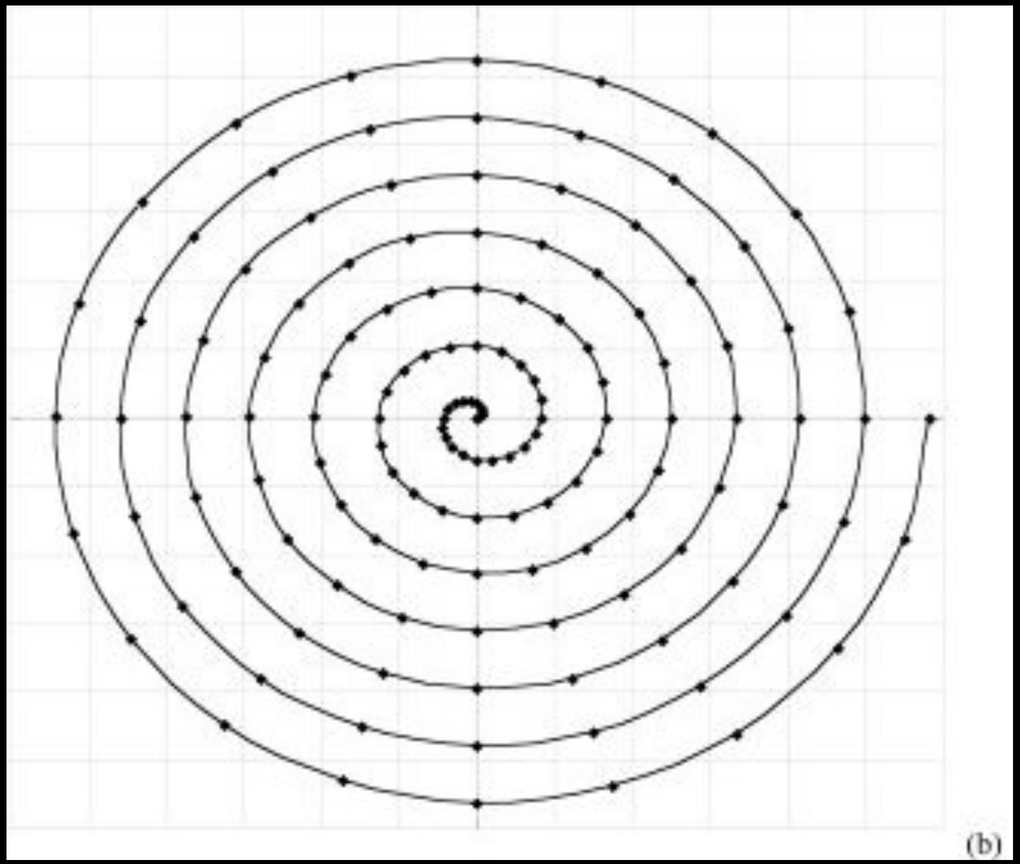


https://users.fmrib.ox.ac.uk/~stuart/thesis/chapter_2/section2_3.html

Paschal and Morris, DOI: 10.1002/jmri.10451

Imaging





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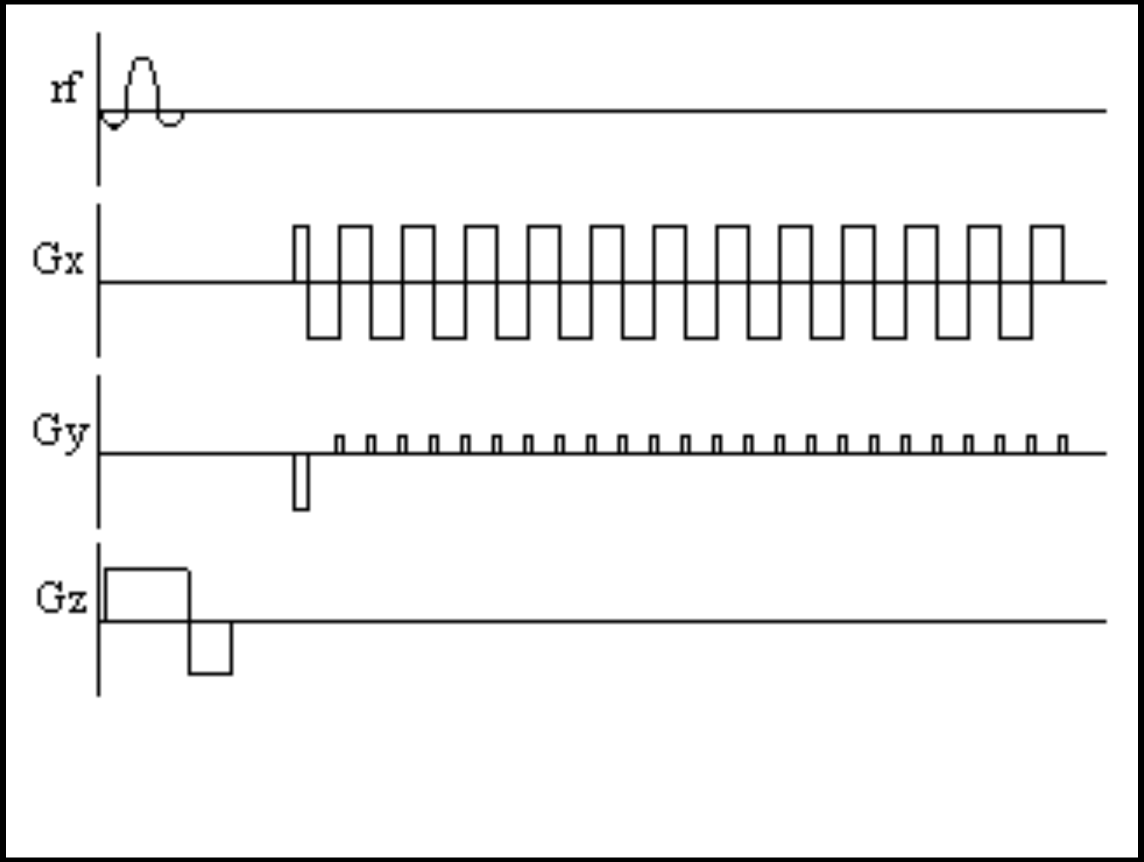
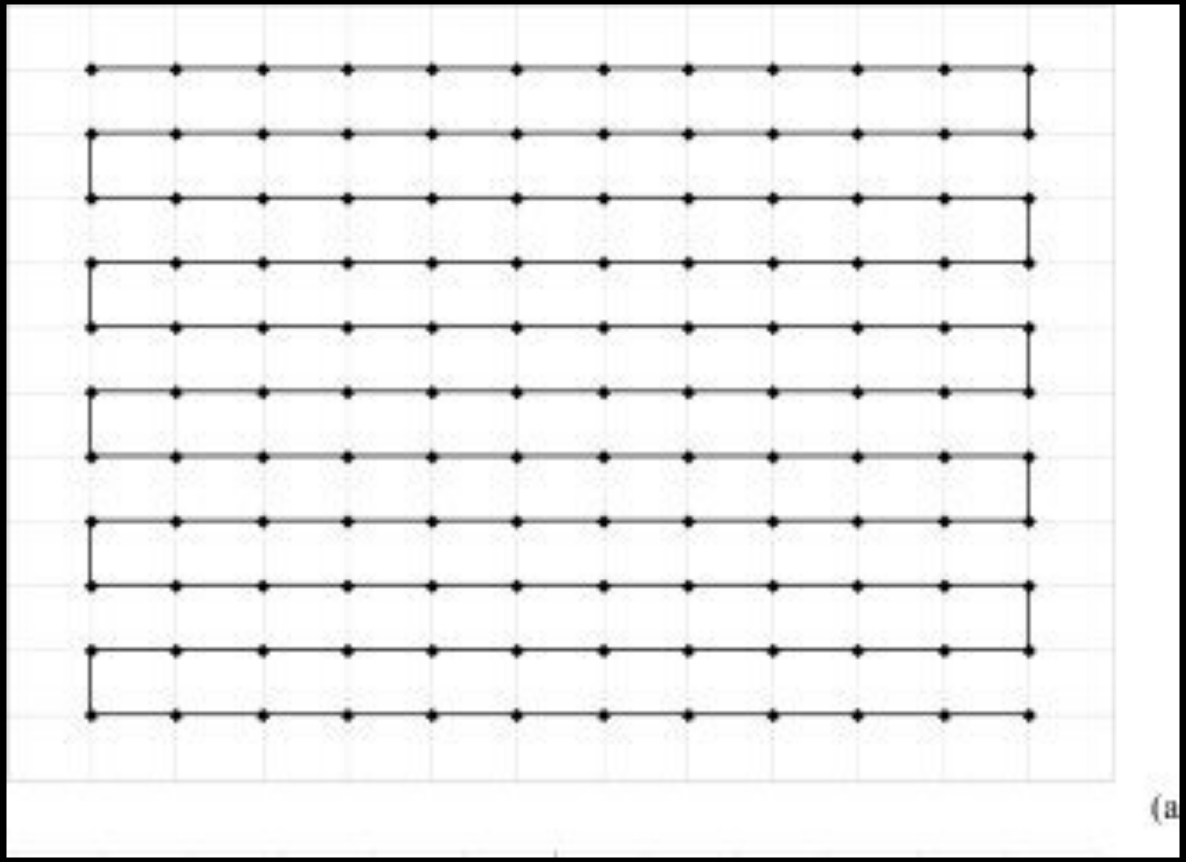
Gradients Nuts and Bolts

- Space / step size in *k*-space is inversely proportional to FOV.
- Extent in *k*-space is inversely proportional to voxel size.
- Covering *k*-space requires strong and fast gradients.
- Gradient switching rate FDA limited (200 mT/m/ms). Detectable below this threshold - subject comfort issues.
- “Local” gradient coils present a possible solution to address FDA limits and power requirements.

Imaging





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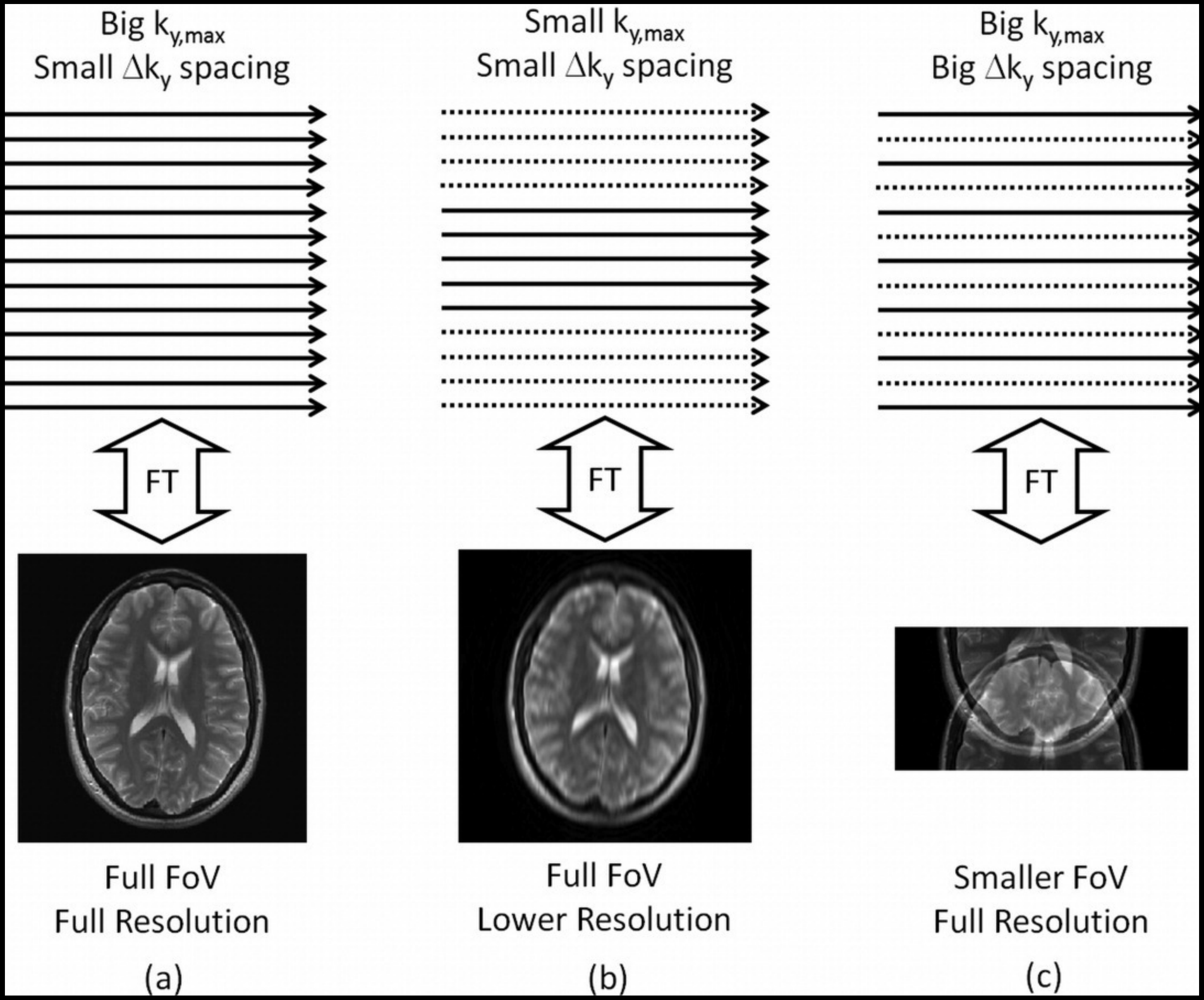
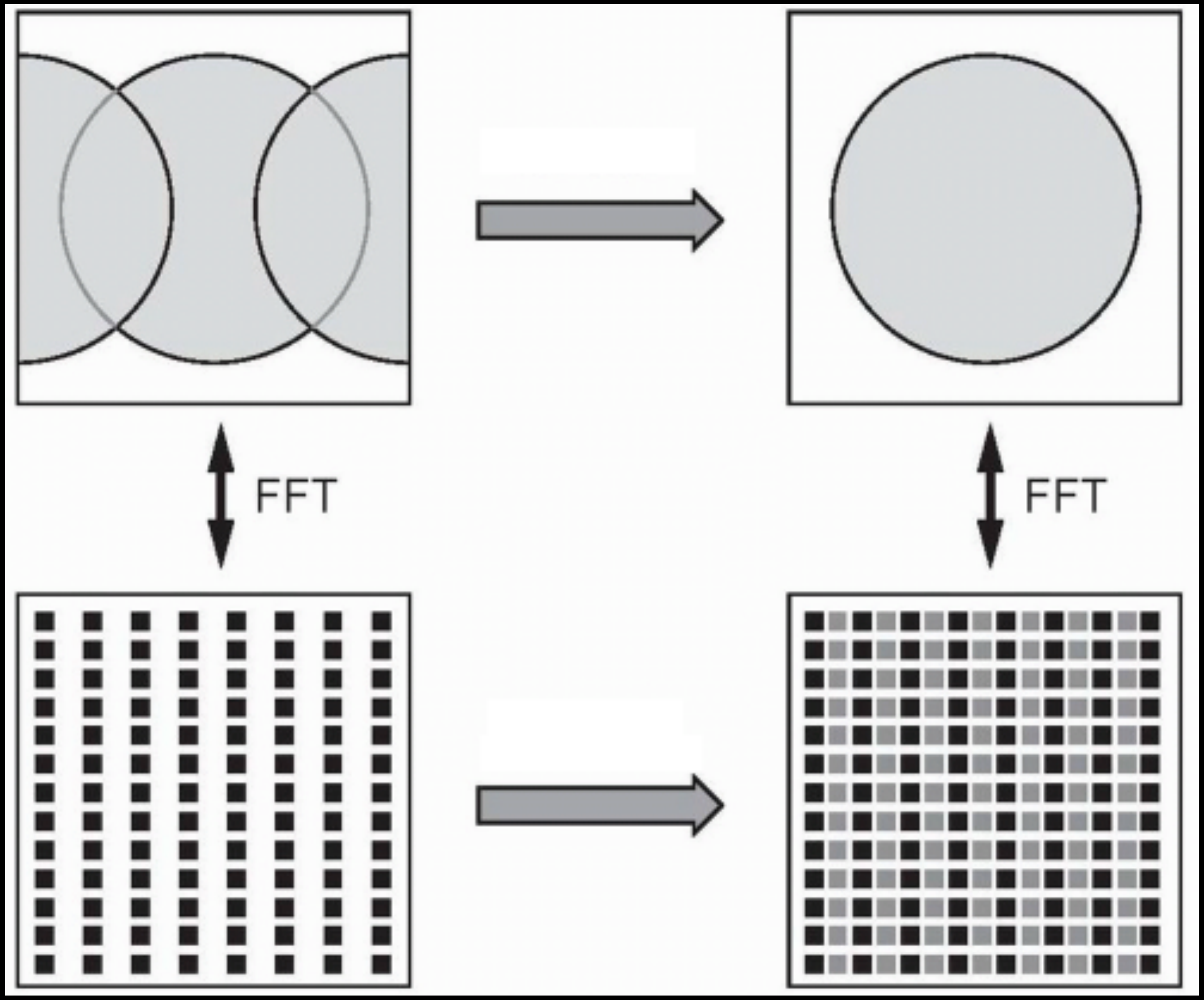
Imaging



DOI: 10.1002/jmri.23639

Imaging



https://radiologykey.com/parallel-imaging/

Imaging

- SENSE - Pruessmann, DOI: 10.1002/(SICI)1522-2594(199911)42:5<952::AID-MRM16>3.0.CO;2-S
- GRAPPA - Griswold, DOI: 10.1002/mrm.10171
- CAIPIRINHA - Breuer, DOI: 10.1002/mrm.20787
- Blipped CAIPIRINHA - Setsompop, DOI: 10.1002/mrm.23097

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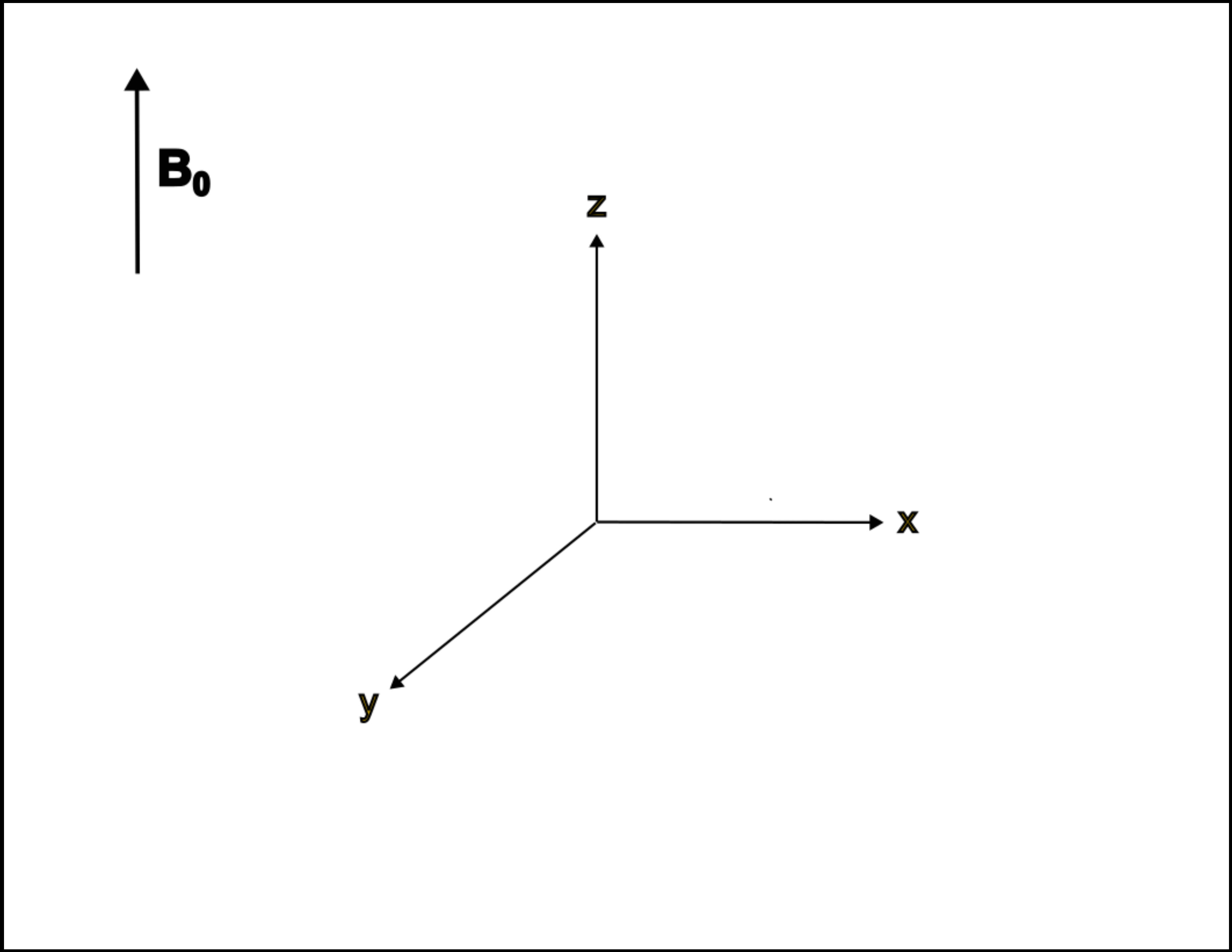
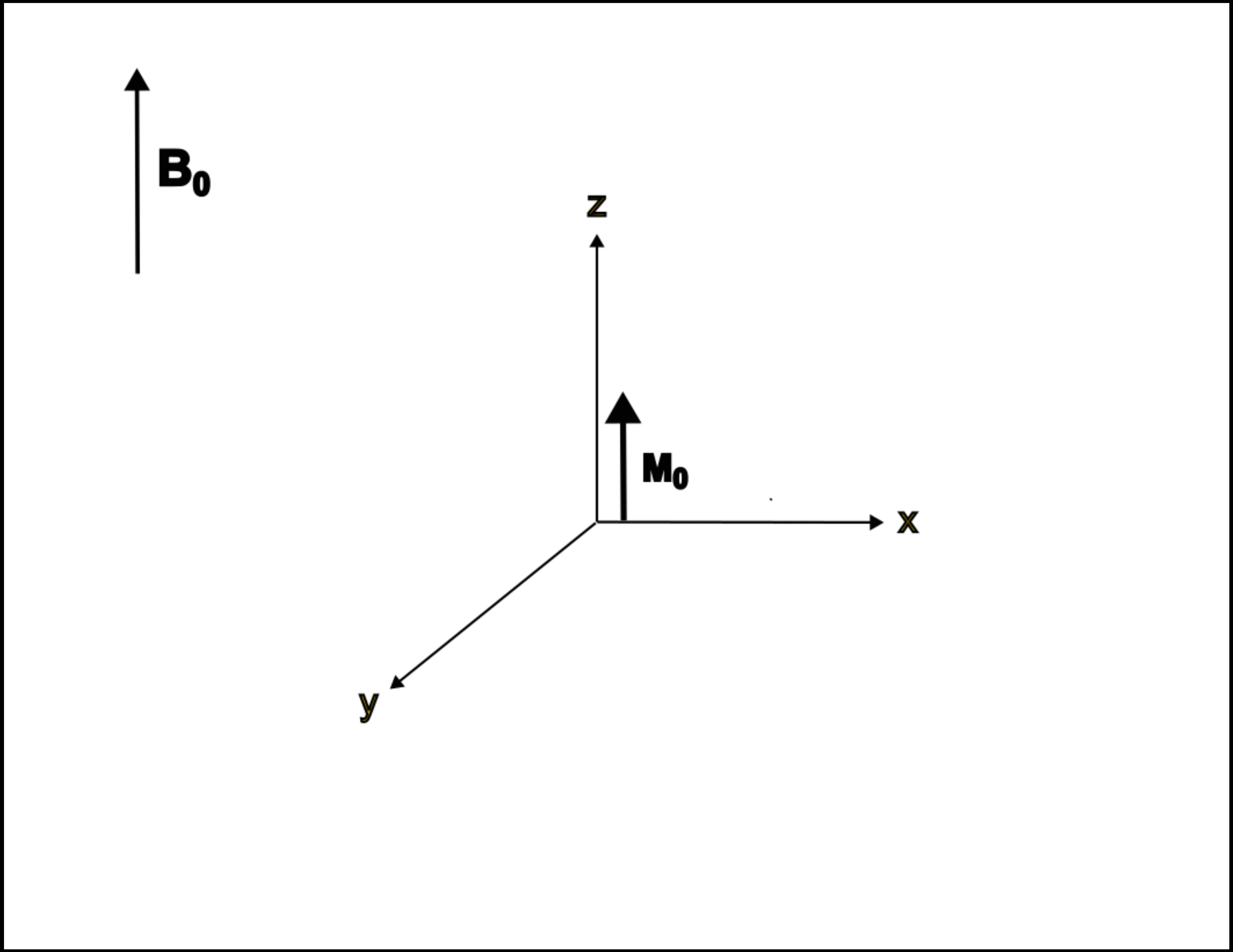
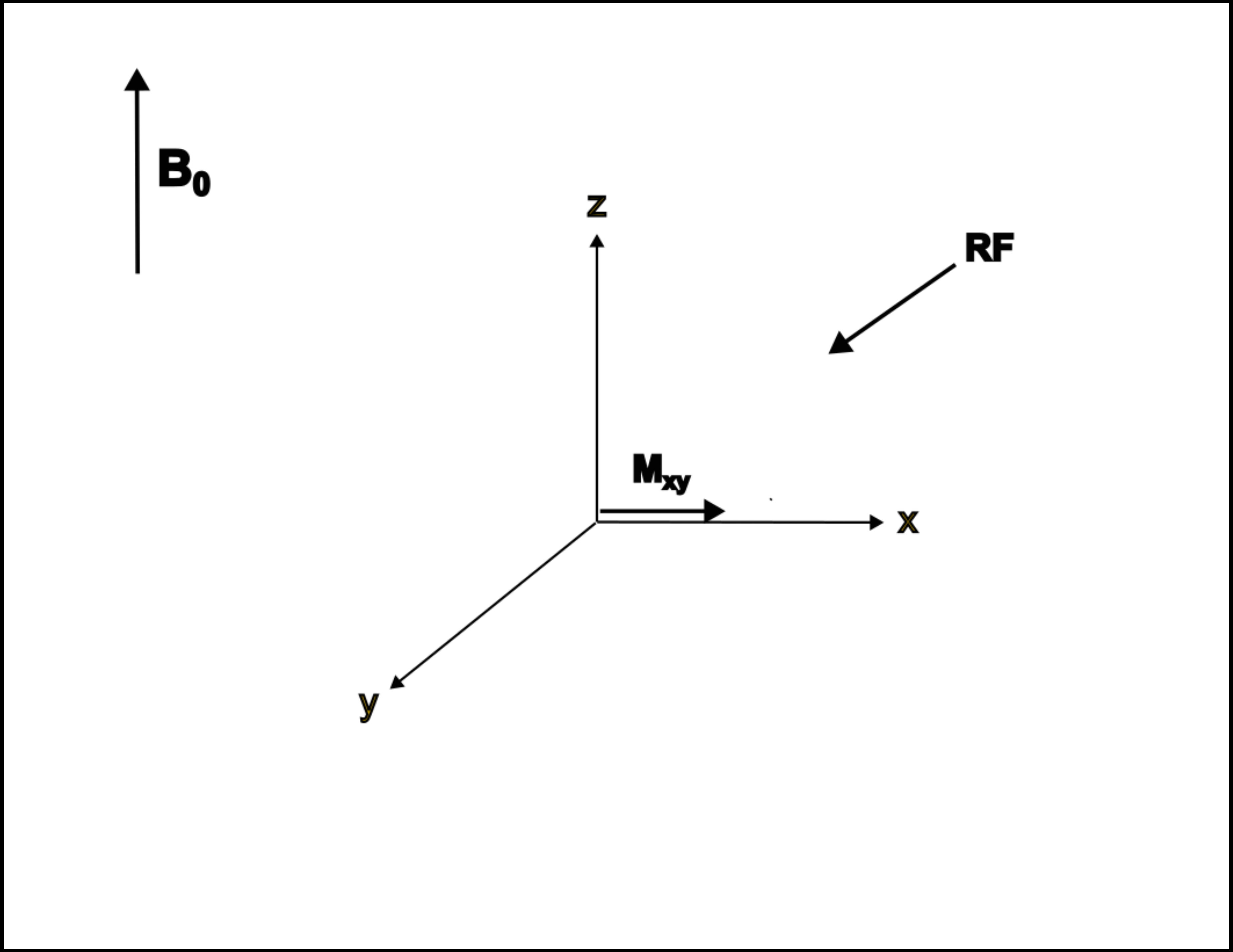
Contrast - basics



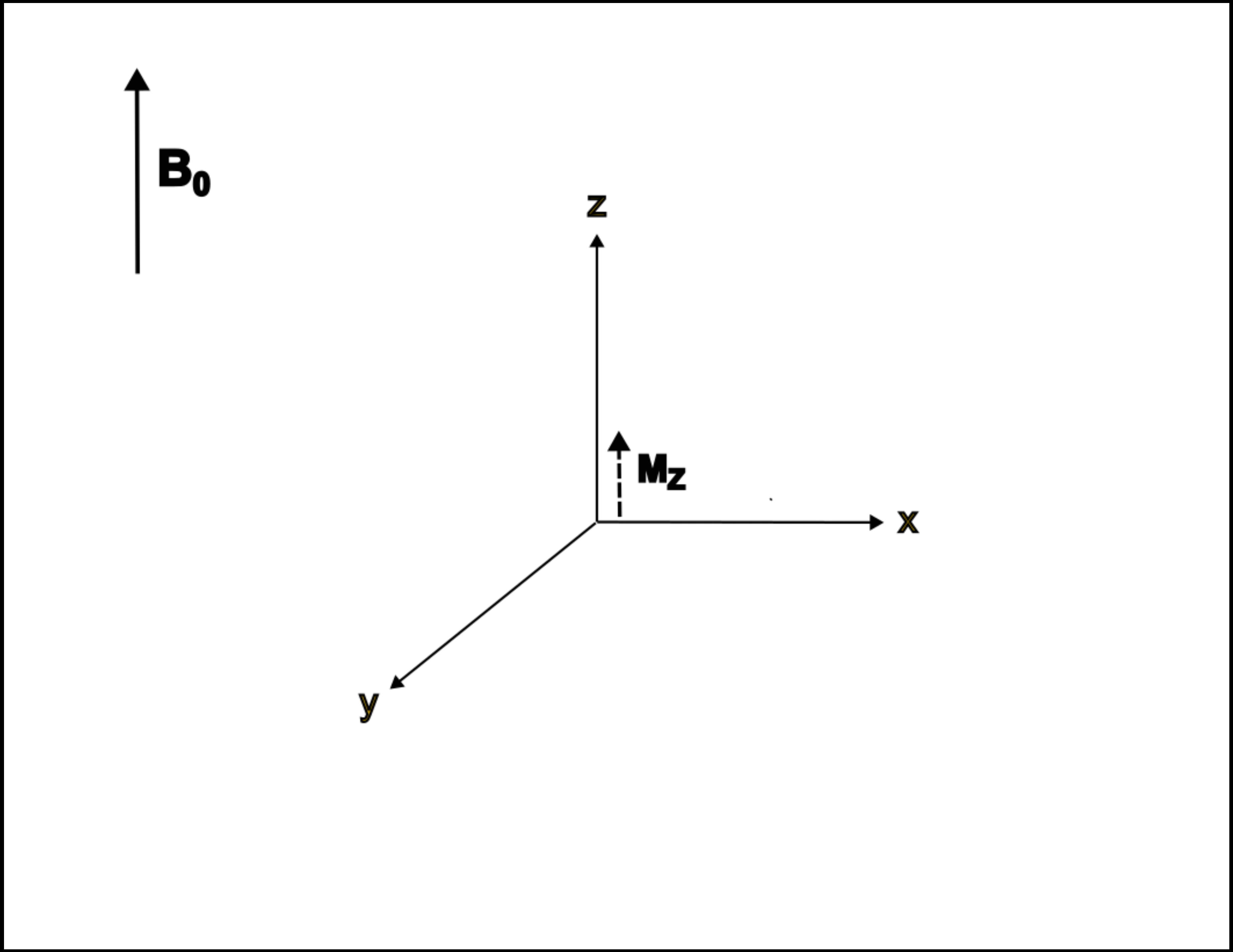
Contrast - basics



Contrast - basics



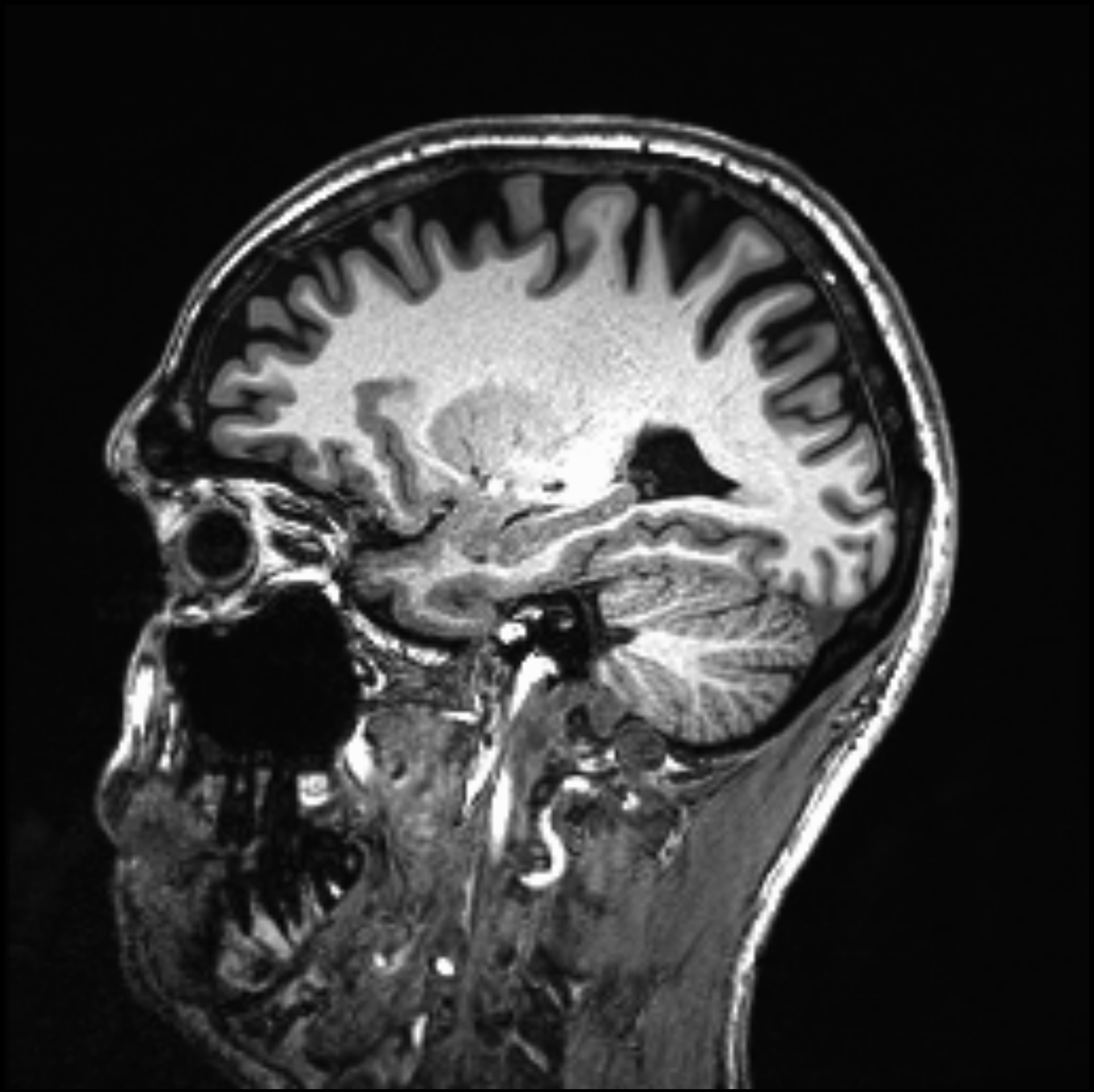
Contrast - T_1



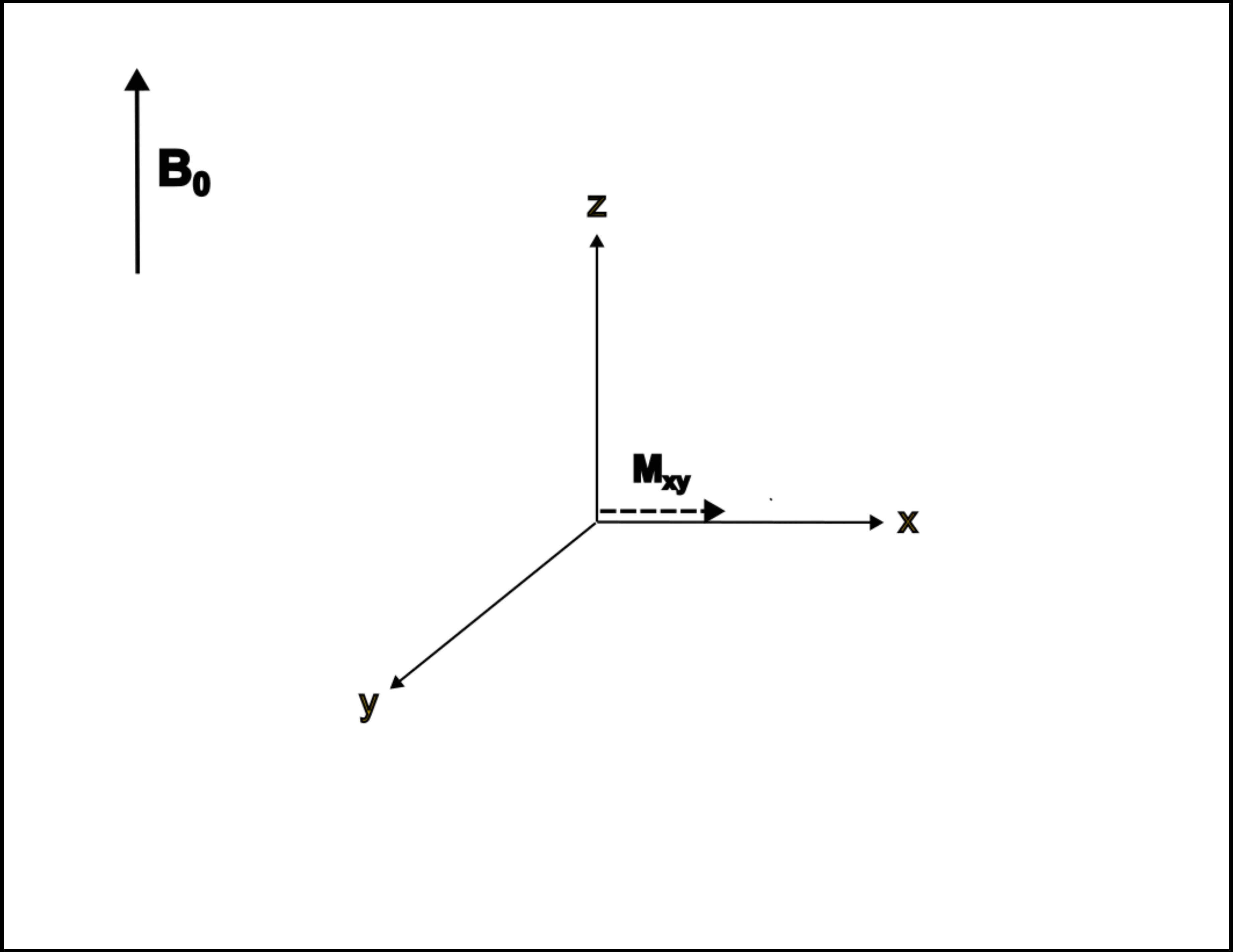
Contrast - T_1

- Regrowth of equilibrium (i.e. M_0) magnetization, along B_0 / z-axis.
- Longer T_1 —> lower signal ...

Contrast - T_1



Contrast - T_2

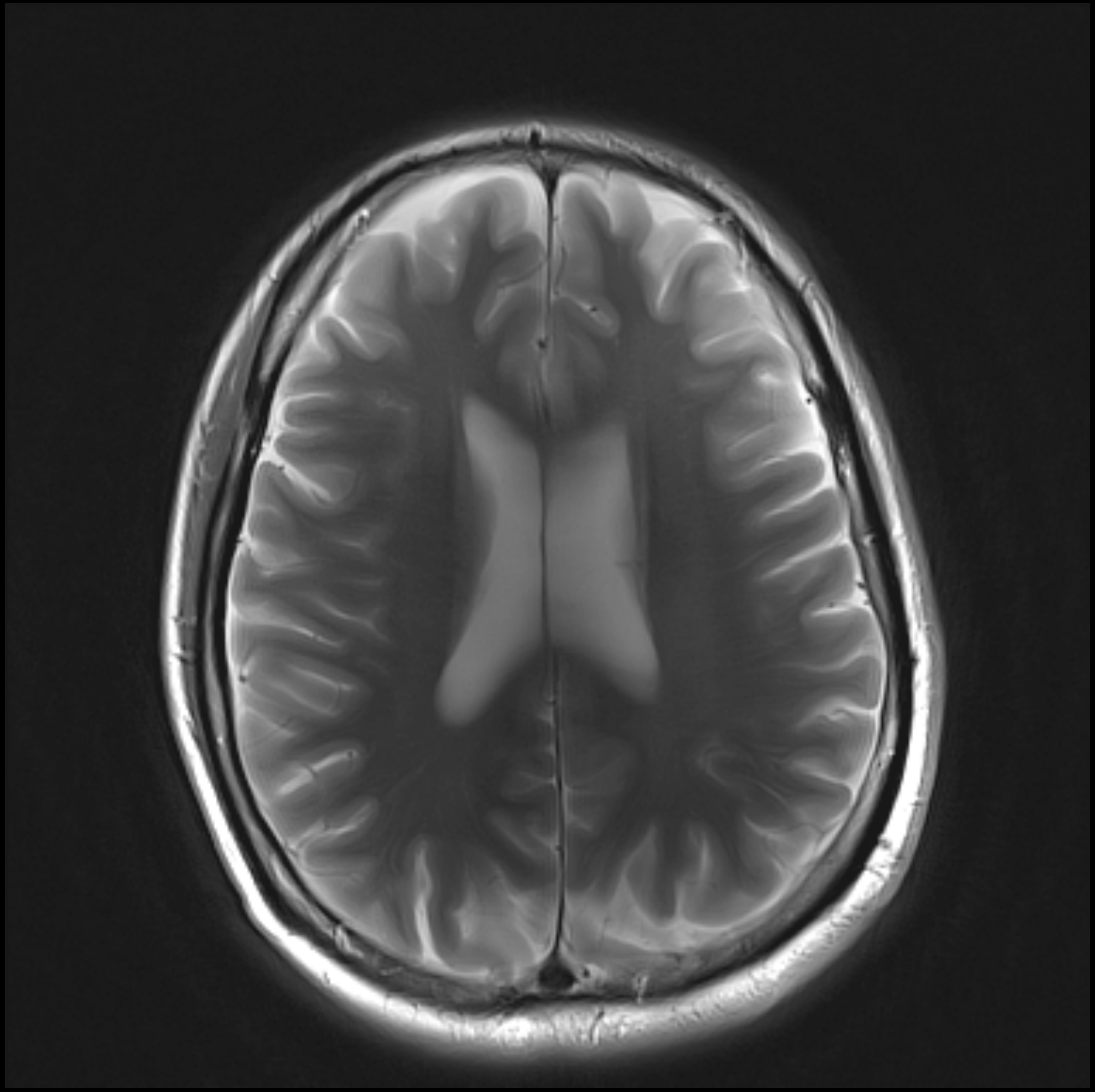


Contrast - T_2

- Dephasing (loss of coherence) of magnetization signal (i.e. M_{xy}).

- Longer T_2 —> higher signal …

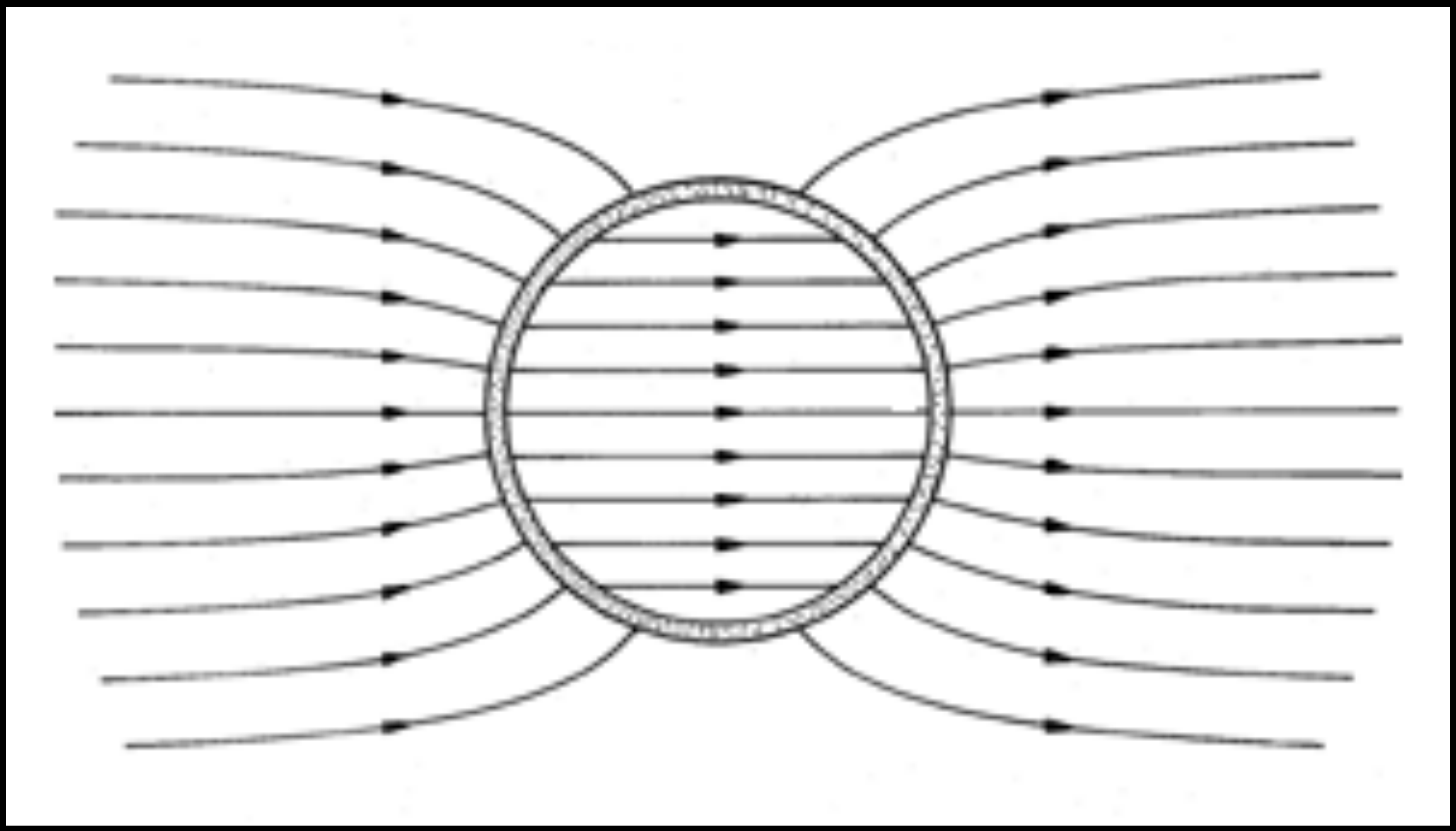
Contrast - T_2



Contrast - BOLD

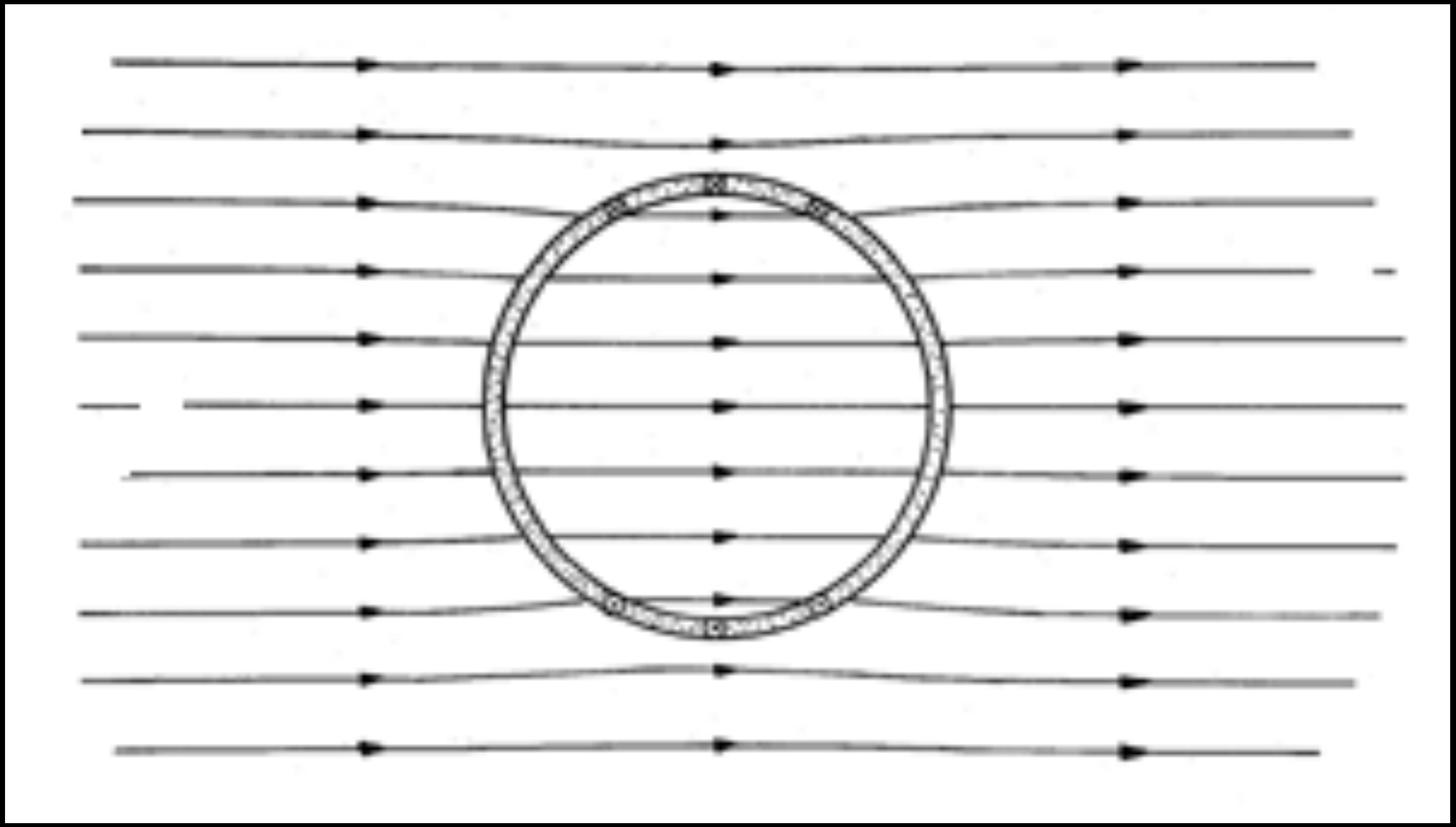
- Similar in principle to T2 relaxation, ‘enhanced’ by background magnetic field gradient —> T_2^*

Contrast - BOLD



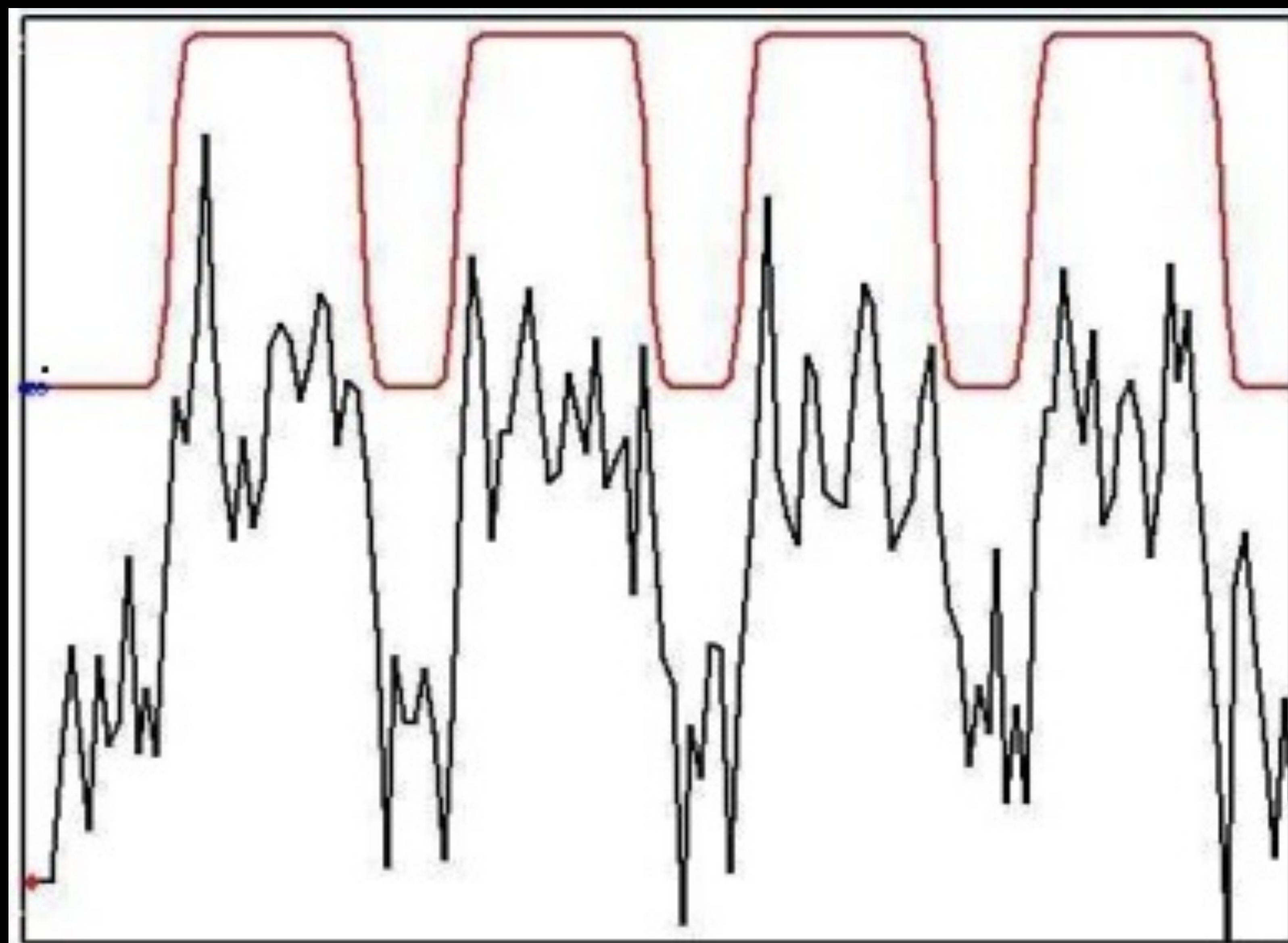
http://web.mit.edu/6.013_book/www/chapter10/10.4.html

Contrast - BOLD

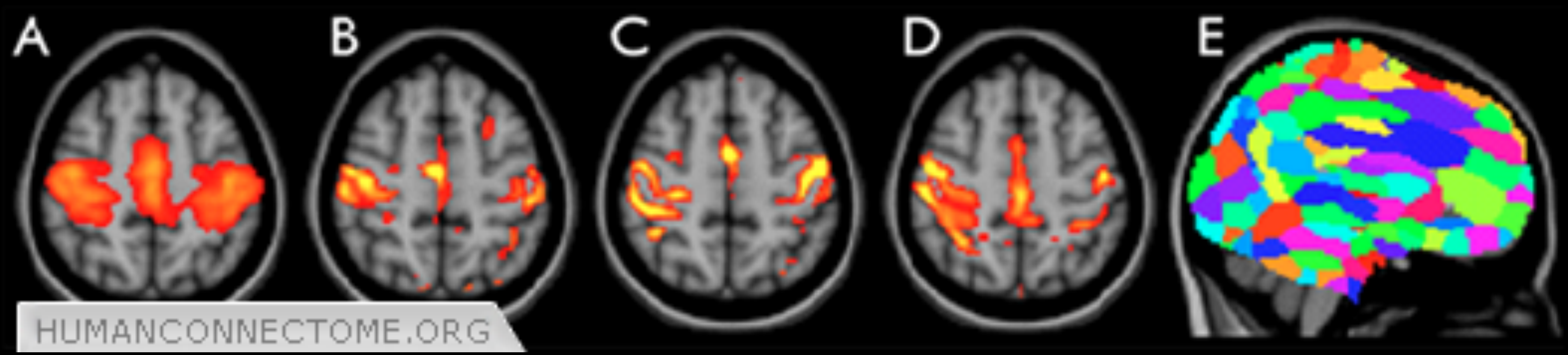


http://web.mit.edu/6.013_book/www/chapter10/10.4.html

Contrast - BOLD



Contrast - BOLD



Contrast

- FLAIR (Fluid Attenuated Inversion recovery)
- Magnetization Transfer (MT) - MRM, 1989 Vol 10:135-144 - Wolff and Balaban
- Perfusion imaging - MRM, 1992 Vol 23:37-45 - Detre et.al.
- Diffusion imaging - Nature Reviews Neuroscience 4, 469-480 (June 2003) - DOI:10.1038/nrn1119 (review paper)
- Phase imaging - PNAS, 2007 Vol 104(28):11796-11801 - Duyn et.al.
- …

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“Main field” considerations

- Stronger main field (larger B_0) - higher frequency (ω_0)
- More signal, i.e. larger net Magnetization (e.g. can be used to acquire higher resolution images)
- Different tissue contrast with stronger main field

"Main field" considerations

- Stronger main field (larger B_0) - higher frequency (ω_0)
- More signal, i.e. larger net Magnetization (e.g. can be used to acquire higher resolution images)
- Different tissue contrast with stronger main field

However …

- Higher frequency RF (larger ω_0) gives rise to more SAR issues
- More issues with keeping B_0 and B_1 uniform
- Might not be appropriate for some applications

Other considerations

- Relaxation times - appropriate for the tissue of interest
- Resolution vs. time trade-off
- How much can I accelerate - what does the hardware allow
- What else can be / should be measured — eye-tracking data, physiology, EEG data, field camera data, other types of MR data (e.g. to help with distortion correction) to help with post-processing and analyses.

System overview

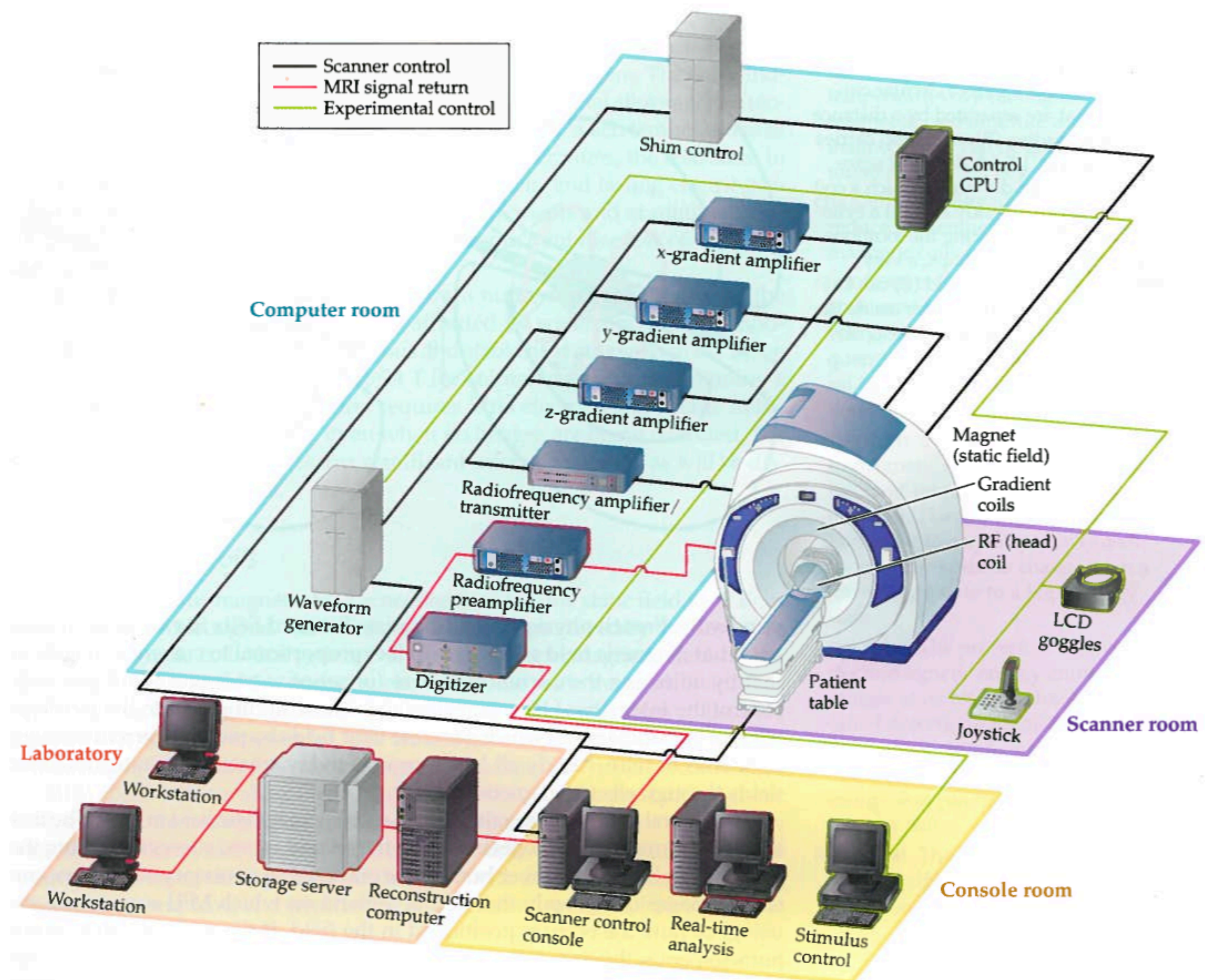

Figure 2.2 Schematic organization of the fMRI scanner and computer control systems. Two systems are important for fMRI studies. The first is the hardware used for image acquisition. In addition to the scanner itself, this hardware consists of a series of amplifiers and transmitters responsible for creating the gradients and pulse sequences (shown in black), and recorders of the MR signal from the head coil (shown in red). The second system is responsible for controlling the experiment in

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