MRI Systems and Safety

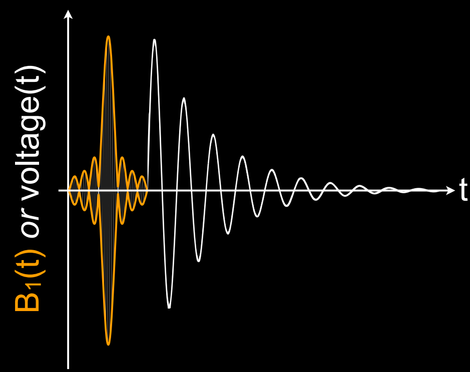
Kyung Sung, Ph.D.
Assistant Professor of Radiology
Magnetic Resonance Research Labs

What is MRI?

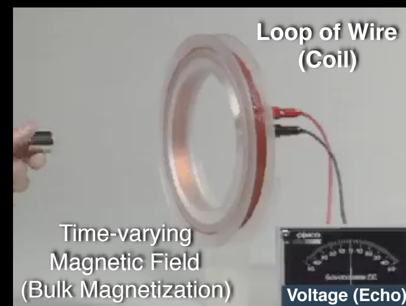
- Magnetic
  - We need a big magnet
- Resonance
  - Excitation energy has to be on-resonance
- Imaging
  - We can make pretty pictures

What is MRI?

MRI follows a classic excitation-reception paradigm.



Excitation (RF Pulse) — Reception (FID or **Echo**)



Faraday's Law of Induction

MRI encodes spatial information and image contrast in the echo.

Requirements for MRI

- NMR Active Nuclei
  - e.g. ^1H in H_20
- Magnetic Field (B_0): Polarizer
- RF System (B_1): Exciter
- Coil: Receiver
- Gradients (G_X, G_Y, G_Z): Spatial Encoding

MRI Hardware

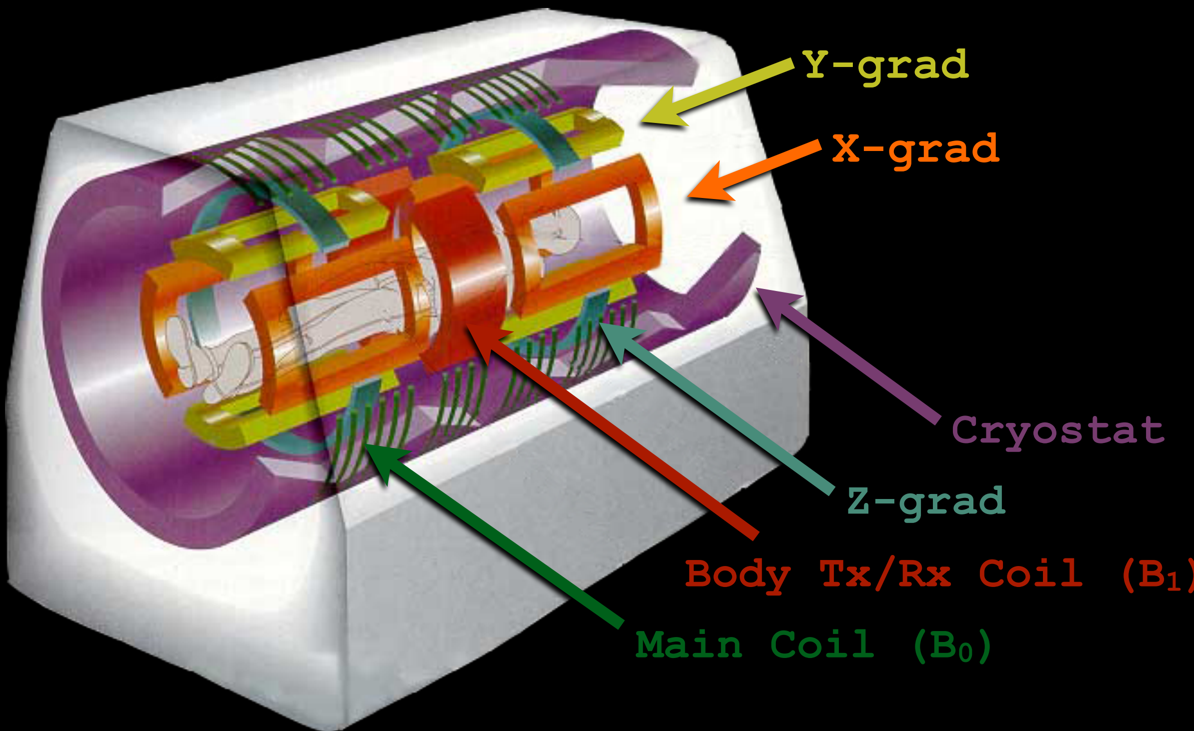
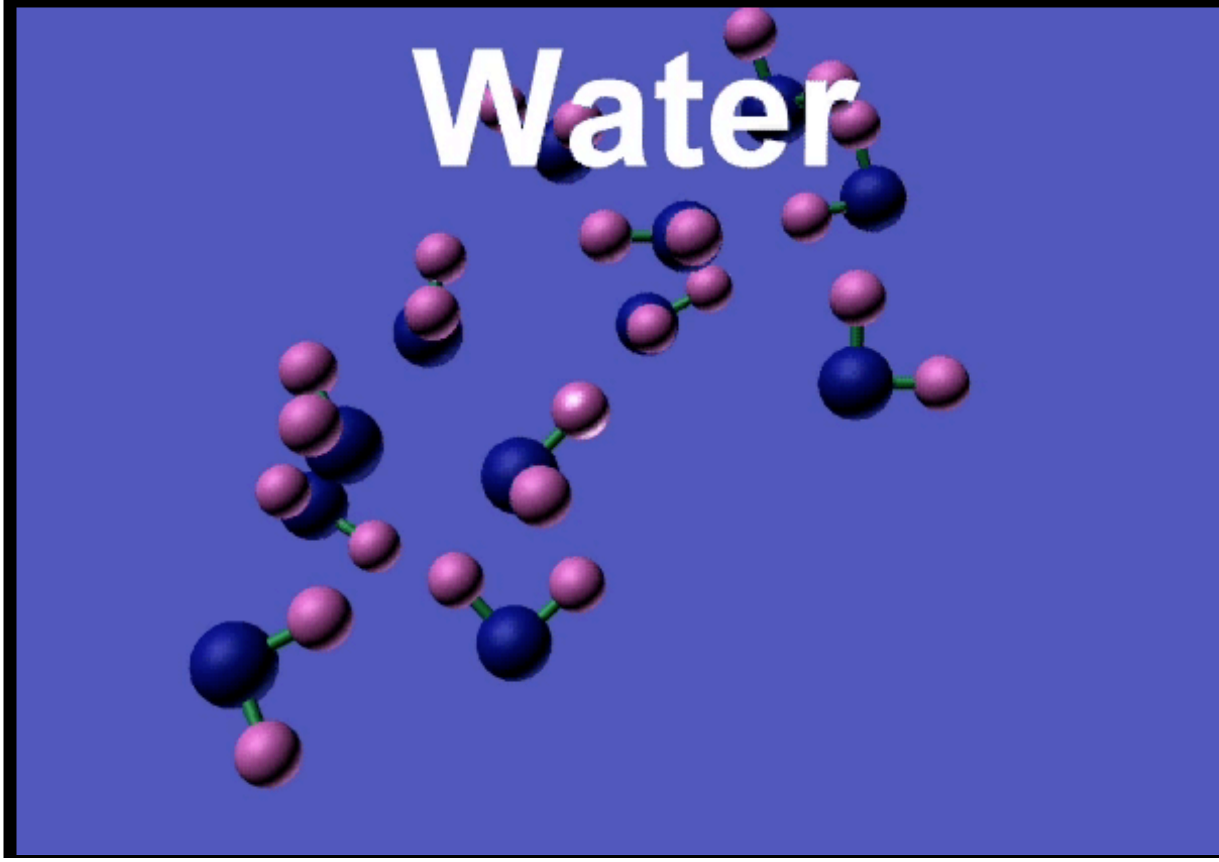


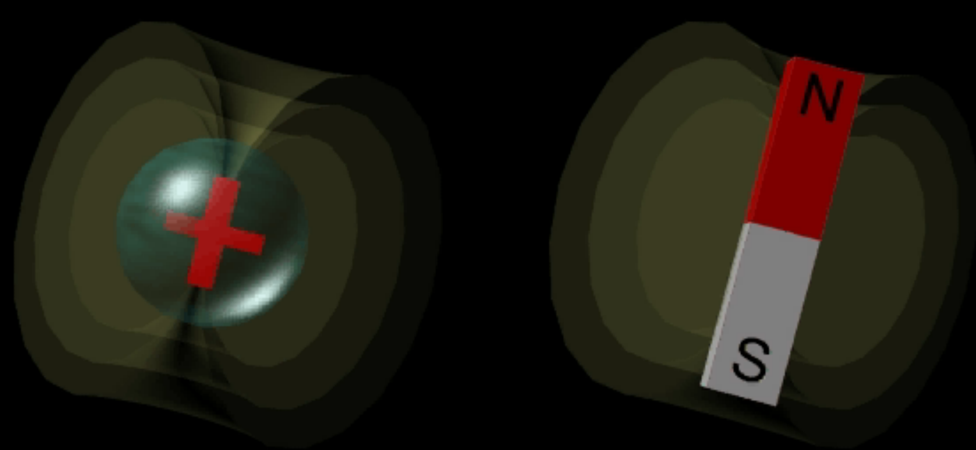
Image Adapted From: http://www.ee.duke.edu/~jshorey

Nuclear Magnetic Resonance

NMR Phenomena



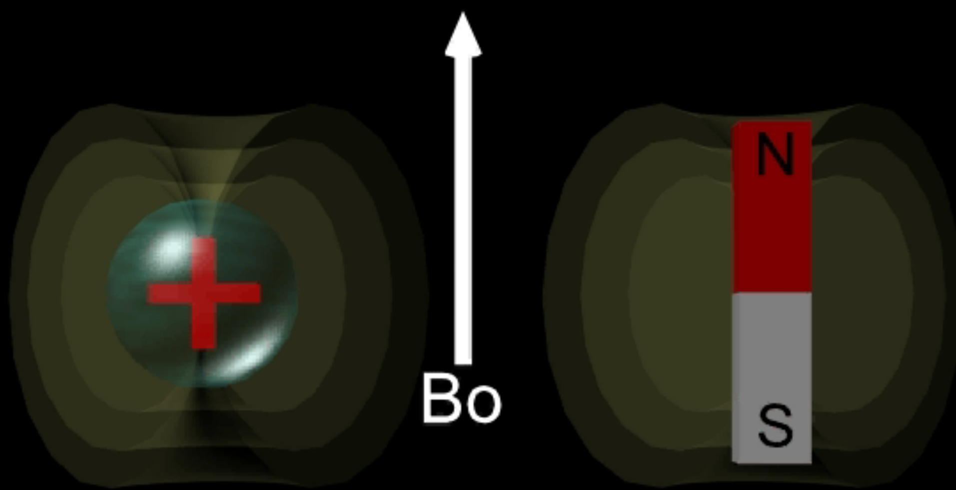
Magnetic Moment



Charge } Magnetic Moment
Spin

Protons behave like small magnets because of spin and charge.

Magnetic Moment



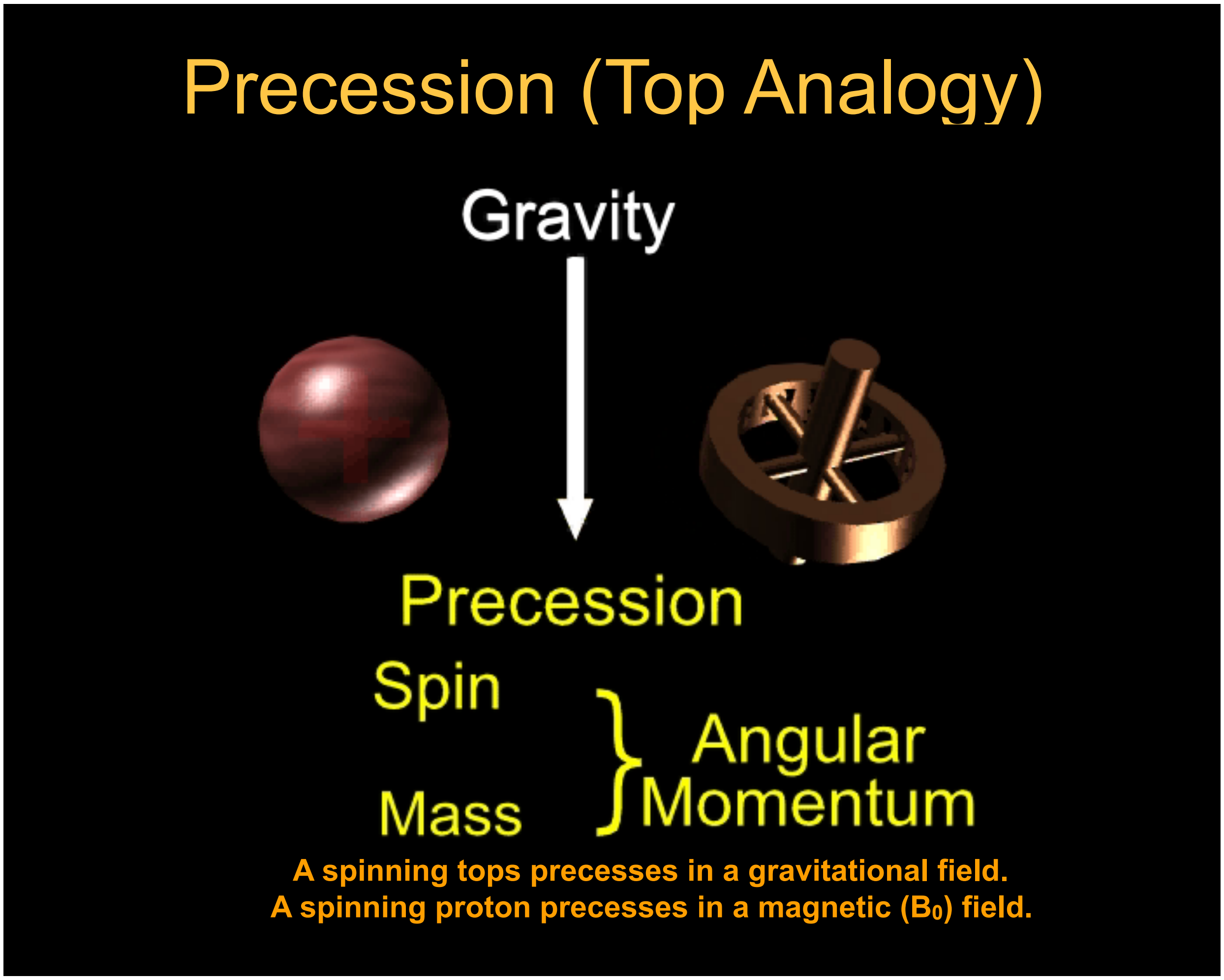
Charge
Spin
} Magnetic Moment

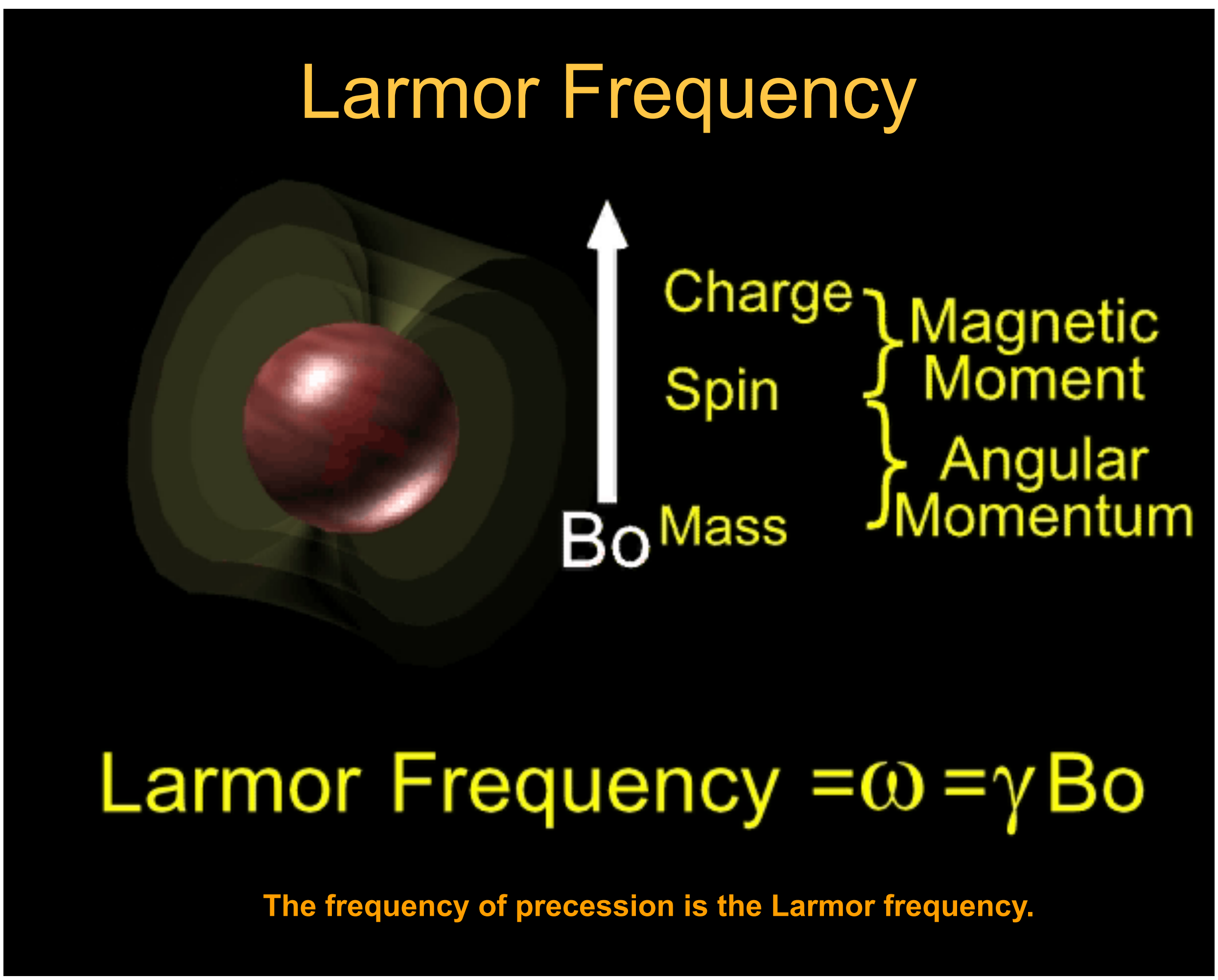
Protons (small magnets) align with an external magnetic field (B_0).

Angular Momentum

Spin
Mass
} Angular Momentum

Protons have angular momentum because of spin and mass.

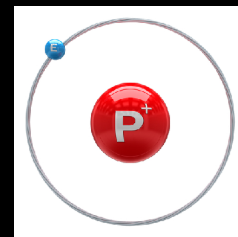

Precession (Top Analogy)
Gravity
Precession
Spin
Mass
Angular
Momentum
A spinning tops precesses in a gravitational field.
A spinning proton precesses in a magnetic (B_0) field.


Larmor Frequency
Charge
Spin
Mass
Bo
Magnetic
Moment
Angular
Momentum
Larmor Frequency $= \omega = \gamma Bo$
The frequency of precession is the Larmor frequency.

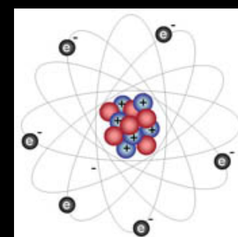
NMR Active Nuclei

- Spin + Charge + Mass $\Longrightarrow$ NMR Active
  - Spin? ***Intrinsic*** form of angular momentum.
- Nuclei have spin angular momentum if:
  - Odd atomic mass (# protons+neutrons)

    And/Or
  - Odd atomic number (# of protons)
- Spin angular momentum
  - Leads to precession
  - Spin ≠ precession (a top spins *and* precesses)
- Frequency of precession (Larmor Frequency)
  - Gyromagnetic Ratio (γ)
    - Physical constant
    - Unique for each NMR active nuclei



Hydrogen



Carbon-13

What is so special about ^{1}H? Spin, charge, and mass!

NMR Active Nuclei

Isotope	*Spin [I]*	Gyromagnetic Ratio [MHz/T]	Relative Sensitivity	Natural Abundance	Absolute Sensitivity
^{1}H	**1/2**	**42.57**	**1**	**0.9980**	**9.98E-01**
^{2}H	1	6.54	9.65E-06	0.0002	1.93E-09
^{12}C	0	---	---	0.9890	---
^{13}C	**1/2**	**10.71**	**0.016**	**0.0110**	**1.76E-04**
^{14}N	1	3.08	0.001	0.9960	9.96E-04
^{15}N	**1/2**	**-4.32**	**0.001**	**0.0040**	**4.00E-06**
^{16}O	0	---	---	0.9890	---
^{17}O	5/2	-5.77	0.029	0.0004	1.16E-05
^{19}F	**1/2**	**40.05**	**0.83**	**1.0000**	**8.30E-01**
^{23}Na	**3/2**	**11.26**	**0.093**	**1.0000**	**9.30E-02**
^{31}P	**1/2**	**17.24**	**0.066**	**1.0000**	**6.60E-02**

The ***relative sensitivity*** is at constant magnetic field and equal number of nuclei
The ***absolute sensitivity*** is the relative sensitivity multiplied by natural abundance

Larmor Equation

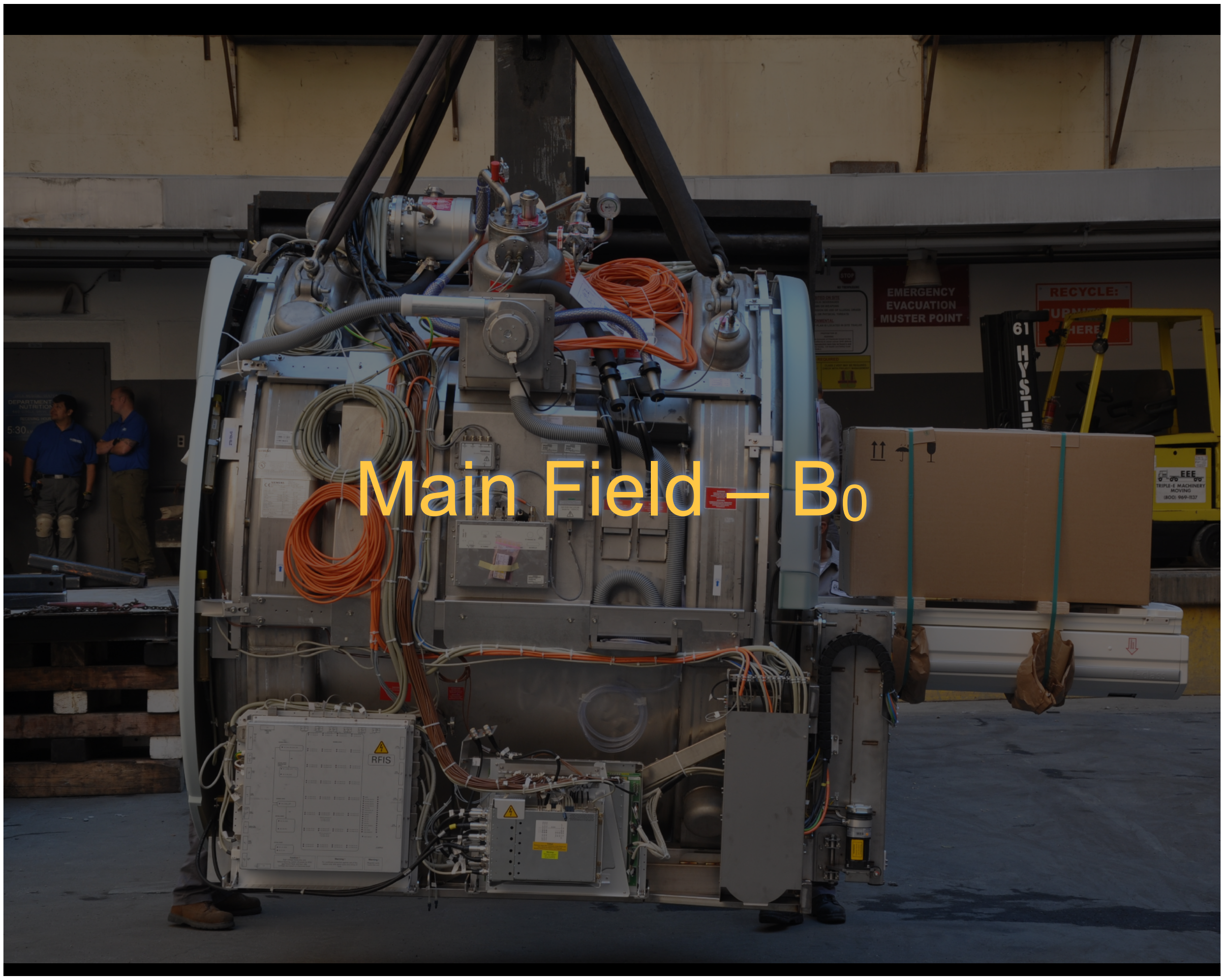
- Spin≠Precession
  - Protons *intrinsically* have spin
  - Protons *precess* in the presence of a B-field
- Larmor frequency increases with:
  - Larger B_0
  - Higher gyromagnetic ratio
  - Higher frequencies produce stronger signals...

$$\omega = \gamma B_0$$

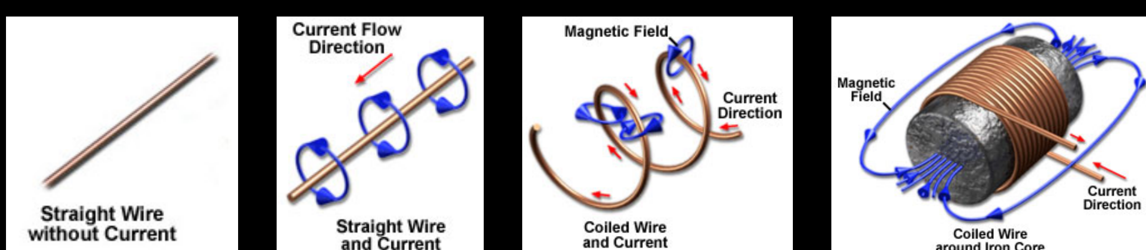
Quiz: NMR - True or False?

1. Electron spin is the key to NMR.
2. MRI is *nothing* without speed, charge, and mass.
3. All atomic nuclei are NMR active.
4. Spin and precession are the same.
5. Higher fields lead to faster precession.

Main Field – B_0



Currents & Magnetic Fields

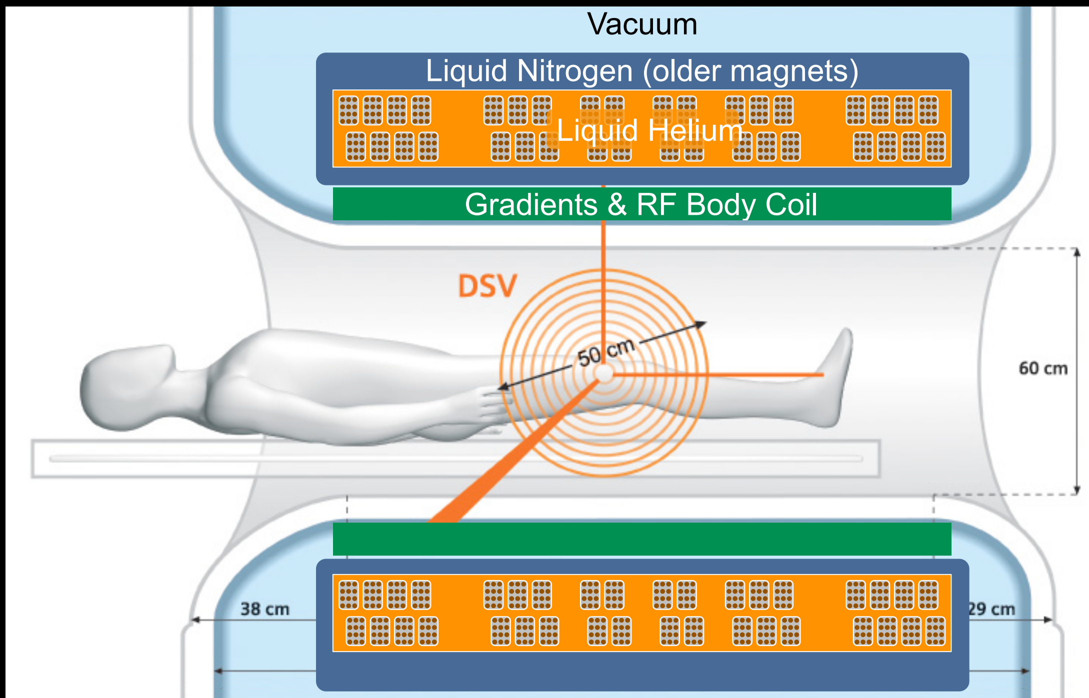


Left-hand Rule

Electromagnet – A current in a wire generates a magnetic field.

http://www.magnet.fsu.edu/education/tutorials/magnetacademy/

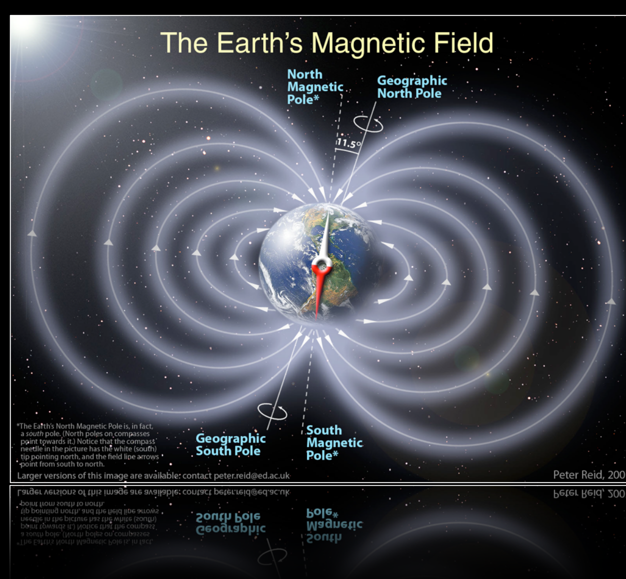
Superconducting Electromagnet



MRI scanners are superconducting electromagnets.

Main Field (B_0) – Strength

- Earth's magnetic field
  - 0.5 Gauss
- Refrigerator magnet
  - 10-100 Gauss
- B_0 Field
  - 0.5T = 5000 Gauss
  - 1.5T = 15000 Gauss
  - 3.0T = 30000 Gauss



B_0 Strength - Advantages

- ⬆ $B_0 \Longrightarrow$ ⬆ Polarization ($|\vec{M}|$) = ⬆ SNR
  - ⬆Polarization, therefore more $\vec{M}$ for imaging.
  - SNR $\propto B_0^{7/4}$ (⬆Polarization + ⬆Larmor Frequency)
    - ⬆ Spatial resolution
    - ⬆ Temporal resolution
    - ⬇ Scan time

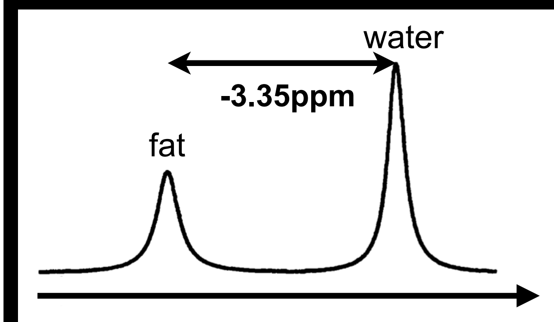
B_0 Strength - Disadvantages

- ⬆ $B_0 \Longrightarrow$ ⬆ Specific Absorption Ratio (SAR)
  - Energy absorbed by body [W/kg]
  - SAR$\propto B_0^2$
- ⬆ $B_0 \Longrightarrow$ ⬆ Cost
  - ~$1,000,000 per Tesla
  - More shielding

Higher B_0 leads to higher SAR for patients and higher costs.

B_0 Strength - Disadvantages

- ⬆ $B_0 \Longrightarrow$ ⬆ Chemical shift (Δf)
  - ⬆ Δf between fat and water
    - Fat and water have different Larmor frequencies
      - ~220Hz different at 1.5T
      - ~440Hz different at 3.0T
    - Fat is *more* spatially mis-registered @ 3T
  - Good for spectroscopy…



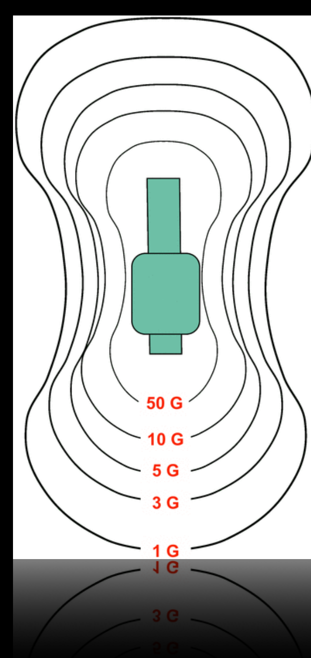
$$B = B_0 \left(1 - \delta\right)$$

$$\delta_{-\mathrm{CH}_2} = 3.35ppm$$

Chemical Shift – Fat (–CH_2) is ~220Hz *lower* at 1.5T

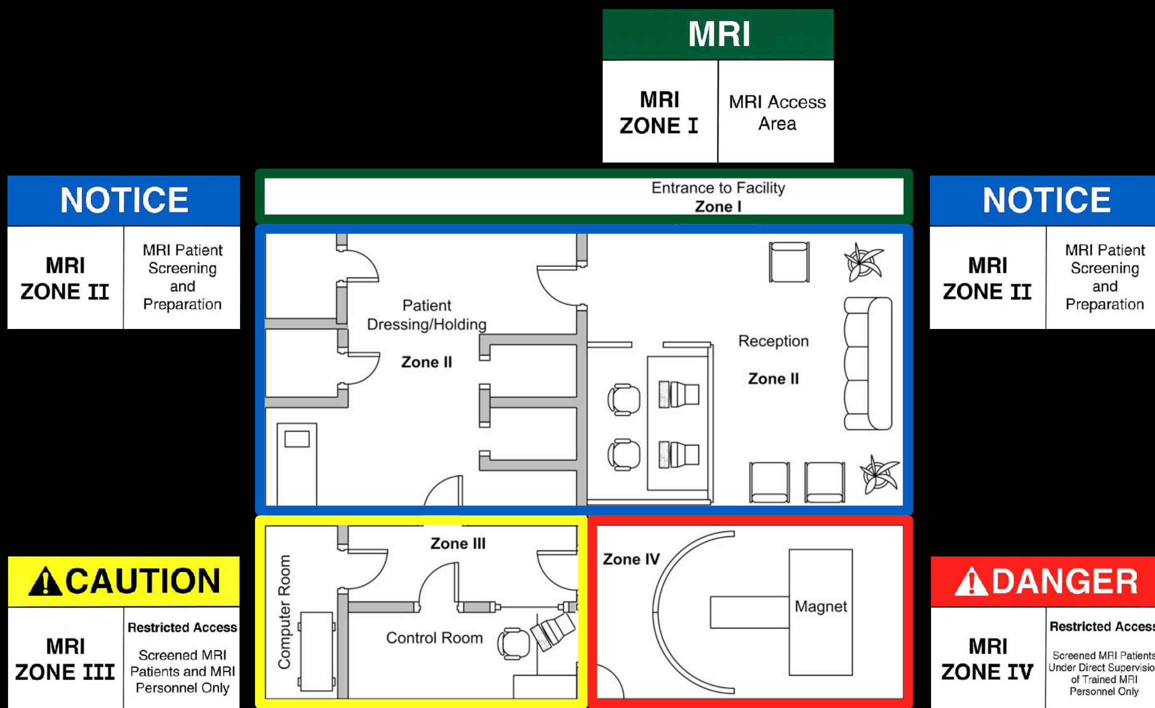
Main Field (B_0) – Shielding

- **Problem**: The B_0 field extends well beyond the scanner.
- **Shielding** reduces B_0 foot print
  - Reduces install cost
  - Reduces interference
- **Passive Shielding**
  - Iron room shielding
  - Heavy, not cheap
- **Active Shielding**
  - Super-conducting coils that oppose (shield) B_0 fringe field
- "**Five Gauss Line**"
  - Threshold beyond which ferromagnetic objects are strictly prohibited
  - 5G=0.5mT



ACR Guidance Document on MR Safe Practices: 2013; *JMRI* 37:501–530 (2013)

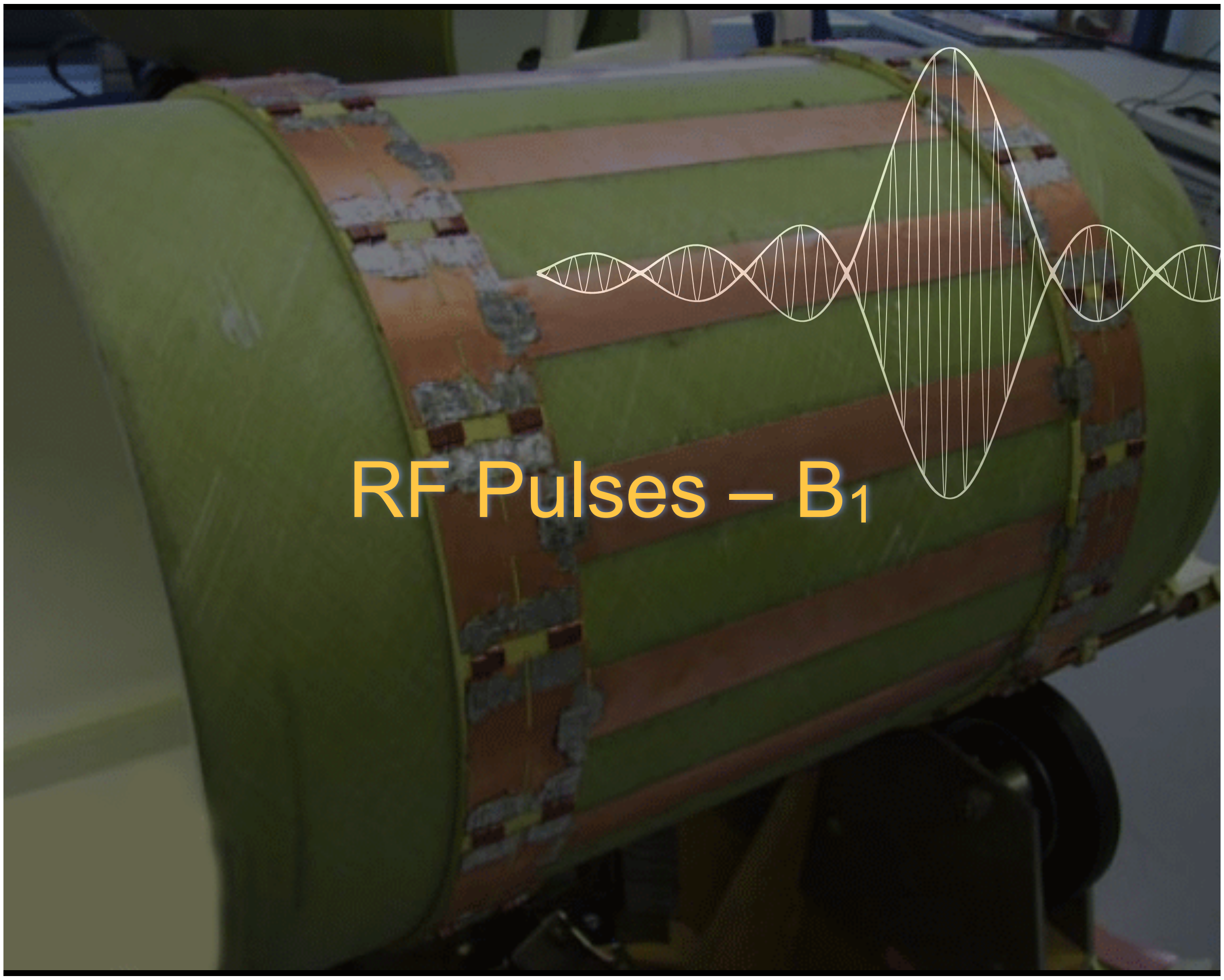
MRI Zones



ACR Guidance Document on MR Safe Practices: 2013; *JMRI* 37:501–530 (2013)

Quiz: Main Field - True or False?

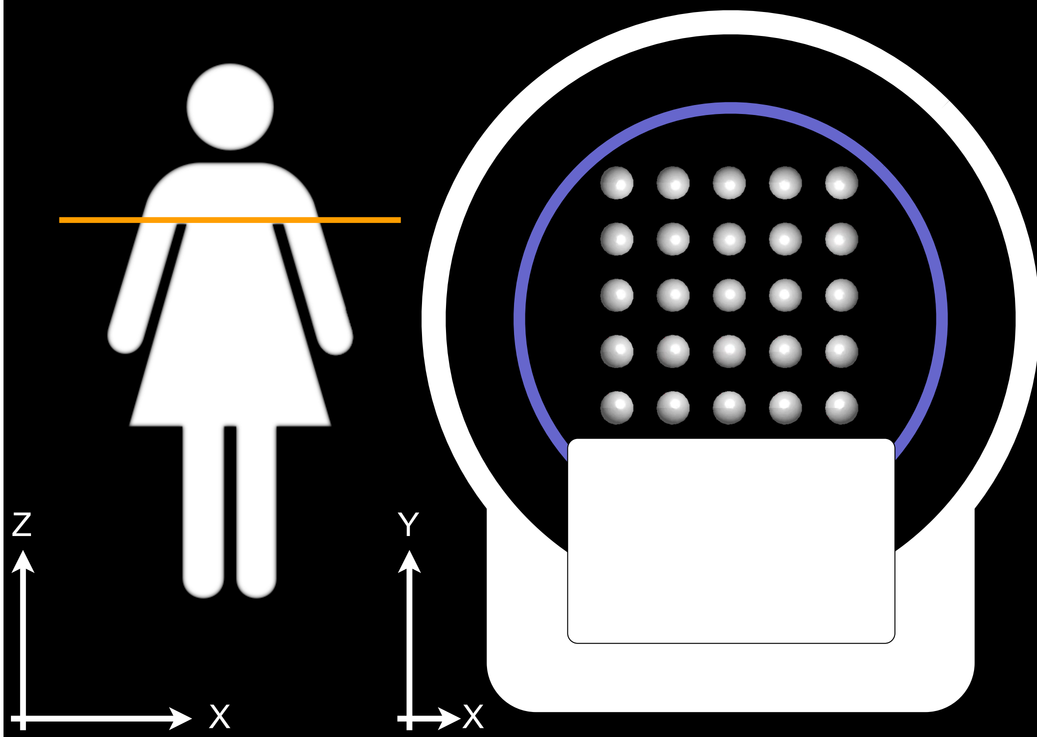
1. B_0 is rare earth permanent magnet.
2. 1 Tesla=1000 Gauss.
3. Higher fields increase polarization, which contributes to better image quality.
4. Exams at higher fields have lower SAR.
5. ^{1}H always precesses at the same Larmor frequency.



B_1 Field - RF Pulse

- B_1 is a
  - radiofrequency (RF)
    - 42.58MHz/T (63MHz at 1.5T)
  - short duration pulse (~0.1 to 5ms)
  - small amplitude
    - <30 μT
  - circularly polarized
    - rotates at Larmor frequency
  - magnetic field
  - perpendicular to B_0

RF (B_1) Excitation



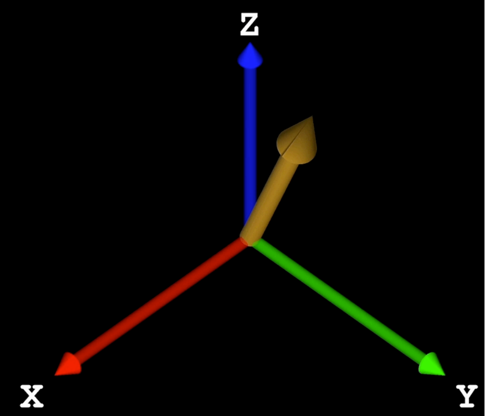
RF pulses generate transverse magnetization for a *slice*.

Types of RF Pulses

- **Excitation Pulses**
- **Inversion Pulses**
- **Refocusing Pulses**
- Saturation Pulses
- Spectrally Selective Pulses
- Spectral-spatial Pulses
- Adiabatic Pulses

Excitation Pulses & Applications

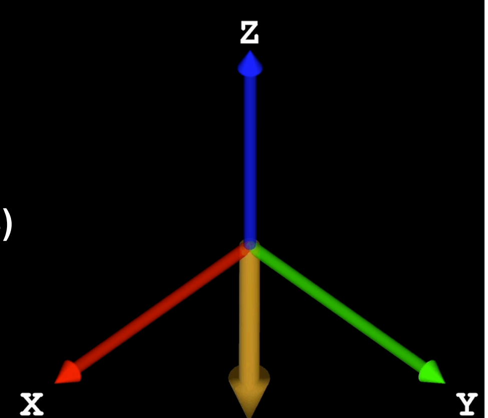
- **90° RF Pulse**
  - Spin Echo
  - Saturation Recovery
- **Small Flip Angle (<~20°)**
  - FLASH (Fast Low Angle Shot)
    - AKA SPGR
- **Moderate Flip Angle (30°-90°)**
  - TrueFISP
    - AKA FIESTA, Balanced FFE



Excitation pulses generate detectable transverse magnetization.

Inversion Pulse & Applications

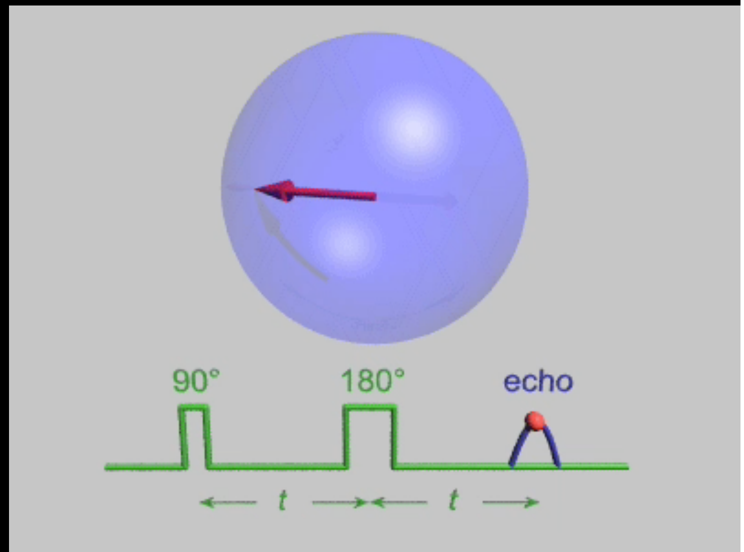
- **Invert Mz to -Mz**
  - Ideally produce no Mxy
- **T1 species nulling/attenuation**
  - STIR (Short Tau Inversion Recovery)
    - Suppress specific tissue-T1
  - SPECIAL (Spectral Inversion at Lipids)
    - Suppress lipid signals (short T1)
  - FLAIR (Fluid Attenuated Inversion Recovery)
    - Suppress fluid signal (long T1)
  - IR-Prep
    - Attenuate T1-species without nulling
- **Quantitative T1 mapping**



Inversion pulses increase T1 contrast and ***null*** tissues.

Refocusing Pulses & Spin Echoes

- **180° RF Pulse**
  - **Provides optimally refocused M_{XY}**
  - **Largest spin echo signal**
- **Refocus spin dephasing due to off-resonance:**
  - **imaging gradients**
  - **local magnetic field inhomogeneity**
  - **magnetic susceptibility variation**
  - **chemical shift**



Refocusing RF pulses mitigate off-resonance spin dephasing.

https://en.wikipedia.org/wiki/Spin_echo

Refocusing Pulses - Applications

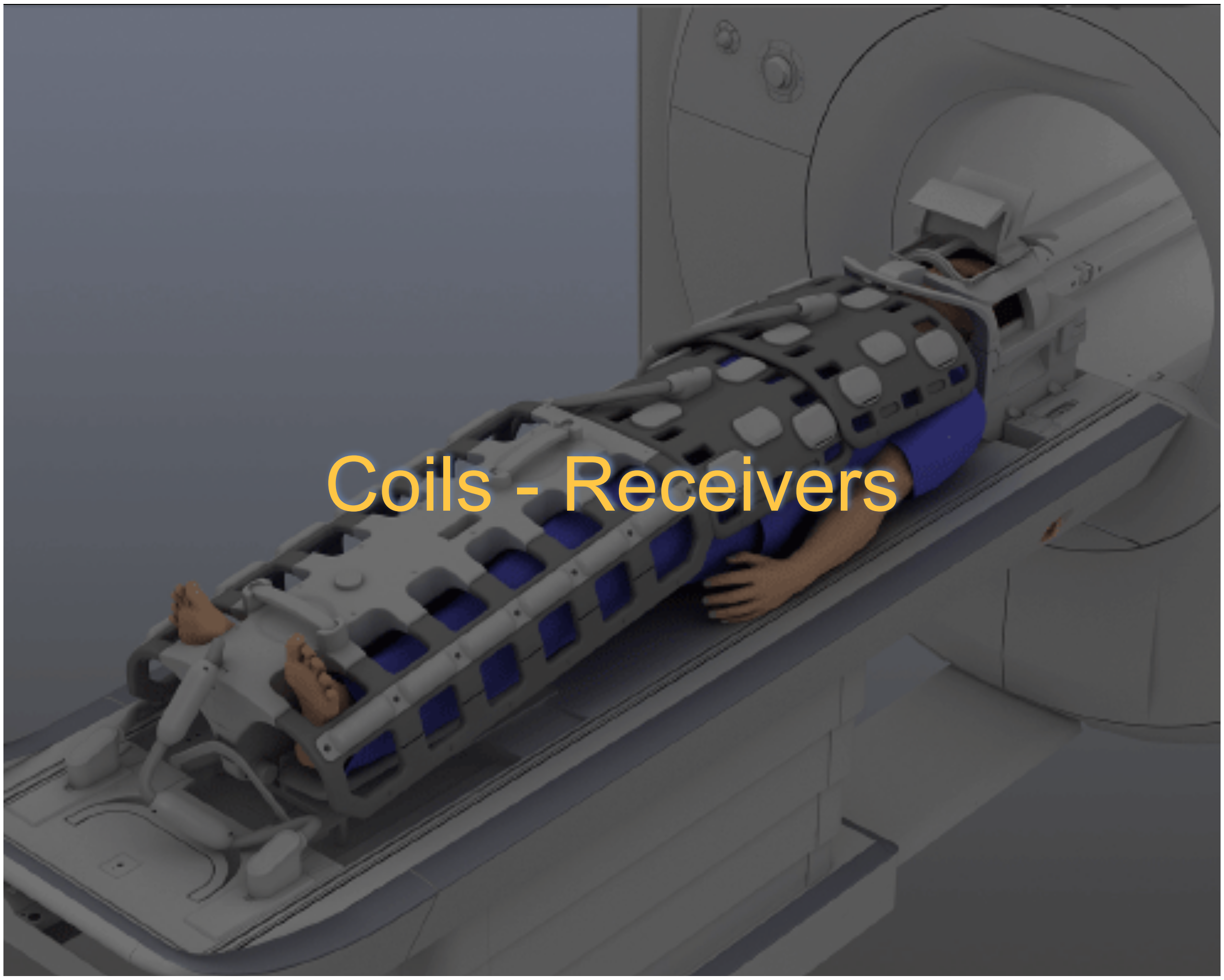
- **Spin Echo imaging**
- **RARE**
  - **Rapid Acquisition with Relaxation Enhancement**
  - **RF Excitation followed by 180° train**
  - **Reduce acquisition time by N-echoes**
  - **Common for T2-weighted imaging**
  - **AKA Fast Spin Echo**
- **Spin-Echo EPI**
  - **Single-shot common for diffusion weighting**
- **Navigator Echoes**
- **Quantitative T2 Mapping**

Quiz: RF Pulses - True or False?

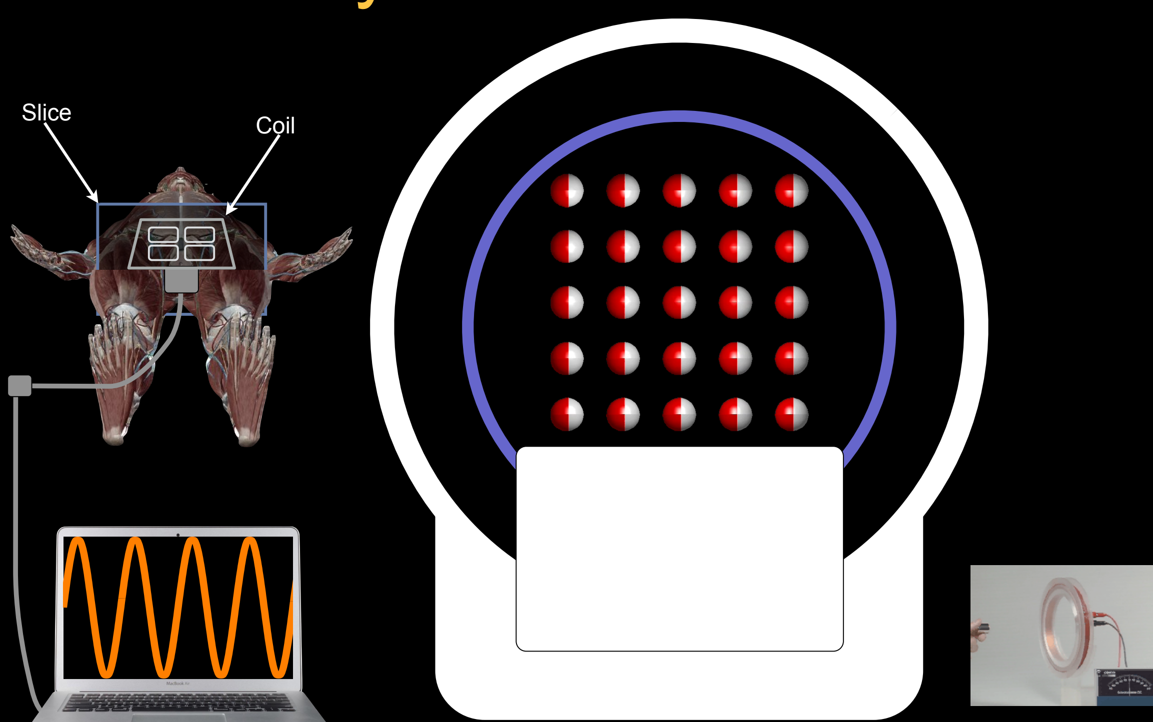
1. RF pulses are the main source of patient heating.
2. RF pulses excite spins and create transverse magnetization.
3. RF pulses are typically 100s of ms long.

Quiz: RF Pulses - True or False?

1. Excitation pulses are not required for imaging.
2. Inversion pulses change image contrast.



Faraday's Law of Induction

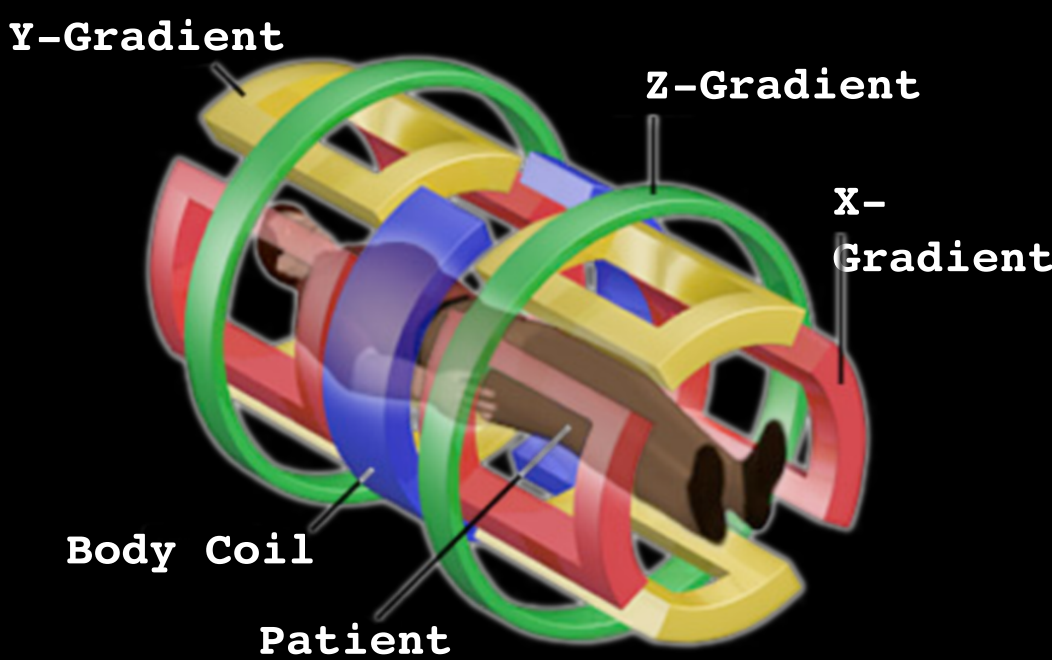


The trick is to encode spatial information and image contrast in the echo.

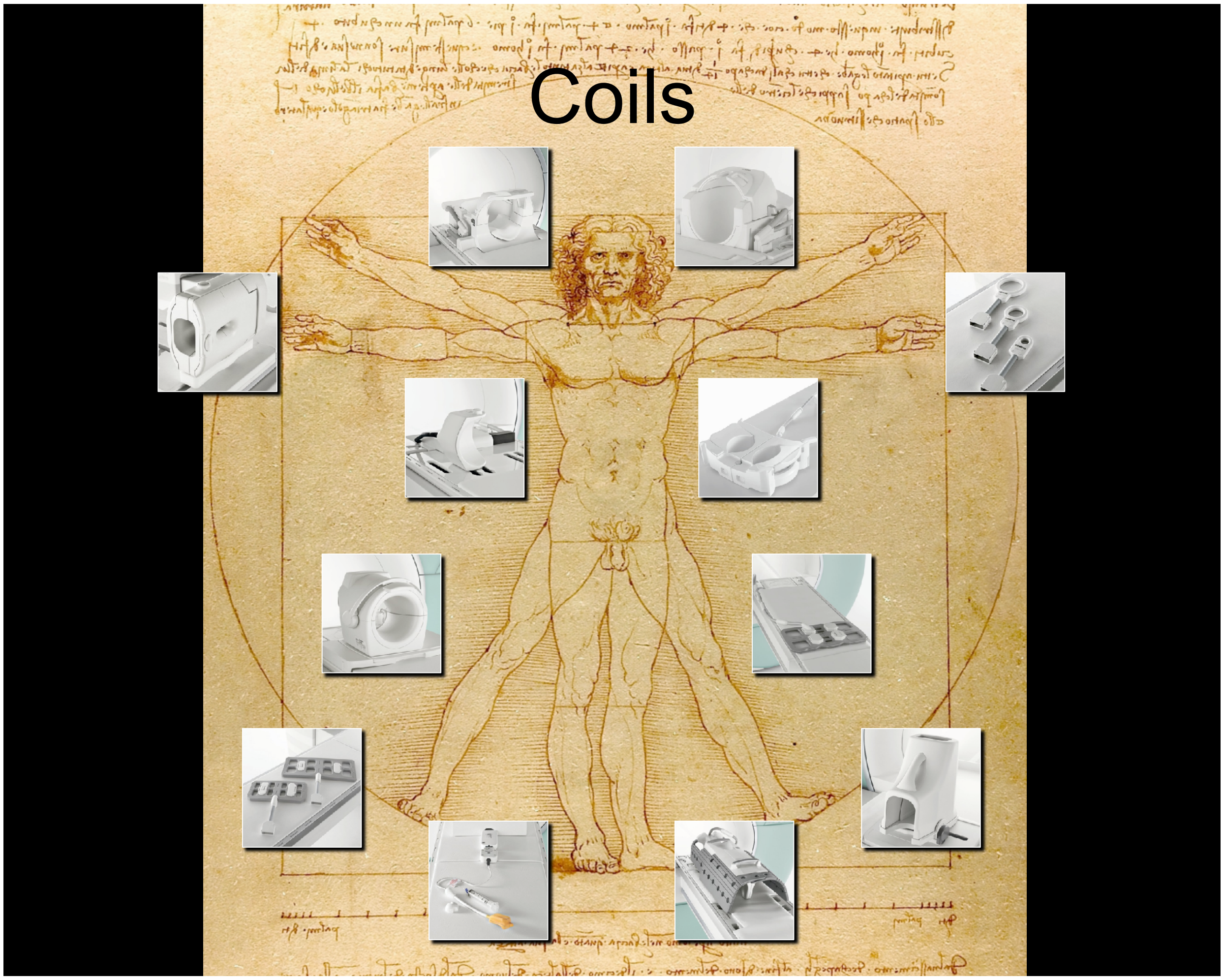
Coils

- Coils transmit the B_1 field
  - Typically Body Coil
  - Sometimes Head or Knee Coil is a Tx/Rx
- Coils receive the NMR signal
  - Very sensitive to MHz (Larmor) signals.
  - Typically Head, Knee, Body, Surface, etc.
  - Very infrequently use the body coil

MRI Instrumentation



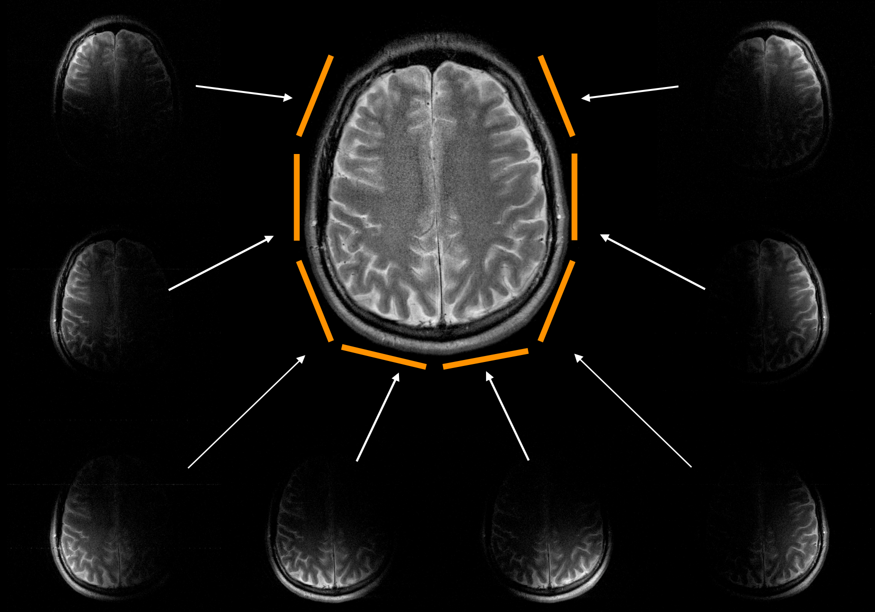
http://www.magnet.fsu.edu



Coils

- Volume Coils (Body, Head, Knee)
  - Typically better SNR than surface coils
  - Typically "birdcage" in design
    - Best RF field homogeneity of all coils
    - Uniform B_1 over extent of volume
- Surface Coils (Torso, Spine, Cardiac)
  - Flexible positioning/placement
  - High SNR near coil
    - SNR falls off quickly with distance
  - Quadrature and phased arrays improve SNR
    - Compared to single channel loop coils

8-Channel Head Coil



Each coil element (channel) has a unique sensitivity profile.

Quiz: Coils - True or False?

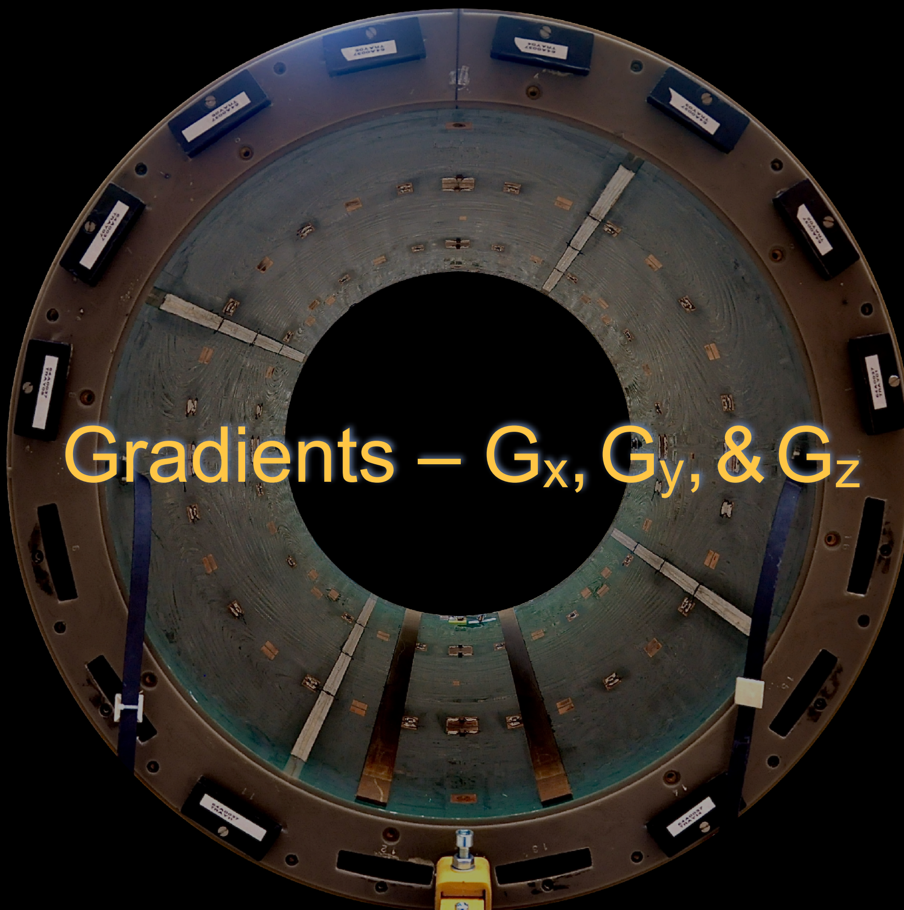
1. Faraday's Law of Induction is the principal underlying signal reception.

2. The body coil is typically used for receiving the MRI signals.

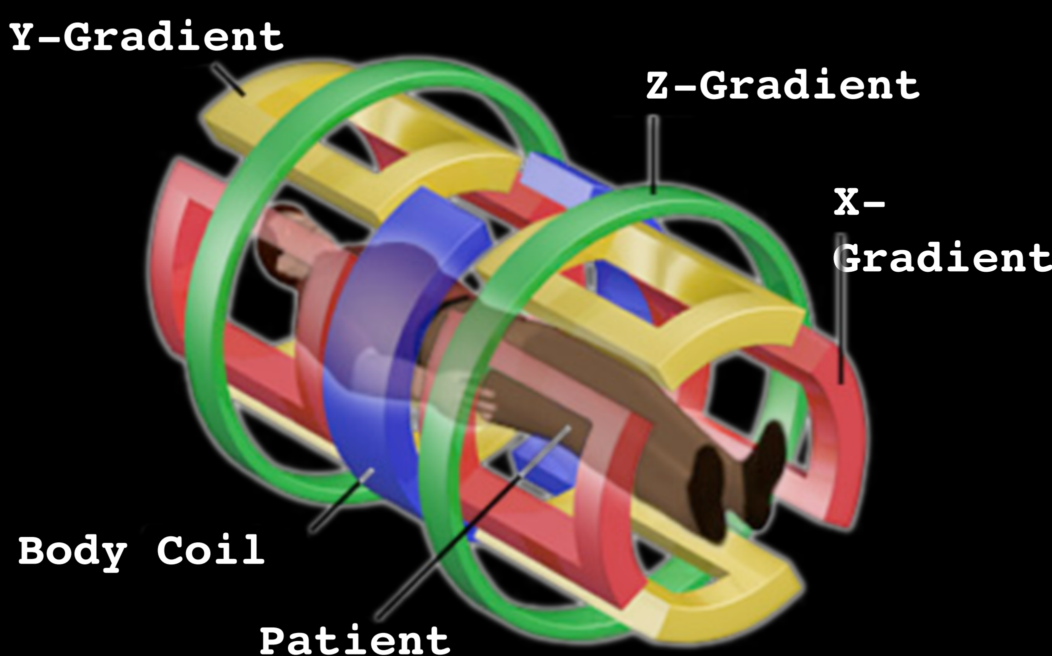
3. Surface coils transmit RF excitation pulses.

4. Coils are designed for specific body parts.

Gradients – G_x, G_y, & G_z



MRI Instrumentation



http://www.magnet.fsu.edu

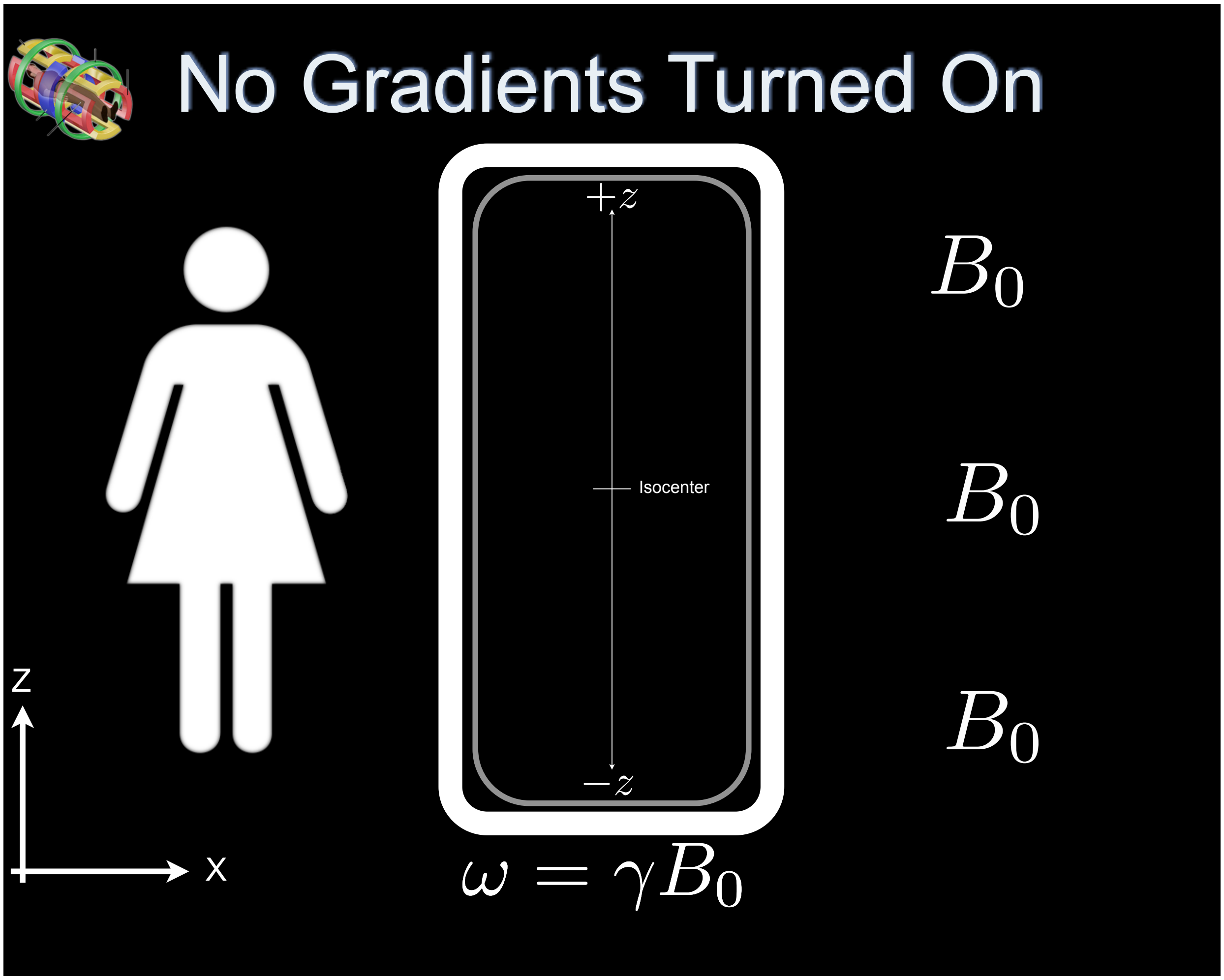
Gradients

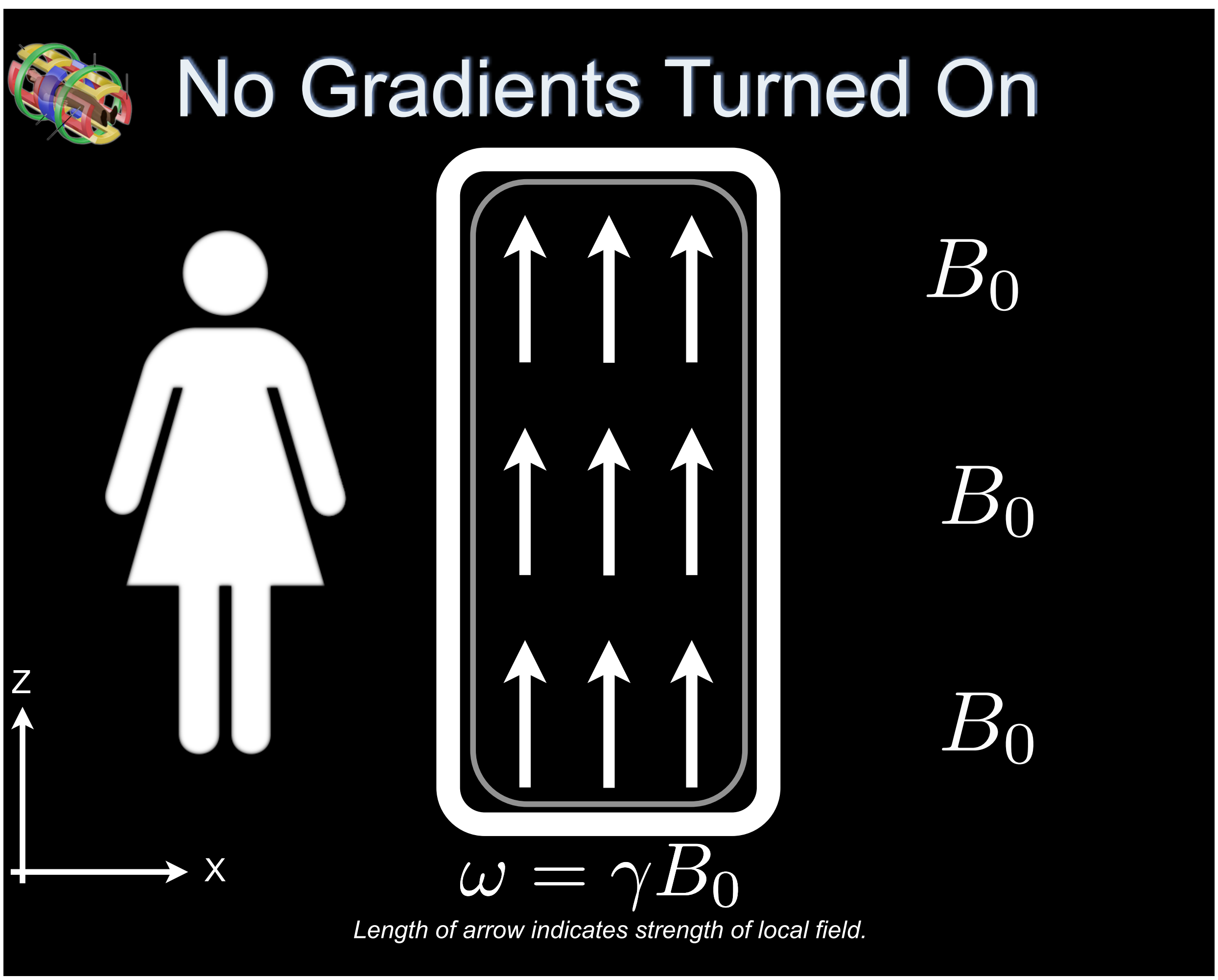
- Primary function
  - Encode spatial information
    - Slice selection
    - Phase encoding
    - Frequency encoding
- Secondary functions
  - Sensitize/de-sensitize images to motion
  - Minimize artifacts (crushers & spoilers)
  - Magnetization re-phasing in slice selection
  - Magnetization de-phasing during readout

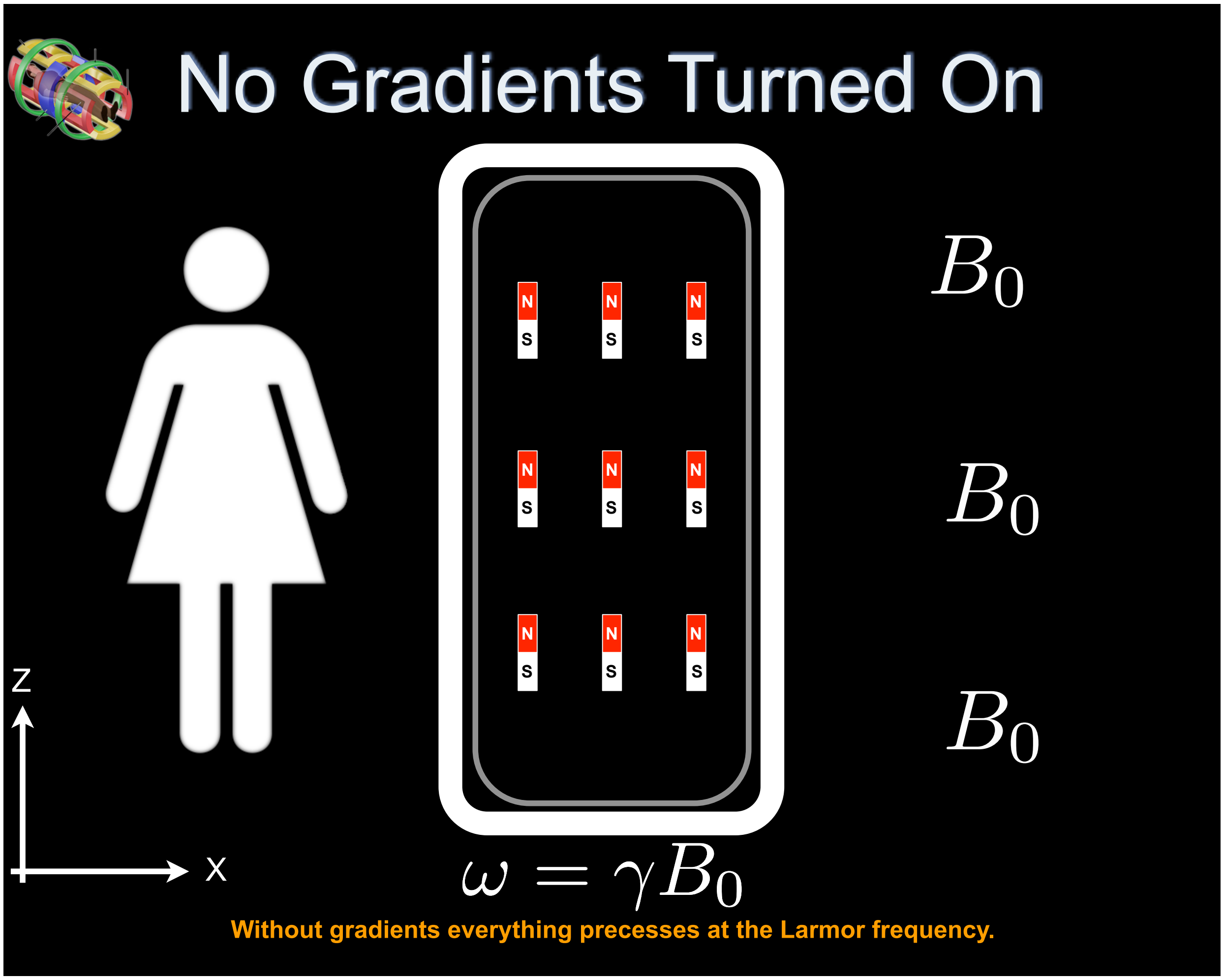
Gradients

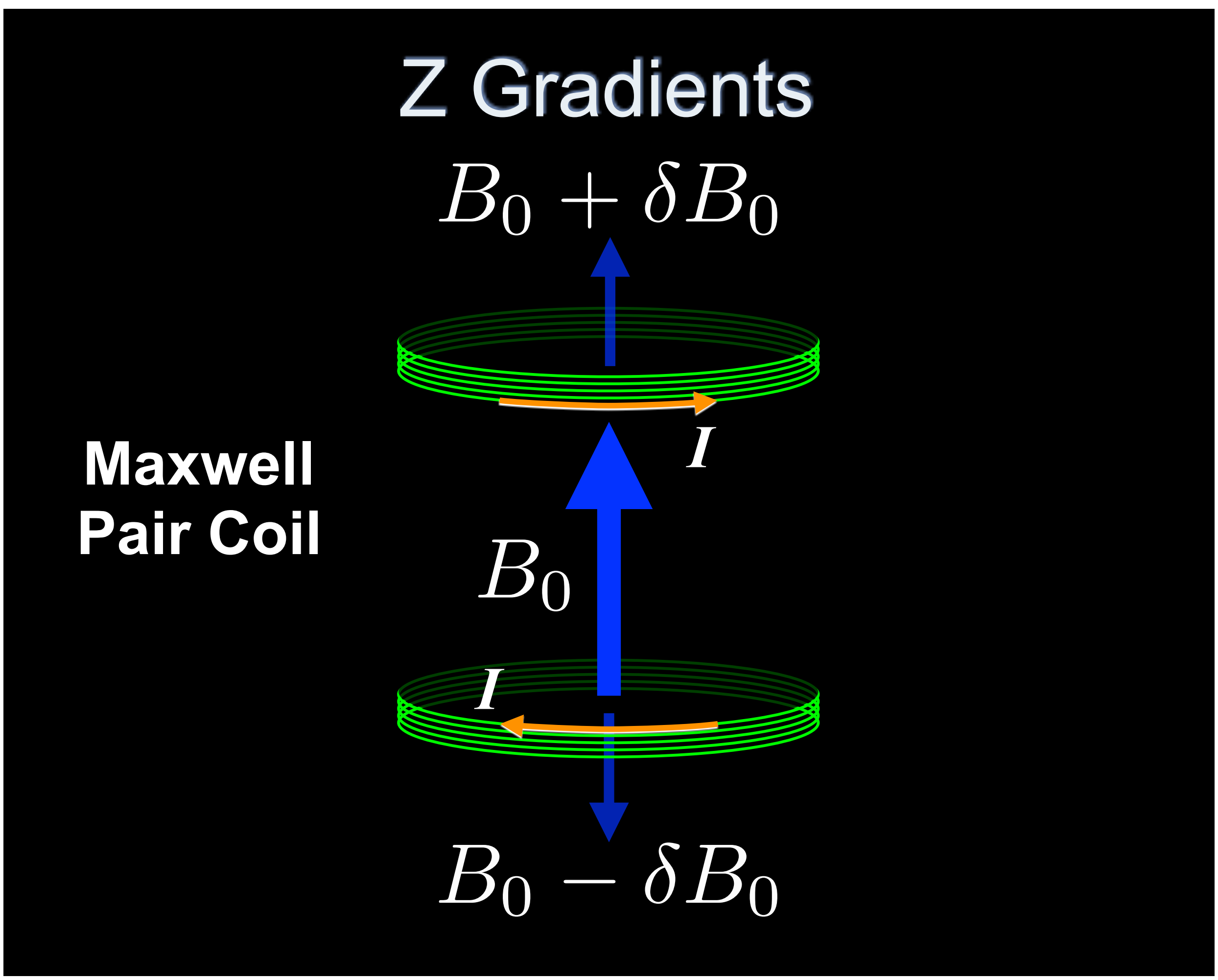
- Gradients are a:
  - Small
    - <5G/cm (±0.0075T @ edge of 30cm FOV)
  - Spatially varying
    - Linear gradients
    - Adds to B_0 only in Z-direction
  - Time varying
    - Slewrate Max. ~150-200mT/m/ms
    - Typically on for a few milliseconds.
  - Magnetic field
    - Adds/Subtracts to the B_0 field
  - Parallel to B_0
- Gradients are NOT:
  - Fields perpendicular to B_0

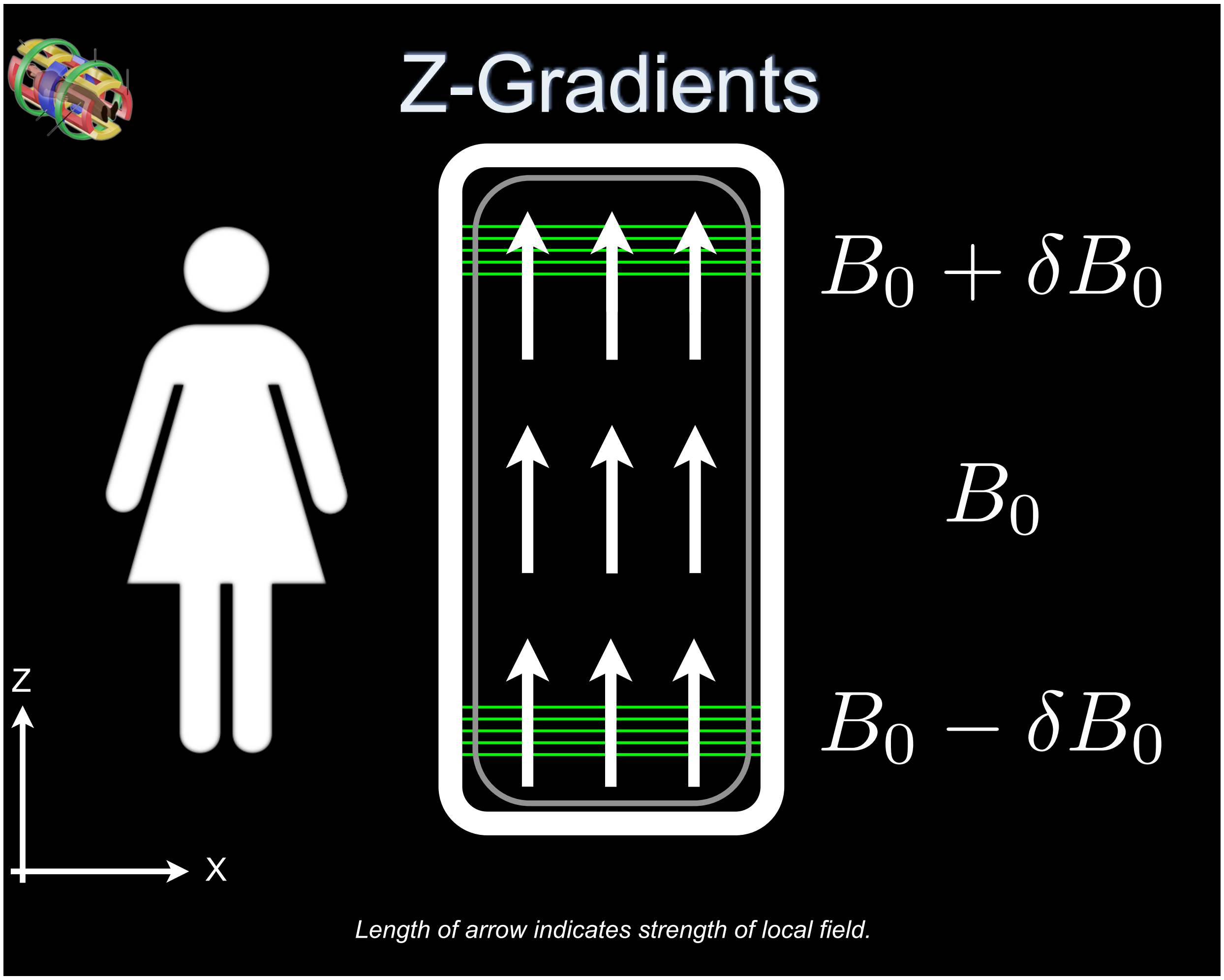
Magnetic field ***gradients*** add linear variations to the B_0 field.

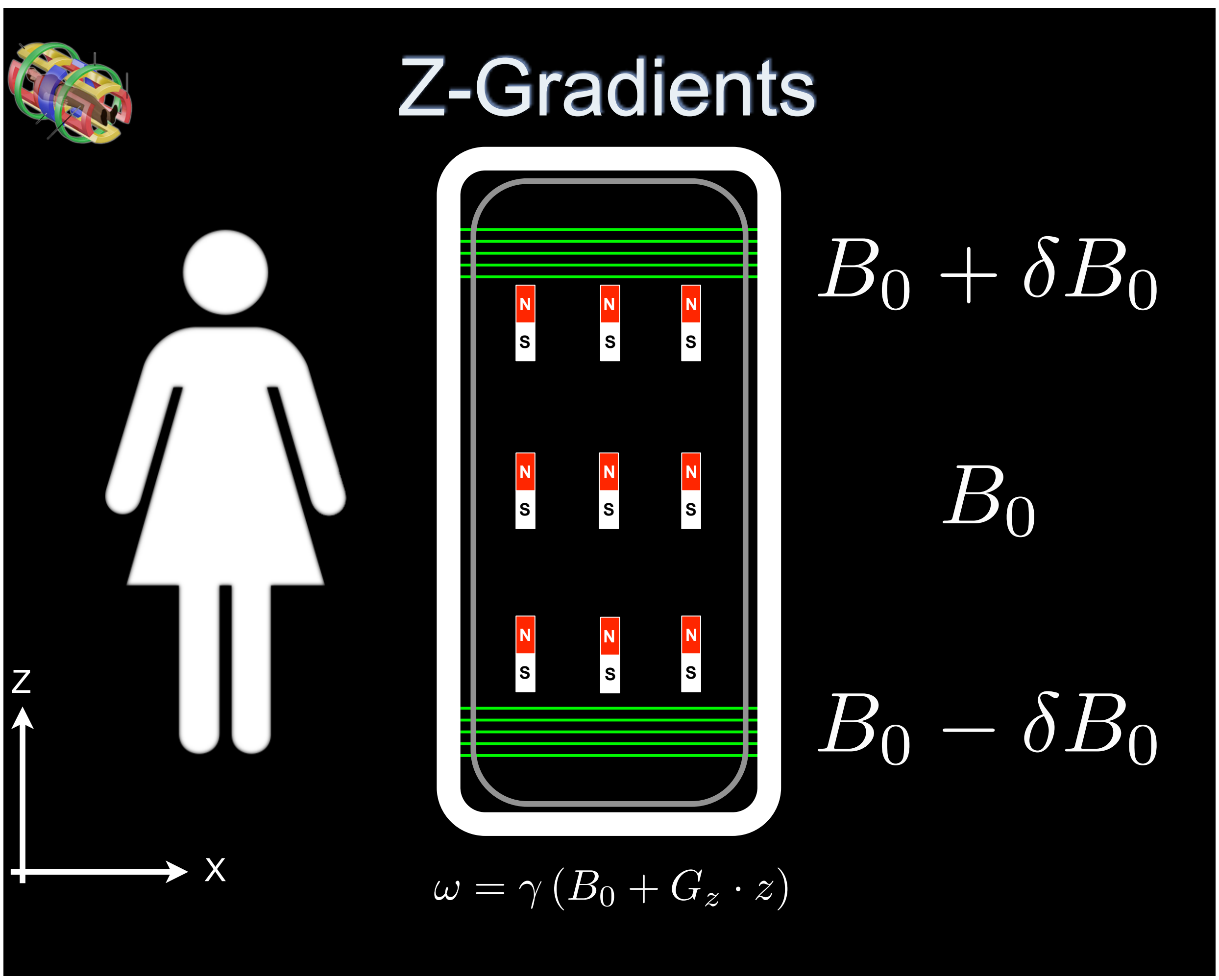

No Gradients Turned On
$+z$
Isocenter
$-z$
B_0
B_0
B_0
z
x
$\omega = \gamma B_0$

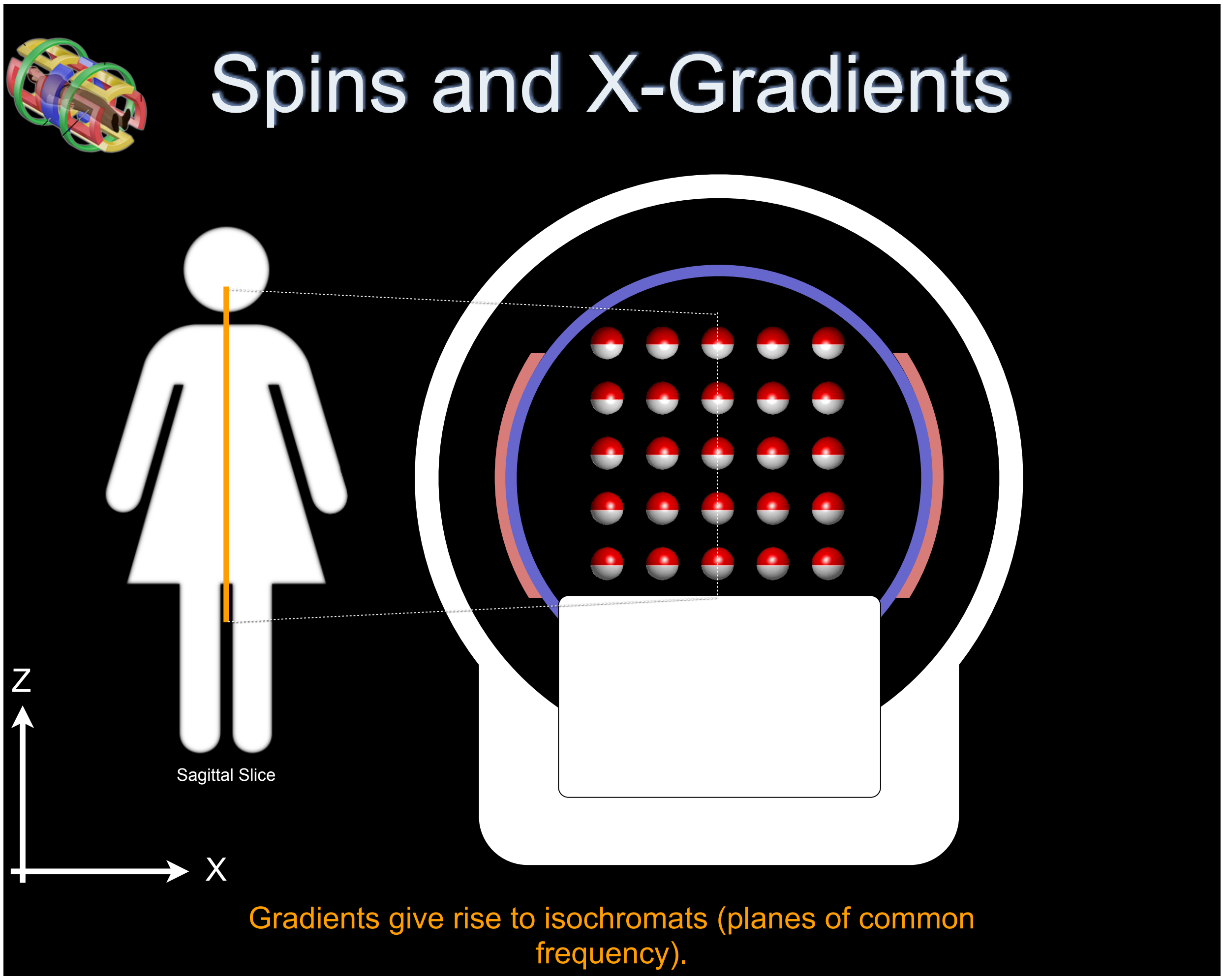

No Gradients Turned On
B_0
B_0
B_0
z
x
$\omega = \gamma B_0$
Length of arrow indicates strength of local field.

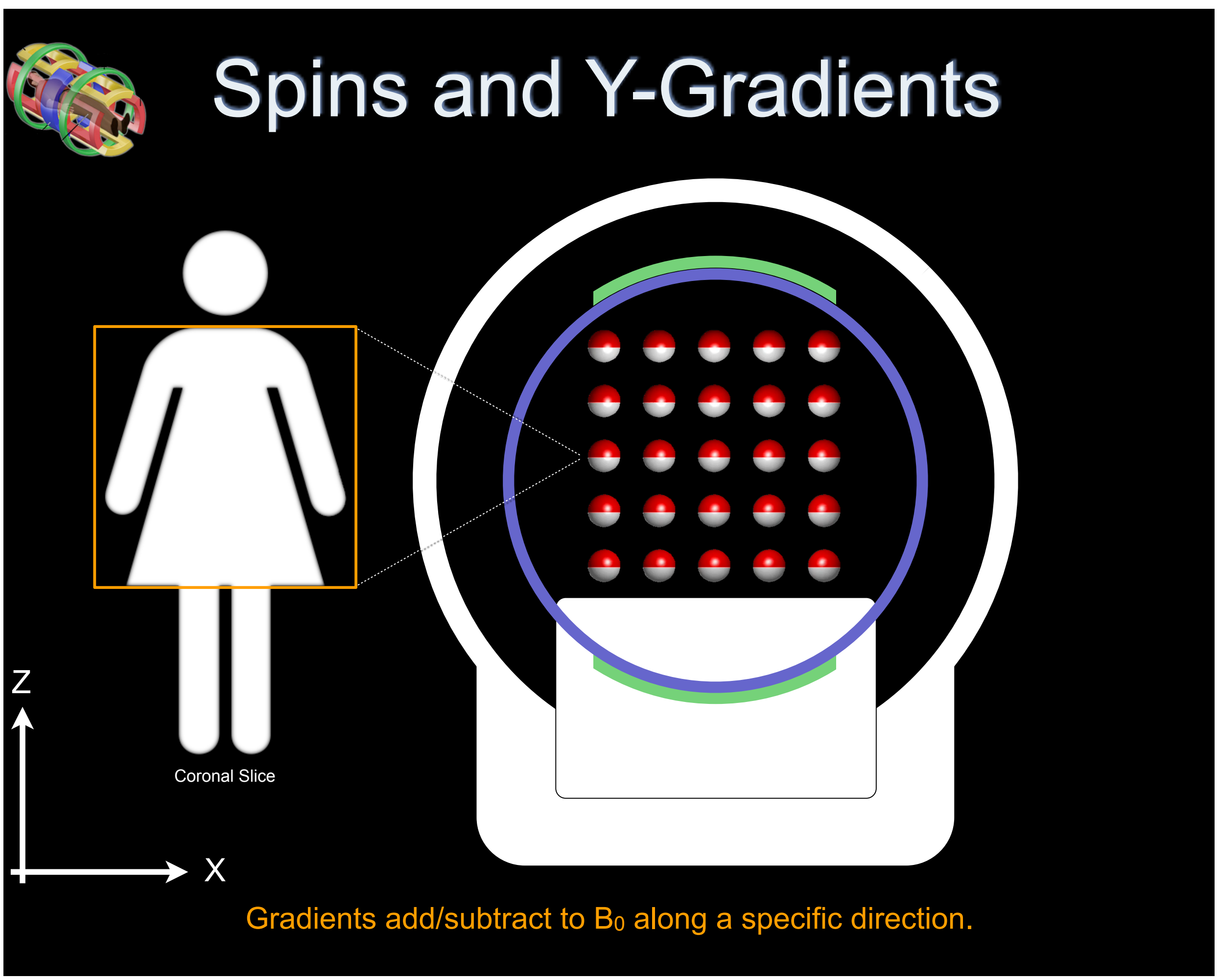

No Gradients Turned On
N
S
B_0
B_0
B_0
Z
X
$\omega = \gamma B_0$
Without gradients everything precesses at the Larmor frequency.

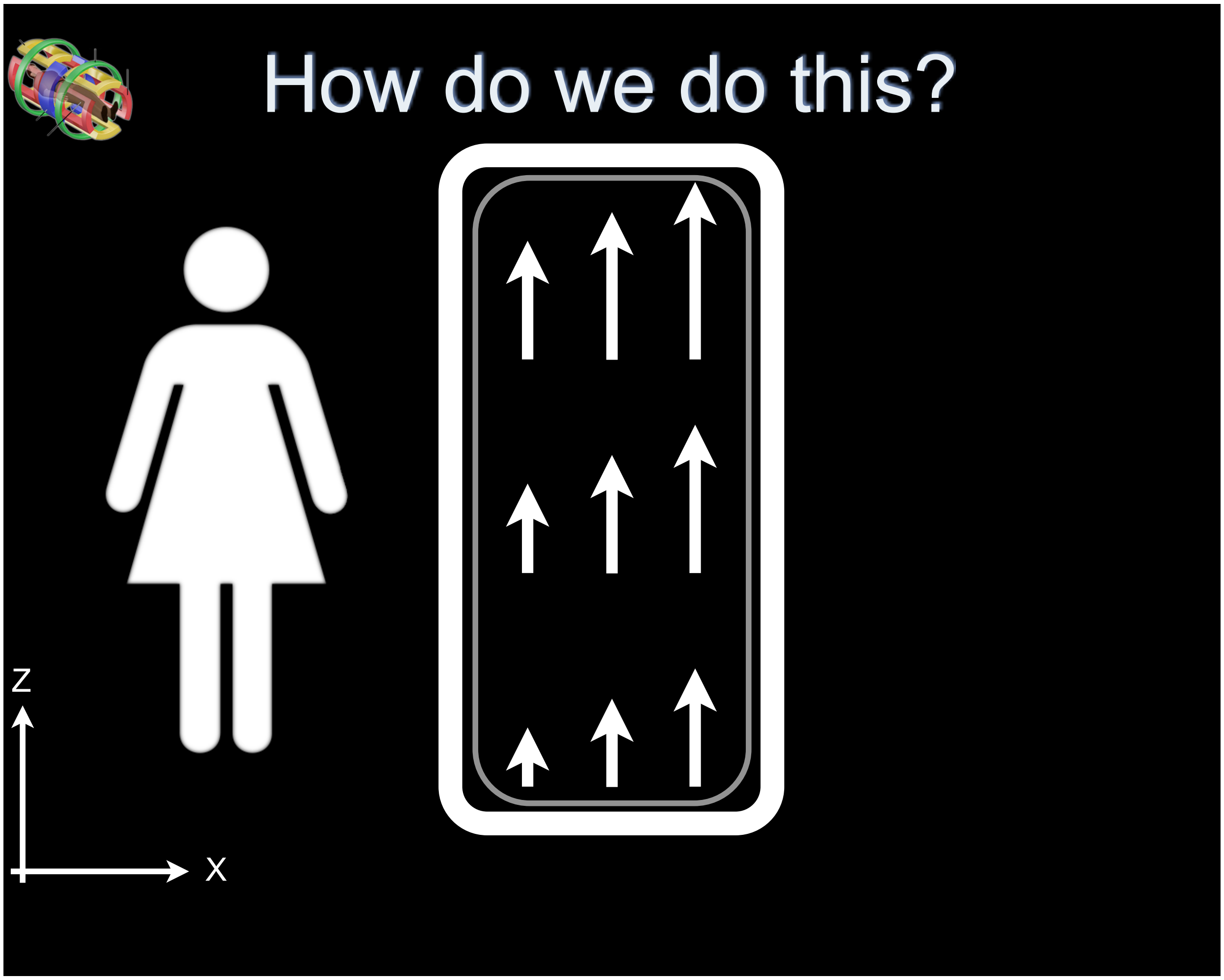

Z Gradients
$B_0 + \delta B_0$
Maxwell Pair Coil
I
B_0
I
$B_0 - \delta B_0$

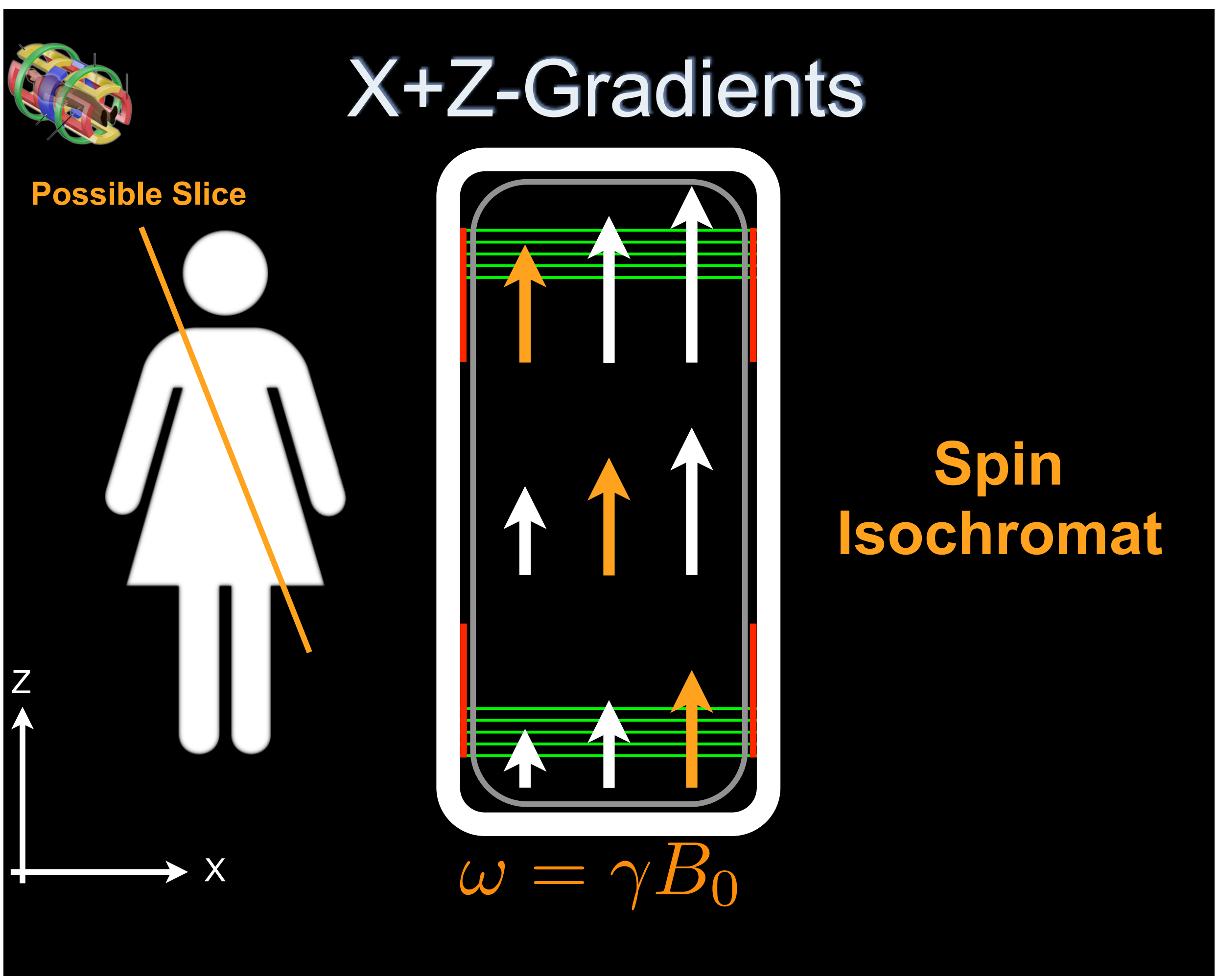

Z-Gradients
$B_0 + \delta B_0$
B_0
$B_0 - \delta B_0$
Z
X
Length of arrow indicates strength of local field.


Z-Gradients
$B_0 + \delta B_0$
N
S
B_0
$B_0 - \delta B_0$
Z
X
$\omega = \gamma\,(B_0 + G_z \cdot z)$

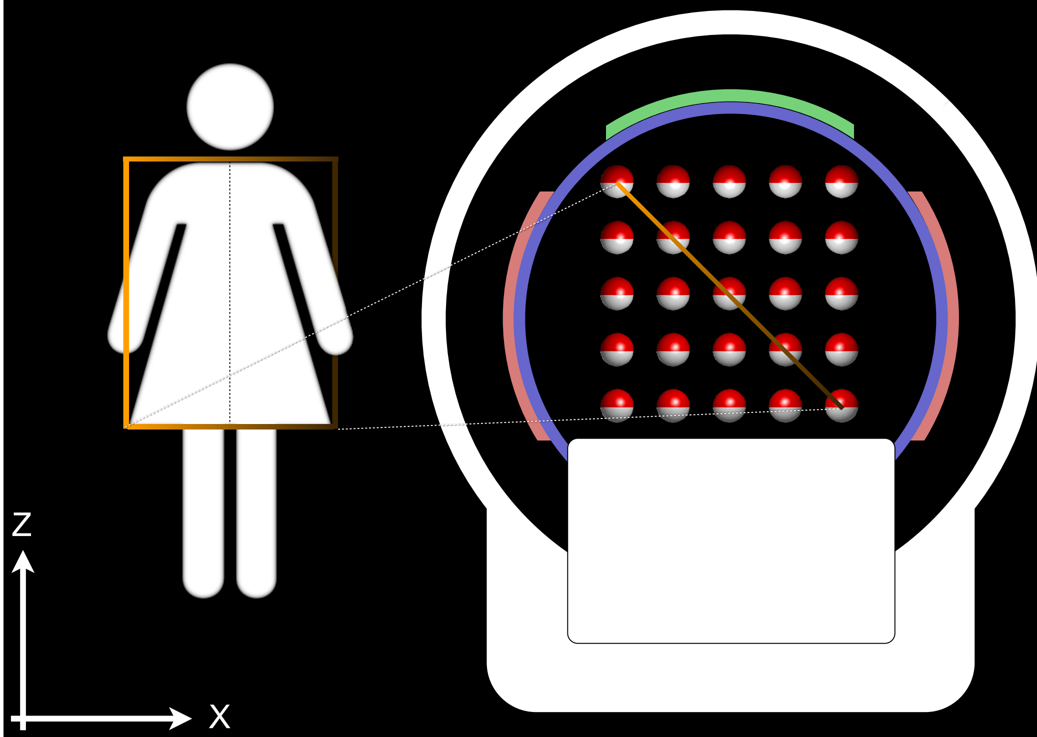

Spins and X-Gradients
Sagittal Slice
Z
X
Gradients give rise to isochromats (planes of common frequency).


Spins and Y-Gradients
Coronal Slice
Z
X
Gradients add/subtract to B0 along a specific direction.


How do we do this?
Z
X


X+Z-Gradients
Possible Slice
Spin
Isochromat
Z
X
$\omega = \gamma B_0$

Spins and X- & Y-Gradients



Simultaneous gradients can create an arbitrary isochromat plane.

Quiz: Gradients - True or False?

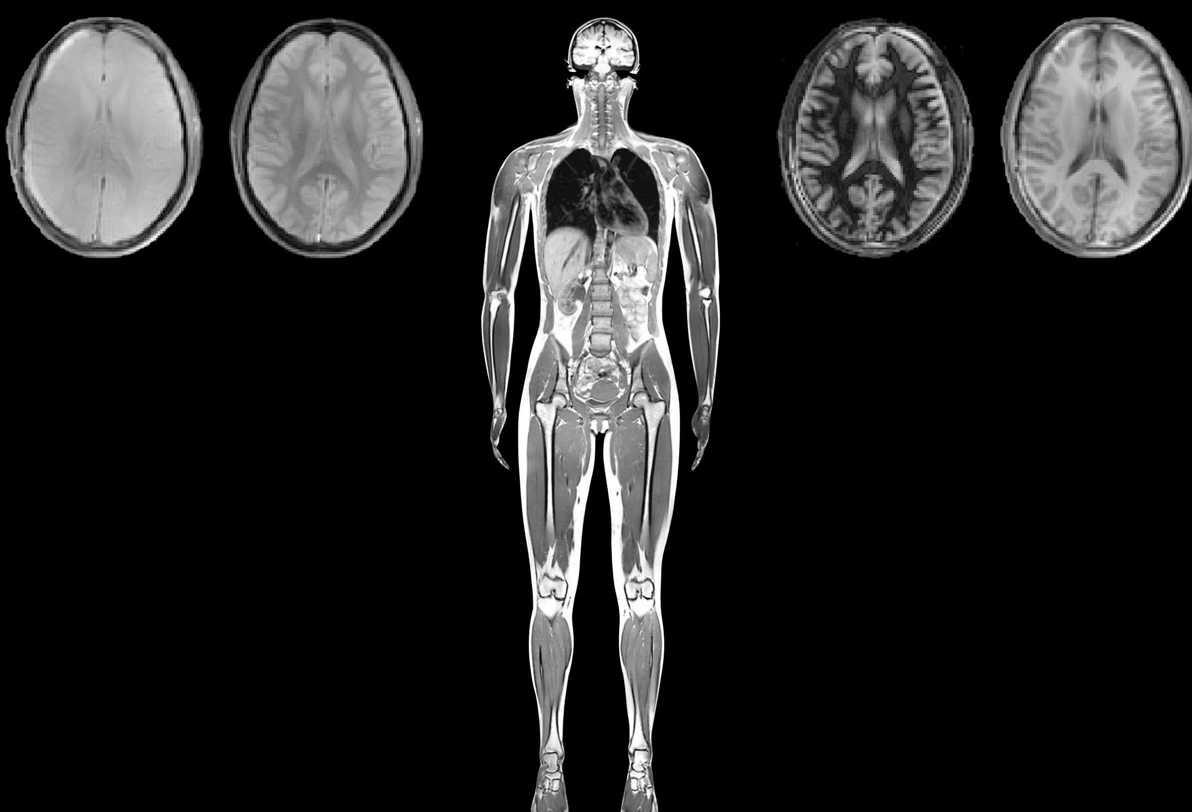
1. Gradients are primarily used to make the B_0-field more homogeneous.

2. Gradients are essential to spatial encoding.

3. X, Y, and Z gradients can not be applied simultaneously.

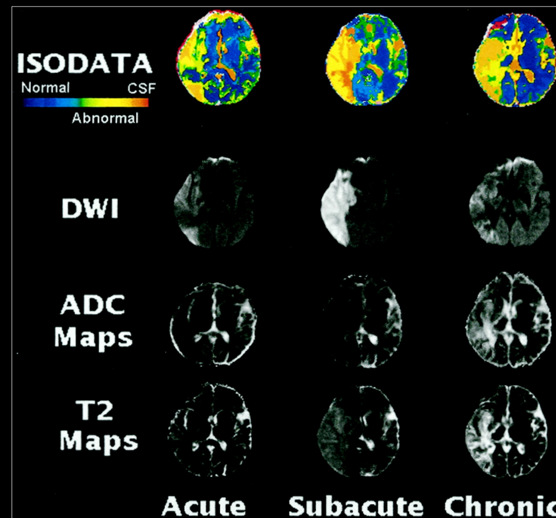
MRI Advantages

Soft Tissue Contrast



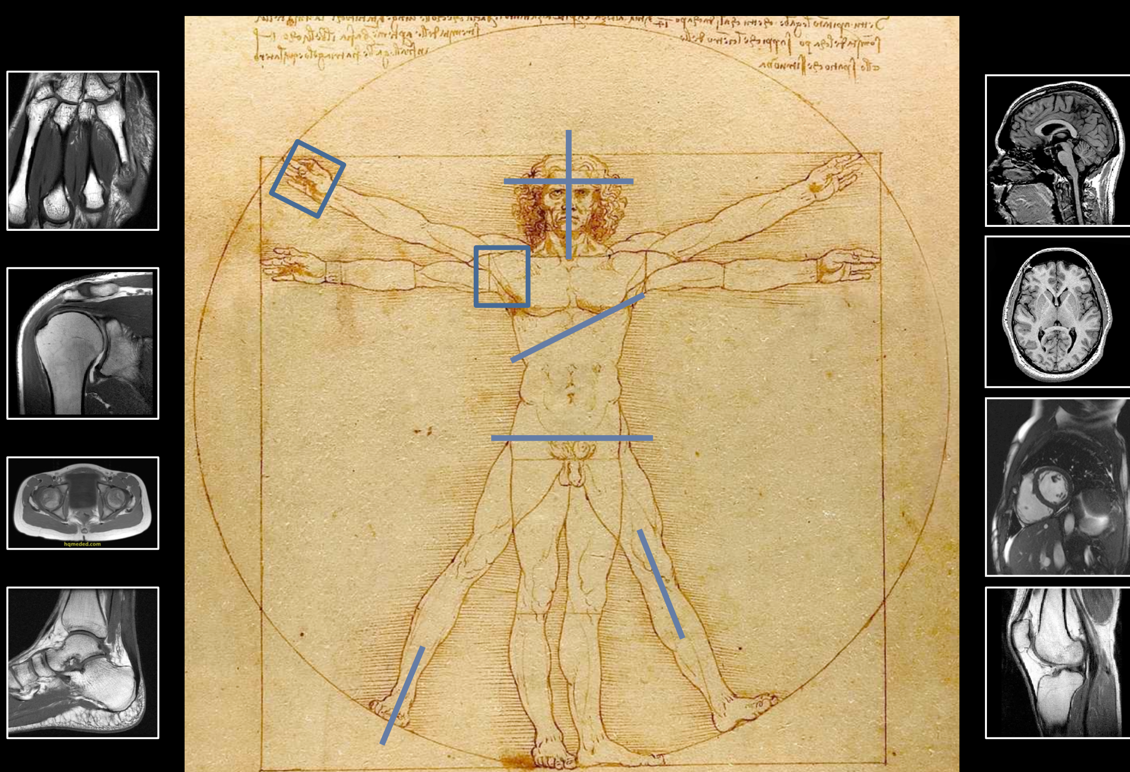
Tissue Characterization

- **Routine**
  - T_1, T_2, T_2^*, proton weighted
  - Perfusion
  - Diffusion
  - Contrast enhancement
    - Tumor evaluation
- **Advanced**
  - T1- and T2-mapping
  - Fat/Water & Iron quantification
  - Spectroscopy (molecular)
  - Susceptibility weighted imaging (SWI) for blood products and calcium
  - Non-contrast angiography



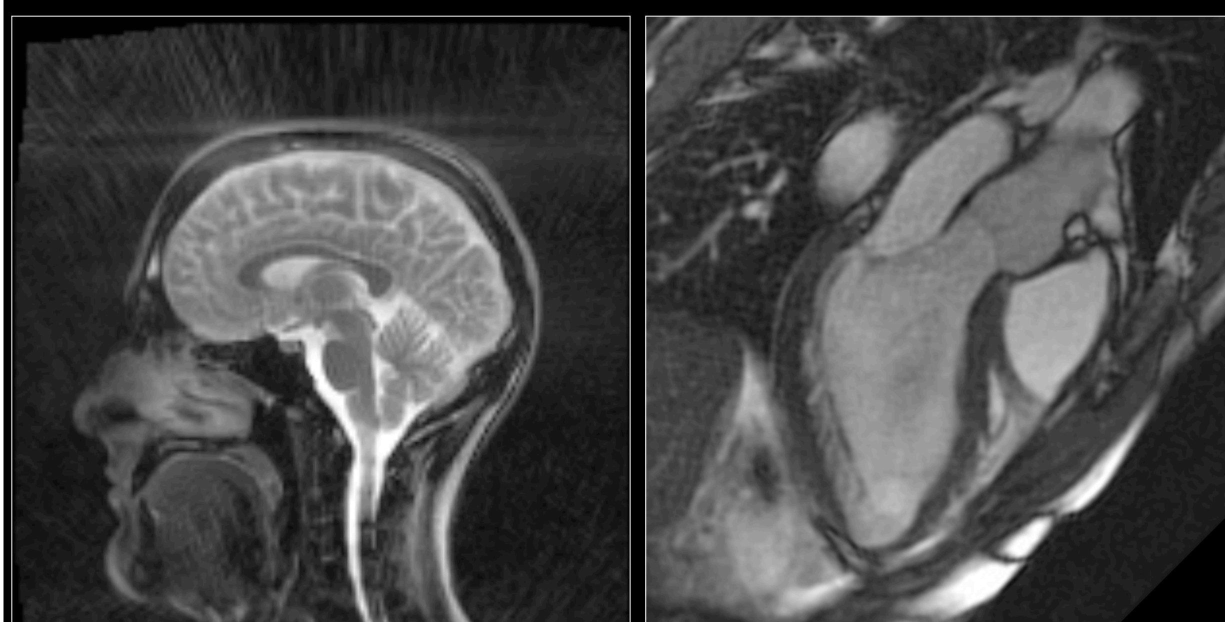
Demonstration of the multiparametric ISODATA segmentation methodology and corresponding DWI (b=1000 s/mm2), ADC map, and T2 map at different times after stroke. *Jacobs M A et al. Stroke. 2001;32:950-957*

Arbitrary Imaging Planes



No Ionizing Radiation

Image Physiologic Motion



MRI Disadvantages

MRI - Disadvantages

- **Safety**
  - Main Field (B_0)
  - Radiofrequency Field (B_1)
  - Gradients (G_x, G_y, and G_z)
- **Slow**
- **Expensive**
- **Technically challenging**

Patient Screening Forms

MAGNETIC RESONANCE (MR) PROCEDURE SCREENING FORM FOR PATIENTS

Date _____/_____/_____ Patient Number ____________________

Name ________________________________ Age ______ Height ______ Weight ______
Last name First name Middle Initial

Date of Birth _____/_____/_____ Male ❒ Female ❒ Body Part to be Examined ____________________
month day year

Address ________________________________ Telephone (home) (_____) _____-_______

City ________________________________ Telephone (work) (_____) _____-_______

State ____________________ Zip Code __________

Reason for MRI and/or Symptoms ____

Referring Physician ____________________________ Telephone (_____) _____-__________

1. Have you had prior surgery or an operation (e.g., arthroscopy, endoscopy, etc.) of any kind? ❒ No ❒ Yes
   If yes, please indicate the date and type of surgery:
   Date _____/_____/_____ Type of surgery ________________________________
   Date _____/_____/_____ Type of surgery ________________________________
2. Have you had a prior diagnostic imaging study or examination (MRI, CT, Ultrasound, X-ray, etc.)? ❒No ❒ Yes
   If yes, please list:

	Body part	Date	Facility
MRI	____________	_____/_____/_____	____________
CT/CAT Scan	____________	_____/_____/_____	____________
X-Ray	____________	_____/_____/_____	____________
Ultrasound	____________	_____/_____/_____	____________
Nuclear Medicine	____________	_____/_____/_____	____________
Other__________	____________	_____/_____/_____	____________

3. Have you experienced any problem related to a previous MRI examination or MR procedure? ❒ No ❒ Yes
   If yes, please describe: ________________________________
4. Have you had an injury to the eye involving a metallic object or fragment (e.g., metallic slivers, shavings, foreign body, etc.)? ❒ No ❒ Yes
   If yes, please describe: ________________________________
5. Have you ever been injured by a metallic object or foreign body (e.g., BB, bullet, shrapnel, etc.)? ❒ No ❒ Yes
   If yes, please describe: ________________________________
6. Are you currently taking or have you recently taken any medication or drug? ❒ No ❒ Yes
   If yes, please list:________________________________
7. Are you allergic to any medication? ❒ No ❒ Yes
   If yes, please list:________________________________
8. Do you have a history of asthma, allergic reaction, respiratory disease, or reaction to a contrast medium or dye used for an MRI, CT, or X-ray examination? ❒ No ❒ Yes
9. Do you have anemia or any disease(s) that affects your blood, a history of renal (kidney) disease, renal (kidney) failure, renal (kidney) transplant, high blood pressure (hypertension), liver (hepatic) disease or seizures? No ❒ Yes
   If yes, please describe: ________________________________

For female patients:

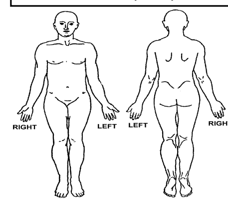
10. Date of last menstrual period:_____/_____/_____ Post menopausal? ❒ No ❒ Yes
11. Are you pregnant or experiencing a late menstrual period? ❒ No ❒ Yes
12. Are you taking oral contraceptives or receiving hormonal treatment? ❒ No ❒ Yes
13. Are you taking any type of fertility medication or having fertility treatments? ❒ No ❒ Yes
    If yes, please describe: ________________________________
14. Are you currently breastfeeding? ❒ No ❒ Yes

⚠ **WARNING:** Certain implants, devices, or objects may be hazardous to you and/or may interfere with the MR procedure (i.e., MRI, MR angiography, functional MRI, MR spectroscopy). Do not enter the MR system room or MR environment if you have any question or concern regarding an implant, device, or object. Consult the MRI Technologist or Radiologist BEFORE entering the MR system room. The MR system magnet is ALWAYS on.

Please indicate if you have any of the following:

❒ Yes ❒ No Aneurysm clip(s)
❒ Yes ❒ No Cardiac pacemaker
❒ Yes ❒ No Implanted cardioverter defibrillator (ICD)
❒ Yes ❒ No Electronic implant or device
❒ Yes ❒ No Magnetically-activated implant or device
❒ Yes ❒ No Neurostimulation system
❒ Yes ❒ No Spinal cord stimulator
❒ Yes ❒ No Internal electrodes or wires
❒ Yes ❒ No Bone growth/bone fusion stimulator
❒ Yes ❒ No Cochlear, otologic, or other ear implant
❒ Yes ❒ No Insulin or other infusion pump
❒ Yes ❒ No Implanted drug infusion device
❒ Yes ❒ No Any type of prosthesis (eye, penile, etc.)
❒ Yes ❒ No Heart valve prosthesis
❒ Yes ❒ No Eyelid spring or wire
❒ Yes ❒ No Artificial or prosthetic limb
❒ Yes ❒ No Metallic stent, filter, or coil
❒ Yes ❒ No Shunt (spinal or intraventricular)
❒ Yes ❒ No Vascular access port and/or catheter
❒ Yes ❒ No Radiation seeds or implants
❒ Yes ❒ No Swan-Ganz or thermodilution catheter
❒ Yes ❒ No Medication patch (Nicotine, Nitroglycerine)
❒ Yes ❒ No Any metallic fragment or foreign body
❒ Yes ❒ No Wire mesh implant
❒ Yes ❒ No Tissue expander (e.g., breast)
❒ Yes ❒ No Surgical staples, clips, or metallic sutures
❒ Yes ❒ No Joint replacement (hip, knee, etc.)
❒ Yes ❒ No Bone/joint pin, screw, nail, wire, plate, etc.
❒ Yes ❒ No IUD, diaphragm, or pessary
❒ Yes ❒ No Dentures or partial plates
❒ Yes ❒ No Tattoo or permanent makeup
❒ Yes ❒ No Body piercing jewelry
❒ Yes ❒ No Hearing aid
(Remove before entering MR system room)
❒ Yes ❒ No Other implant ____________________
❒ Yes ❒ No Breathing problem or motion disorder
❒ Yes ❒ No Claustrophobia

Please mark on the figure(s) below the location of any implant or metal inside of or on your body.



⚠ **IMPORTANT INSTRUCTIONS**

Before entering the MR environment or MR system room, you must remove all metallic objects including hearing aids, dentures, partial plates, keys, beeper, cell phone, eyeglasses, hair pins, barrettes, jewelry, body piercing jewelry, watch, safety pins, paperclips, money clip, credit cards, bank cards, magnetic strip cards, coins, pens, pocket knife, nail clipper, tools, clothing with metal fasteners, & clothing with metallic threads.

Please consult the MRI Technologist or Radiologist if you have any question or concern BEFORE you enter the MR system room.

NOTE: You may be advised or required to wear earplugs or other hearing protection during the MR procedure to prevent possible problems or hazards related to acoustic noise.

I attest that the above information is correct to the best of my knowledge. I read and understand the contents of this form and had the opportunity to ask questions regarding the information on this form and regarding the MR procedure that I am about to undergo.

Signature of Person Completing Form: ____________________________ Date _____/_____/_____
Signature

Form Completed By: ❒ Patient ❒ Relative ❒ Nurse ____________________ ____________________
Print name Relationship to patient

Form Information Reviewed By: ____________________ ____________________
Print name Signature

❒ MRI Technologist ❒ Nurse ❒ Radiologist ❒ Other______________________

Patient *and* personnel screening before an MRI exam is critical.

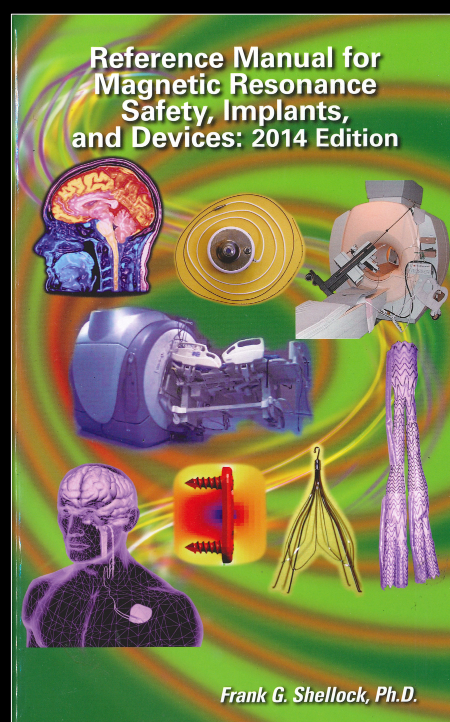
MRI - Contraindication?

Box 2 Example of a check list with potential contraindications to an MRI examination

If any of the following is checked, evaluation of the individual risk has to be performed before the MRI examination

- Aneurysm clip(s)
- Any metallic fragment or foreign body
- Coronary and peripheral artery stents
- Aortic stent graft
- Prosthetic heart valves and annuloplasty rings
- Cardiac occluder devices
- Vena cava filters and embolisation coils
- Haemodynamic monitoring and temporary pacing devices, eg, Swan–Ganz catheter
- Haemodynamic support devices
- Cardiac pacemaker
- Implanted cardioverter-defibrillator (ICD)
- Retained transvenous pacemaker and defibrillator leads
- Electronic implant or device, eg, insulin pump or other infusion pump
- Permanent contraceptive devices, diaphragm, or pessary
- Cochlear, otologic, or other ear implant
- Neurostimulation system
- Shunt (spinal or intraventricular)
- Vascular access port and/or catheter
- Tissue expander (eg, breast)
- Joint replacement (eg, hip, knee, etc)
- Any type of prosthesis (eg, eye, penile, etc)
- Tattoo or permanent makeup
- Known claustrophobia
- Body piercing jewellery
- Hearing aid
- Renal insufficiency
- Known/possible pregnancy or breast feeding

Modified from: Shellock FG, Crues JV. MR procedures: biologic effects, safety, and patient care. *Radiology* 2004;**232**:635–52.



Contraindications to Magnetic Resonance Imaging. T Dill. *Heart* 2008;94;943-948.

MRI Safety Designations

MR Safe: "An item that poses no known hazards in all MR environments." (e.g. a plastic Petri dish)

MR Conditional: "An item that has been demonstrated to pose no known hazards in a specified MR environment with specified conditions of use. Field conditions that define the specified MR environment include field strength, spatial gradient, dB/dt (time rate of change of the magnetic field), radio frequency fields, and specific absorption rate. Additional conditions, including specific configurations of the item, may be required." (e.g. a Patient Monitor)

MR Unsafe: "An item that is known to pose hazards in all MR environments." (e.g. Floor Buffer)

"MRI Compatible" is not an FDA term.

B_0 Safety – Room Safety

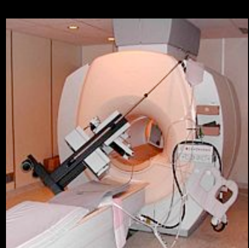
$2.9 Million Settlement Closes Colombini MRI Death Case

5 Replies

This week the settlement documents were released — closing the chapter on the lawsuit that arose from the seminal event in MRI safety, the 2001 oxygen tank fatality of then-six-year-old Michael Colombini.

Not MRI Compatible

MRI Compatible



B_0 is VERY strong and ALWAYS on.

B_0 Safety – Implanted Devices

B_0 exerts a force or torque on implanted ferromagnetic devices.

RF (B_1) Safety - SAR Limits

- **RF pulses deposit energy in the body.**
- **Specific Absorption Rate [W/kg]**
  – Rate of energy absorption during exposure to RF
- High-field (>1.5T) imaging with high flip angles (>45-90°) can be challenging. $\mathrm{SAR} \propto \omega_0^2 B_1^2 \propto B_0^2 \alpha^2$

Limit	Whole-Body Average
Normal (all patients)	2 W/kg (0.5°C)
First level (supervised)	4 W/kg (1°C)

The scanner (FDA!) limits SAR, which in turn limits the max. flip angle.

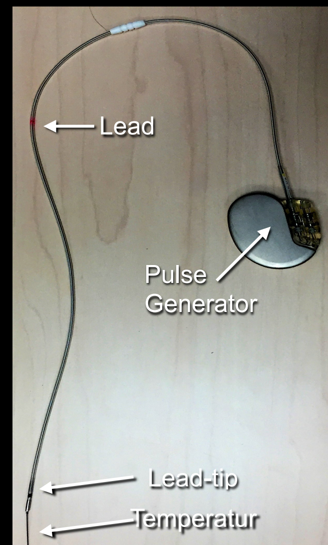
Bottomley PA. Turning up the heat on MRI. J Am Coll Radiol 2008;5(7):853-855.

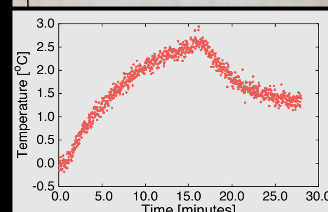
RF (B_1) Safety - Burns & Heating

- **Tissue burns**
- **RF induced heating of implanted devices**

Eising EG et al. J. Clin. Imaging 2010;34(4):293-297.

Solution: Avoid skin-to-skin loops; avoid arms directly touching scanner bore.

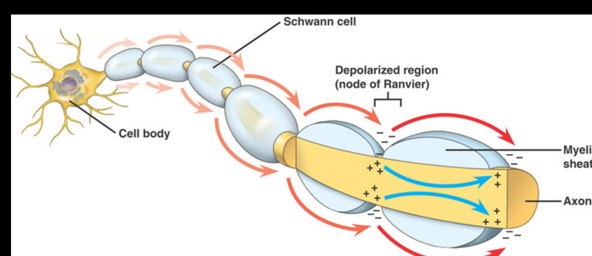


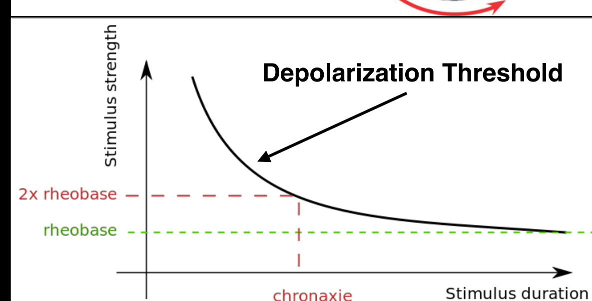


RF energy contributes to patient and device heating (or burns!).

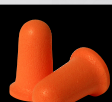
Gradient Safety

- **Noise**
- **Peripheral nerve stimulation (PNS)**





Solution: De-rate gradient slew rates, but this increases scan time.



Solution: Ear plugs Head phones

Time-varying gradients induce mechanical vibrations and PNS.

MRI is Expensive

- **Purchase**
  - **$1-3 million**
- **Site**
  - **$0.5-1.0 million**
- **Maintain (Service Contract)**
  - **$100,000 per year**
- **Operate**
  - **$500-1000/hour**

Technically Challenging

- **Numerous scan parameters**
  - Dependent upon clinical question
  - Spin Echo vs Gradient Echo
  - TE, TR, TI, Flip Angle, Bandwidth
- **Physiologic Monitoring**
  - ECG
  - Respiration
  - Blood Pressure
  - General anesthesia/Sedation
- **Breath holding**
- **Contrast agents**
- **Coil Selection**
- **Anatomic Localization**

Quiz: MRI Safety - True or False?

1. Gradients heat the patient and RF pulses causes peripheral nerve stimulation (PNS).
2. RF pulses can dislodge and torque implanted devices.
3. SAR limits constrain scan parameters.
4. Increasing the flip angle and decreasing the TR helps reduce patient heating.
5. Cryogen gases are oxygen rich and MRI contrast agents are 100% safe.

Summary

- NMR Active Nuclei
  - e.g. ^1H in H_20
- Magnetic Field (B_0): Polarizer
- RF System (B_1): Exciter
- Coil: Receiver
- Gradients (G_X, G_Y, G_Z): Spatial Encoding

Thanks

Kyung Sung, PhD

ksung@mednet.ucla.edu

http://mrrl.ucla.edu/sunglab/

Images/Slides Courtesy of
Daniel Ennis, Ph.D.

On-Line Resources

- https://www.healthcare.siemens.com/magnetic-resonance-imaging/magnetom-world/publications/mr-basics
  “Magnets, Spins, and Resonances: An introduction to the basics of Magnetic Resonance” and more…
- http://www.magnet.fsu.edu/education/tutorials/magnetacademy
- http://www.mr-tip.com
- http://www.cis.rit.edu/htbooks/mri/
- Many more...