Introduction

M219 - Principles and Applications of MRI

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1/3/2022

Department of Radiological Sciences
David Geffen School of Medicine at UCLA

Introduction

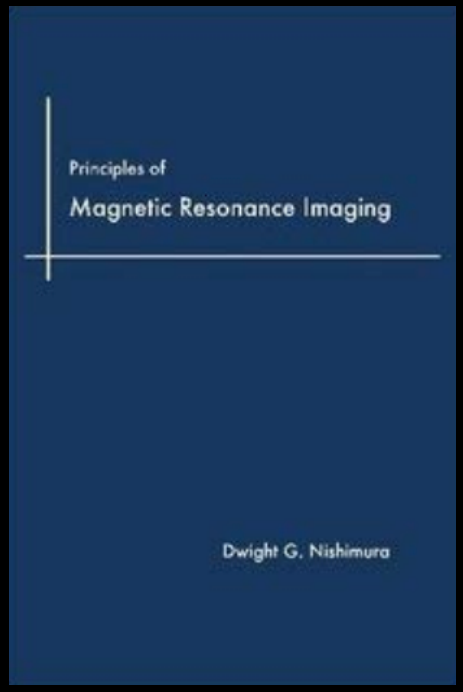
- Your instructor
  - Kyung Sung
- Your TA
  - TBD
- Guest lecturers
  - Drs. Albert Thomas, Ben Ellingson, Holden Wu
- You

Video on Zoom

Course Overview

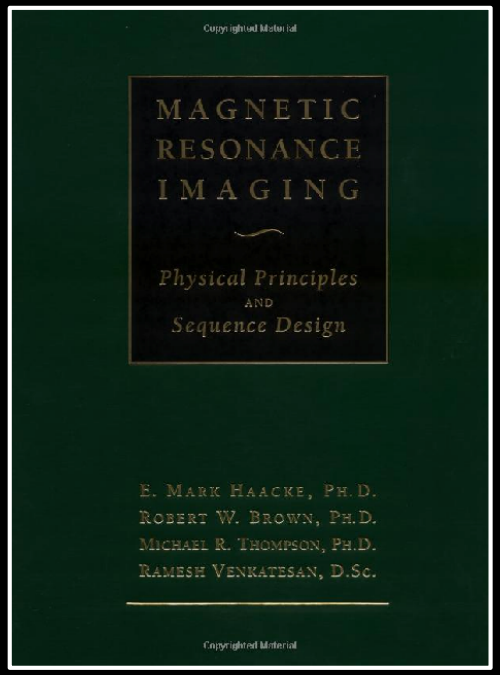
- https://mrrl.ucla.edu/pages/m219
- Assignments
  - 3 homework assignments (20 points each)
  - 1 final exam (30 points)
  - Class participation (10 points)
- Bring questions to class!
  - Slides will be available prior to lecture
- MATLAB
  - Required for homework

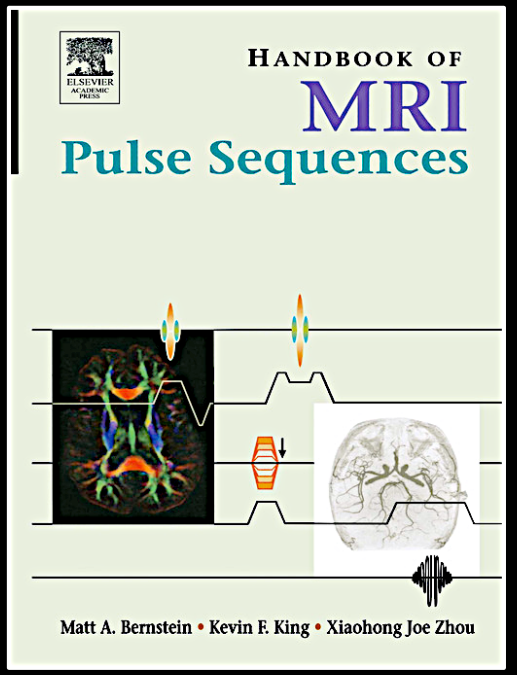
Primary Books

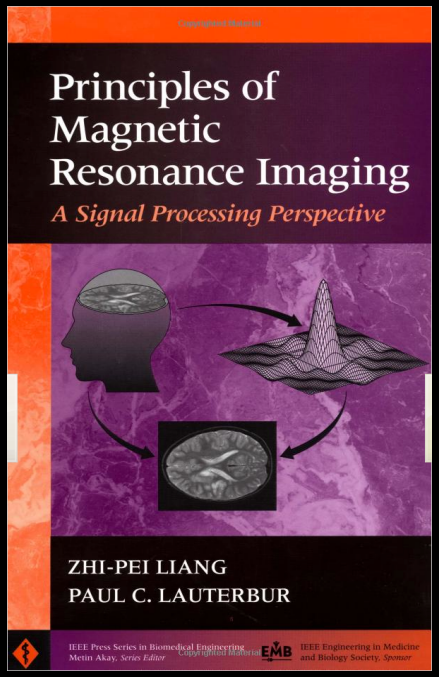


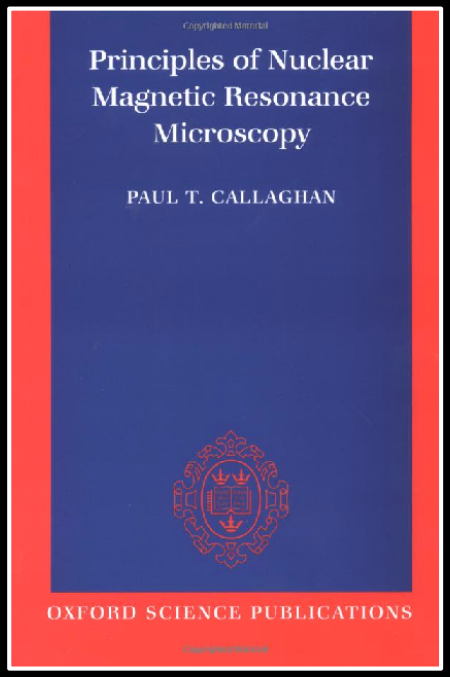
https://ee.stanford.edu/~dwight/

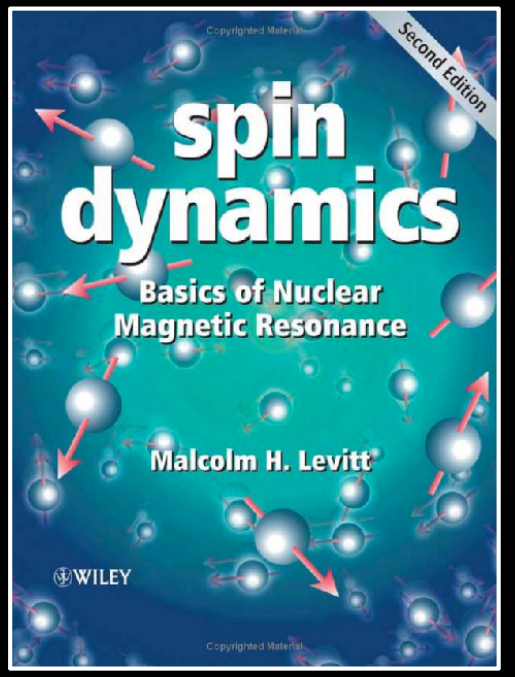
Supplementary Books











Prerequisites

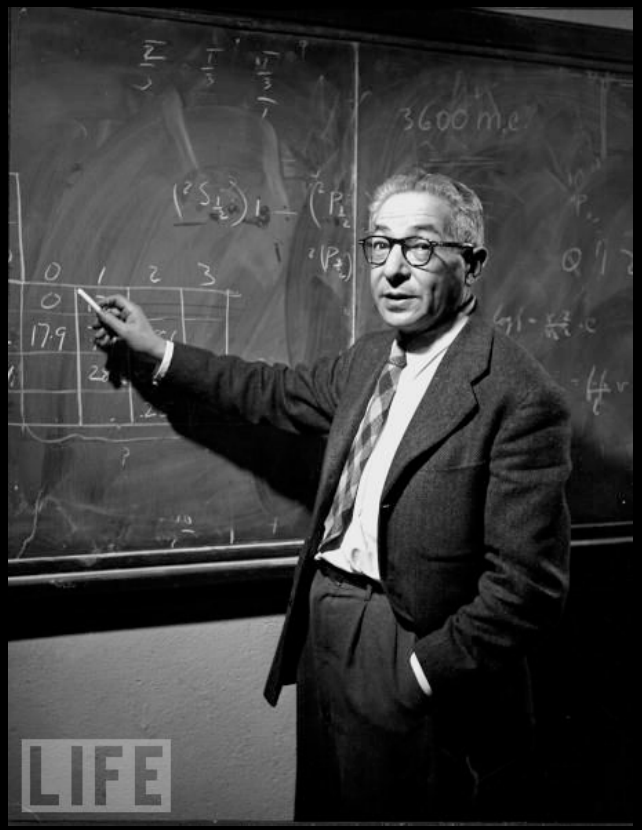
- Vectors and Vector Operations
  - dot product
  - cross product
- Basic Matrix Algebra
  - Determinant
  - Inverse
  - Transpose
  - Matrix Multiplication
  - Eigenvectors

A Brief History of MRI

Detection of the Signal

1944 Nobel Prize in Physics

"for his resonance method for recording the magnetic properties of atomic nuclei"

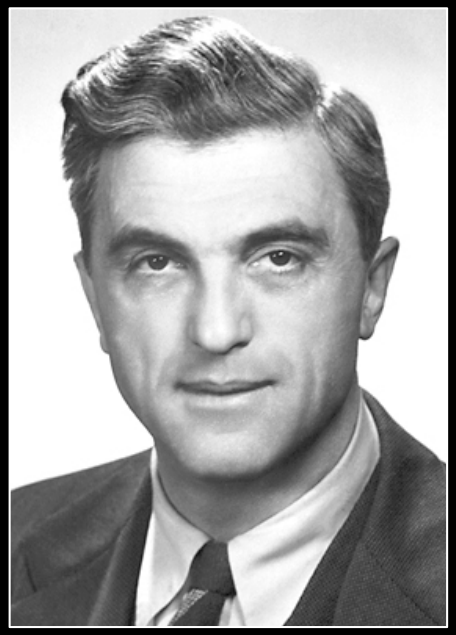


Discovery of NMR

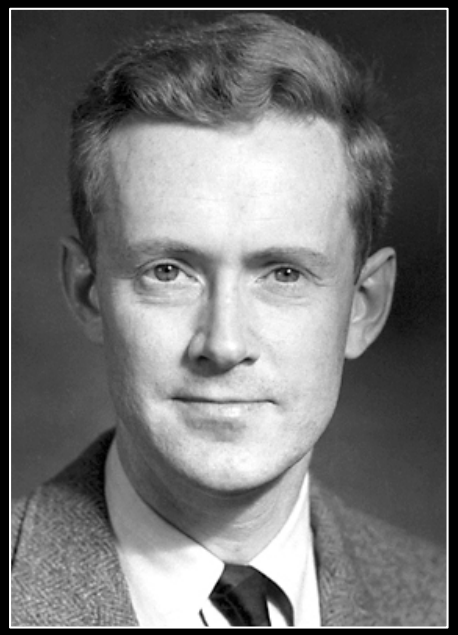
Isidor Isaac Rabi
b. 22 Jul 1898
d. 11 Jan 1988

1952 Nobel Prize in Physics

"for their development of new methods for nuclear magnetic precision measurements and discoveries in connection therewith"



Felix Bloch
b. 23 Oct 1905
d. 10 Sep 1983

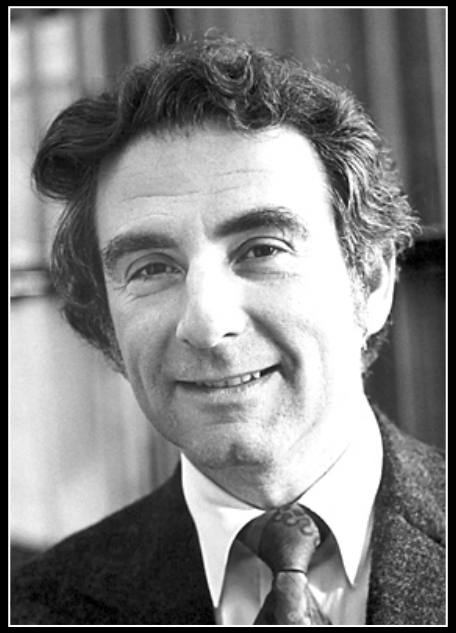


Edward Purcell
b. 30 Sep 1912
d. 07 Mar 1997

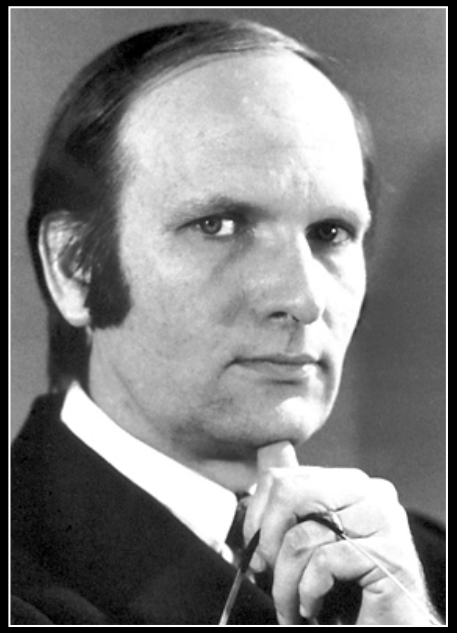
1972 Nobel Prize in Physics

"for their jointly developed theory of superconductivity, usually called the BCS-theory"

John Bardeen
b. 23 May 1908
d. 30 Jan 1991



Leon N. Cooper
b. 28 Feb 1930
d. —



Robert Schrieffer
b. 31 May 1931
d. —

Improved NMR Detection

1991 Nobel Prize in Chemistry

"for his contributions to the development of the methodology of high resolution nuclear magnetic resonance (NMR) spectroscopy"

Richard Ernst
b. 14 Aug 1933
d. –

Magnetic Resonance Spectroscopy

2002 Nobel Prize in Chemistry

"for his development of nuclear magnetic resonance spectroscopy for determining the three-dimensional structure of biological macromolecules in solution."

Kurt Wüthrich
b. 1938.10.04
d. —

Magnetic Resonance Imaging

2003 Nobel Prize in Medicine

"for their discoveries concerning magnetic resonance imaging"

Paul C. Lauterbur
b. 1929.05.06
d. 2007.03.27

Peter Mansfield
b. 1993.10.09
d. –

Interview with Mansfield

- **http://www.nottingham.ac.uk/news/pressreleases/2013/february/the-story-of-mri.aspx**

Tumor Detection by NMR

"Tumor Detection by Nuclear Magnetic Resonance."
– *Science* 171:1151 (March 19, 1971).

Raymond Vahan Damadian
b. 16 Mar 1936
d. –

Tumor Detection by NMR

Damadian, R. (1971). "Tumor detection by nuclear magnetic resonance." *Science* 171(976): 1151-1153.

movements showed a much stronger zigzag course. As trails formed from secretions of Dufour's glands released almost no nest-mate recruitment but attracted isolated or homing ants strongly, we conclude that it functions essentially as a homing signal (*3*).

Field observations of lasting track trails radiating from nests may be understood in terms of such compounded individual homing trails, which are chemically marked by Dufour's gland secretion. Often the workers leave the nest individually on such tracks and after foraging return to them when homing.

As mentioned above, displaced ants recognized near the nest entrance the area of a strange colony. In addition, *Pogonomyrmex badius* are able to distinguish the odor of their own nest material from that of other nests (*4*). Since olfactometer tests show no colony specificity of Dufour's gland secretions, we conclude that near the nest entrance also a colony-specific chemical factor may be important as a homing signal.

Finally, we have to examine the role of visual landmarks in the homing behavior of *Pogonomyrmex*. In some ant species such cues are important in orientation (*5*). Workers of *Cataglyphis bicolor* orient mainly to visual landmarks and switch over to sun orientation only when the former become ineffective (*6*). In this species Wehner and Menzel found no evidence for chemical orientation (*6*). To investigate the role of visual landmarks in *Pogonomyrmex badius* homing behavior we placed several black- and white-striped plates on the walls of the arenas. These patterns were left in place for a week before experimentation. Chemical signals are dominant over the visual landmarks in homing (Fig. 3). Only when the chemical field is disturbed do the landmarks become significant. We conclude that the precise homing in *Pogonomyrmex badius* is achieved mainly by chemical homing trails and sun orientation, whereas visual landmarks are of minor importance.

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References and Notes

1. A. C. Cole, Jr., *Pogonomyrmex Harvester Ants* (Univ. of Tennessee Press, Knoxville, 1968).
2. F. Santschi, *Rev. Suisse Zool.* **19**, 303 (1911); V. Cornetz, *Les Explorations et les Voyages des Fourmis* (Flammarion, Paris, 1914); R. Brun, *Die Raumorientierung der Ameisen* (Fischer, Jena, 1914); R. Jander, *Z. Vergl. Physiol.* **40**, 162 (1957).
3. Separate experiments indicate that poison gland substance is primarily responsible for recruitment (B. Hölldobler and E. O. Wilson, in preparation). Poison gland trails are short-living (minutes) and release a strong recruitment, whereas Dufour's gland trails are long-living (hours) and attract homing ants.
4. W. Hangartner, J. M. Reichson, E. O. Wilson, *Anim. Behav.* **18**, 331 (1970).
5. R. Jander and C. Voss, *Z. Tierpsychol.* **20**, 1 (1963).
6. R. Wehner and R. Menzel, *Science* **164**, 192 (1969).
7. H. Markl, *Z. Vergl. Physiol.* **48**, 552 (1964); E. Batschelet, *Statistical Methods for the Analysis of Problems in Animal Orientation and Certain Biological Rhythms* (American Institute of Biological Sciences, Washington, D.C., 1965).
8. I thank Prof. E. O. Wilson and Mr. D. S. Woodruff for stimulating discussions and critical reading of the manuscript and Prof. A. J. Meyerriecks for his hospitality during the field studies. This work was supported by a grant of Max Kade Foundation and National Science Foundation grant GB-7734.

19 November 1970

Tumor Detection by Nuclear Magnetic Resonance

Abstract. *Spin echo nuclear magnetic resonance measurements may be used as a method for discriminating between malignant tumors and normal tissue. Measurements of spin-lattice (T_1) and spin-spin (T_2) magnetic relaxation times were made in six normal tissues in the rat (muscle, kidney, stomach, intestine, brain, and liver) and in two malignant solid tumors, Walker sarcoma and Novikoff hepatoma. Relaxation times for the two malignant tumors were distinctly outside the range of values for the normal tissues studied, an indication that the malignant tissues were characterized by an increase in the motional freedom of tissue water molecules. The possibility of using magnetic relaxation methods for rapid discrimination between benign and malignant surgical specimens has also been considered. Spin-lattice relaxation times for two benign fibroadenomas were distinct from those for both malignant tissues and were the same as those of muscle.*

At present, early detection of internal neoplasms is hampered by the relatively high permeability of many tumors to x-rays. In principle, nuclear magnetic resonance (NMR) techniques combine many of the desirable features of an external probe for the detection of internal cancer. Magnetic resonance measurements cause no obvious deleterious effects on biologic tissue (*1*), the incident radiation consisting of common radio frequencies at right angles to a static magnetic field. The detector is external to the sample, and the method permits one to resolve information emitted by the sample to atomic dimensions. Thus the spectroscopist has available for study a wide range of nuclei for evidence of deviant chemical behavior.

The resonance technique selected for this particular application belongs to a group of techniques known as "transient" or induction methods. In this experimental arrangement the sample continues to emit a radio-frequency signal for a brief but measurable period after the incident radiation (pulse) has been removed. This method makes possible the direct measurement of spin-lattice (T_1) and spin-spin (T_2) relaxation times, thus avoiding the uncertainties of estimating them from the line width measurements of steady-state NMR spectra. In addition, it also makes possible the characterization of biologic tissues on the basis of the properties of their emitted radio frequency.

In order to determine whether neoplastic tissues could be recognized from their NMR signals, I studied the proton resonance emissions from cell water. Recent NMR work of Cope (*2*), Hazlewood *et al.* (*3*), and Bratton *et al.* (*4*) has provided fresh insight into the physical nature of cell water. These authors have independently concluded that the decreased NMR relaxation times observed for cell water relative to distilled water (Tables 1 and 2) are due to the existence of a highly ordered fraction of cell water in which the protons of the water molecules have correlation times substantially less than the Larmor period. The reduction of the correlation times is presumably due to the adsorption of water molecules at macromolecular interfaces, findings that are consistent with the proposal by Ling (*5*) that intracellular water (endosolvent) exists as multiple polarized layers adsorbed onto cell proteins.

Two lines of evidence suggested that proton signals from the water in cancerous tissue would be distinct from the radio-frequency emissions of normal tissue. My own experiments with *Escherichia coli* (*6*) suggested that altered selectivity coefficients of alkali cations in biologic tissue, such as occur in neoplastic tissue (*5*), can indicate alterations in tissue water structure. In addition, Hazlewood and his co-workers have recently reported evidence from NMR measurements that growth and maturation of skeletal muscle in the newborn rat is accompanied by simultaneous changes in water structure and

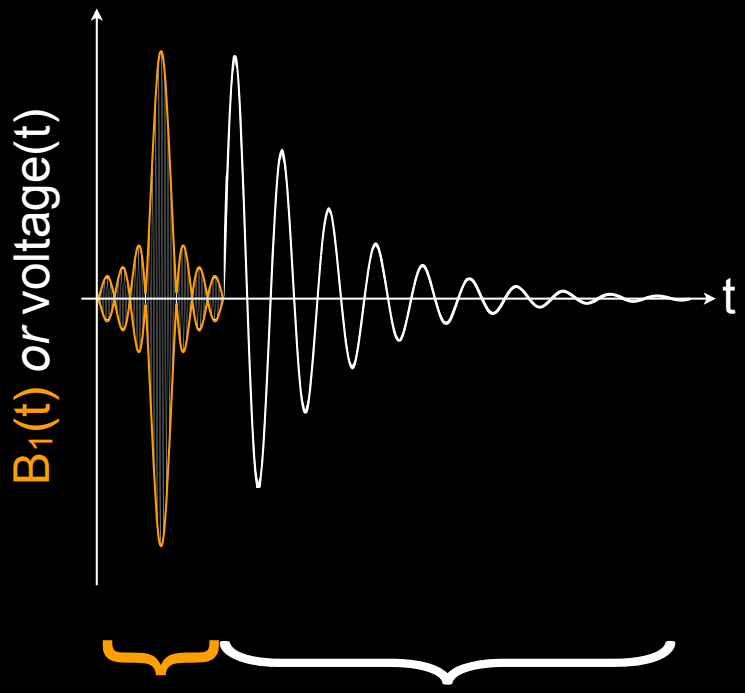
"These studies indicate that NMR methods may be used to discriminate between two malignant tumors and a representative series of normal tissues. The results suggest that this technique may prove useful in the detection of malignant tumors."

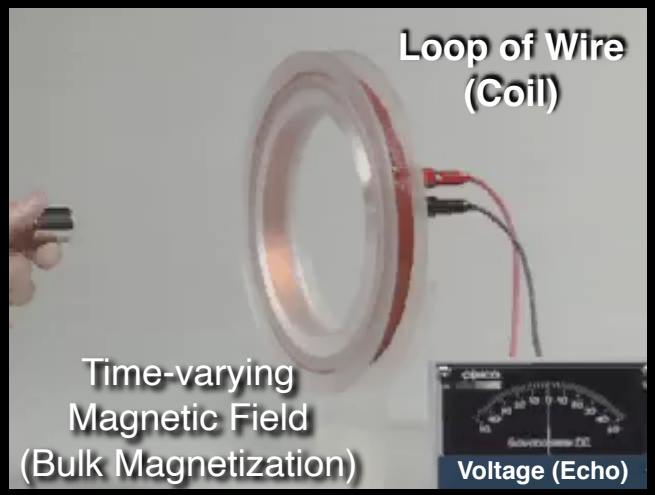
What is MRI?

- 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.





Faraday's Law of Induction

MRI encodes spatial information and image contrast in the echo.

Requirements for MRI

- NMR Active Nuclei
  - e.g. ^{1}H 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

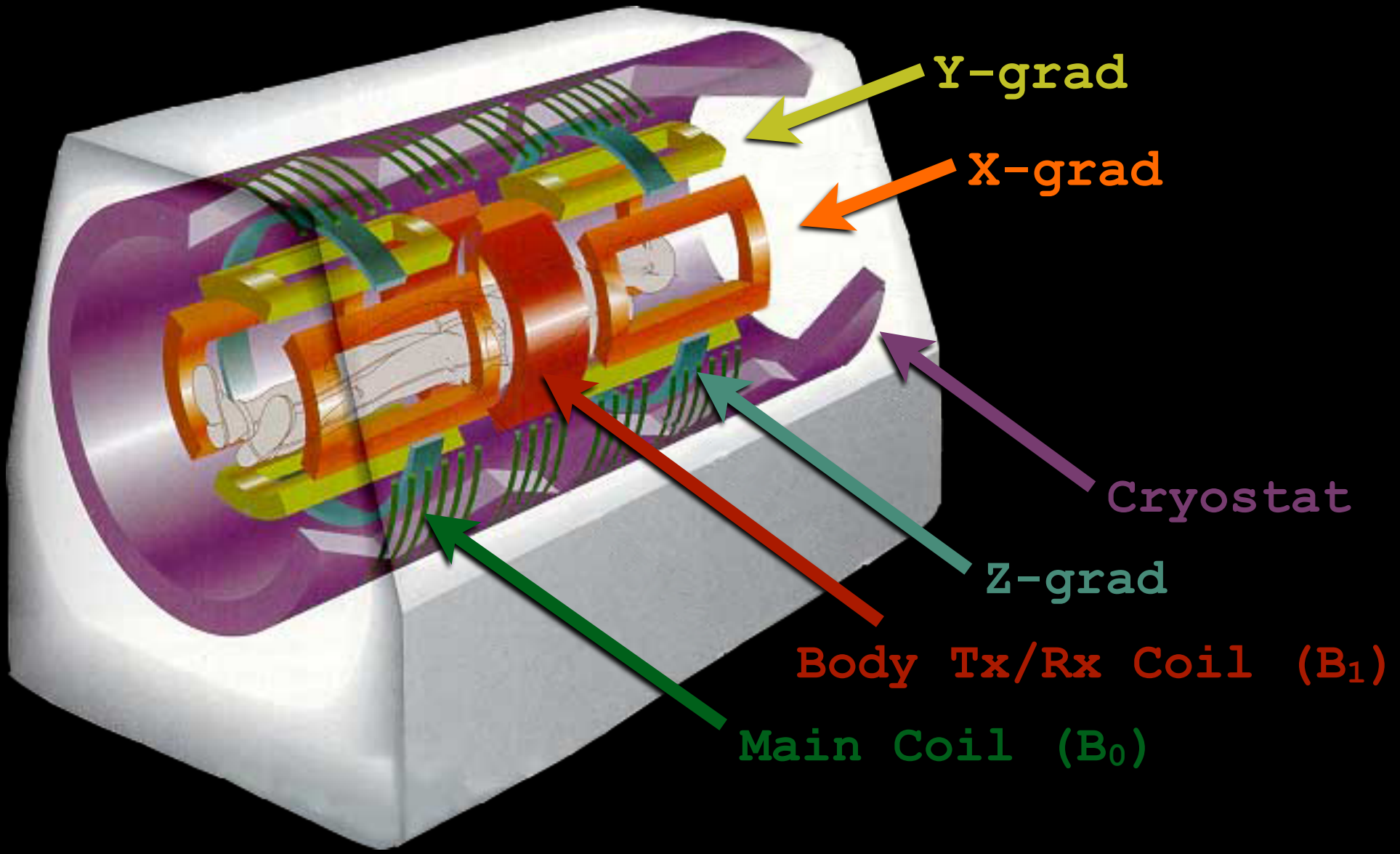


Image Adapted From: http://www.ee.duke.edu/~jshorey

Questions?

- Related courses of interest
  - M229 Advanced Topics in MRI (https://mrrl.ucla.edu/pages/m229)
  - PBM 222 MR Spectroscopy
  - PBM 225 MR Contrast Mechanisms

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