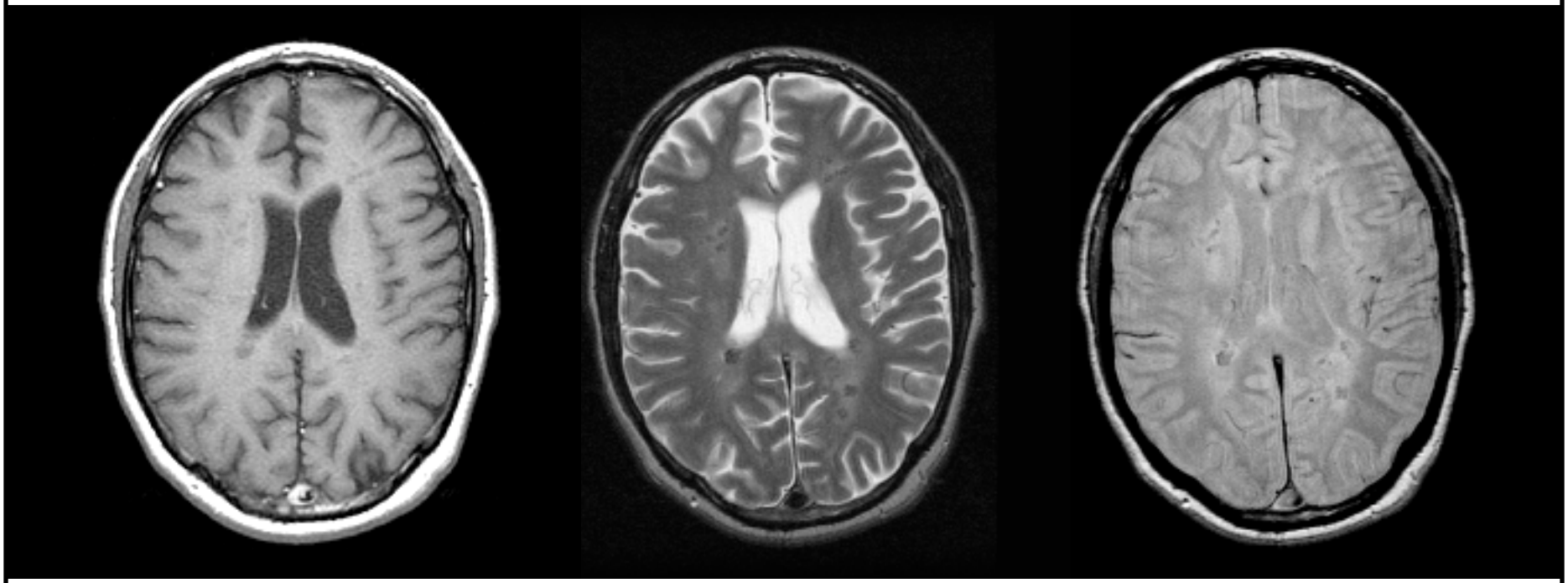
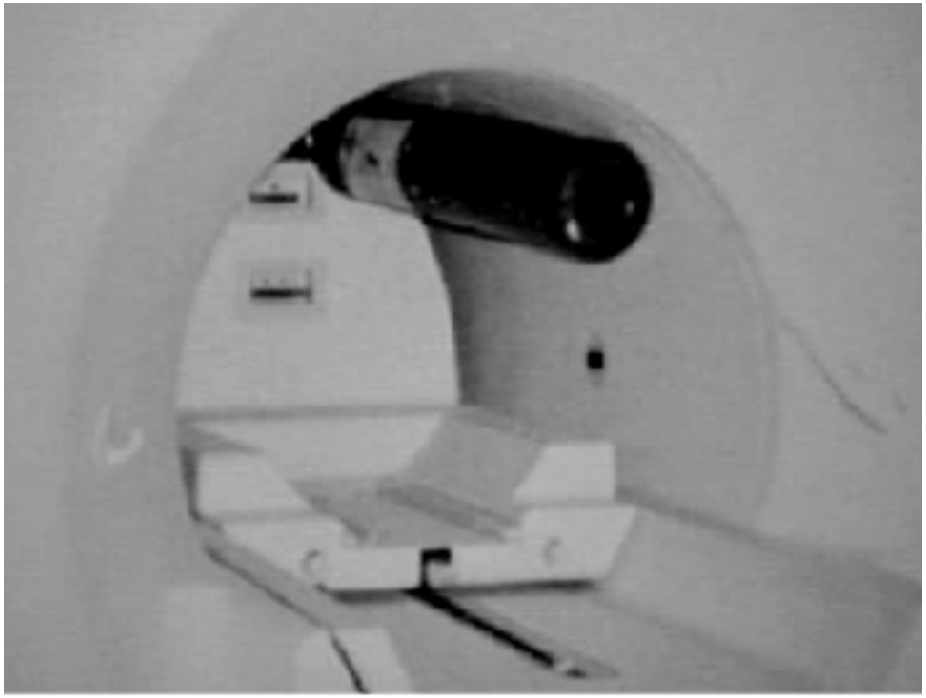
Introduction to MRI and fMRI



The magnet

Field strength



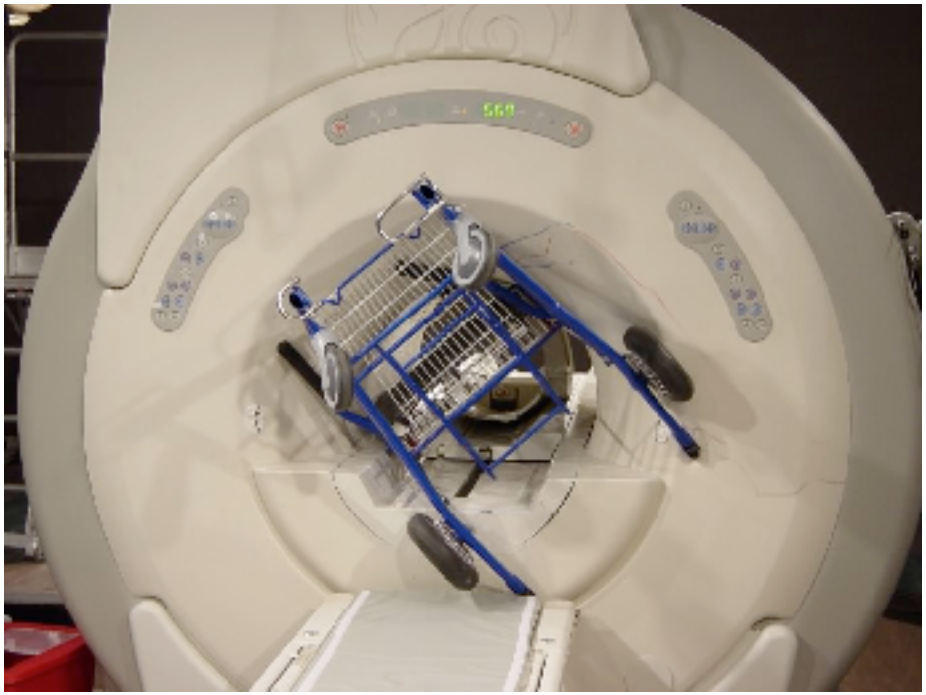
Field strength

Field strength

Field strength

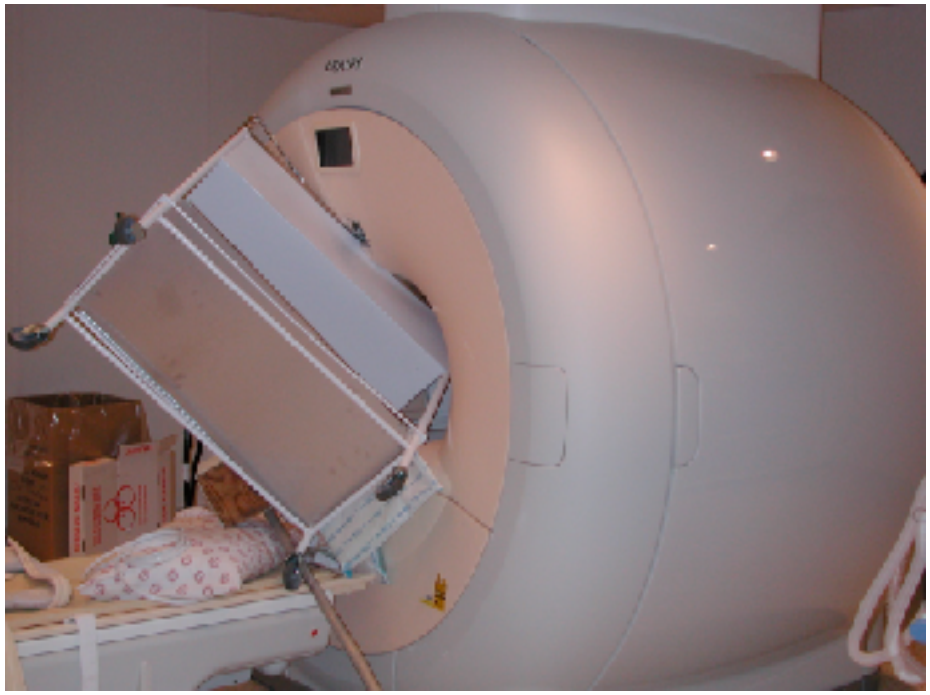
Field strength

Field strength



Field strength

Field strength



Field strength

Field strength

Field strength

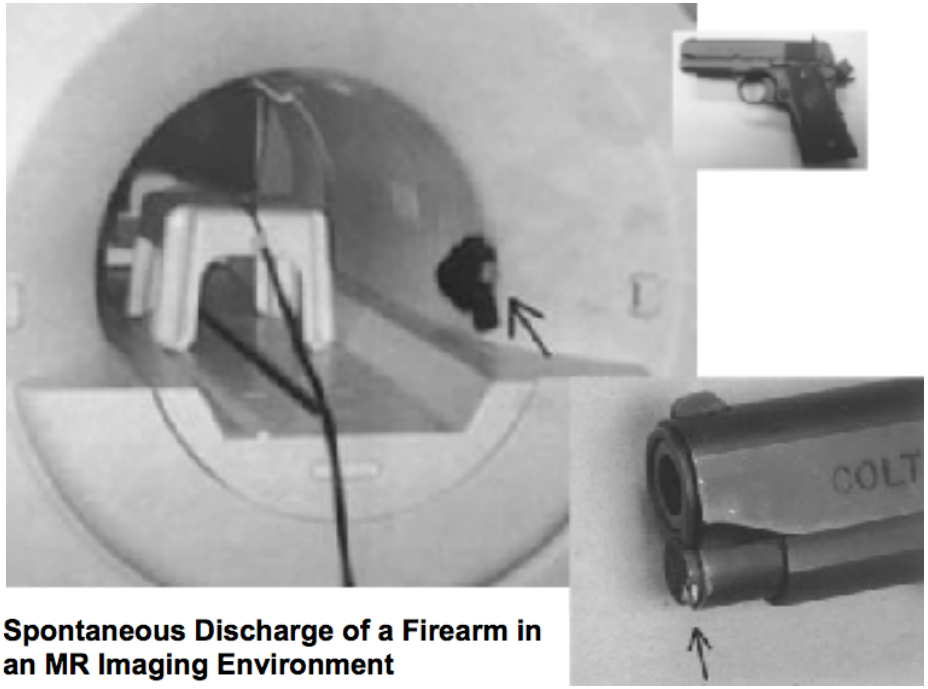
Field strength

Field strength

Field strength

Field strength

Field strength



American Journal of Roentgenology

Spontaneous Discharge of a Firearm in an MR Imaging Environment

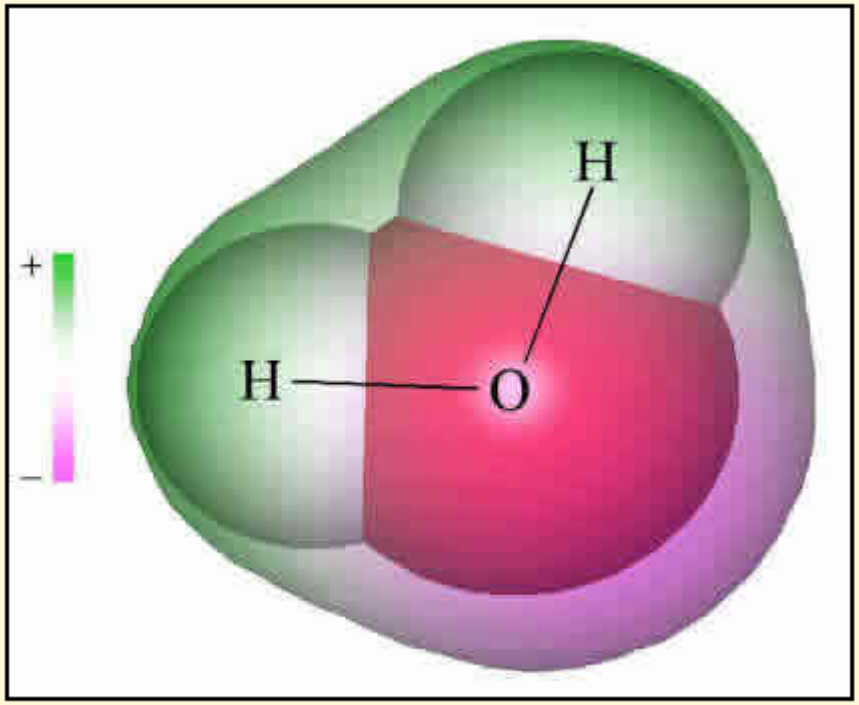
Anton Oscar Beitia[1], Steven P. Meyers[1], Emanuel Kanal[2] and William Bartell[3]

[1] Department of Radiology, University of Rochester Medical Center, 601 Elmwood Ave., Box 648, Rochester, NY 14642.
[2] Department of Radiology (D-132), University of Pittsburgh Medical Center, 200 Lothrop St., Pittsburgh, PA 15213.
[3] Rochester Police Department, Rochester, NY 14624.

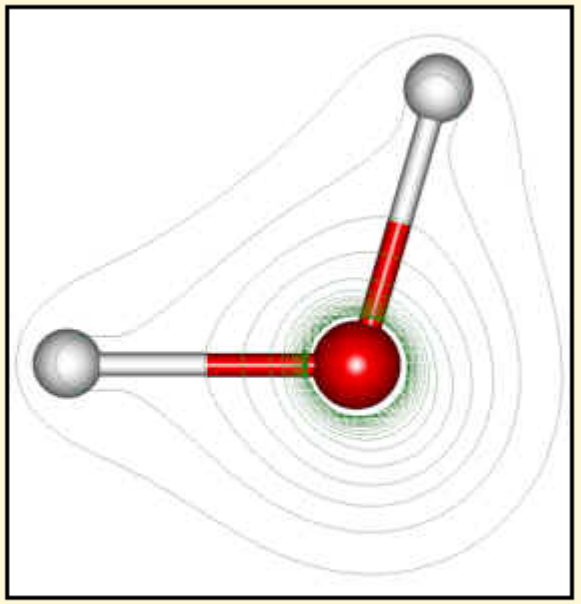
Received September 4, 2001; accepted after revision November 6, 2001.

Field strength

Water



The approximate shape and charge distribution of water.



Note that the average electron density around the oxygen atom is about 10x that around the hydrogen atoms.

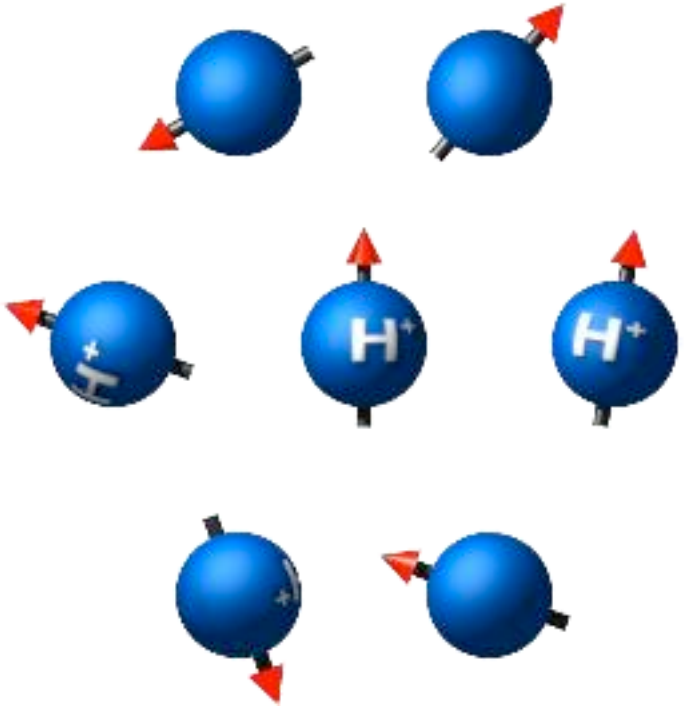
Other nuclei such as 13C, 19F, 31P, 23Na have a net nuclear spin and can be imaged in MRI.

www.lsbu.ac.uk/water/

Proton

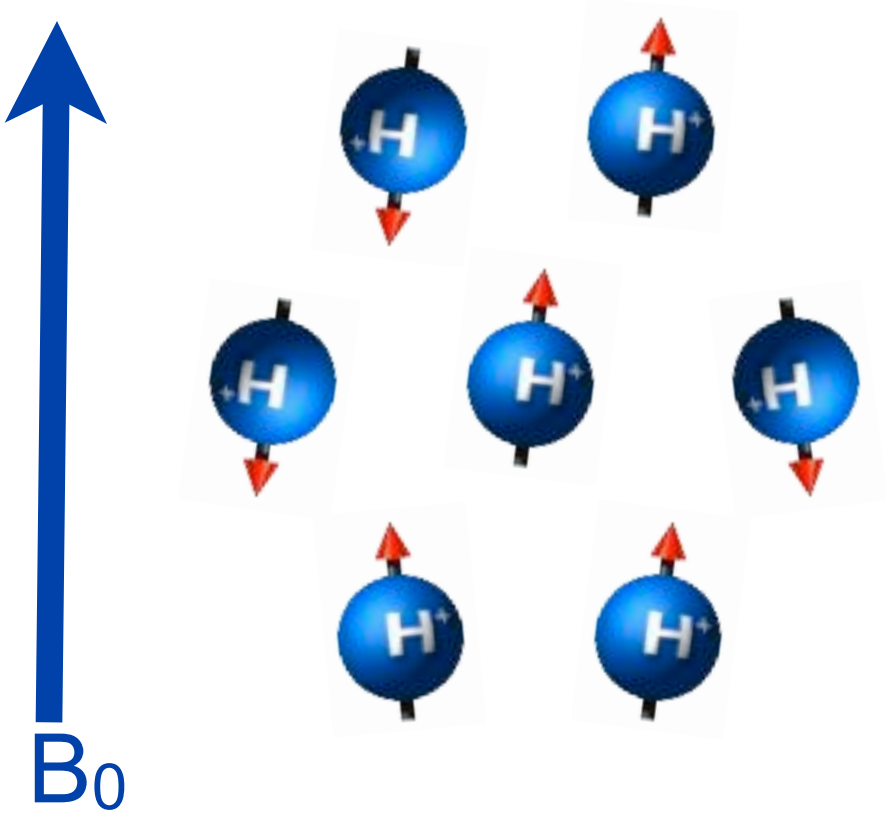
Proton

Protons in uniform B_0 field



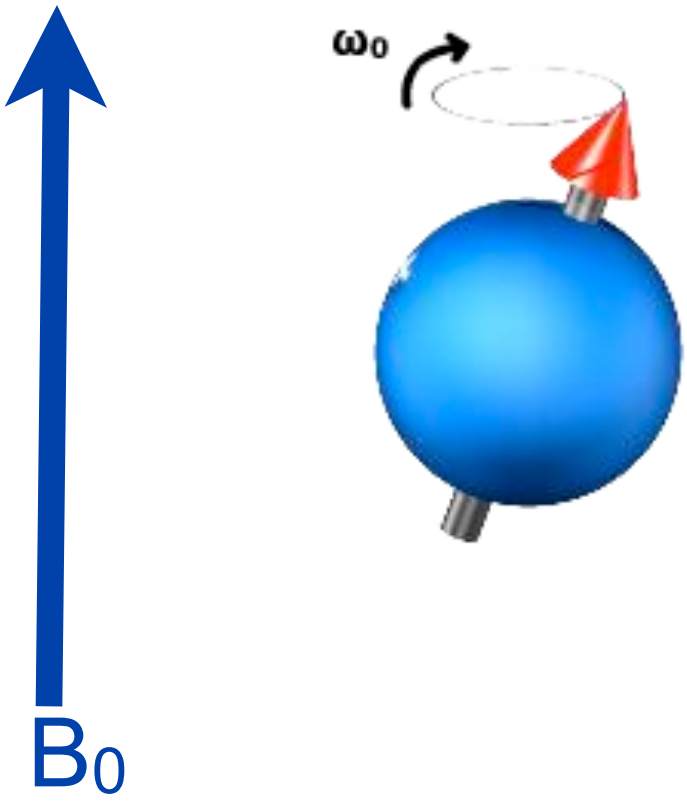
As spins do not rotate in phase, the sum of all the microscopic magnetizations of each spin is a null macroscopic magnetization.

Alignment with B_0 field

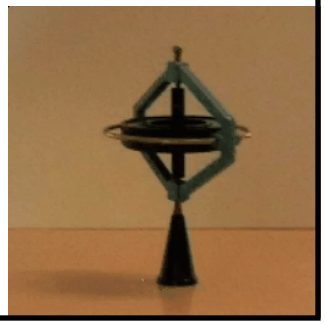


3 per million parallel vs. anti-parallel at 1T

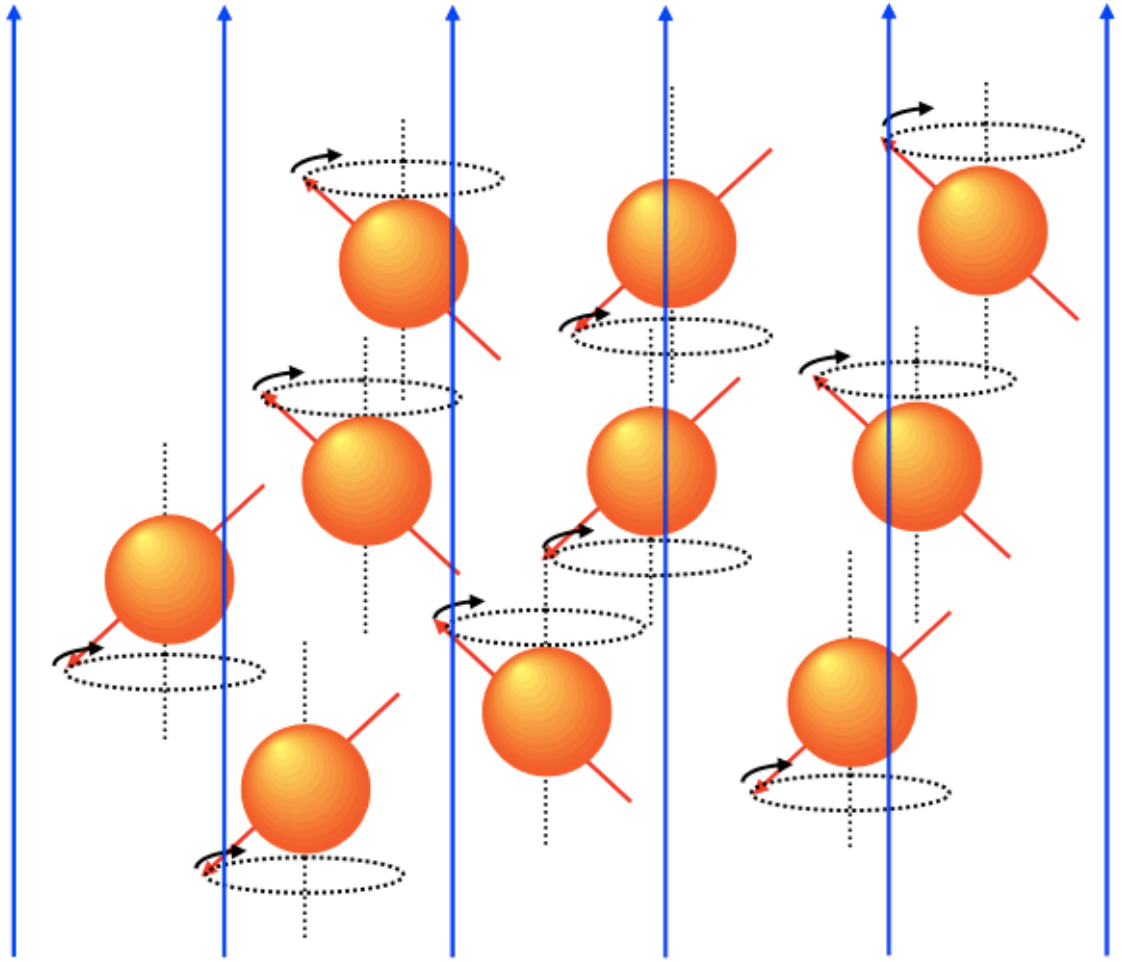
Larmor precession



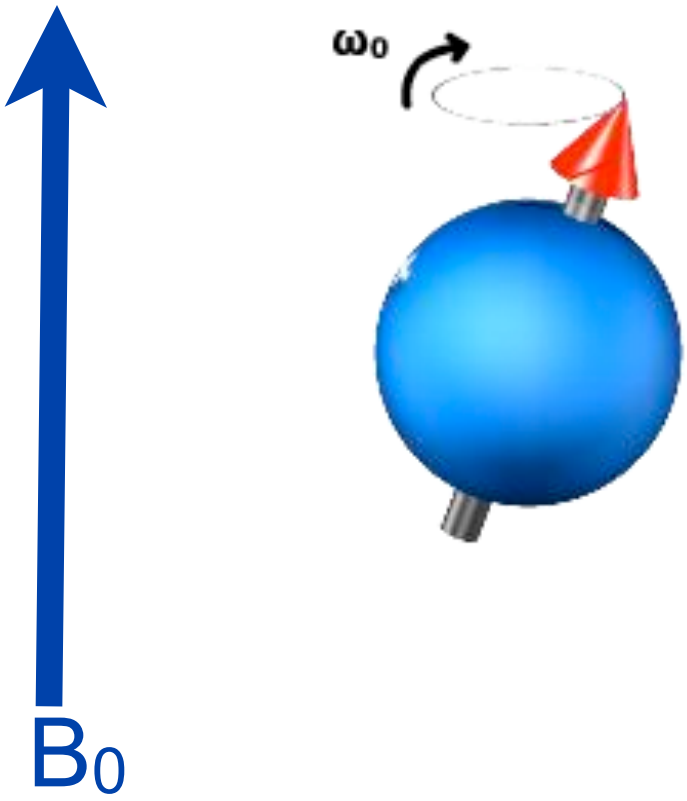
Spins in a static magnetic field precess



Larmor precession

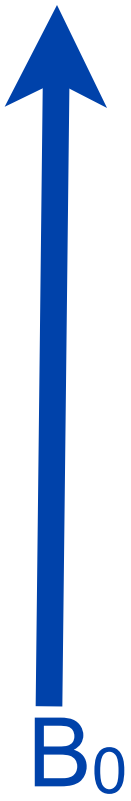


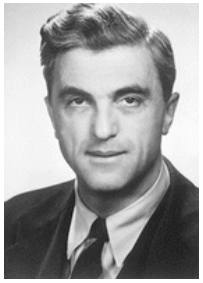
Larmor precession

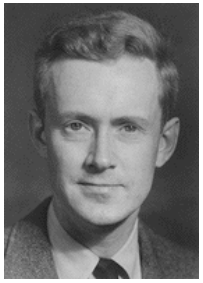


Resonance:
exchange of energy between two systems at a specific frequency.
Magnetic resonance:
interaction between spins and electromagnetic radiofrequency (RF).

Larmor precession




Bloch

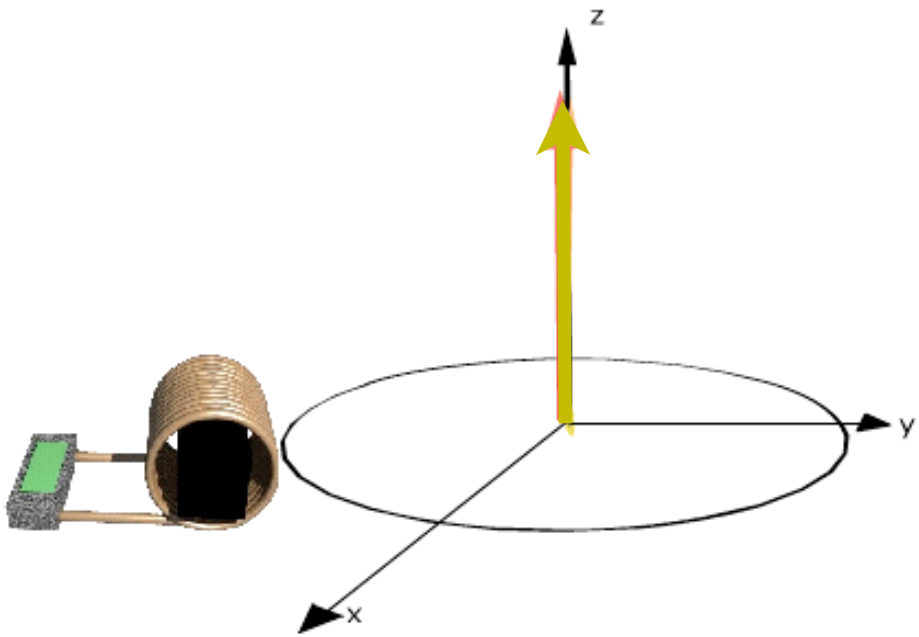

Purcell

Resonance:
exchange of energy between two systems at a specific frequency.
Magnetic resonance:
interaction between spins and electromagnetic radiofrequency (RF).

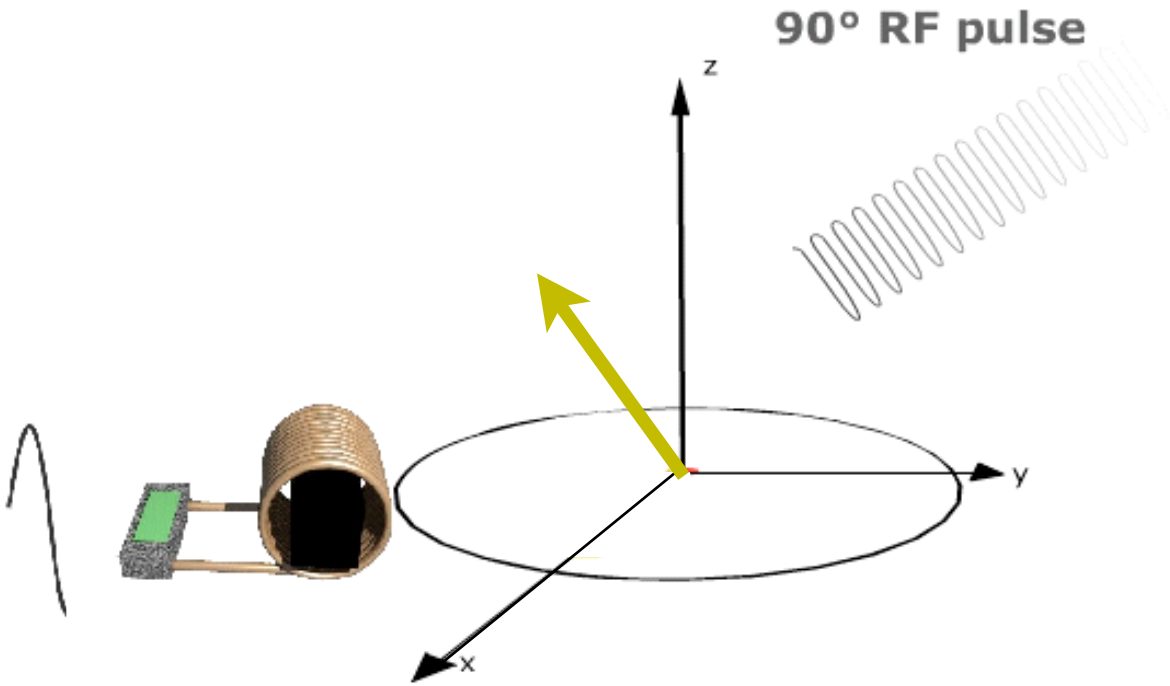
1946:

Energy applied at a resonant frequency is absorbed by matter, and the re-emission can be measured in detector coils.

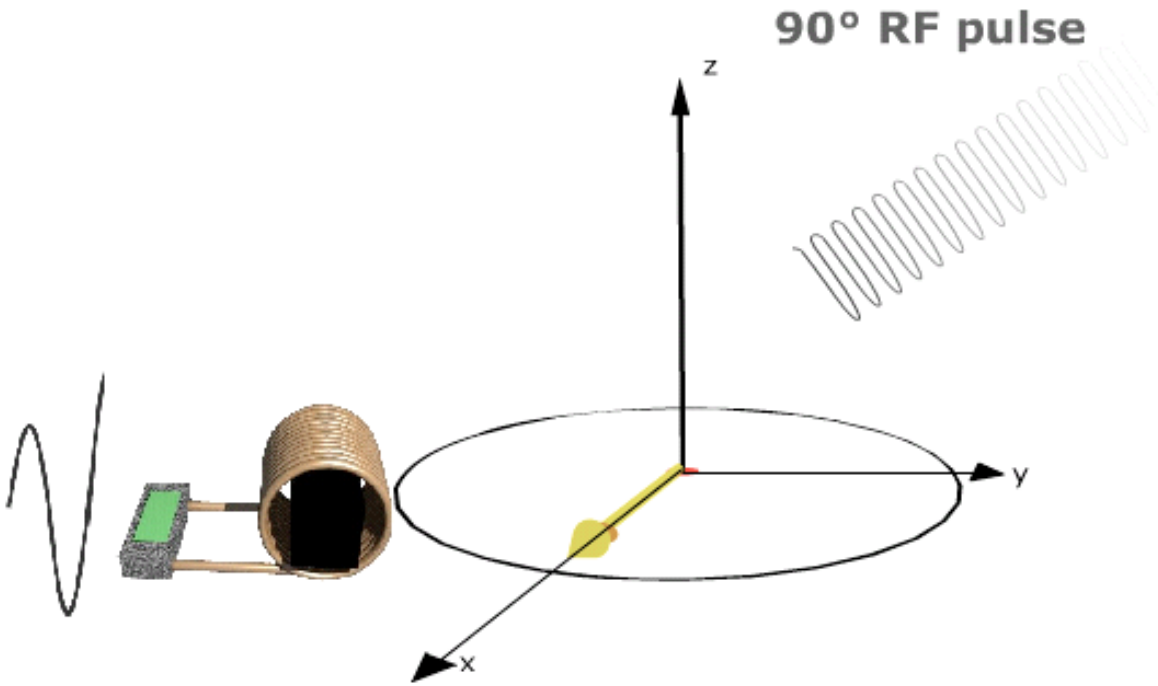
Signal: excitation & relaxation



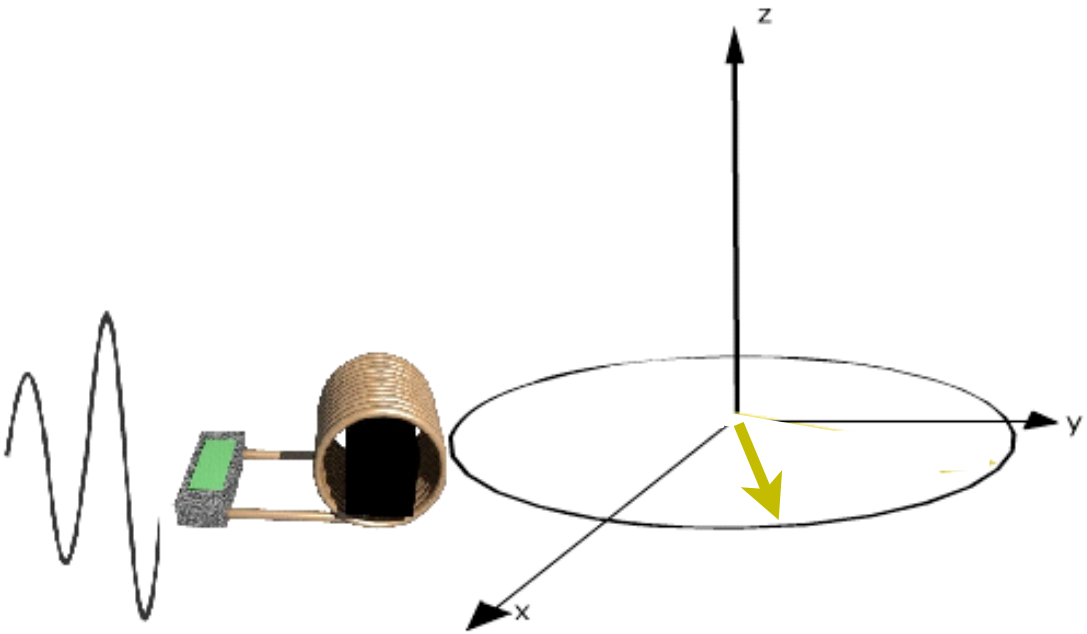
Excitation



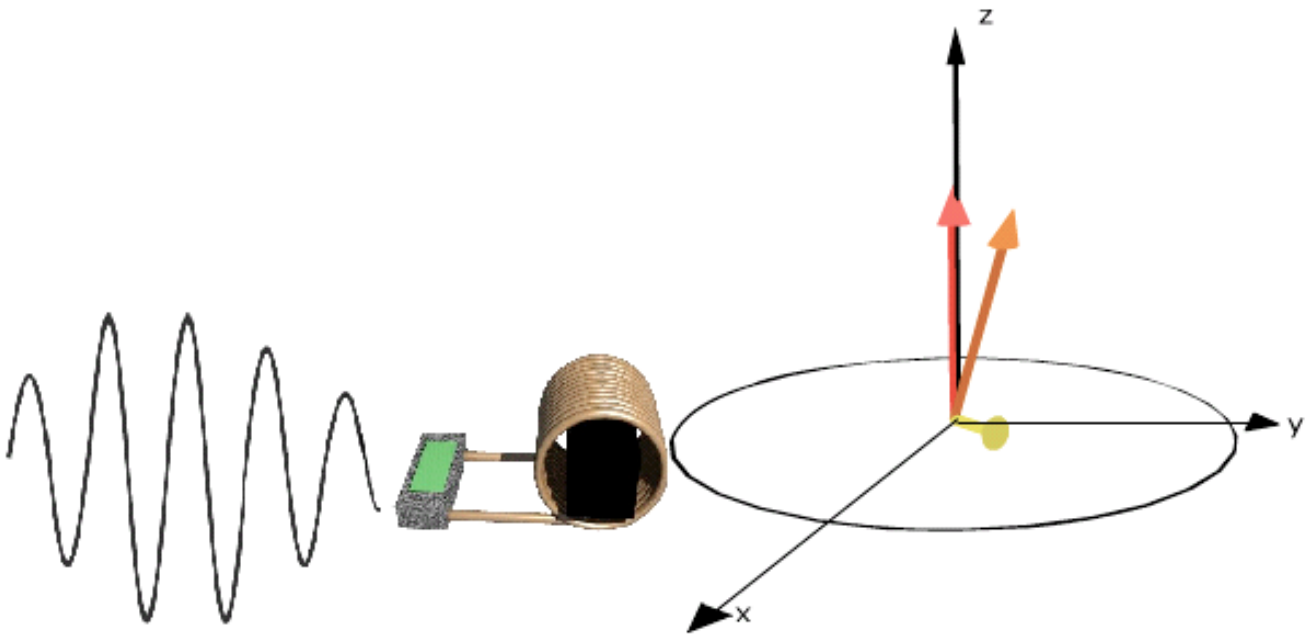
Excitation



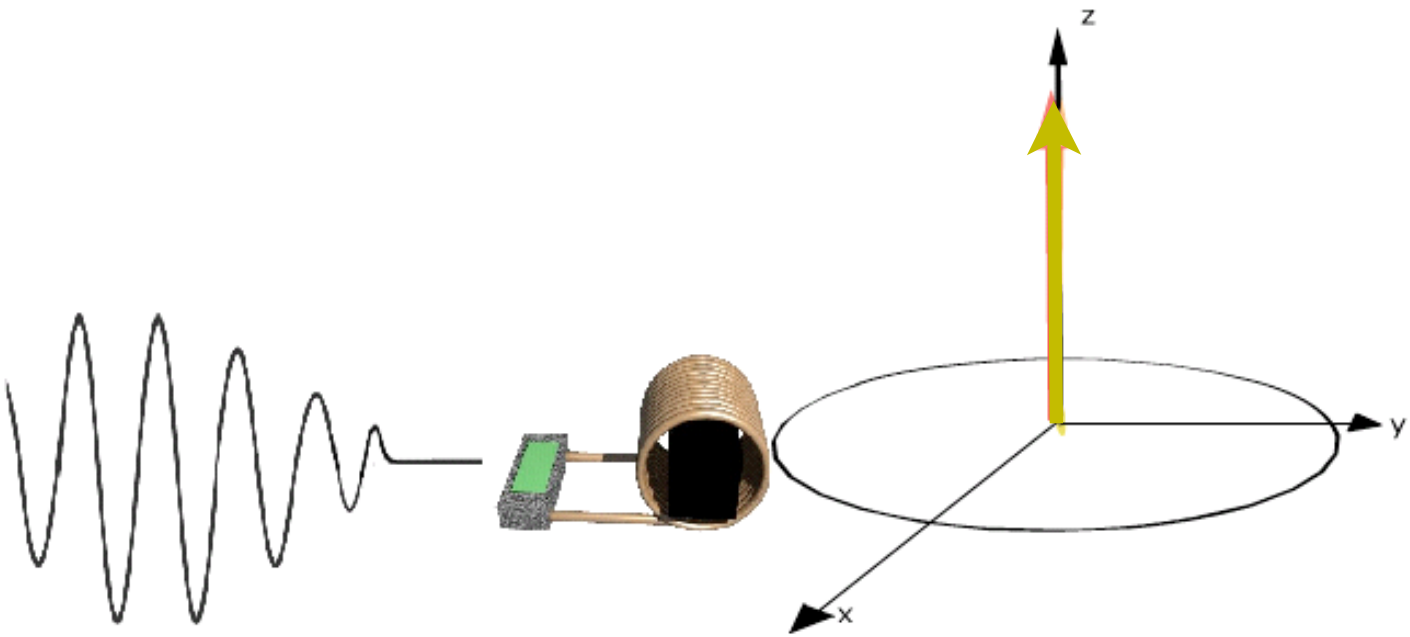
Relaxation



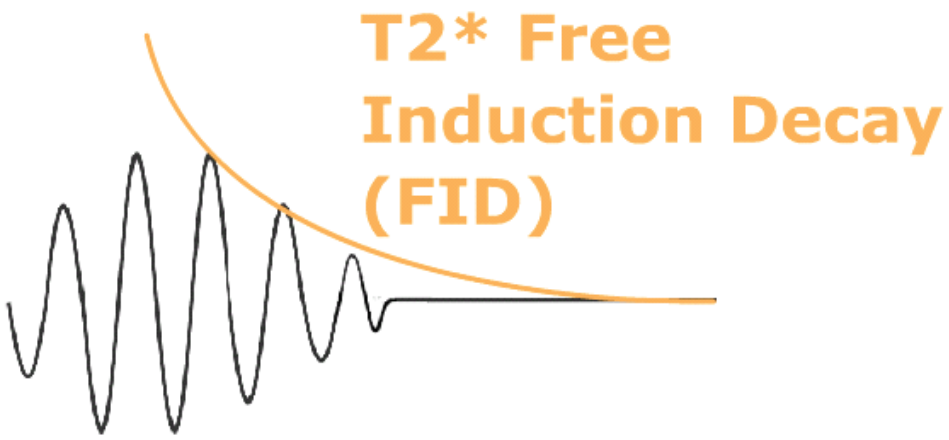
Relaxation



Relaxation

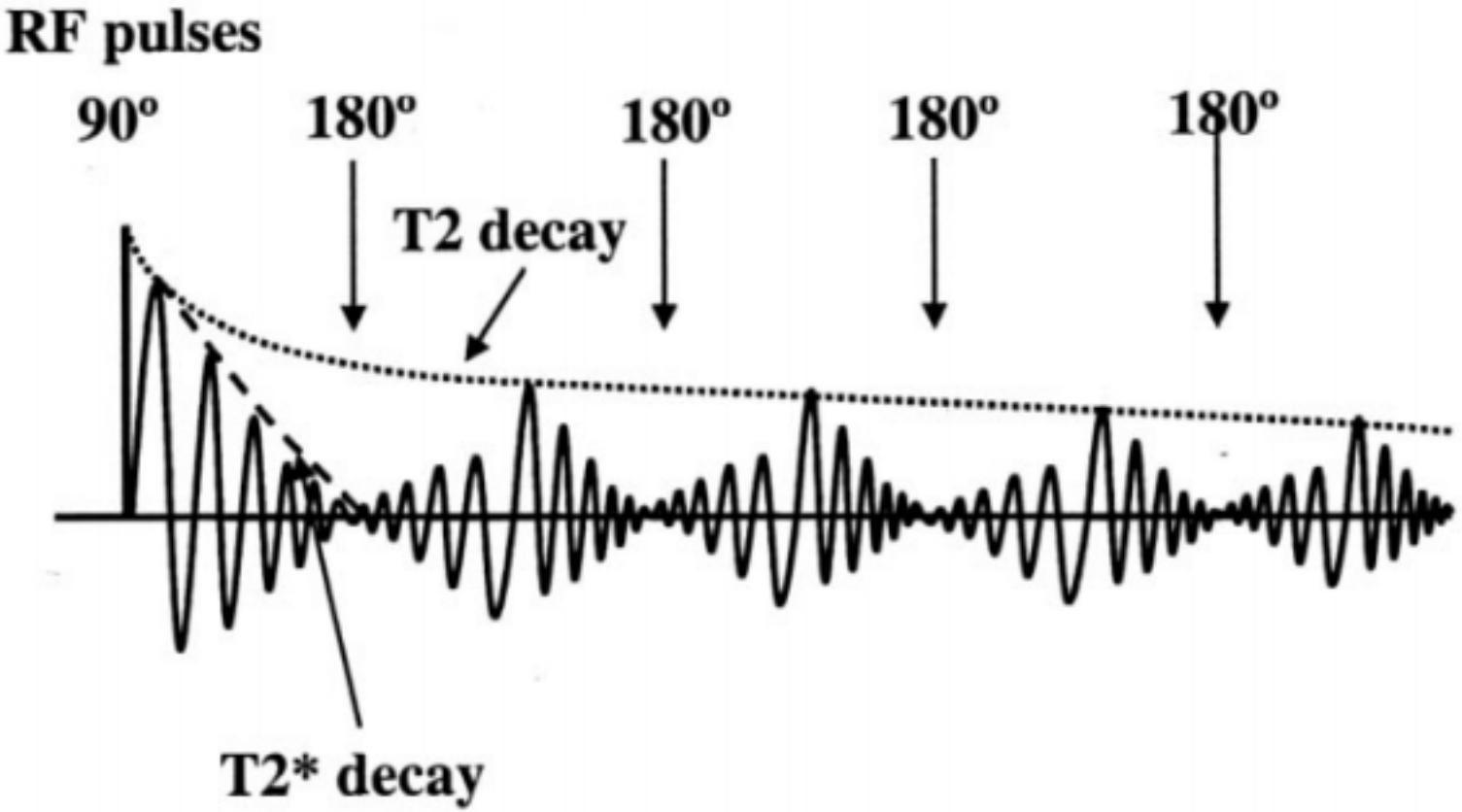


Relaxation

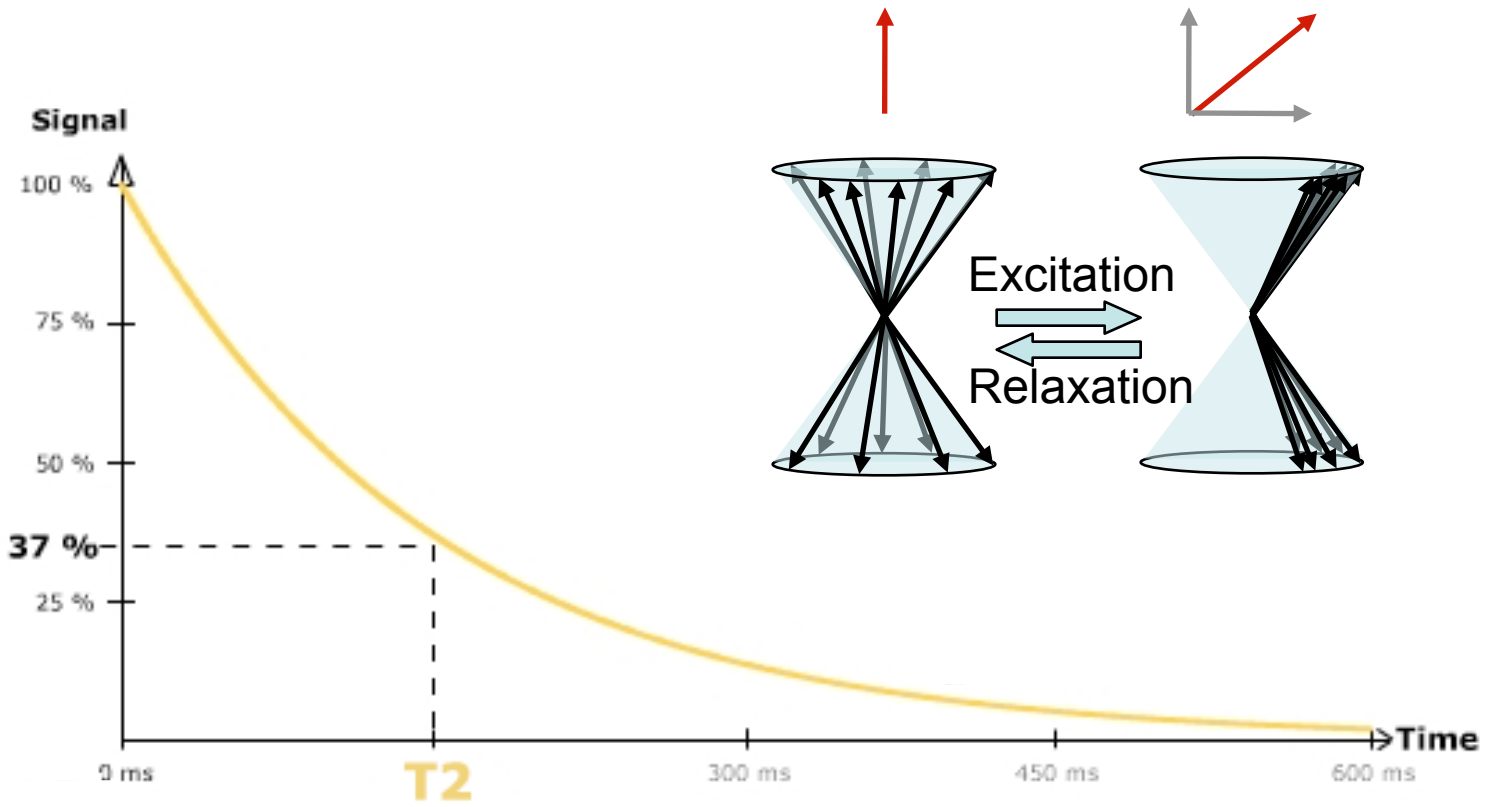


Static inhomogeneities in magnetic fields accelerate spins dephasing.

Relaxation

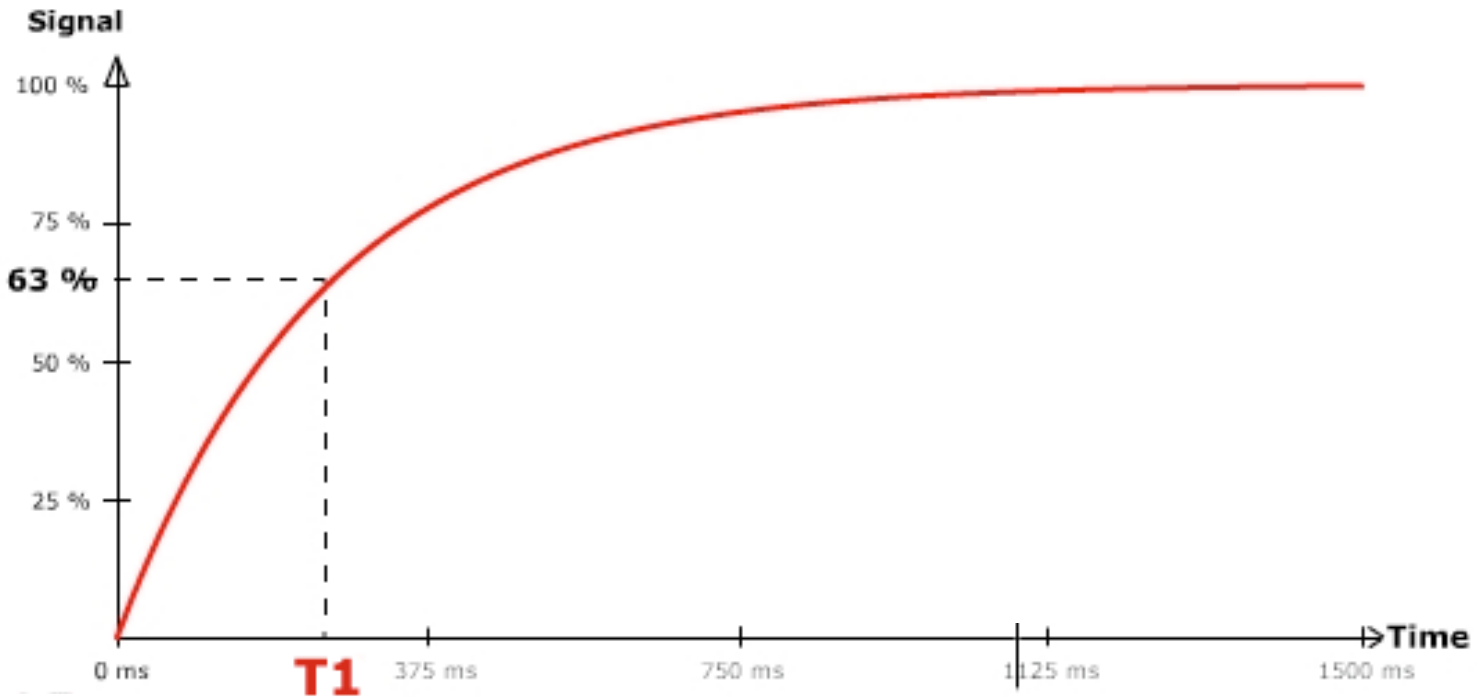


Relaxation



Decay of transverse magnetization, due to spins getting out of phase (spin-spin interactions), according to an exponential curve characterized by time constant T2.
T2 values are lower than T1 values and are unrelated to field strength.

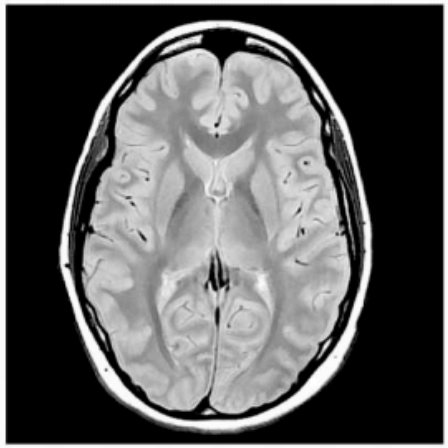
Relaxation



Recovery of longitudinal magnetization, aligned with B_0,
following an exponential curve characterized by time constant T1.
With a 1.5 T field strength, T1 values are about 200 to 3000 ms.
T1 values are longer at higher field strengths.

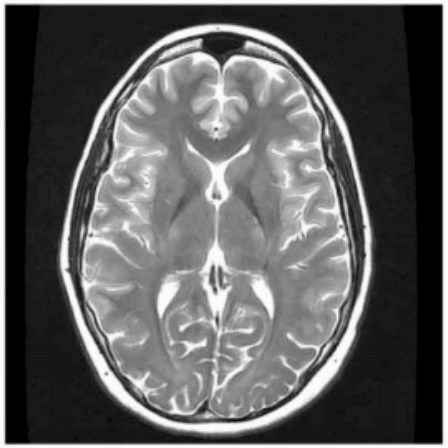
T1-, T2-, PD-weighting

	P_D	T_2 (ms)	T_1 (ms)
White matter	0.61	67	510
Gray matter	0.69	77	760
CSF	1.00	280	2650



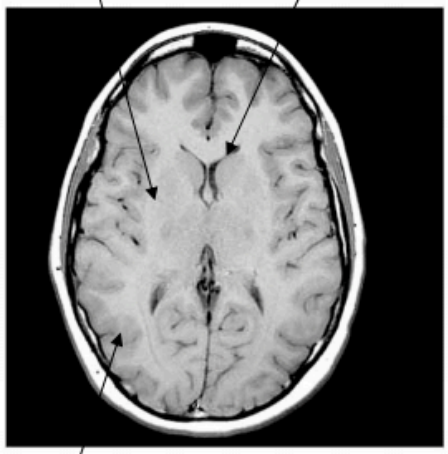
(a)

PD weighted



(b)

T2- weighted



(c)

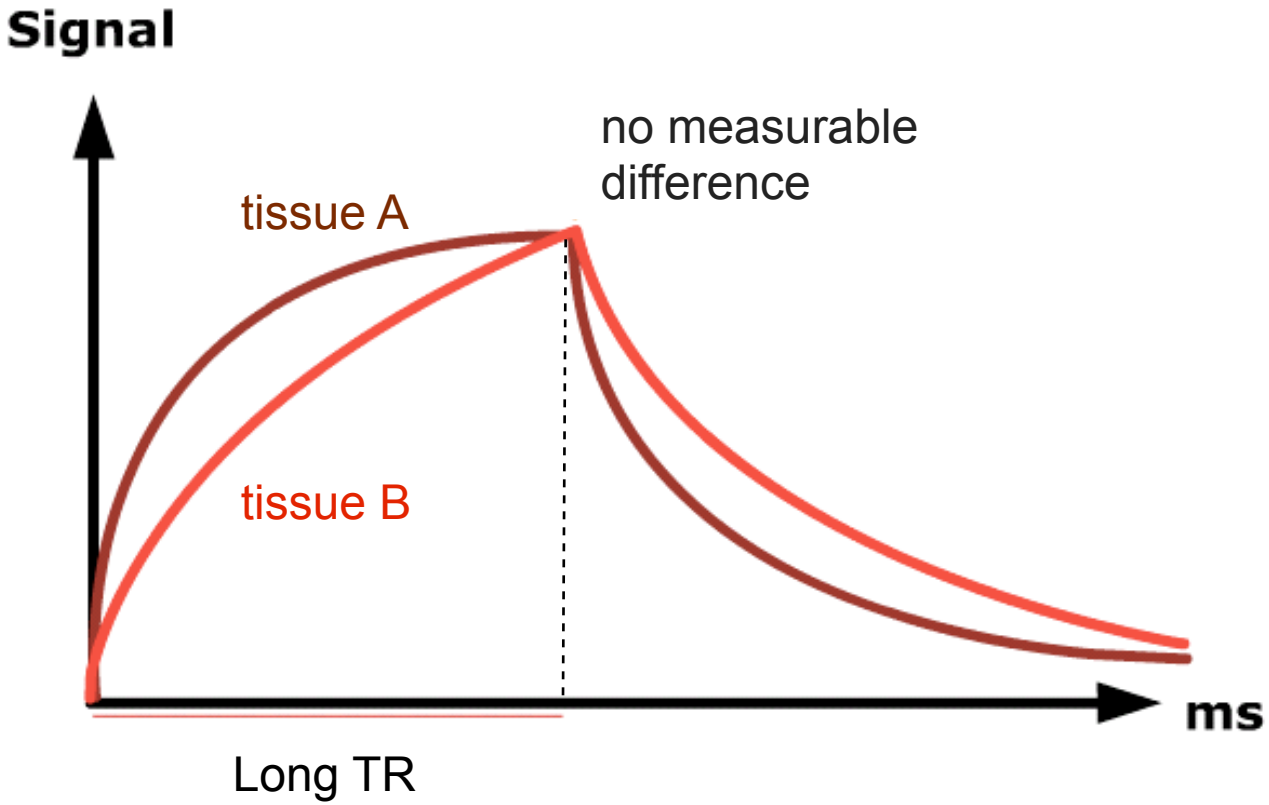
T1- weighted

White matter

CSF

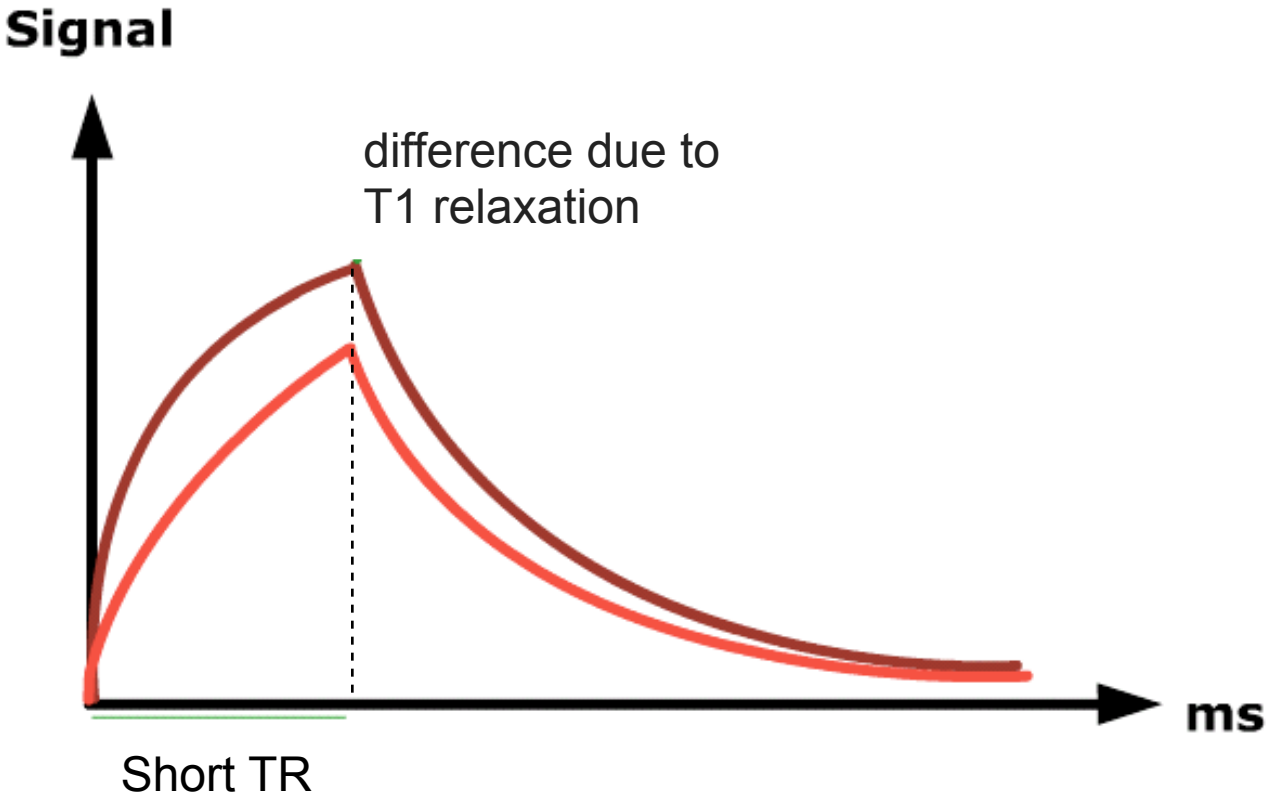
Gray matter

Tissue contrast



t = TR × [# phase encoding steps] × [# acquisitions to average]

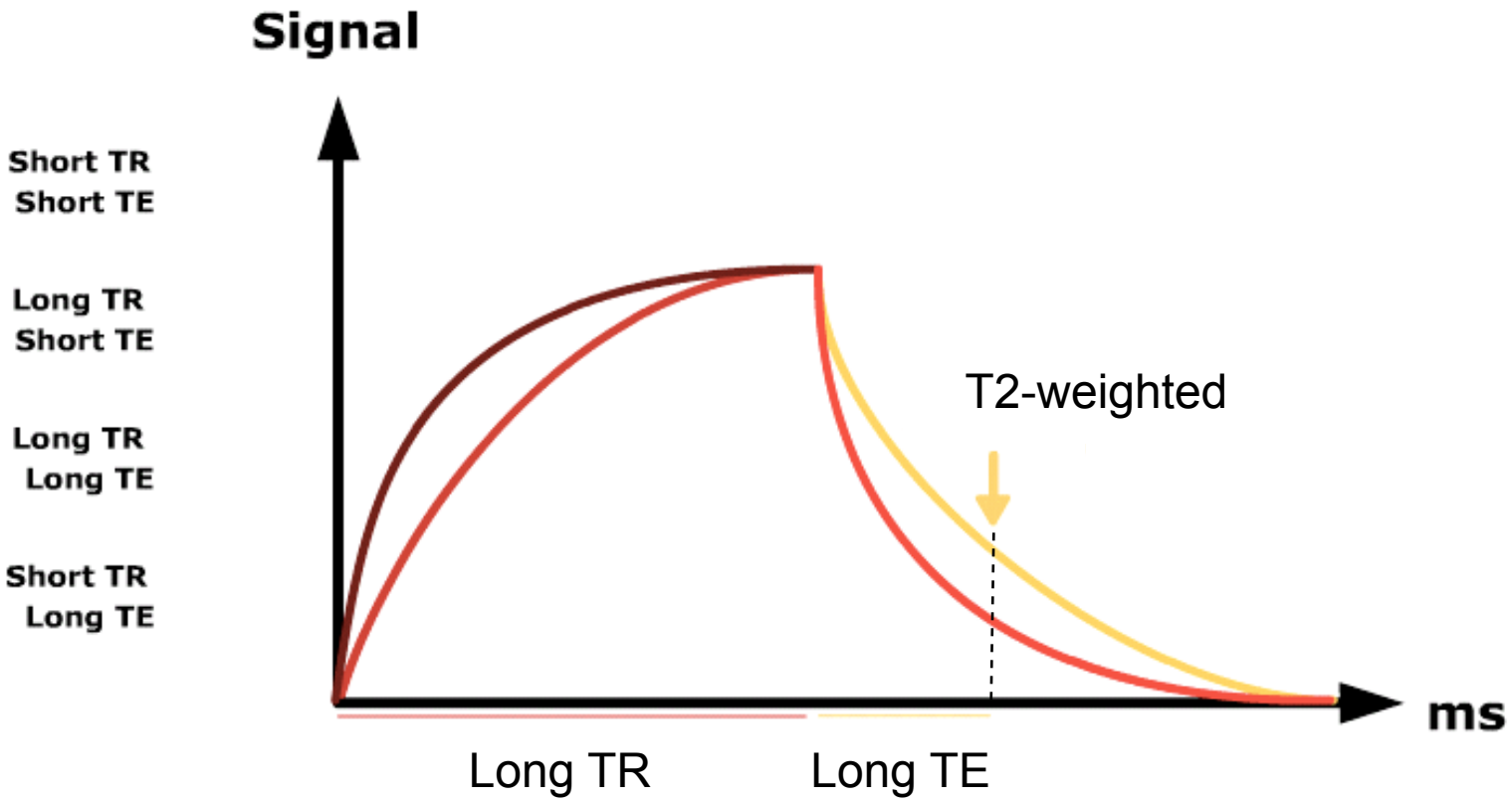
Tissue contrast



By setting the TR to short values, tissue contrast will depend on differences in longitudinal magnetization recovery (T1).

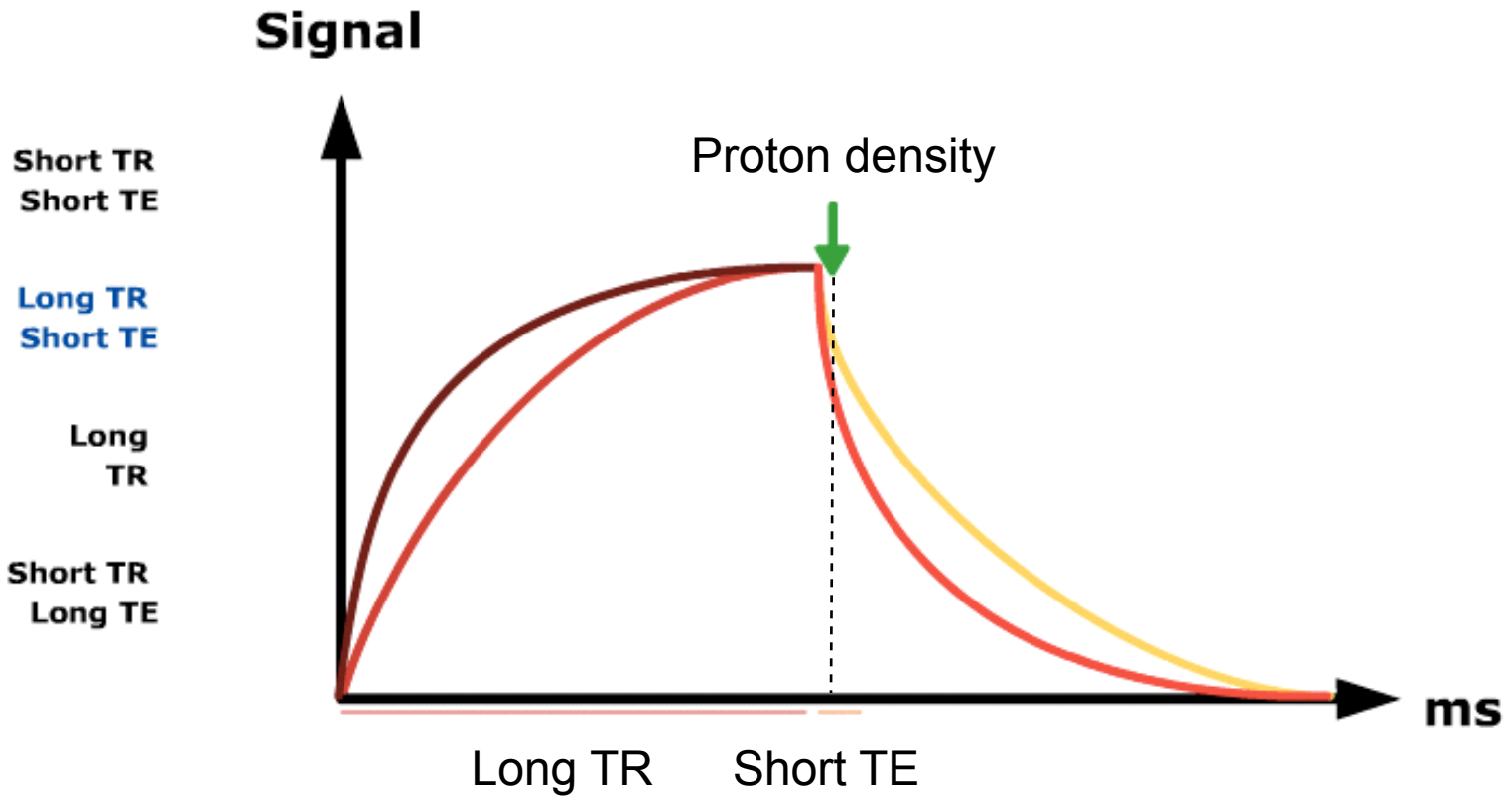
Tissue contrast

(Spin-echo)

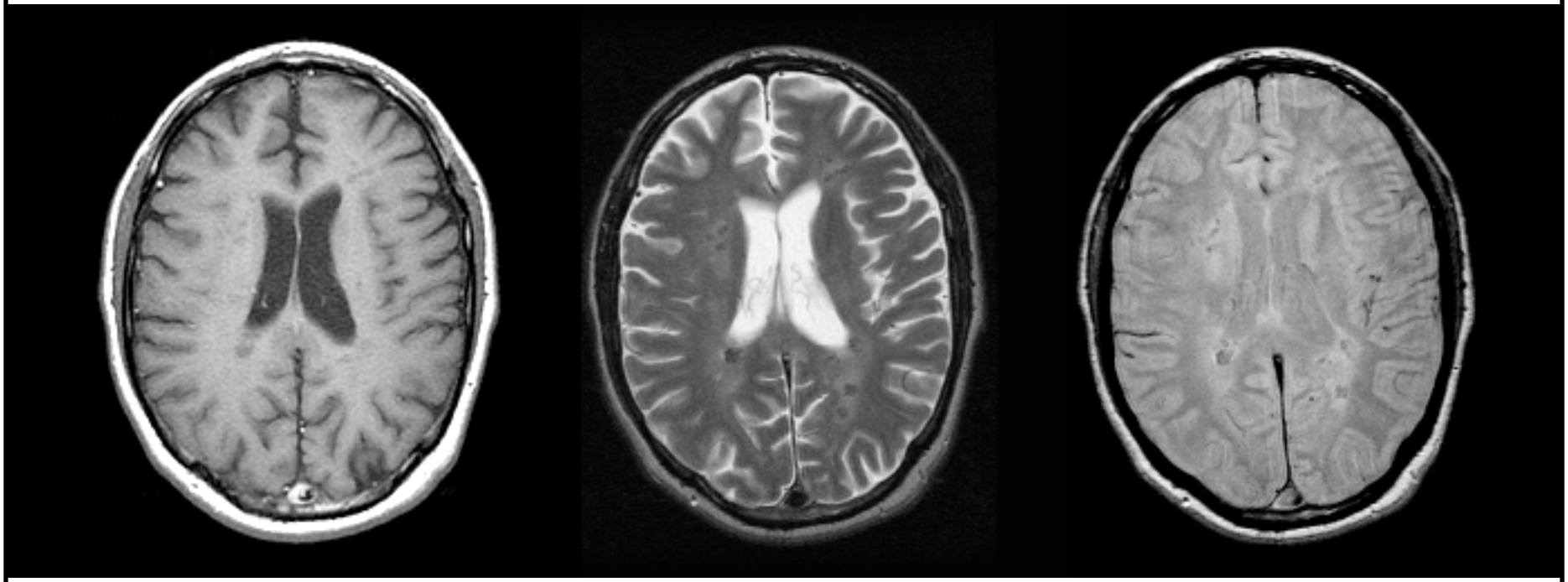


Tissue contrast

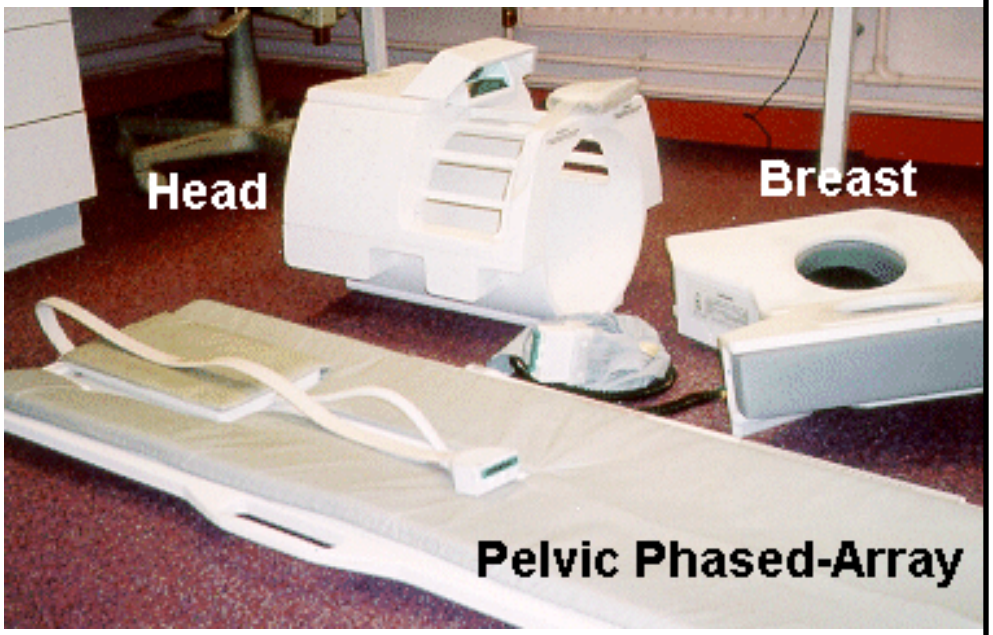
(Spin-echo)



Spatial encoding

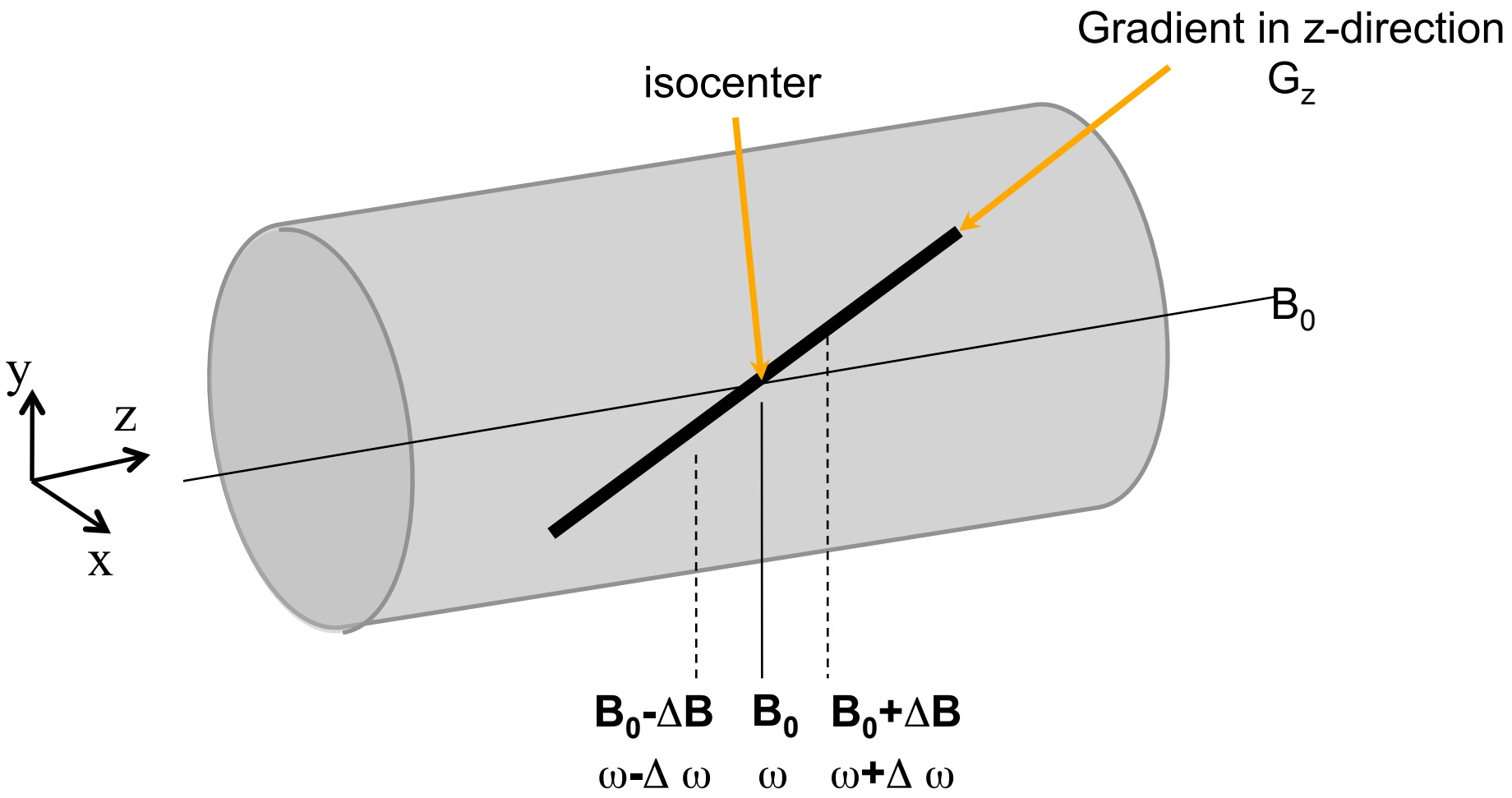


Spatial encoding

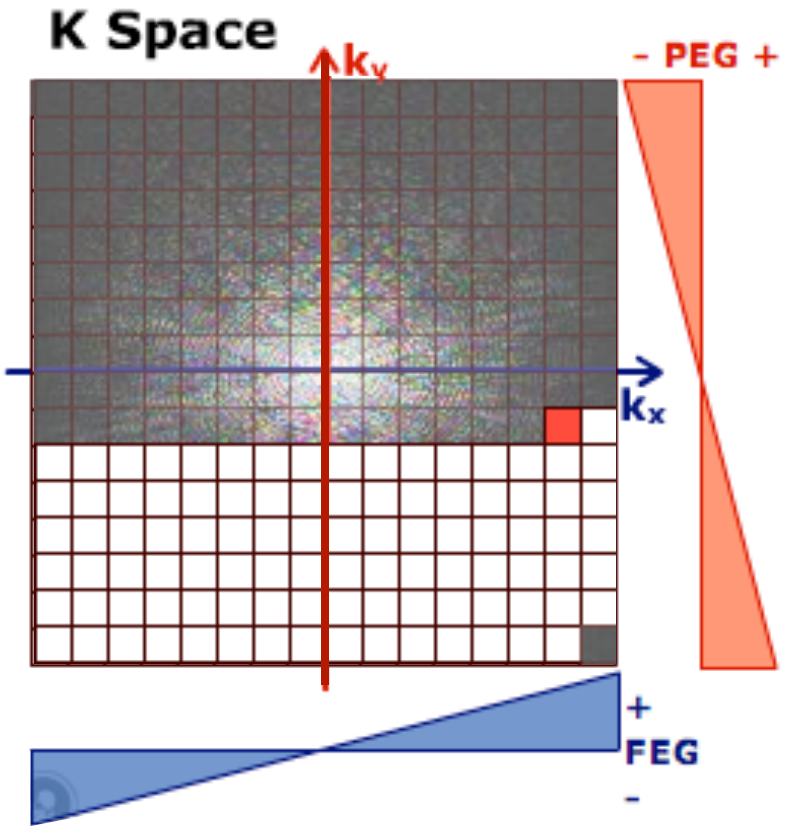


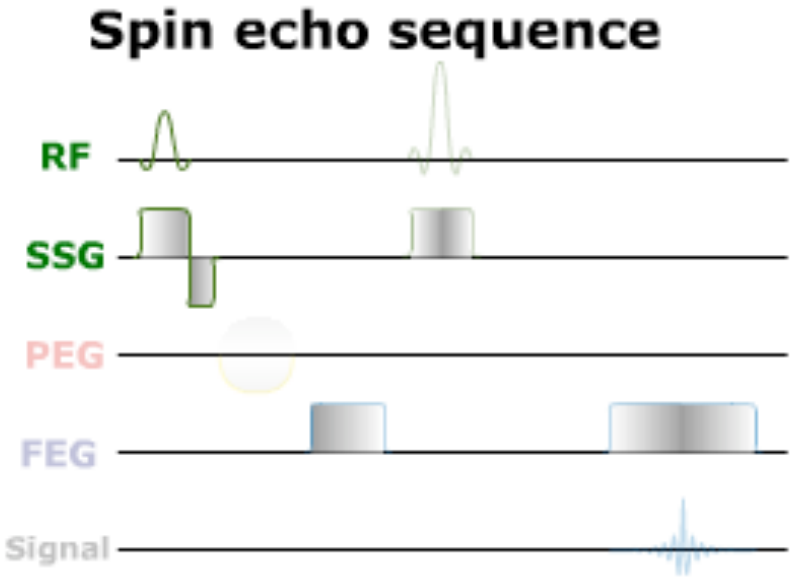
Spatial encoding

Slice selection in z



Spatial encoding





1. RF pulse + Slice select gradient
2. Phase encoding gradient
3. Frequency encoding gradient (dephasing lobe)
4. 180 RF pulse + Slice select gradient
5. Frequency encoding gradient + Signal recording

Parameters for Neuroimaging

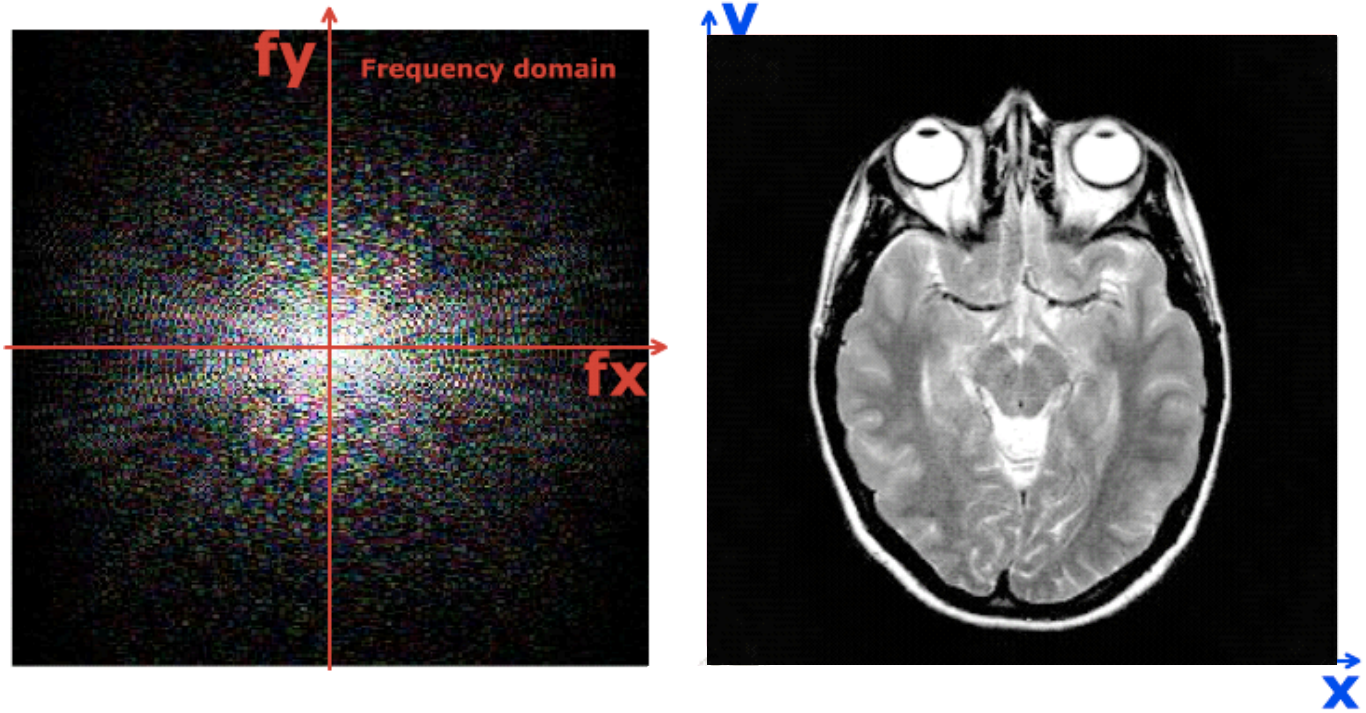
You decide:

- number of slices
- slice orientation
- slice thickness
- in-plane resolution (field of view and matrix size)
- volume acquisition time (usually = TR)
- length of a run
- number of runs
- duration and sequence of epochs within each run
- counterbalancing within or between subjects

Your physicist can help you decide:

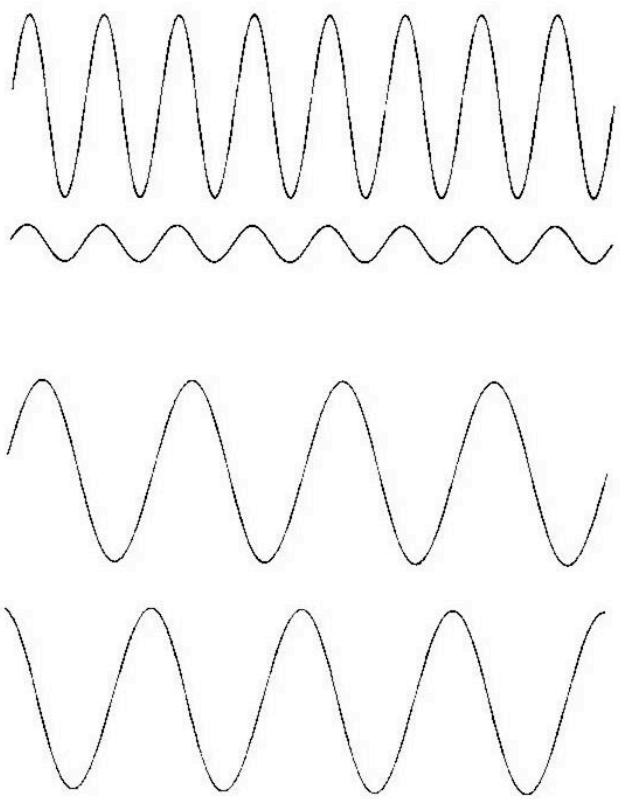
- pulse sequence (e.g., gradient echo vs. spin echo)
- k-space sampling (e.g., echo-planar vs. spiral imaging)
- TR, TE, flip angle, etc.

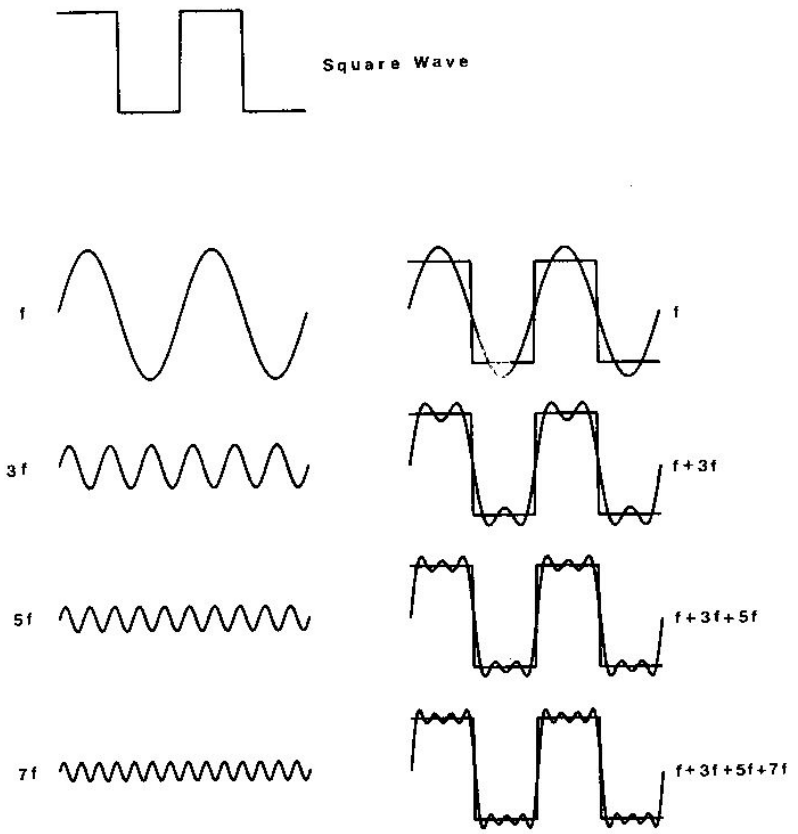
Frequency encoding



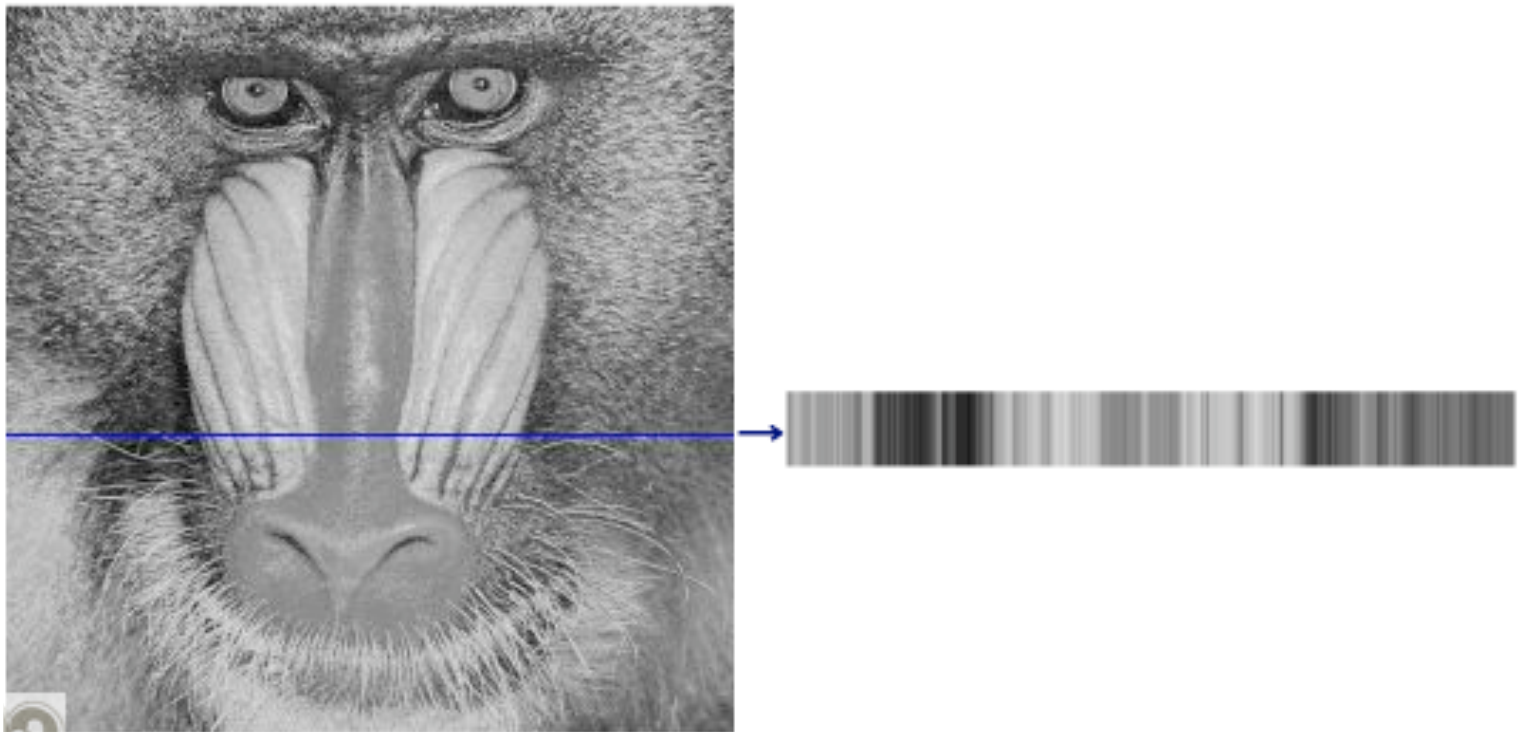
Fourier analysis

Any wave form can be decomposed into a series of sine waves

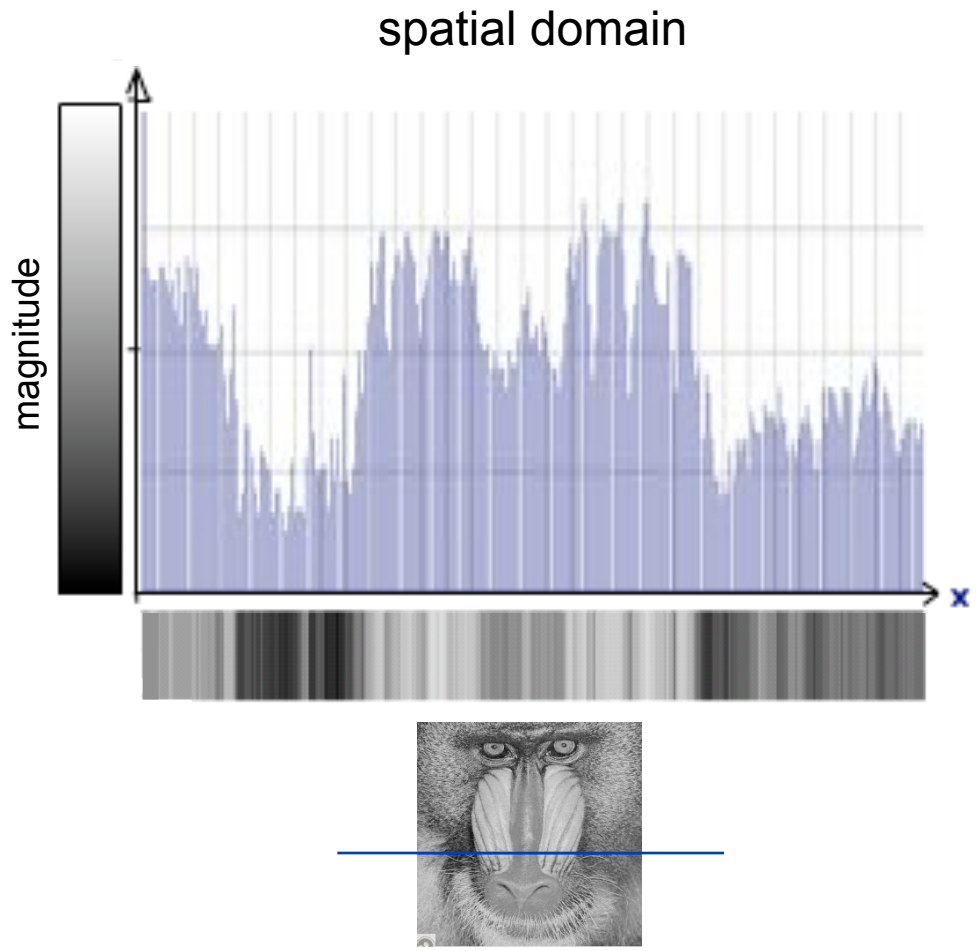




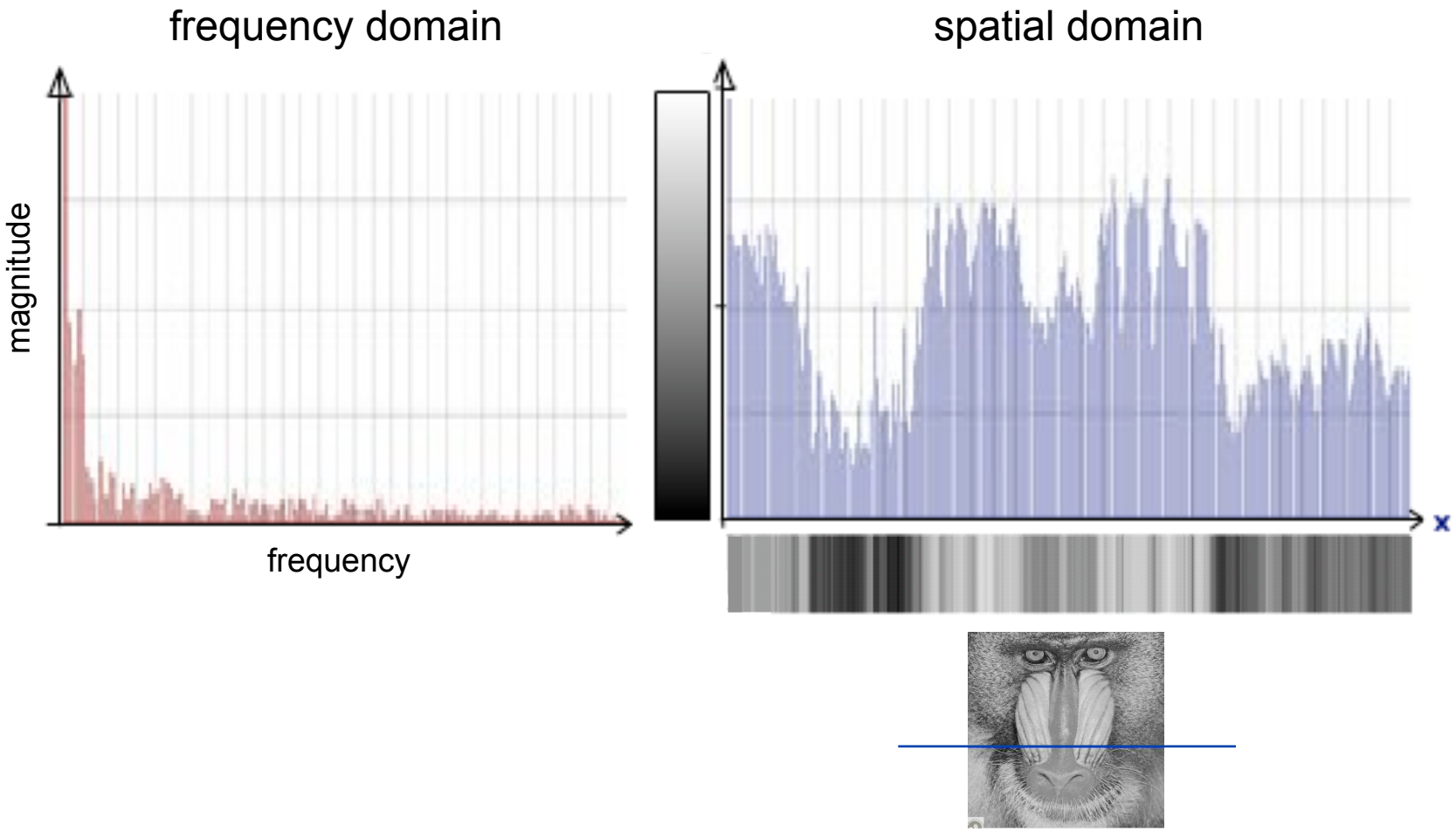
Fourier analysis



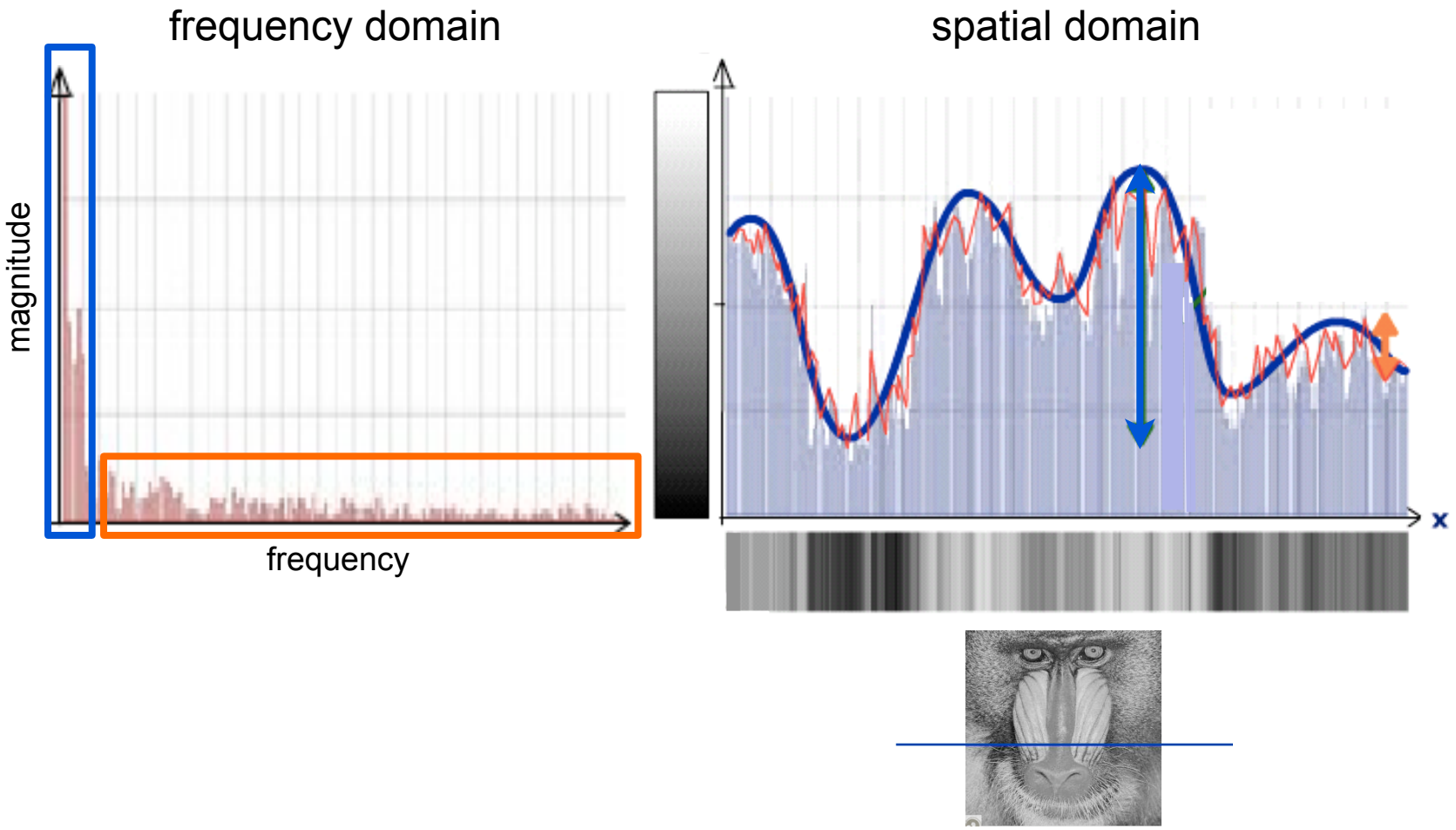
Fourier analysis



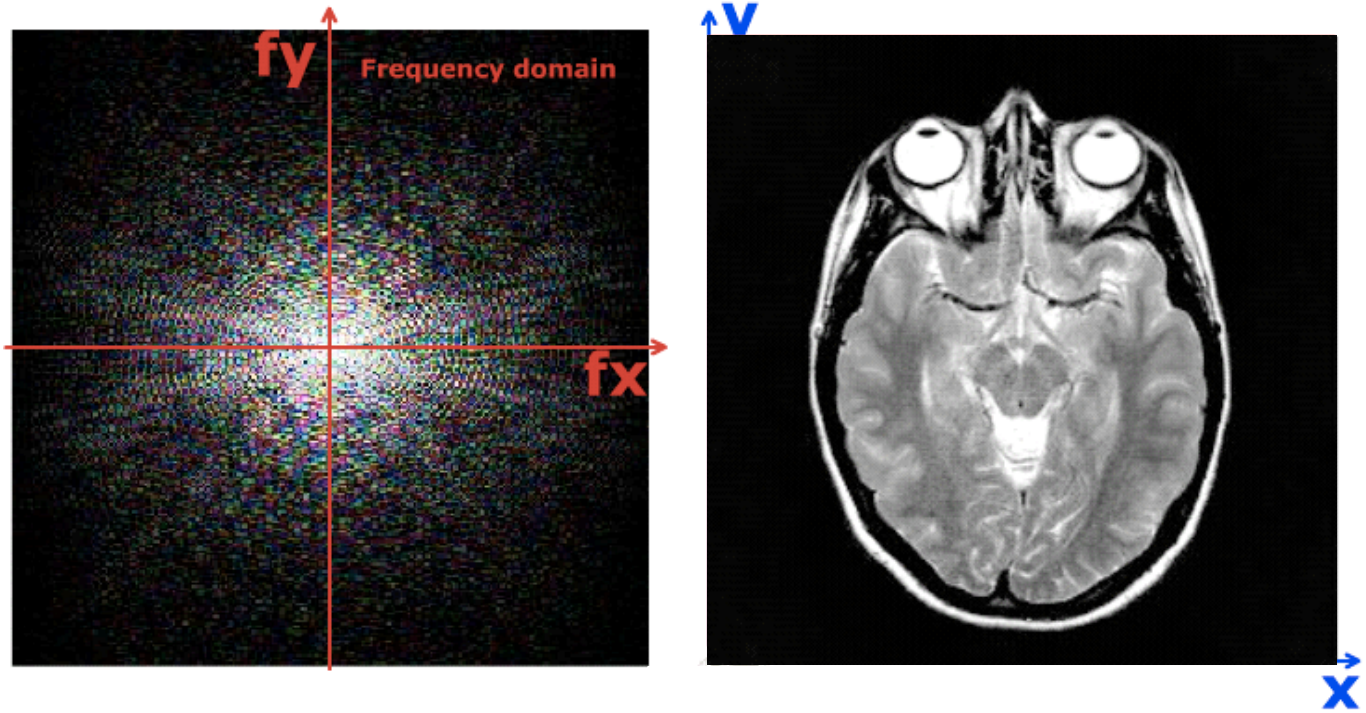
Fourier analysis



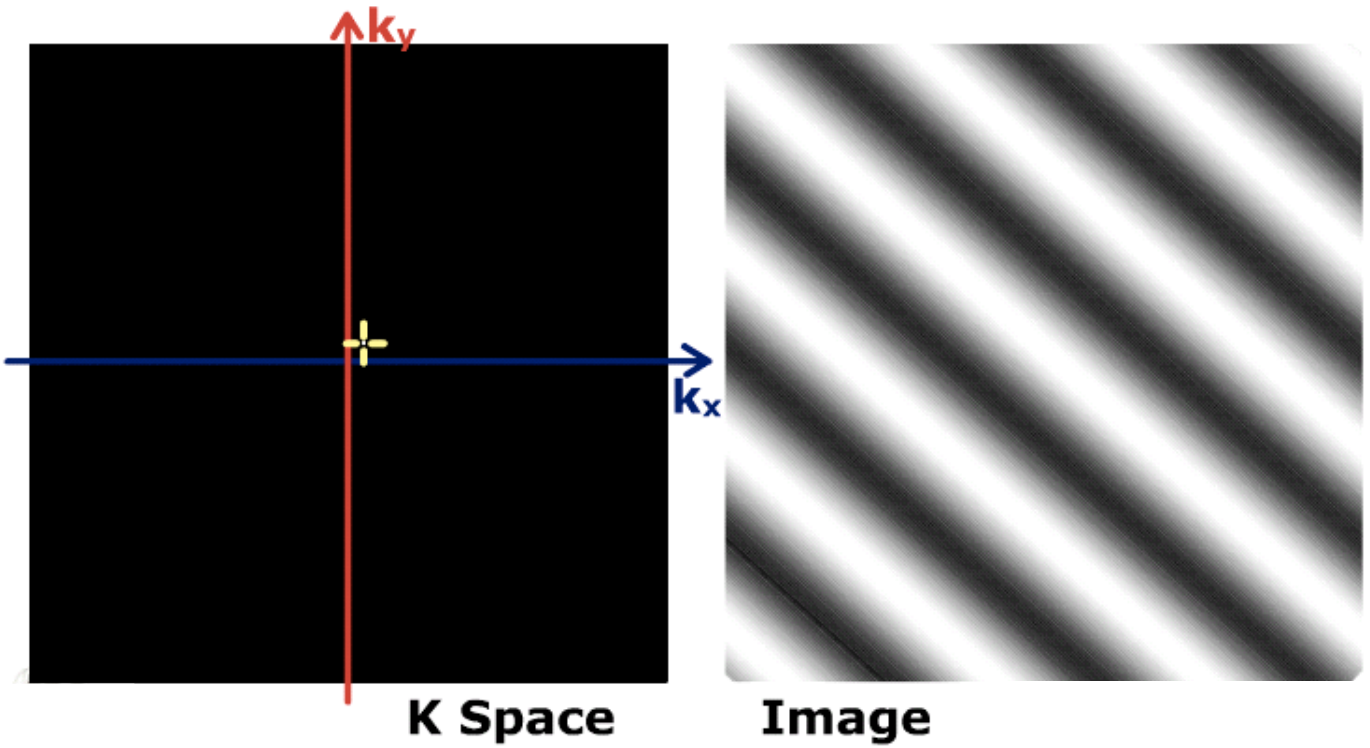
Fourier analysis



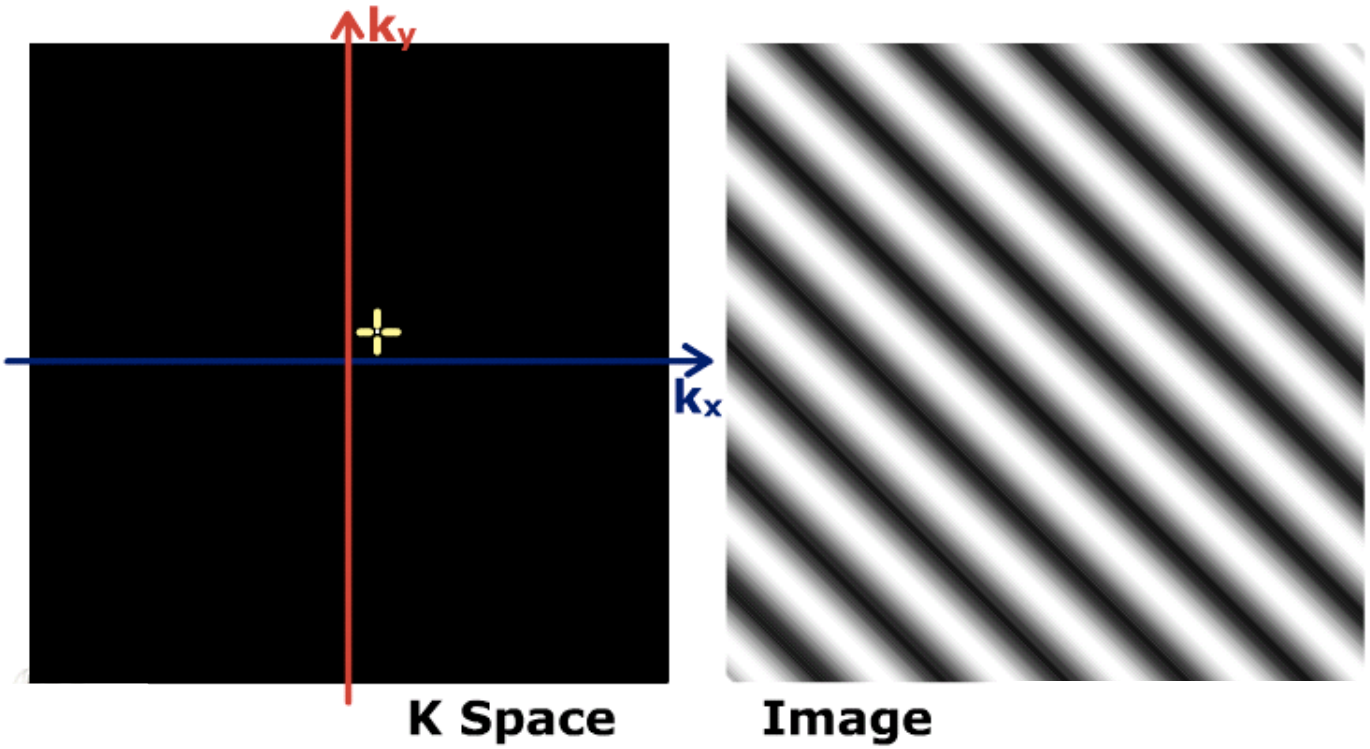
k-space



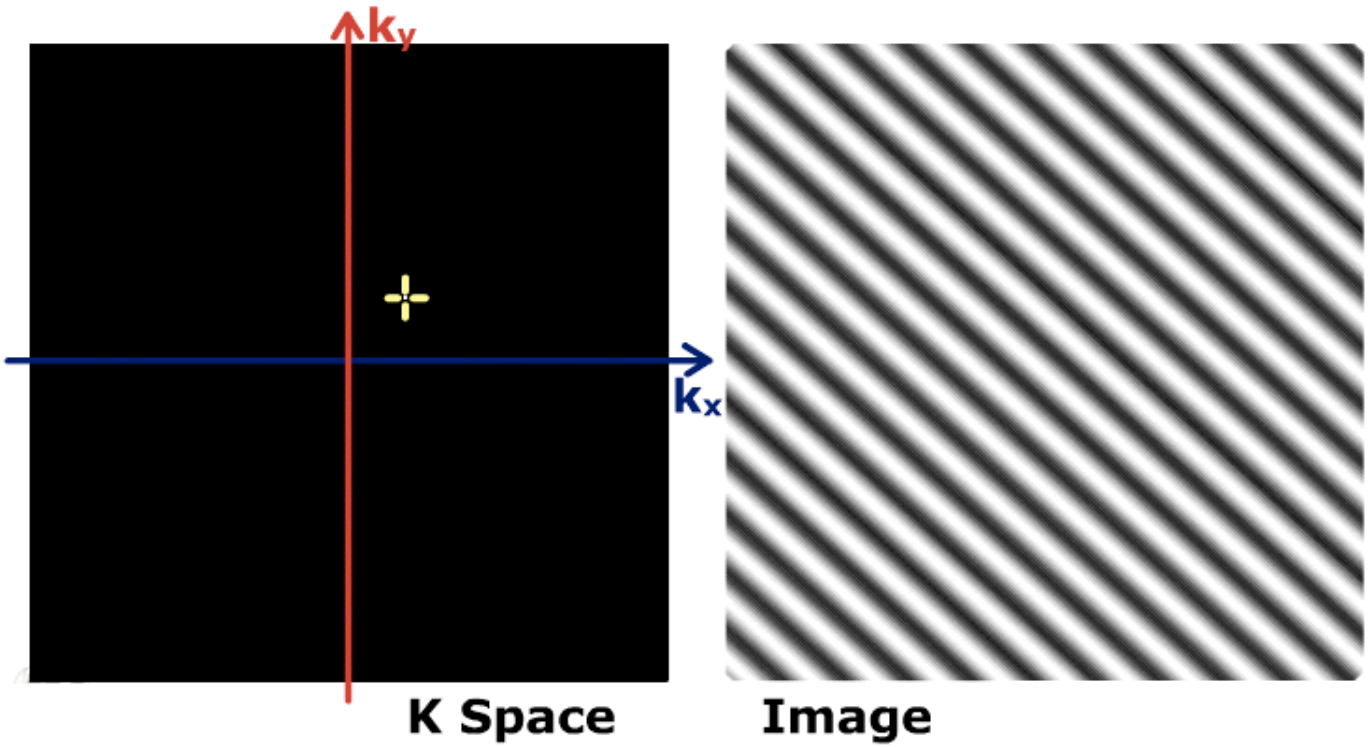
k-space



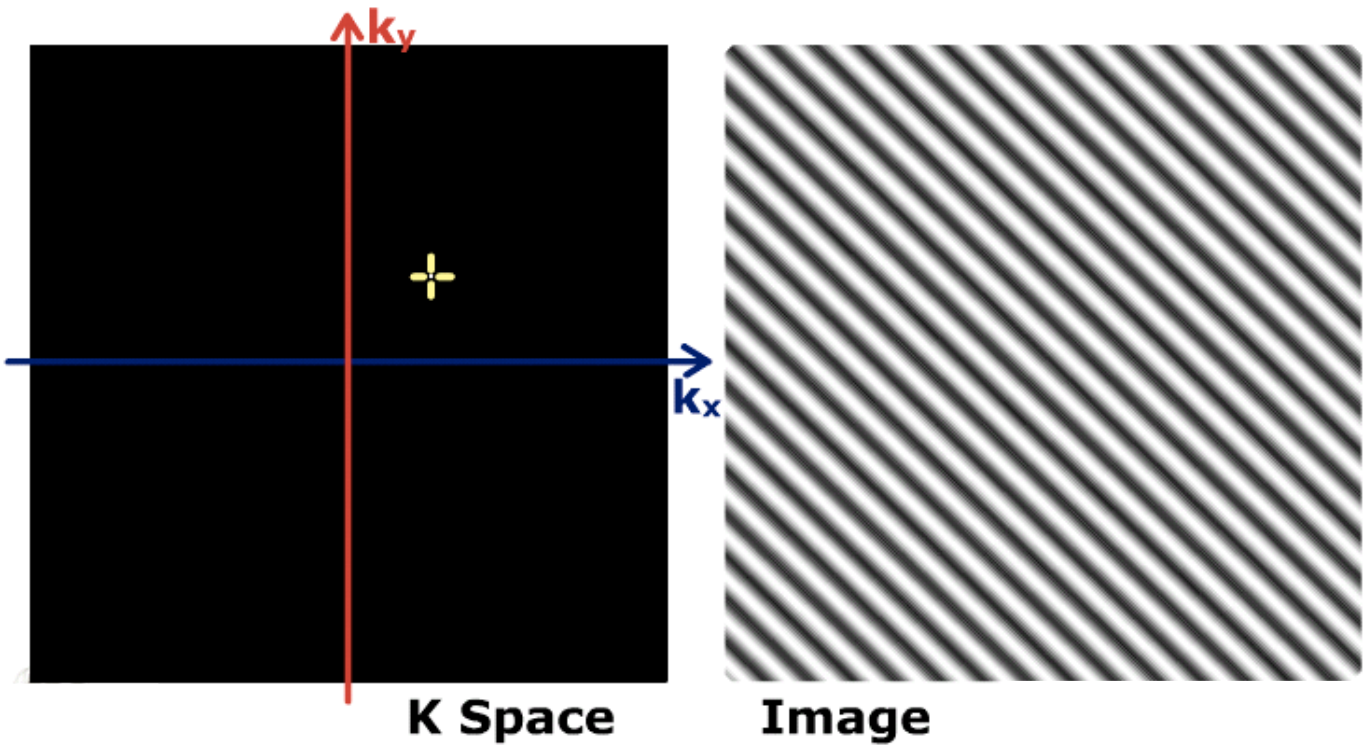
k-space



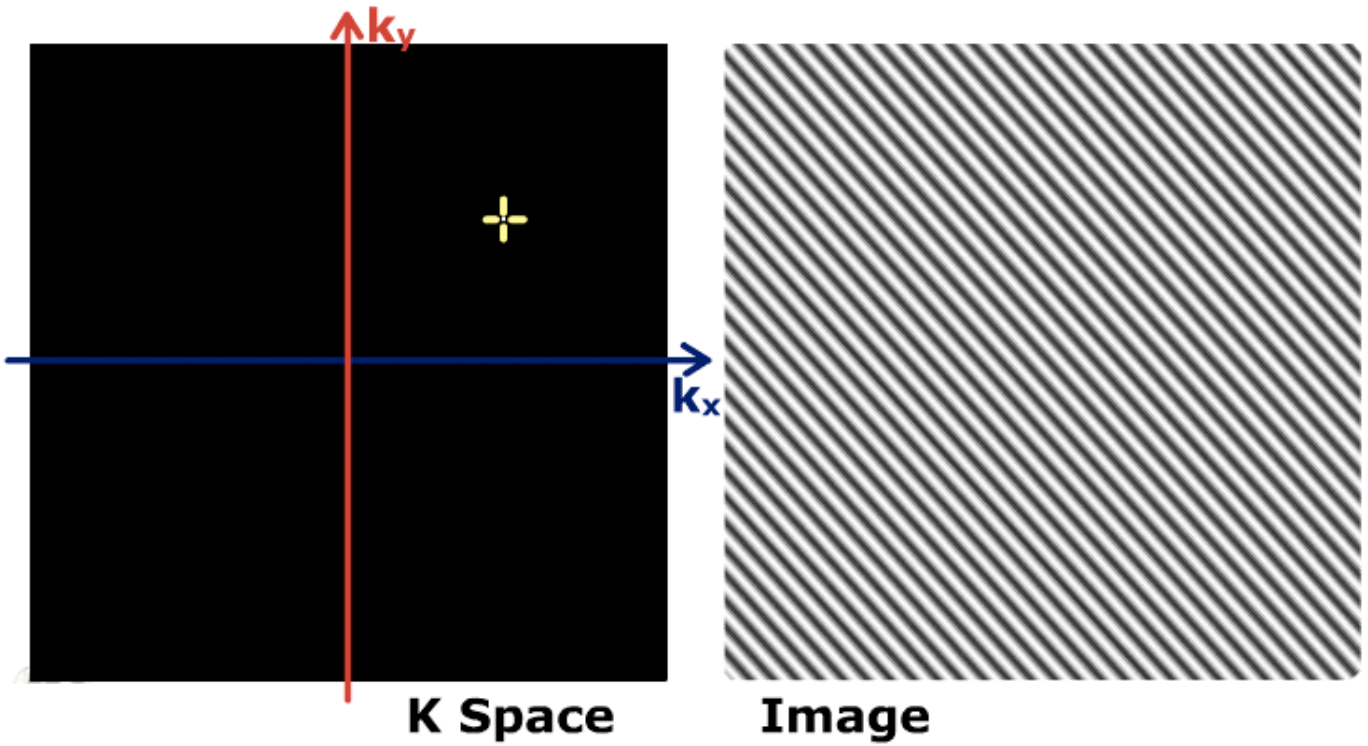
k-space



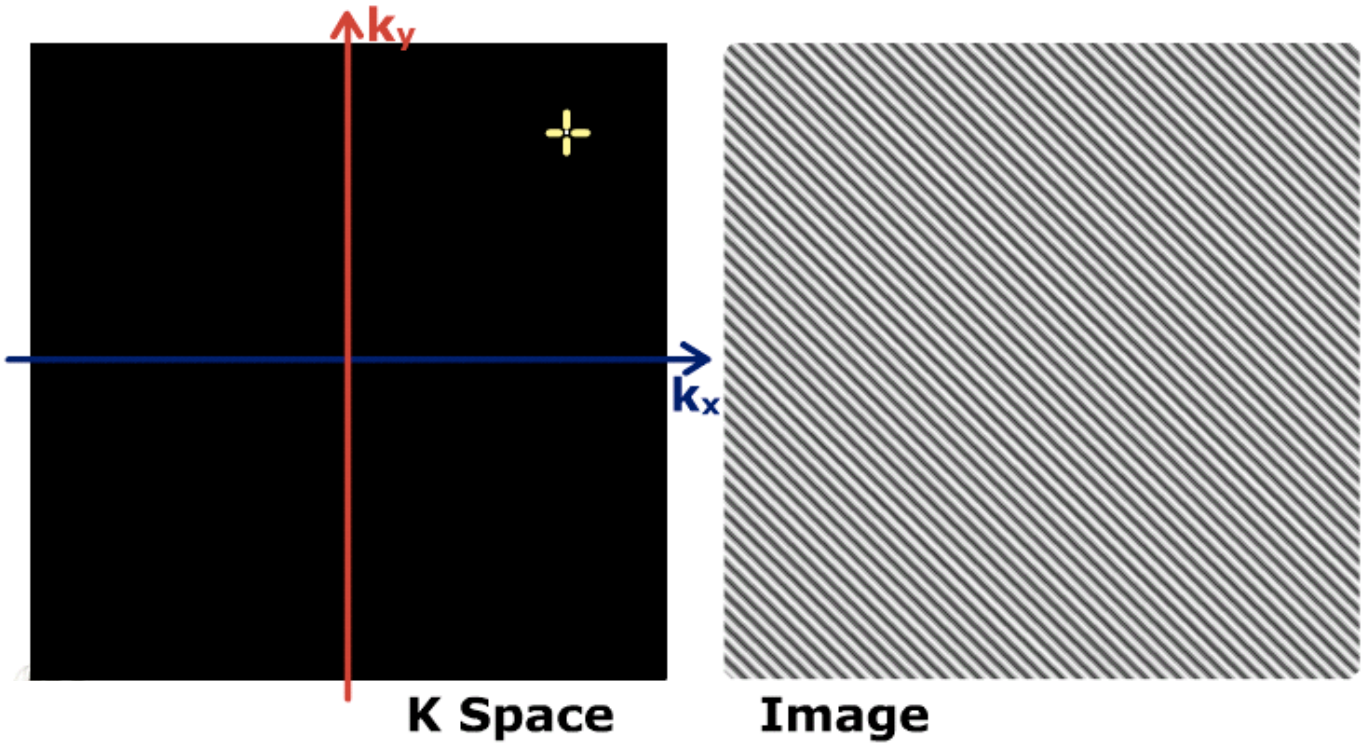
k-space



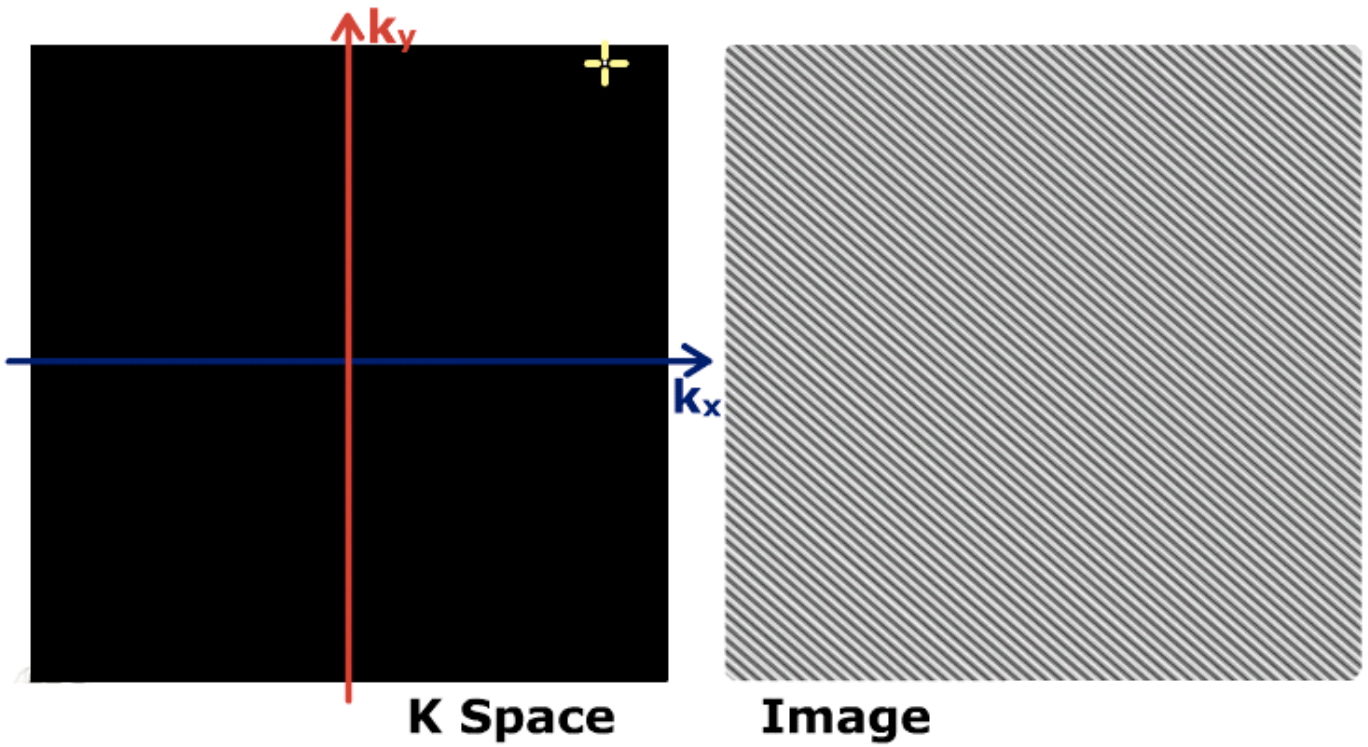
k-space



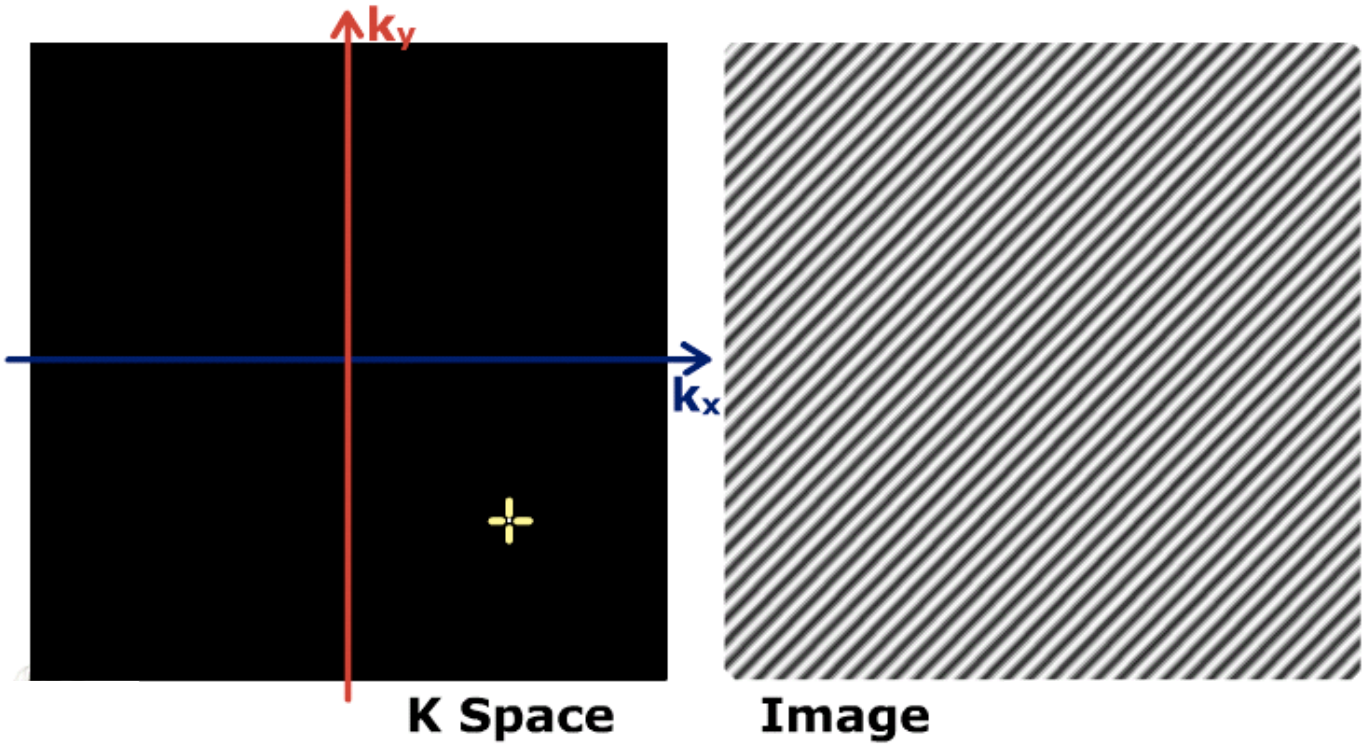
k-space



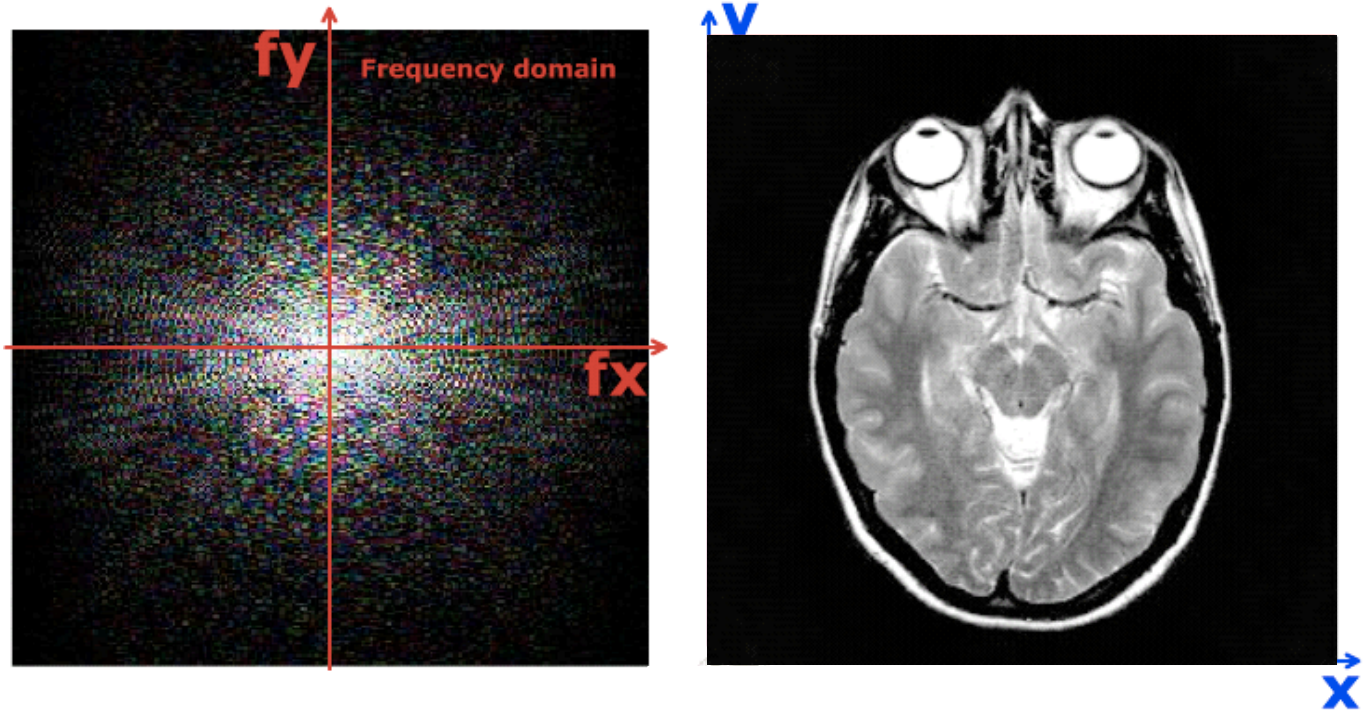
k-space



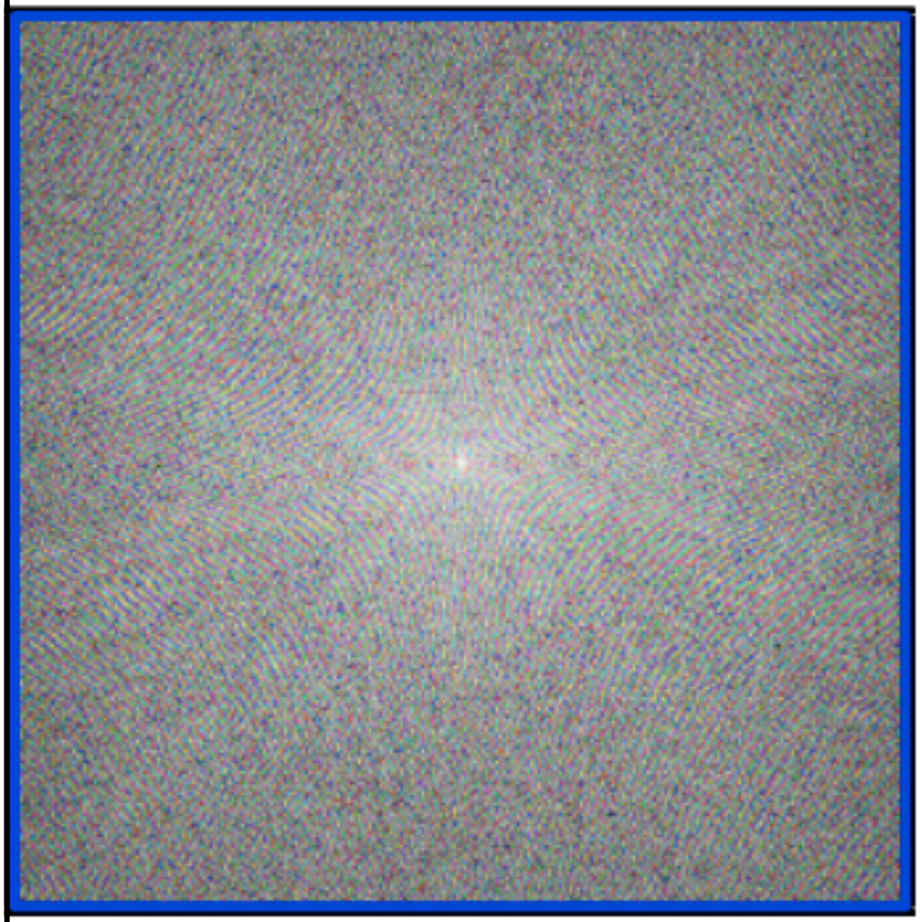
k-space

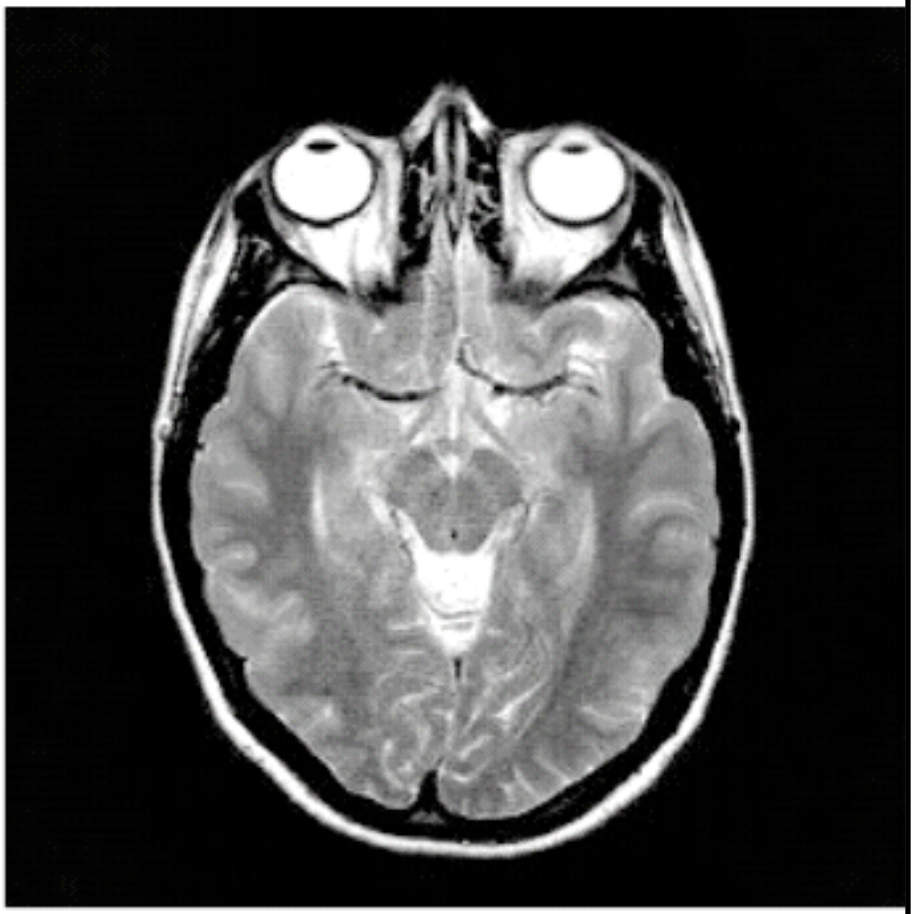


k-space

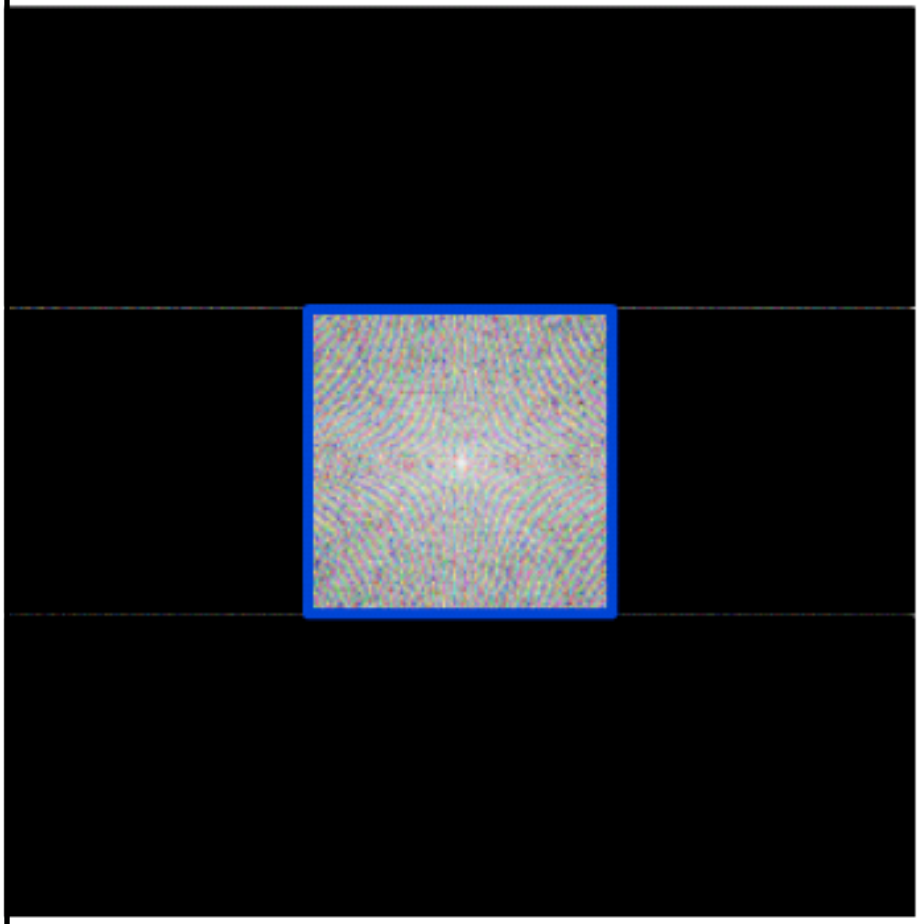


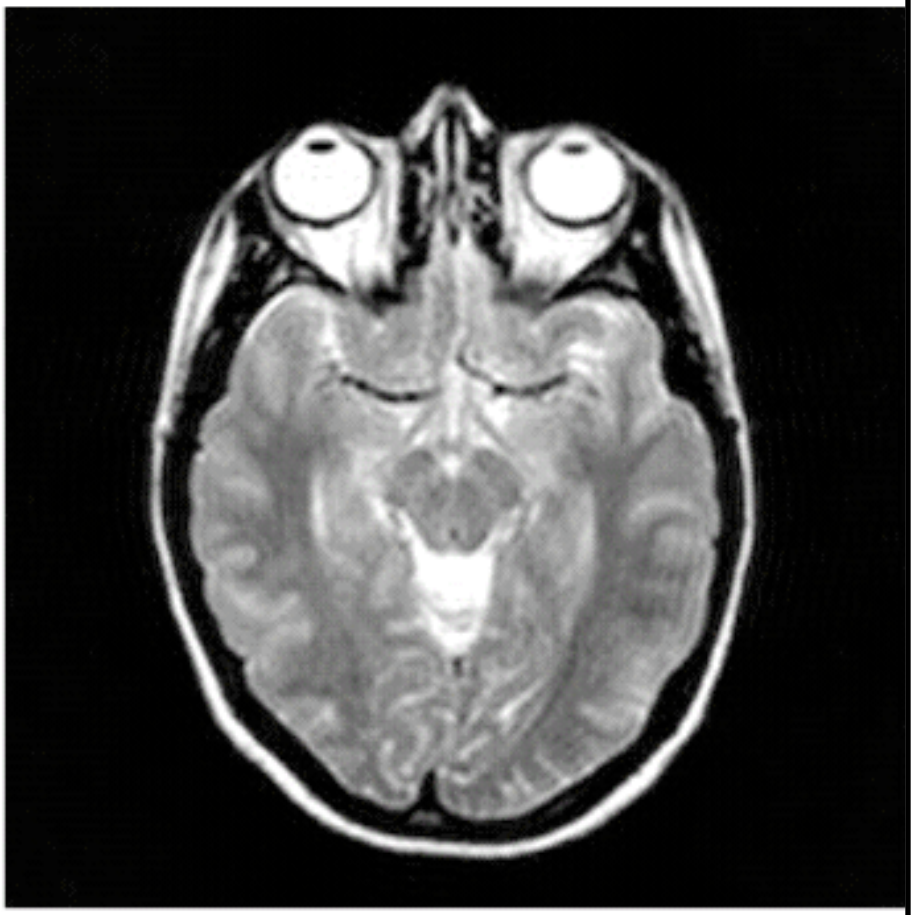
k-space



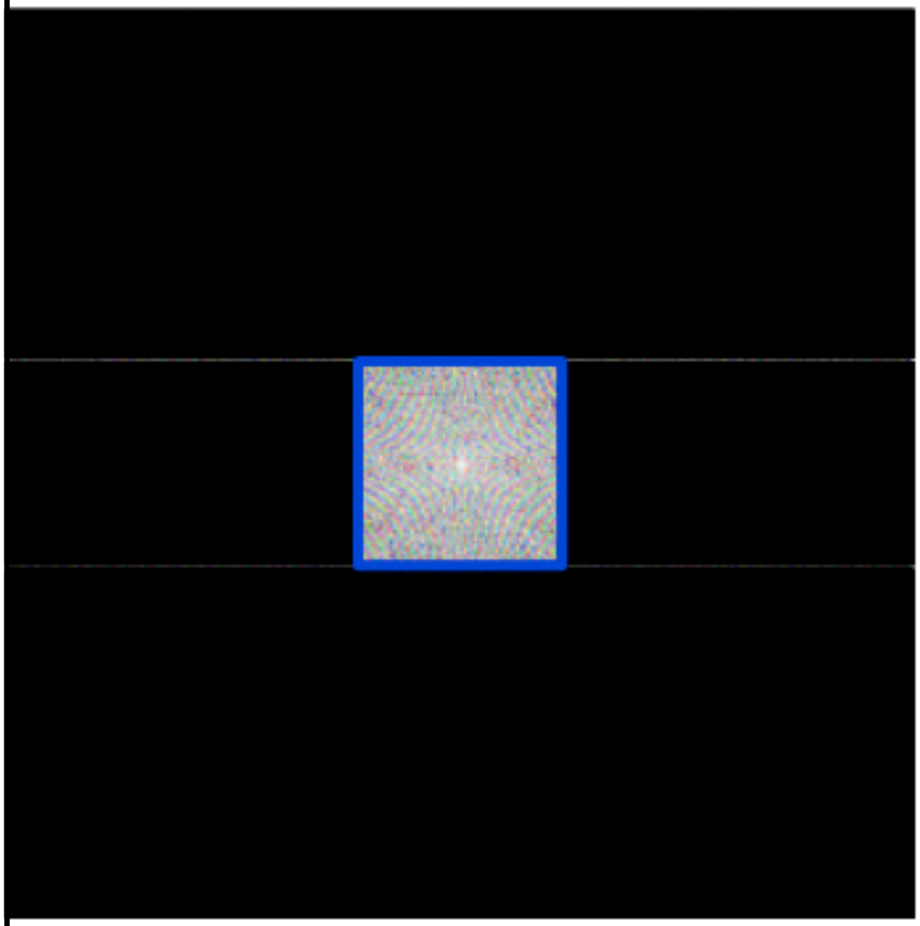


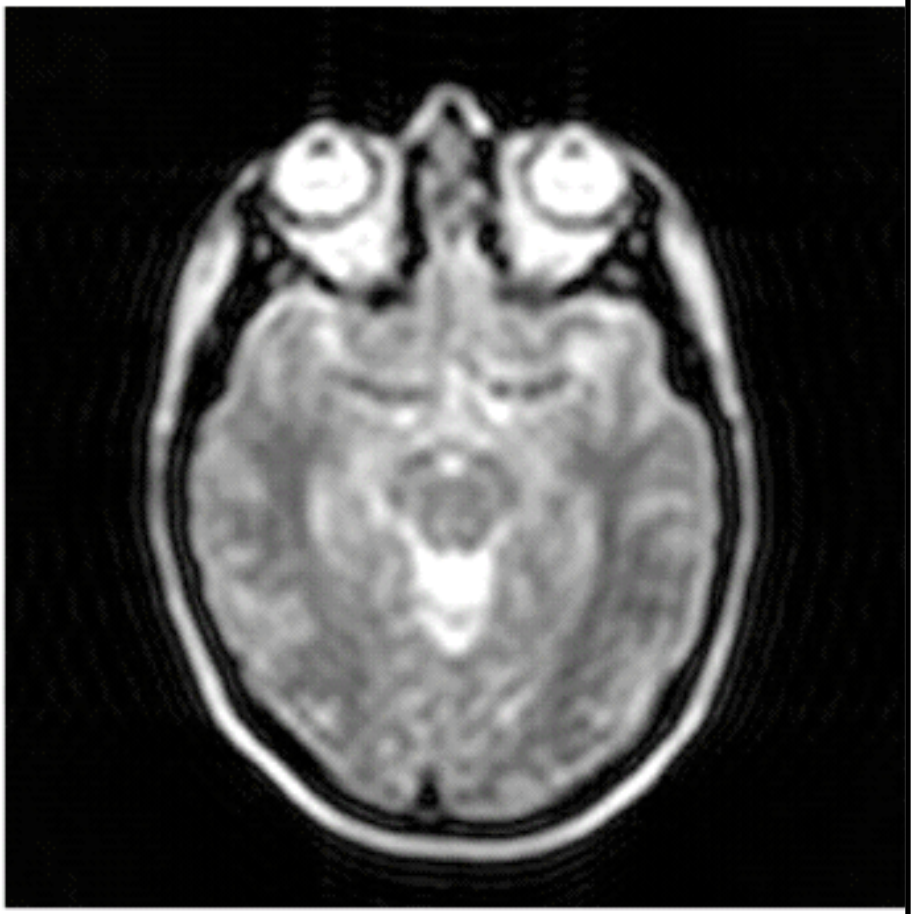
k-space



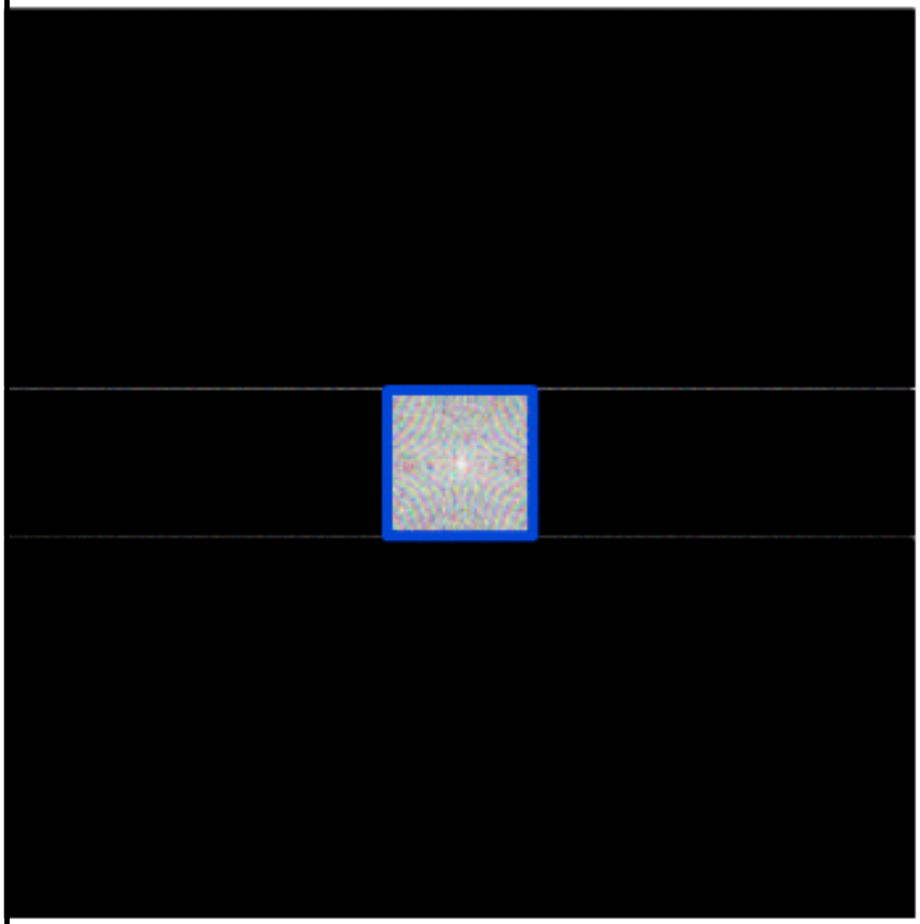


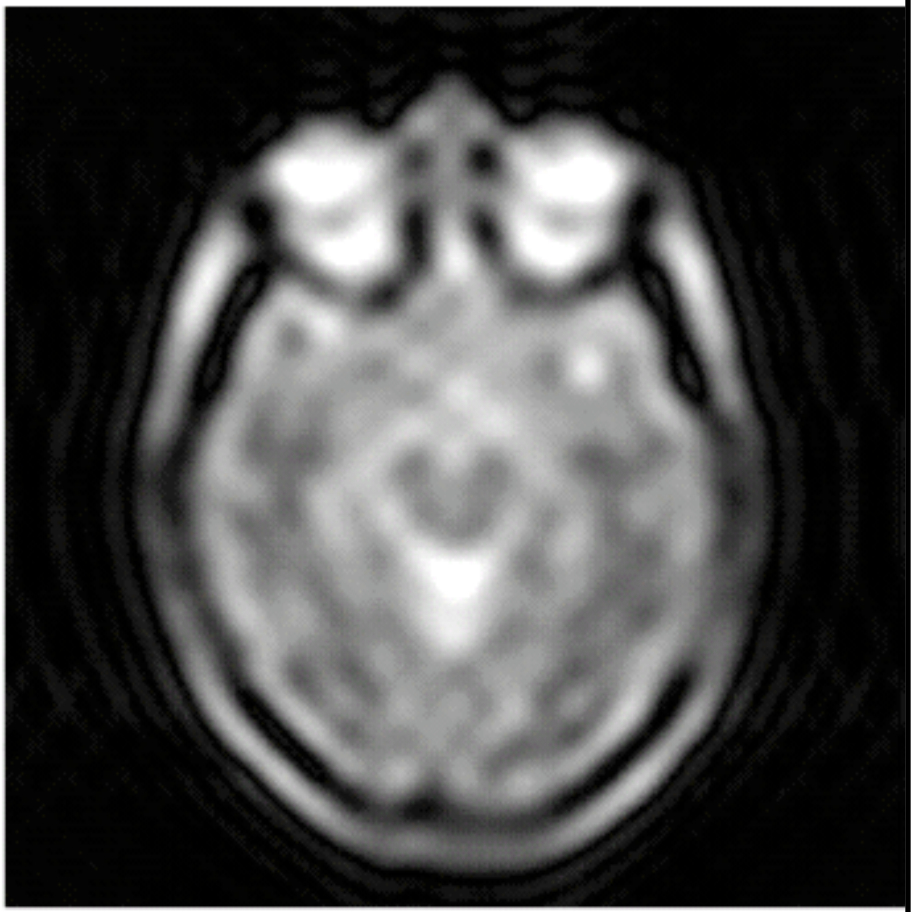
k-space



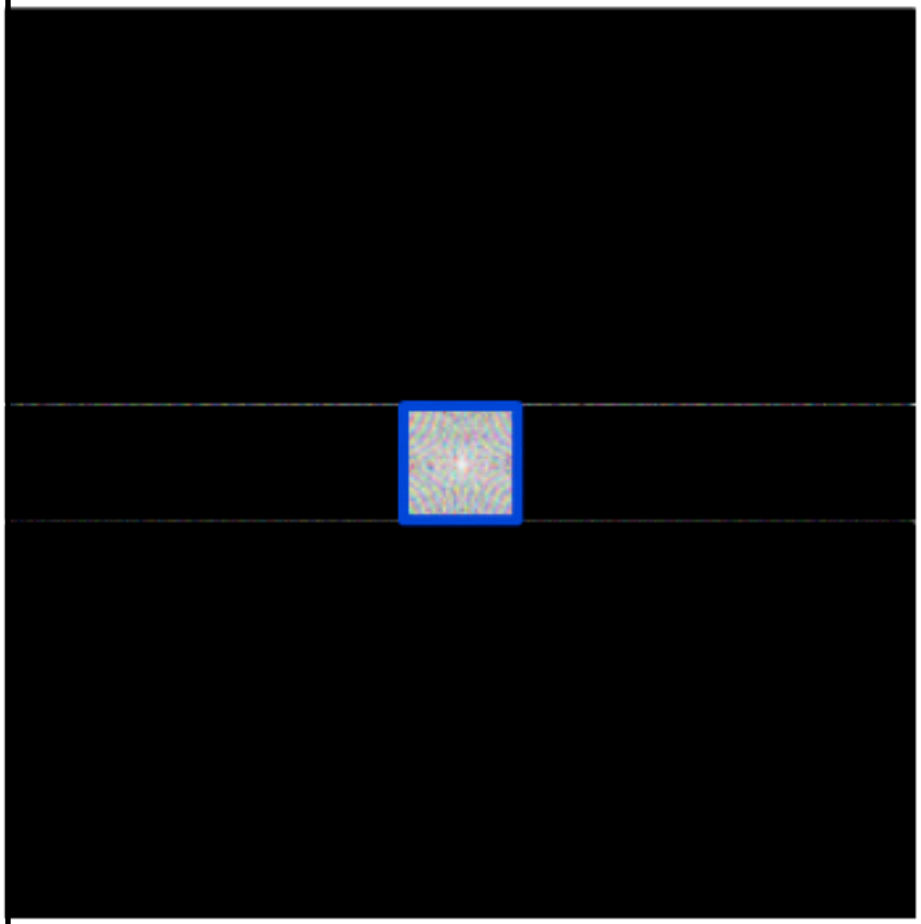


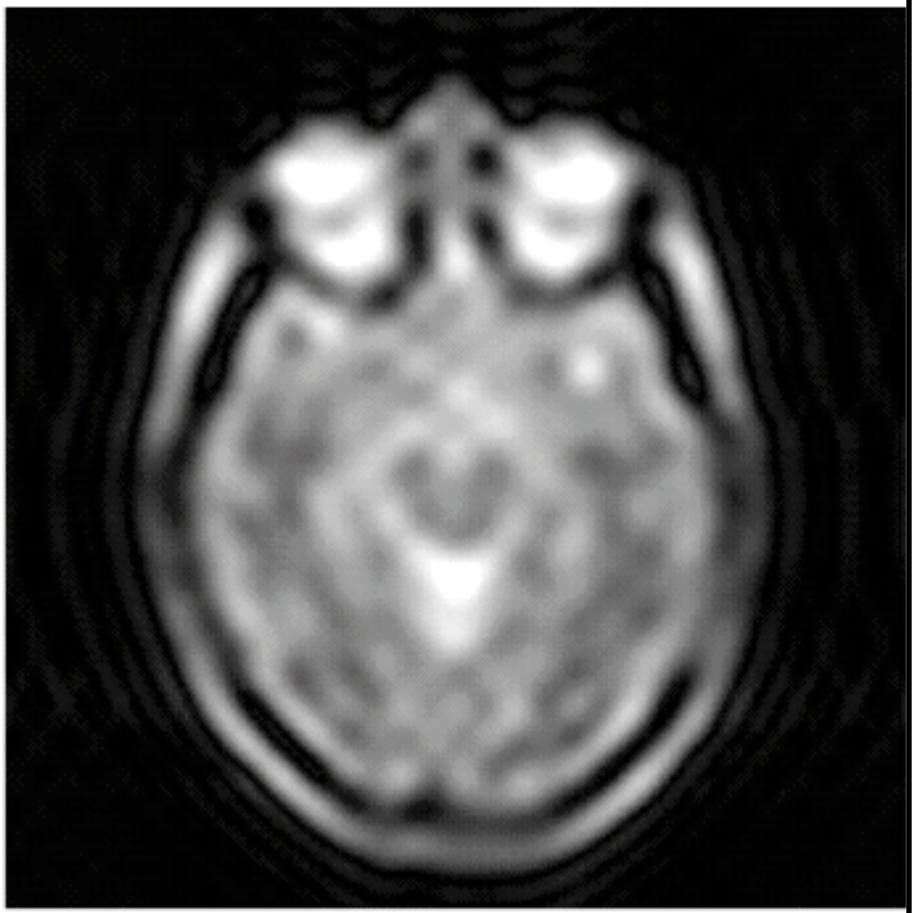
k-space



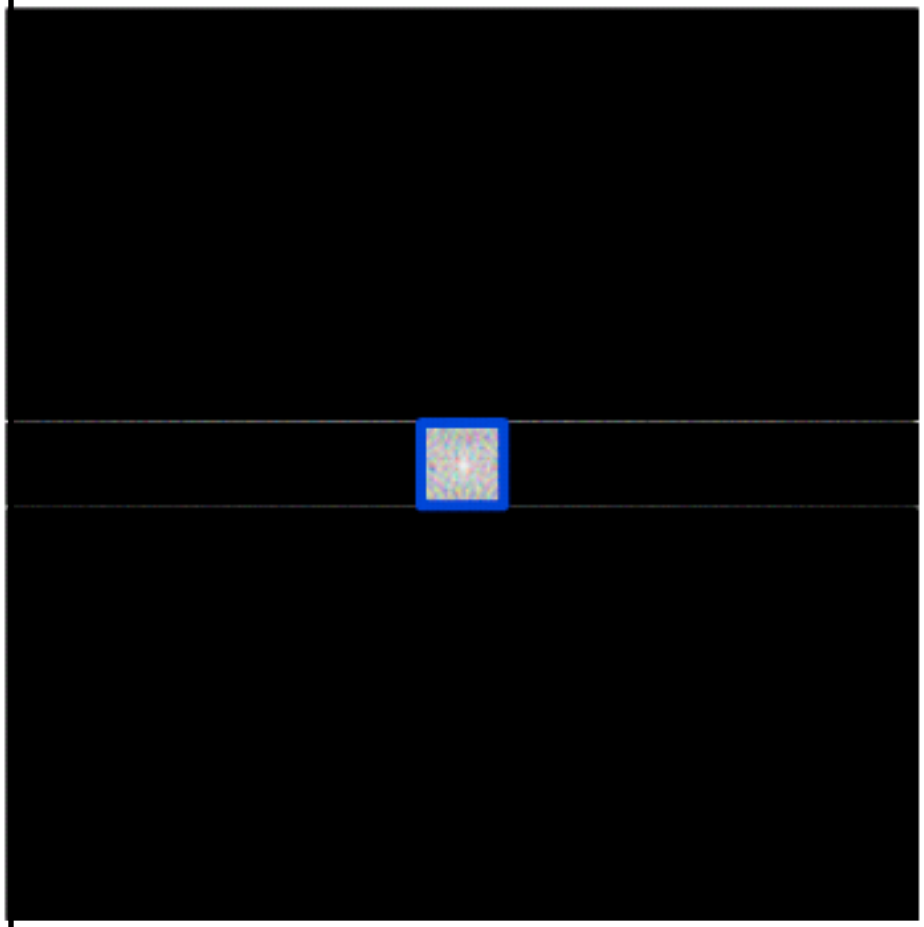


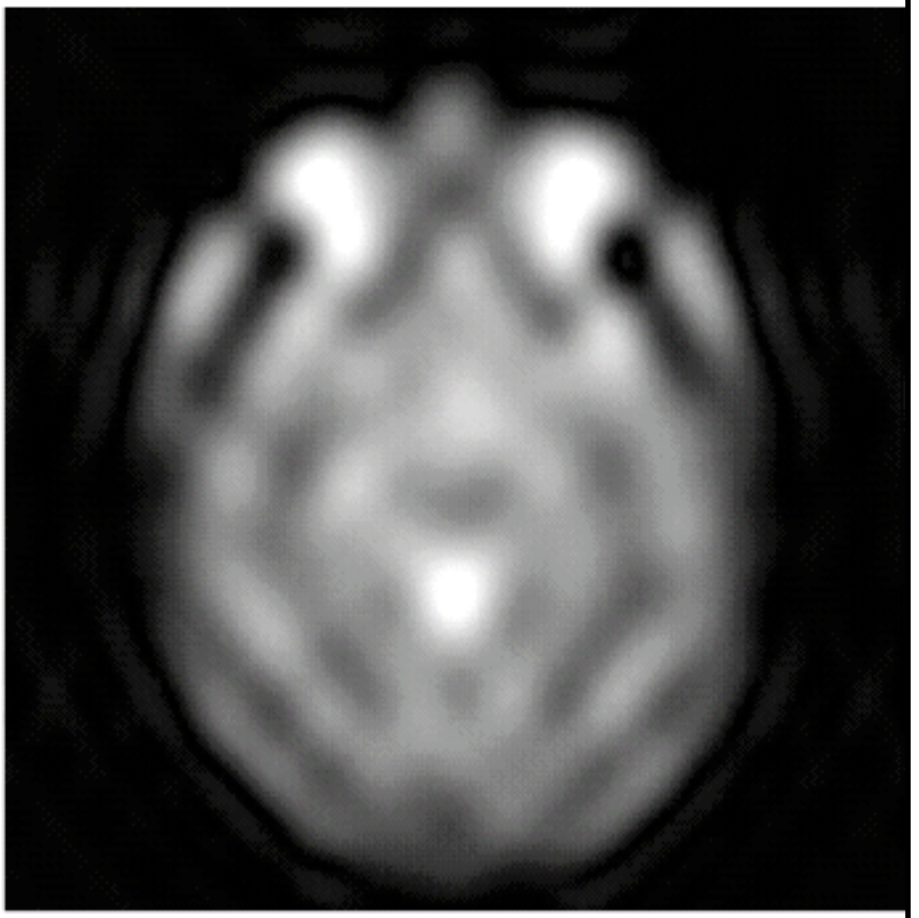
k-space



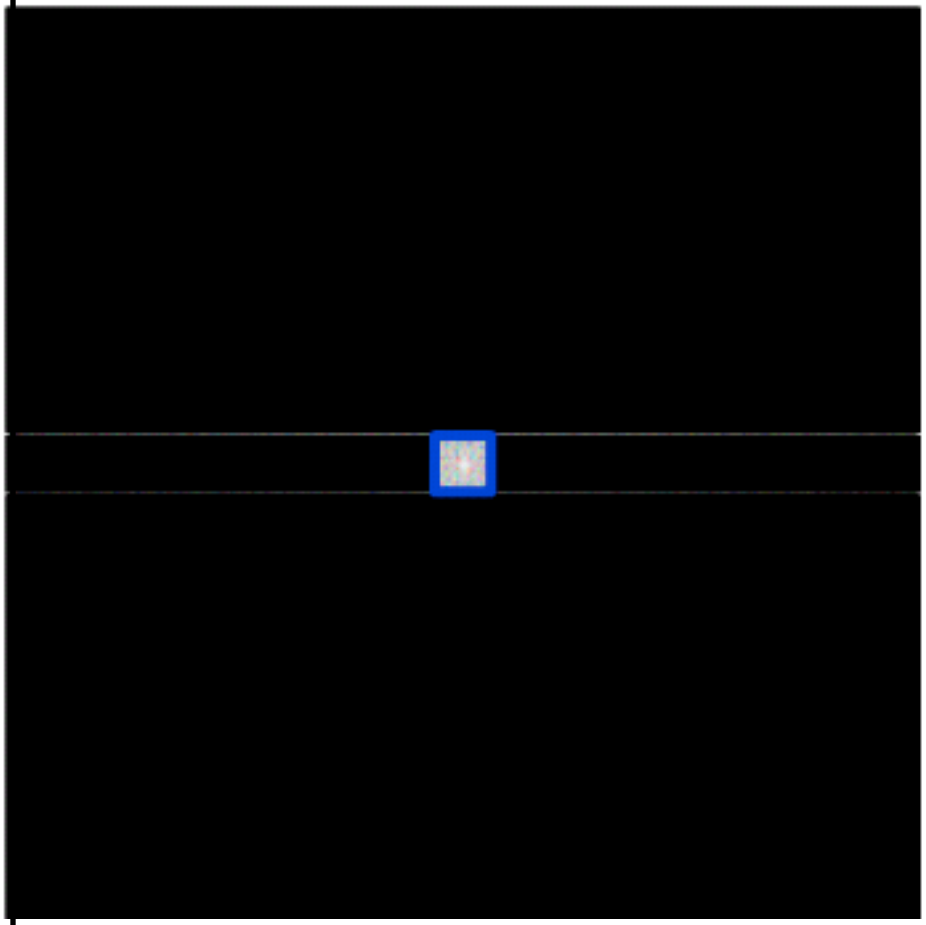


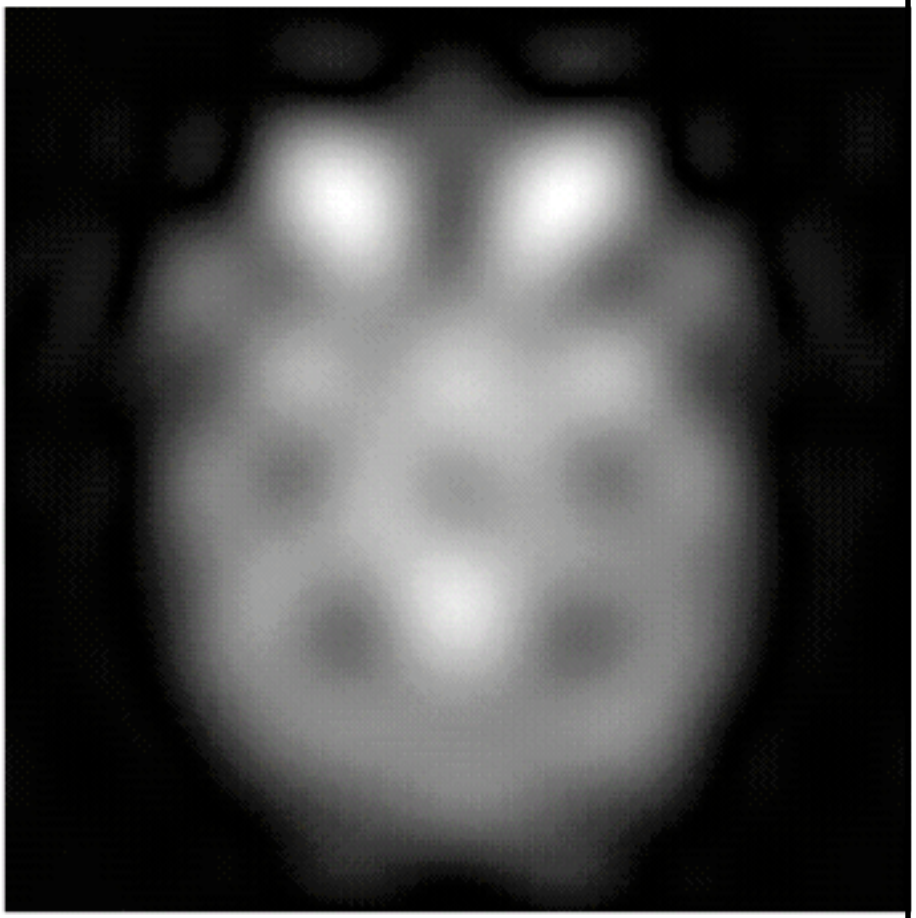
k-space



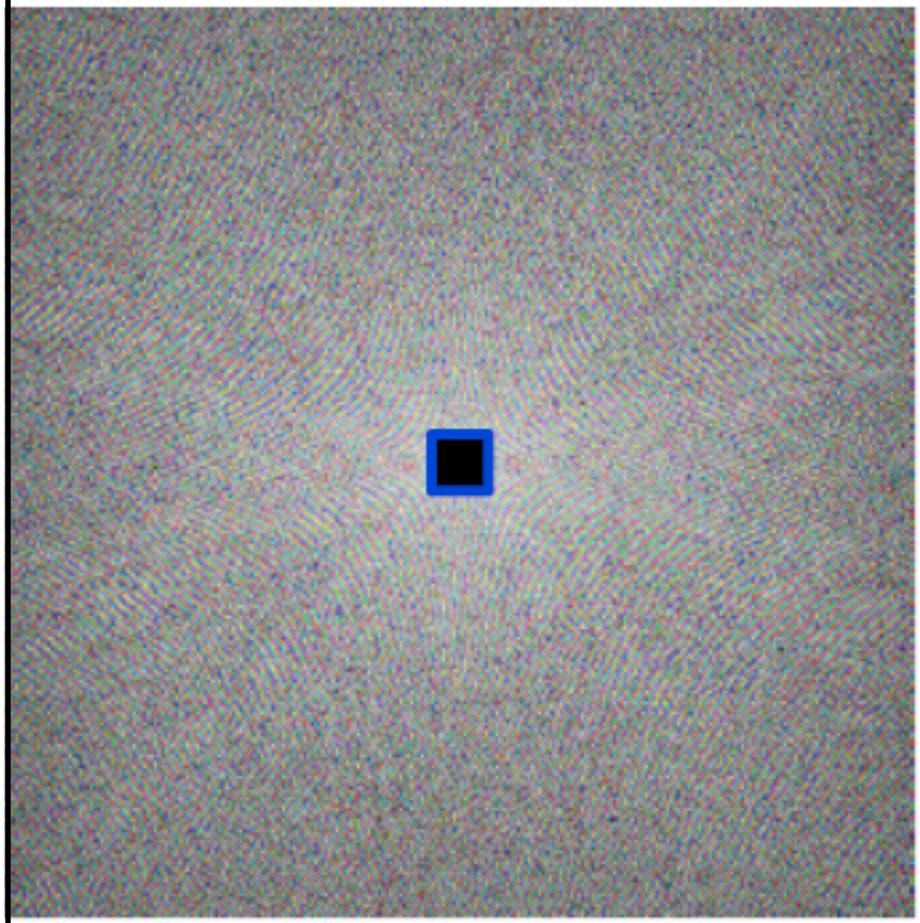


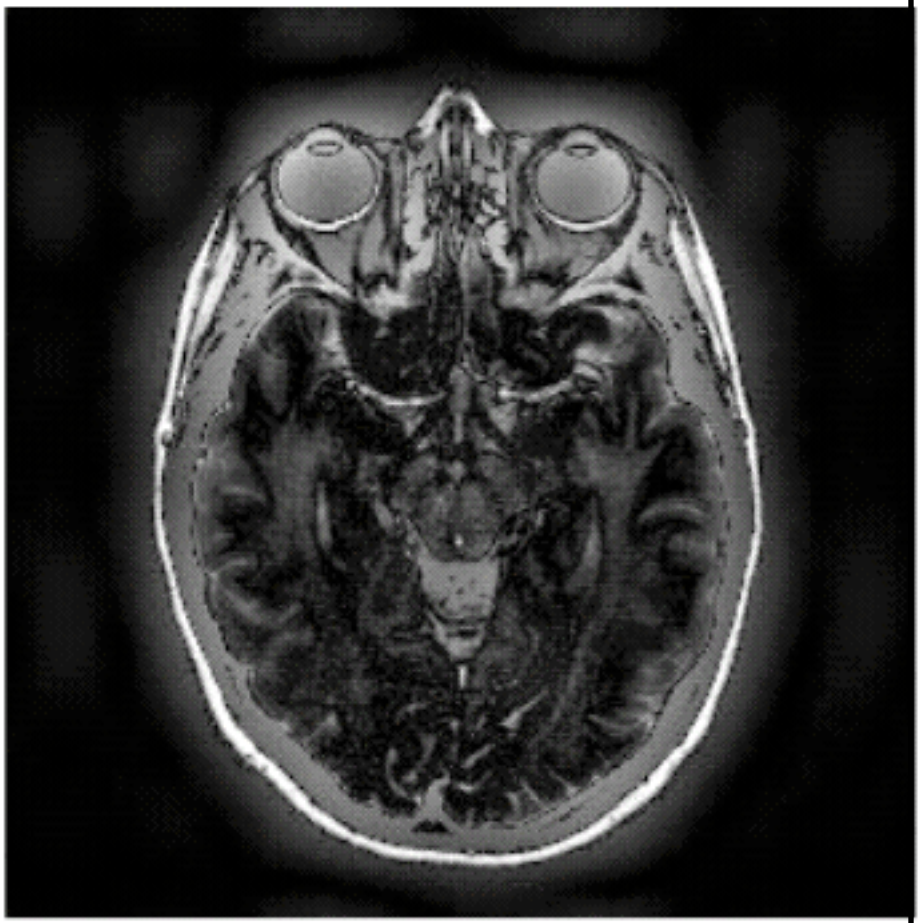
k-space



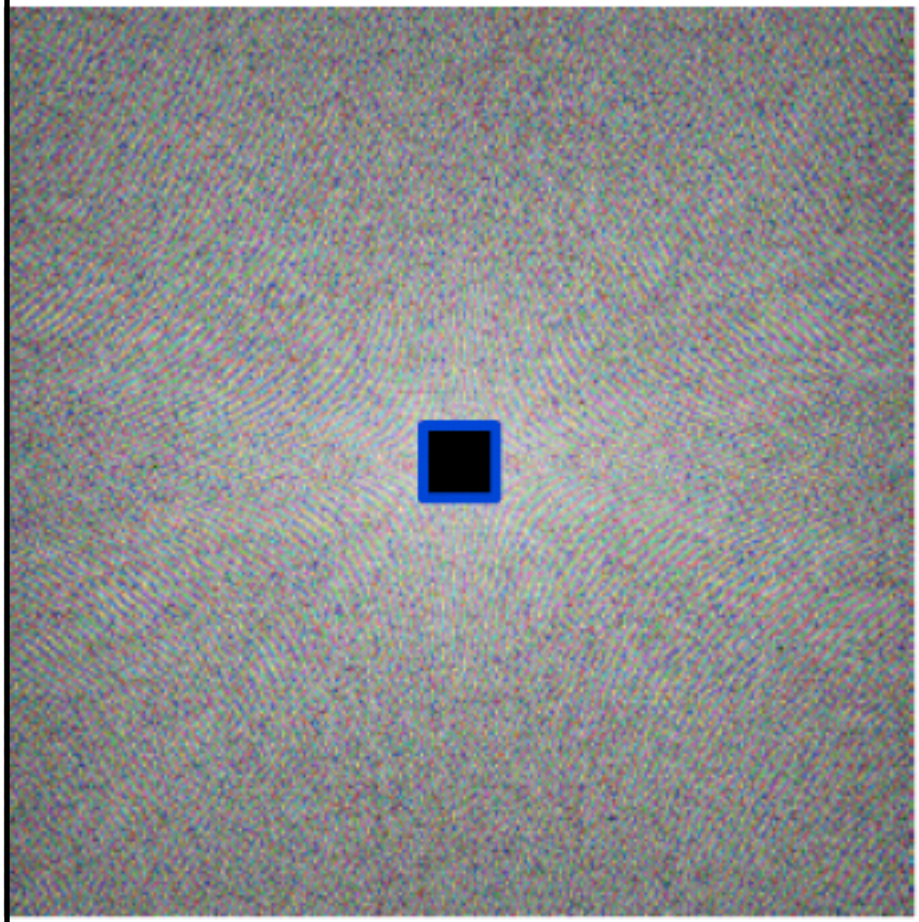


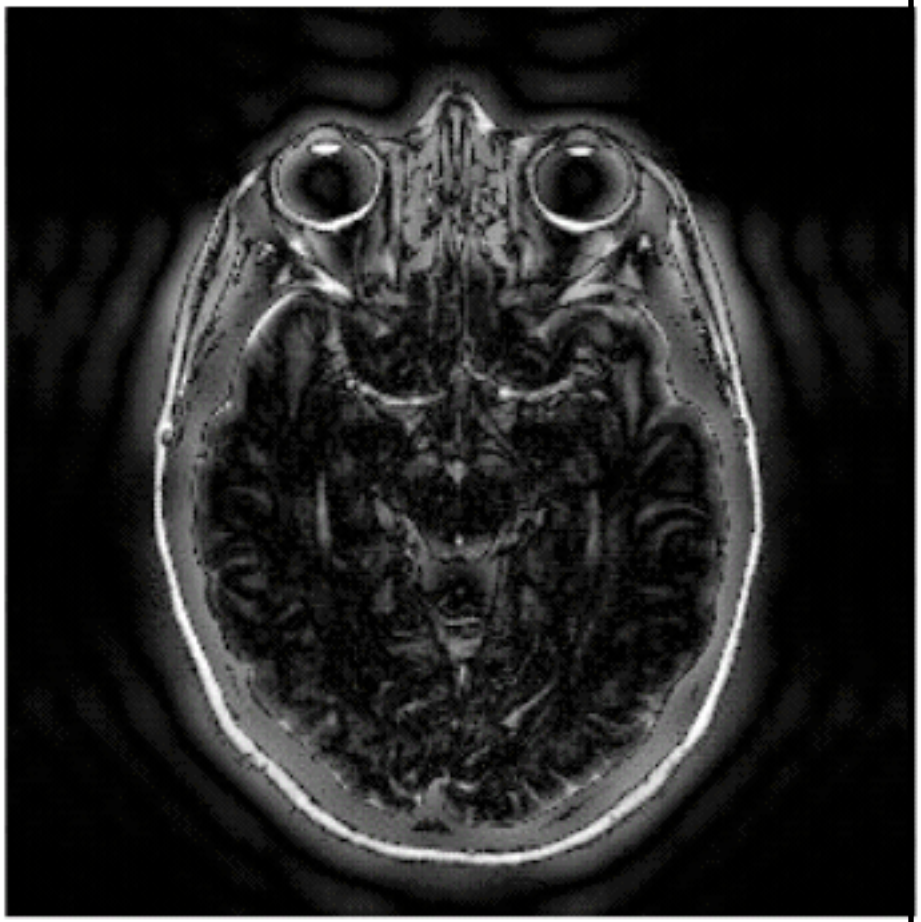
k-space



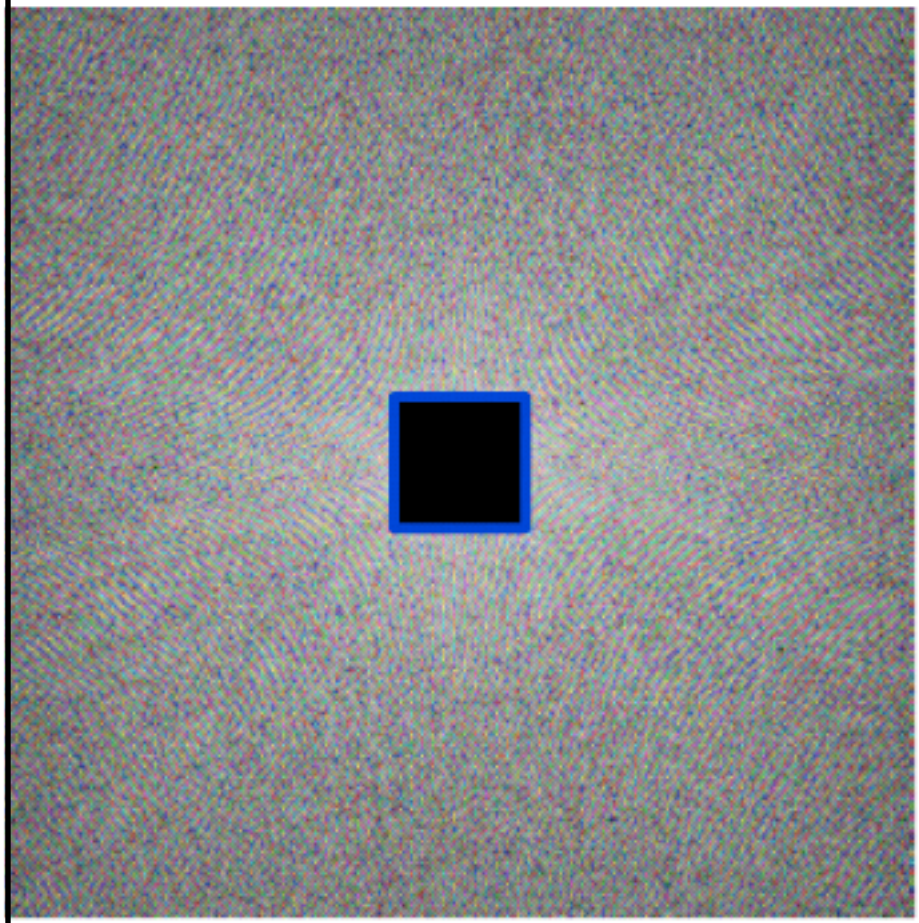


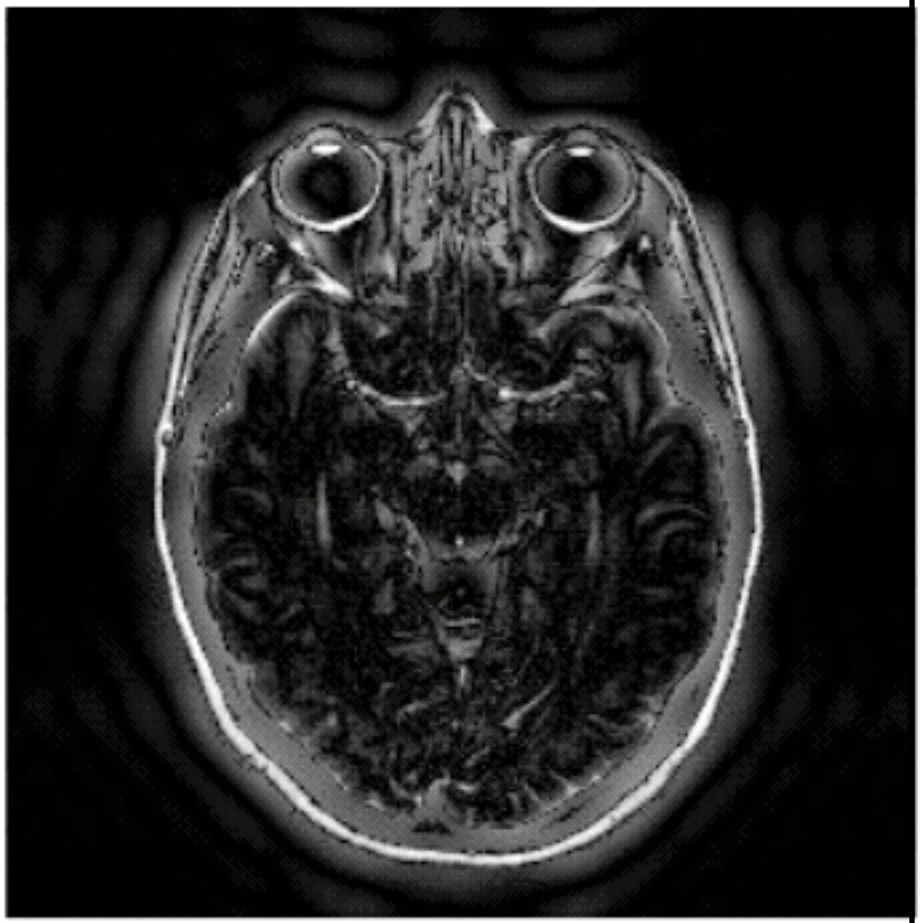
k-space



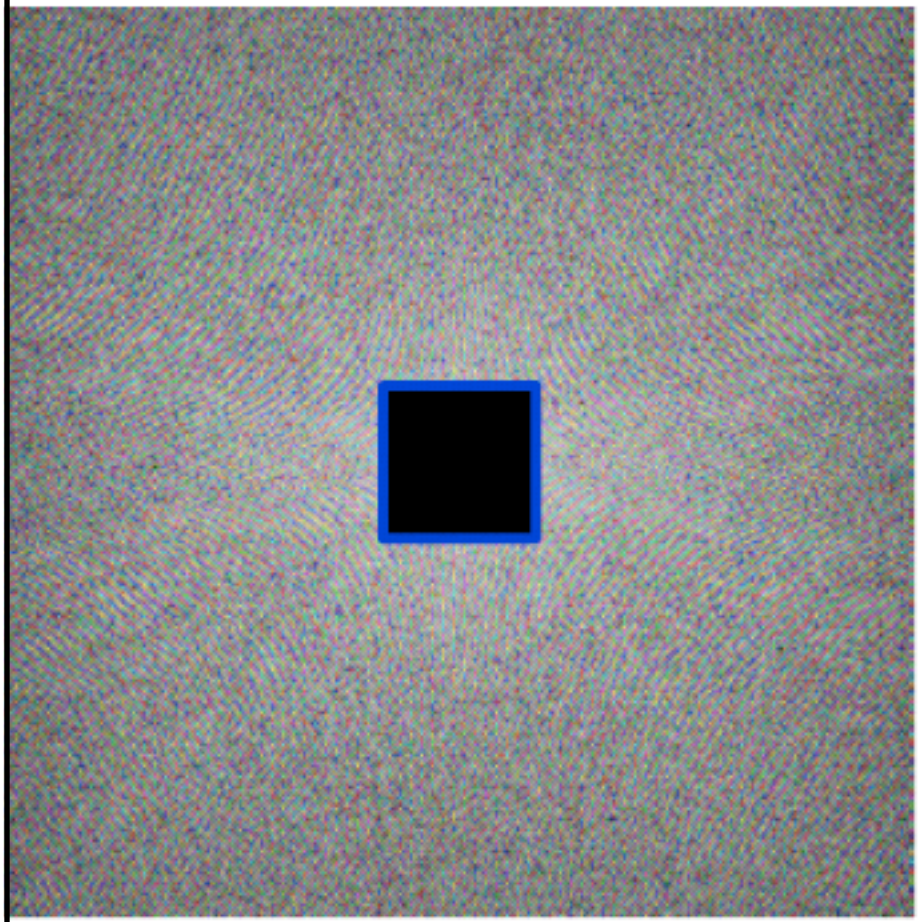


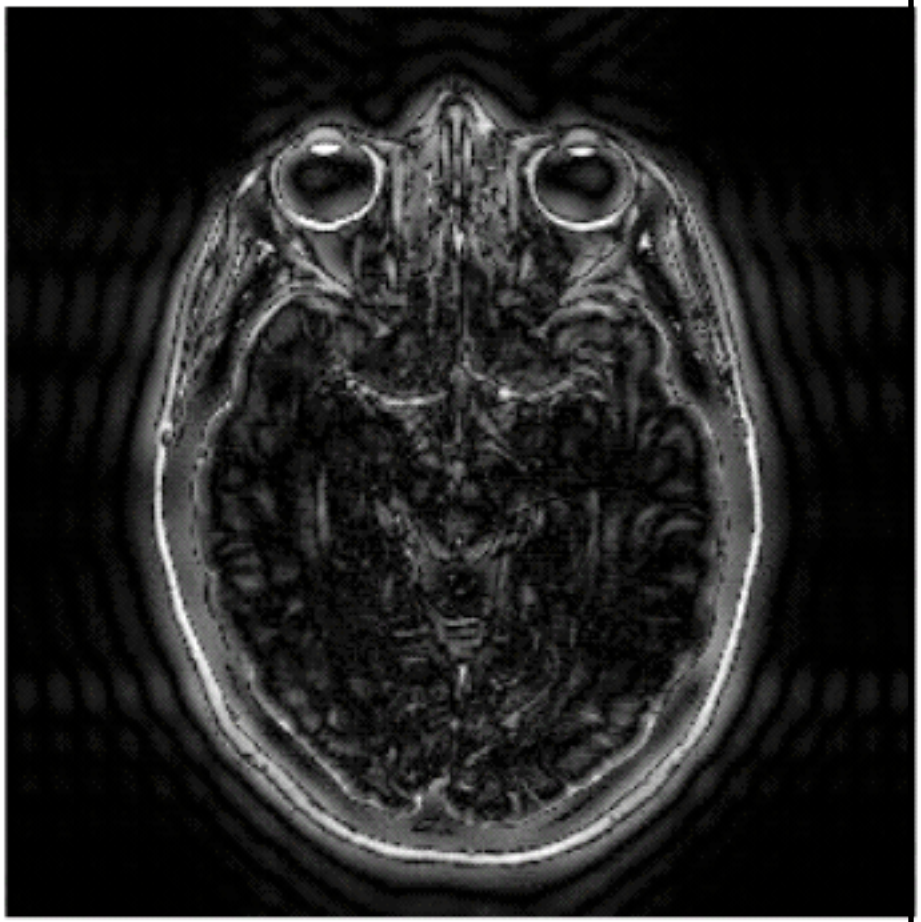
k-space



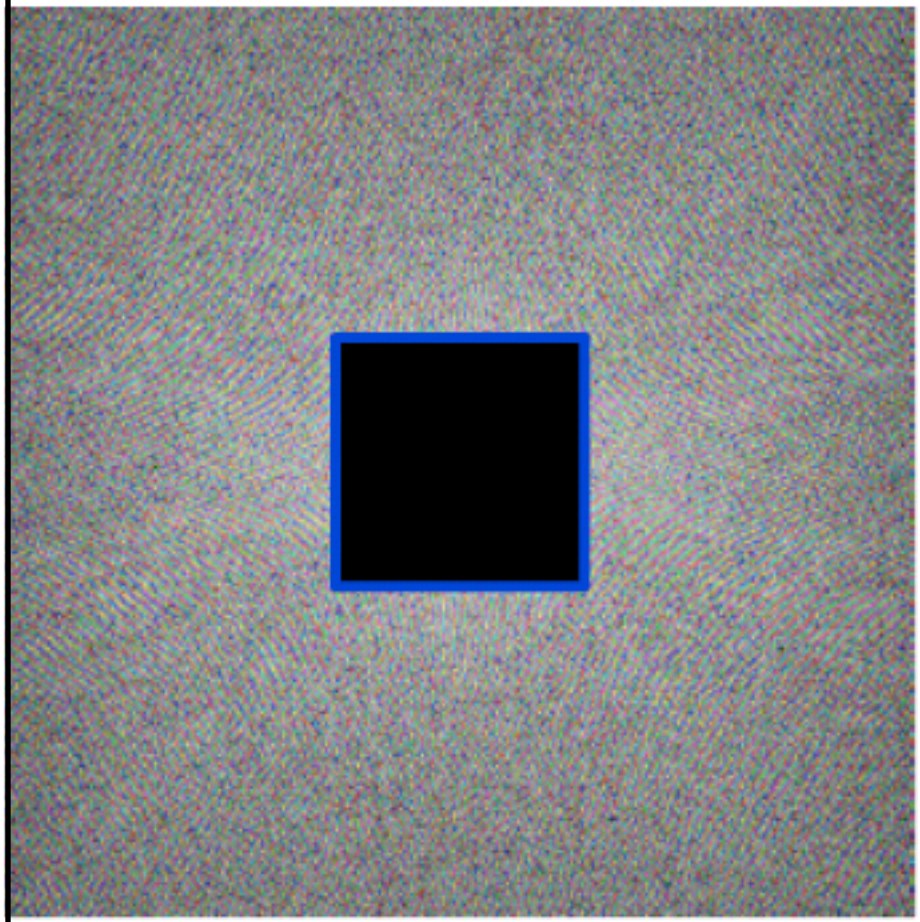


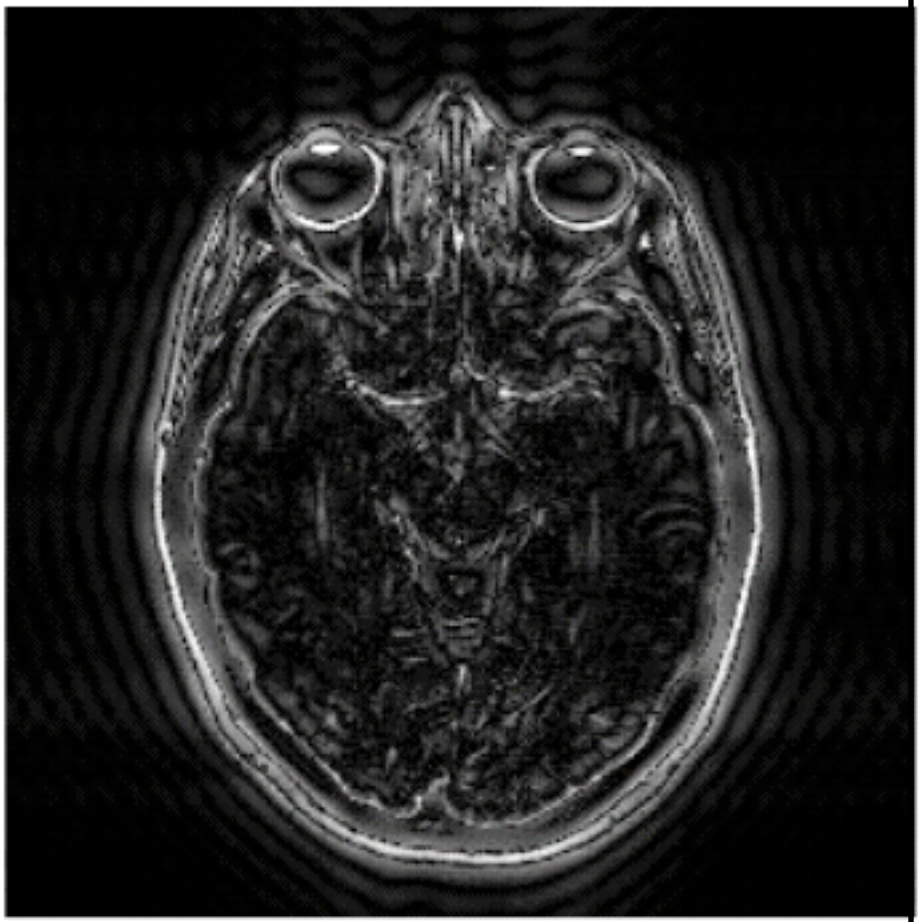
k-space



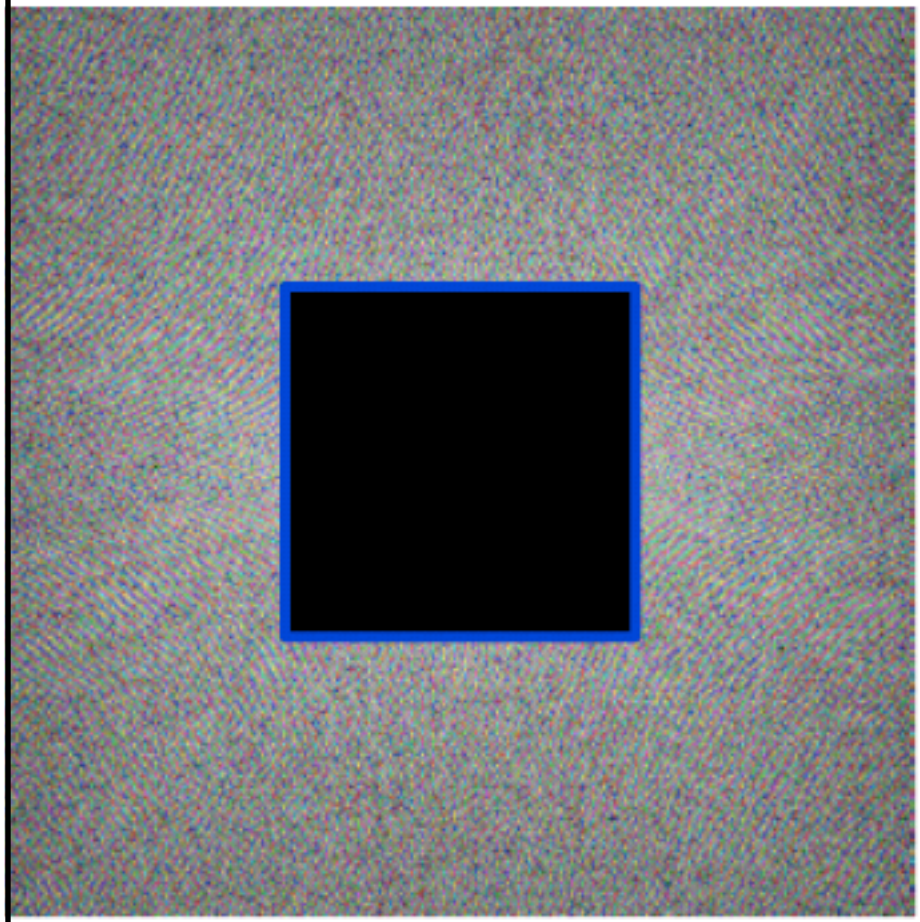


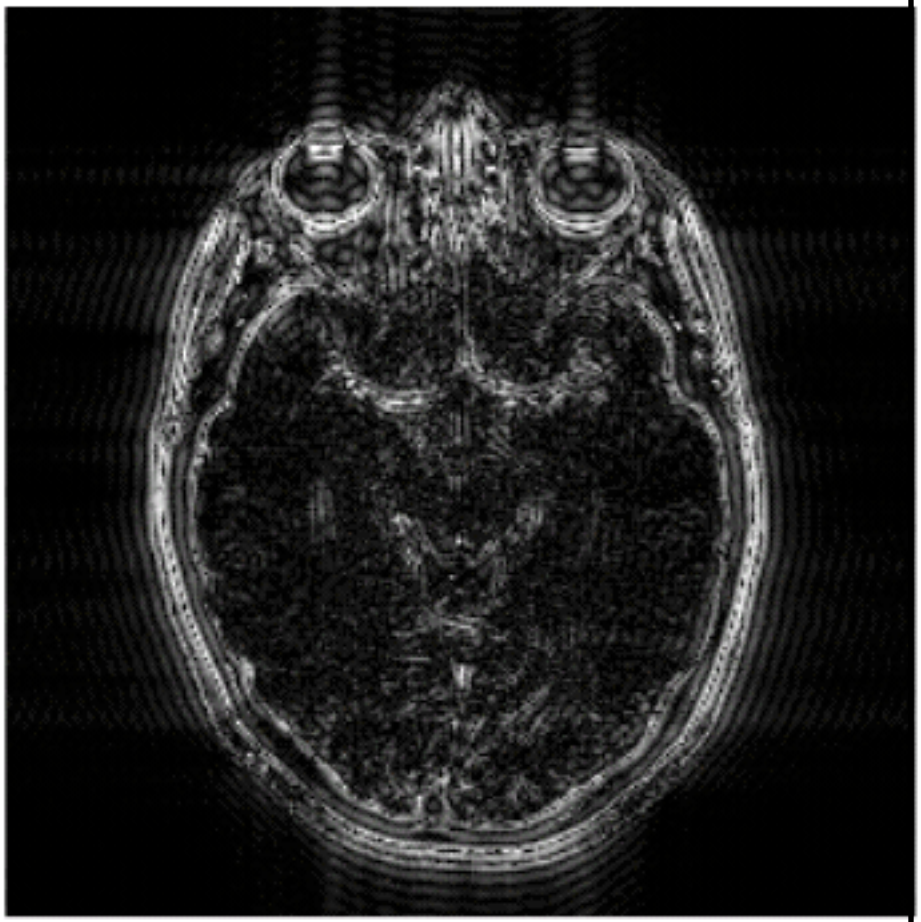
k-space



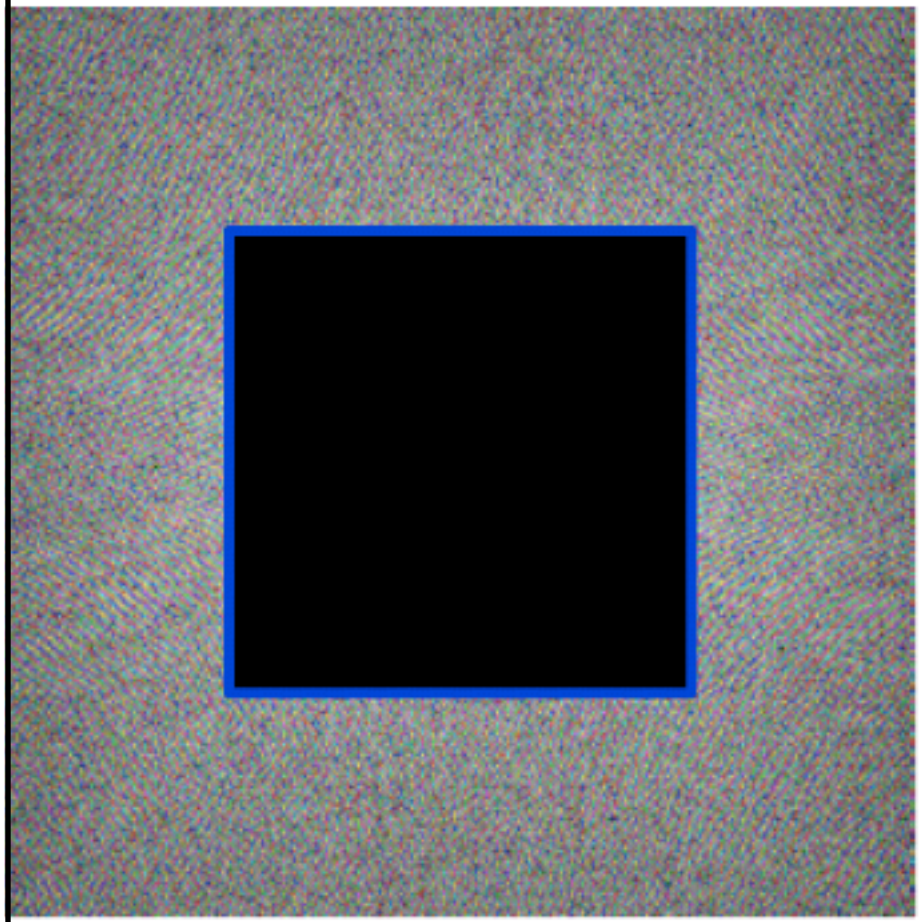


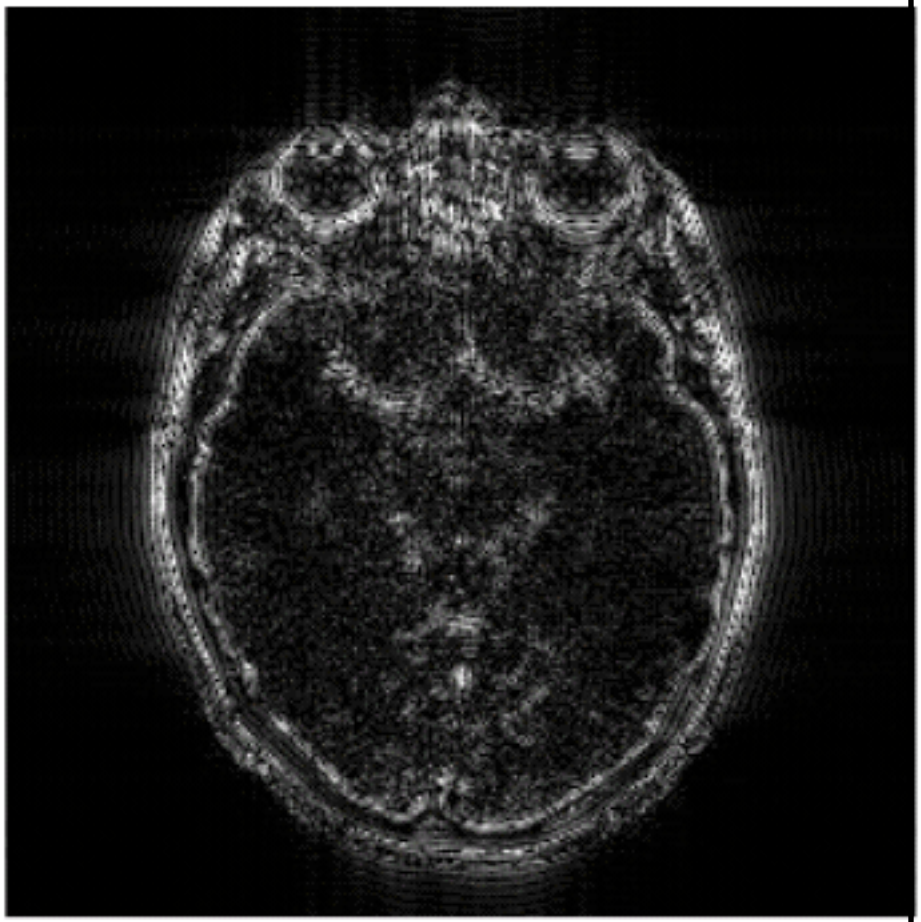
k-space



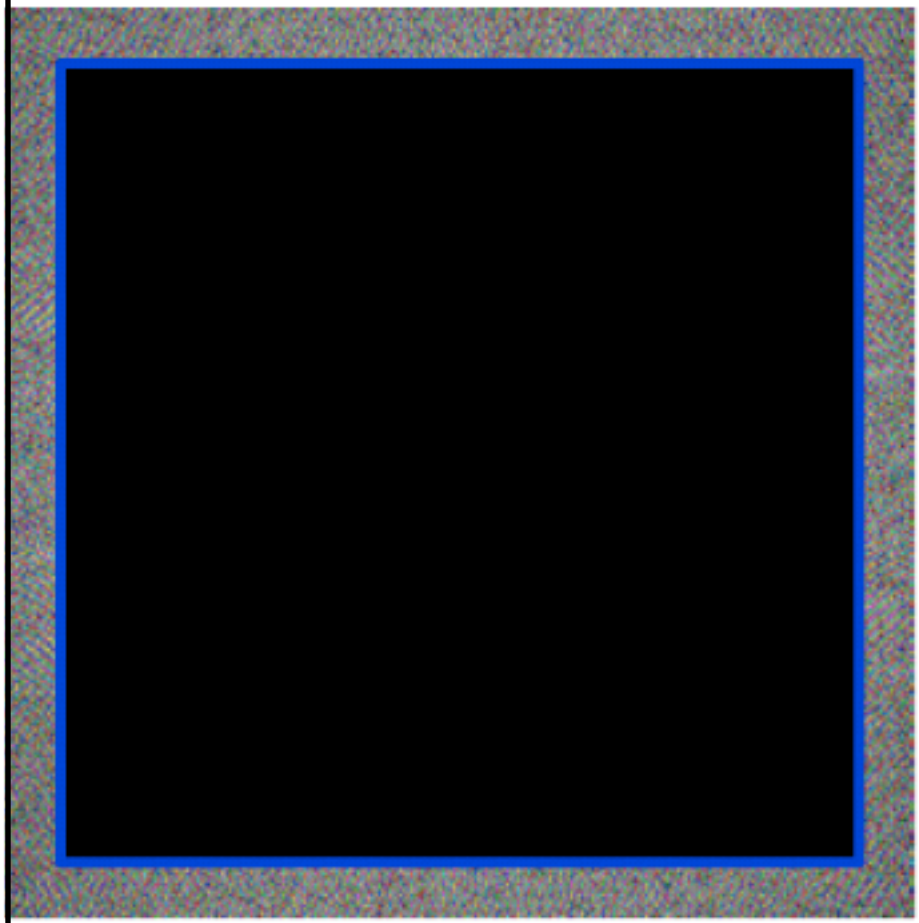


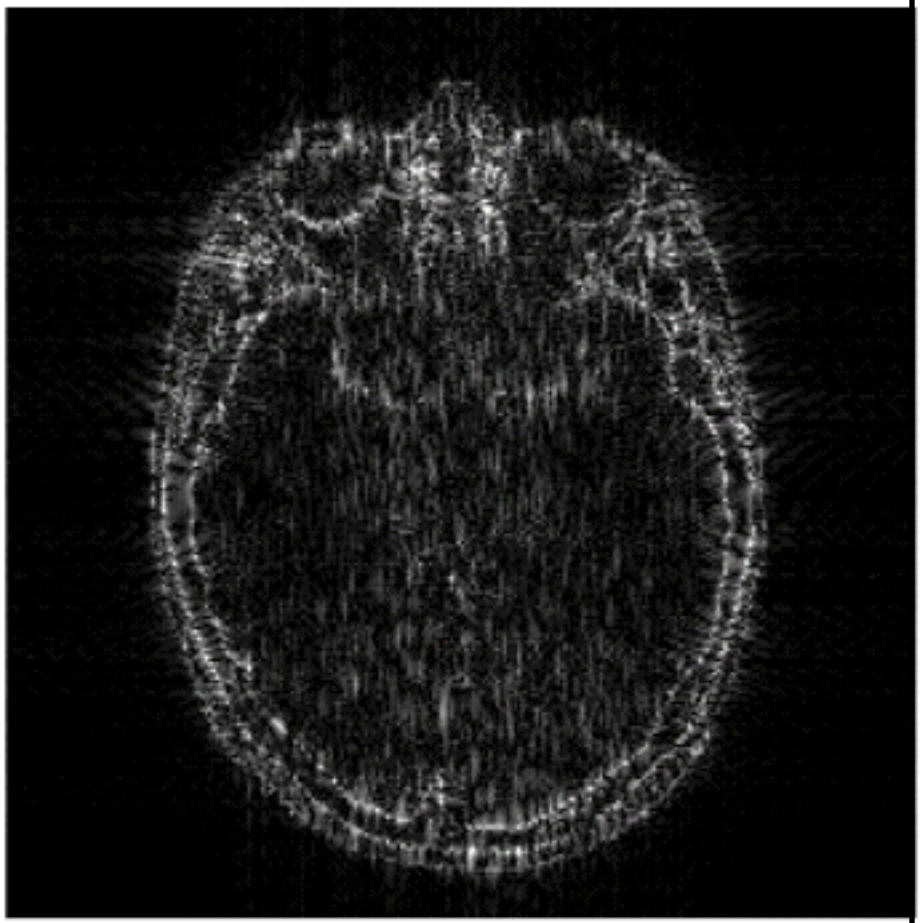
k-space



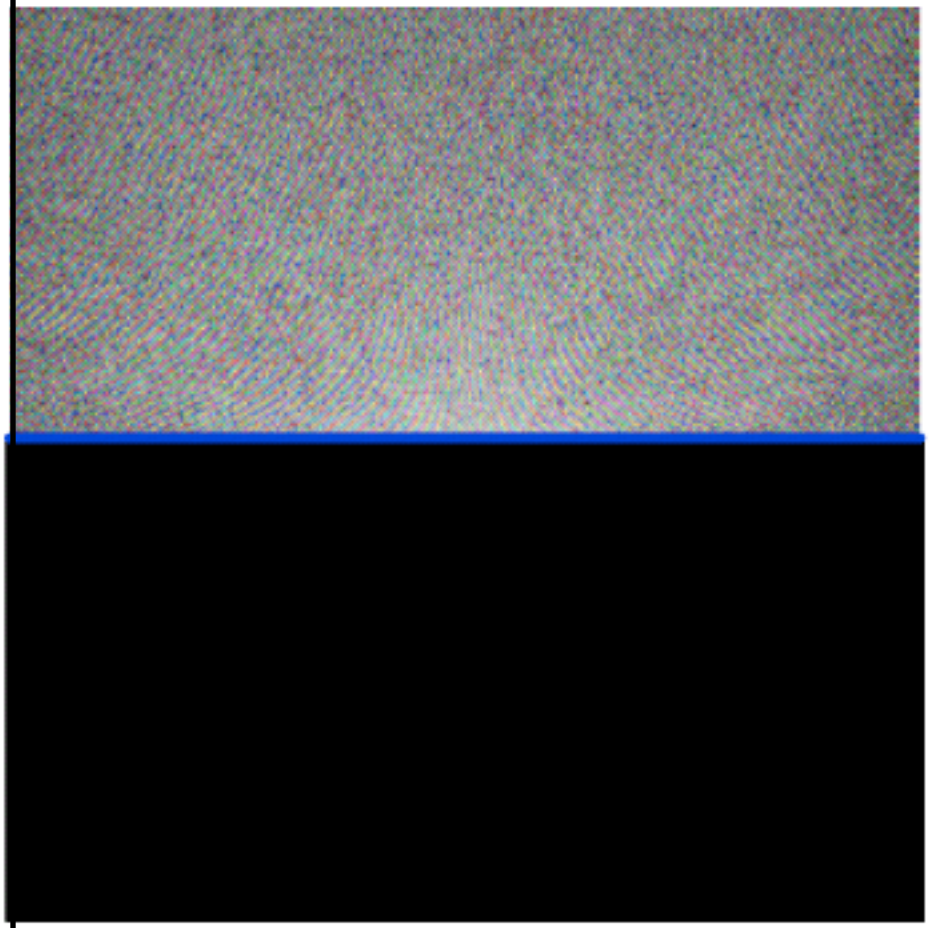


k-space

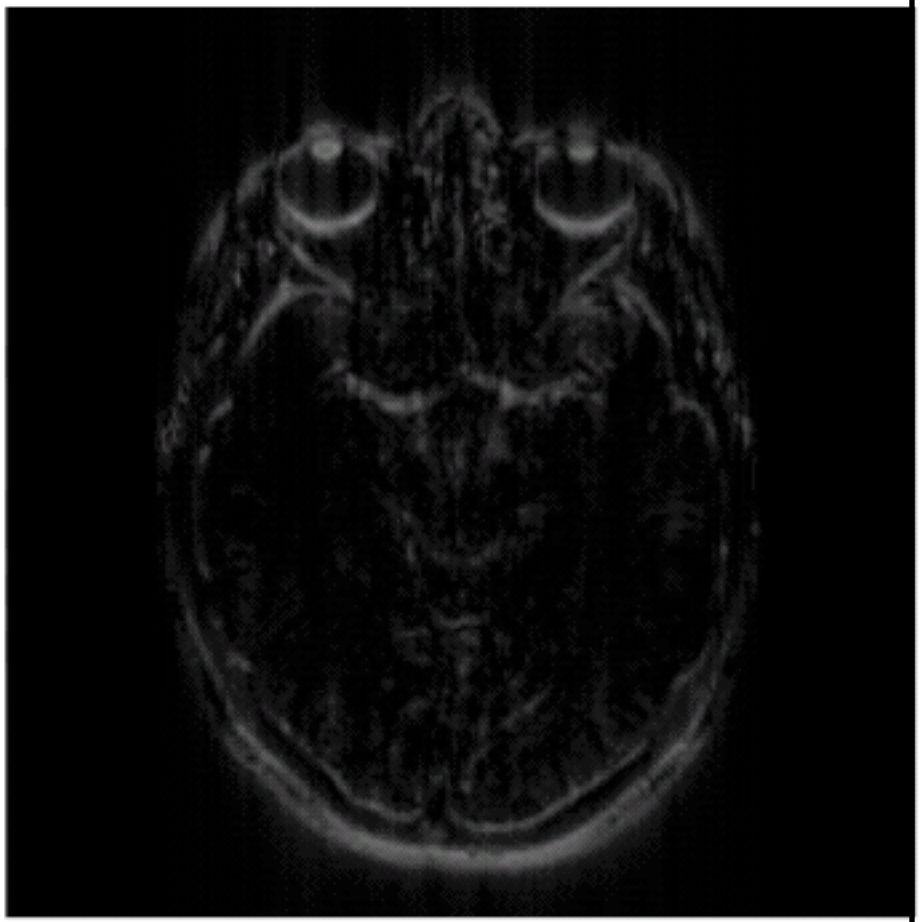




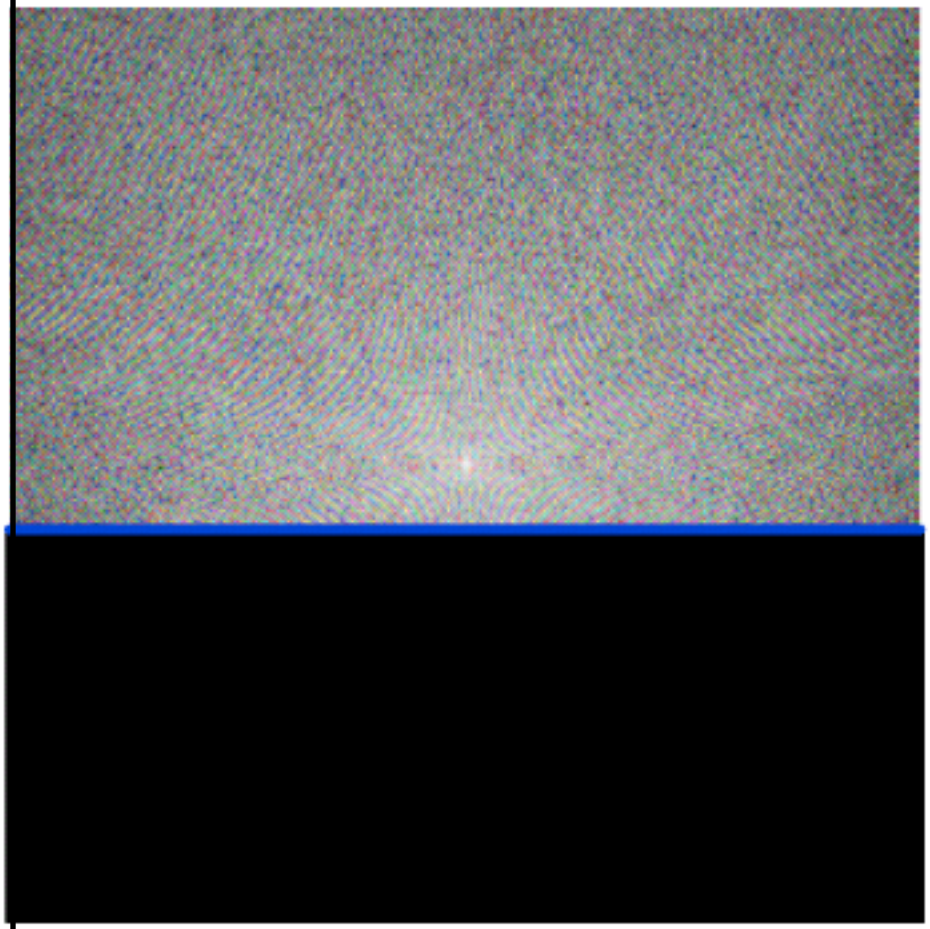
k-space

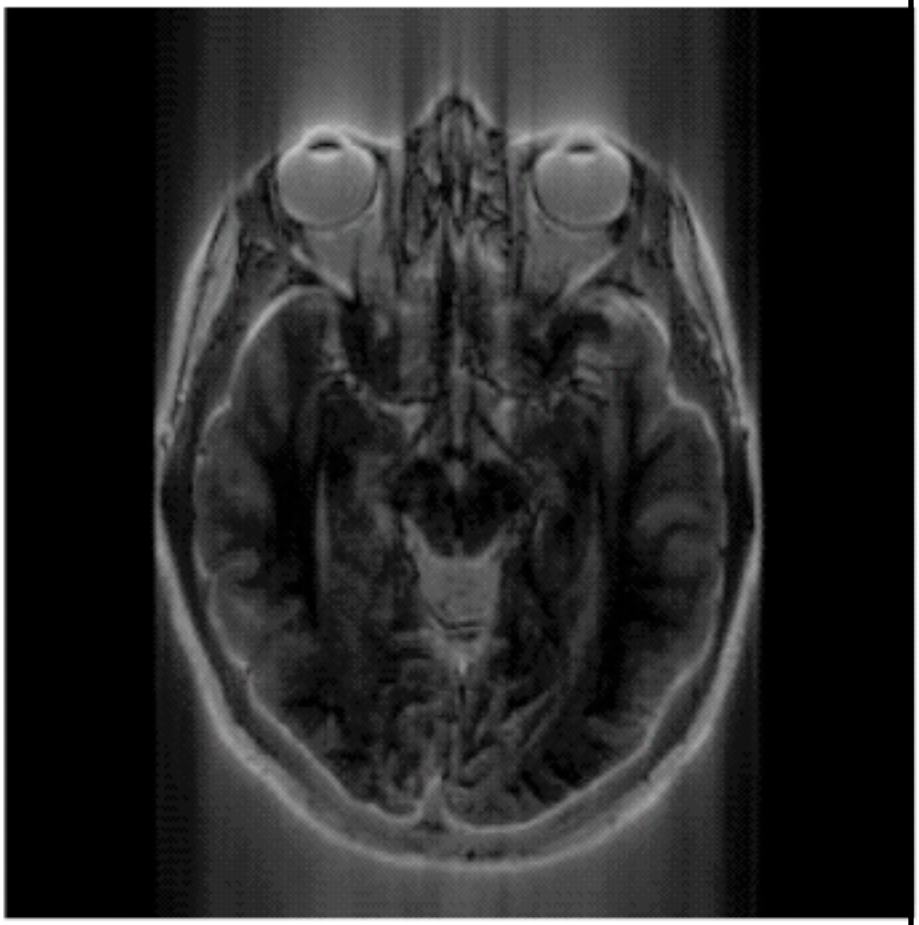


Linear trajectory

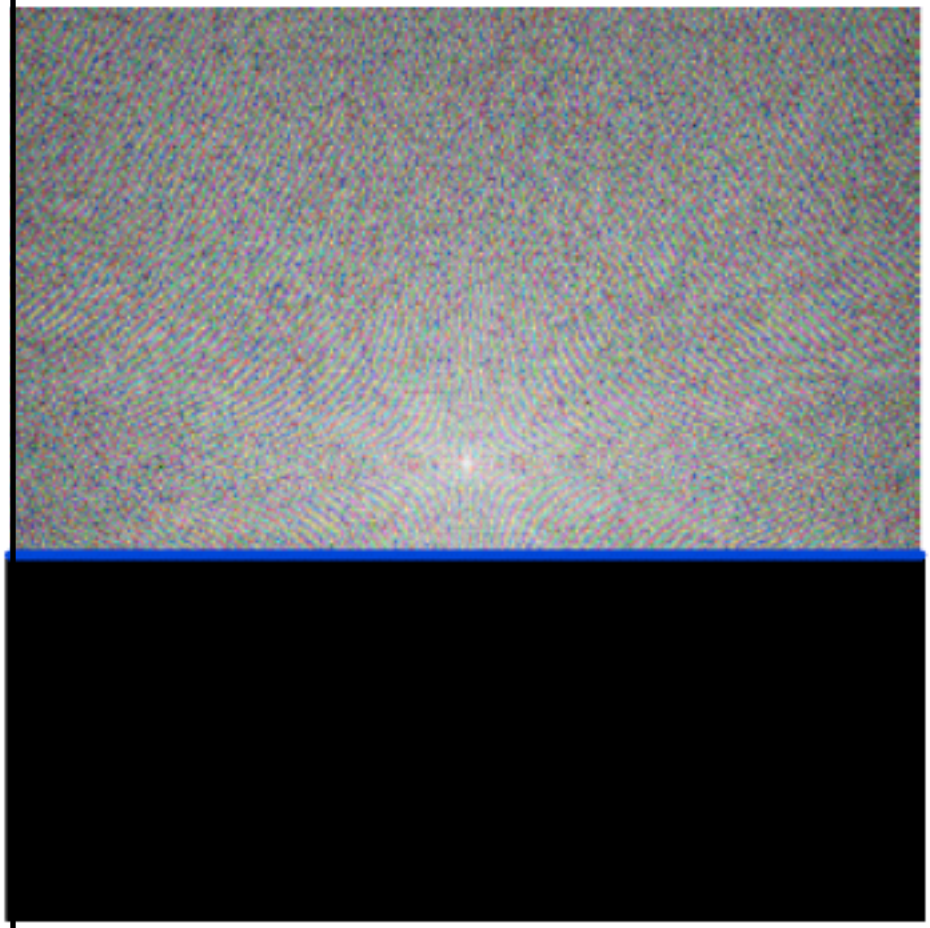


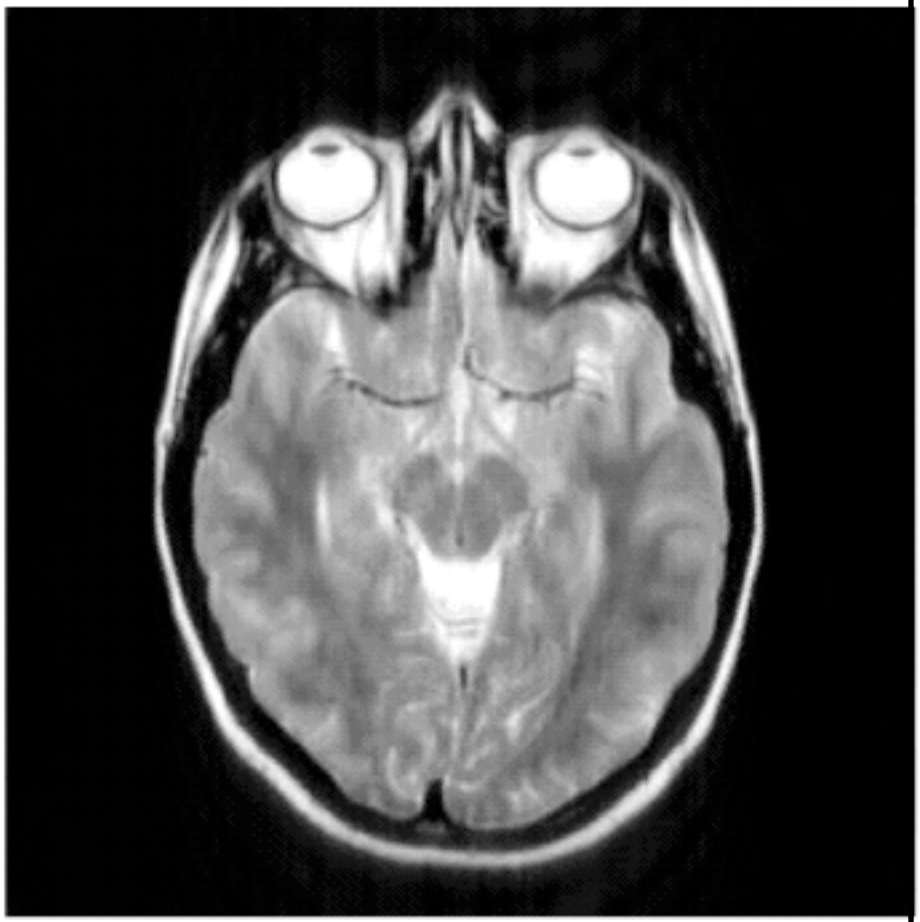
k-space



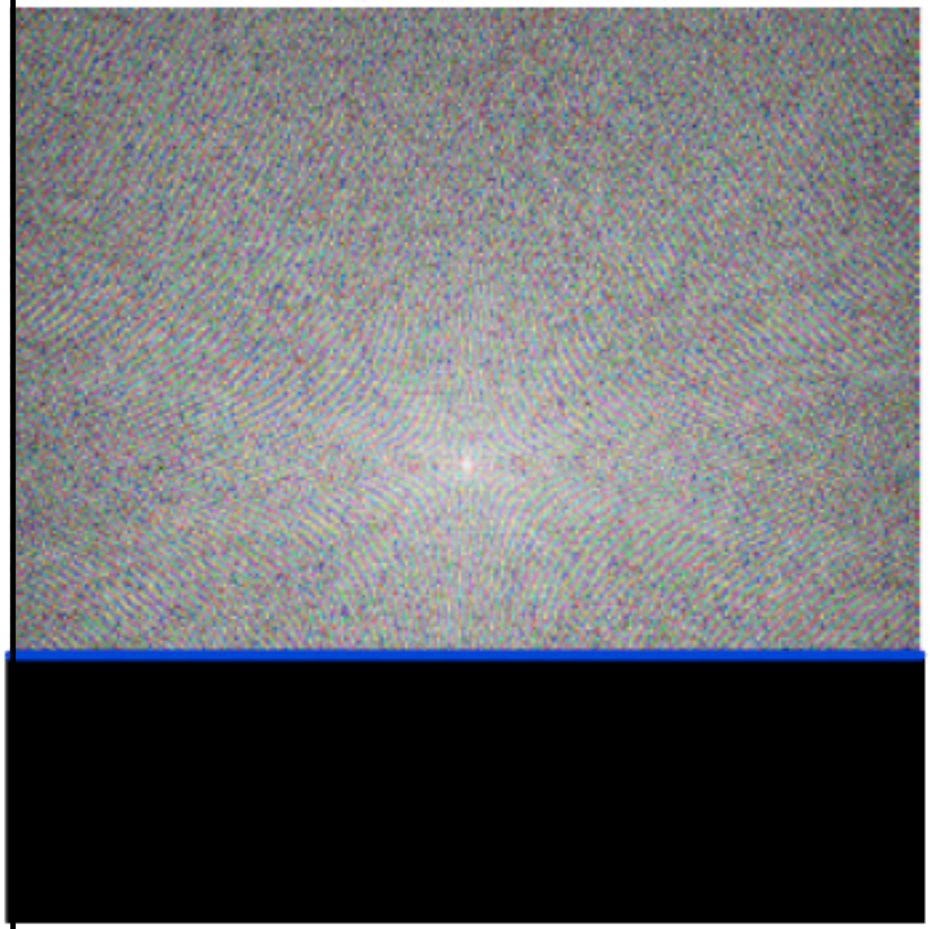


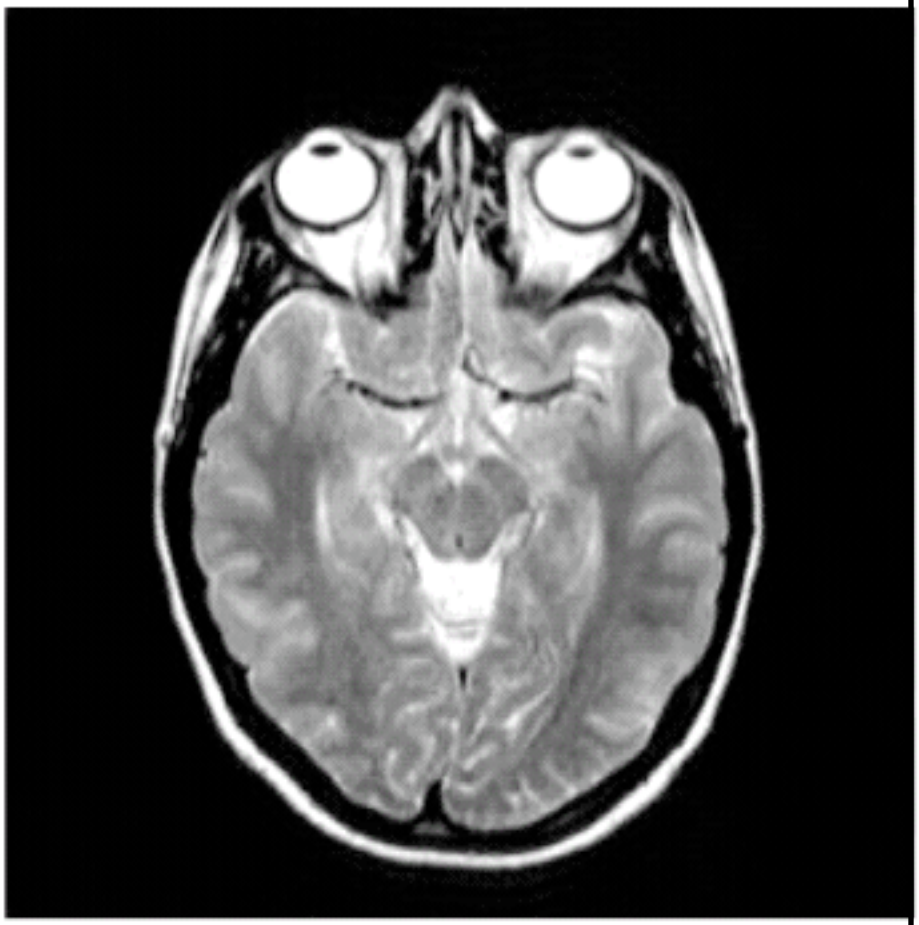
k-space





k-space

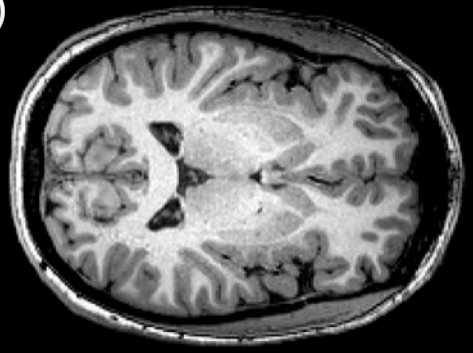




MRI vs. fMRI

MRI

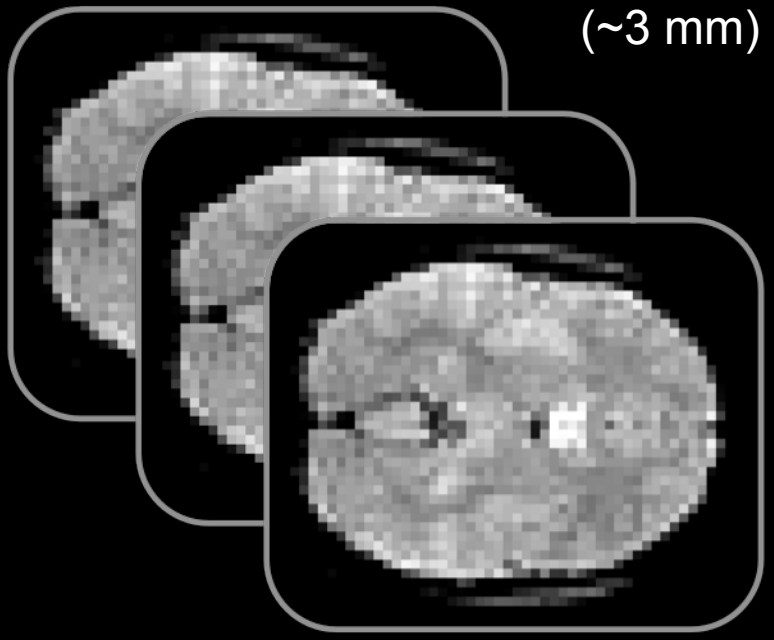
high resolution
(1 mm)



One 3D volume

fMRI

low resolution
(~3 mm)



...

series of 3D volumes (i.e., 4D data)
(e.g., every 2 sec for 5 mins)

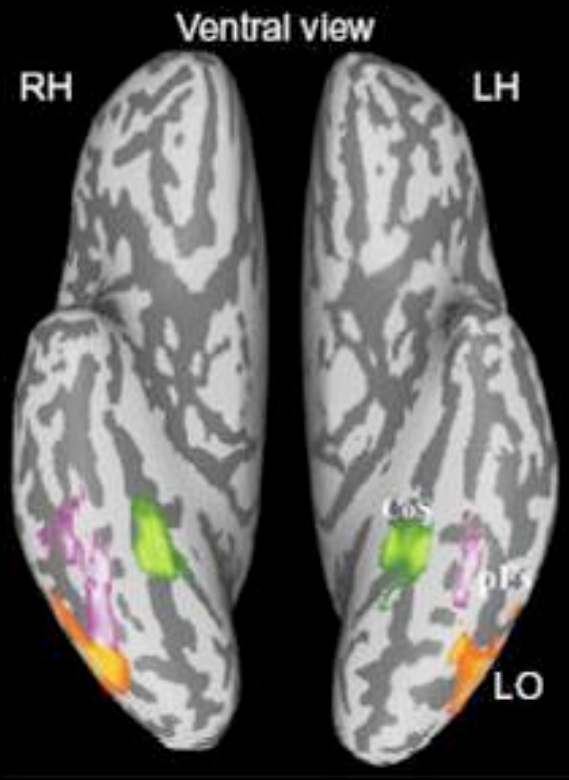
fMRI 4 Newbies .com

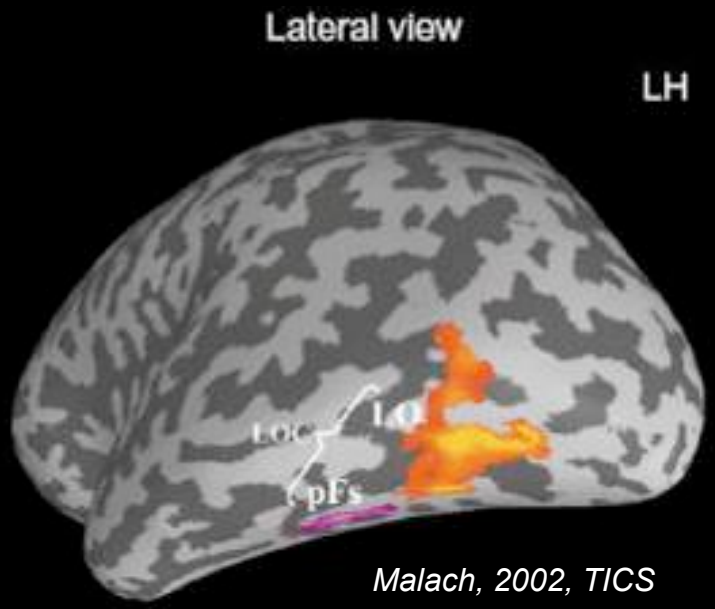
Category-Specific Visual Areas

objects

faces

places





Malach, 2002, TICS

- Lateral Occipital (LO)
  - object-selective
  - objects > (faces & scenes)
  - objects > scrambled images

- Parahippocampal Place Area (PPA)
  - place-selective
  - places > (objects and faces)
  - places > scrambled images

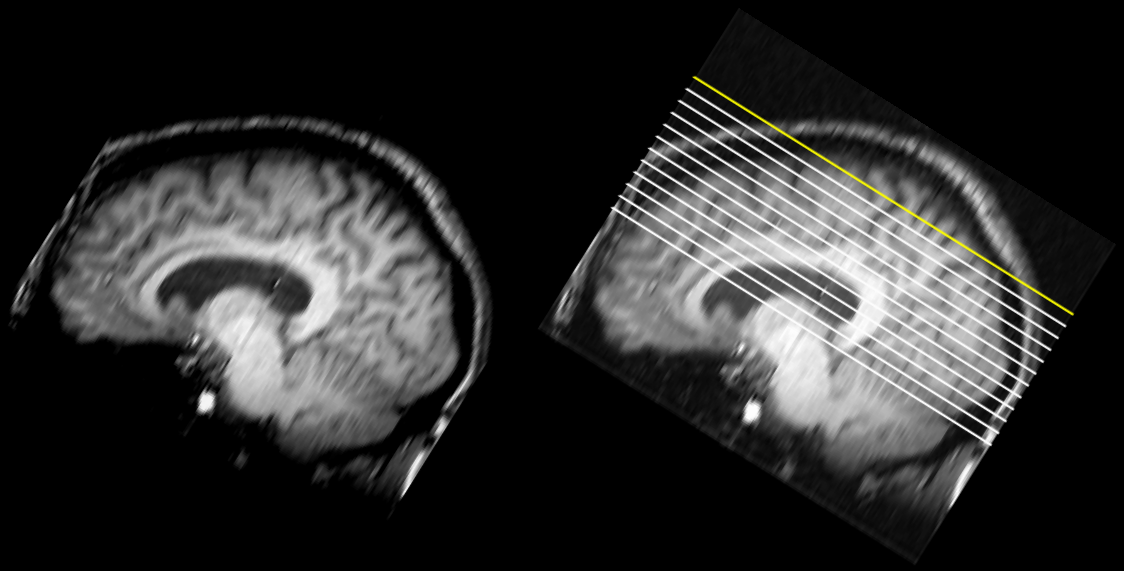
- Fusiform Face Area (FFA) or pFs
  - face-selective
  - faces > (objects & scenes)
  - faces > scrambled images
  - ~ posterior fusiform sulcus (pFs)

fMRI 4 Newbies .com

fMRI Experiment Stages: Prep

1) Prepare subject
   - Consent form
   - Safety screening
   - Instructions and practice trials if appropriate
2) Shimming
   - putting body in magnetic field makes it non-uniform
   - adjust 3 orthogonal weak magnets to make magnetic field as homogenous as possible
3) Sagittals

   Take images along the midline to use to plan slices

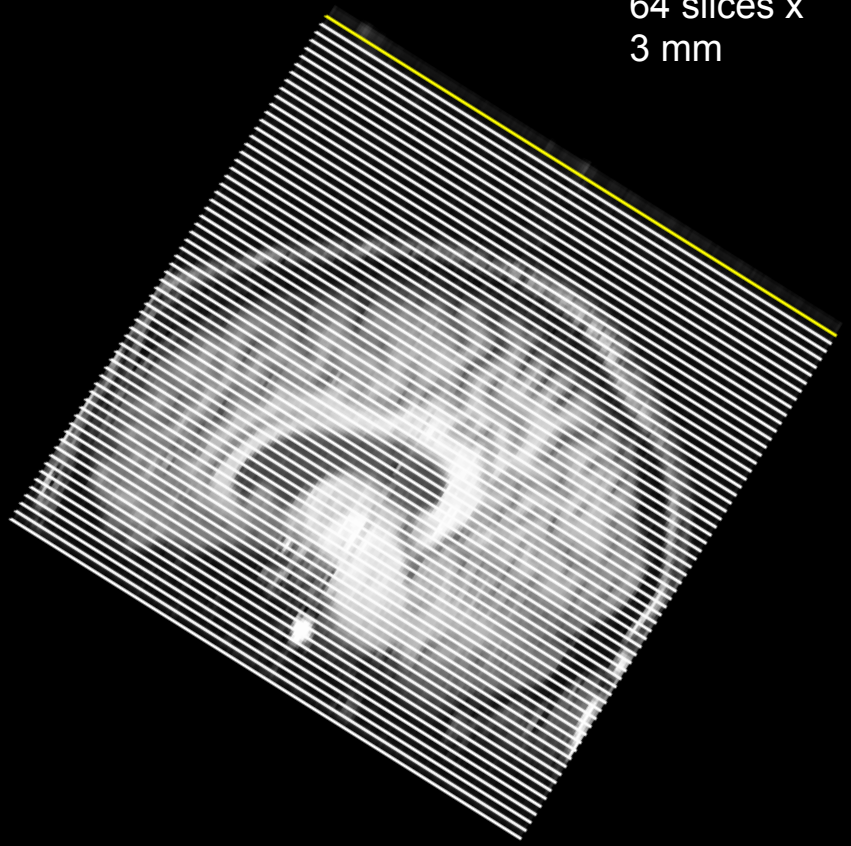


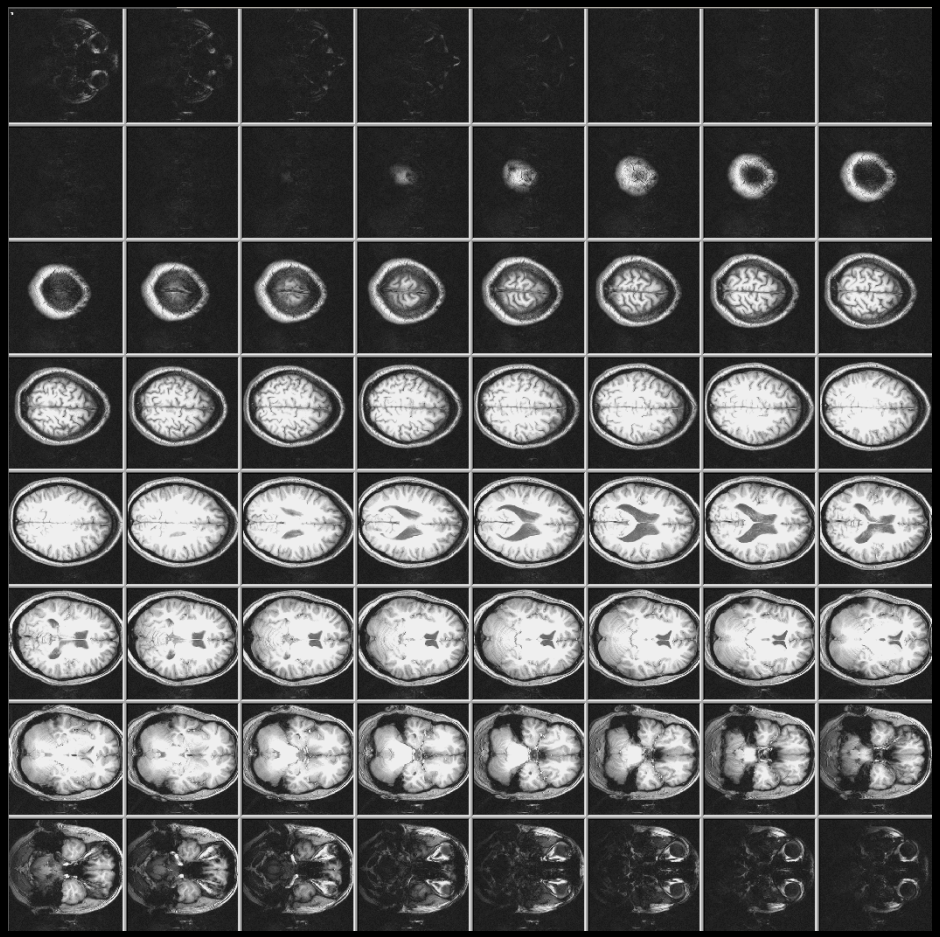
fMRI 4 Newbies .com

fMRI Experiment Stages: Anatomicals

4) Take anatomical (T1) images

- high-resolution images (e.g., 0.75 x 0.75 x 3.0 mm)
- 3D data: 3 spatial dimensions, sampled at one point in time
- 64 anatomical slices takes ~4 minutes





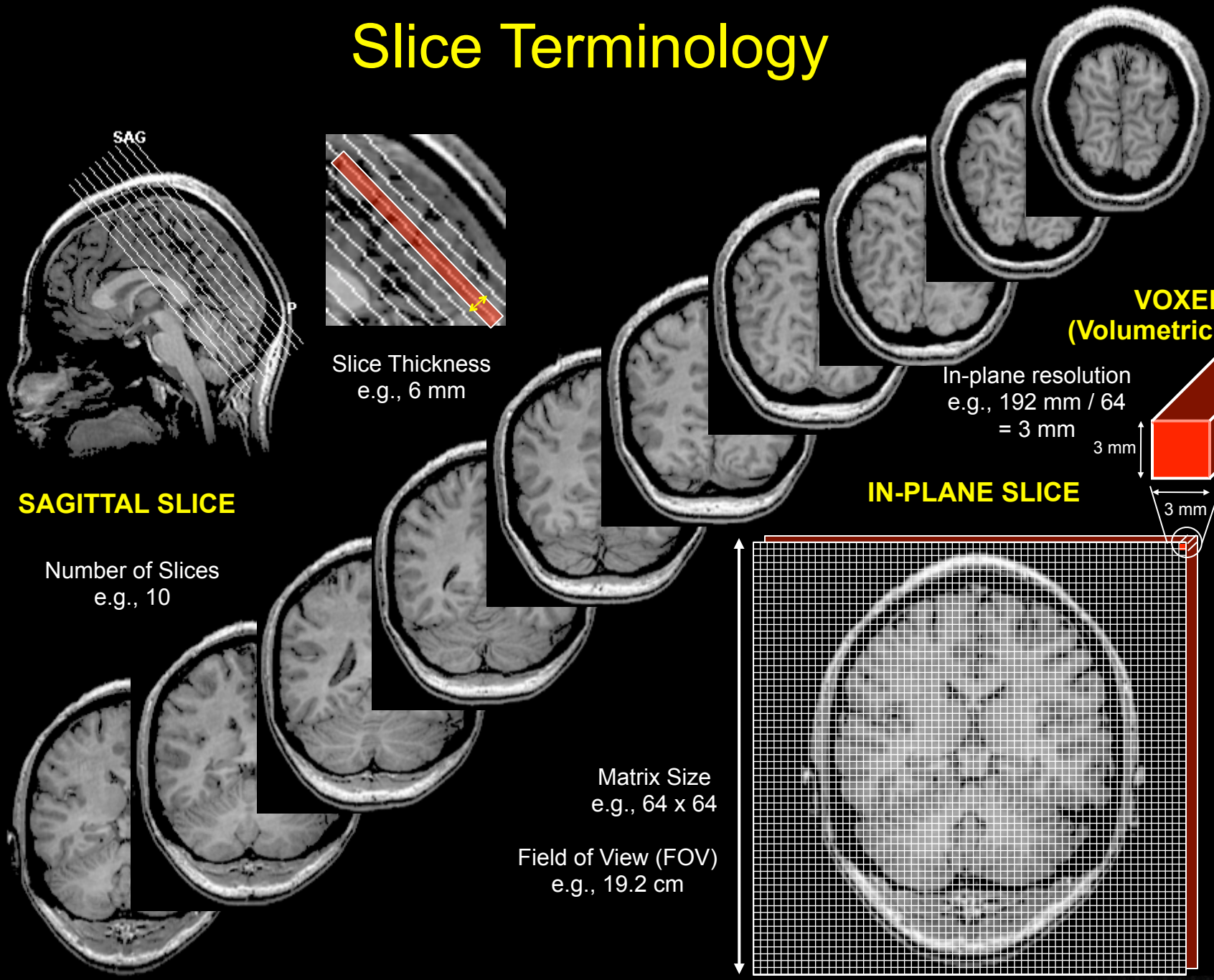
fMRI 4 Newbies .com

Slice Terminology

SAGITTAL SLICE

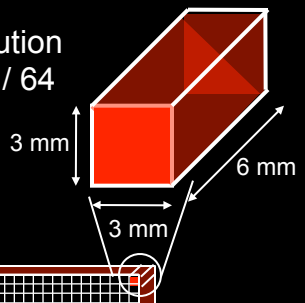
Slice Thickness
e.g., 6 mm

Number of Slices
e.g., 10



In-plane resolution
e.g., 192 mm / 64
= 3 mm

VOXEL
(Volumetric Pixel)



IN-PLANE SLICE

Matrix Size
e.g., 64 x 64

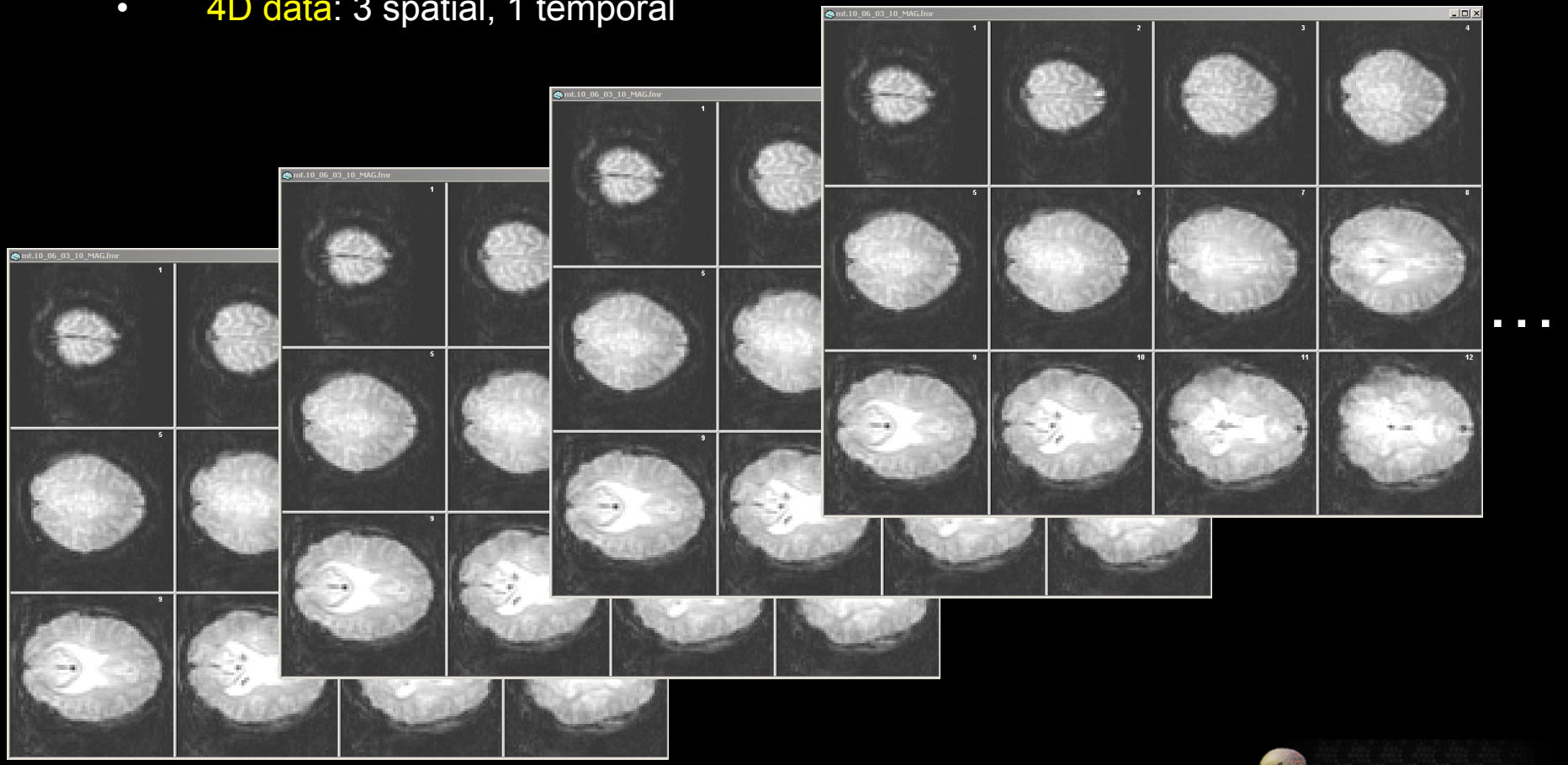
Field of View (FOV)
e.g., 19.2 cm

fMRI 4 Newbies.com

fMRI Experiment Stages: Functionals

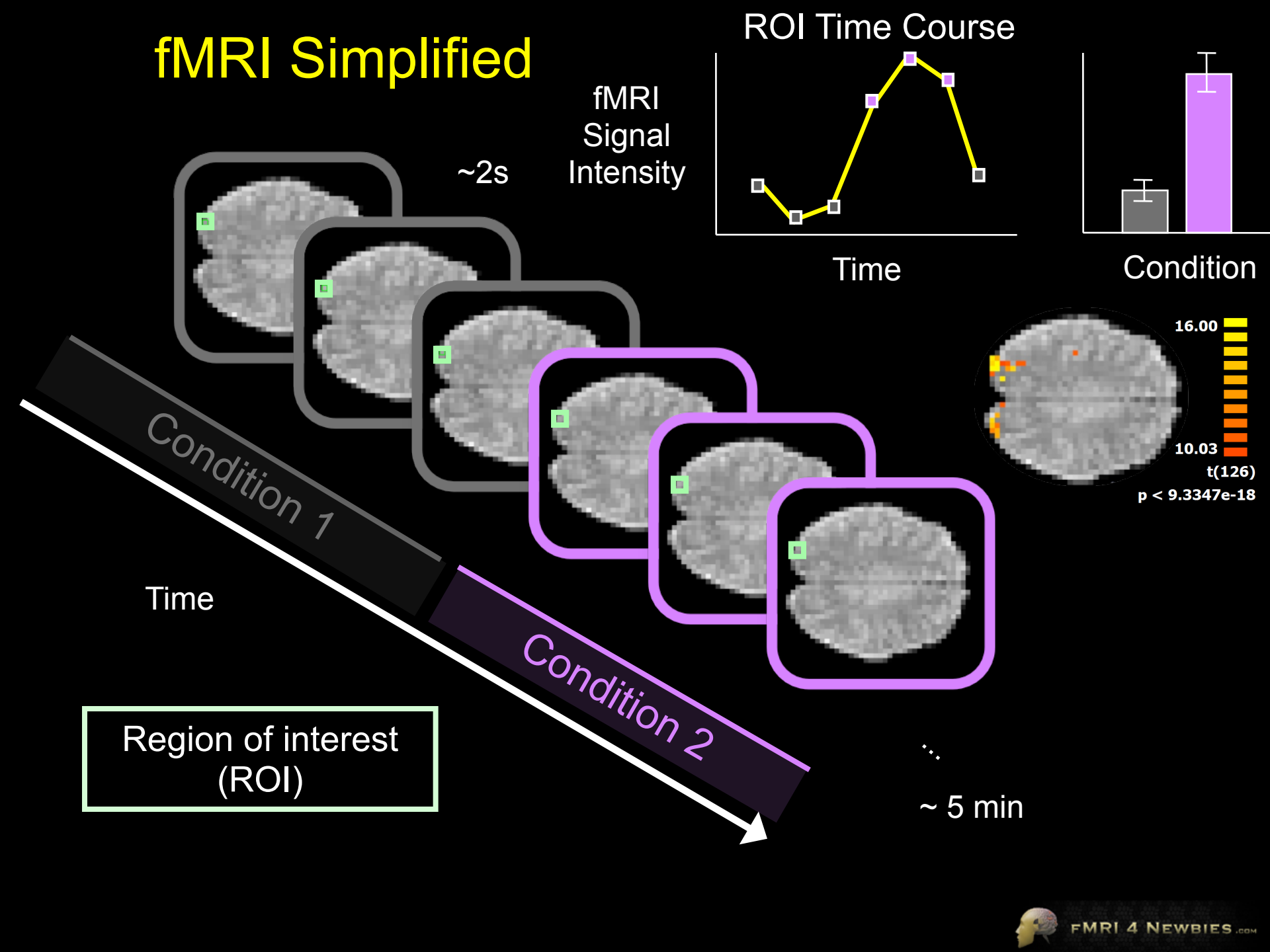
5) Take functional (T2*) images

- images are indirectly related to neural activity
- usually low resolution images (3 x 3 x 6 mm)
- all slices at one time = a volume (sometimes also called an image)
- sample many volumes (time points) (e.g., 1 volume every 2 seconds for 136 volumes = 272 sec = 4:32)
- 4D data: 3 spatial, 1 temporal



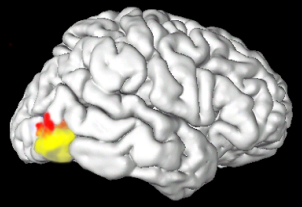
fMRI 4 Newbies .com

fMRI Simplified



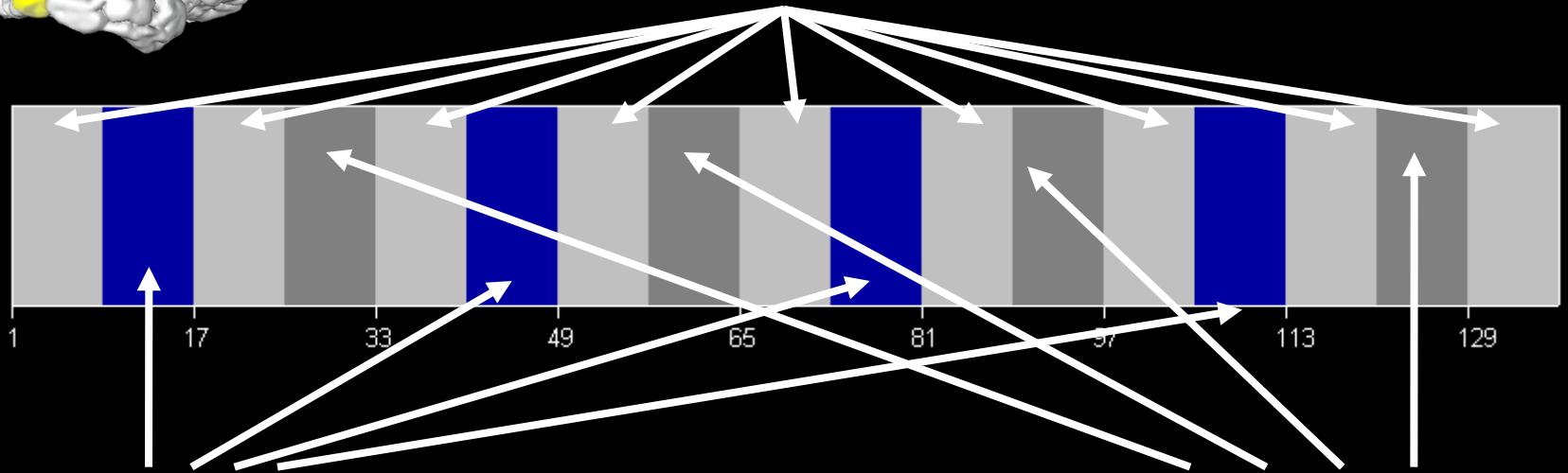
fMRI 4 Newbies .com

A Simple Experiment: LO Localizer

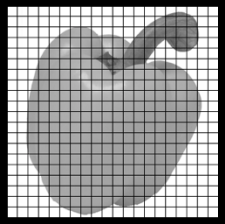


Lateral Occipital Complex
• responds when subject views objects

Blank Screen

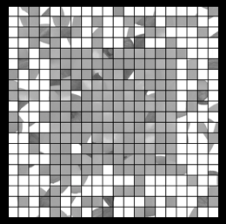


Intact Objects



TIME →

Scrambled Objects



One volume (12 slices) every 2 seconds for 272 seconds (4 minutes, 32 seconds)

Condition changes every 16 seconds (8 volumes)

fMRI 4 Newbies .com

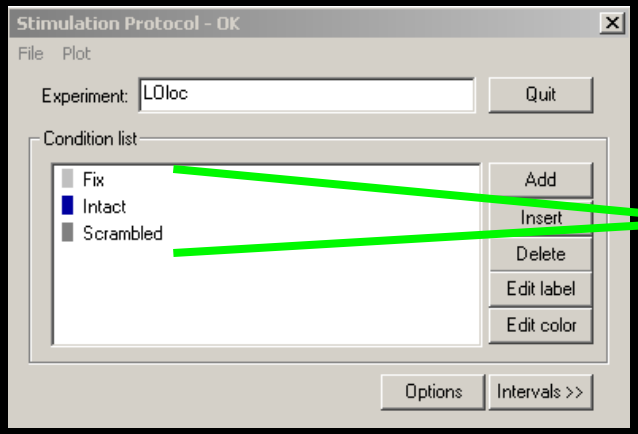
Design Jargon: Runs

session: all of the scans collected from one subject in one day

run (or scan): one continuous period of fMRI scanning (~5-7 min)

experiment: a set of conditions you want to compare to each other

condition: one set of stimuli or one task

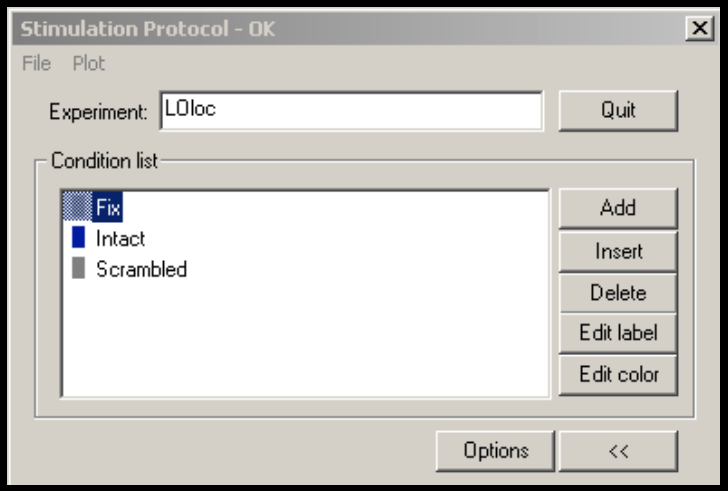


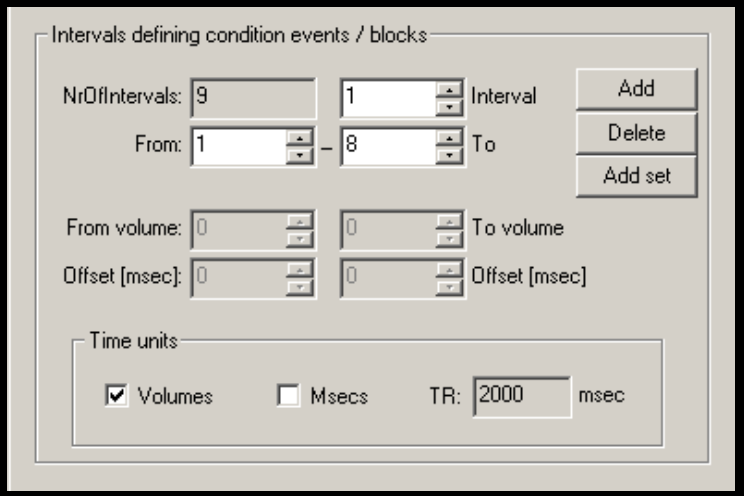
2 stimulus conditions
+ 1 baseline condition (fixation)

A session consists of one or more experiments.
Each experiment consists of several (e.g., 1-8) runs

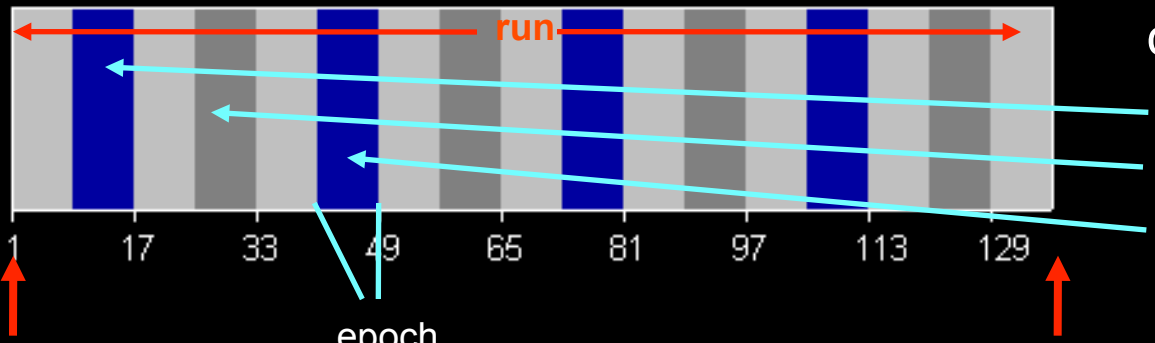
fMRI 4 Newbies .com

Design Jargon: Paradigm





paradigm (or protocol): the set of conditions and their order used in a particular run



epoch: one instance of a condition

- first “intact objects” epoch
- first “scrambled objects” epoch
- second “intact objects” epoch

volume #1
(time = 0)

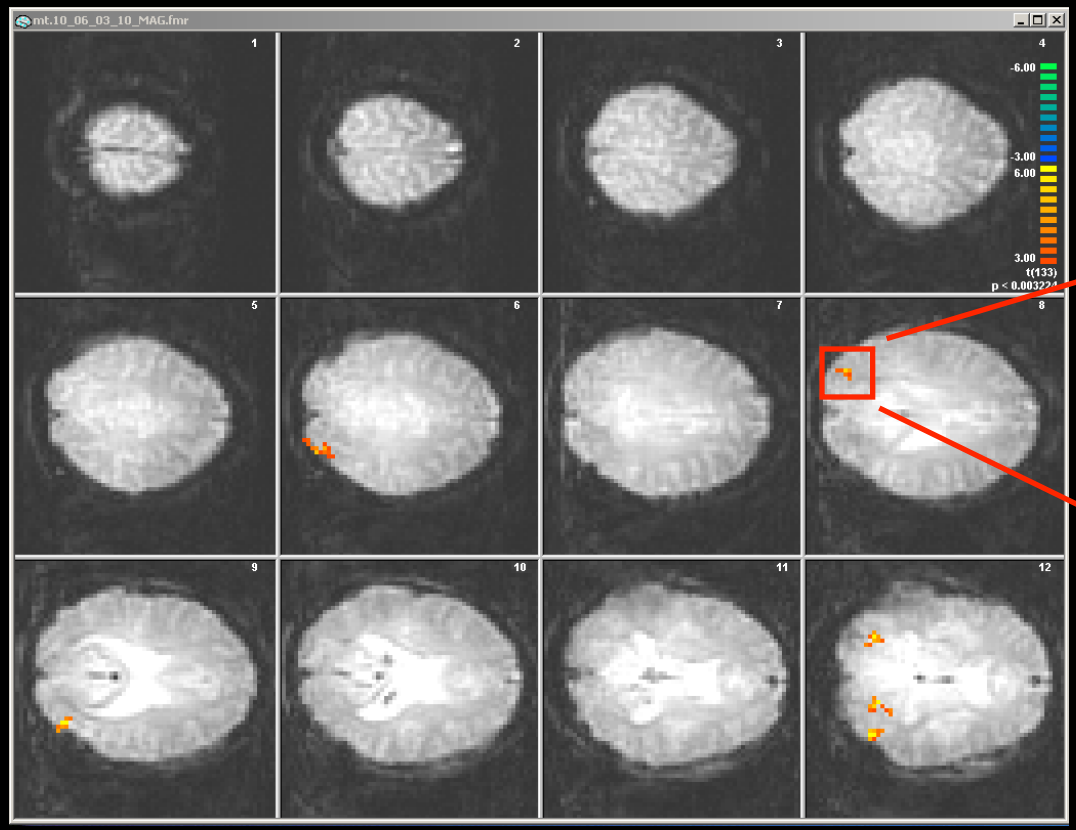
epoch
8 vol x 2 sec/vol = 16 sec

volume #136
(time = 136 vol x 2 sec/vol = 272 sec = 4:32)

Time

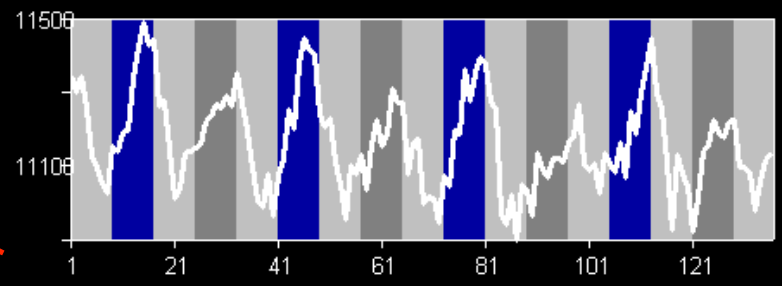
fMRI 4 Newbies .com

Statistical Maps & Time Courses



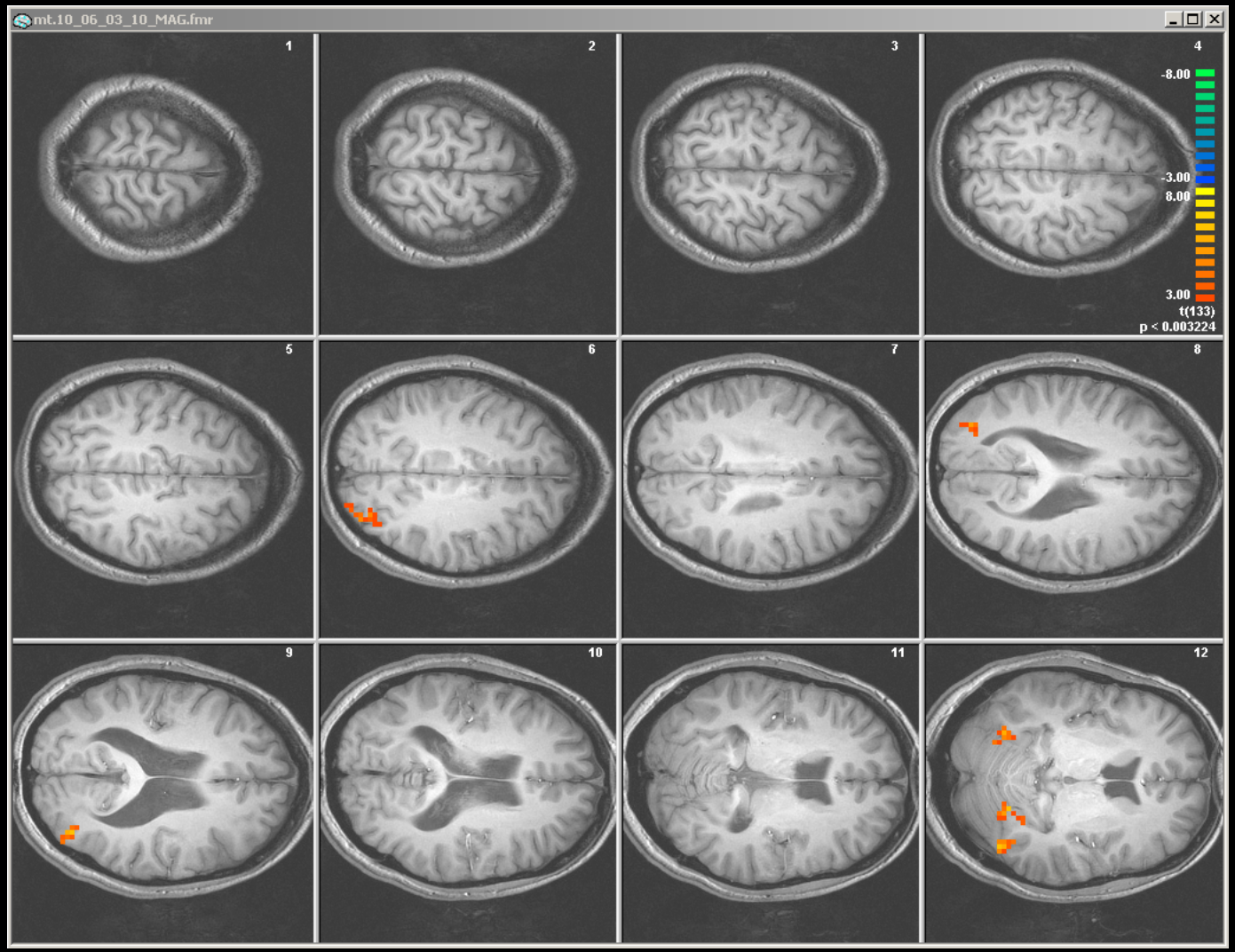
Use stat maps to pick regions

Then extract the time course



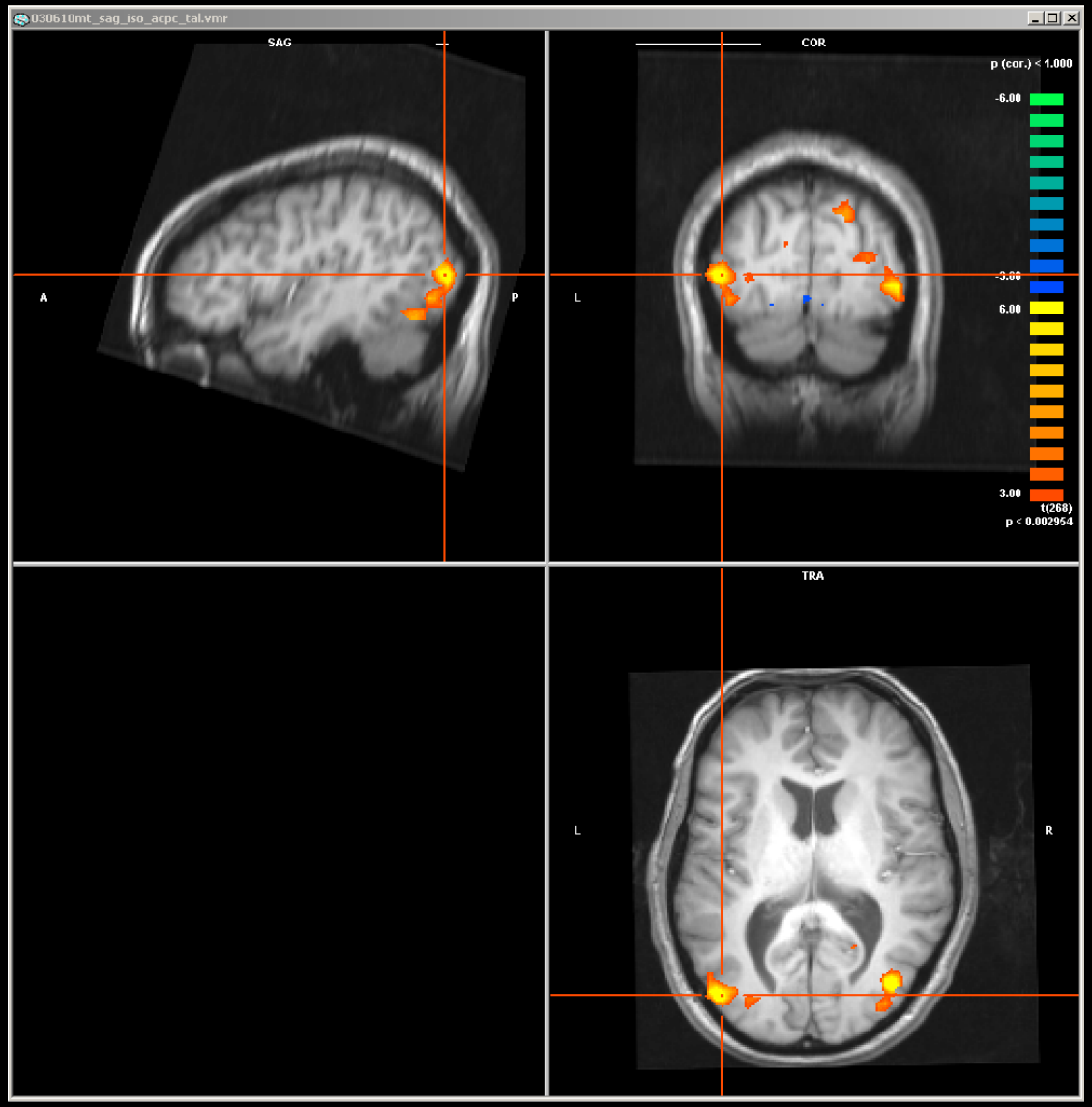
fMRI 4 Newbies .com

Stats on Anatomical



fMRI 4 Newbies .com

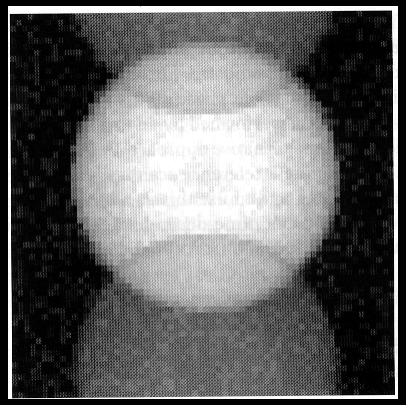
2D ➔ 3D



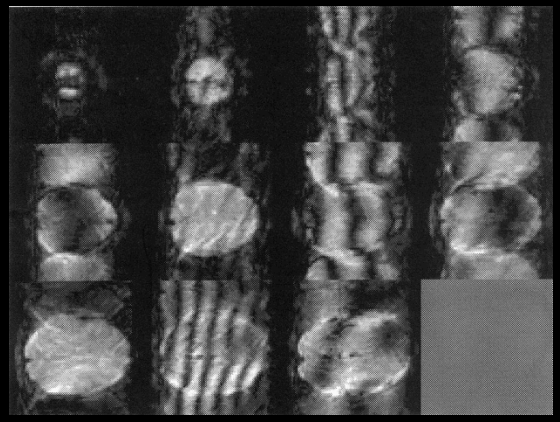
fMRI 4 Newbies .com

Sample Artifacts

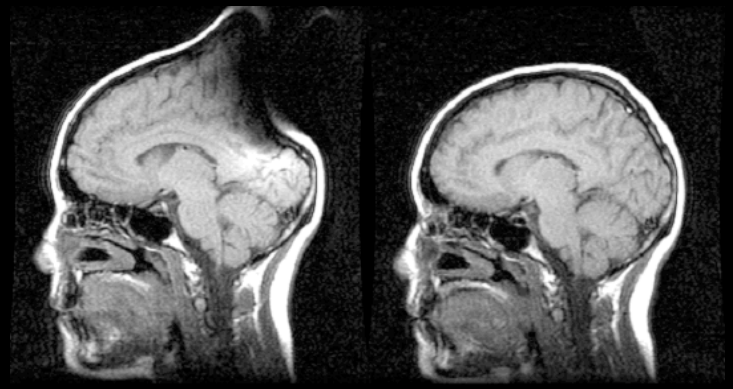
Ghosts



Hardware Malfunctions



Metallic Objects (e.g., hair tie)



Spikes

fMRI 4 Newbies .com

What affects SNR?

Physiological factors

PHYSIOLOGICAL FACTORS	SOLUTION & TRADEOFF
Head (and body) motion	Use experienced or well-warned subjects – limits useable subjects Use head-restraint system – possible subject discomfort Post-processing correction – often incompletely effective – 2nd order effects – can introduce other artifacts Single trials to avoid body motion
Cardiac and respiratory noise	Monitor and compensate – hassle
Low frequency noise	Use smart design Perform post-processing filtering
BOLD noise (neural and vascular fluctuations)	Use many trials to average out variability
Behavioral variations	Use well-controlled paradigm Use many trials to average out variability

Source: Doug Noll's online tutorial

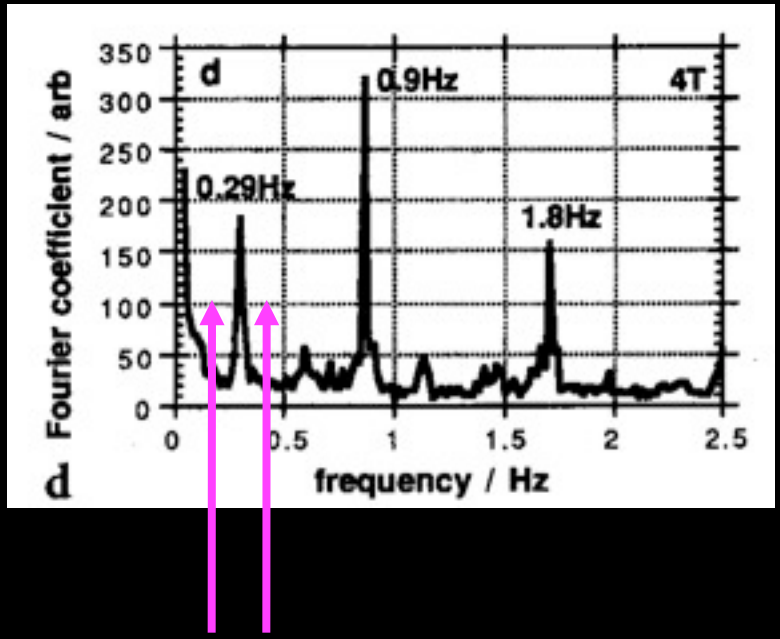
fMRI 4 Newbies .com

Find the “Sweet Spots”

Respiration
- every 4-10 sec (0.3 Hz)
- moving chest distorts susceptibility

Cardiac Cycle
- every ~1 sec (0.9 Hz)
- pulsing motion, blood changes

Solutions
- gating
- avoiding paradigms at those frequencies



You want your paradigm frequency to be in a “sweet spot” away from the noise

fMRI 4 Newbies .com

Data Preprocessing Options

reconstruction from raw k-space data

- frequency space → real space

artifact screening

- ensure the data is free from scanner and subject artifacts

vessel suppression

- reduce the effects of large vessels (which are further away from activation than capillaries)

slice scan time correction

- correct for sampling of different slices at different times

motion correction

- correct for sampling of different slices at different times

spatial filtering

- smooth the spatial data

temporal filtering

- remove low frequency drifts (e.g., linear trends)
- remove high frequency noise (not recommended because it increases temporal autocorrelation and artificially inflates statistics)

spatial normalization

- put data in standard space (Talairach or MNI Space)

fMRI 4 Newbies .com

Links

http://www.cis.rit.edu/htbooks/mri/inside.htm

http://www.e-mri.org/

http://www.cis.rit.edu/htbooks/mri/inside.htm

http://www.simplyphysics.com

http://www.hull.ac.uk/mri/lectures/gpl_page.html

http://vision.psych.umn.edu/users/caolman/courses/Fall2006/Lectures/Lecture1.ppt

http://upload.wikimedia.org/wikibooks

http://www.fMRI4newbies.com

http://afni.nimh.nih.gov/pub/dist/edu/latest/afni01_intro/afni01_intro.ppt

http://eeweb.poly.edu/~yao/EL5823/MRI_physics_ch12.pdf

http://web2.uwindsor.ca/courses/physics/high_schools/2006/Medical_Imaging/mriphysics1.html