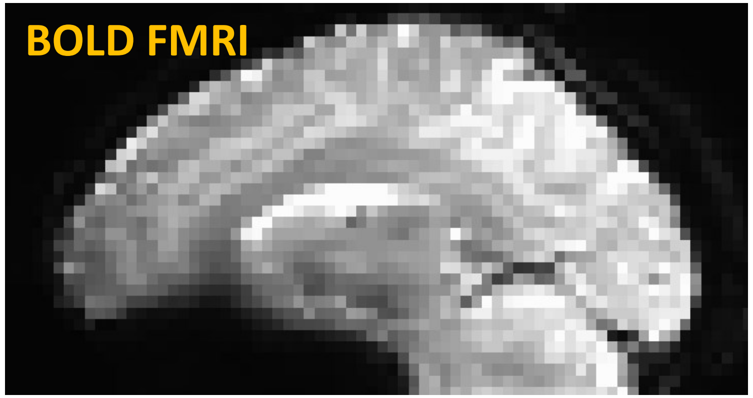
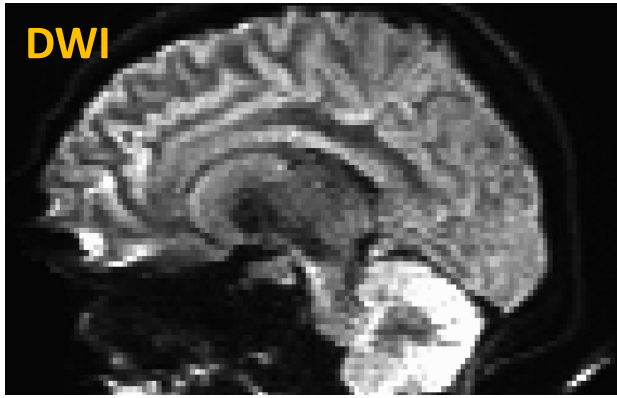
CS463/516

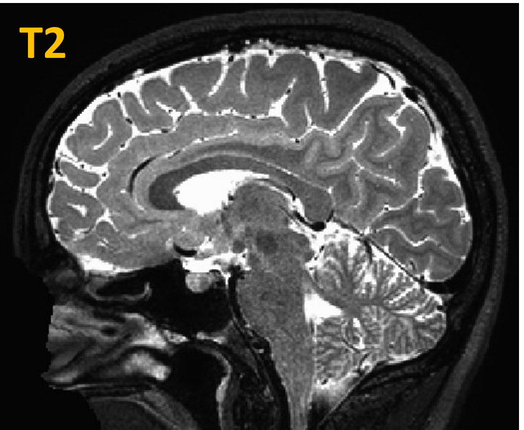
Lecture 5

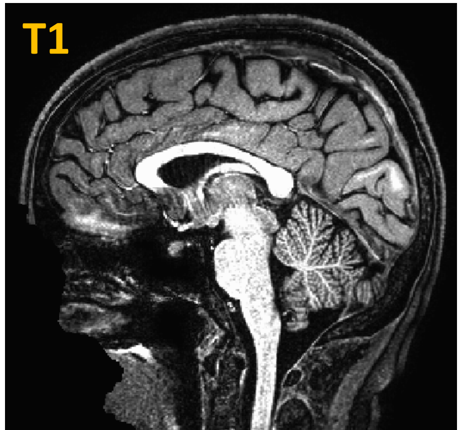
More MRI modalities

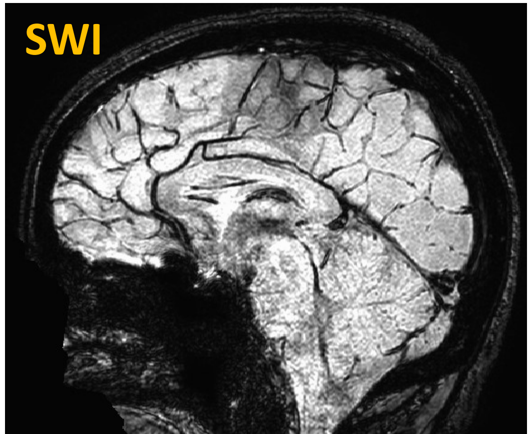
- We have seen T1 and T2 contrast, and basic MRI acquisition methods
- We will now see how MRI can generate even more interesting contrasts:
  - Blood oxygen level functional magnetic resonance imaging (BOLD fMRI)
  - Susceptibility weighted imaging (SWI)
  - Time of flight imaging (TOF)
  - Diffusion-weighted imaging (DWI)
  - You will work with all these modalities in this course, so its good to know how the contrast is generated

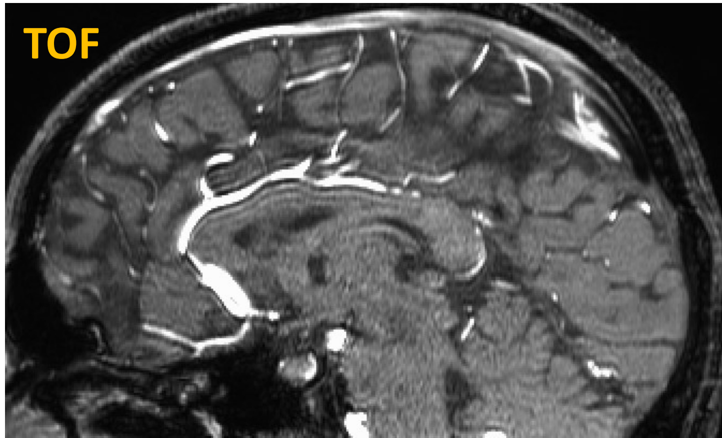






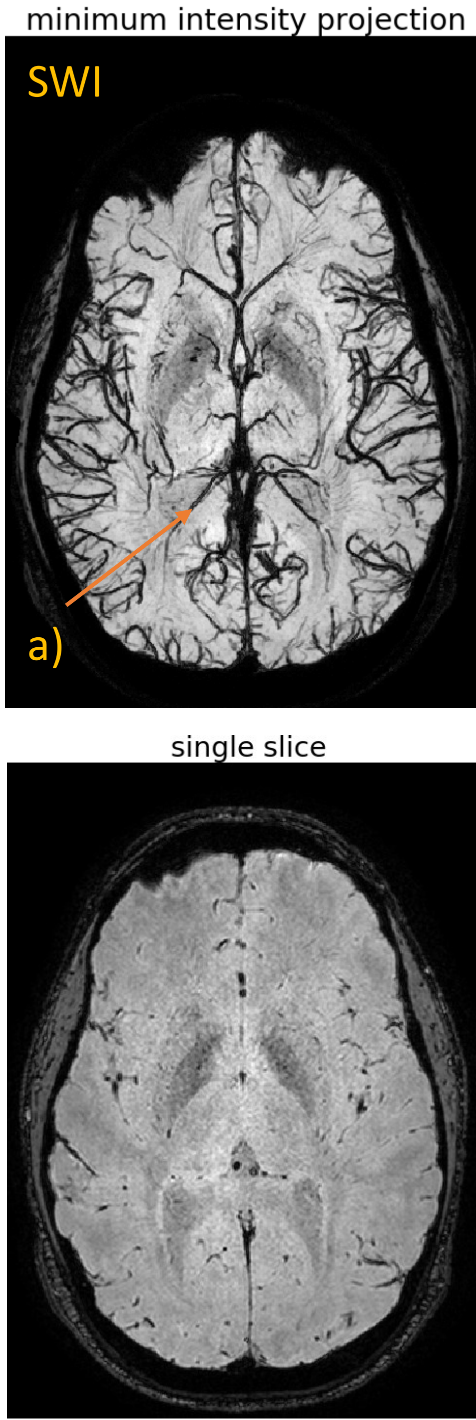






Susceptibility weighted imaging (SWI)

- Why are the veins dark on a SWI? (a)
- Magnetic susceptibility: a measure of how much a tissue will become magnetized in an applied magnetic field B_0
  - Differences in susceptibility between tissues creates contrast
- Veins carry deoxygenated blood away from the brain (b)
  - Deoxygenated blood has a higher concentration of the *deoxyhemoglobin* molecule (c)
  - Deoxyhemoglobin is *paramagnetic*, which increases magnetic susceptibility
- At sufficient long echo time (TE), spins in tissue with higher magnetic susceptibility dephase relative to surrounding, reducing the MRI signal, and appearing dark



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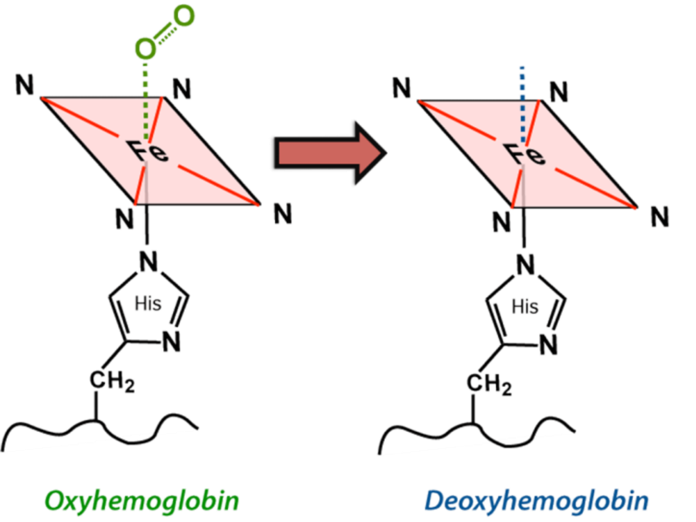

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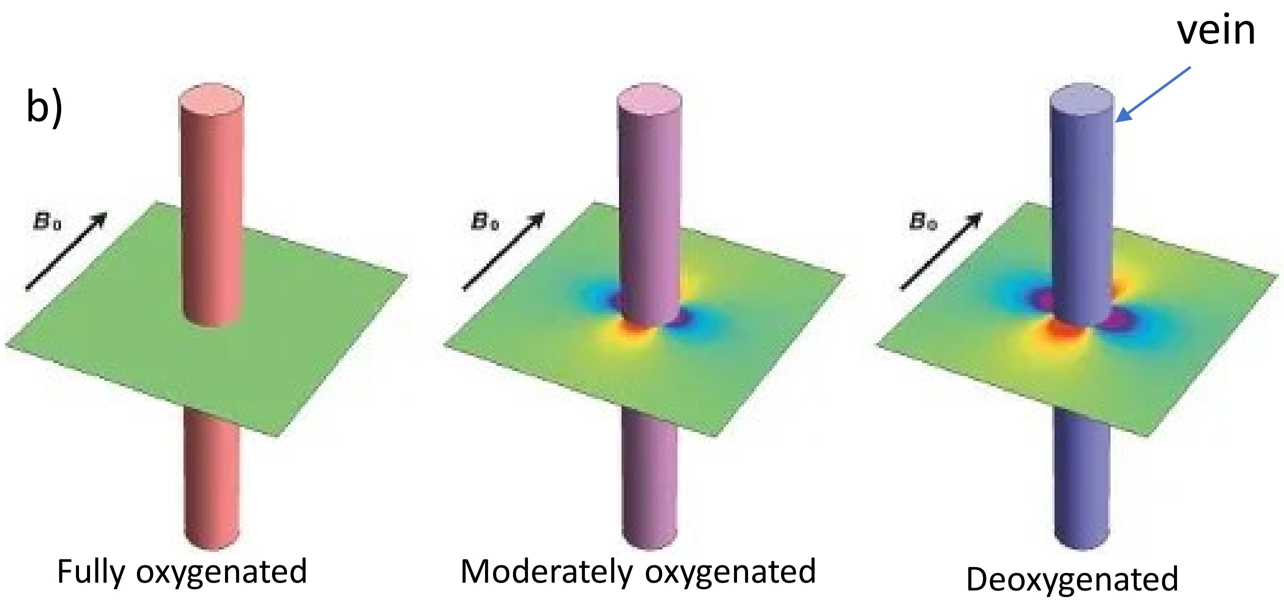
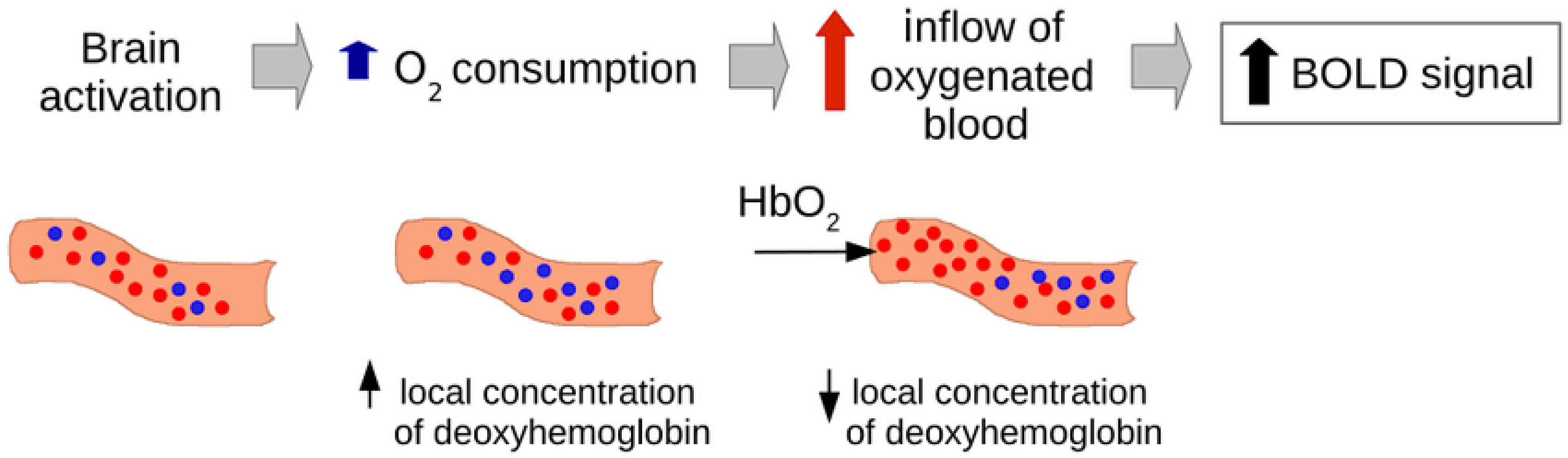


BOLD fMRI

- Blood oxygen level dependent functional magnetic resonance imaging (BOLD FMRI) is the most widely method for imaging human brain activity (2,000+ studies per year)
- BOLD effect: measures *changes* in deoxyhemoglobin *over time.* Mechanism:
  - brain region activates (a), demanding more energy (oxygen) (b).
  - Fresh oxygenated blood is sent to the region, washes away the deoxyhemoglobin (c)
  - BOLD signal increases due to decreased deoxyhemoglobin in vein
- Observe these changes by rapidly acquiring low-resolution SWI images over time (d)

a) b) c)



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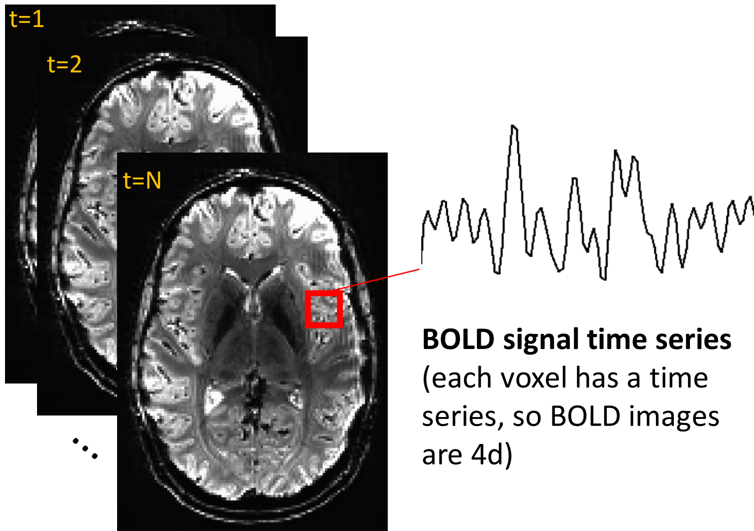
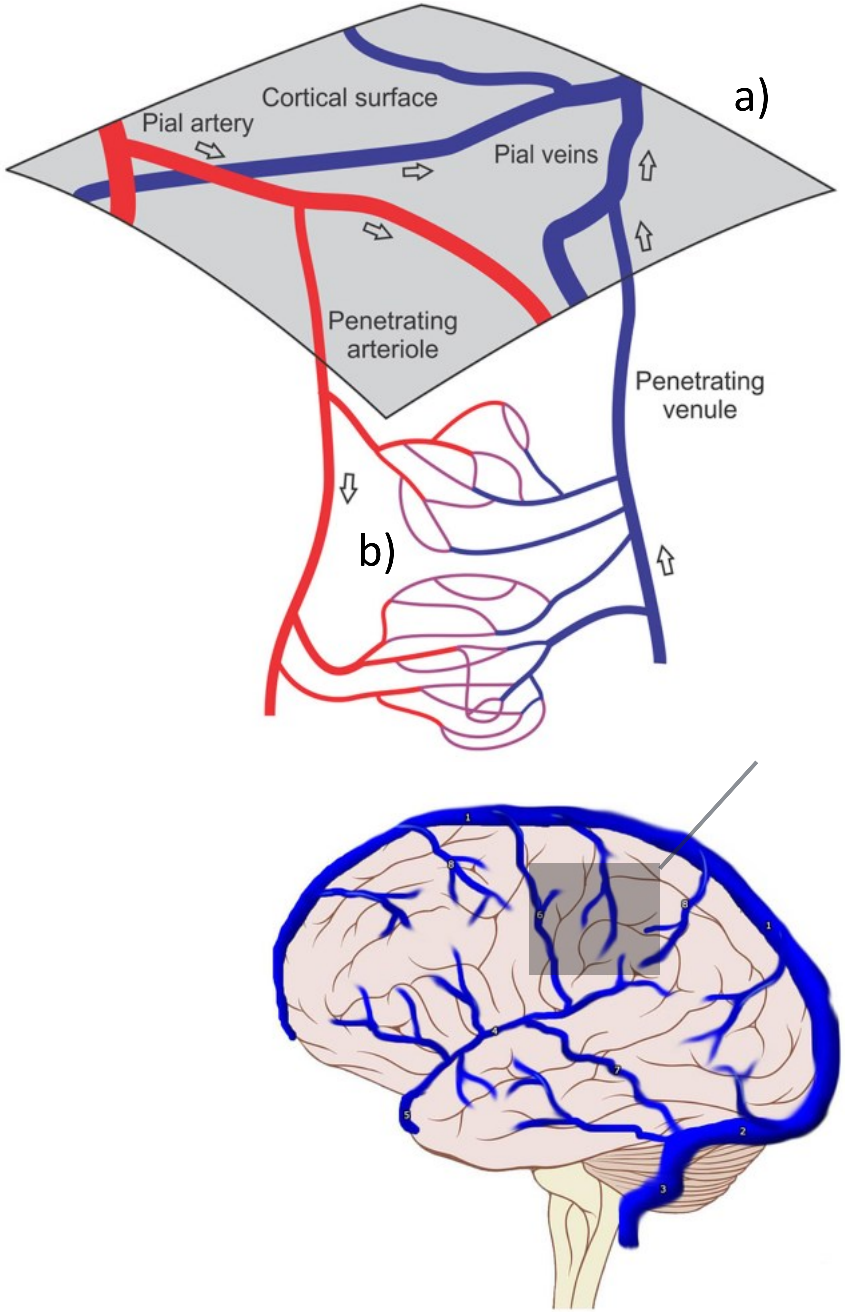


BOLD signal time series (each voxel has a time series, so BOLD images are 4d)

BOLD fMRI

- Difficult to overstate the power of BOLD
  - Non-invasive, full-brain measurement
  - Excellent spatial resolution
    - voxel sizes <1mm, if desired
  - Good temporal resolution
    - can acquire 1 image every ~500 ms
- One caveat of BOLD: not a *direct* measure of neuronal activity
  - BOLD measures changes in deoxyhemoglobin content in the large pial veins on the cortical surface (a)
    - This is quite far 'downstream' from the true source of activity
    - The pial veins also pool the blood from multiple regions
  - To get a more accurate measure of neuronal activity, would prefer to measure deep in the cortex (b)



One of my articles linking neuronal activity to BOLD

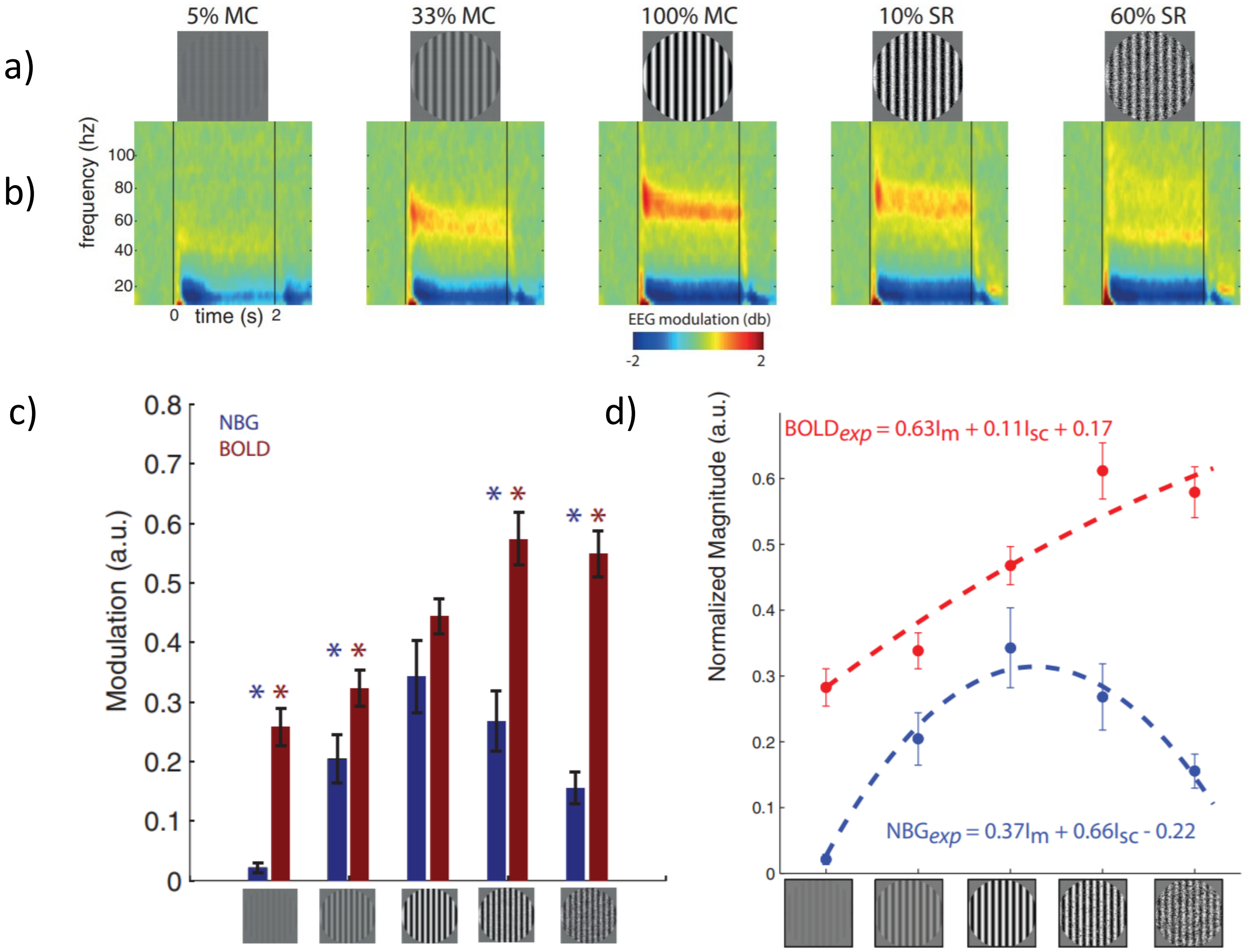
- My PhD supervisor was obsessed with disproving BOLD
  - wanted to show BOLD != neuronal activity
- Performed experiments during my PhD with visual stimuli designed to *increase* BOLD while *decreasing* neuronal activity
  - We called this the ‘dissociation experiment’ because it dissociates neuronal activity and BOLD
  - a) the 5 visual stimuli used in our experiment (top) and the accompanying neuronal response
    - MC = Michelson contrast, SR = spatial randomization
    - SR designed to dissociate EEG and BOLD
  - b) the neuronal (EEG) response to the 5 stimuli (more on EEG later)
  - c) NBG vs BOLD for the 5 stimulus types
    - NBG stands for ‘narrow-band gamma’, is the EEG frequency band from 60-80 Hz which is thought to best represent neuronal activity
    - SR dissociates NBG and BOLD
  - d) modeling results (read full paper) → https://www.jneurosci.org/content/37/22/5408.abstract

JNeurosci
THE JOURNAL OF NEUROSCIENCE

Decorrelated Input Dissociates Narrow Band γ Power and BOLD in Human Visual Cortex

Russell Butler, Pierre-Michel Bernier, Jérémie Lefebvre, Guillaume Gilbert, and Kevin Whittingstall

Journal of Neuroscience 31 May 2017, 37 (22) 5408-5418; DOI: https://doi.org/10.1523/JNEUROSCI.3938-16.2017

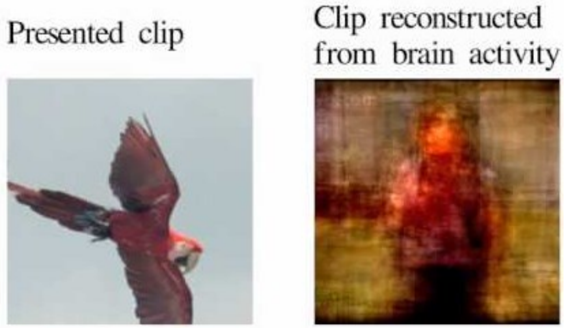


Good talk on some recent developments in fMRI: https://youtu.be/8BHufizQzC8

BOLD fMRI

- Despite its shortcomings, BOLD still *by far* the best tool we have for non-invasive measurement of human brain activity
- Some exciting applications:
  - Mind reading: https://www.youtube.com/watch?v=0o17Zwzam1g
    - This video is old, new methods using deep learning perform better
  - Identifying psychopaths (b)
    - https://www.sciencedirect.com/science/article/pii/S0896627317305548
  - Neurosurgical planning (c)
    - https://thejns.org/focus/view/journals/neurosurg-focus/47/6/article-pE15.xml

a)



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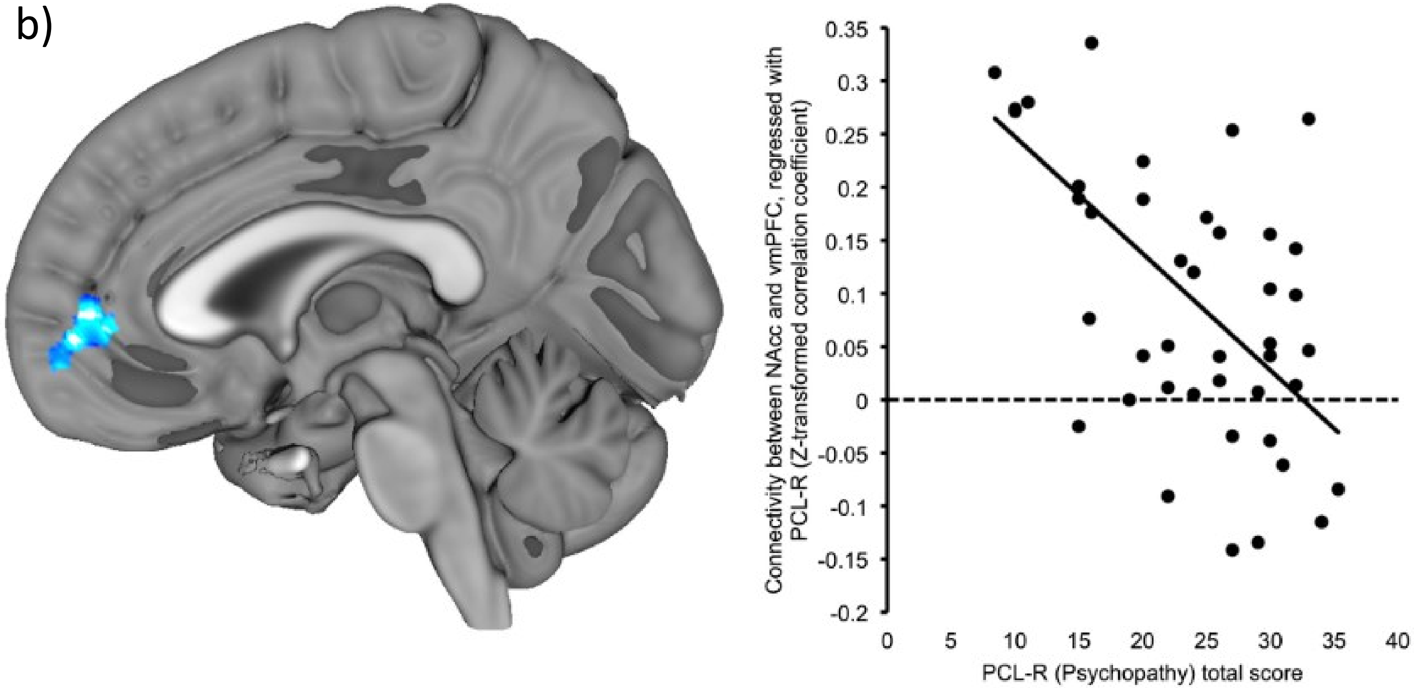

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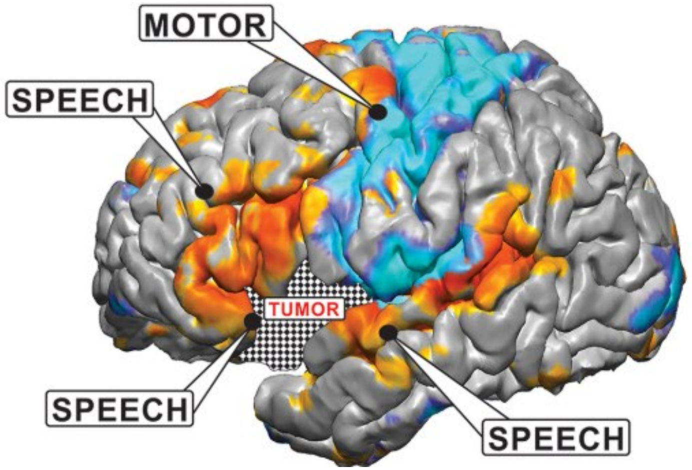
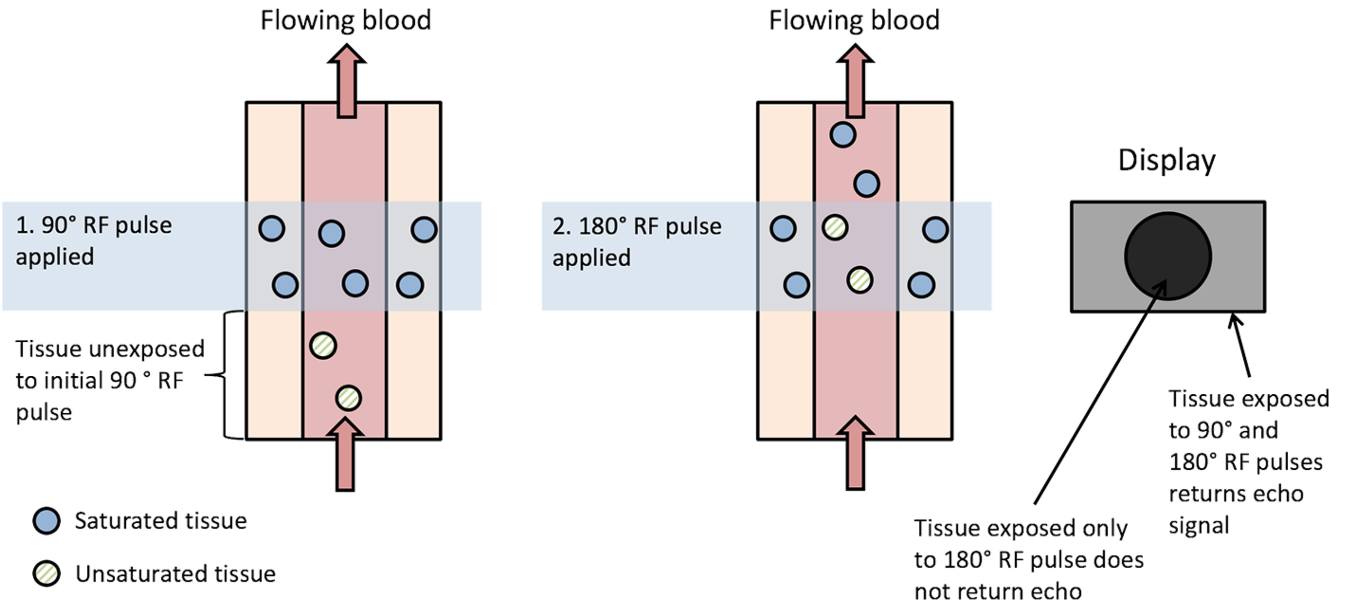
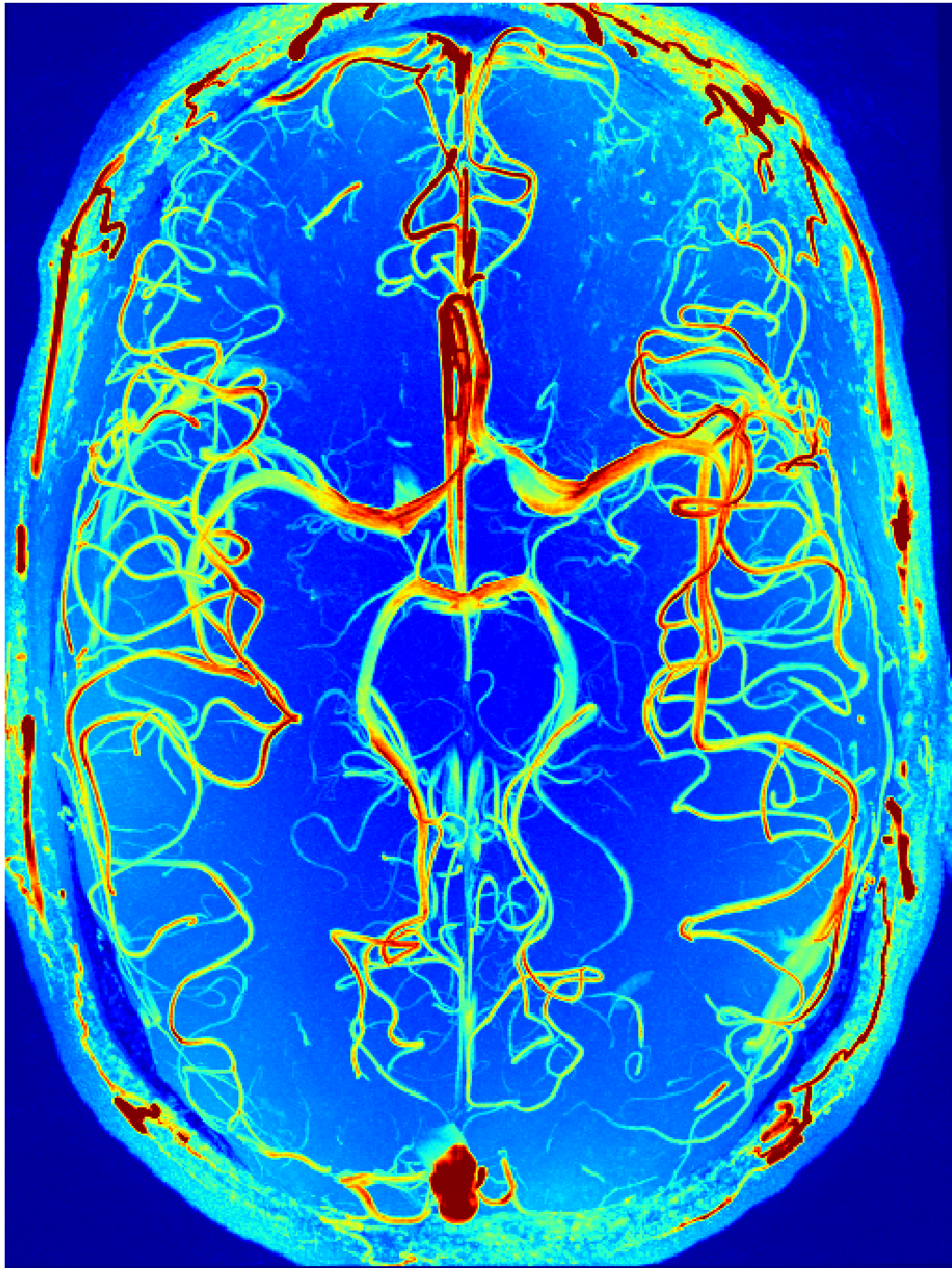


Time of flight (TOF) imaging

- Time of flight angiography (TOF) is an MRI technique to visualize arterial blood vessels
- Uses ‘saturation’ RF pulse to manipulate the magnetization of tissue such that magnetization of *moving spins* is large, and stationary spins is small
  - Spins move quickly in the arterial vasculature (blood is flowing quickly)
  - If we wait some time after saturating a slice, fresh blood will flow in, and appear brighter on the resulting image
  - Gives excellent contrast between arteries and surrounding tissue



Maximum intensity projection through z-axis of TOF

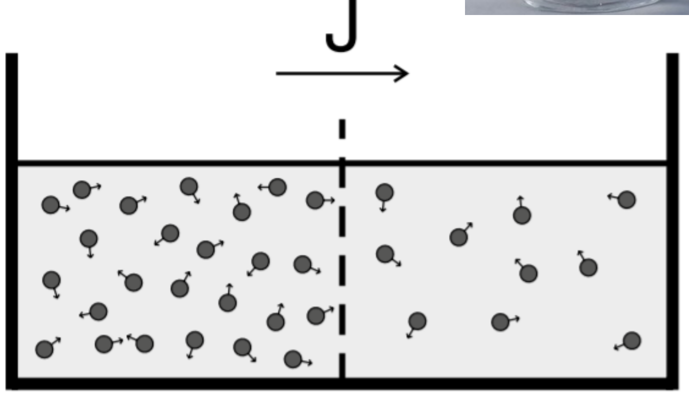


Diffusion weighted imaging (DWI)

- a) Diffusion is a mass transport system arising in nature which results in particle mixing without requiring bulk motion
- b) Fick's first law describes phenomenon, relates diffusive flux to any concentration difference: $\boldsymbol{J} = -D\nabla C$
  - Where $\boldsymbol{J}$ is net particle flux (vector), C is particle concentration, and D is proportionality constant called 'Diffusion coefficient'
- c) Einstein used probabilistic framework to describe motion of ensemble: $\langle x^2 \rangle = 2D\Delta$
  - Where $\langle x^2 \rangle$ is mean-squared displacement of particle during diffusion time Δ, D is same as above
- **Diffusion MRI**: can infer features of local tissue anatomy and microstructure from particle displacement measures

a)

b)



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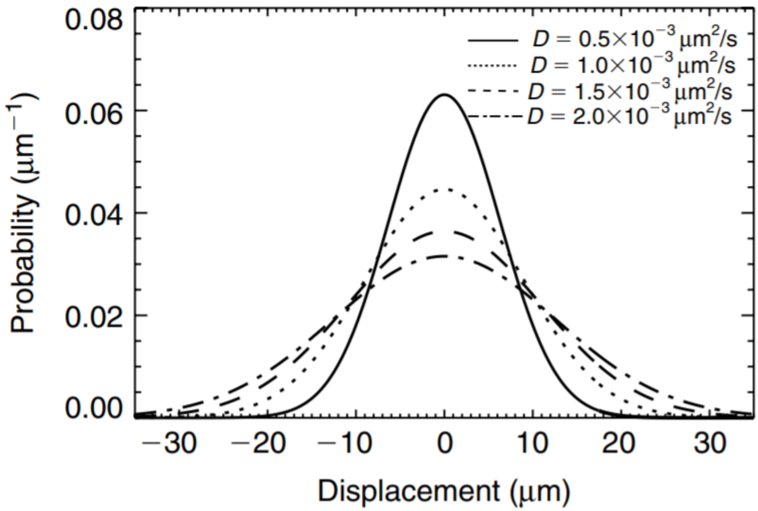
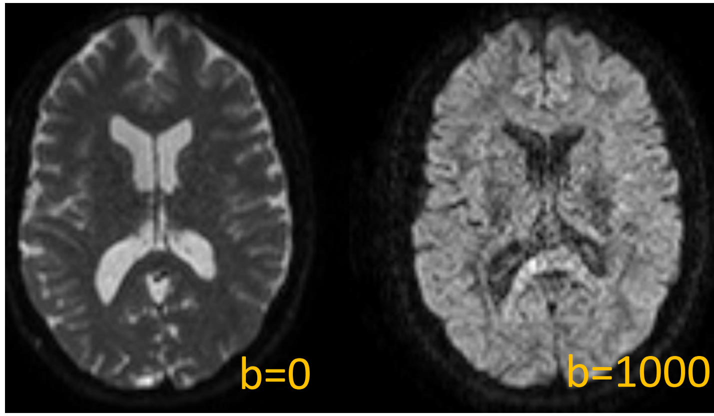


Recent webinar from my Ph.D. supervisor: https://www.youtube.com/watch?v=HwT4vFIvqzw

Diffusion MRI

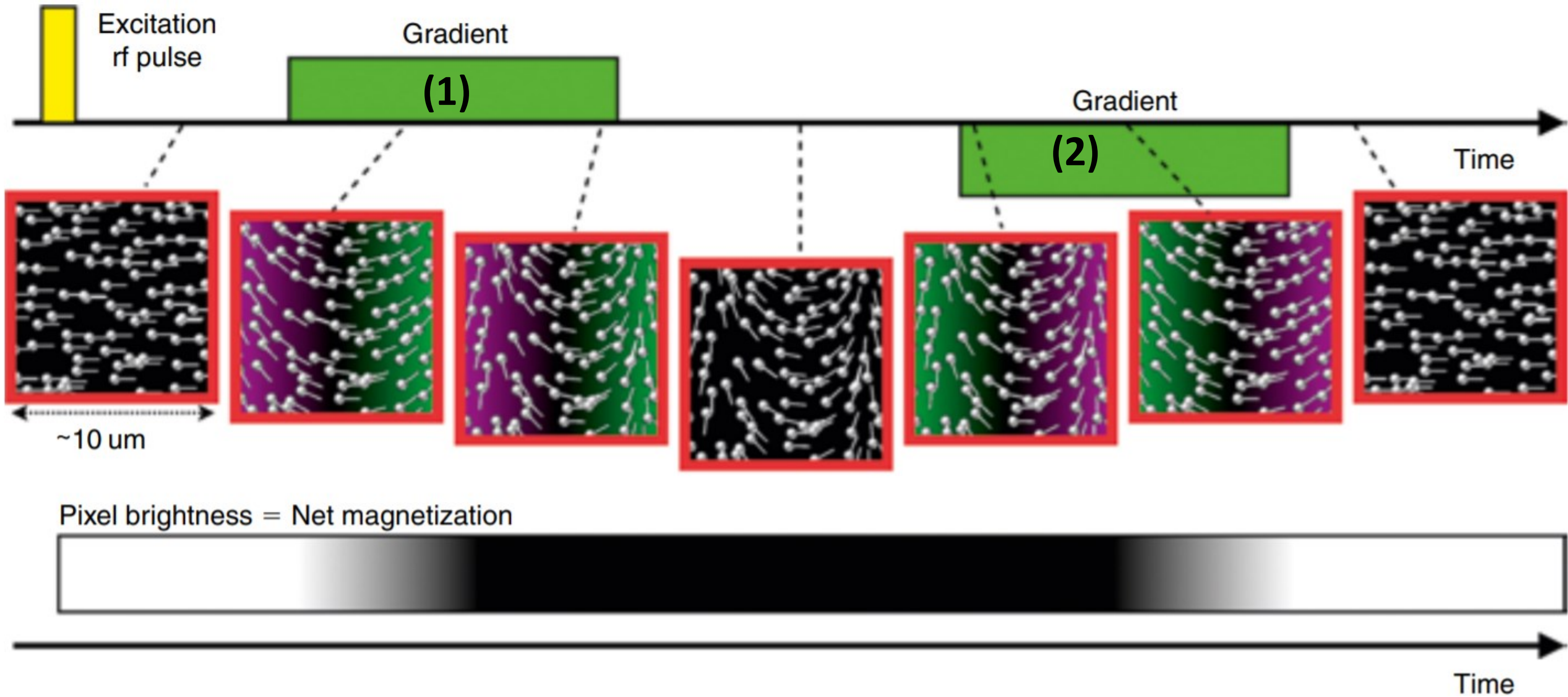


- How to make MRI sensitive to diffusion?
- Need to add *diffusion weighting* to MRI pulse sequence
- After RF excitation pulse, apply *bipolar gradient:*

a)

$$f(x,y) = M_0(1 - e^{-TR/T1})e^{-TE/T2}e^{-bD}$$

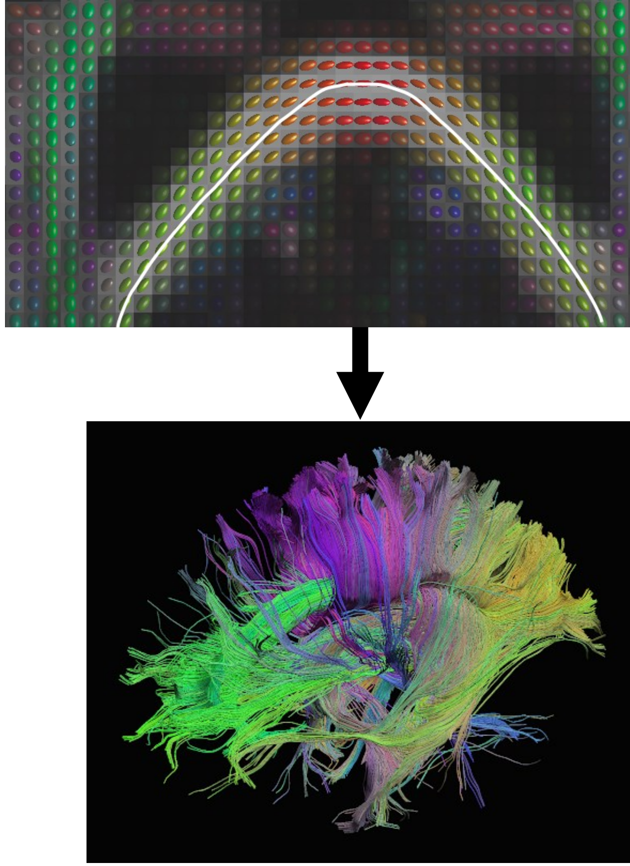
- Bipolar gradient adds to each spin's precession a positive phase proportional to its average position along gradient direction during first gradient lobe **(1)** and a negative phase proportional to spin's average position during second lobe **(2)**
- Sum of these phases is related to difference between these two positions
- Bipolar gradient has no effect on spins which don't move, they are completely 'in phase' after gradient
- If spins are displaced due to diffusion, the signal is attenuated exponentially by a product of diffusion coefficient D and a factor b which is a function of the bipolar gradients (a)



Diffusion MRI

- Diffusion MRI one of the most powerful and flexible methods
- Some exciting applications:
- Diffusion tractography (a)
    - Reconstruct connections between brain areas by tracing a line along diffusion direction in individual voxels
- Microstructure imaging (b)
    - Use diffusion properties of tissue to infer local microstructure
- Perfusion of microvasculature (c)
    - Also known as ‘intra-voxel incoherent motion’, diffusion MRI can be used to provide information on blood volume and blood velocity in the capillary network

a)



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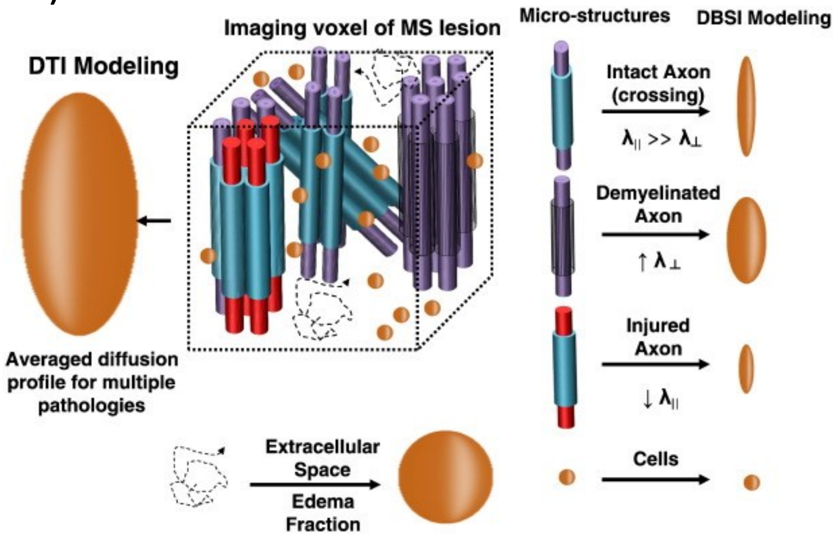

c)