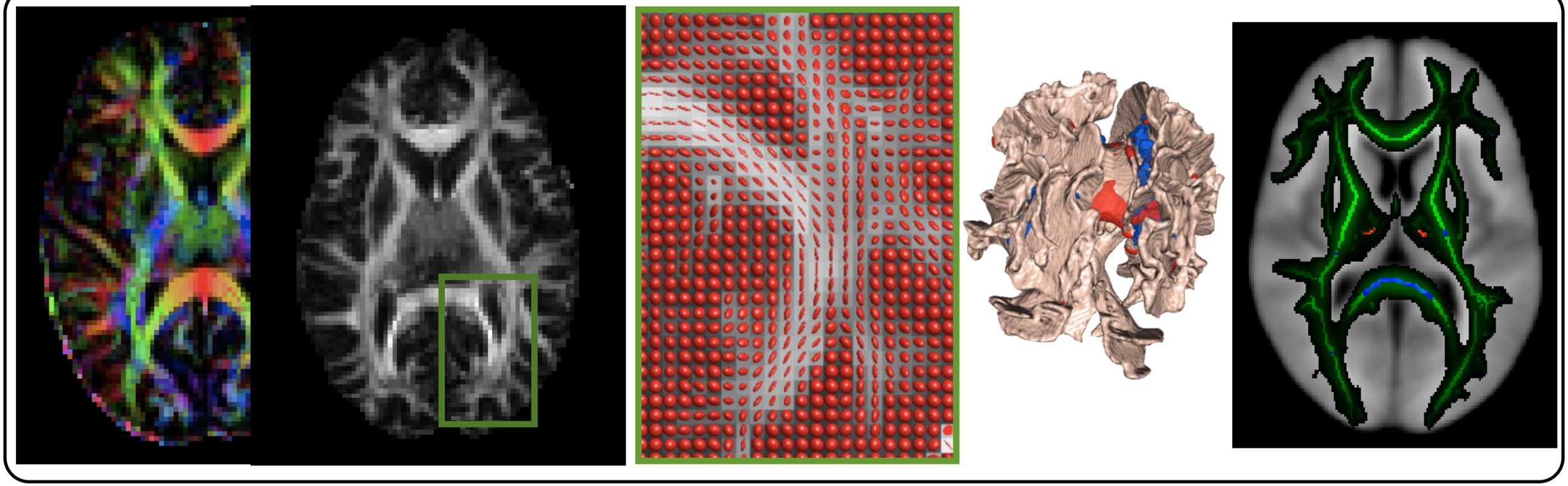
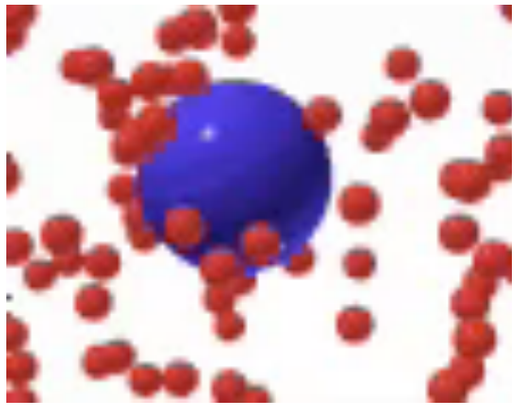
Introduction to Diffusion MRI



Diffusion - Brownian Motion

Robert Brown (1773-1858)**



Molecules are in constant motion at non-zero absolute temperatures (> -273^{o} C)

Diffusion = thermally-driven random motion

**Rudolph Hoffmann / Public domain
https://commons.wikimedia.org/wiki/File:Robert_Brown.jpg

Diffusion - Brownian Motion

Albert Einstein (1879-1955)**

How can we describe this motion?
For an ensemble of molecules, in *n*-dimensional space:

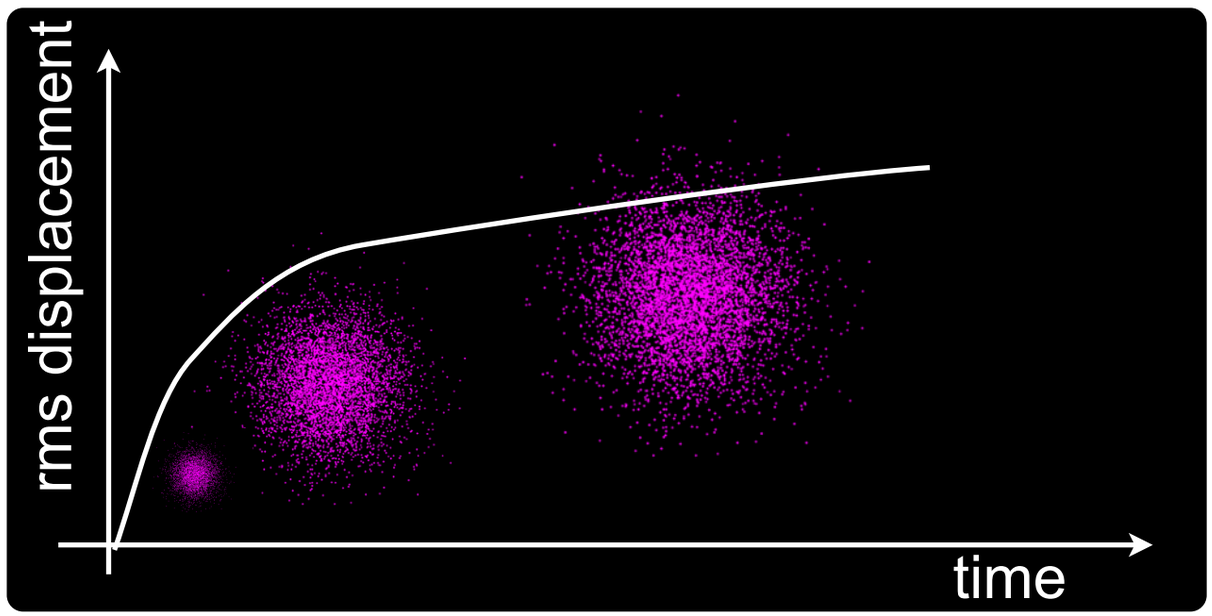
$$< x^2 >= 2nDt$$

mean squared displacement

Diffusion coefficient

time

Valid for a homogeneous, barrier-free medium.



** https://commons.wikimedia.org/wiki/File:Einstein_patentoffice.jpg
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Water Diffusion in the Brain. Why is it Interesting?

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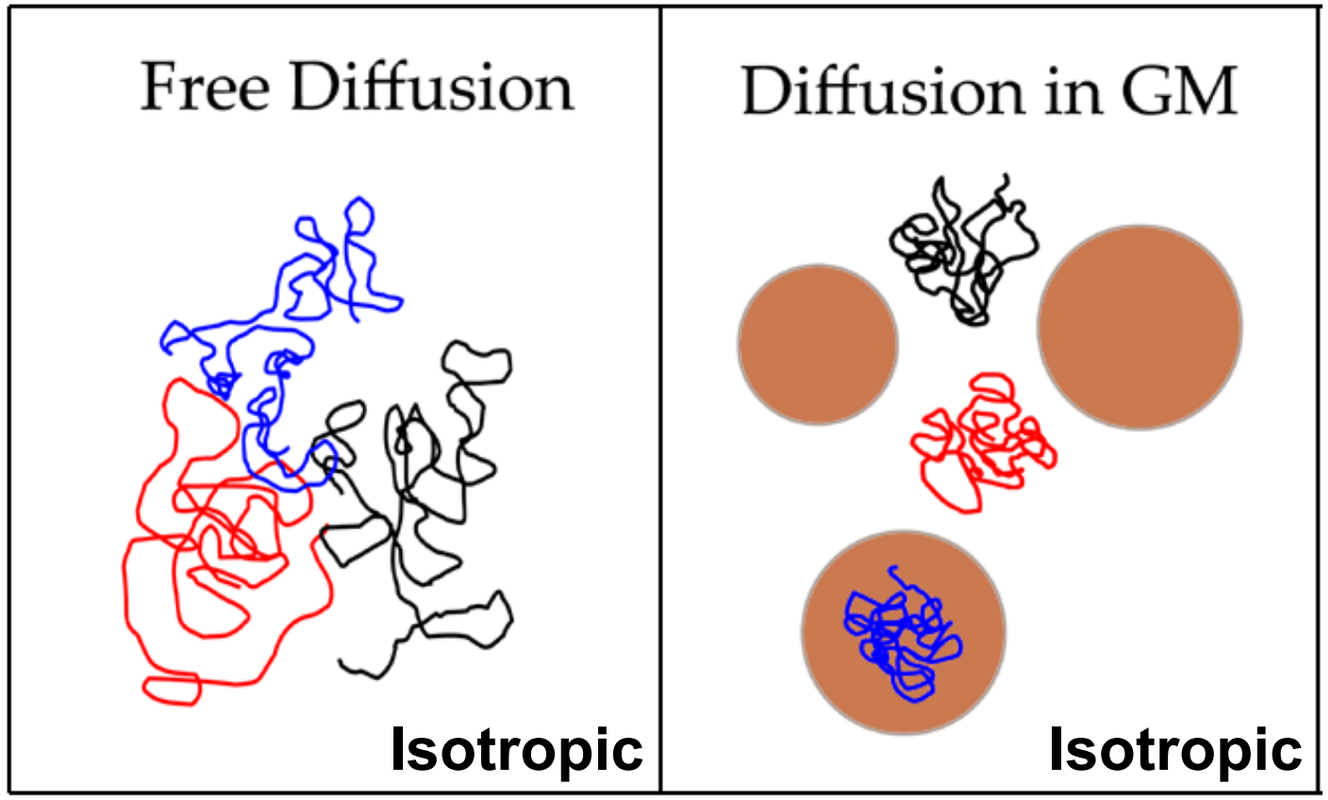

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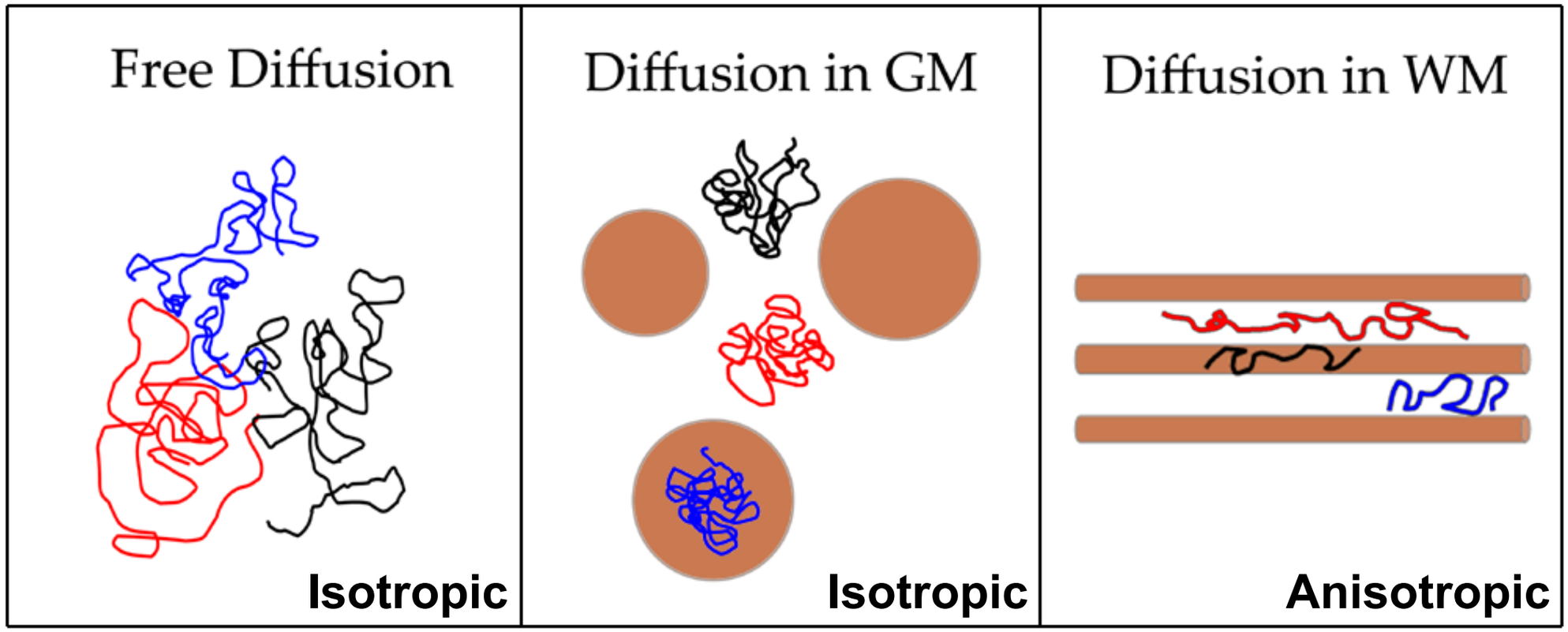
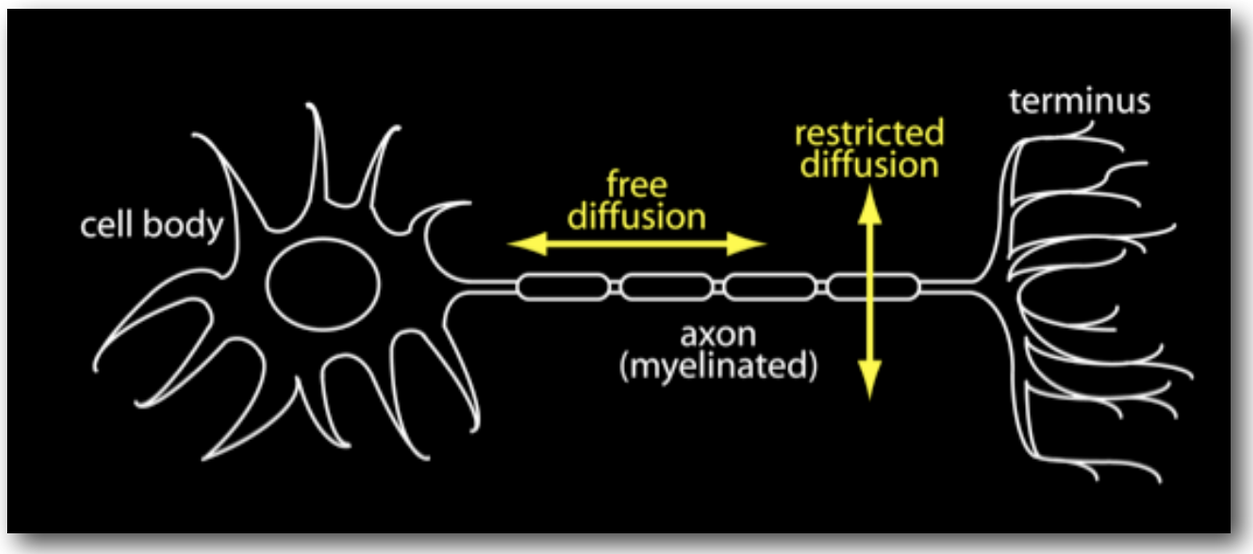
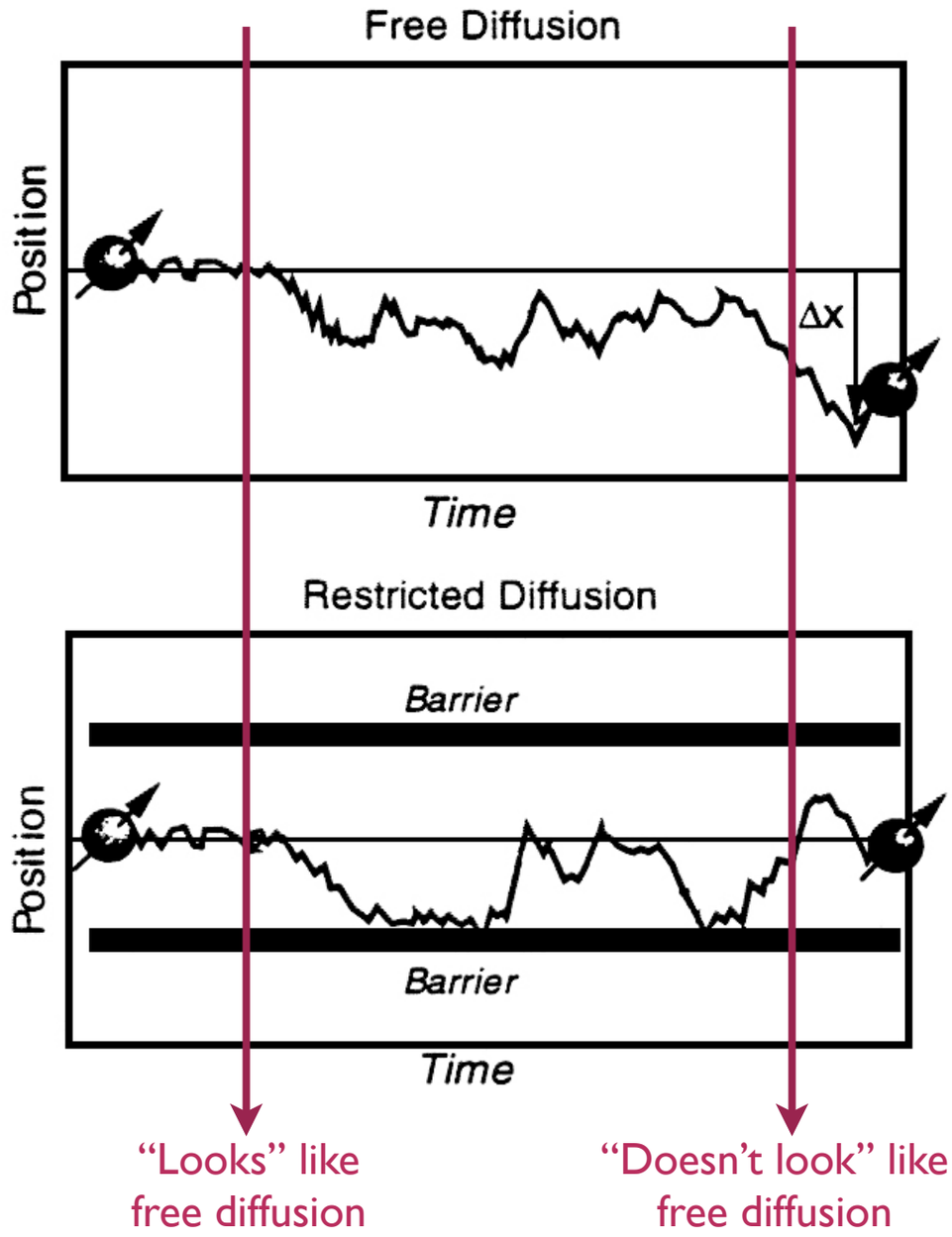




Diffusion is restricted by tissue boundaries, membranes, etc.
Marker for tissue microstructure (healthy and pathology)
Diffusion is **anisotropic** in white matter [Beaulieu, NMR Biomed, 2002]

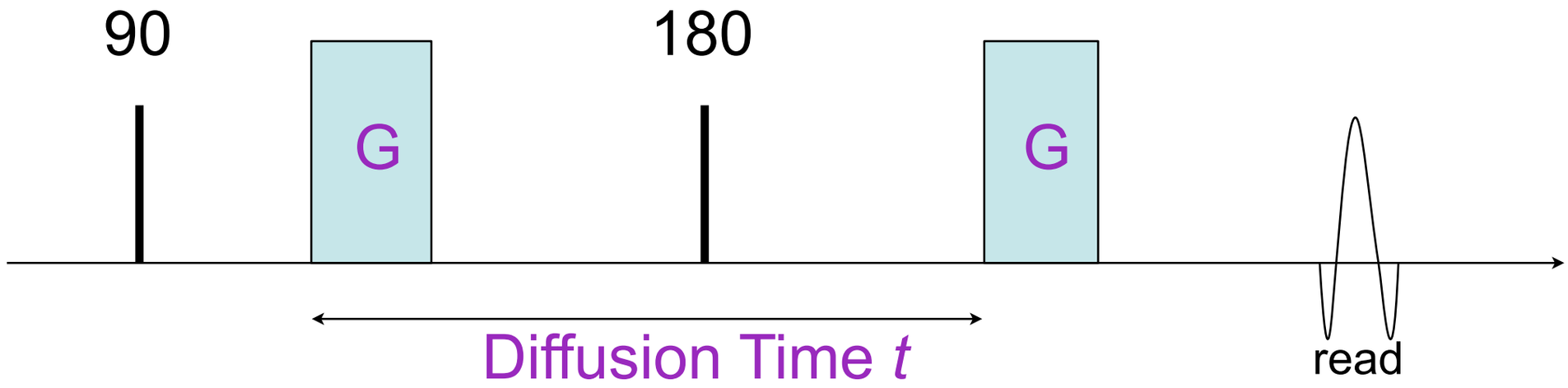
Apparent Diffusion Coefficient (ADC)



Apparent diffusion coefficient depends on the experimental details (e.g., diffusion time)

Measuring Diffusion with MRI: Diffusion MRI (dMRI)

Pulsed-Gradient Spin-Echo Sequence:
To achieve diffusion-weighting along a direction **x**, apply strong magnetic field gradients along **x**.



If particles diffuse along **x** during the allowed time (DiffTime), a signal attenuation is observed, compared to the signal with G=0.

[Stejskal & Tanner, 1965]

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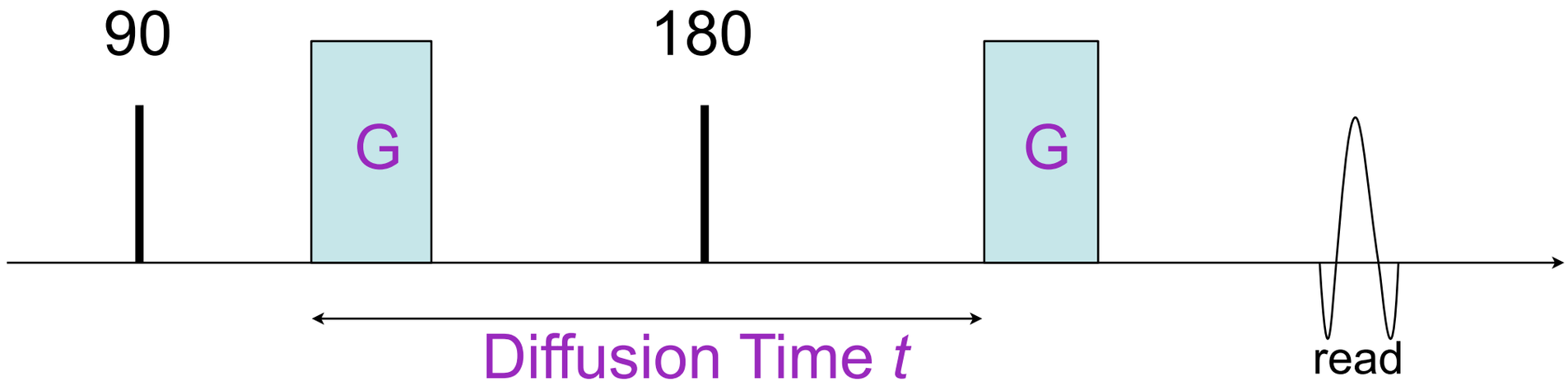

D ~ 2.4 μm²/ms
t~50ms

$x=\sqrt{6Dt}$ *~27μm*

st. deviation of displacements

[Stejskal & Tanner, 1965]

Measuring Diffusion with MRI: Diffusion MRI (dMRI)

T2w Image
No Diffusion-weighting
(G=0)
S_0

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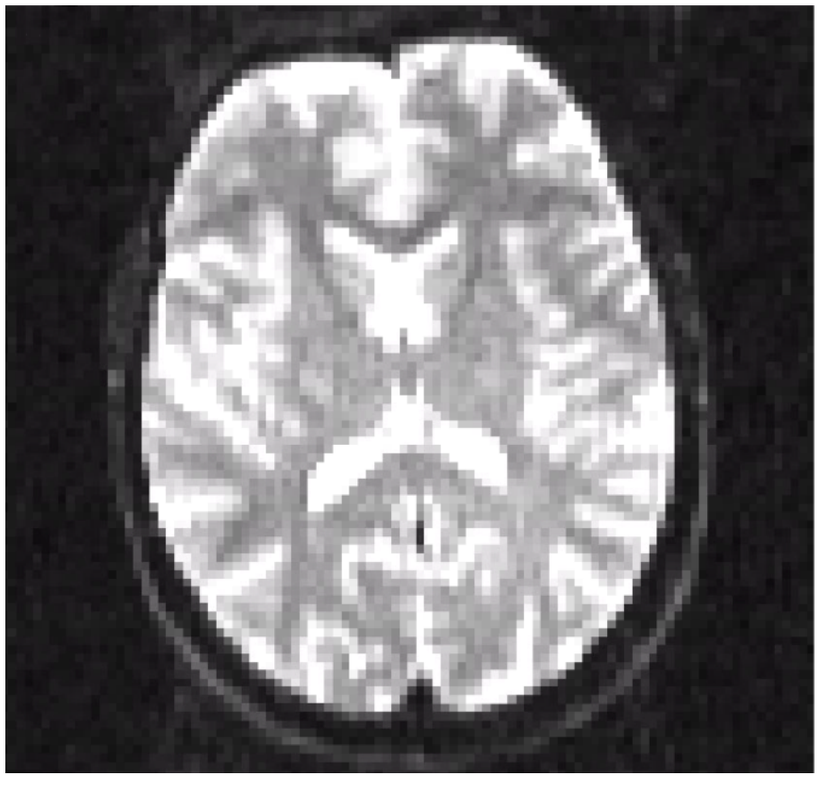
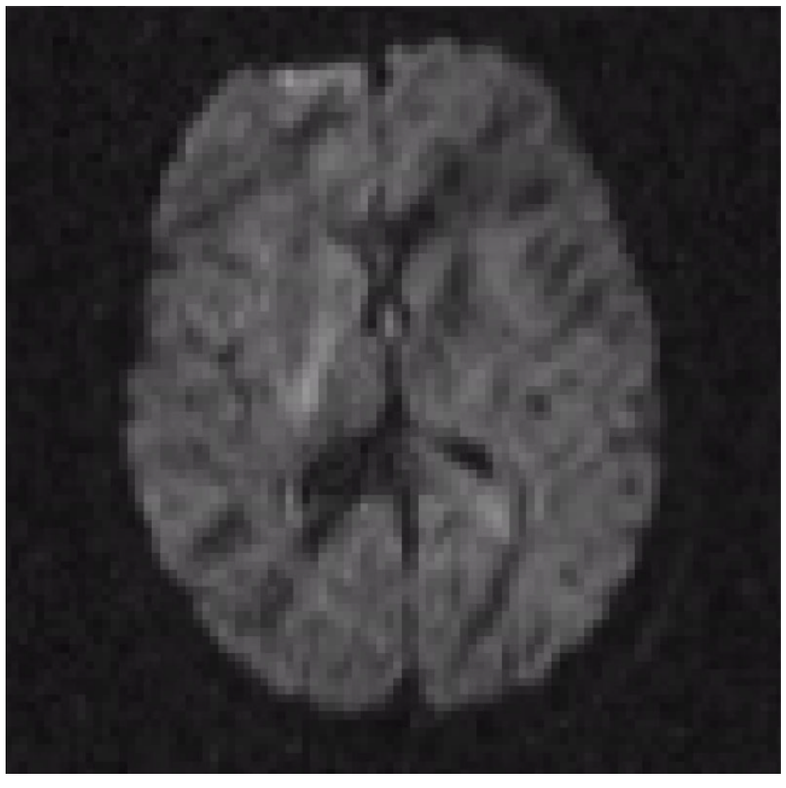


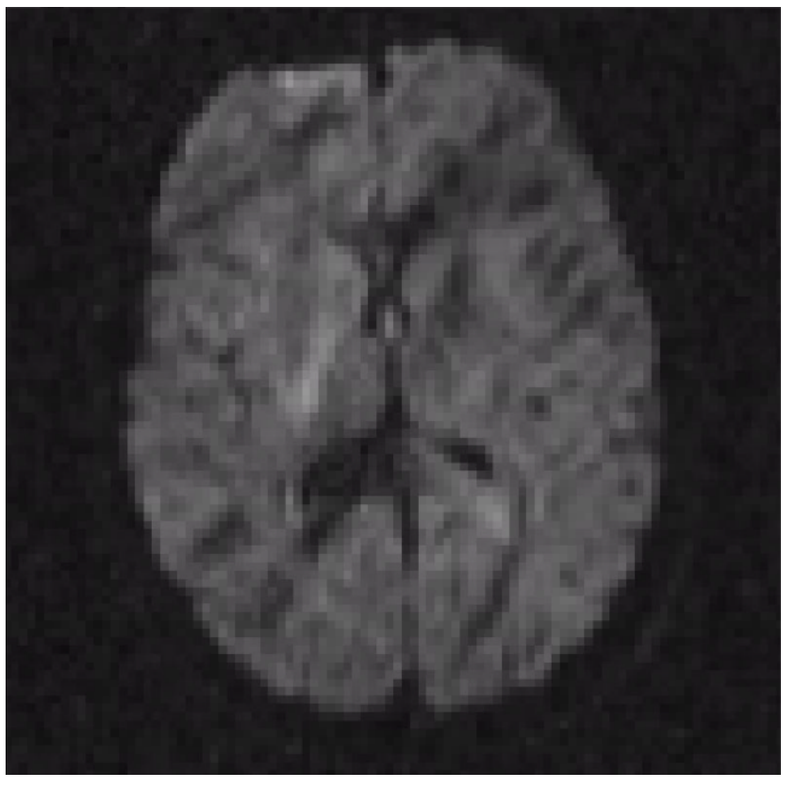
Diffusion-weighted
Image
S



Measuring Diffusion with MRI: Diffusion MRI (dMRI)

T2w Image
No Diffusion-weighting
(G=0)
S_0

Diffusion-weighted
Image
S



Ratio
S/S_0

Removes T2w contrast

Measuring Diffusion with MRI: Diffusion MRI (dMRI)

Diffusion contrast can be modulated by:

A) Diffusion weighting: Gradient **strength,** Diffusion **time**

b value ~ G^2 . DiffTime (units in s/mm^2)

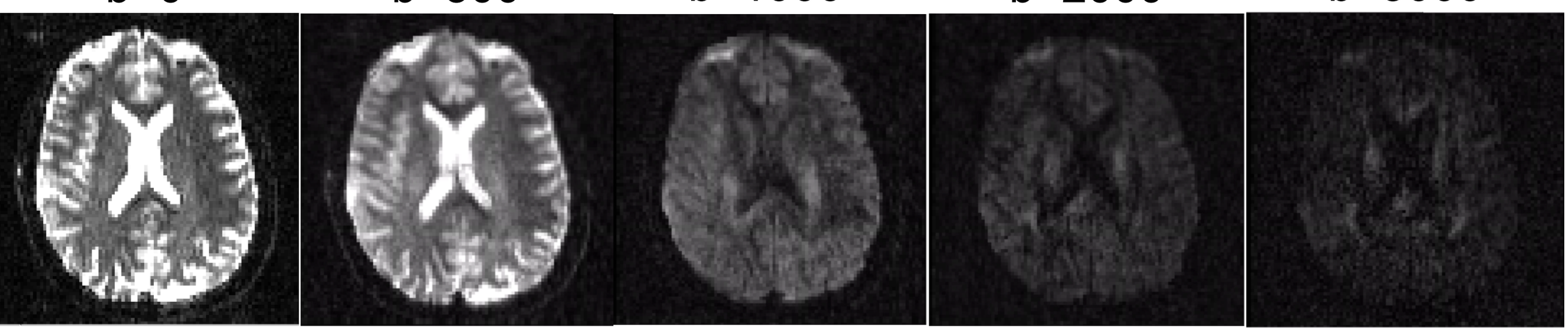
Measuring Diffusion with MRI: Diffusion MRI (dMRI)

Diffusion contrast can be modulated by:

A) Diffusion weighting: Gradient **strength,** Diffusion **time**

b value ~ G^2 . DiffTime (units in s/mm^2)

b=0 b=300 b=1000 b=2000 b=3000



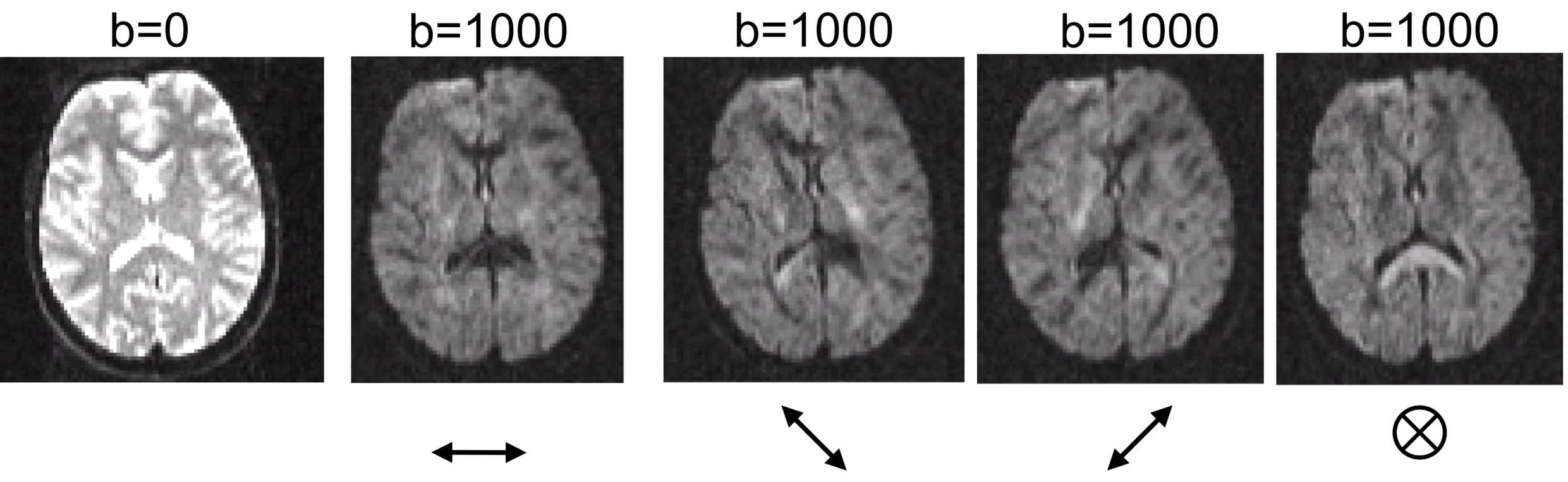
More diffusion contrast with higher b :)

…But less signal left - exponential decay :(

Measuring Diffusion with MRI: Diffusion MRI (dMRI)

Diffusion contrast can be modulated by:

B) Gradient Direction

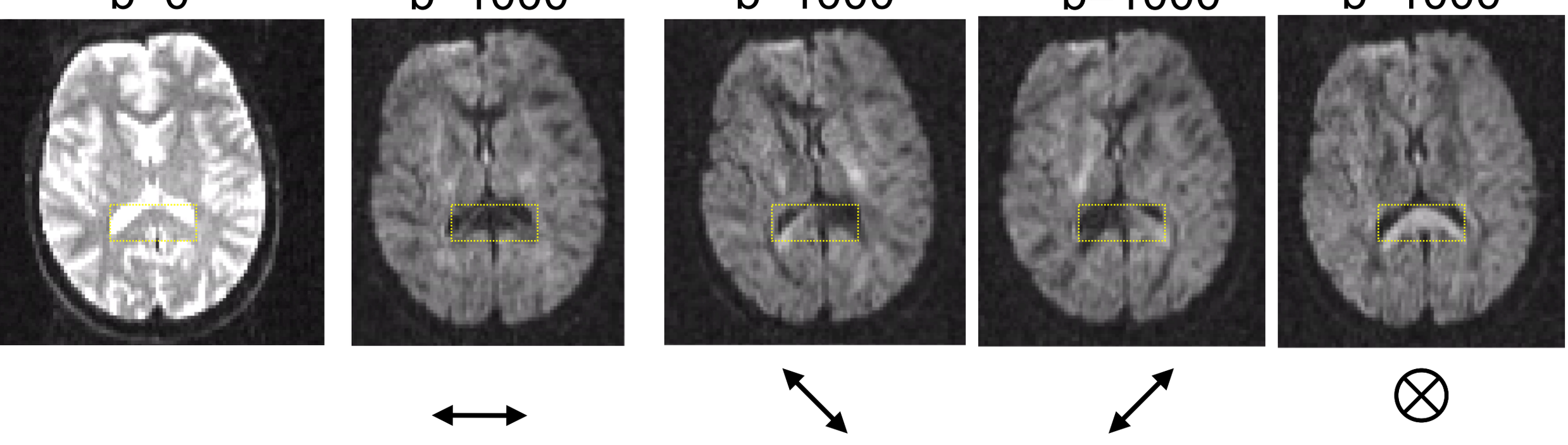


Measuring Diffusion with MRI: Diffusion MRI (dMRI)

Diffusion contrast can be modulated by:

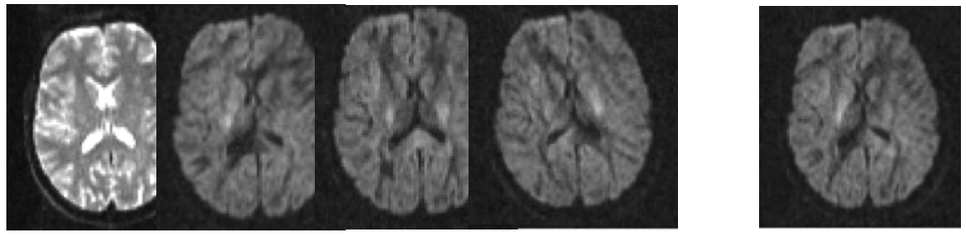
B) Gradient Direction

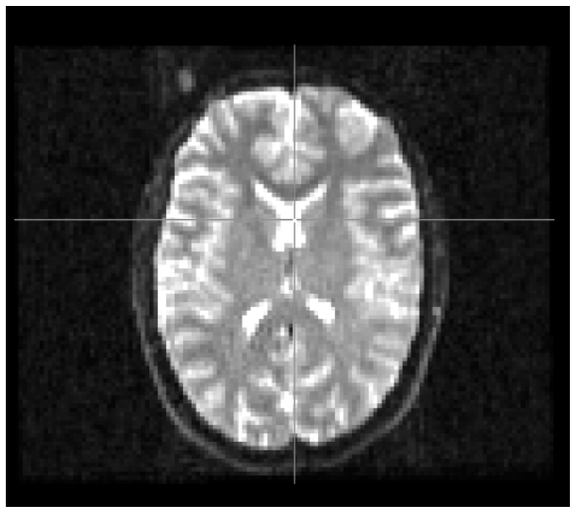
b=0 b=1000 b=1000 b=1000 b=1000

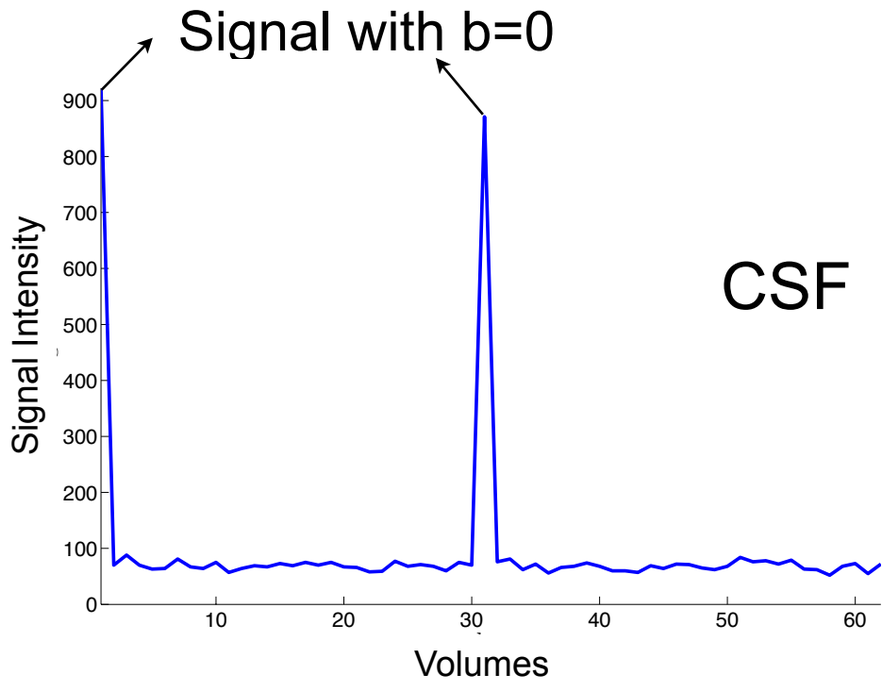


A Typical dMRI Protocol

- Normally a few (at least one) b=0 volumes acquired, along with volumes at higher b (~1000 s/mm^2).
- Different gradient directions are applied for the high b volumes.







CSF

A Typical dMRI Protocol

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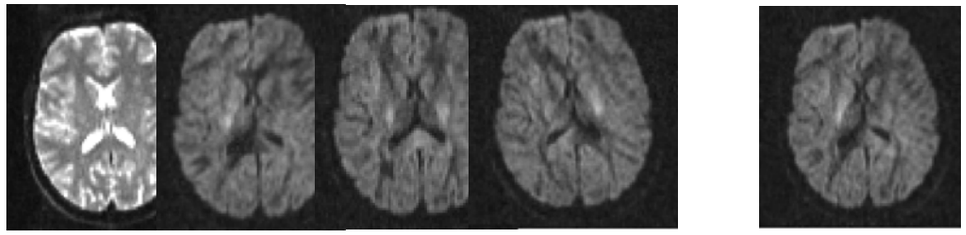
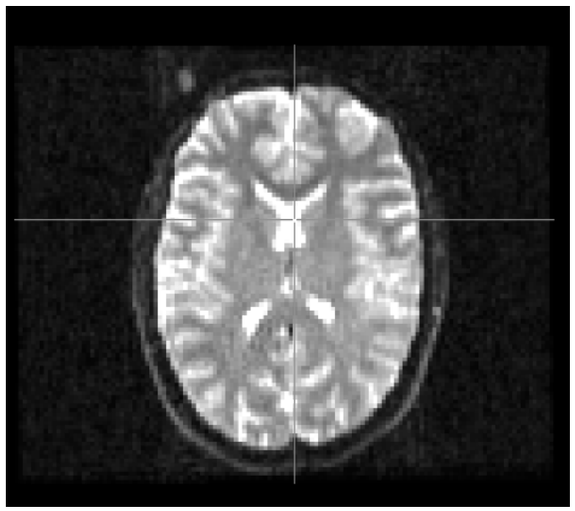
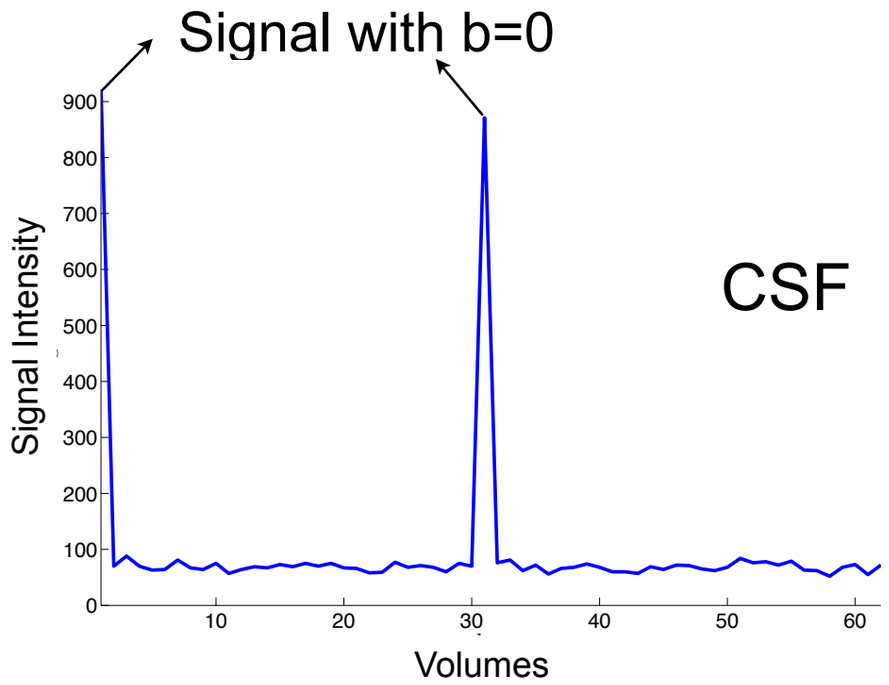
- Different gradient directions are applied for the high b volumes.

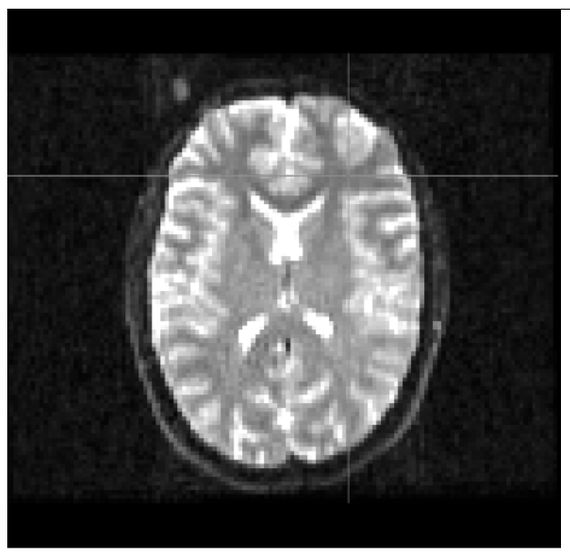


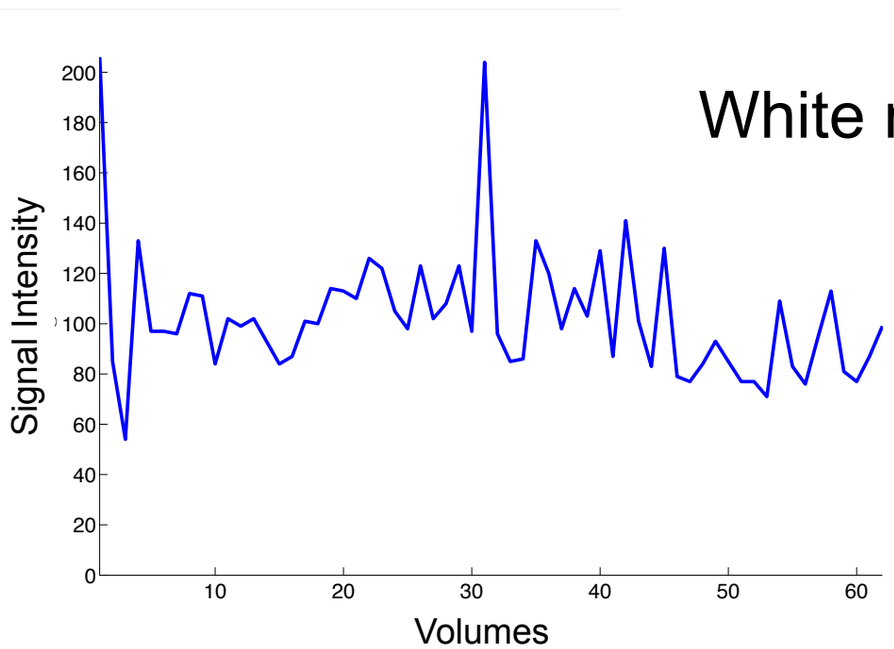




CSF

relates to ADC





White matter

relates to anisotropy

dMRI Summary

- Images acquired with a Gradient along direction **x**, have contrast that is sensitive to diffusion of water molecules along direction **x**.

- When diffusion occurs, signal is attenuated compared to no diffusion-weighting.

- In WM, measurements are anisotropic. There is a preferred direction of diffusion.

- In GM and CSF, measurements are roughly isotropic.