UNIVERSITÀ DEGLI STUDI DI MILANO

Brain Connectivity Center
I.R.C.C.S. C. Mondino – Pavia

Investigation of the cerebellar microstructure with diffusion MRI

Giovanni Savini

Supervisor: Prof A. Lascialfari

First-year students Workshop, 21st Oct. 2016

Brain? Never heard before…

Principal organ of the central nervous system

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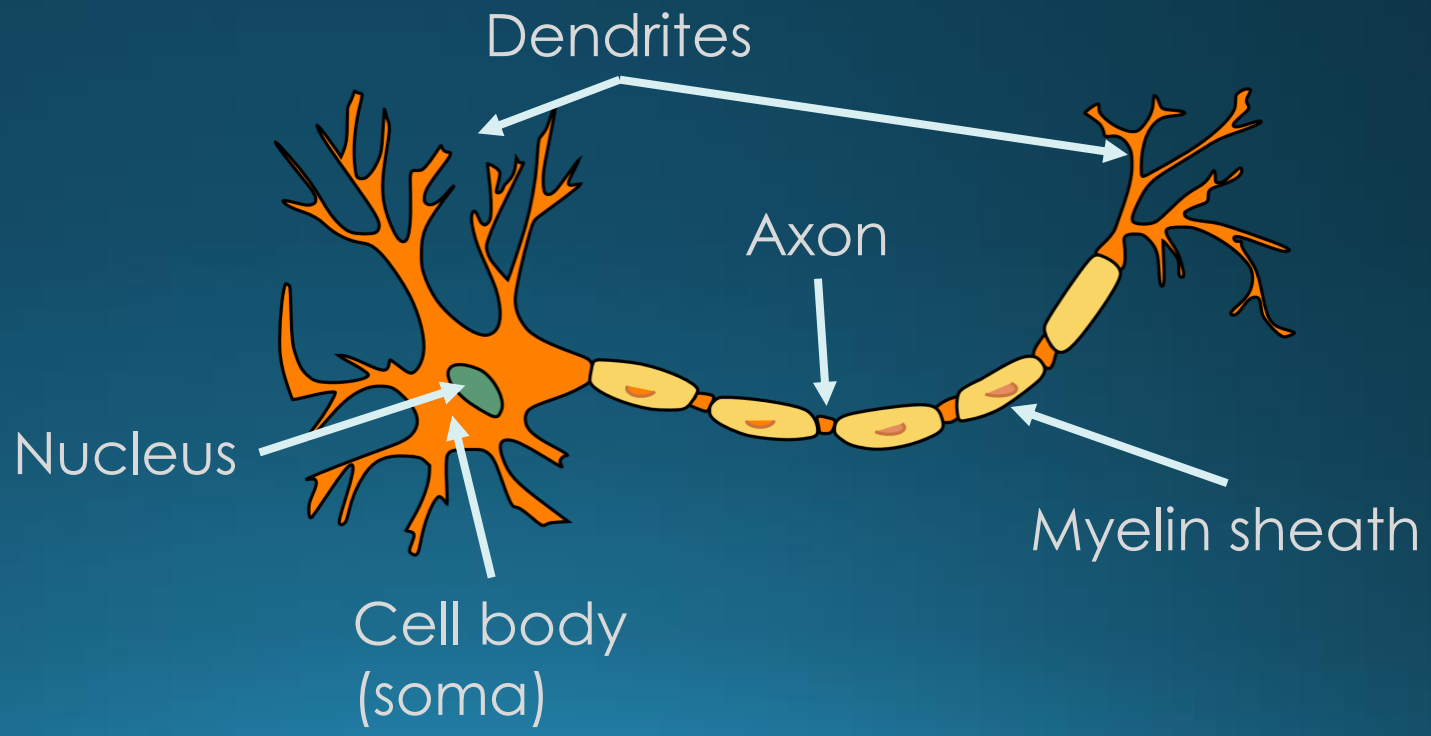
Principal organ of the central nervous system

Made of neurons



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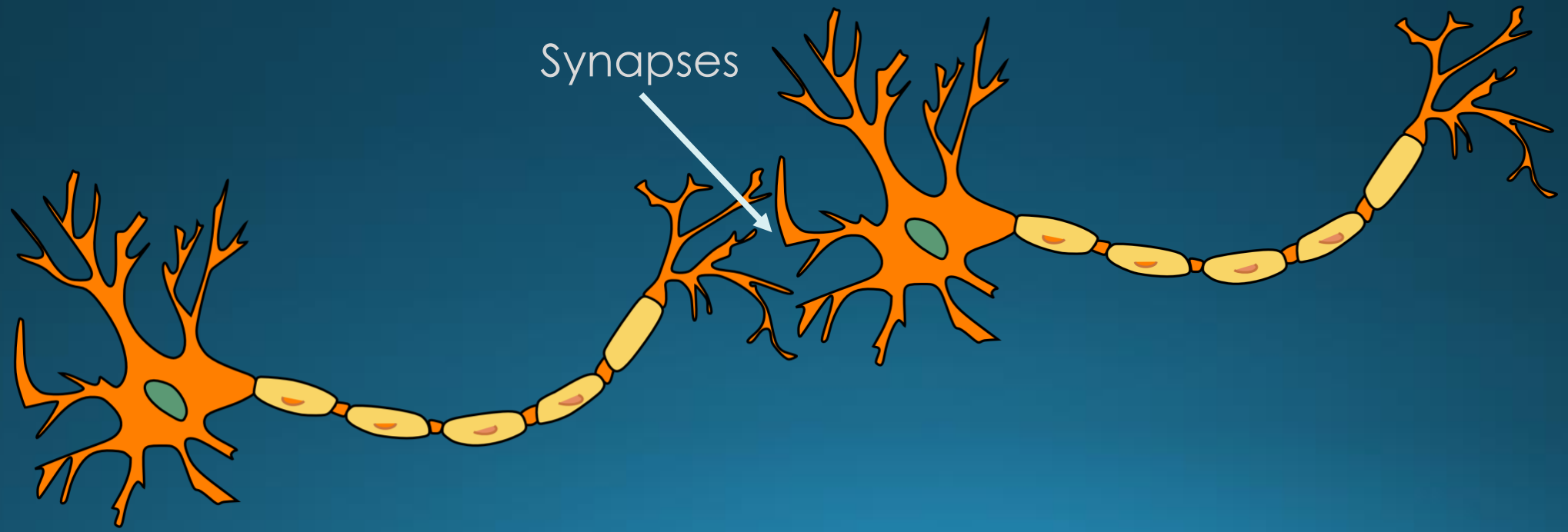

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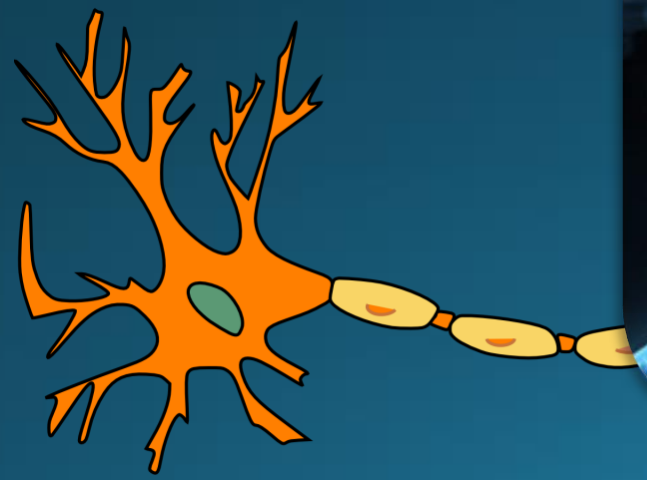

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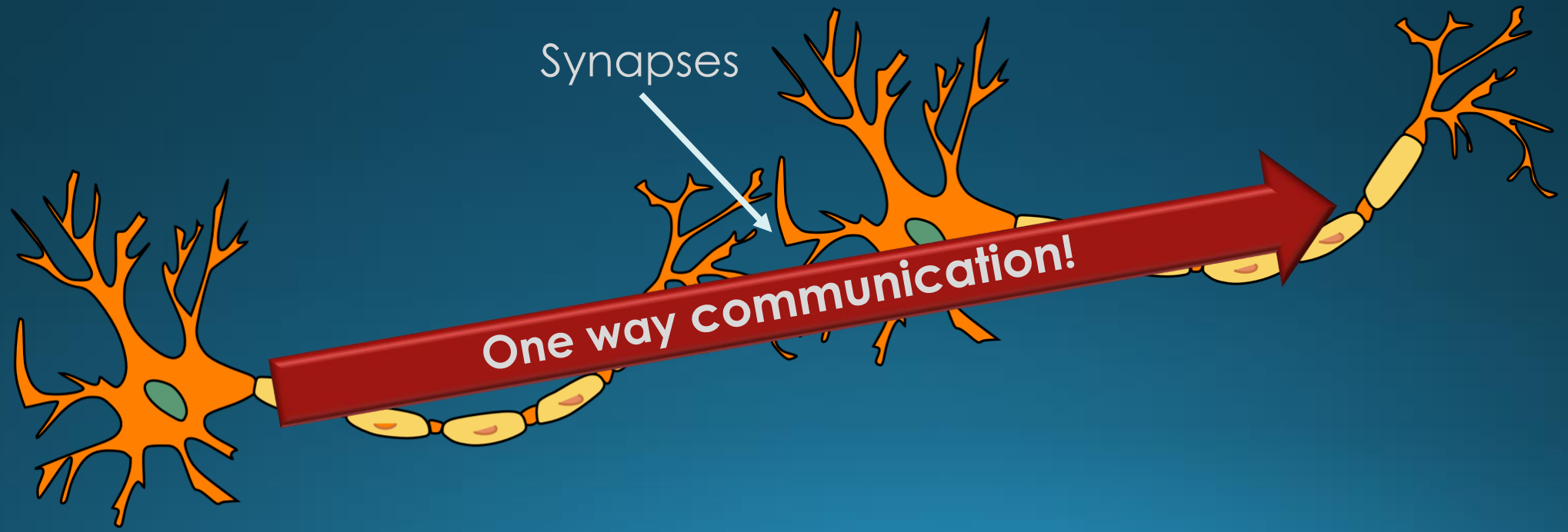
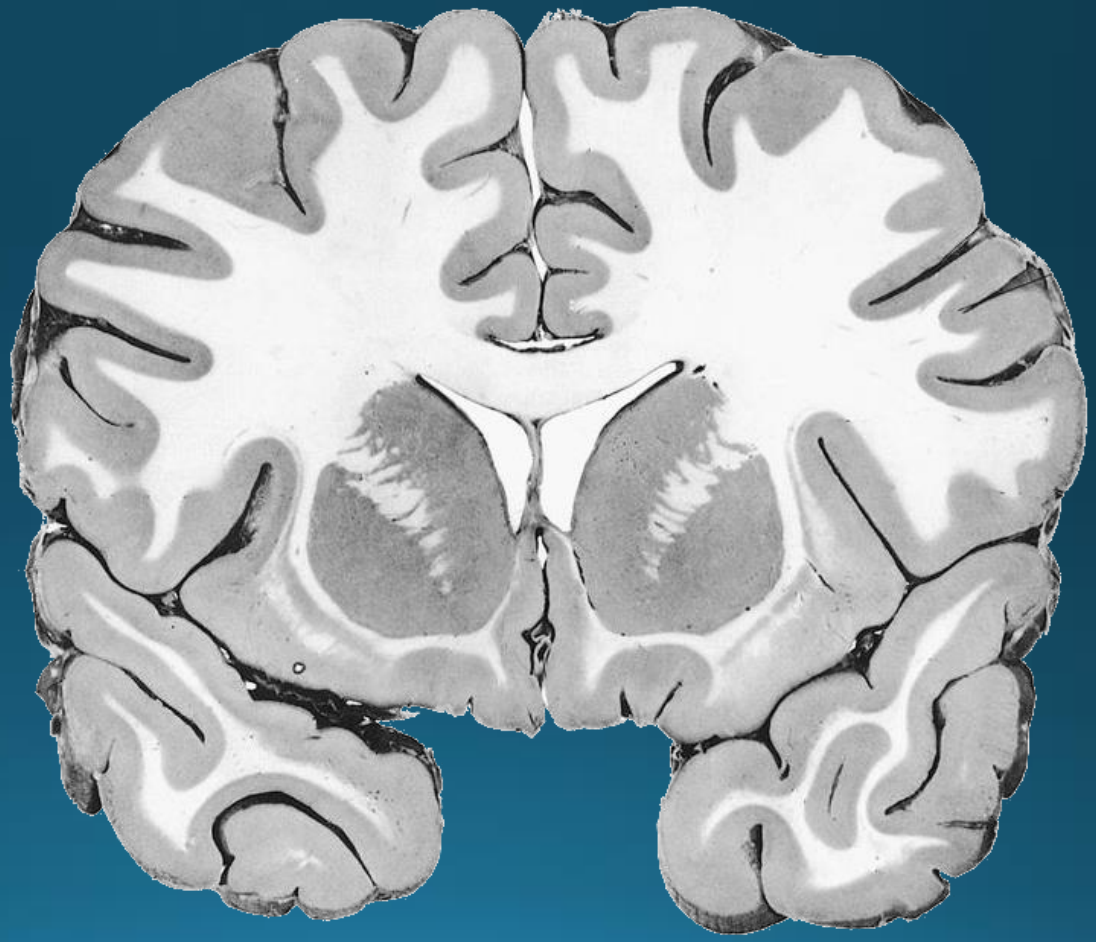


Grey and white matter

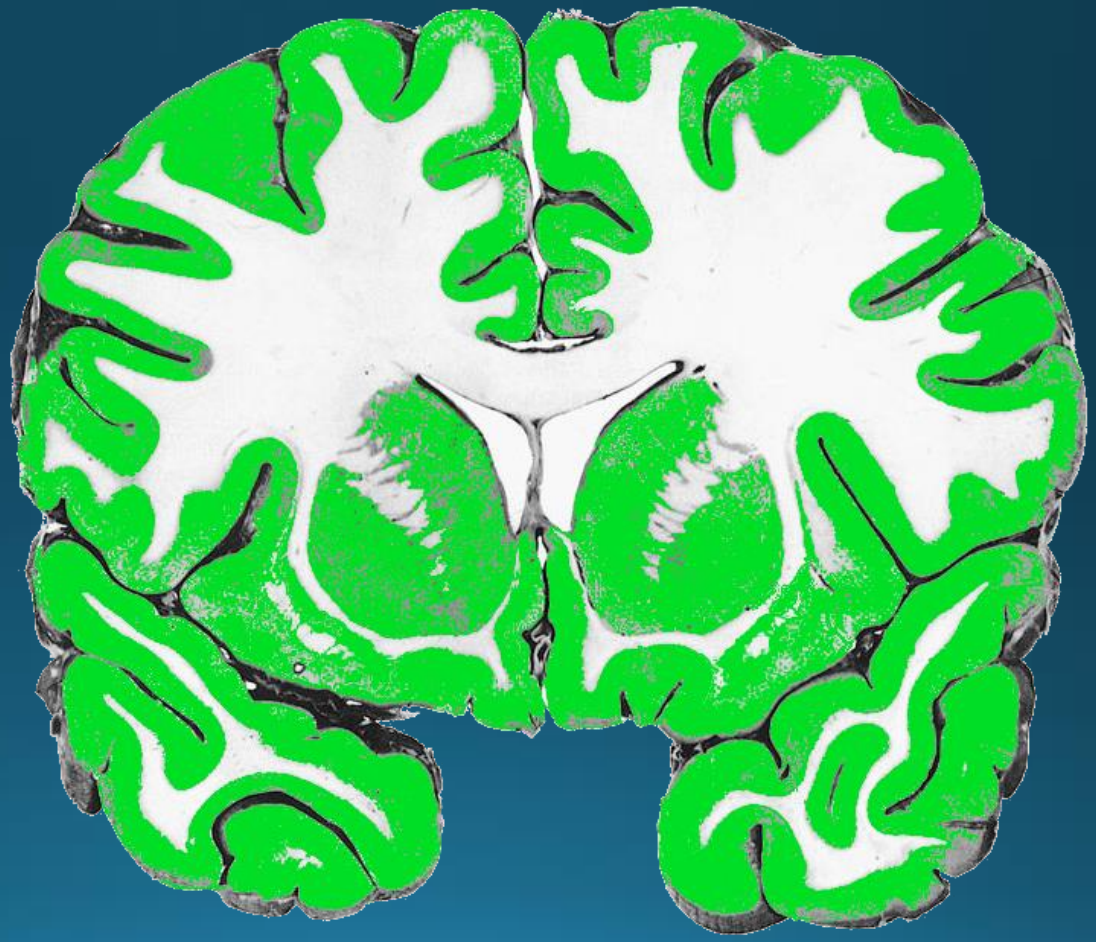
One slice:



Grey and white matter

One slice:

Grey matter



Grey and white matter

One slice:

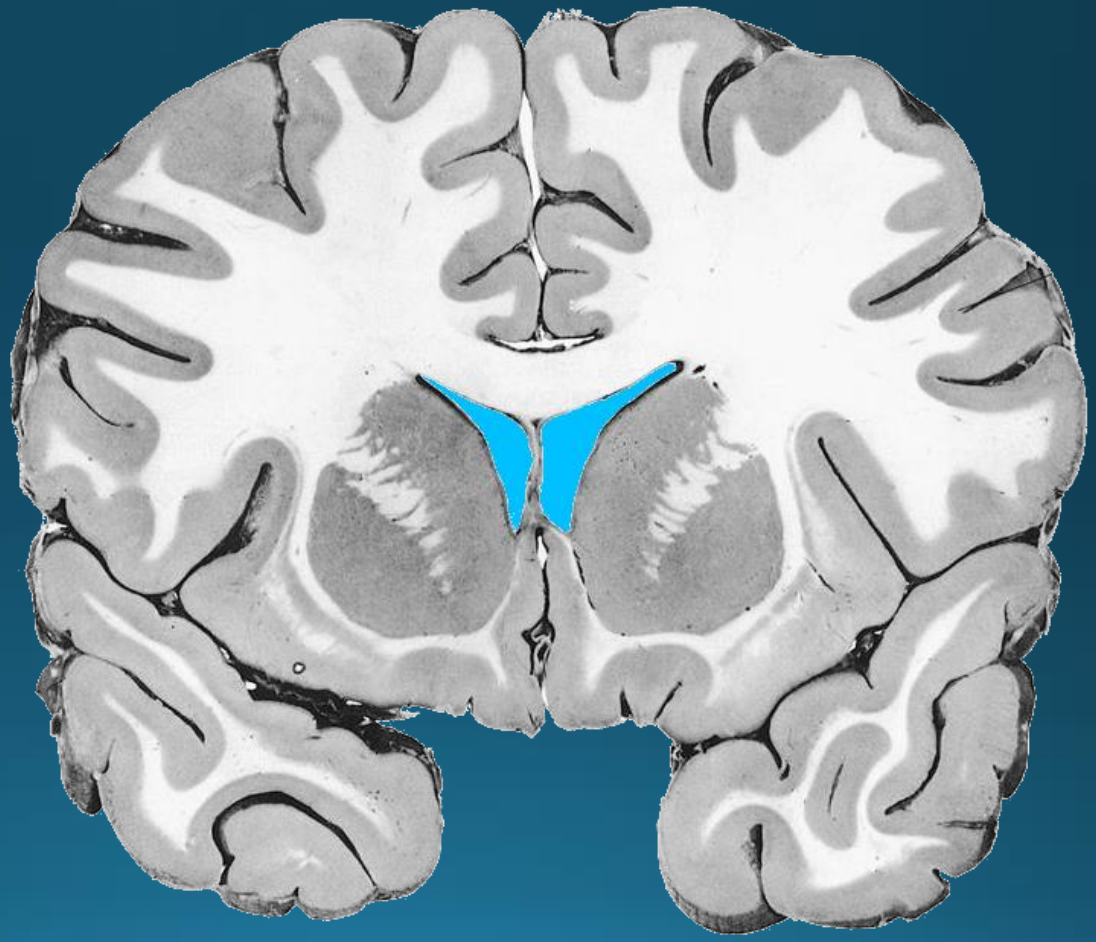
Grey matter

White matter

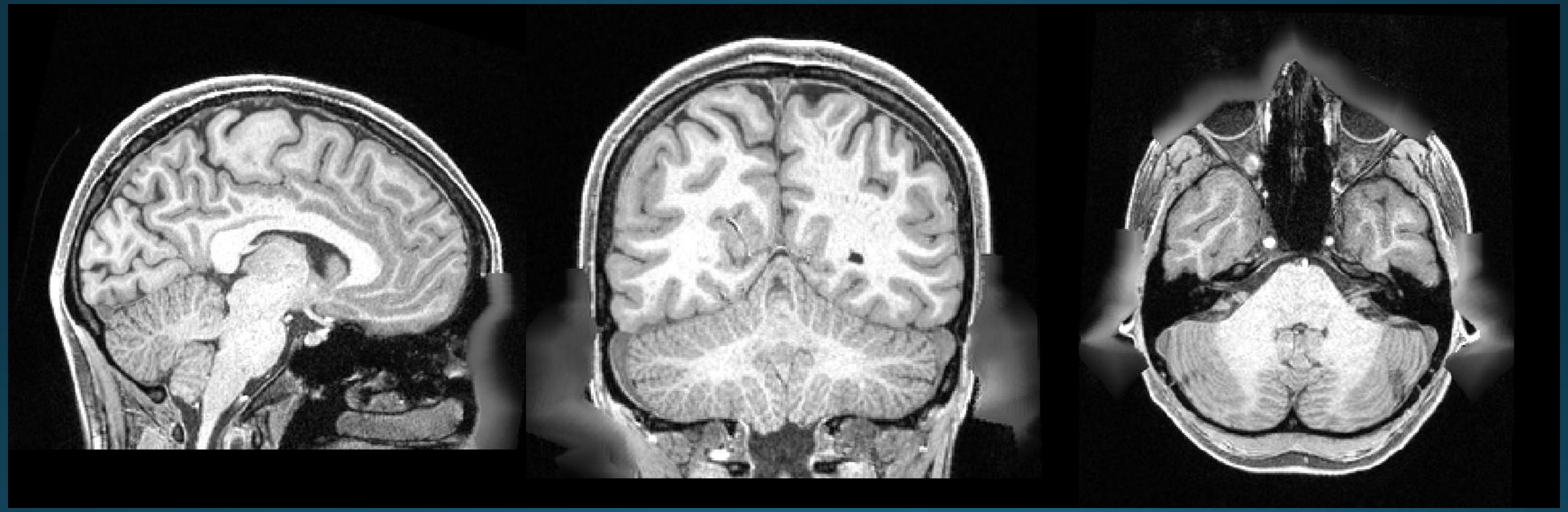
Grey and white matter

One slice:

Grey matter
White matter
Cerebrospinal fluid

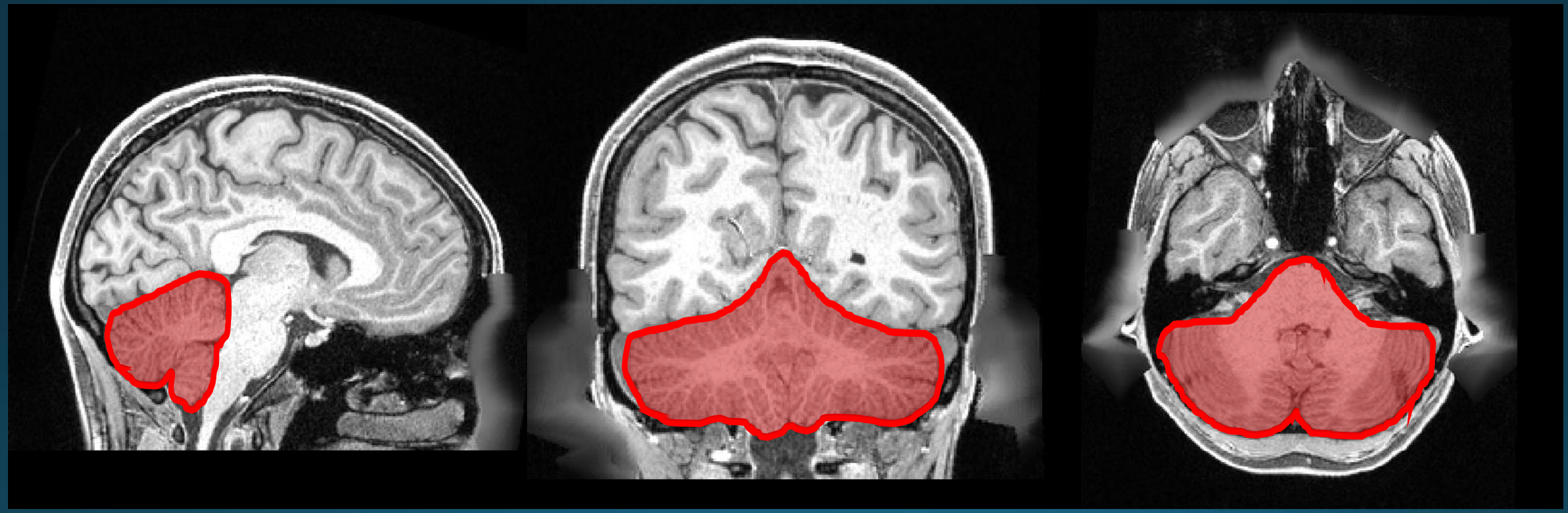


The cerebellum



Many functions: motor control and cognition

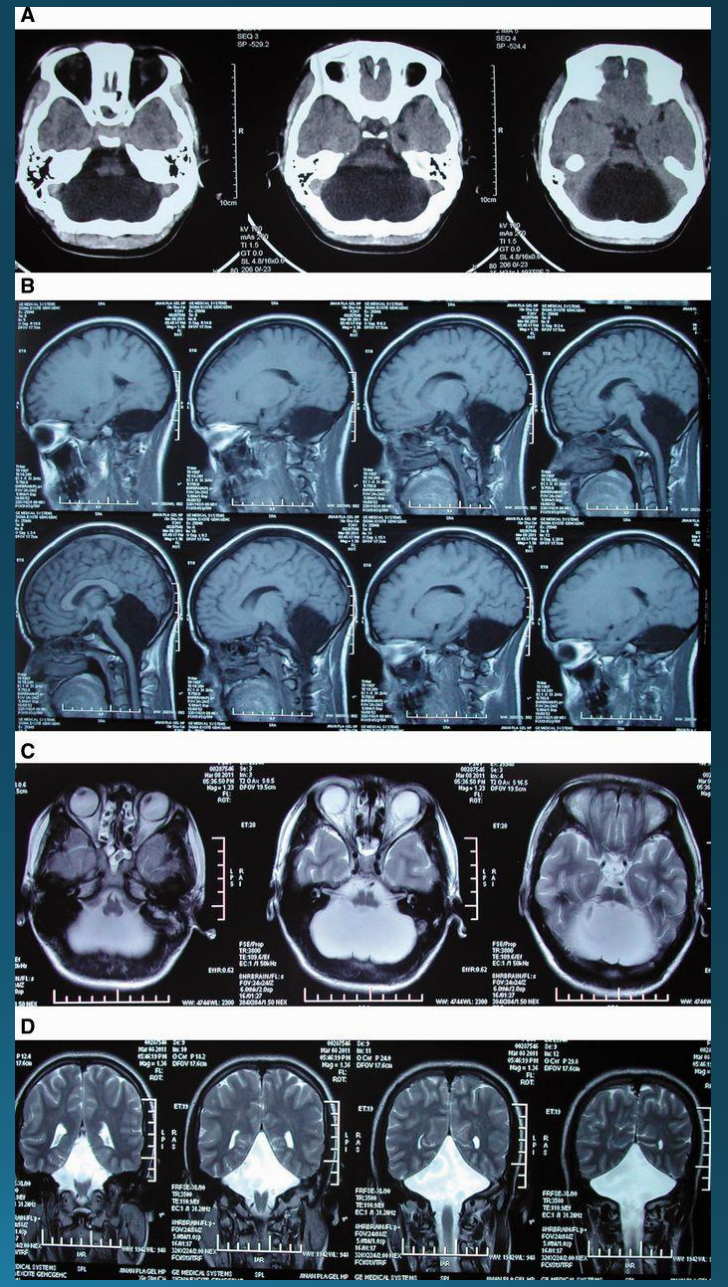
The cerebellum



Many functions: motor control and cognition

Is it strictly necessary?

Maybe not…



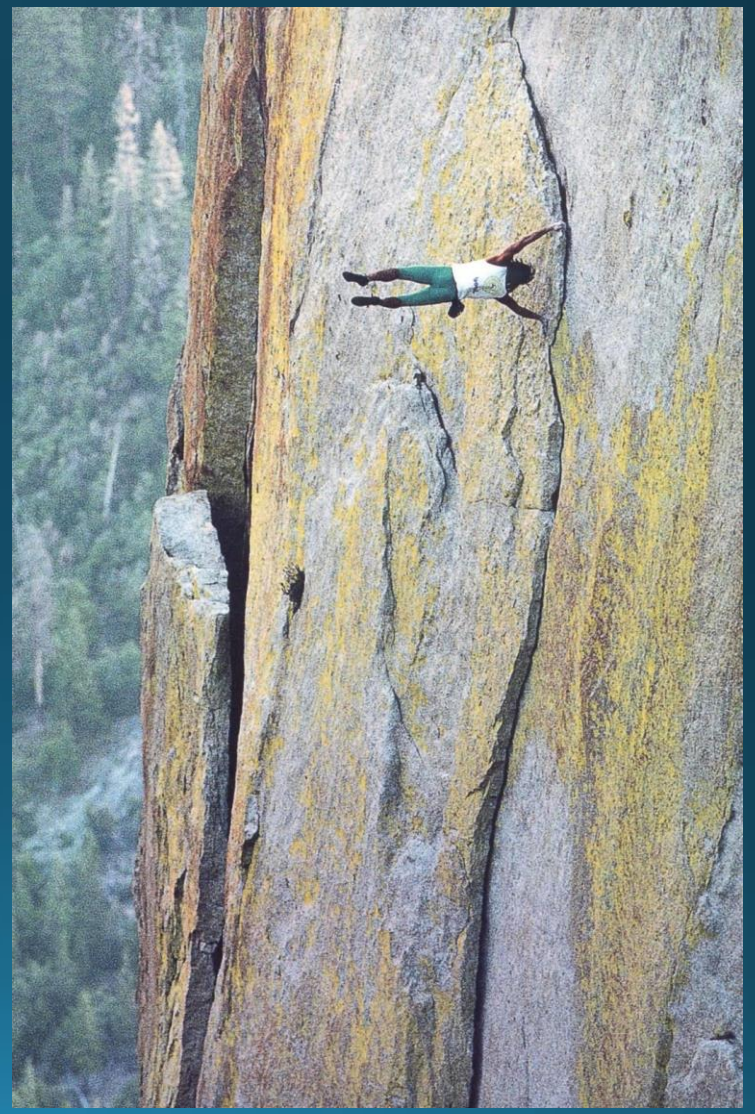
…but it is probably useful!

50% of neurons in 10% of the volume

Why is all this stuff interesting?

The brain controls nearly everything in the human body

Motion and balance



Why is all this stuff interesting?

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Motion and balance

Feelings

Why is all this stuff interesting?

The brain controls nearly everything in the human body

Motion and balance

Feelings

Thinking

Why is all this stuff interesting?

The brain controls nearly everything
in the human body

Motion and balance
Feelings
Thinking
Language

Why is all this stuff interesting?

The brain controls nearly everything
in the human body

Motion and balance
Feelings
Thinking
Language
Senses
…

Why is all this stuff interesting

Brain function is still a mystery

Moreover, everybody has a brain

BUT

unfortunately, not every brain works properly…

How can physics help neuroscience?

Great interest from international scientific community

Many funded projects

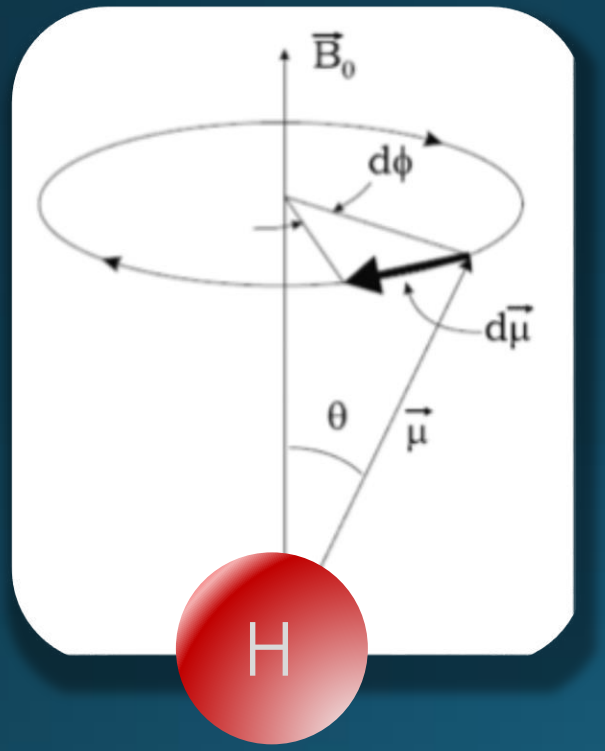
Multidisciplinarity

What do physicists have to do with this?
MRI! (for example…)

MRI – recipe for *in vivo* imaging

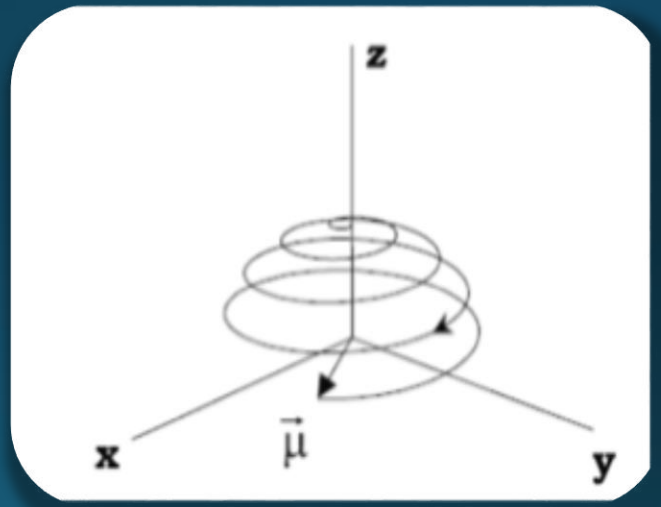
Take some NMR principle

$$\frac{d\vec{M}}{dt} = \gamma\vec{M} \times \vec{B}_{ext} + \frac{1}{T_1}\left(M_0 - M_z\right)\hat{z} - \frac{1}{T_2}\vec{M}_{\perp}$$

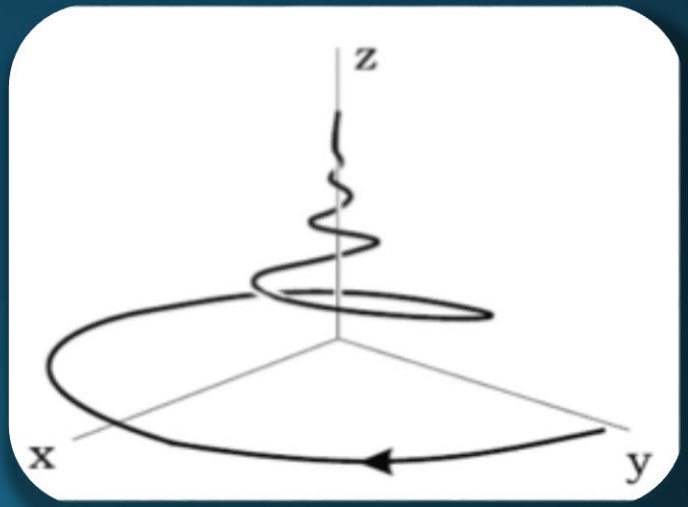


Precession

$\omega_L = \gamma B_0$



RF pulse

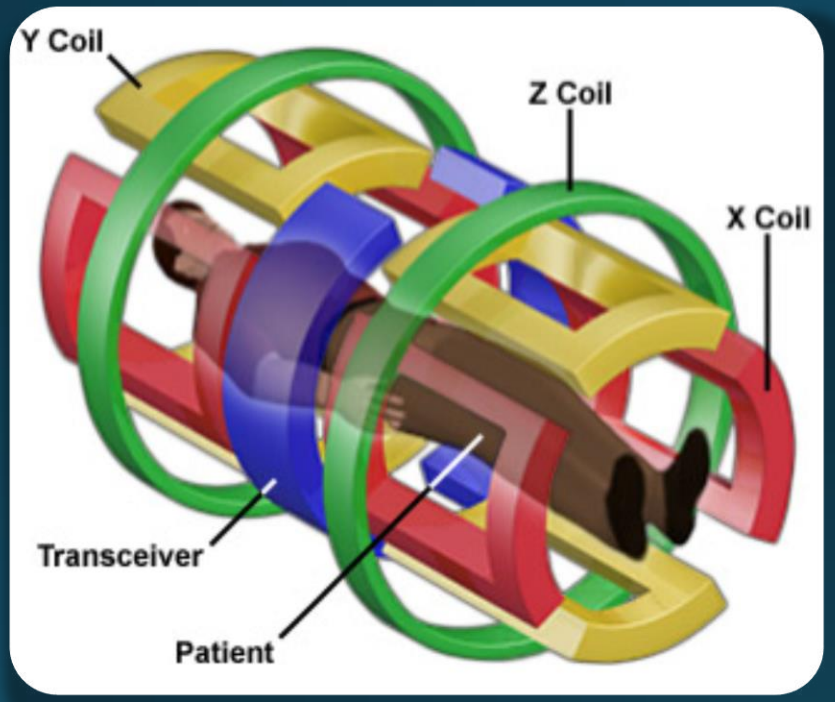


Magnetization recovery

MRI – recipe for *in vivo* imaging

Take some NMR principles

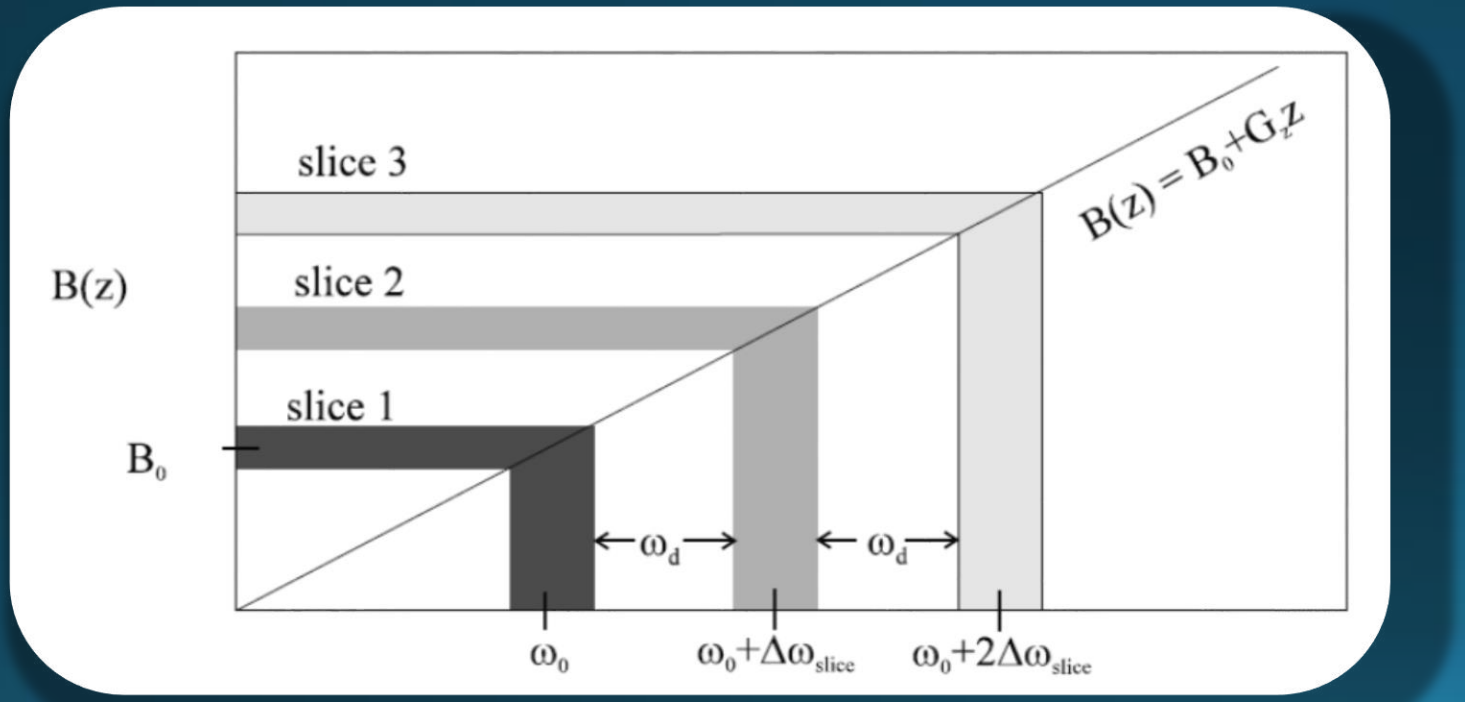
Add some magnetic gradients



MRI – recipe for *in vivo* imaging

Take some NMR principles

Add some magnetic gradients



MRI – recipe for *in vivo* imaging

Take some NMR principles

Add some magnetic gradients

$$\rho(\vec{r}) = \int d^3k S(\vec{k}) e^{i2\pi\vec{k}\cdot\vec{r}}$$

MRI – recipe for *in vivo* imaging

Take some NMR principles

Add some magnetic gradients

Buy a VERY expensive scanner

MRI – recipe for *in vivo* imaging

Take some NMR principles

Add some magnetic gradients

Buy a VERY expensive scanner

Mix well…

MRI – recipe for *in vivo* imaging

Take some NMR principles
Add some magnetic gradients
Buy a VERY expensive scanner
Mix well…

Et voilà! Images!

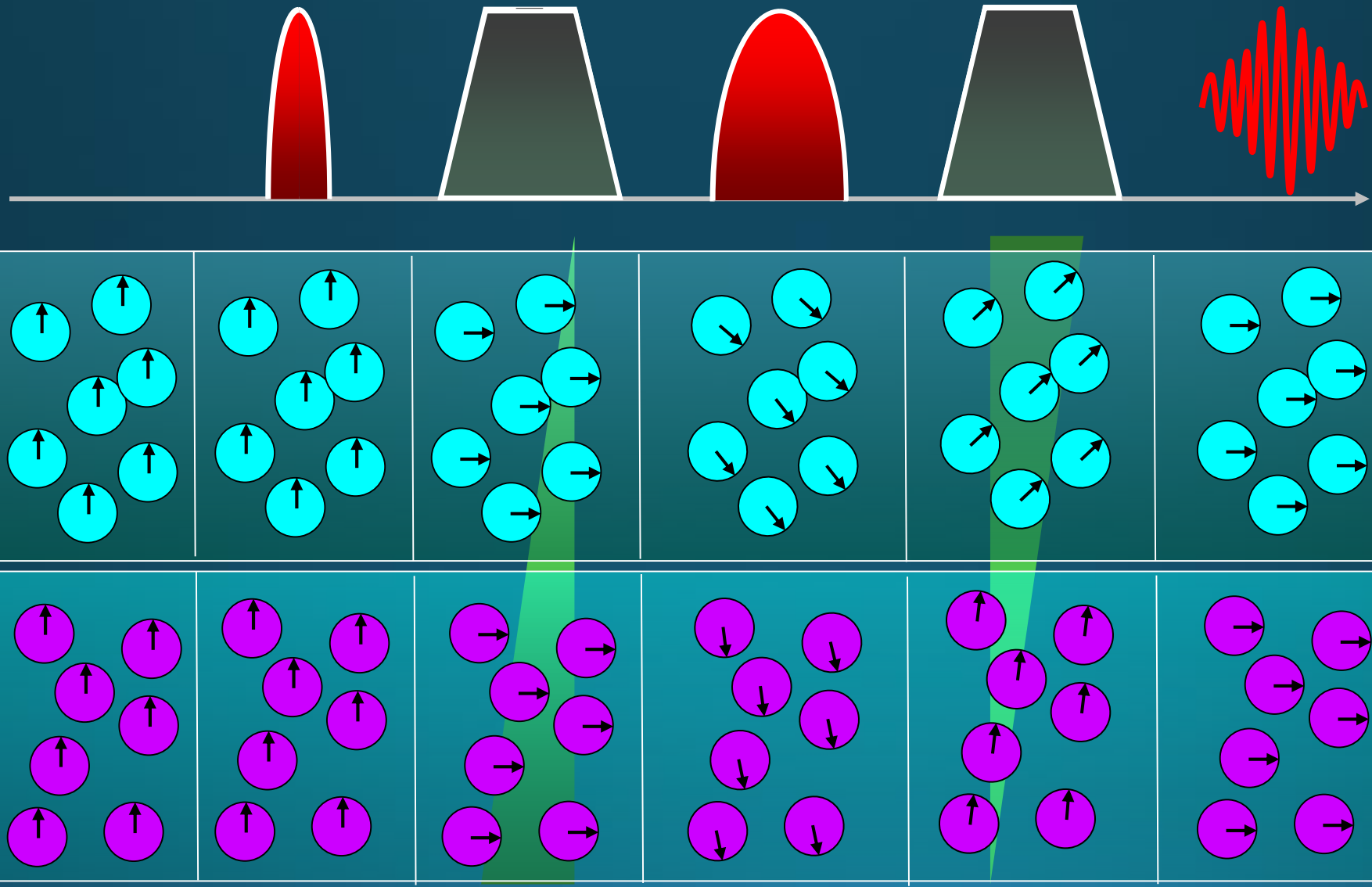
Not only anatomical images!

MRI can be sentitive to several sample properties and effects

For example to the random thermal motion of molecules, *i.e.* DIFFUSION

How?

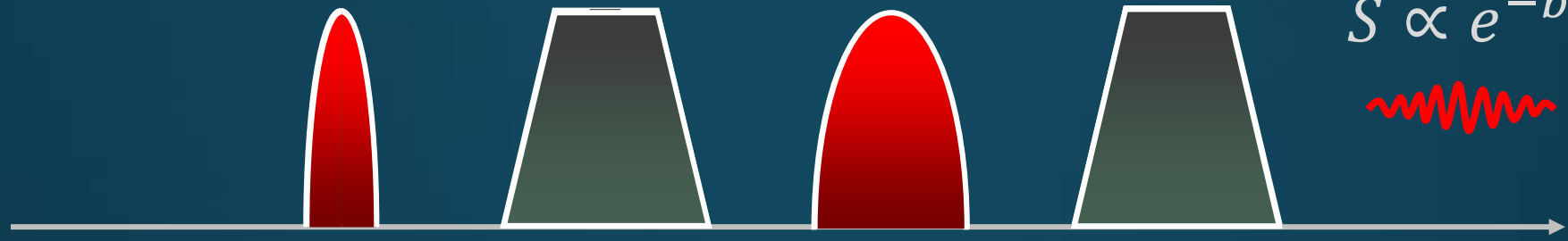
Diffusion MRI - basics

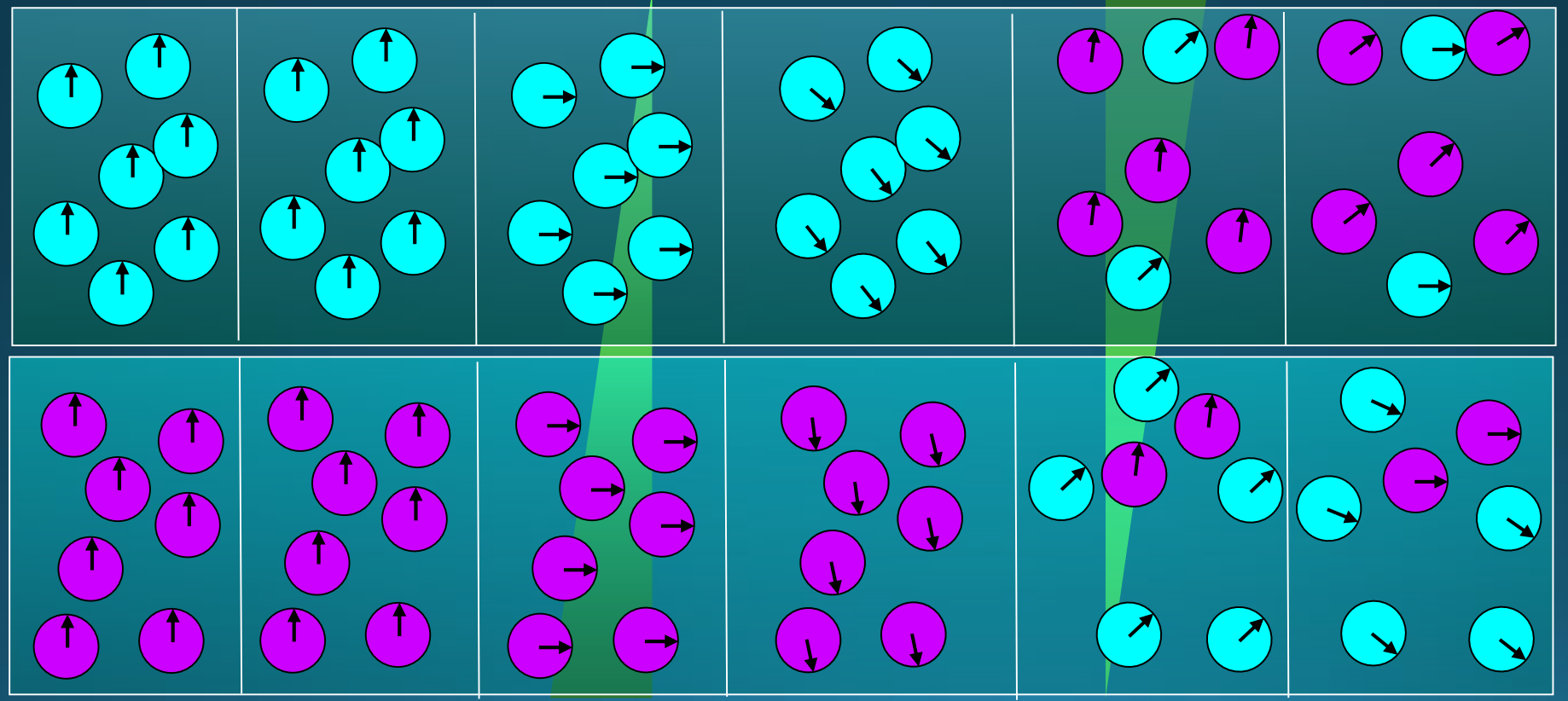


Diffusion MRI - basics

Signal decreases

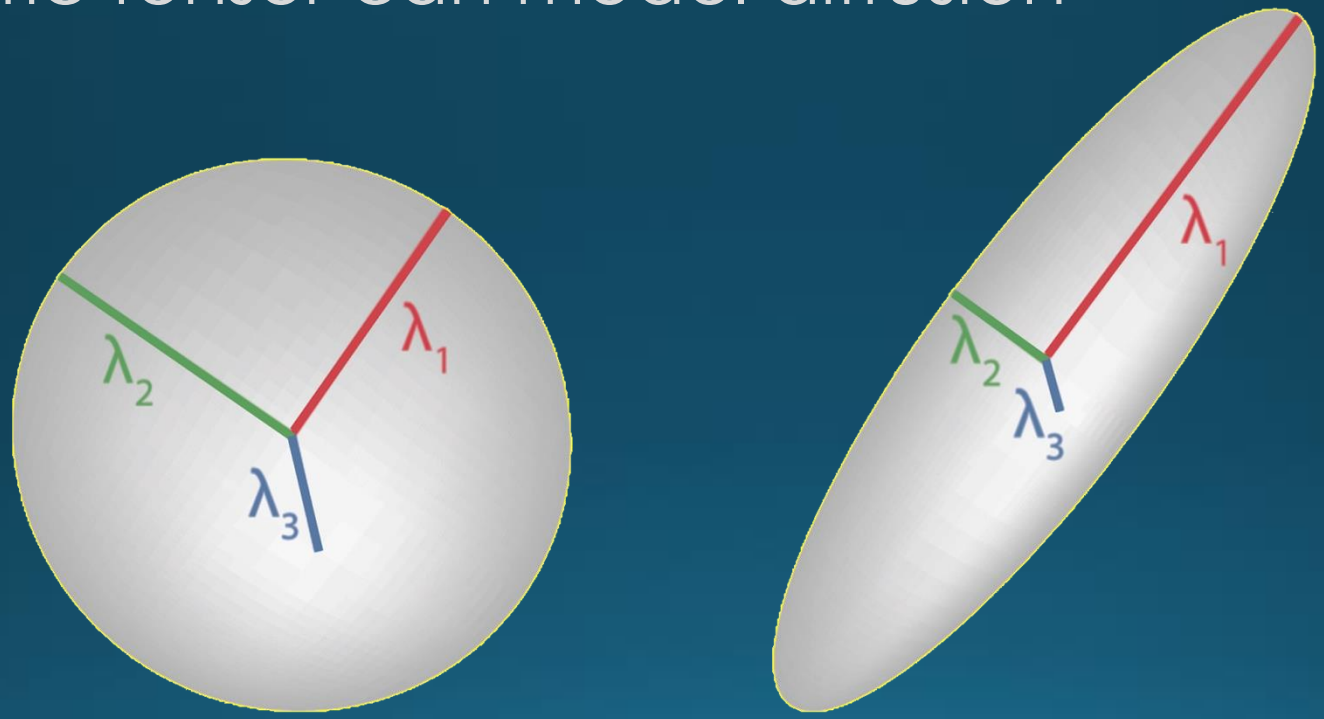
$S \propto e^{-bD}$





Diffusion MRI - basics

A symmetric tensor can model diffusion



Isotropic diffusion

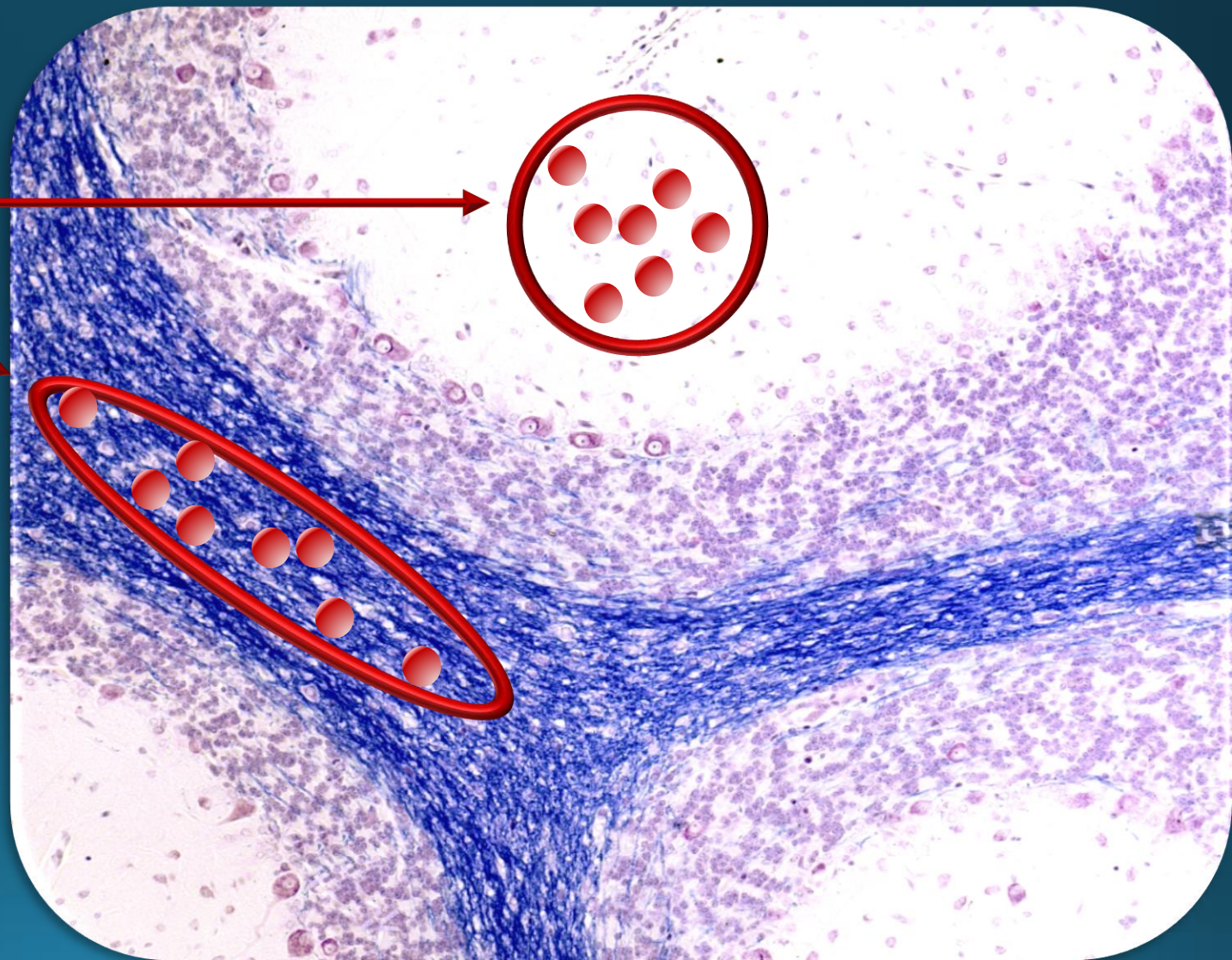
Anisotropic diffusion

Neurons and diffusion

CSF: Free diffusion

GM: Hindered diffusion

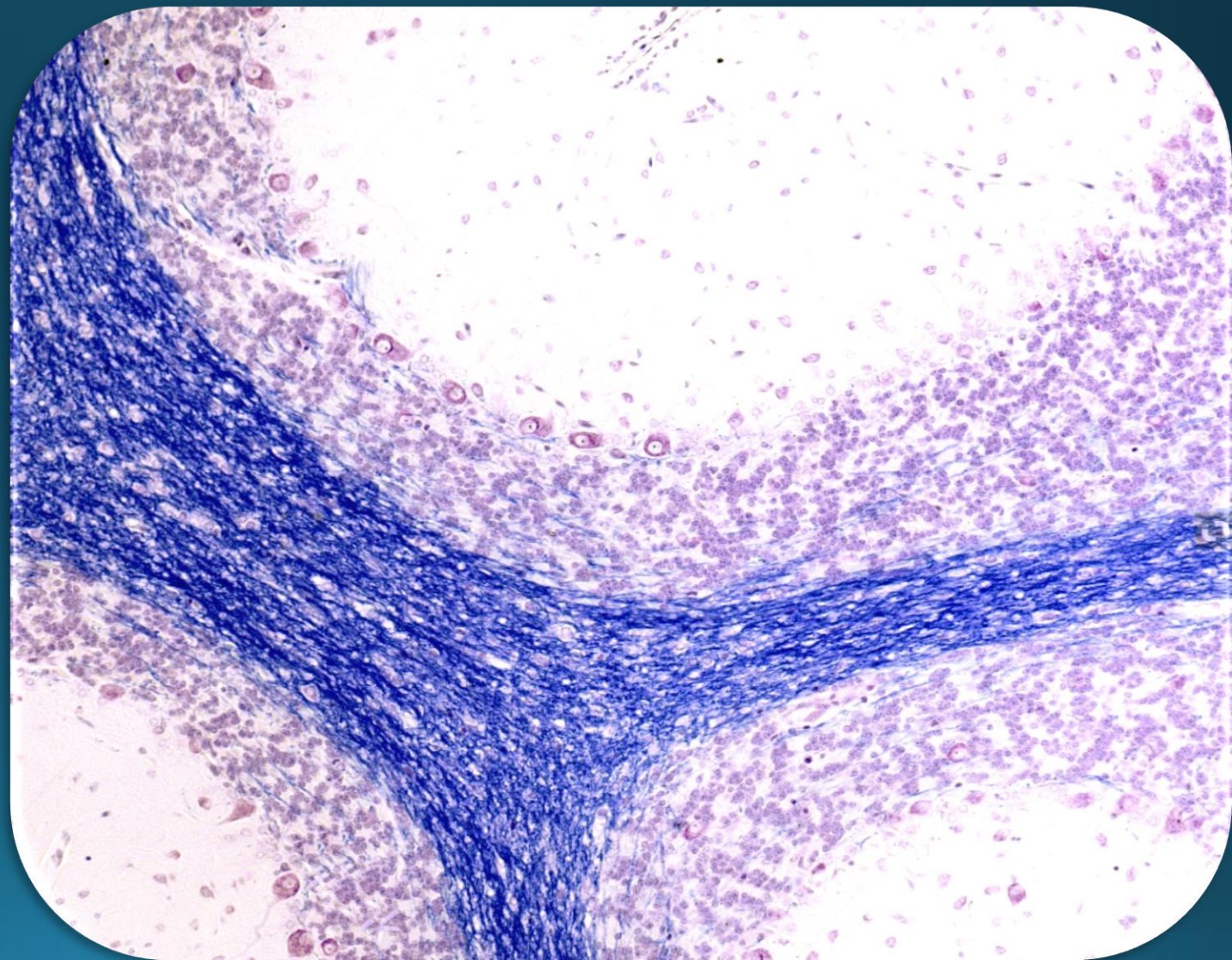
WM: Restricted diffusion



Neurons and diffusion

CSF: Free diffusion
GM: Hindered diffusion
WM: Restricted diffusion

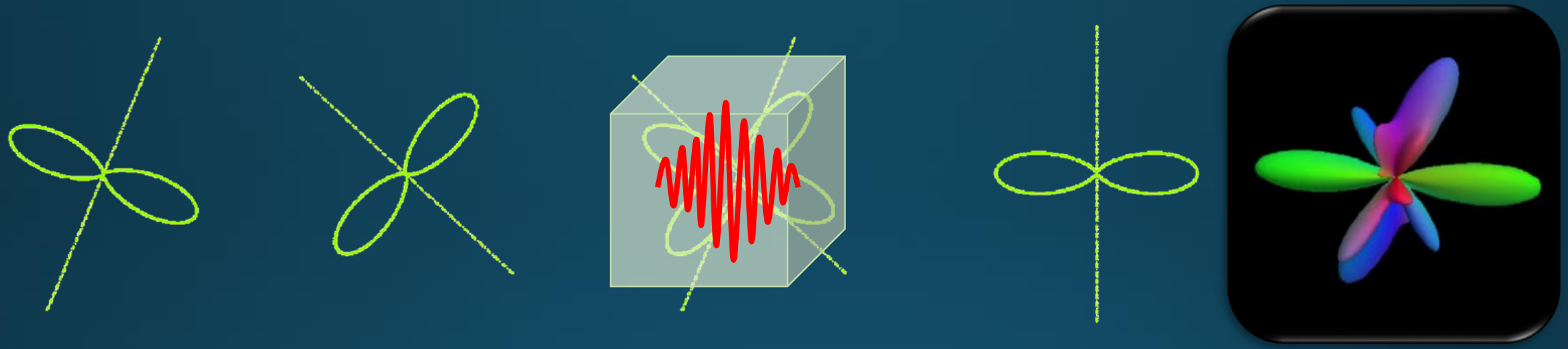
Each compartment contributes in a unique way to the diffusion signal



Convolution and deconvolution

$f_1 S_1(\theta,\phi) \quad + \quad f_2 S_2(\theta,\phi) \quad = \quad S(\theta,\phi) \quad = \quad R(\theta) \quad \otimes \quad F(\theta,\phi)$

Convolution and deconvolution



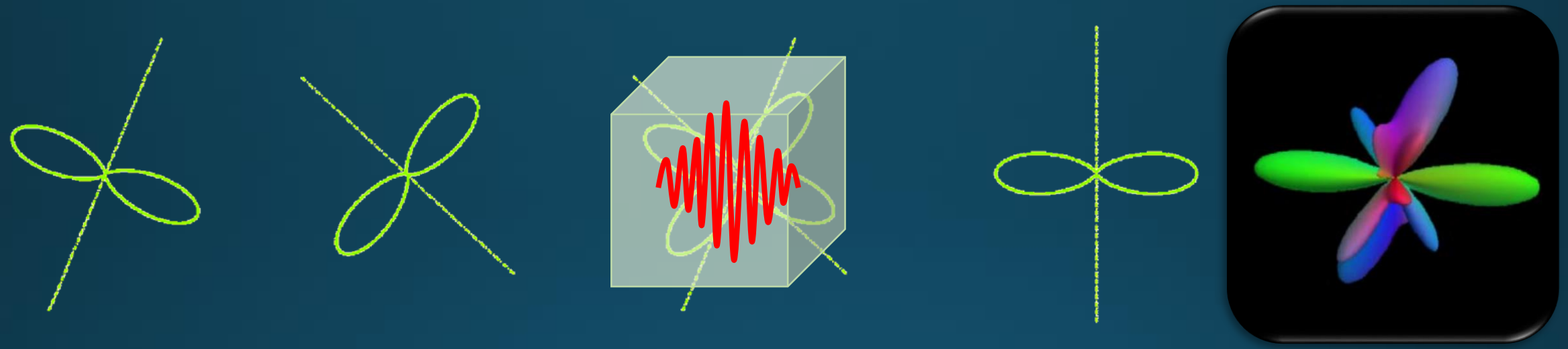
$$f_1 S_1(\theta,\phi) \quad + \quad f_2 S_2(\theta,\phi) \quad = \quad S(\theta,\phi) \quad = \quad R(\theta) \quad \otimes \quad F(\theta,\phi)$$

Signal at the voxel scale

Microscopic diffusion signal profile

Fiber orientation distribution

Convolution and deconvolution



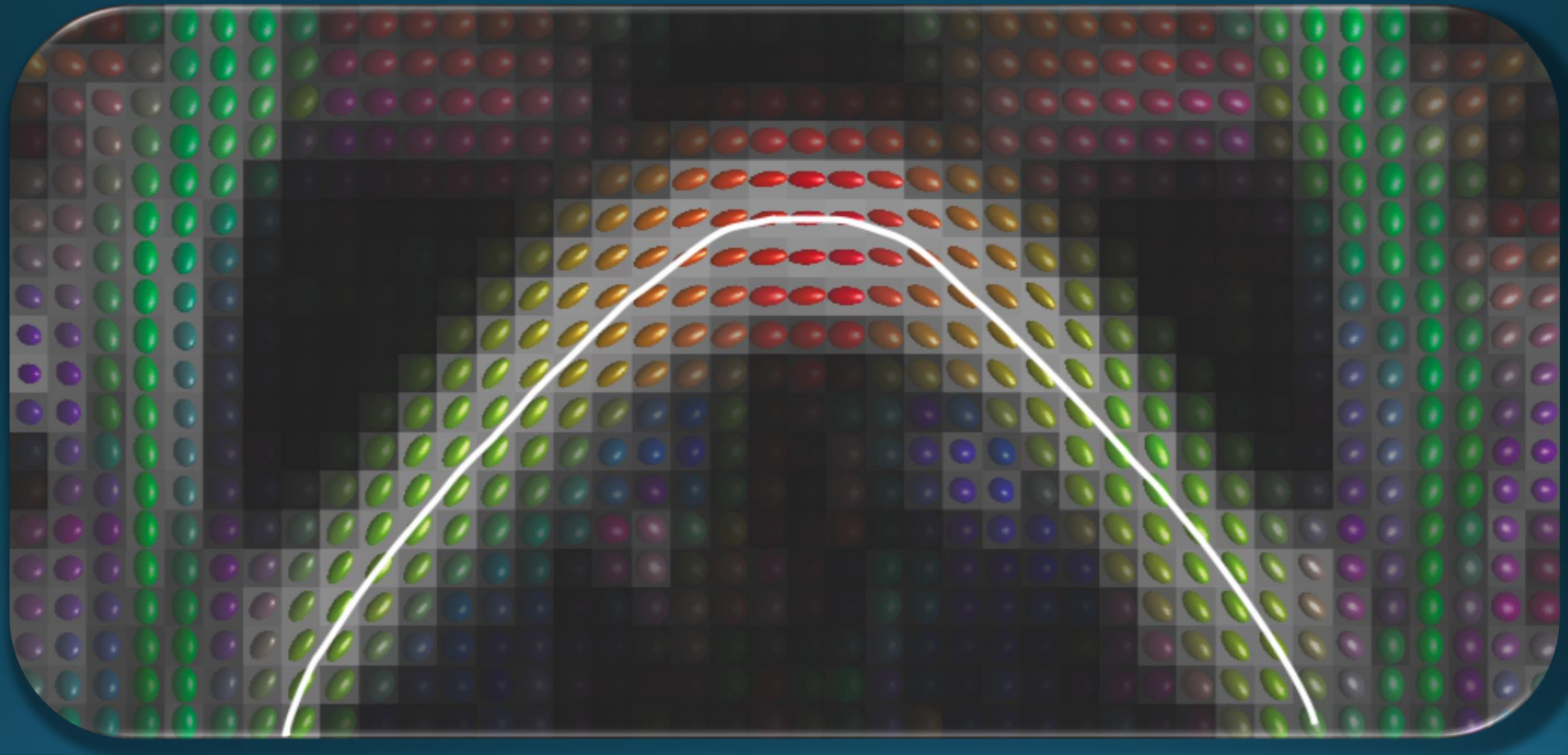
Deconvolution can separate the two sources **BUT** assumptions on one are needed to recover the other

Tractography

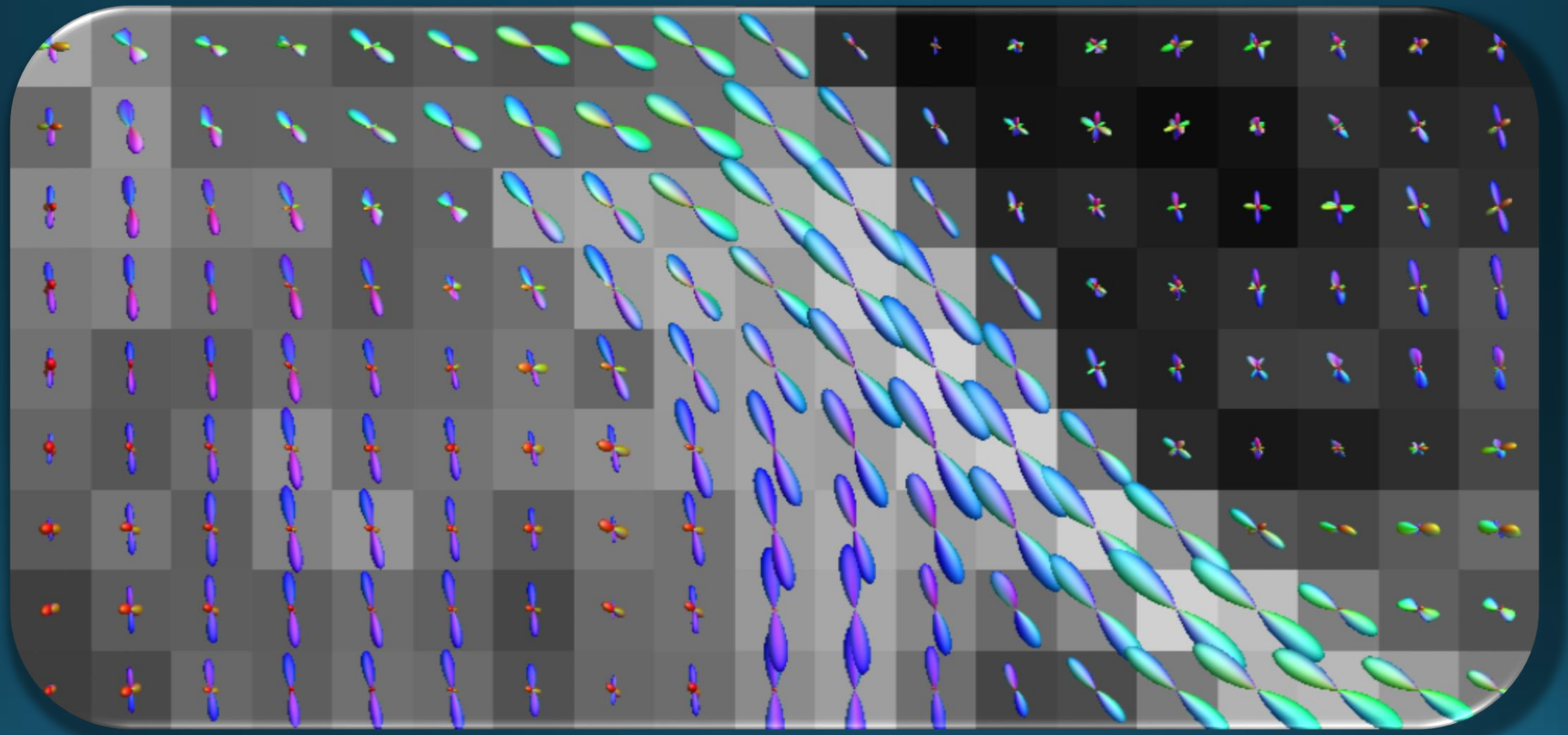
We can follow the tensor main eigenvalue from voxel to voxel

We can trace WM fibers bundles

Tractography

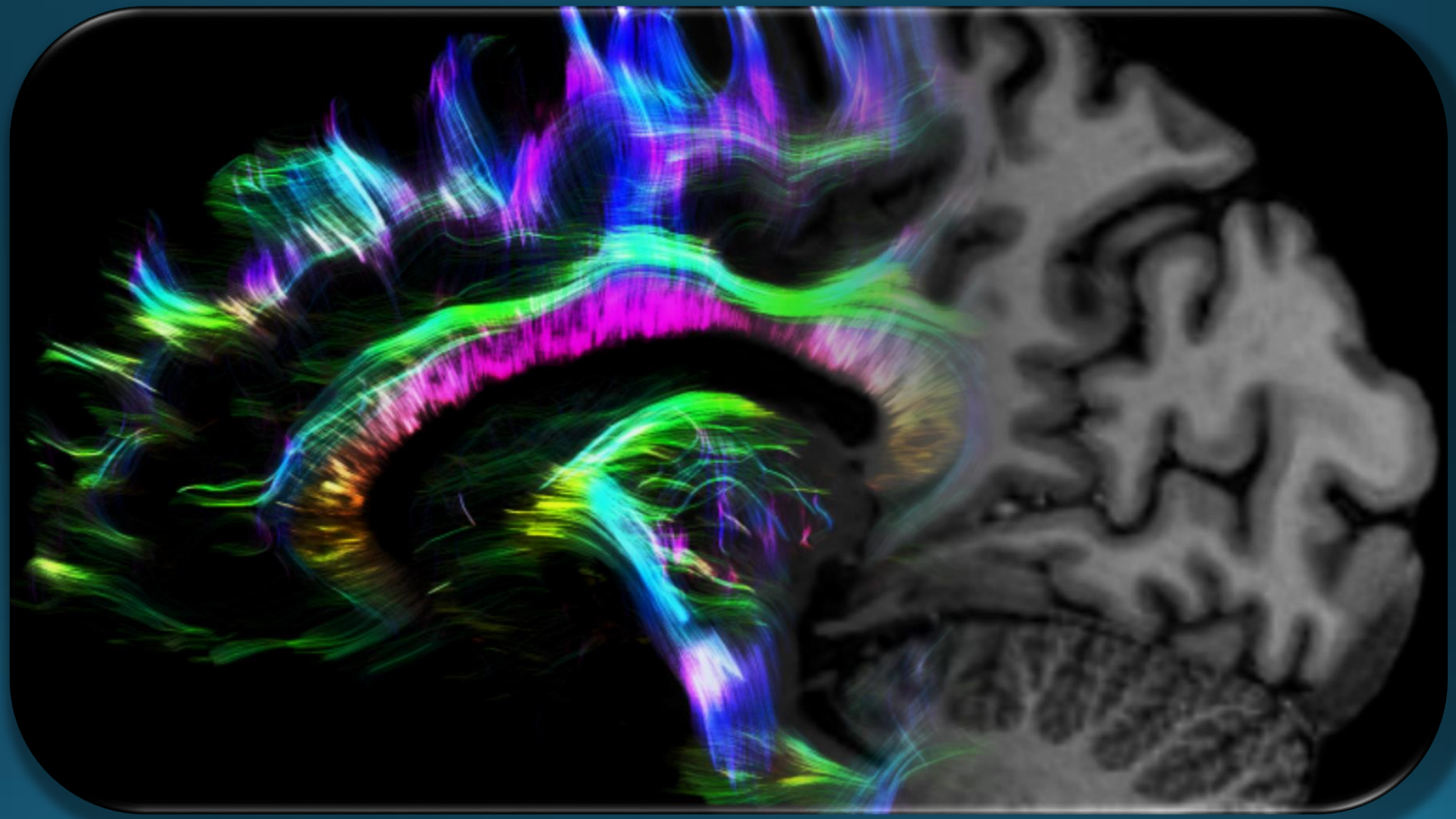


Tractography



Tractography

Tractography



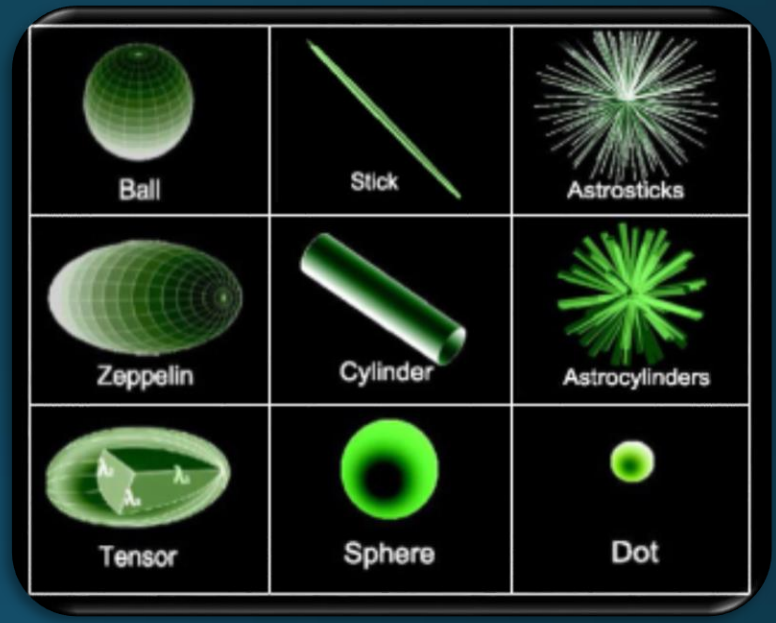
Microstructure models

Create a model and fit its parameters

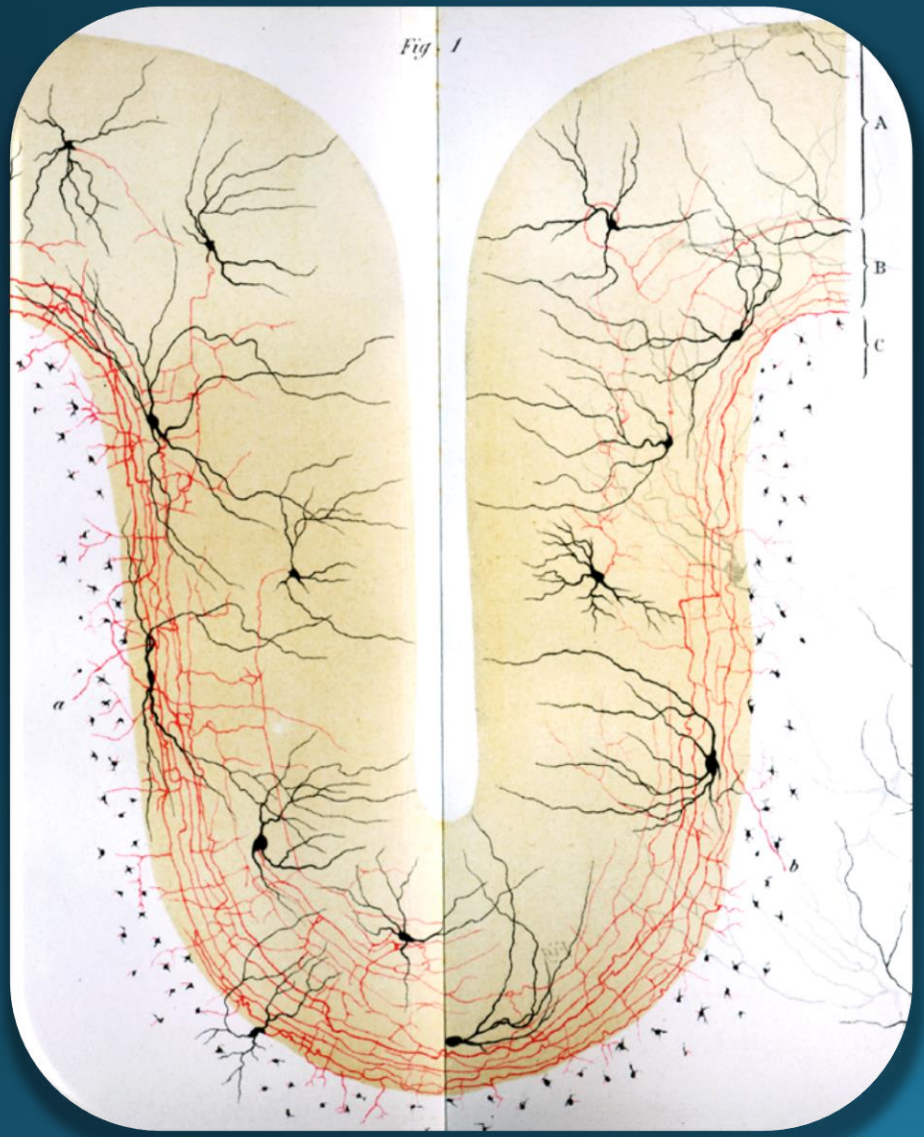
Multi-compartment example:

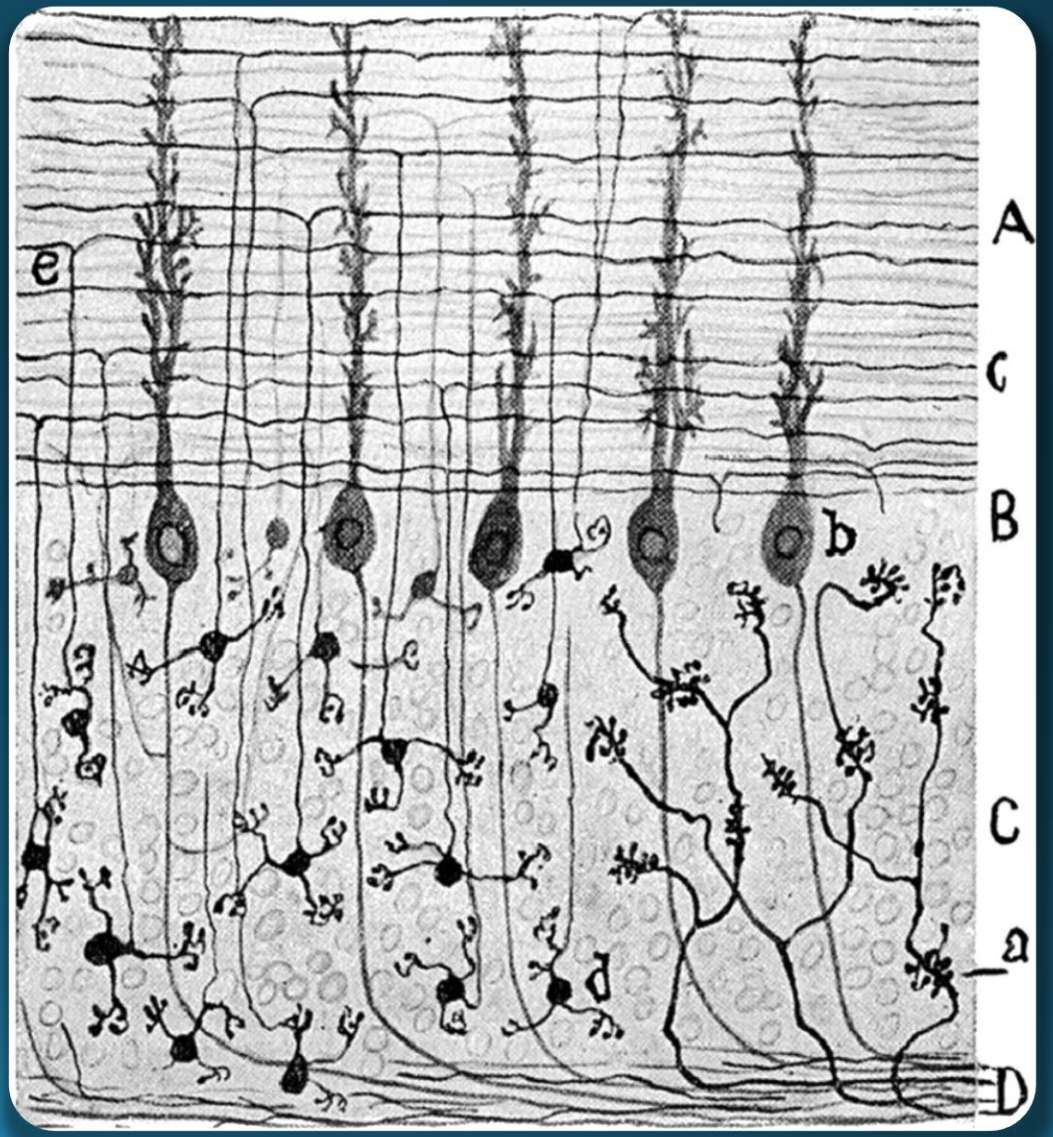
$$A = (1 - v_{iso})(v_{ic}A_{ic} + (1 - v_{ic})A_{ec}) + v_{iso}A_{iso}$$

Sensitive and specific metrics for pathology



Cerebellar microstructure

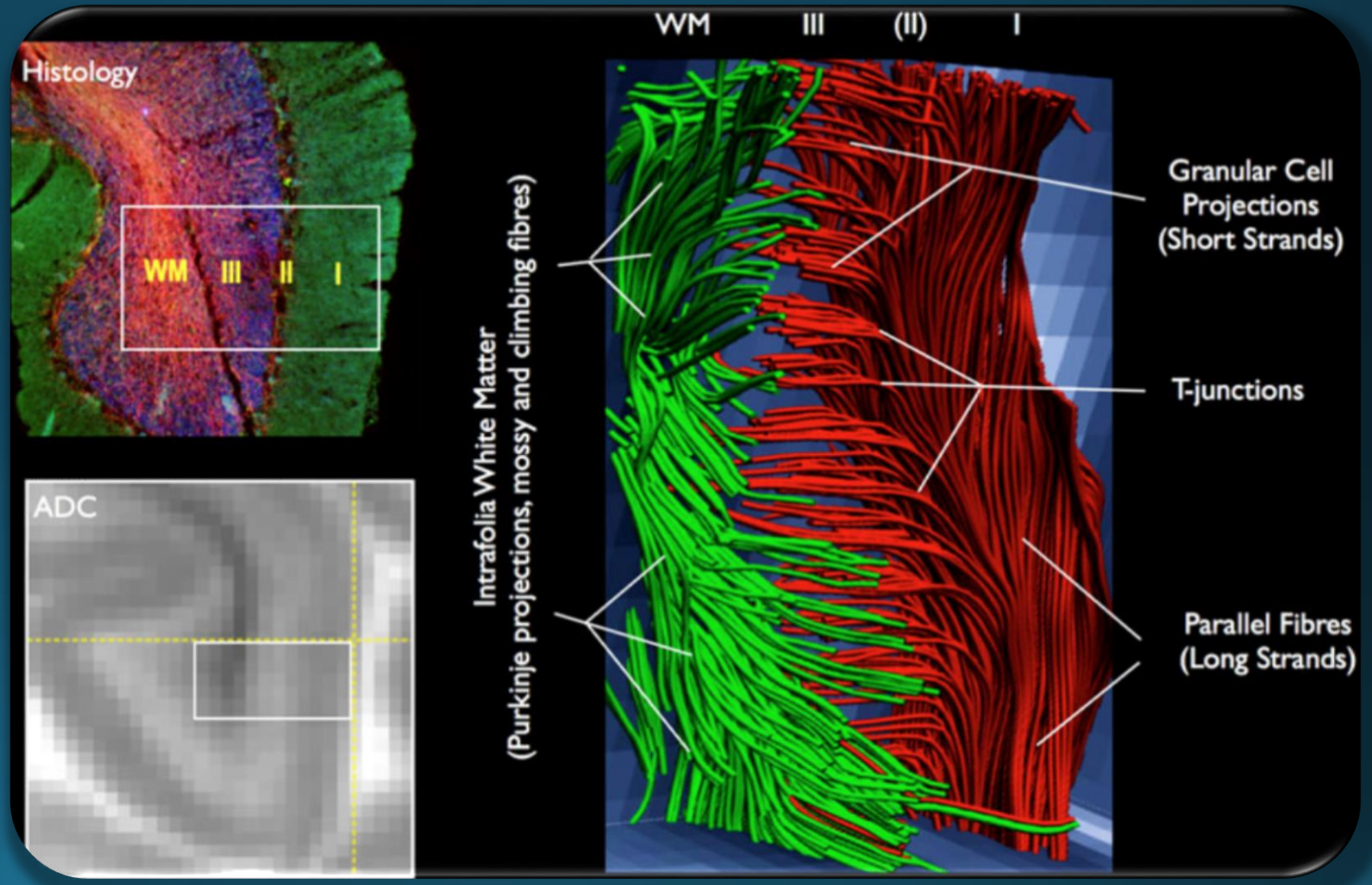




Cerebellar microstructure

Post mortem study
100x100x200 μm^3
140 h

Maybe we are asking too much from a living...



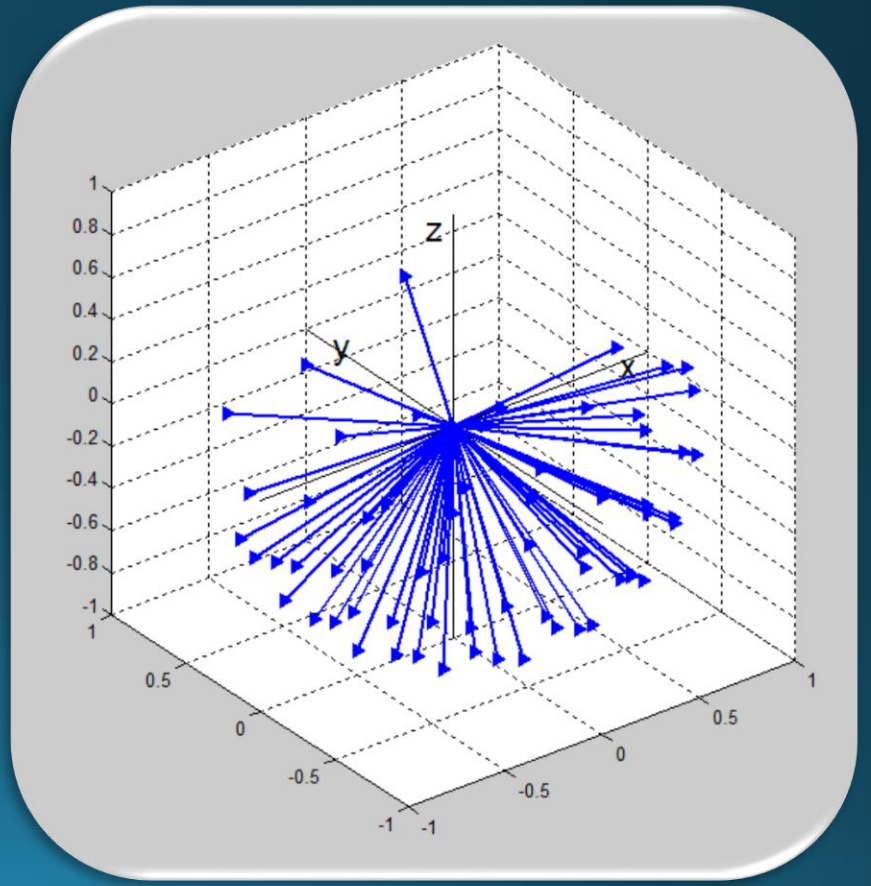
Ultimate goal

Diagnostics and pathology investigation

Connectomics: the study of connections in the brain with graph theory

We need advanced sequences:

- Many diffusion directions (≥60)
- More than one b-value
- High spatial resolution
- Low acquisition time
- High SNR



Thanks for your attention

No Brains Were Harmed in the Making of this Presentation