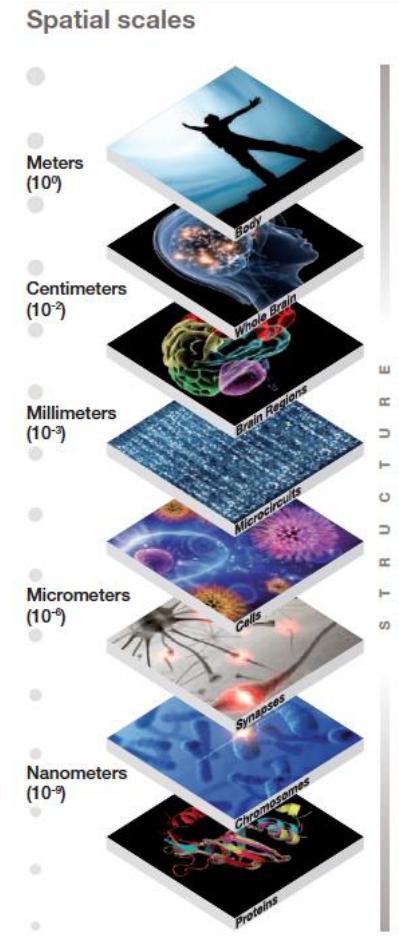
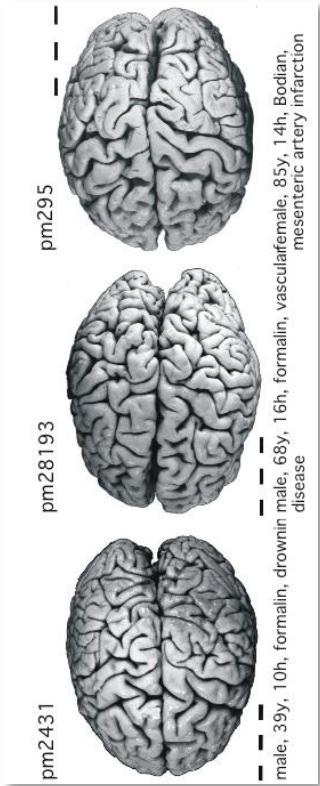




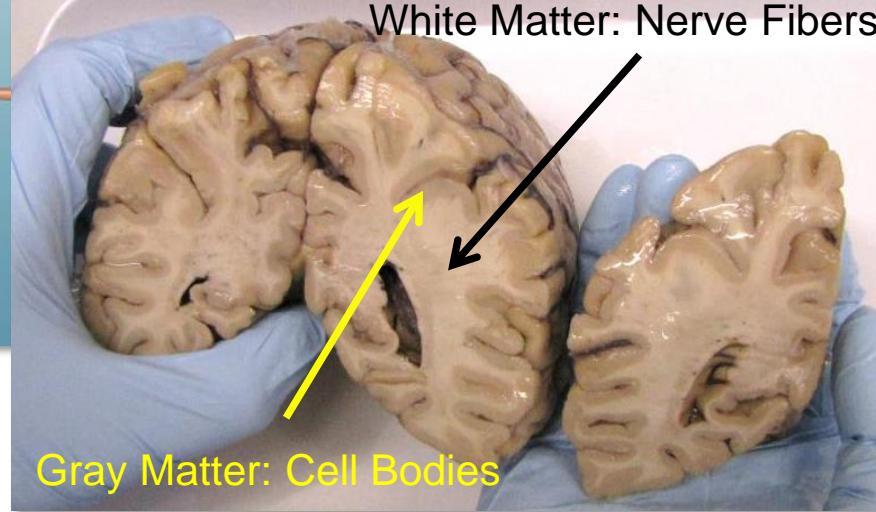
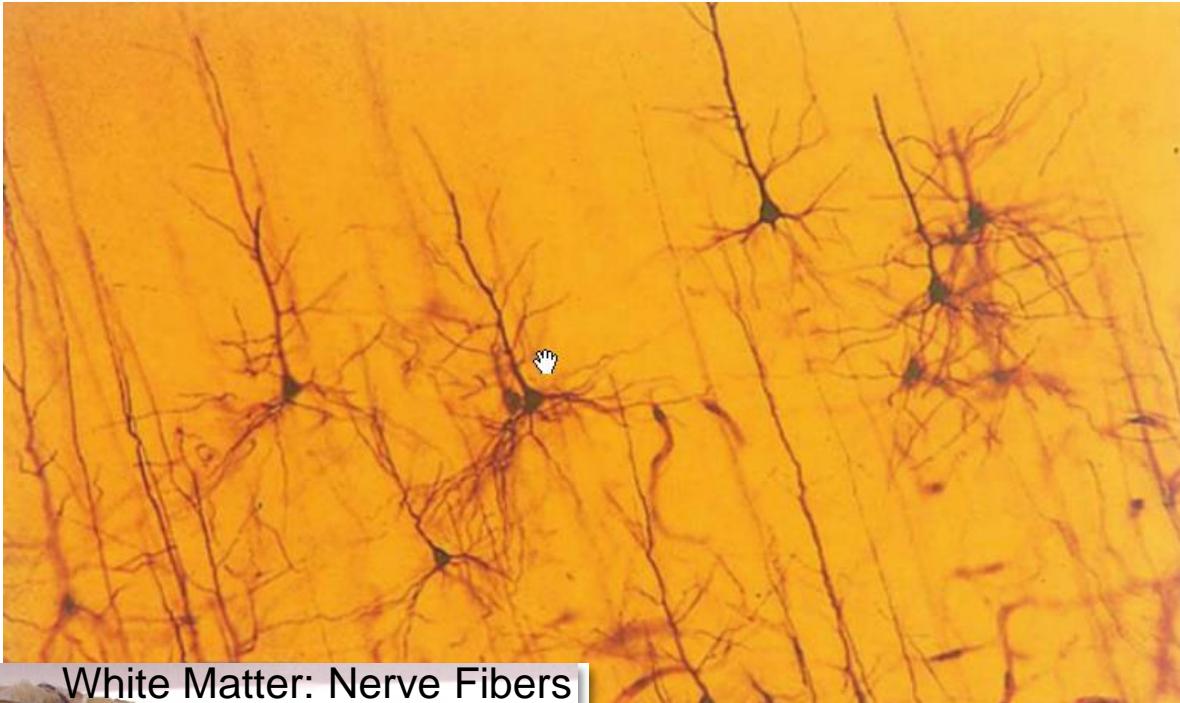
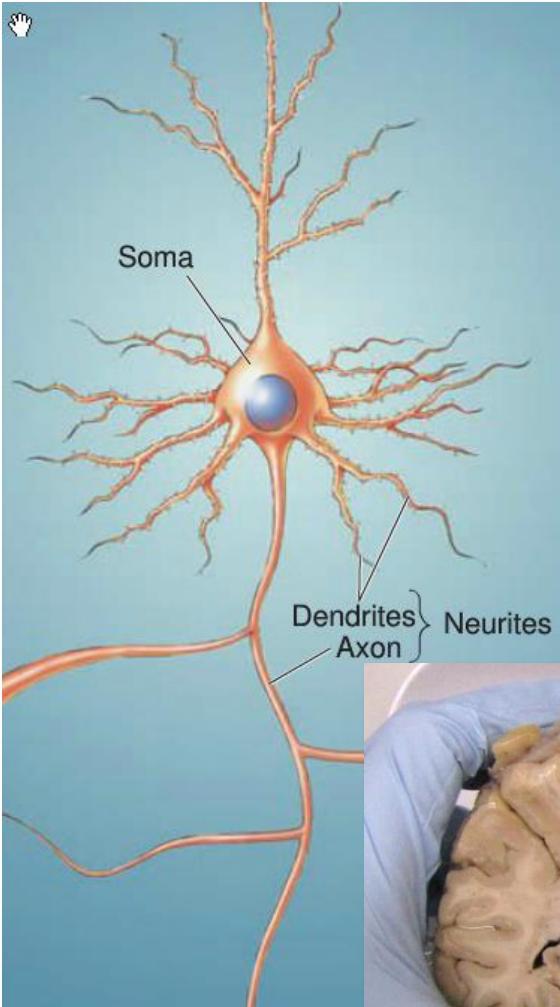
Pushing Global Brain Tractography towards Micrometer Resolution with Exascale Computing

21.09.22 | Felix Matuschke | Institute of Neuroscience and Medicine (INM-1)

The Human Brain



The Human Brain



Page 3

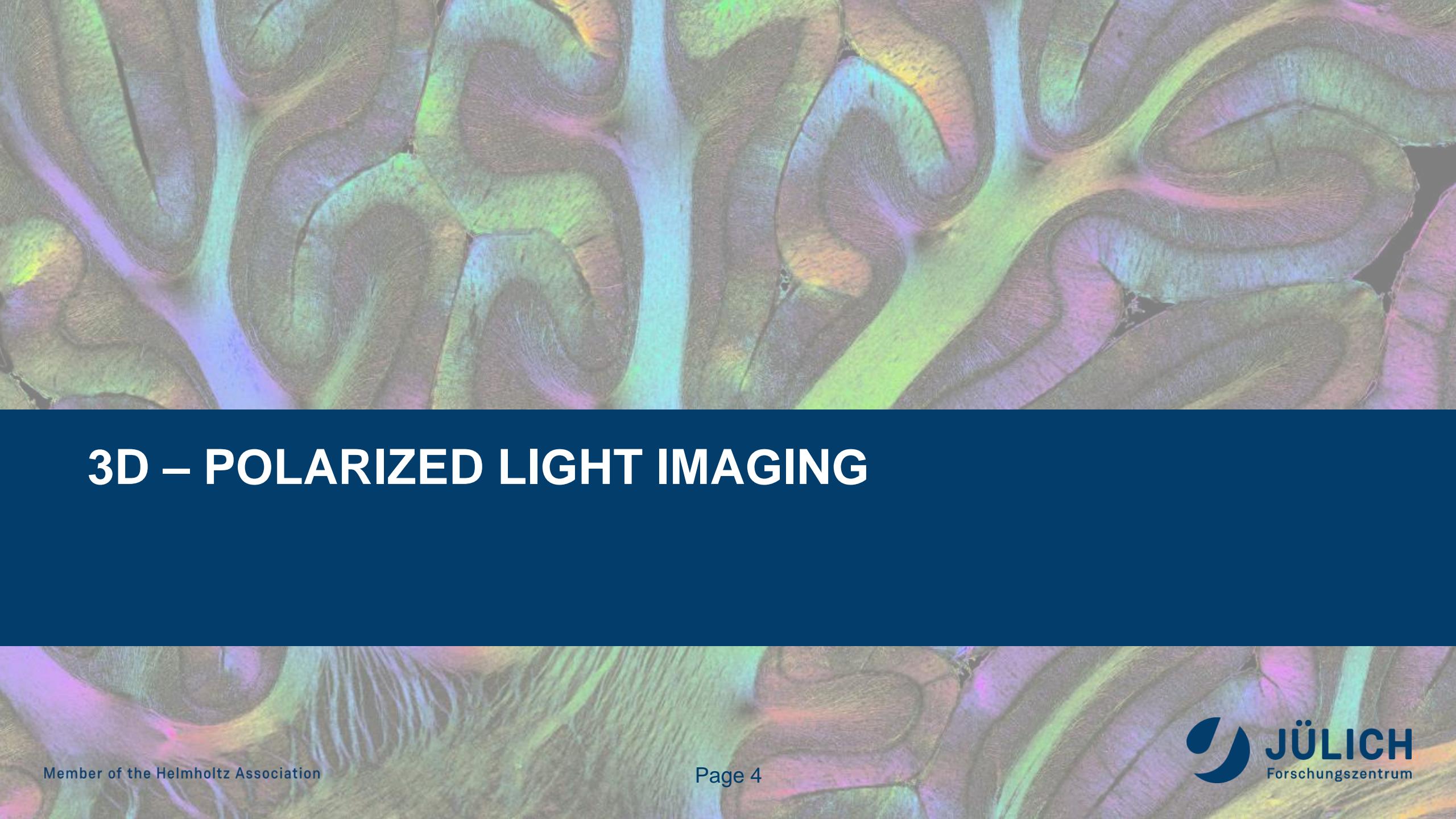
Length Nerve Fibers: $\mu\text{m} - \text{m}$

\varnothing Nerve Fibers: $1 - 20 \mu\text{m}$

\varnothing Single Hair: $50 - 70 \mu\text{m}$

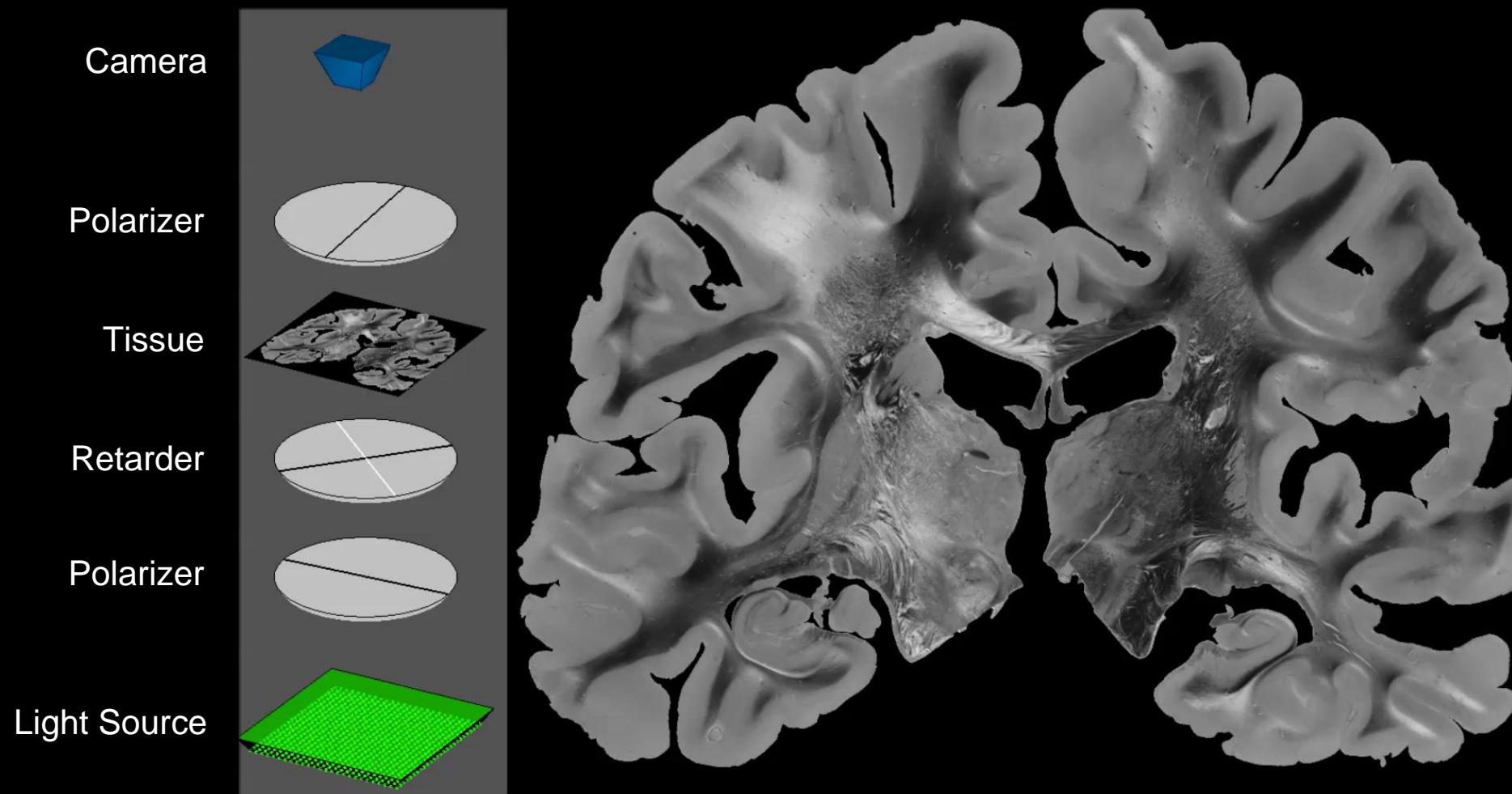
100 Mrd. Neuronen

10.000 Synapsen pro Neuron



3D – POLARIZED LIGHT IMAGING

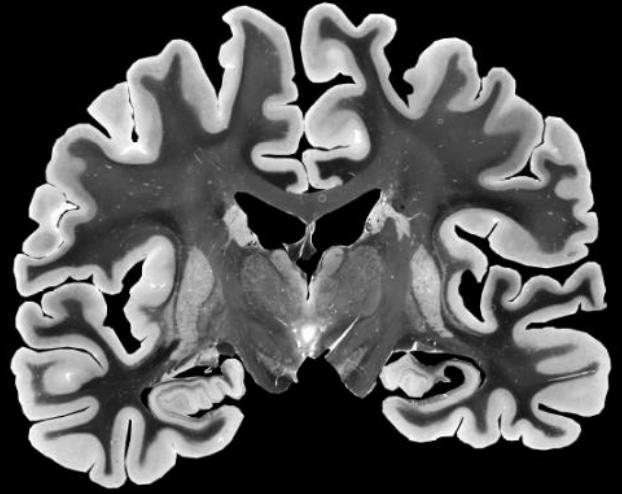
3D - Polarized Light Imaging



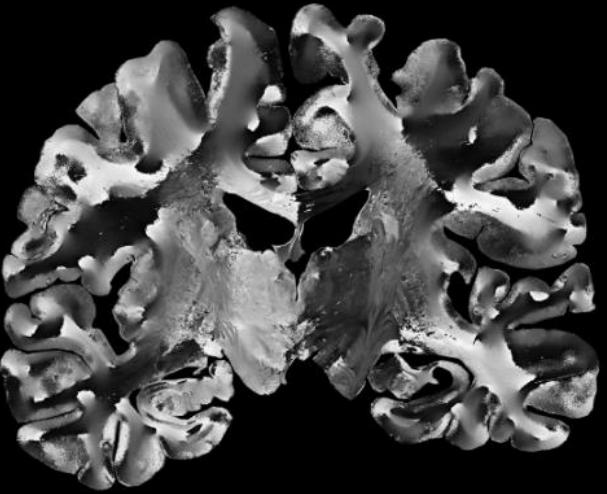
INM-1 | Fiberarchitecture Group

3D - Polarized Light Imaging

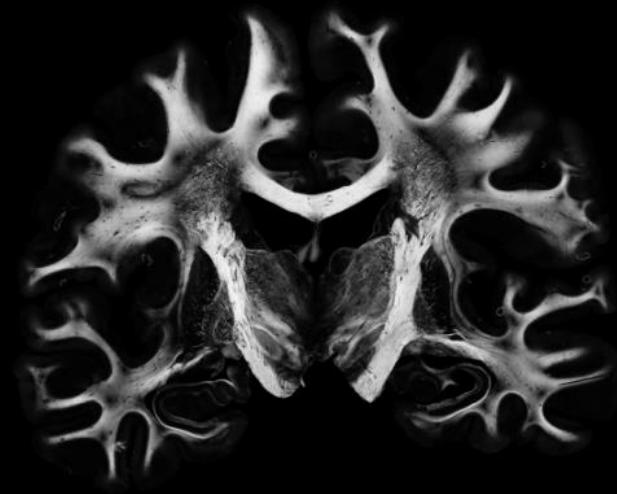
INM-1 | Fiberarchitecture Group



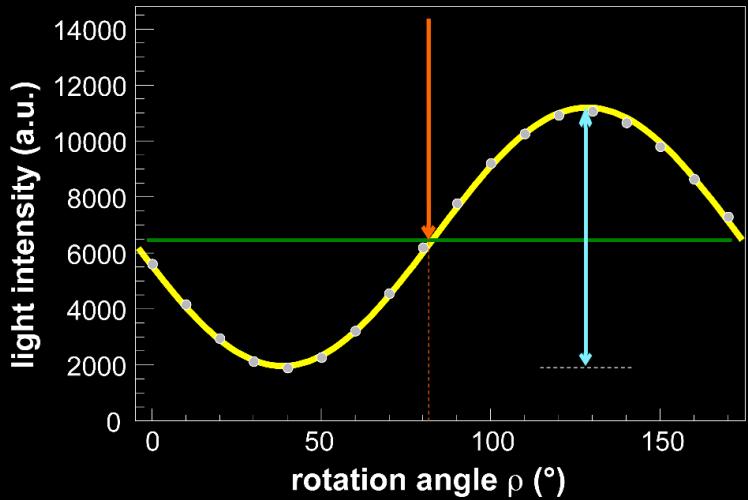
Transmittance



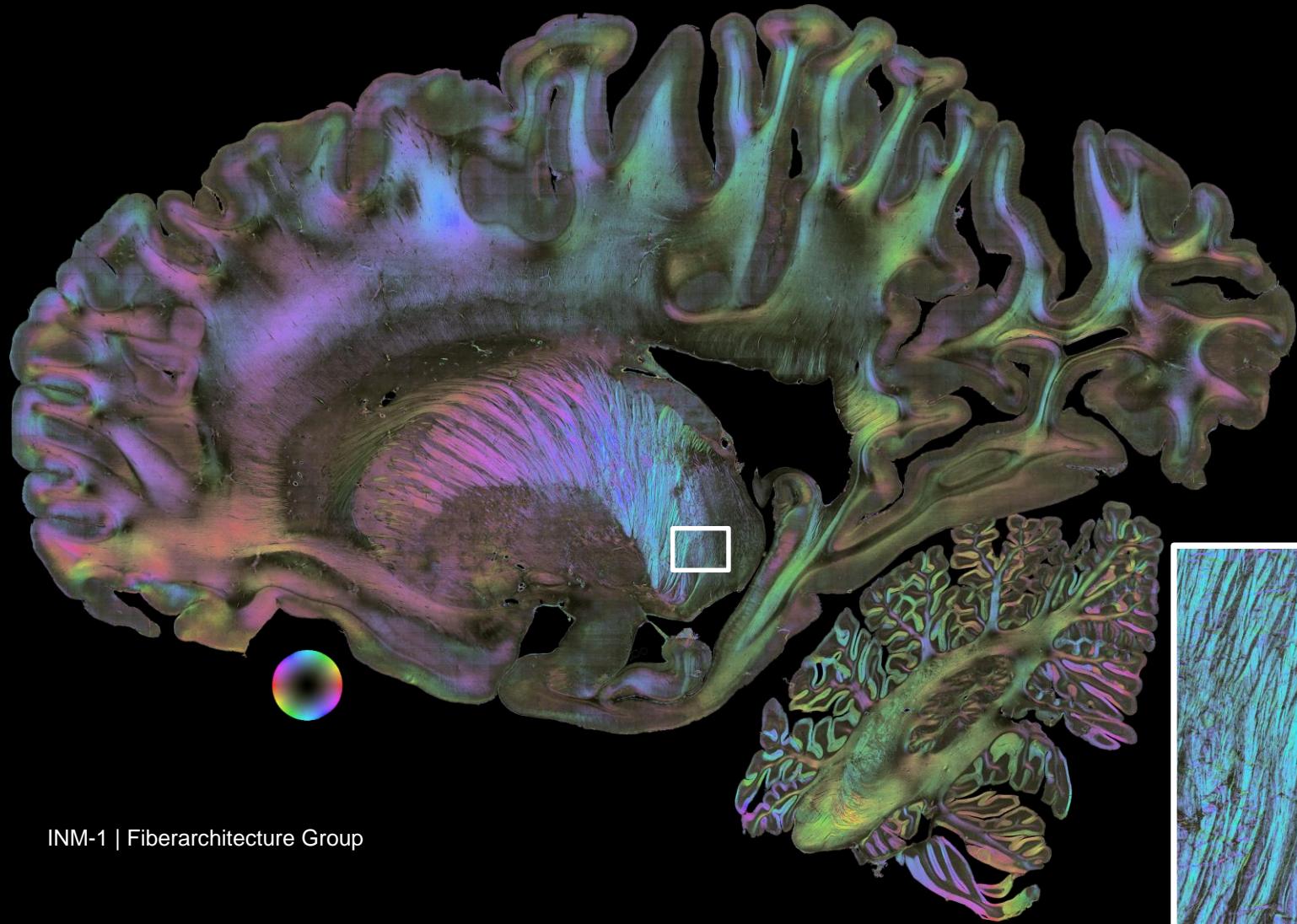
Direction



Retardation



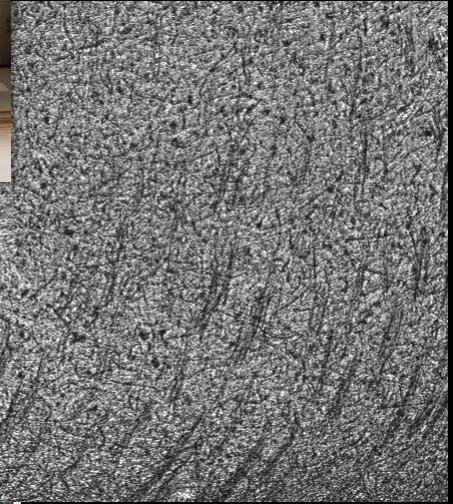
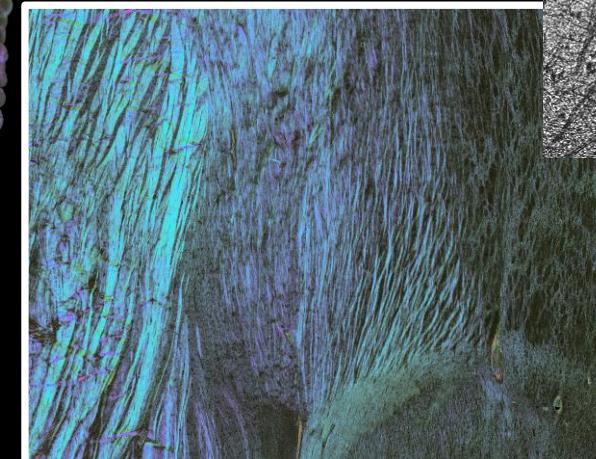
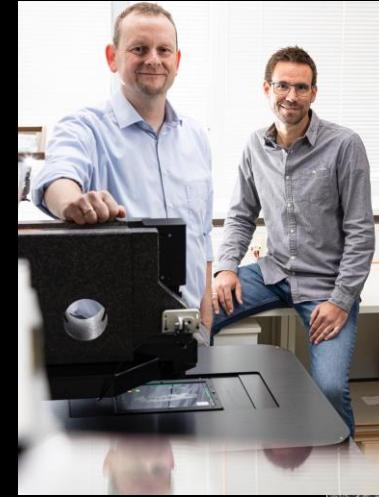
3D - Polarized Light Imaging



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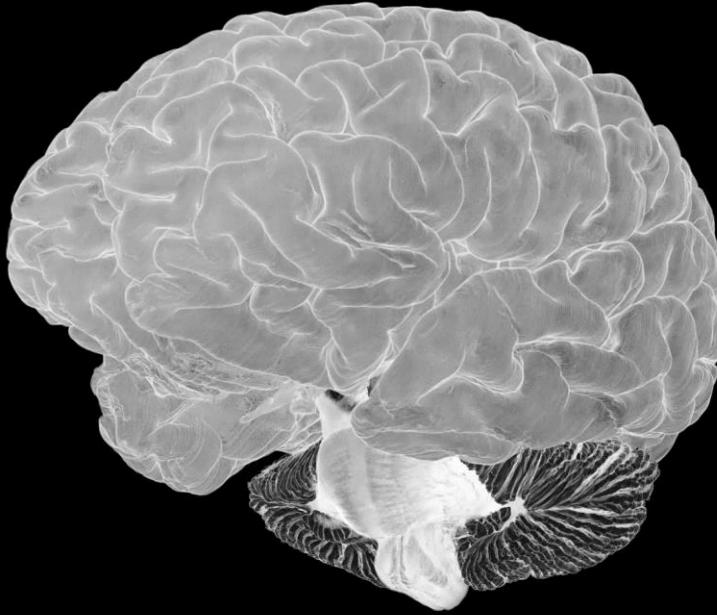
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Page 7

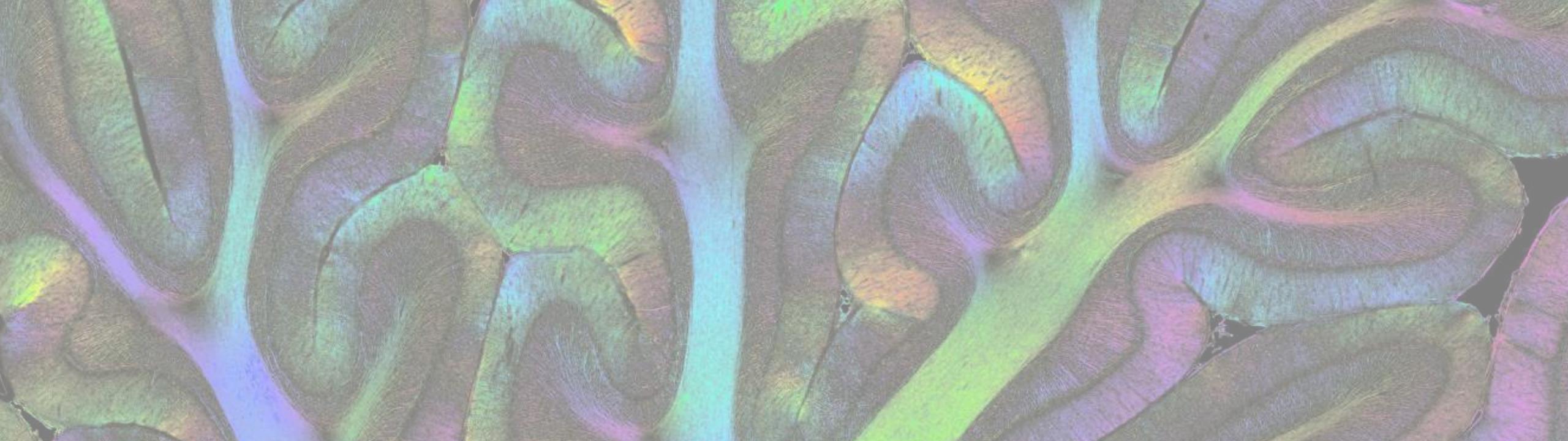


 JÜLICH
Forschungszentrum

3D-PLI - Volume Reconstruction



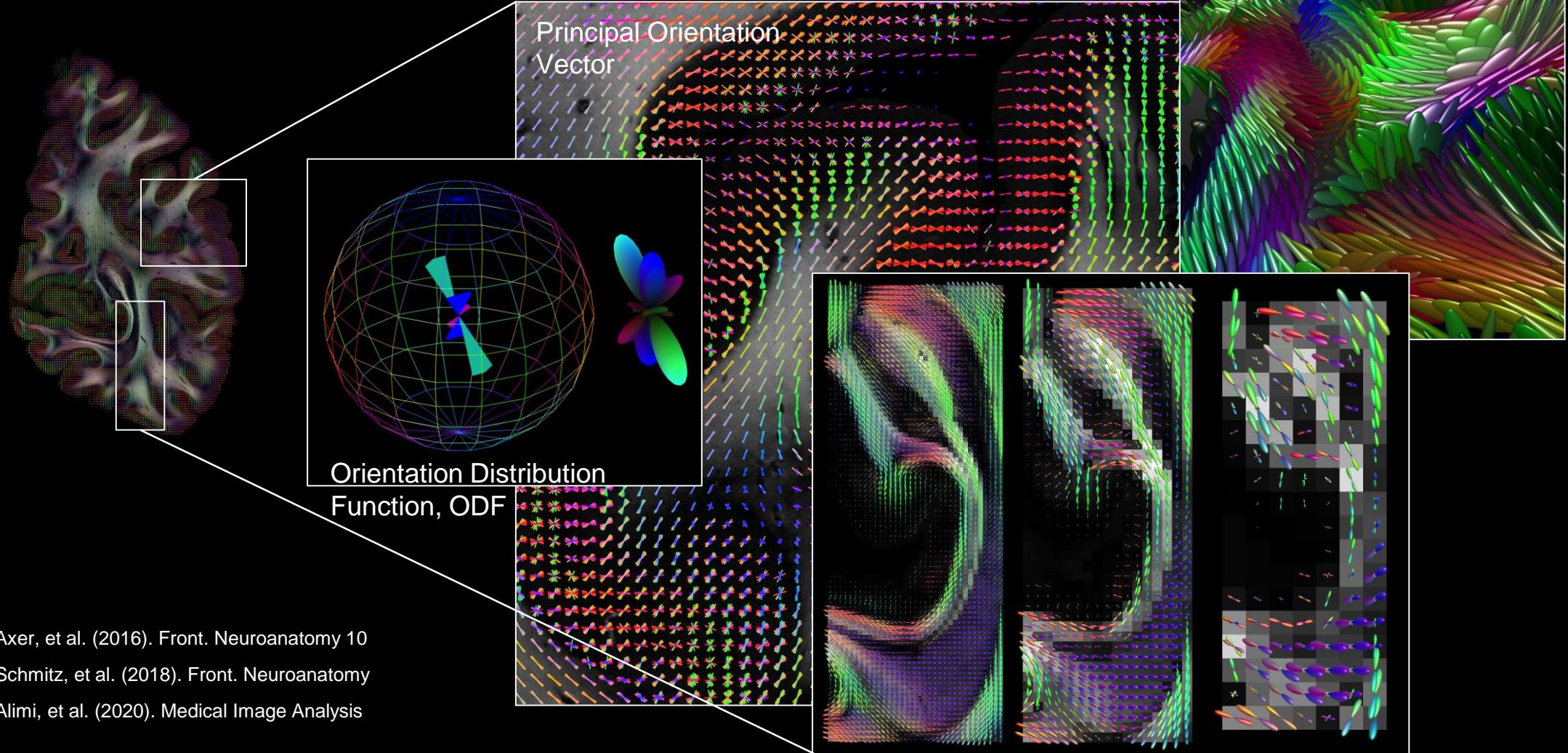
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TRACTOGRAPHY

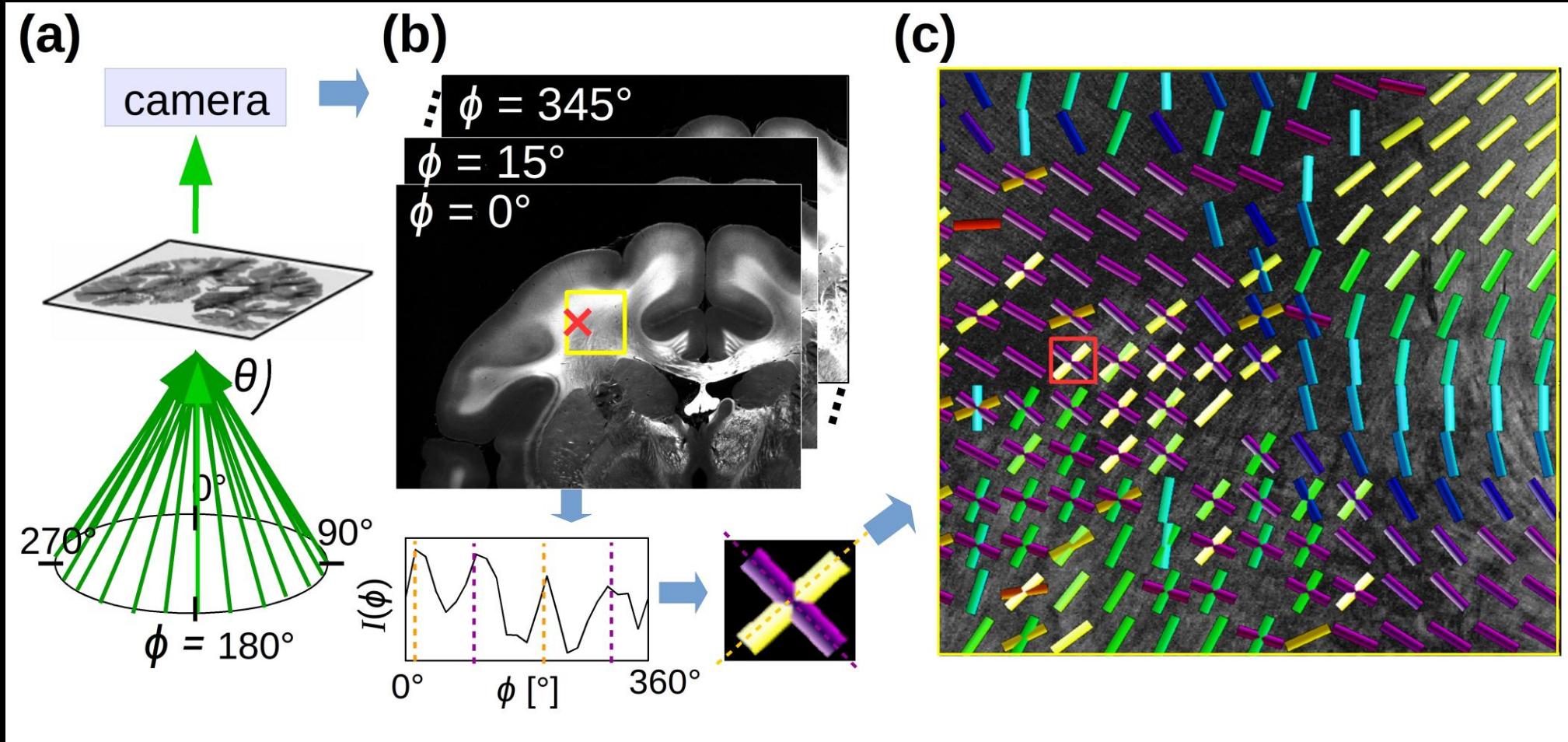
Data Preparation

Orientation Statistic



Orientation Statistic

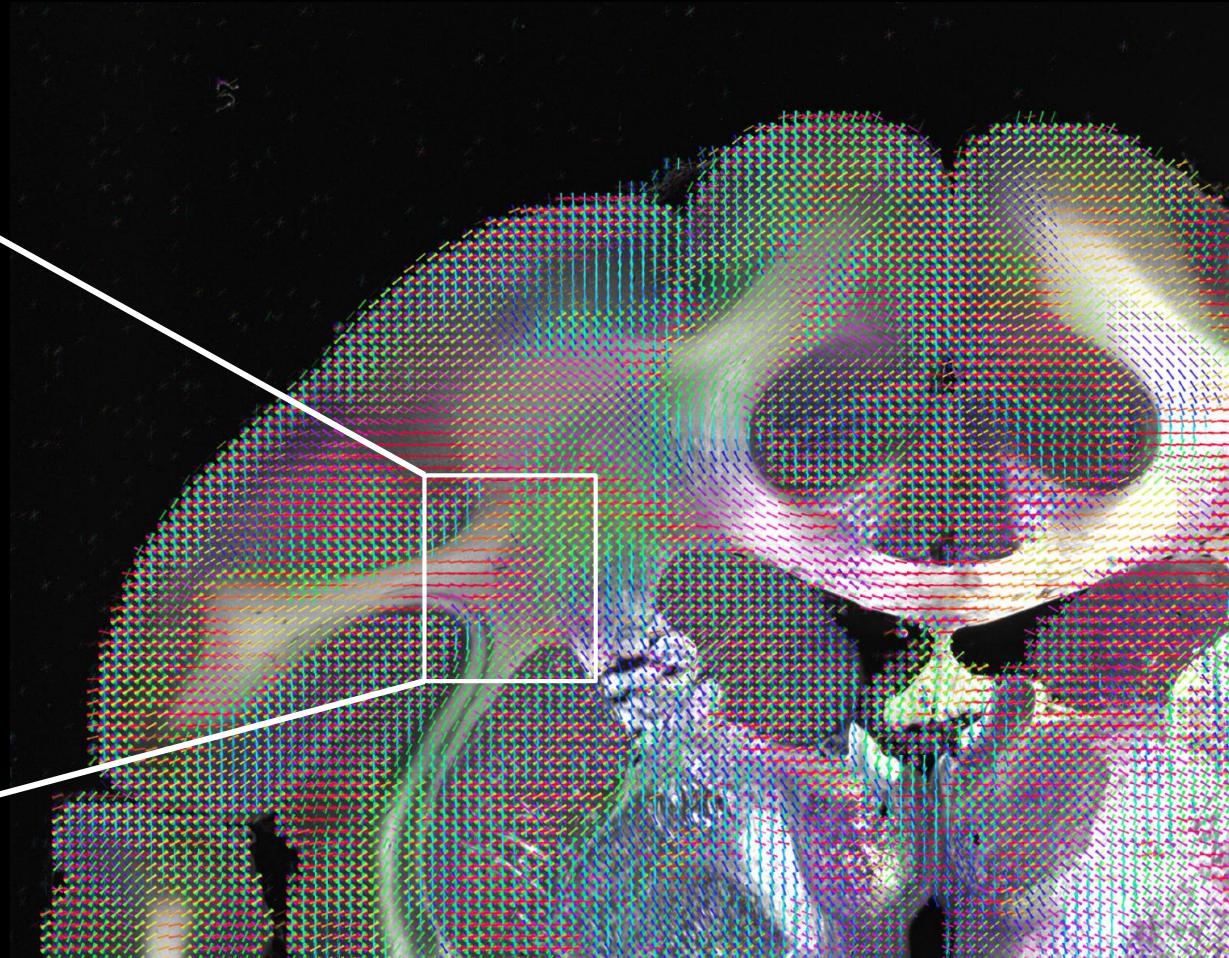
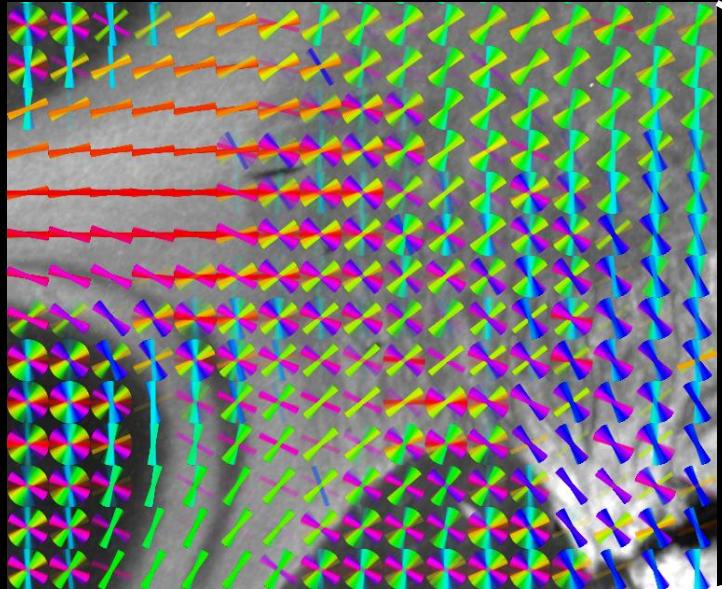
Scattered Light Imaging



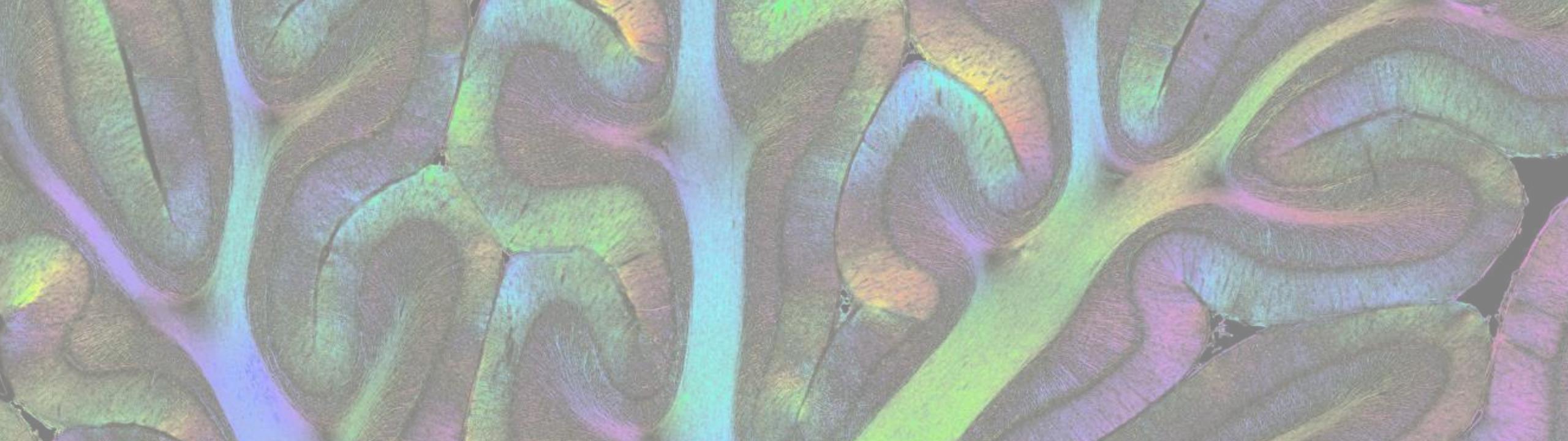
Menzel et al. NeuroImage (2021)

Orientation Statistic

Scattered Light Imaging



Jan Reuter & Miriam Menzel



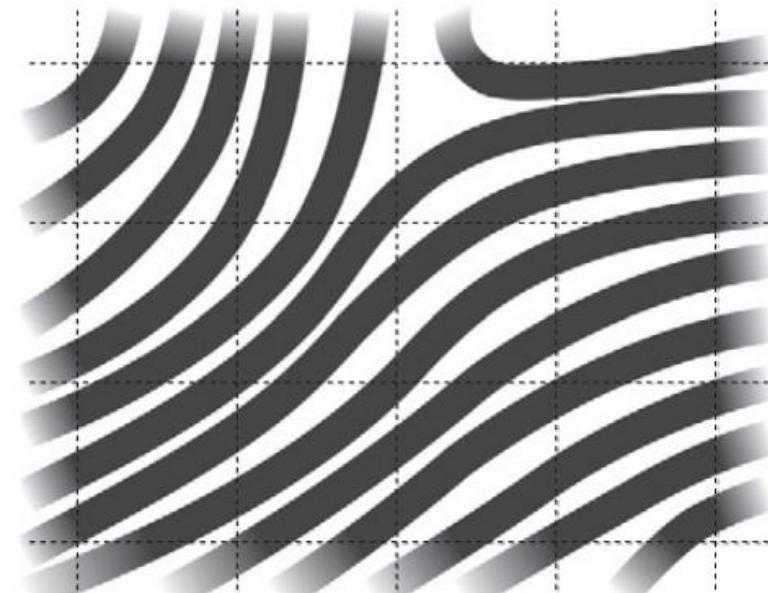
TRACTOGRAPHY

The Basics

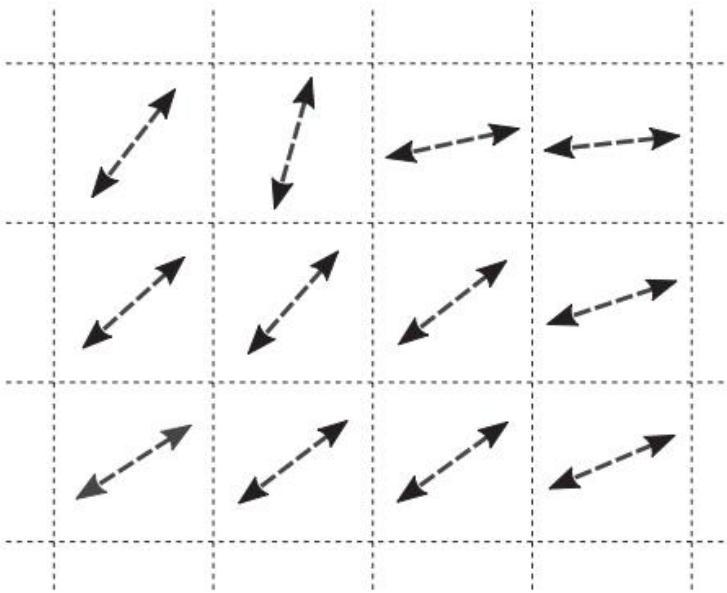
Tractography

Basics

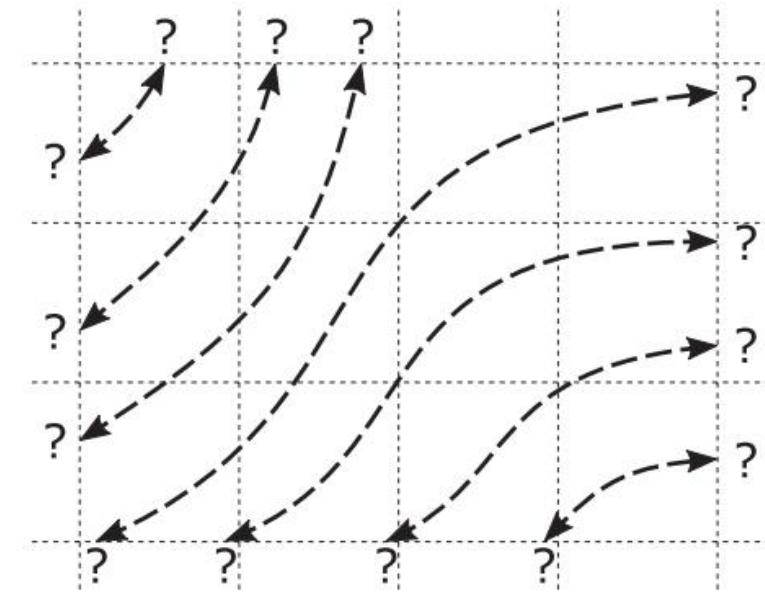
Fibers



Fiber orientations

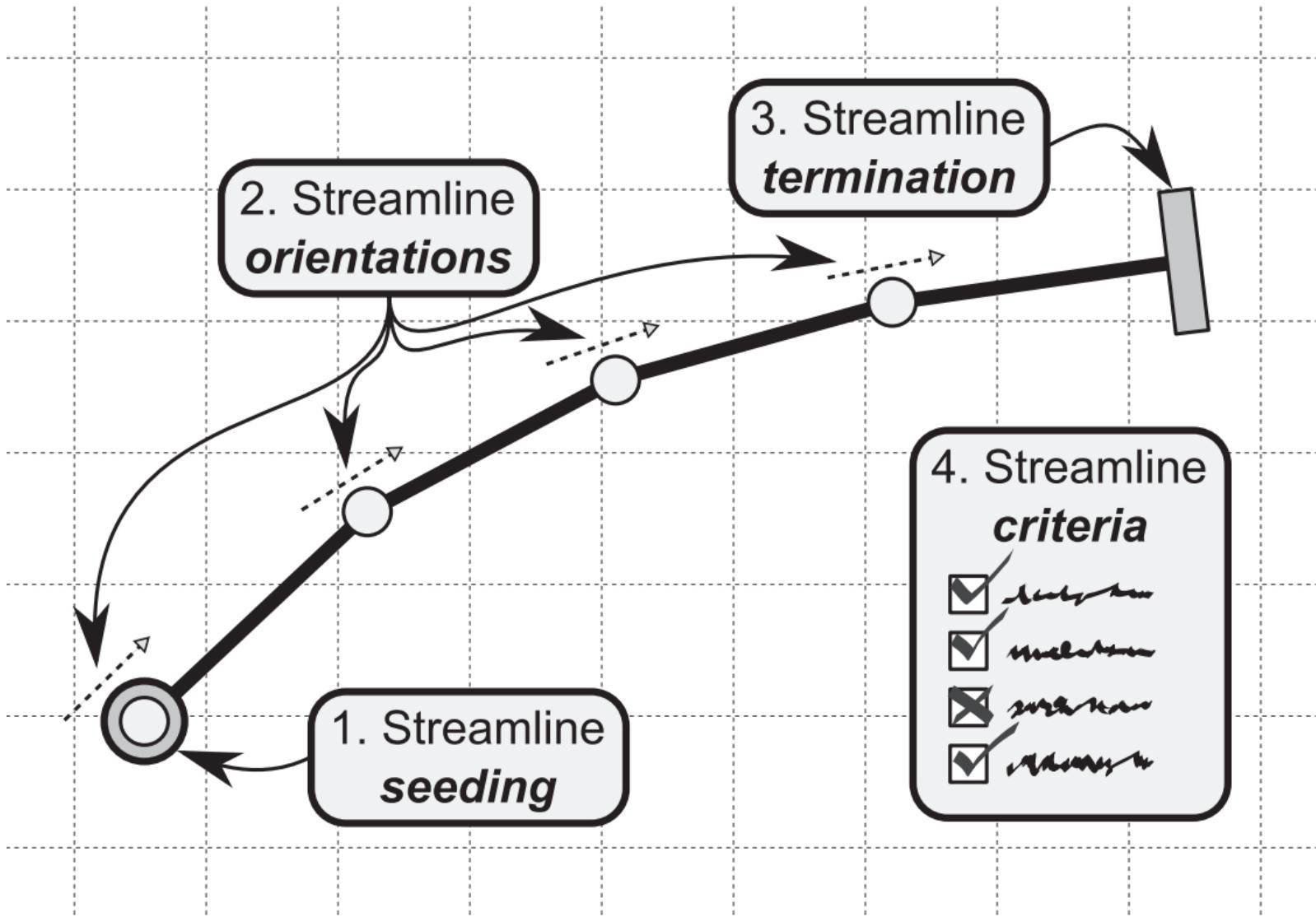


Tractography



Tractography

Basics

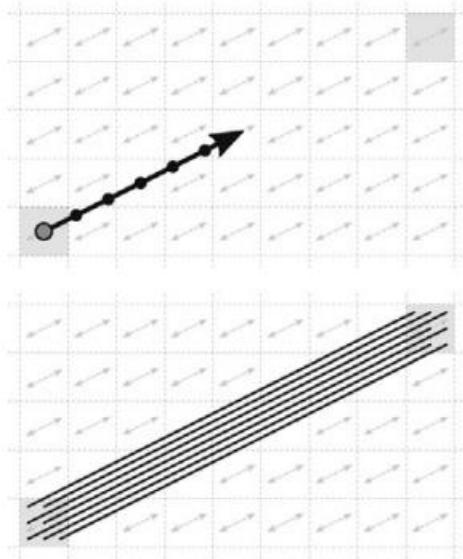


Smith et.al. - Diffusion MRI
Fiber Tractography - 2020

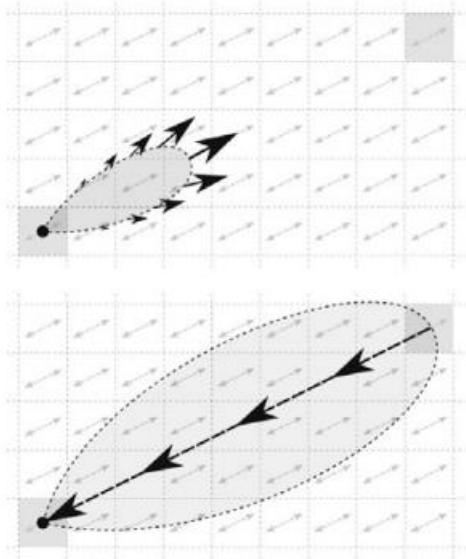
Tractography

Basics

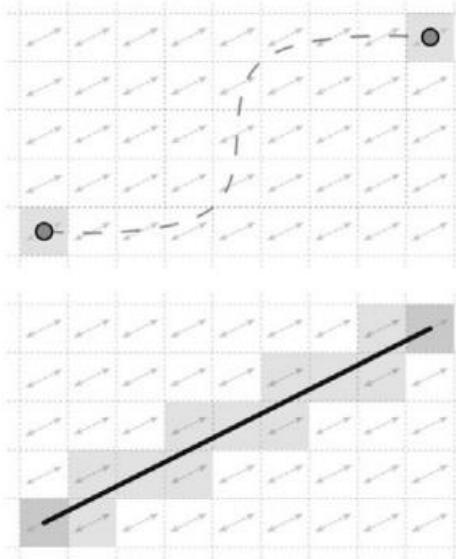
Streamlines



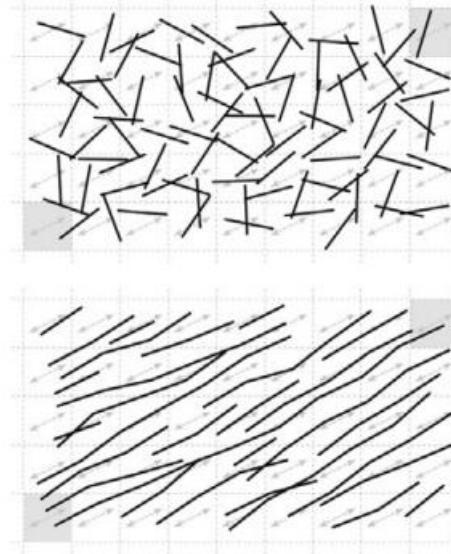
Front evolution



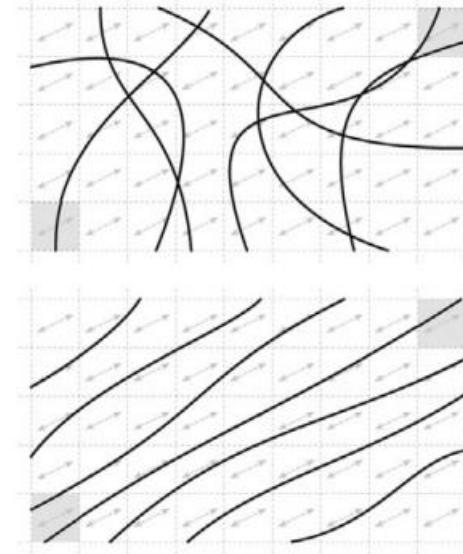
Geodesic



Global (segment-wise)



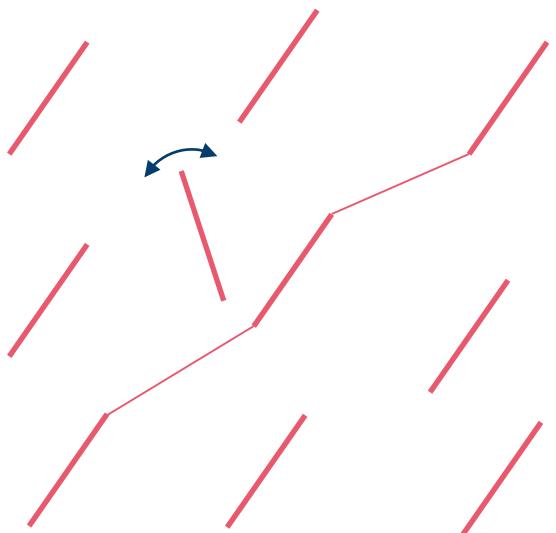
Global (fiber-wise)



Smith et.al. - Diffusion MRI
Fiber Tractography - 2020

Global Tractography

From Particles to Fibers

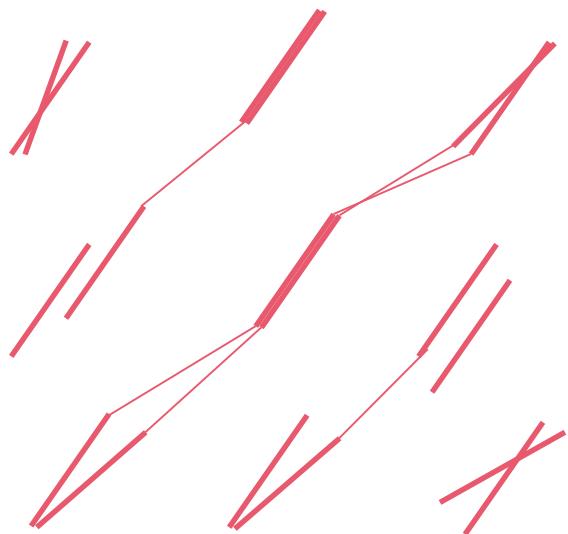


Markov Random Strategy:

- Pick random Spins
- Sample a random orientation according to the data
- Randomly move Spin
- Check if connection is reasonable

Global Tractography

From Particles to Fibers

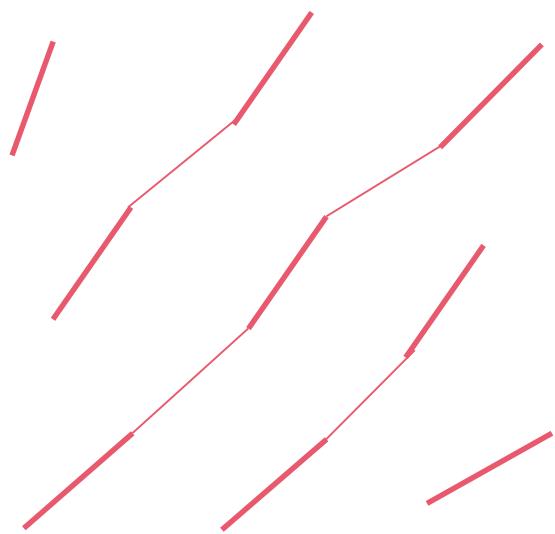


Markov Random Strategy:

- Pick random Spins
- Sample a random orientation according to the data
- Randomly move Spin
- Check if connection is reasonable

Global Tractography

Overcoming the Gab

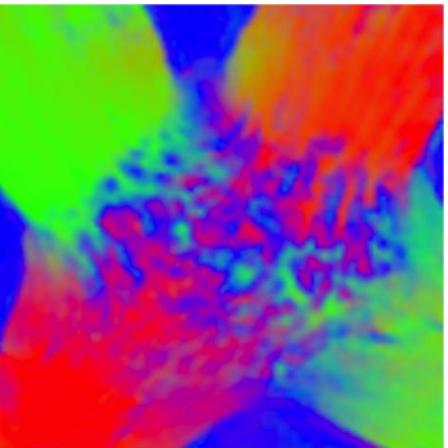
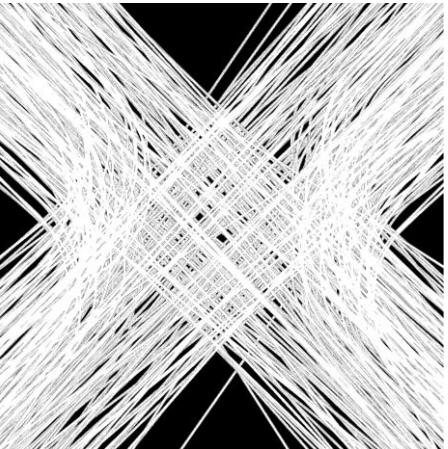
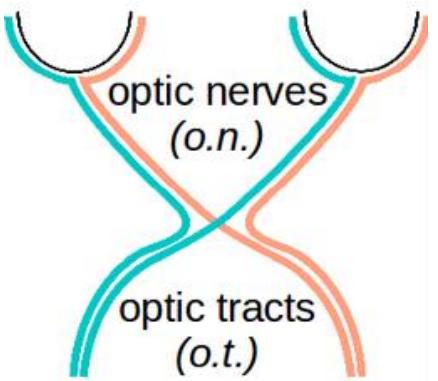


Markov Random Strategy:

- Pick random Spins
- Sample a random orientation according to the data
- Randomly move Spin
- Check if connection is reasonable
- Fibers are allowed to grow

An Example

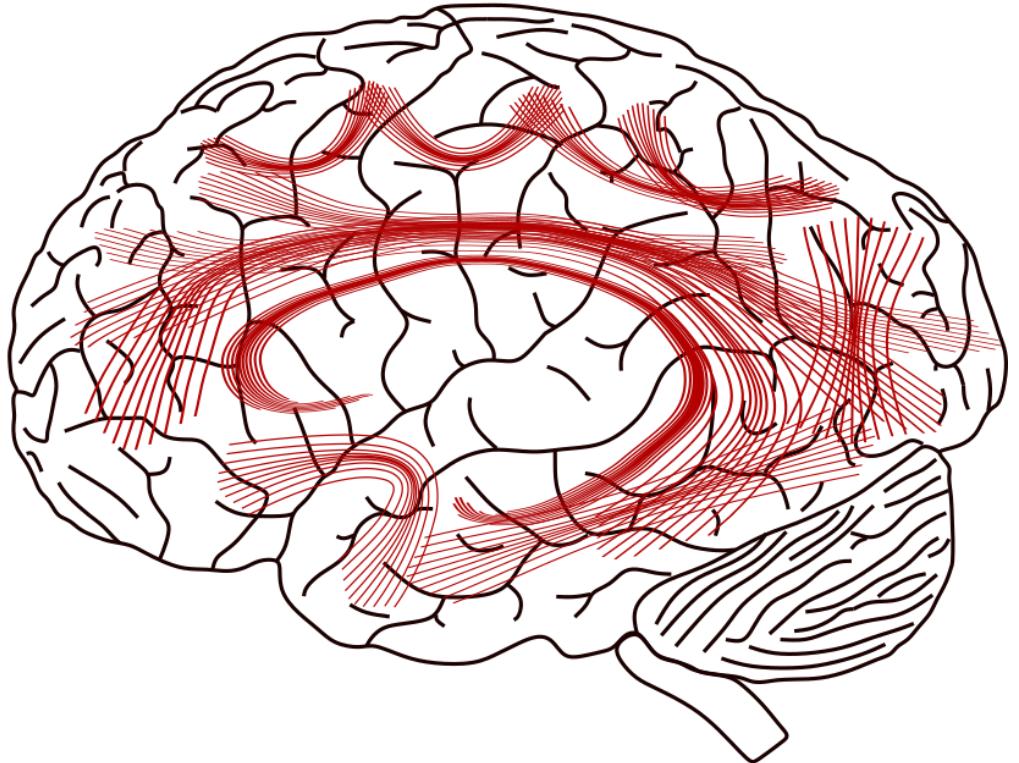
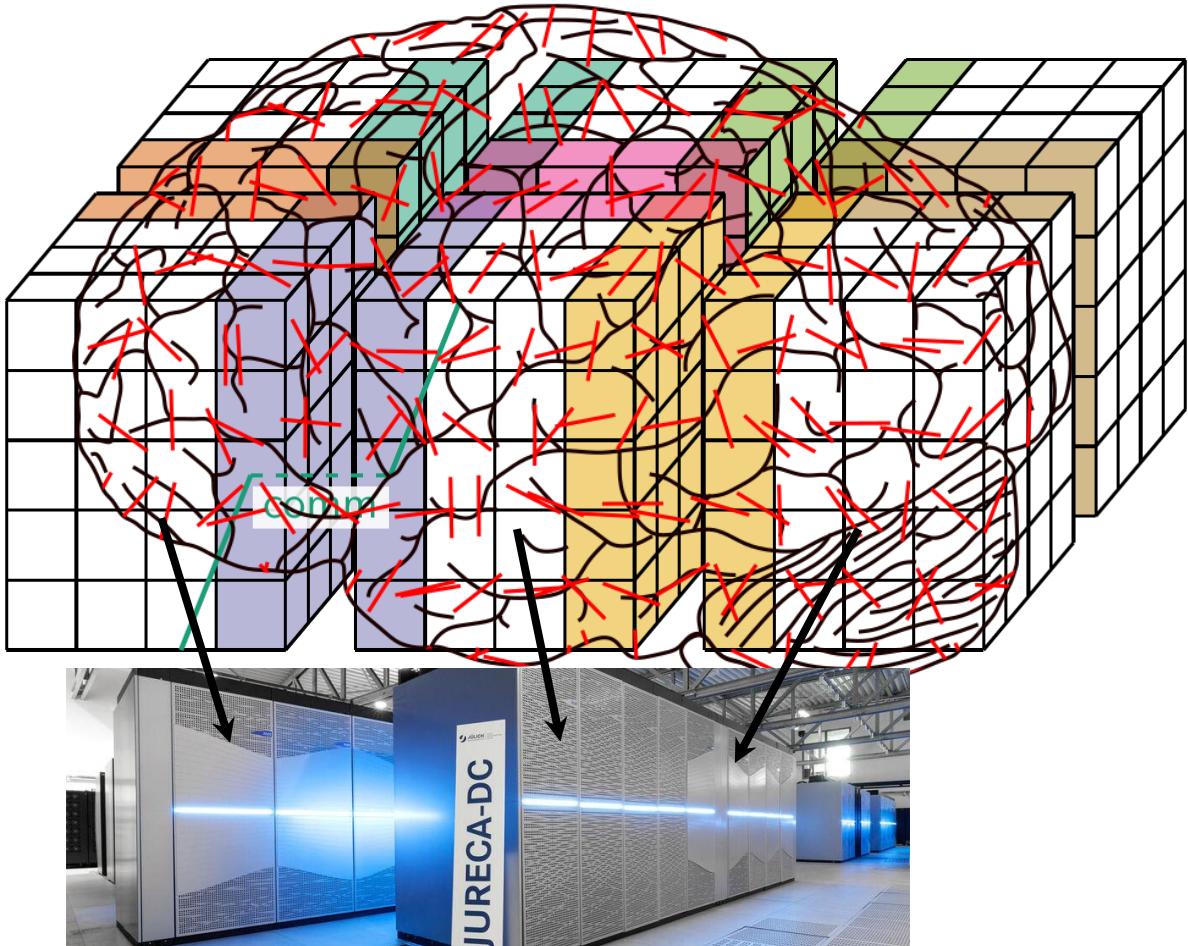
Optic Chiasm

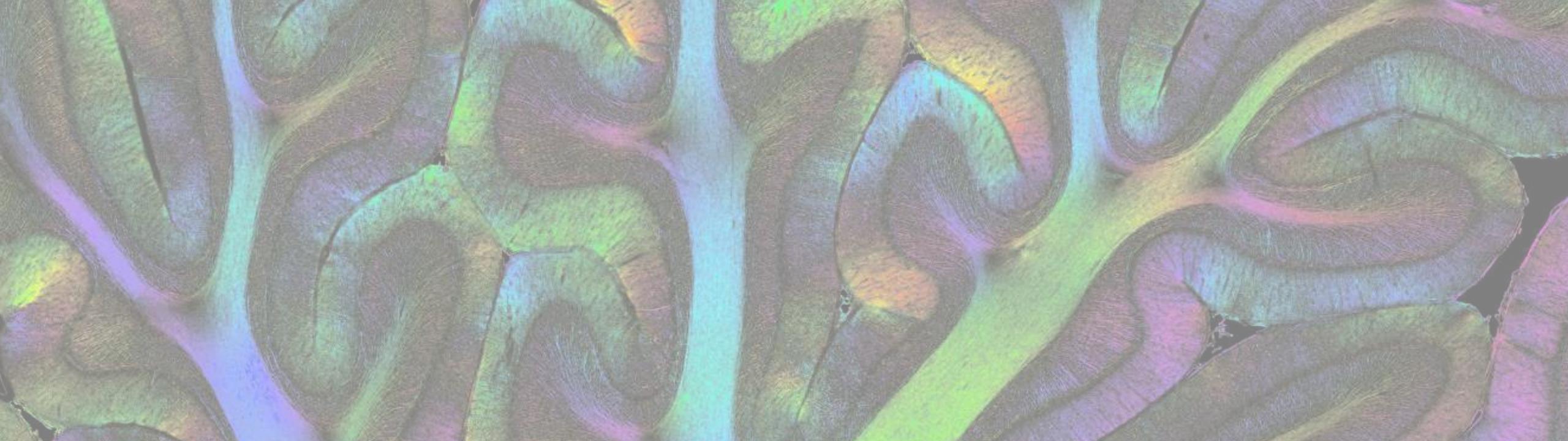


Concept

INM-1 | Fiberarchitecture Group | Felix Matuschke

Global Tractography



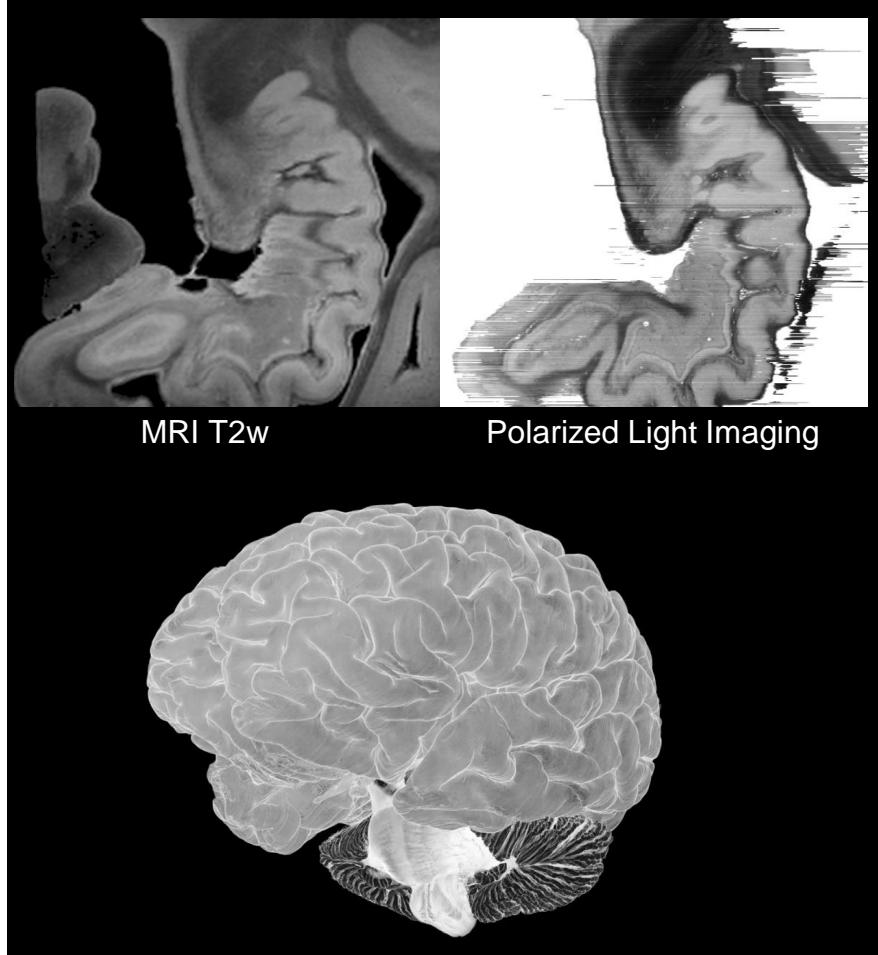


TRACTOGRAPHY

The Human Datasets

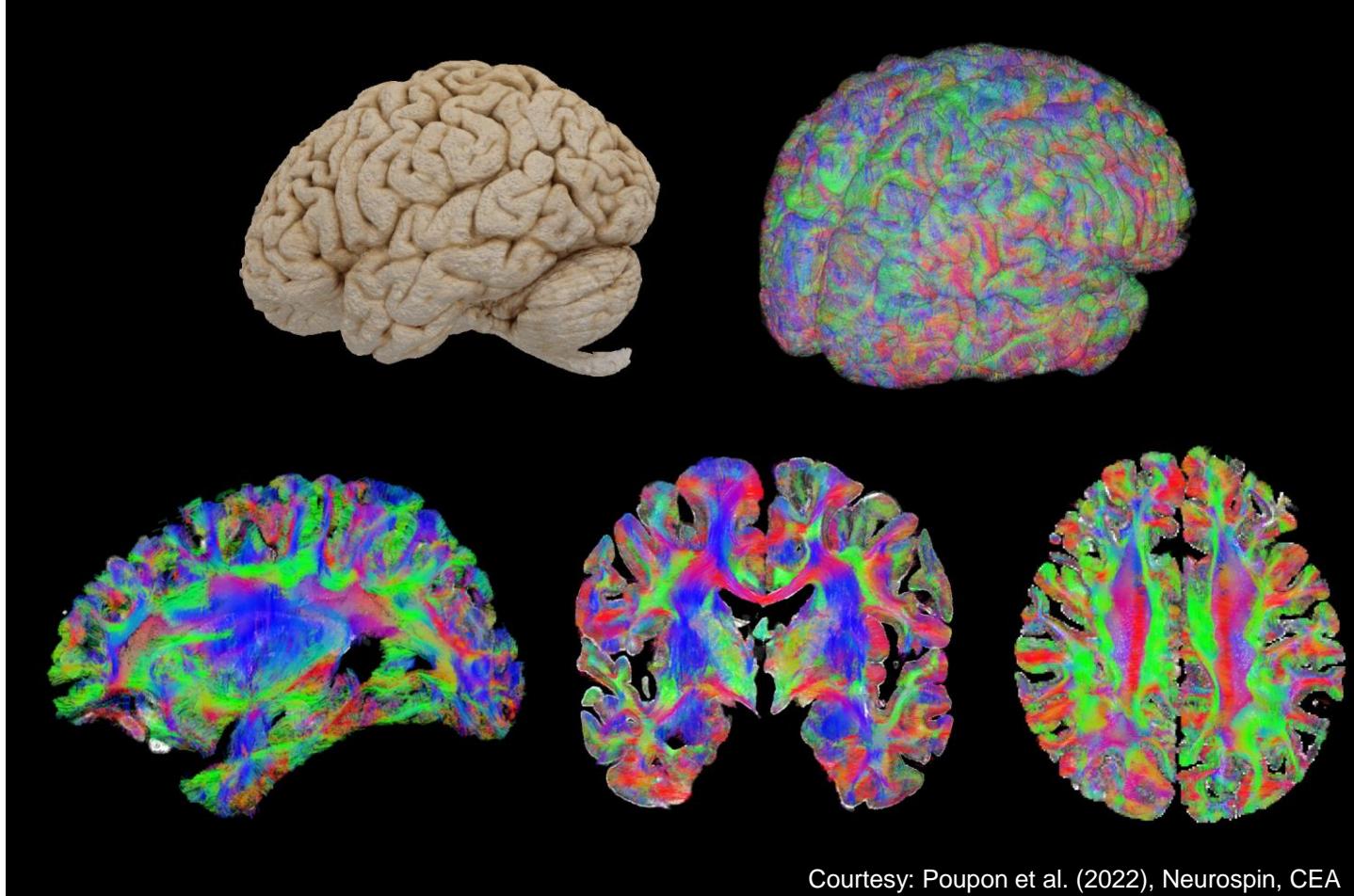
Human Datasets

Hippocampus



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Whole-brain postmortem diffusion MRI at 200µm resolution



Courtesy: Poupon et al. (2022), NeuroSpin, CEA

Human Data Sets

Towards a Nerve Fiber Atlas

High Resolution dMRI:

- 200µm x 200µm x 200µm T1/T2
- 400µm x 400µm x 400µm diffusion

3D-PLI:

- 1.3µm x 1.3µm x 50µm
- ~1.500 section per hemisphere
- **~2 PBytes** Raw Data

SLI:

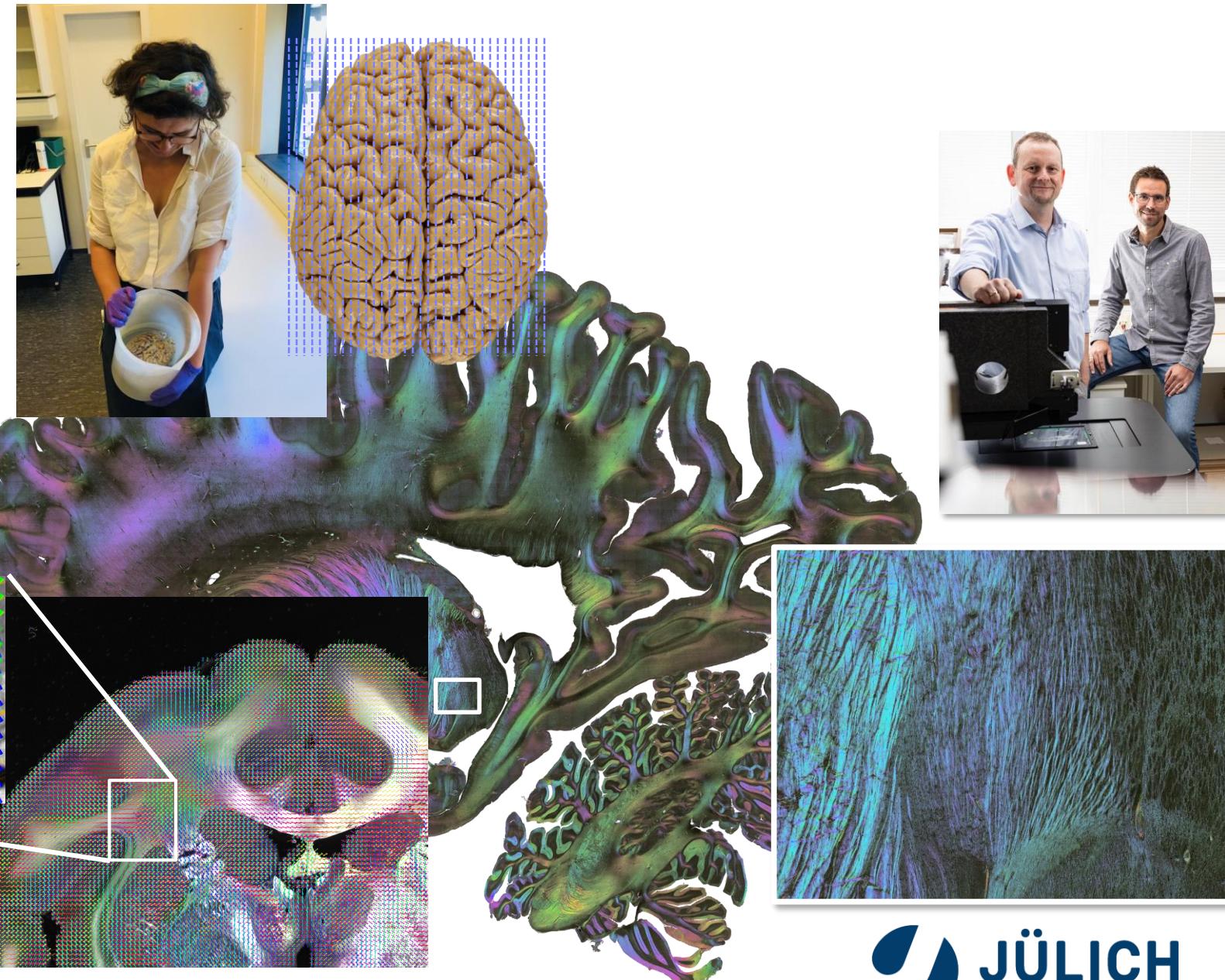
- ~10th section

Immunohistochemistry:

- ~10th section

Multimodal Partner Projects:

- ...



JSC for the rescue

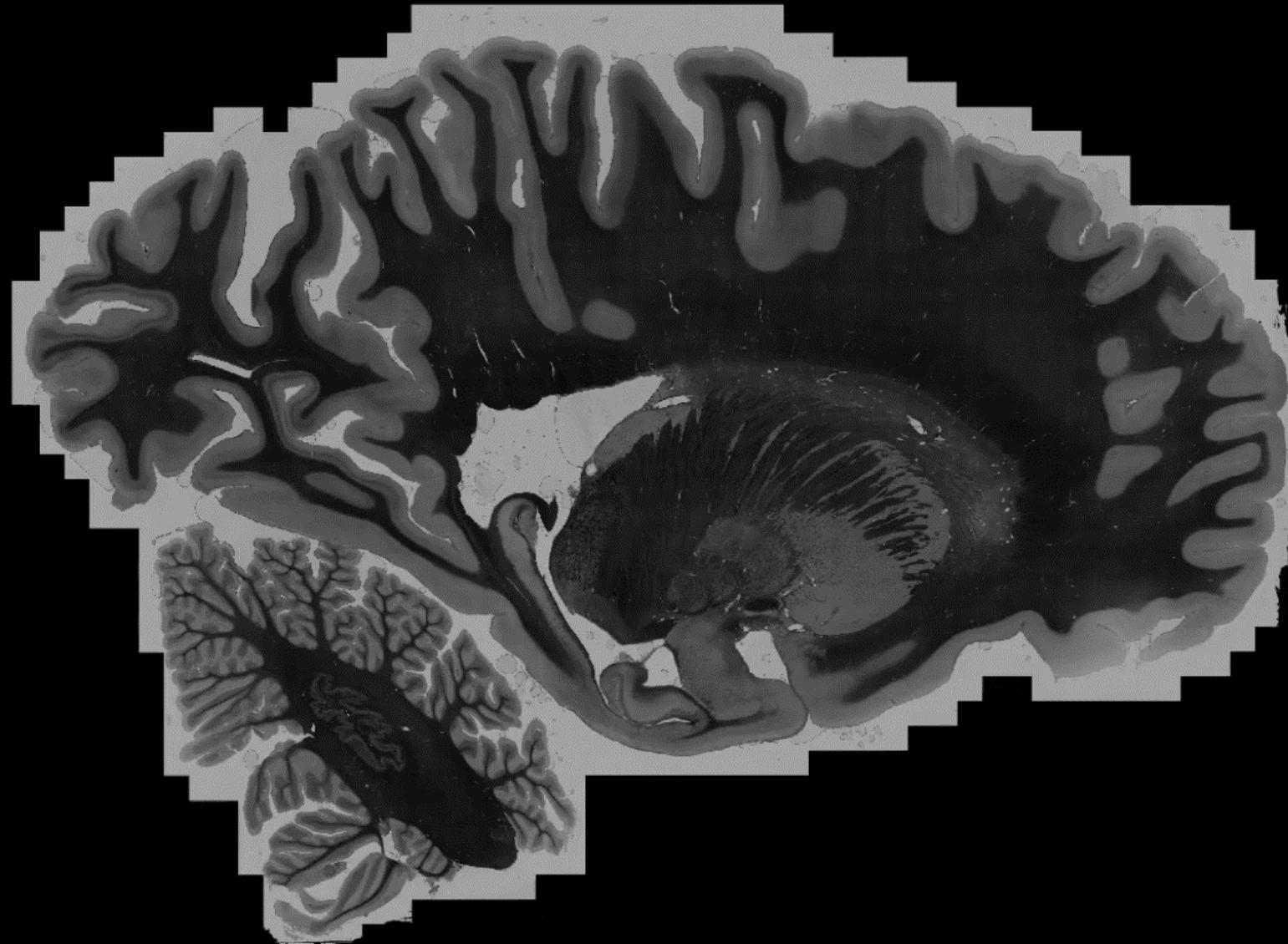


192 accelerated compute nodes:

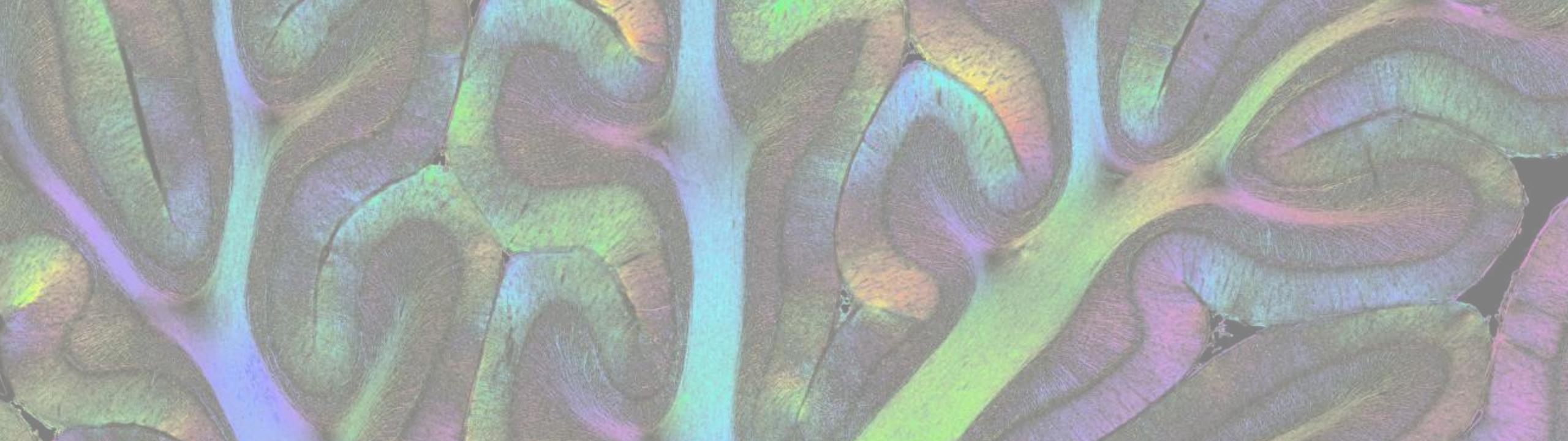
- 2x AMD EPYC 7742, 2x 64 cores, 2.25 GHz
- 512 (16x 32) GB DDR4, 3200 MHz
- 4x NVIDIA A100 GPU, 4x 40 GB HBM2e
- 2x InfiniBand HDR (NVIDIA Mellanox Connect-X6)



Exciting ❤

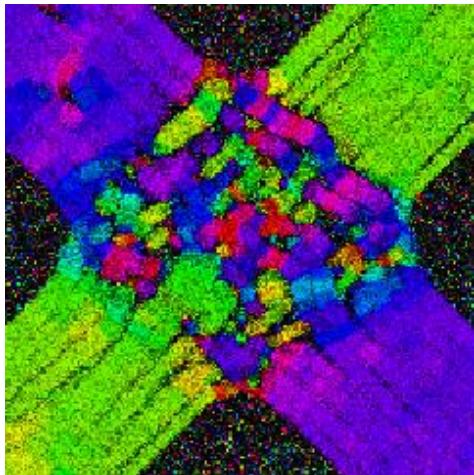
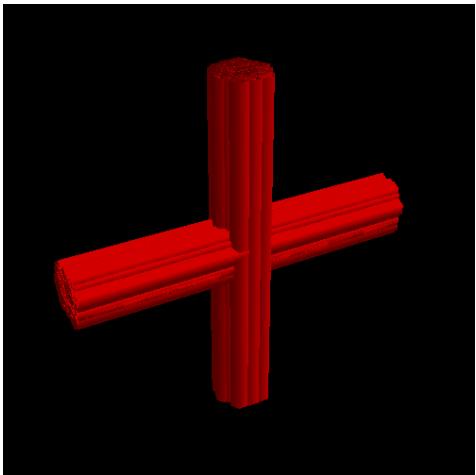
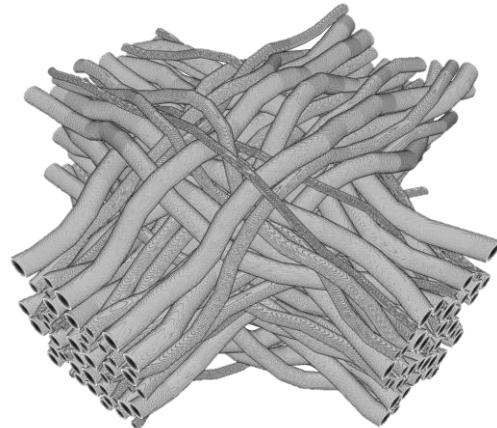
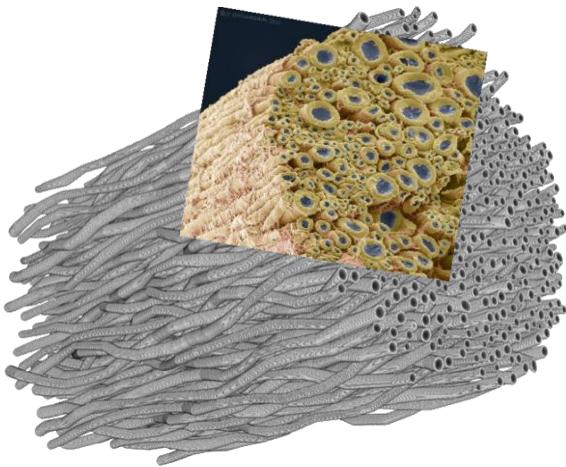


Transmittance



Synthetic Fiber Models

Modeling Collision Free Fiber Models



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Nerve Fiber Modeling and 3D-PLI Simulations of a Tilting Polarization Microscope

Inaugural-Dissertation

zur Erlangung des Doktorgrades der
Mathematisch-Naturwissenschaftlichen Fakultät der
Heinrich-Heine-Universität Düsseldorf

vorgelegt von
Felix Matuschke
aus Meschede

Düsseldorf, Juli 2022

JOS
The Journal of Open Source Software

fastPLI: A Fiber Architecture Simulation Toolbox for 3D-PLI

Felix Matuschke¹, Katrin Amunts^{1,2}, and Marcus Axerl^{1*}

¹ Institute of Neuroscience and Medicine (INM) 50159 Cologne, Germany
² German Center for Brain Research (GCB) 50159 Cologne, Germany
University of Cologne, 50204, Düsseldorf, Germany

DOI: 10.21203/rs.3.rs-20042

Software

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fastPLI is a Fiber Architecture Simulation Toolbox for 3D-PLI. It is a microscopic neuroimaging technique used to study the three-dimensional architecture of unmyelinated biological brain structures at the micrometer scale (Matuschke et al., 2019). fastPLI is based on the principle of polarization microscopy. The technique enables reconstruction of 3D nerve fiber orientation. The physical effect behind fastPLI is the optical property of the nerve fibers called birefringence. Due to this effect, birefringent nerve fibers change the polarization state of light. This change is directly related to the 3D orientation of the nerve fibers.

To understand the influence of the birefringent tissue structures, simulations are an essential tool. In this paper, we present the fastPLI toolbox, which provides a framework for generating simulations that simulate with scanned light within tissue regions models with irregularly shaped nerve fibers. The toolbox also provides a framework for generating simulations that include birefringent structures such as fiber crossing that have been difficult to implement in previous 3D-PLI software.

In addition, the generated nerve fiber models can be used in other imaging simulation techniques such as diffusive magnetic resonance imaging (dMRI).

In recent years, various methods have been developed to model nerve fiber structures. These have been mainly based on the assumption that nerve fibers are represented by cylindrical representations, especially collagen fibers. In the last decade, an increasing number of studies have shown that nerve fibers are not always represented by cylindrical structures (Liu et al., 2011; Choudhury et al., 2015; Giedd et al., 2016; Miquet et al., 2017). While these studies have shown that nerve fibers are not always represented by cylindrical structures, they have also shown that the current methods for simulating 3D-PLI are based on the assumption that nerve fibers are represented by linear fibers. Here, the focus is on the previously developed algorithm for simulating 3D-PLI, which is based on a direct method for generating collagen-like structures for white matter structures in the brain.

Different types of simulations for polarized light are example described in (Axerl et al., 2019). The toolbox also provides a framework for generating simulations that include some of these techniques have been used to simulate the effect of polarized light on nerve fibers, except axerl et al. (2019), which is included in this toolbox.

Summary

fastPLI is an open source toolbox based on Python and C++ for modeling myelinated axons, i.e. nerve fibers and simulating the results of measurement of orientation of a polarized microscope using 3D-PLI.

Fiber Architecture Simulation Toolbox for 3D-PLI

FASTPLI

The Fiber Architecture Simulation Toolbox for 3D-PLI (`fastpli`) is a toolbox for polarized light imaging (PLI) with three main purposes:

- **Build** - designing of nerve fiber models: The first module allows the user to create different types of nerve fiber bundles and additionally fill them with individual nerve fibers.
 - Details
 - Tutorial
- **Solve** - generating collision free models: The second module takes as input a configuration of nerve fibers and checks them for spatial collisions. Since nerve fibers cannot overlap in reality, one must ensure that the models follow the same rules. The solver module implements a simple algorithm that checks for collisions and, if it finds any, pushes the colliding segments of the fibers slightly apart. This is repeated until all collisions are solved.
 - Details
 - Tutorial
- **Simulate** - simulation of 3D-Polarized Light Imaging: The simulation module enables the simulation of 3D-Polarized Light Imaging (3D-PLI). This is a microscopic technique that allows the polarization change of light moving through a brain section to be measured. Due to the birefringence property of the myelin surrounding the nerve fibers, the polarization state changes. This change enables the calculation of the 3d orientation of the nerve fibers in the brain slice.
 - Details
 - Tutorial

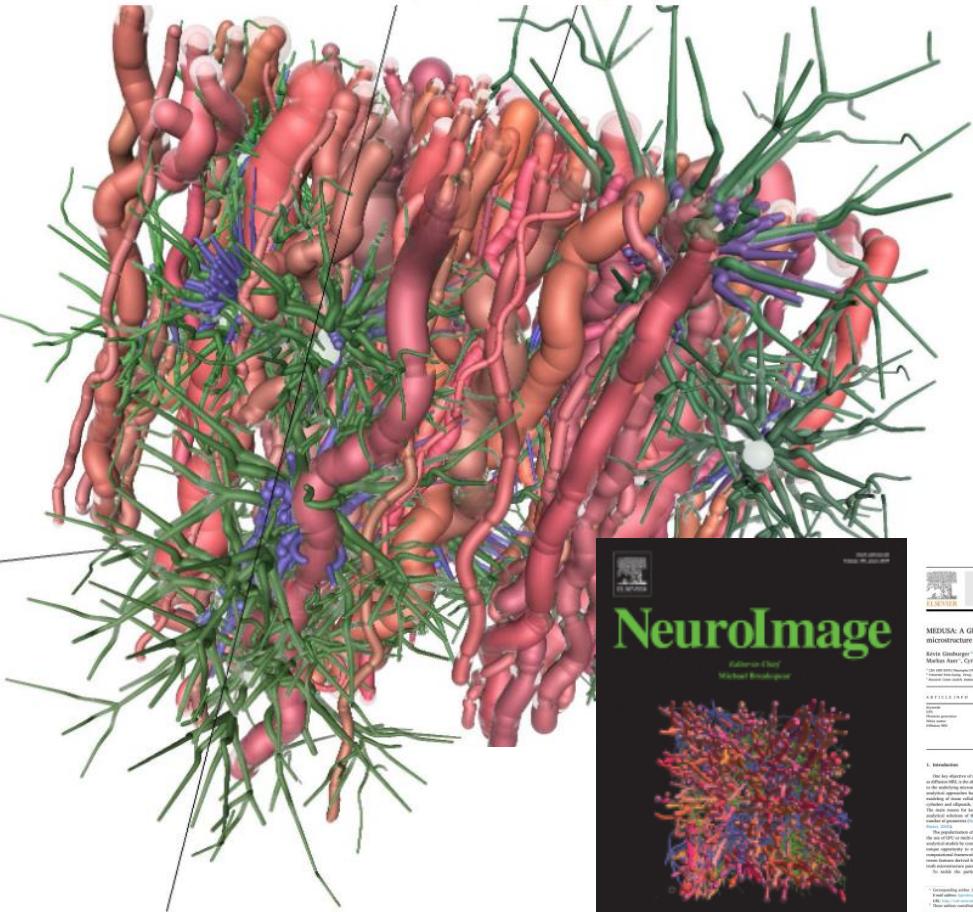
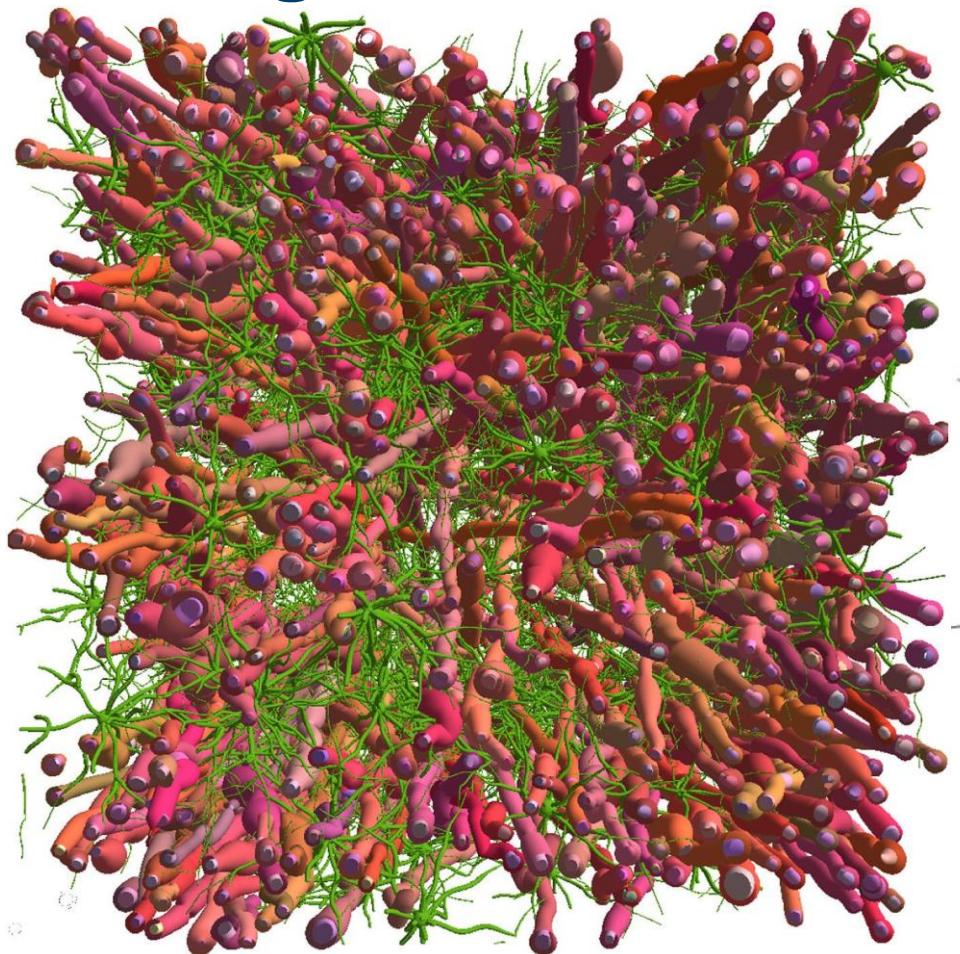


<https://github.com/3d-pli>



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WM Modeling



Kevin Ginsburger, Felix Matuschke,
Cyril Poupon, Markus Axer, et al. (2019)

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Outlook

- Juelich Brain Atlas
- AI driven tractography
- Open Source Code
 - Support of clinical Data
- Improvements of dMRI tractographies by better understanding the microscopic structure

Generating of a multimodal Nerve Fiber Atlas



Special thanks to:

- Markus Axer (FZJ | INM1)
- Jan Reuter (FZJ | INM1)
- Simon Legeay (CEA | Neurospin)
- Katrin Amunts (FZJ | INM1)
- Cyril Poupon (CEA | Neurospin)

Thanks!