Phase contrast imaging in mouse brain: anisotropy and structure analysis

Semester Project Presentation by Madeline Harlow

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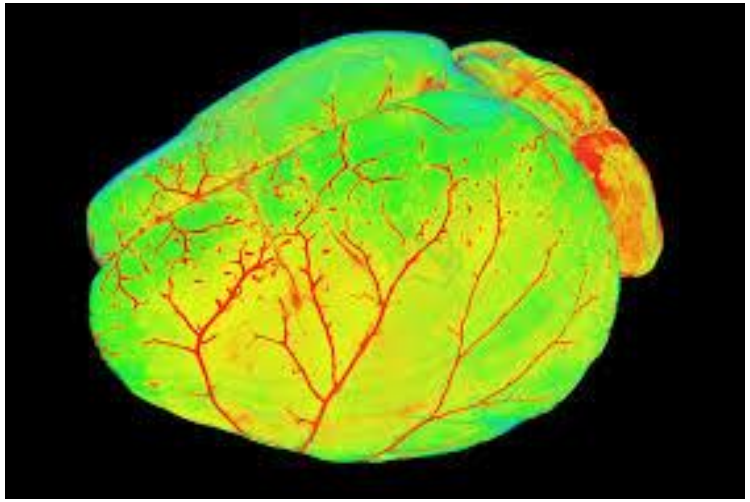
Agenda

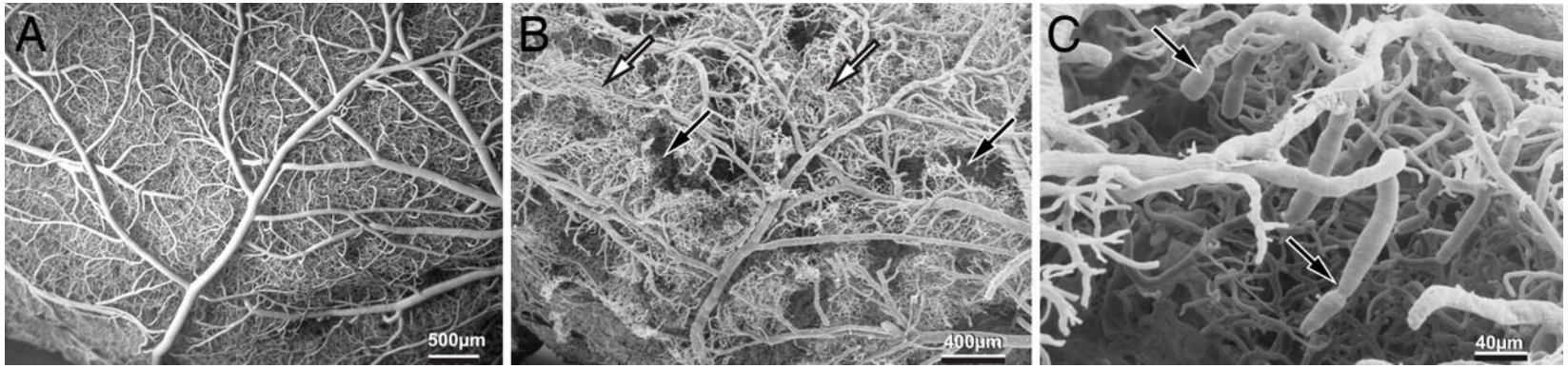
- Introduction / Background
  - Methods of measuring vasculature
  - Phase Contrast Imaging (PCI)
- Image Acquisition
- Image Processing
- Anisotropy Analysis
- Discussion

Measuring Vasculature

- Cerebral Blood Flow critical in many pathologies
  (Girouard and Iadecola 2006)
  - Hypertension
  - Alzheimer's
  - Stroke
- Understanding BOLD signal



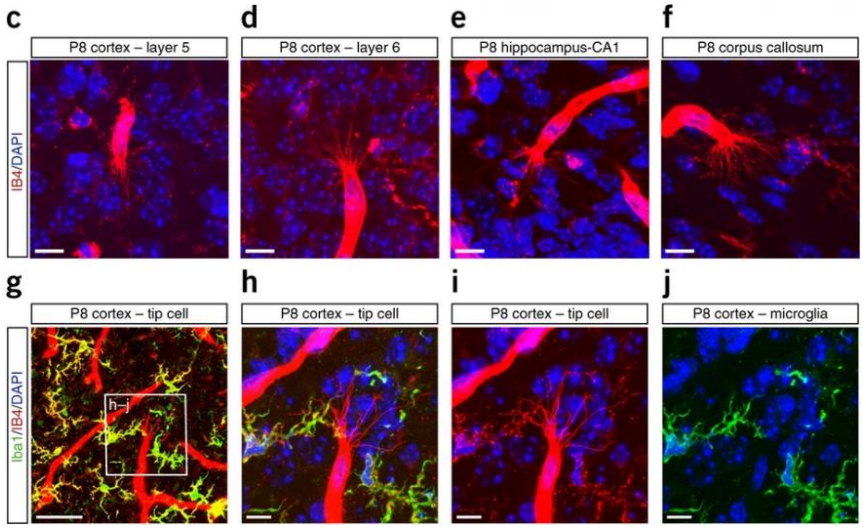
Mouse brain imaged by 3DISCO
(Erturk, Becker et al. 2012)



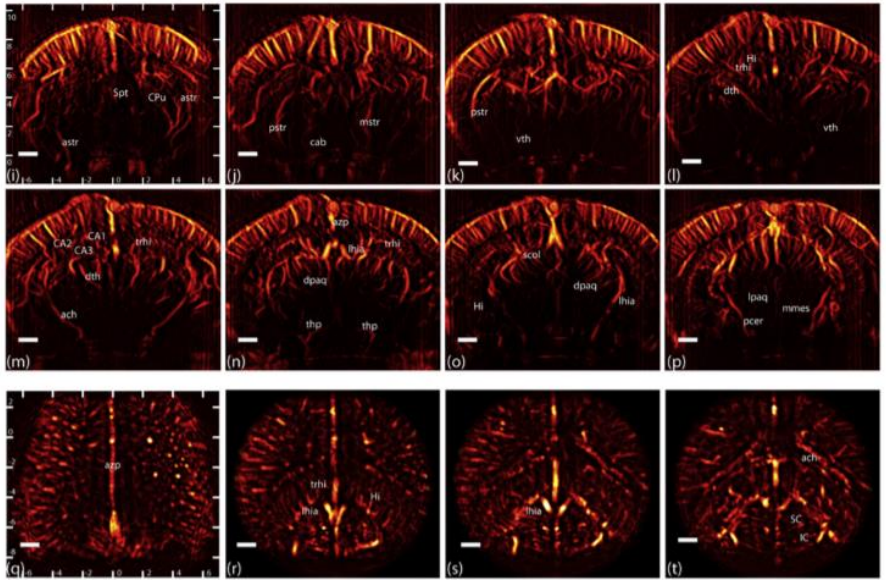
18 month old healthy mouse (A) compared to one with Alzheimer's (B,C)
(Meyer, Ulmann-Schuler et al. 2008)

Previous Methods

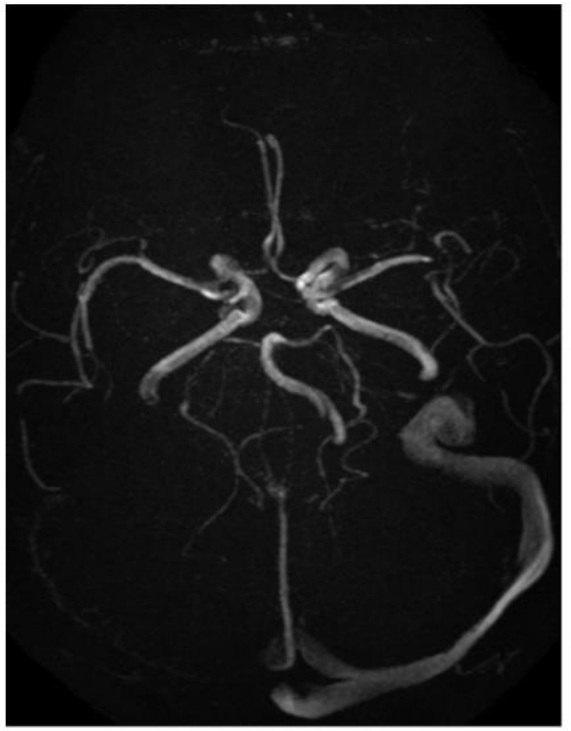
- Histology
- MRA
- CTA
- Ultrasound



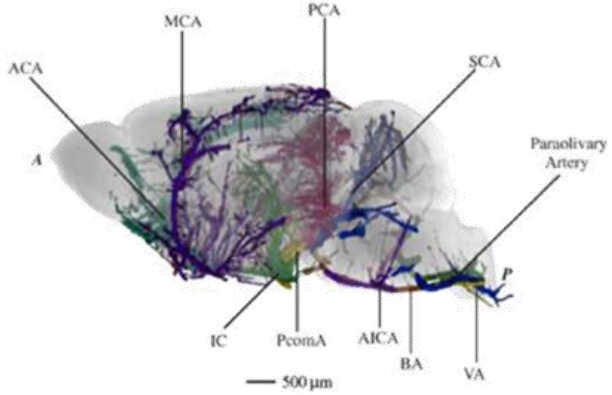
(Walchli, Mateos et al. 2015)



(Demene, Tiran et al. 2016)



(Chung, Noble et al. 2004)



(Dorr, Sled et al. 2007)

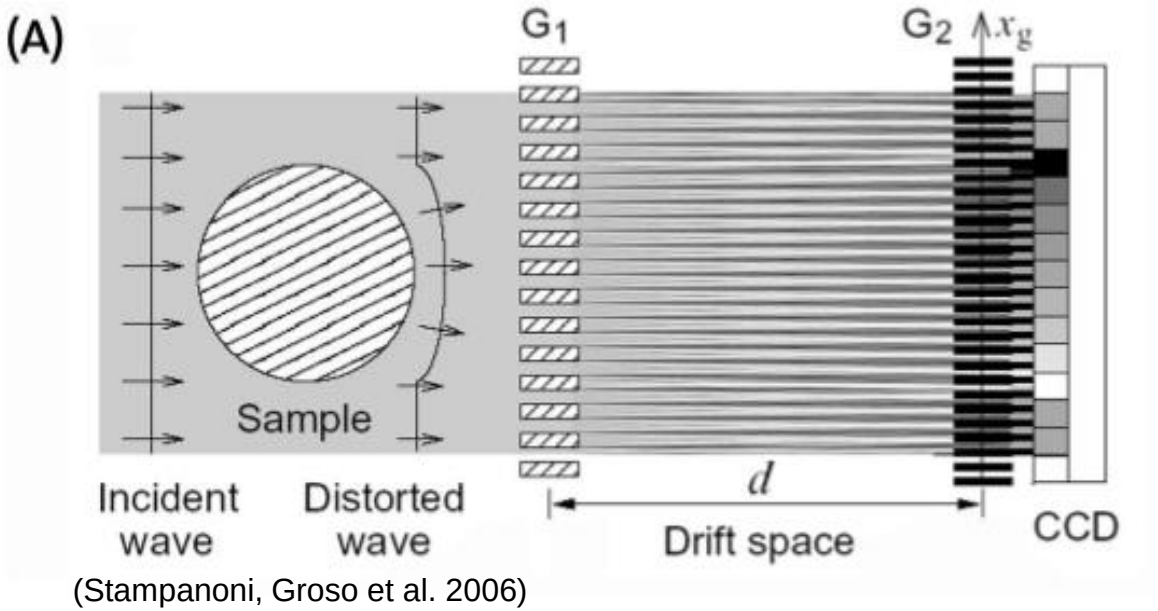
Phase Contrast Imaging

Absorption

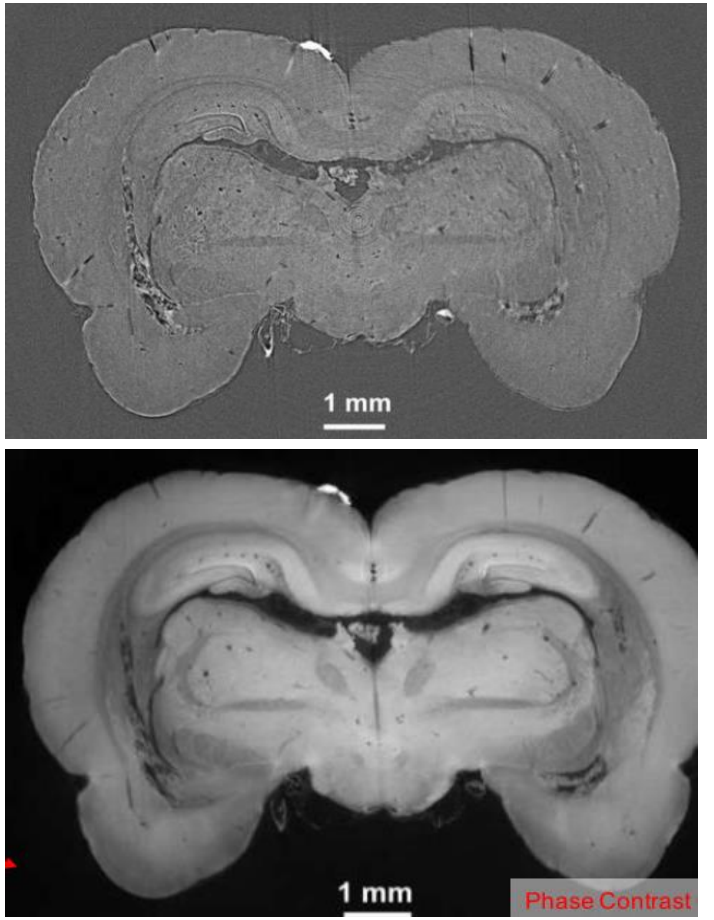
Phase

$$Index\ of\ Refraction\ v = 1 - \delta + i\beta$$

- Absorption vs. Phase

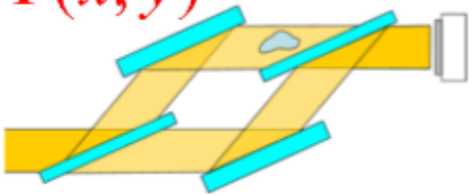


(Stampanoni, Groso et al. 2006)



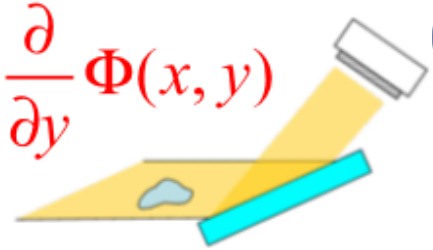
Rat brain: Absorption (top) vs. PCI using grating interferometer (bottom)
(McDonald, Marone et al. 2009)

$\Phi(x,y)$



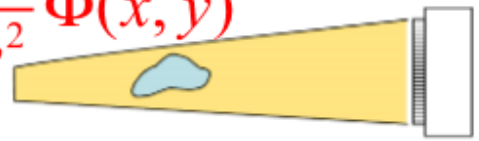
Crystal interferometry
Bonse et al. APL 6, 155 (1965)

$\frac{\partial}{\partial y}\Phi(x,y)$



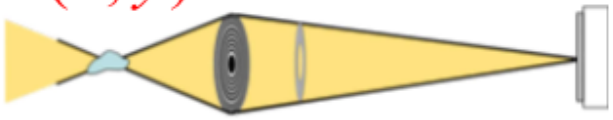
Analyser-based (DEI)
Chapman et al., *PMB,* 42, 2015 (1997)
Davis et al., JOSA A 13, 1193 (1996)

$\frac{\partial^2}{\partial y^2}\Phi(x,y)$



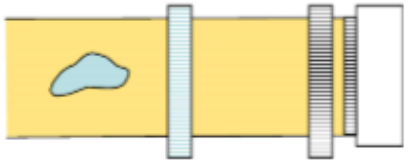
Free Space Propagation (TIE)
Snigirev et al., RSI 66, 5486 (1995)
Cloetens et al., APL 75, 2912 (1999)
Groso et al., OptExp 14, 8103 (2006)

$\Phi(x,y)$



Zernike Phase Contrast
Weiss et al., UM 84, 185 (2000)
Stampanoni et al., PRB 81, 140105R (2010)

$\frac{\partial}{\partial y}\Phi(x,y)$



Grating interferometry (DPC)
Weitkamp et al., OptExp 13, 6296 (2005)
Pfeiffer et al., Nature Phys 2, 258 (2006)


PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
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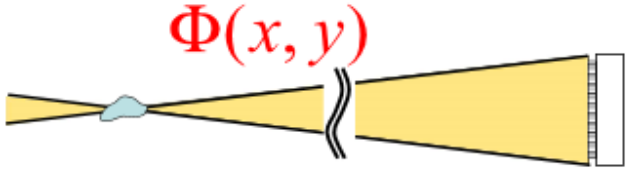
Review
On the evolution and relative merits of hard X-ray phase-contrast imaging methods
S. W. Wilkins†, Yu. I. Nesterets, T. E. Gureyev, S. C. Mayo, A. Pogany‡ and A. W. Stevenson
CSIRO Materials Science and Engineering, PB33, Clayton South, Victoria 3169, Australia

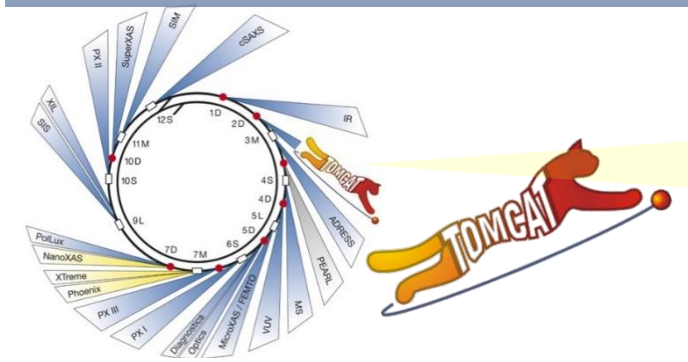
$\Phi(x,y)$

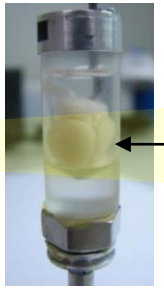


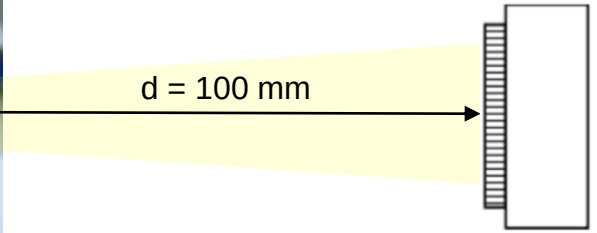
Coherent Diffraction Imaging (CDI)
Miao et al., Nature 400 (1999)
Thibault et al., Science, 321, 379 (2008).

Project Overview

SLS → TOMCAT Beamline → Sample → Free Space Propagation → Detector







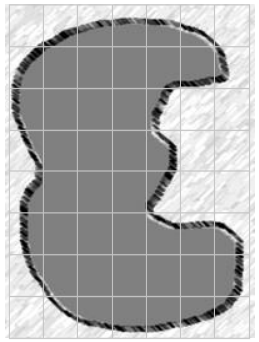
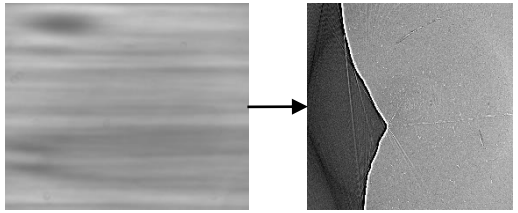
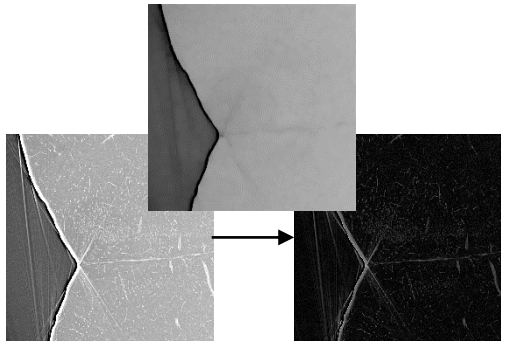
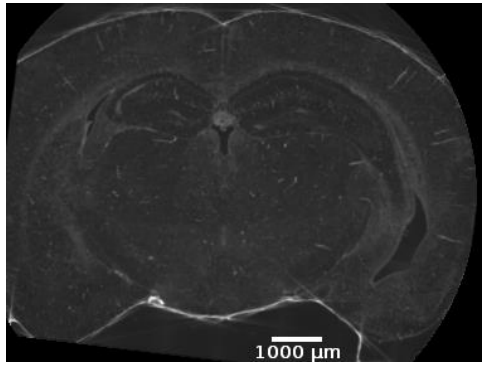


Image of results at the end ;)

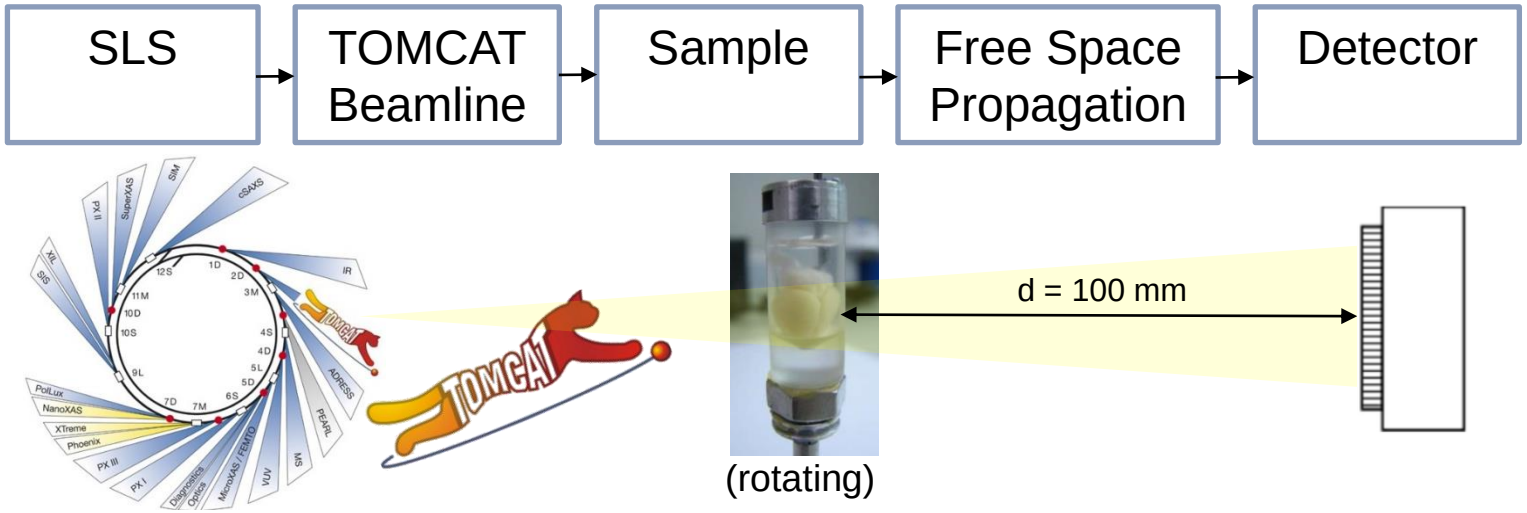
- Local CT Acquisition
- Paganin Reconstruction
- Correct Background
- Stitch
- Down sample Voxels
- Structure Tensor Analysis
- Rotate & Display

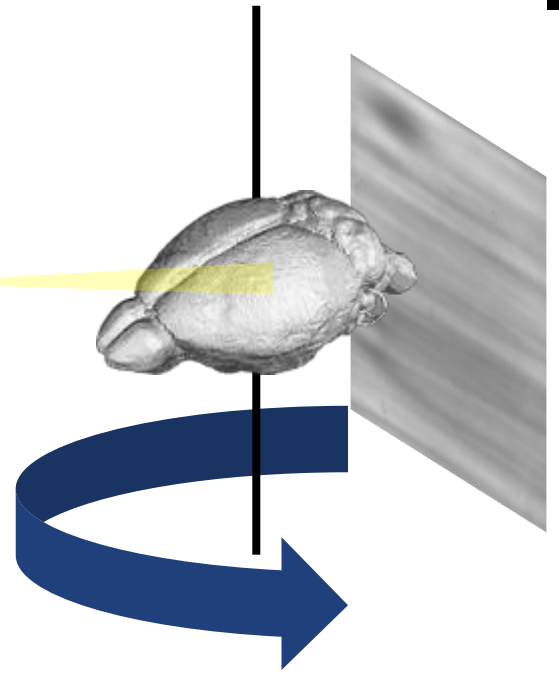






PCI at PSI

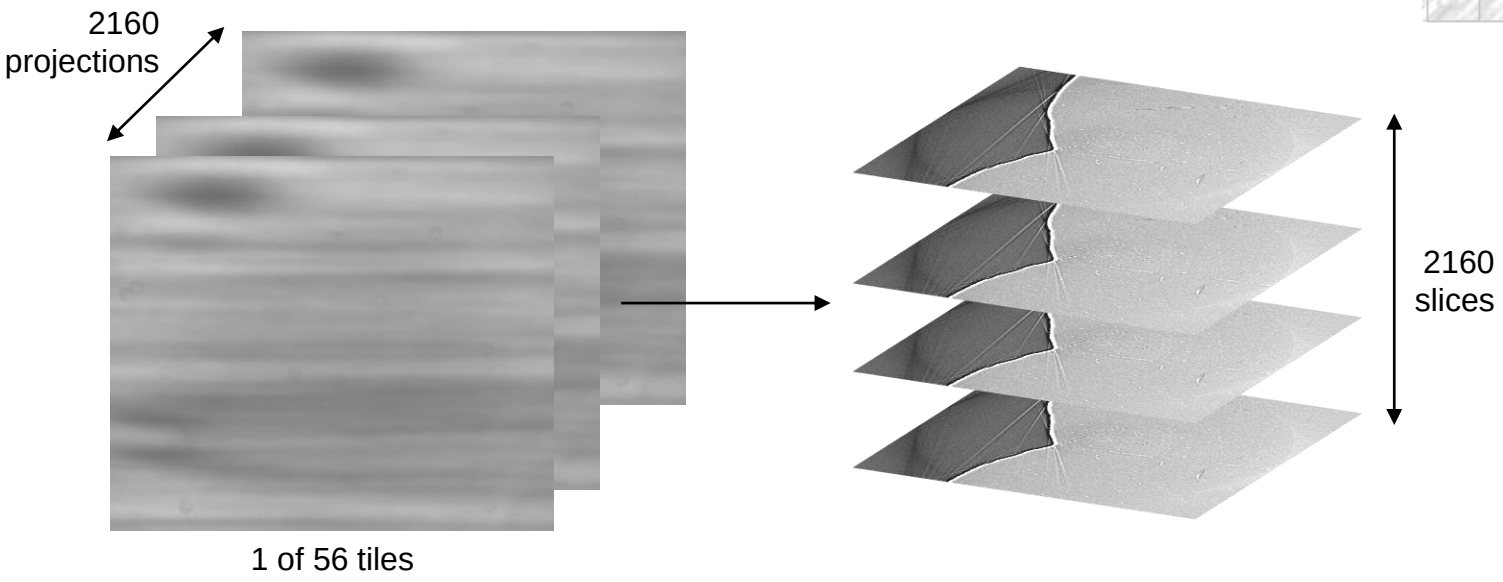


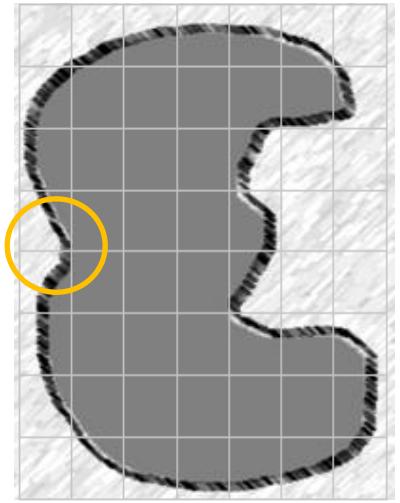


- SLS produces high brilliance photon beam (Energy of 2.4 GeV)
- TOMCAT beamline exploits coherence for high-resolution phase images
- Allow beam to propagate before detecting
- Small d → detect X-Ray absorption image
- Increase d and phase distortions become interference fringes

Image Processing

- Local CT two sets of 7x8 = 56 overlapping tiles
- Paganin Reconstruction





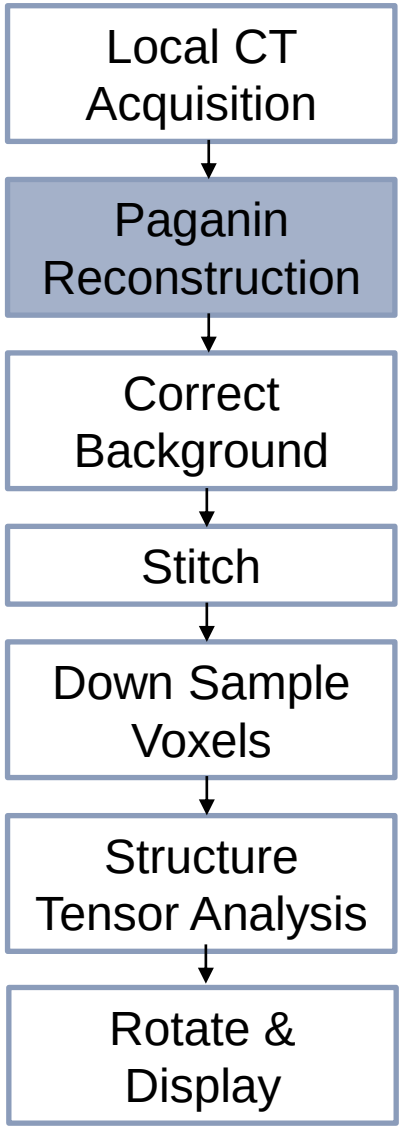
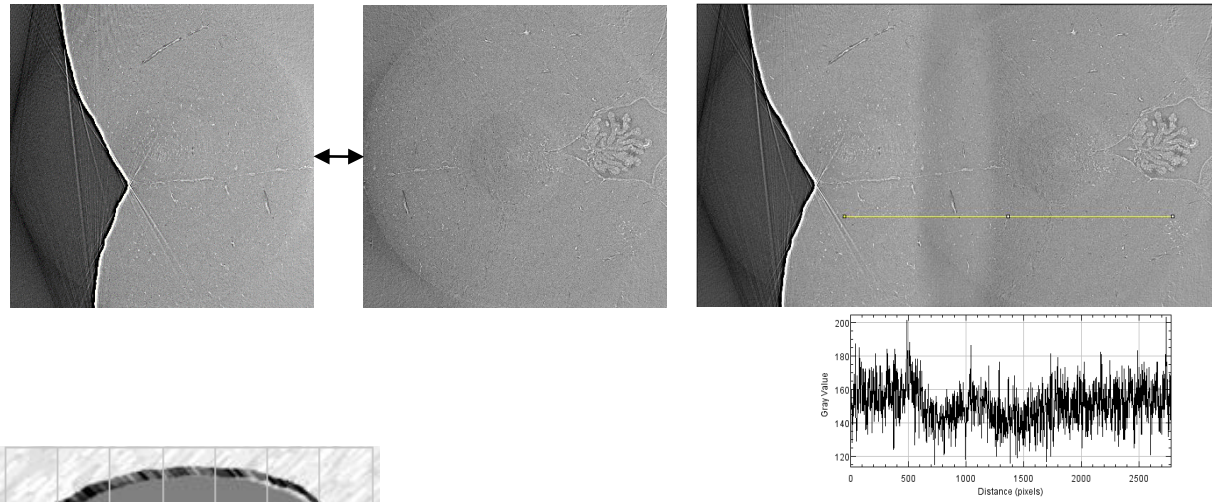
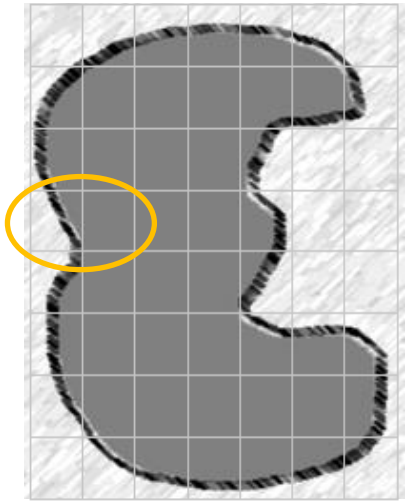


Image Processing

- No correction
  - Varying background signal





Local CT Acquisition

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Paganin Reconstruction

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Correct Background

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Stitch

↓

Down Sample Voxels

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Structure Tensor Analysis

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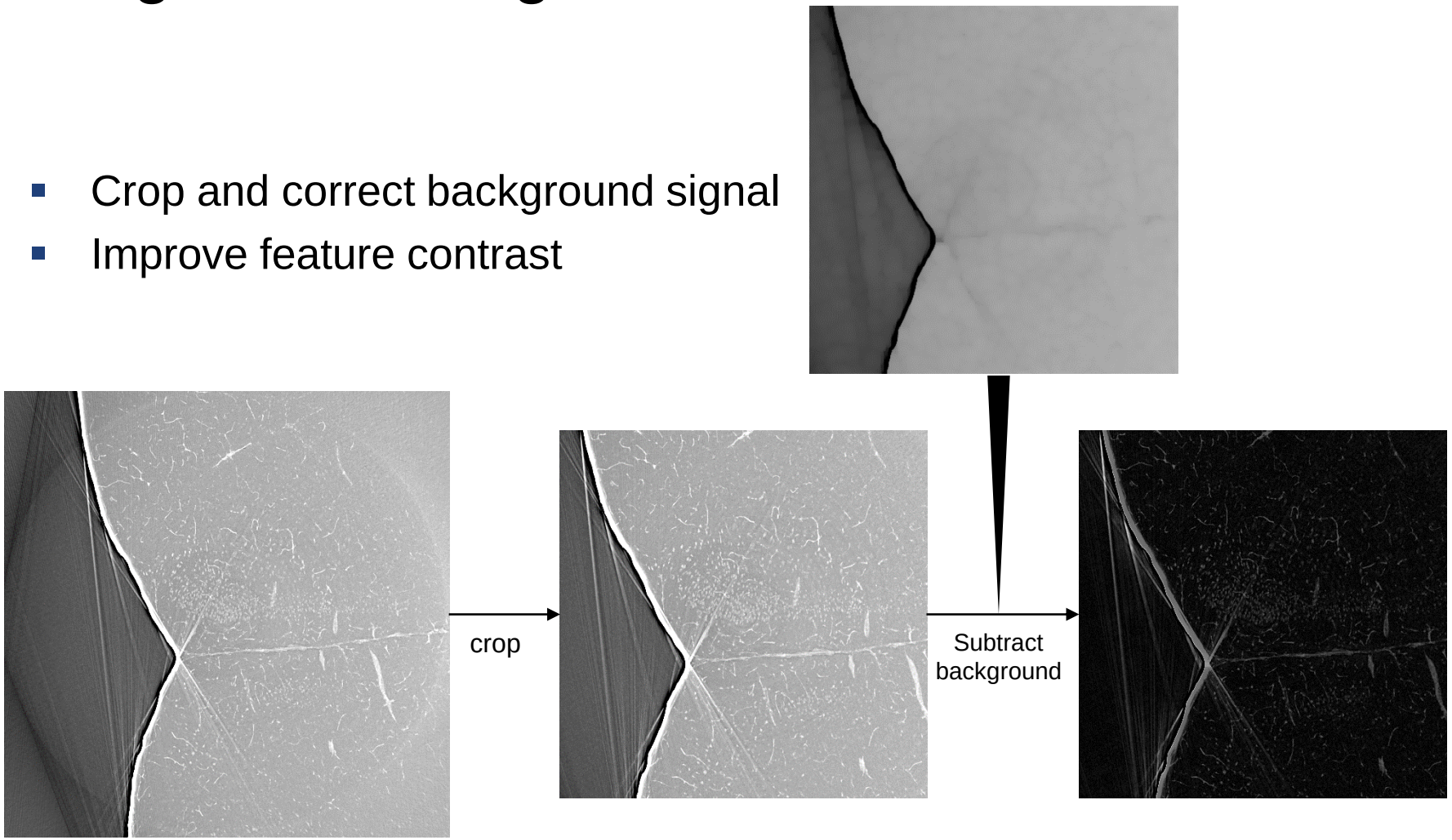
Rotate & Display

Image Processing

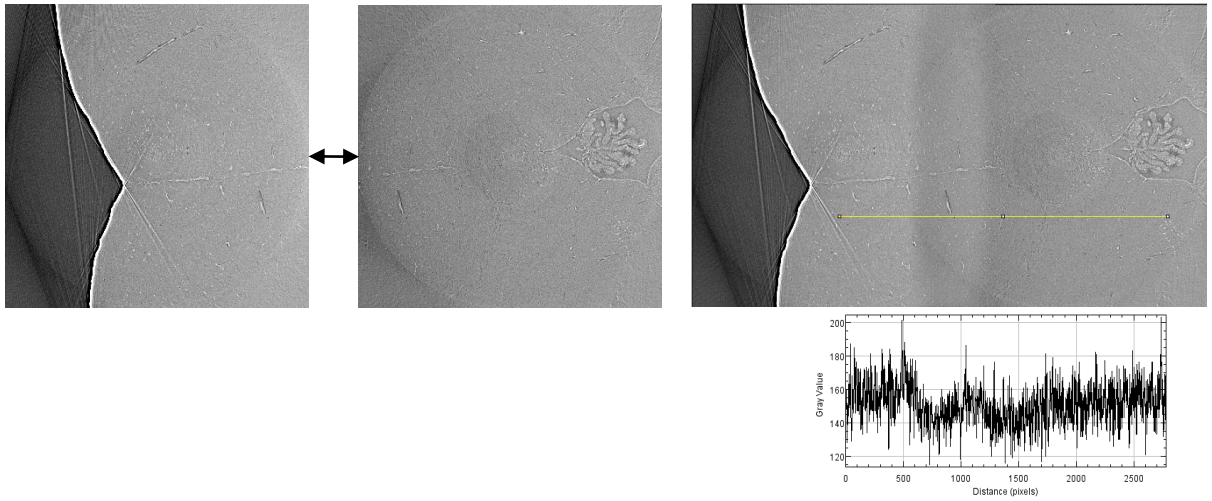
- Crop and correct background signal
- Improve feature contrast



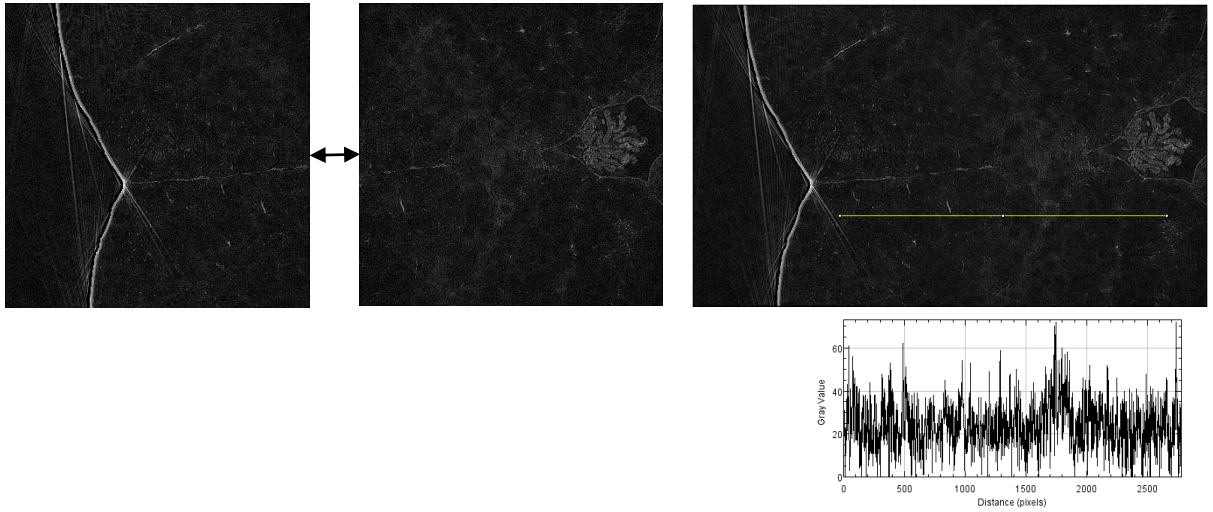
Local CT Acquisition
↓
Paganin Reconstruction
↓
Correct Background
↓
Stitch
↓
Down Sample Voxels
↓
Structure Tensor Analysis
↓
Rotate & Display

Image Processing

- No correction
  - Varying background signal



- Correction
  - Subtracted
  - More constant



Local CT Acquisition

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Paganin Reconstruction

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Correct Background

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Stitch

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Down Sample Voxels

↓

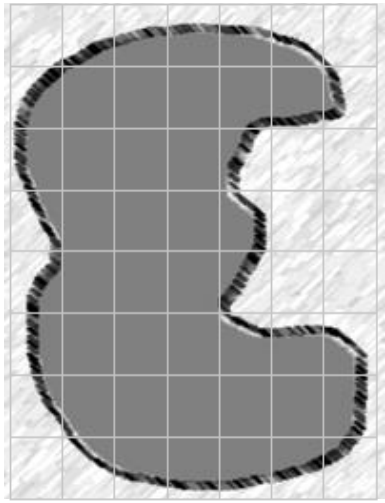
Structure Tensor Analysis

↓

Rotate & Display

Image Processing

- Local CT – 7x8 = 56 overlapping tiles (~30% overlap)
- FIJI plugin “Grid/Collection stitching”
- Same registration matrix for the whole stack



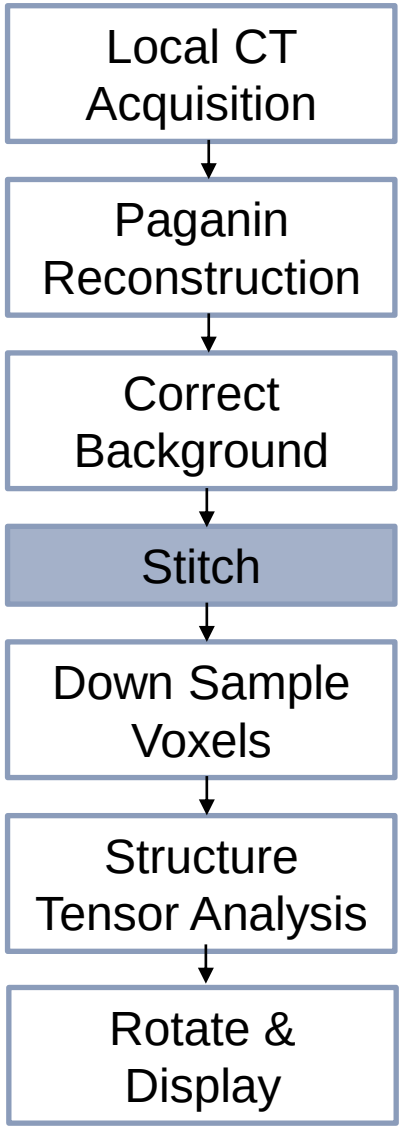
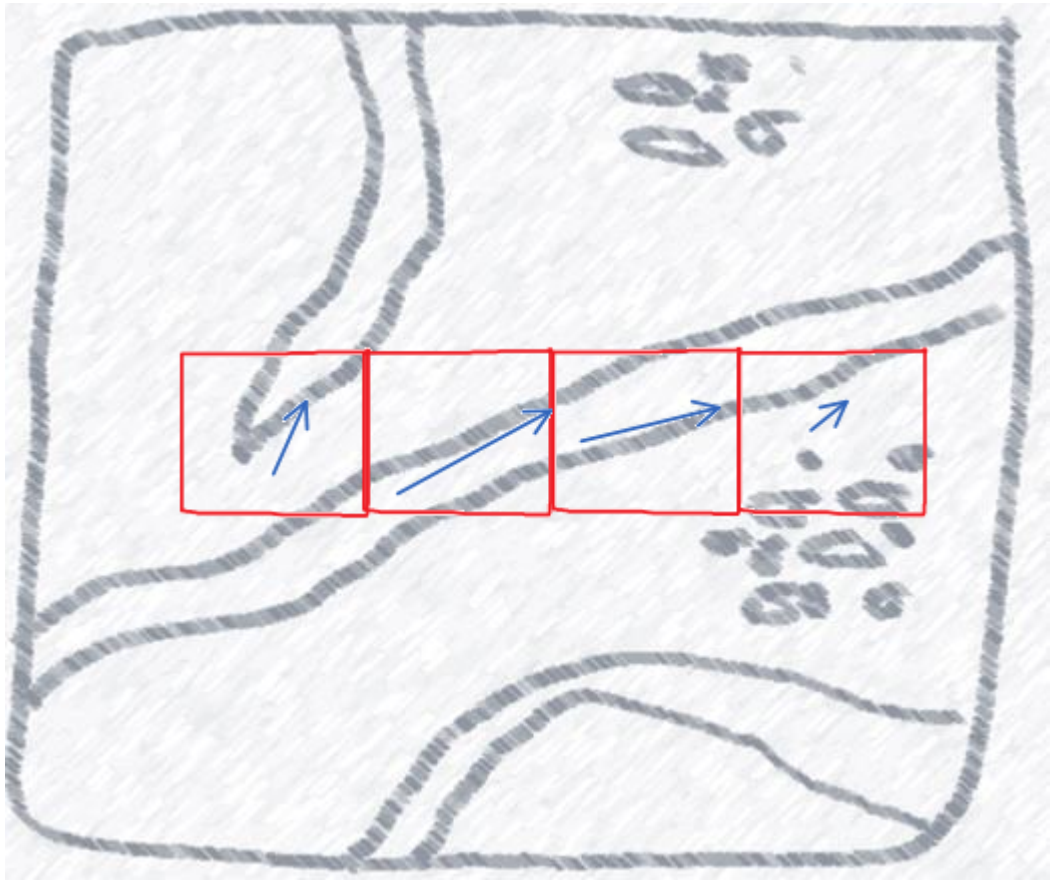


Image Processing



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Structure Tensor Analysis

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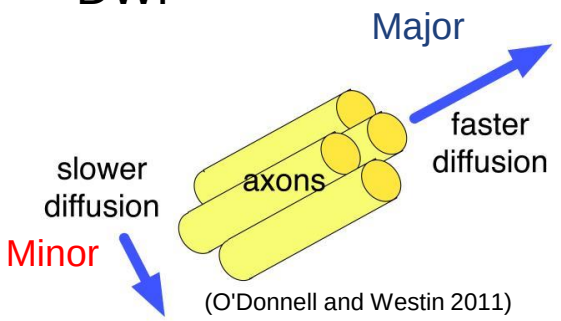
Rotate & Display

Anisotropy in the Brain

- Diffusion weighted MRI measures the diffusion tensor
  - major eigenvector is parallel to direction of diffusion
  - Fractional Anisotropy
- Structure tensor calculated from image gradient
  - minor eigenvector is parallel to major orientation
  - Coherency

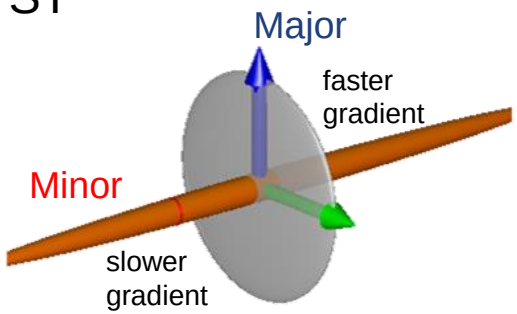
$$S = \begin{bmatrix} I_x I_x & I_x I_y & I_x I_z \\ I_y I_x & I_y I_y & I_y I_z \\ I_z I_x & I_z I_y & I_z I_z \end{bmatrix}$$

DWI



(O'Donnell and Westin 2011)

ST



$$FA = \sqrt{\frac{1}{2}} \frac{\sqrt{(\lambda_1 - \lambda_2)^2 + (\lambda_2 - \lambda_3)^2 + (\lambda_3 - \lambda_1)^2}}{\sqrt{\lambda_1^2 + \lambda_2^2 + \lambda_3^2}}$$

$$Coherency = \frac{\lambda_{max} - \lambda_{min}}{\lambda_{max} + \lambda_{min}}$$

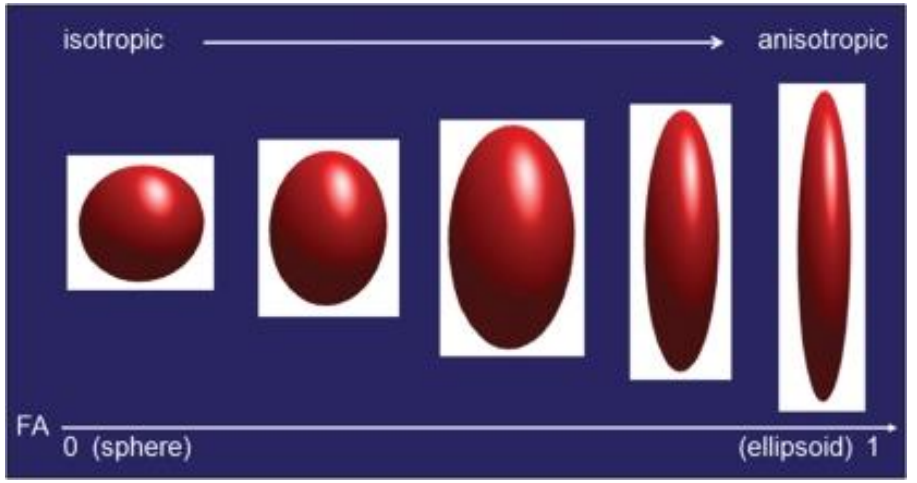
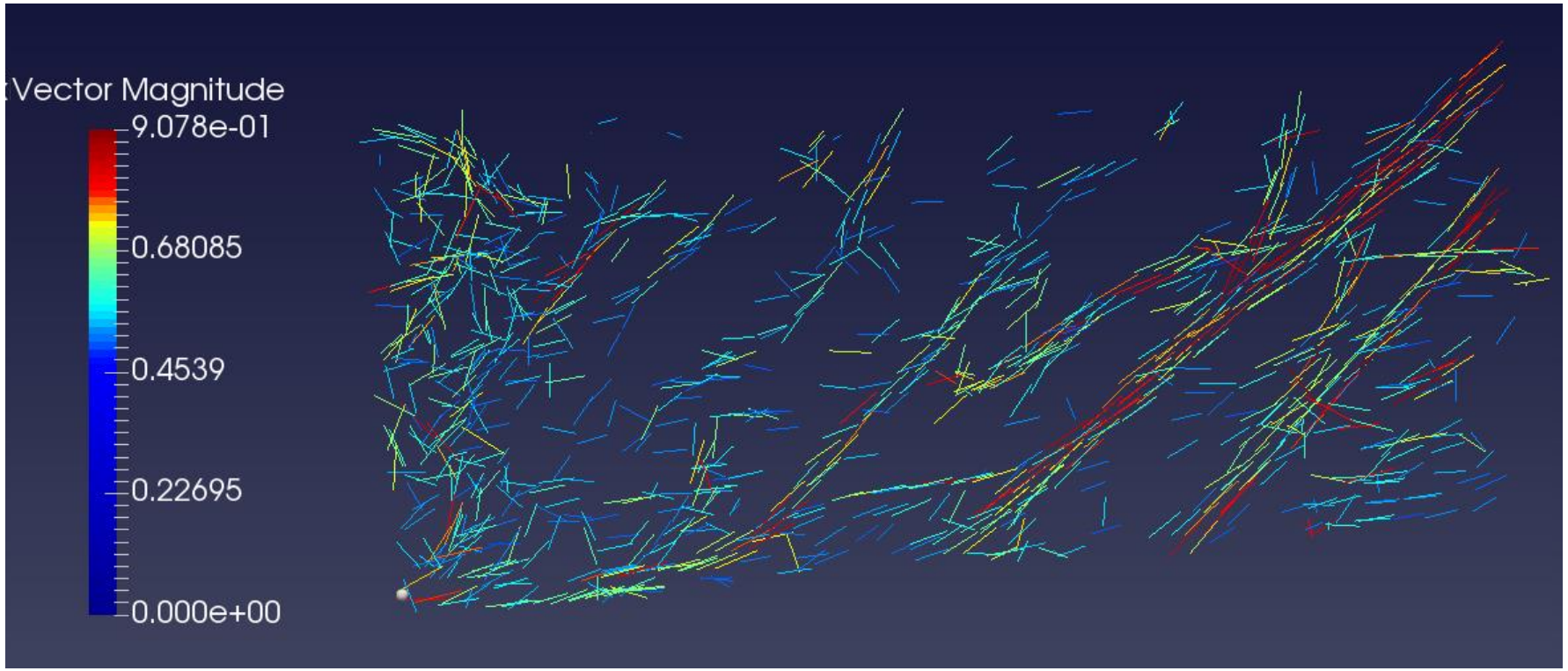
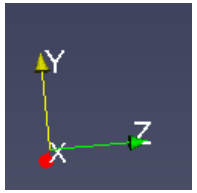


Image Processing





Local CT Acquisition

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Paganin Reconstruction

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Correct Background

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Stitch

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Down Sample Voxels

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Structure Tensor Analysis

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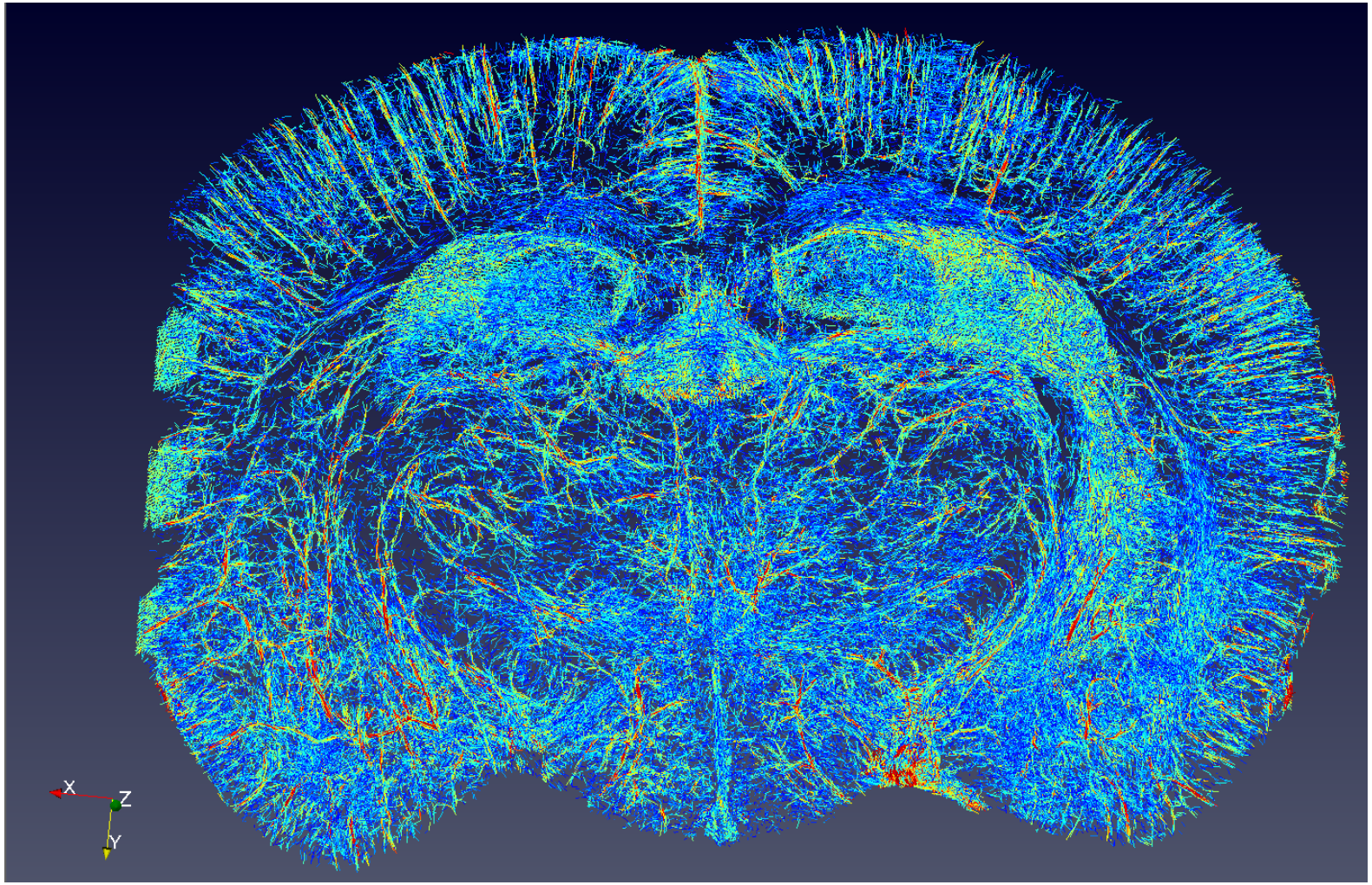
Rotate & Display

Image Processing



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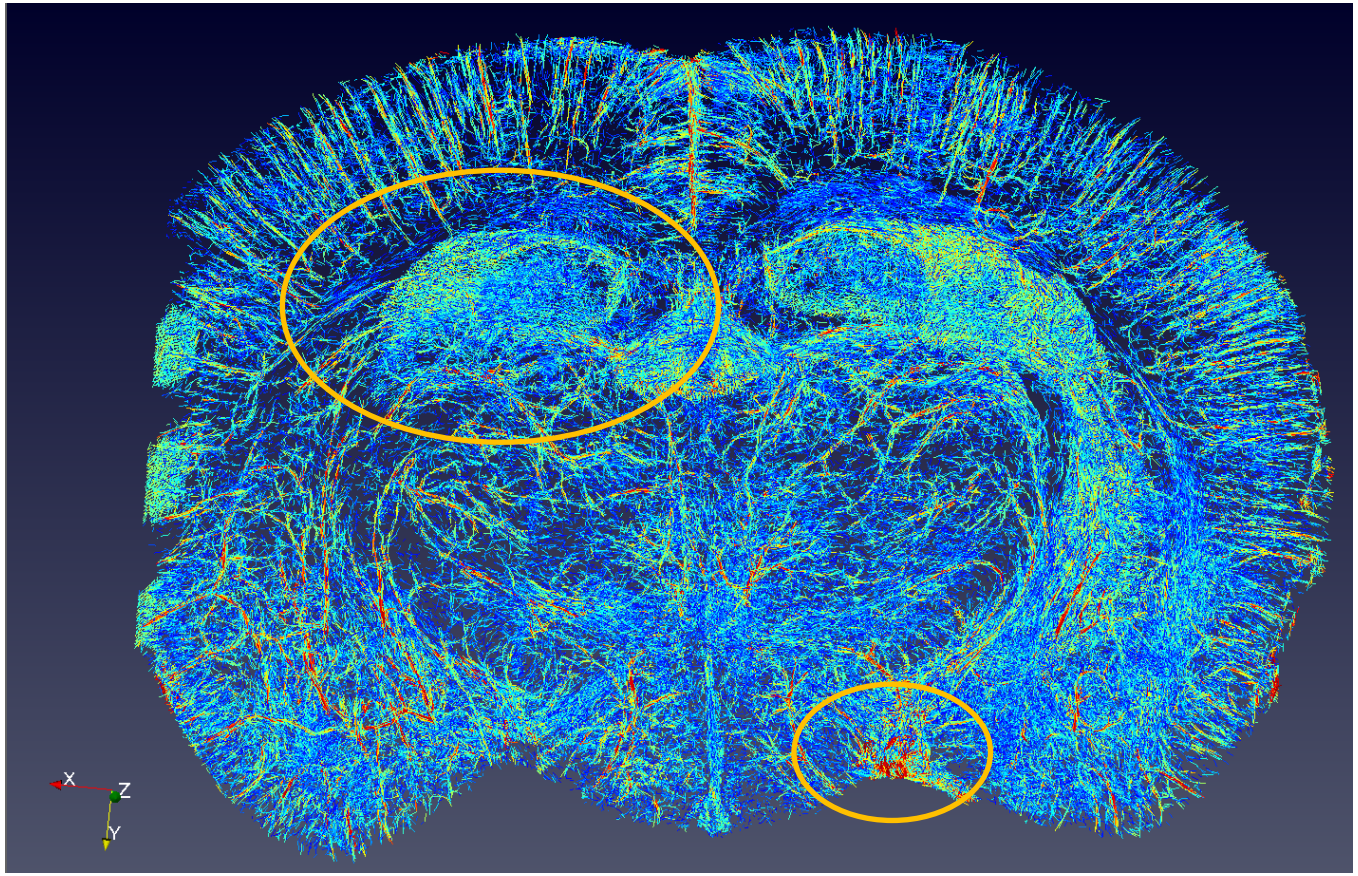
Discussion

- Advancements:
  - High contrast high resolution images
  - Observe directionality in the brain
- Limitations:
  - Contrast agent, ex vivo
  - Artefacts
  - All structure – not just vessels
- Outlook
  - Connectivity of vasculature
  - Correlate with axonal directionality
  - Improvements on analysis



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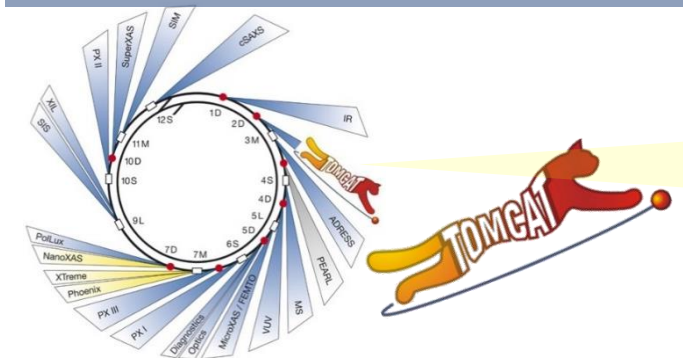
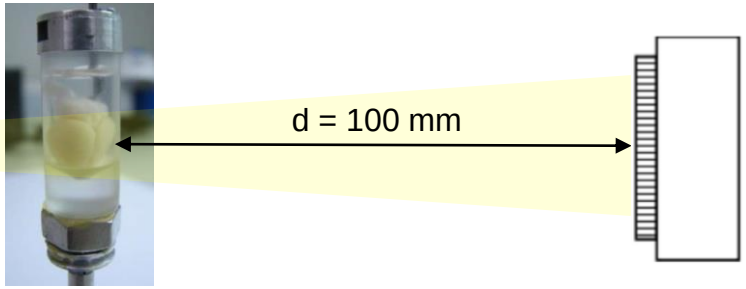
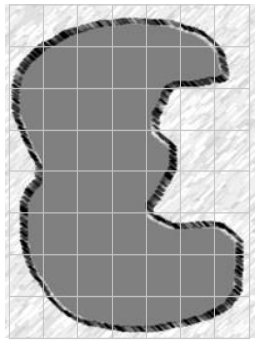
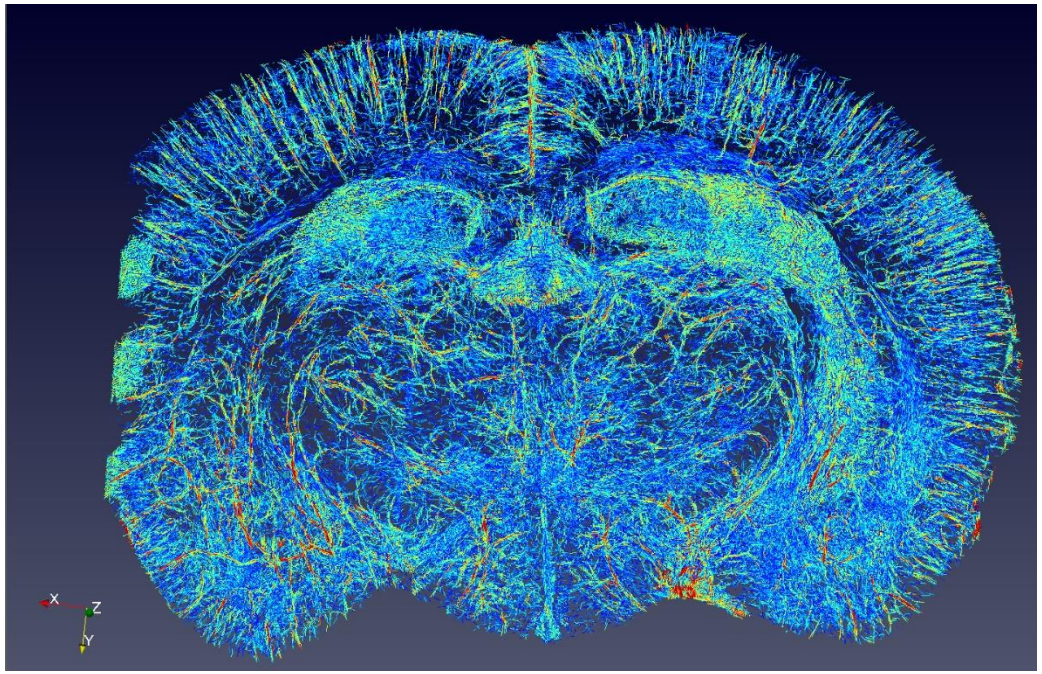
Project Overview

SLS → TOMCAT Beamline → Sample → Free Space Propagation → Detector









- Local CT Acquisition
- Paganin Reconstruction
- Correct Background
- Stitch
- Down sample Voxels
- Structure Tensor Analysis
- Rotate & Display