The Anisotropy of Myelin Susceptibility

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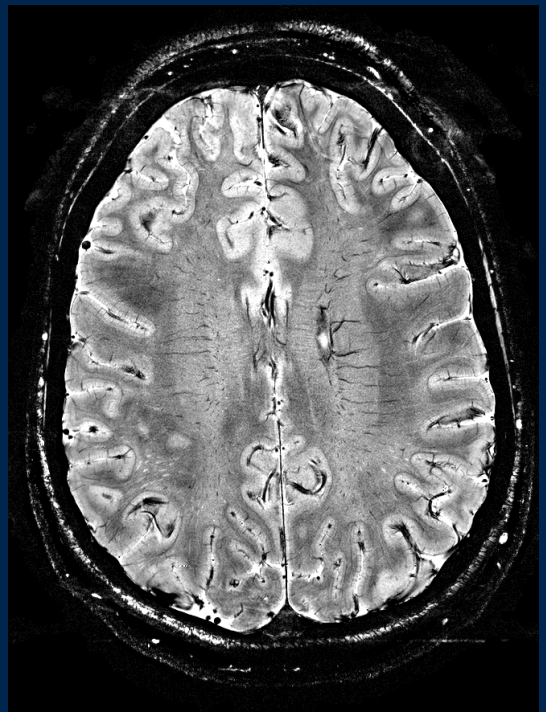
Declaration of Relevant Financial Interests or Relationships

Speaker Name: Peter van Gelderen

I have no relevant financial interest or relationship to disclose with regard to the subject matter of this presentation.

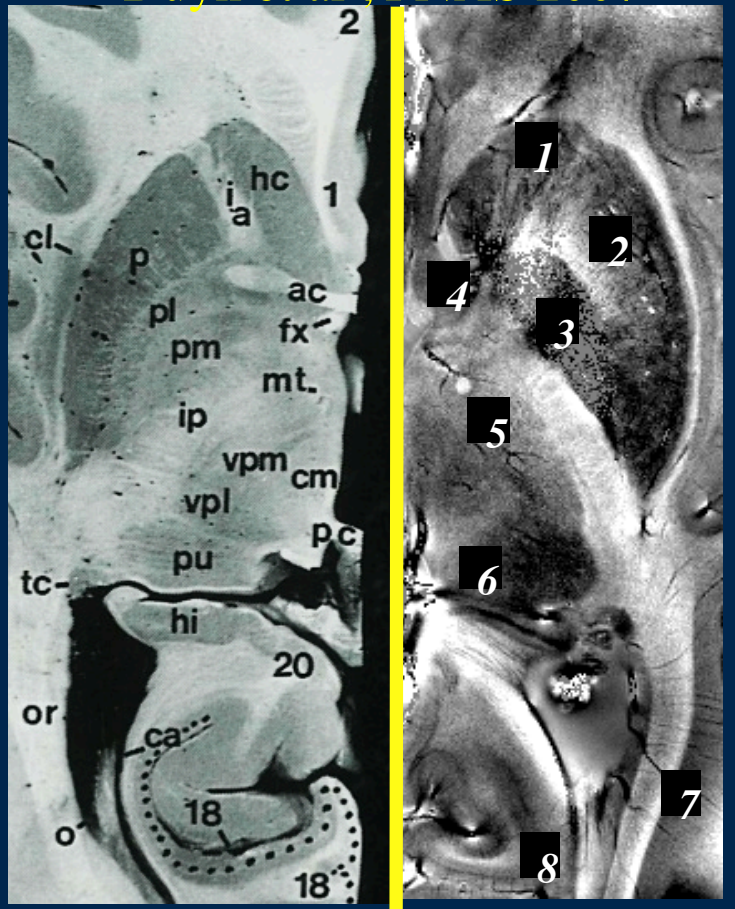
Introduction

High resolution susceptibility weighted imaging reveals anatomical structure



T_2^* weighted signal

Duyn et al , PNAS 2007

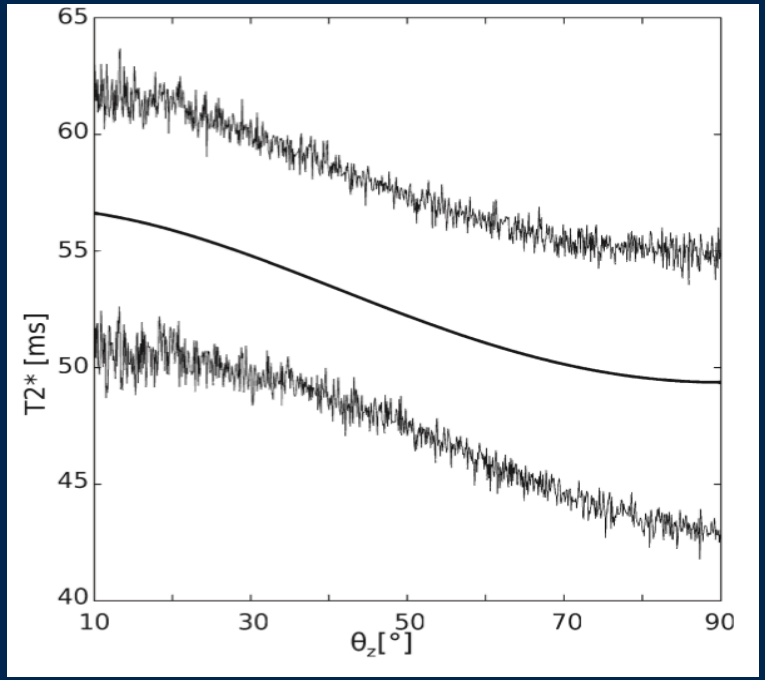


Anatomy/Duvernoy | MRI frequency

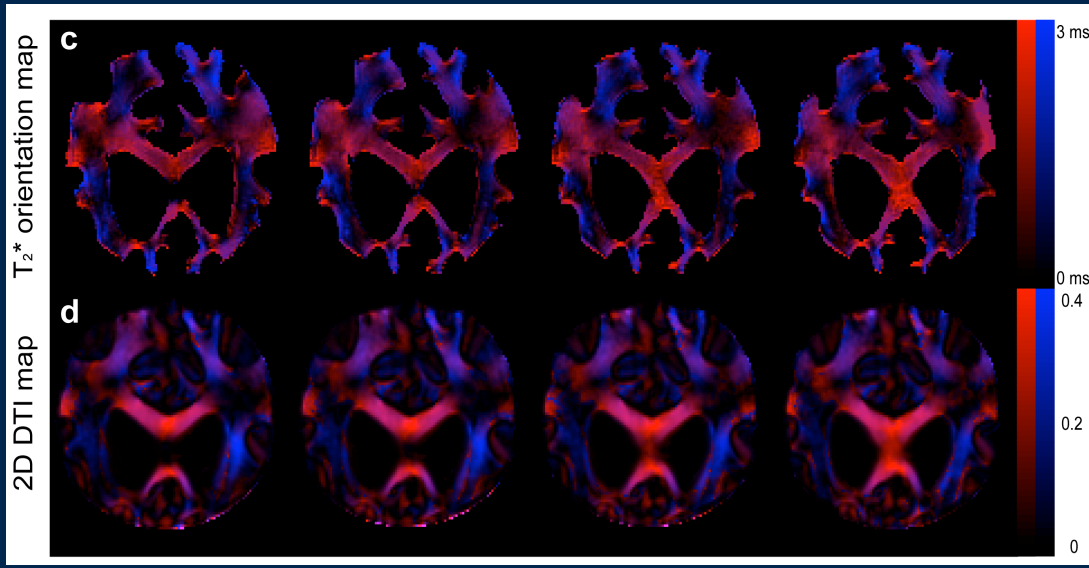
Introduction

T_2^* is orientation dependent

Bender and Klose, NMR Biomed 2010



Lee et.al., Neuroimage 2011

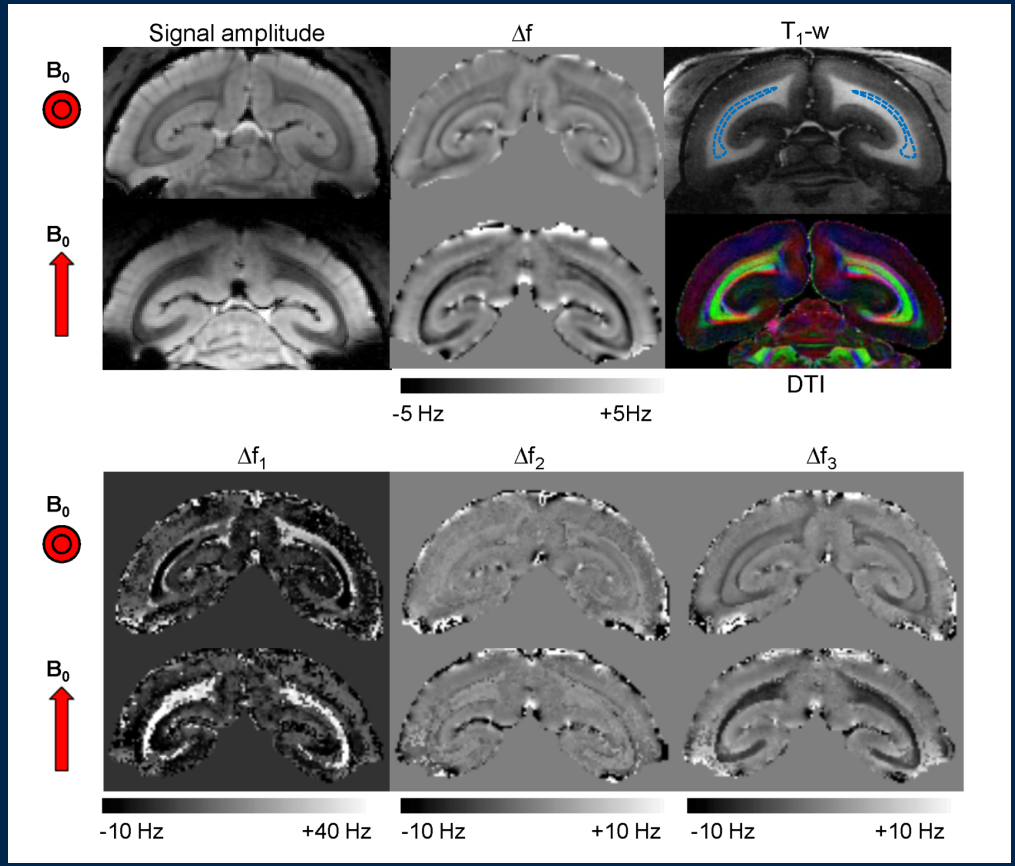


Introduction

T_2^* decay is not mono-exponential

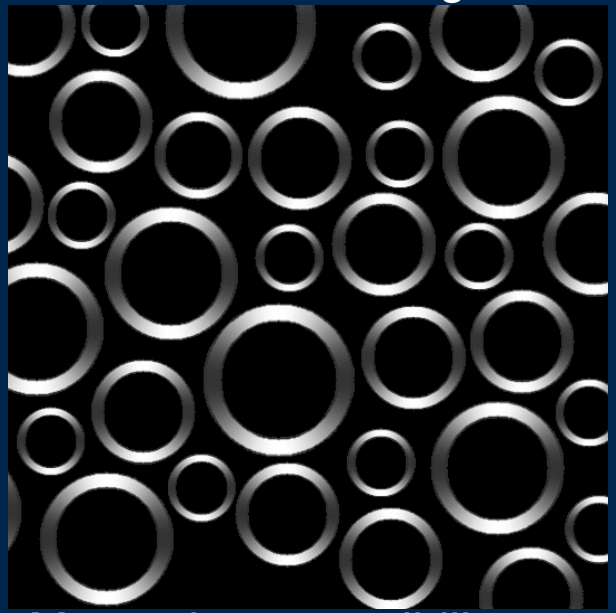
$$S = A_1 e^{(-R_1 + i\Delta f_1)t} + A_2 e^{(-R_2 + i\Delta f_2)t} + A_3 e^{(-R_3 + i\Delta f_3)t}$$

Sati et al, Neuroimage 2013 (in press), ISMRM 2013

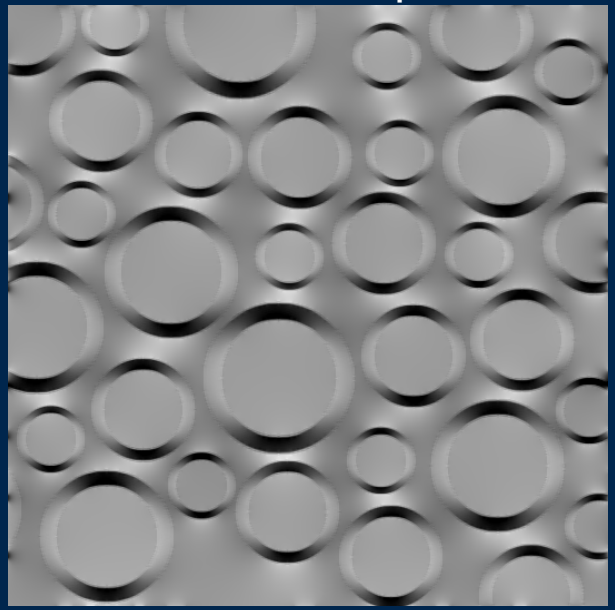


Introduction

Simulation of field distribution: anisotropy required to explain frequency difference of axonal and extra cellular signal and their orientation dependence



Magnetic susceptibility

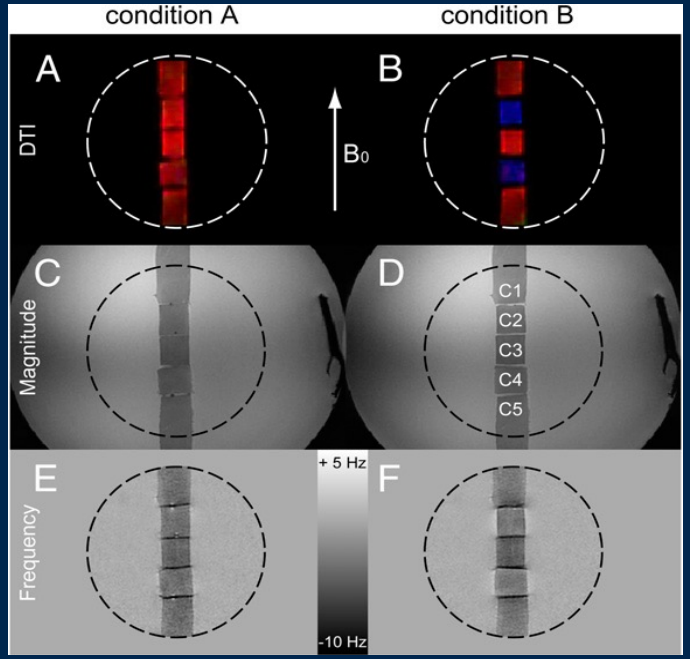


Frequency

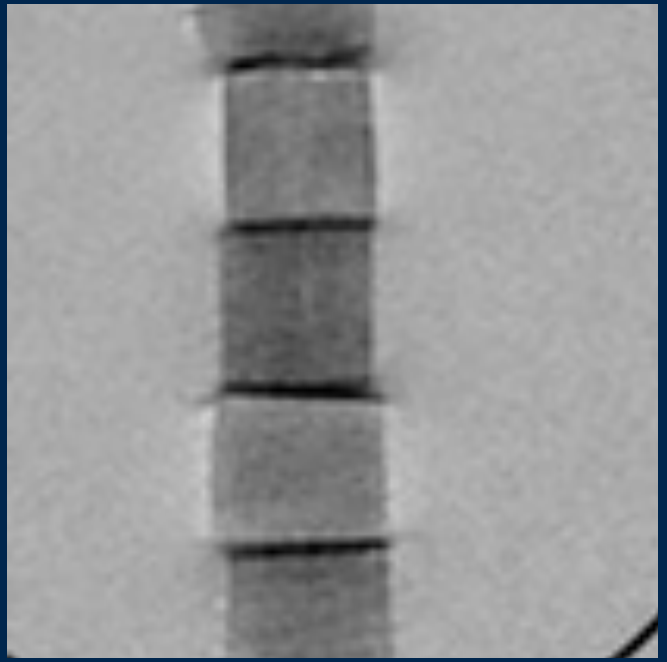
Sati et al, Neuroimage 2013 (in press); Wharton & Bowtell, PNAS 2012.

Introduction

Anisotropy effects in section of corpus callosum



Lee et al., PNAS 2010.



Frequency

$\chi_{\parallel} - \chi_{\perp} = 0.01$ ppm

B_0

Measurement of Anisotropy of Susceptibility

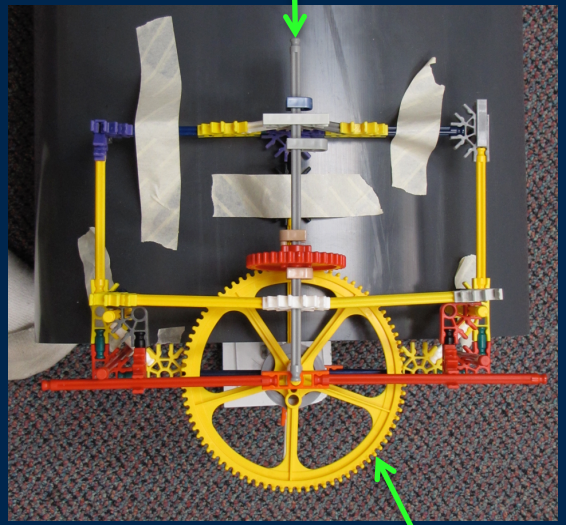
Lecitin vesicles align with magnetic field

Scholz, Biophys. J. 1984

Measurement of Anisotropy of Susceptibility

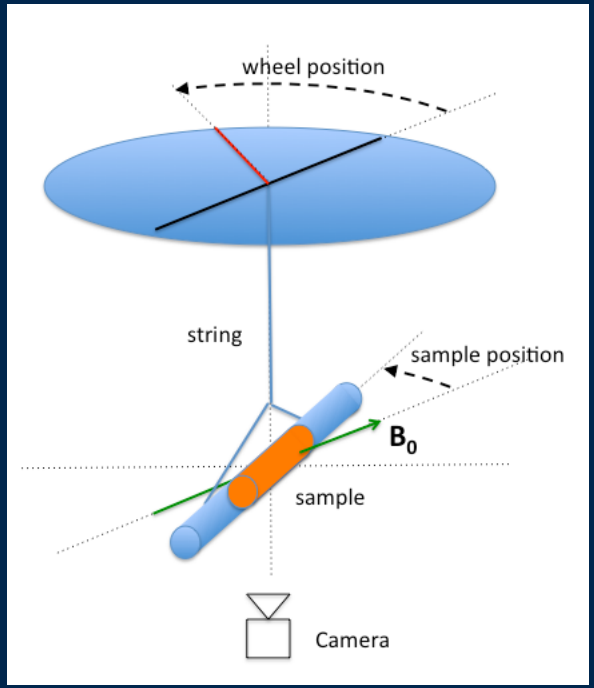
Experimental setup

drive shaft to turn wheel remotely



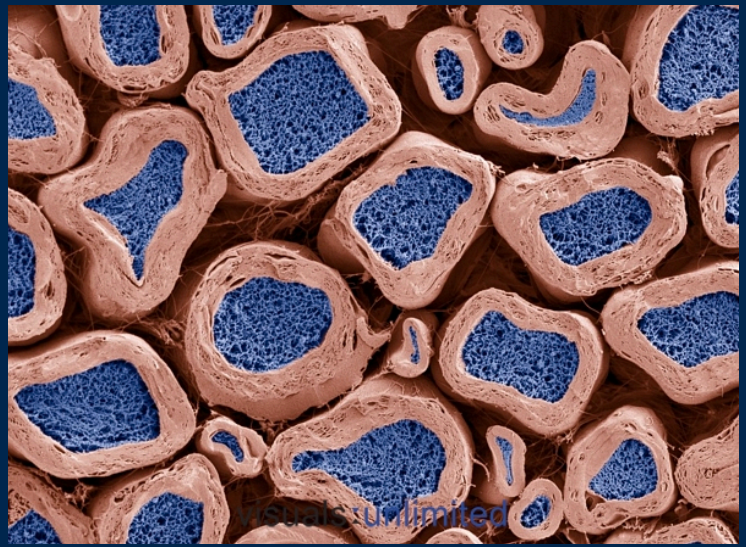
wheel

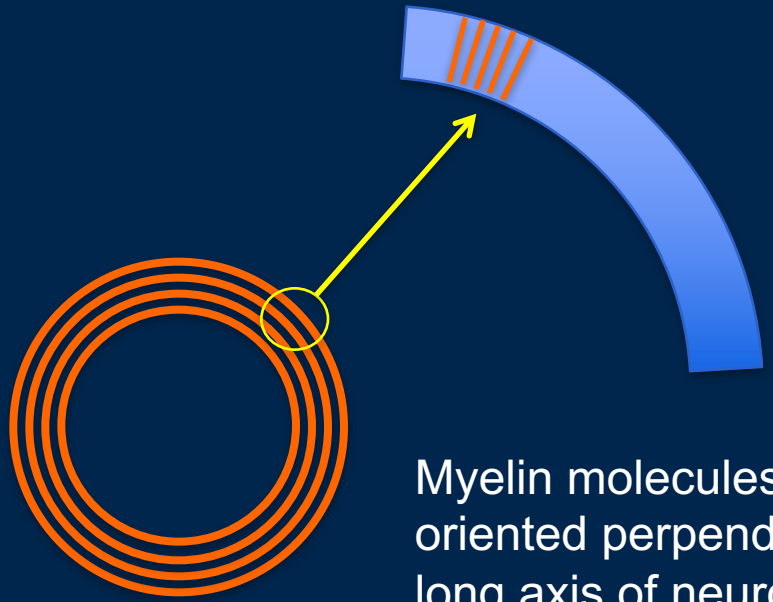
Arnold et al , PNAS 1958



Measurement of Anisotropy of Susceptibility

Samples: fixed spinal cord sections, 20-50mm total length

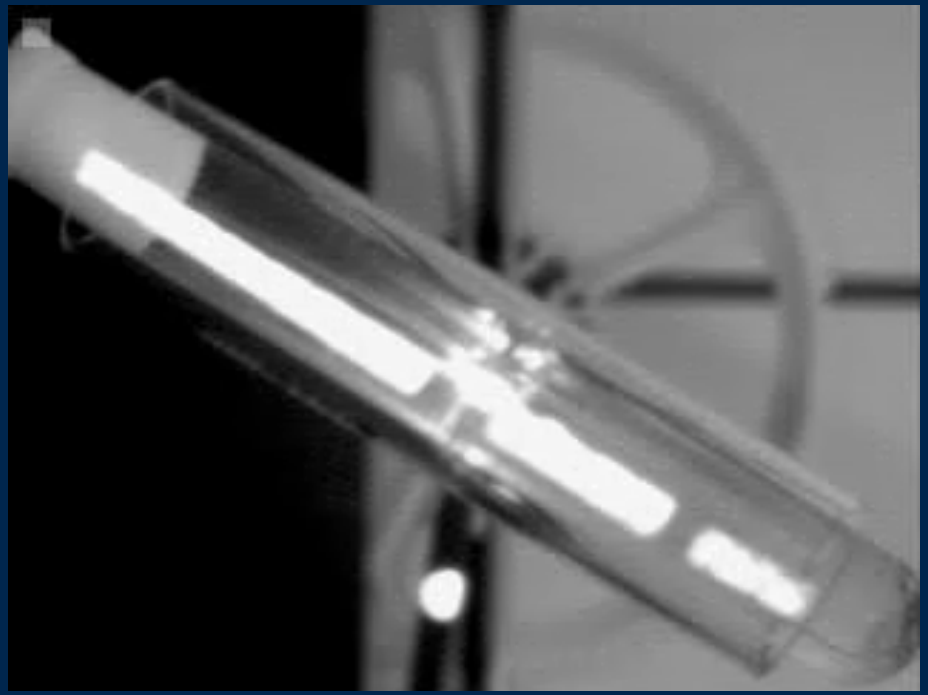




Myelin molecules all oriented perpendicular to long axis of neuron

Measurement of Anisotropy of Susceptibility

Orientation effect of ordered macroscopic sample in high B_0

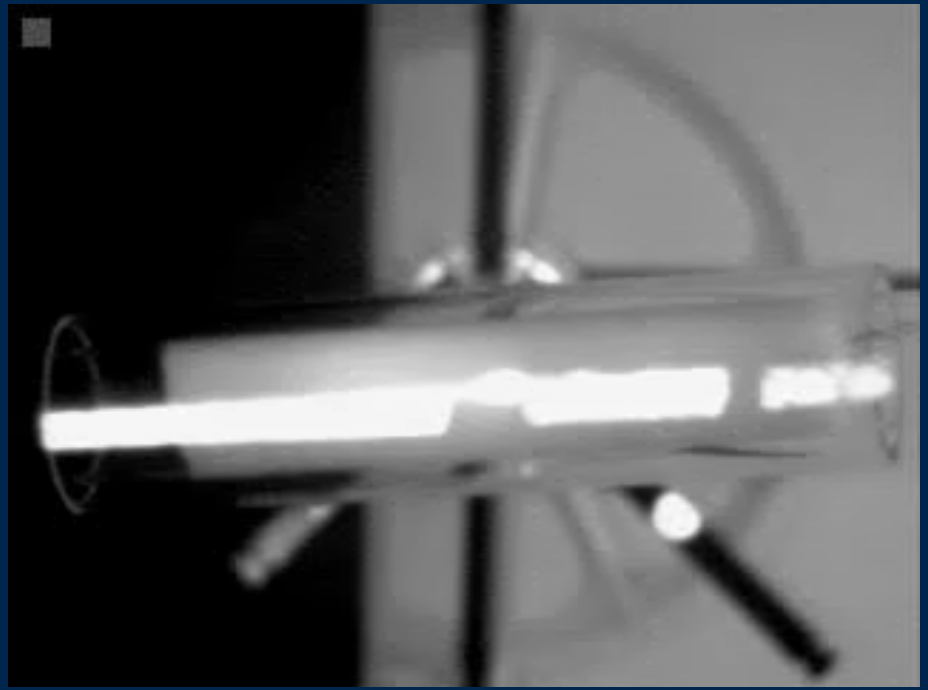


Water playing at 6x

B_0

Measurement of Anisotropy of Susceptibility

Orientation effect of ordered macroscopic sample in high B_0

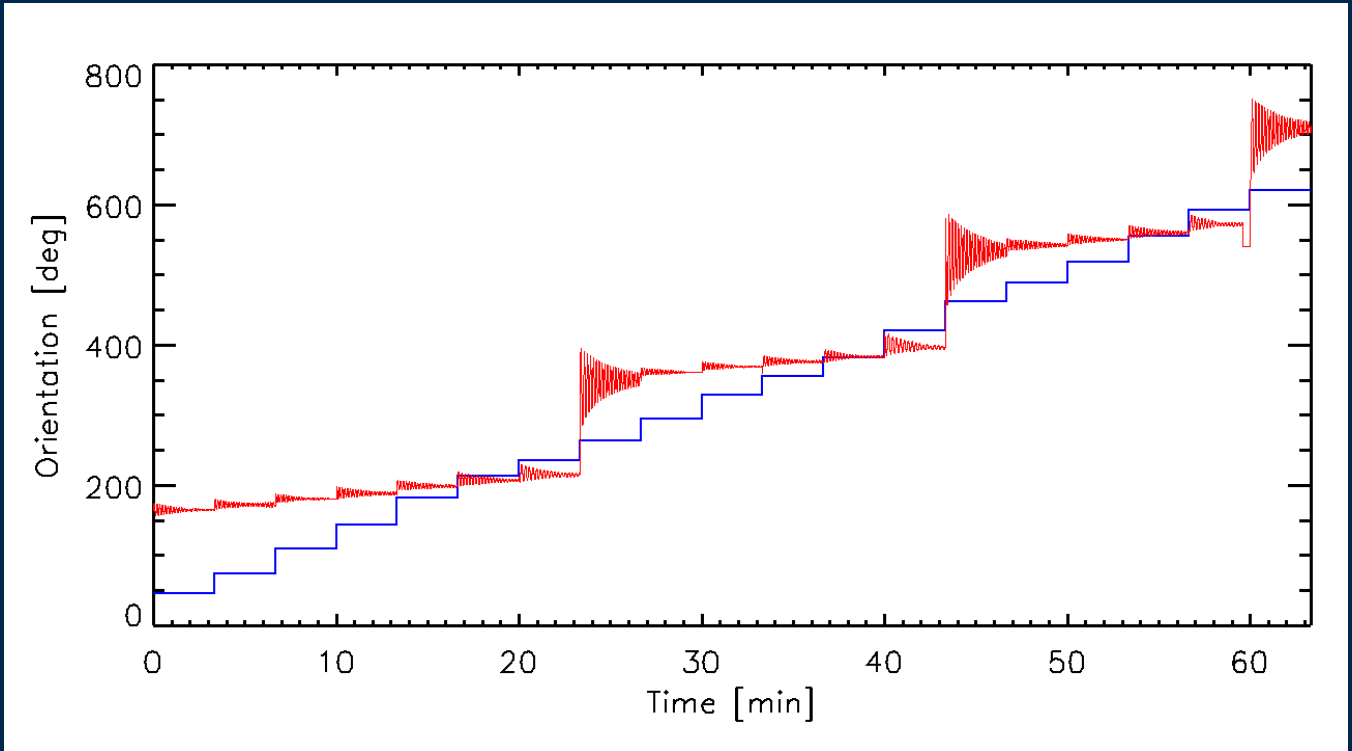


Spinal Cord Movie 6x accelerated

B_0

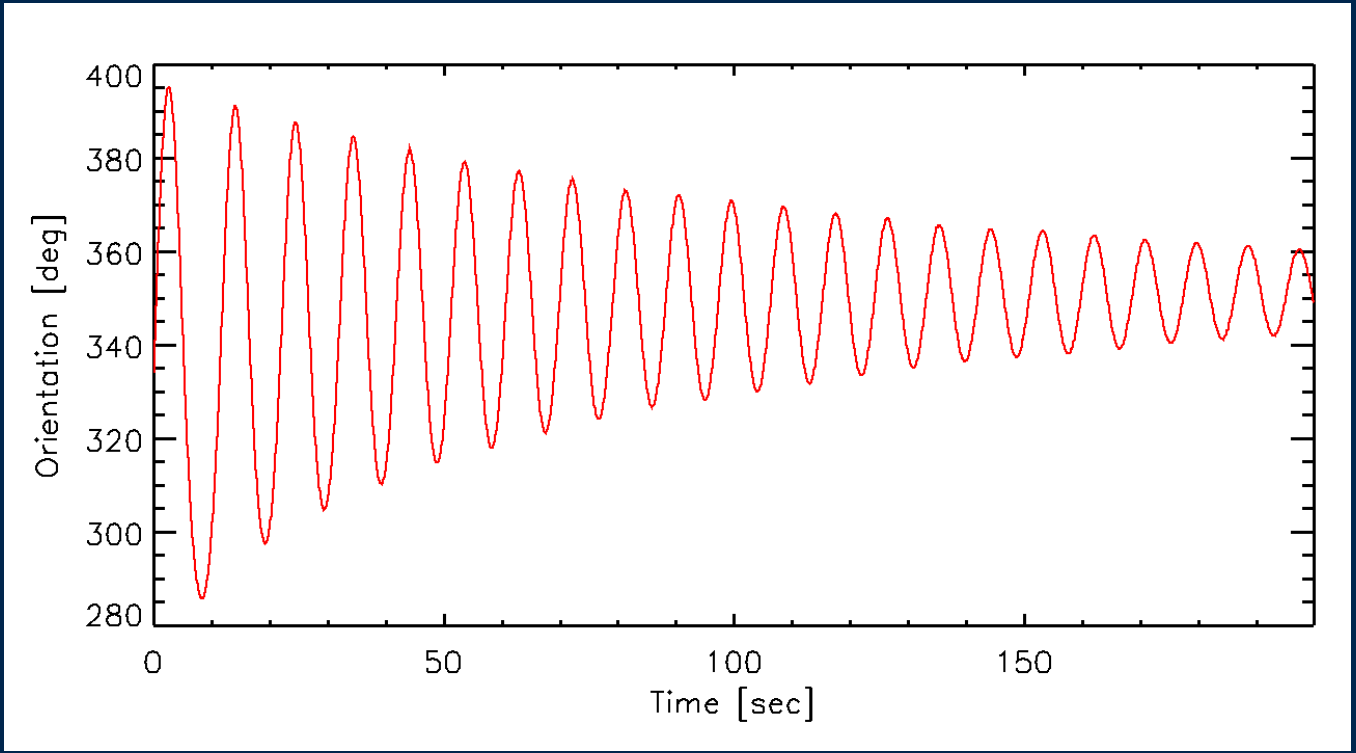
Measurement of Anisotropy of Susceptibility

Orientation of sample and wheel angle over time



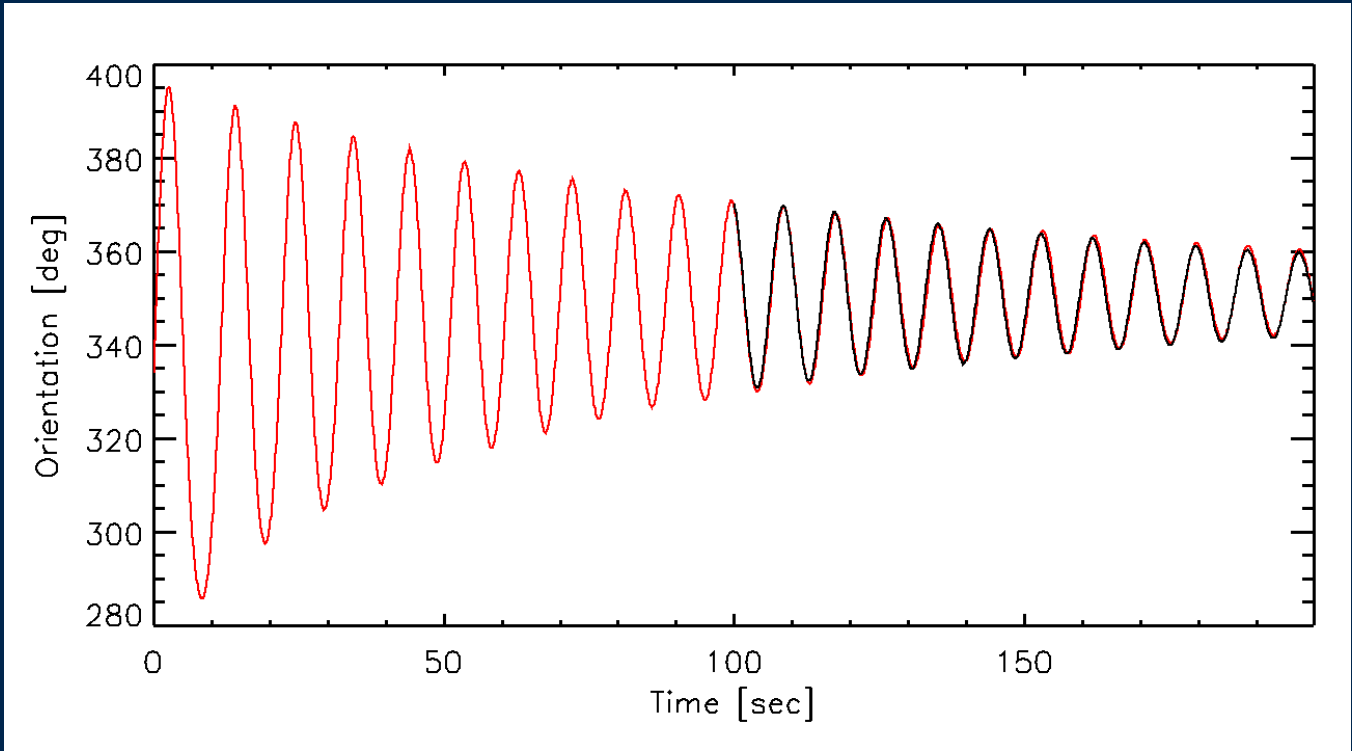
Measurement of Anisotropy of Susceptibility

Setup for quantification, one trial



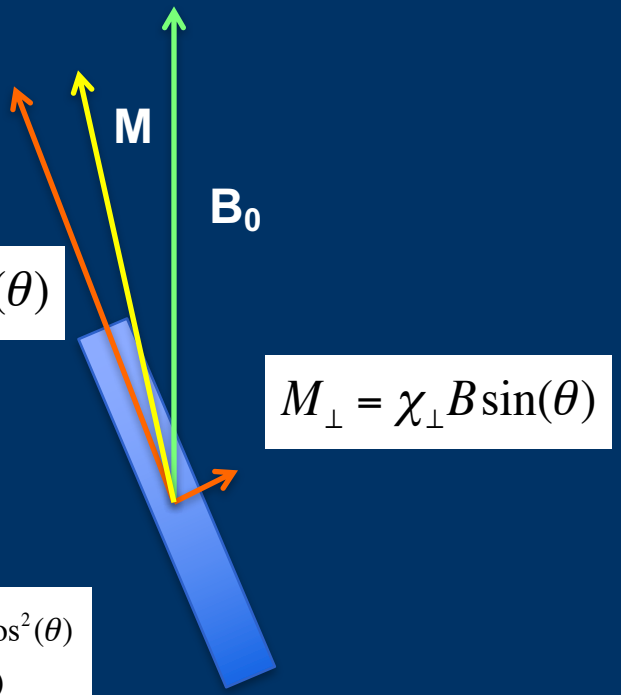
Measurement of Anisotropy of Susceptibility

Setup for quantification, fitting of orientation



Measurement of Anisotropy of Susceptibility

Torque on anisotropic sample



$$M_{//} = \chi_{//} B \cos(\theta)$$

$$M_{\perp} = \chi_{\perp} B \sin(\theta)$$

M not parallel to B ($M_x \neq 0$), resulting in torque on object.

$$M_z = M_{\perp} \sin(\theta) + M_{//} \cos(\theta) = \chi_{\perp} B \sin^2(\theta) + \chi_{//} \cos^2(\theta)$$
$$M_x = M_{\perp} \cos(\theta) - M_{//} \sin(\theta) = (\chi_{\perp} - \chi_{//}) B \sin(2\theta)$$

Measurement of Anisotropy of Susceptibility

Torque on anisotropic sample

Magnetic torque $T_m = -(\chi_{//} - \chi_{\perp})\sin(2\theta)\frac{B_0^2}{\mu_0}V$

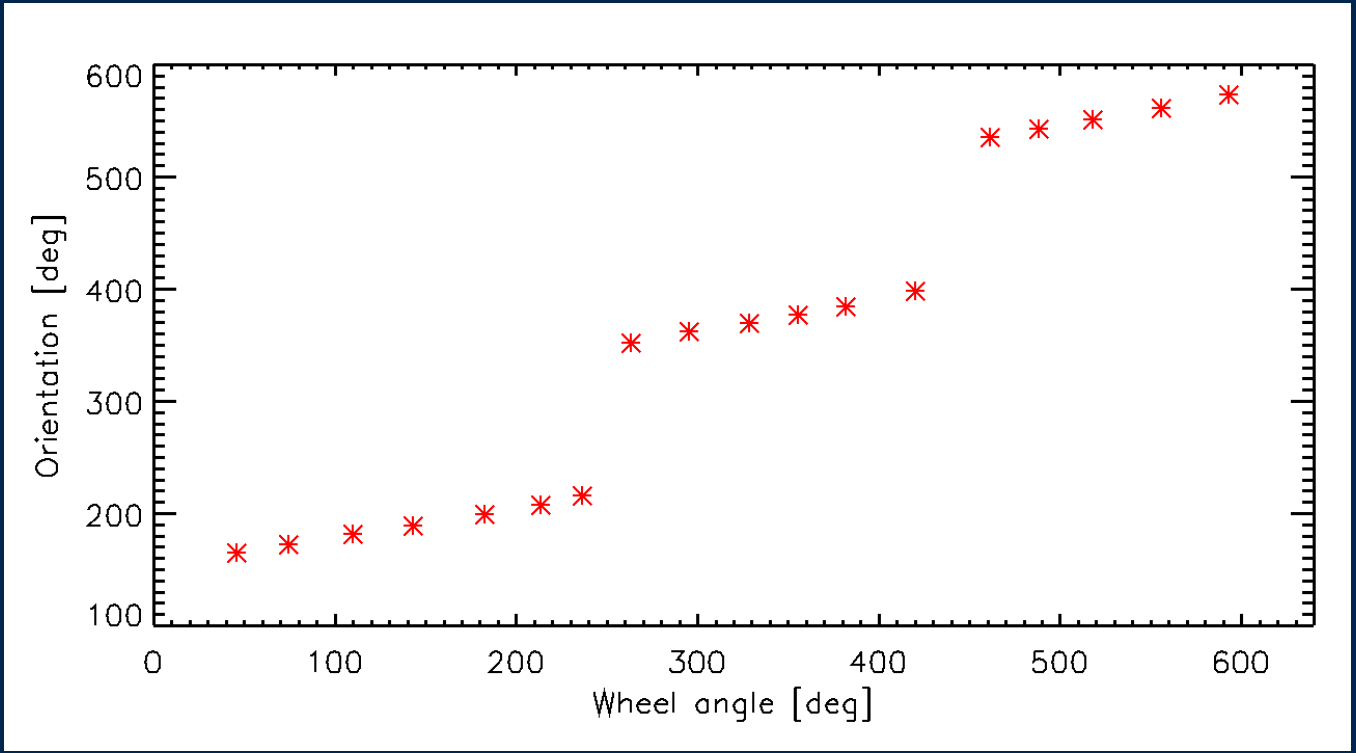
String torque $T_s = k(\varphi - \varphi_0 - \theta)$

Equilibrium $T_m + T_s = 0$

String constant (k) calculated from oscillation frequency of cylinder with well defined dimensions and weight.

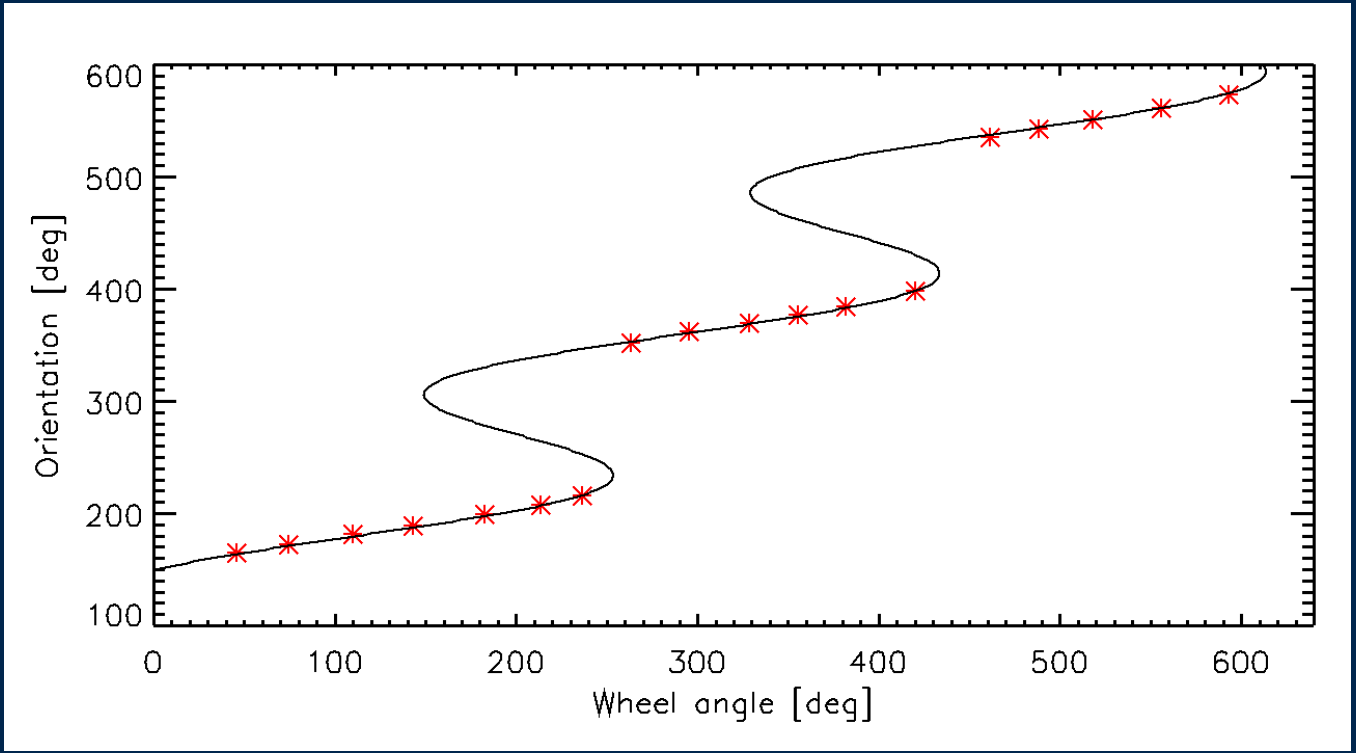
Measurement of Anisotropy of Susceptibility

Equilibrium orientation versus wheel angle



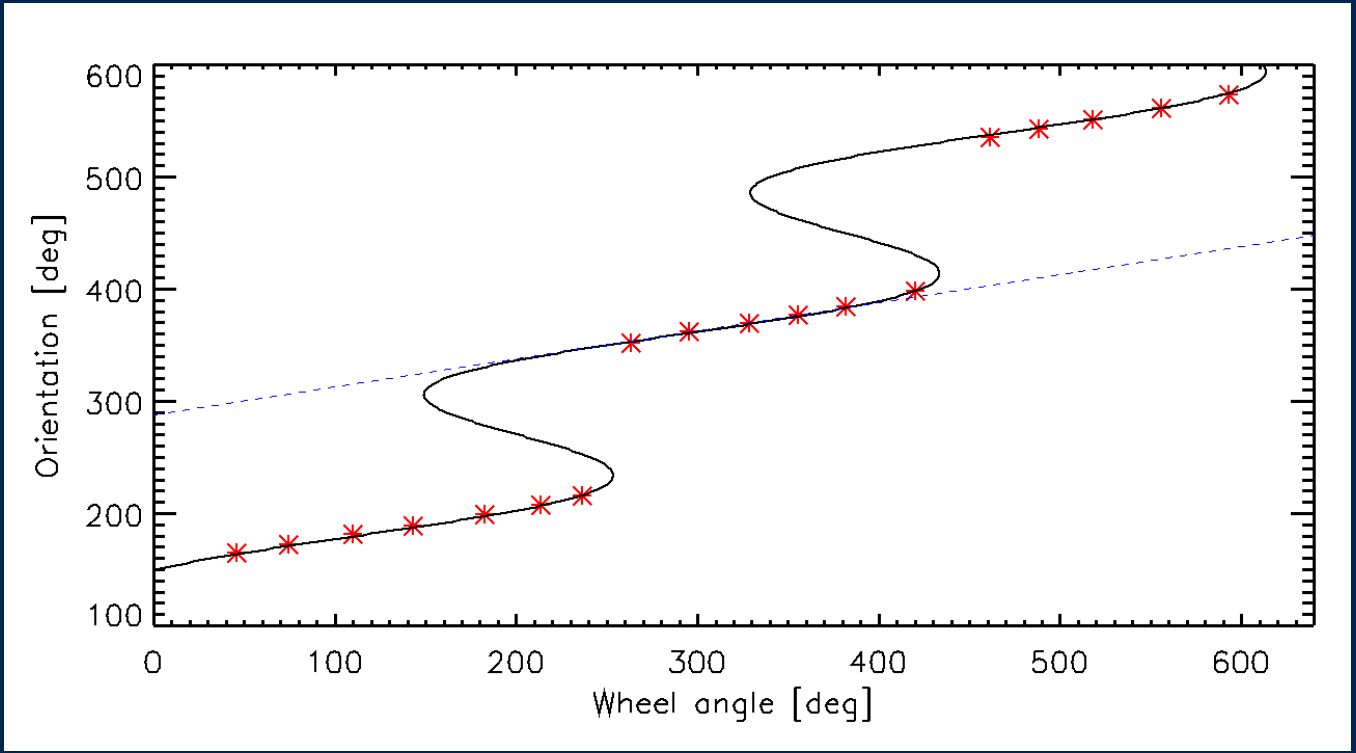
Measurement of Anisotropy of Susceptibility

Fitted equilibrium orientation versus wheel angle



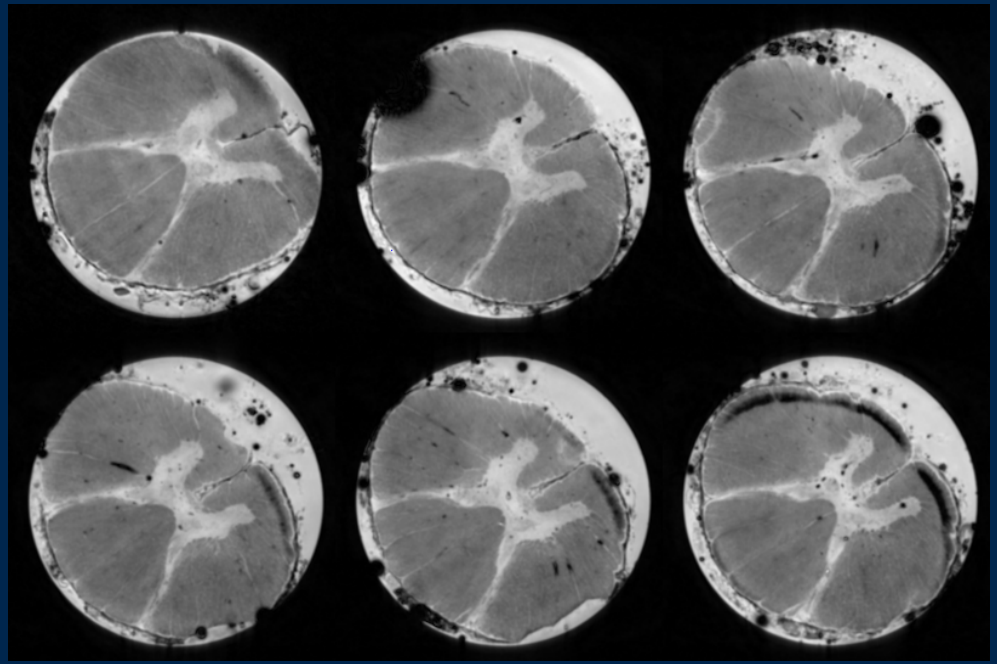
Measurement of Anisotropy of Susceptibility

Fitted equilibrium orientation versus wheel angle



Results

White matter content of samples



100um resolution 3D gradient echo images on 16T system:

White matter 85-88% of samples

Results

The anisotropy of susceptibility of spinal cord white matter

result from 5 samples:

$$\chi_{\parallel} - \chi_{\perp} = 0.026 \text{ to } 0.035 \text{ppm}$$

Note parallel and perpendicular refer to the fiber axis, not to the myelin lipid molecules, which are perpendicular to this axis.

Discussion

Magnetic torque balance can quantify the magnetic susceptibility anisotropy

Spinal cord shows clear effect of susceptibility anisotropy

Values in range with literature on lipids (Lonsdale, PRS 1939) and values (0.2-0.22 ppm) for myelin sheet susceptibility anisotropy in T_2^* decay modeling (Warton & Bowtell, PNAS 2012; Sati et al, Neuroimage 2013 *in press*).

More work needed to understand spread in results and the possible temperature dependence