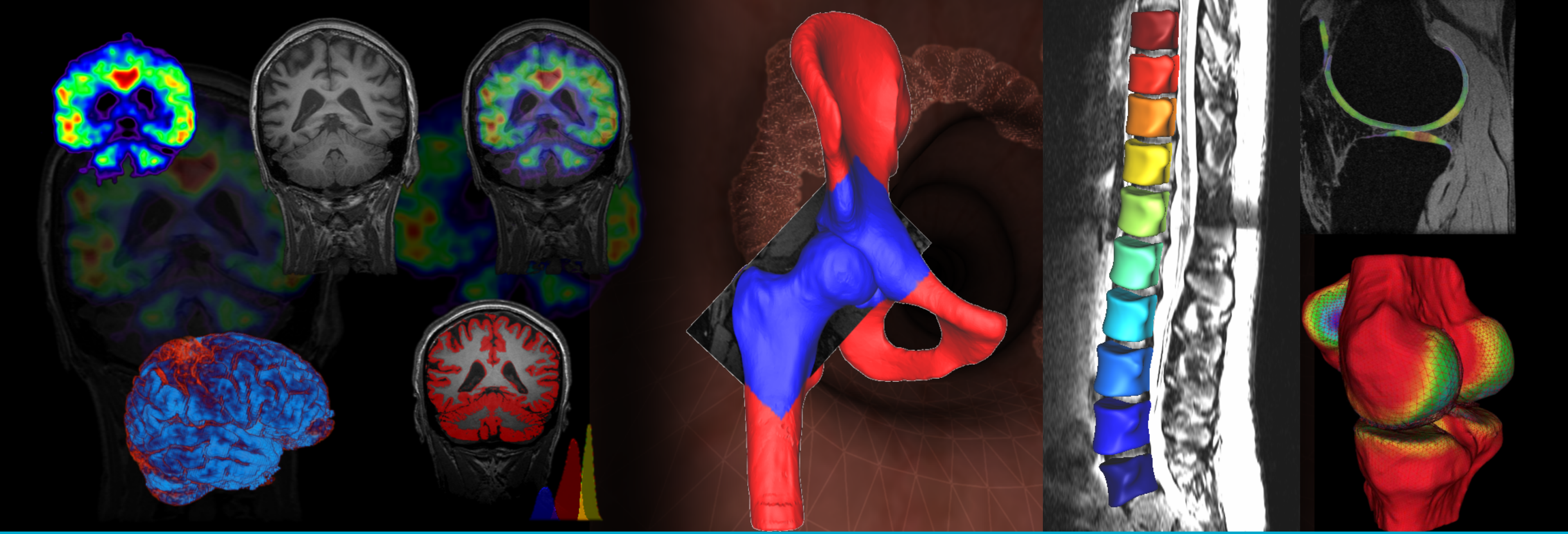


Medical Image Processing and Analysis

Kaikai Shen, PhD
Visiting Fellow, Department of Biomedical Sciences, Macquarie University;
Research Scientist, Australian eHealth Research Centre, CSIRO; Australian Alzheimer's Research Foundation

25 June 2018

AUSTRALIAN EHEALTH RESEARCH CENTRE, CSIRO
www.csiro.au

Australian Alzheimer's Research Foundation

MACQUARIE University
SYDNEY · AUSTRALIA

CSIRO

Medical Imaging and Image Analysis

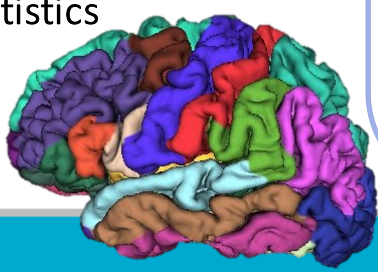
What we do

- Develop and apply advanced computational tools to turn individual (and populations of) images into information (imaging biomarkers).
  - Accurate and reliable automated image analysis (reduces costs and may improve care),
  - provide new insights (Validity, reproducibility and predictive value),
  - enables new and improved diagnostics, screening and treatments.

Medical Images

Image analysis team

- image processing
- registration
- segmentation
- pattern recognition
- machine learning
- statistics

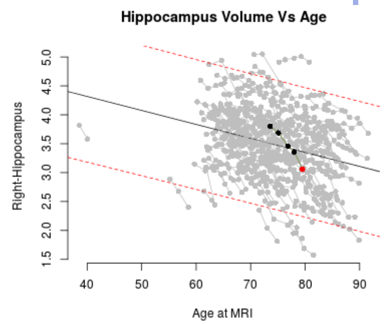


Personalized medicine

- Monitor individuals changes.
- Patient specific treatments
- Characterize phenotype variability of disease.

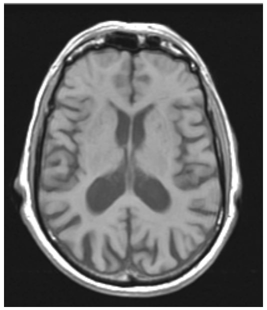
Preventing diseases

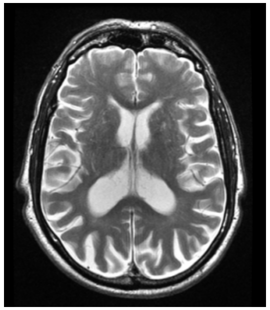
- Population studies
- Early detection/screening
- Diagnosis tools

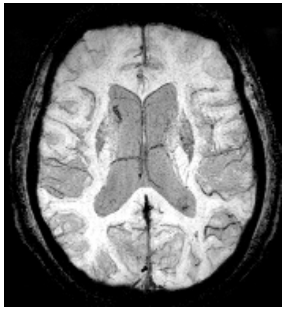


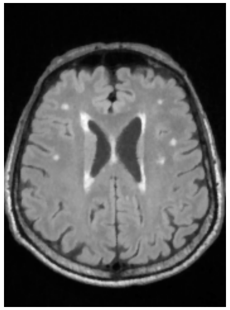
Quantitative Image Analysis

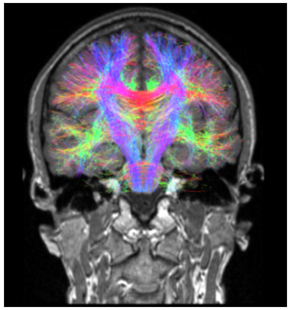
Overview of Neuroimaging Biomarkers we extract

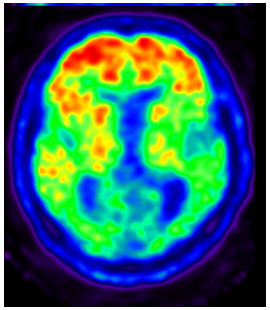












T1W

Anatomy

T2W

CSF and structures

Tissue atrophy

Cortical thickness

Hippocampus volume

Atrophy patterns

Tissue contrast

SWI

Venous tree

Microbleeds

Iron deposit

FLAIR

White matter lesions

White matter lesions

DWI

White matter connections

Connectivity strength

Axonal integrity

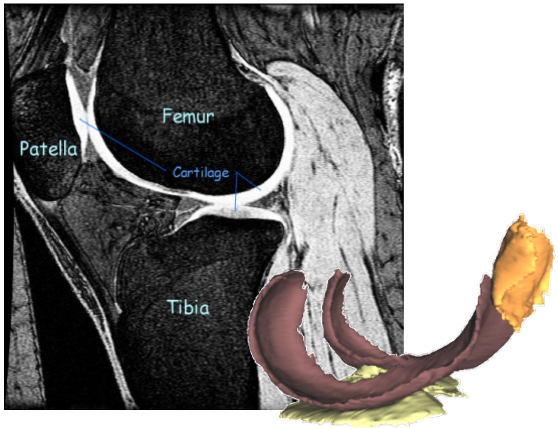
PET

Amyloid beta load
Glucose metabolism

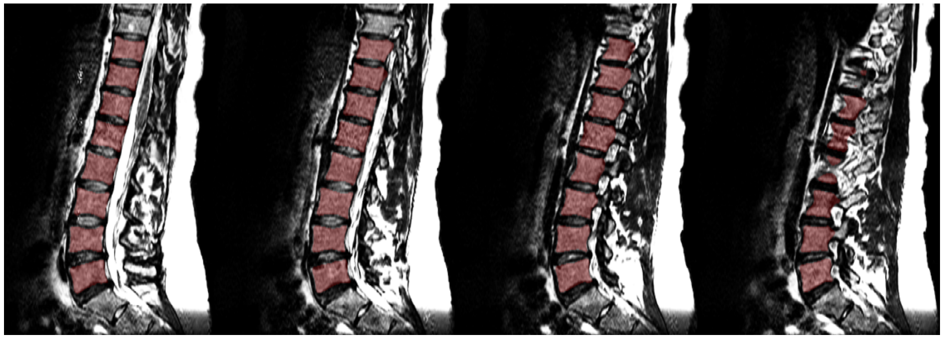
Neocortical uptake

Patten of uptake

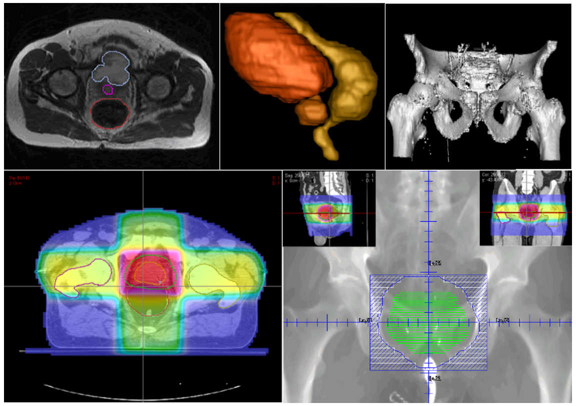
Quantitative Image Analysis



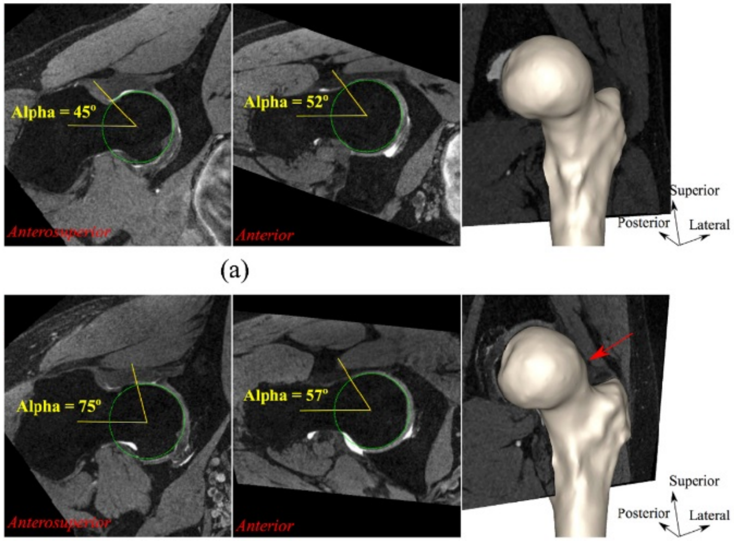
Knee



Vertebrae



Prostate radiotherapy planning with MRI

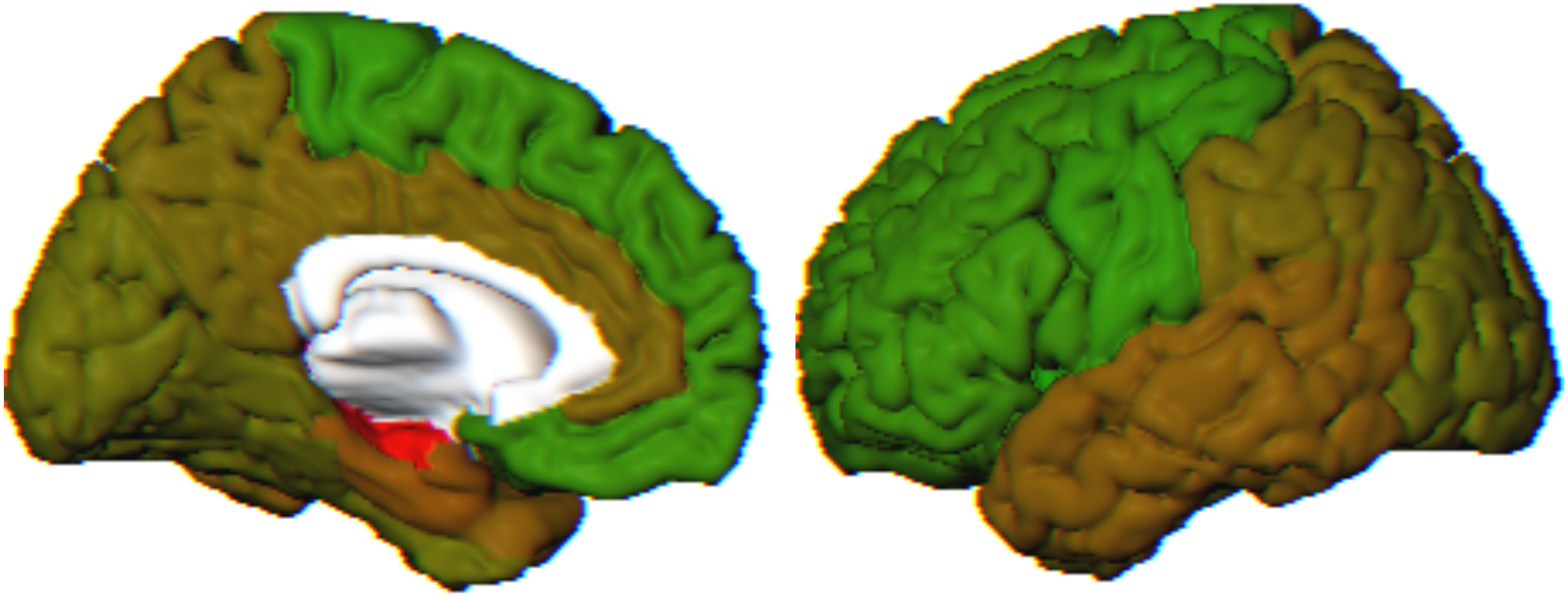


Hip

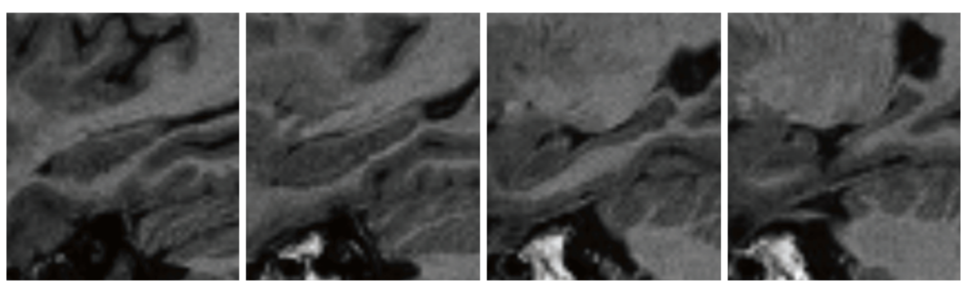
Structural MRI: structural changes in neurodegenerative diseases

Normal Alzheimer's

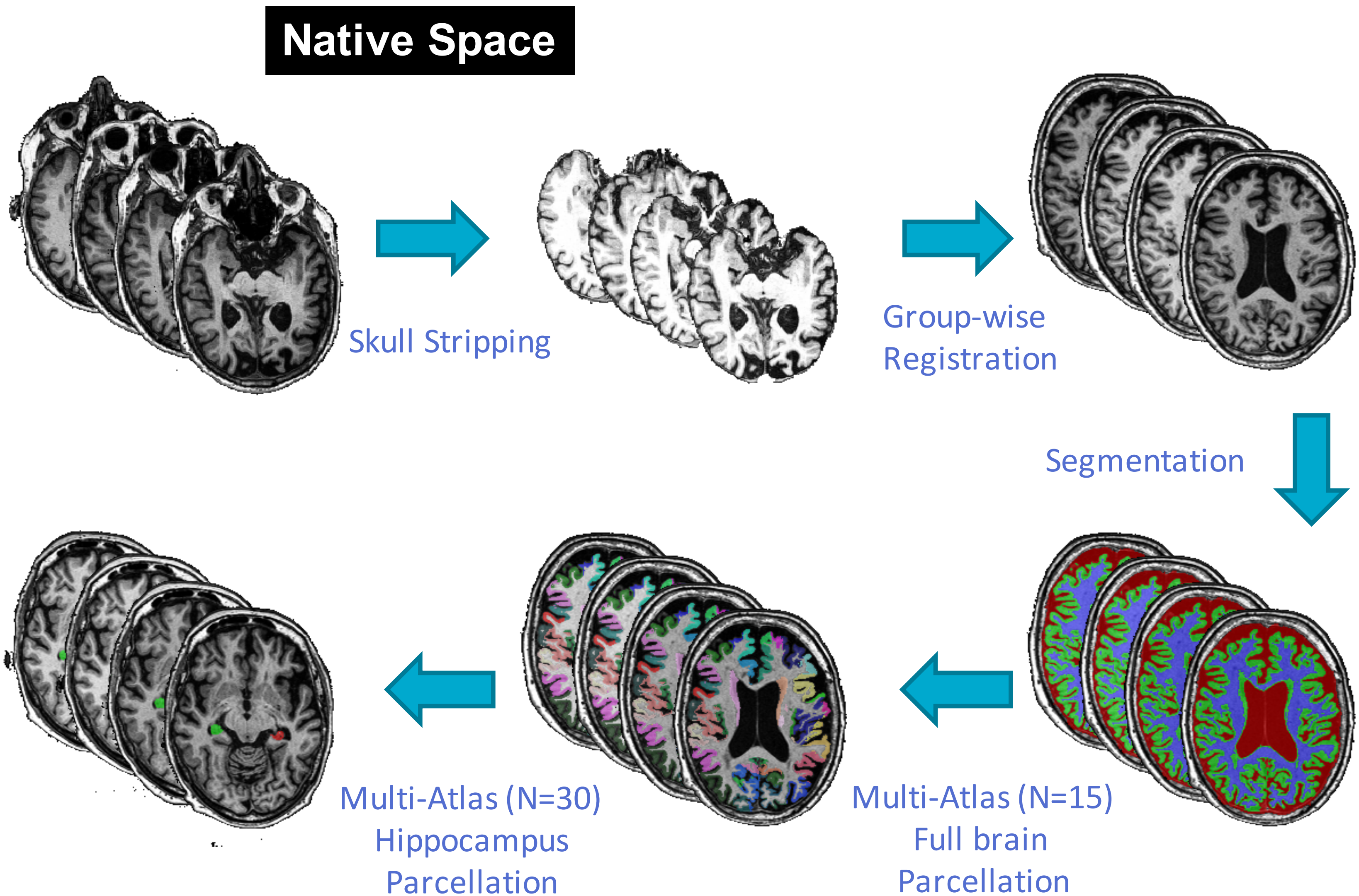
Structural MRI: structural changes in neurodegenerative diseases



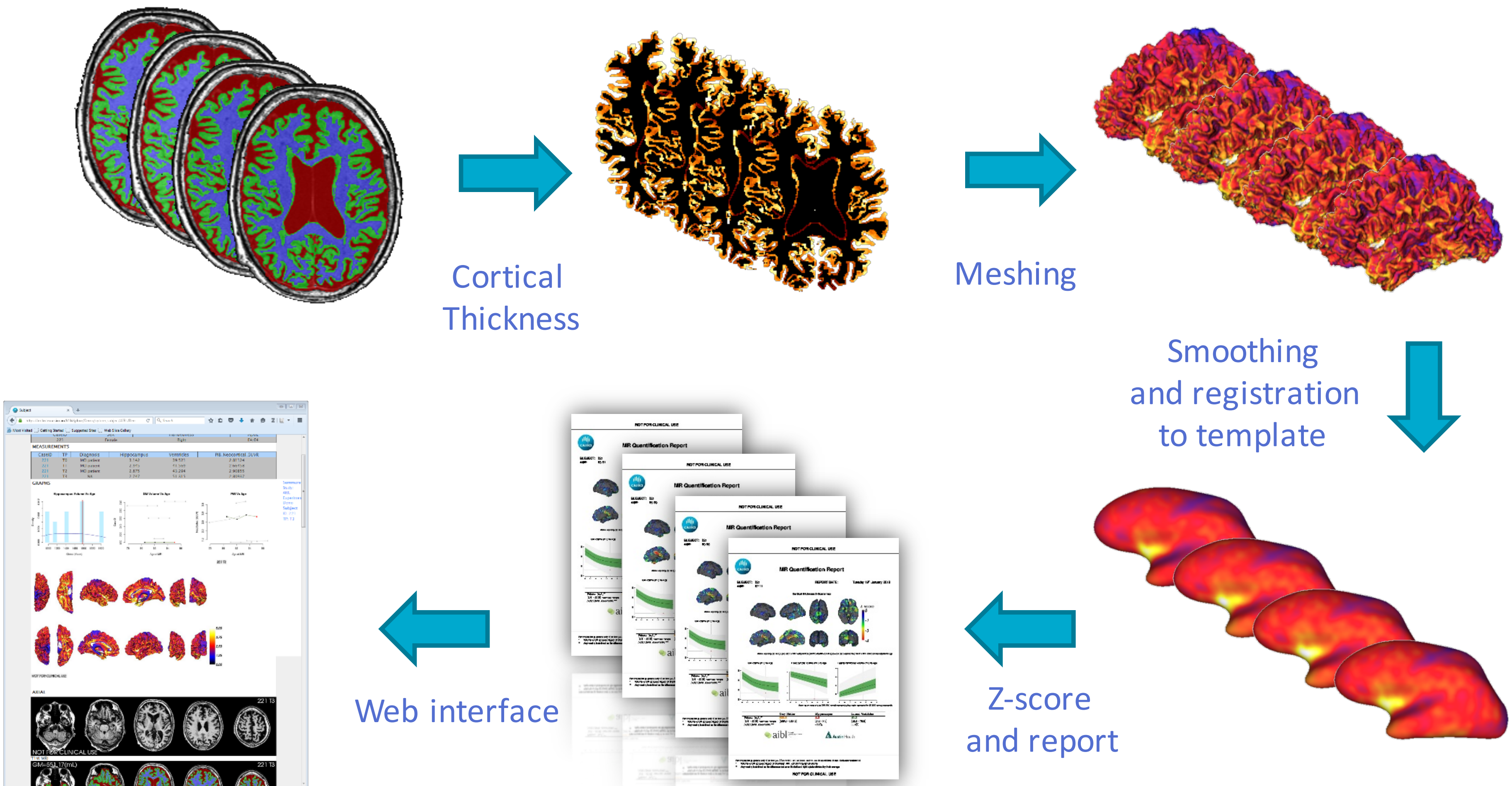
Atrophy compared to Healthy control in early Alzheimer's disease



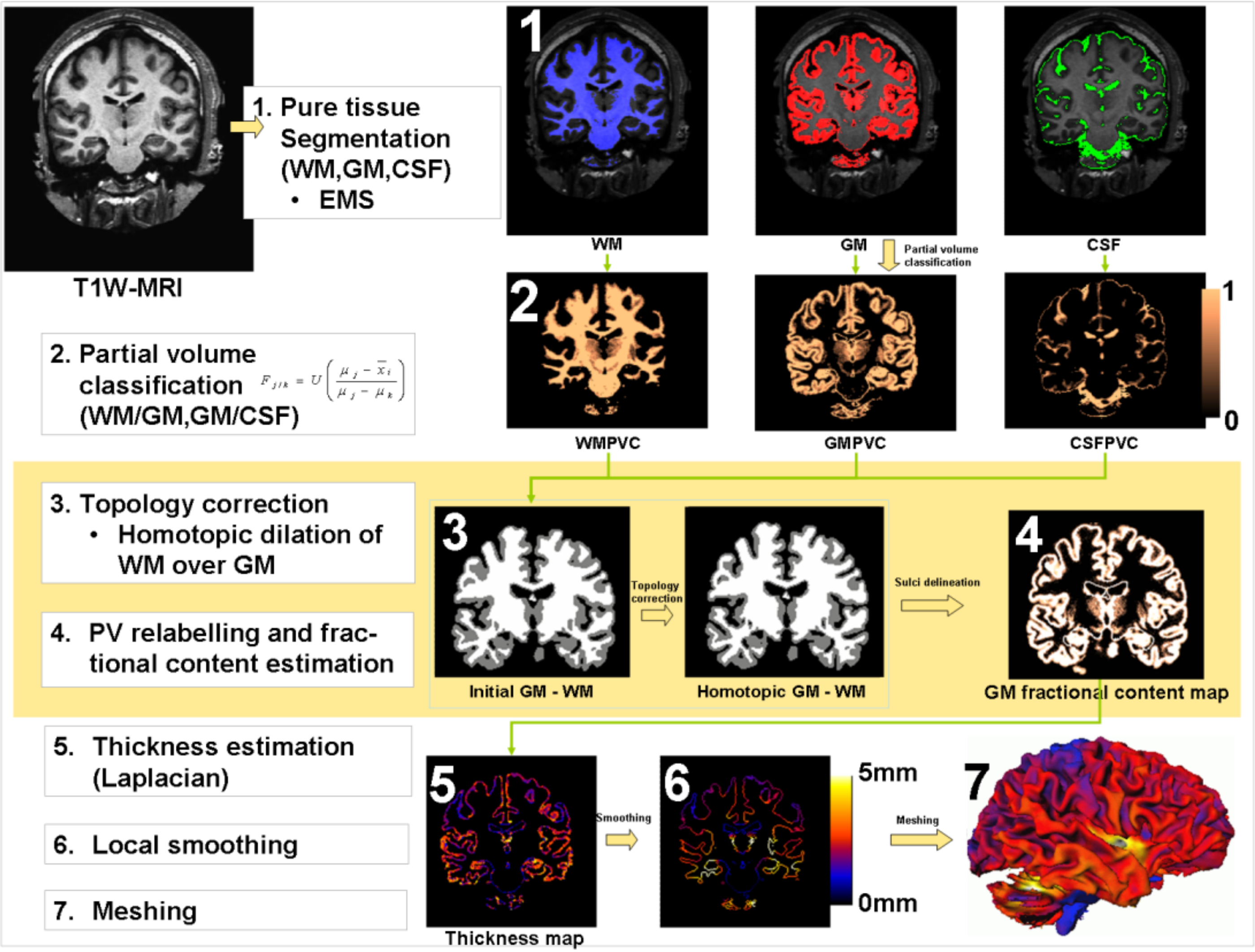
Structural MRI: Volumetric Analysis



Structural MRI: Cortical thickness

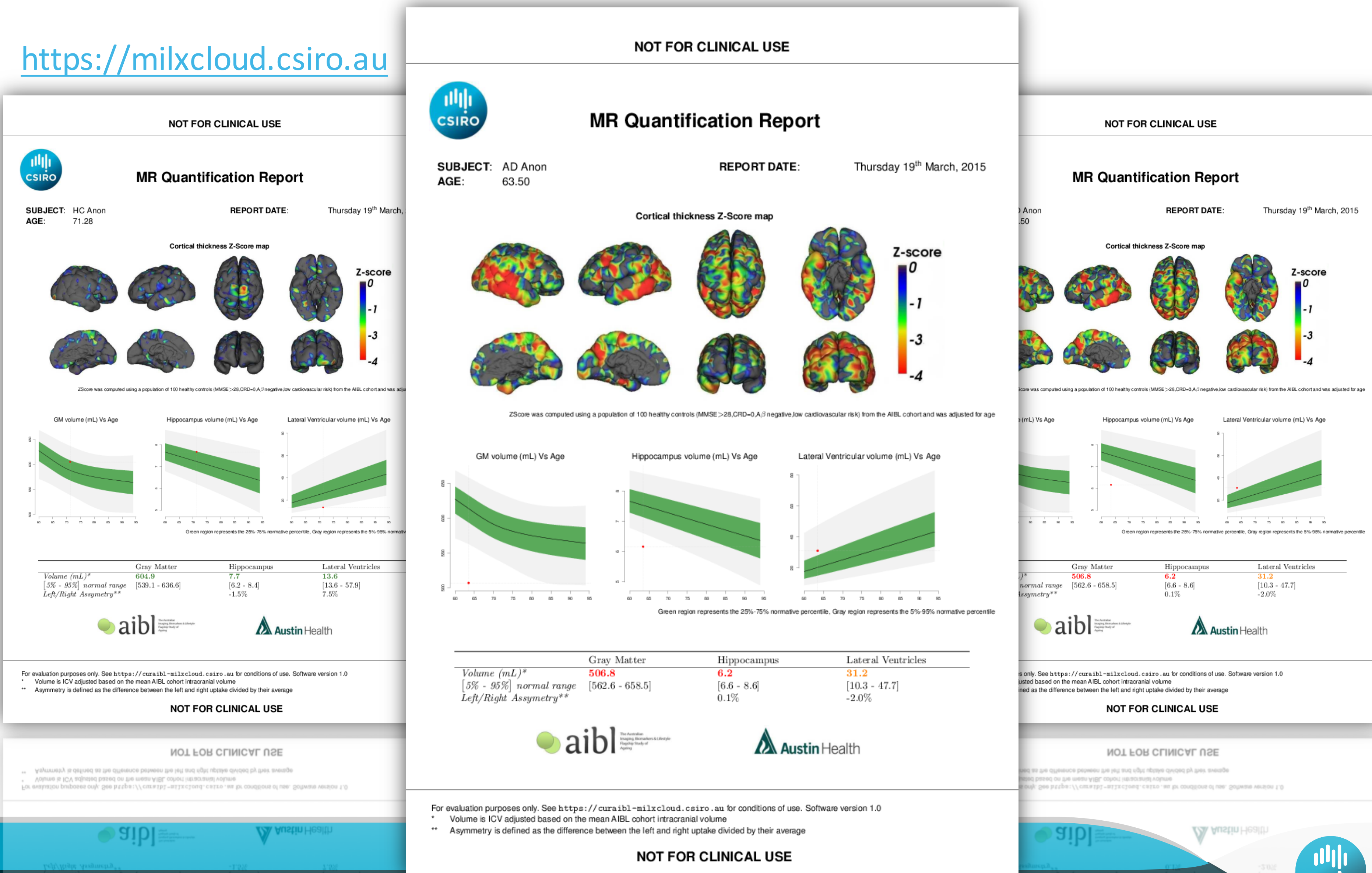


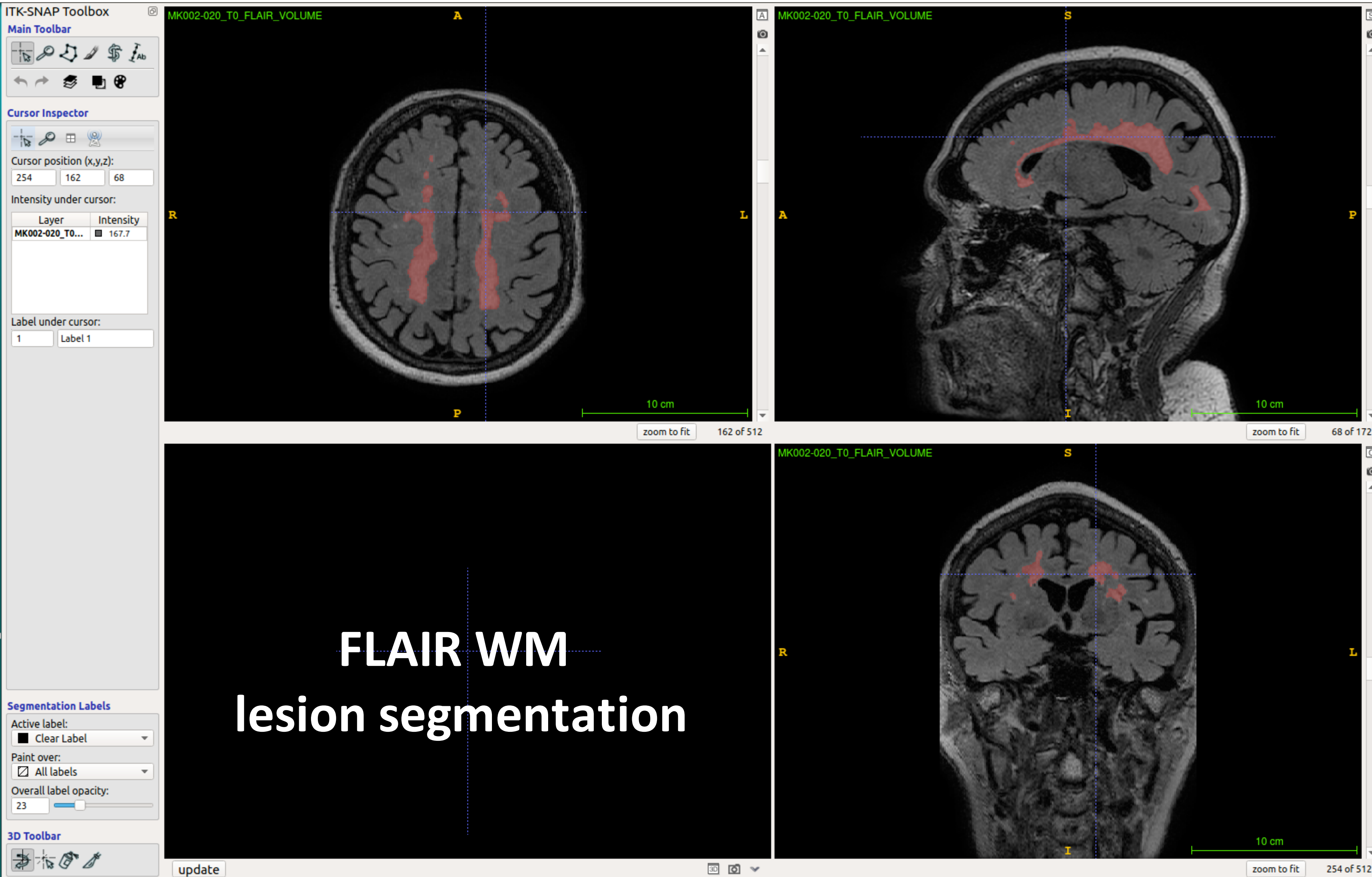
Structural MRI (cont.)



CurAIBL: MR Assessment of Neurodegeneration

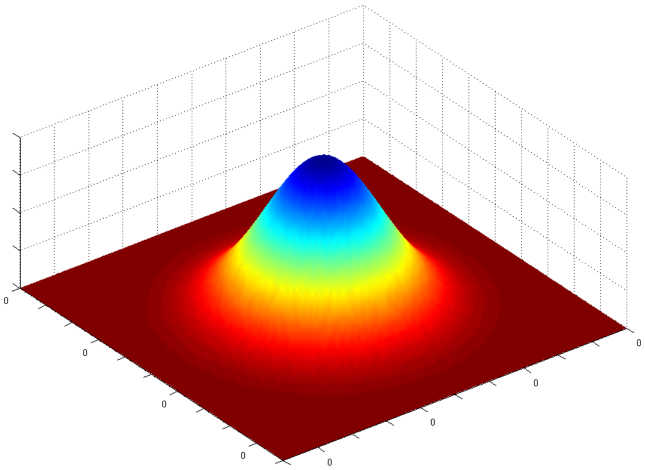
https://milxcloud.csiro.au

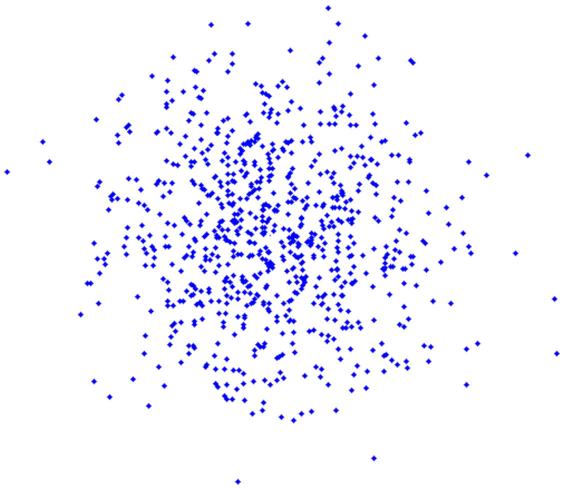


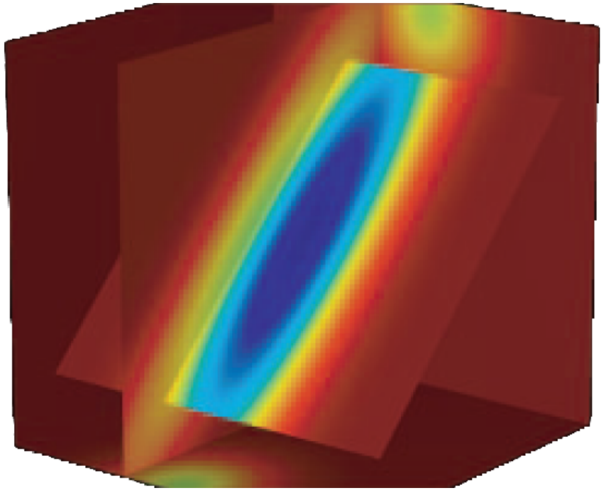

ITK-SNAP Toolbox
Main Toolbar
Cursor Inspector
Cursor position (x,y,z):
254
162
68
Intensity under cursor:
Layer
Intensity
MK002-020_T0...
167.7
Label under cursor:
1
Label 1
Segmentation Labels
Active label:
Clear Label
Paint over:
All labels
Overall label opacity:
23
3D Toolbar
MK002-020_T0_FLAIR_VOLUME
A
R
L
P
10 cm
zoom to fit
162 of 512
MK002-020_T0_FLAIR_VOLUME
S
A
P
I
10 cm
zoom to fit
68 of 172
FLAIR WM
lesion segmentation
update
MK002-020_T0_FLAIR_VOLUME
S
R
L
I
10 cm
zoom to fit
254 of 512

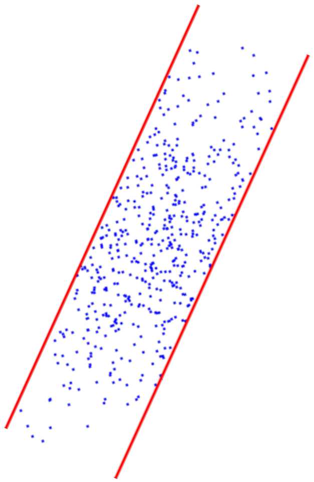
Diffusion MRI: Background

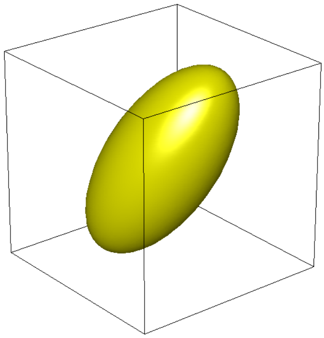
Unrestricted diffusion
Brownian motion





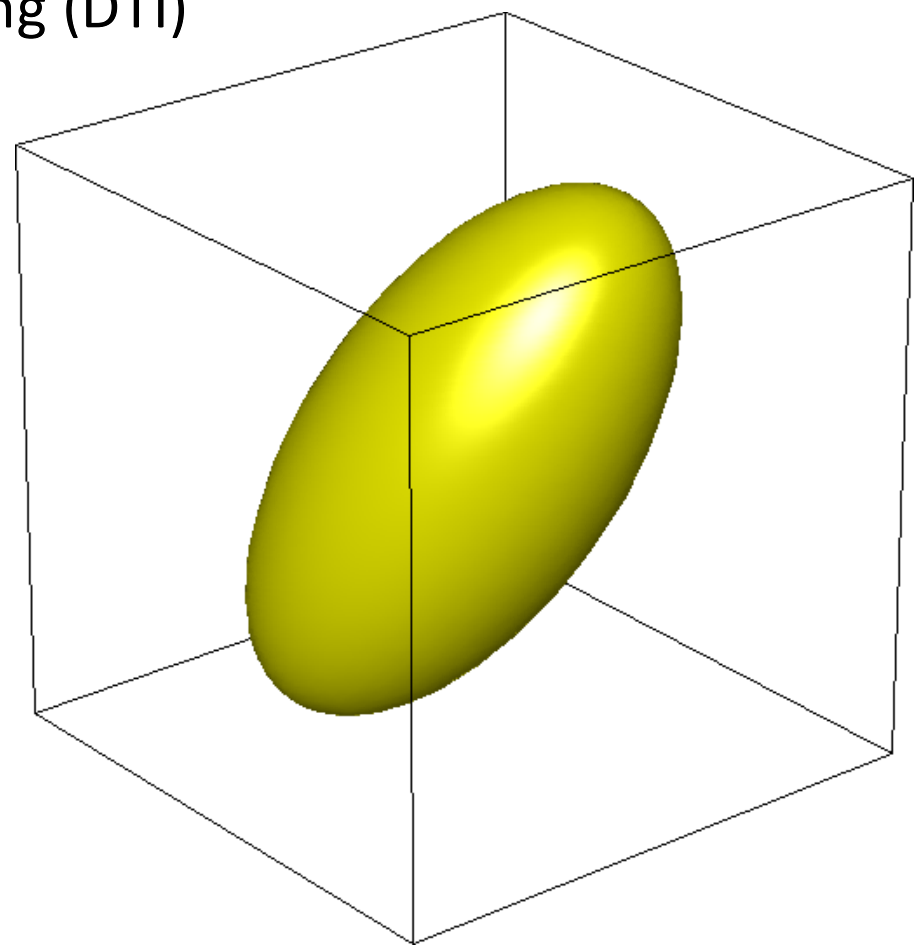


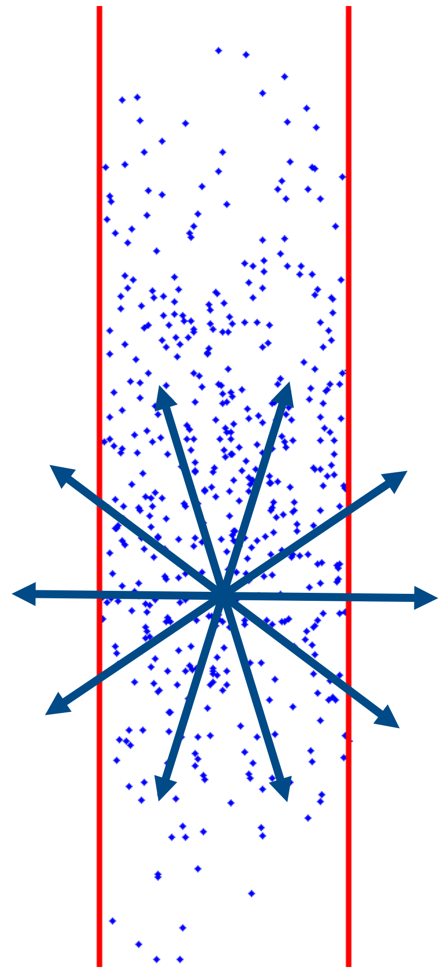


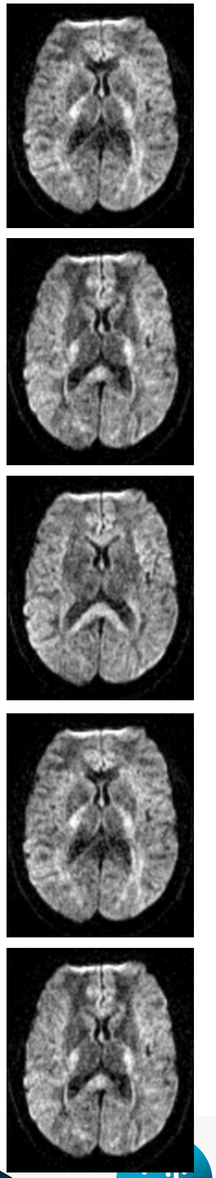


Diffusion MRI: Background

Diffusion Tensor Imaging (DTI)

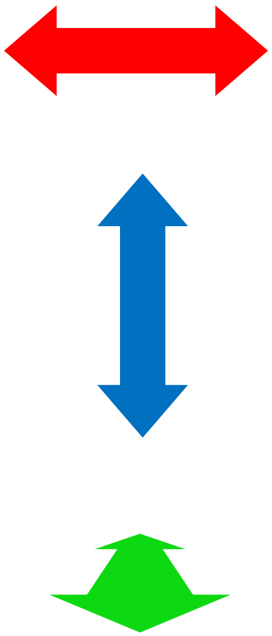


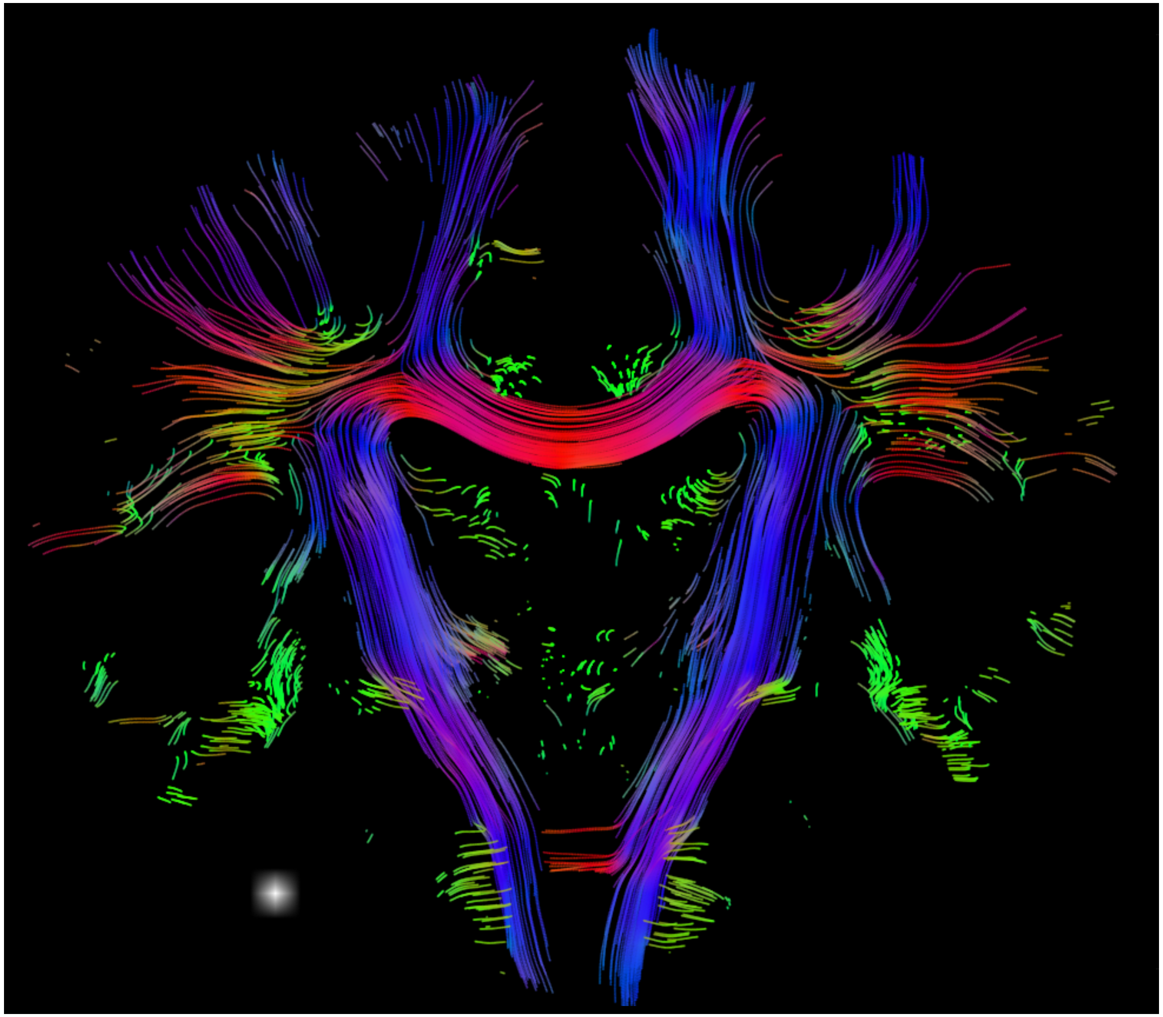




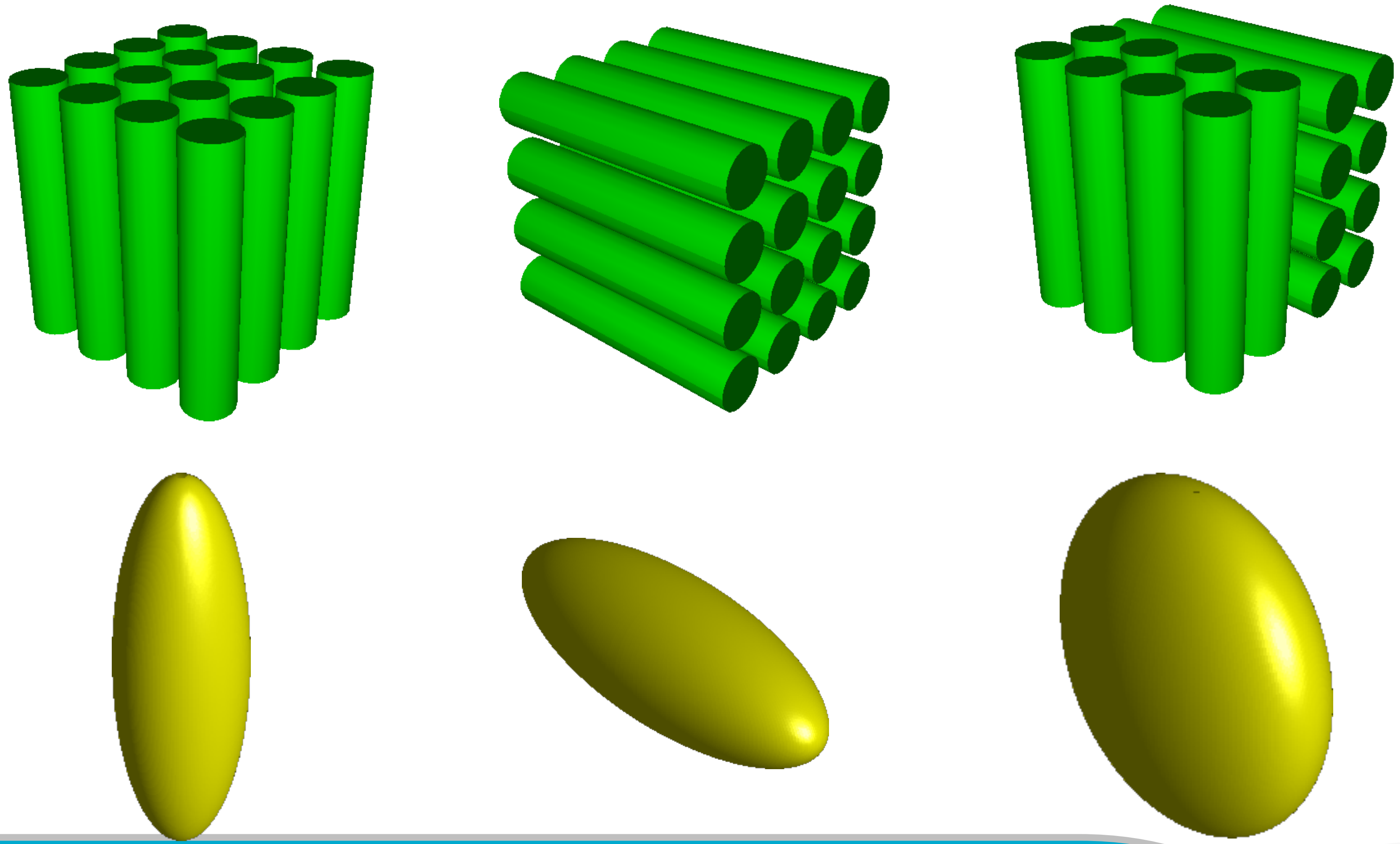
Diffusion MRI: Background

Colour codes
for orientation



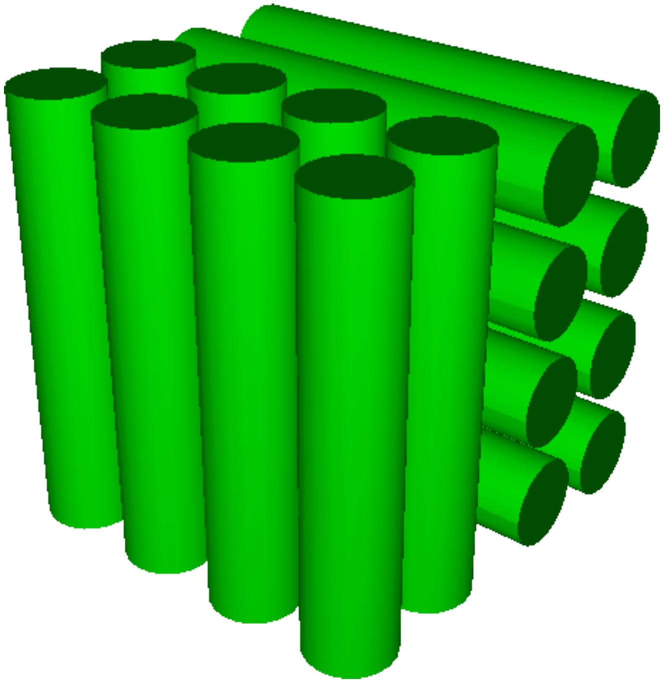


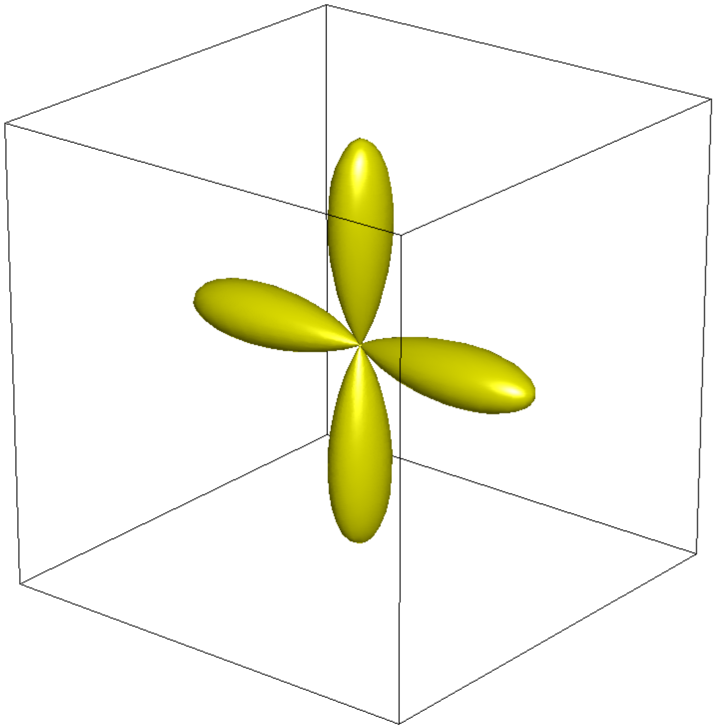
Diffusion MRI: Background



Diffusion MRI: Background

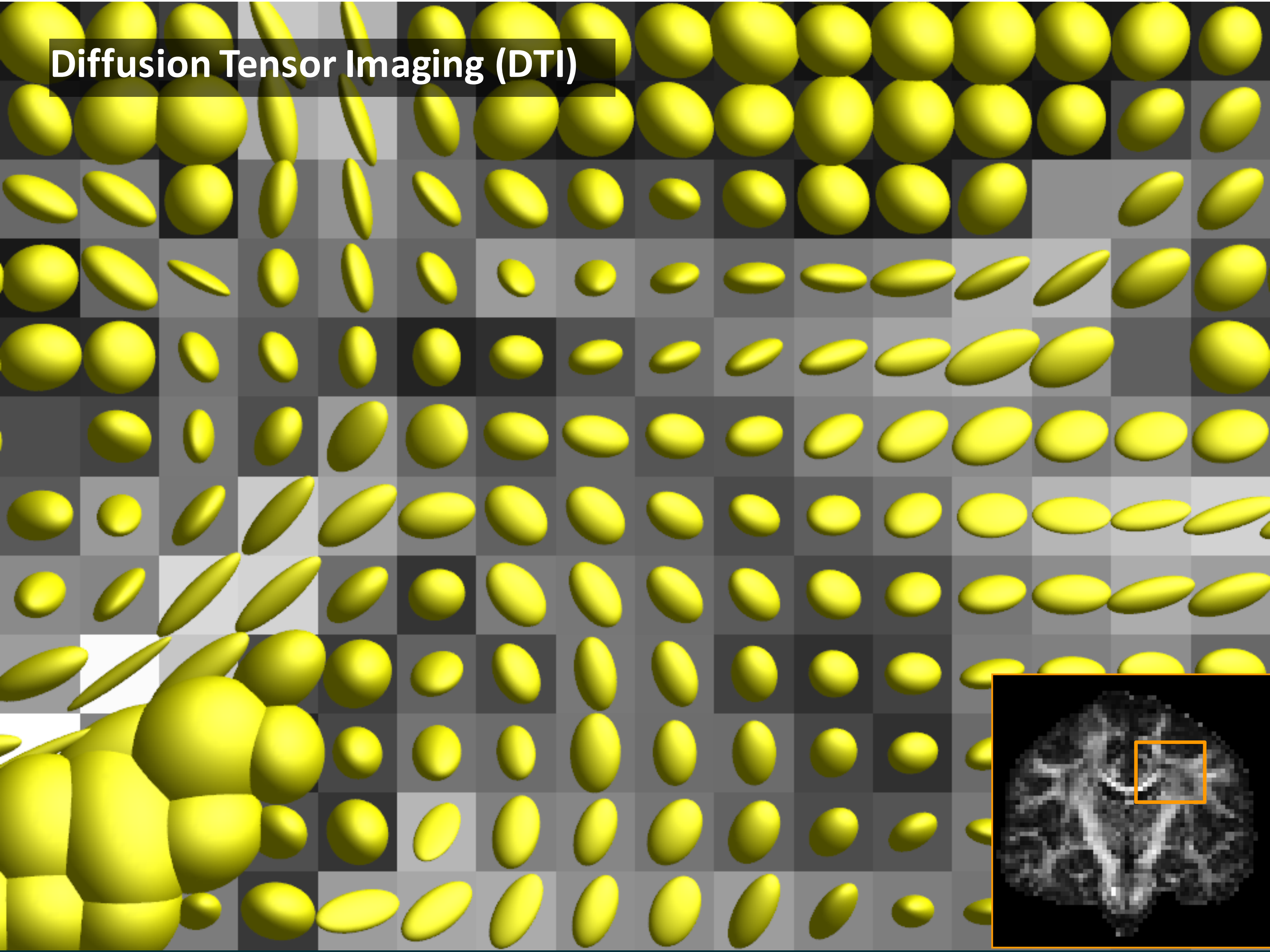
- Fibre Orientation Distribution (FOD)
  - Constrained spherical deconvolution (Tounier *et al*., 2008)

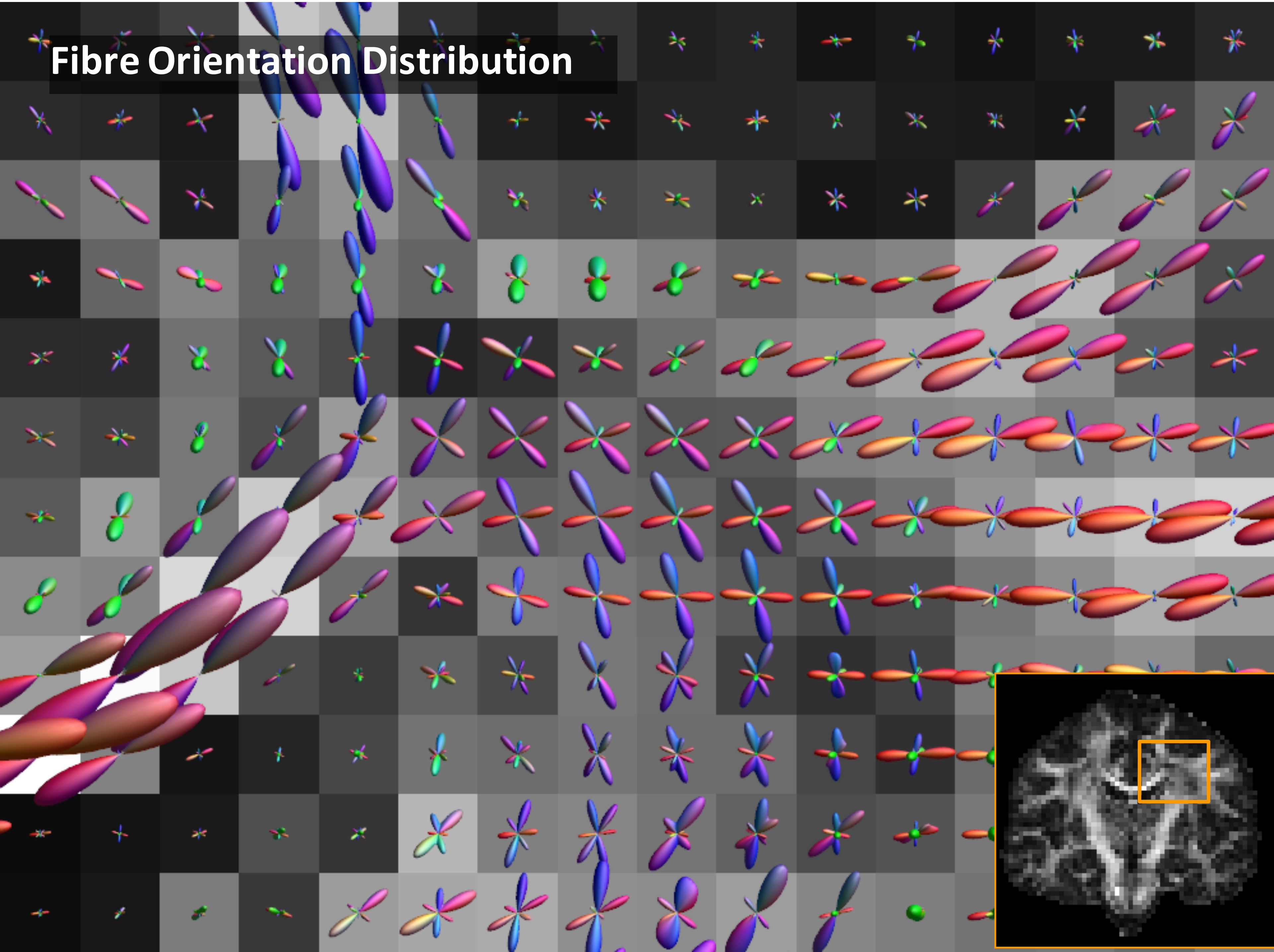




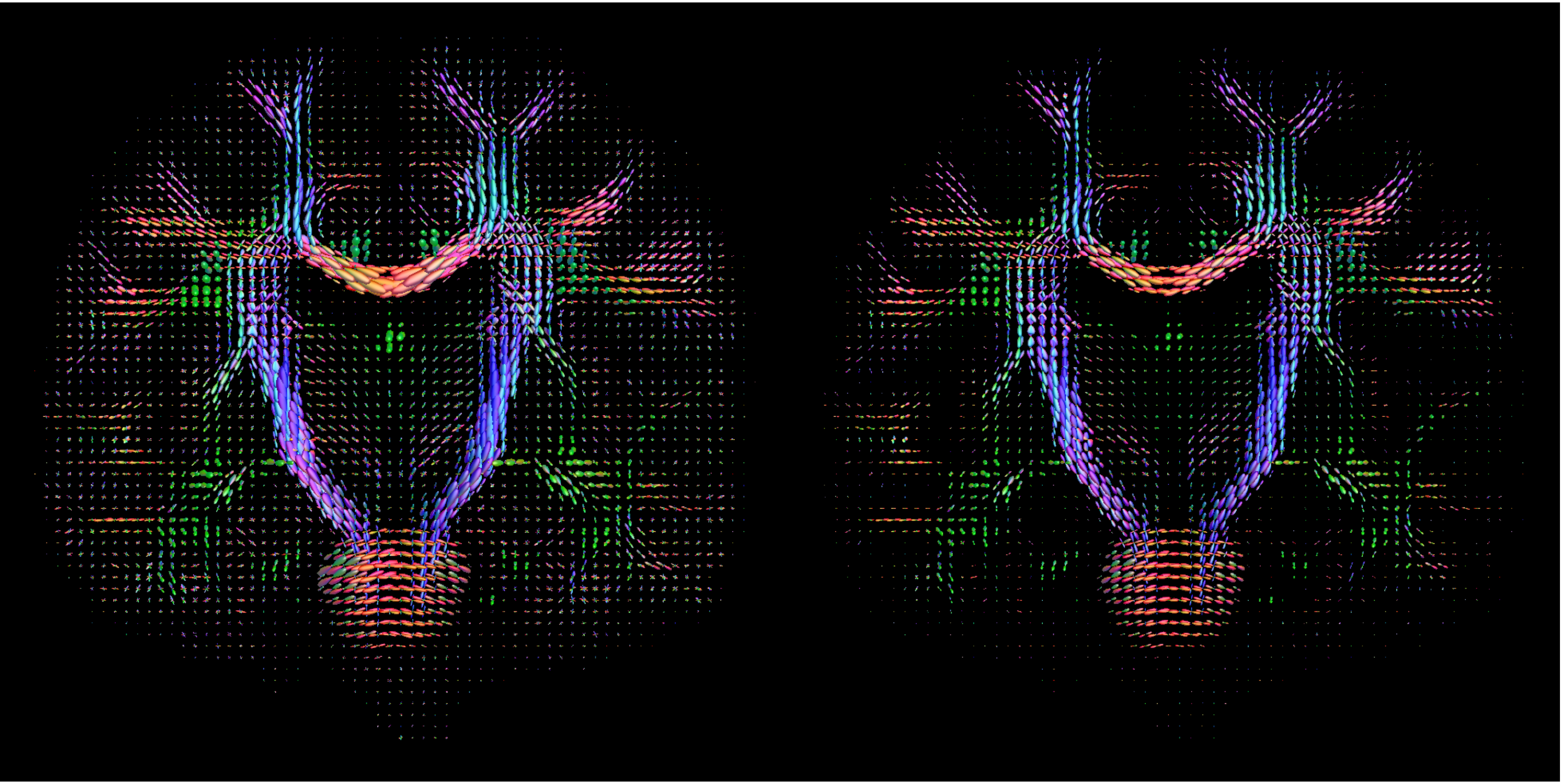
Fibre Orientation Distribution (FOD)

Tournier, J.-D., *et al.*, 2008. Resolving crossing fibres using constrained spherical deconvolution: Validation using diffusion-weighted imaging phantom data. *NeuroImage* 42, 617–625.

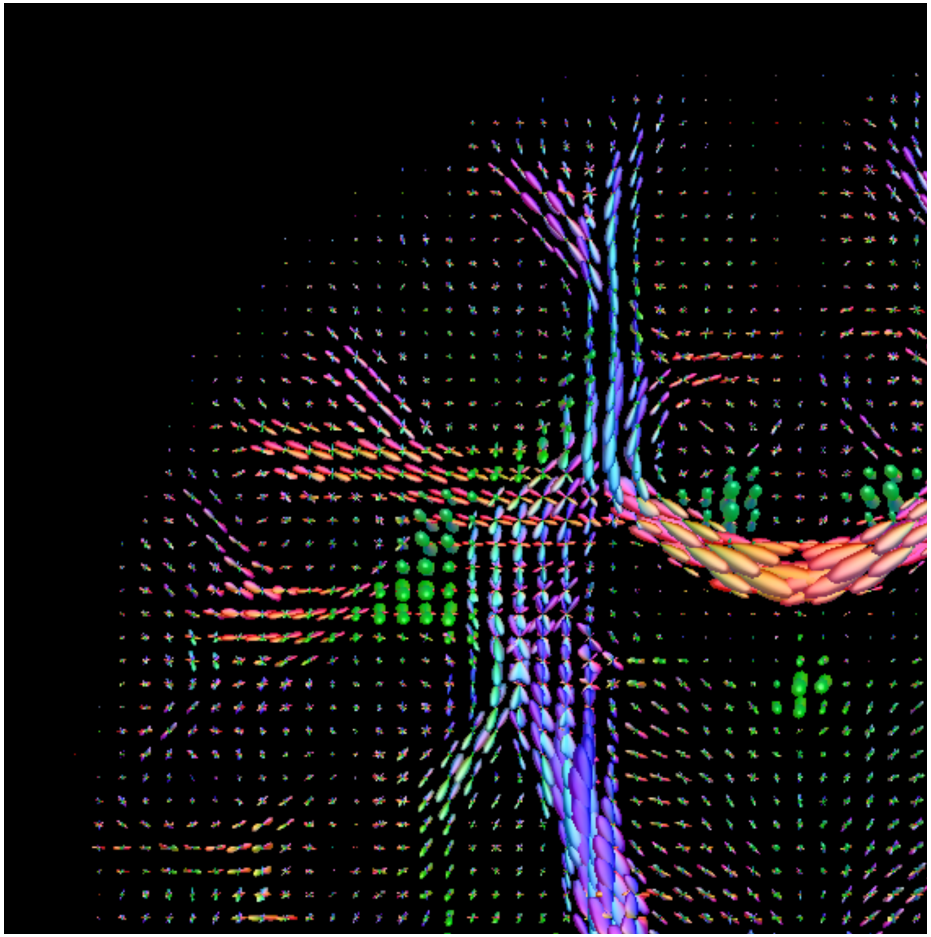

Diffusion Tensor Imaging (DTI)


Fibre Orientation Distribution

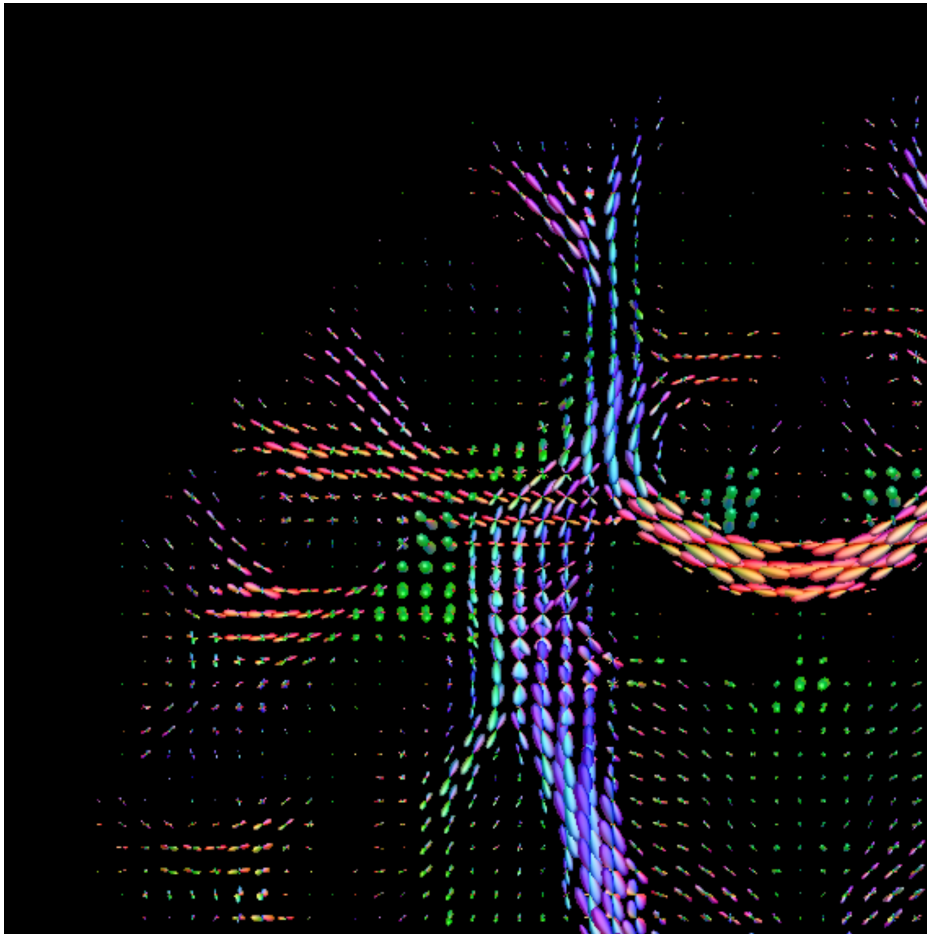
single-shell single-tissue FOD (b = 3000 s/mm^2) multi-shell multi-tissue FOD



FOD @ b = 3000 s/mm^2

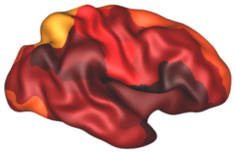


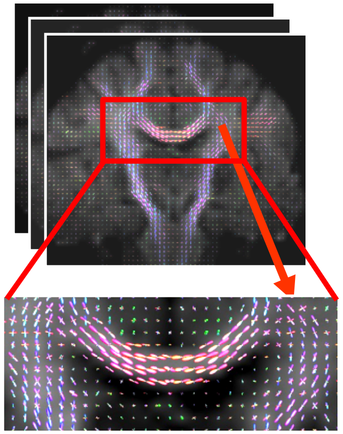
multi-shell multi-tissue FOD



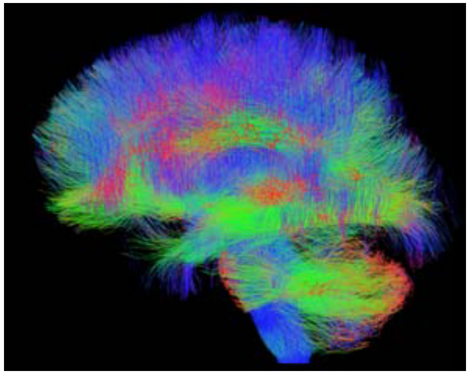
Genetic influence on connectivity

- Aims
  - To develop new insights into brain development
  - To understand how our brains work in health, illness, youth, and old age
  - To study the cerebral cortex and the underlying neural connectivity, from the structural and diffusion MR images
  - To investigate the influence of genes by imaging monozygotic (MZ) and dizygotic (DZ) twins





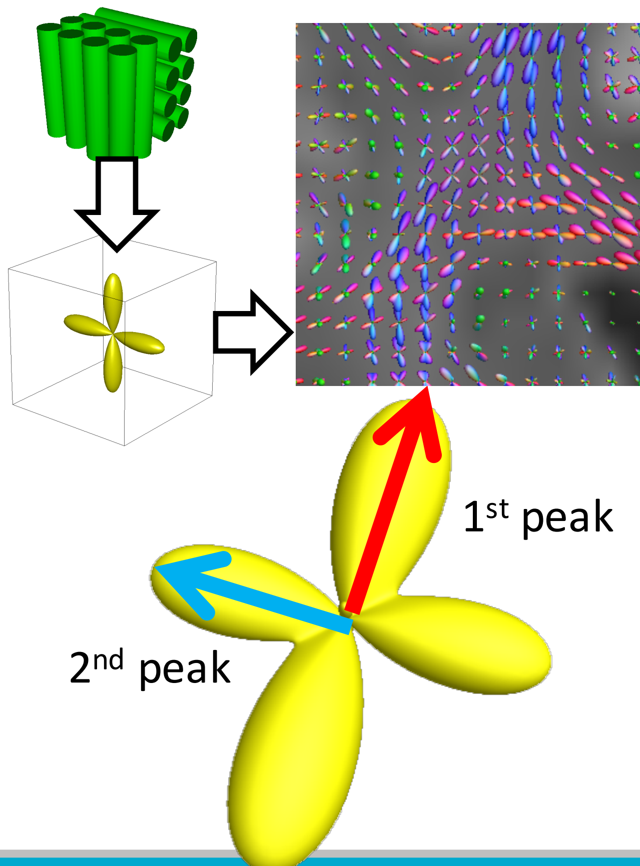
- Twin Study
  - Queensland Twin IMaging study (QTIM)
  - CSIRO and Queensland Institute of Medical Research (QIMR)



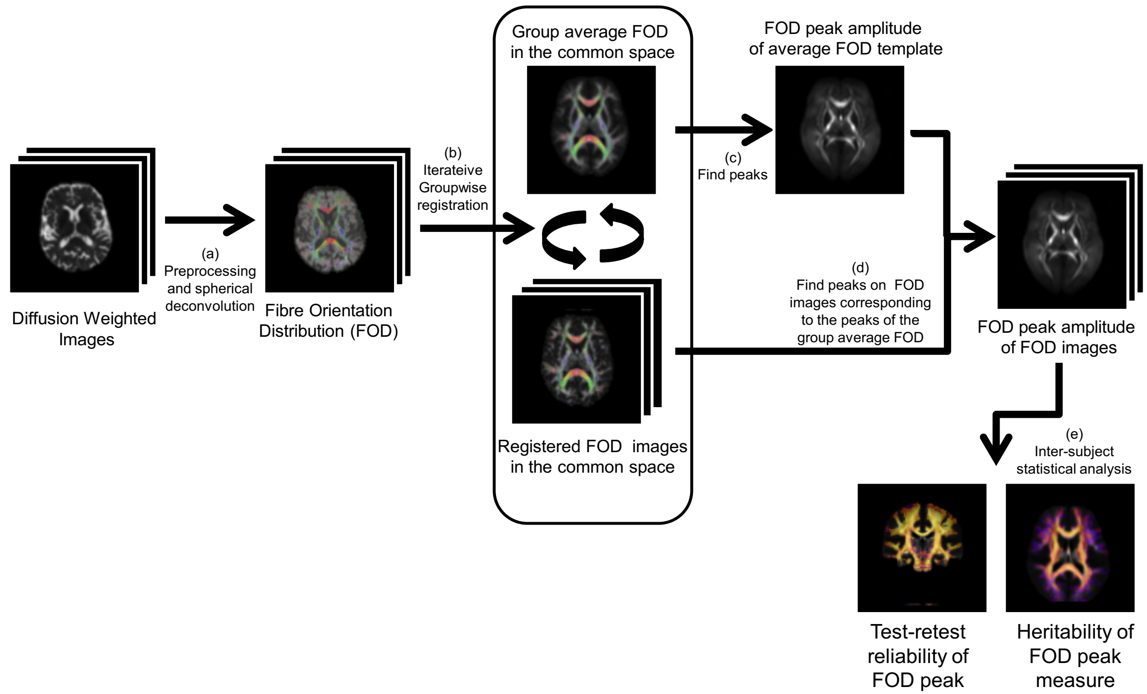
de Zubicaray, G.I., Chiang, M.C., McMahon, K.L., Shattuck, D.W., Toga, A.W., Martin, N.G., Wright, M.J., Thompson, P.M., 2008. Meeting the challenges of neuroimaging genetics. *Brain Imaging Behav.* 2, 258–263.

Genetic influence on connectivity: Methods

- Measure the FODs
  - Peak amplitude



- Processing/Analysis framework
  - Raffelt *et al.*, 2012



Raffelt, D., *et al.*, 2012. Apparent Fibre Density: A novel measure for the analysis of diffusion-weighted magnetic resonance images. *NeuroImage* 59, 3976–3994.

Genetic influence on connectivity: Methods

- Diffusiton MR: 94 gradient directions at b = 1159 s/mm^2
- Twin cohort
  - N=328 subjects (118M, 210F), age 22.7(2.3)
  - 71 pairs (N=142, 48M, 94F) of monozygotic twins (MZ) + 90 pairs (N=180, 69M, 111F) of dizygotic twins (DZ)
- Heritability
  - ACE model: Additive genetics + Common environment + unique Environment

$$\text{FOD} = A + C + E$$

  - Heritability

$$h^2 = \frac{\mathrm{Var}(A)}{\mathrm{Var}(A) + \mathrm{Var}(C) + \mathrm{Var}(E)}$$

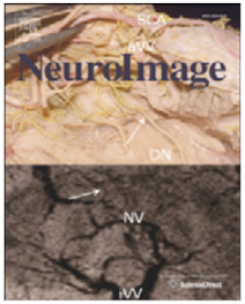
Falconer's formula

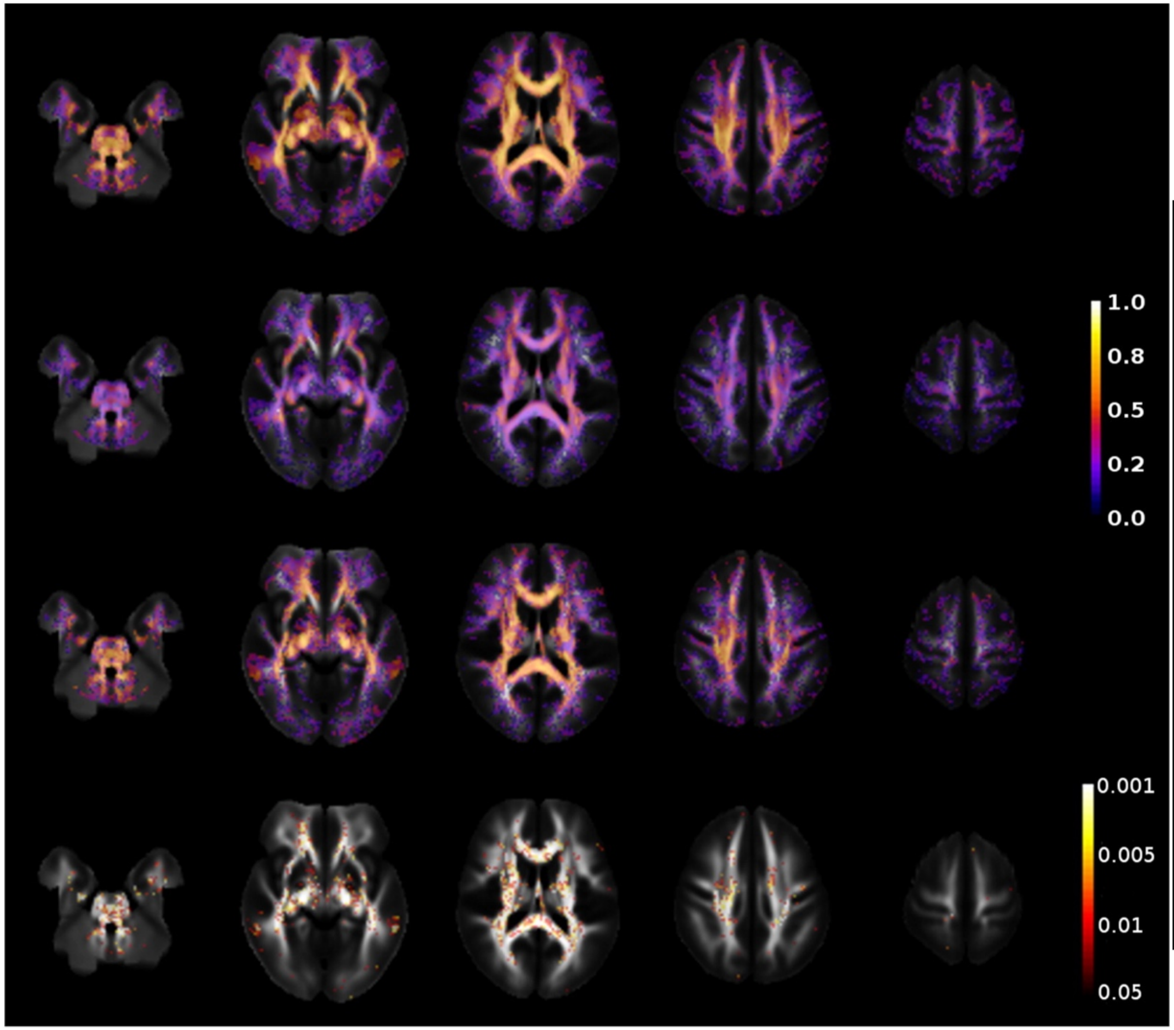
$$h^2 = 2(r_{\mathrm{MZ}} - r_{\mathrm{DZ}})$$

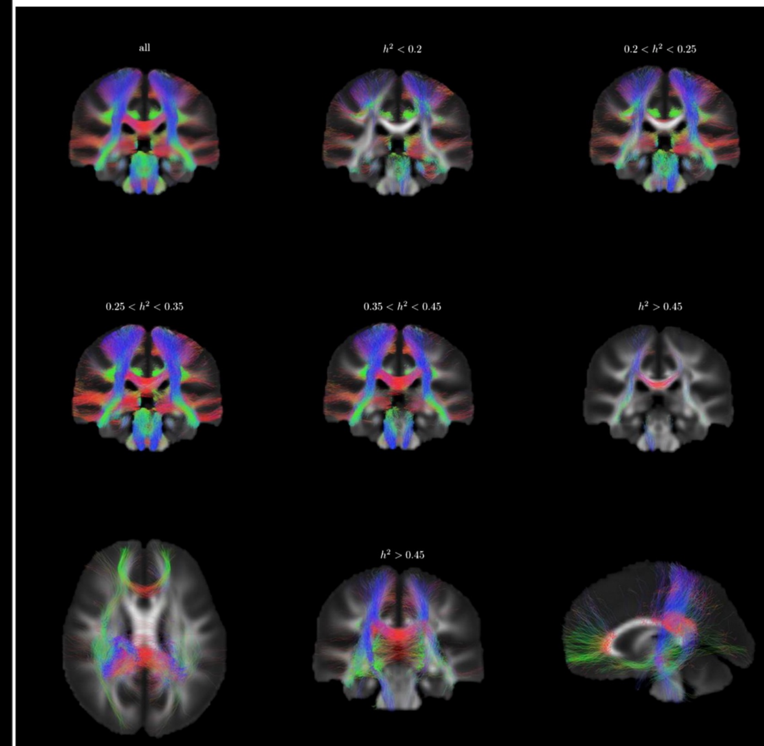
Investigating brain connectivity heritability in a twin study using diffusion imaging data

CrossMark

Kai-Kai Shen [a], Stephen Rose [a], Jurgen Fripp [a], Katie L. McMahon [b], Greig I. de Zubicaray [c], Nicholas G. Martin [d], Paul M. Thompson [e], Margaret J. Wright [d], Olivier Salvado [a]



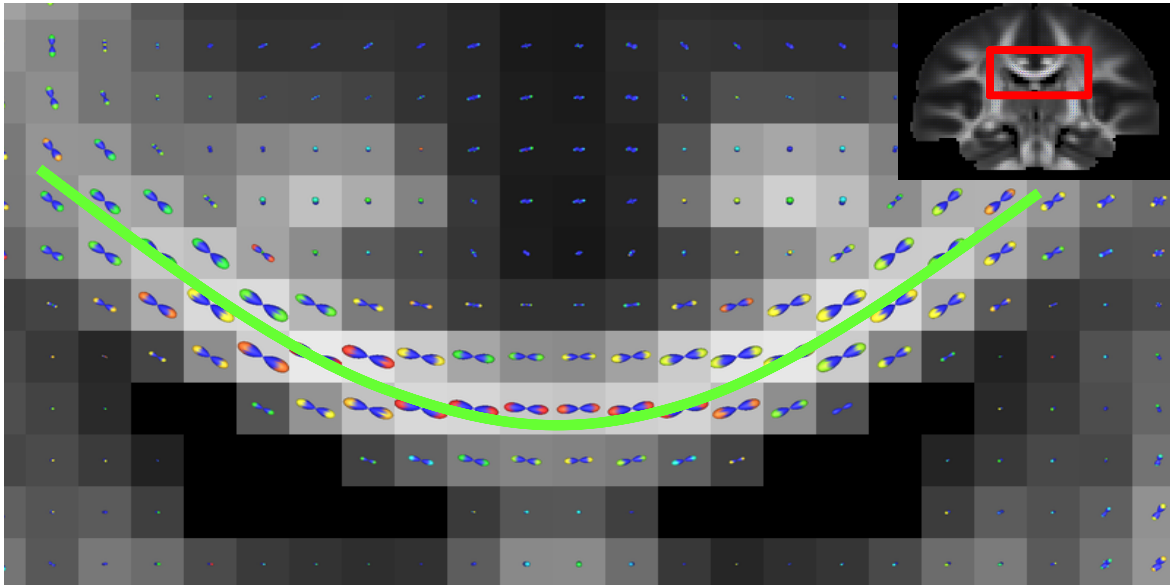


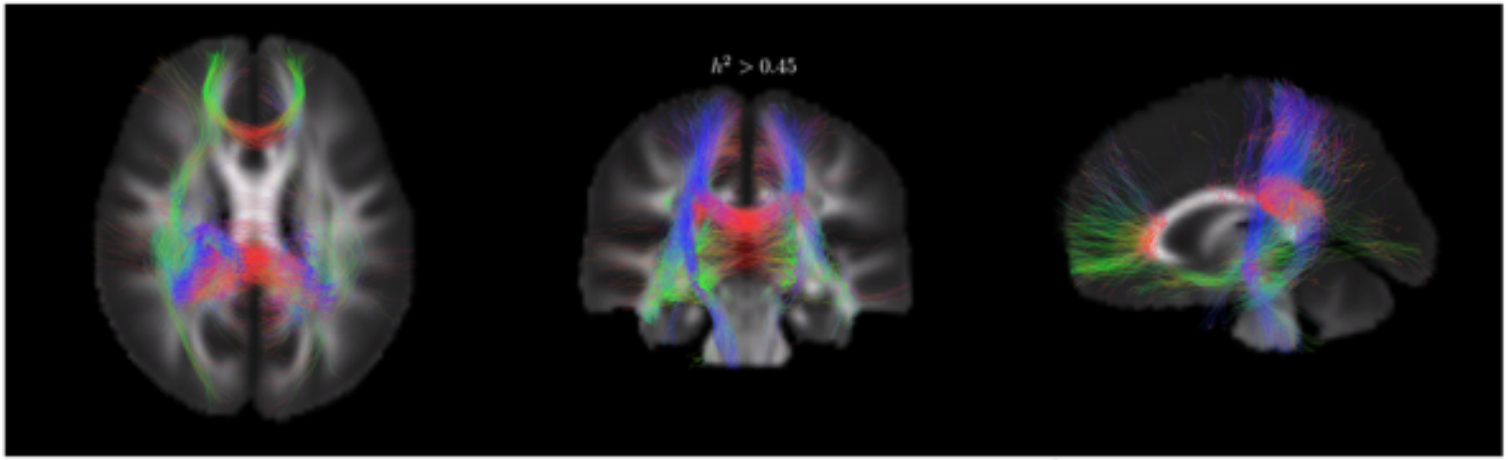


CSIRO

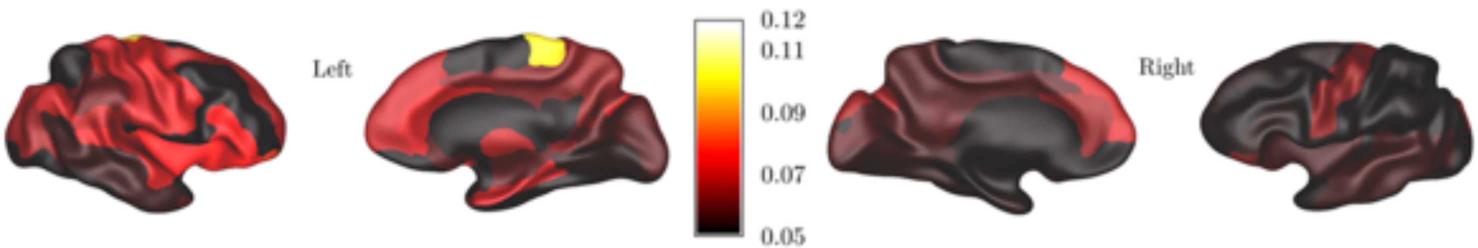
Genetic influence on connectivity: Methods

- Tractography
  - Whole brain, probabilistic using FOD
- Tract-wise heritability
  - Interpolation of heritabilities of nearest peaks
  - Tract average heritability



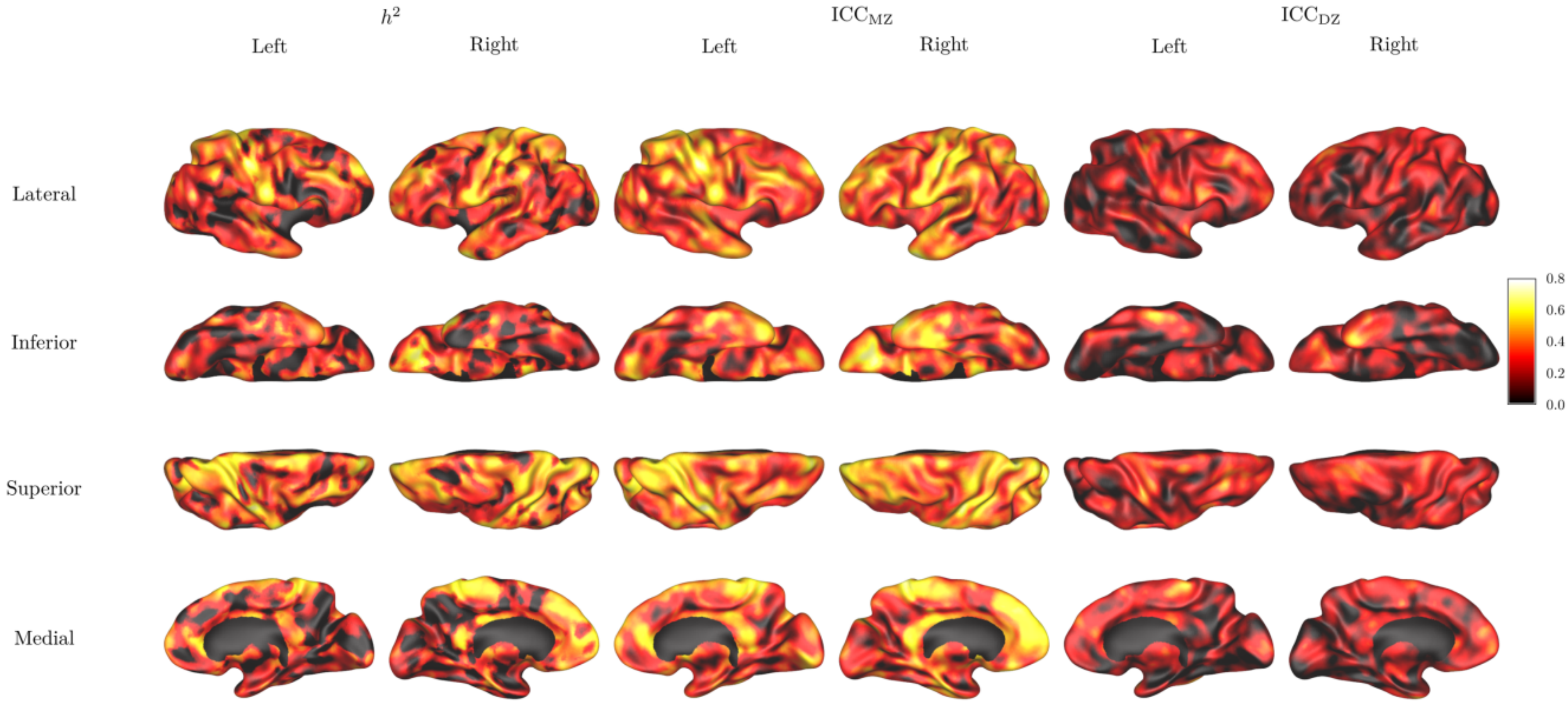


(a) A tractogram of fiber tracts with average $h^2 > 0.45$.

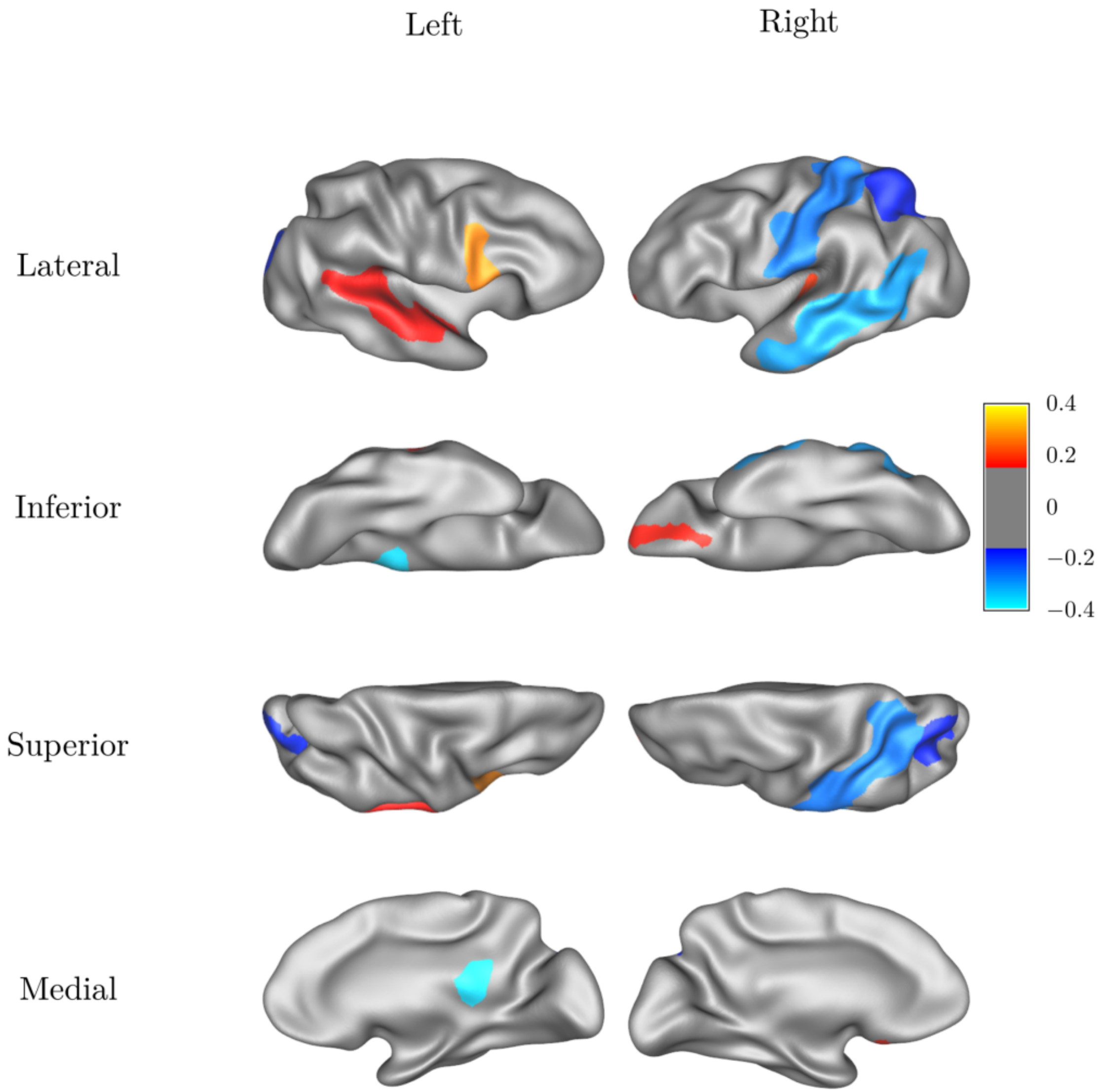


(b) mean h^2 of fiber tracts connected to each cortical region

Human Brain Mapping
Volume 37, Issue 6, pages 2331-2347, 23 MAR 2016 DOI: 10.1002/hbm.23177
http://onlinelibrary.wiley.com/doi/10.1002/hbm.23177/full#hbm23177-fig-0004



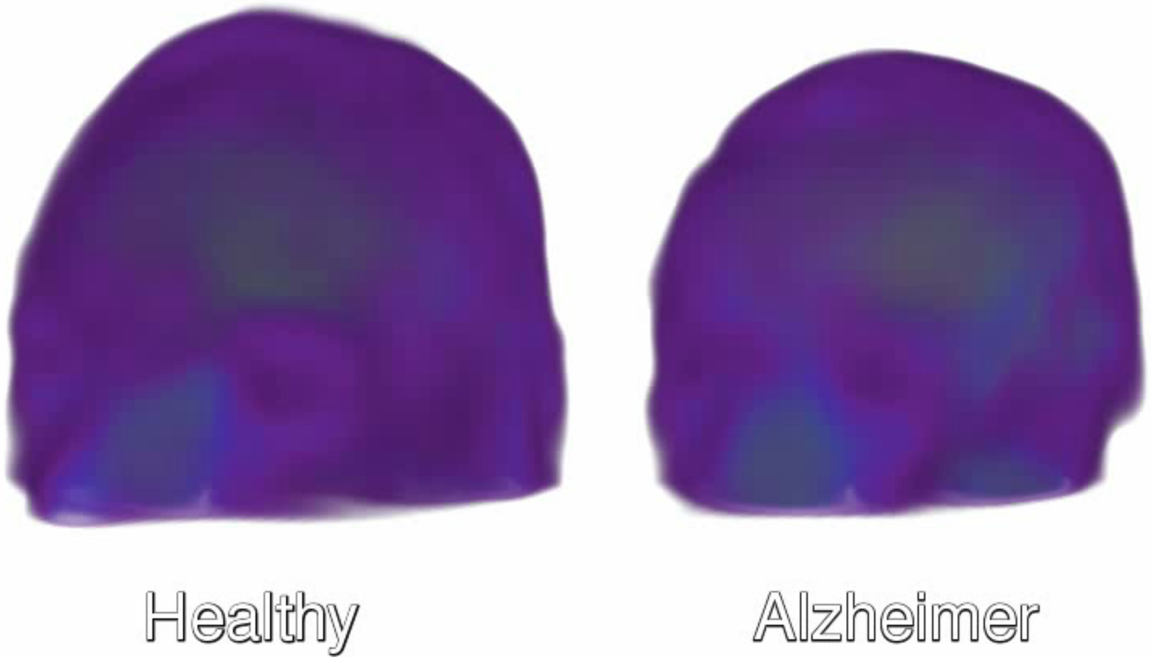
Heritability maps of cortical thickness. From left to right: heritability index h^2, intraclass correlation between monozygotic twins ICC_{MZ}, intraclass correlation between dizygotic twins ICC_{DZ}.



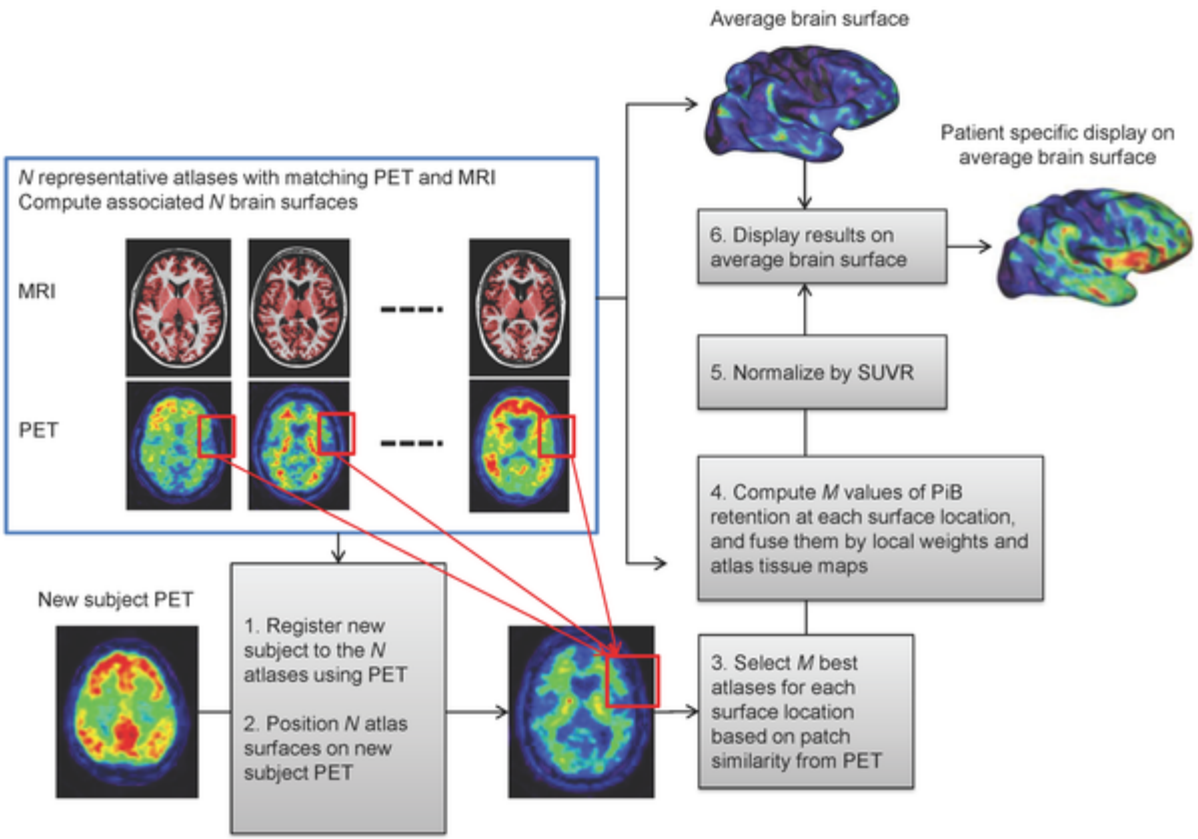
The genetic correlation r_g between the cortical thickness and white matter connectivity measured for each cortical region.

Positron Emission Tomography (PET)

- β-amyloid plaque in Alzheimer's disease
- PET ^{11}C-PiB has been used as the tracer in many clinical studies since 2006



PET: Quantification

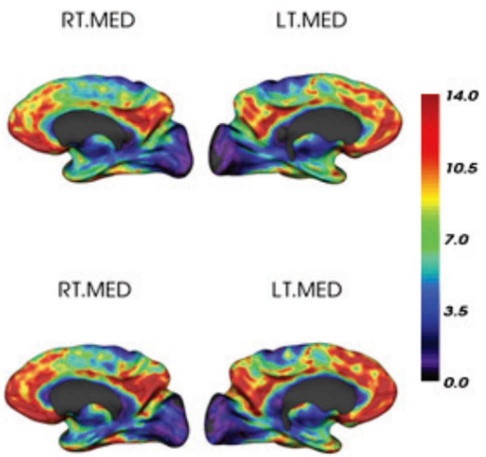


Multi-atlas

- Local Patch based selection.

- Bayesian Fusion

- Estimated GM



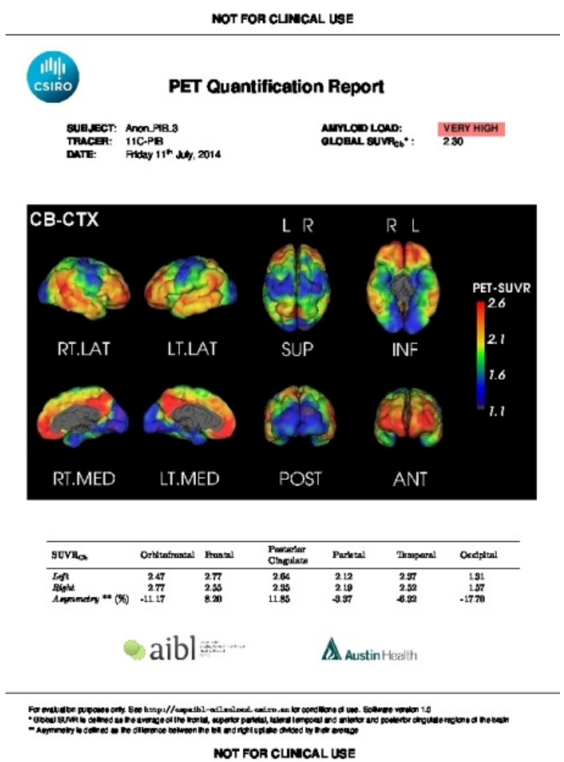
Results:
MR based top
PET only bottom

Zhou *et al*. (*PloS one*; Jan, 2014: DOI: 10.1371/journal.pone.0084777)

CapAIBL: PET Assessment of Neurodegeneration

MILXCloud: https://milxcloud.csiro.au/

- CapAIBL: PET quantification
- CurAIBL: MRI


NOT FOR CLINICAL USE

PET Quantification Report

SUBJECT: Anon_PIB.3
TRACER: 11C-PIB
DATE: Friday 11th July, 2014

AMYLOID LOAD: VERY HIGH
GLOBAL $SUVR_{Cb}$* : 2.30

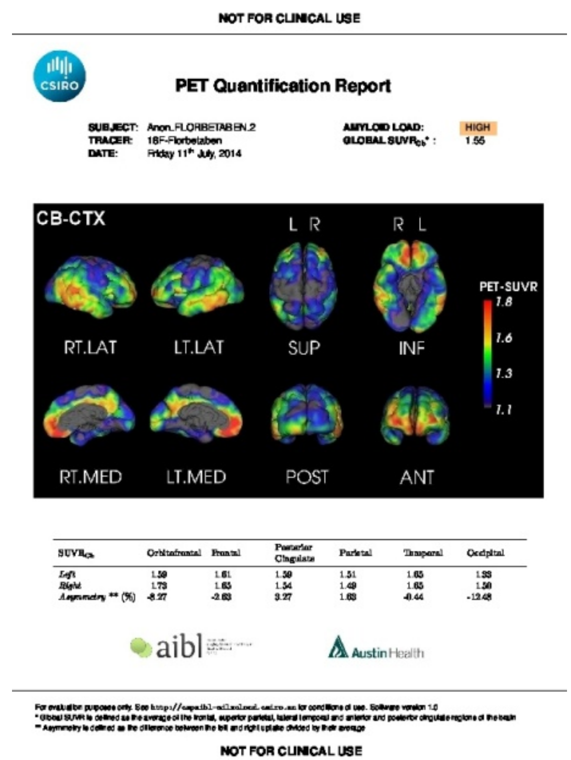
$SUVR_{Cb}$	Orbitofrontal	Frontal	Posterior Cingulate	Parietal	Temporal	Occipital
Left	2.47	2.77	2.64	2.12	2.37	1.31
Right	2.77	2.55	2.35	2.19	2.52	1.57
Asymmetry ** (%)	-11.17	8.20	11.85	-3.37	-6.32	-17.70

aibl

Austin Health

For evaluation purposes only. See https://capaibl-milxcloud.csiro.au for conditions of use. Software version 1.0
* Global SUVR is defined as the average of the frontal, superior parietal, lateral temporal and anterior and posterior cingulate regions of the brain
** Asymmetry is defined as the difference between the left and right uptake divided by their average

NOT FOR CLINICAL USE


NOT FOR CLINICAL USE

PET Quantification Report

SUBJECT: Anon_FLORBETABEN.2
TRACER: 18F-Florbetaben
DATE: Friday 11th July, 2014

AMYLOID LOAD: HIGH
GLOBAL $SUVR_{Cb}$* : 1.55

$SUVR_{Cb}$	Orbitofrontal	Frontal	Posterior Cingulate	Parietal	Temporal	Occipital
Left	1.59	1.61	1.59	1.51	1.65	1.33
Right	1.73	1.65	1.54	1.49	1.65	1.50
Asymmetry ** (%)	-8.27	-2.63	3.27	1.63	-0.44	-12.48

aibl

Austin Health

For evaluation purposes only. See https://capaibl-milxcloud.csiro.au for conditions of use. Software version 1.0
* Global SUVR is defined as the average of the frontal, superior parietal, lateral temporal and anterior and posterior cingulate regions of the brain
** Asymmetry is defined as the difference between the left and right uptake divided by their average

NOT FOR CLINICAL USE

Acknowledgement

Olivier Salvado
Jurgen Fripp
(CSIRO)

Pierrick Bourgeat
Shekhar Chandra
Amy Chan
David Conlan
Vincent Doré
Amir Fazlollahi
Aleš Neubert
Kerstin Pannek
Anthony Paproki
Parnesh Raniga
Lee Reid
Ying Xia

Prof. Ralph Martins
(MQ, AARF)

Pratishtha Chatterjee
Cintia Dias
Mitra Elmi
Sunil Gupta
Maryam Mohamaadi
Danit Saks
Tejal Shah

Sabine Bird
Belinda Brown
Samatha Gardener
Simon Laws
Stephanie Rainey-Smith
Hamid Sohrabi
Kevin Taddei
Sherilyn Tan
Michael Weinborn

Thank you

Kaikai Shen

Kaikai.Shen@csiro.au