Institute of Neurosciences and Medicine: Medical Imaging Physics

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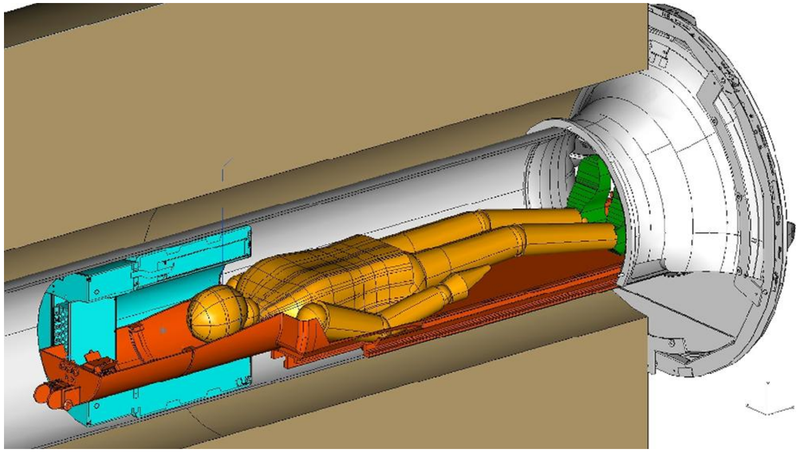

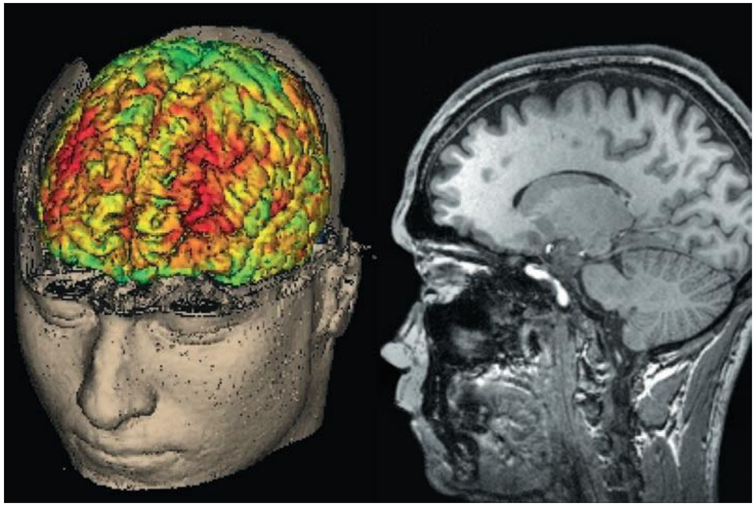

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Physics of MRI

Interdisciplinary team of physicists, engineers, technicians, psychologists, neurologists, biologists, and others

Hardware development

Pulse sequence development

Novel contrasts, biophysical background

fMRI (functionl MRI)

Combined MRI - PET (Positron Emission Tomography)

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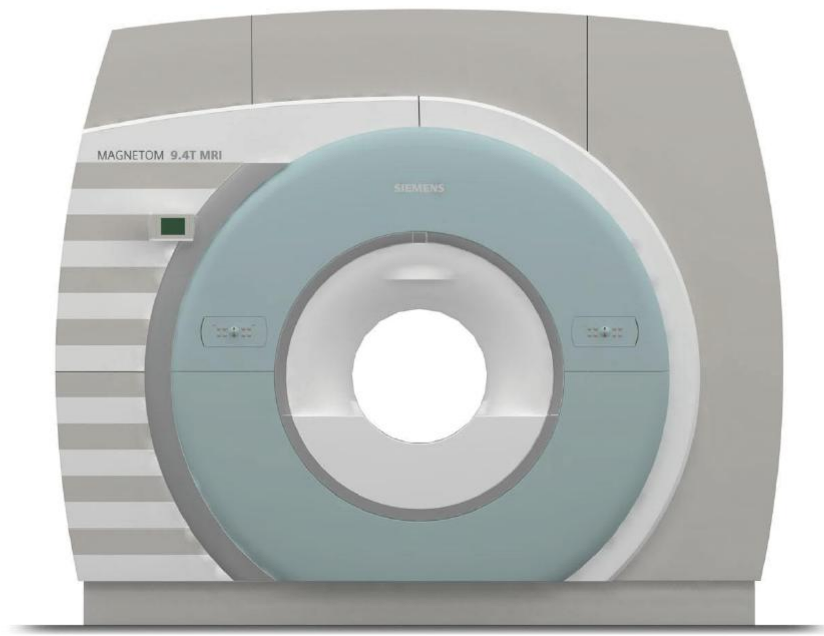
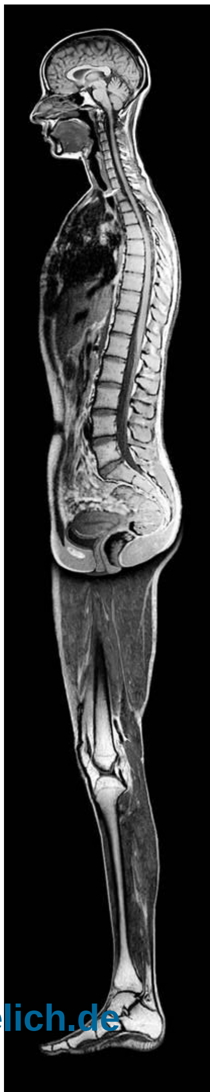
9.4T Whole-Body Scanner in Jülich

The 9.4 tesla hybrid device is a genuine technological giant—a 57 tonne magnet, whose magnetic field is shielded with the help of 900 tonnes of iron...

- 60 cm patient bore
- TQ-engine gradient coil
- 50 cm FoV
- Magnet weight: 57 tonnes
- 870 tonnes of iron shielding
- 3.70 m length
- Stored energy: 182.0 MJ
- Length of wire: 750 km





Complete with Hybrid PET Capability!

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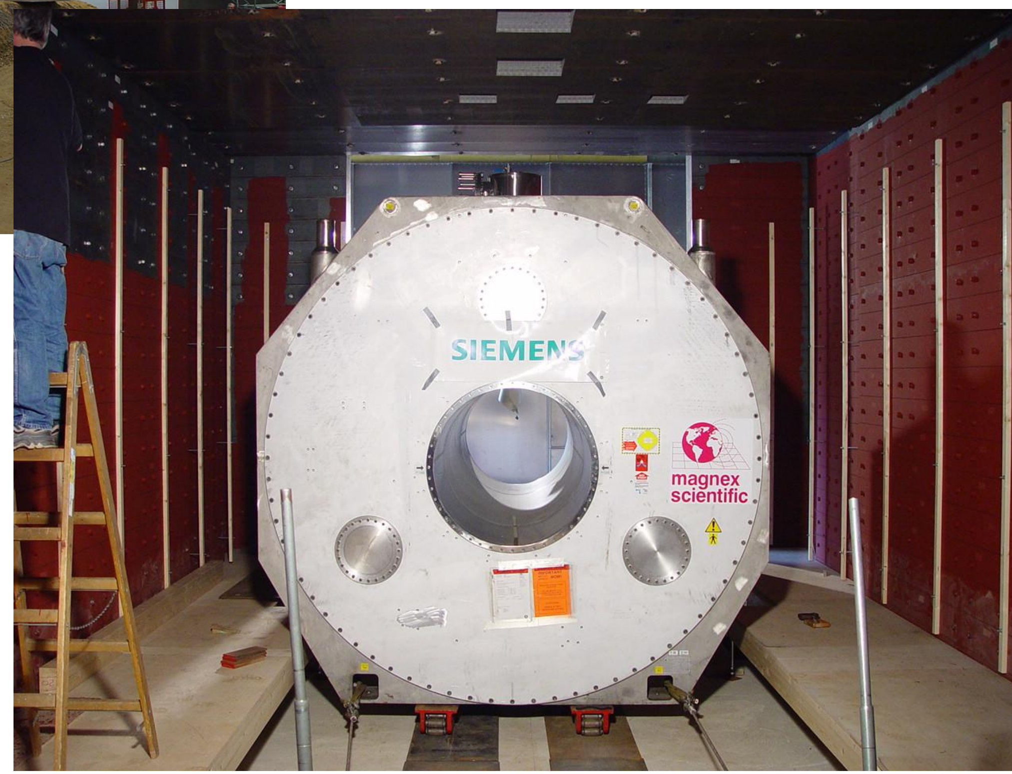

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Outline

Introduction

Ultra-high field MRI

Hybrid MR-PET

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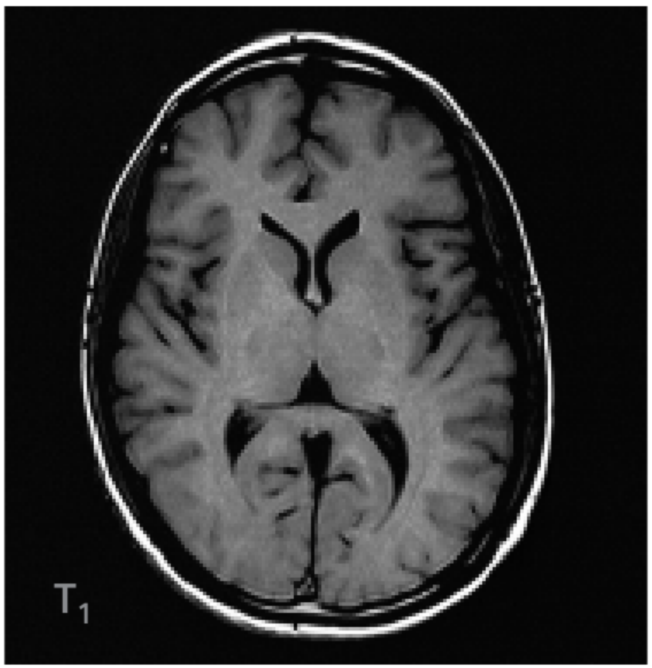
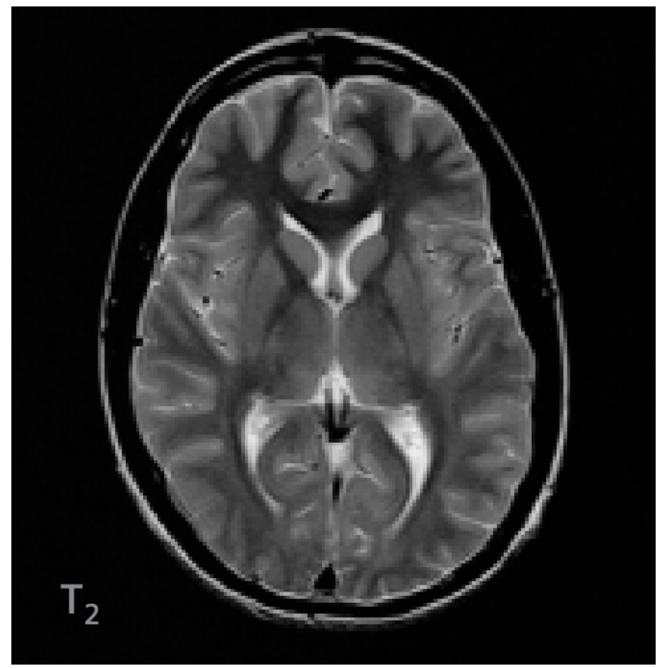
Tissue contrast mechanisms

Proton density, T1 and T2 relaxation rates
Apparent diffusivity
Variation of magnetic susceptibility
Variations and in-flow of blood plasma protons





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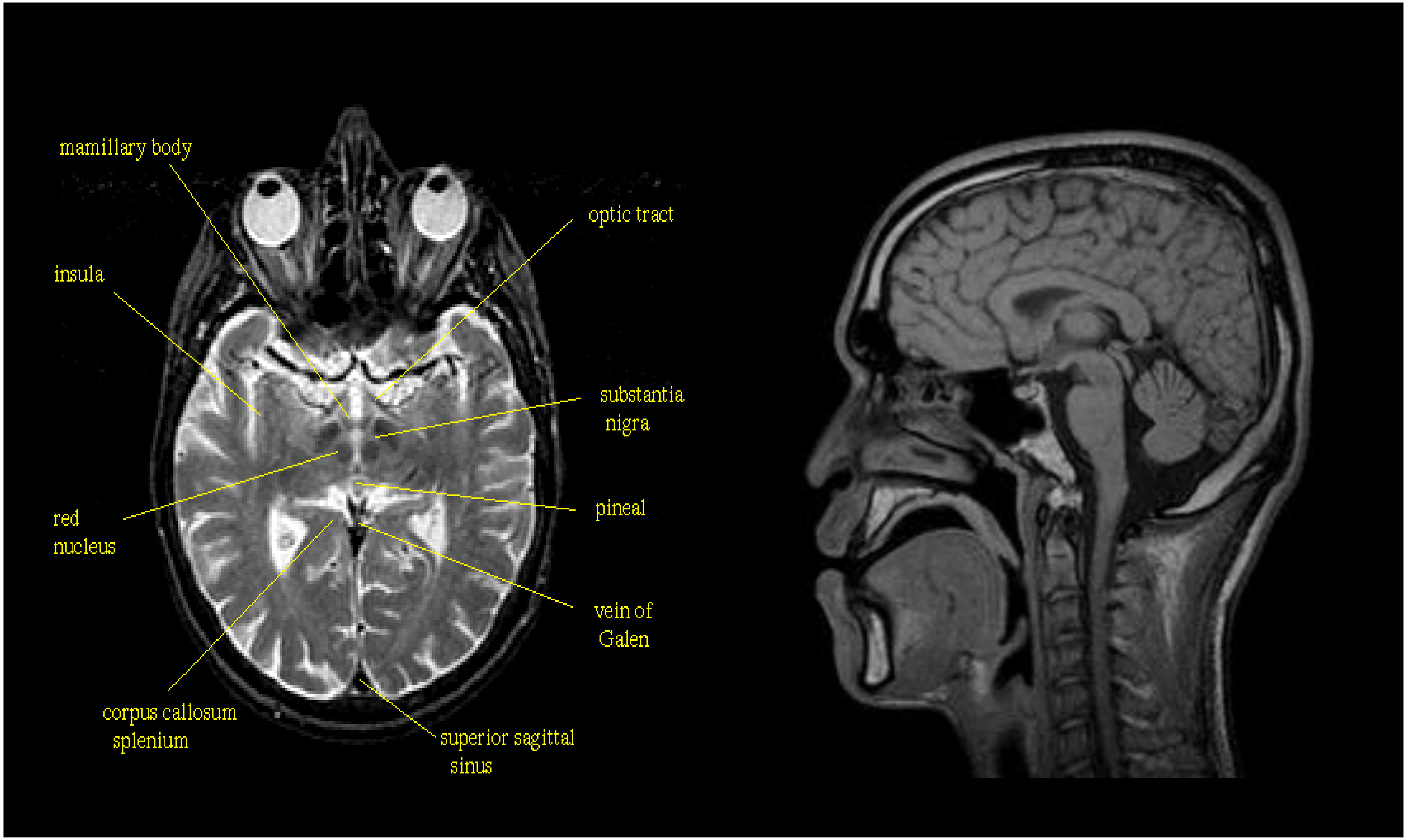
Human brain as seen by MRI: anatomy



Data sources : Left - The Whole-brain Atlas, K. A. Johnson and J. A. Becker, Harvard; Right - SMIS UK Ltd.

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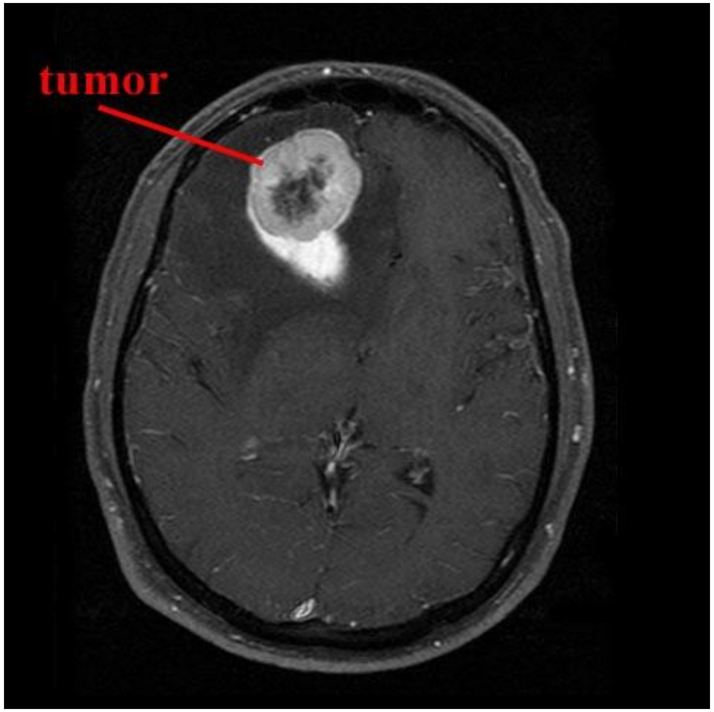
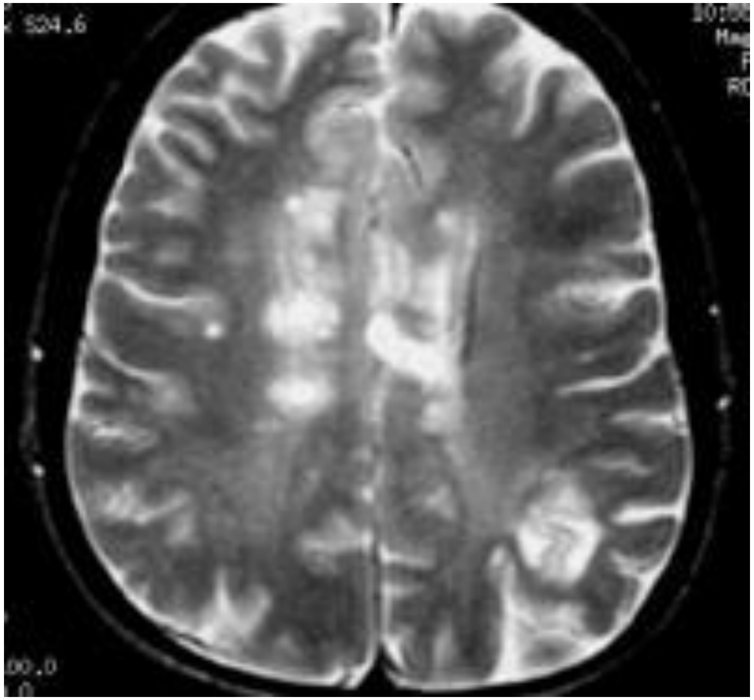
Diagnostics in clinical applications

Tumours



White matter plaques in MS
multiple sclerosis



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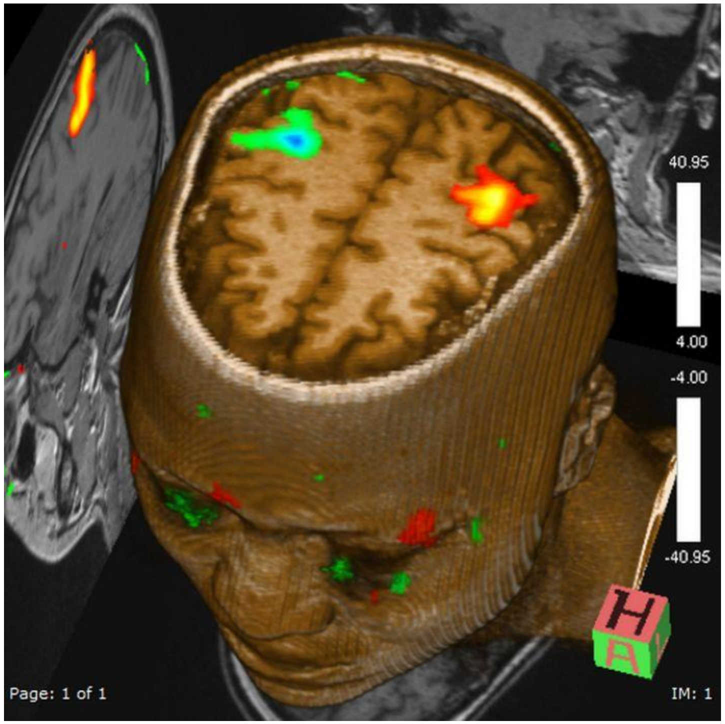
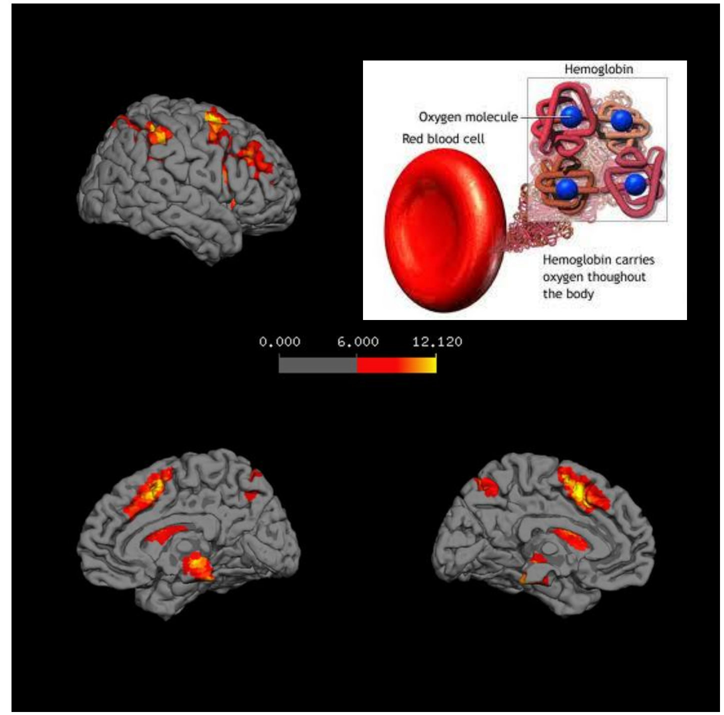
fMRI: “BOLD” effect in activated regions "blood oxygenation level dependent“





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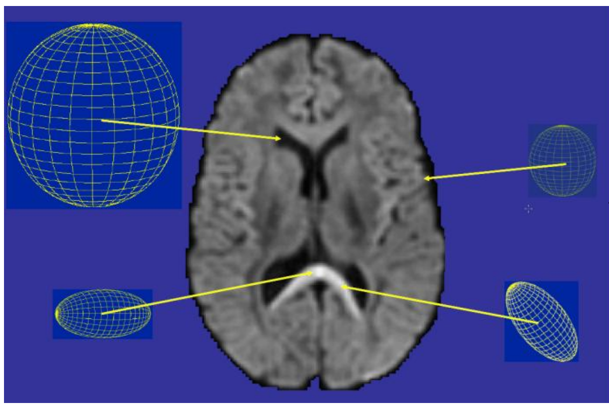
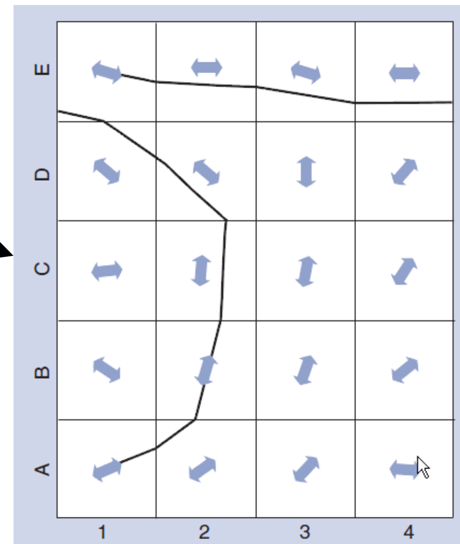
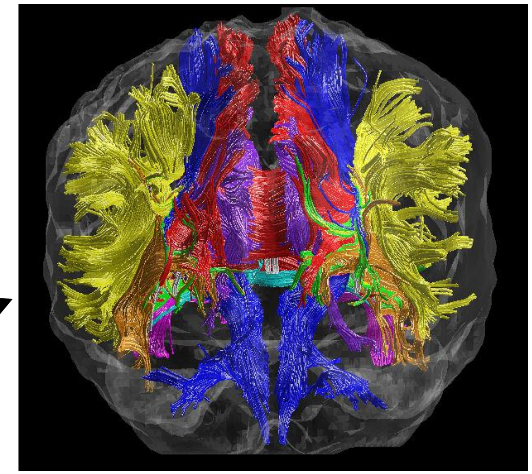
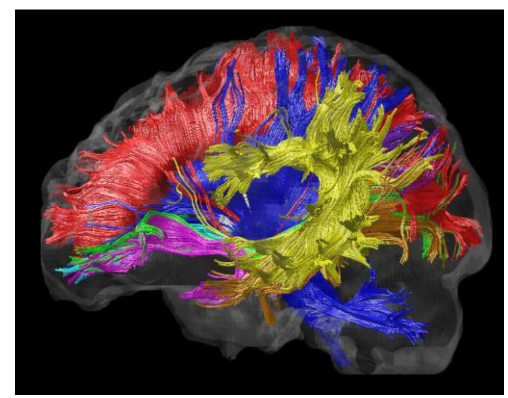
Diffusion measurements: axonal architecture (“fibre tracking”)

different gradient directions









Many challenges for theoretical and experimental physicists in developing new improved methods and algorithms

From image gallery
www.neuroimaging.tau.ac.il

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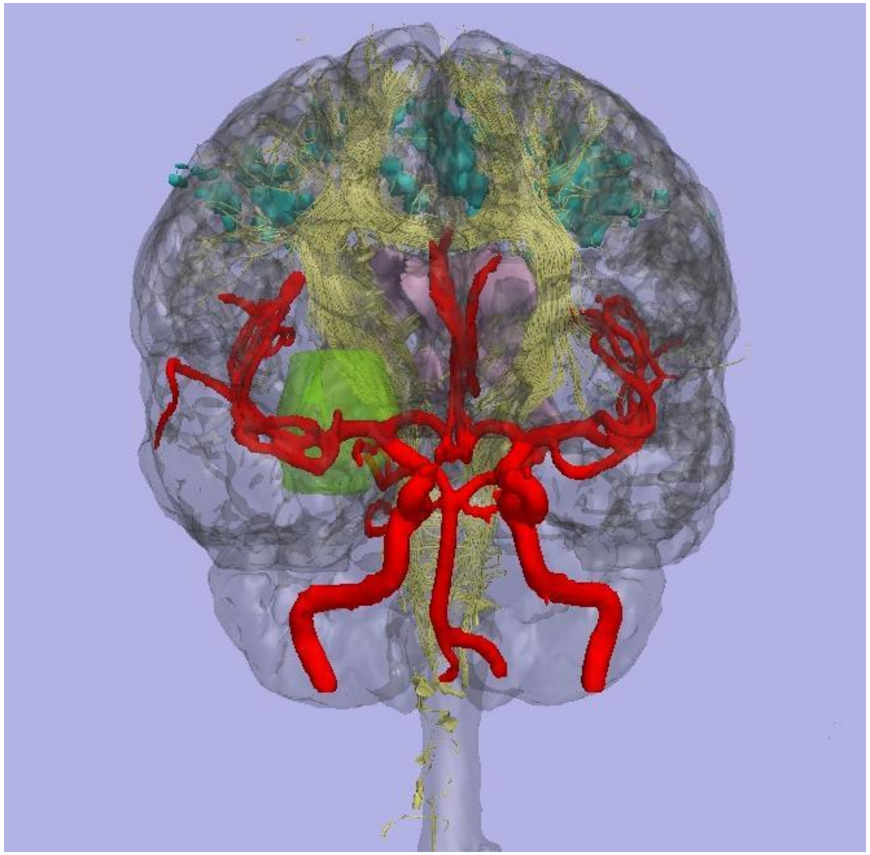
Use in neurosurgery



http://groups.csail.mit.edu/vision/medical-vision/DTIGuidedSurgery/

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Mitglied der Helmholtz-Gemeinschaft

Ultra-High-Field MRI

Opportunities

… MRI

⇒ Higher spatial resolution (structural imaging)
⇒ Higher functional (BOLD) contrast
⇒ Better image quality (contrast)
⇒ Non-proton MRI and spectroscopy

… PET

⇒ Partial volume correction with MRI
⇒ Attenuation correction with MRI
⇒ Motion correction with MRI (navigator echoes)

… Hybrid MR-PET

⇒ Patient / volunteer compliance: 2 scans in 1 (at 3T and 9.4T)
⇒ Metabolic imaging (e.g. FDG + 17O + 31P + 23Na + MP-RAGE)
⇒ Accurate receptor density mapping
⇒ Novel paradigms for brain function

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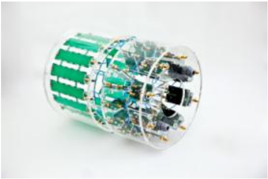
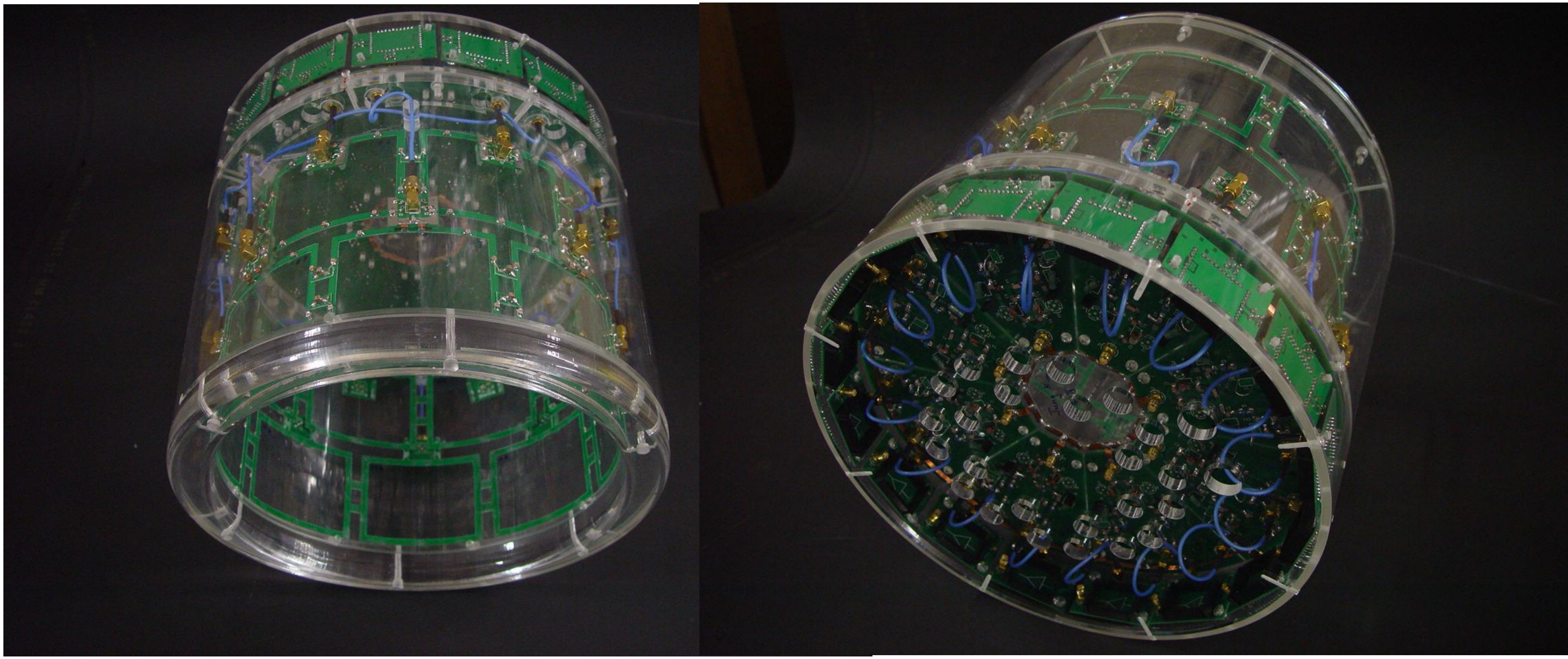
Hardware



A major focus is the design of new coils and coil arrays for human as well as animal applications at high fields



Multi-transmit, multi-recieve channels

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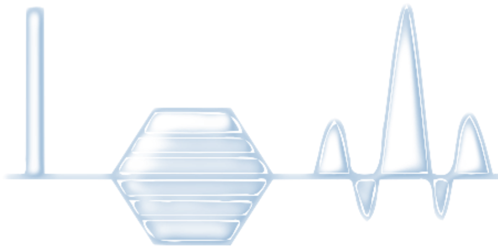
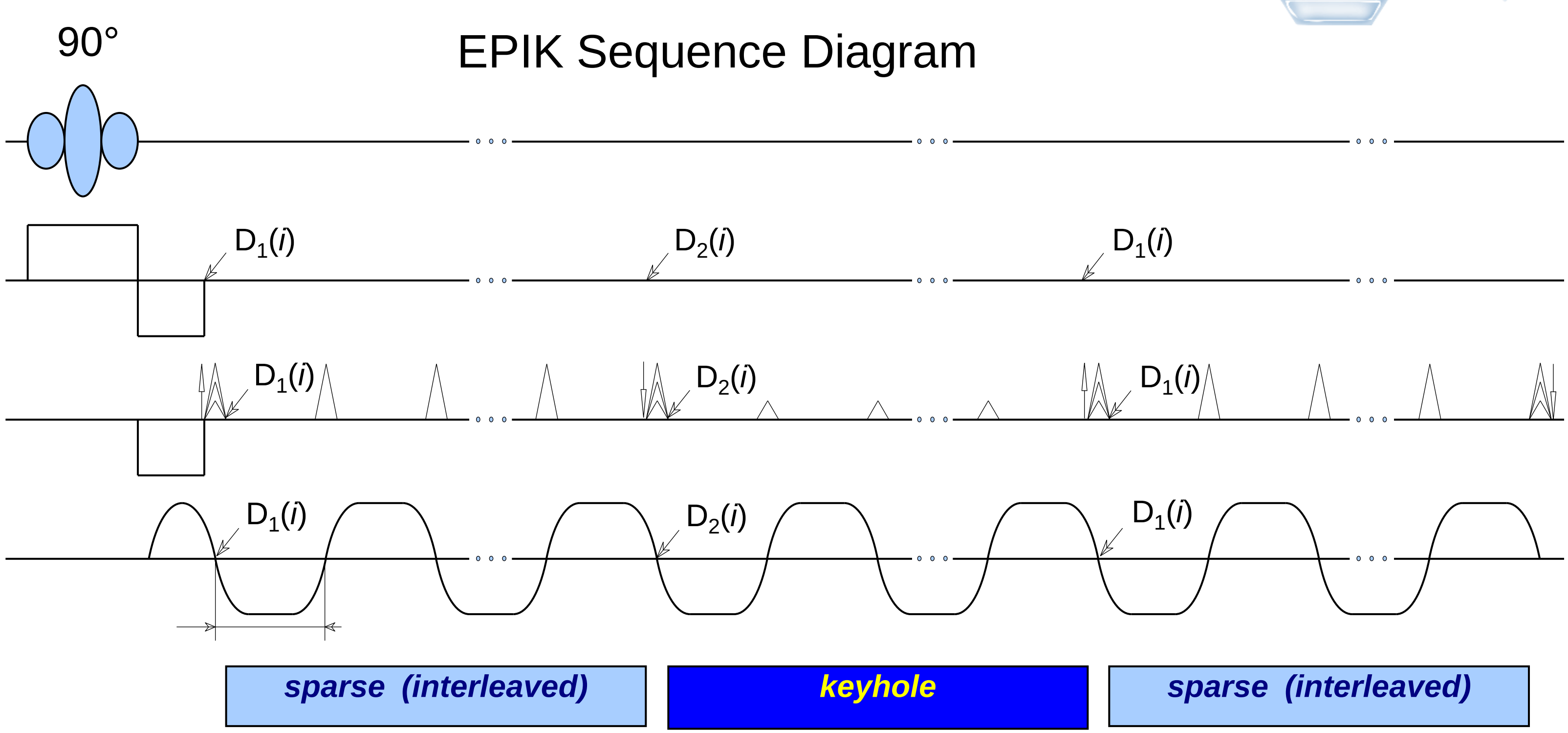
Pulse sequences



the design of new Magnetic Resonance Imaging (MRI) techniques tailored to neuroscientific applications

EPIK Sequence Diagram



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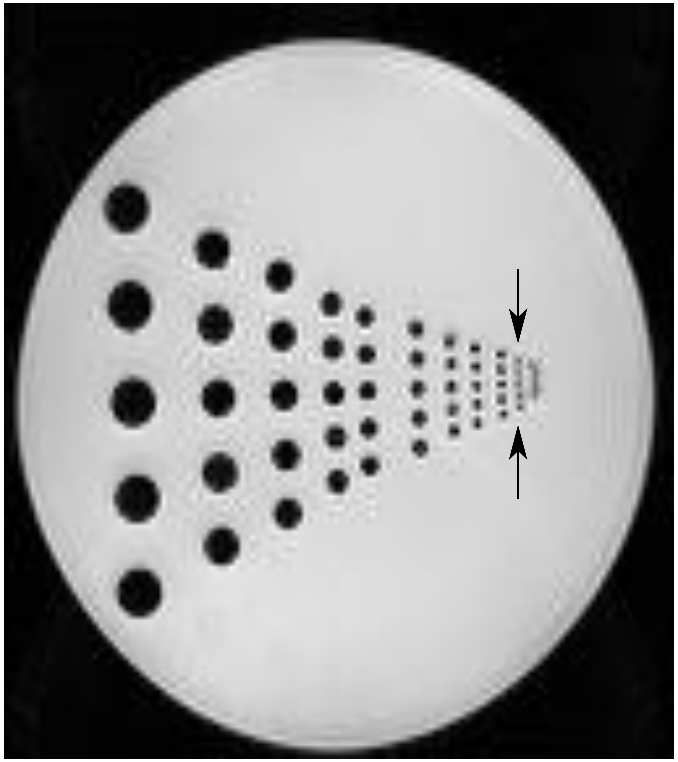
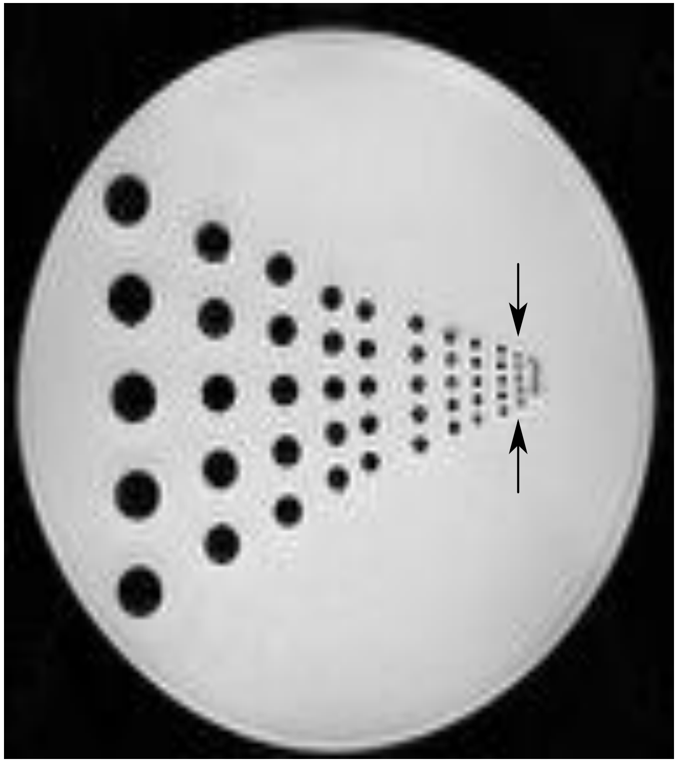
Spatial Resolution of EPIK



EPI



EPIK

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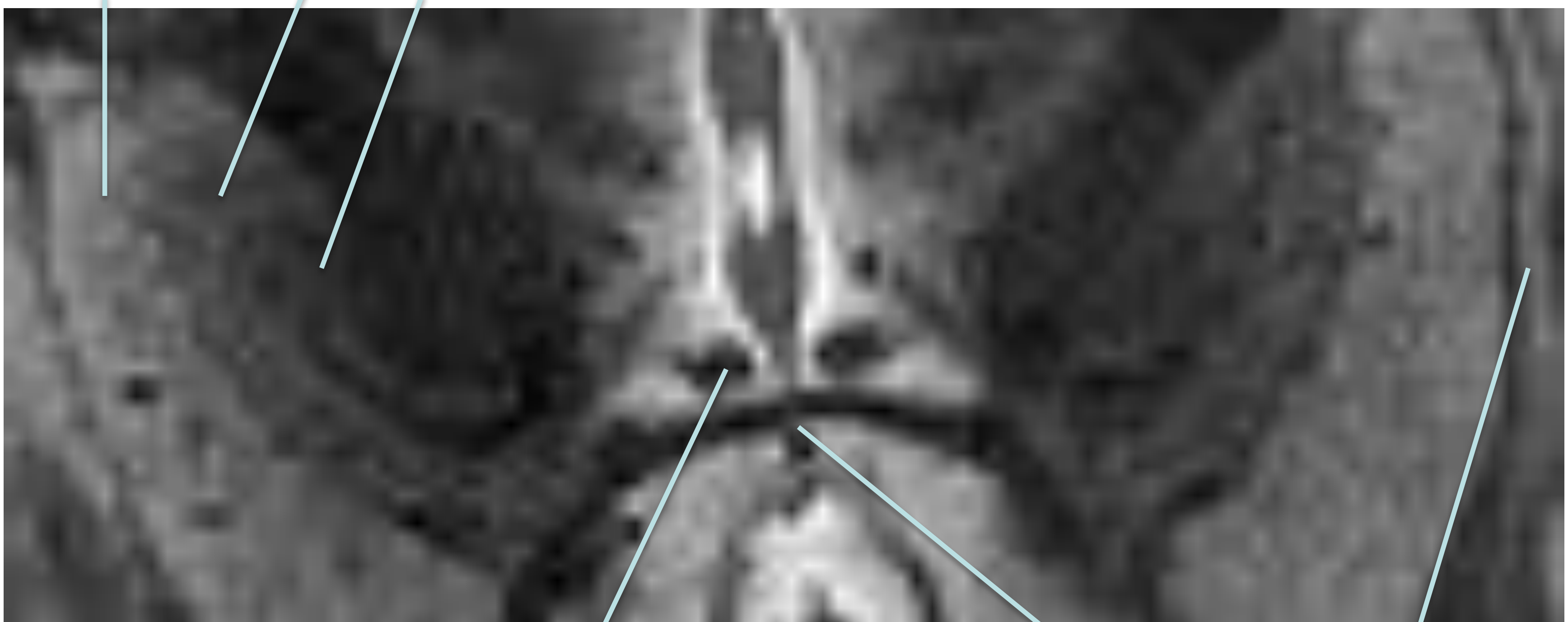
Structural imaging

Basal ganglia, 3T, axial

A.M. Oros-Peusquens



600x600x600µm^3

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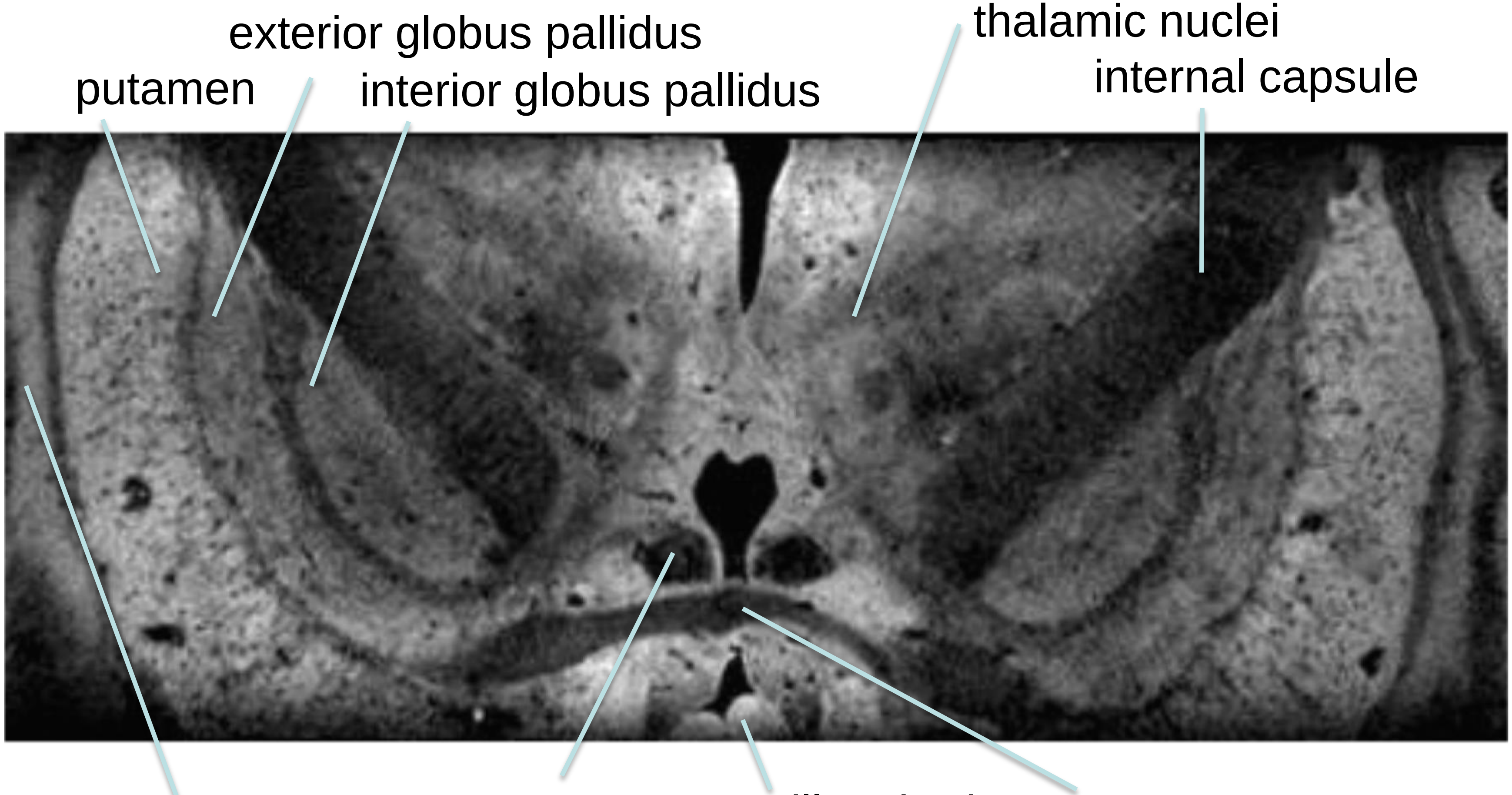
Basal ganglia, 9.4T, axial



$120x120x120\mu m^3$

125 times smaller voxels

A.M. Oros-Peusquens

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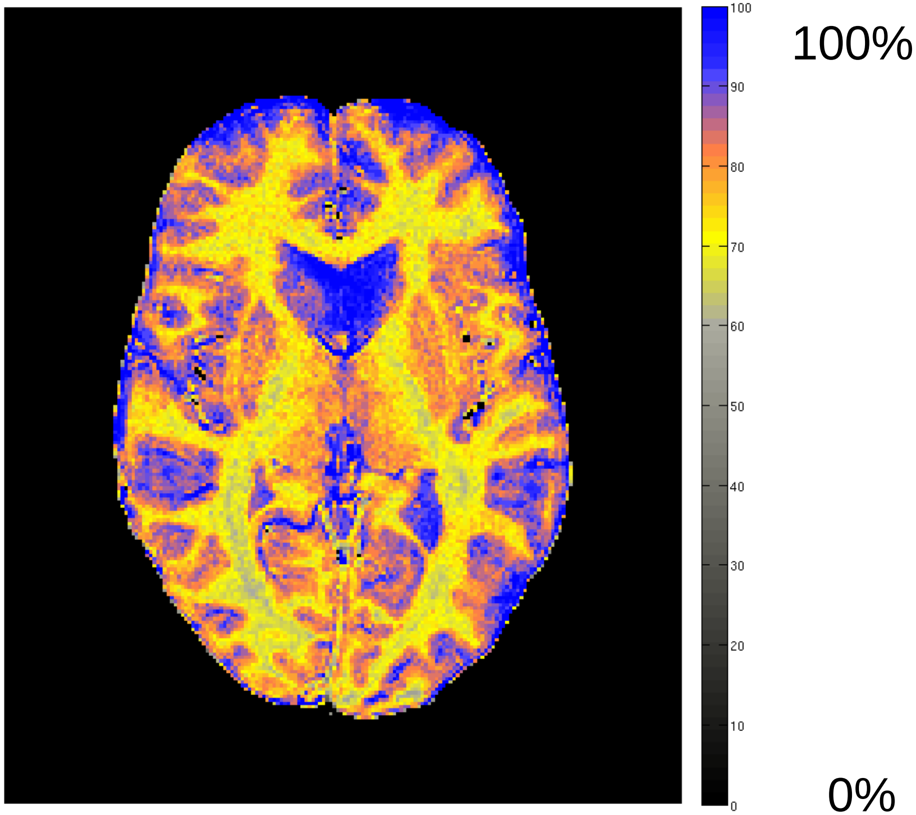
Quantitative imaging

Quantitative imaging of the brains a challenging perspective in the MRI community, aiming to extract physical parameters from native MRI images

Watermap



(Fabian Keil)

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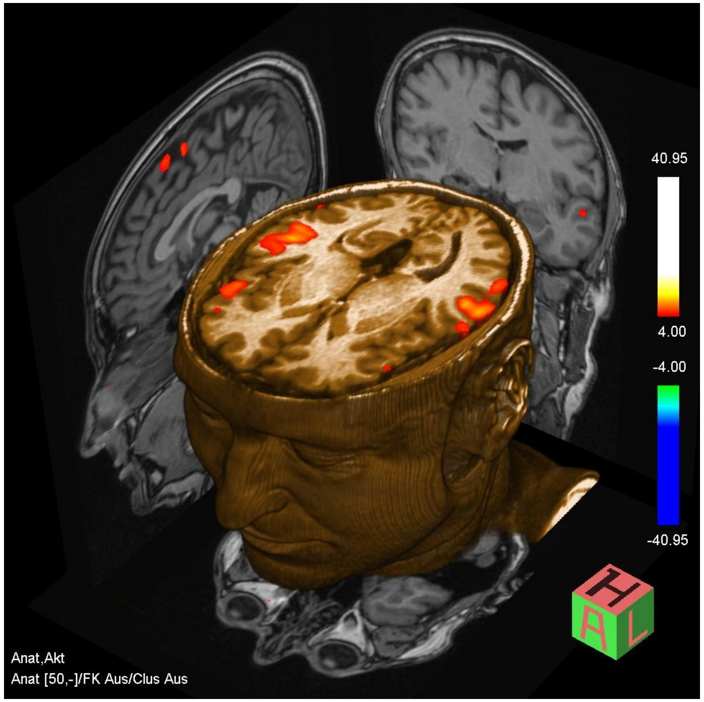
Benefits for fMRI: more signal, higher resolution

… in progress



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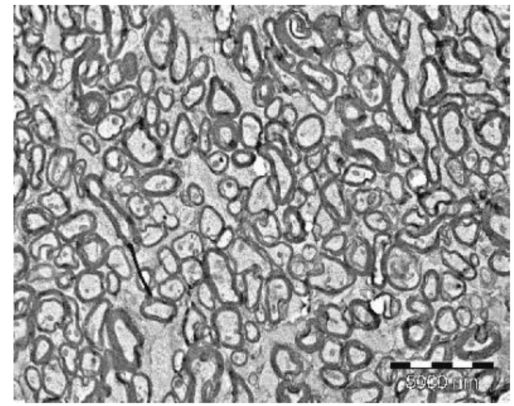
Diffusion MRI is a unique modality of MRI

Diffusion “samples” the microstructure

- Tissue microstructure

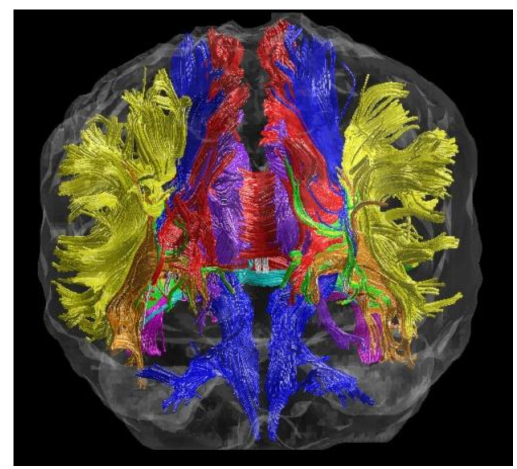
  (~ 1-10 µm)



Cellular level

- Global white matter organization

  (~ 0.1 - 10 cm)



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dMRI provides biomarkers of tissue integrity

Our aims are to establish advanced techniques and to develop new applications in the field of the neurological brain research and diagnostics.

- neurodegenerative pathologies (Alzheimer’s and Parkinson’s diseases, etc.)

- development and aging

- stroke

- tumours

- neurosurgical planning

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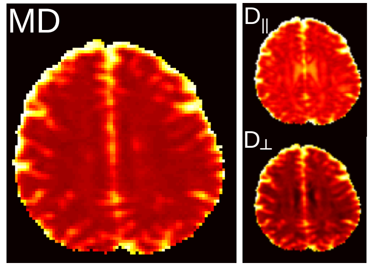
Gaussian model

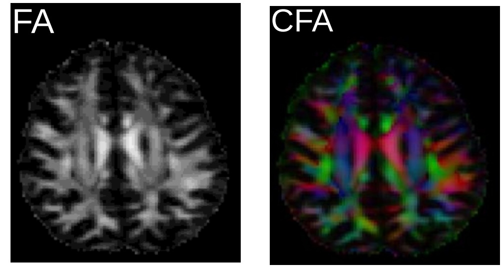
DTI

$S(b) = \exp(-bD)$

ADC

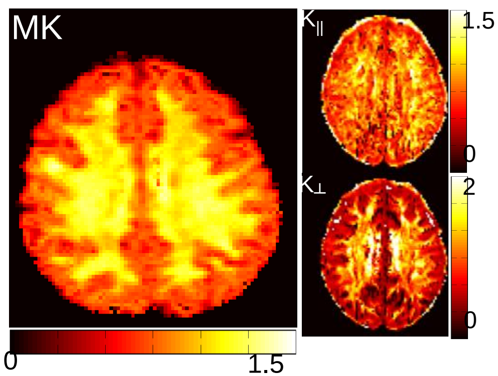


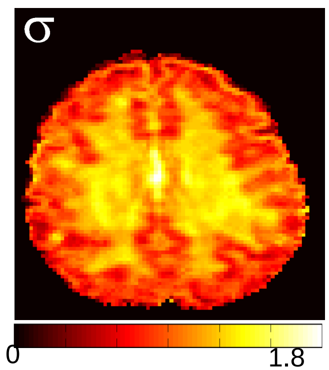
Fractional anisotropy

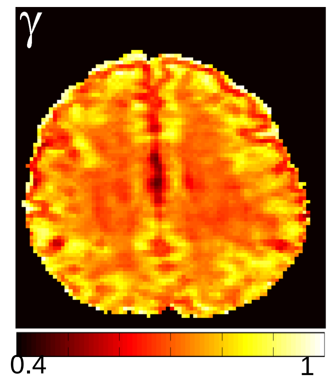


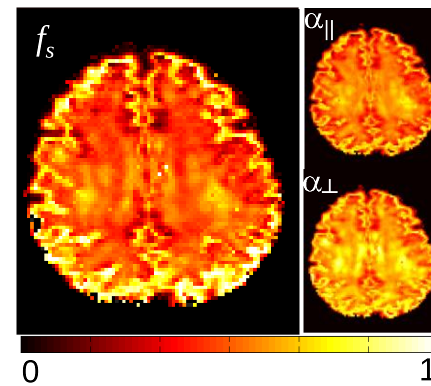
3T Siemens MAGNETOM Trio, healthy volunteer

Non-Gaussian: all DTI metrics + a rich variety of novel maps









DKI

$S(b)=\exp\left(-bD+\frac{1}{6}(bD)^2K\right)$

kurtosis

LNDFI

$S(b)=\int P(D)\exp(-bD)\,dD$

$P(D)=\frac{1}{D\sigma\sqrt{2\pi}}\exp\left(-\frac{(\ln D-\ln D_{LD})^2}{2\sigma^2}\right)$

Log-normal distribution

Anomalous DI

$S(b)=\exp\left[-(bD)^{\gamma}\right]$

Stretched-exponential

BEDTA

$S(b)=f_f e^{-bD_f}+(1-f_f)e^{-bD_s}$

$f_s=1-f_f$

Bi-exponential tensor

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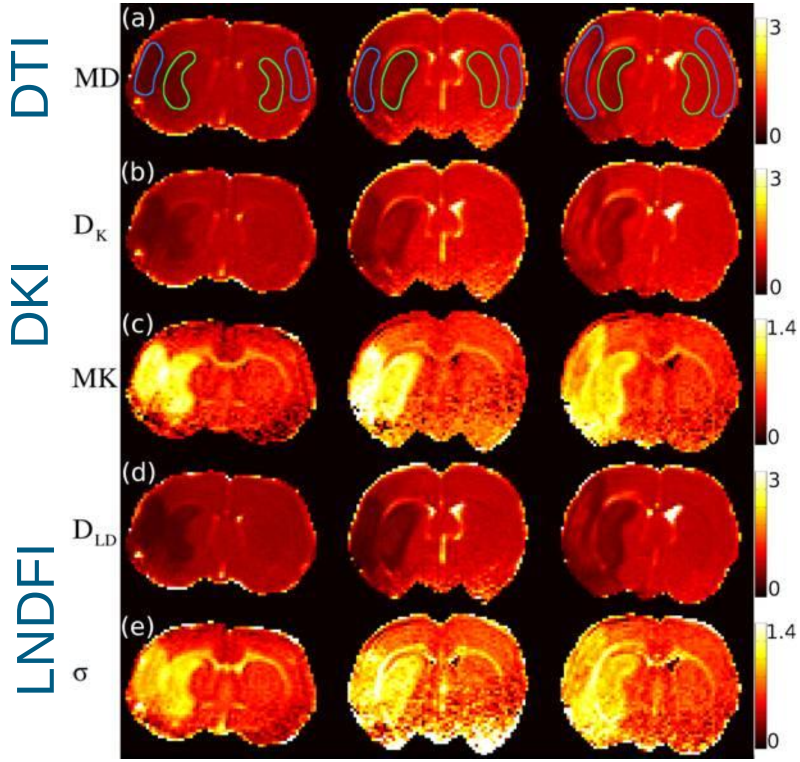
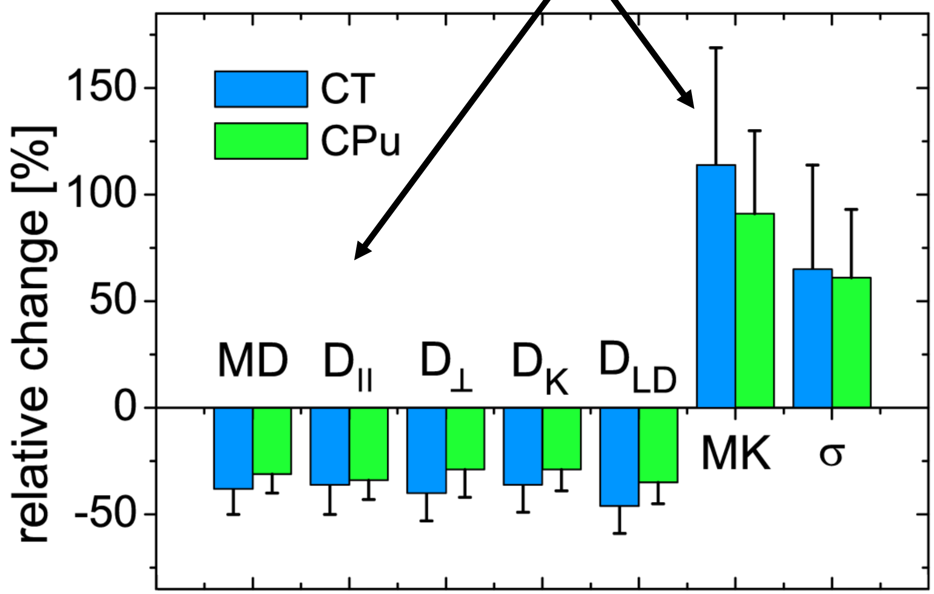
Non-Gaussian metrics in stroke

a remarkable contrast!



DKI and LNDFI show much larger change in stroke than DTI



ADC ~ 40 %

MK ~ 100 -150%

σ ~ 60 - 75%

F. Grinberg et al., NMR Biomed, 2011

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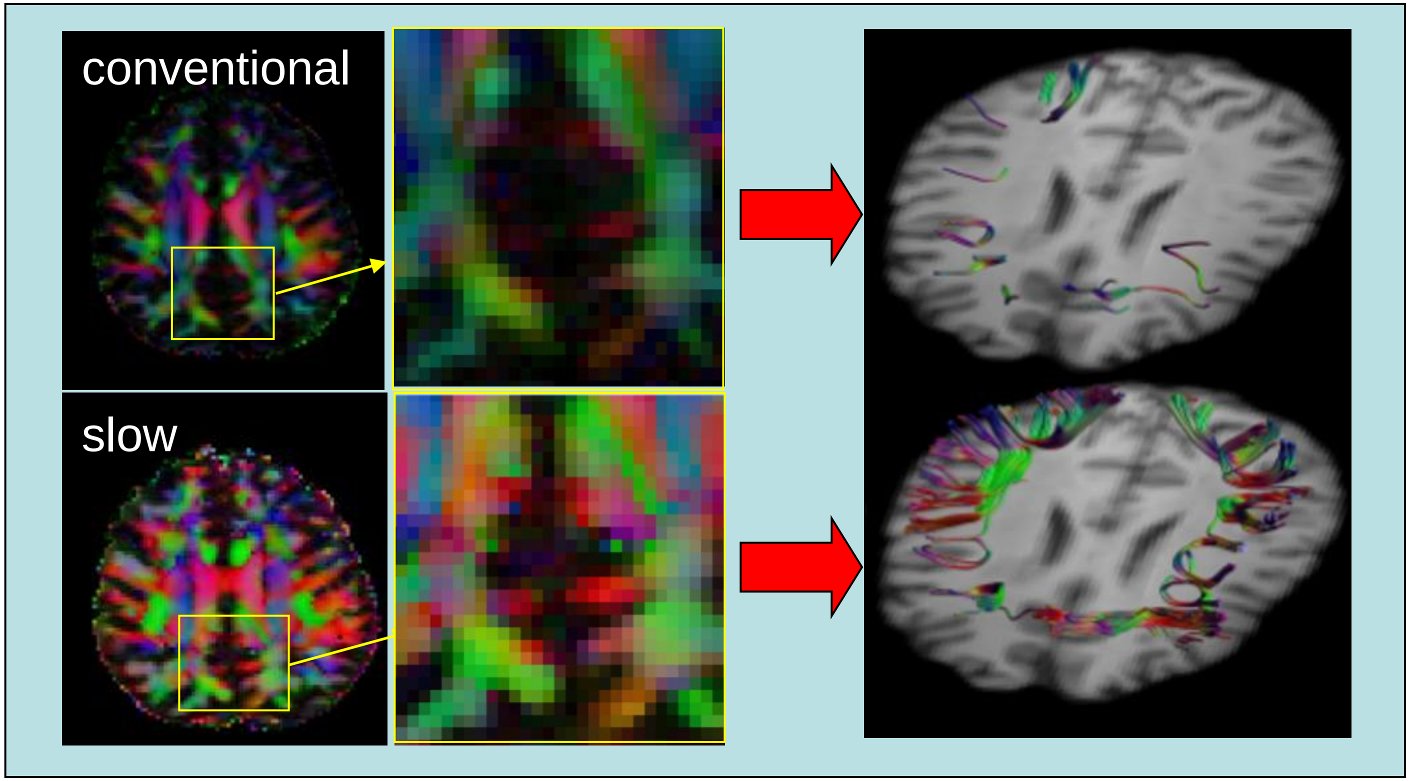
BEDTA: benefits for fibre tracking

Pre-cortical fibres



more WM structures and more fibre tracks are visualised!

Grinberg F., et al., Neuroimage, 2011

Fibre tracks – Dr. I. Maximov, E. Farrher

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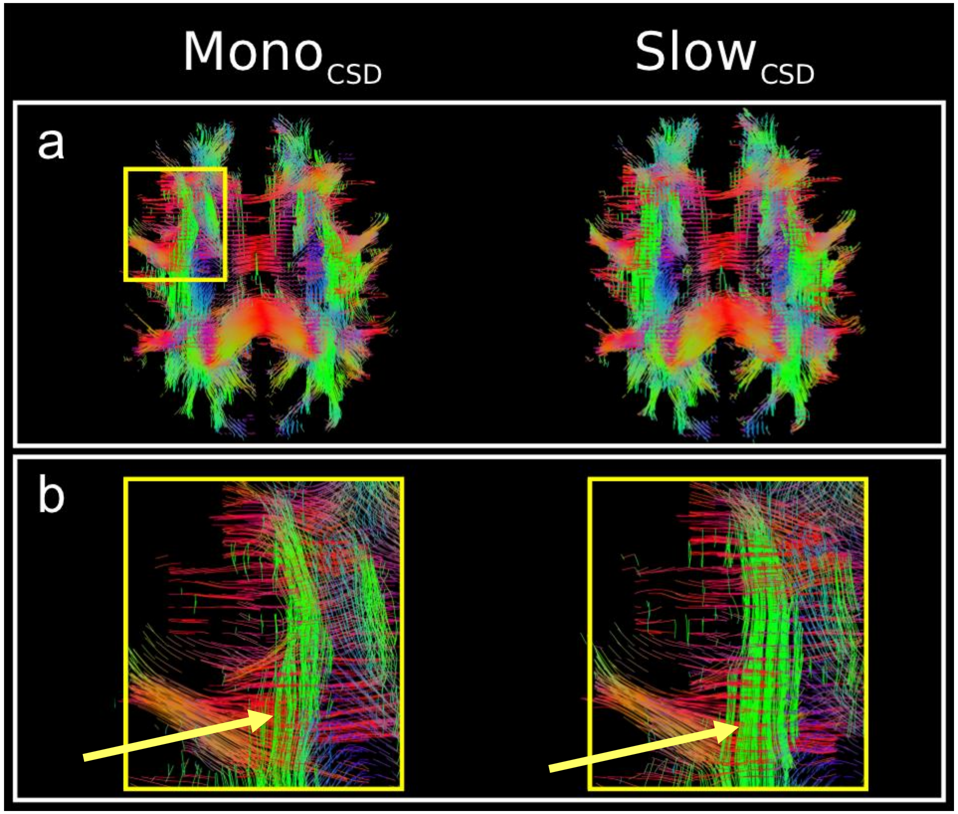
Crossing-fibre regions



MI - SDIFT (Microstructure Informed Slow Diffusion Fibre Tracking) improves visualization in crossing-fibre regions

Grinberg F., et al., JMRI, subm.

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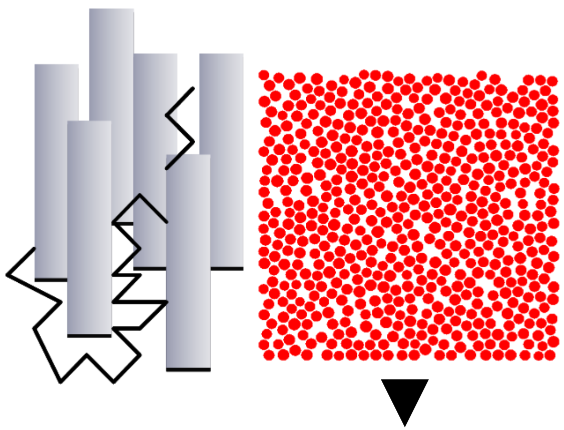
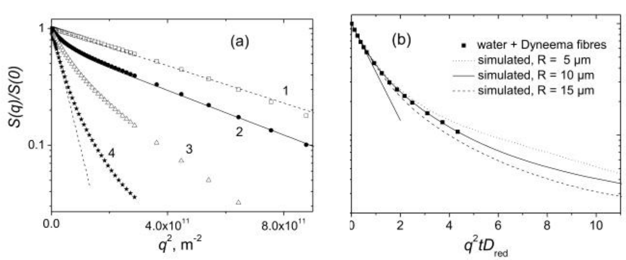
Biophysical background

Random Walks in the Model Brain Tissue

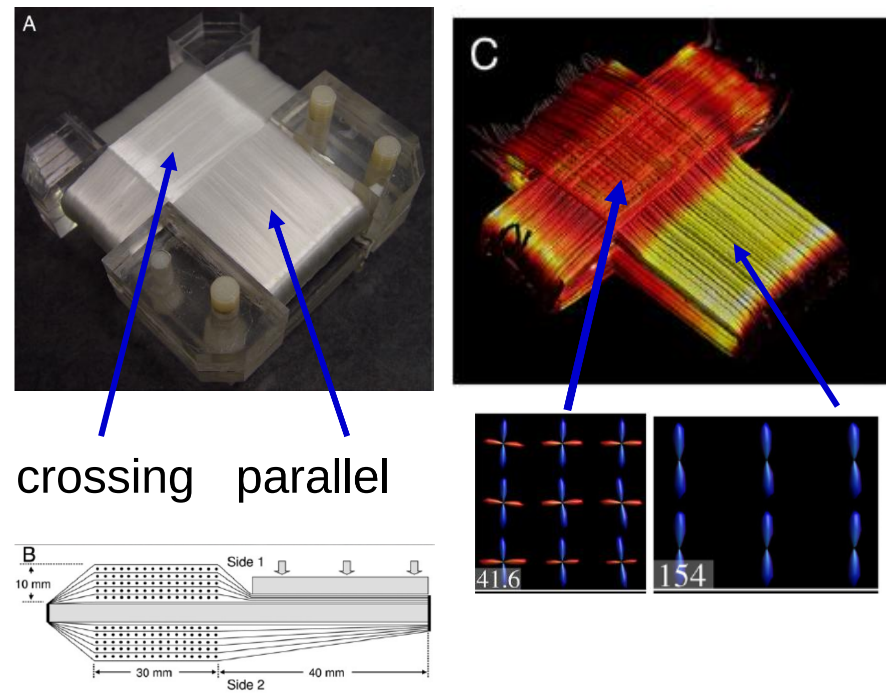
Monte Carlo simulations





Grinberg F, et al., AIP Conf Proc, 2011

Development of artificial systems



Farrher E, et al., Magn Reson Imaging, 2012

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Perspectives

- More efficient biomarkers of degenerative diseases, aging, etc.?
- Correlation of structural and functional connectivity?
- Dynamic features (neuroplasticity)?
- Combinations with other MRI and non-MRI modalities
- Novel 2D pulse sequences, new features (micro-anisotropy)

We are looking forward to interdisciplinary co-operations!

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Opportunities – Metabolic Imaging

… Sodium
⇒ Na / K Pump
⇒ Disturbances of the pump often leads to cell death
⇒ Intra vs extracellular sodium with TQF

… Phosphorus
⇒ Energy metabolism of the cell
⇒ In vivo pH

… Oxygen
⇒ Intimately involved in metabolism!
⇒ …..

… Glucose
⇒ Energy substrate of the brain
⇒ FDG PET

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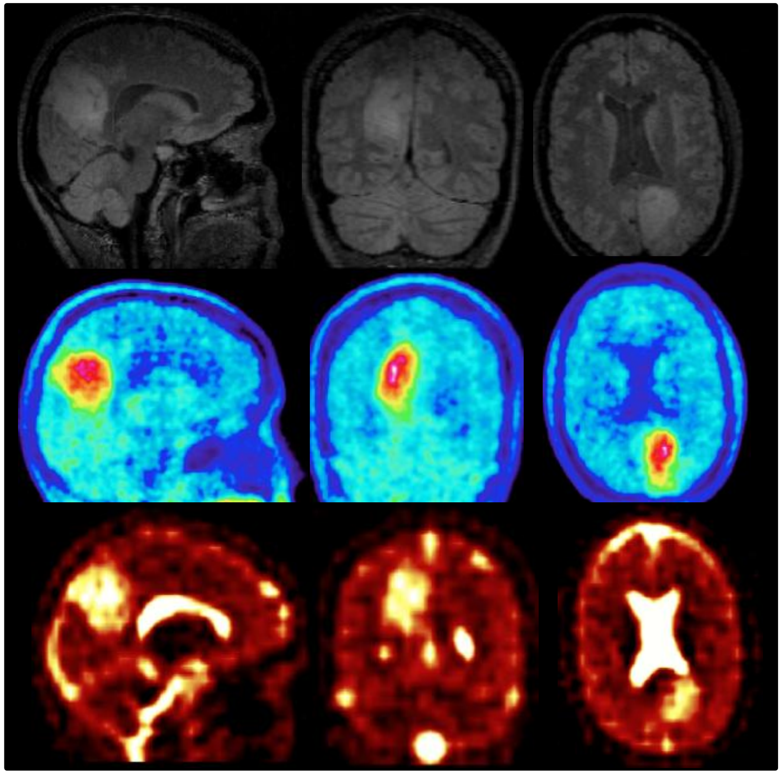
Examples: Metabolism (^{23}Na-Imaging)

Oligodendroglioma Grade II

FLAIR

FET-PET

Sodium @ 4T



Sodium is one of the most important ions for the physiology of the cell, essential for a variety of cellular functions. In healthy tissue, sodium is present in the intracellular and in the extracellular compartments at highly regulated concentrations.

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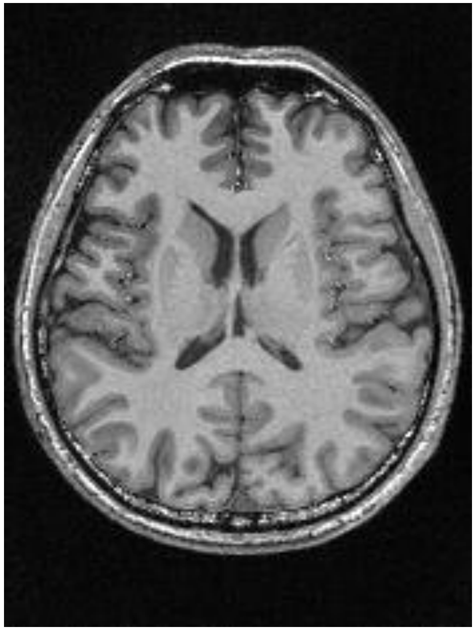
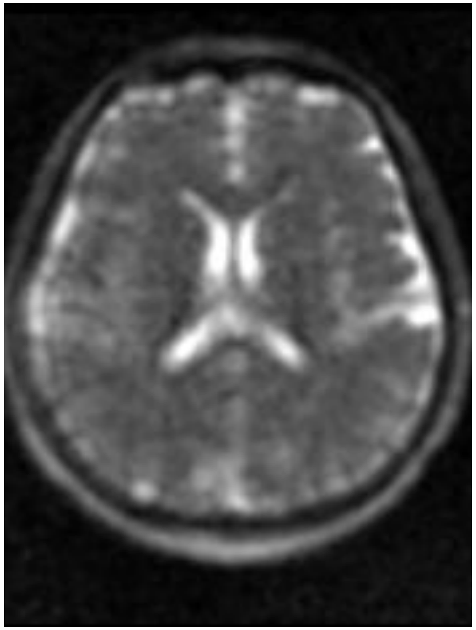
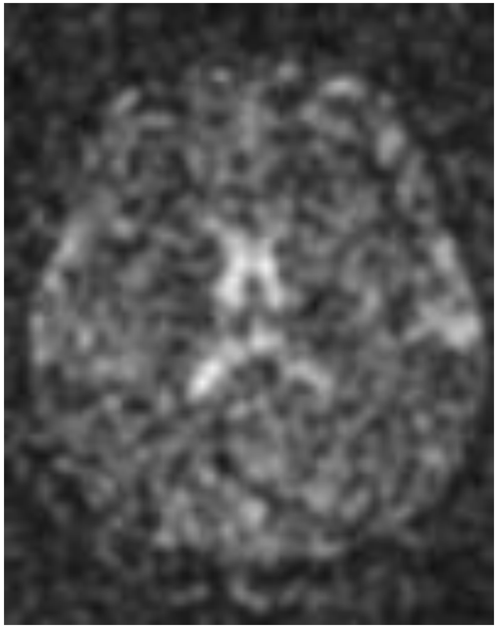
Sodium MRI: first *In vivo* 9.4 T results



Anatomy - 1H
MP-RAGE 4T
1 mm isotropic
5 min acq. time



Sodium – 9.4T
TPI
2 mm isotropic
15 min acq. time



Sodium – 4T
TPI
2 mm isotropic
15 min acq. time

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Excitation of a region of interest

- **High field enables high resolution** imaging (MRI microscopy)
- However, high resolution spatial encoding *needs long acquisition time*
- Solution: reduce the acquisition to the *region of interest by means of selective excitation*

9.4T post mortem brain

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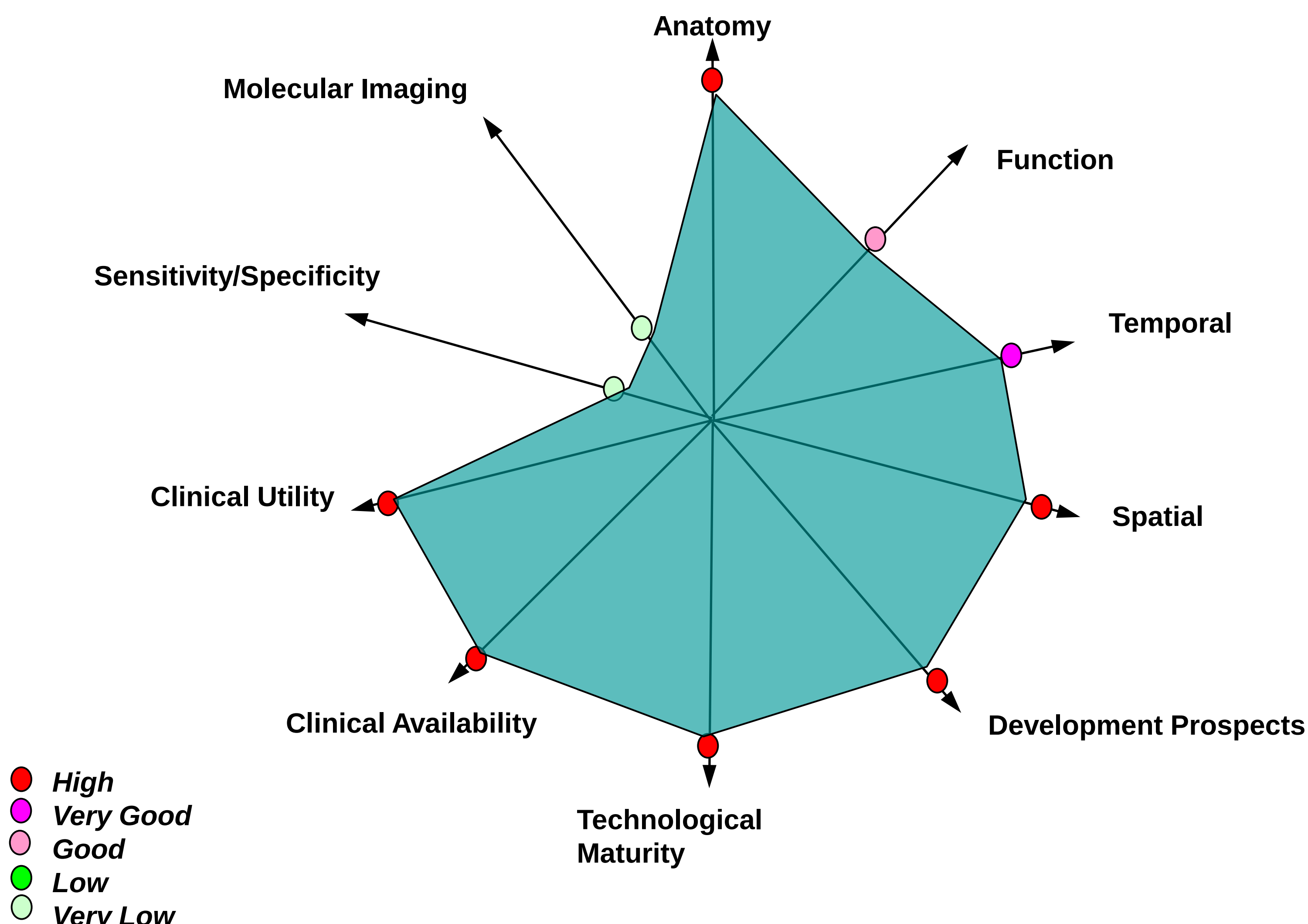
Hybrid MR-PET

new scientific achievements by using the synergetic potential of the combined MR-PET imaging.

Magnetic Resonance Imaging



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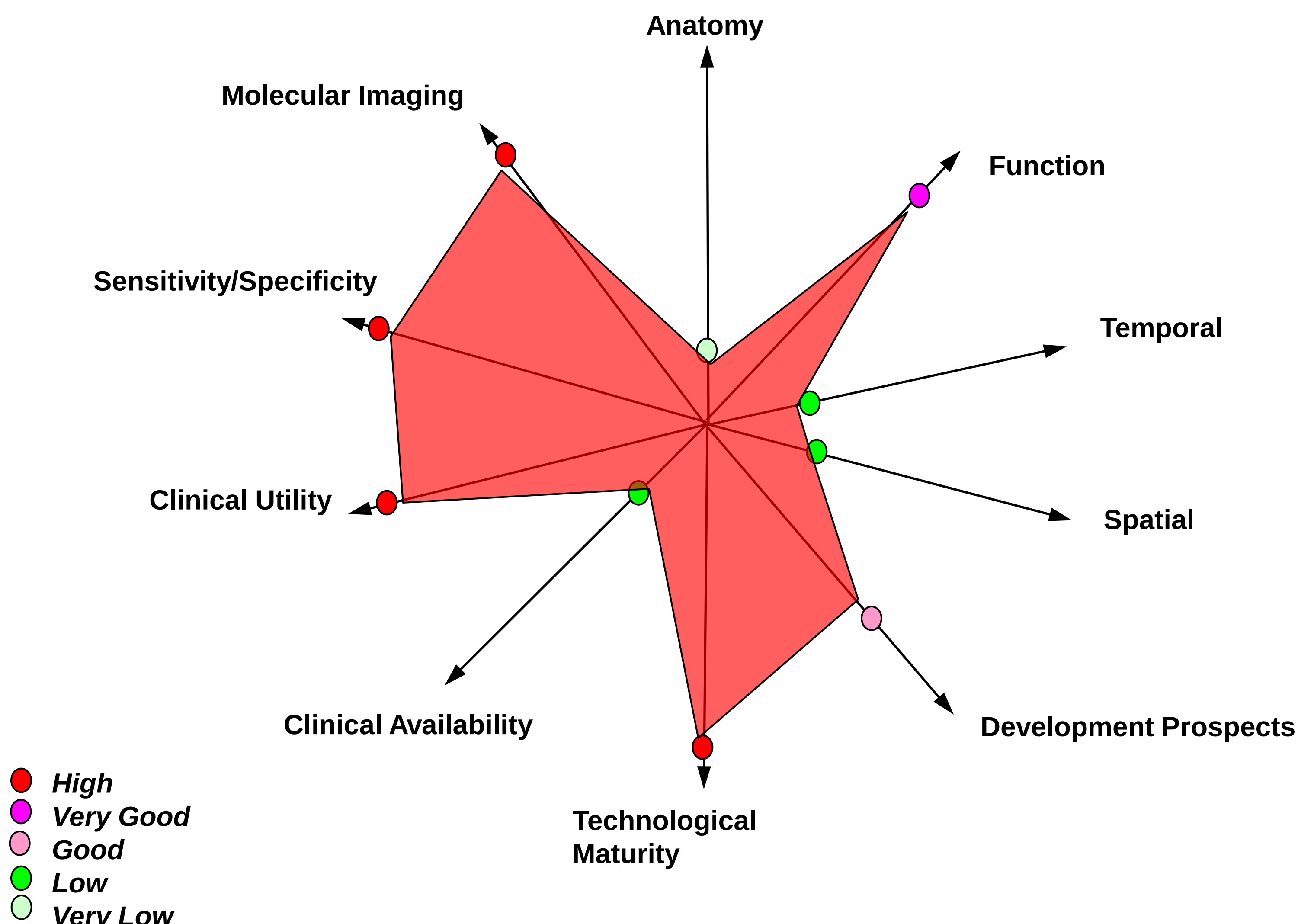
Positron Emission Tomography



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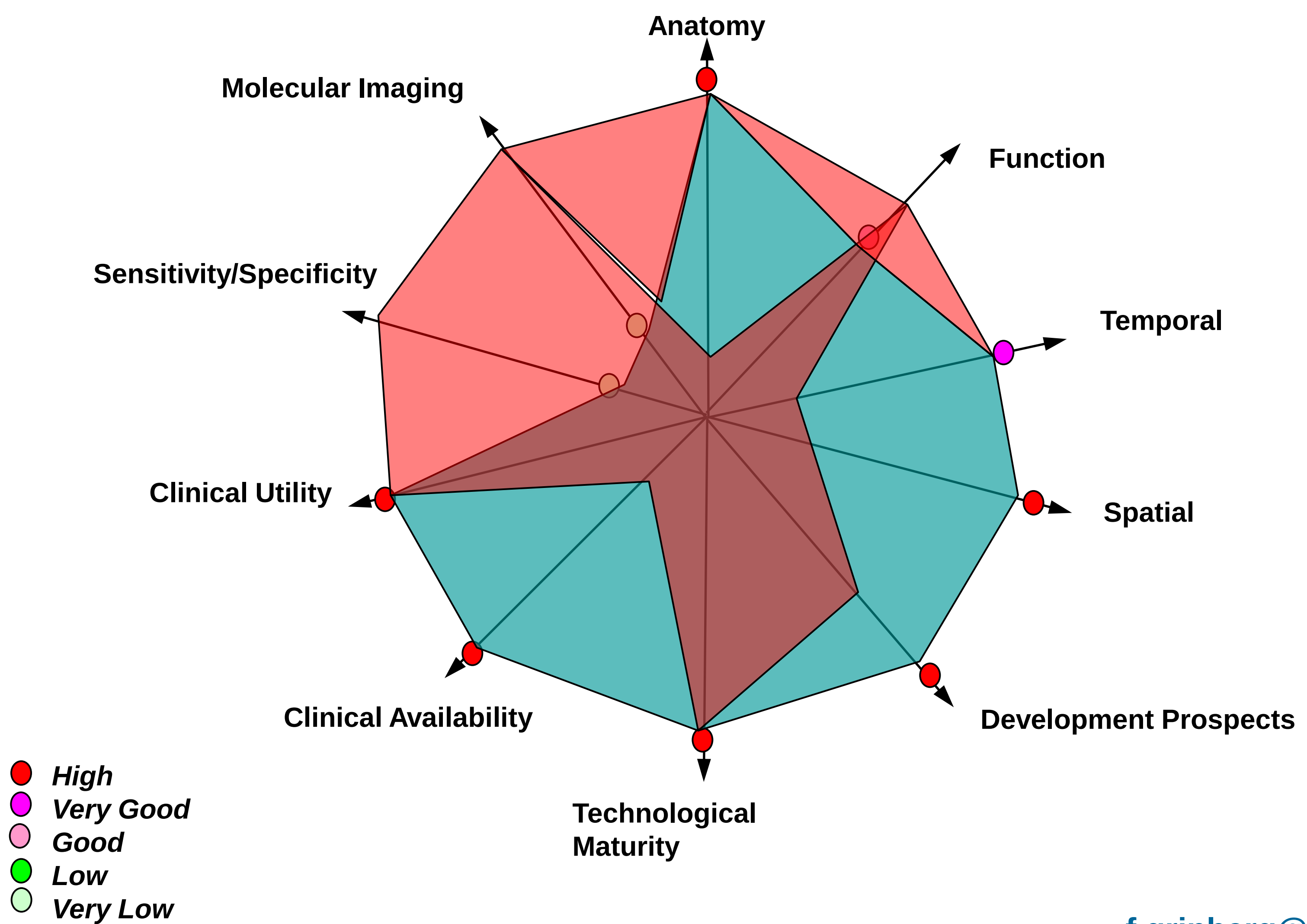
Hybrid MR-PET



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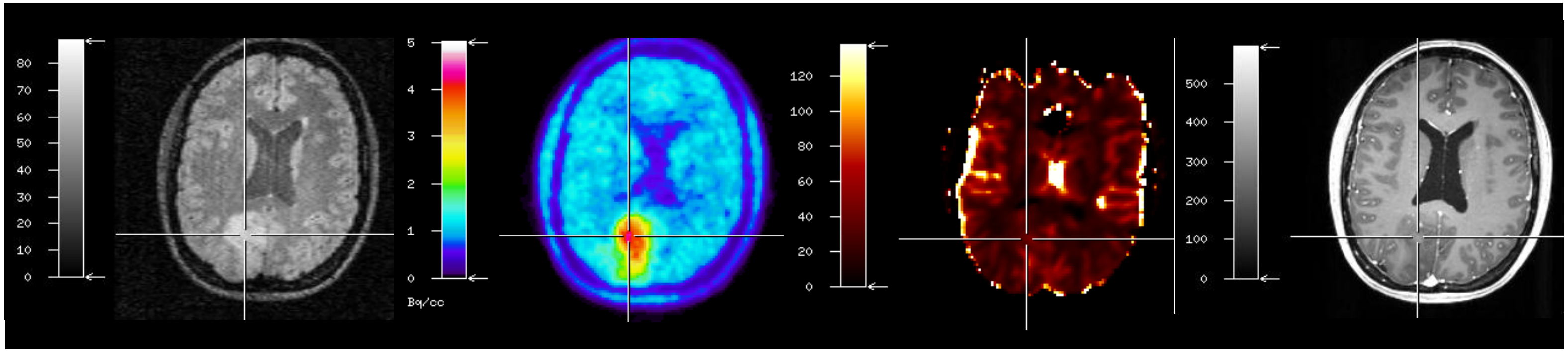
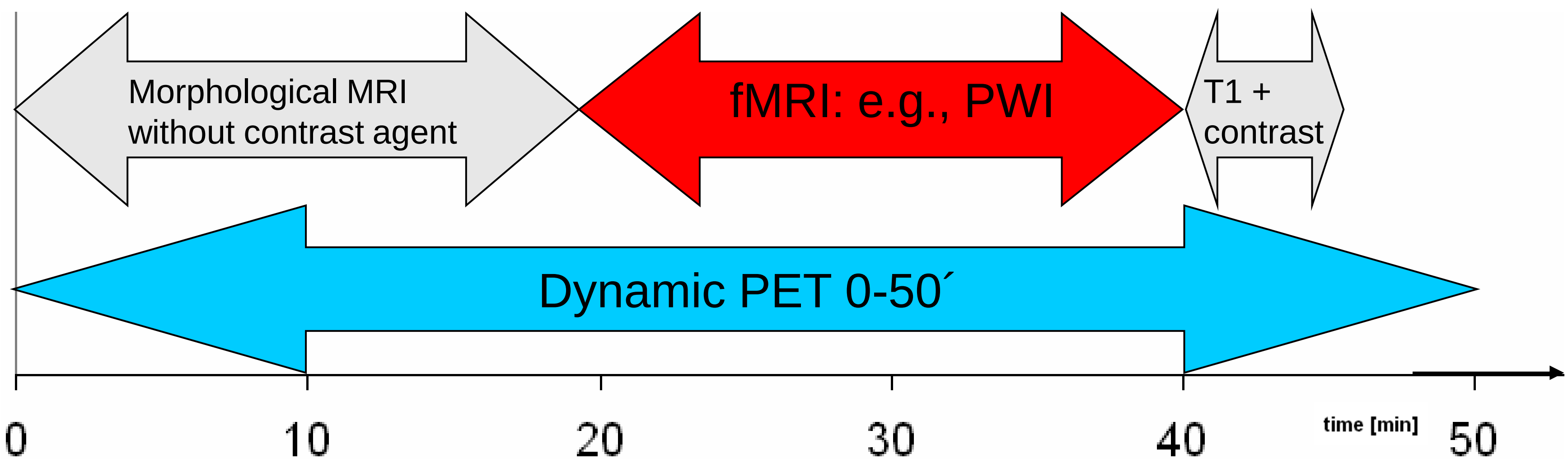
MR-PET





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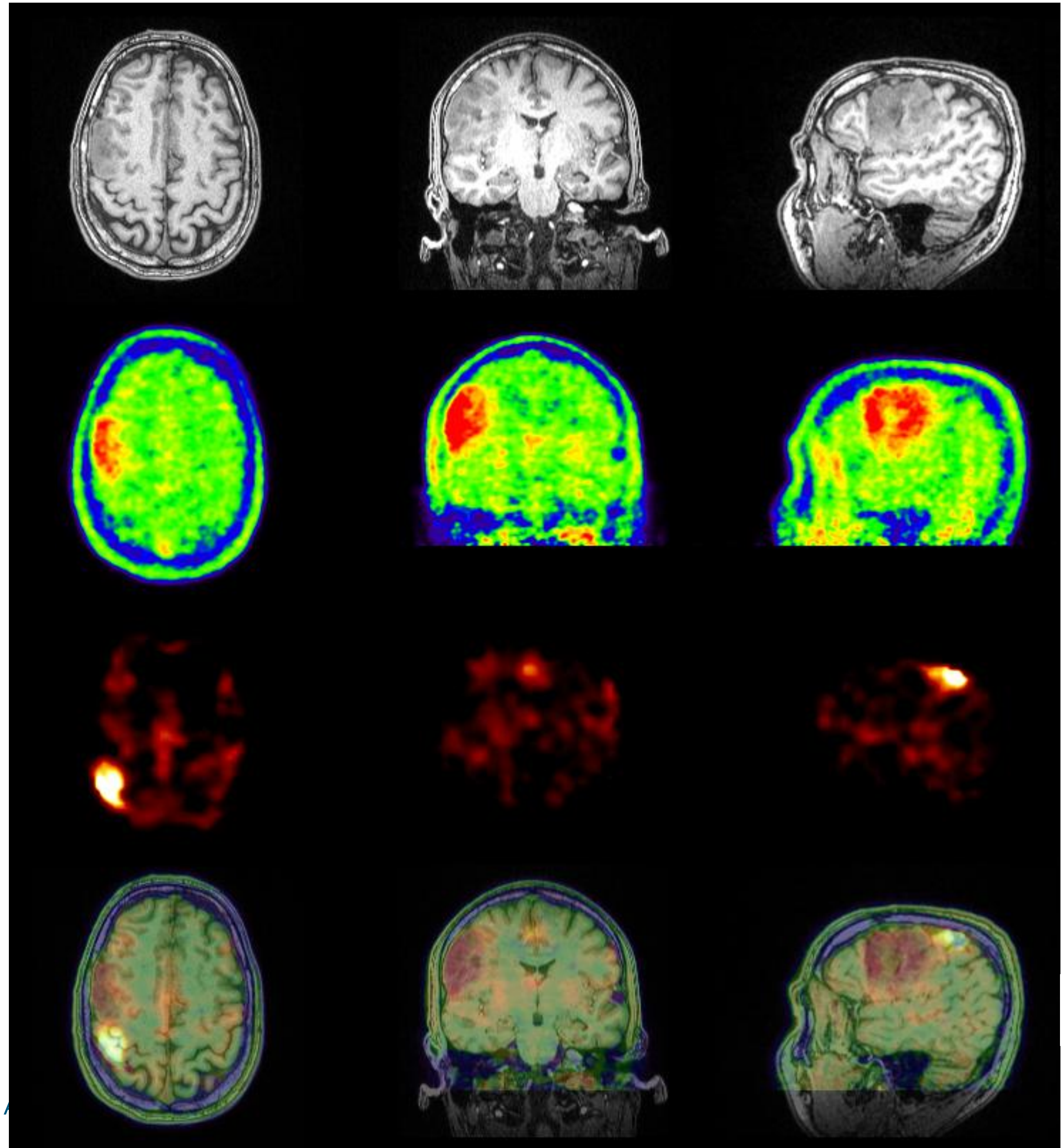
Clinical applications: presurgical imaging



T1 MPRAGE (6 min)

PET:
[^{18}F]-fluor-ethyl-tyrosine
20 - 40 min p.i.

BOLD imaging:
Finger tapping
left hand

3T MR-BrainPET

Fusion

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E. Farrher
A. Celik
Dr. I. Neuner
D. Brenner
C. Mirkes
MR Group

SIEMENS / BMBF

Dr. J. Scheins
Dr. E. Rota-Kops
C. Weirich
L. Tellmann

PET Group

Prof. K.-J. Langen
Brain Tumour Group

END

… thank you for attention!

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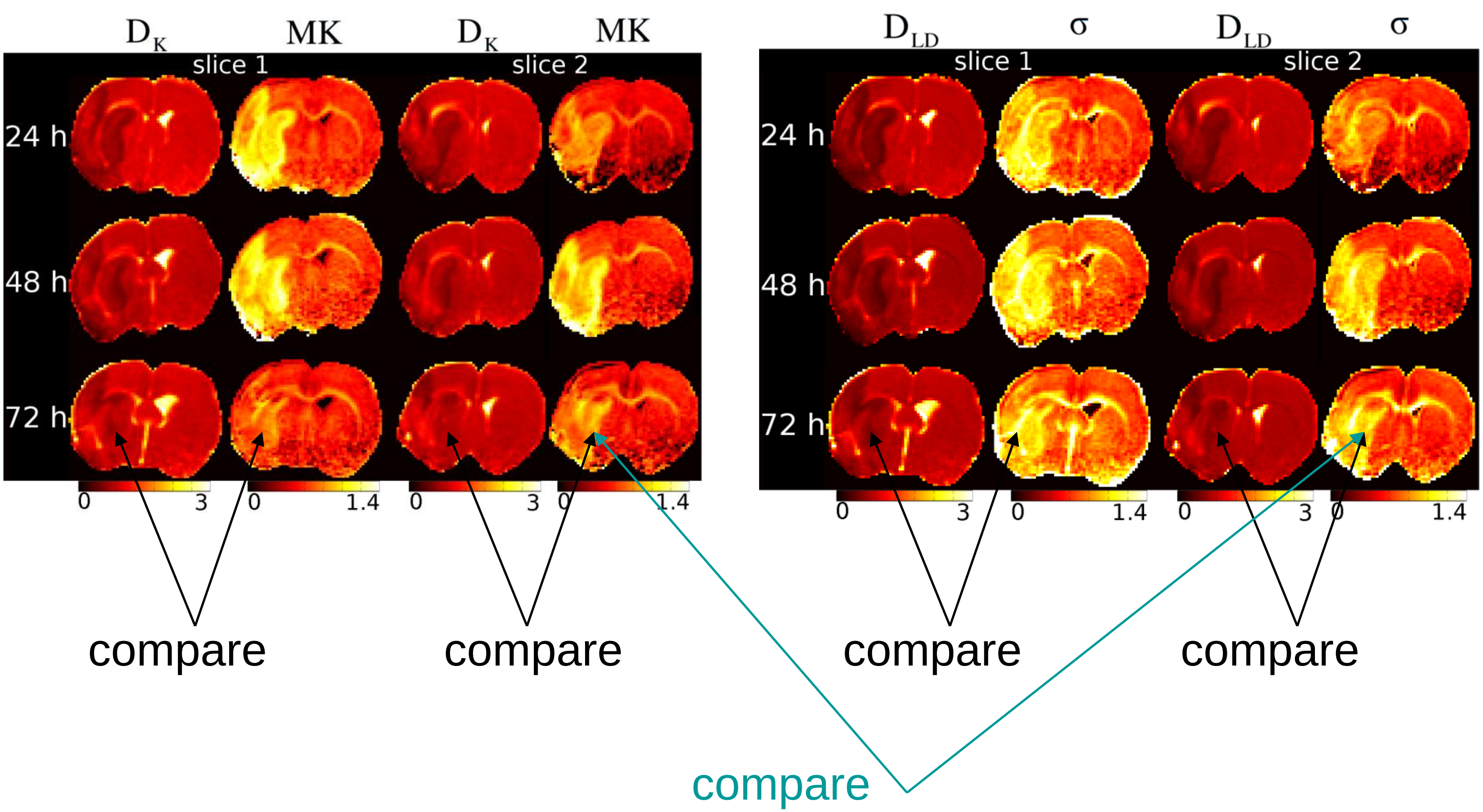
Deviations from the Gaussian model

…very promising in monitoring changes after stroke



Metabolism: other nuclei

17O

31P - adenosine triphosphate
(ATP)

In progress…

(Sandro Romanzetti)

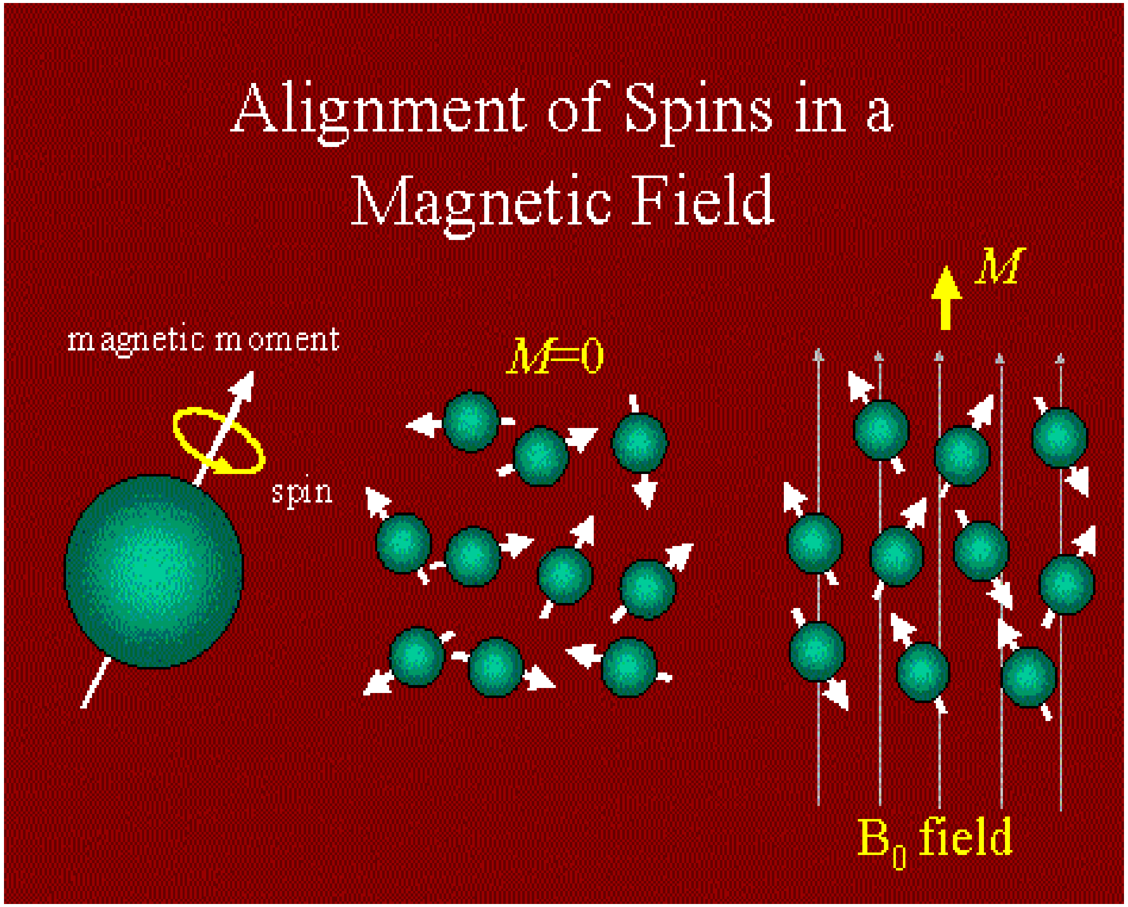
Selective Excitation (Zoomed MRI)

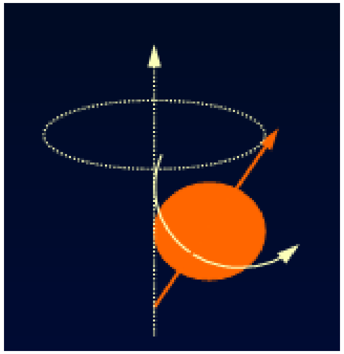
$$\mathbf{P}_{des}(\mathbf{x}) = \sum_{c=1}^{C} \mathbf{B}_{1,c}\mathbf{F}(\mathbf{S}_c(\mathbf{x}))$$

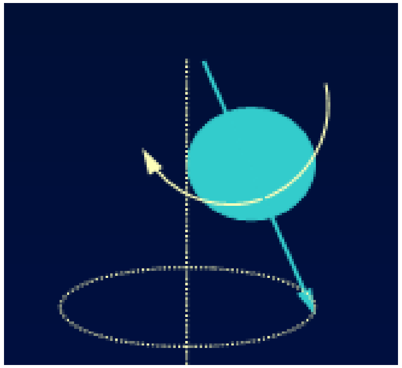
➔ **High resolution ROI imaging in short scan times!**

Vahedipour, Stöcker, Shah; FZ Jülich

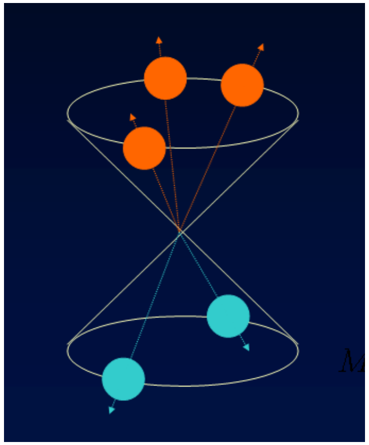
Introduction to MRI



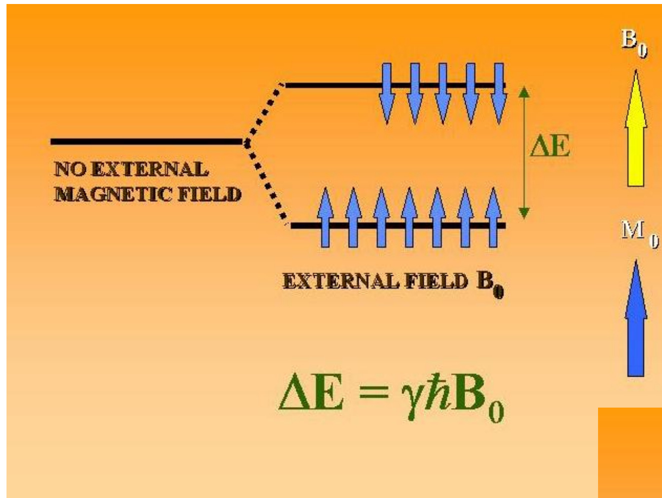


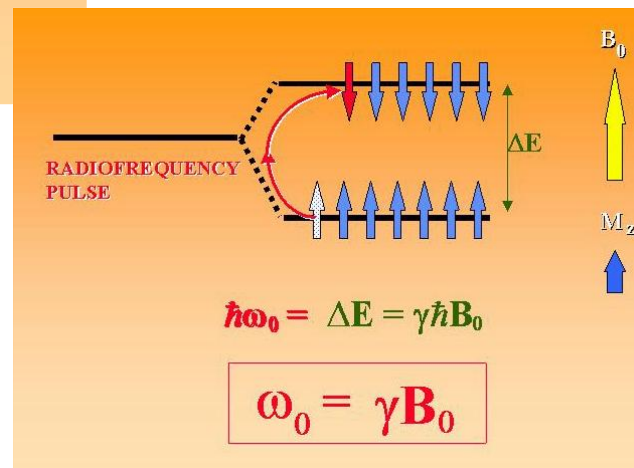


Introduction to MRI



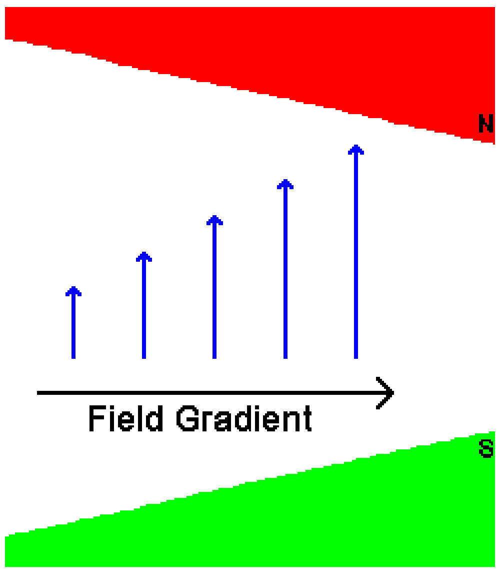
Zeeman energy levels

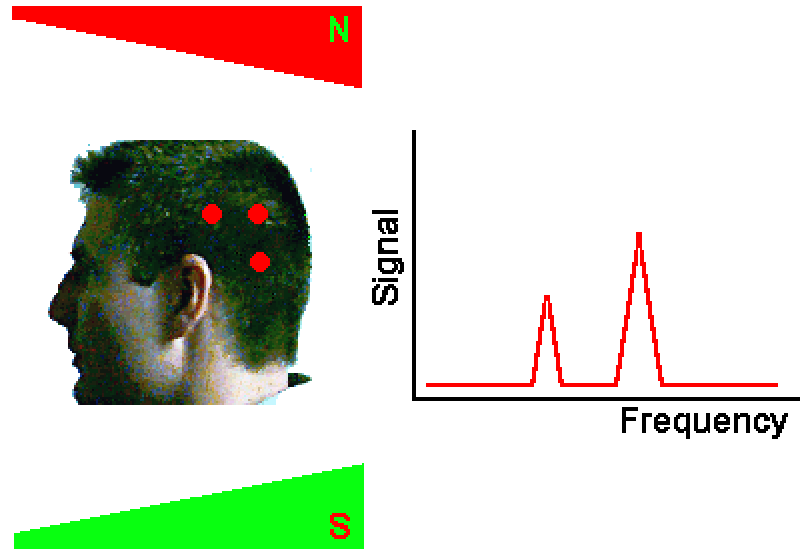




RF pulse on: excitation
RF pulse off: relaxation

Introduction to MRI



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JCB
GERKEN
GERKEN


BEKA


Framax
Framax
Framax


S 300
S 300
S 300
S 300
S 200
S 200


SIEMENS
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H.C.WILSON
COLLAS-KIES
4×12M
30T


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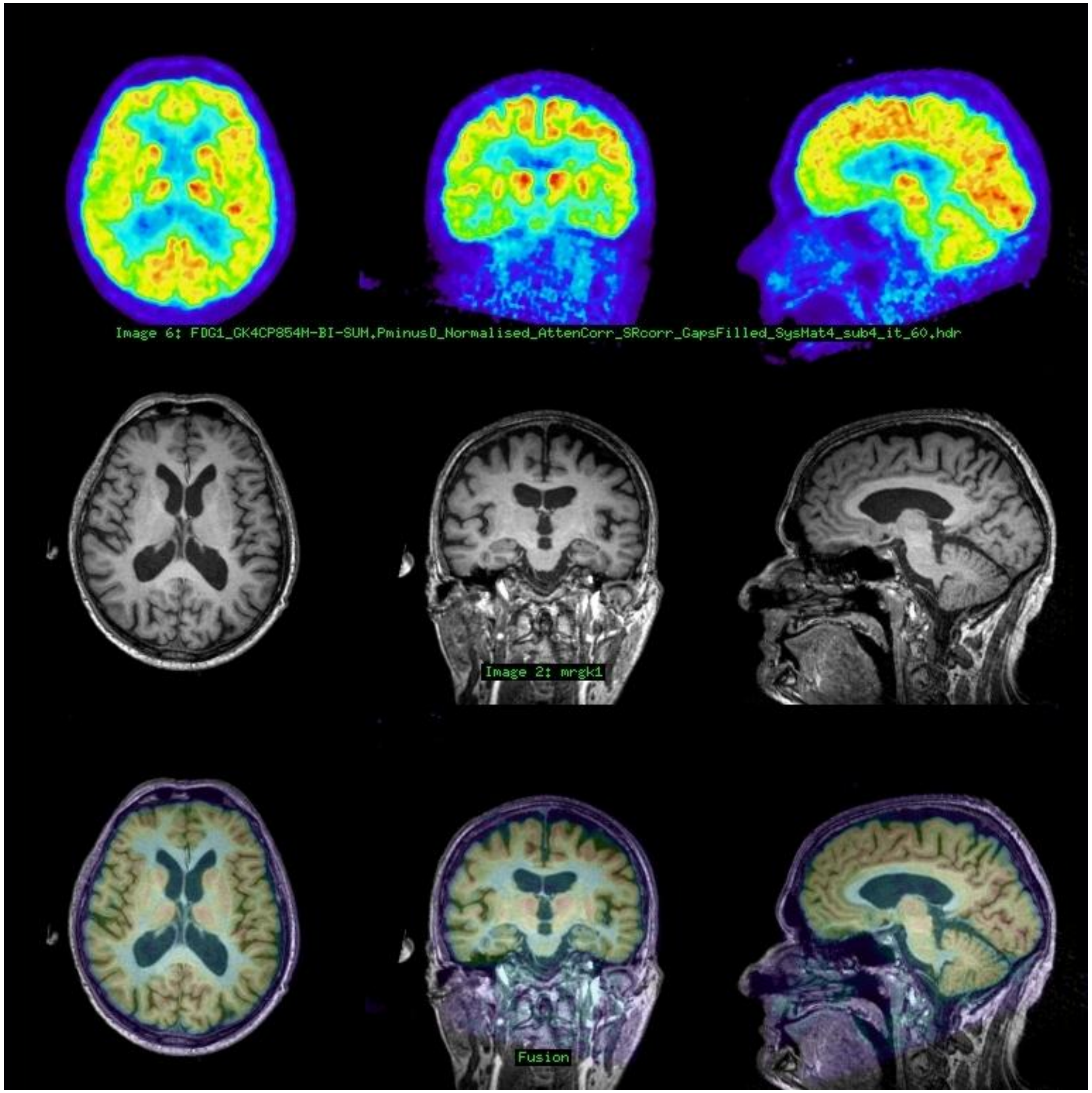
Our First MR-FDG-PET Images



20-50 min p.i. ^{18}FDG-PET reconstructed with PRESTO

The PET data are normalized, attenuation corrected, not scatter corrected.

Simultaneous T1 MPRAGE

Fusion

Molecular level:

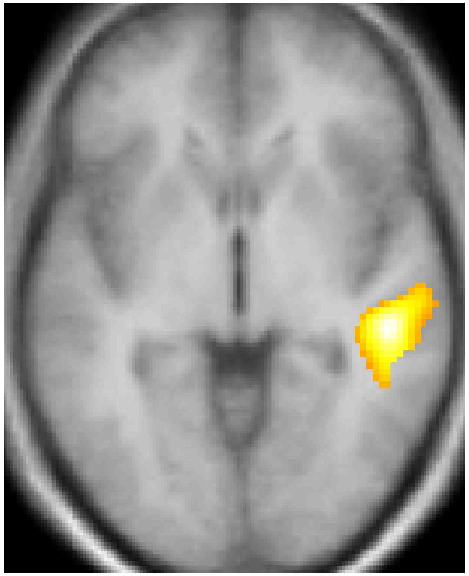
Neurotransmission

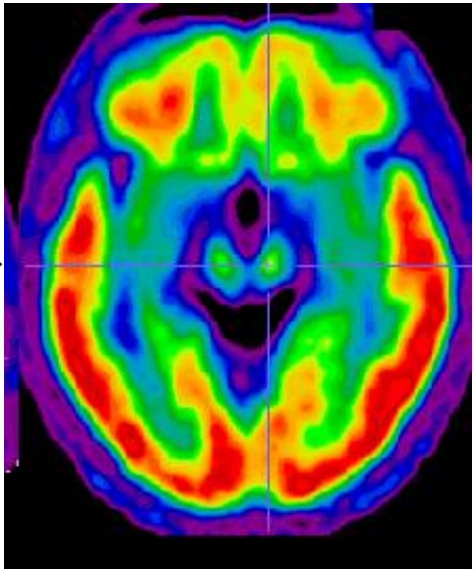
driven by neurotransmitters and receptors
or modulated by drugs
Domain of PET

Hybrid-Imaging

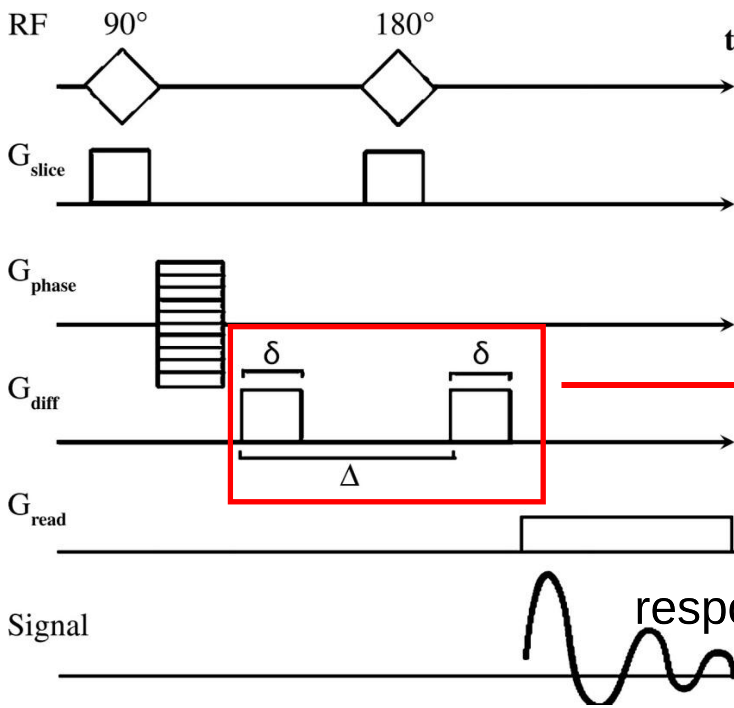
Systemic level:
Complex neural functions

Localization and analysis of complex neural mechanisms
Domain of fMRI





Diffusion MRI: pulsed field gradients



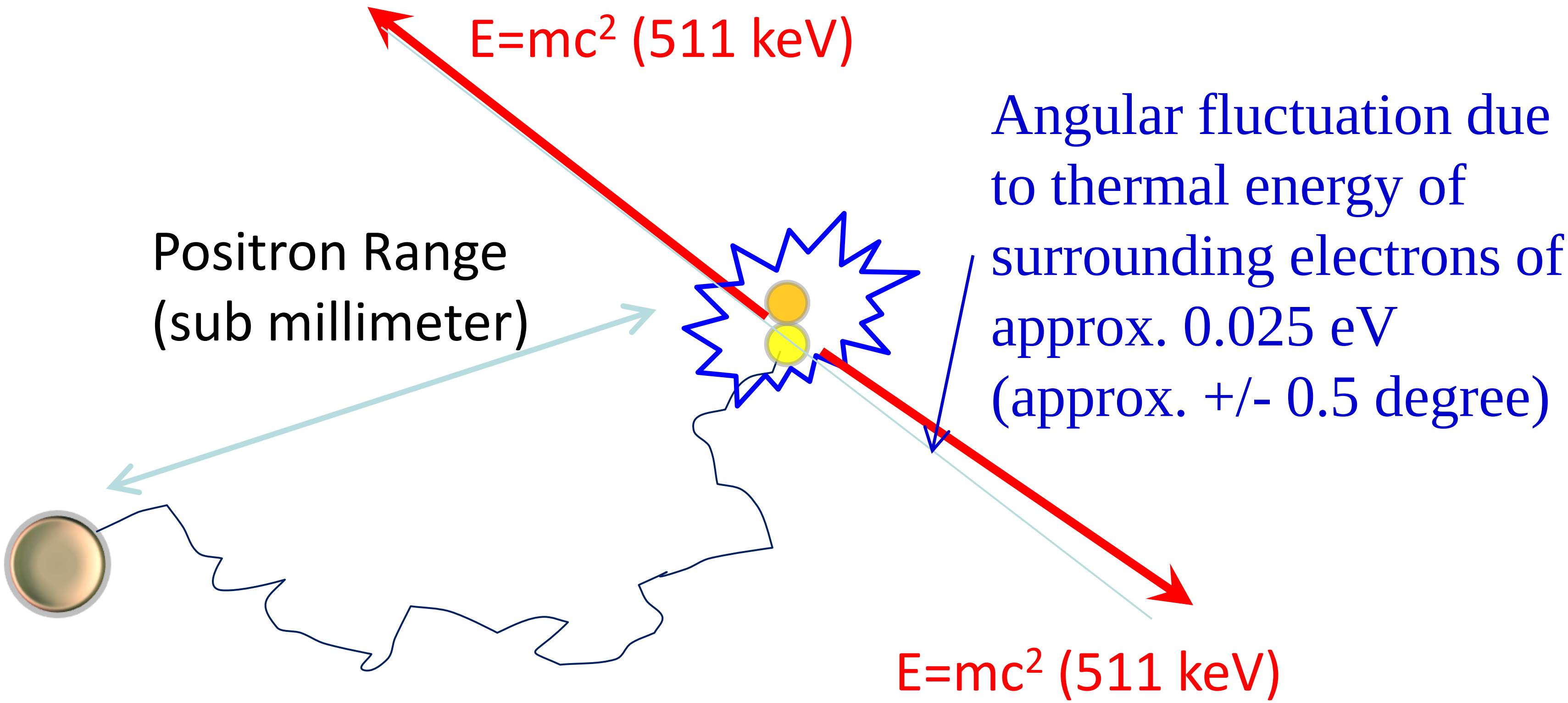
Diffusion weighting

response signal

propagator

$$\psi_{diff} = \int P(z,t)\, e^{i\gamma G\delta z}\, dz$$

Positron Emission and Annihilation Process
Magnetic field = 0 T



Positron Emitter

(eg ^{11}C, ^{13}N, ^{15}O, ^{18}F, etc)