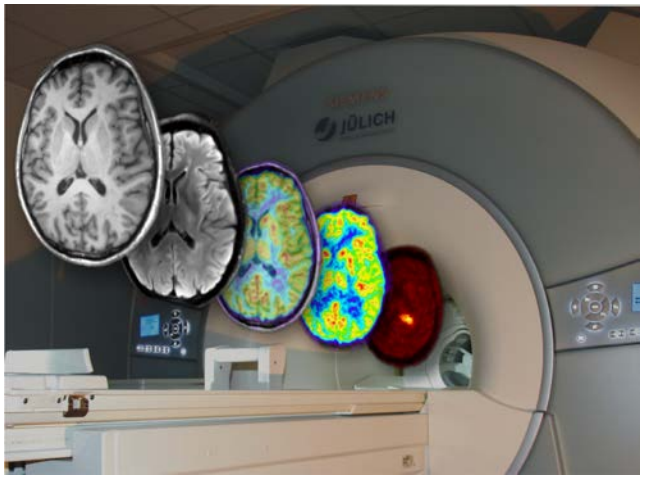


JÜLICH
FORSCHUNGSZENTRUM

From the Basics of MRI and PET to Hybrid MR-PET

N. Jon Shah
Institute of Neuroscience and Medicine – 4
Research Centre Juelich
52425 Juelich
GERMANY

On the Road Towards Metabolic Imaging: Recent Advances

Shah (2014) *Brain Structure and Function* (in press)

Quantitative Imaging

N. J. Shah et al.

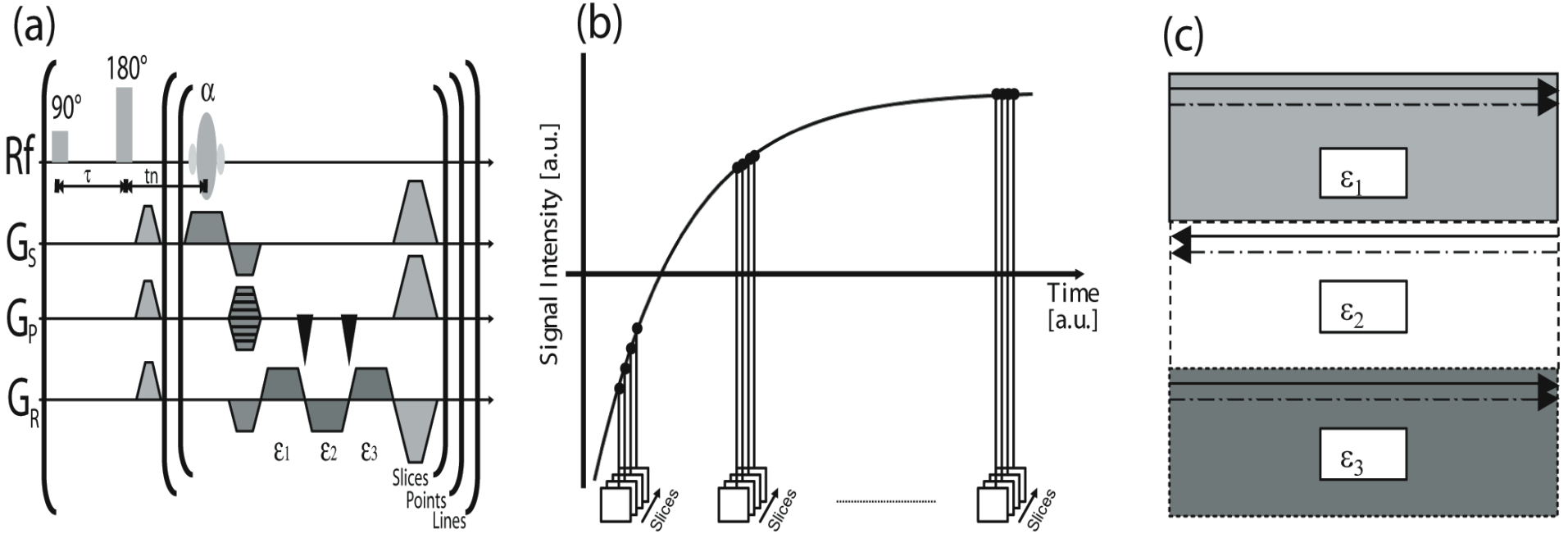
T_1 Mapping

Look and Locker, Rev. Sci. Instr. 41: 250-251

Deichmann and Haase, JMR 1992 96: 608-612

Deichmann et al., MRM 1999 42: 206-209

Implementation



TAPIR (**T_1** m**A**pping of **P**artial **I**nversion **R**ecovery)

Shah et al.,; US Patent No.: 6,803,762

Shah et al., NeuroImage: 2001 14(5): 1175-85

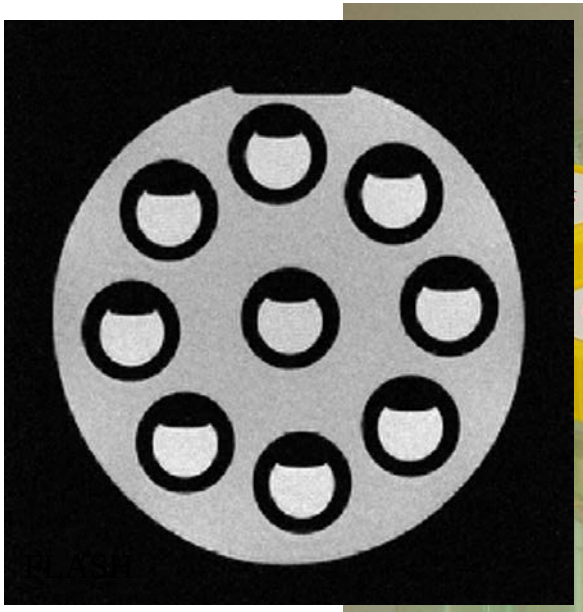
Steinhoff et al., Magn. Reson. Med.: 46(1) 131-140 2001

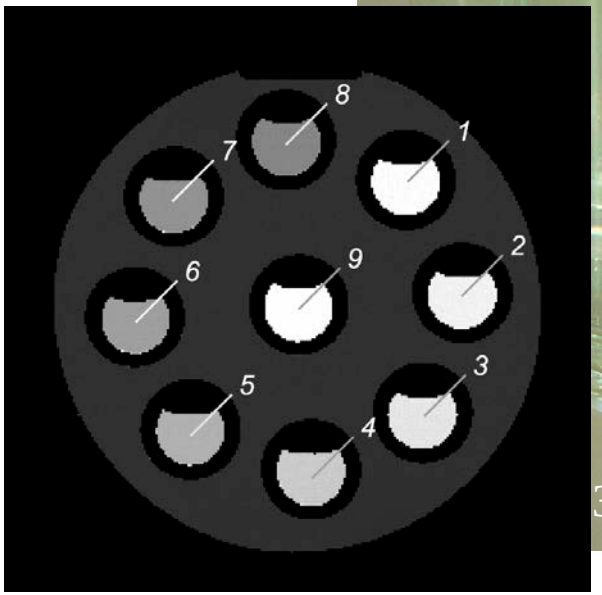
Zaitsev, et al; Magn. Reson. Med.: 49(1) 1121-1132 2003

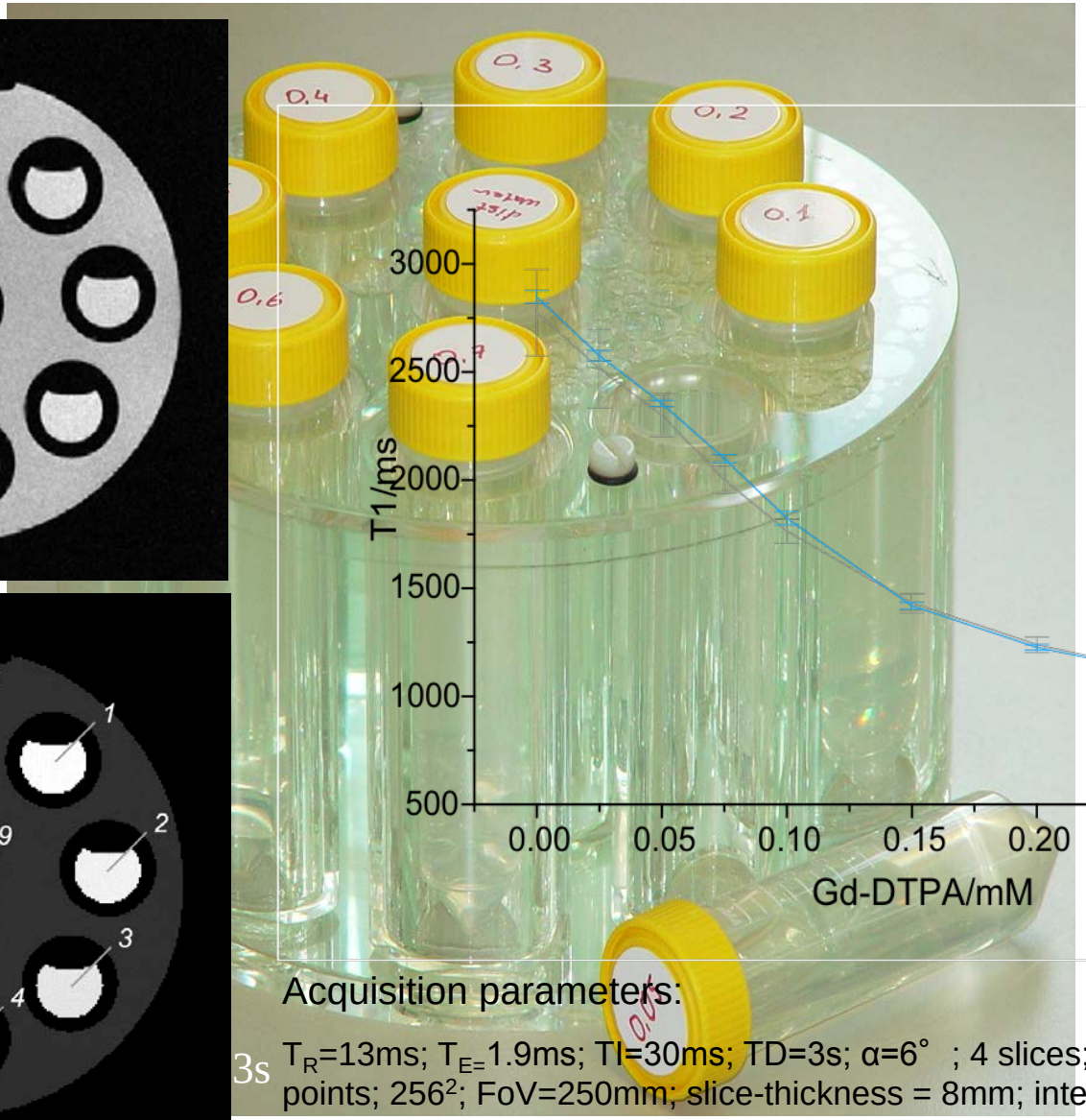
Shah et al., Hepatology: 2003 38: 1219-26

Tapir: any perissodactyl mammal of the genus Tapirus …. of South and central America and SE Asia, having an elongated snout, **three-toed** hind legs, and four-toed forelegs.

Phantom Results





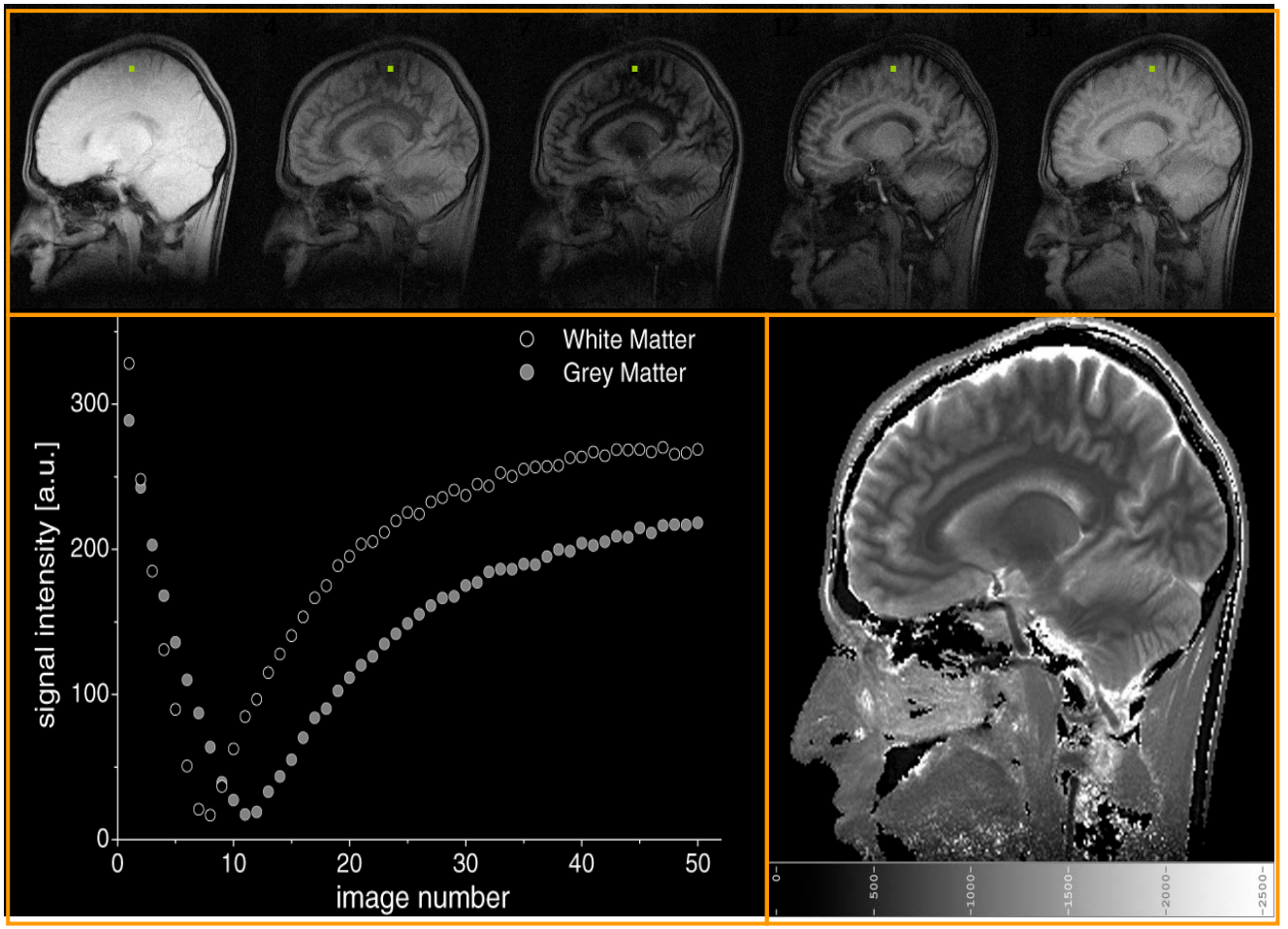


Acquisition parameters:

3s T_R=13ms; $T_{E=}$1.9ms; TI=30ms; TD=3s; α=6° ; 4 slices; 48 time points; 256^2; FoV=250mm; slice-thickness = 8mm; interleaved

TAPIR: *In vivo* T_1 Mapping

- Large number of points affords reconstruction of accurate maps
- Multi-exponential fitting is feasible
- T_1 mapping enables ***quantitative*** measurement of water content.
- $S(t) = M_0 \{1-2\exp(t/T_1)\}$
- … life is not so simple!



Shah et al.,; US Patent No.: 6,803,762

Shah et al., NeuroImage: 2001 14(5): 1175-85

Steinhoff et al., Magn. Reson. Med.: 46(1) 131-140 2001

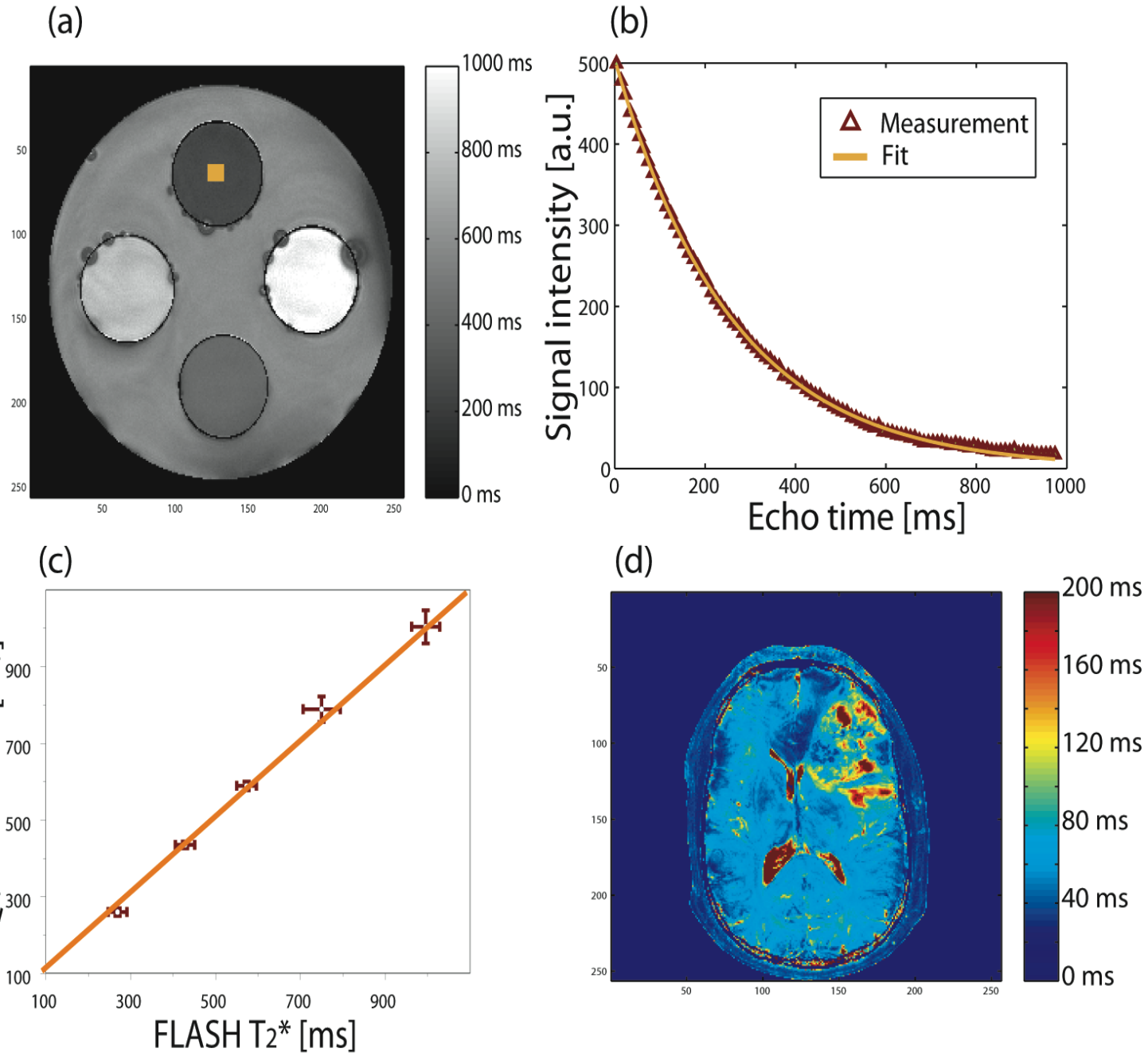
Zaitsev, et al; Magn. Reson. Med.: 49(1) 1121-1132 2003

Shah et al., Hepatology: 2003 38: 1219-26

T_2^* Mapping

Mansfield: 1984 Spectroscopic Imaging (EPSI)

Phantom and *in vivo* Results



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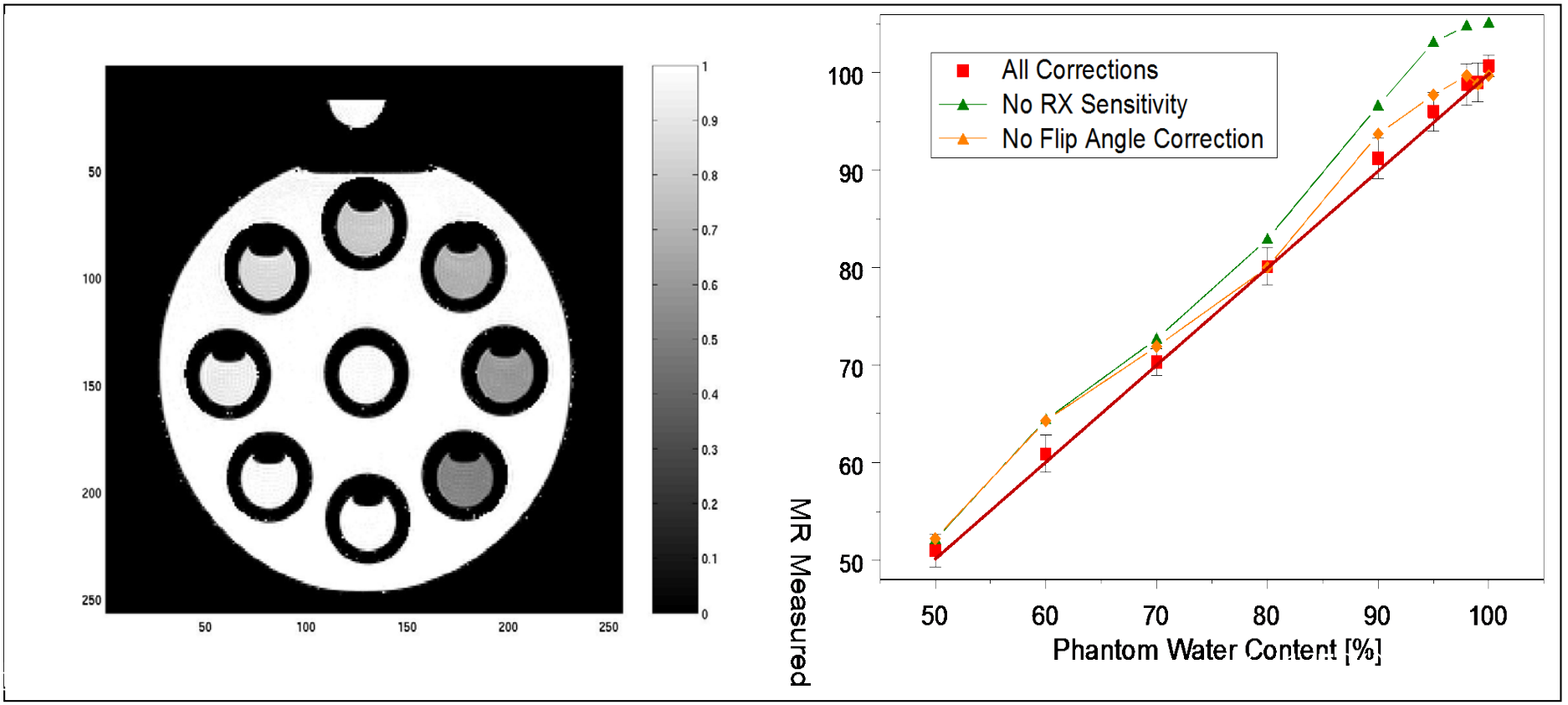
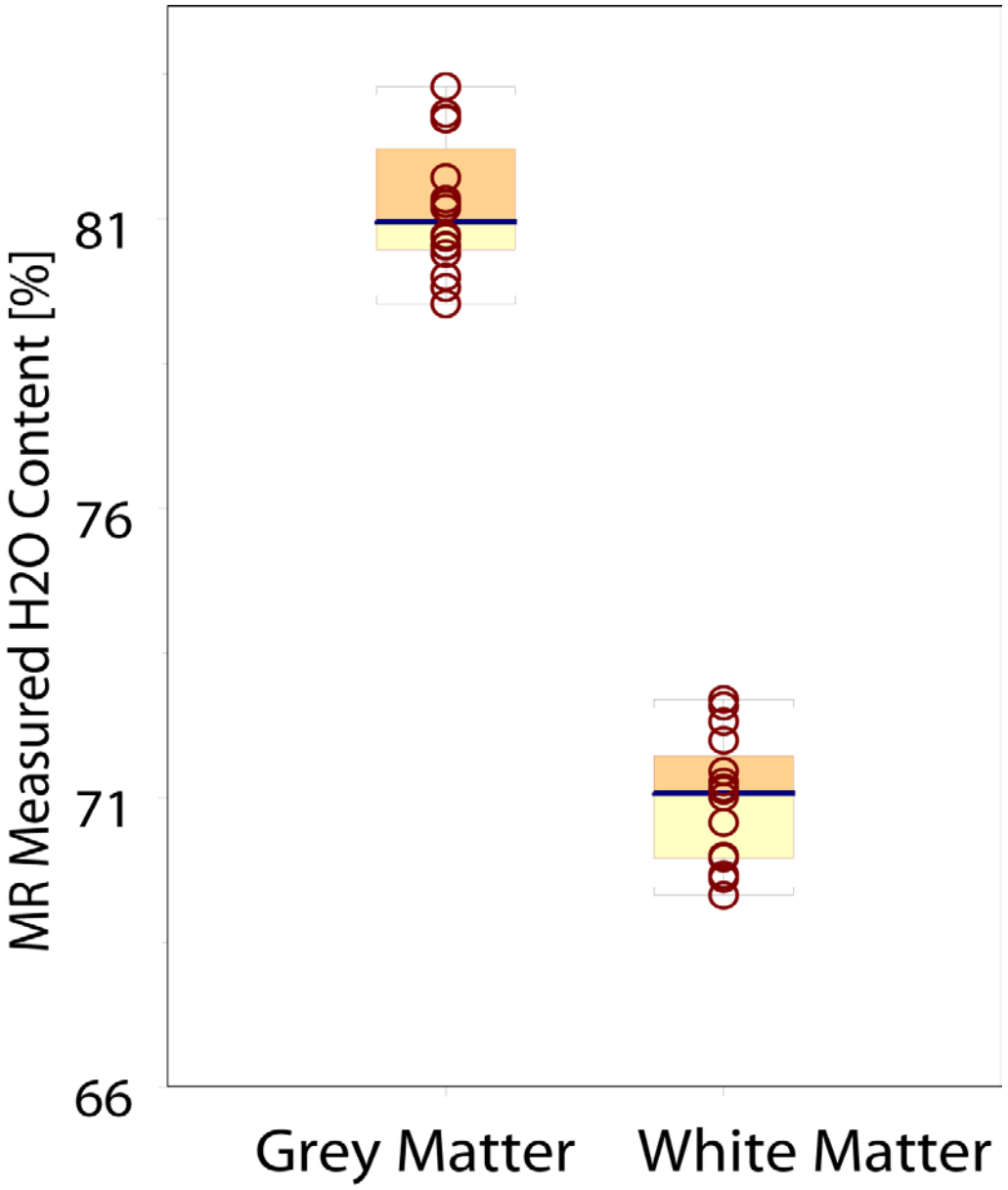
Water Mapping

N. Jon Shah, Zaheer Abbas, Vincent Gras, Klaus Moellenhoff, Anca Oros-Peusquens

Water Content Mapping

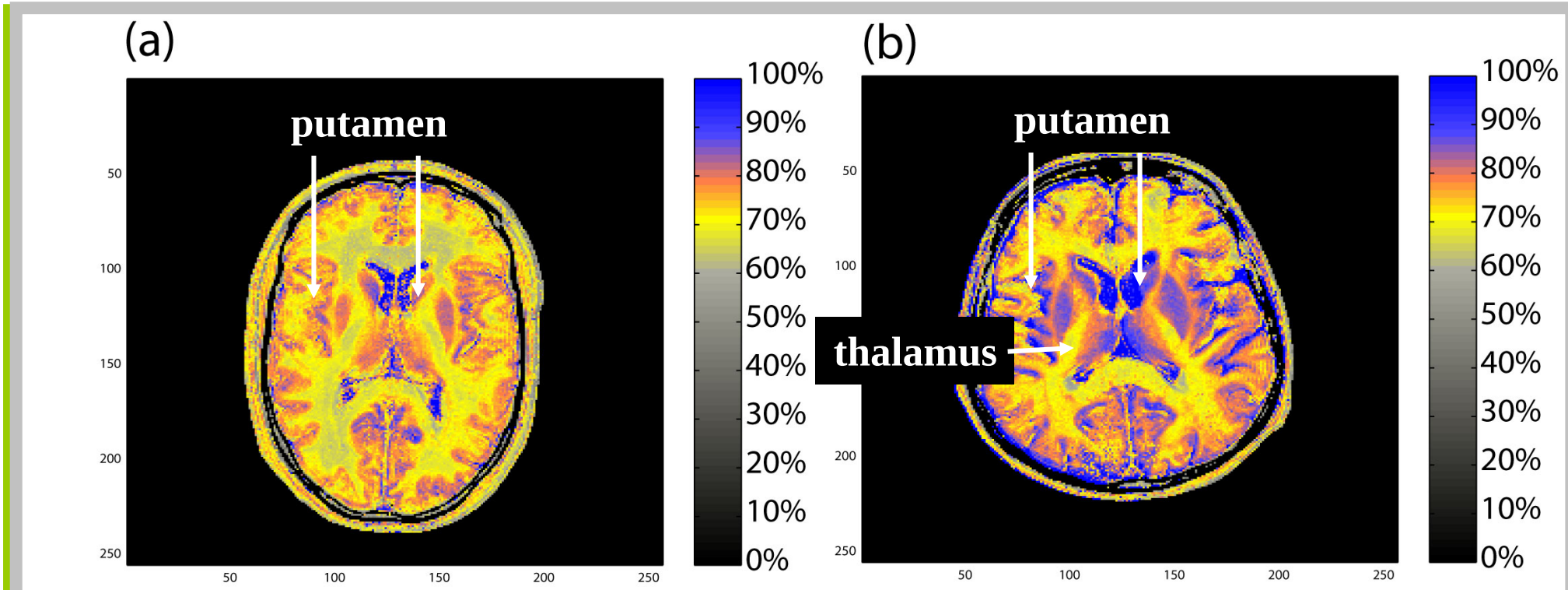


Water Content in Grey/White Matter In Controls



Neeb et al., 2006a, NeuroImage 31 1156-1168

Water Content Mapping @ 1.5T

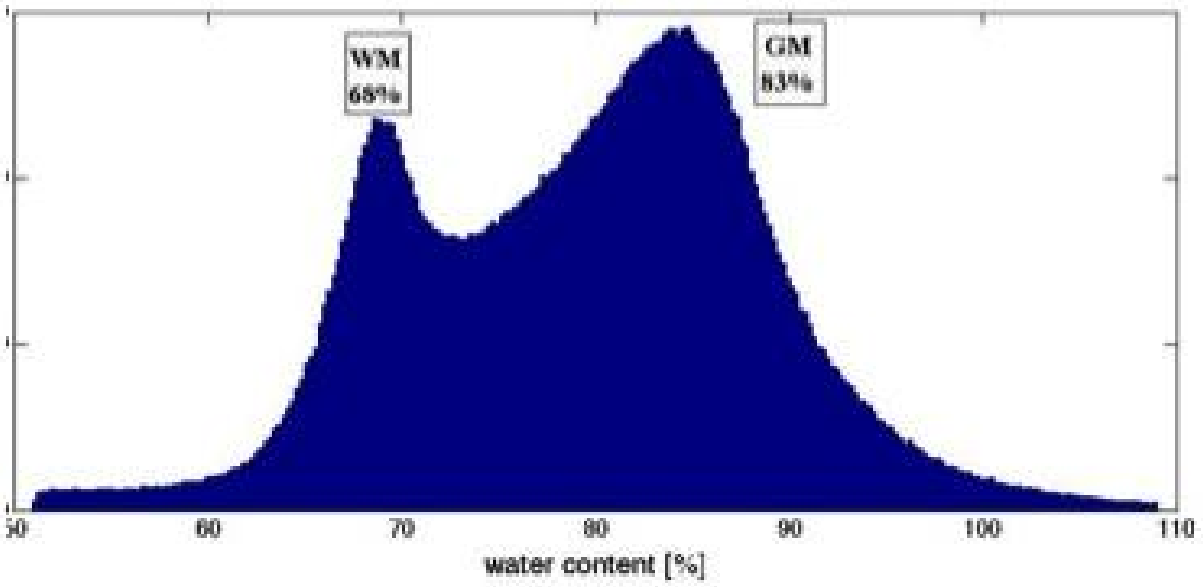


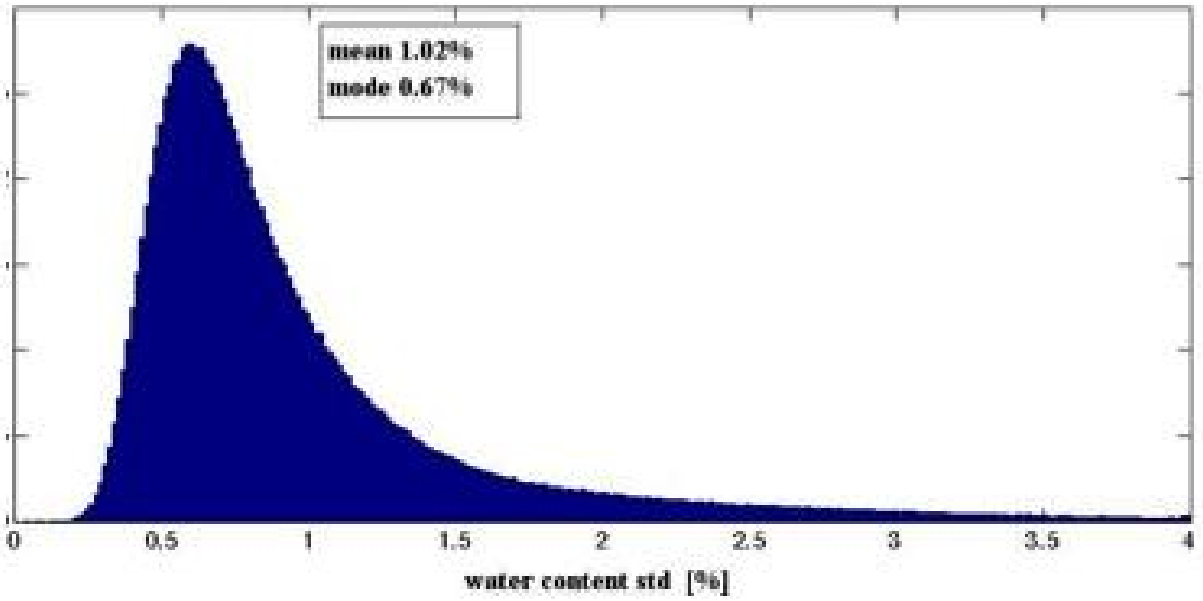
Hepatic Encephalopathy grade HE 0 **Hepatic Encephalopathy grade HE II**

Shah et al., US Patent No.: 6,803,762
Shah et al., NeuroImage: 2001 14(5): 1175-85
Steinhoff et al., Magn. Reson. Med.: 46(1) 131-140 2001
Zaitsev et al; Magn. Reson. Med.: 49(1) 1121-1132 2003
Shah et al., German Patent No.: 10028171

Shah et al., Hepatology: 2003 38: 1219-26
Neeb H, Shah NJ. Magn Reson Med. 2006 56(1):224-9.
Neeb H, Zilles K, Shah NJ. NeuroImage. 2006 31(3):1156-68.
Neeb H, Zilles K, Shah NJ. NeuroImage. 2006 29(3):910-22.
Shah et al., NeuroImage: NeuroImage 2008 41(3):706-17

Test-retest stability





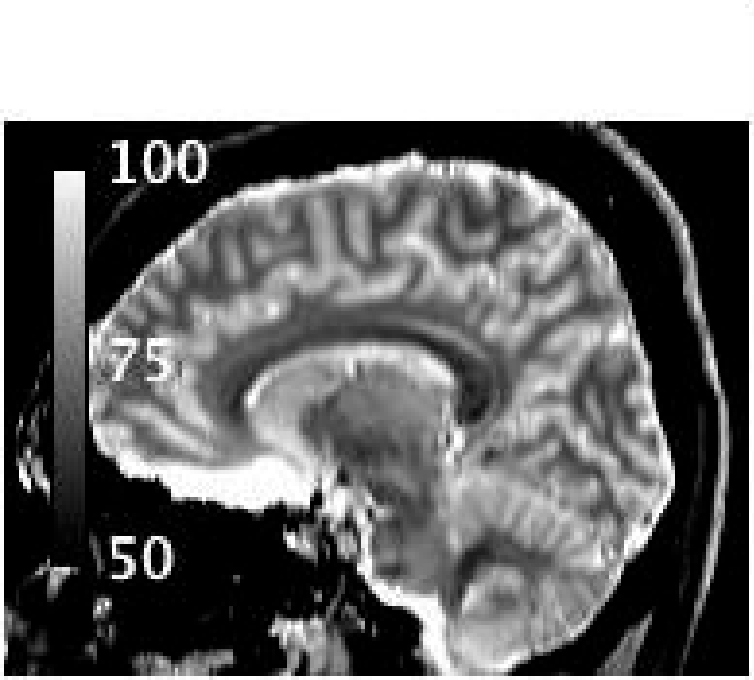
12 measurements

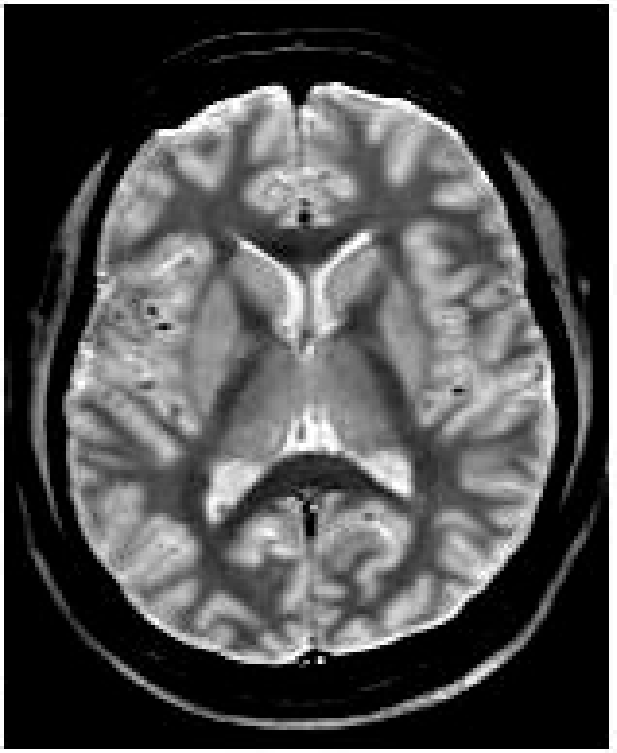
Repositioning

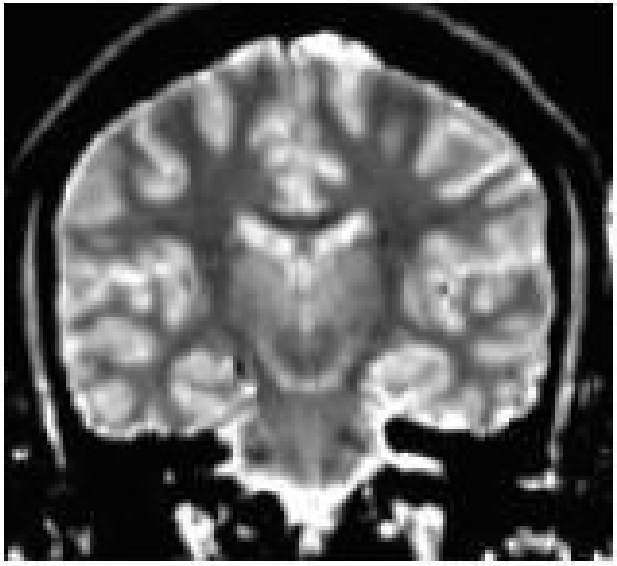
SD of mean values: **0.3%**

Voxel-based SD: **1%** mean value

Test-retest stability: mean water content map

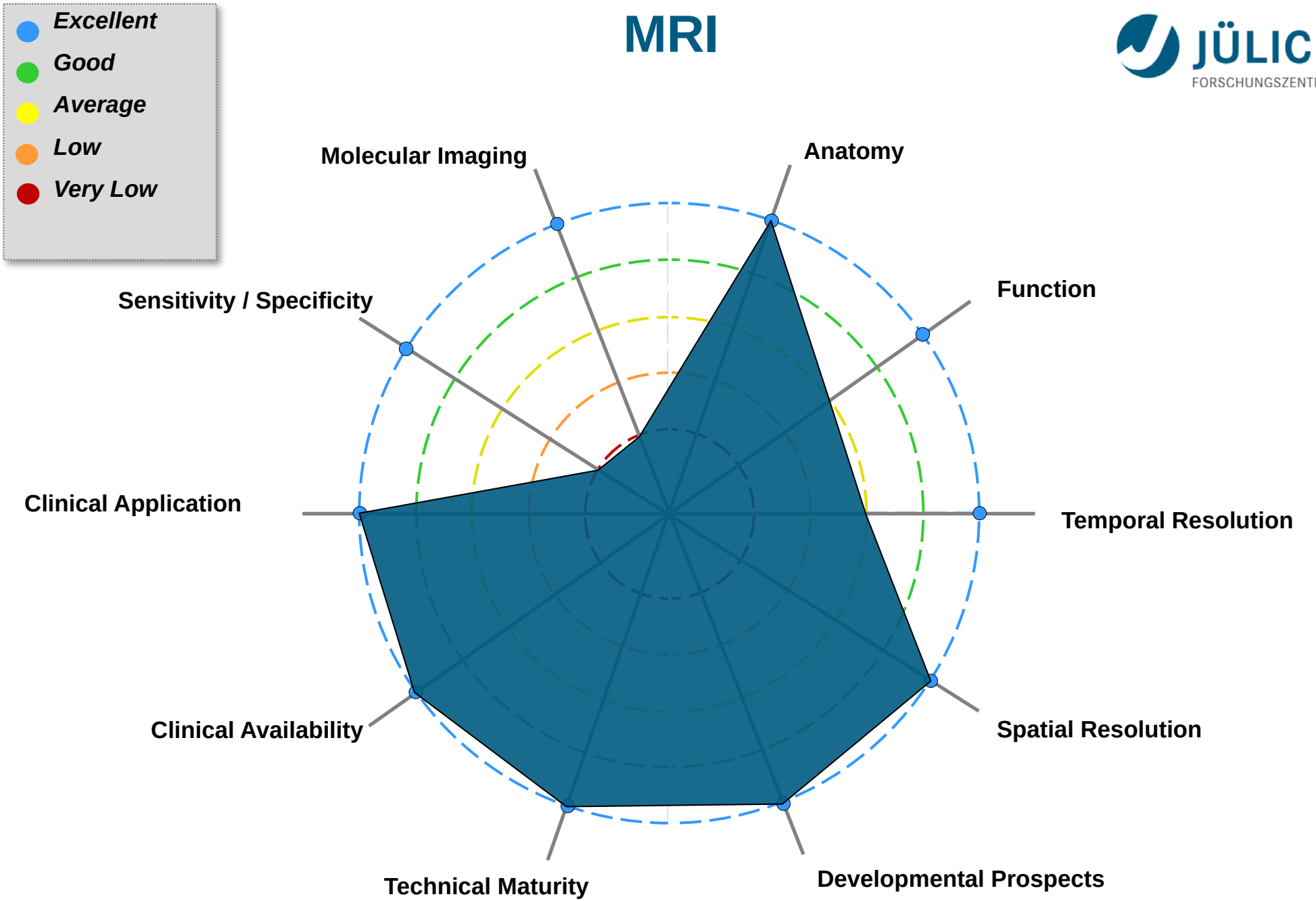




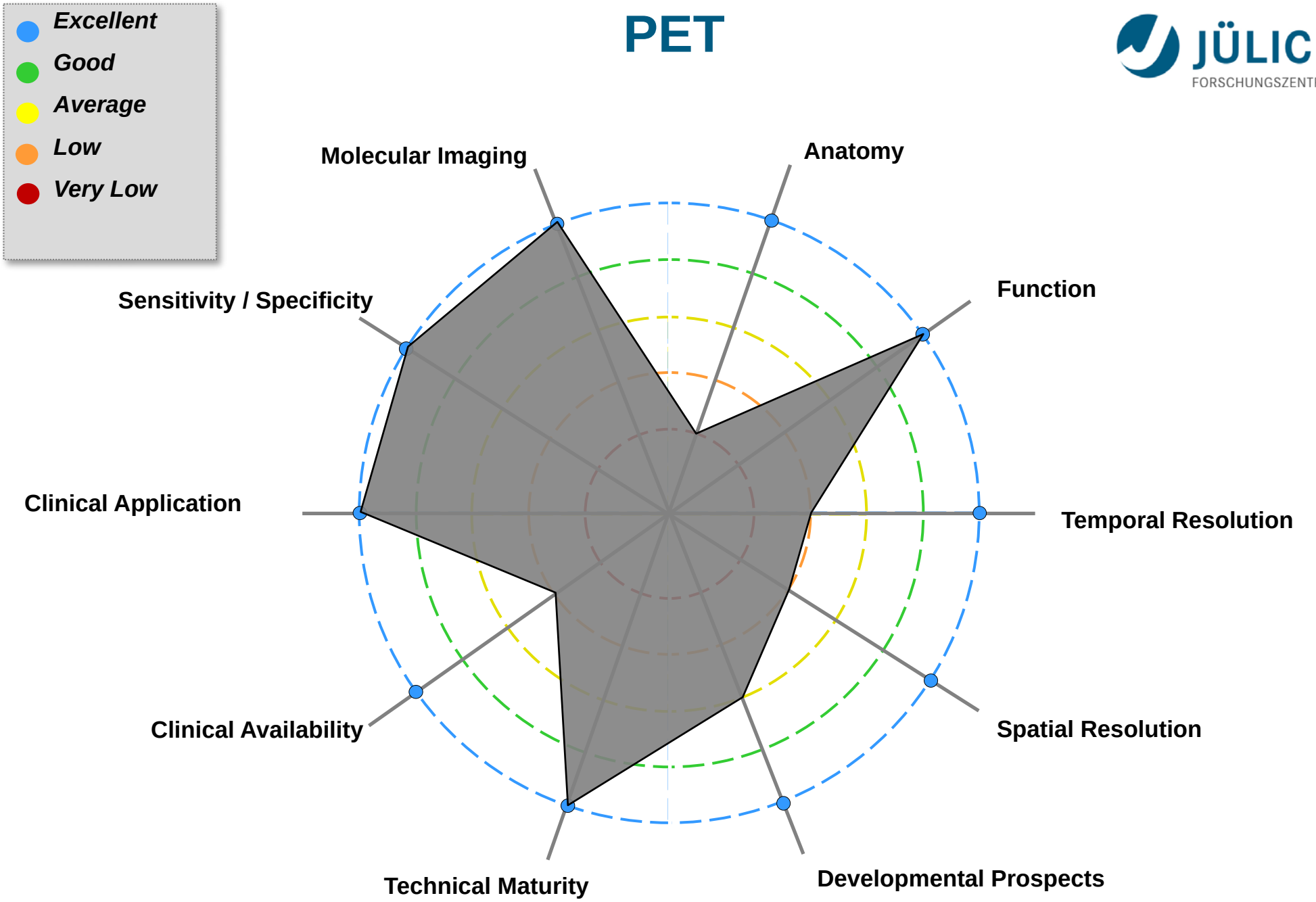


Exquisite anatomical detail, e.g. brain stem, thalamus

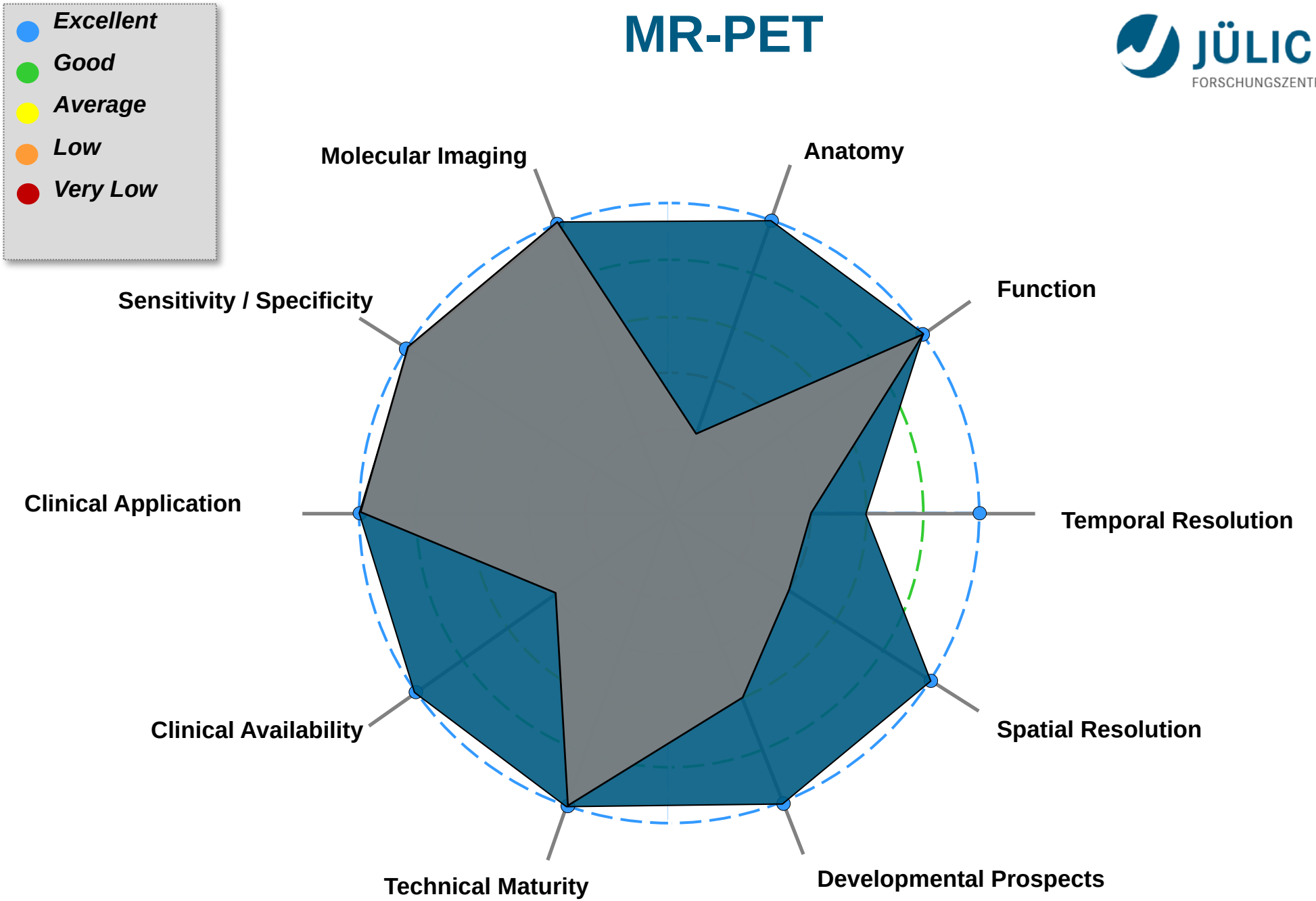
MRI


Excellent
Good
Average
Low
Very Low
Molecular Imaging
Anatomy
Function
Sensitivity / Specificity
Clinical Application
Temporal Resolution
Clinical Availability
Spatial Resolution
Technical Maturity
Developmental Prospects

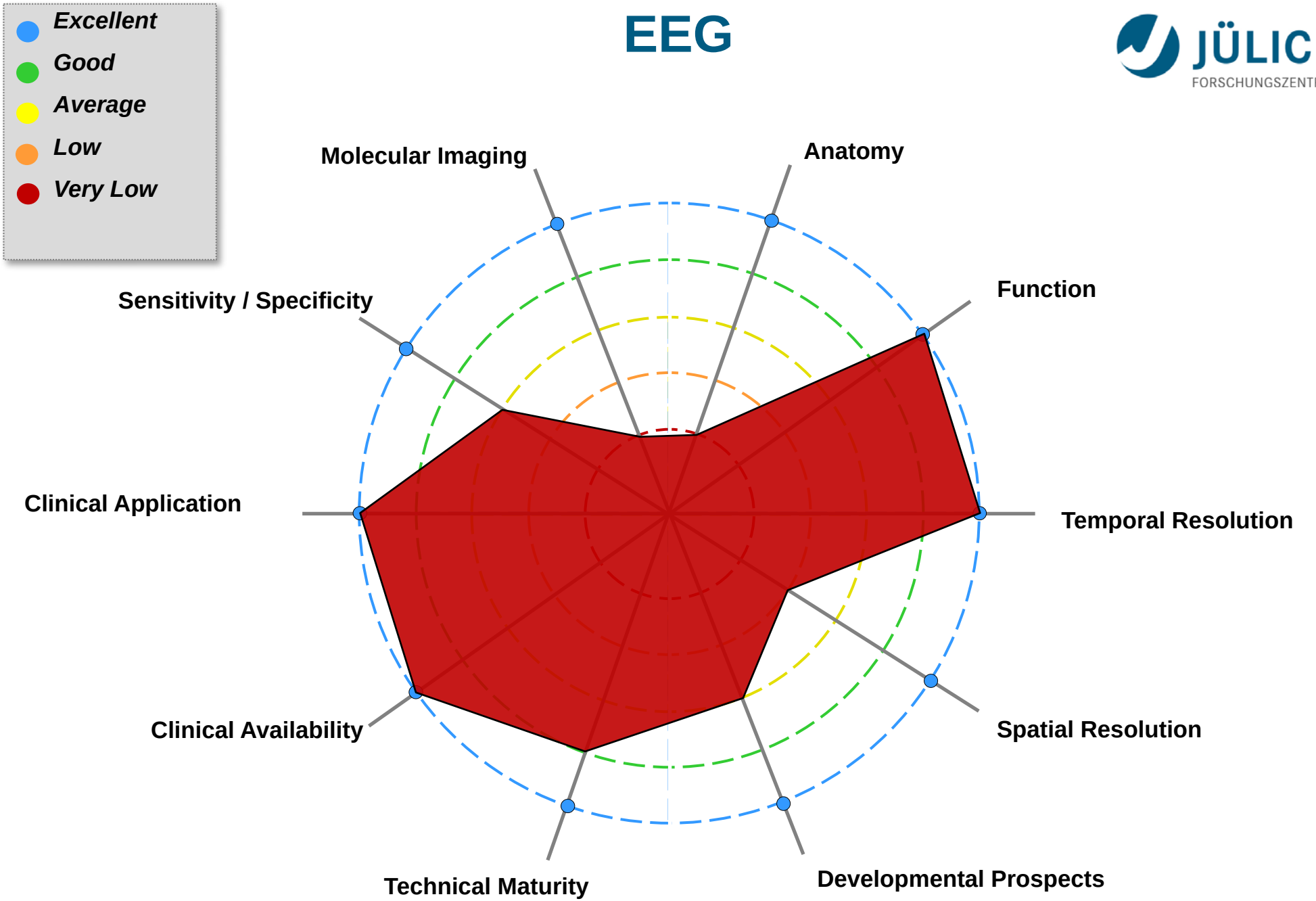
PET


Excellent
Good
Average
Low
Very Low
Molecular Imaging
Anatomy
Function
Temporal Resolution
Spatial Resolution
Developmental Prospects
Technical Maturity
Clinical Availability
Clinical Application
Sensitivity / Specificity

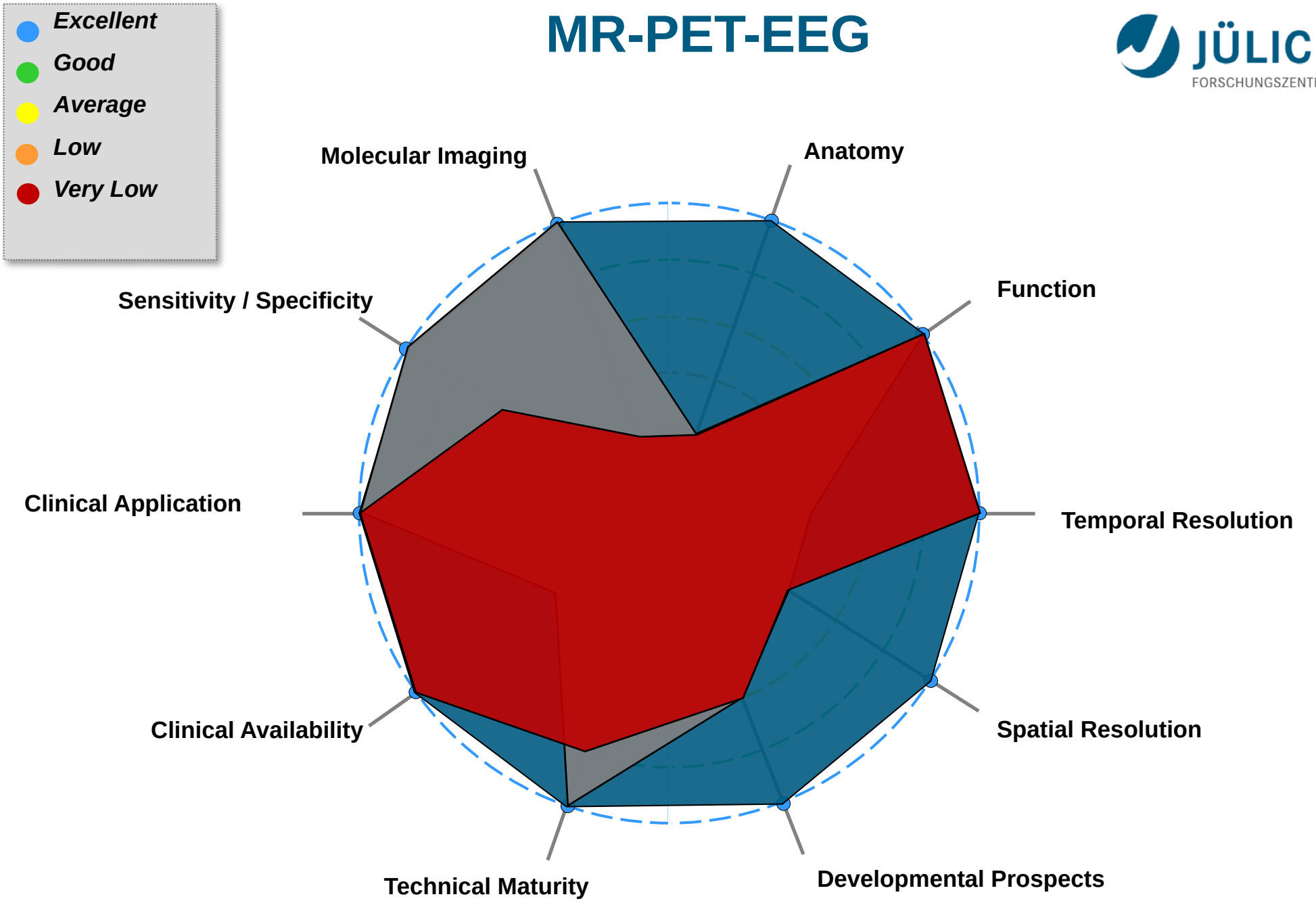
MR-PET


Excellent
Good
Average
Low
Very Low
Molecular Imaging
Anatomy
Function
Temporal Resolution
Spatial Resolution
Developmental Prospects
Technical Maturity
Clinical Availability
Clinical Application
Sensitivity / Specificity

EEG

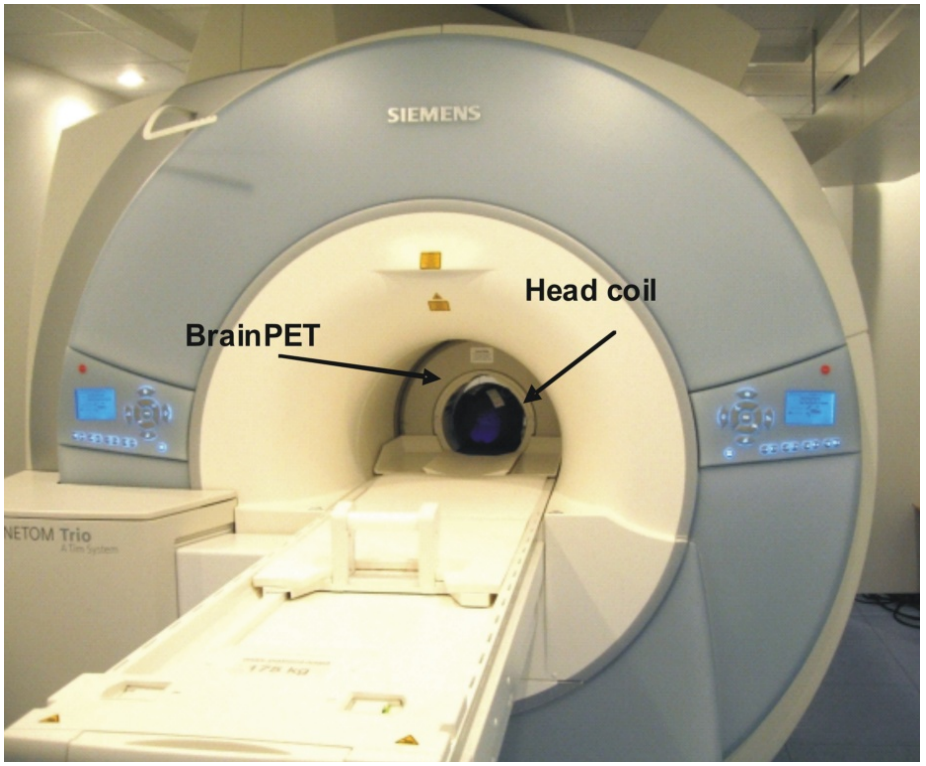

Excellent
Good
Average
Low
Very Low
Molecular Imaging
Anatomy
Function
Sensitivity / Specificity
Clinical Application
Temporal Resolution
Clinical Availability
Spatial Resolution
Technical Maturity
Developmental Prospects

MR-PET-EEG

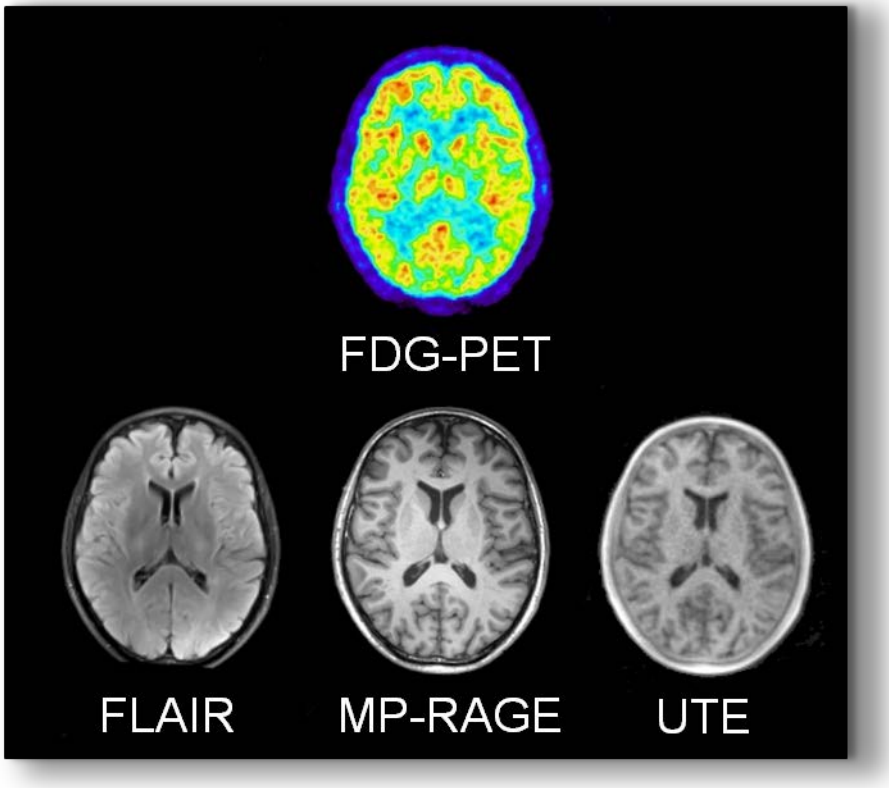

Excellent
Good
Average
Low
Very Low
Molecular Imaging
Anatomy
Function
Temporal Resolution
Spatial Resolution
Developmental Prospects
Technical Maturity
Clinical Availability
Clinical Application
Sensitivity / Specificity

3T MR-PET

Simultaneous 3T MR-PET Hybrid Measurements



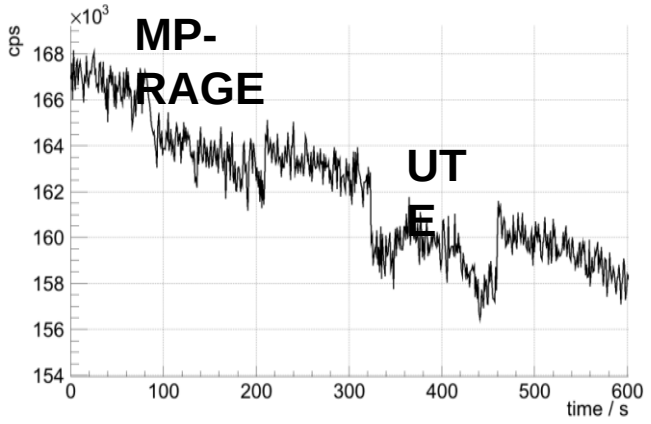
3T MR-PET hybrid scanner showing BrainPET and head coil



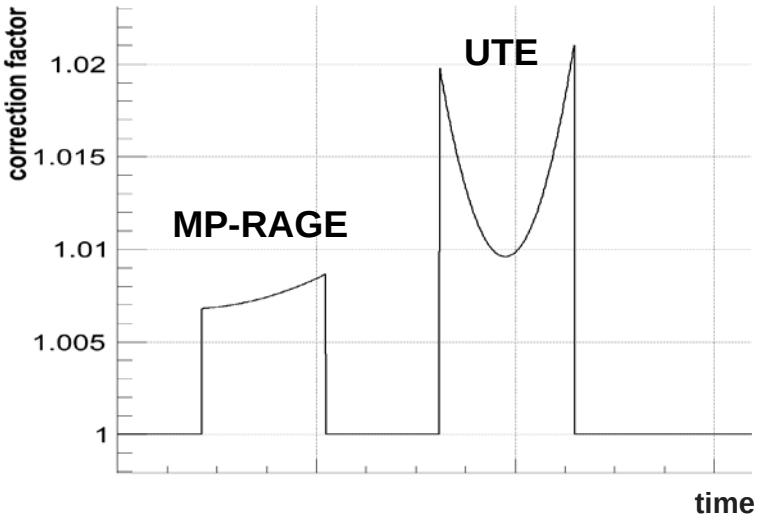
Simultaneous acquisition of ^{18}F-FDG-PET and MR images

DEVELOPMENT OF PROTOTYPE 3T MR PET

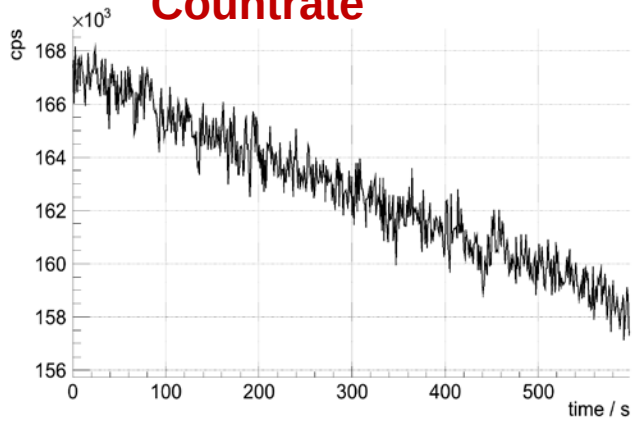
Uncorrected Countrate



Correction Factor



Corrected Countrate



Cross Calibration of the PET Scanners

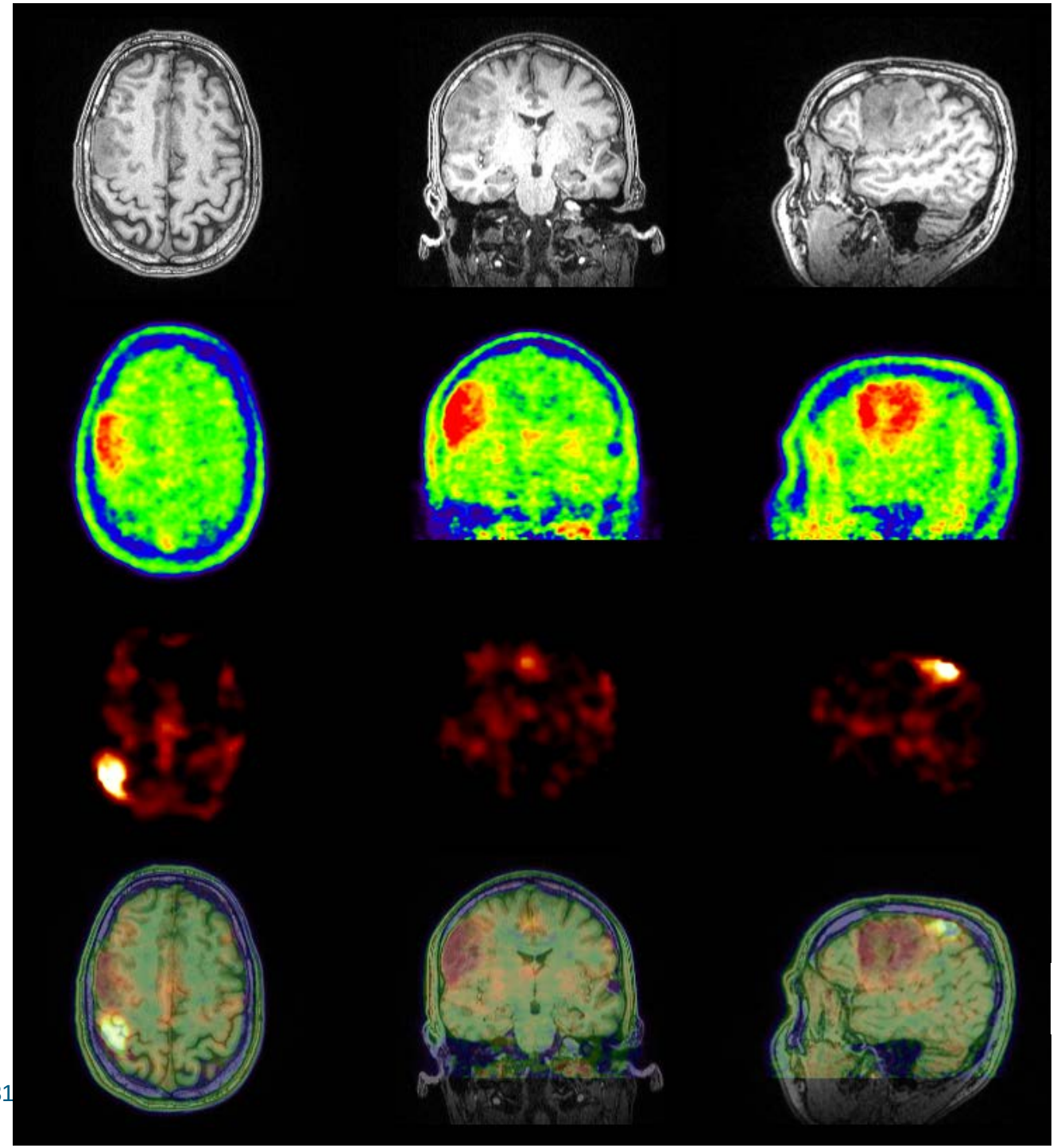
- Randoms Correction
- Scatter Correction
- Attenuation Correction of Head
- Normalisation of Crystal Efficiencies
- Deadtime and Pileup Correction
- Attenuation Correction of RF Coil
- MRI Interference Correction

Weirich,…, Shah (2012) *IEEE Trans. Med. Imaging*

Clinical Applications

K.-J. Langen et al.

Presurgical Imaging on a 3T MR-BrainPET



T1 MPRAGE (6 min)

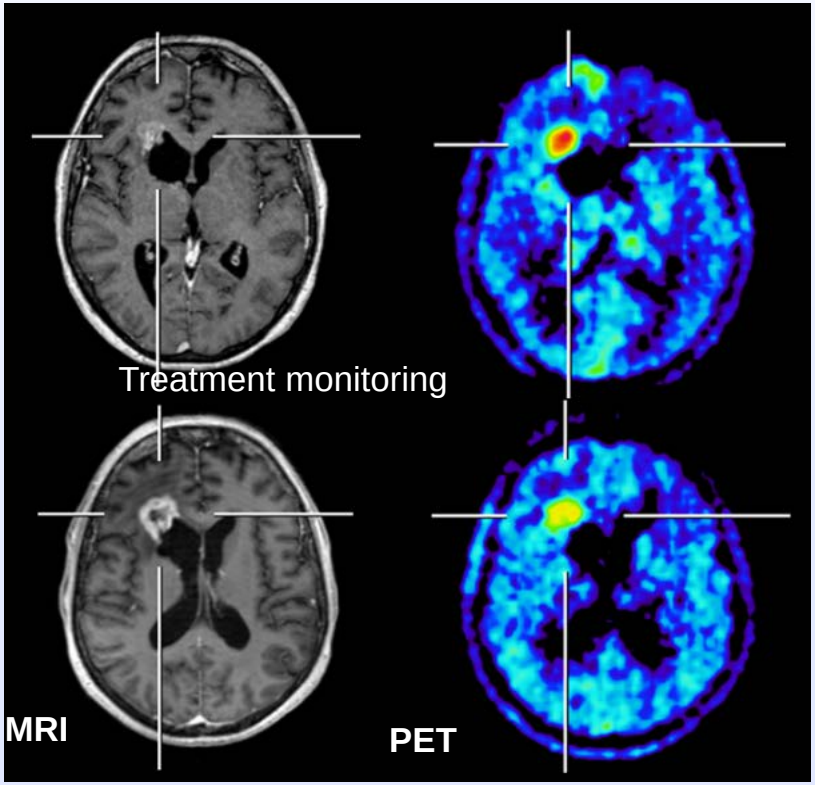
PET:
[^{18}F]-fluor-ethyl-tyrosine
20 - 40 min p.i.

BOLD imaging:
Finger tapping
left hand

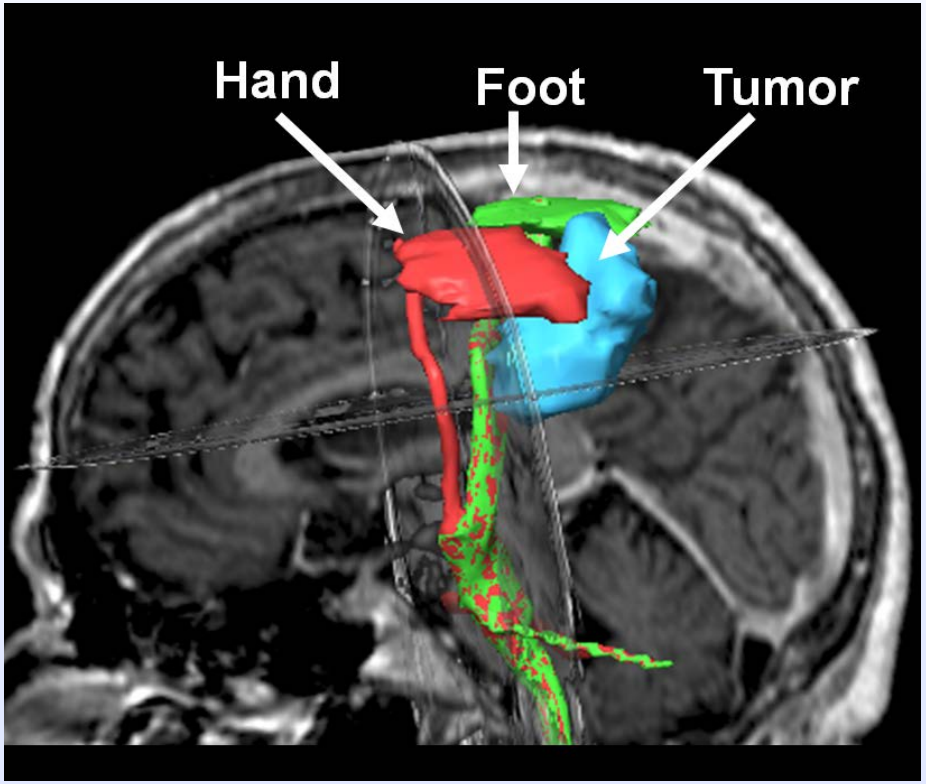
Fusion

Brain Tumours

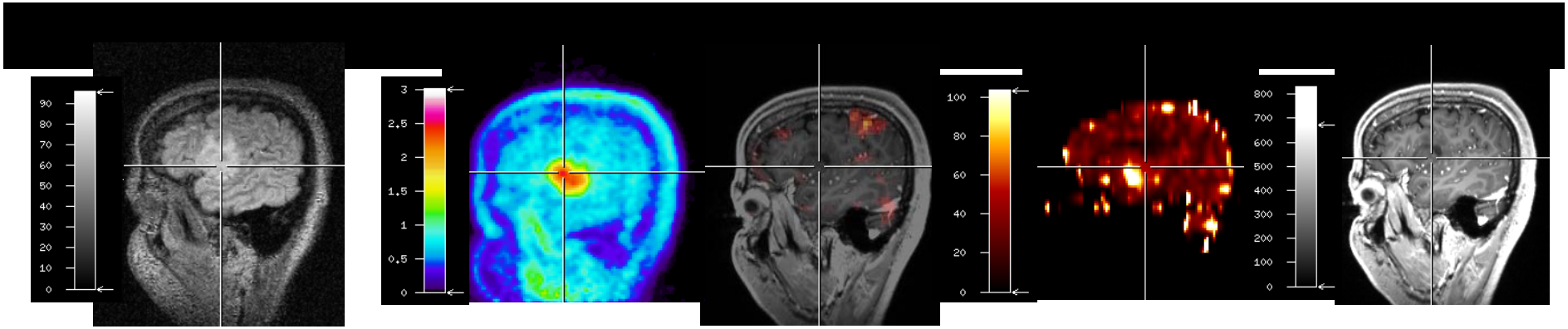
^{18}F- FET PET
Clinical Studies

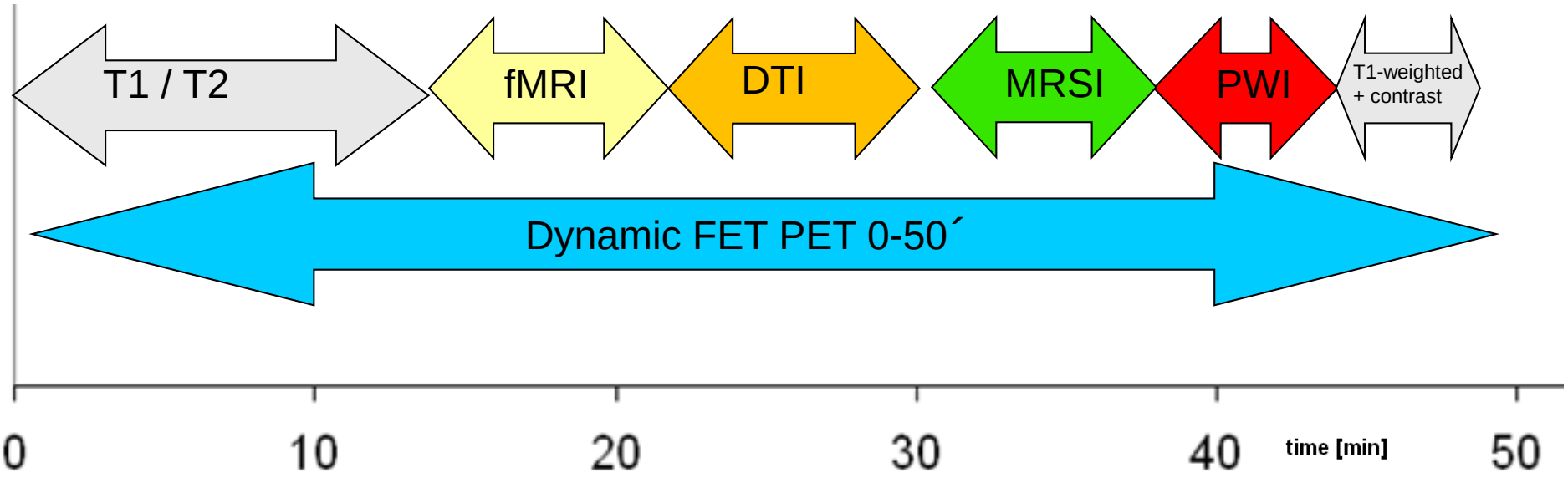


Hybrid
MR-PET Imaging



Hybrid MR-PET imaging





CBF
^{15}O-Water PET
Arterial Spin Labelling

K. Zhang, H. Herzog et al.

First Truly Simultaneous Comparison of CBF Assessed by ^{15}O-Water PET and ASL

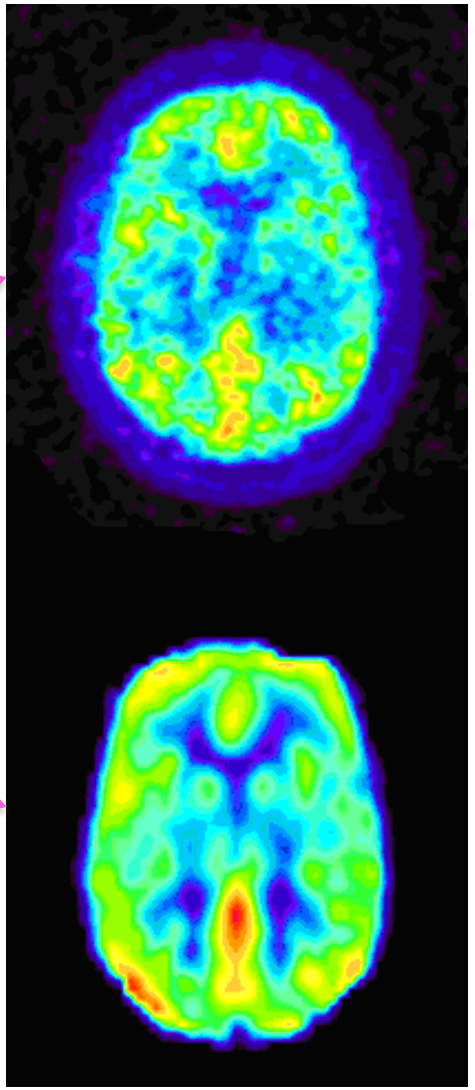
Bolus $H_2{}^{15}O$

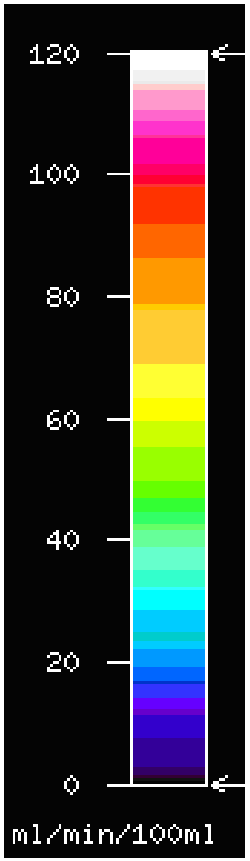
PET

3 min

pcASL

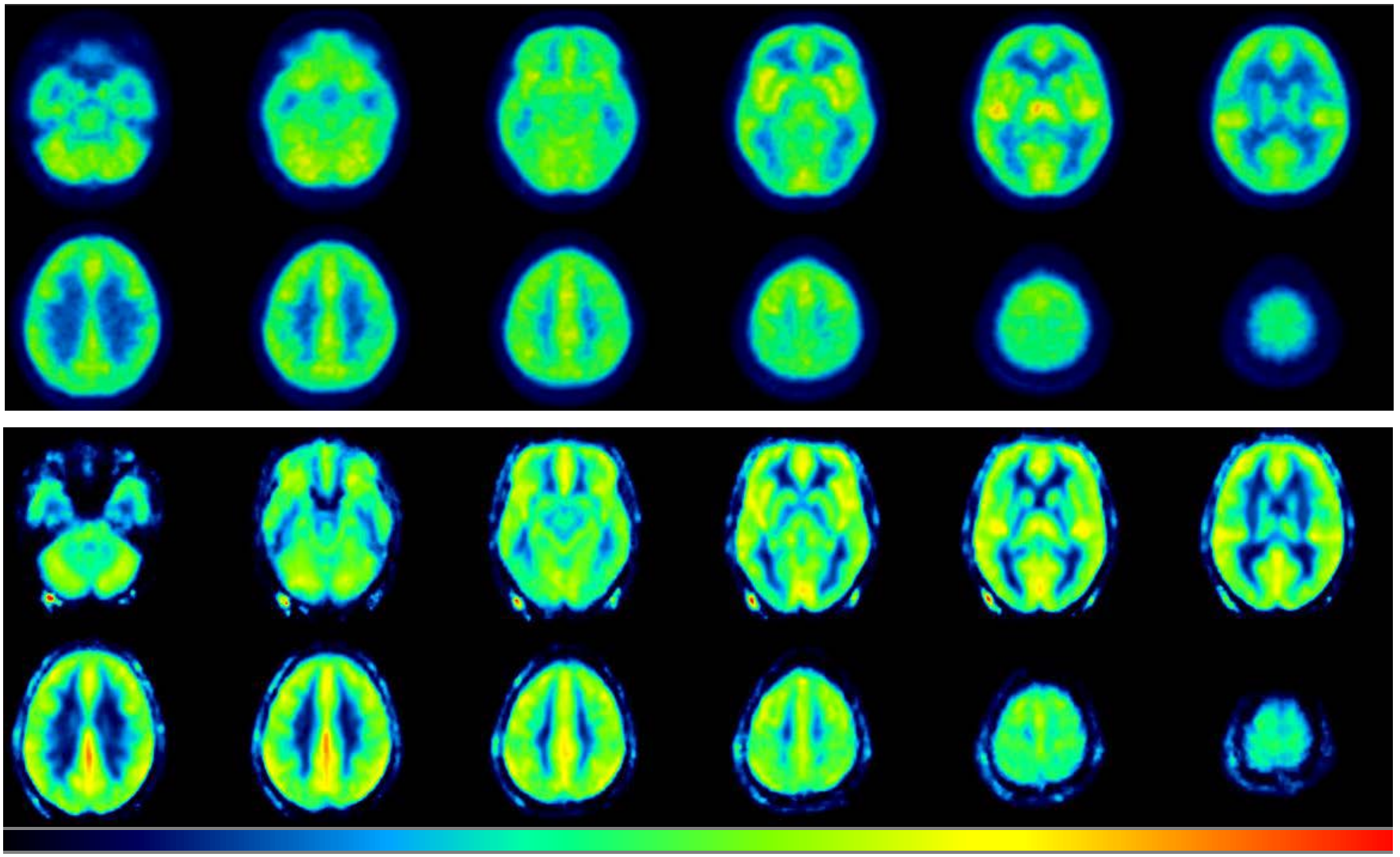
7 min





Sequence courtesty of Tom Okell and Peter Jezzard (FMRIB, Oxford)

Averaged Results



Averaged CBF images (n=10) after normalisation to MNI space

ASL: 51.9 ± 7.1 ml/100g/min

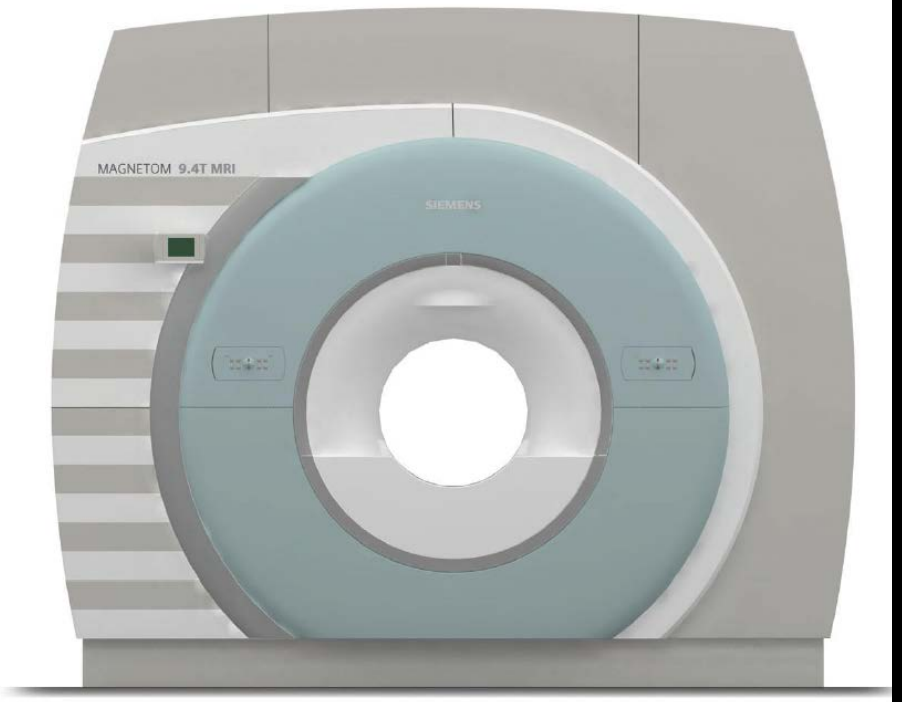
PET: 48.1 ± 9.9 ml/100g/min

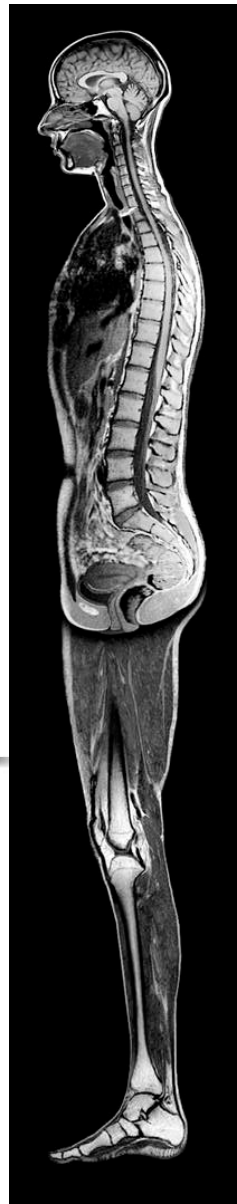
JÜLICH
FORSCHUNGSZENTRUM

High-Field MRI

9.4T Whole-Body Scanner in Jülich

- 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



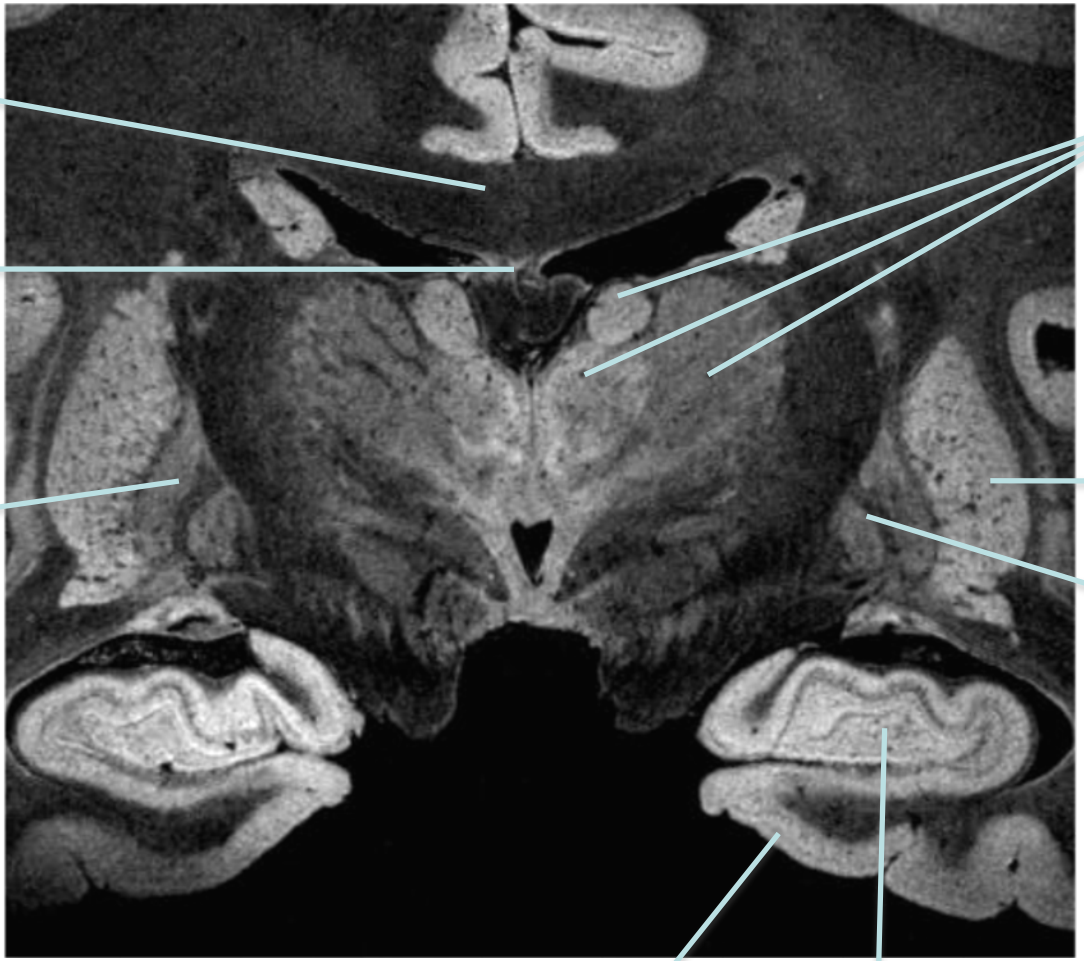


Complete with Hybrid PET Capability!

Structural Imaging

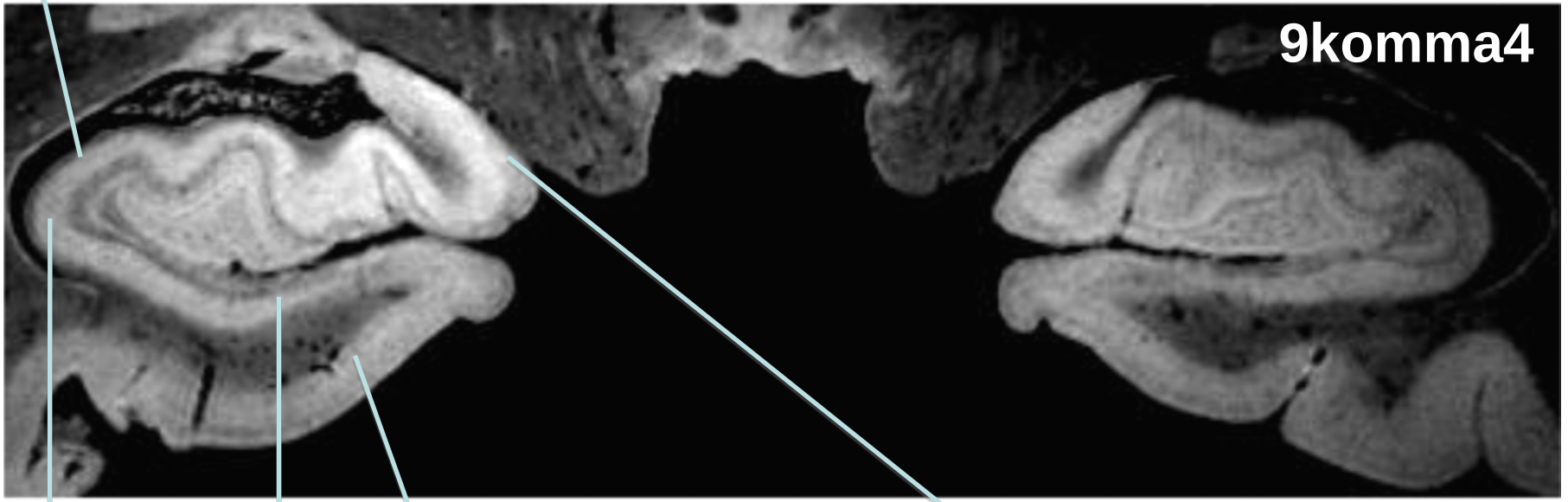
A.-M. Oros-Peusquens, J. Lindemeyer et al.

Hippocampus, thalamus



Anterior Hippocampus

cornu ammonis (CA2)



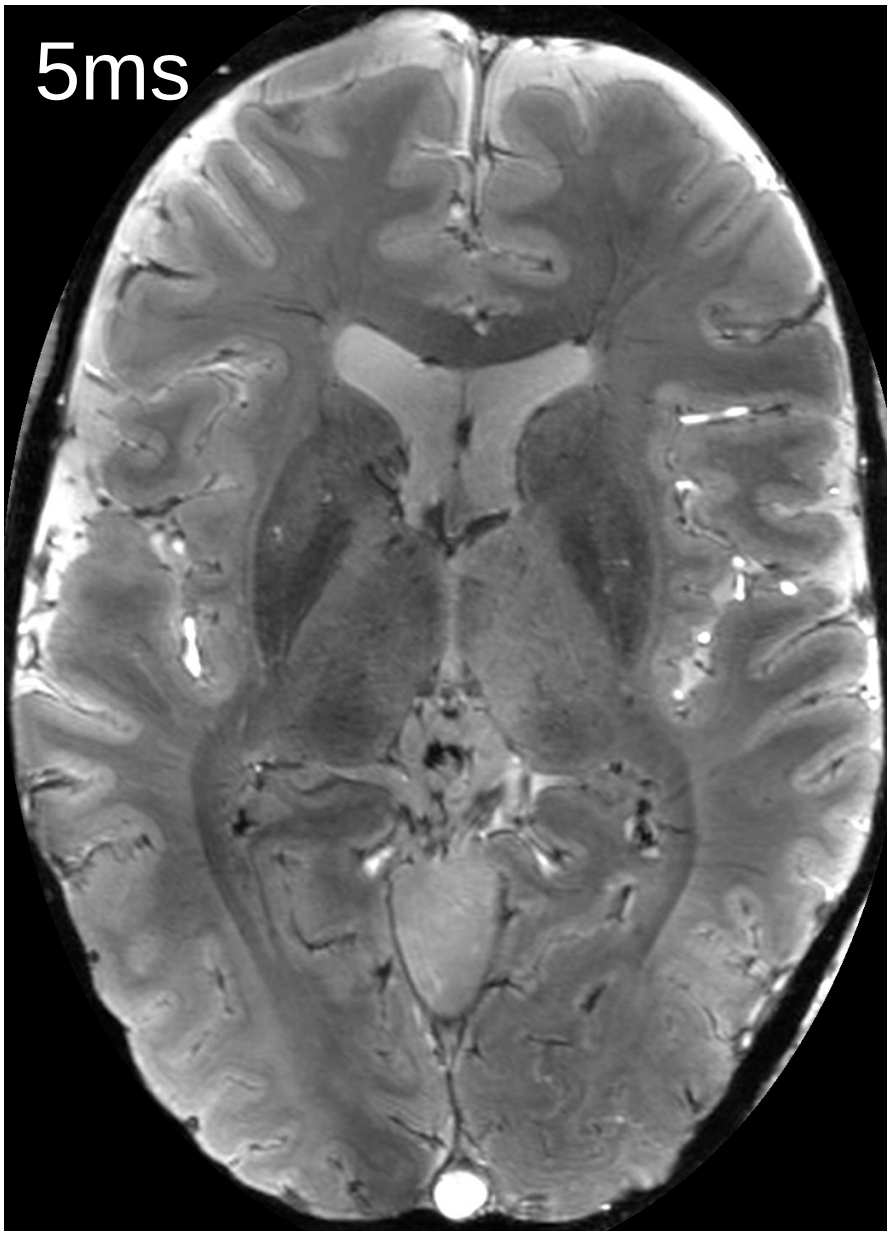
cornu ammonis (CA1)

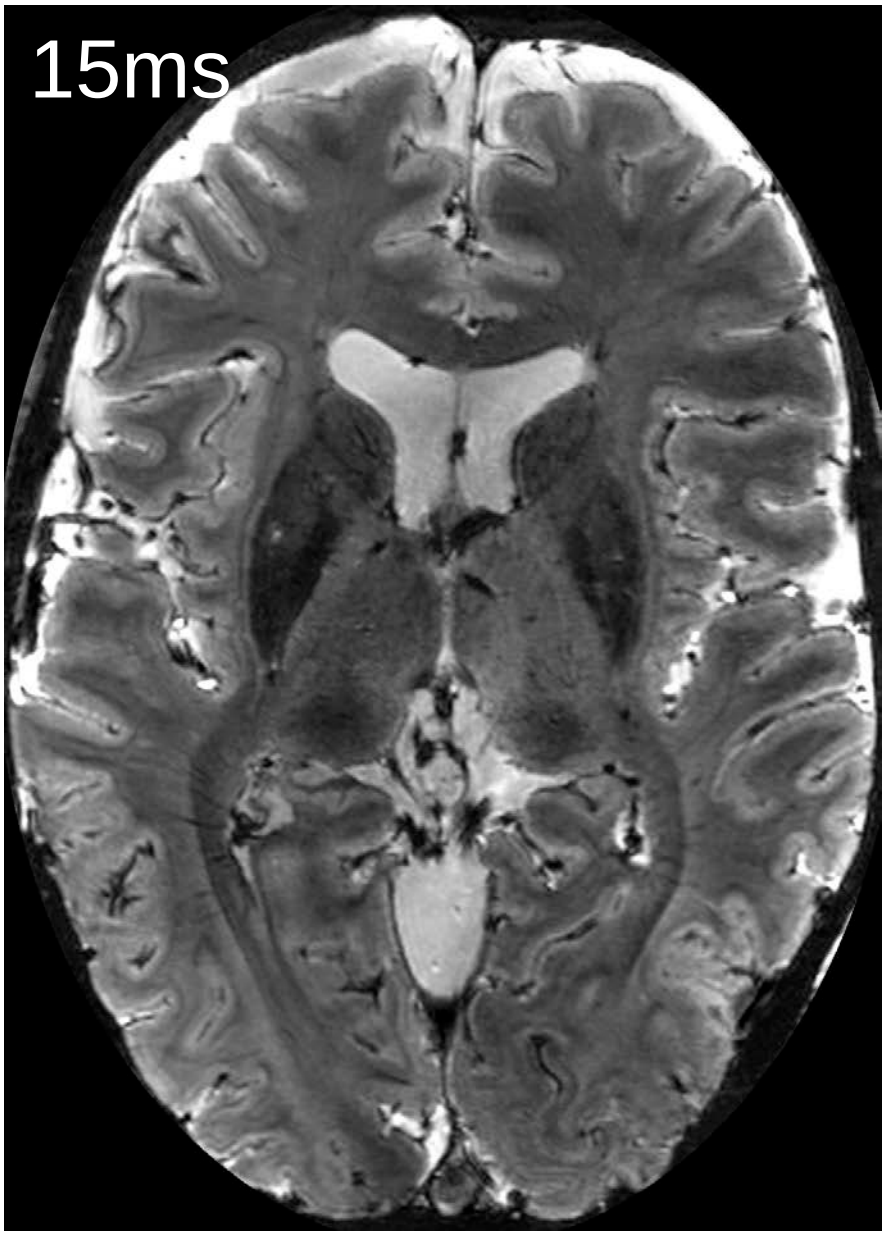
subiculum

entorhinal cortex

gyrus dentatus

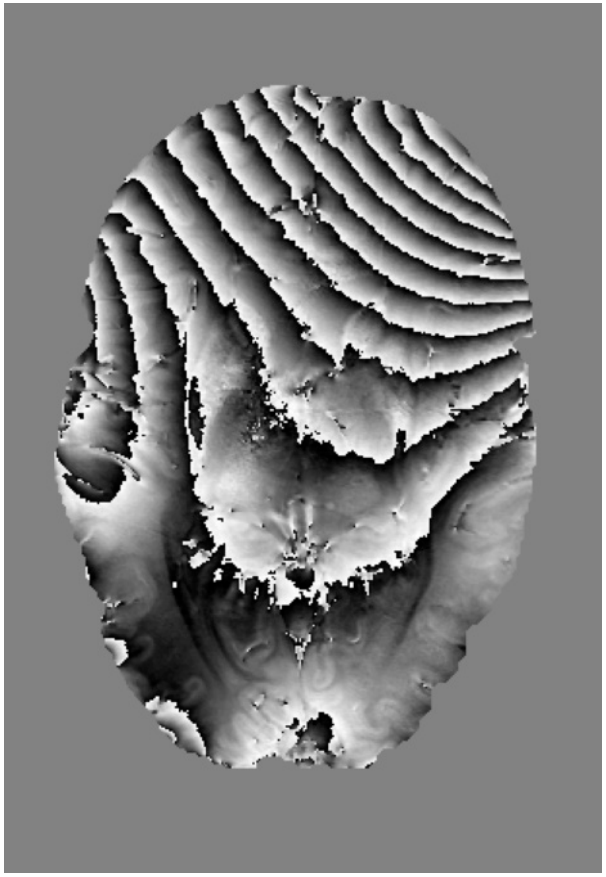
Structural imaging at 9.4T with $(0.5mm)^3$ resolution



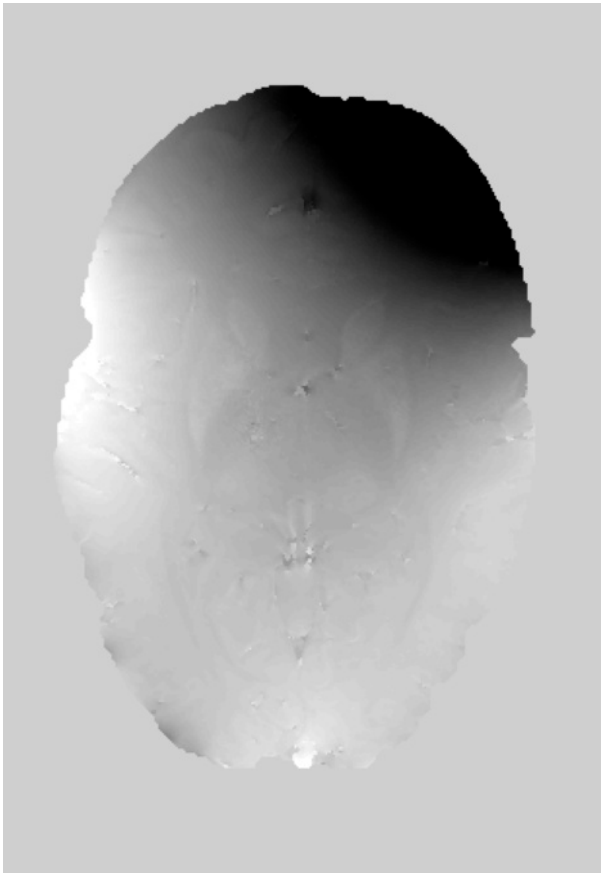


Phase Imaging at 9.4T (*in vivo*)

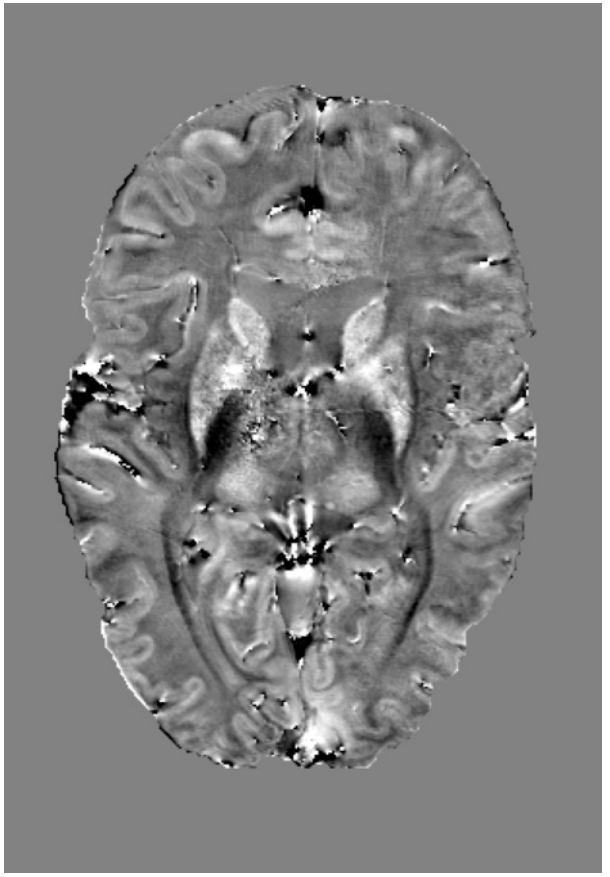
Phase



Unwrapped Phase (URSULA) → Fieldmap



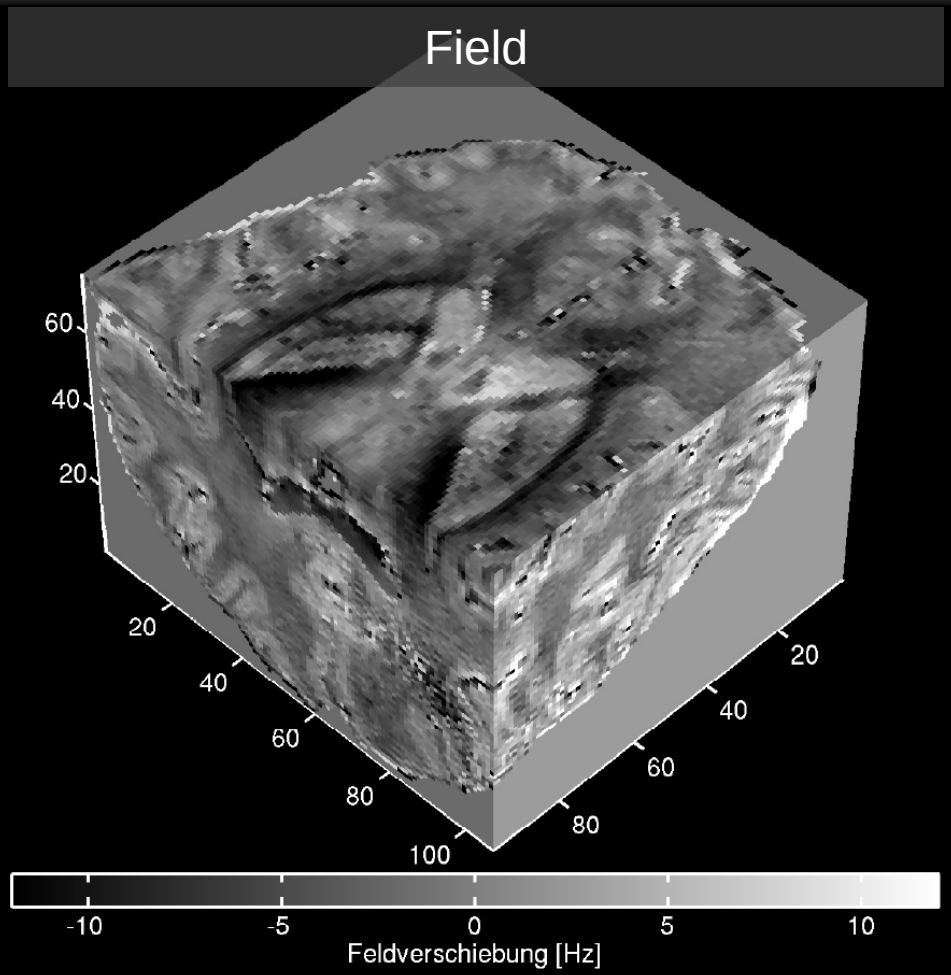
Background-Corrected (MUBAFIRE)

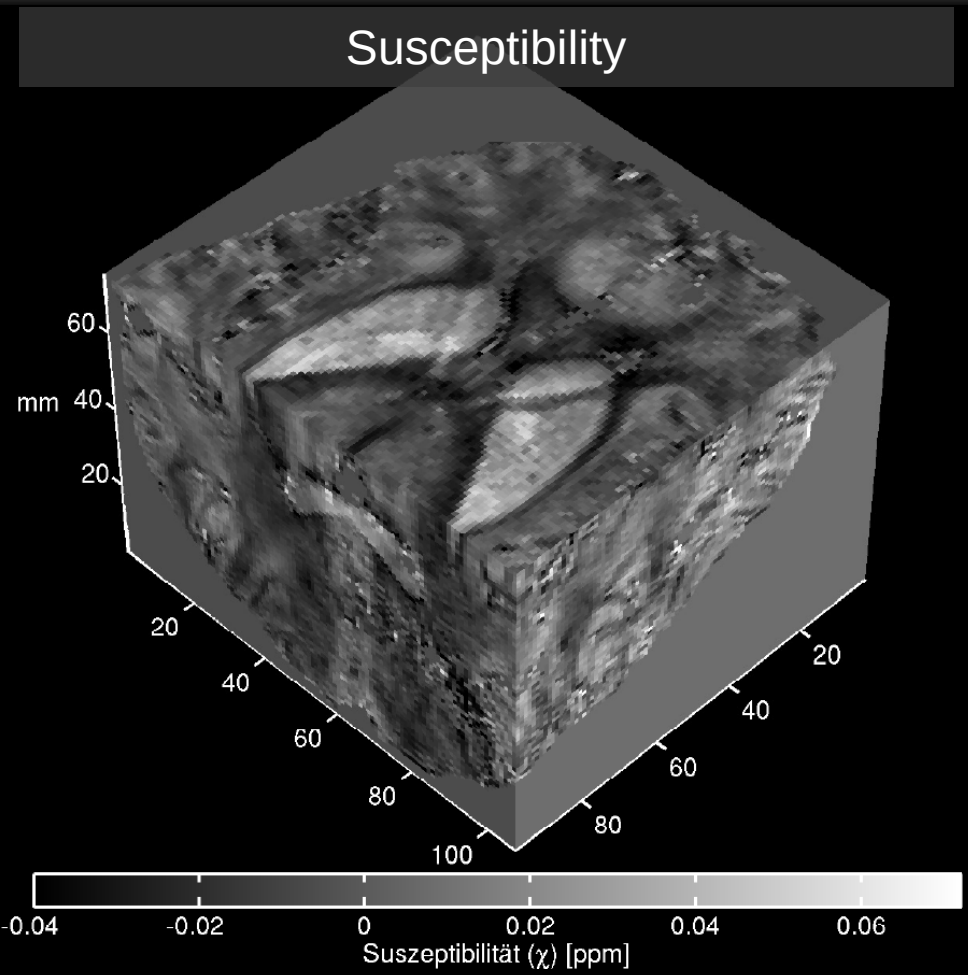


GRE 0.5mm isotropic, slab-selective excitation (central brain)

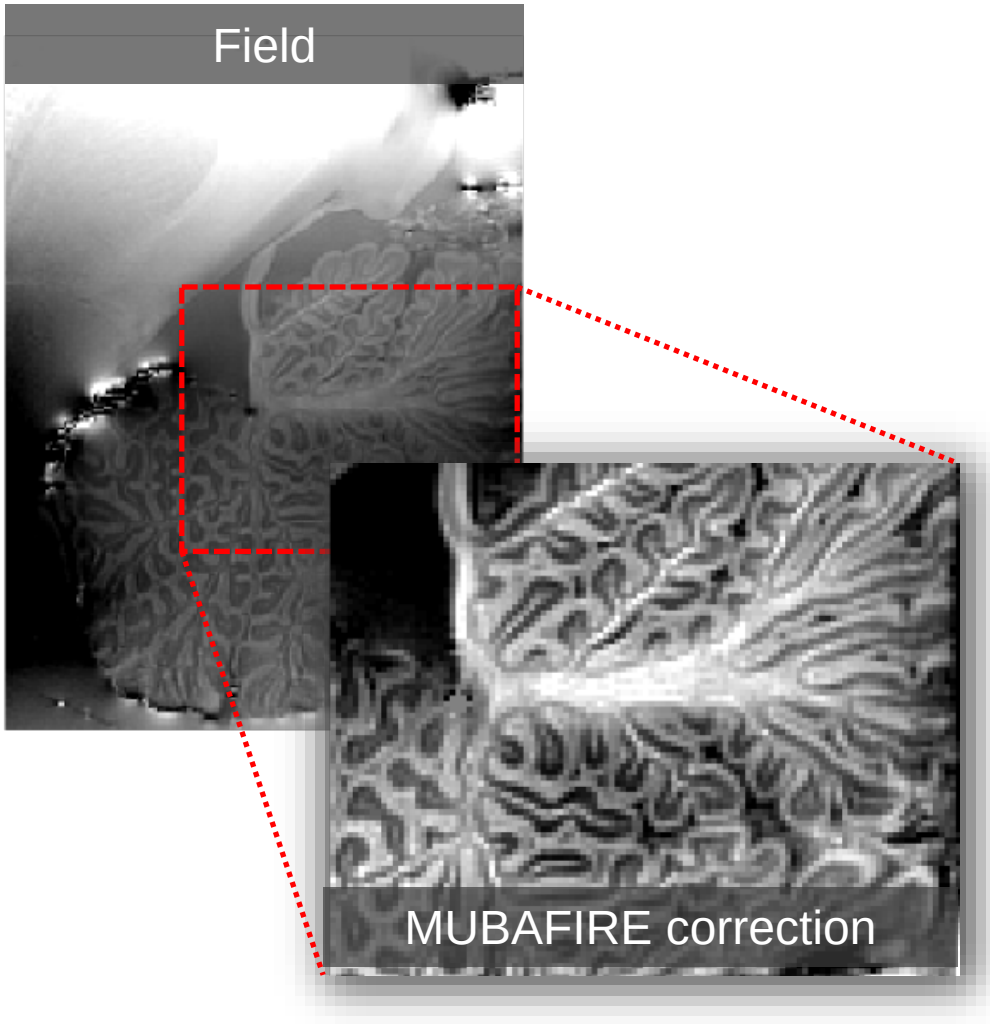
Phase Imaging at 9.4T (*in vivo*)

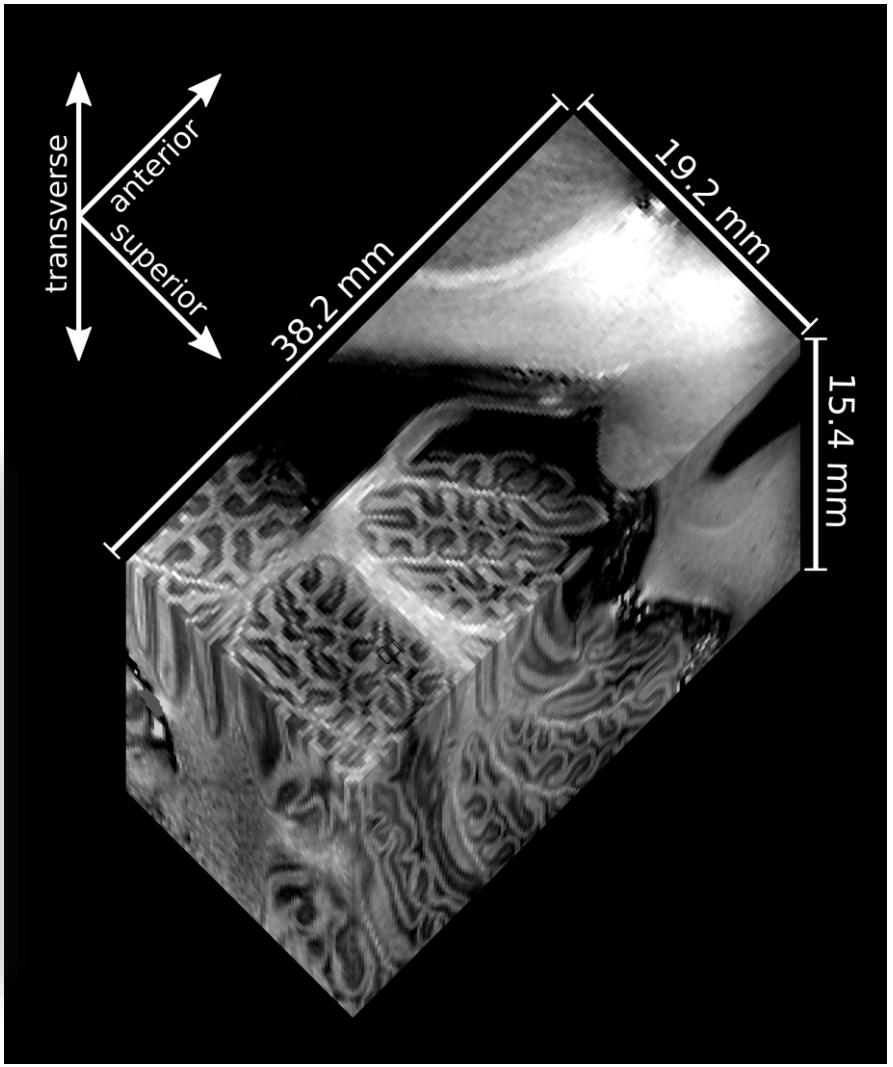
- Background-corrected field and susceptibility at 1mm isotropic, whole brain coverage





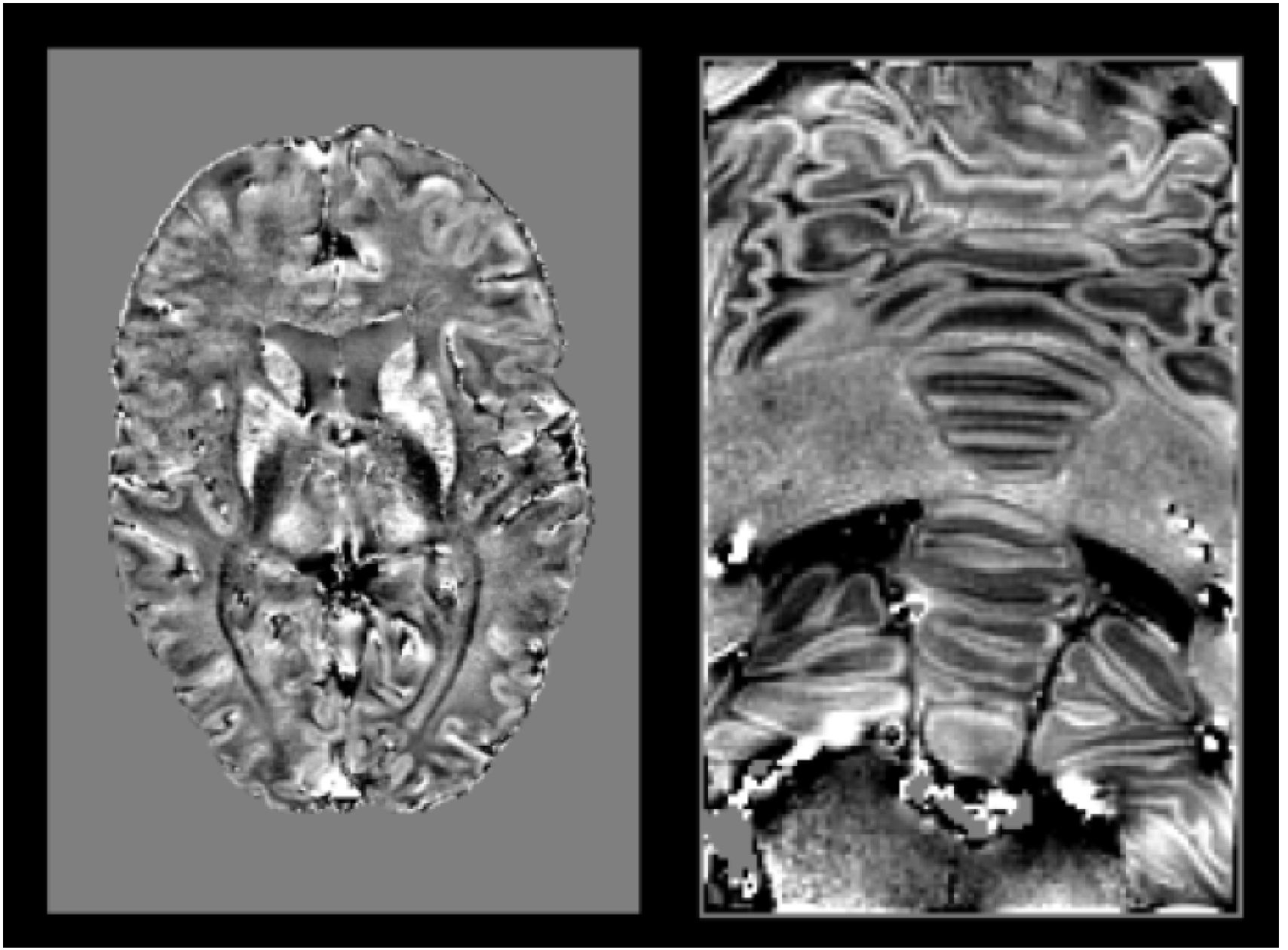
Phase Imaging at 9.4T (*post mortem*)





- Phase of cerebellum at 0.24mm isotropic

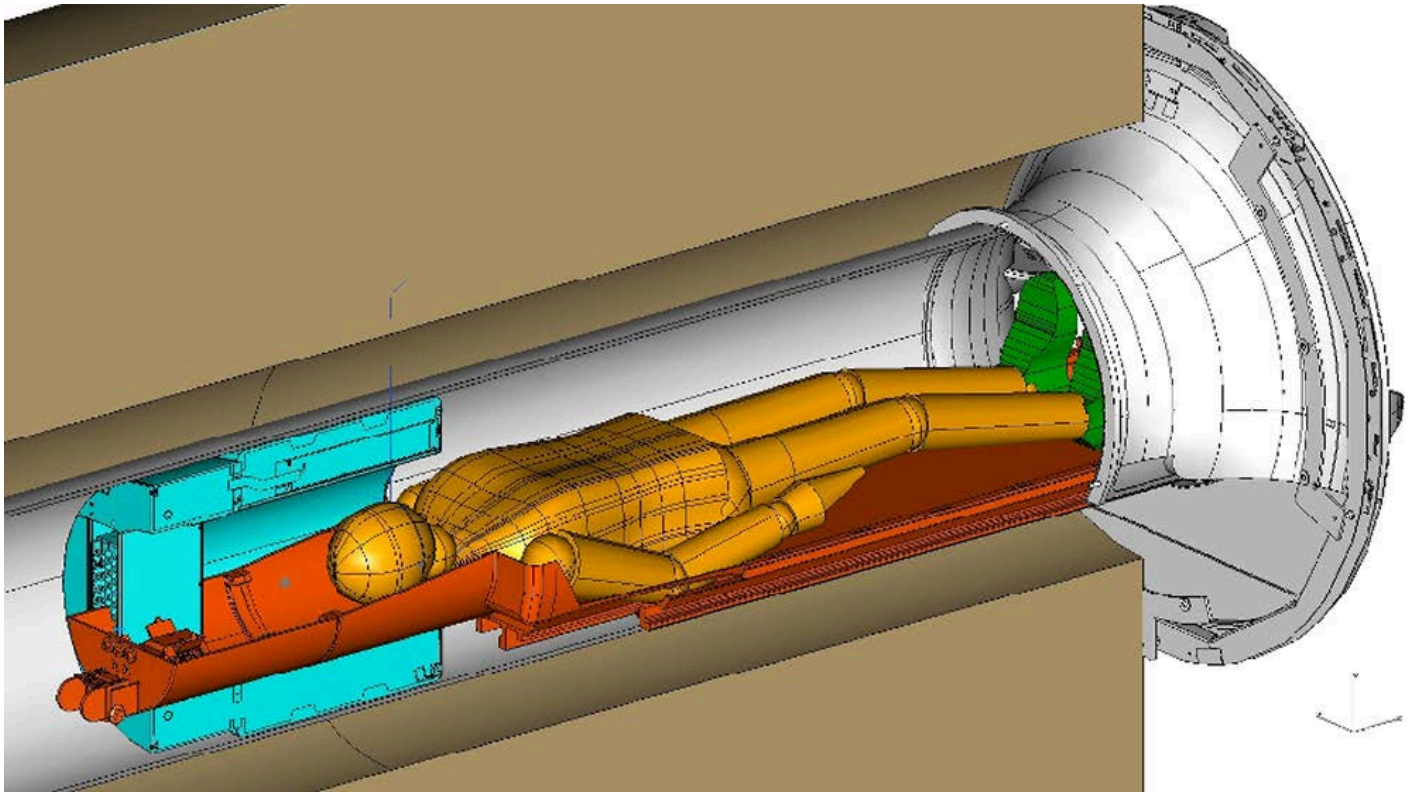
Towards MR histology…



MR-PET @ 9.4T

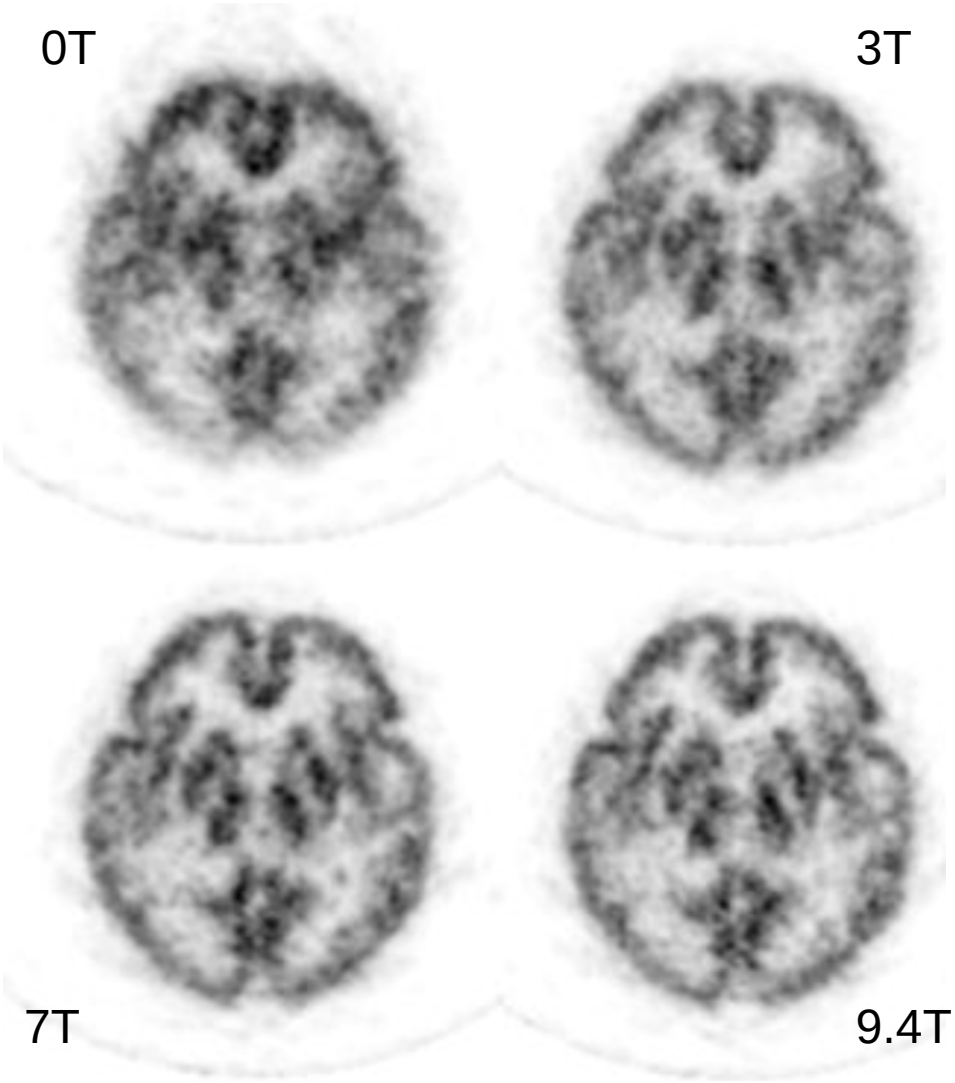
N. J. Shah, H. Herzog, C. Weirich et al.

9.4T MR-PET



Positron Range at 9.4T using the “Iida” Brain Phantom

Shah et al. (2014)
PLoS ONE
(in press)



Polymer brain phantom filled with ^{120}I

Rat Bone Scan with ^{18}F-Fluoride

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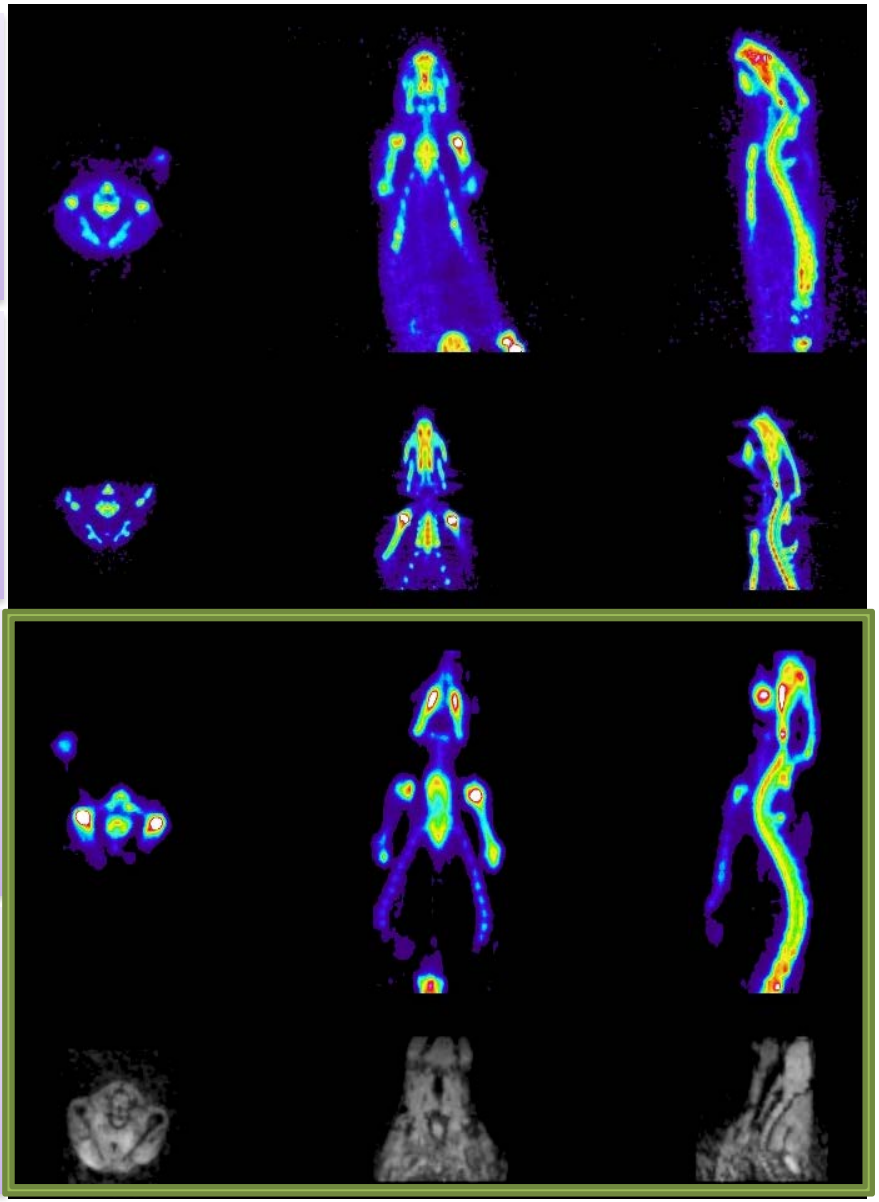
BrainPET @ 3 T	
Inveon PET	
BrainPET @ 9.4 T	
T2-weighted MRI @ 9.4 T	

Shah (2014) *BS&F* (in press)

Opportunities for Hybrid MR-PET

… MRI

⇒Higher spatial resolution (structural imaging)
⇒Higher functional (BOLD) contrast => columnar resolution fMRI?
⇒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

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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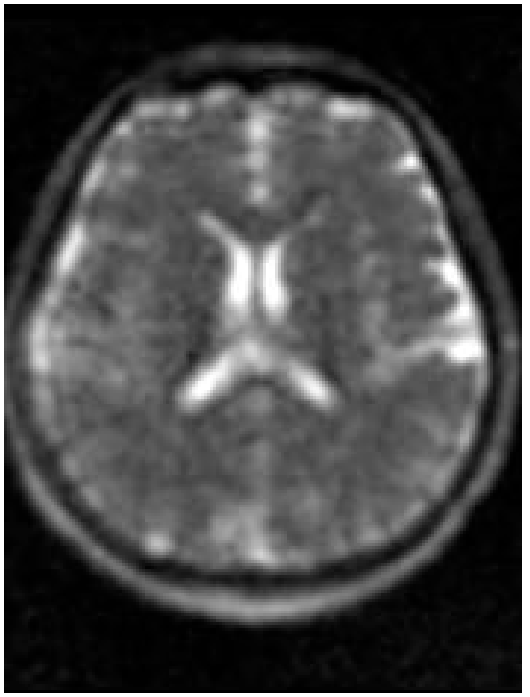
Sodium Imaging

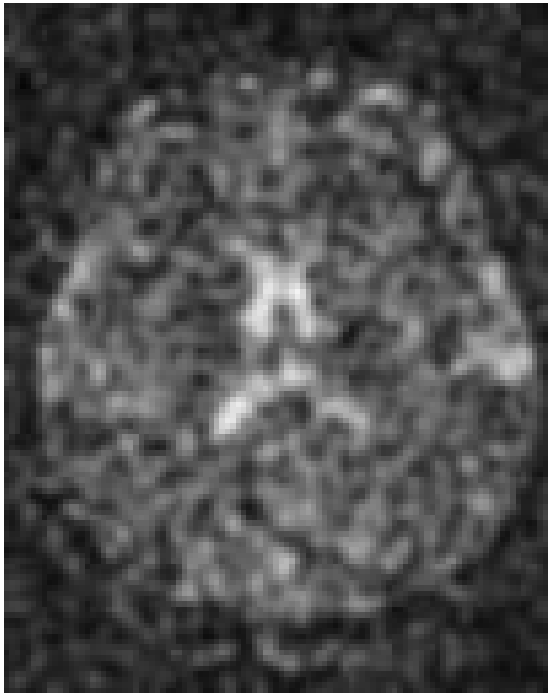
S. Romanzetti, D. Fiege, N. J. Shah et al.

First *In vivo* 9.4 T results

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

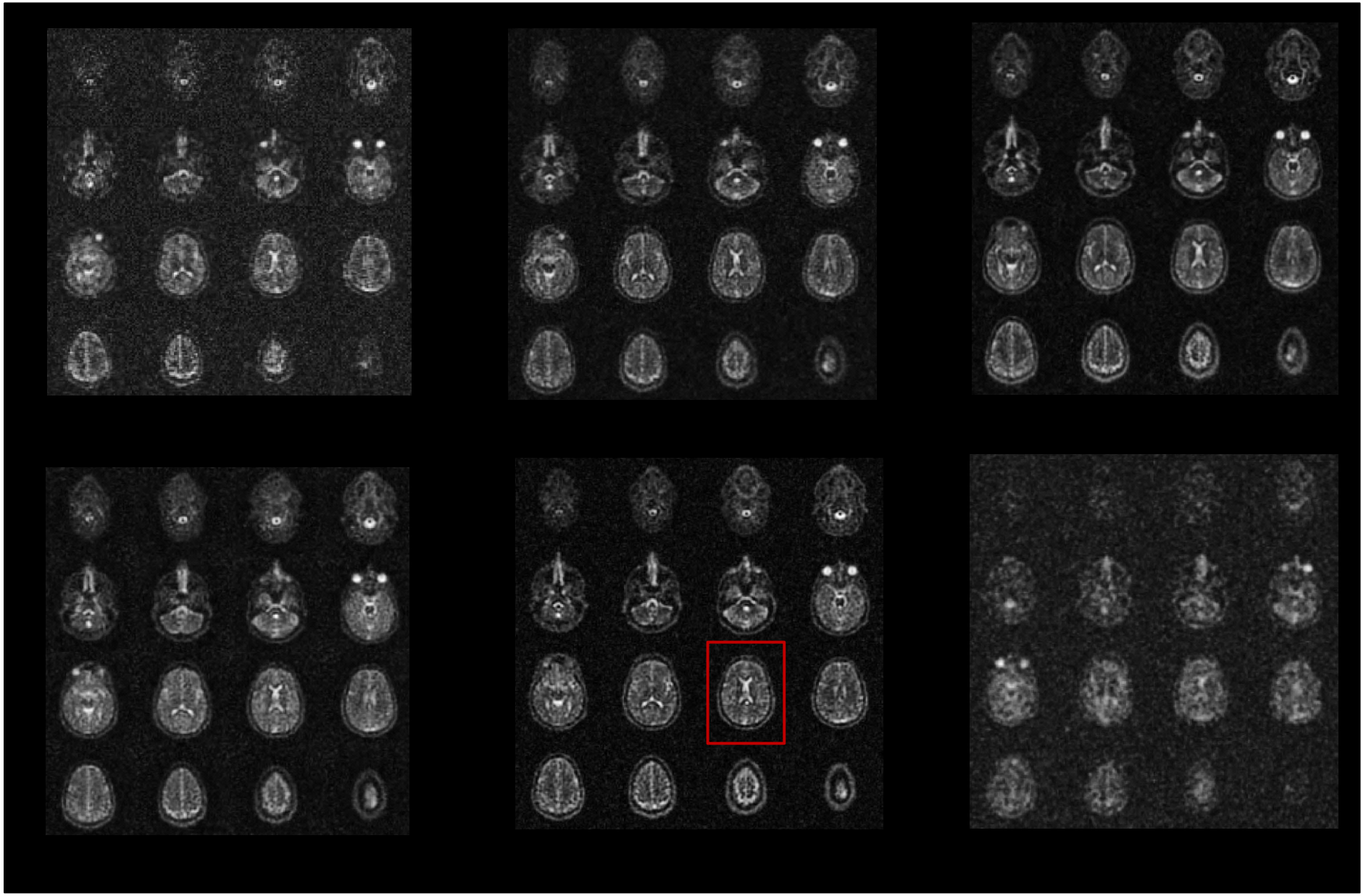


Sodium – 9.4T
TPI
2 mm isotropic
15 min acq. time

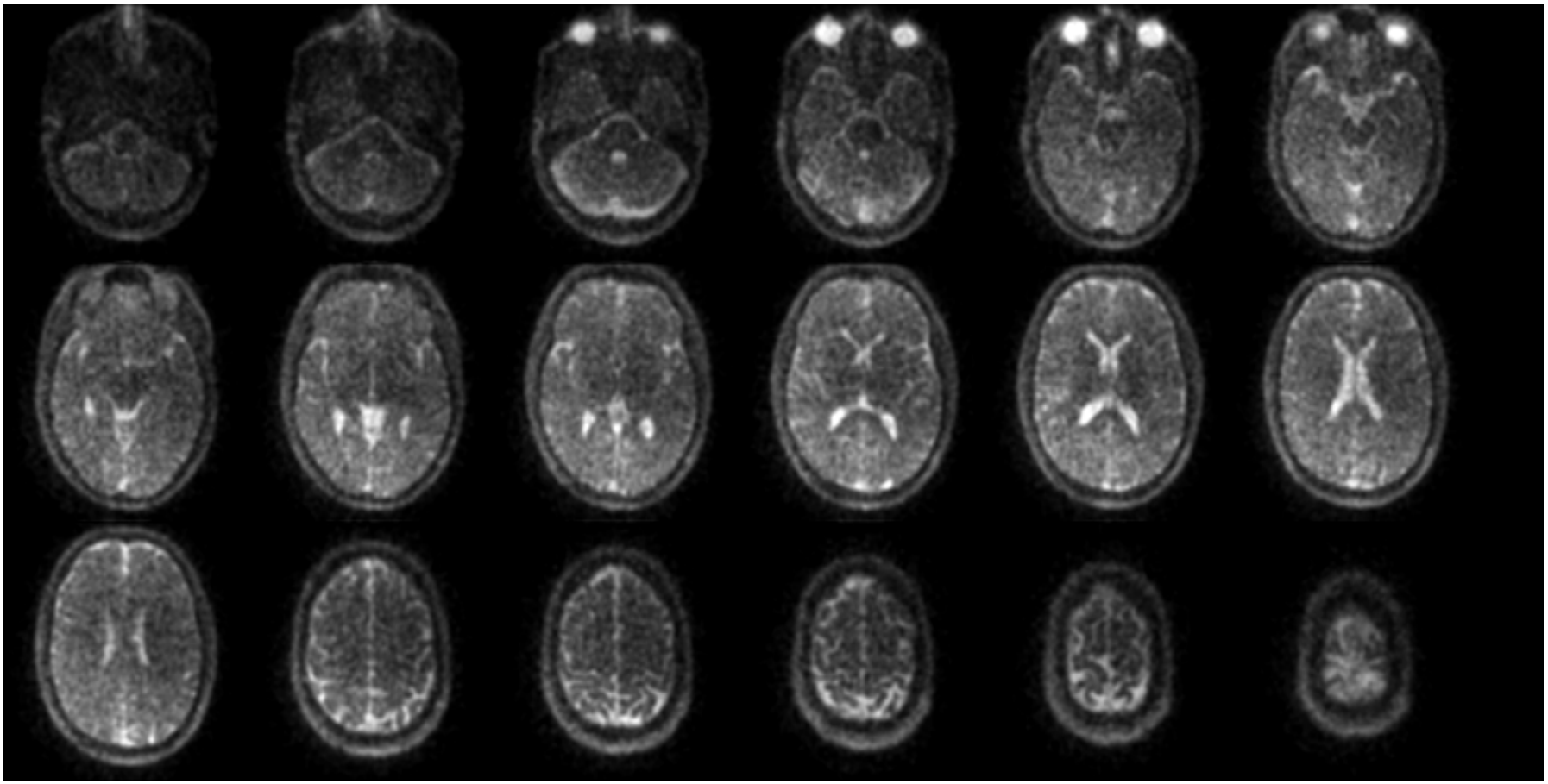


Sodium – 4T
TPI
2 mm isotropic
15 min acq. time

In vivo measurements (23Na)



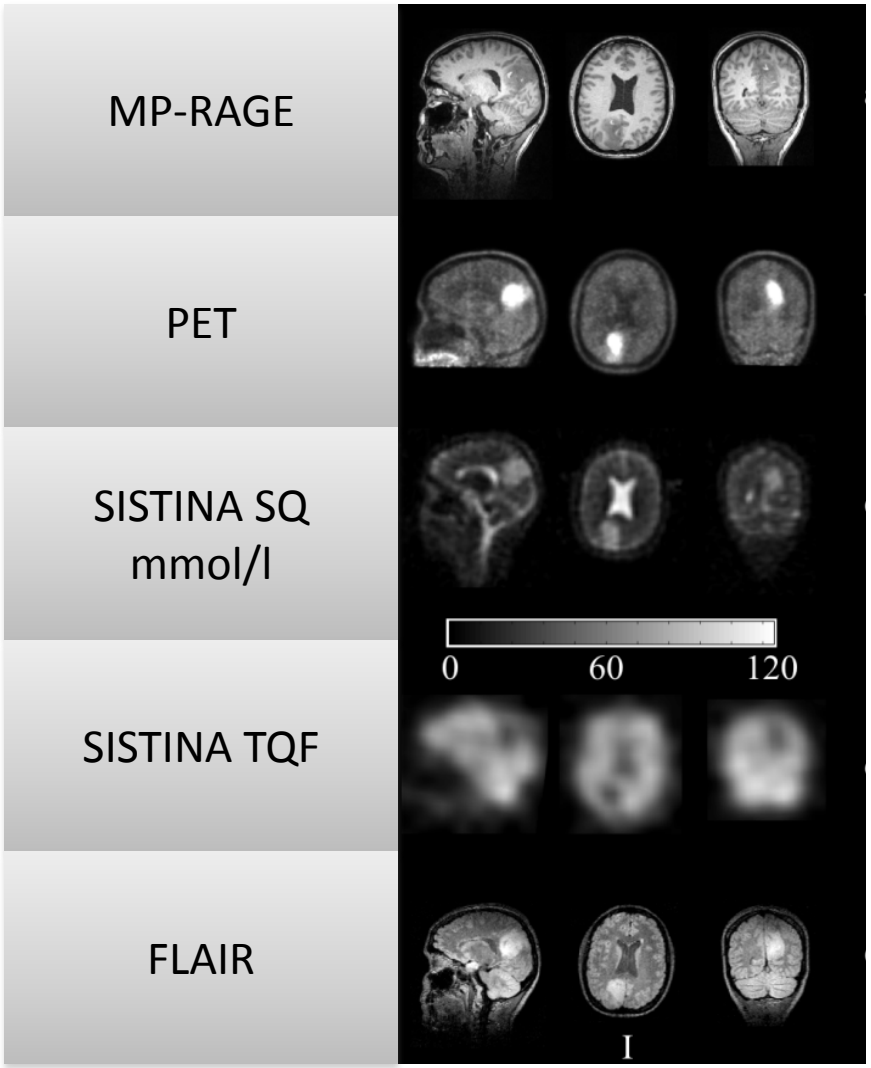
Sodium Imaging (2x2x2mm^3 in 7 minutes)



In vivo ^{23}Na Imaging with TPI steady state (TR/TE/flip = 50/0.4/60 [ms/ms/deg])

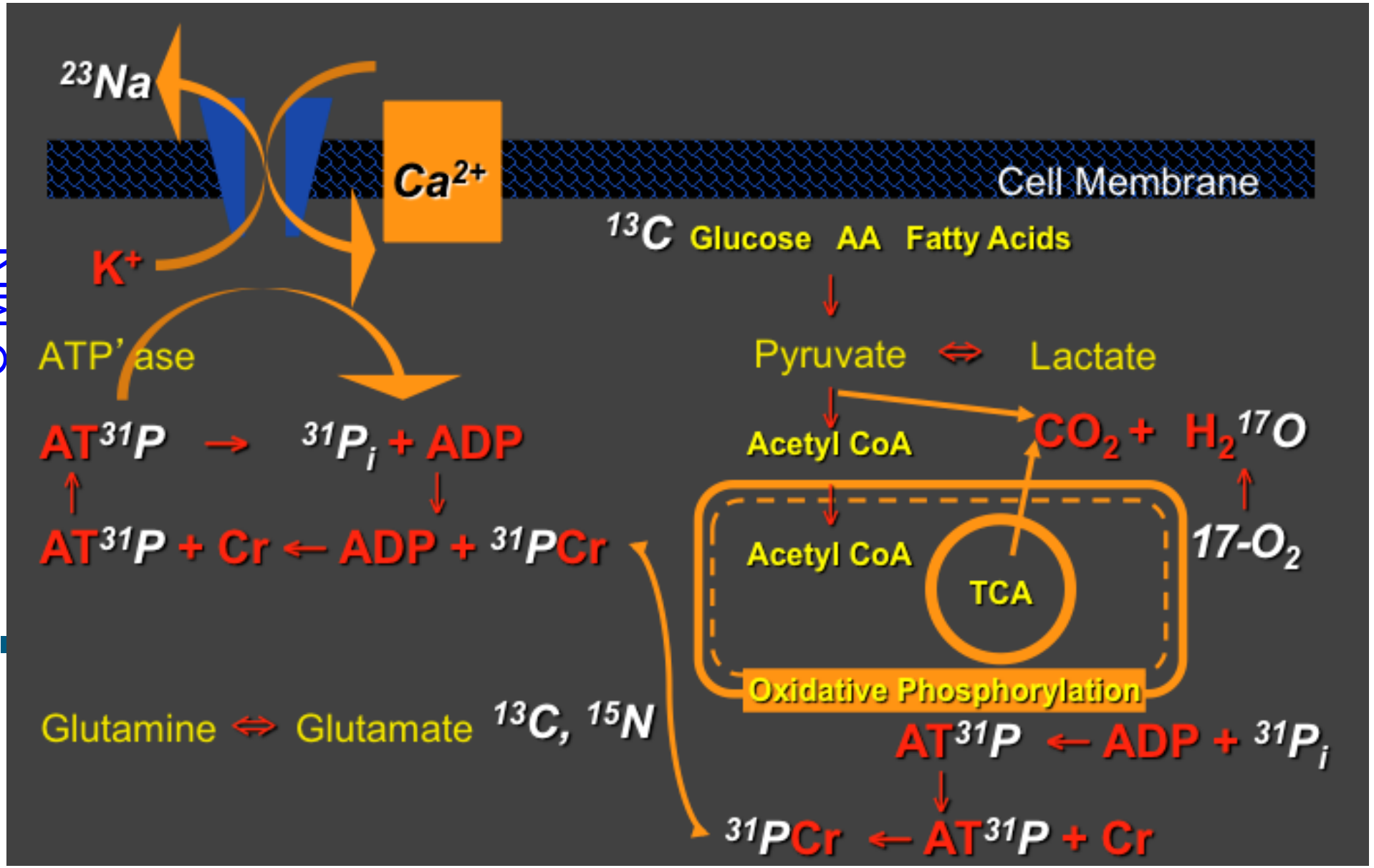
Fiege, Romanzetti, …, and Shah (2013) *Magn. Reson. Med.*
Fiege, Romanzetti, …, and Shah (2013) *J. Magn. Reson.*
Romanzetti, …, and Shah (2014) *NeuroImage (in press)*

^{23}Na TQF *in vivo* 9.4 T results



In vivo results from three tumour patients.

Goal: Non-invasive Quantitative Metabolic Imaging of Oxygen



Slide: Atkinson et al. U. of Chicago

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Oxygen Imaging

K. Moellenhoff and N. J. Shah

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^{1}H MR Spectroscopy

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^{31}P MR Spectroscopy

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Temporal Aspects

I. Neuner, J. Arrubla and N. J. Shah


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JCB


BEKA


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Dr. C. Filß

Brain Tumour Group

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Thank You!!

Collaboration Opportunities

Visiting Scholars / Guest Scientists

- Postdocs
- Graduate Students