

# Cambridge 7T: first 100 days

8<sup>th</sup> March 2017

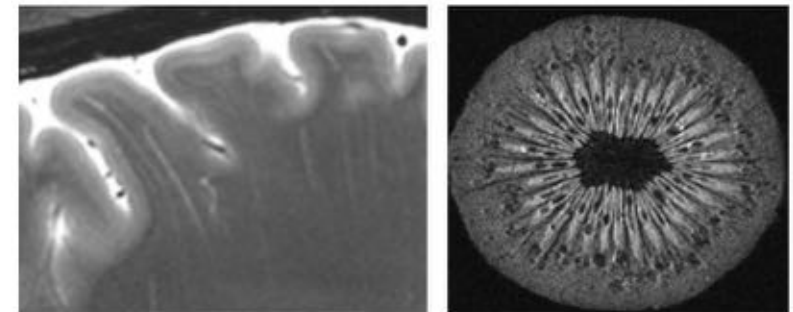
Catarina Rua

# Outline of talk

- Overview of first 100 days
- Optimized Sequences at 7 Tesla
- Future Sequences
- WBIC Stimulus Delivery
- Final Remarks

# First 100 days...

- 1<sup>st</sup> participant scanned on the 2<sup>nd</sup> December 2016
- Sequence optimization at the scanner:
  - 16 head scans on healthy subjects;  
(1 subject dropped out)
  - 3 knee scans on healthy subjects.



**Figure 1:** Ground-breaking 7T TERRA MRI research at the WBIC has demonstrated directly for the first time that both the cortex of the kiwi fruit (left) and the cortex of the Regius Professor of Physic (right) are internally laminated. Rowe et al (2016) *unpublished data*

(WBIC Christmas Newsletter, 2016)

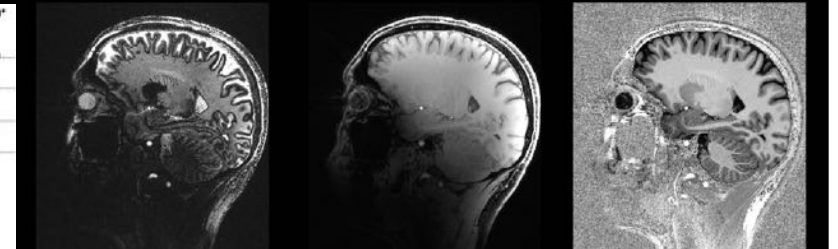
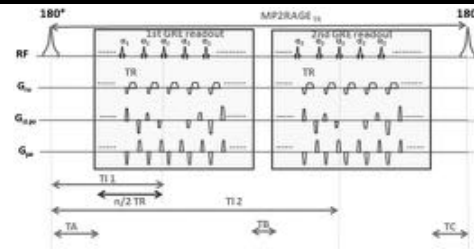
# Optimized Sequences at 7 Tesla: T1 structural 3D

- MPRAGE scan: 0.75mm isotropic
  - TR=2200ms, TE=3.05ms, TI=1050ms, FA=8, BW=250Hz, iPAT=2

TA=6'35''

**MP2RAGE:** Self biased corrected sequence for improved saturation and T1-mapping at high field

(Marques et al., 2010)



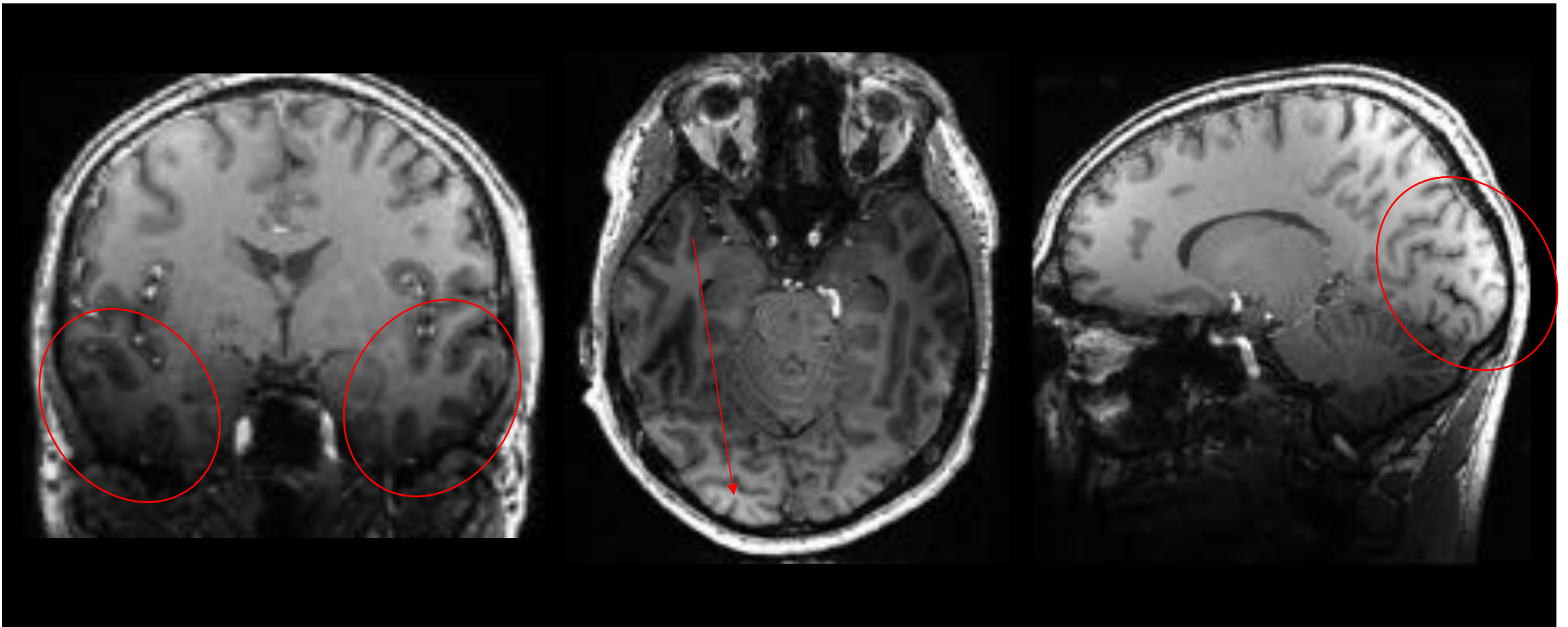
- MP2RAGE high resolution scan: 0.75mm isotropic
  - TR=4300ms, TE=1.99ms, TI=840/2370ms, FA=5/6, BW=250Hz, iPAT=3, no pF
- MP2RAGE fast scan: 1mm isotropic
  - TR=4300ms, TE=1.84ms, TI=840/2370ms, FA=5/6, BW=250Hz, iPAT=3, pF=6/8

TA=8'50''

TA=5'24''

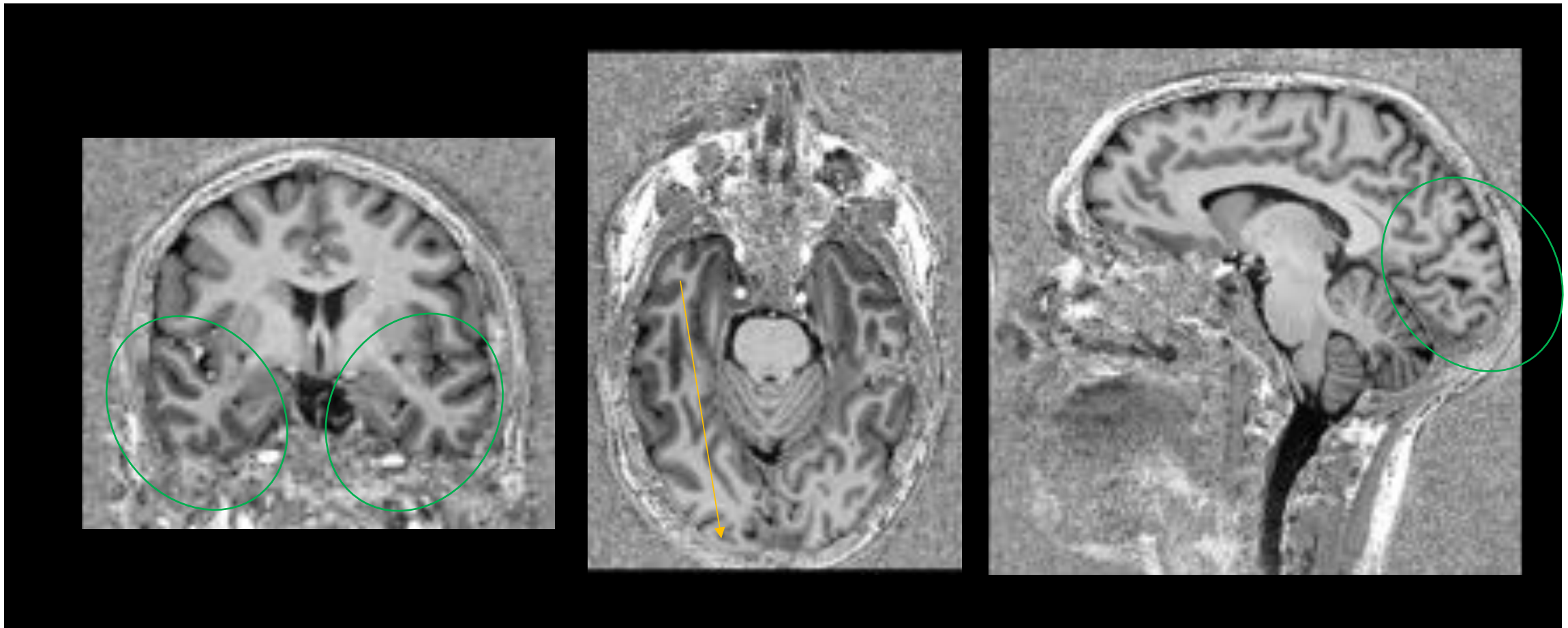
# Optimized Sequences at 7 Tesla: T1 structural 3D

**MPRAGE scan: 0.75mm isotropic, TA=6'35''**



# Optimized Sequences at 7 Tesla: T1 structural 3D

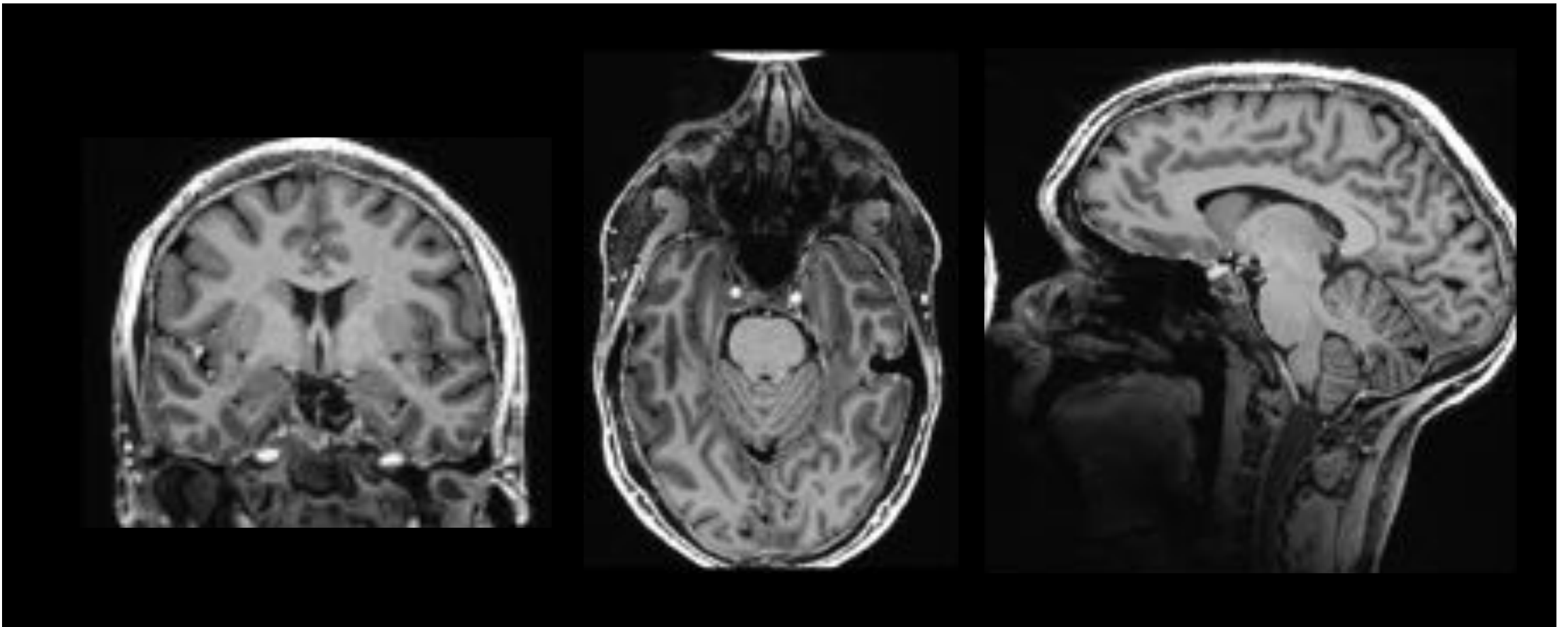
MP2RAGE scan high resolution (TA=8'50'')





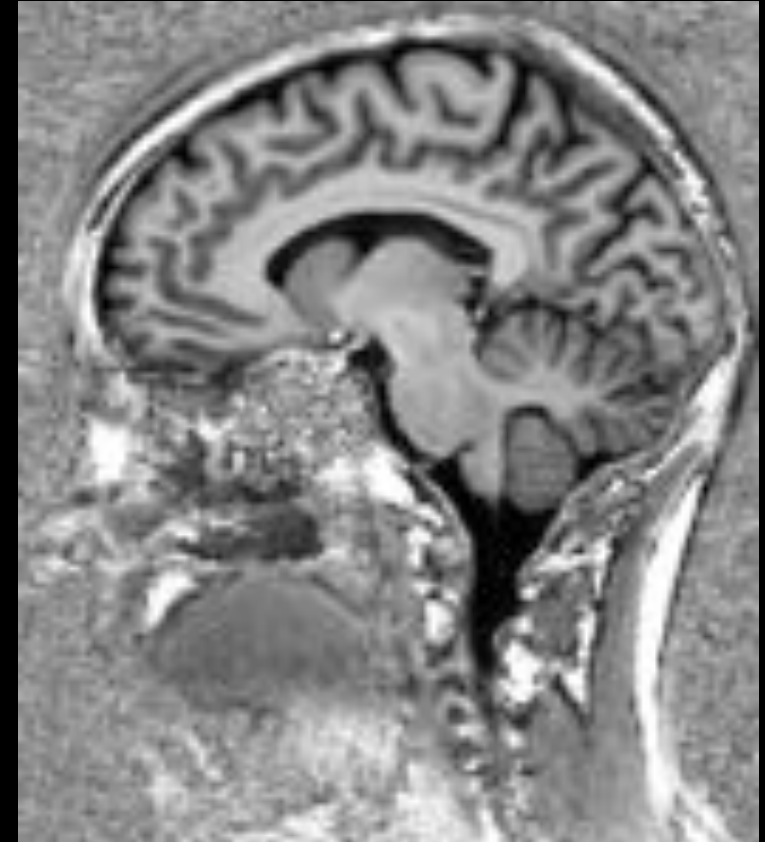
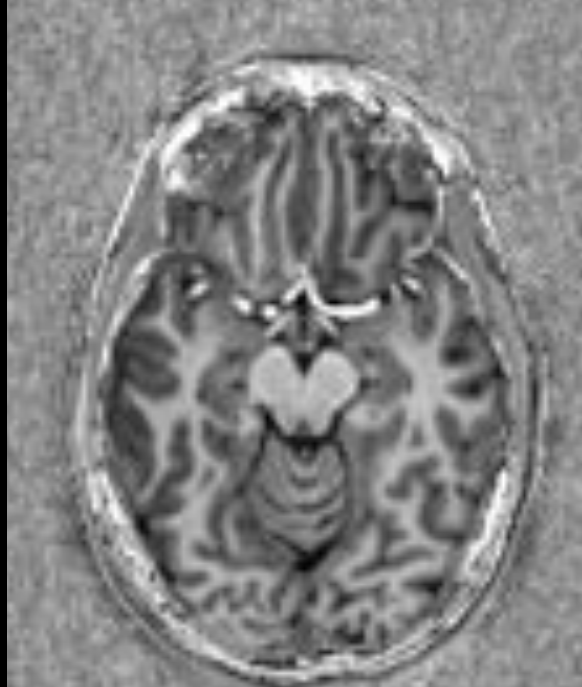
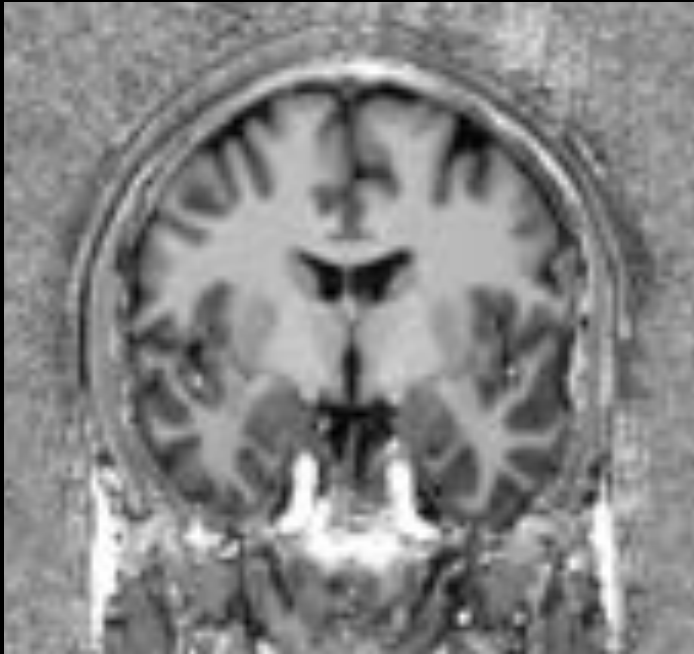
# Optimized Sequences at 7 Tesla: T1 structural 3D

**MP2RAGE scan high resolution, background corrected**



# Optimized Sequences at 7 Tesla: T1 structural 3D

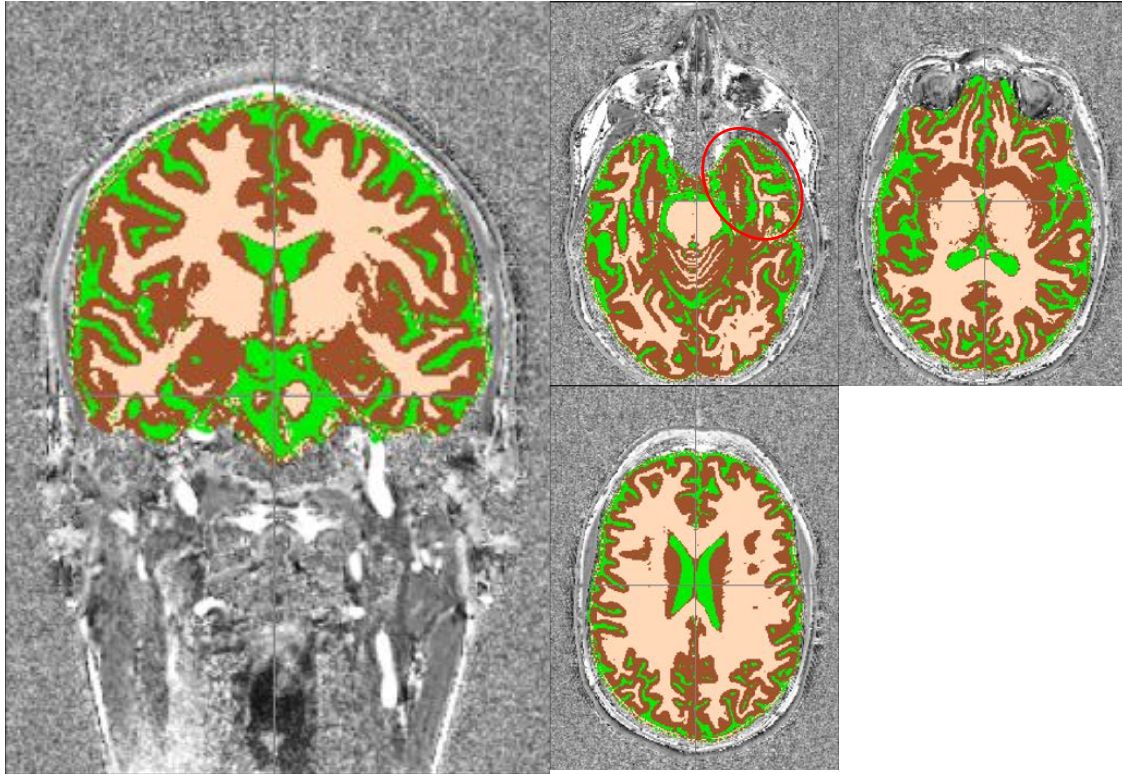
**MP2RAGE scan standard resolution 1mm isotropic (TA=5'24'')**





# T1 Segmentations with MP2RAGE scans

## Segmentations in FSL:



## Segmentations and Surfaces with FreeSurfer:

- New for FreeSurfer v6.0.0 (Jan2017 release): -hires option for submillimeter acquisition;
- Doesn't handle noise in background;
- Skull-stripping is inefficient.

See also:

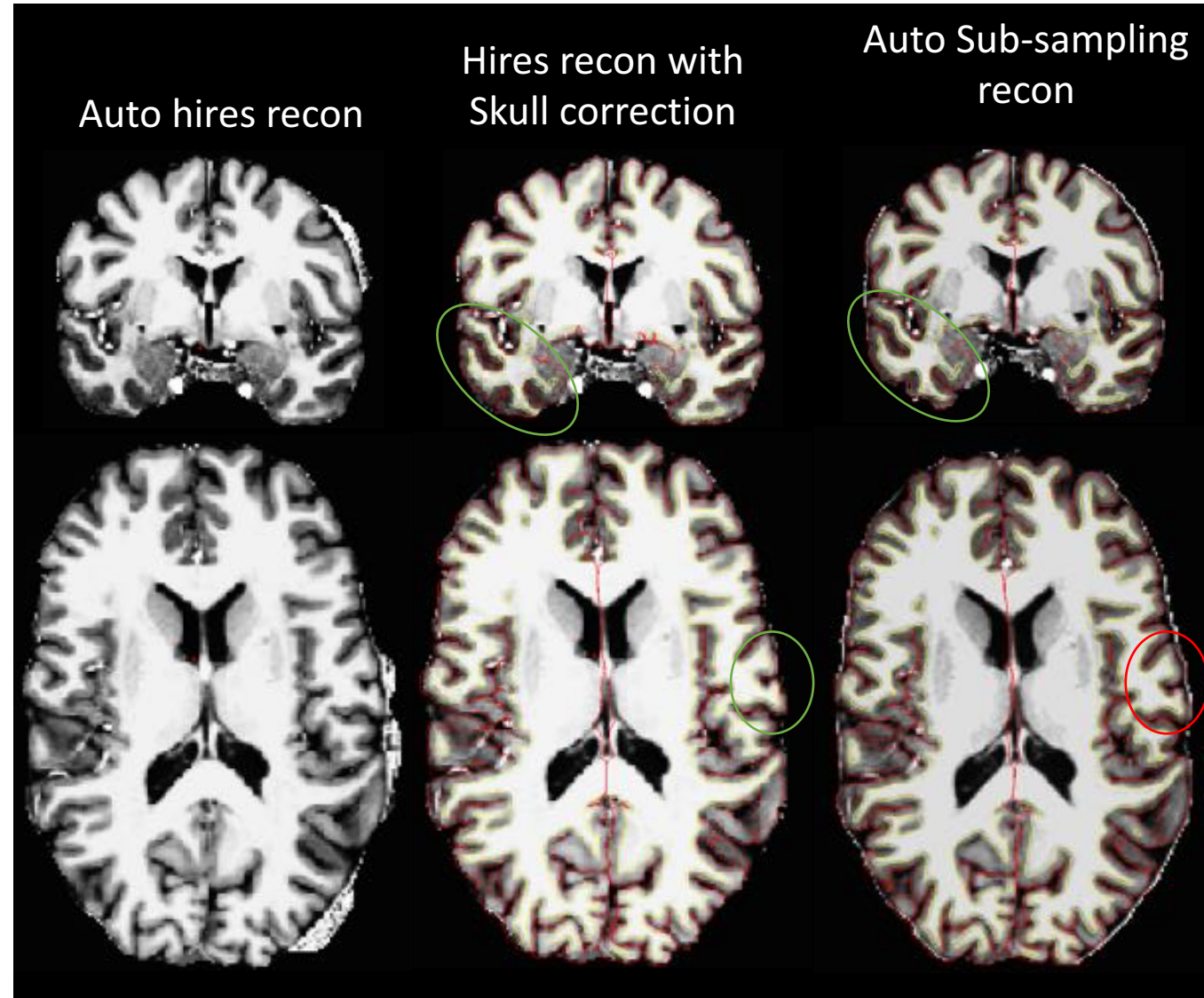
Fujimoto et al. (2014) Neuroimage: developed a two-stage preprocessing scheme for MP2RAGE image data

Falkovskiy et al. (2016) ISMRM: Quantitative comparison of MP2RAGE skull-stripping strategies

Luesebrink et al. (2013) Neuroimage: Cortical thickness determination of the human brain using high resolution 3T and 7T MRI data.

# T1 Segmentations with MP2RAGE scans

**Segmentations and  
Surfaces with FreeSurfer:**

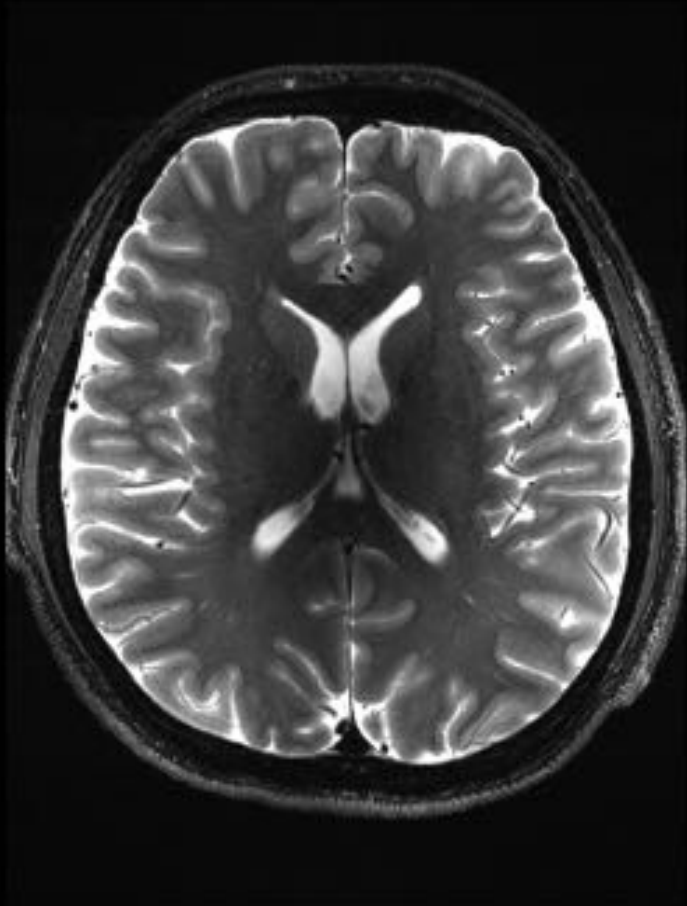


# Optimized Sequences at 7 Tesla: T2 structural 2D

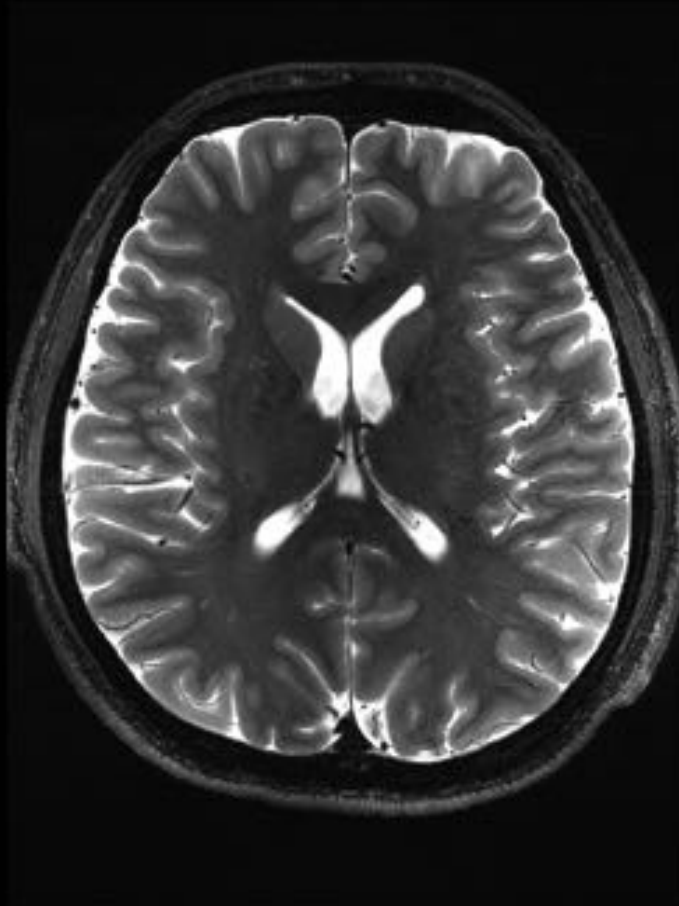
- T2 TSE Transverse Clinical Scan  $0.2 \times 0.2 \times 3 \text{ mm}^3$  TA=3'35''
  - 34 slices, dist fac = 30%, turbo Factor = 7; PE-dir R>>L; FoV 230mm
- T2 TSE Transverse Fast Clinical Scan  $0.2 \times 0.2 \times 3 \text{ mm}^3$  TA=1'56''
  - 34 slices, dist fac = 30%, turbo Factor = 16; PE-dir R>>L; FoV 230mm
- Still to be tested:
  - T2 TSE focused high in-plane resolution with slice thickness 1-2mm (tailored to ROI; partial coverage)
    - e.g.: T2 TSE coronal  $0.1 \times 0.1 \times 1.0 \text{ mm}^3$  TA=4'26''  
(34 slices, TR=6s, TE=48ms, FA=120deg, FatSat, Turbo Factor =7(16?), PE-dir R>>L; FoV 220mm)

# Optimized Sequences at 7 Tesla: T2 structural 2D

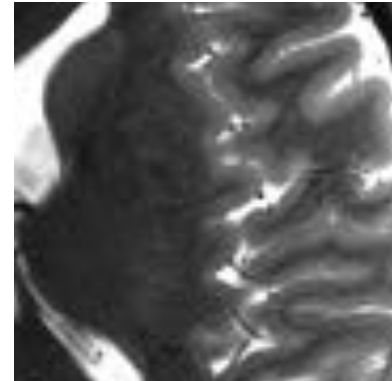
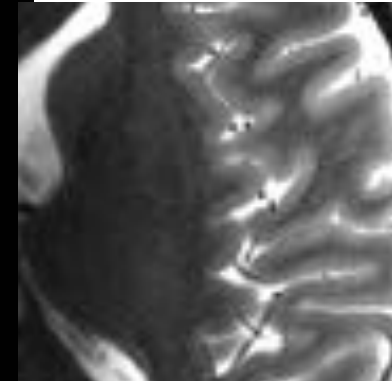
T2 TSE



T2 TSE fast



Fast T2: Global signal loss and more artifacts, but major reduction in TA.



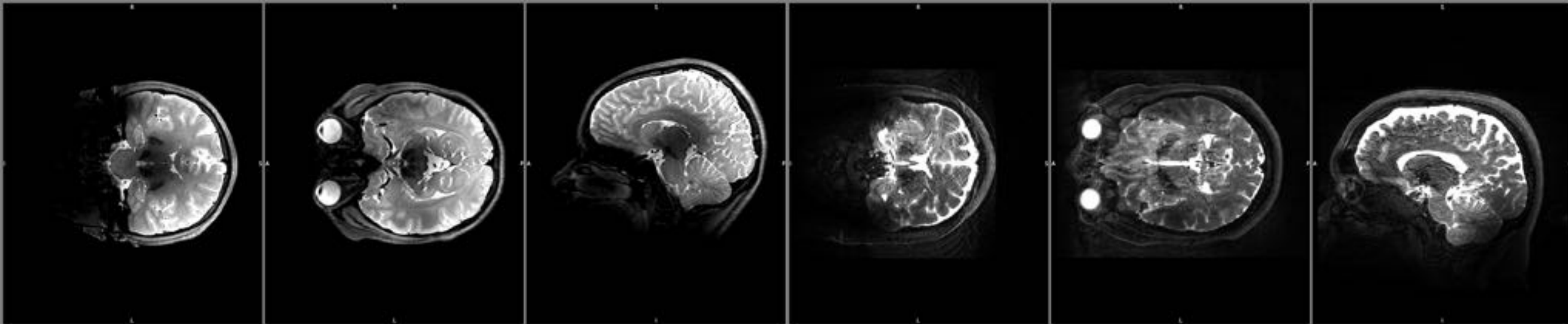


# Optimized Sequences at 7 Tesla: T2 structural 3D

- T2 SPCR whole brain @  $0.4 \times 0.4 \times 0.9 \text{mm}^3$  TA=7'
  - 176 slices in slab, GRAPPA=3; PE-dir A>>P; slice PF=7/8; FoV 240mm

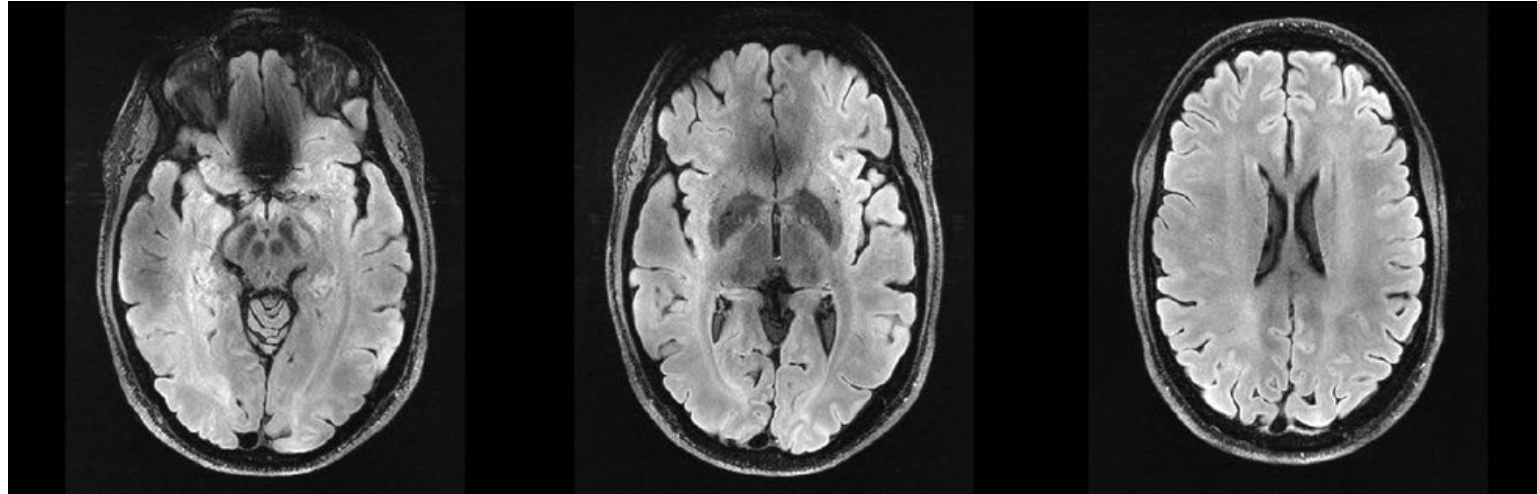
No Movement

With Subject movement:

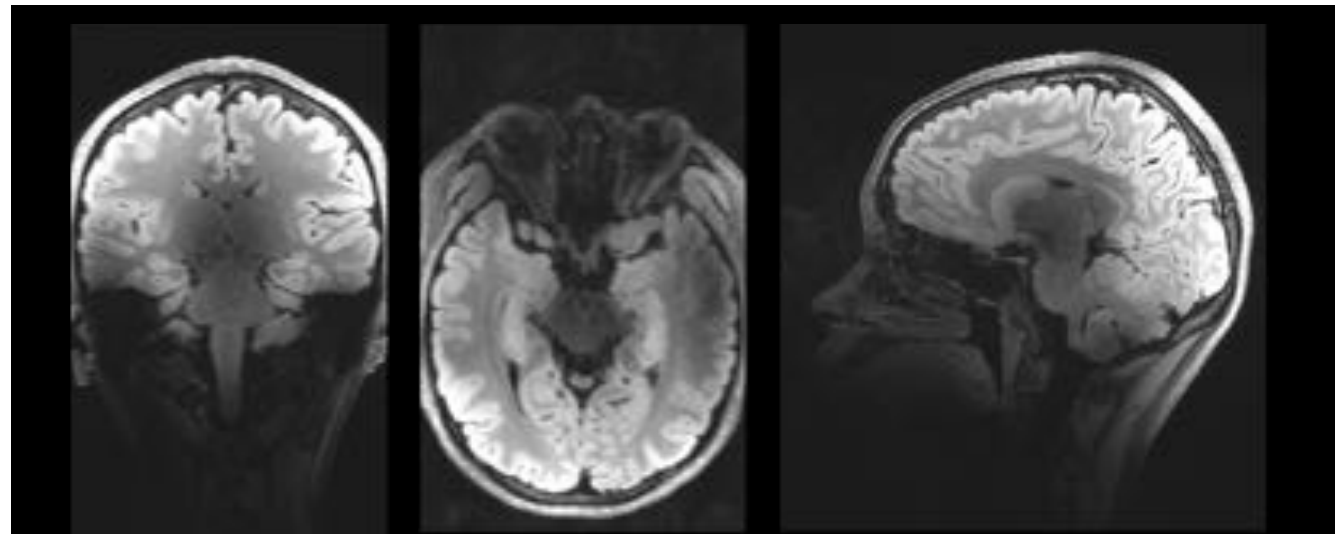


# Optimized Sequences at 7 Tesla: FLAIR (2D & 3D)

- FLAIR TSE 0.4x0.4x3.0mm<sup>3</sup> partial coverage TA=4'50''
  - 38 Slices, TI=2600ms, TR=9000ms, TE=68ms, FoV=178x220mm, iPAT=3.



- FLAIR SPCR 0.38x0.38x1.0mm<sup>3</sup> full brain TA=7'05''
  - 144 slices in slab, TI=2400ms, TR=9s, TE=467ms, FoV=240mm, iPAT=3, slice pF=6/8.



(See also: Zwanenburg et al. 2010. Eur Radiol. "Fluid attenuated inversion recovery (FLAIR) MRI at 7.0 Tesla: comparison with 1.5 and 3.0 Tesla")

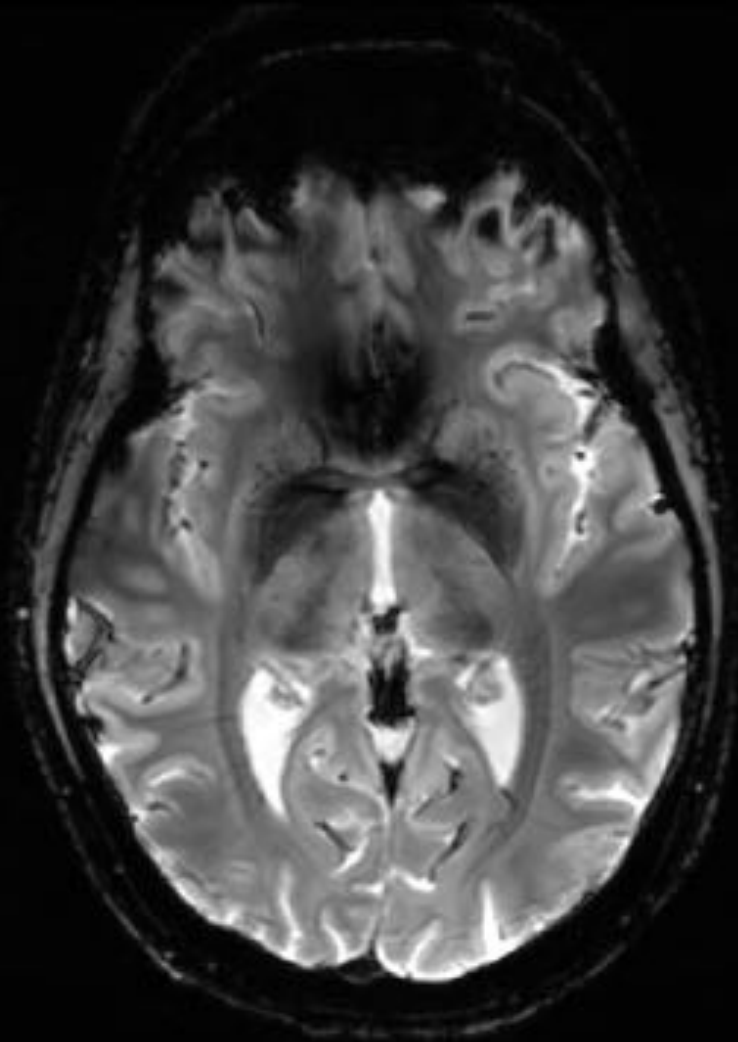


# Optimized Sequences at 7 Tesla: T2 star 2D

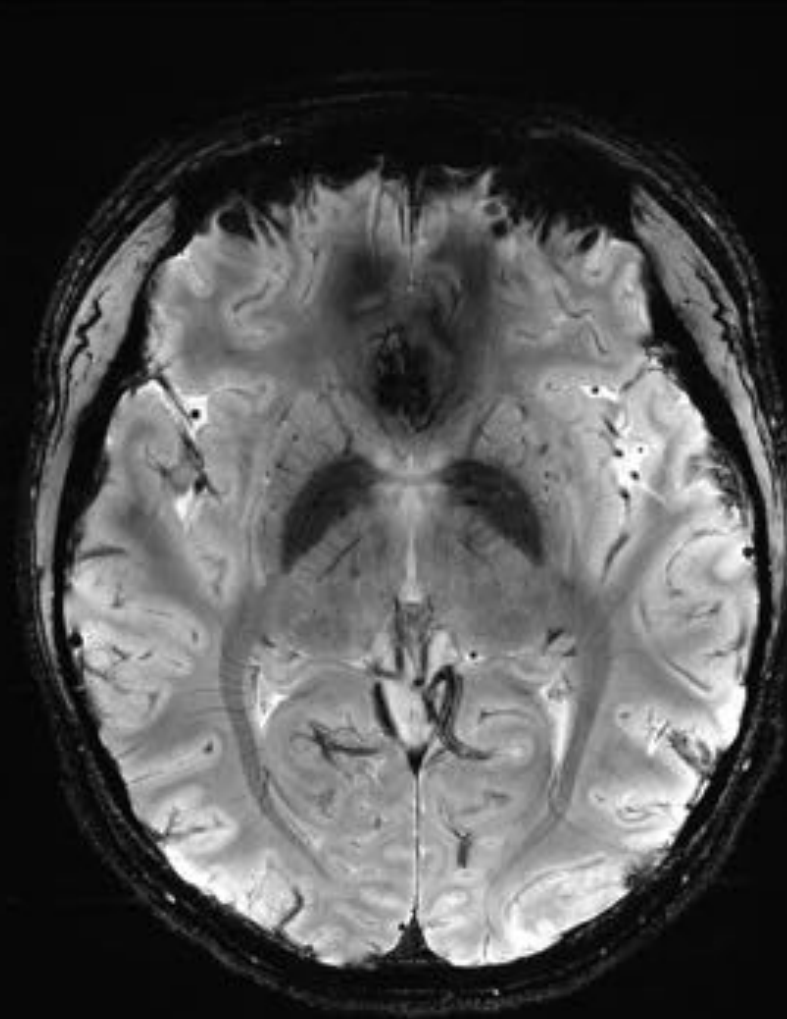
- T2 Star Transverse whole brain coverage  $0.4 \times 0.4 \times 1.5 \text{ mm}^3$  TA=5'08''
  - 75 slices, PE dir R>>L, TR=1530ms, TE=22ms, FA=52°, FoV=220mm, iPAT=3, pF=7/8.
- T2 star Transverse high resolution  $0.2 \times 0.2 \times 1.5 \text{ mm}^3$  TA=5'42''
  - 38 slices, PE dir R>>L, TR=800ms, TE=22ms, FA=52°, FoV=220mm, iPAT=3, pF=OFF.
- Still to be tested: T2\* high-resolution smaller thickness, pseudo-coronal orientation.
  - Application in segmentation of subcortical structures (For review: Giuliano et al., 2017)
    - e.g.: T2\* coronal  $0.2 \times 0.2 \times 1.0 \text{ mm}^3$  TA=6'51''  
(38 slices, PE dir R>>L, TR=962ms, TE=22ms, FA=52°, FoV=220mm, iPAT=3, pF=OFF.

# Optimized Sequences at 7 Tesla: T2 star 2D (1)

T2 Star Transverse whole brain coverage



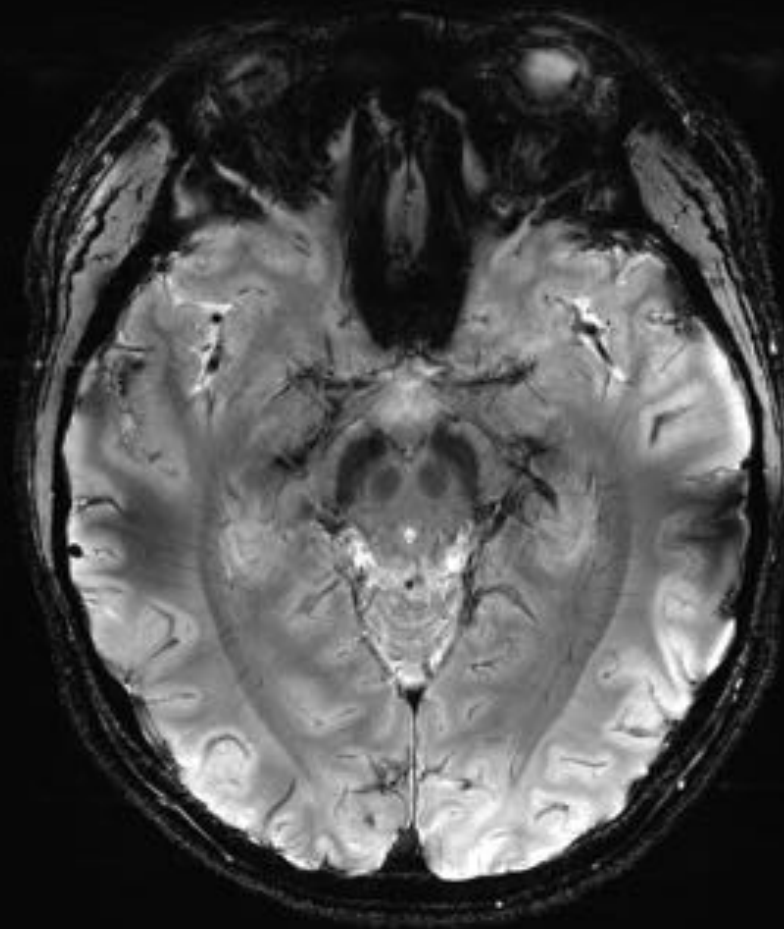
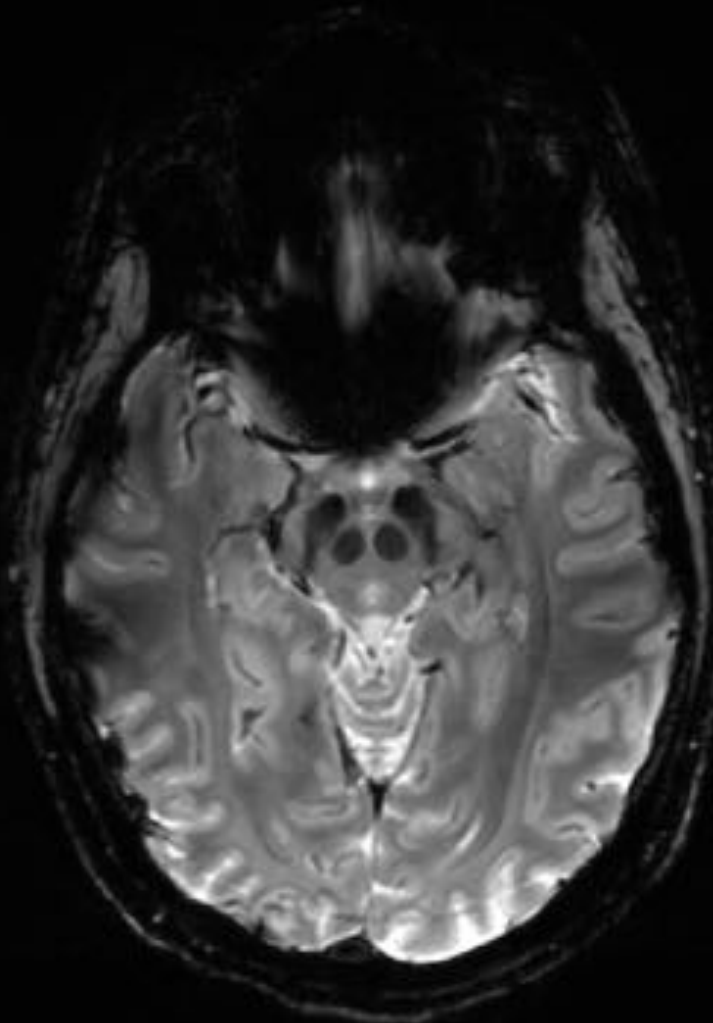
T2 Star Transverse high-res partial coverage



# Optimized Sequences at 7 Tesla: T2 star 2D (2)

T2 Star Transverse whole brain coverage

T2 Star Transverse high-res partial coverage



# Optimized Sequences at 7 Tesla: SWI

- T2 SWI Fast Acquisition, whole brain,  $0.2 \times 0.2 \times 1.2 \text{ mm}^3$  TA=4'35''
  - 96 slices per slab, PE dir R>>L, TR=22.0ms, TE=15.0ms, FA=10°, FoV=220mm, iPAT=3, acc. factor 3D=1, phase pF=7/8, slice pF=6/8, PEdir R>>L.
- T2 SWI “High Resolution”, whole brain,  $0.1 \times 0.1 \times 1.5 \text{ mm}^3$  TA=7'29''
  - 96 slices per slab, PE dir R>>L, TR=21.0ms, TE=14.0ms, FA=10°, FoV=220mm, iPAT=3, acc. factor 3D=1, phase pF=OFF, slice pF=OFF, PEdir R>>L.

DATA obtained:

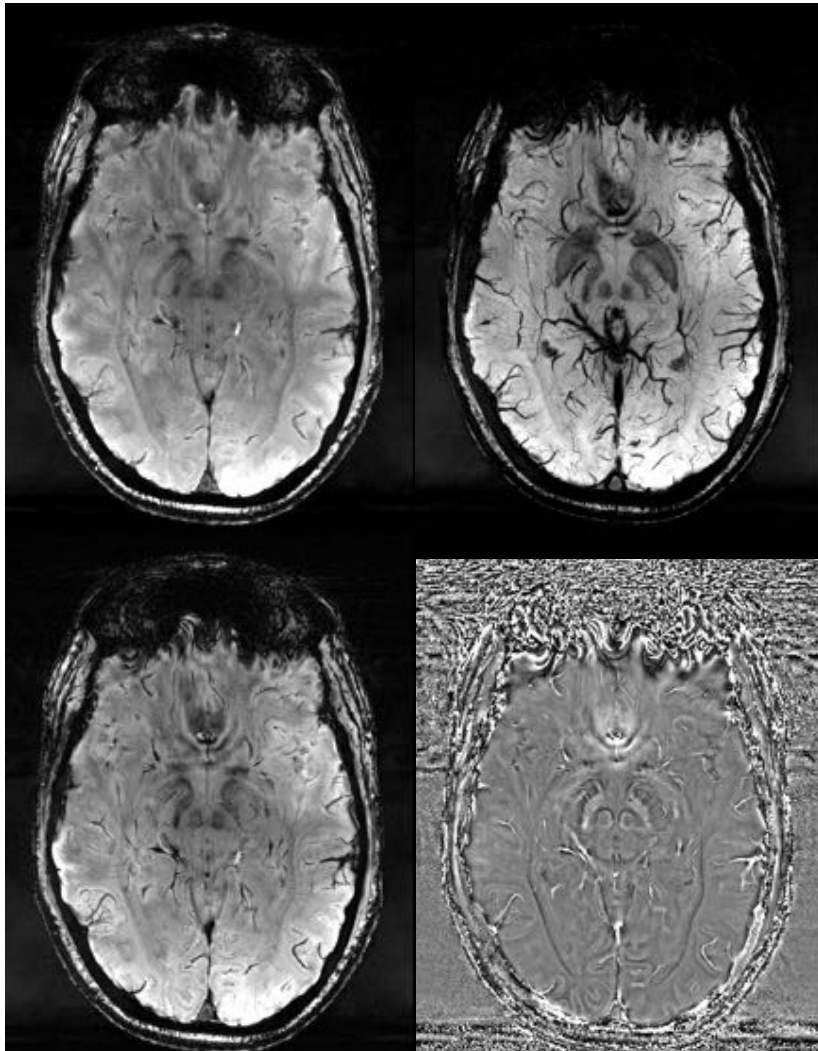
- Magnitude;
- Unwrapped filtered phase;
- MIP;
- SWI.

*(SWI Reference: Haacke et al., 2004)*

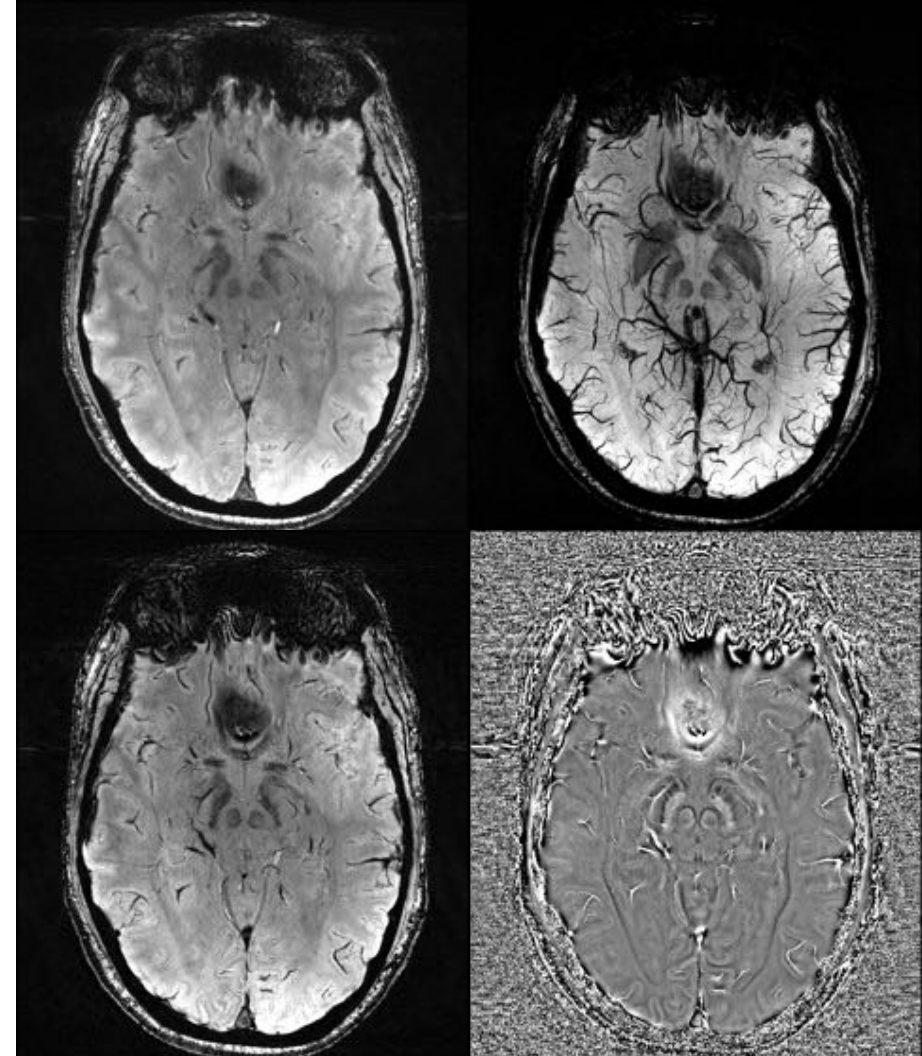


# Optimized Sequences at 7 Tesla: SWI

- T2 SWI Fast Acquisition



- T2 SWI “High Resolution”



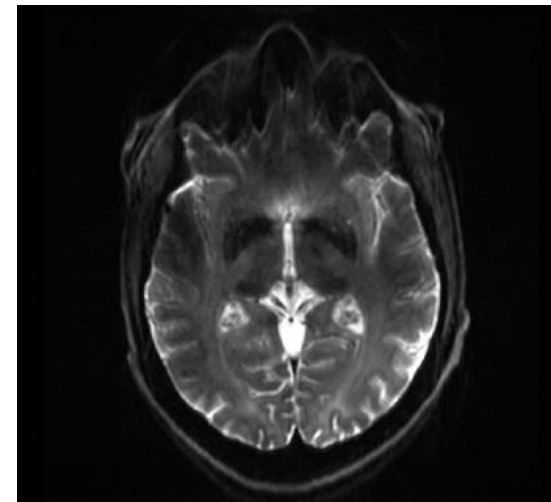
# Optimized Sequences at 7 Tesla: Diffusion Trace

**Simultaneous-Multi-Slice (SMS):** allows increased acquisition efficiency by exciting several slices simultaneously. Data is unfolded using the spatial sensitivity of multichannel array coils.

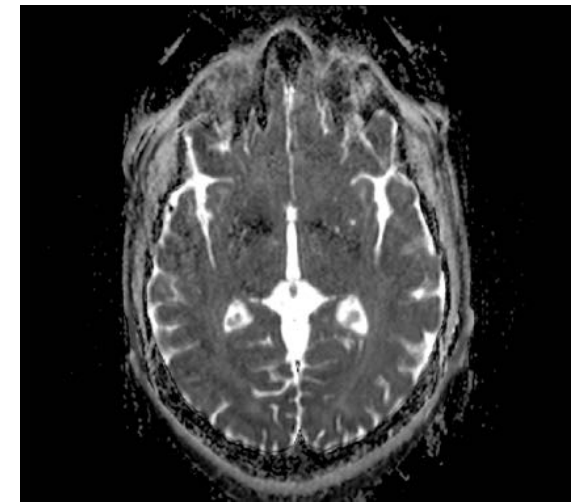
- 2D EPI SMS Trace 1.5mm isotropic TA=2'13''
  - 90 slices, TR=6.9s, TE=55ms, FoV=230mm, iPat=4, acc slice=2, BW=1984Hz/px, esp=0.61ms.

- 2D EPI SMS Trace 0.5x0.5x3mm<sup>3</sup> TA=1'31''
  - 90 slices, TR=2.8s, TE=55ms, FoV=230mm, iPat=4, acc slice=2, BW=1502Hz/px, esp=0.79ms.

DW b=0s/mm<sup>2</sup>



ADC map





# Optimized Sequences at 7 Tesla: Diffusion Tensor

- **2D EPI SMS DTI 1.4mm isotropic**

**TA=4'53"**

- 80 slices, TR=4.1s, TE=56ms, FoV=220mm, iPat=4, acc slice=2, pF=6/8, BW=1984Hz/px, esp=0.61ms (b-value=0s/mm<sup>2</sup> & b-value=1000s/mm<sup>2</sup>; 30 diff directions).

**Read-out segmented EPI (RESOLVE):** acquisition of k-space in the readout direction is segmented to shorten the echo-spacing and the echo train duration, thereby reducing phase-encode distortion artifacts and T2\* blurring.

- **2D RESOLVE DTI 1.4mm isotropic**

**TA=16'35"**

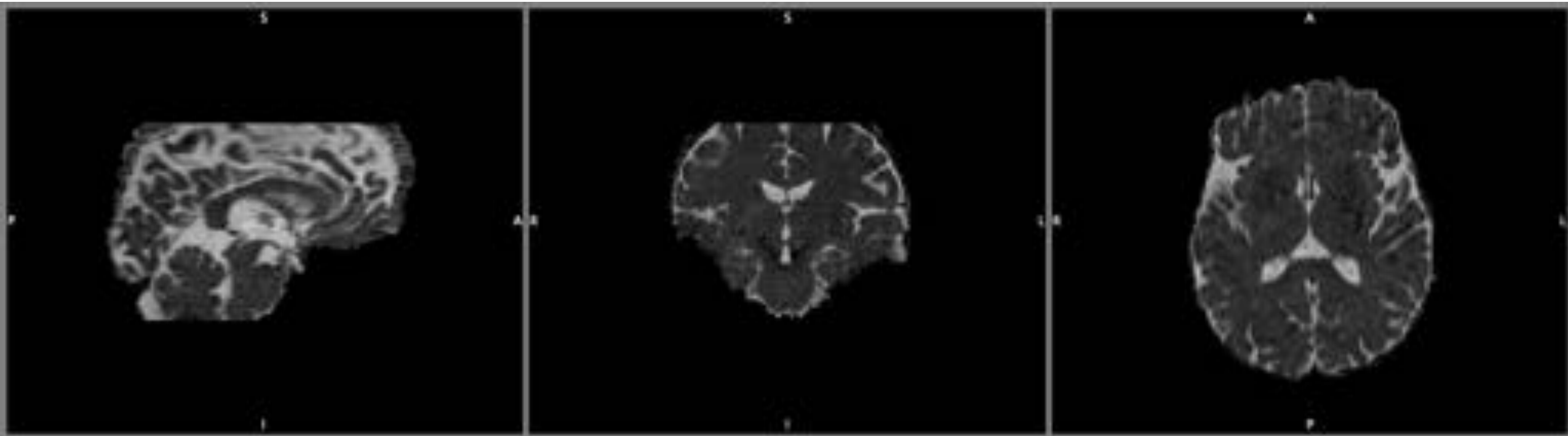
- 51 slices, TR=7.7s, TE<sub>1</sub>=55ms, TE<sub>2</sub>=84ms, FoV=220mm, iPat=3, BW=1002Hz/px, esp=0.36ms (b-value=0s/mm<sup>2</sup> & b-value=1000s/mm<sup>2</sup>; 20 diff directions).

➤ *Getting the best of both worlds: SMS-RESOLVE DTI* (Frost et al., 2015)

# Optimized Sequences at 7 Tesla: Diffusion Tensor

- 2D EPI SMS DTI 1.4mm isotropic

TA=4'53''

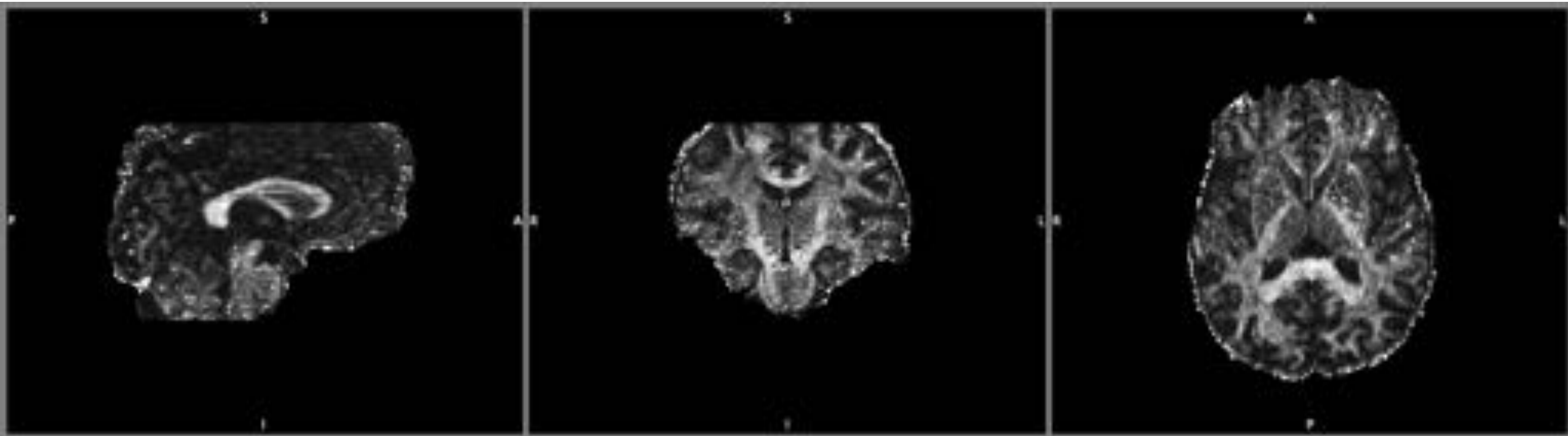


MD map

# Optimized Sequences at 7 Tesla: Diffusion Tensor

- 2D EPI SMS DTI 1.4mm isotropic

TA=4'53''

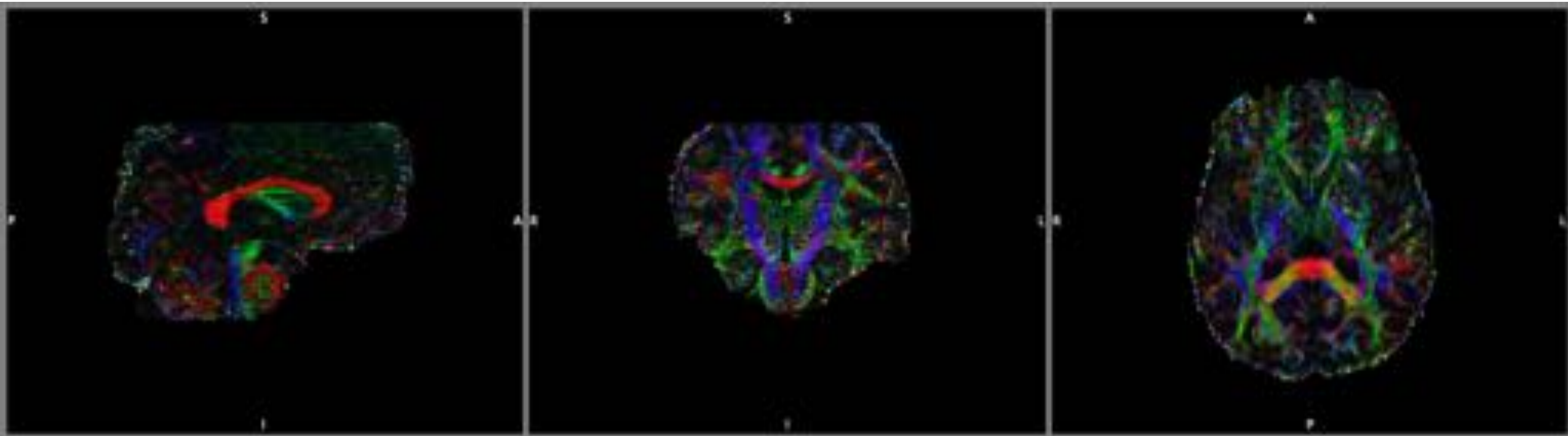


FA map

# Optimized Sequences at 7 Tesla: Diffusion Tensor

- 2D EPI SMS DTI 1.4mm isotropic

TA=4'53''

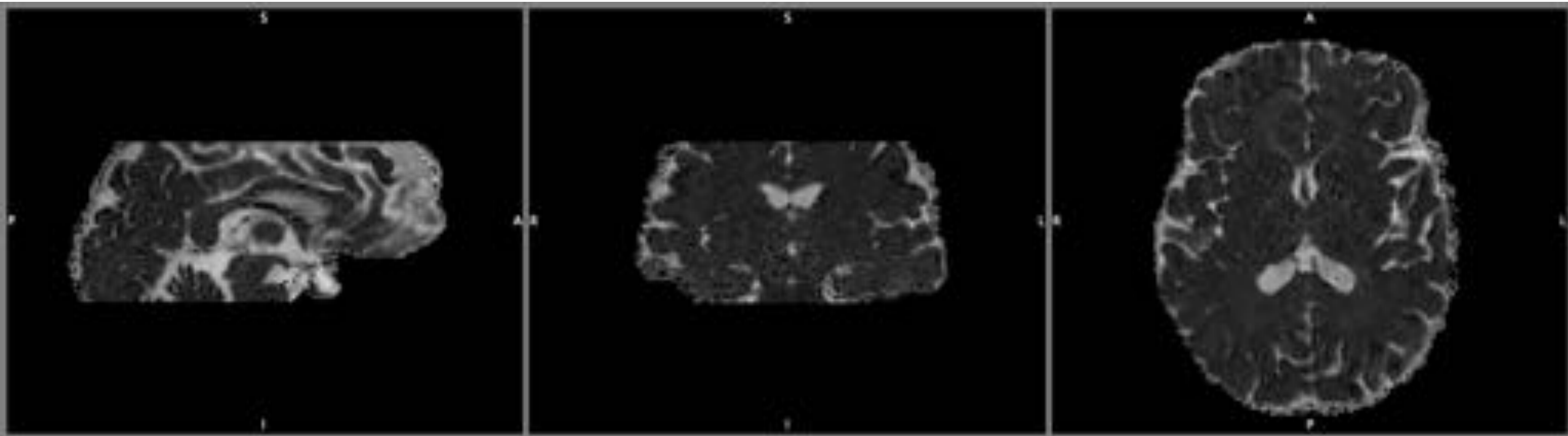


Tensor map

# Optimized Sequences at 7 Tesla: Diffusion Tensor

- 2D RESOLVE DTI 1.4mm isotropic

TA=16'35''

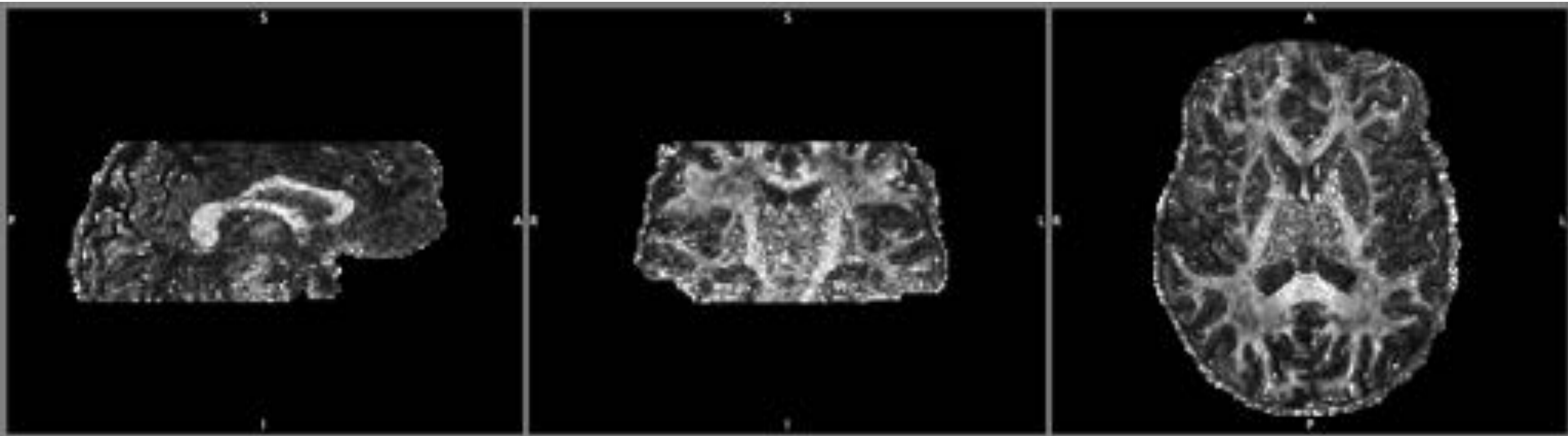


MD map

# Optimized Sequences at 7 Tesla: Diffusion Tensor

- 2D RESOLVE DTI 1.4mm isotropic

TA=16'35''



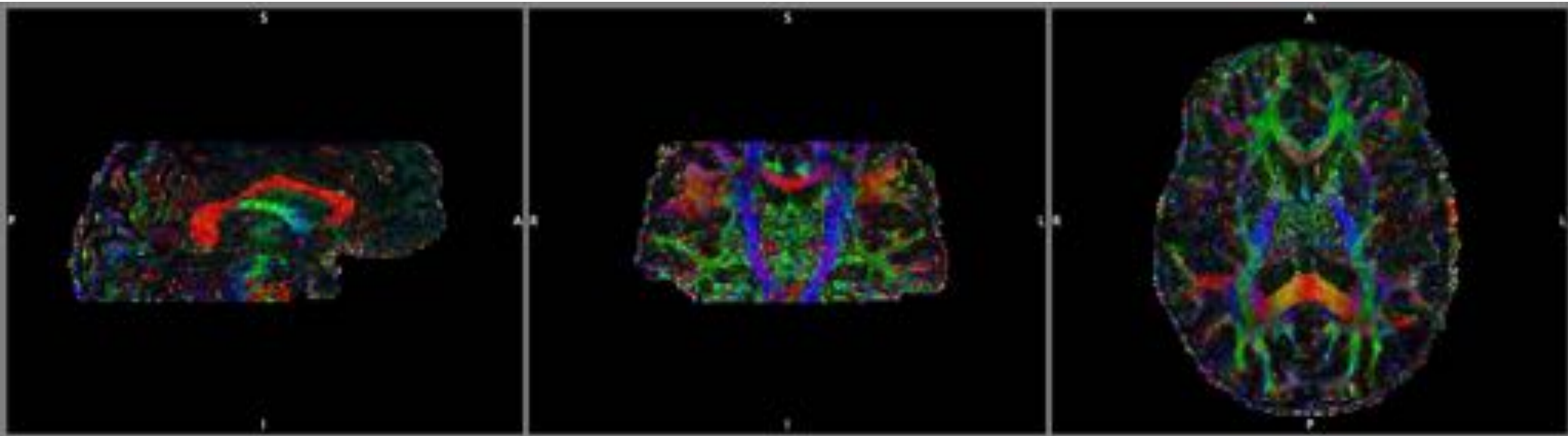
FA map



# Optimized Sequences at 7 Tesla: Diffusion Tensor

- 2D RESOLVE DTI 1.4mm isotropic

TA=16'35''

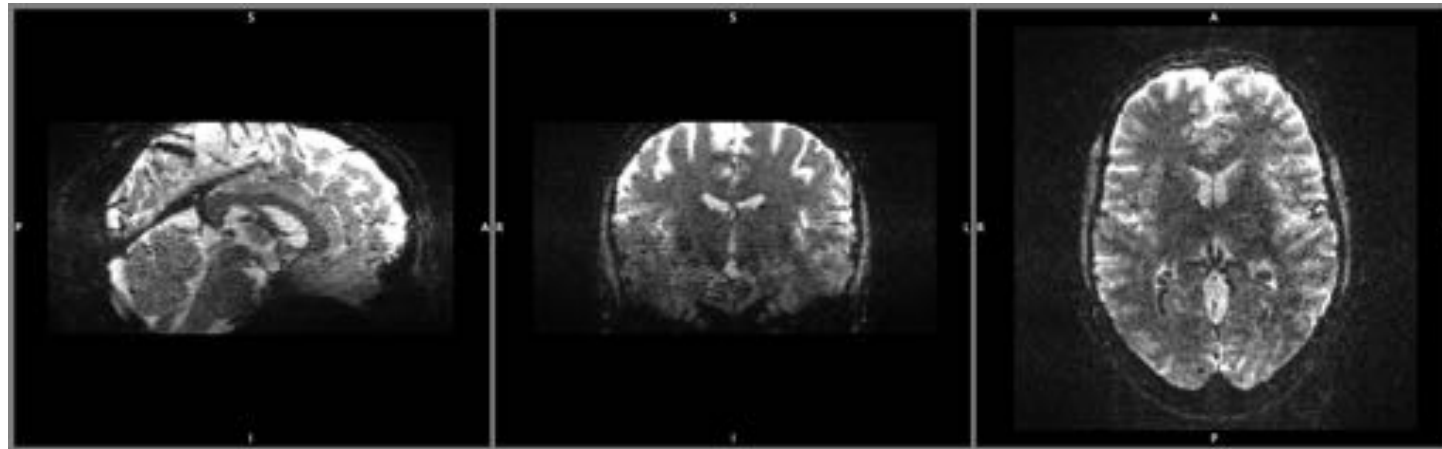


Tensor map

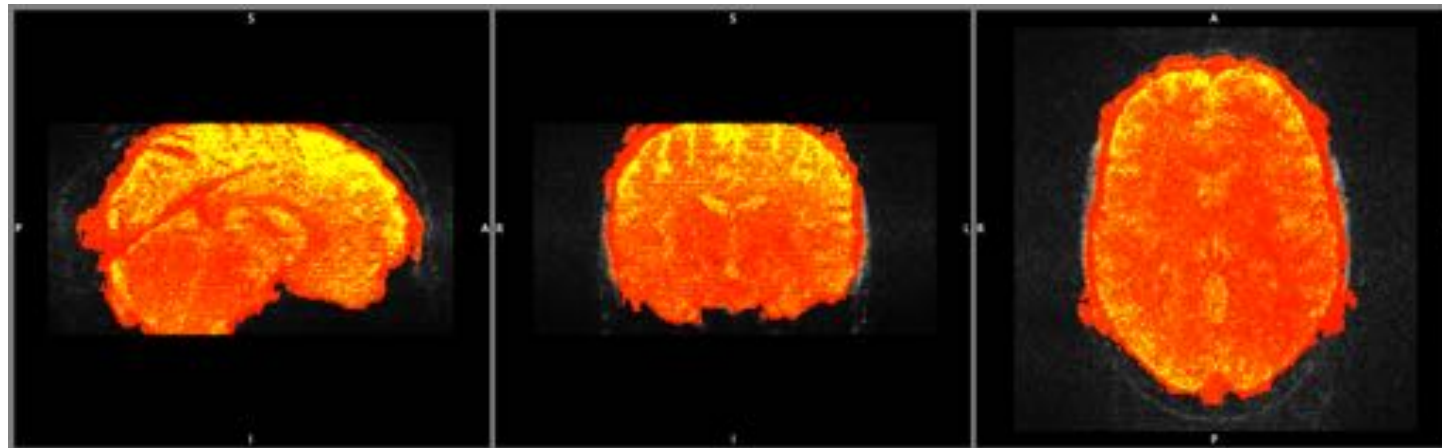
# Optimized Sequences at 7 Tesla: GRE-EPI BOLD

Standard EPI 1.4mm isotropic

TR=4090ms; TE=20ms; Nr Slices=84; iPAT=4; no pF; FoV=224mm.



Magnitude data  
(single volume)



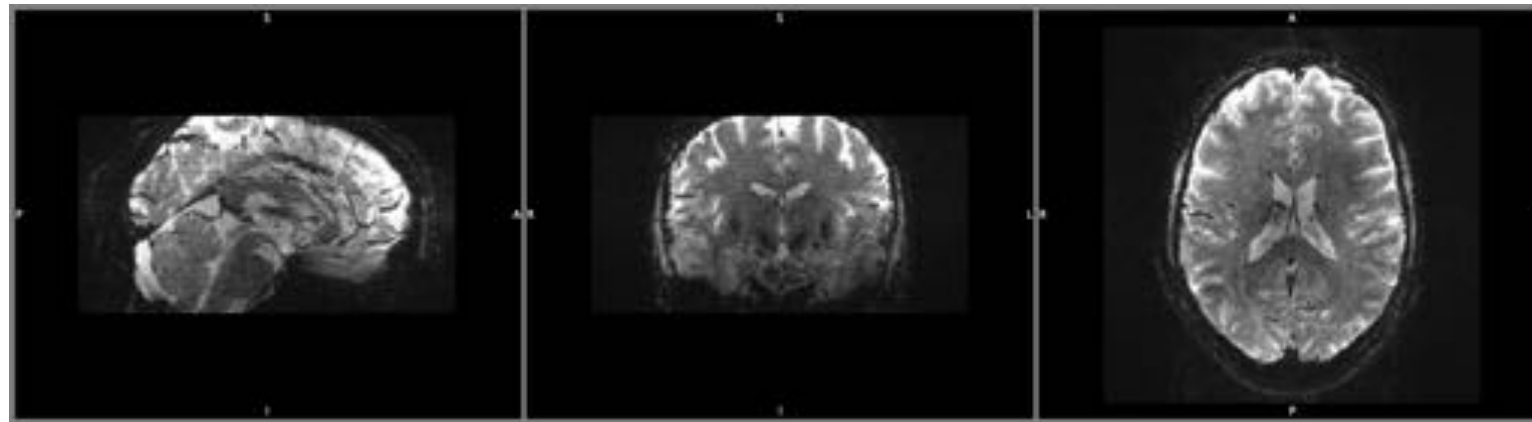
tSNR  
30  
0

(Note: tSNR  
measurement from only  
10 time-points)

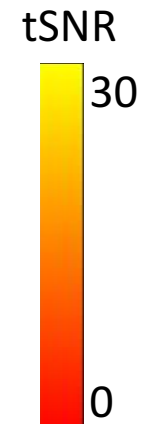
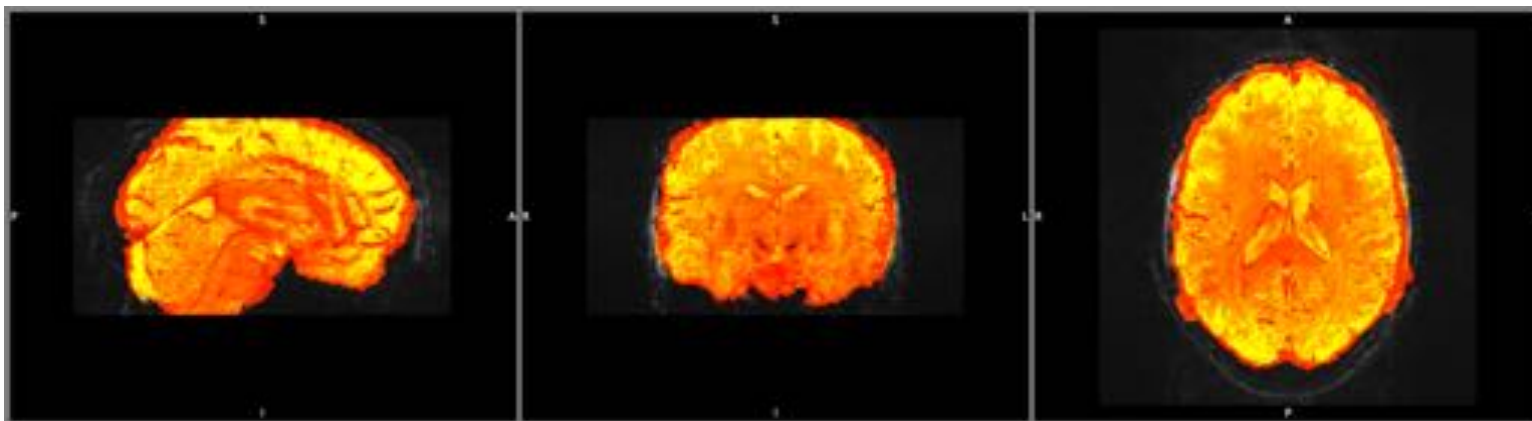
# Optimized Sequences at 7 Tesla: GRE-EPI BOLD SMS

SMS EPI 1.4mm isotropic whole brain

TR=1970ms; TE=20ms; Nr Slices=84; iPAT=4; acc slice=2; no pF; FoV=224mm; BW=1838Hz/px, esp=0.65ms.



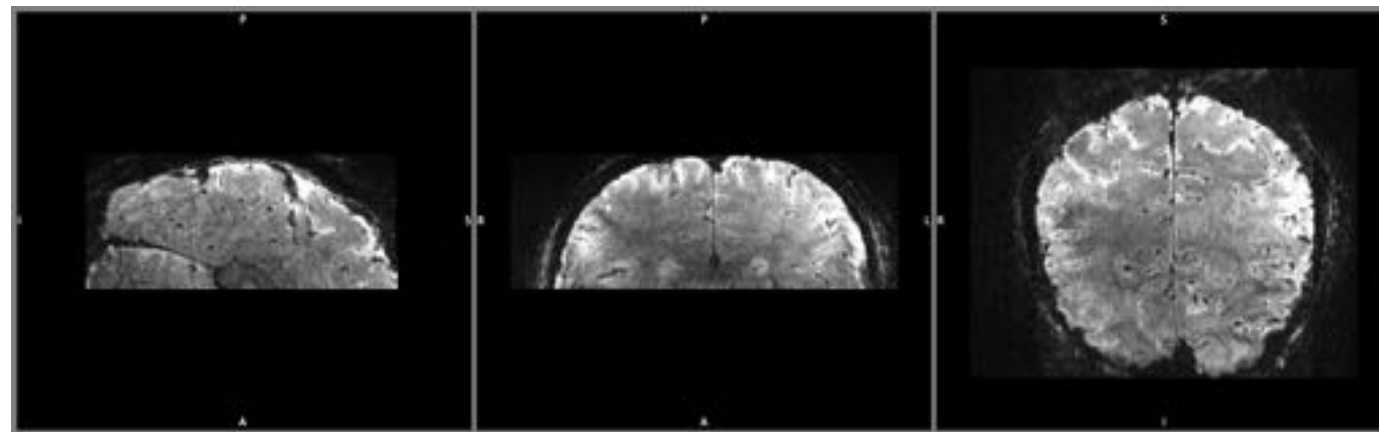
Magnitude data  
(single volume)



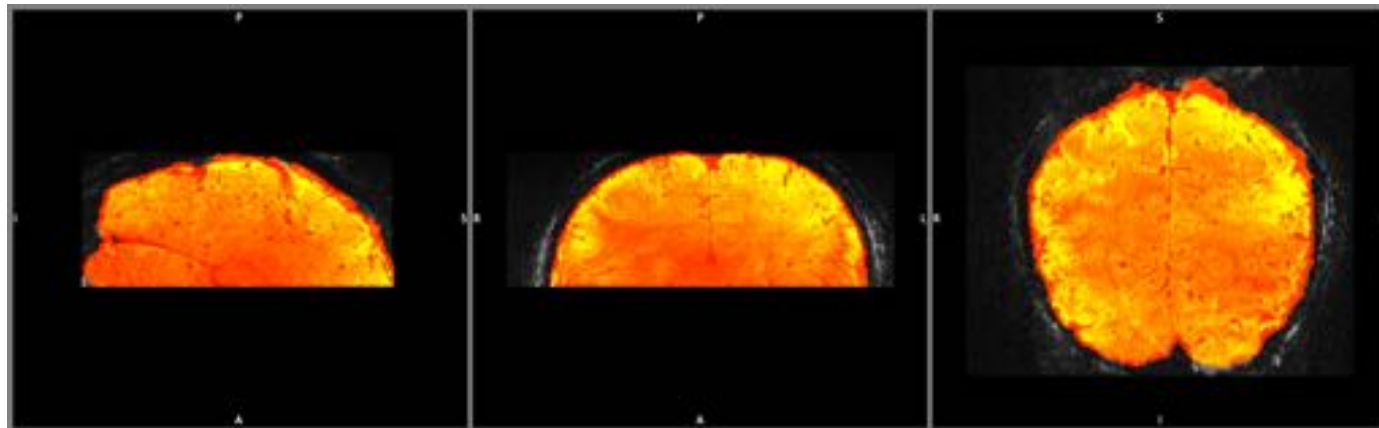
# Optimized Sequences at 7 Tesla: BOLD SMS 0.9iso

SMS EPI 0.9mm isotropic, FH phase encoding

TR=2270ms; TE=23ms; Nr Slices=70; iPAT=3; acc slice=2; pF=6/8; FoV=224mm; FA=80, BW=1136Hz/px, esp=1.01ms.



Magnitude data  
(single volume)

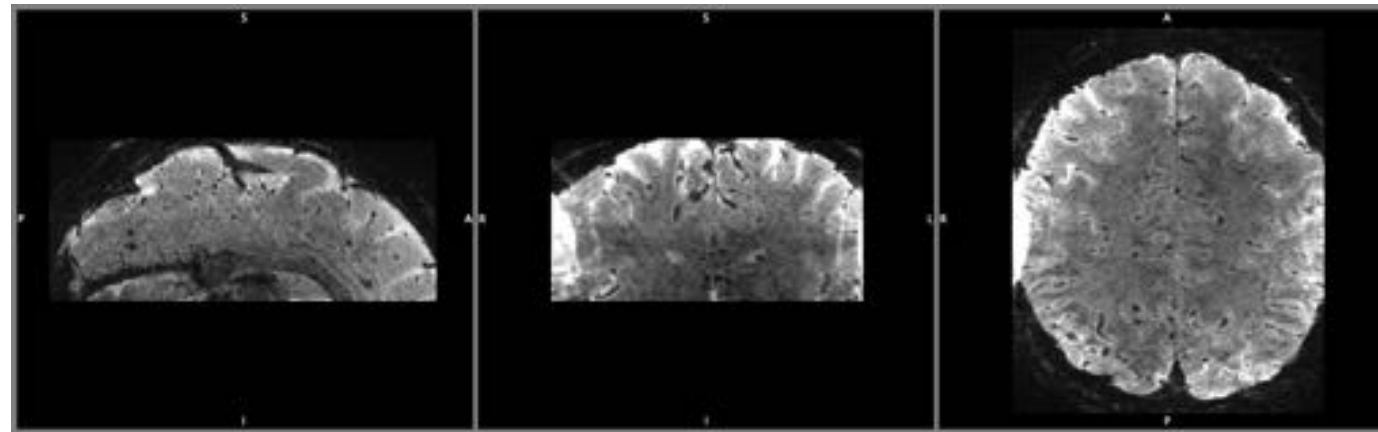


tSNR  
30  
0

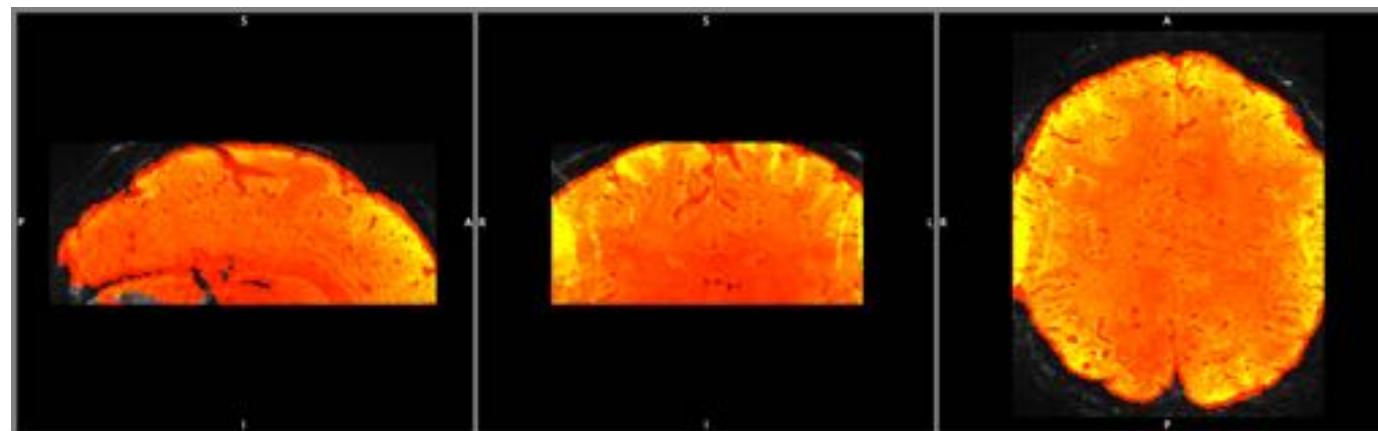
# Optimized Sequences at 7 Tesla: BOLD SMS 0.8iso (V1)

SMS EPI 0.8mm isotropic, RL phase encoding

TR=2000ms; TE=20ms; Nr Slices=84; iPAT=4; acc slice=2; no pF; FoV=224mm; BW=1838Hz/px, esp=0.65ms.



Magnitude data  
(single volume)



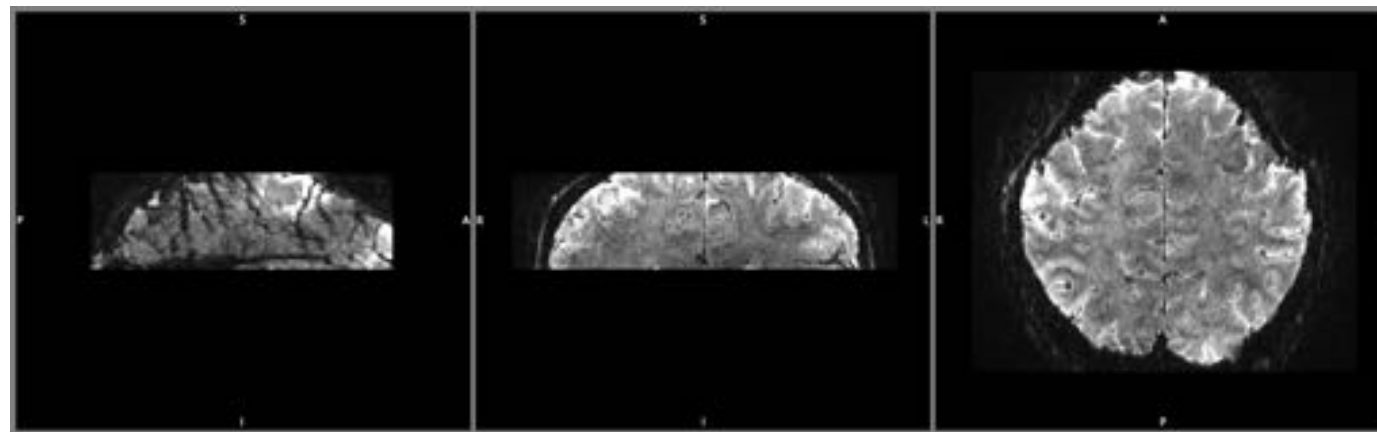
tSNR  
30  
0



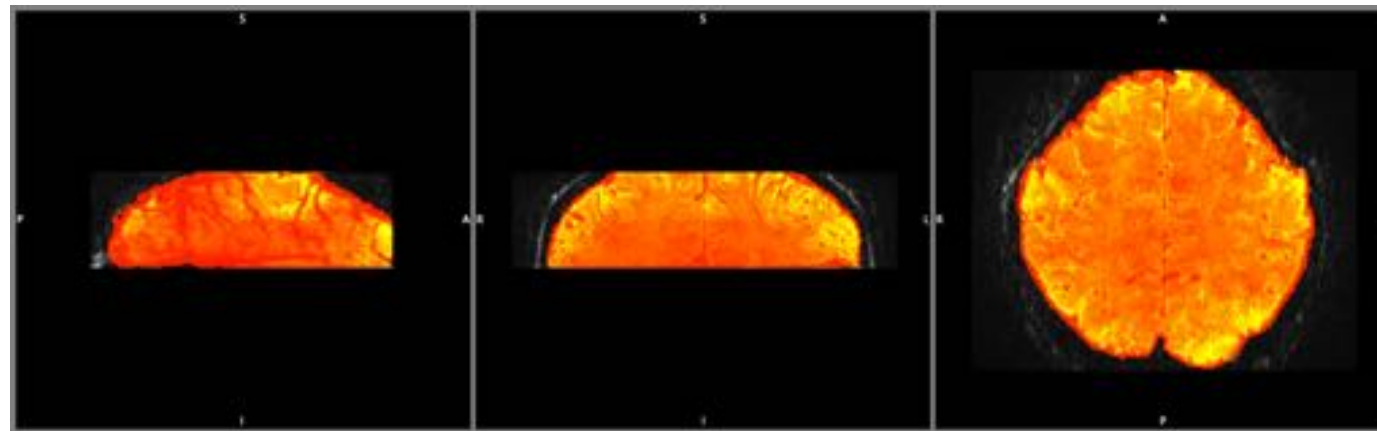
# Optimized Sequences at 7 Tesla: BOLD SMS 0.8iso (V2)

SMS EPI 0.8mm isotropic, AP phase encoding with phase oversampling

TR=2000ms; TE=27ms; Nr Slices=50; iPAT=3; acc slice=2; pF=6/8; FoV=160mm; FA=80, BW=1136Hz/px, esp=1.03ms.



Magnitude data  
(single volume)

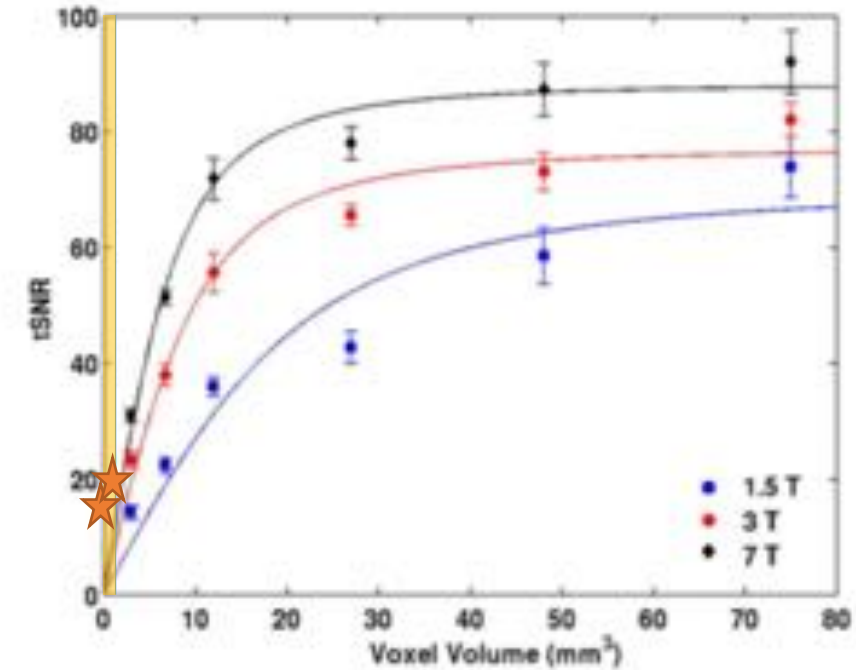
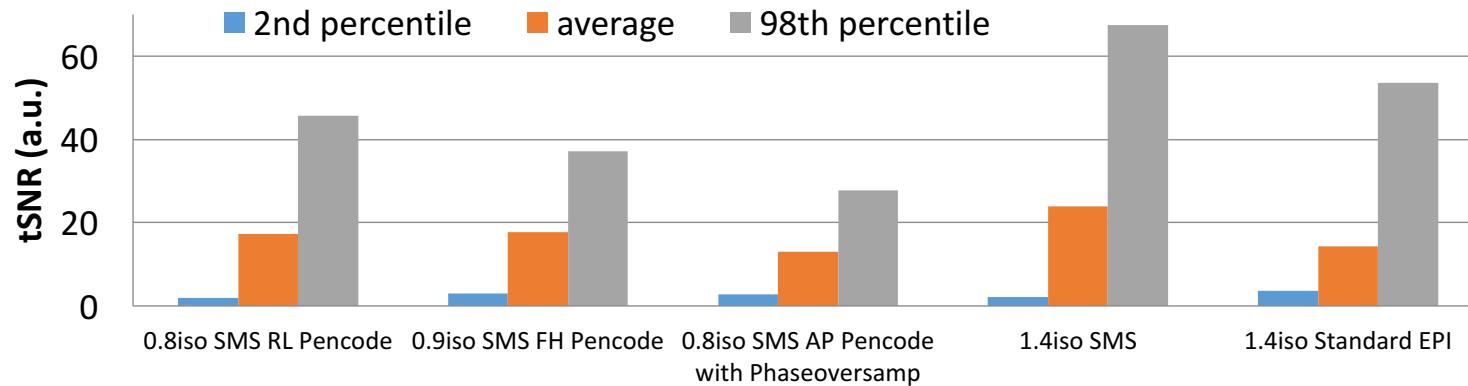


tSNR  
30  
0

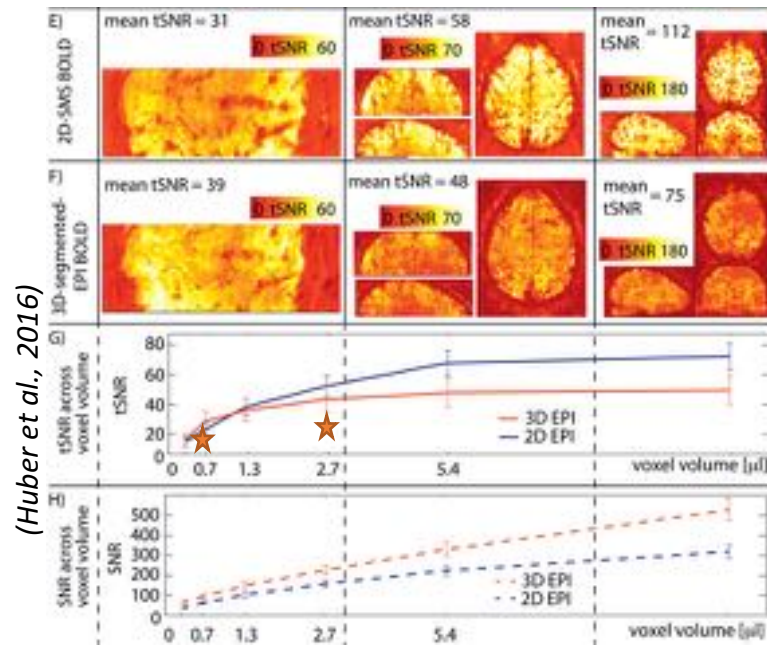


# GRE-EPI BOLD – sub-millimeter & standard resolutions

tSNR measurements Cambridge Terra:



(Triantafyllou et al., 2005)



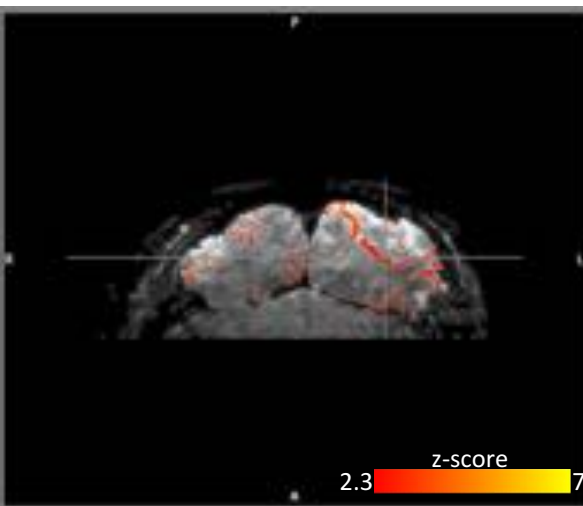
tSNR measurements are lower than what is reported in the literature.  
Possible explanations:

- SMS implementations are different on reconstruction;
- Brain region scanned + ROI selection.

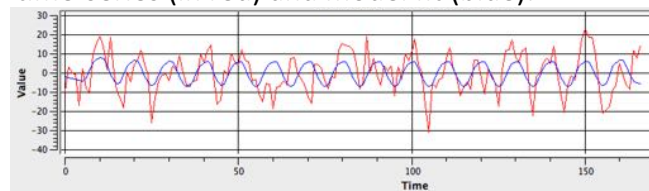
# Sub-millimeter BOLD fMRI in the visual cortex: first pilot tests

## A: 0.9mm isotropic acquisition

Visual block design: 16 epochs [12s ON + 10s OFF]

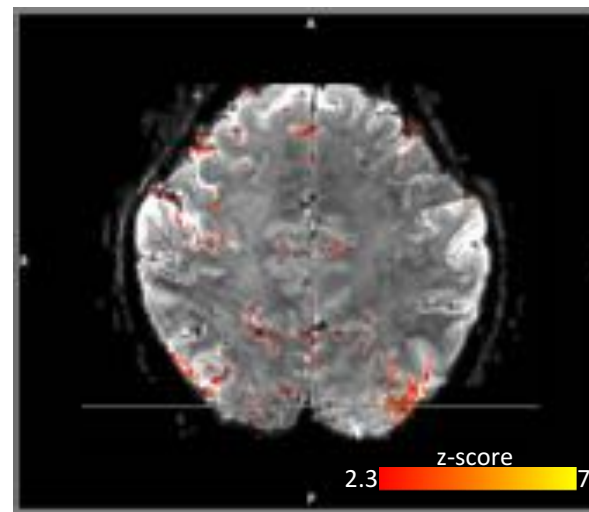


Most active voxel ( $z=6.15$ )  
time-series (in red) and model fit (blue):

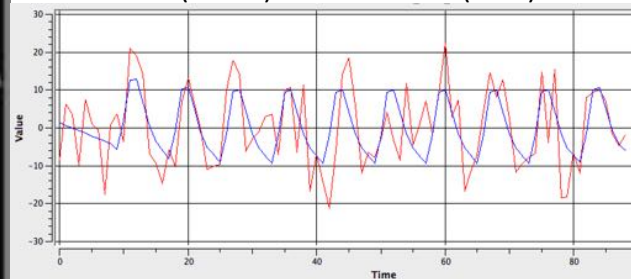


## B: 0.8mm isotropic acquisition

Visual event-related design: 10 epochs [2s ON + 14s OFF]



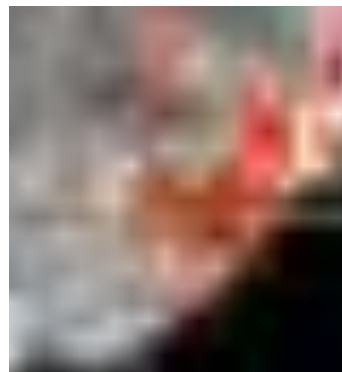
Most active voxel ( $z=6.71$ )  
time-series (in red) and model fit (blue):



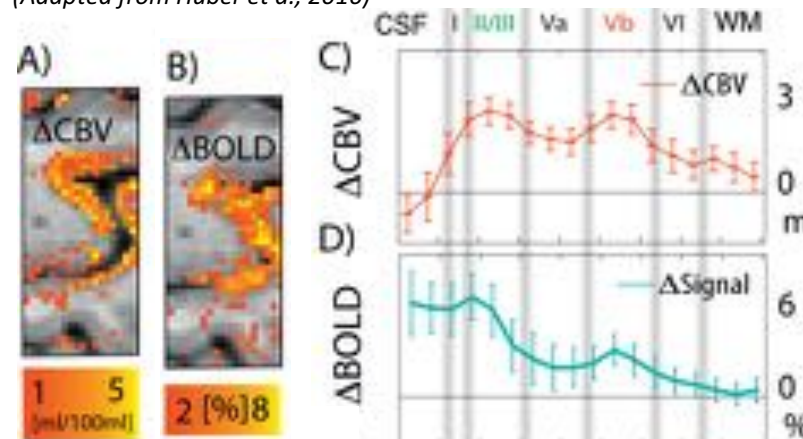
Measurement A:



Measurement B:



(Adapted from Huber et al., 2016)



- Limitations of sub-millimeter fMRI;
- At high-res: VASO CBV outperforms GRE-BOLD

# Future Sequences

- MRS:
  - SVS unavailable at the 7T – needs sequence modifications (IPA Agreement 13 Terra product code, submitted January 2017, pending signature)
  - Semi-laser (Uzay Emir, FMRIB Oxford) (C2P requested on December 2016)
- 3D-EPI:
  - C2P with Lausanne. Code received March 6<sup>th</sup>.
- Multiband-EPI:
  - C2P with Minnesota. Approvals granted; but Terra version not yet available.
  - (Siemens product SMS installed).
- VASO:
  - IPA Agreement for ASL source code (submitted November 2016)
  - ASL will need VASO blocks inserted in sequence

# WBIC Stimulus delivery systems

## Projector + mirror visual display setup:

- Currently we have the original projector (old scanner setup).
- LED Projector PROPixx to be implemented this week
  - 1920x1080 DLP color projector
  - Can integrate system for the display of 3D images
- Stimulus computers at the WBIC: installed Matlab, Eprime, Presentation.
  - NI card is configured to mimic the setup at the CBSU:
    - pin PA0 scanner pulse
    - pin PA1 button 1 (left to right as you look at the button box)
    - pin PA2 button 2
    - pin PA3 button 3
    - pin PA4 button 4



Refer to CBU wiki for using scanner pulse and button box in matlab:

<http://imaging.mrc-cbu.cam.ac.uk/mri/ScannerSynchronisation>

# WBIC Stimulus delivery systems

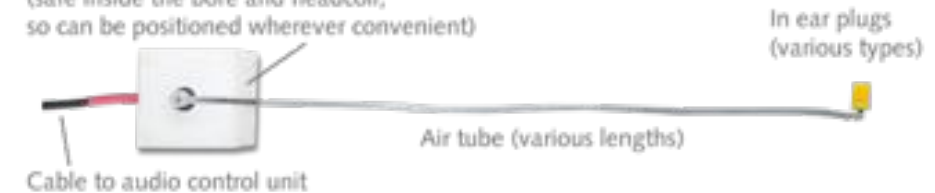
## Audio for fMRI:

- Headphone systems do not fit the 32-channel head coil.
- Alternatives:
  - BOLDfonic system (Cambridge Research Systems)
    - Acoustic performance tests at the WBIC -> April 2017.
  - Sensimetrics S15
    - Upgrade from Sensimetrics S14s model which was only certified at 3T.
    - No release date specified yet.

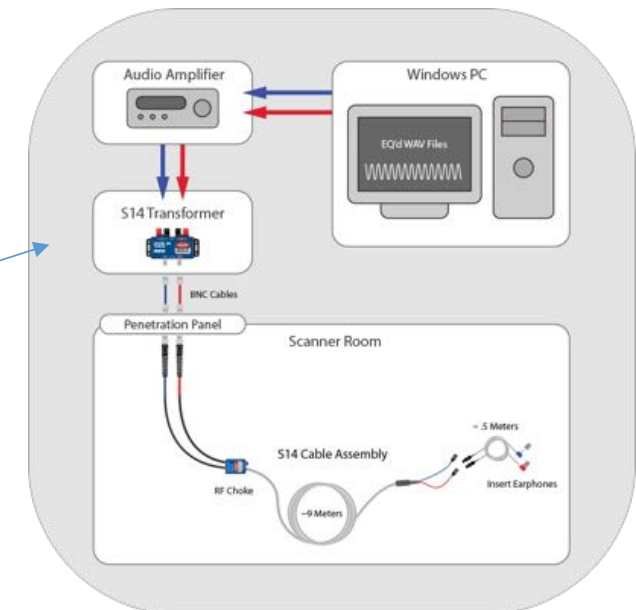
*Headphone driver unit outside the coil, and delivery of the audio to the ear via a short airtube and passive earbud.*

### Earphones Type HP AT01

Electro-dynamic headphone drivers  
(safe inside the bore and headcoil,  
so can be positioned wherever convenient)



(<http://www.crs Ltd.com/tools-for-functional-imaging/audio-for-fmri/boldfonic/nest/mri-compatible-earphones-2#npm>)





# Final Remarks

- Subject recruitment and safety checking for the 7T:
  - Important to have a detailed feedback on the screening statistics (how many discarded prospective subjects and why?)
  - Vicky Lupson is responsible for screening enquiries.
  - MRI questionnaire after scanning.
- Contacts for future research studies at the 7T:
  - Catarina Rua, Research Associate (cr439@wbic.cam.ac.uk)
  - Vicky Lupson, Superintendent Radiographer (vcl21@wbic.cam.ac.uk)
  - Guy Williams, Assistant Director of Research WBIC (gbw1000@cam.ac.uk)
  - Adrian Carpenter, Director of Research WBIC (tac12@wbic.cam.ac.uk)
- Next 7T meetings: feedback on first studies??

Assessed  
for 3T  
Pages 2-6

Assessed  
for 7T  
Pages 6-8


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### Wolfson Brain Imaging Centre MRI Safety Screening

Please read through the following items. Do you have or have you had any of the following:

	NO	YES
ANY surgery or dental work in the last 6 weeks?		
Cardiac (heart) pacemaker, implanted defibrillator or pacing wires?		
Artificial Heart Valve?		
Aneurysm (blood vessel) clips?		
Other Surgical Clips or Staples?		
Intra-ventricular (brain) shunt?		
Programmatic Neuro-stim or shunt?		
Electronic nerve stimulator or bio-stimulator?		
Other internal electrode, electronic or mechanical implant?		
Cochlear implant or any other ear implant?		
Hearing Aid?		
Implanted insulin pump or drug delivery device?		
Swan-Ganz vascular (blood vessel) catheter?		
Hard vest or metallic neck fixation device?		
Long-term line, filter, stent or coil in any blood vessel or water seal?		
Eye orbital prosthesis (false or glass eye)?		
Foreign body or metallic fragment in the eye?		
Foreign body or metallic fragment in the body?		
Staples, shot or bullet wound?		
Artificial limb or joint replacement?		
Orthopaedic implants (bone pins, screws, wires or plates)?		
Denture, dental plate or brace?		
Filling?		
Contraceptive diaphragm, IUD / IUS (coil)?		
Patches for drug delivery (e.g. NRT, nicotine)?		
Penile / Breast or other surgical implants?		
Tattoos or permanent eyeliner?		
Piercings, metallic jewellery?		
Asthma or breathing apparatus?		
Seizure or motor disability?		
Do you take any recreational drugs?		
Ever had a head / Brain injury?		
Ever lost consciousness?		
Are you wearing any clothing, (the underwear) that contain metallic threads or has been shot / fragmented (e.g. Anti-mine)?		
Is there any possibility you may be pregnant? LMP:		

I declare that the above information is correct to the best of my knowledge. I have read and understood the contents of this form and I have had the opportunity to ask questions regarding the information on this form regarding the MRI procedure that I am about to undergo.

Your Name: \_\_\_\_\_ Signature: \_\_\_\_\_ Date: \_\_\_\_\_

MR Staff Name: \_\_\_\_\_ Signature: \_\_\_\_\_ Date: \_\_\_\_\_ PTO


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### MRI Exam Questionnaire

The volunteer is kindly invited to fill in this questionnaire related to the tolerance of the MRI examination, specifying any events and feelings that occurred before and/or during the exam.

Before the exam: 1 2 3 4 5 6 7 8 9 10

During the exam: 1 2 3 4 5 6 7 8 9 10

After the exam: 1 2 3 4 5 6 7 8 9 10

Have you ever had an MRI scan before?

If Yes: At 3T? ☐ At 7T? ☐ At 1T? ☐

Did you find any difference between the preceding exams? (please specify): \_\_\_\_\_

Generally did you find the MRI exam comfortable? (lighting, ventilation, position of the bed, etc): \_\_\_\_\_

Would you be willing to participate again in an MRI exam if necessary?

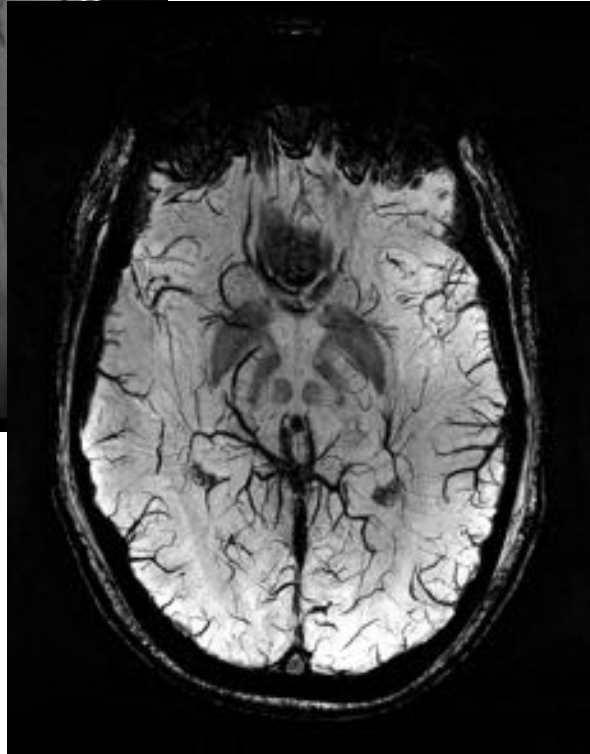
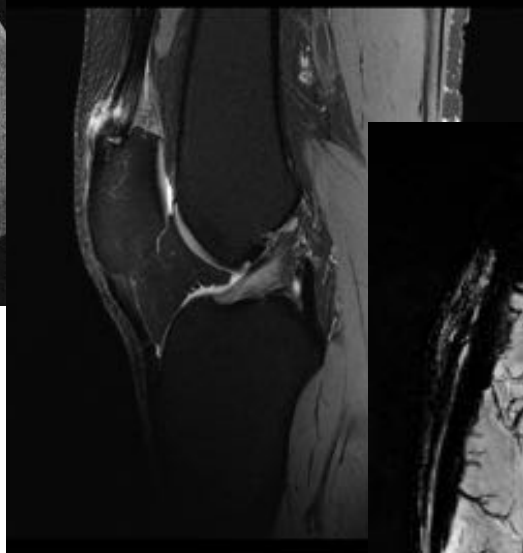
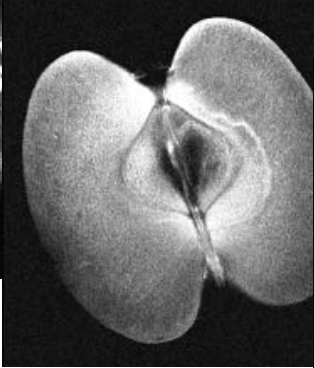
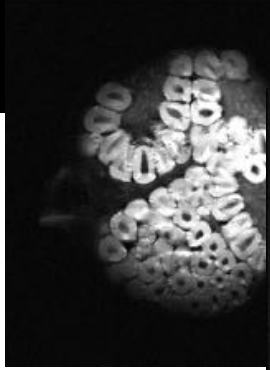
Comments: \_\_\_\_\_

Type of Exam: \_\_\_\_\_

Date: \_\_\_\_\_ Age: \_\_\_\_\_ Gender: \_\_\_\_\_ Height: \_\_\_\_\_ Weight: \_\_\_\_\_

# Acknowledgements

- Siemens (Erlangen, Germany)
  - Robin Heidemann
  - Thomas Benner
- CBU
  - Gary Chandler and Mark Townsend
- WBIC
  - Matt O'Neale, MRI Customer Service Engineer



Thank You!