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Signal Sources and Acquisition Choices for Columnar and Laminar fMRI

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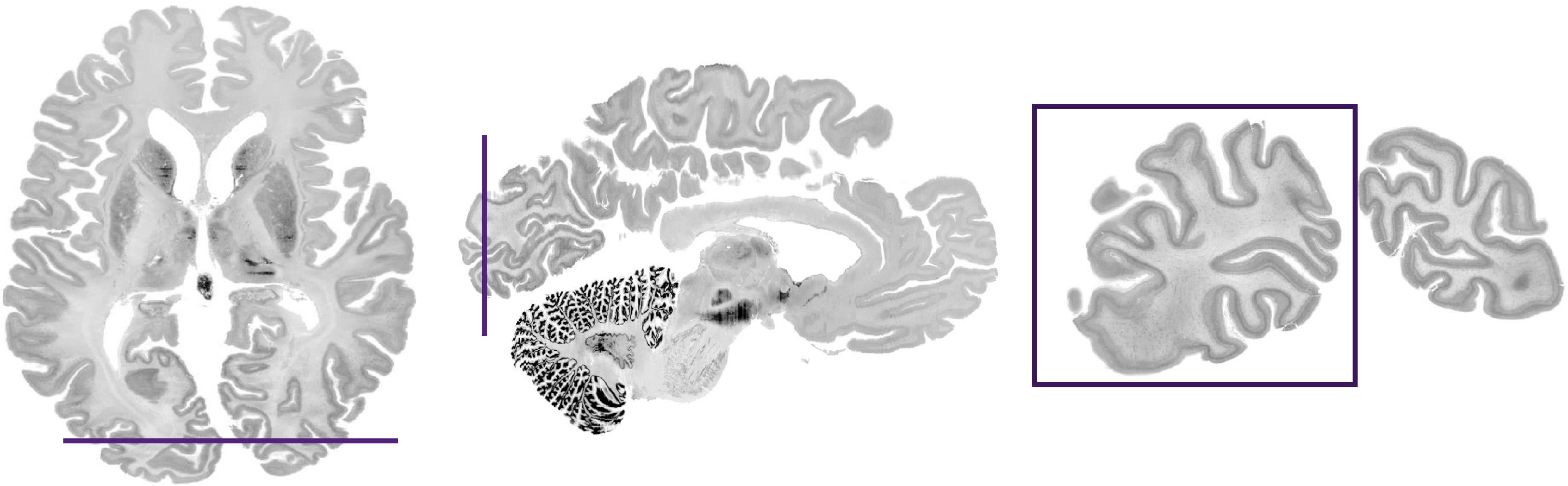
Cortical Architecture



Amunts et al., Science, 2013

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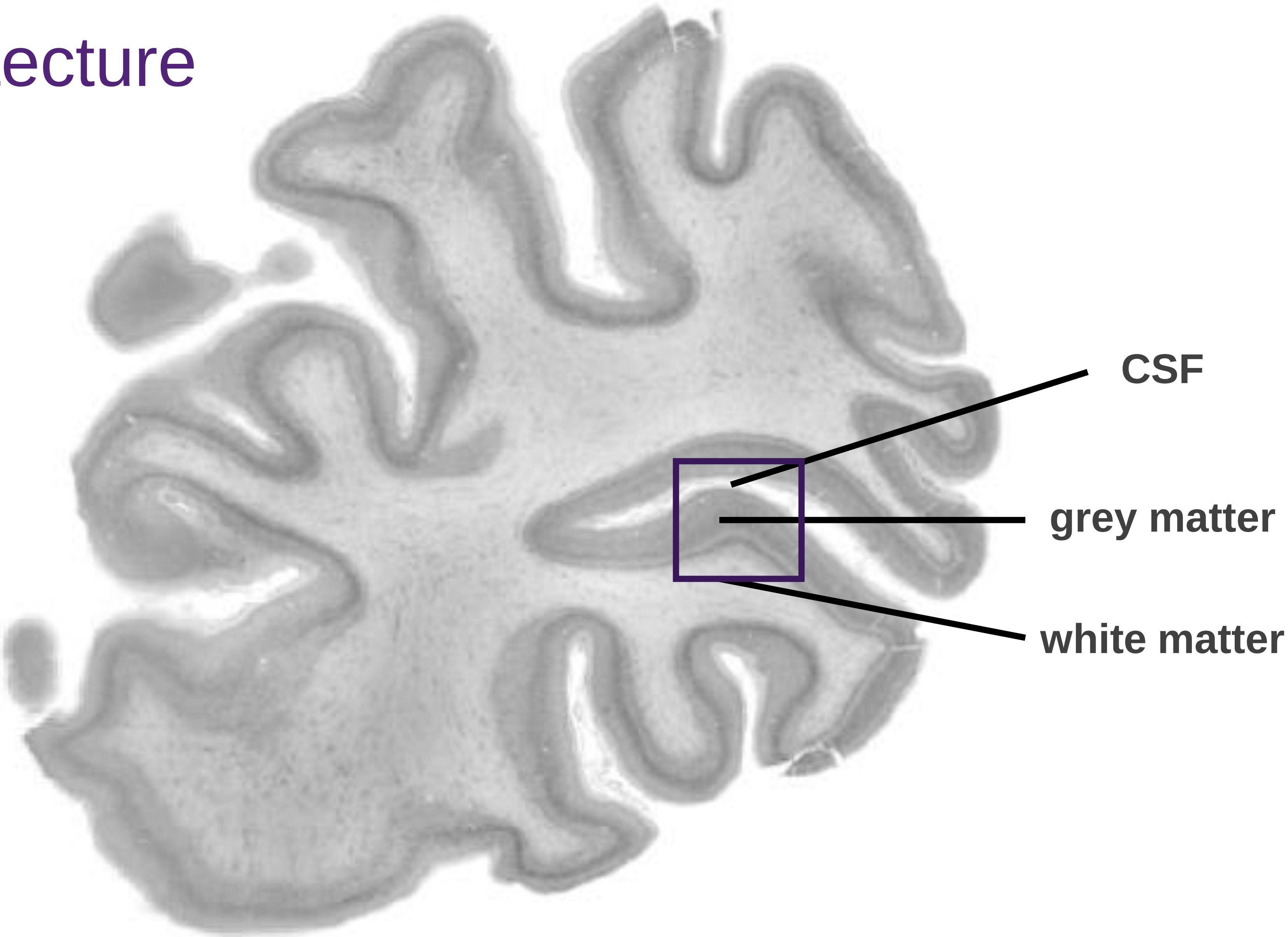

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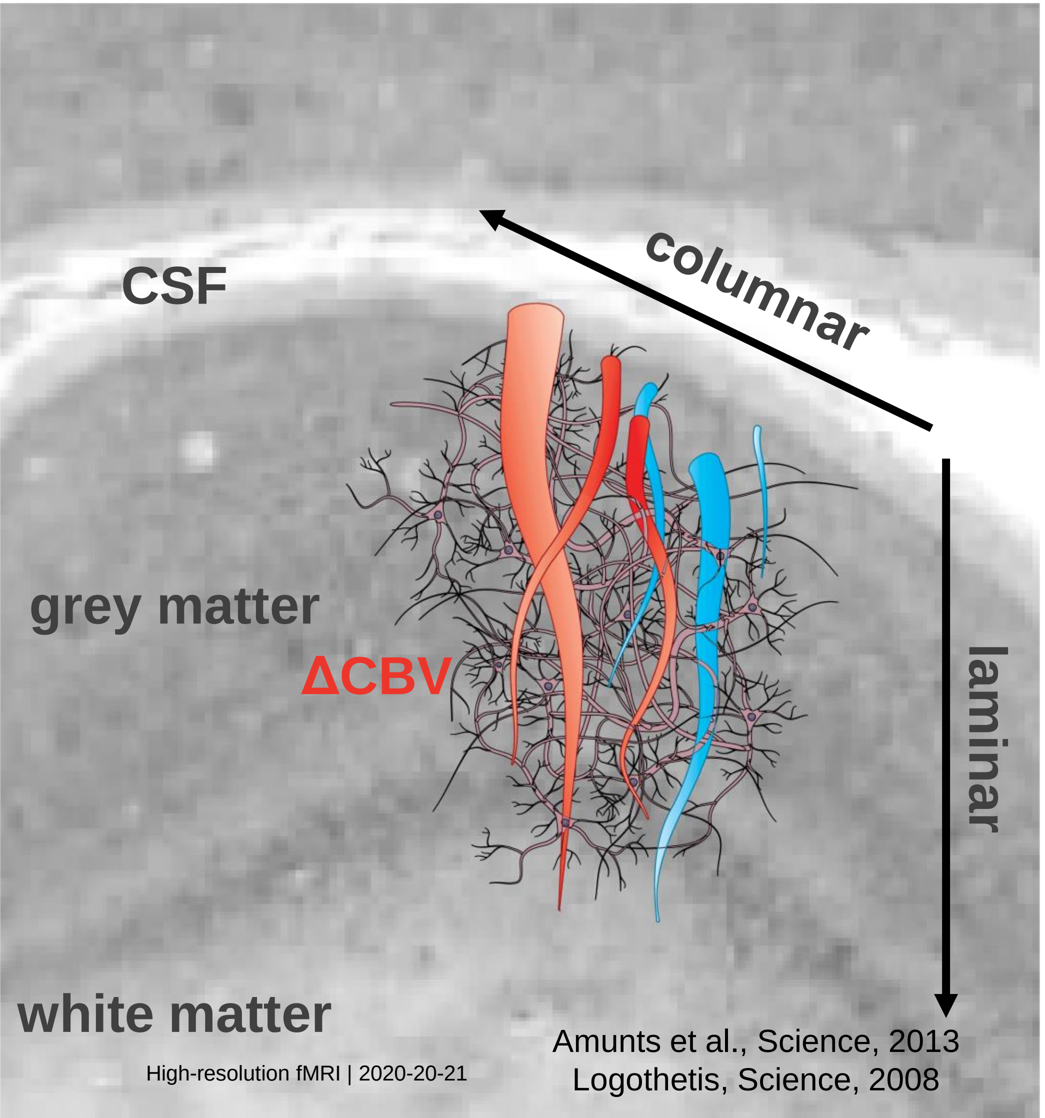
Measuring brain function using functional MRI



- 2 main partitioning axes of the cortex[1]
  - perpendicular to the surface → laminar
  - parallel to the surface → columnar

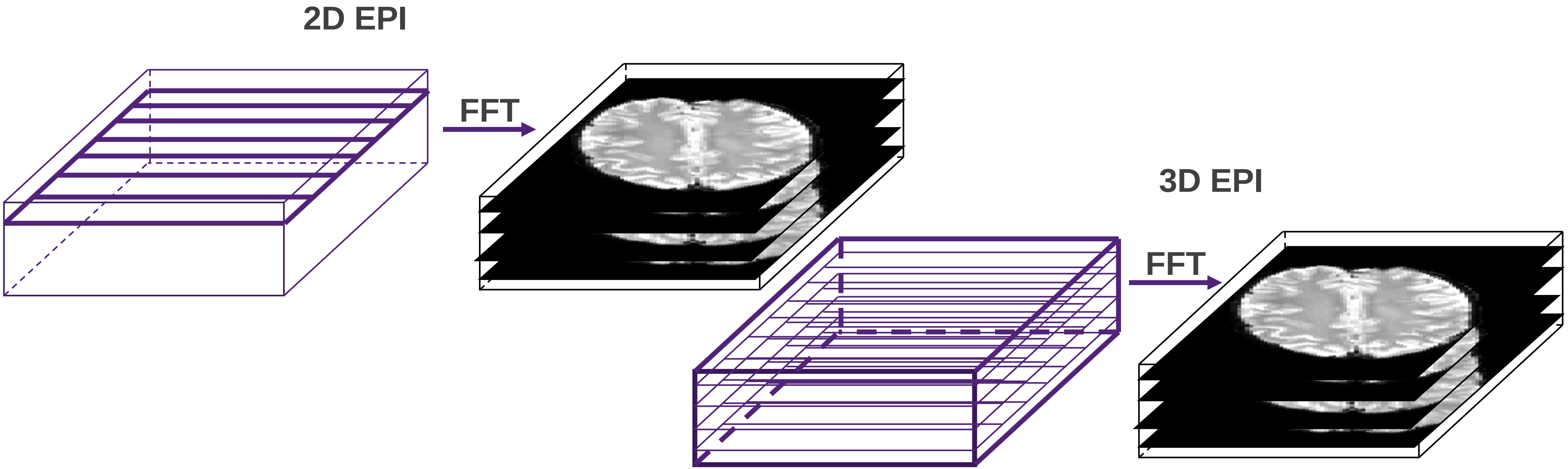
- fMRI measures tightly controlled[2] vascular response following activity in large ensembles of neurons[3]

- high-resolution fMRI at ultra-high field provides the necessary resolution and sensitivity[4] to resolve *depth-dependent*[5] and *topographic*[6] signals

[1]Harris and Mrsic-Flogel, Nature, 2013; Shamir and Assaf, medRxiv, 2020
[2]Silva and Koretsky, PNAS, 2002; Sheth et al., J Neurosci, 2004; Hillman et al., NI, 2007; Tian et al., 2010, PNAS
[2]Iadecola, Nat Neurosci Reviews, 2004
[4]Bollmann and Barth, Progress in Neurobiology, 2020 (in print)
[5]Barth and Norris, NMR Biomed, 2007; Polimeni et al., NI, 2010; Olman et al., PlosOne, 2012; Huber et al., Neuron, 2017
[6]Engel et al., Nature, 1994; Sereno et al., Science, 1995; Wandell et al., Neuron, 2007; Silver and Kastner, Trends in Cogn Sciences, 2009; Sanchez-Panchuelo et al., J Neurosci, 2012; Besle et al., J Neurphysiology, 2013; Puckett et al., Neuroimage, 2017; Wessinger et al., HBM, 1997; Bilecen et al., Hearing Research. 1998; Talavage et al., J Neurphysiology, 2004; Ahveninen et al., NI, 2016

High-resolution fMRI acquisition

- high-resolution fMRI → sub-millimetre resolution
- majority of studies utilize a 3D EPI acquisition



[1]Poser et al., NI, 2010

High-resolution fMRI acquisition

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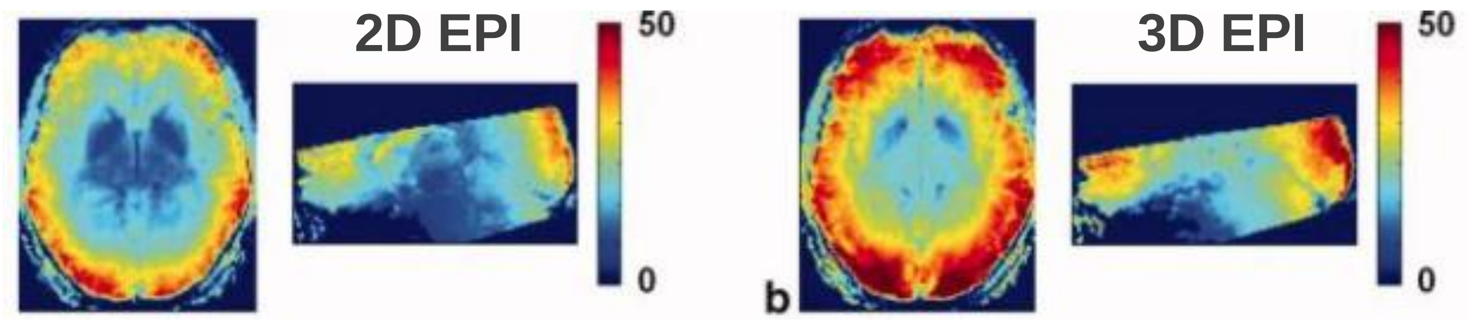
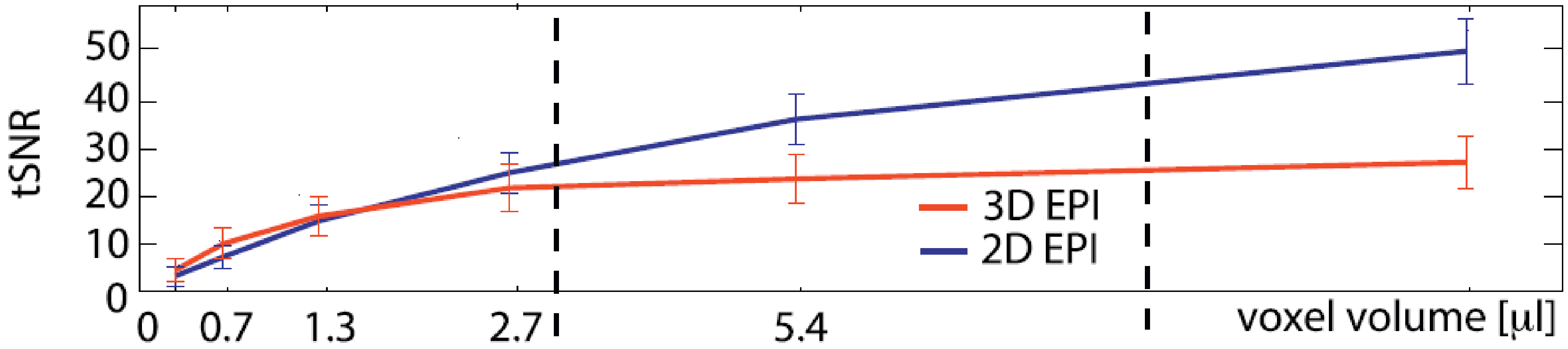
  - higher temporal SNR than 2D at sub-millimetre resolution[1]





[1]Lutti et al., MRM, 2013; Huber et al., NI, 2018

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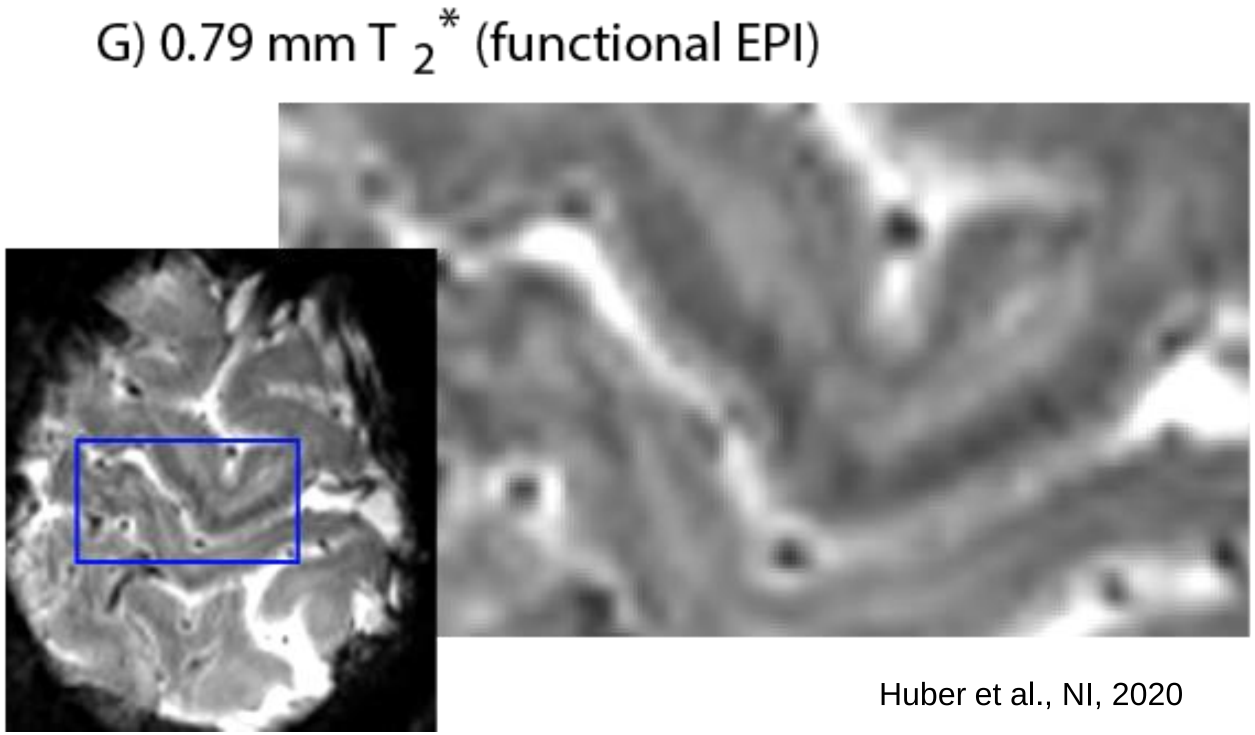
High-resolution fMRI acquisition

- high-resolution fMRI → sub-millimetre resolution
- majority of studies utilize a 3D EPI acquisition
  - higher temporal SNR than 2D at sub-millimetre resolution[1]
  - low SAR/better slice profile
- current parameter 'optimum'
  - 0.7 – 1 mm resolution
  - 25 – 35 ms TE
  - 2 – 3 s TR (partial coverage)
  - R = 4
  - 6/8 – no PF
- current limitations
  - image fidelity (blurring & B_0)
  - resolution/TE



Huber et al., NI, 2020

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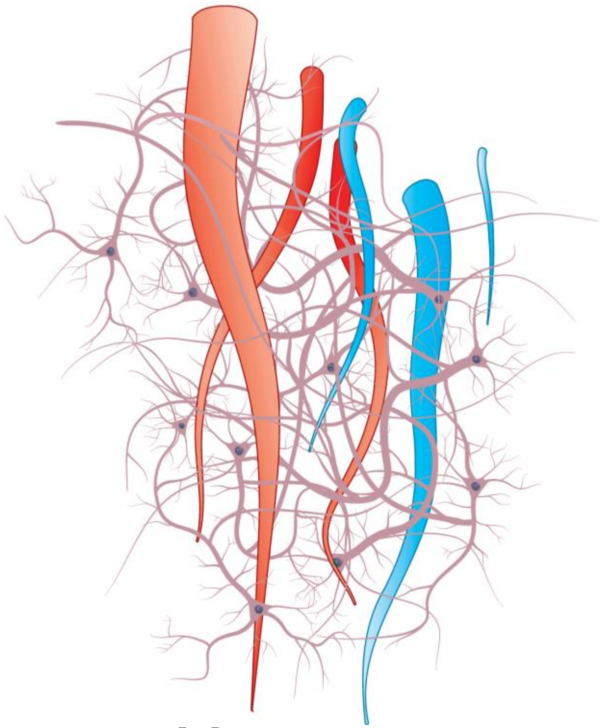
Modelling depth-dependent fMRI signal changes in human V1[1]



Atena Akbari

[1]Markuerkiaga et al., NI, 2016; Akbari et al., ISMRM, 2020; [2]Poser et al., NI, 2014; [3]Huber et al., MRM, 2014

Modelling laminar fMRI signal changes in human V1[1]

blood oxygenation

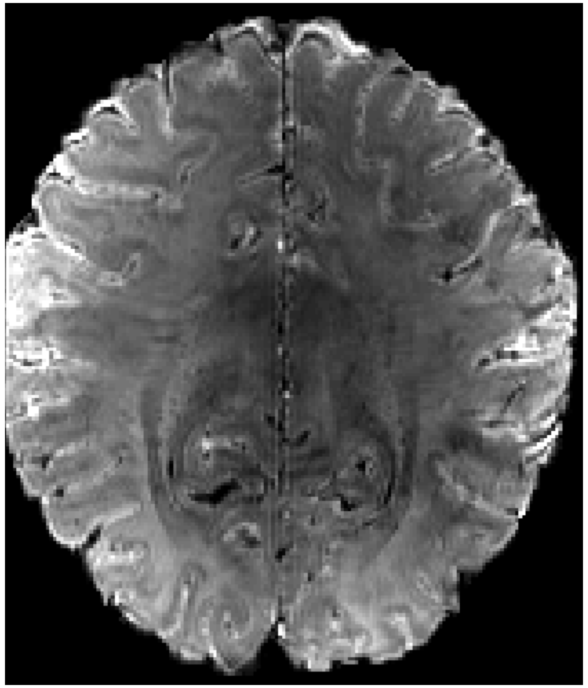
blood-oxygen-level dependent (BOLD)

T_2^*

cerebral blood volume

vascular-space-occupancy (VASO)

T_1



SS-SI-VASO[1]

3D EPI readout[2]

voxel size = 0.8mm x 0.8mm x 0.8 mm

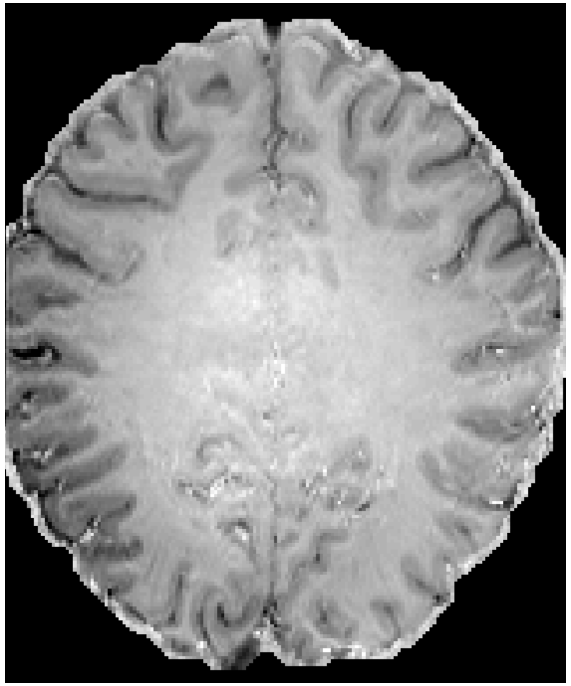
TR = 2 x 2500 ms

TE = 26 ms

TI = 650 ms

FOV = 160mm x 160mm x 21mm

T_{ACQ} = 51 min



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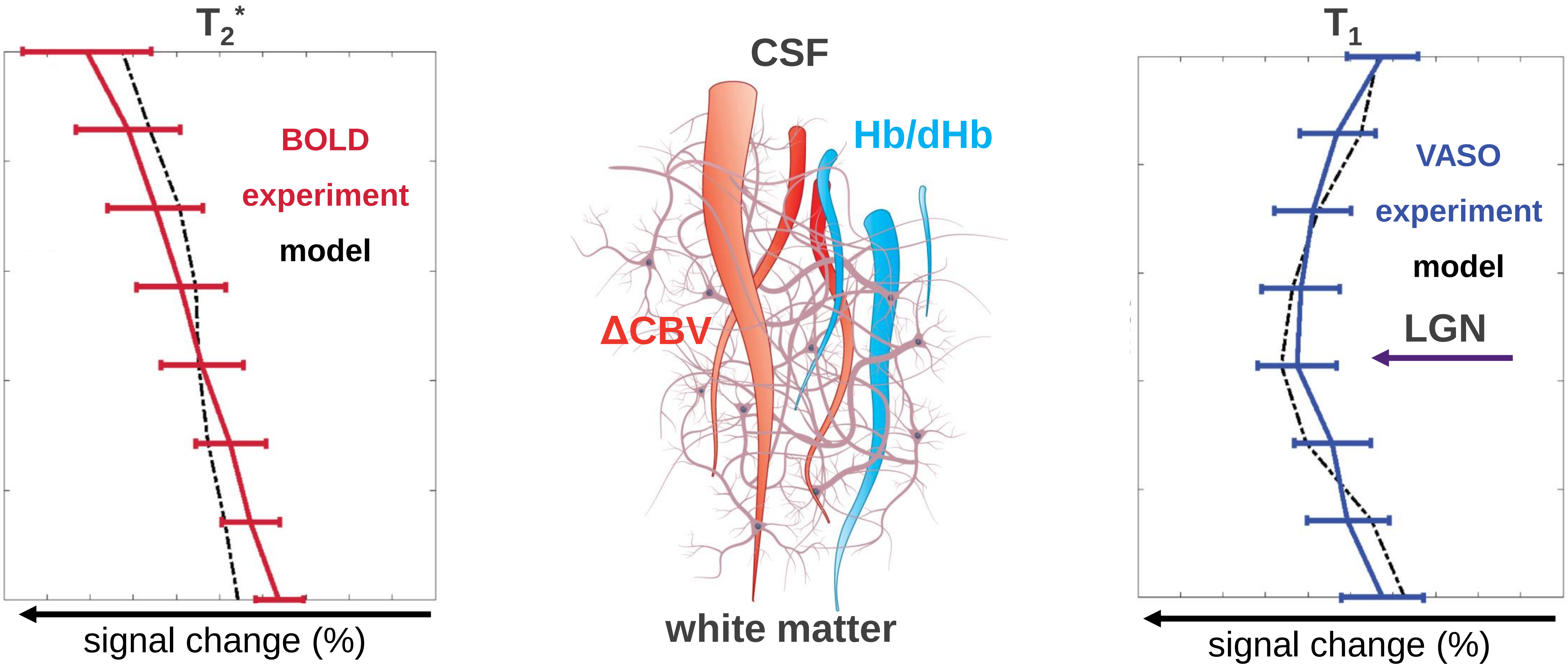

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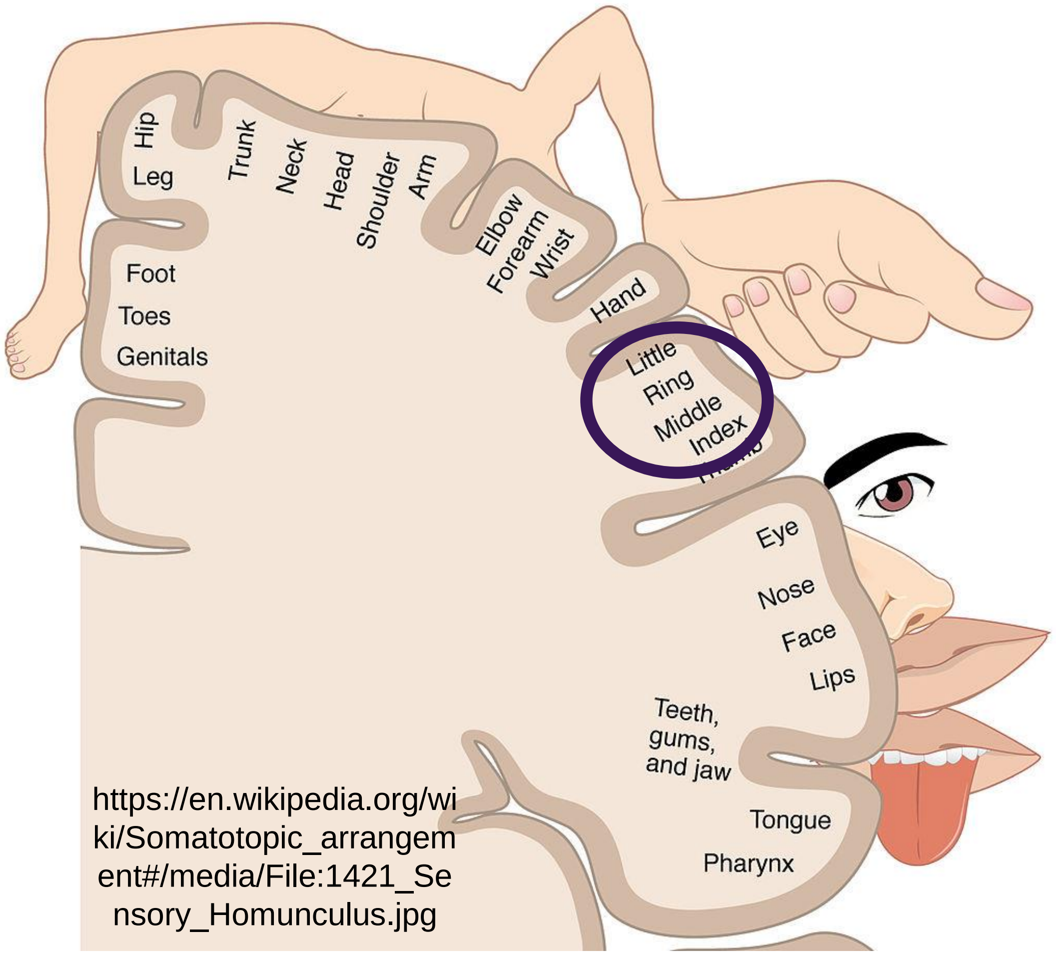
Measuring the effects of attention to individual fingertips in somatosensory cortex[1]



https://en.wikipedia.org/wiki/Somatotopic_arrangement#/media/File:1421_Sensory_Homunculus.jpg

Ashley York

Alex Puckett

[1]Puckett et al., NI, 2017; York et al., ISMRM, 2020
[2]Poser et al., NI, 2010

Measuring the effects of attention to individual fingertips in somatosensory cortex[1]

3D EPI readout[2]

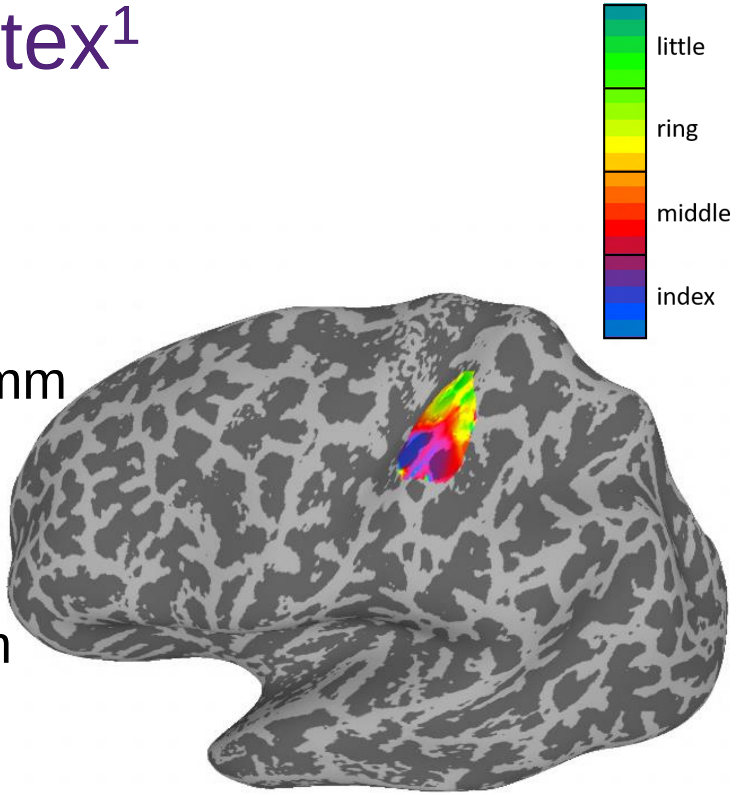
voxel size = 0.8mm x 0.8mm x 0.8mm

TR = 2000 ms

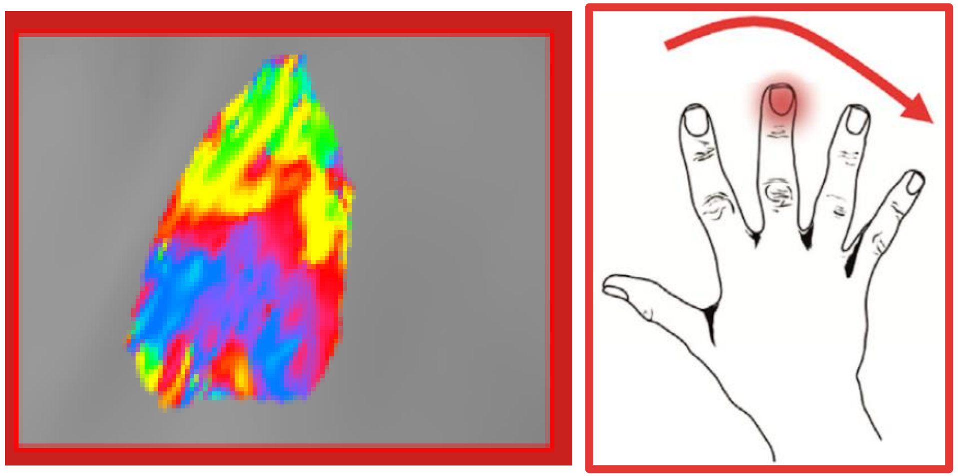
TE = 30 ms

FOV = 160mm x 160mm x 39mm

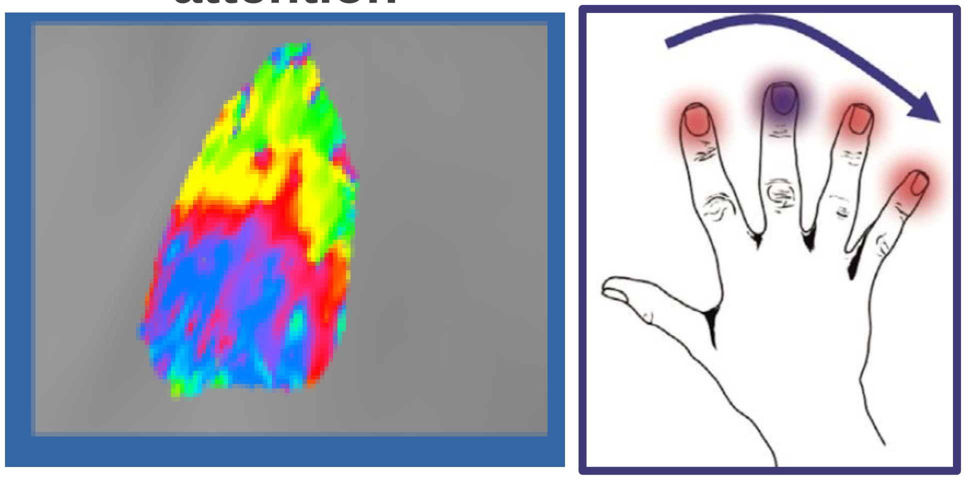
T_{ACQ} = 60 min (per condition)



sensory



attention



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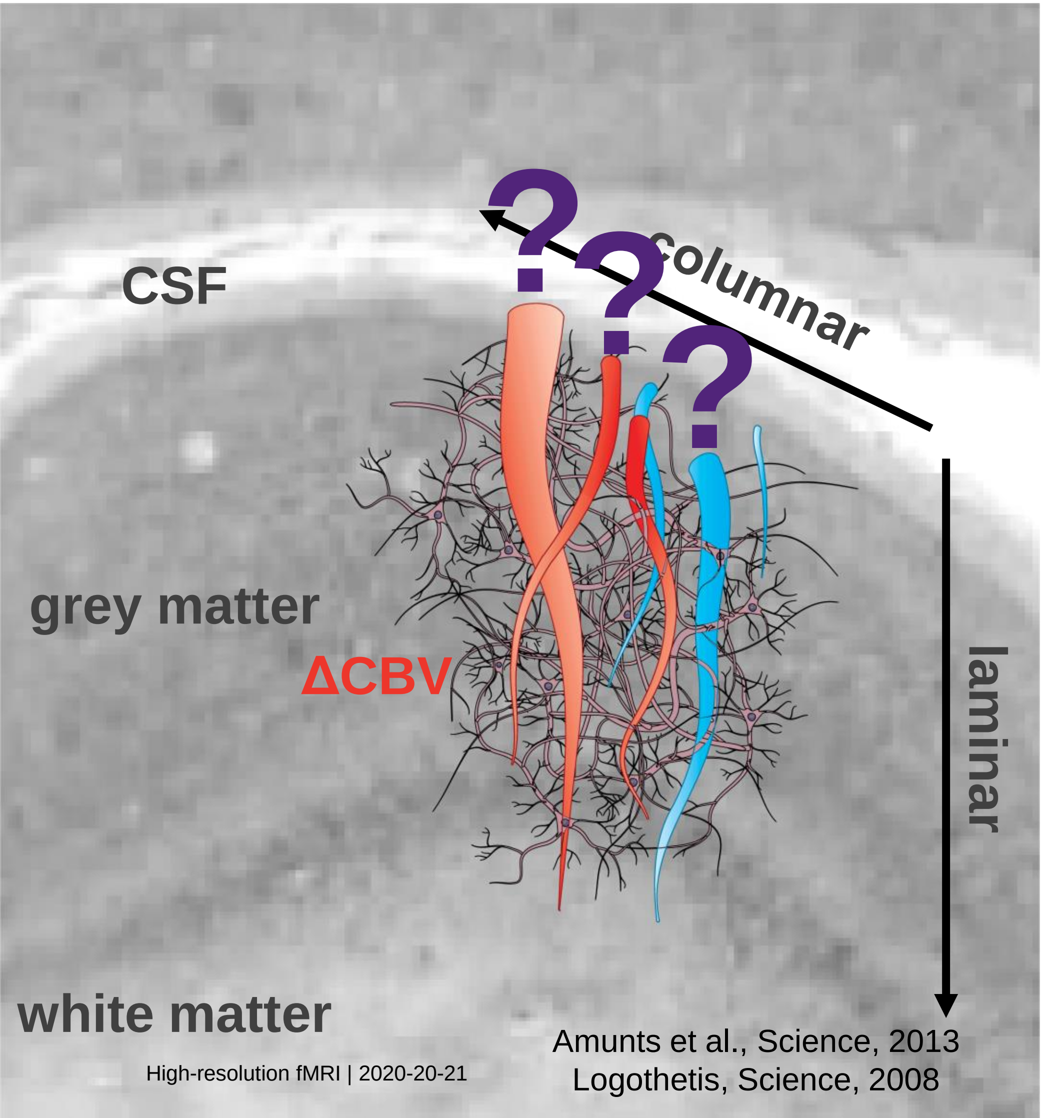

Amunts et al., Science, 2013
Logothetis, Science, 2008

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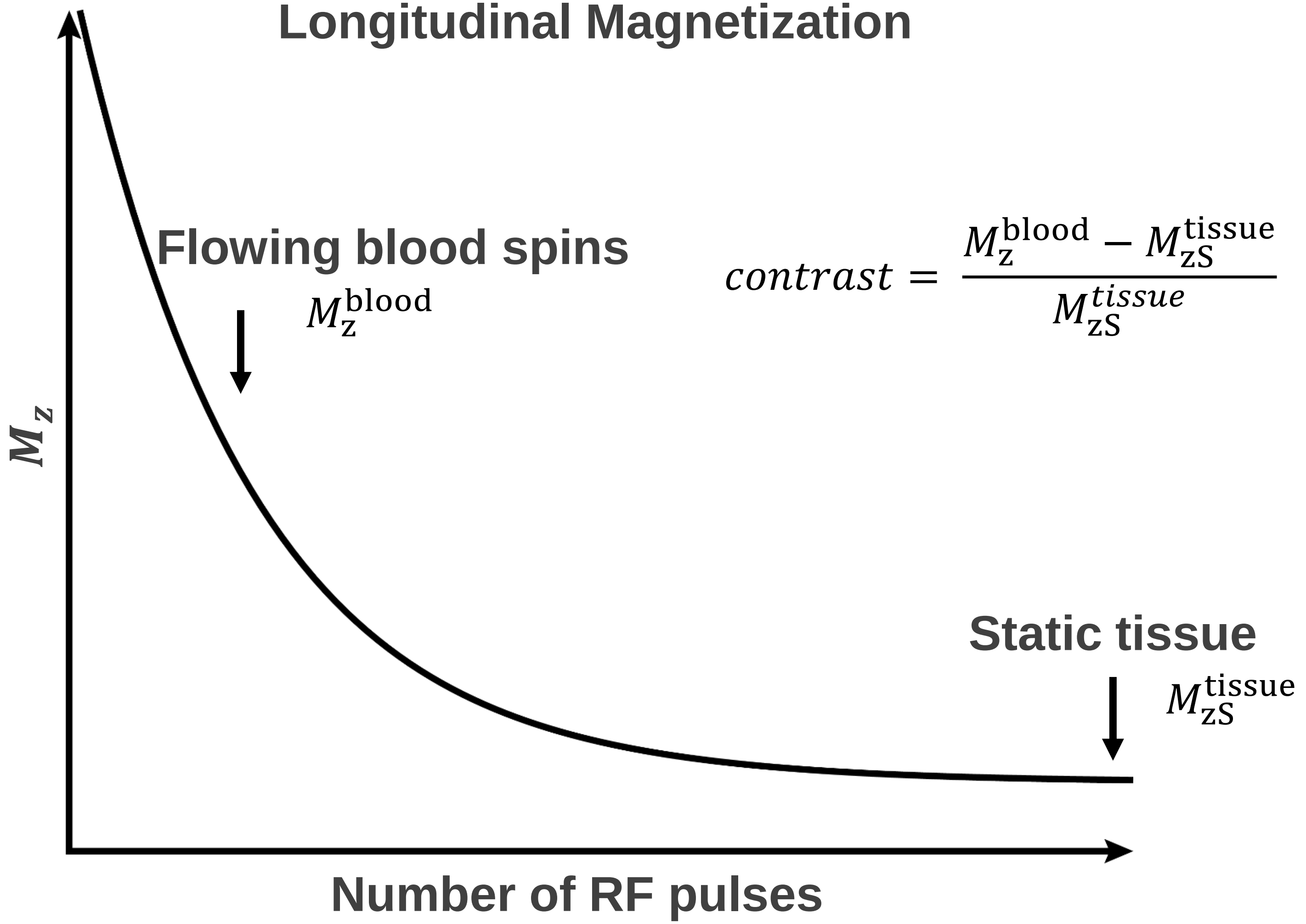
Contrast mechanism in time-of-flight (TOF) angiography



$$contrast = \frac{M_{\mathrm{z}}^{\mathrm{blood}} - M_{\mathrm{zS}}^{\mathrm{tissue}}}{M_{\mathrm{zS}}^{tissue}}$$

Blood deliver time

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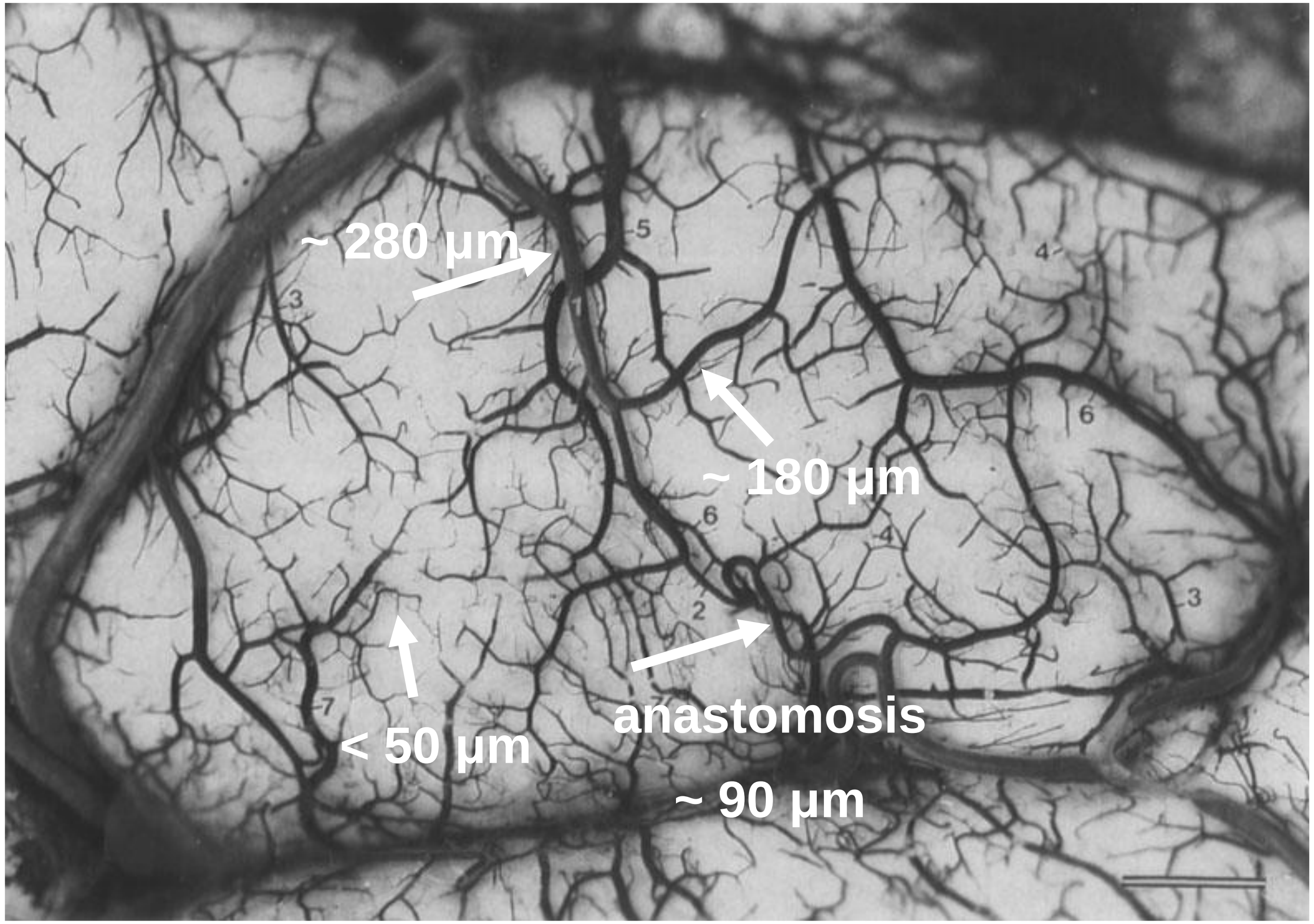
Architecture of the pial arterial vasculature



Duvernoy, Springer, 2000

- blood delivery times[1]
  - 200 – 700 ms
- imaging regime of small vessels[2]
  - Ø ≤ 200 µm
- branching pattern[3]
  - right-angled

[1]Alsop et al., MRM, 2015
[2]Duvernoy et al., Brain Research Bulletin, 1981
[3]Rowbotham and Little, Br. J. Surg., 1965

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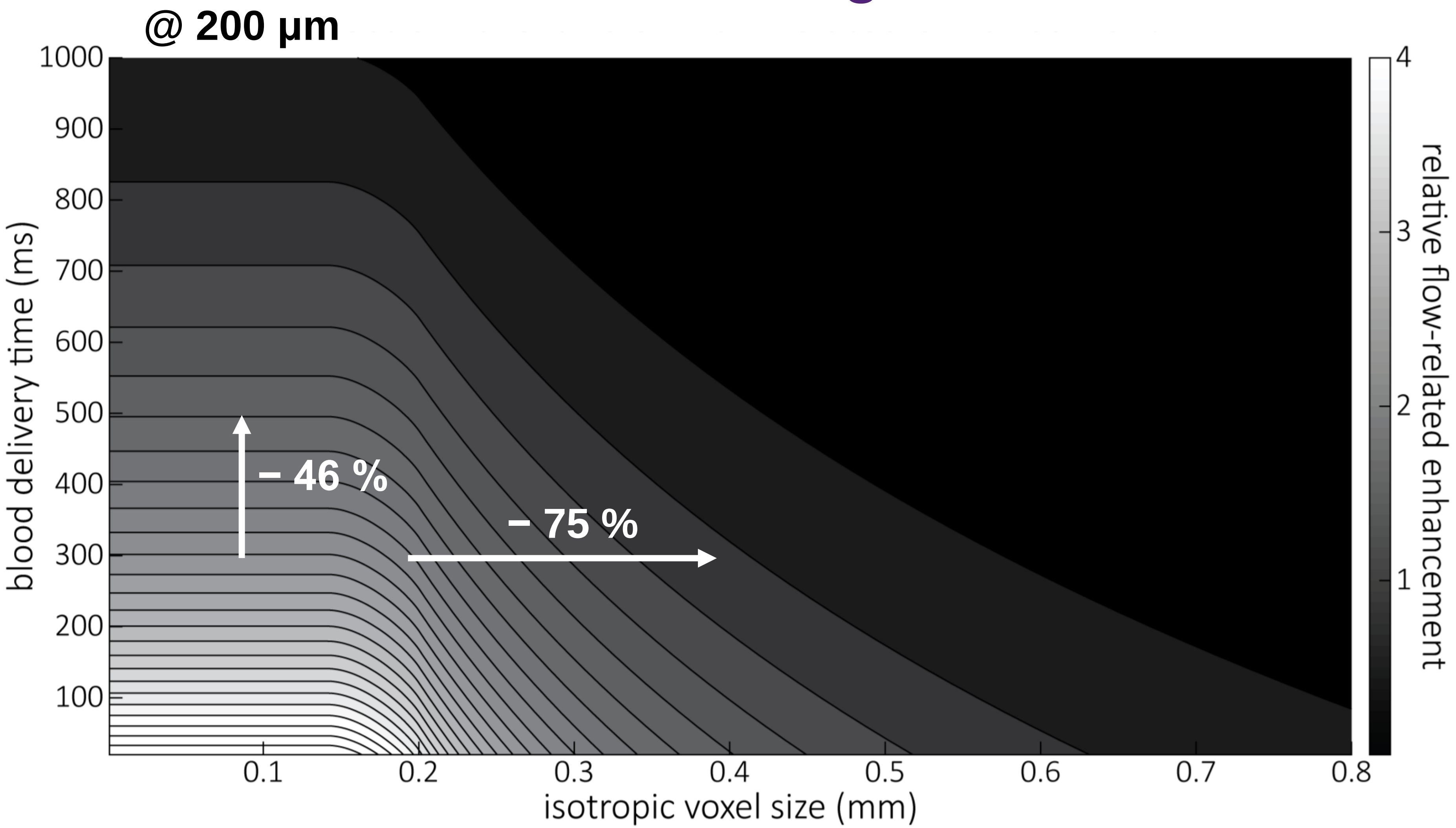
Haacke et al., MRM, 1990
von Morze et al., JMRI, 2007
Mattern et al., MRM, 2018

Effect of voxel size on time-of-flight contrast



Pial arterial vasculature I

TR = 20 ms

θ = 18°

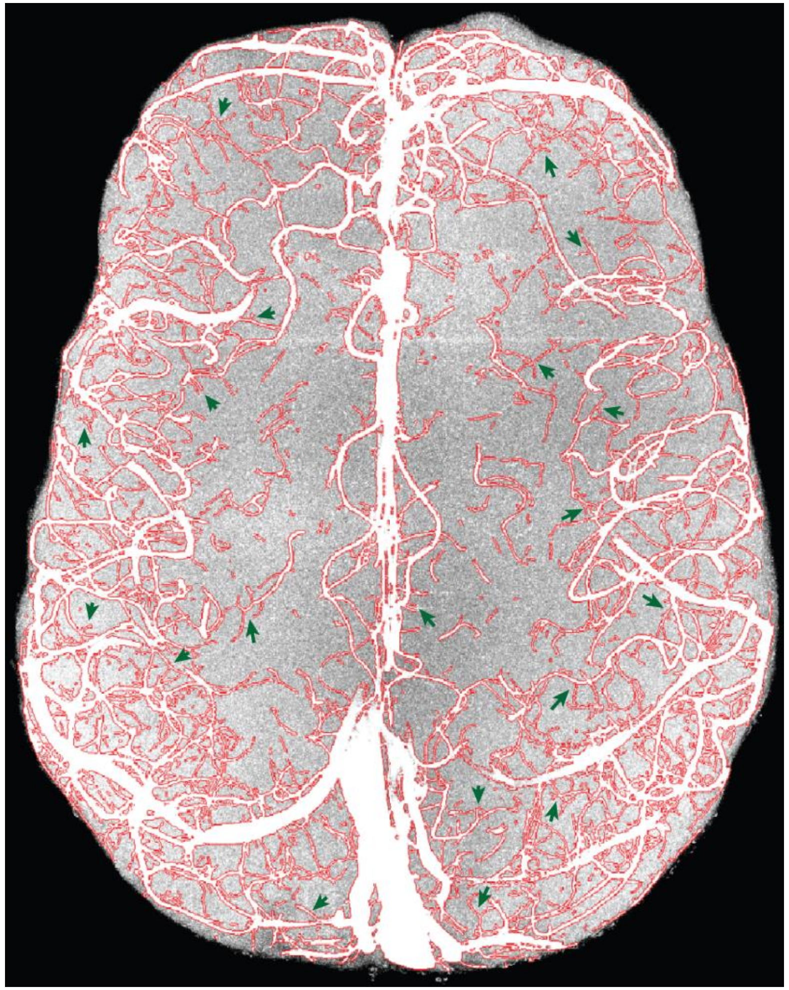
TE = 6.56 ms

slab thickness = 8.32 mm

GRAPPA = 2

T_{ACQ} = 11 min 16 s

6 slabs



0.16 x 0.16 x 0.16 mm^3

Pial arterial vasculature II

TR = 20 ms

θ = 18°

TE = 6.99 ms

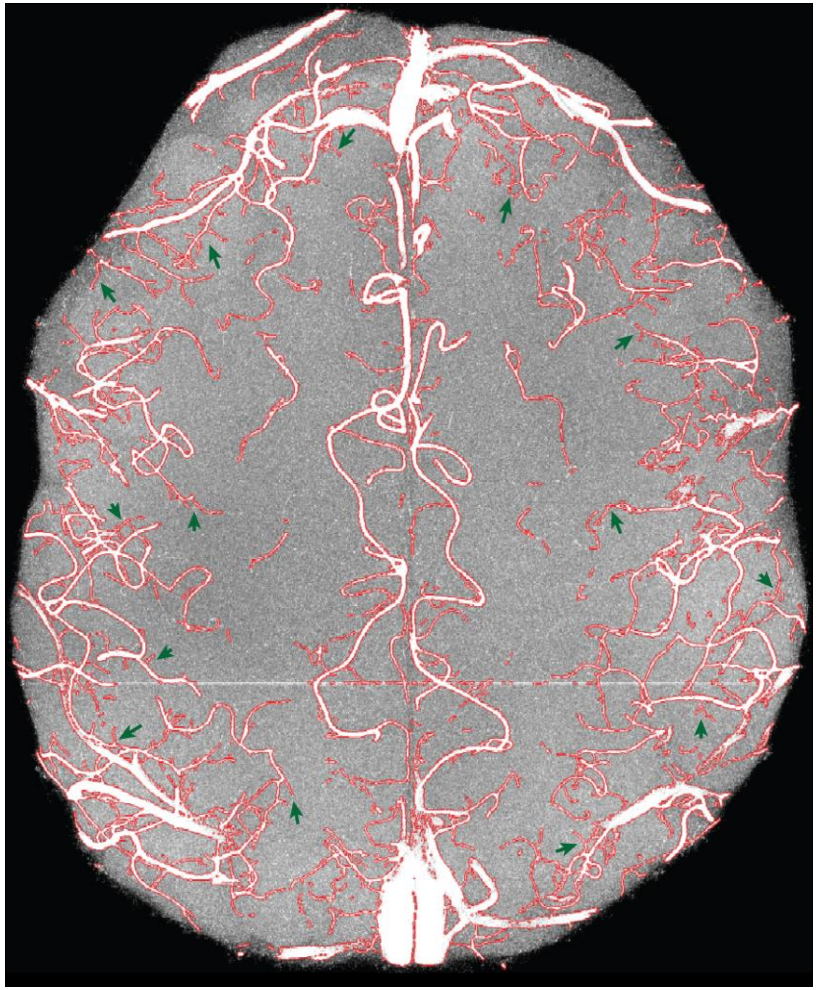
slab thickness = 7.28 mm

T_{ACQ} = 21 min 53 s

3 slabs

prospective motion correction

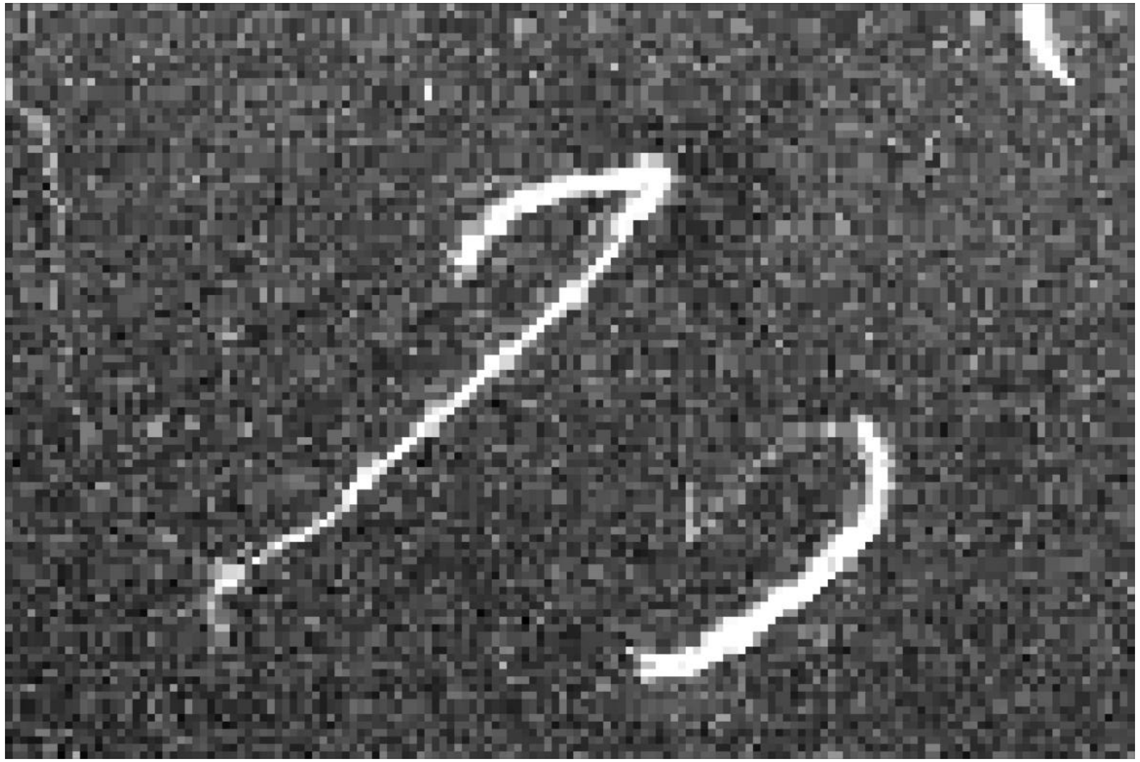
Mattern et al., MRM, 2018



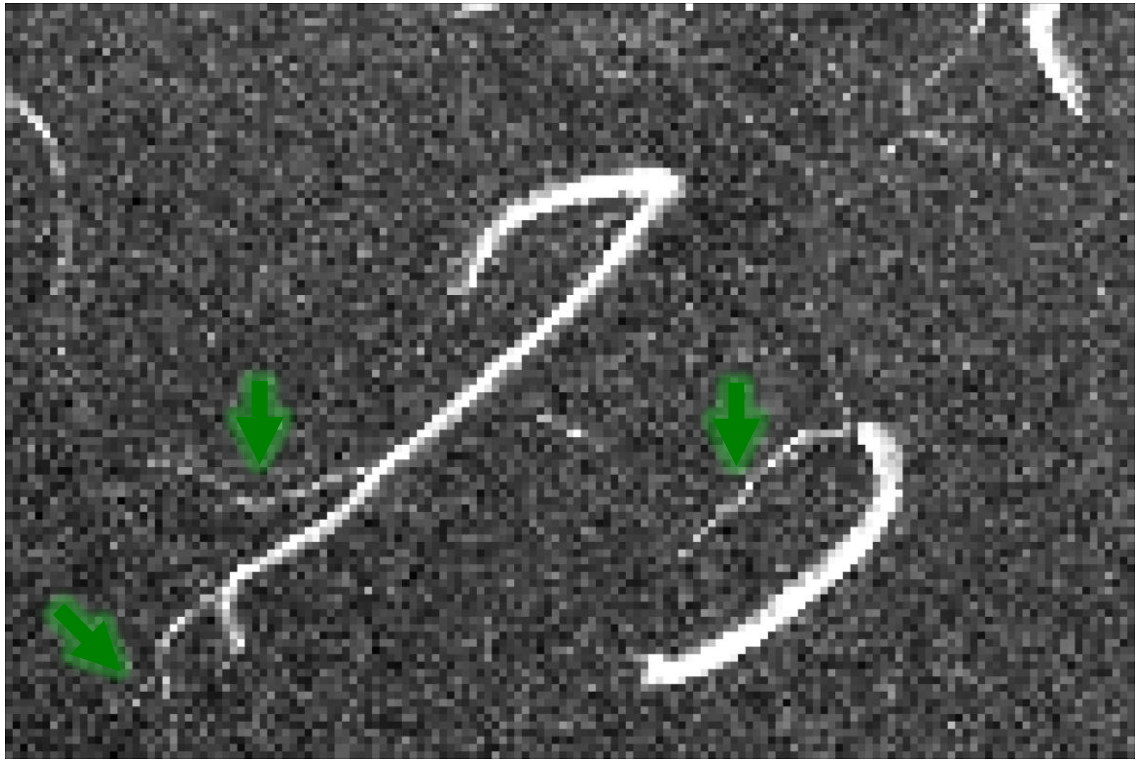
0.14 x 0.14 x 0.14 mm³

Empirical results: effect of voxel size

0.16 x 0.16 x 0.16 mm^3



0.14 x 0.14 x 0.14 mm^3



1 mm

Conclusion

- High-resolution (f)MRI is a valuable tool to study human brain function
  - versatile → various contrast mechanisms
  - non-invasive → characterize variability
  - large field-of-view → brain as a network

- Current limitations are acquisition related, not physiological
  - address venous bias through modelling or acquisition
  - main limitation is the image encoding

Thank you

Markus Barth
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Michaël Bernier
Daniel Park
Avery Berman

Oliver Speck
Hendrik Mattern

The University Of Queensland
Australia

National Imaging Facility

NIH National Institutes of Health

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Brain Research Through Advancing Innovative Neurotechnologies

Biomedizinische Magnetresonanz

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