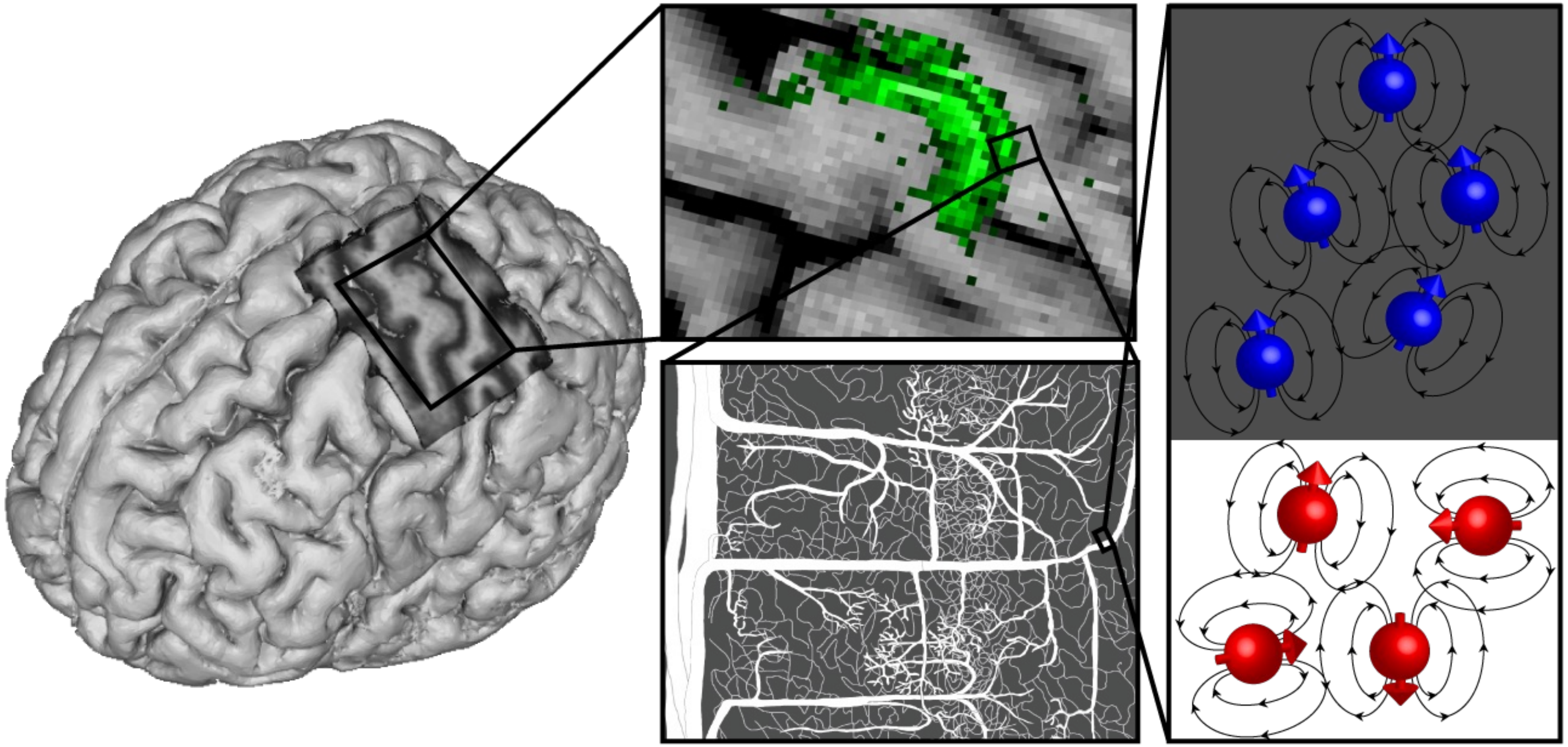
Functional contrast and processing strategies at high field and high resolution



Renzo (Laurentius) Huber

FMRI facility (FMRIF) at the NIMH/NINDS
of the National Institutes of Health (NIH)

Background Material

Relevant review article:


NeuroImage
Available online 20 July 2017
In Press, Corrected Proof

Non-BOLD contrast for laminar fMRI in humans: CBF, CBV, and CMR_{O2}

Laurentius Huber [a], Kâmil Uludağ [b, 1], Harald E. Möller [c, 1]

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https://doi.org/10.1016/j.neuroimage.2017.07.041

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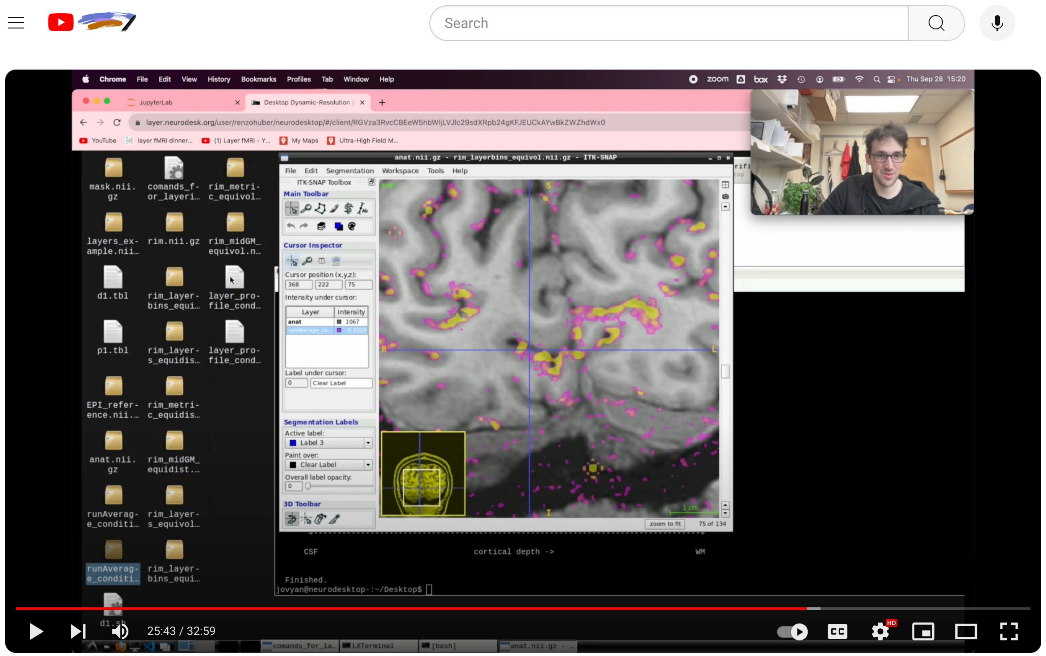
Highlights

- Non-BOLD-fMRI methods are reviewed for layer-dependent application in humans.
- ASL, VASO, and calibrated fMRI are promising candidates.
- Representative depth-dependent ASL/VASO/calibrated fMRI results are shown.
- ASL/VASO/calibrated fMRI are less sensitive but more specific than GE-BOLD.

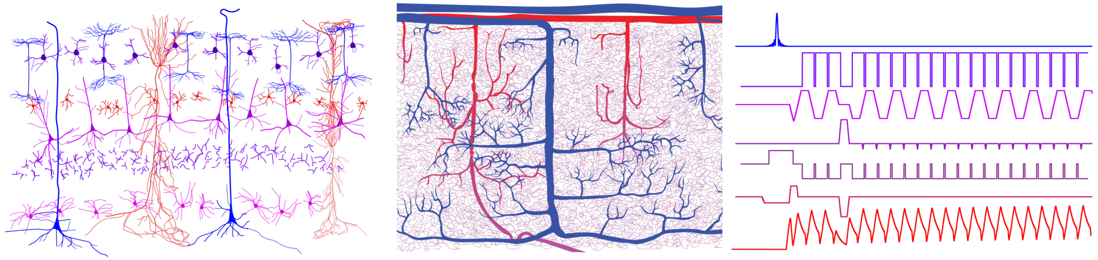
Abstract

Functional magnetic resonance imaging (fMRI) using the blood oxygenation level-dependent (BOLD) contrast indirectly probes neuronal activity changes via evoked

Hand-on layerification, https://youtu.be/tSA77mFTwcg?si=cQ_PqFXFu-VBINxX

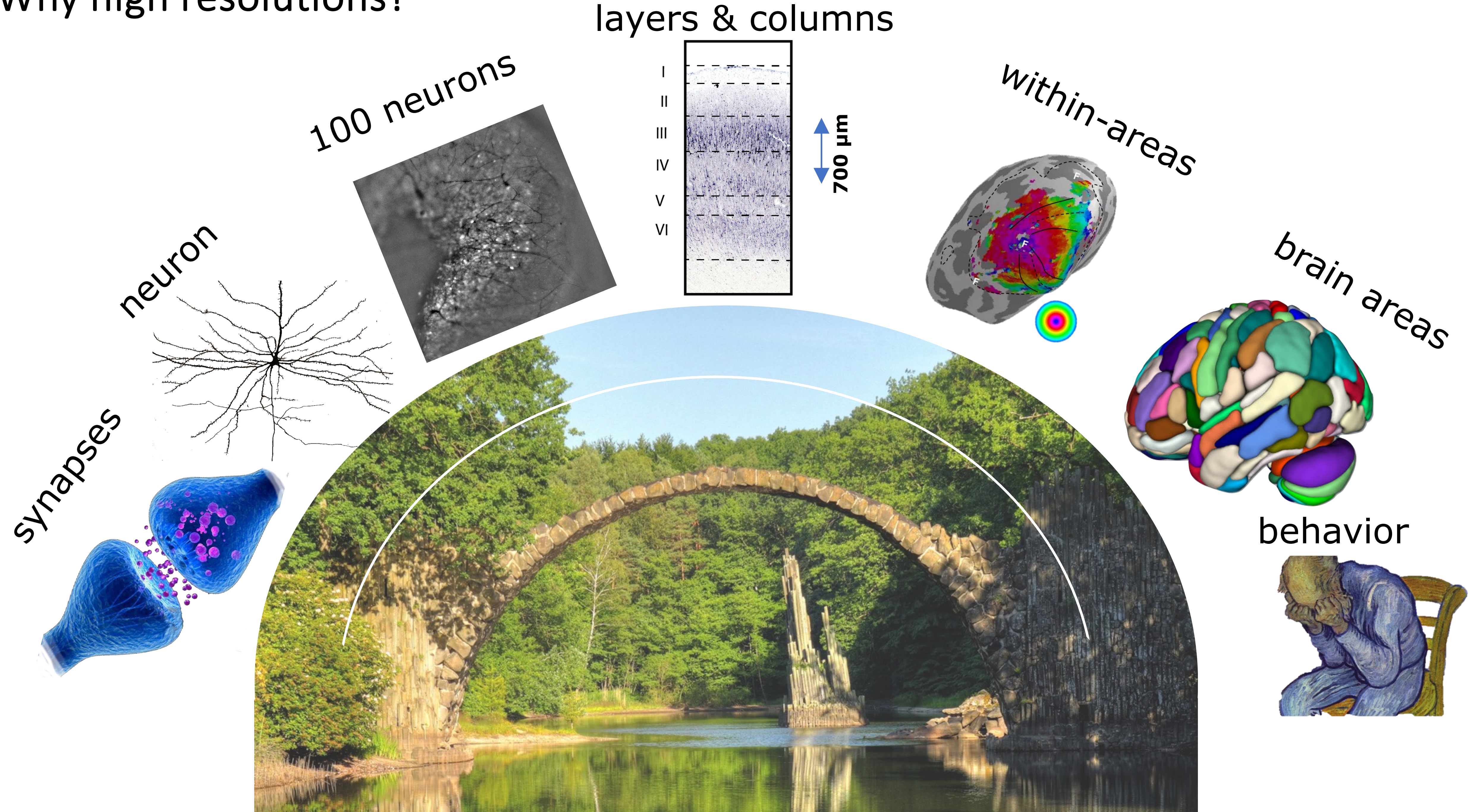


https://education.martinos.org/workshop-on-laminar-fmri/

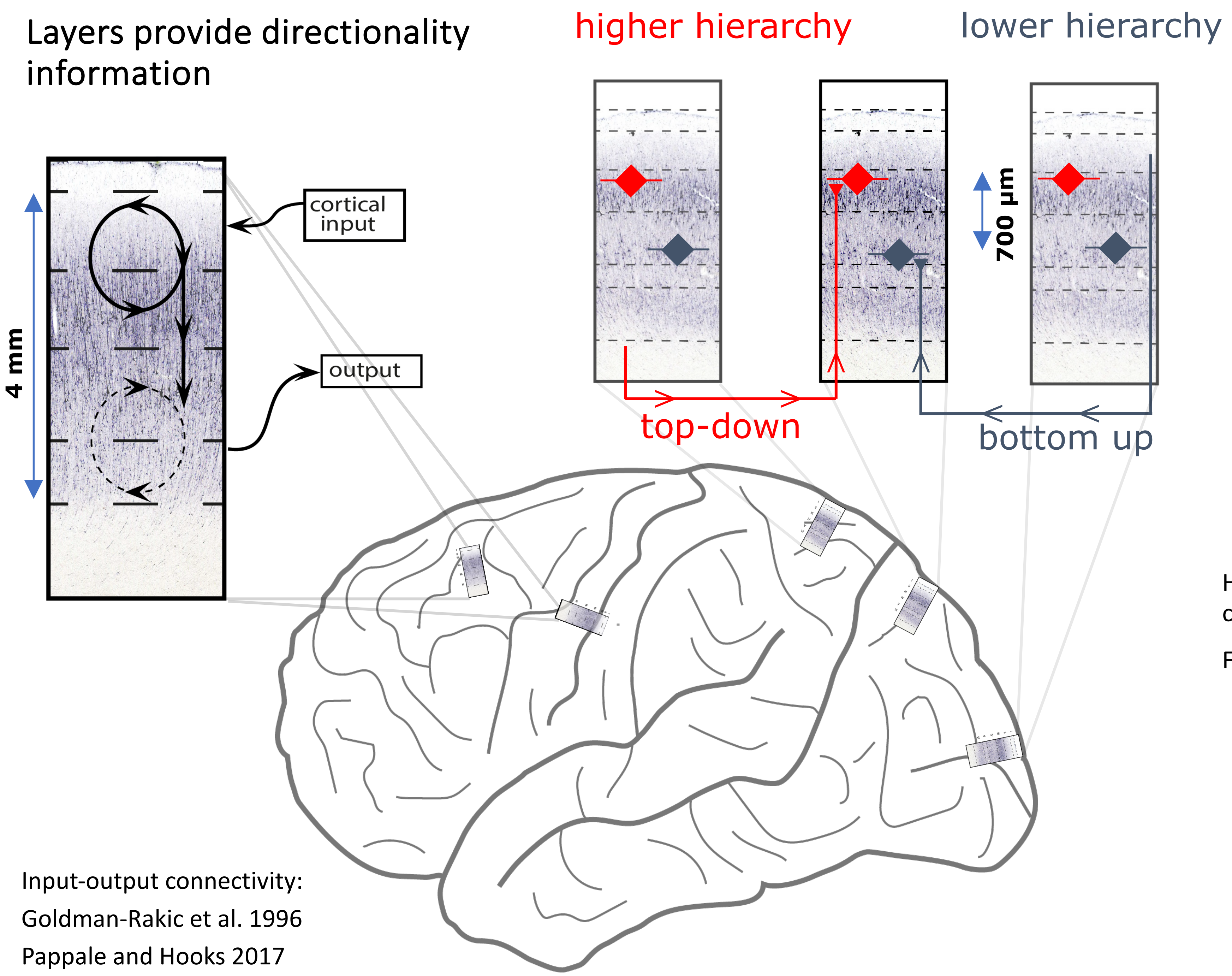


Ask me for recordings

Why high resolutions?



Layers provide directionality information



Hierarchical connectivity in the canonical micro-circuit:

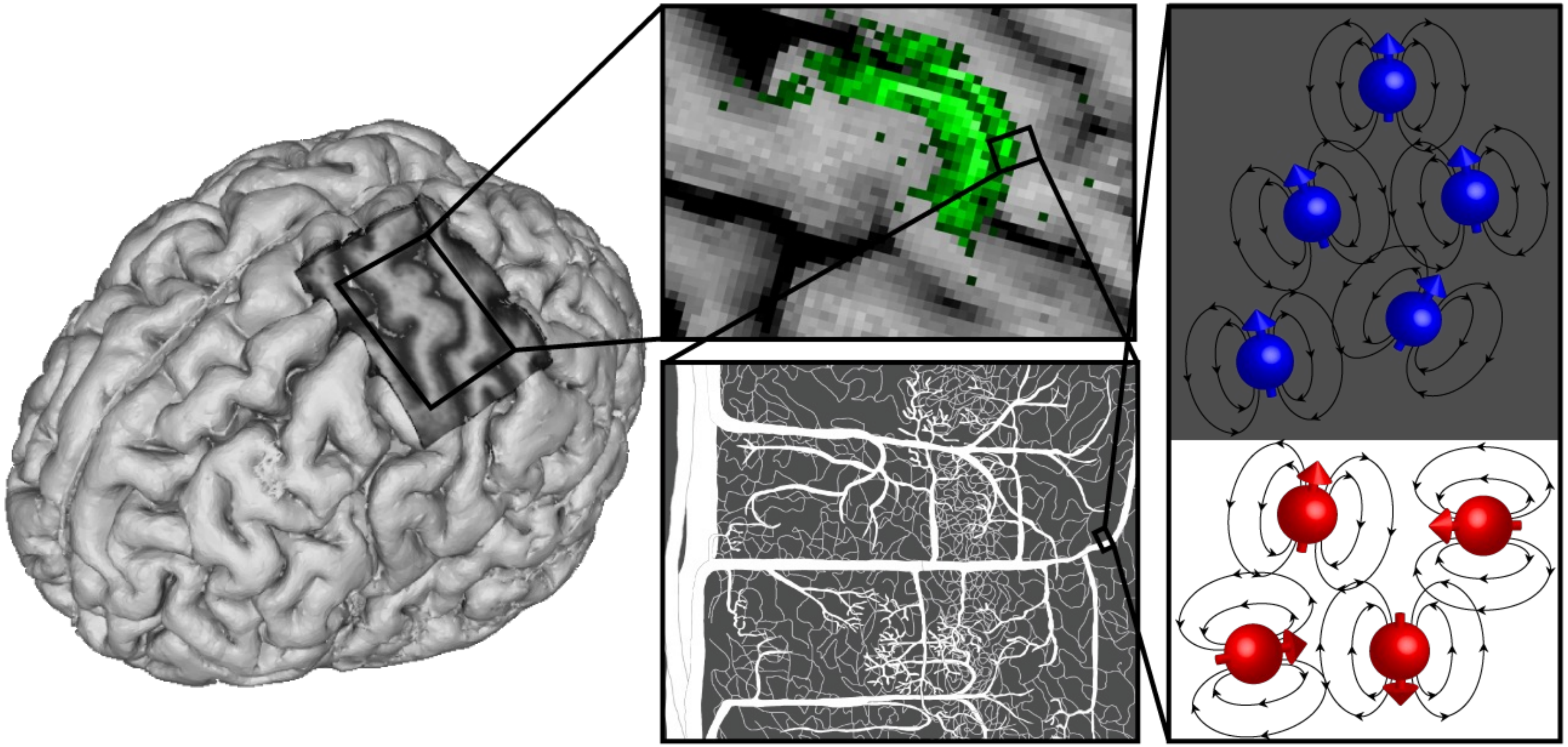
Felleman and Van Essen 1991

Input-output connectivity:

Goldman-Rakic et al. 1996

Pappale and Hooks 2017

Functional contrast and processing strategies at high field and high resolution



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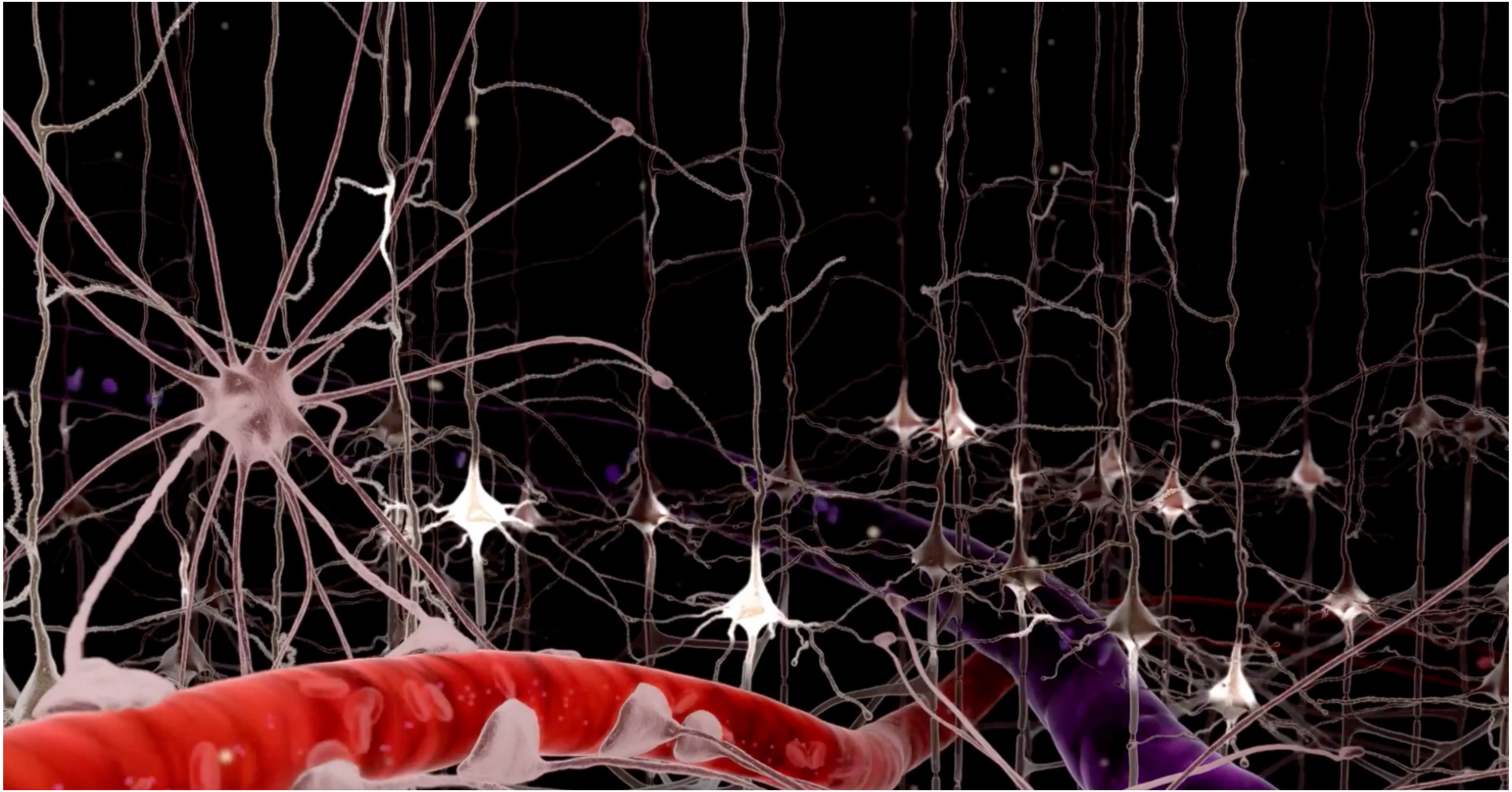
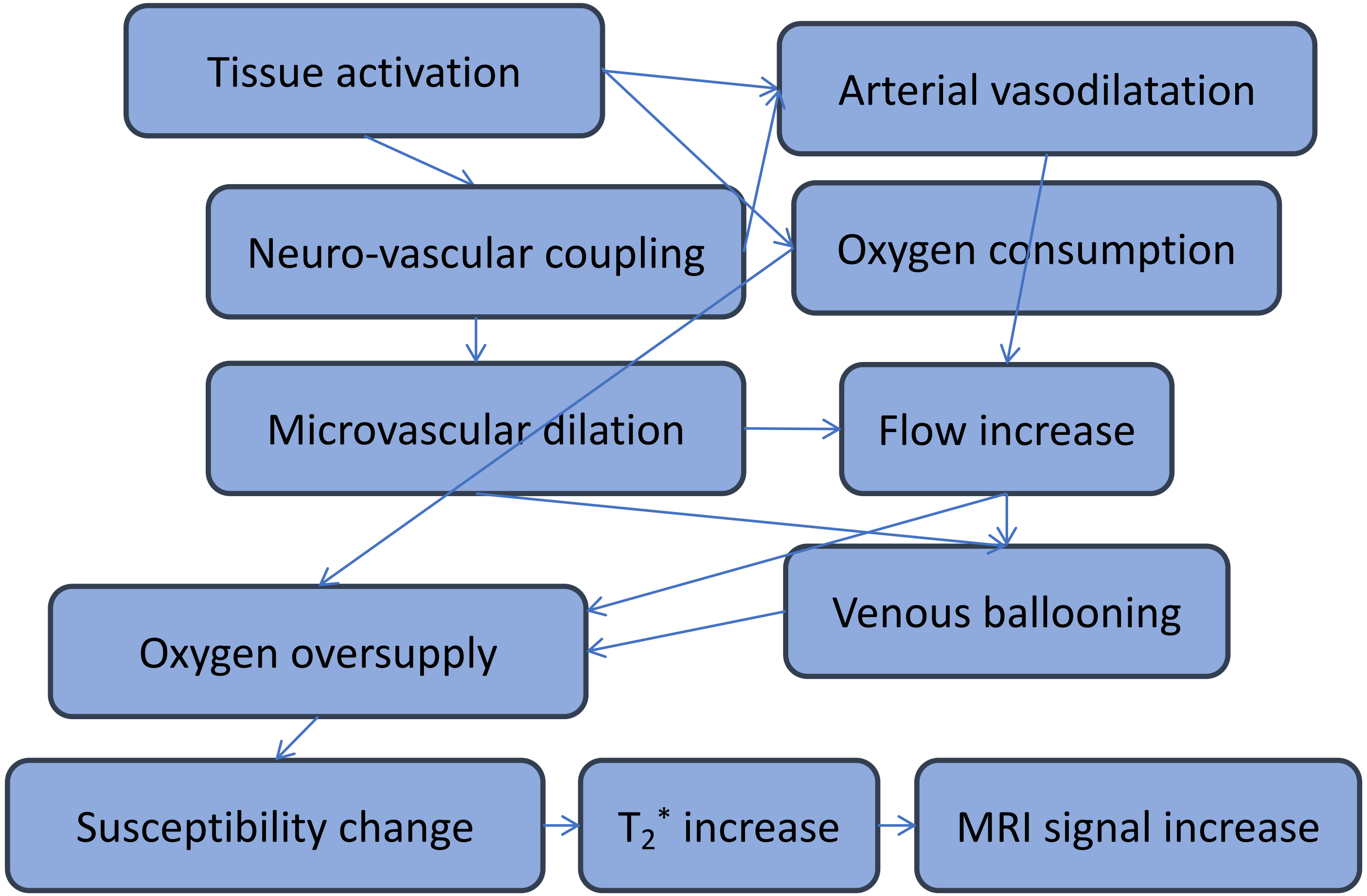
Neurovascular coupling: fMRI is an indirect measure of neural activity



www.neurobureau.org Art competition 2018, fMRI and the BOLD Signal, Jim Stanis, USC, licensed with Creative Commons

Quantifiability of GE-BOLD

BOLD contrast origin is not straight-forward:



Quantifiability of GE-BOLD

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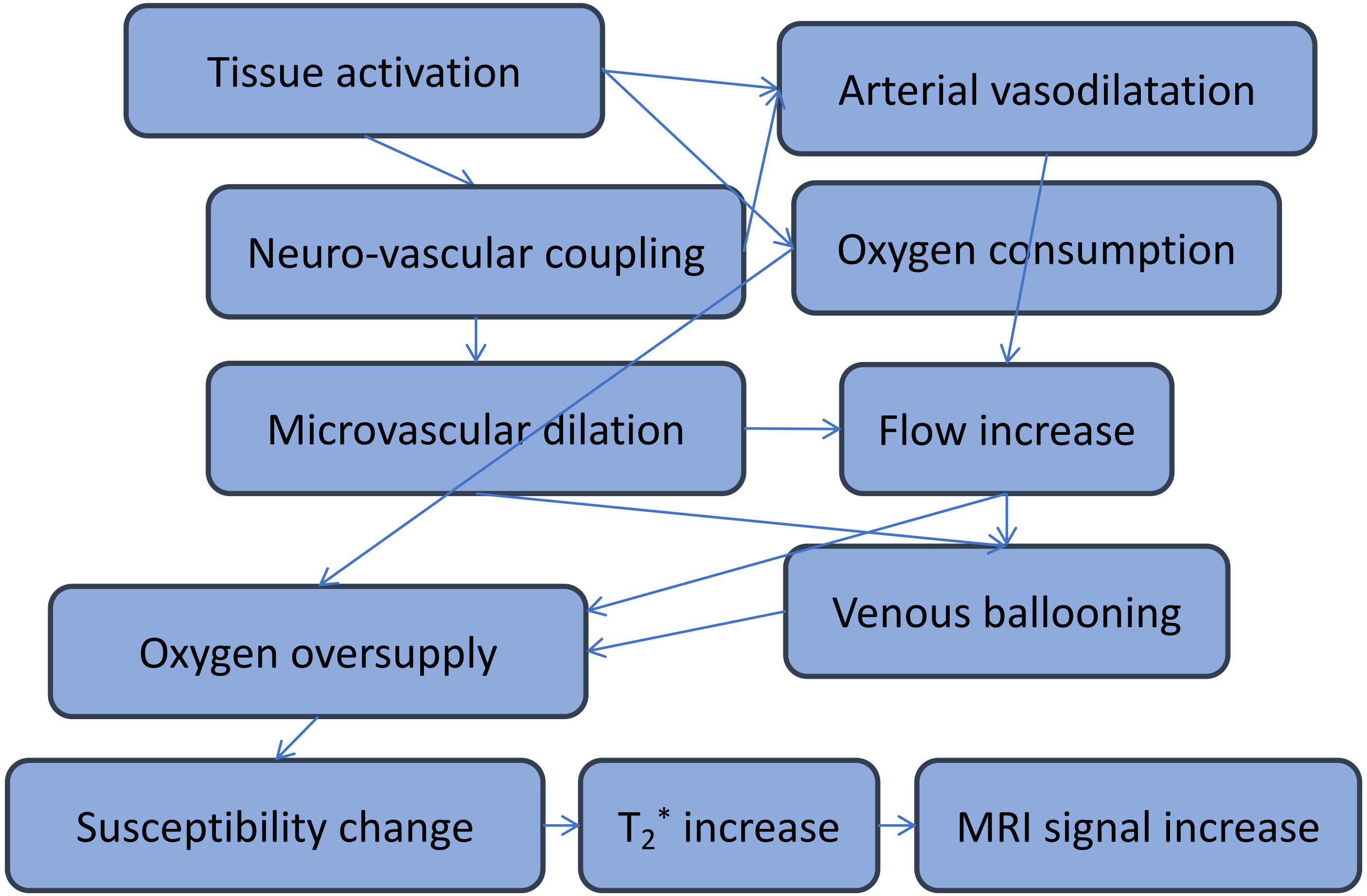
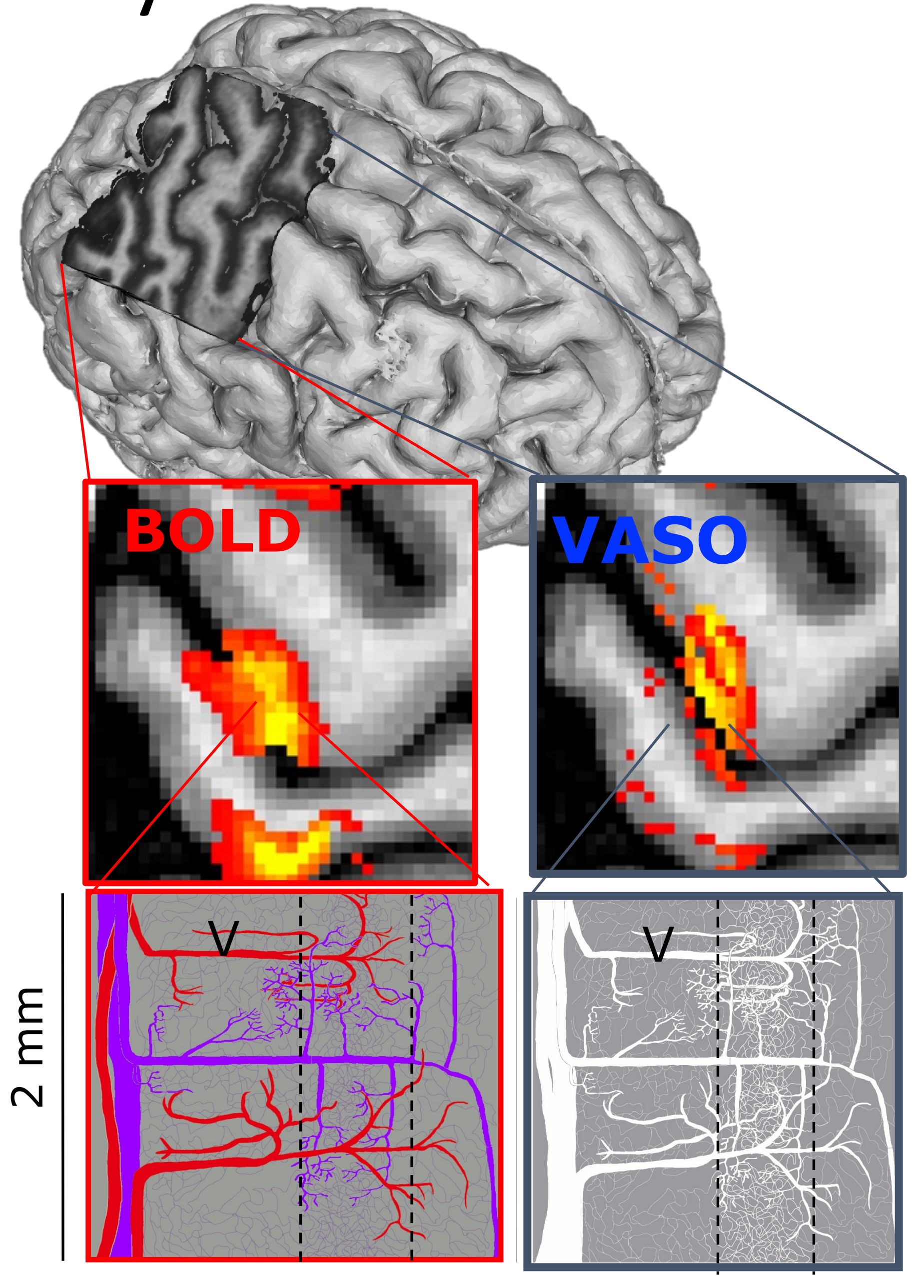


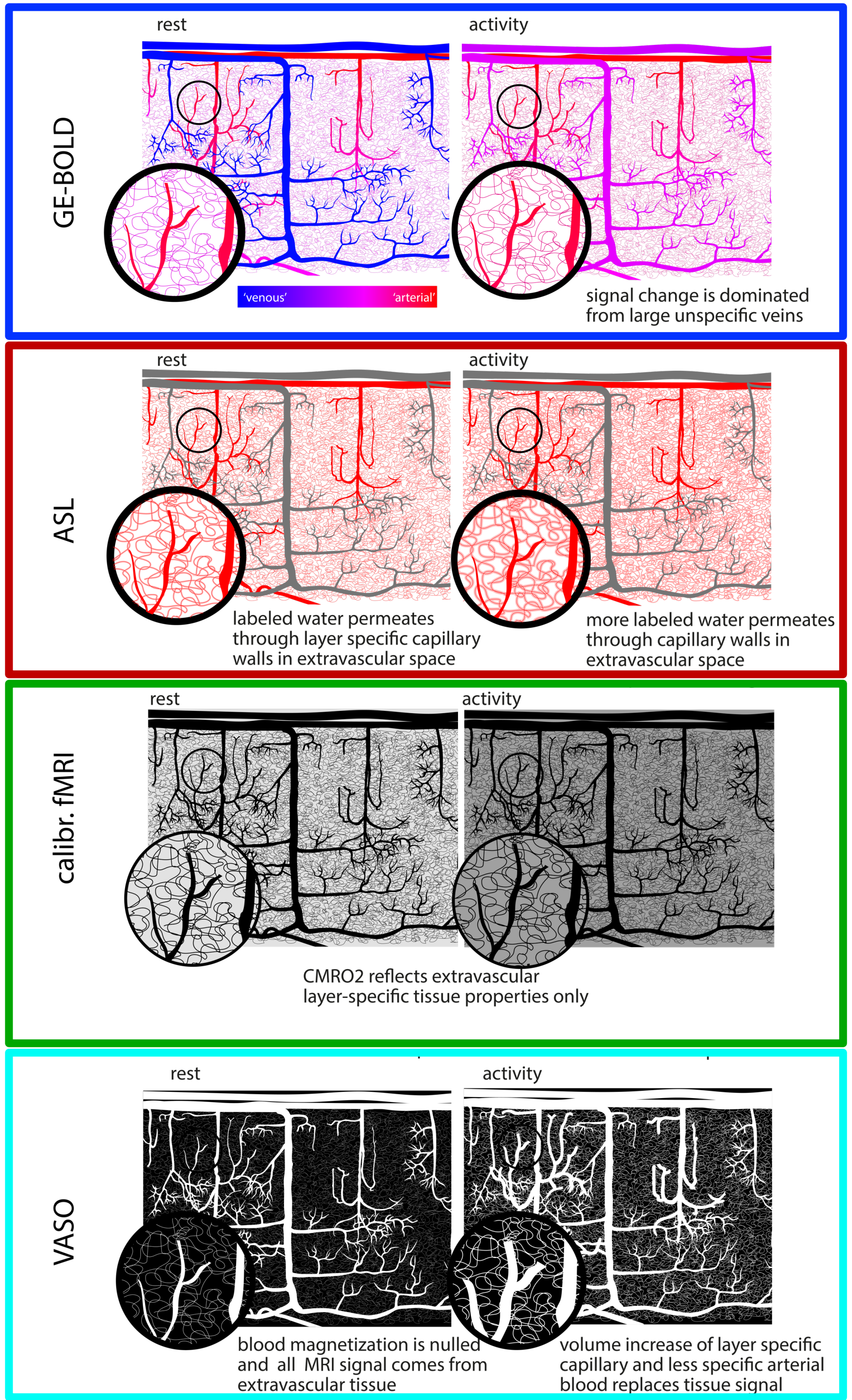
Specificity of GE-BOLD



[Huber et al., NeuroImage, 2015]

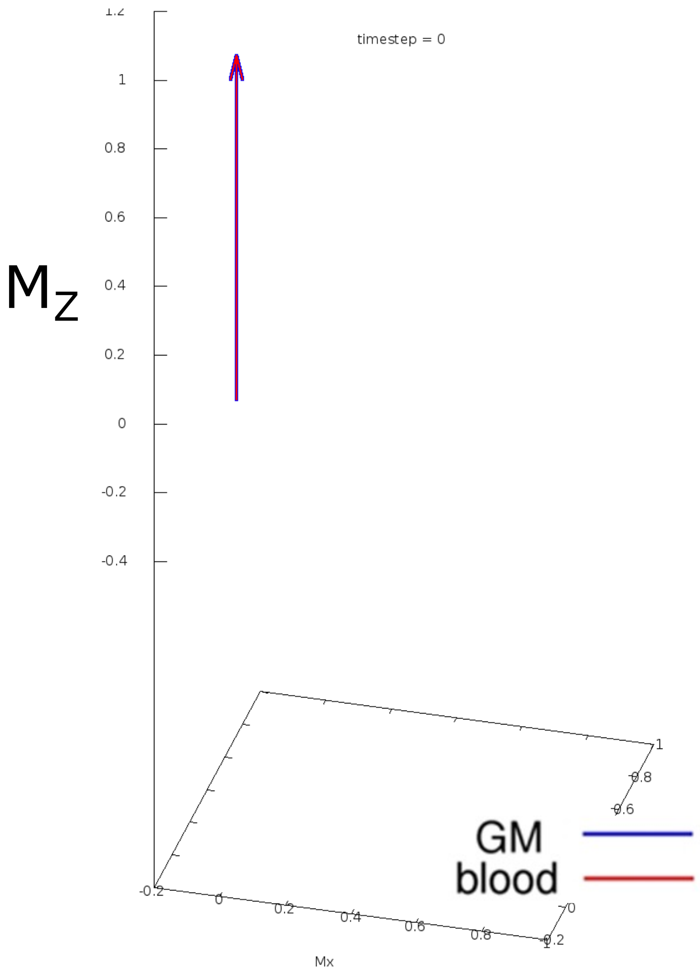
[Lu et al., MRM, 2003]

Popular alternative contrast



CBV contrast in Vascular Space Occupancy (VASO)

VASO is based on blood nulling in an inversion-recovery sequence



[Lu et al., MRM, 2003: Jin and Kim 2008]

CBV contrast in Vascular Space Occupancy (VASO)

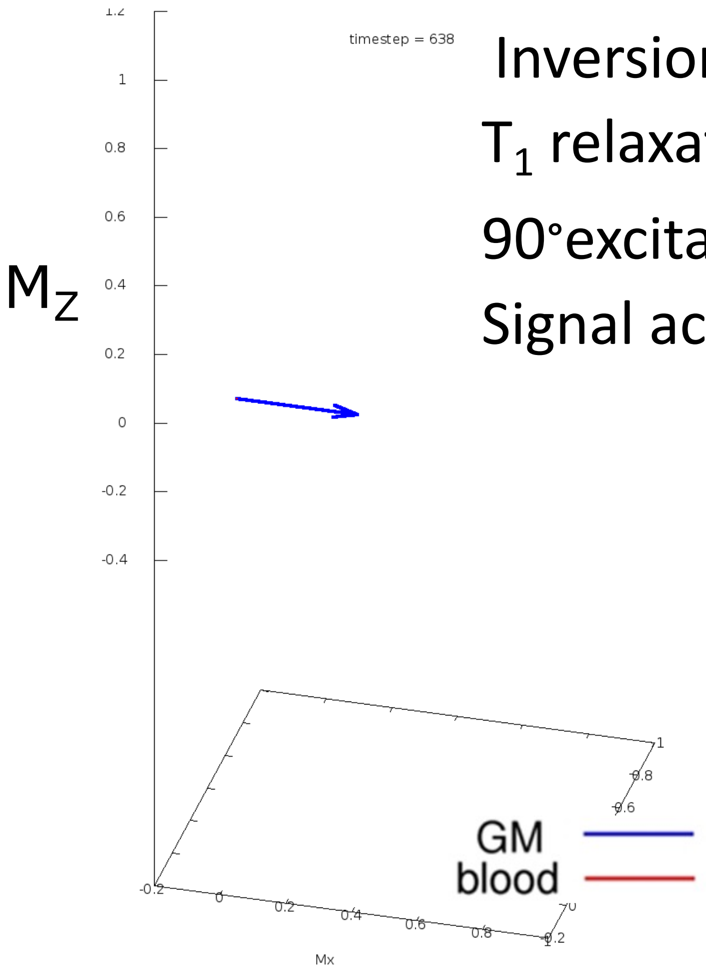
VASO is based on blood nulling in an inversion-recovery sequence

Inversion pulse

T_1 relaxation

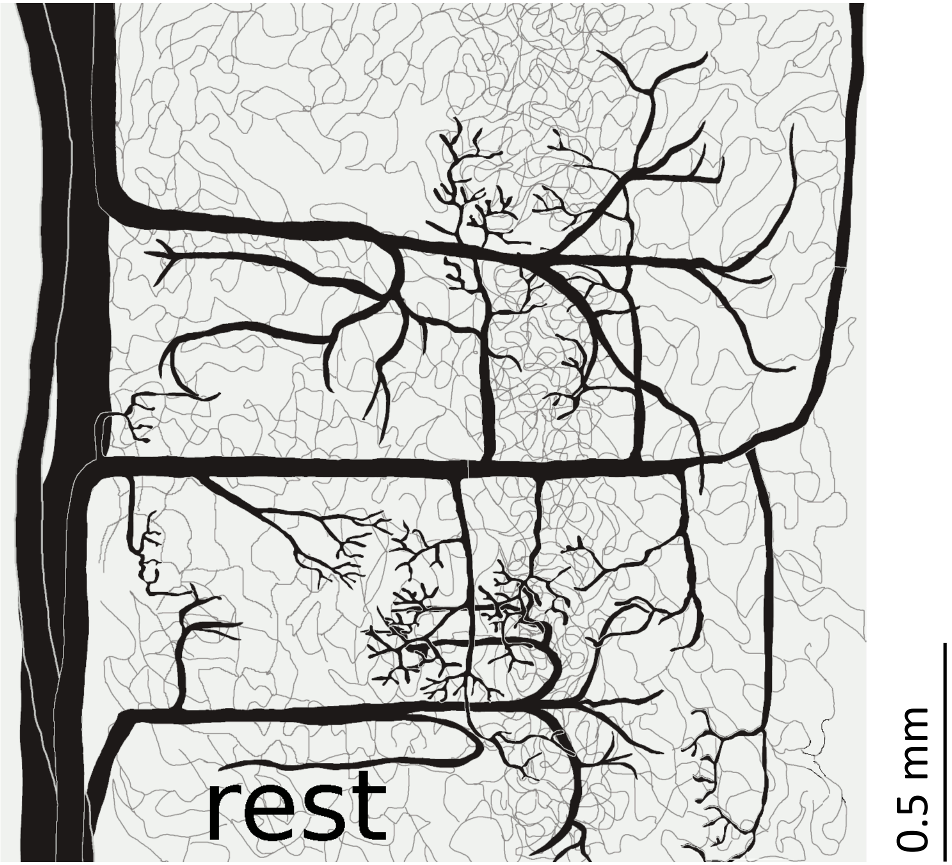
90°excitation pulse

Signal acquisition

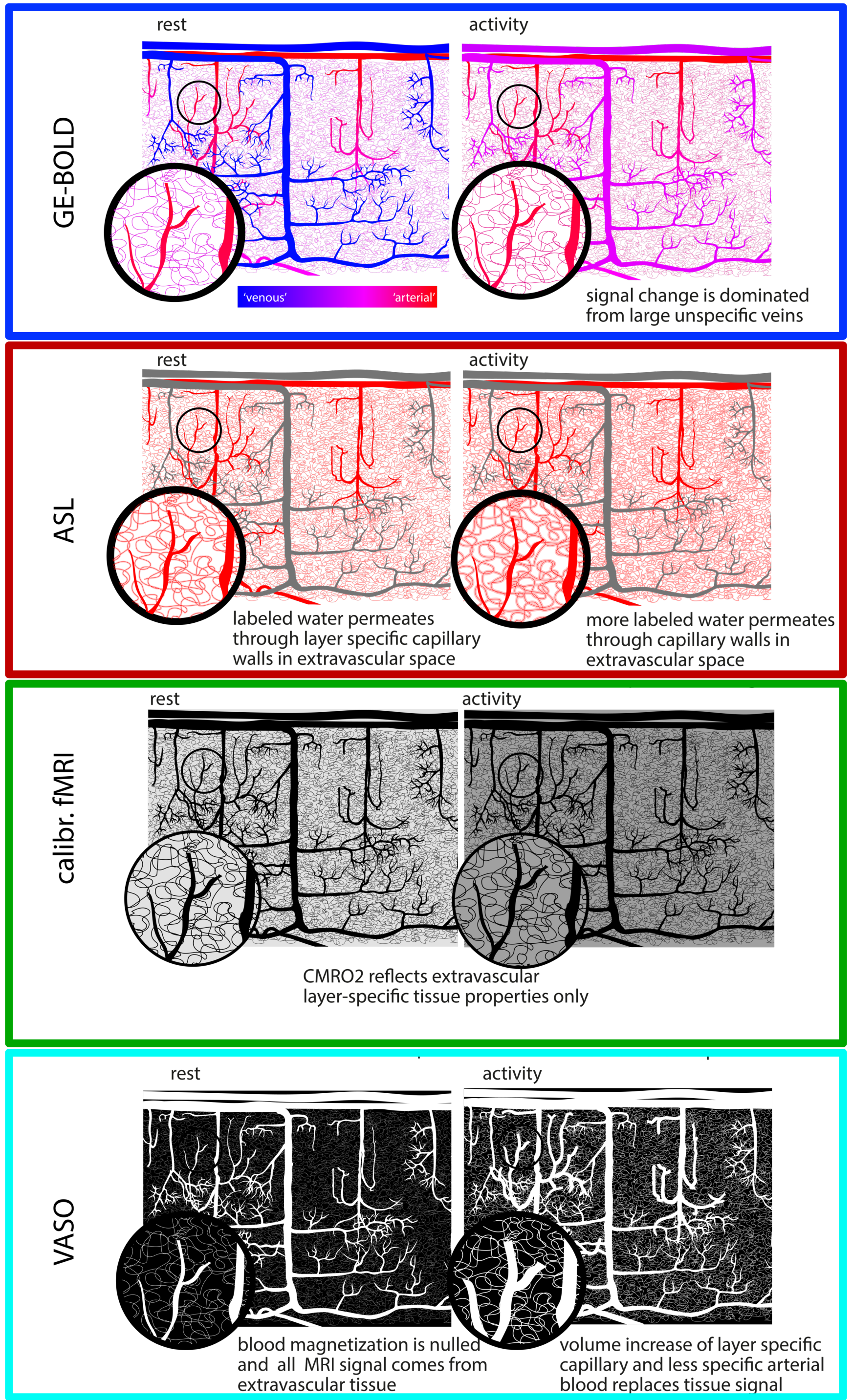


[Lu et al., MRM, 2003: Jin and Kim 2008]

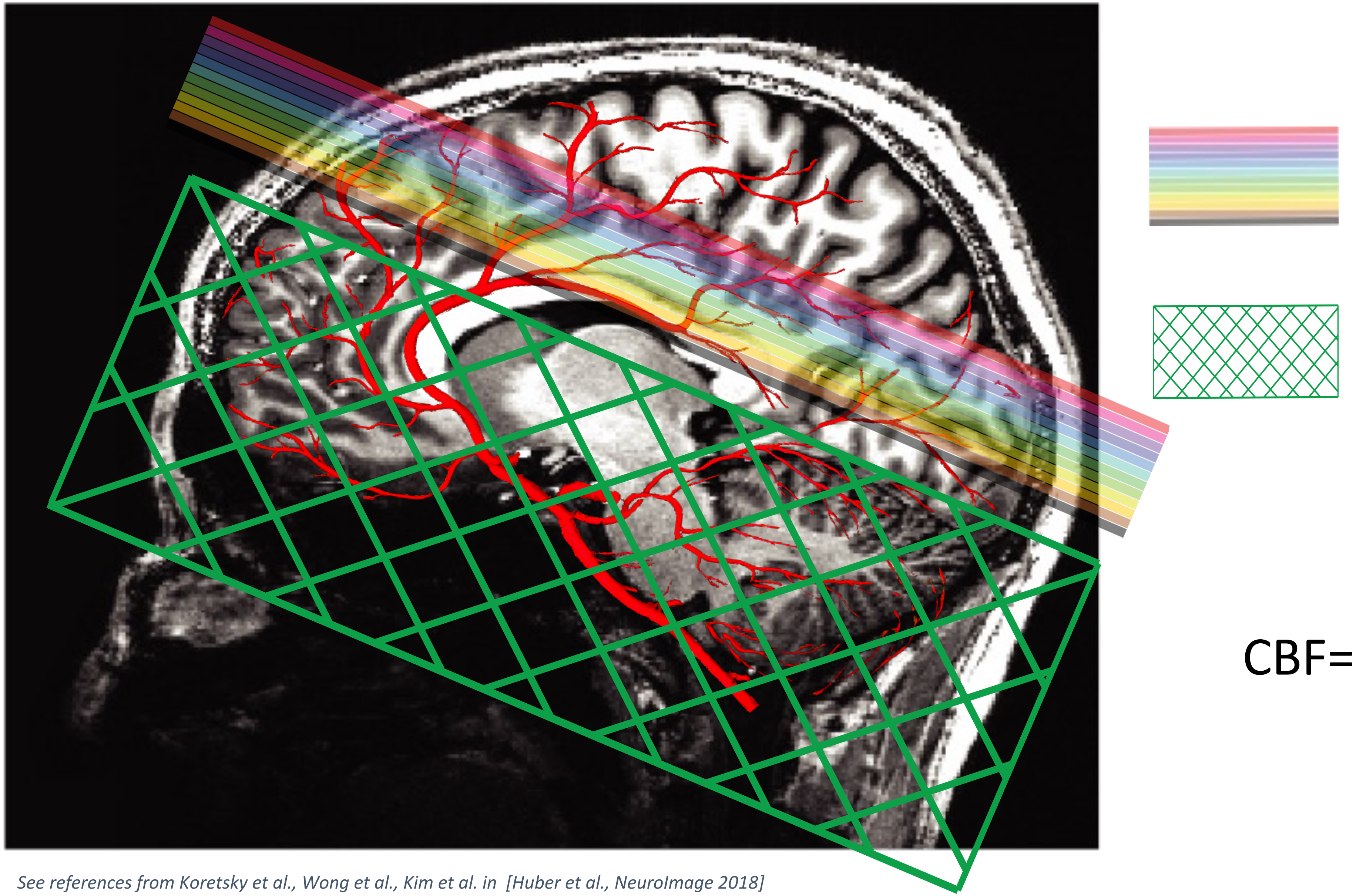
VASO is a negative contrast



Popular alternative contrast



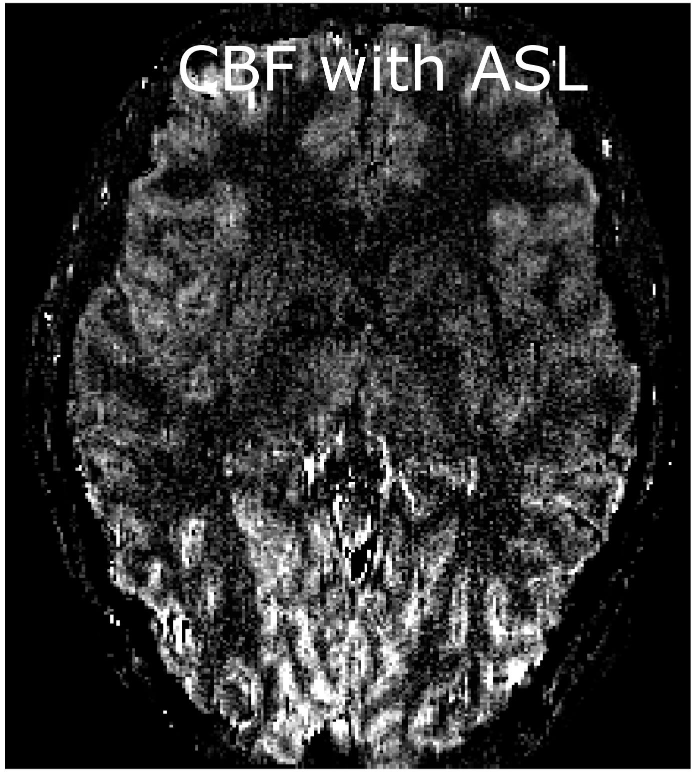
ASL (arterial spin labeling) for CBF measurements (FAIR)

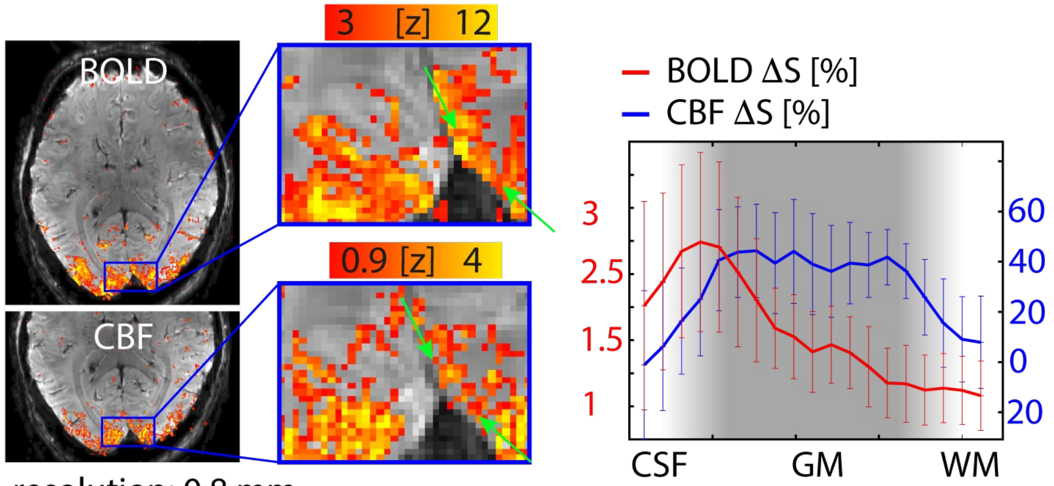


$$CBF = \frac{S_{label} - S_{control}}{S_{equilibrium}}$$

See references from Koretsky et al., Wong et al., Kim et al. in [Huber et al., NeuroImage 2018]

functional CBF with ASL

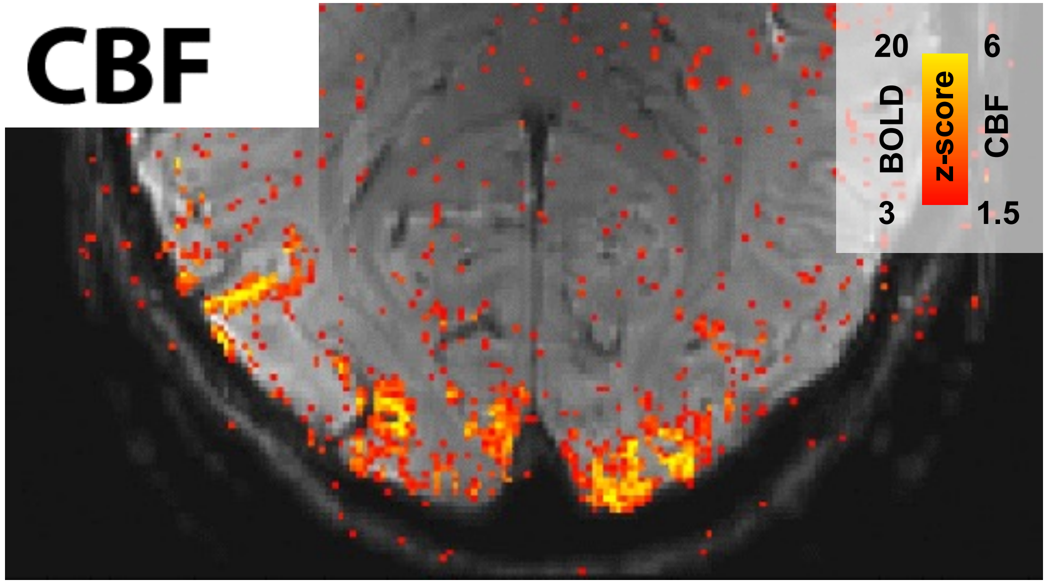




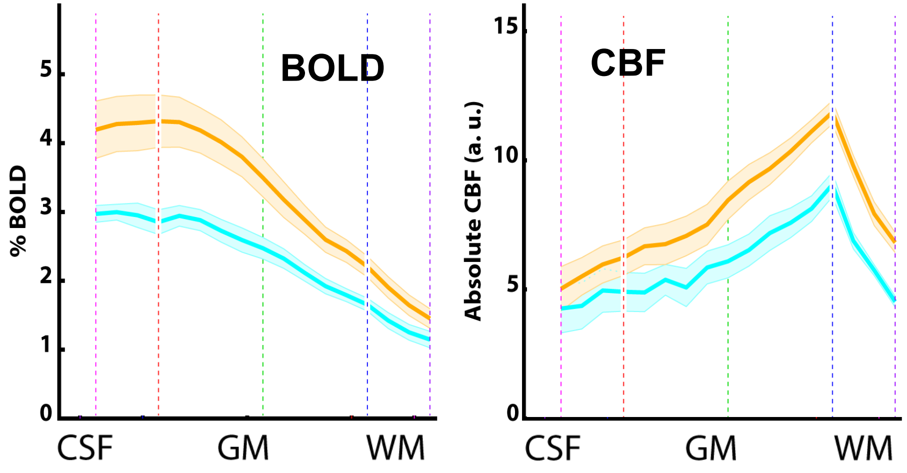
resolution: 0.8 mm

Data from Dimo Ivanov, MBIC, Maastricht

[Huber, Uludağ, Möller, NeuroImage, 2018]

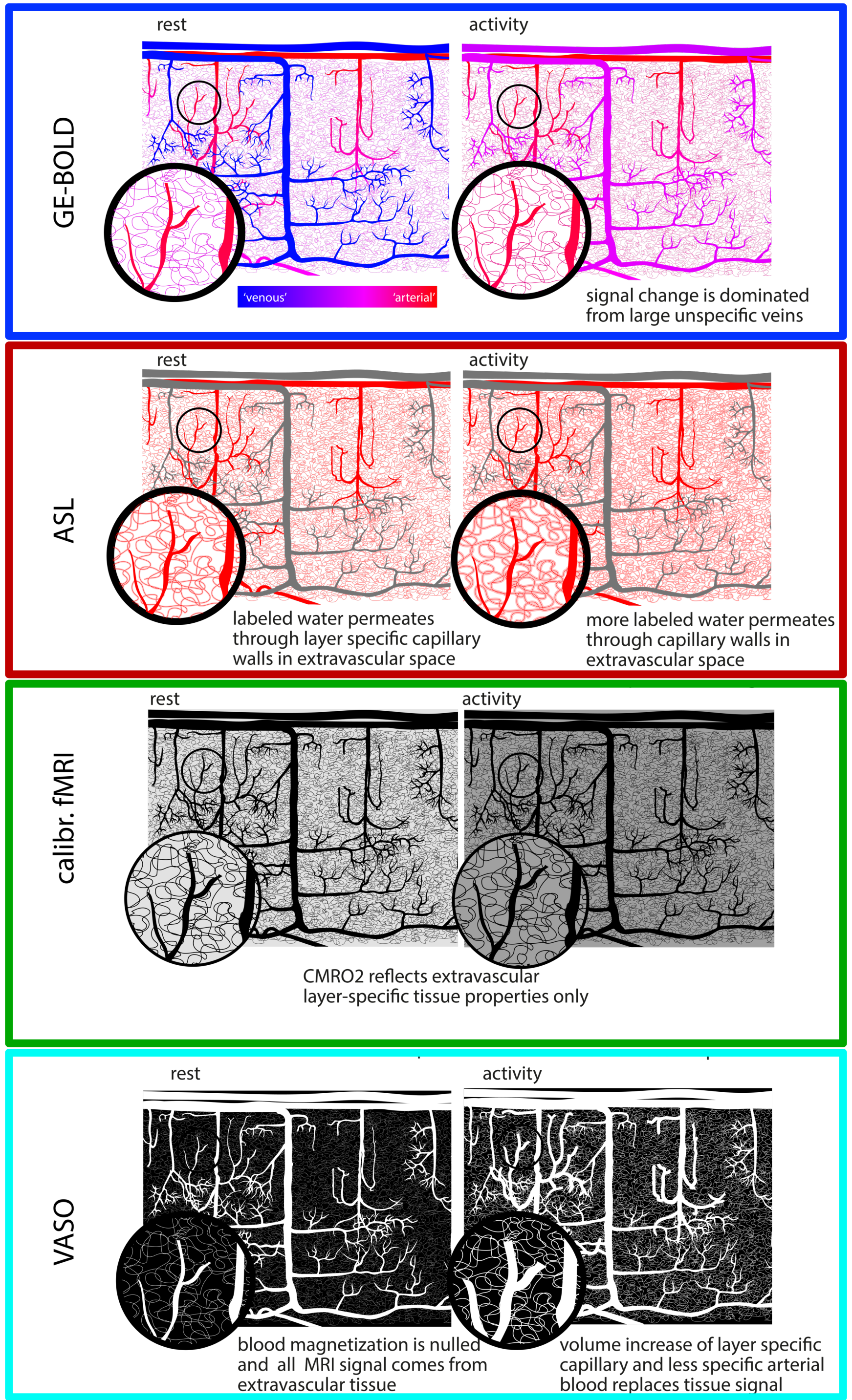


0.9mm iso, FAIR PASL, 7T



adapted from [Kashyap, PLOS One, 2021]

Popular alternative contrast



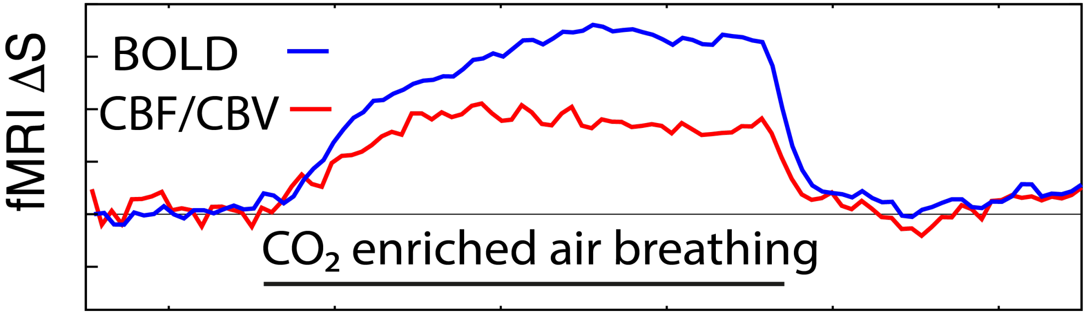
Calibrated BOLD: estimation of $CMRO_2$

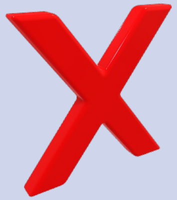
$$\frac{\Delta BOLD}{BOLD} = M\left[1-\left(\frac{CMR_{O_2}}{CMR_{O_2}|_{rest}}\right)^{\beta}\left(\frac{CBV_v}{CBV_v|_{rest}}\right)^{\frac{\alpha_v-\beta}{\alpha_t}}\right]$$

[Hoge, 1999], [Davis, 1998]

hypercapnia

calibration experiment



	Vessel dilation	Oxygen consumption
gas calibration		

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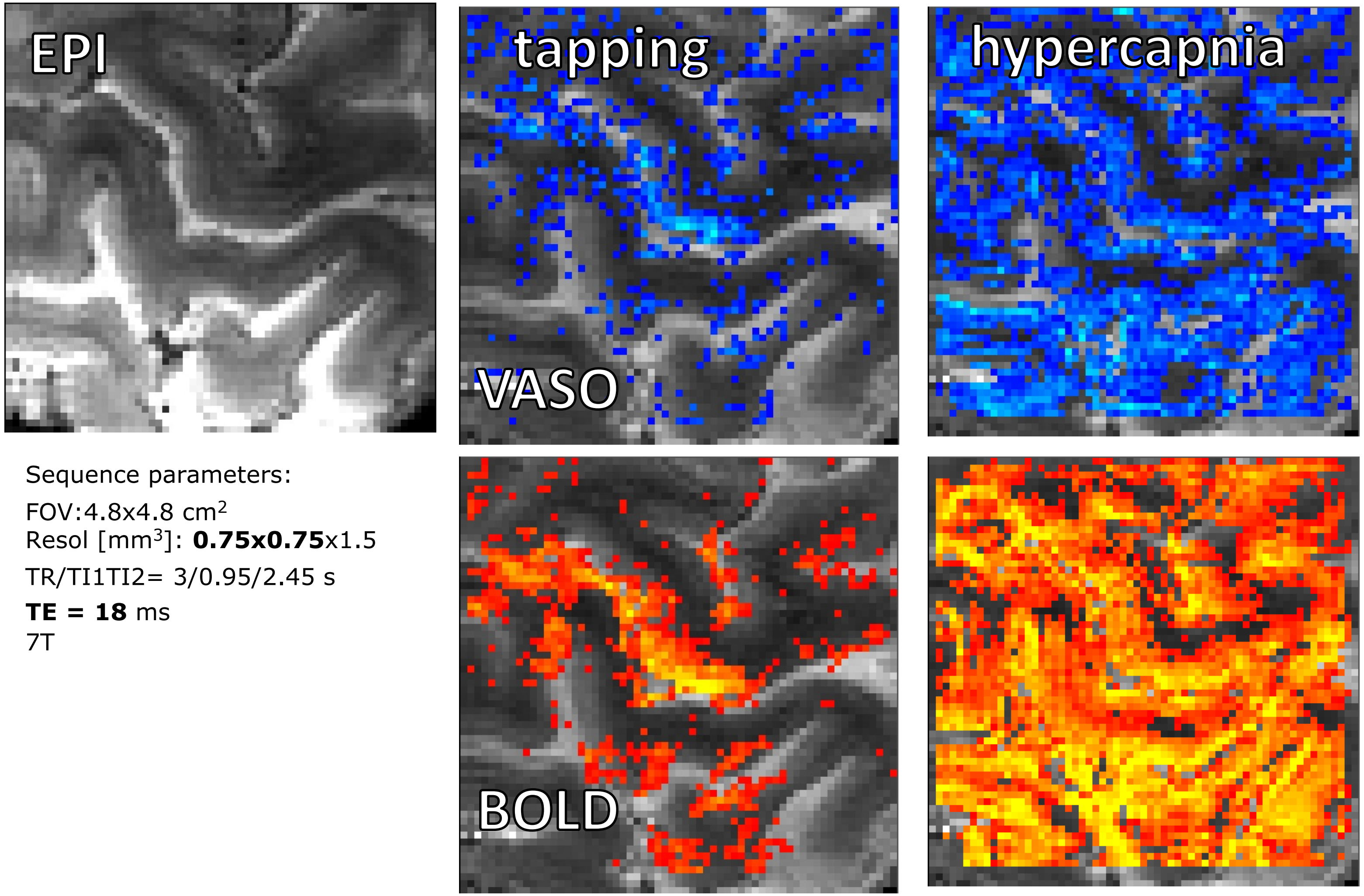


Sequence parameters:

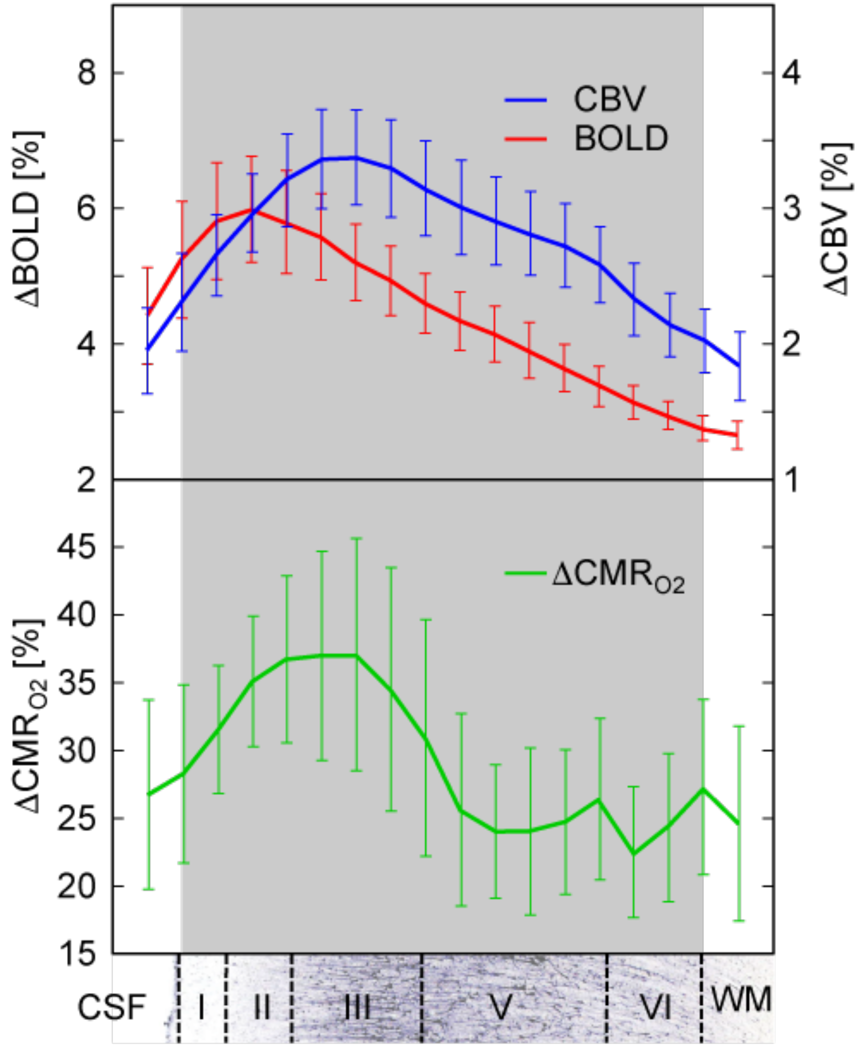
FOV:4.8x4.8 cm^2

Resol [mm^3]: **0.75x0.75**x1.5

TR/TI1TI2= 3/0.95/2.45 s

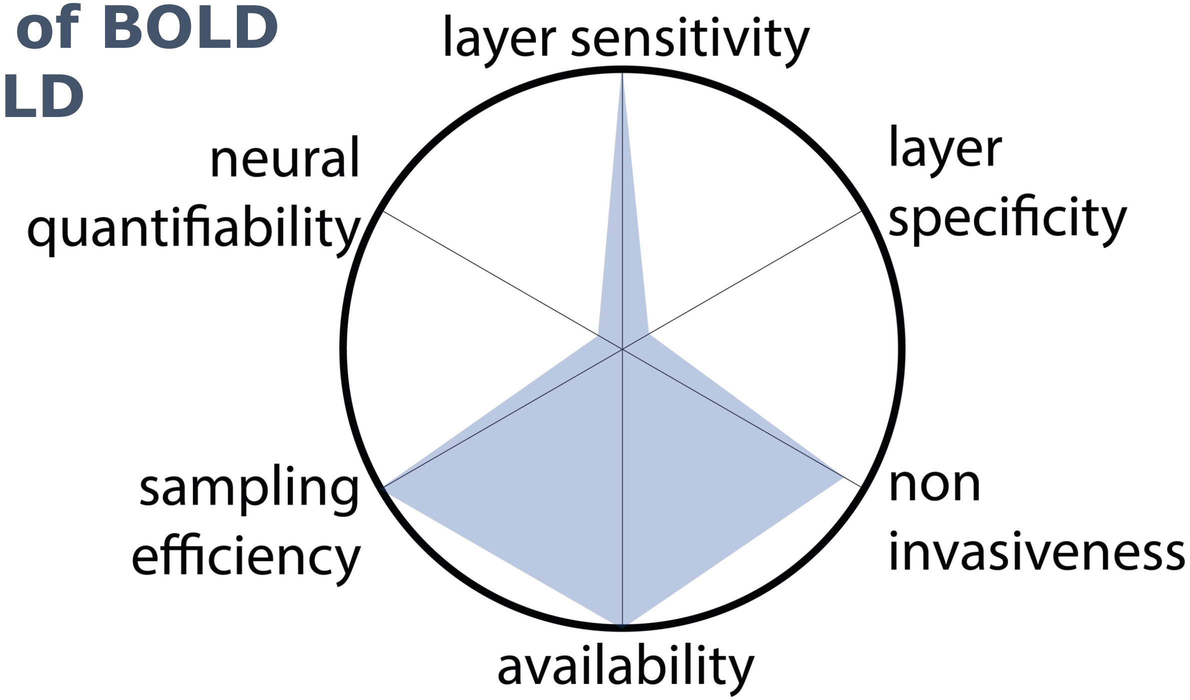
TE = 18 ms

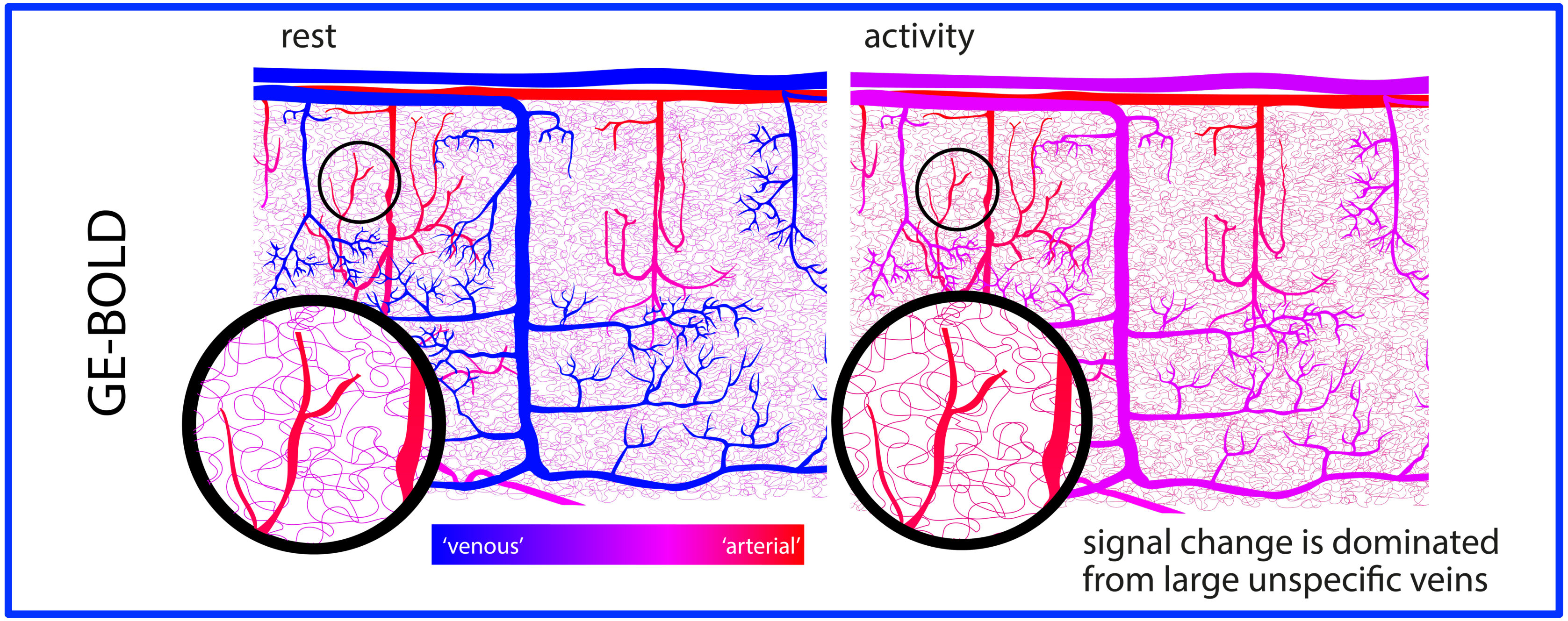
7T

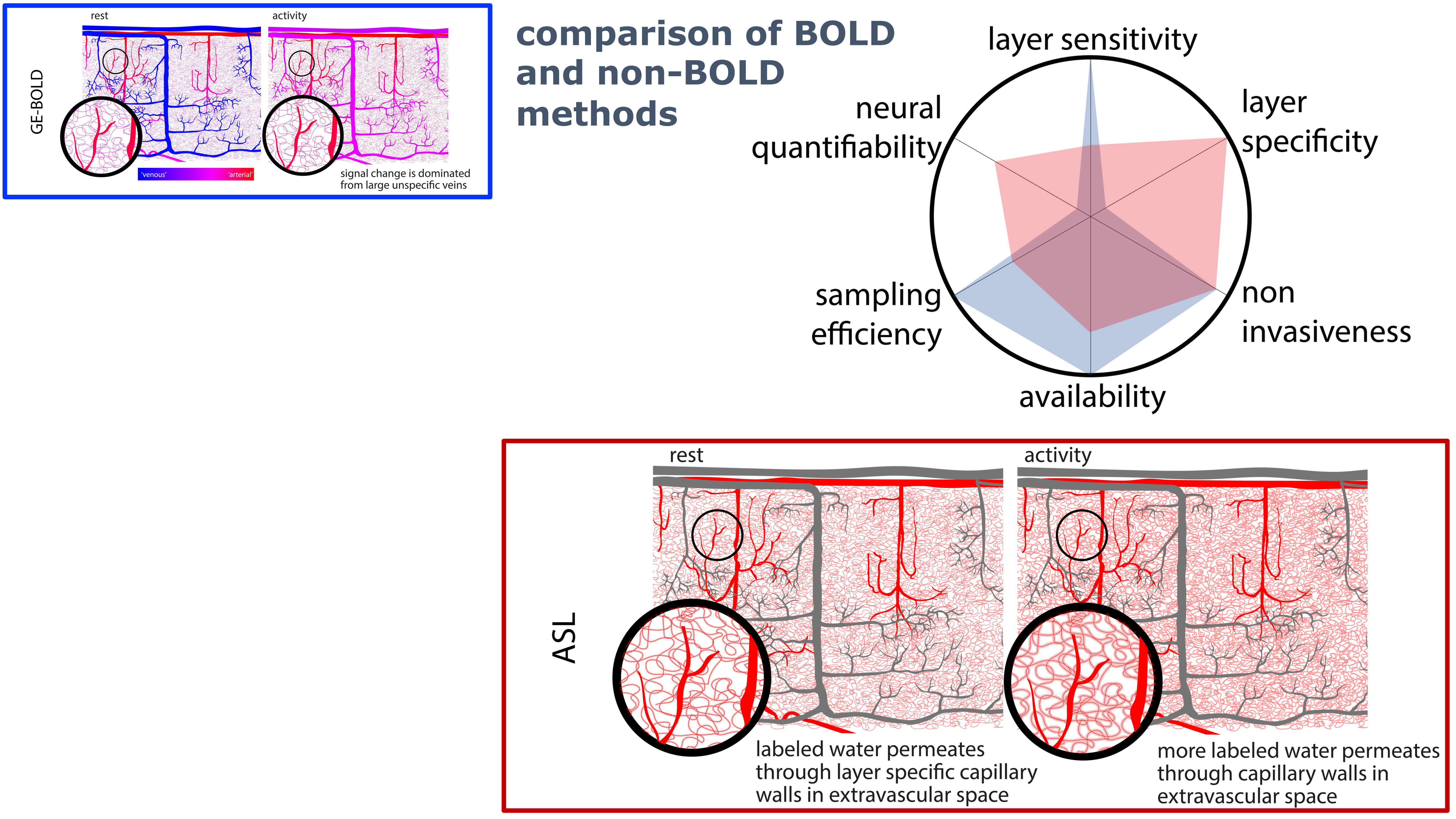


[Guidi, NeuroImage, 2019]

comparison of BOLD and non-BOLD methods

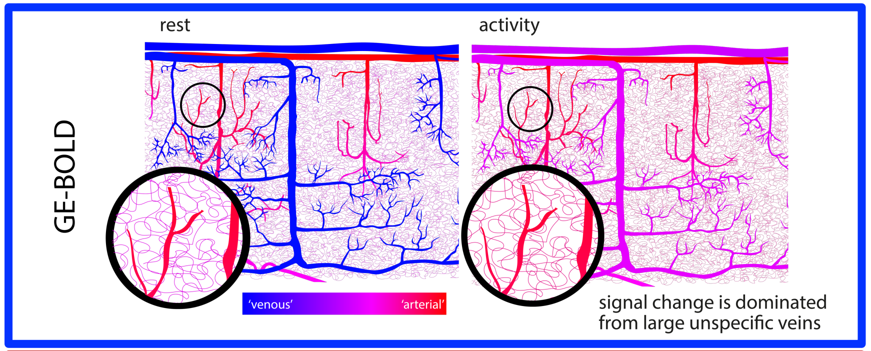


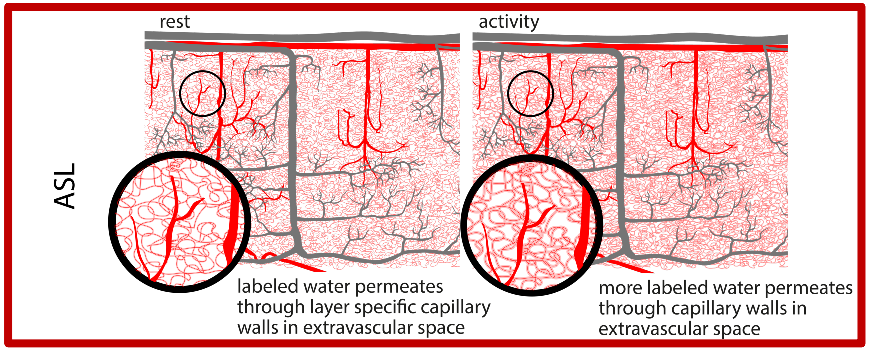


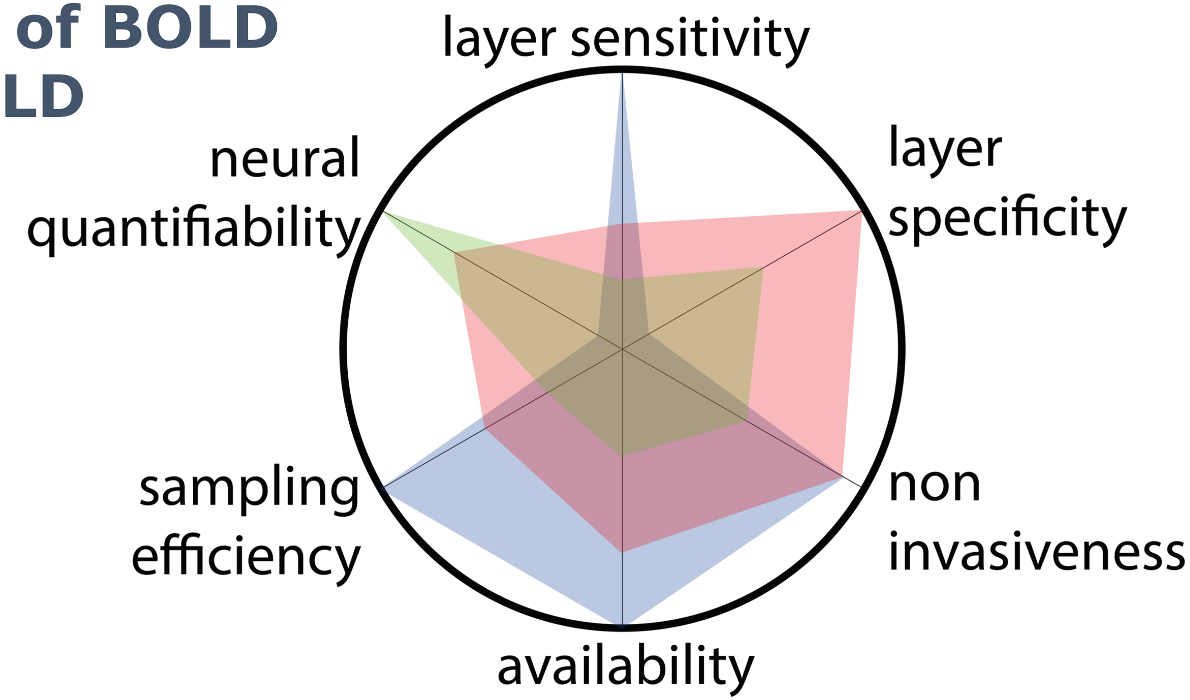


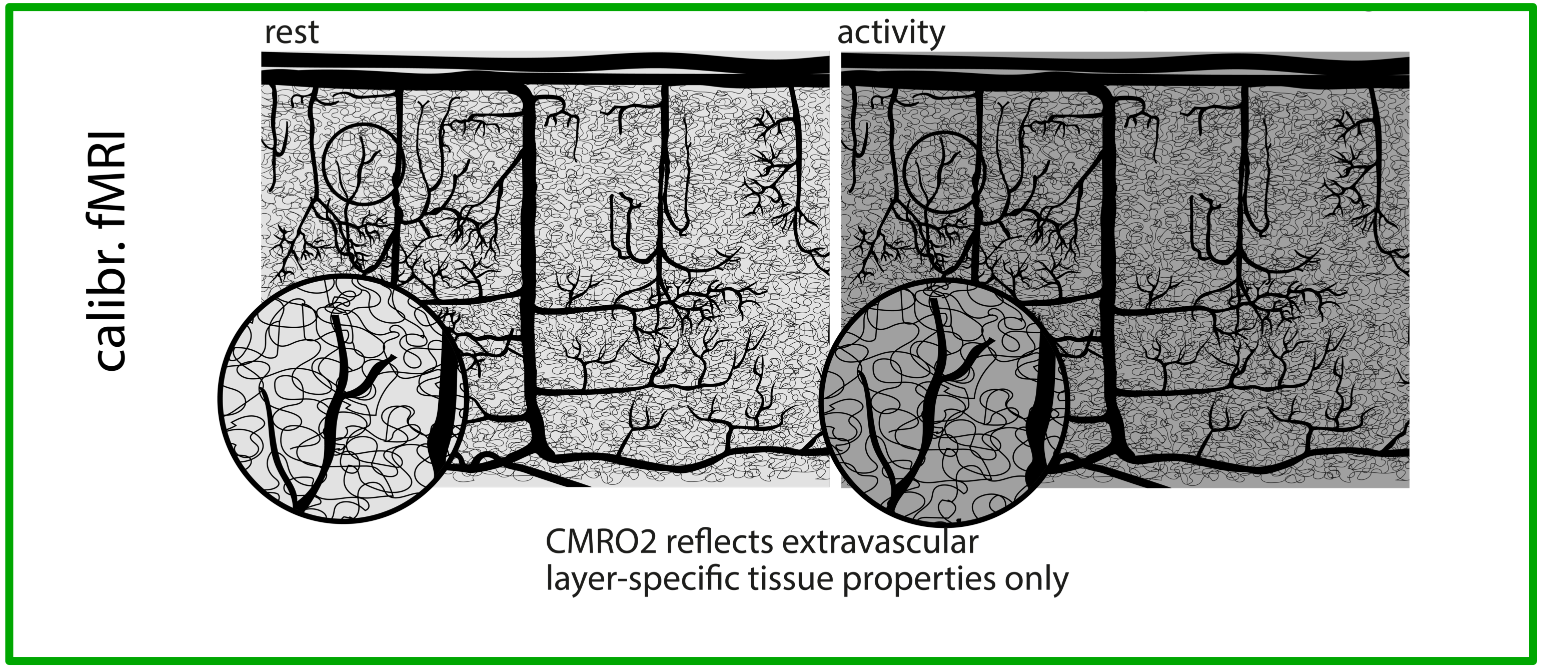
comparison of BOLD and non-BOLD methods
GE-BOLD
rest
activity
'venous'
'arterial'
signal change is dominated from large unspecific veins
layer sensitivity
layer specificity
non invasiveness
availability
sampling efficiency
neural quantifiability
ASL
rest
activity
labeled water permeates through layer specific capillary walls in extravascular space
more labeled water permeates through capillary walls in extravascular space

comparison of BOLD and non-BOLD methods

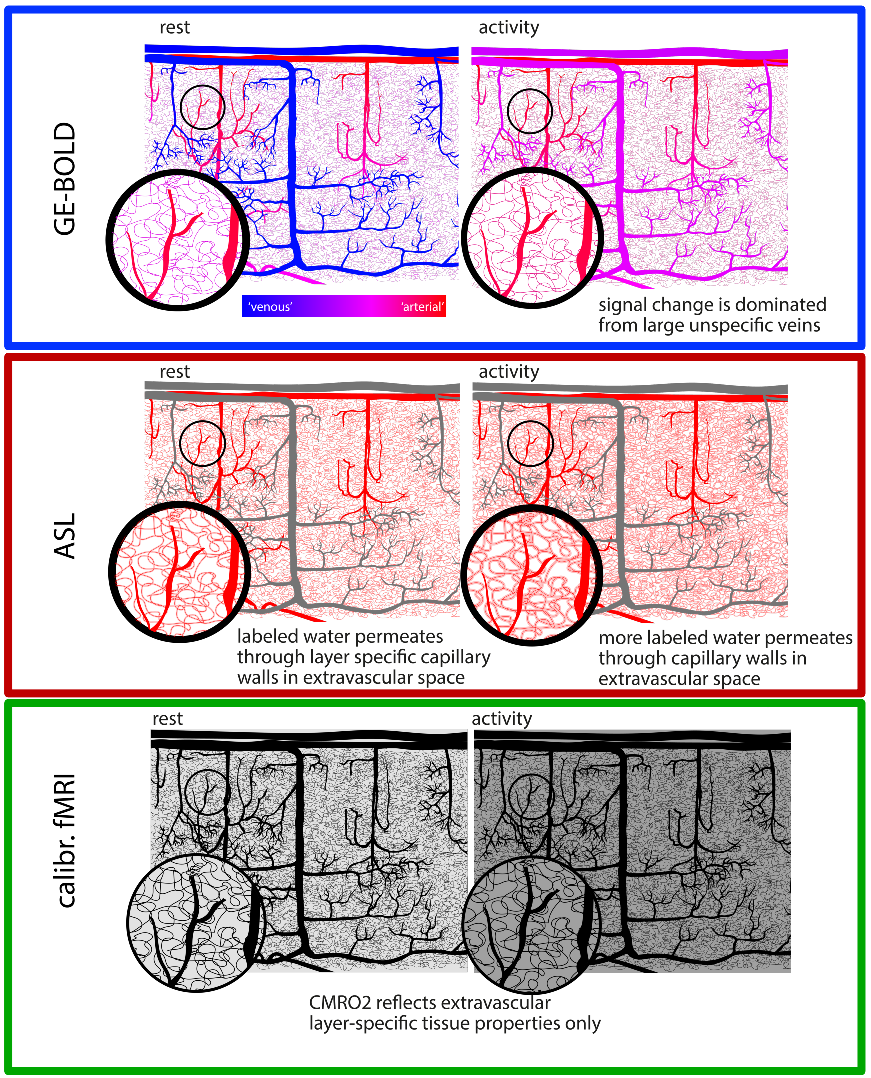


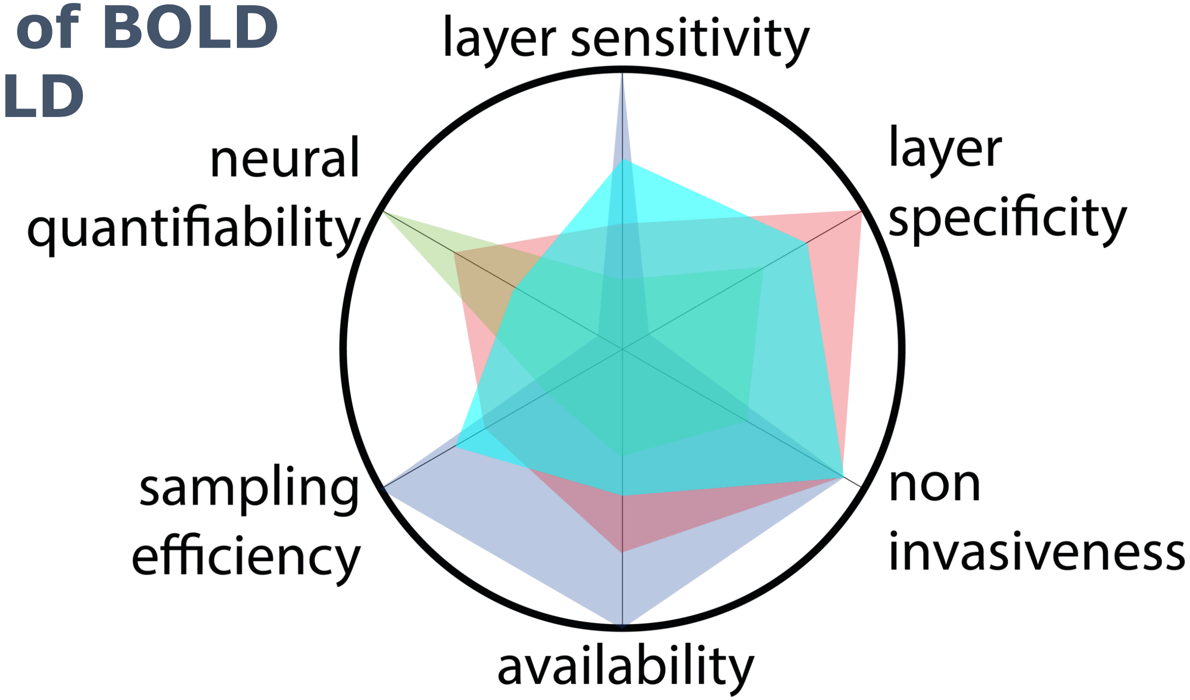


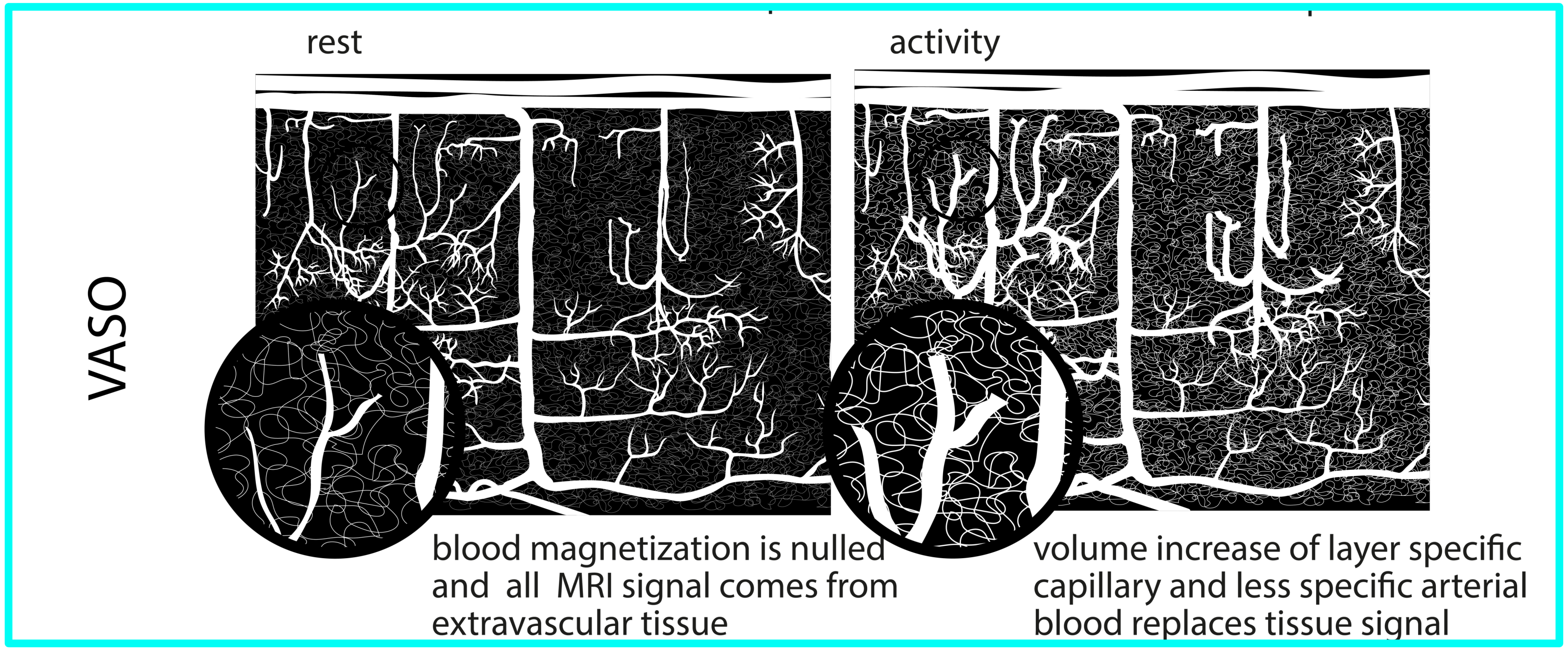


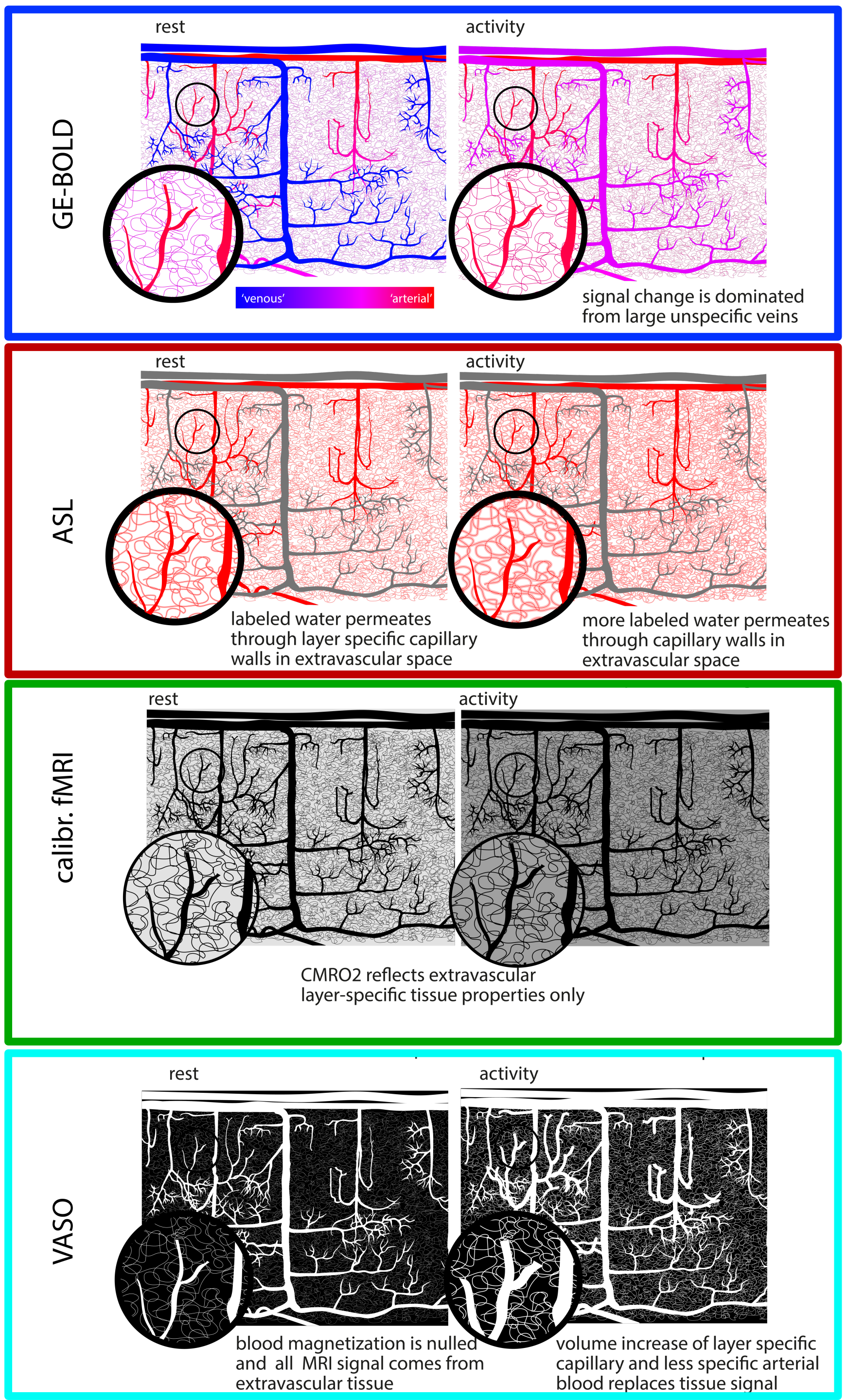


comparison of BOLD and non-BOLD methods

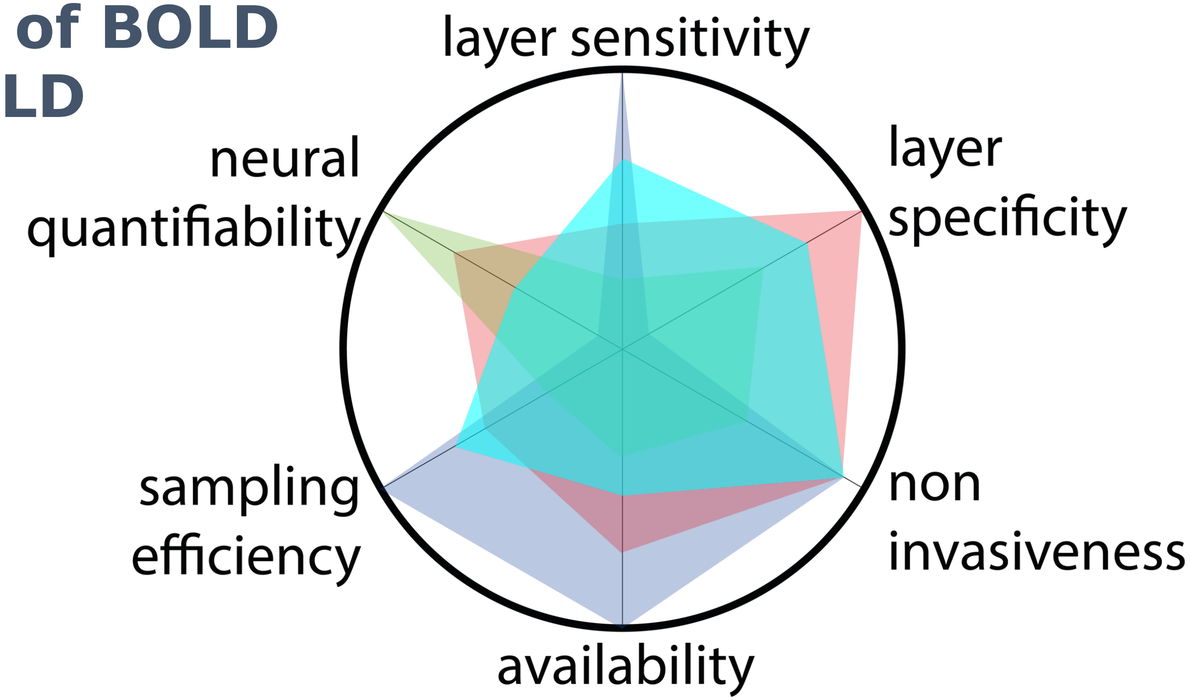








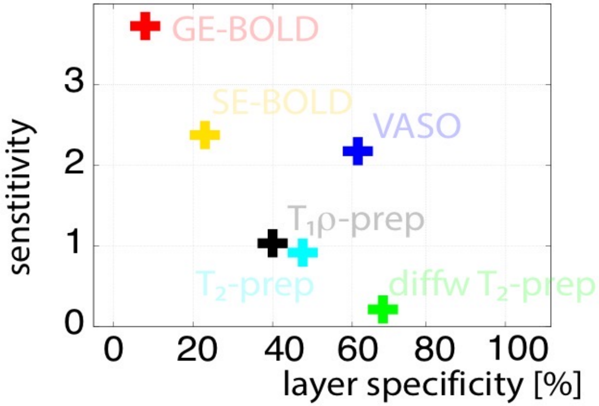
comparison of BOLD and non-BOLD methods

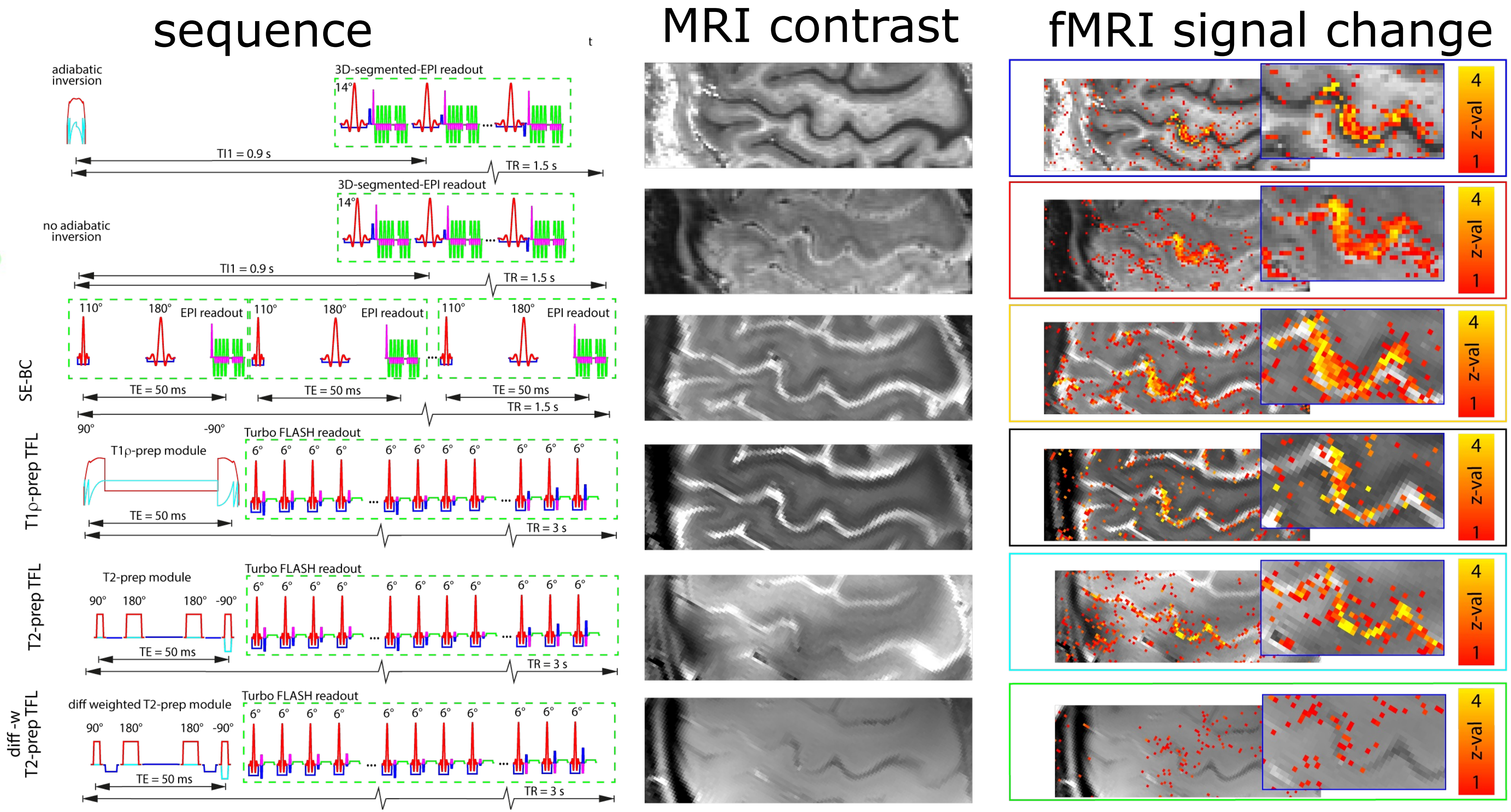


Summary:

- Non-BOLD layer-fMRI is noisier (reducing unwanted signal)
- Non-BOLD layer-fMRI is more specific
- Non-BOLD layer-fMRI is more quantitative

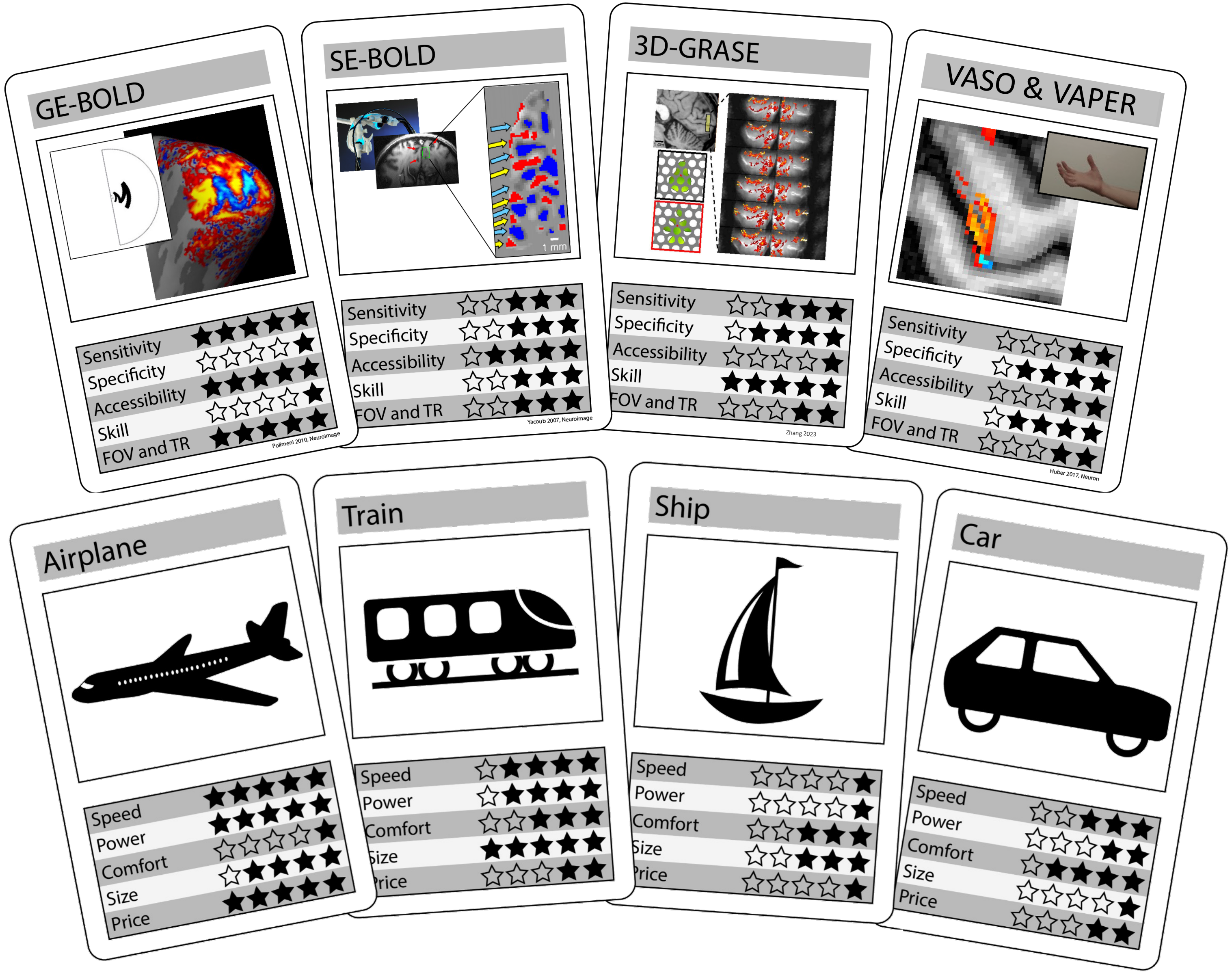
What about spin echo?

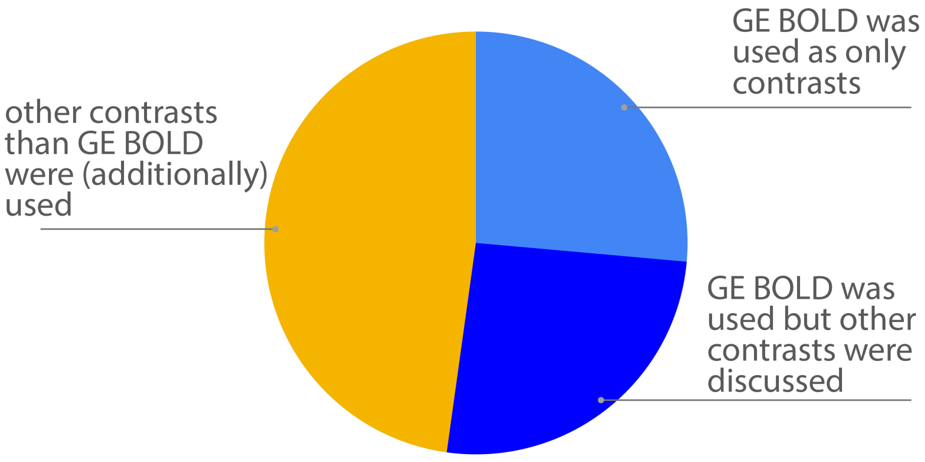




[Huber et al., Neuron, 2017]

GE-BOLD vs. other sequences

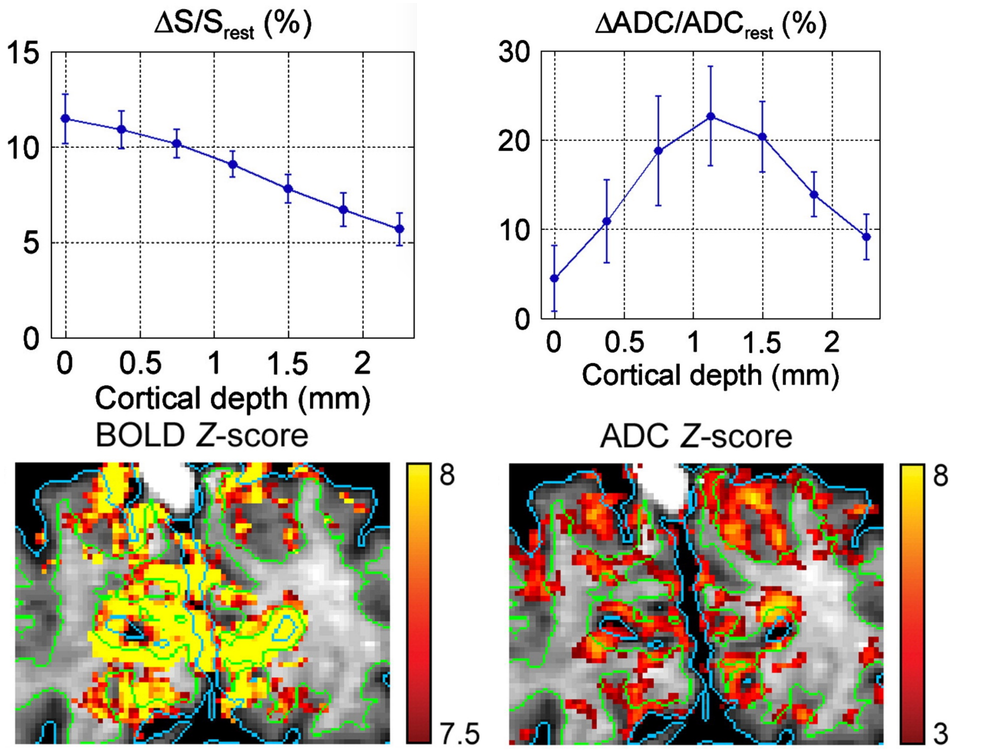




layerfmri.com

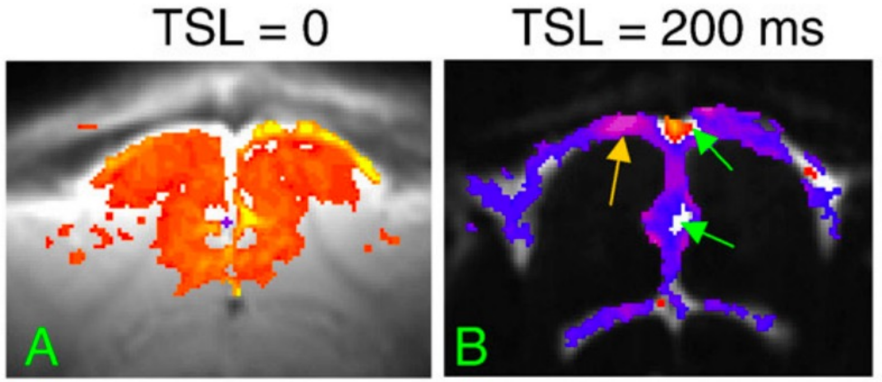
Other contrasts

Allen Song et al. functional diffusion

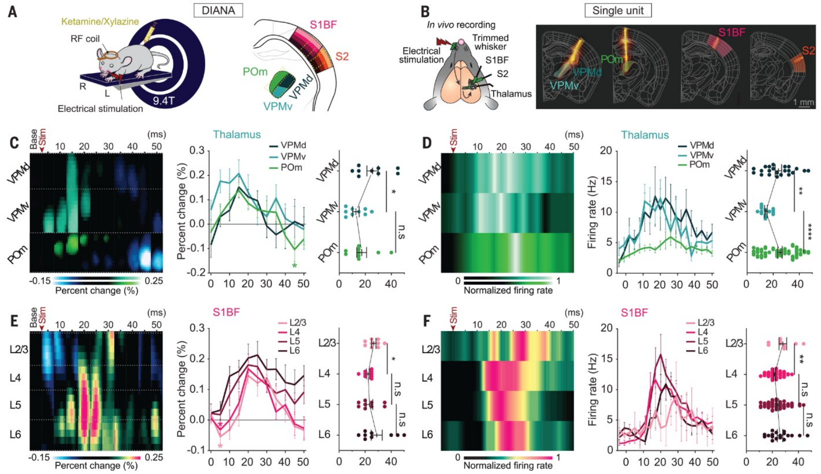


[Truong and Song 2009]

SG Kim et al.: functional $T_{1\rho}$ captures CSF volume change

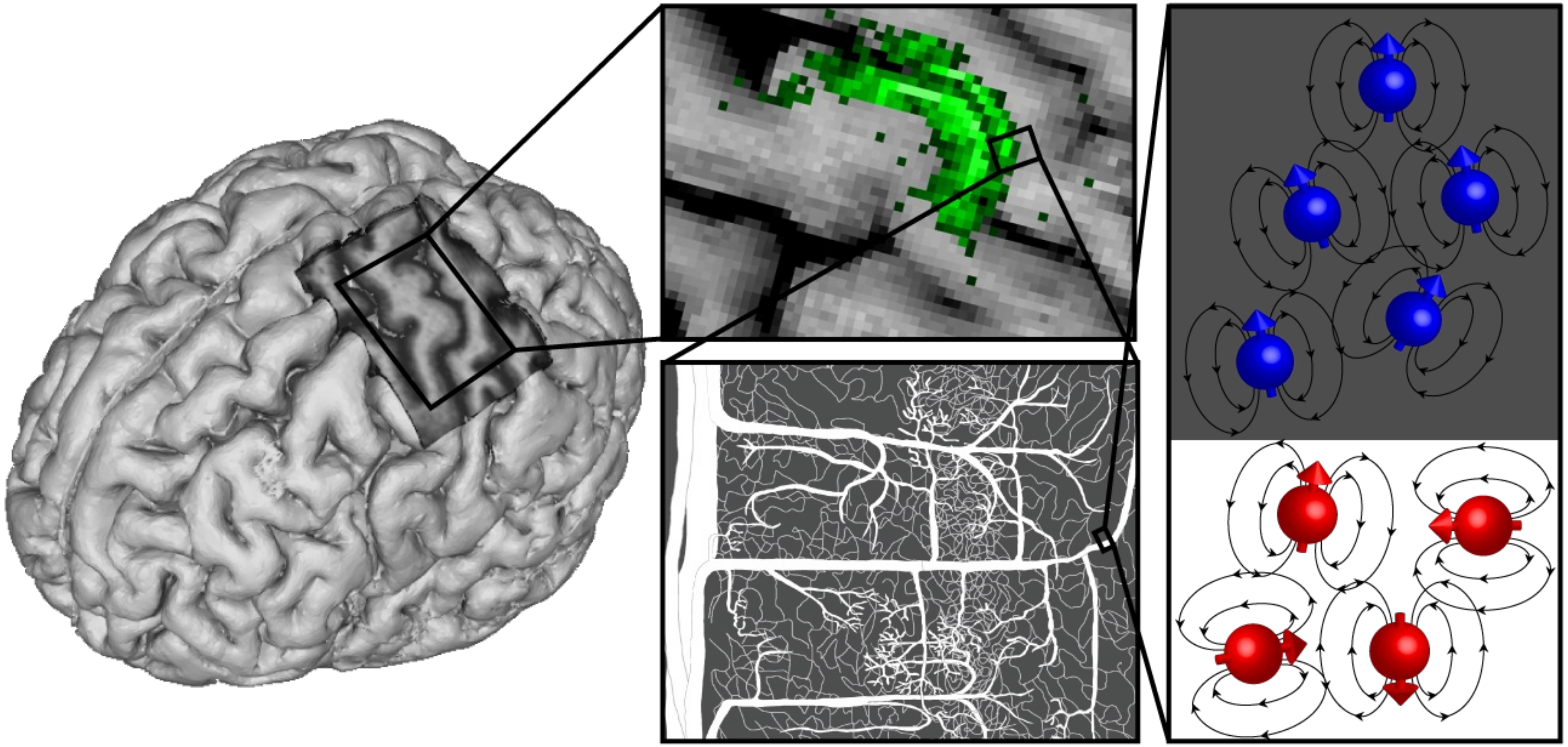


[Jin and Kim 2010]



[Toi et al. 2022]

Functional contrast and **processing strategies** at high field and high resolution



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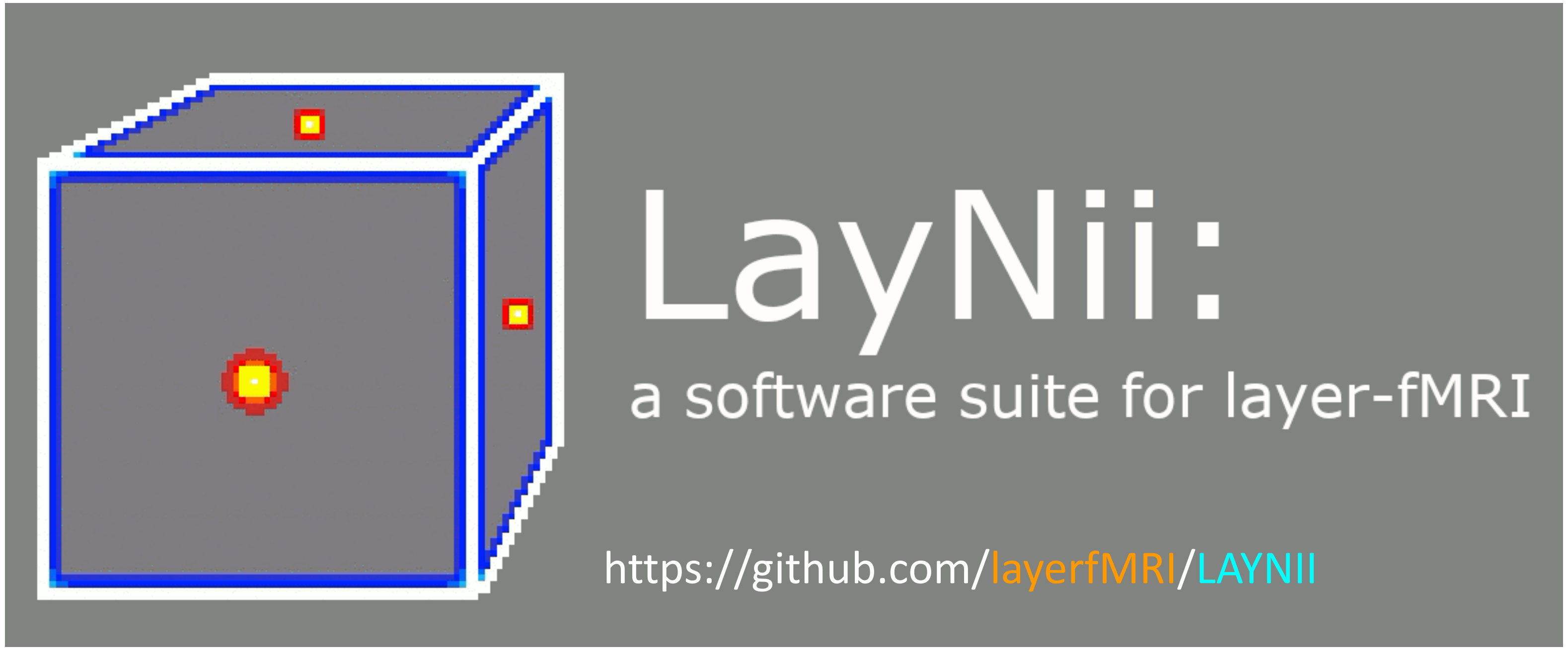
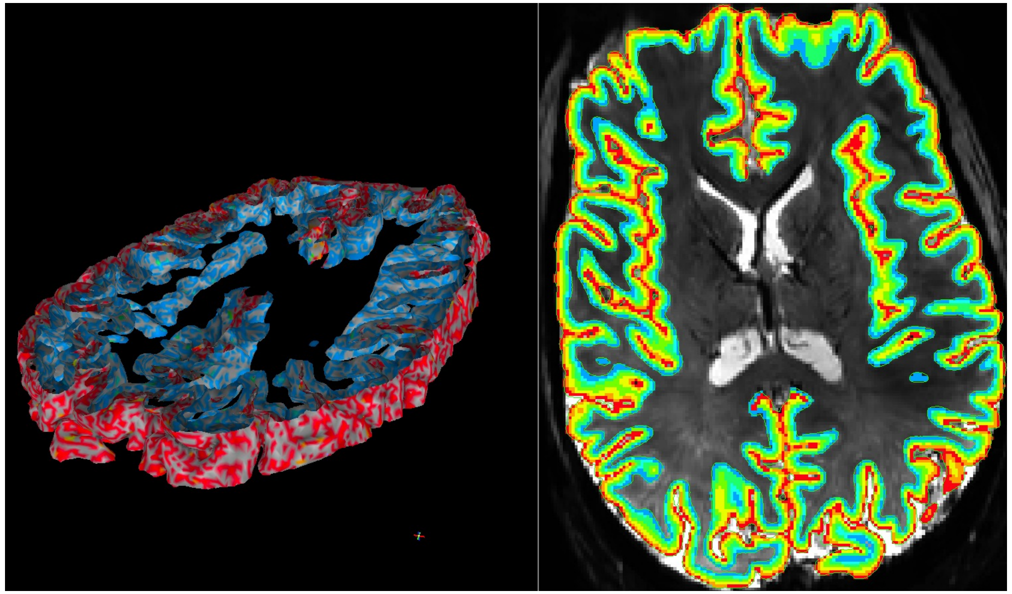


Faruk Gulban

Huber R. Poser BA ,Bandettini PA, Arora K, Wagstyl K, Cho S, Goense J, Nothnagel N, Morgan AT, Van Den Hurk J, Reynold RC, Glen, DR, Goebel RW, Gulban, Omer **Faruk**, LAYNII: A software suite for layer-fMRI. Neuroimage. 2021.

Why LAYNII

Small FOV complicates surface-based layerification



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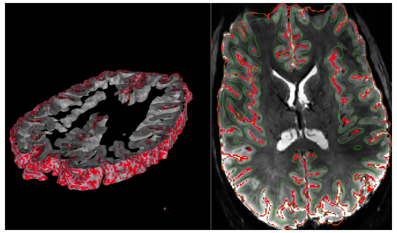

beer-wine dilemma

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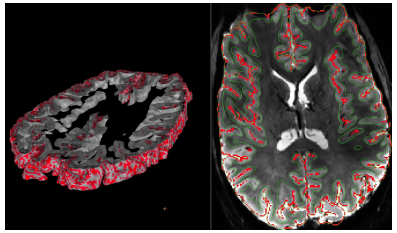
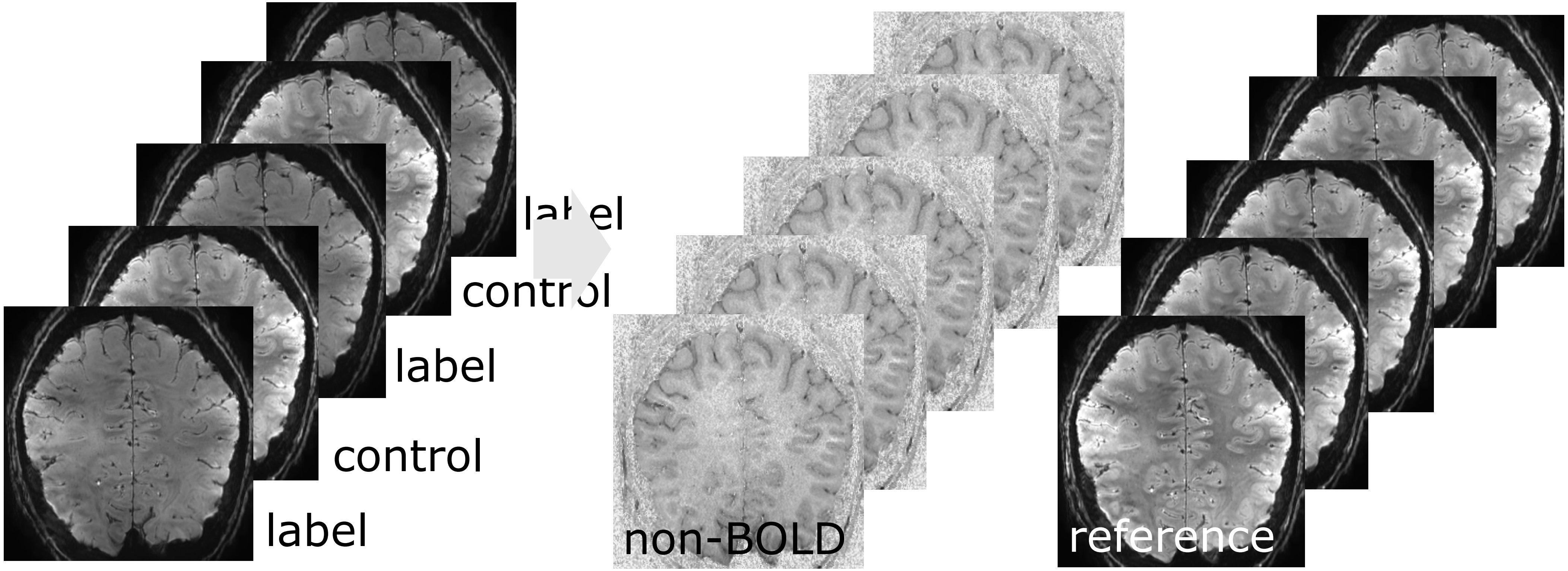
Small FOV complicates surface-based layerification



beer-wine dilemma

Non-BOLD contrasts



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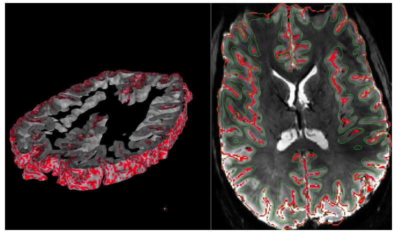
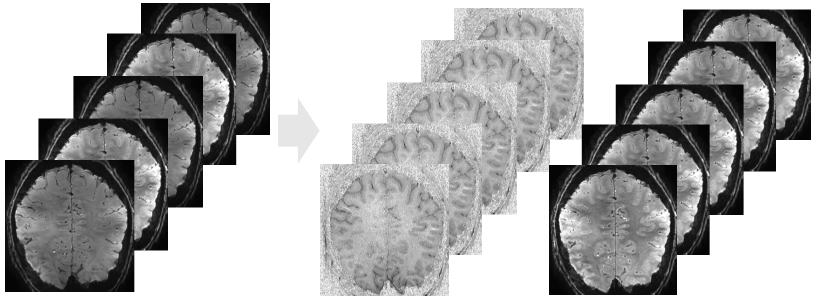
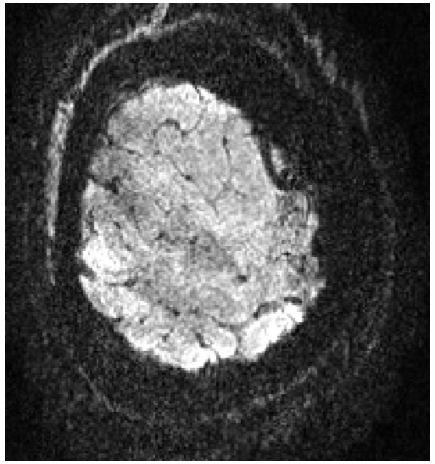


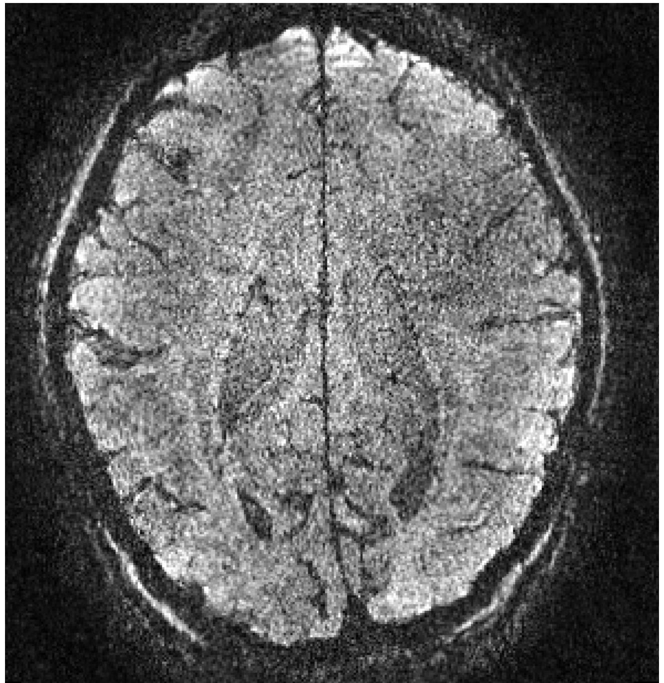
beer-wine dilemma

Non-BOLD contrasts



Artifacts, and noise





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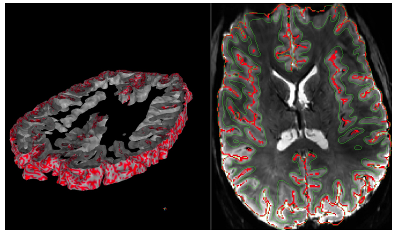
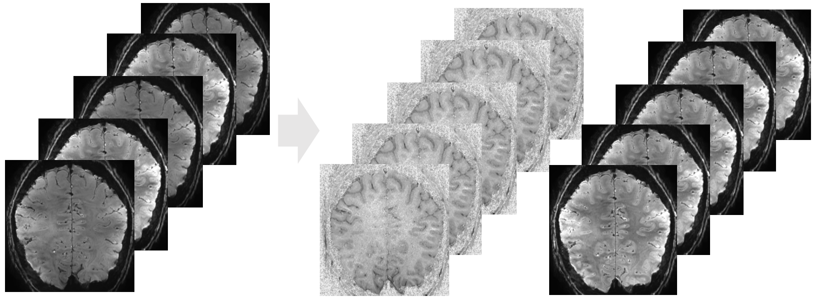
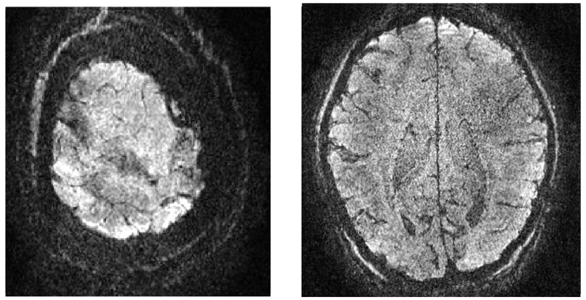


beer-wine dilemma

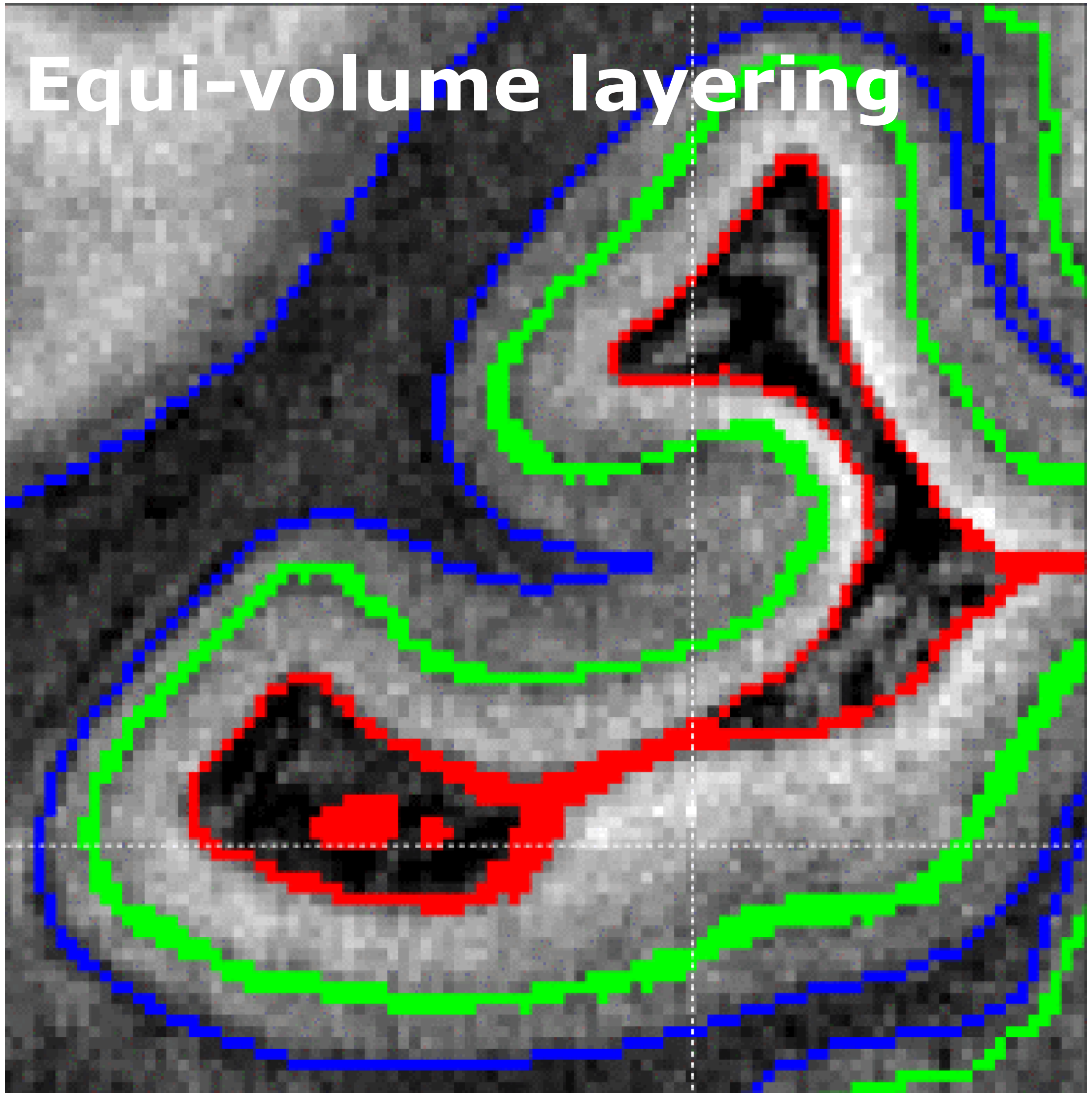
Non-BOLD contrasts



Artifacts, and noise

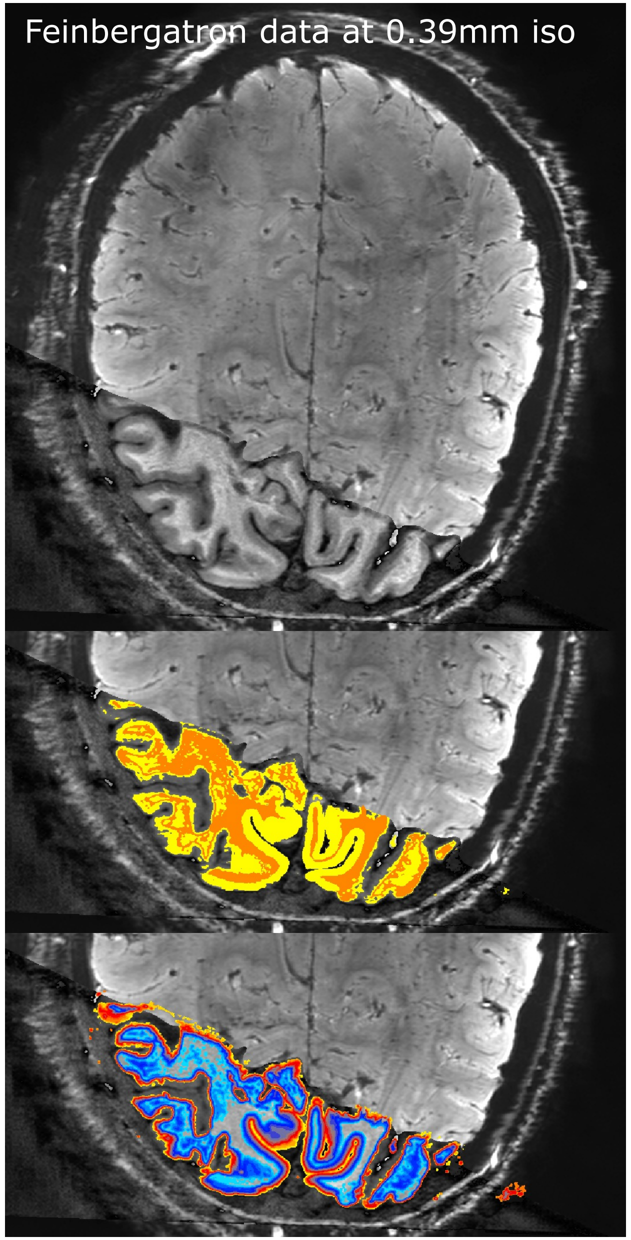


Layerification with the LayNii program LN2_LAYERS

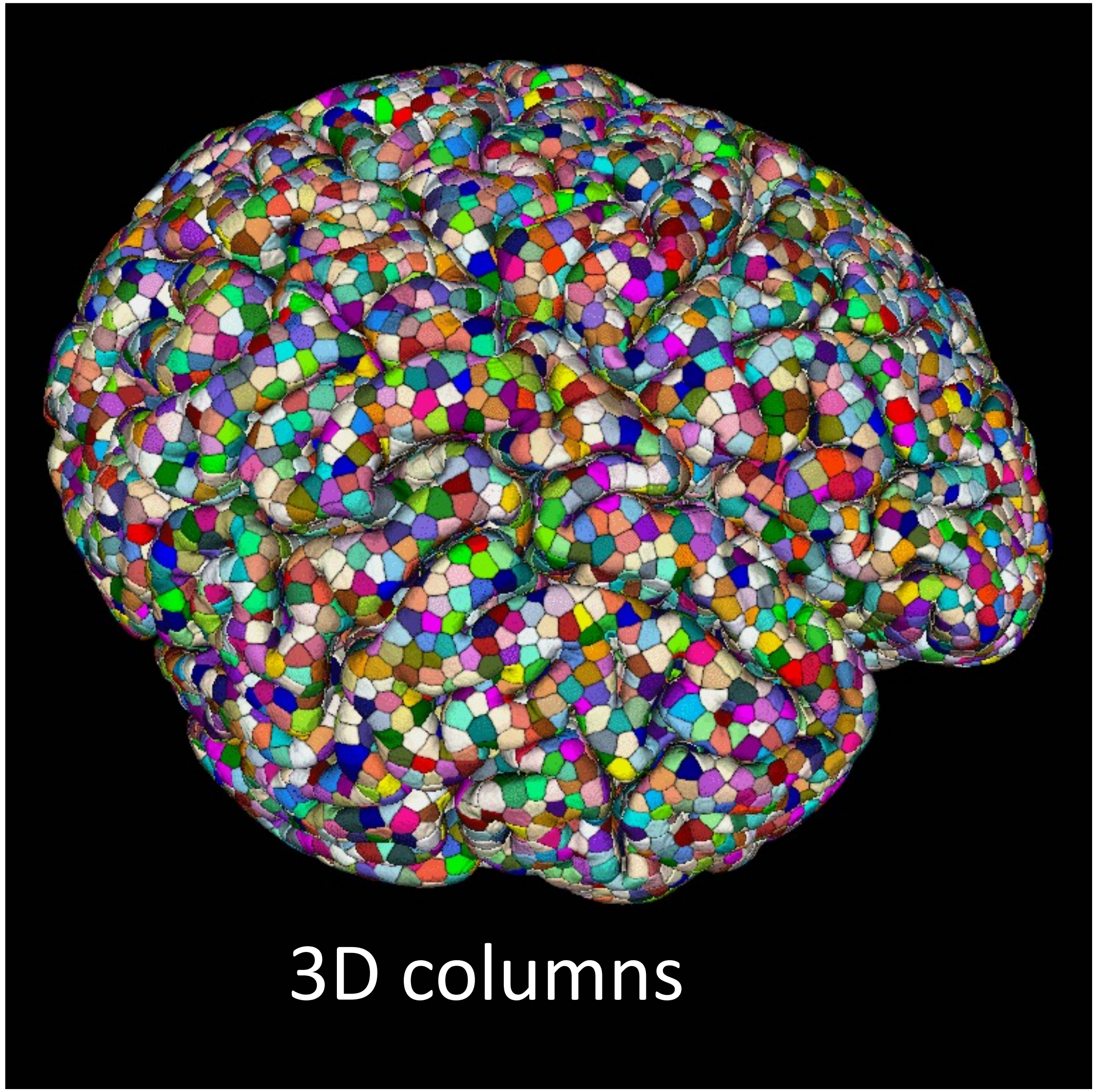


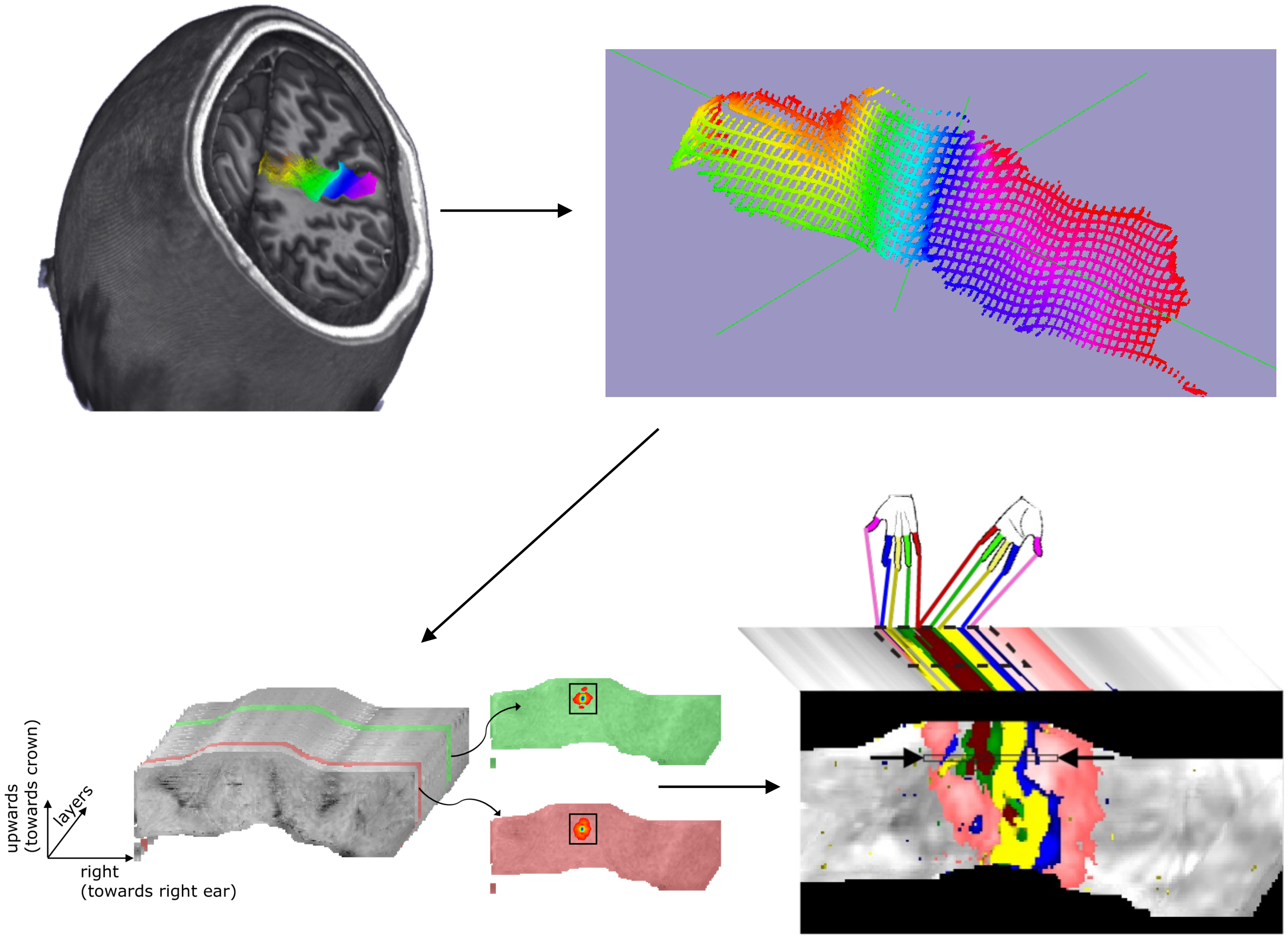
Ding et al. (2016), T2*-weighted, small section of V1.

See also:
Waehnert et al. 2014
Kemper et al., 2018
Wagstyl et al., 2020
Bazin et al., 2014
Huntenburg et al., 2018
Laminar Python 2017
Van Mourik et al., 2019
Wagstyl et al. (2020),

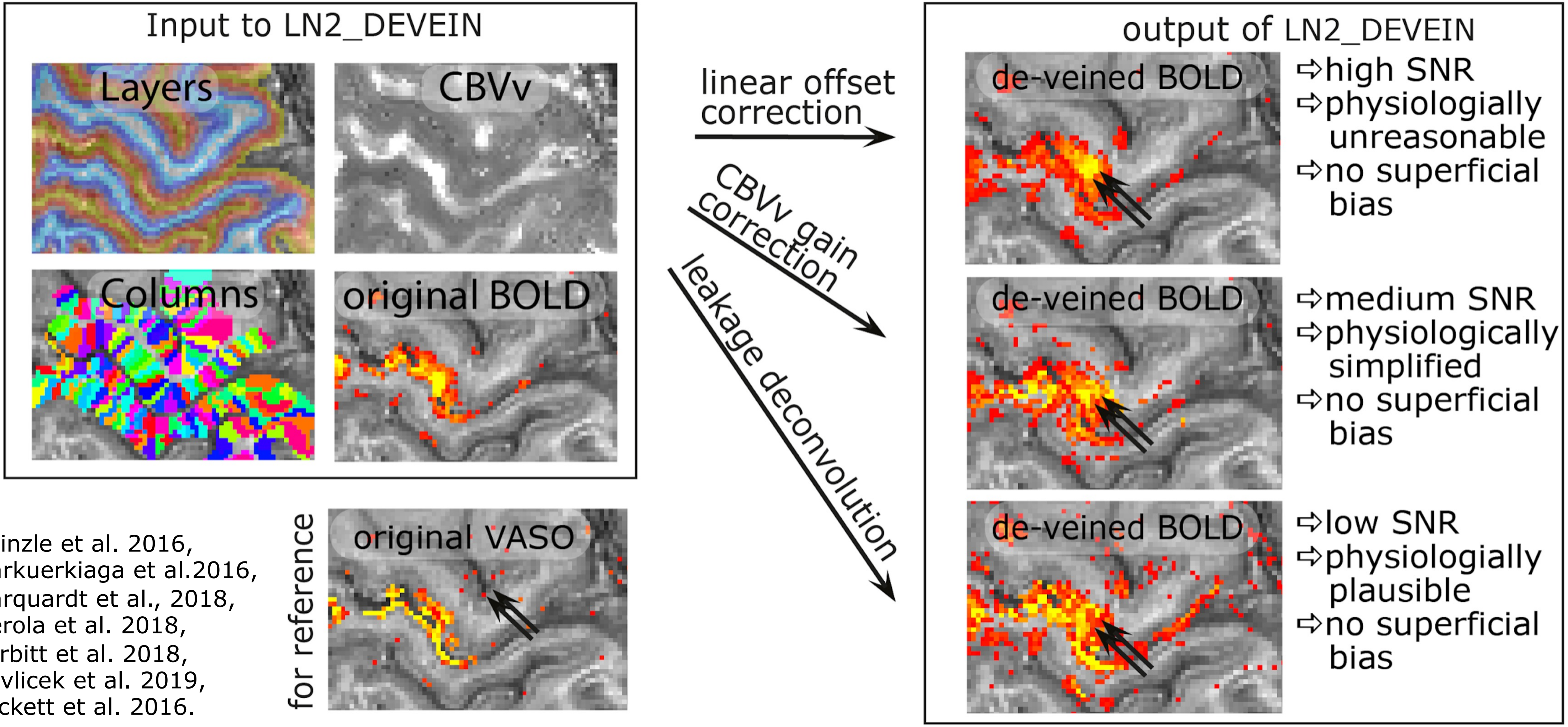


Column generation



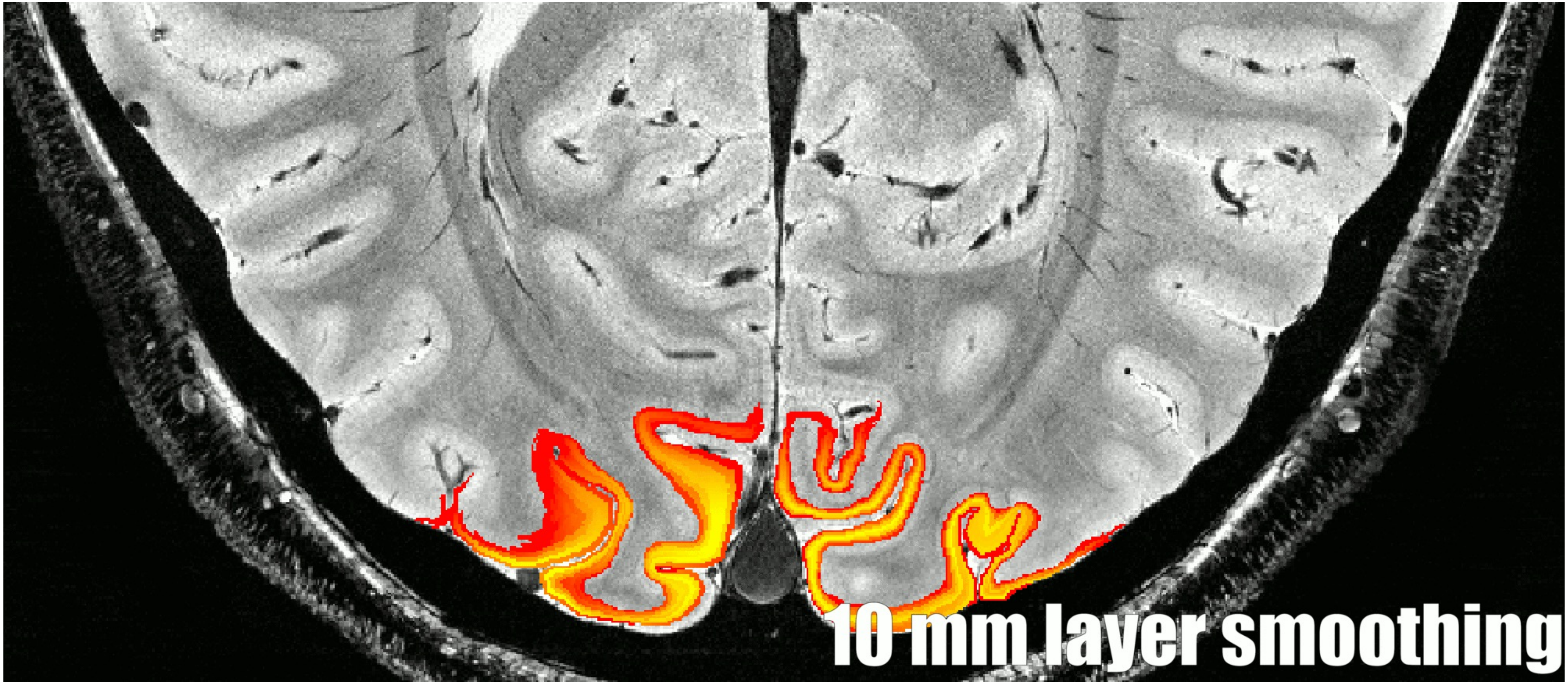


De-veining
(a.k.a. model based GE-BOLD vein-effect mitigation)



Heinzle et al. 2016,
Markuerkiaga et al.2016,
Marquardt et al., 2018,
Merola et al. 2018,
Corbitt et al. 2018,
Havlicek et al. 2019,
Puckett et al. 2016.

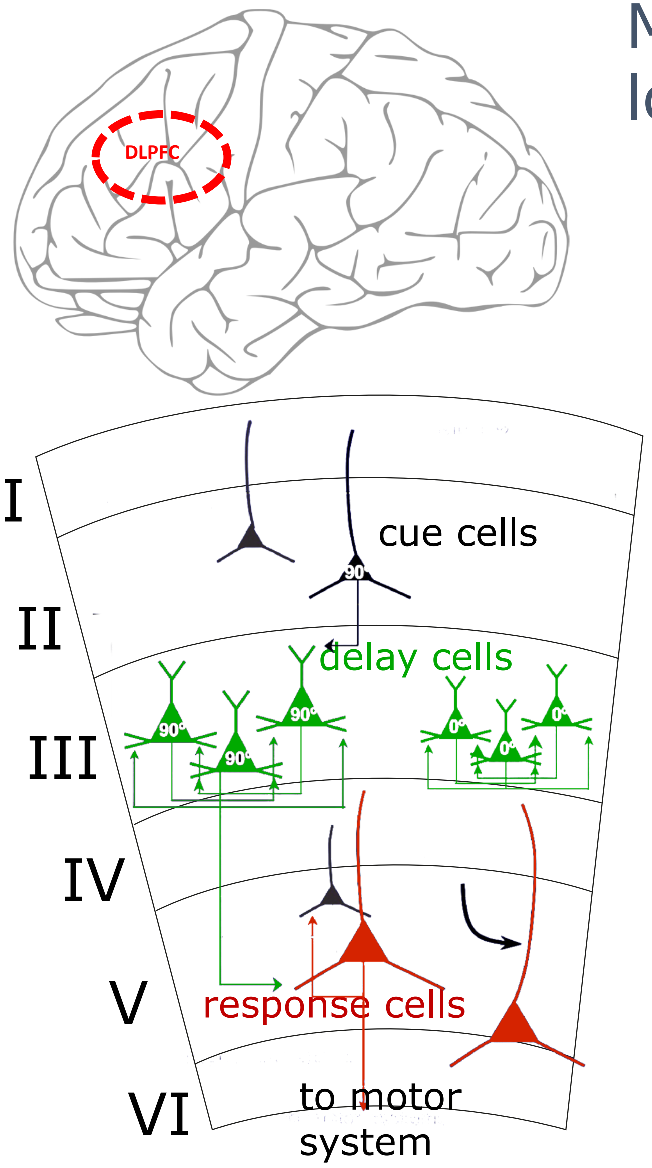
Layer-specific smoothing



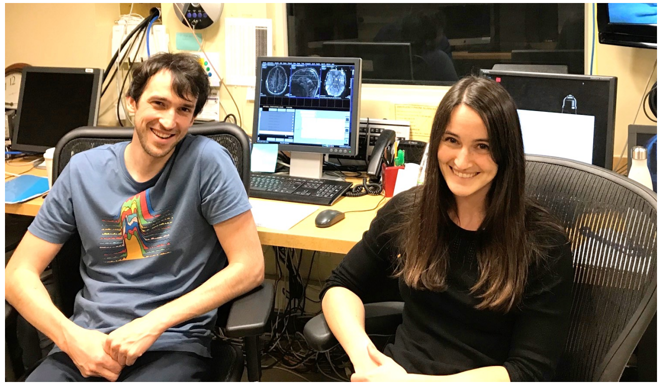
See also Blazejewska et al., 2019

layer-fMRI (post) processing

Most common layer-fMRI:
locating activity changes by subtracting task conditions

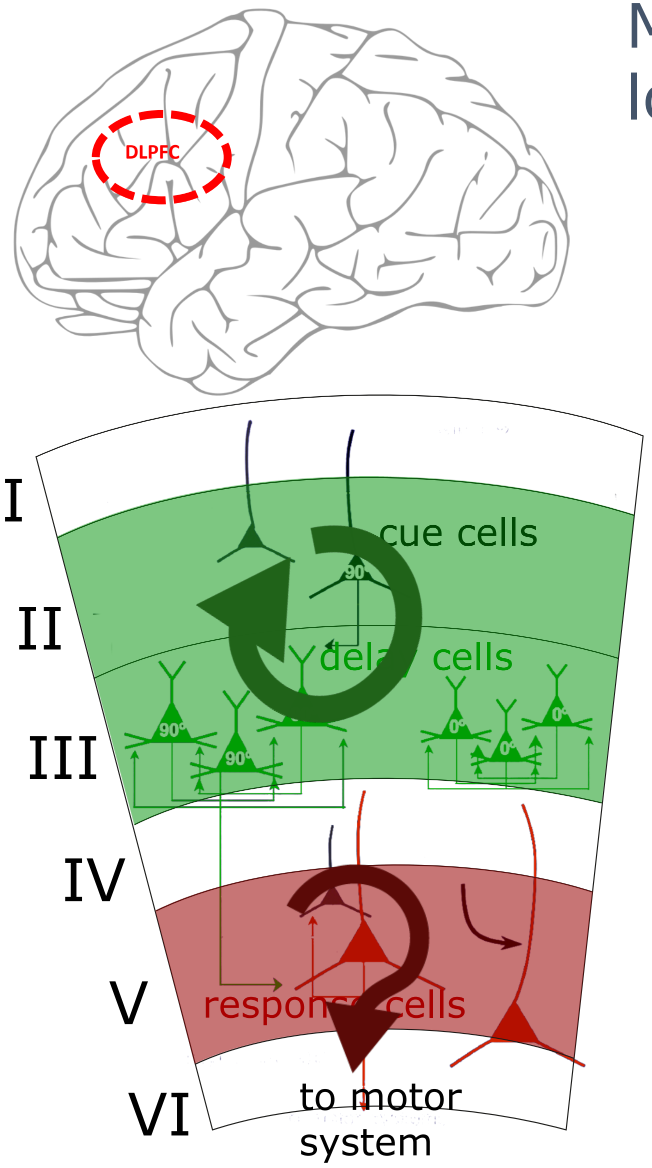


Adapted from Arnsten et al., 2012
Wang et al., 2004; Opris et al., 2011;
Markowitz et al., 2015; Bastos et al., 2018



Emily Finn [2019]

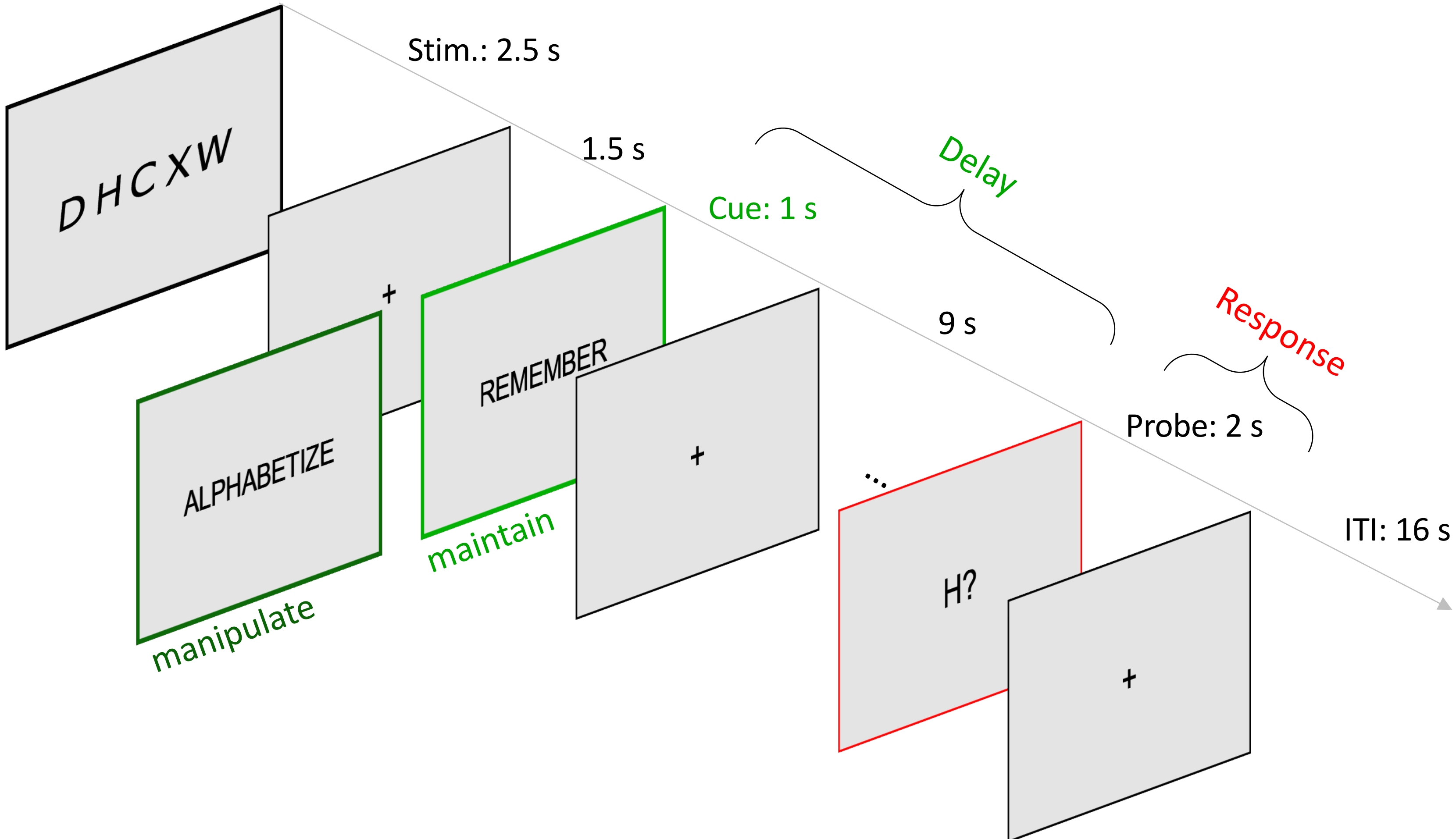
Most common layer-fMRI:
locating activity changes by subtracting task conditions



Adapted from Arnsten et al., 2012
Wang et al., 2004; Opris et al., 2011; Markowitz et al., 2015; Bastos et al., 2018

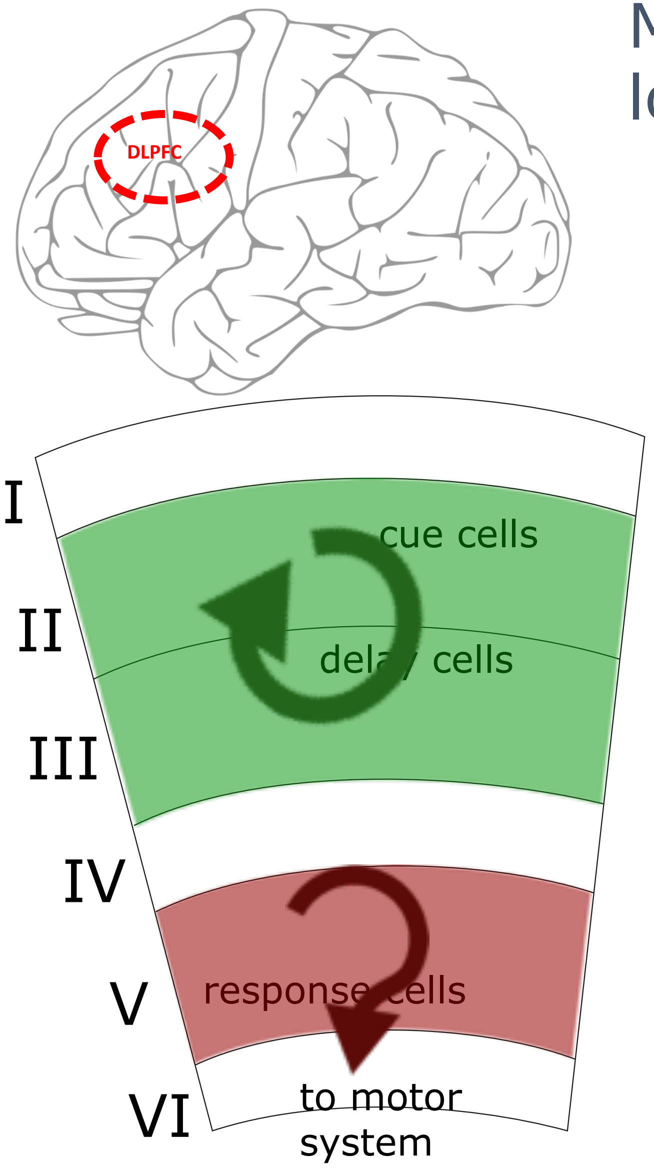
Task: manipulation vs. maintenance
response vs. letter sorting

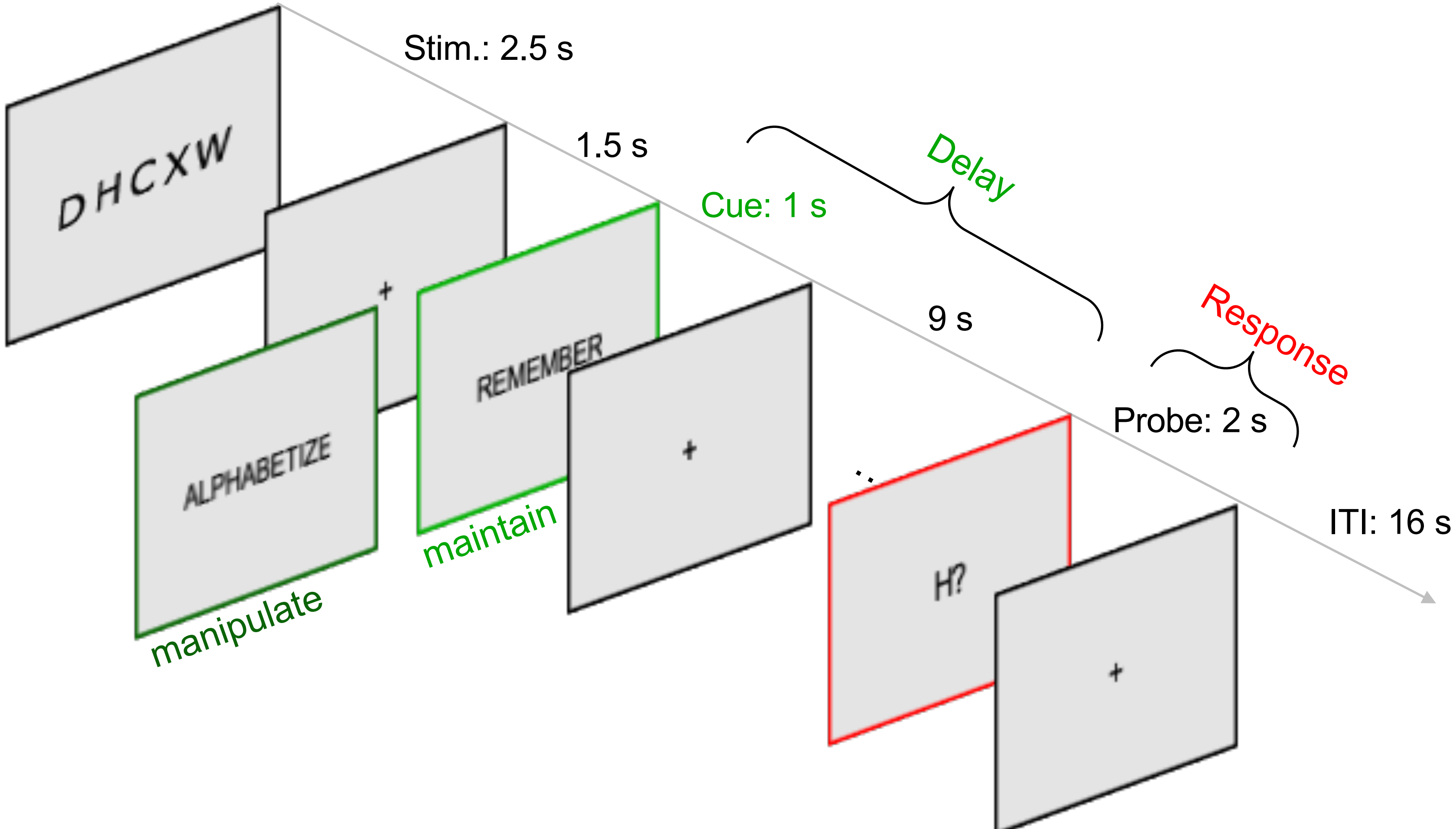
[D'Esposito et al., 1999]



Most common layer-fMRI:
locating activity changes by subtracting task conditions

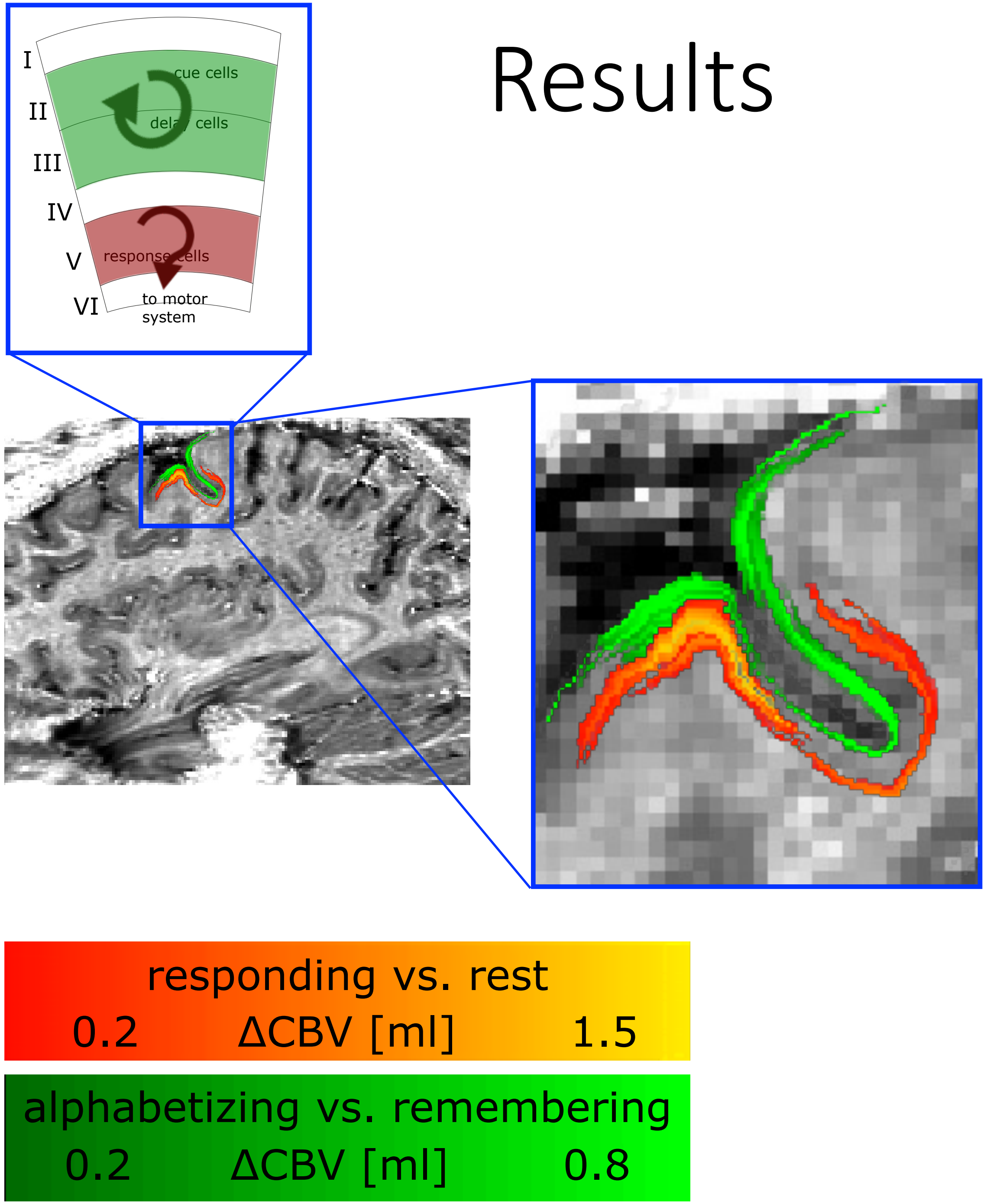
Task: manipulation vs. maintenance
response vs. letter sorting

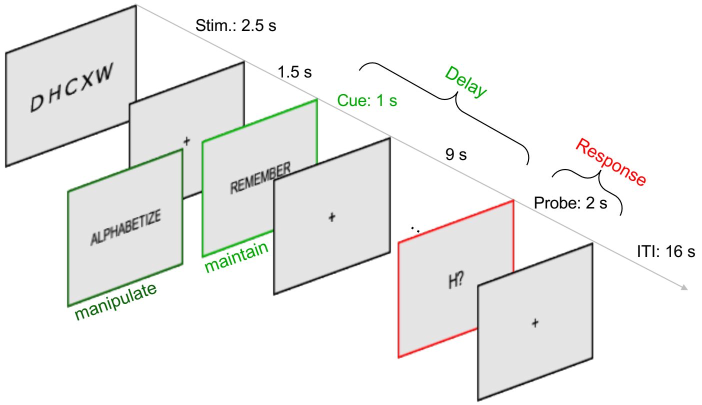


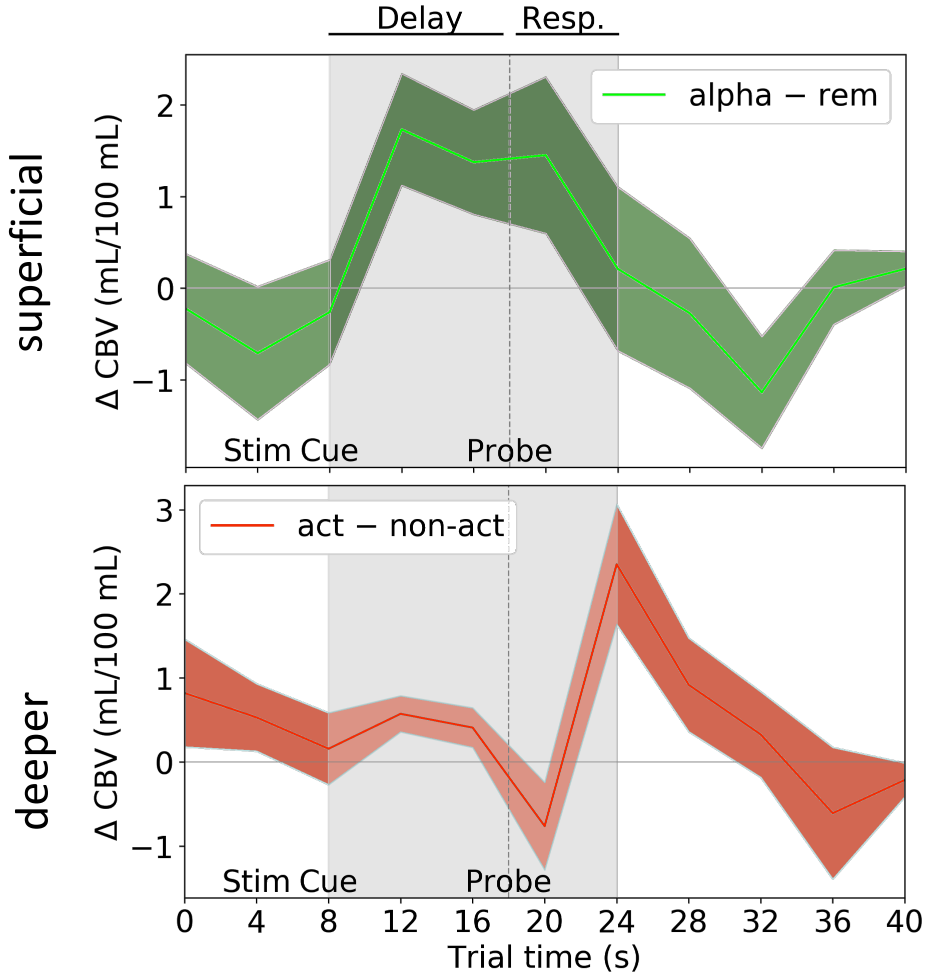


Adapted from Arnsten et al., 2012
Wang et al., 2004; Opris et al., 2011;
Markowitz et al., 2015; Bastos et al., 2018

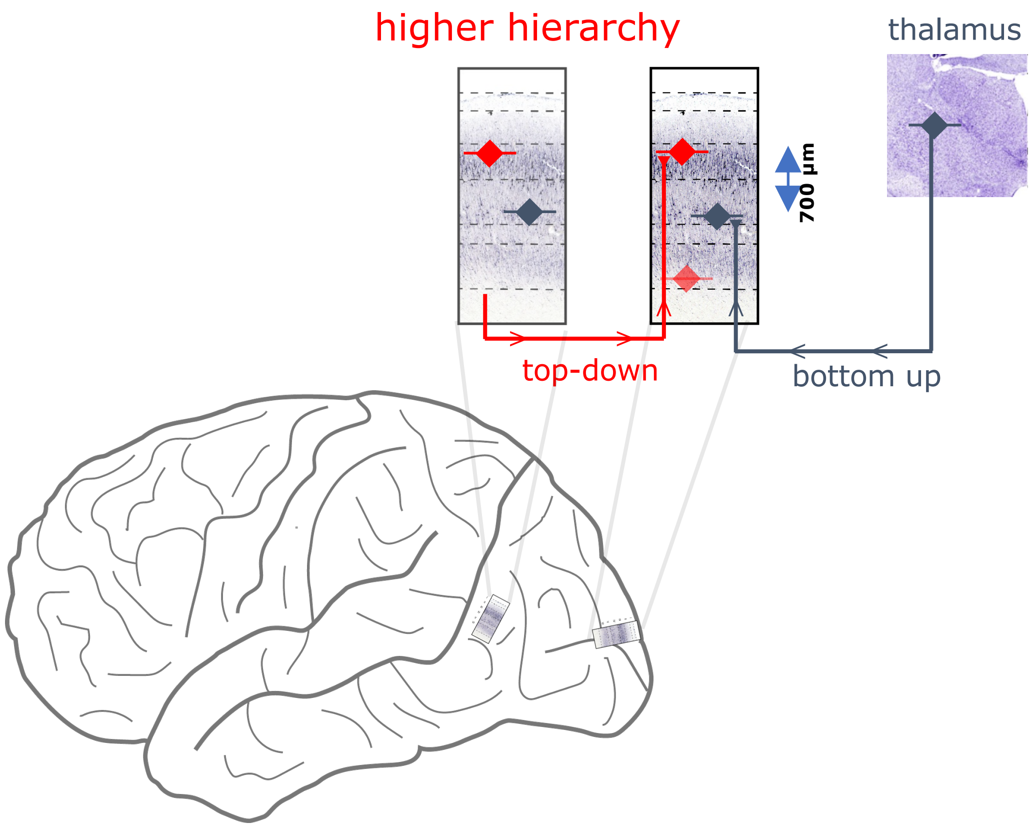
Results

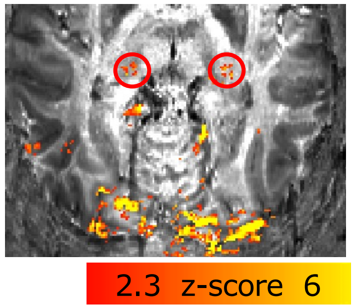

I
II
III
IV
V
VI
cue cells
delay cells
response cells
to motor system
responding vs. rest
0.2 ΔCBV [ml] 1.5
alphabetizing vs. remembering
0.2 ΔCBV [ml] 0.8


DHCXW
Stim.: 2.5 s
1.5 s
Cue: 1 s
Delay
9 s
Response
Probe: 2 s
ITI: 16 s
ALPHABETIZE
manipulate
REMEMBER
maintain
H?

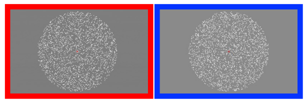

Delay
Resp.
superficial
deeper
Δ CBV (mL/100 mL)
alpha − rem
act − non-act
Stim Cue
Probe
Trial time (s)
0
4
8
12
16
20
24
28
32
36
40

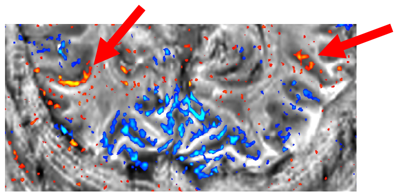
Resting-state connectivity

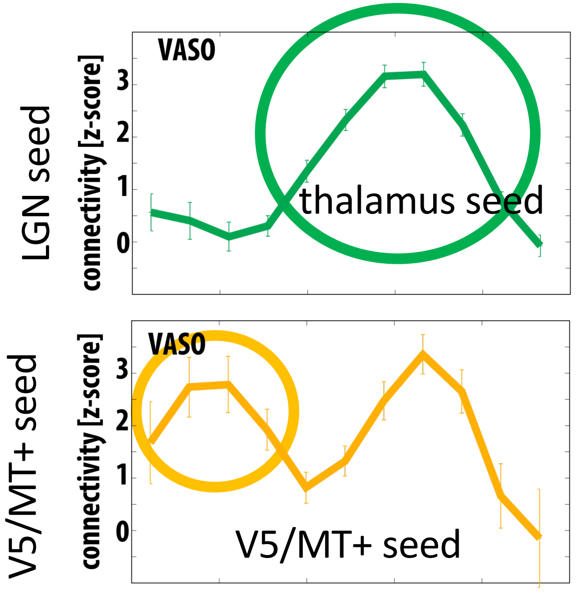




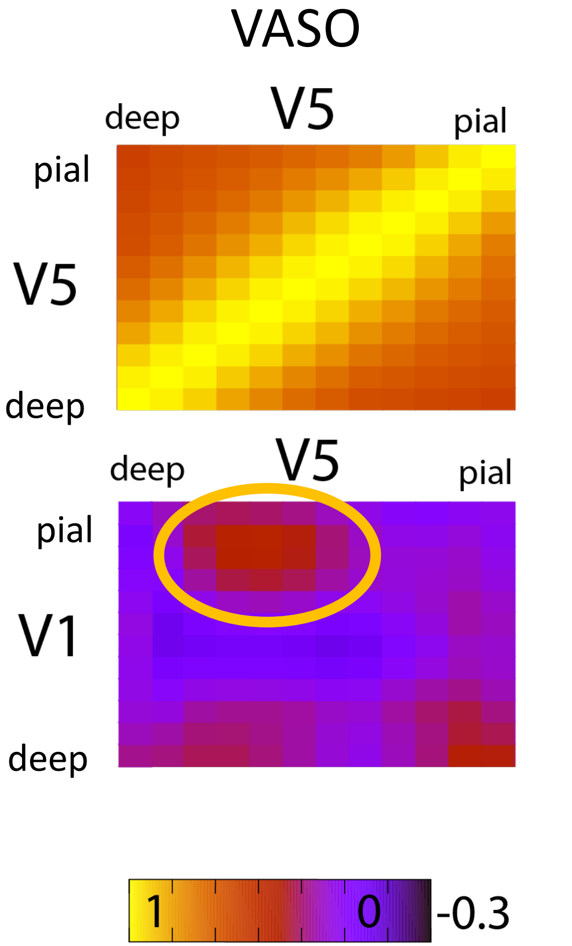
MT+ (containing V5) is selected based on a functional localizer: motion vs static







Seed-based connectivity in V1 across layers



V5-V1 feedback originated in deeper layers of V5 and terminates in upper layers of V1

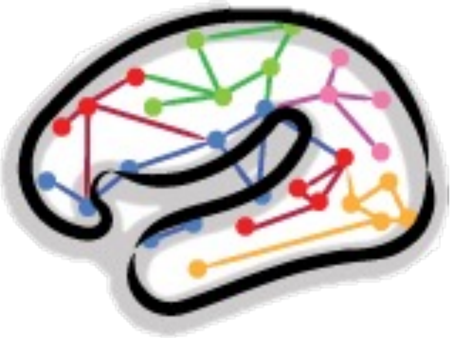
Free movie watching

Human connectome data:

- 93 non-sibling HCP participants at 1.6 mm, TR = 1s whole brain
- 15 min movie consisting of 5 short clips with rest
- ICA-fixed, 7T

Layer-fMRI data:

- 6 participants at 2mm and 0.8mm (VASO)
- TR = 2.5 s, 7T
- 5 times same movie
- HCP signal traces are taken as regressor
- VASO vessel correction



Participants are clustered in three groups (based on similarity in task positive network).