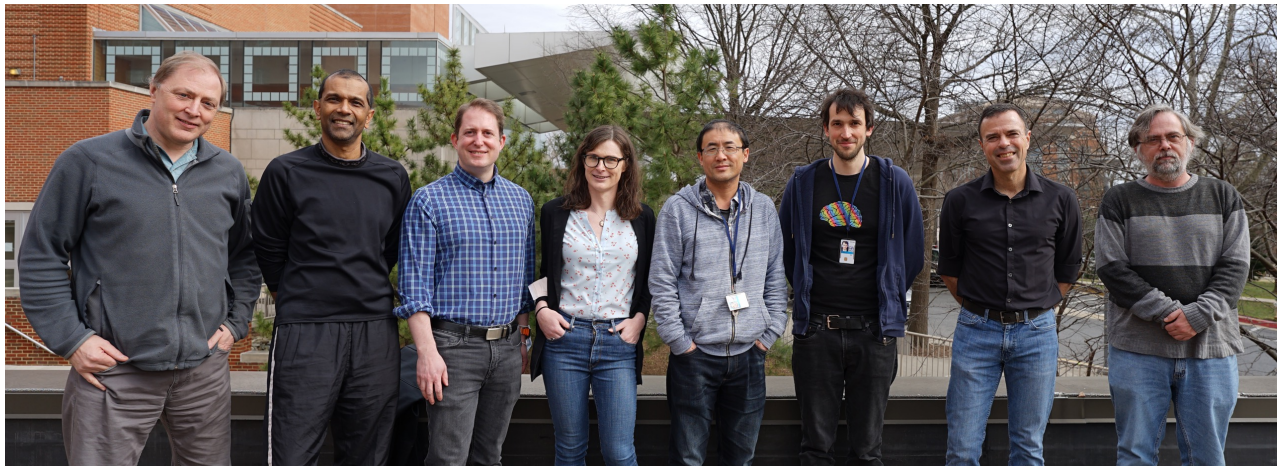
High-resolution MRI and fMRI



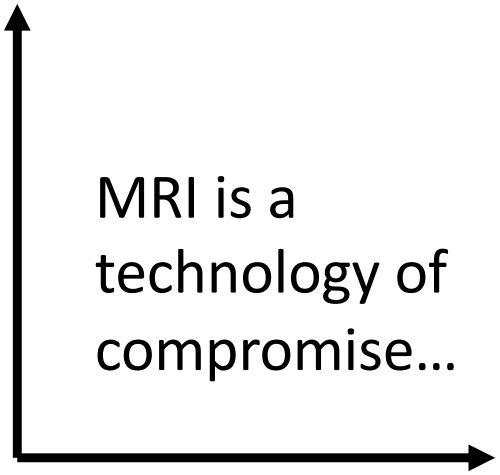
Renzo (Laurentius) Huber
Tyler Morgan

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

How do we increase resolution?

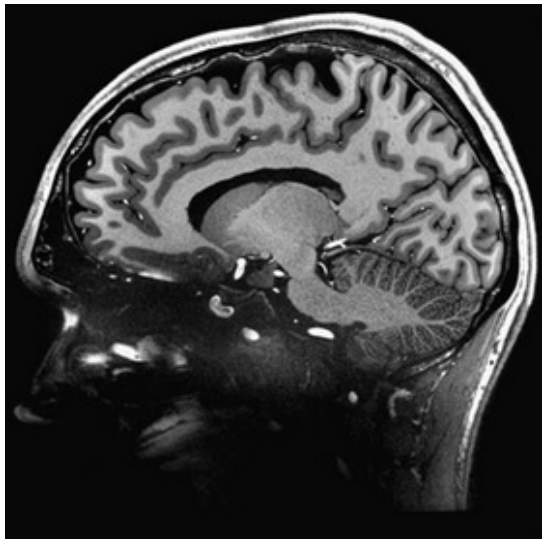
Increase
Field Strength

(get same amount signal
in shorter time)



MRI is a
technology of
compromise…

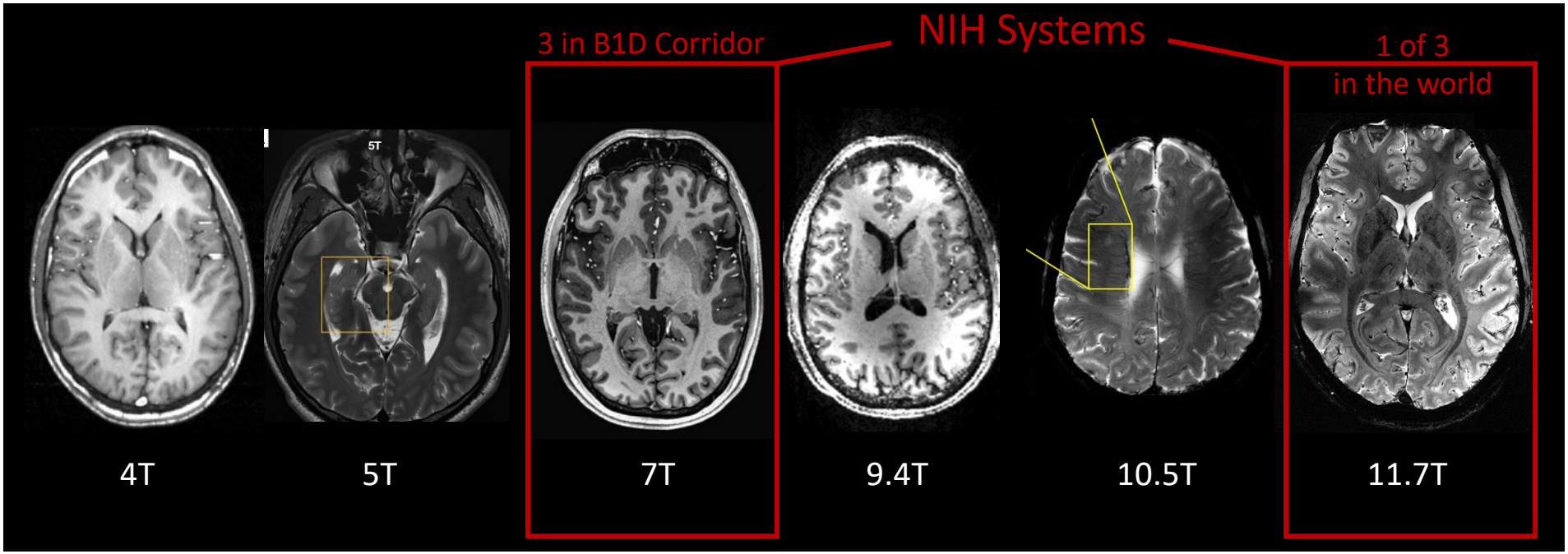
Scan for longer



250 um, but **3.5** hours!

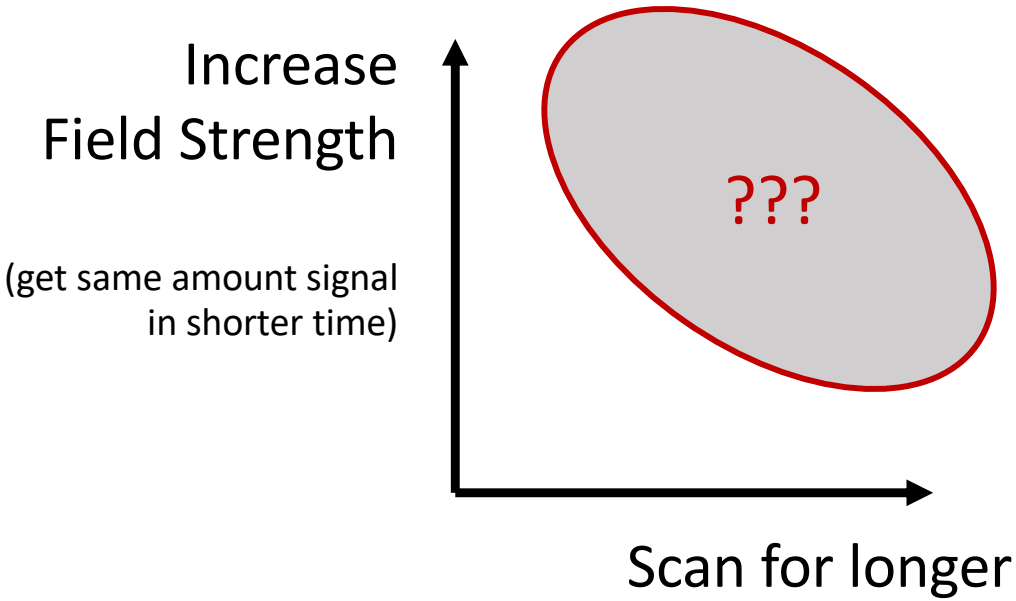
Lüsebrink, et al. 2017

Higher fields = more signal to use for resolution



CMRR; CAoS; Magdeburg; Maastricht; CMRR; CEA Paris-Saclay

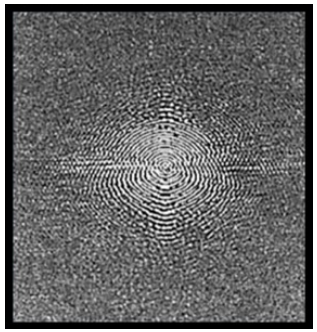
Are there any shortcuts?



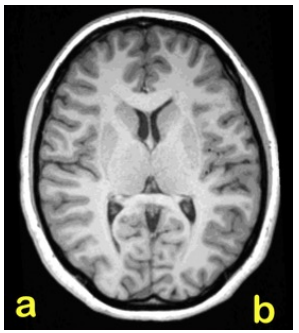
Are there any shortcuts?

BUT WHAT ABOUT THE SPEED UP????

We want to record k-space

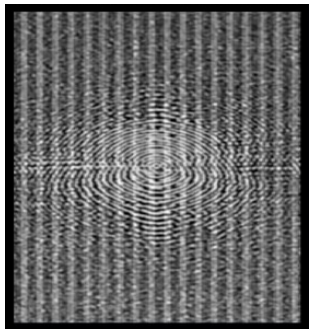


Fourier Transform ⟷



To reconstruct our images

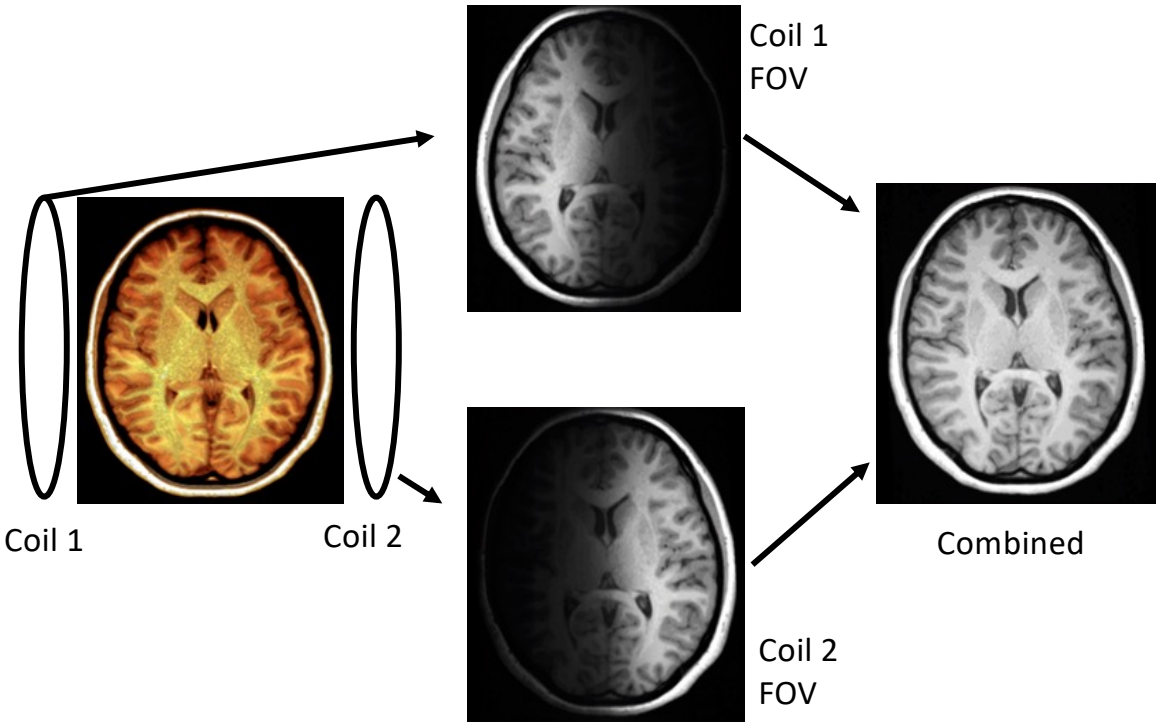
It would be great to skip lines…

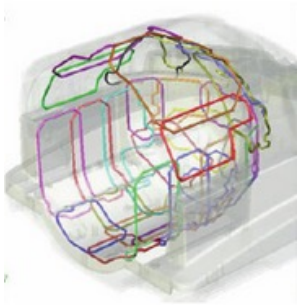


Fourier Transform ⟷

But then we are left with reduced FOV and wrapping artifacts!

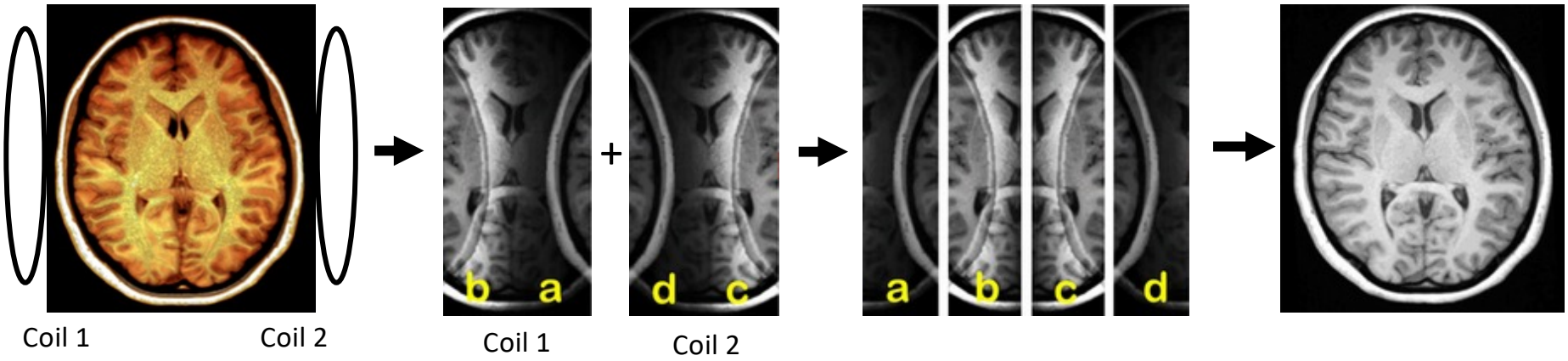
Enter… Parallel Imaging





MRI Questions; Paolini, et al. 2015

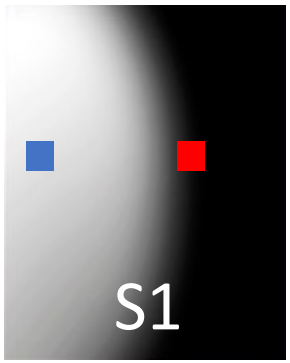
The Acceleration Problem

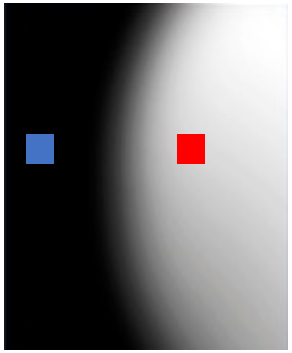


So how do we go from this?

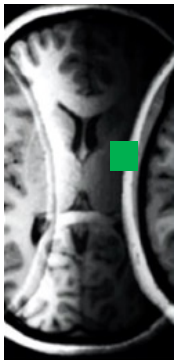
To this???

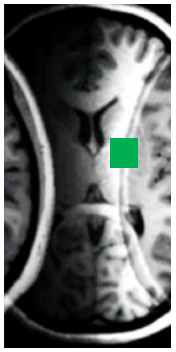
SENSE / ASSET



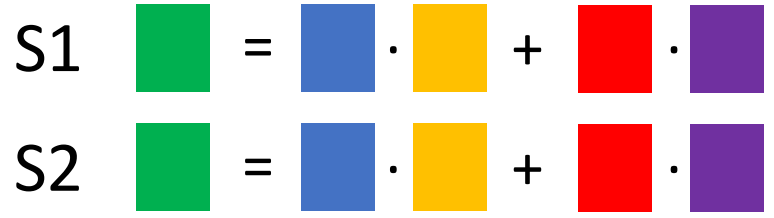


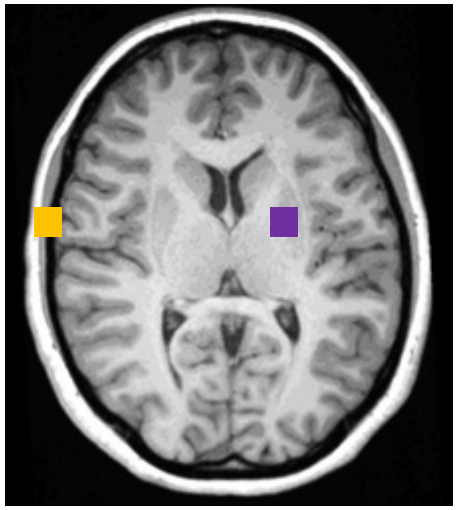
Coil Sensitivity Maps





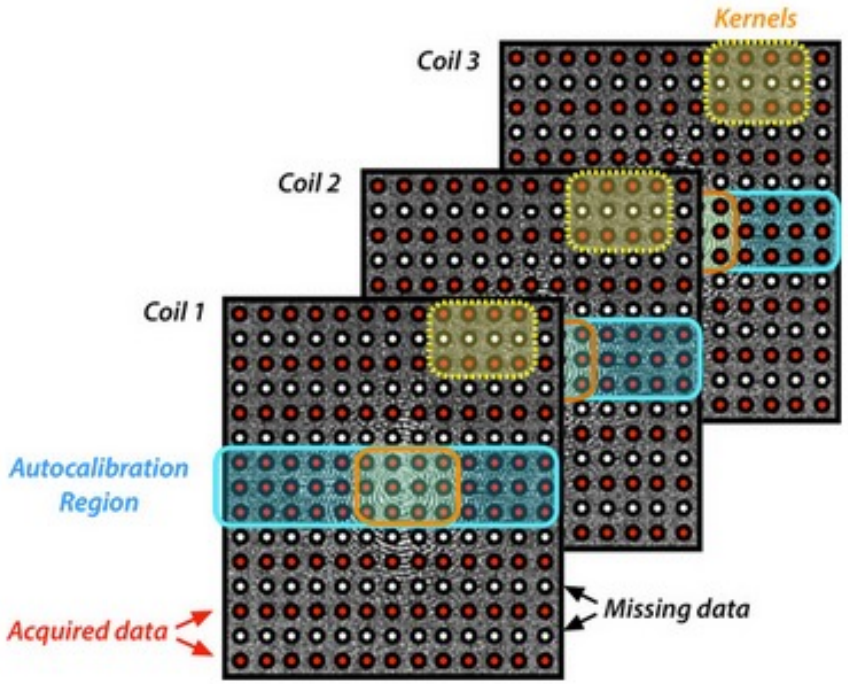
Measured Images

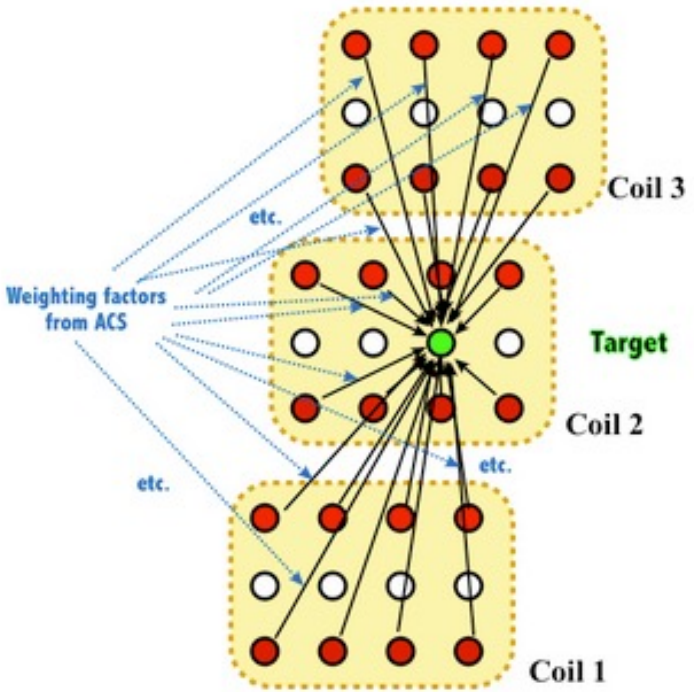




Full FOV Image

GRAPPA / ARC

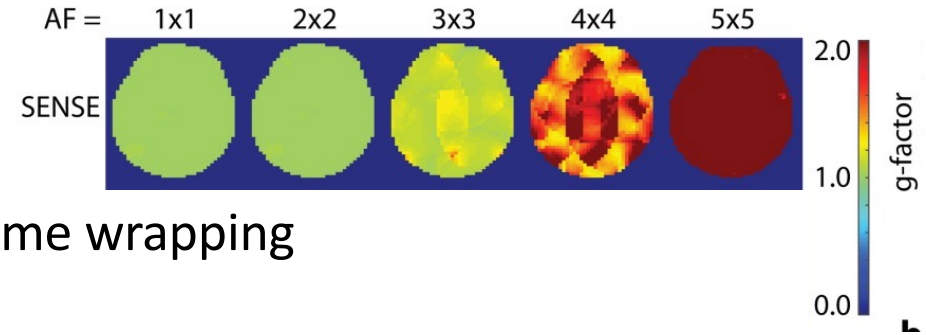

Kernels
Coil 3
Coil 2
Coil 1
Autocalibration Region
Acquired data
Missing data


Coil 3
etc.
Weighting factors from ACS
Target
Coil 2
etc.
etc.
Coil 1

What are our limitations?

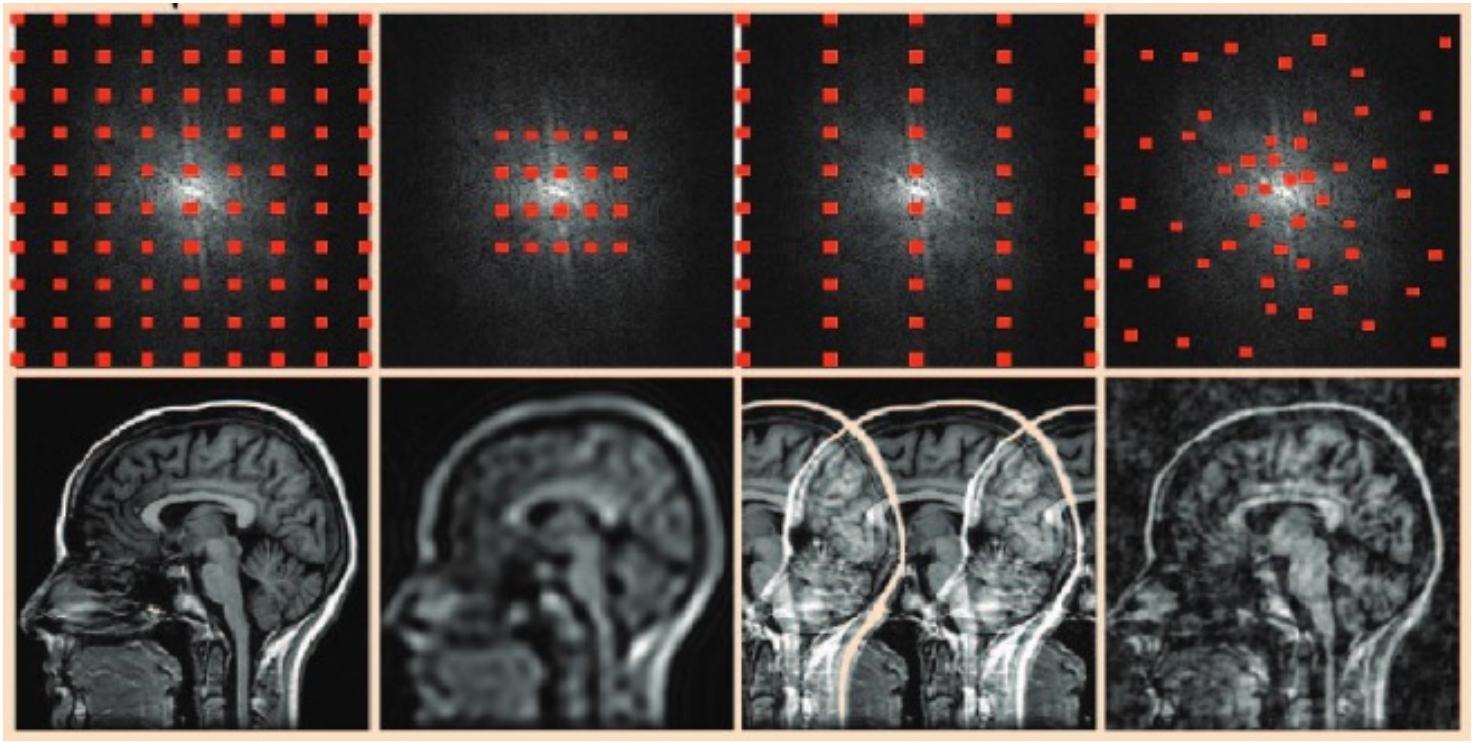
- All Parallel Imaging techniques are limited by the number of receiver coils, and their arrangement!

- Noise is cumulative! Voxels with similar sensitivity across all coils are harder to untangle (G-Factor penalty).



- Algorithms are never perfect…. some wrapping artifacts will always be present

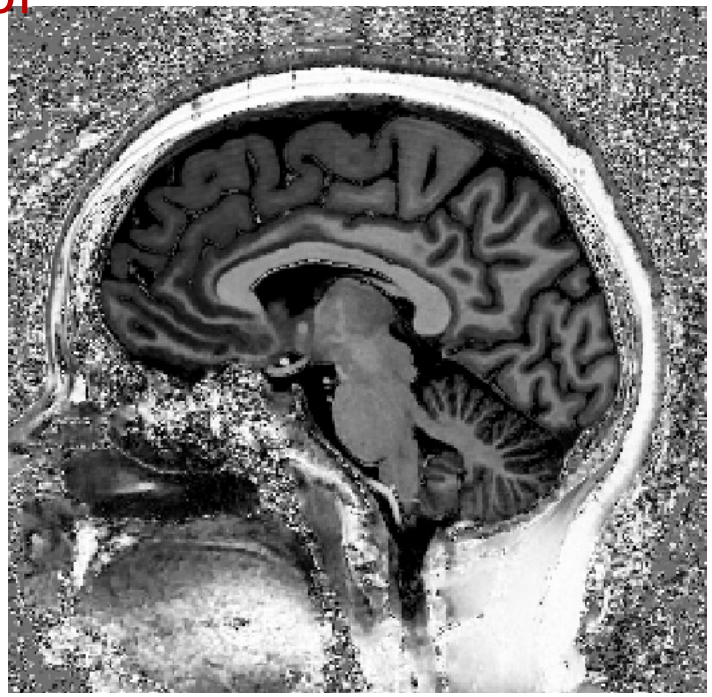
Reducing Artifact Coherence (Compressed Sensing)



Lustig, et al. 2008

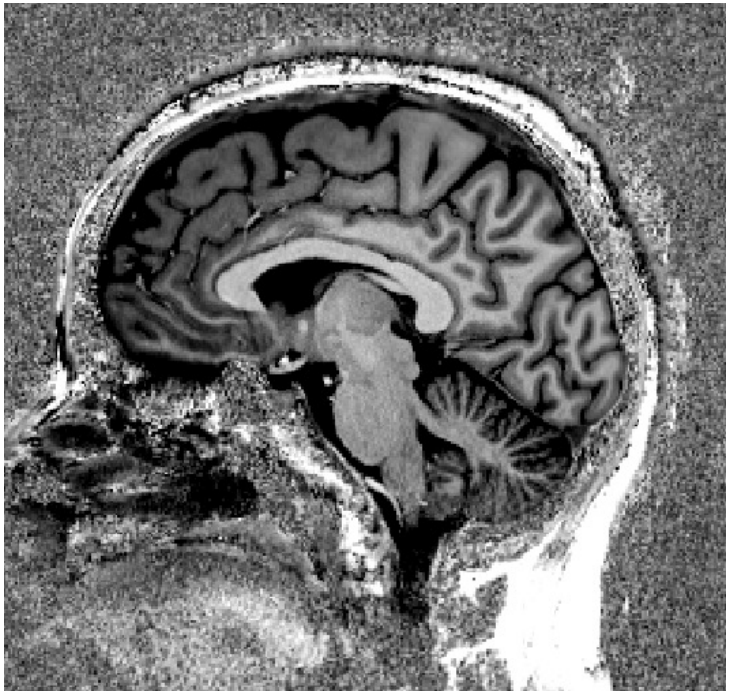
Compressed Sensing (0.75 mm anatomical)

~18% of kspace



CS – USx5.1 (6:04)

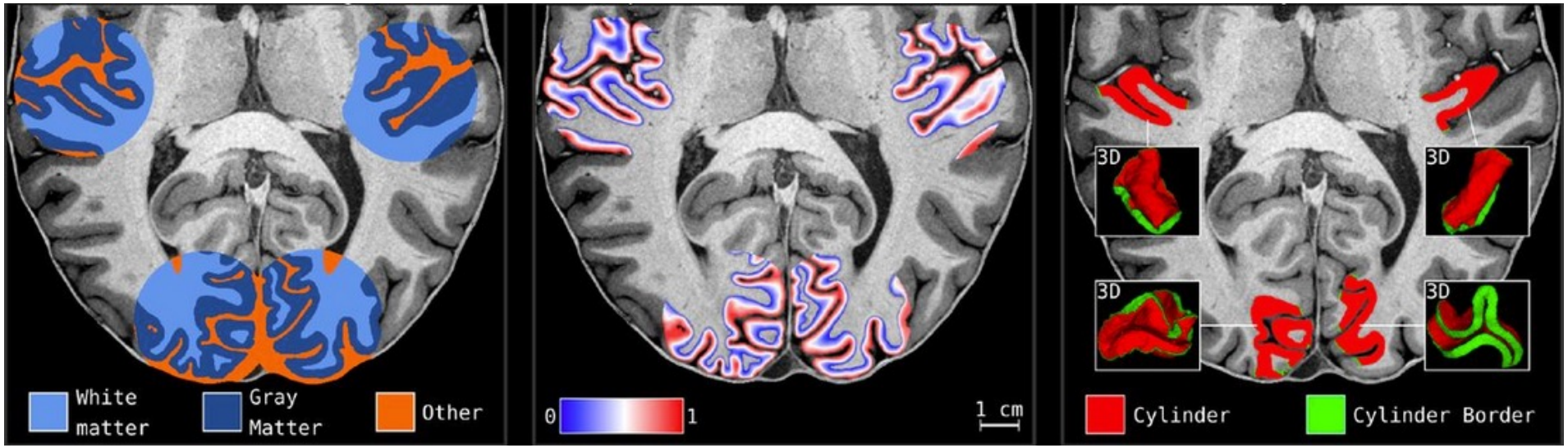
~35% of kspace



GRAPPA 3 (9:37)

High-resolution -> Layers

Visit the
Layer fMRIF Blog!

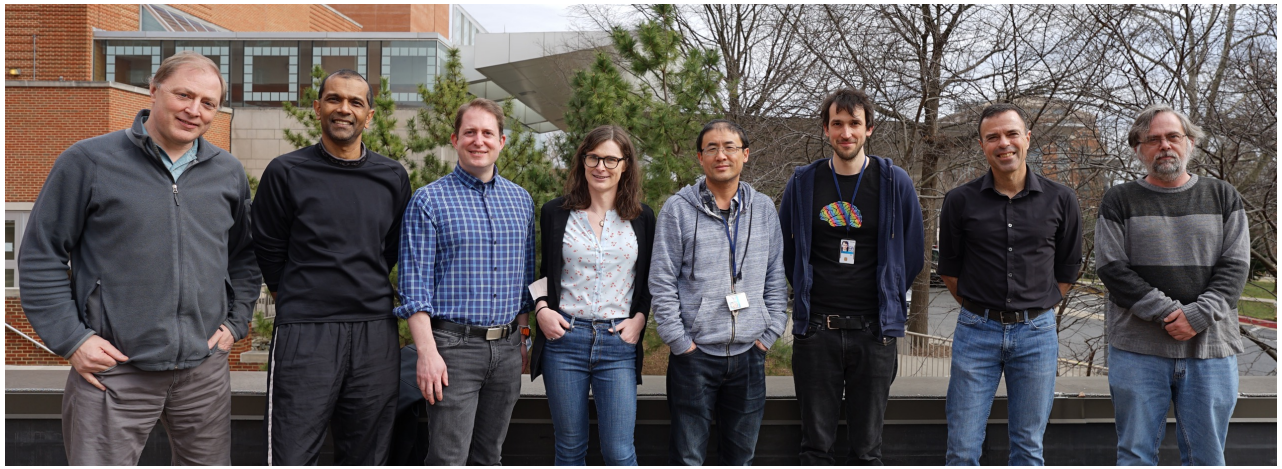


Gulban, et al. 2022

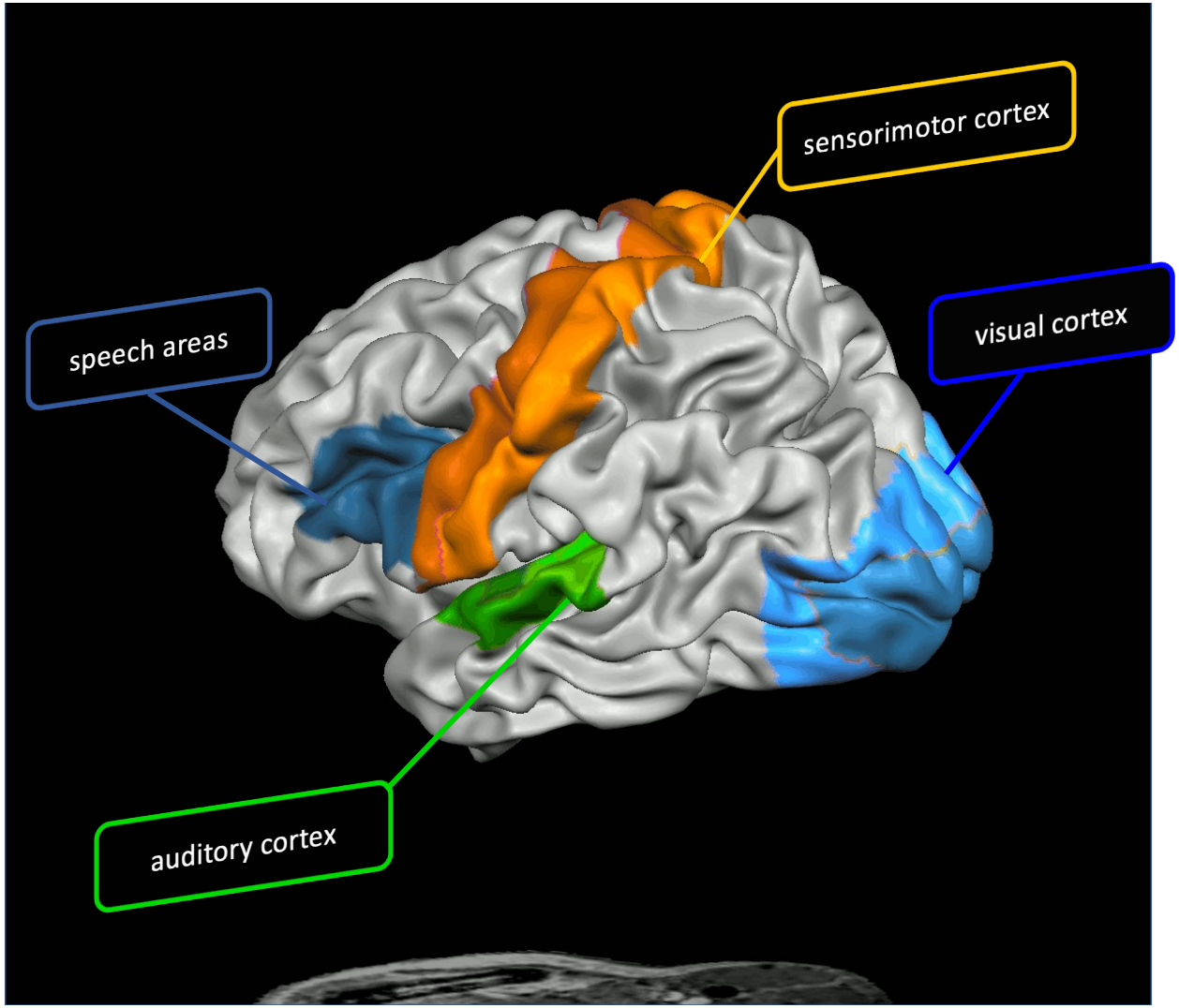

IT's
Intermission
TIME!

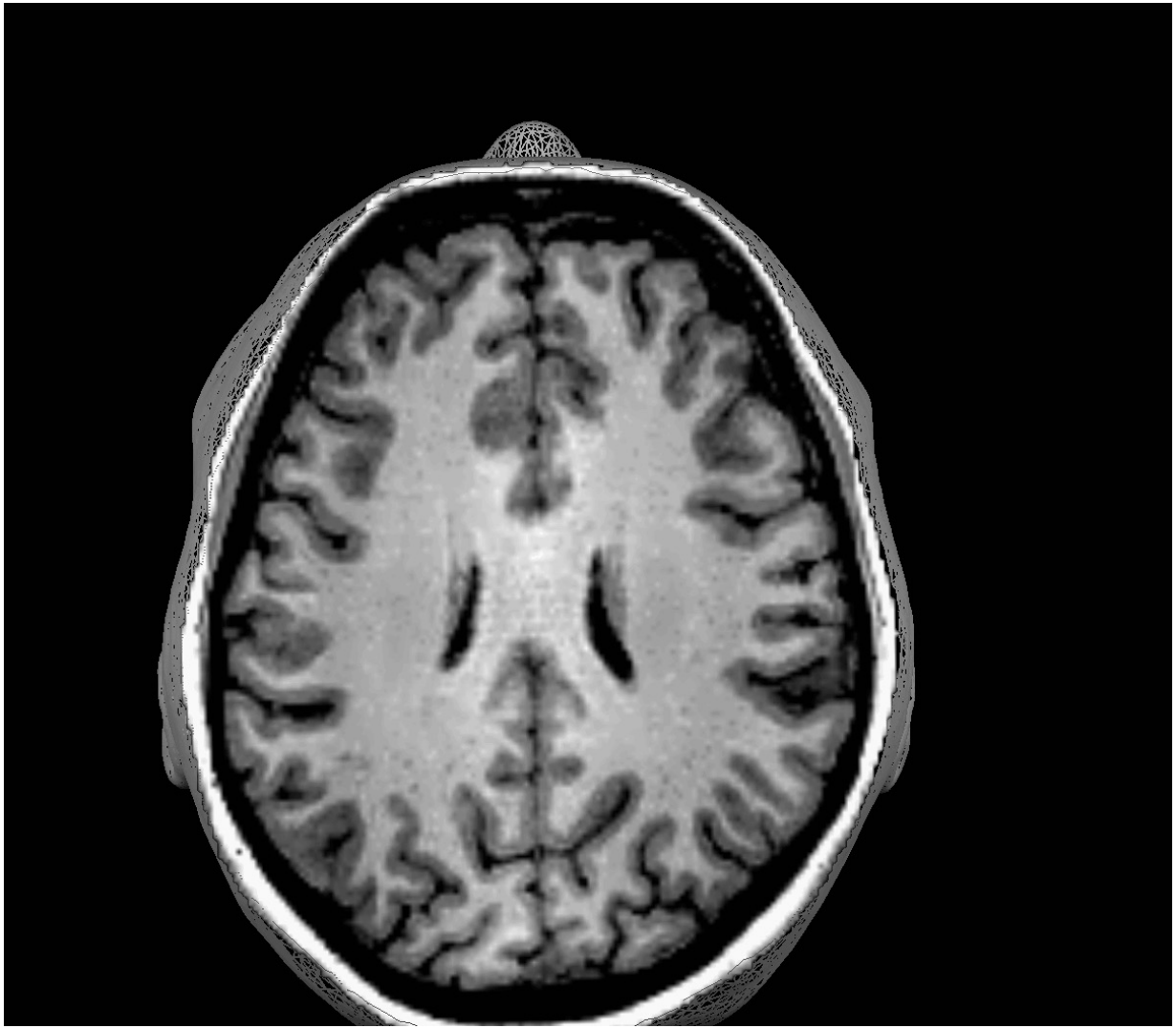
High-resolution fMRI

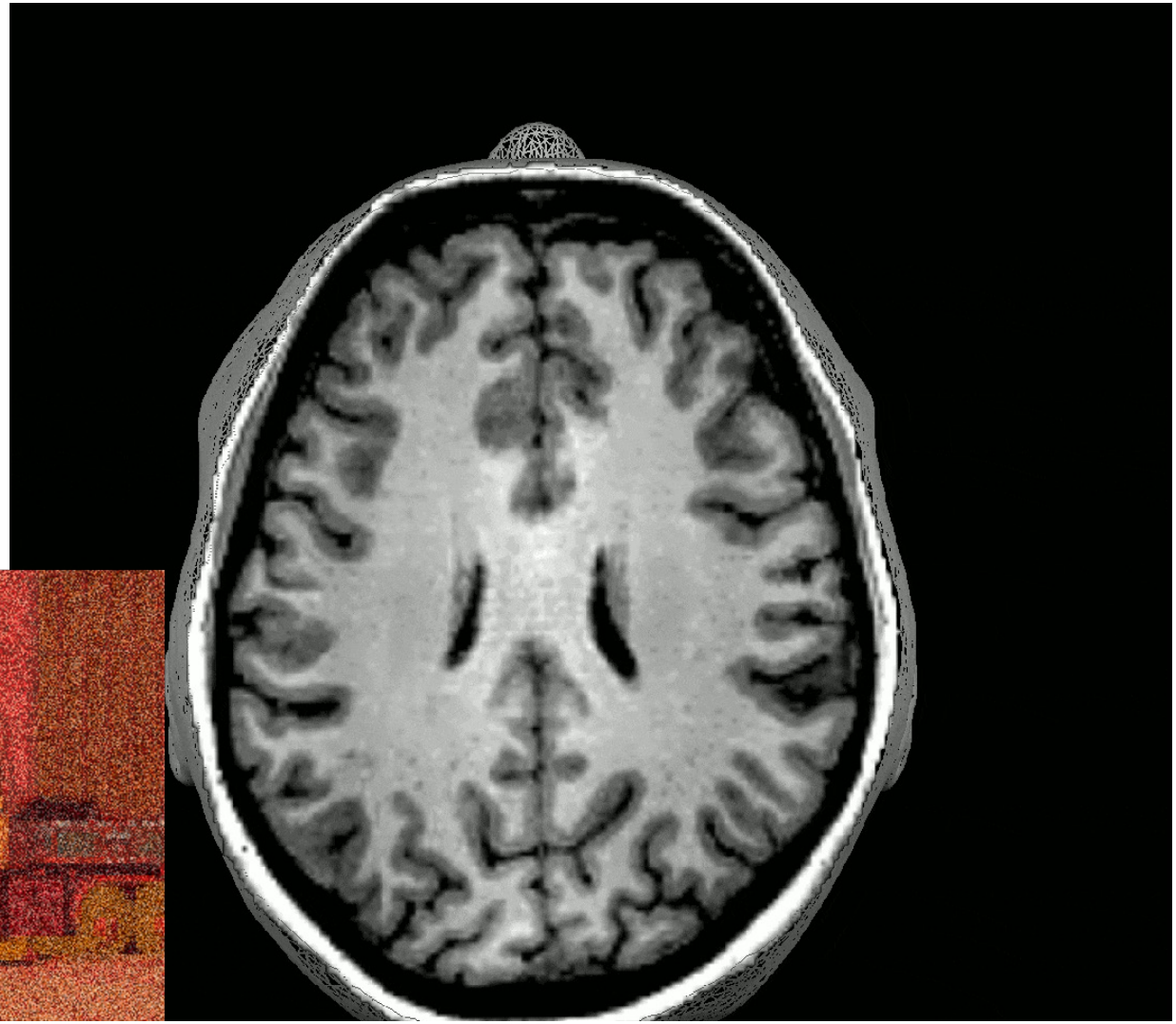
Renzo (Laurentius) Huber

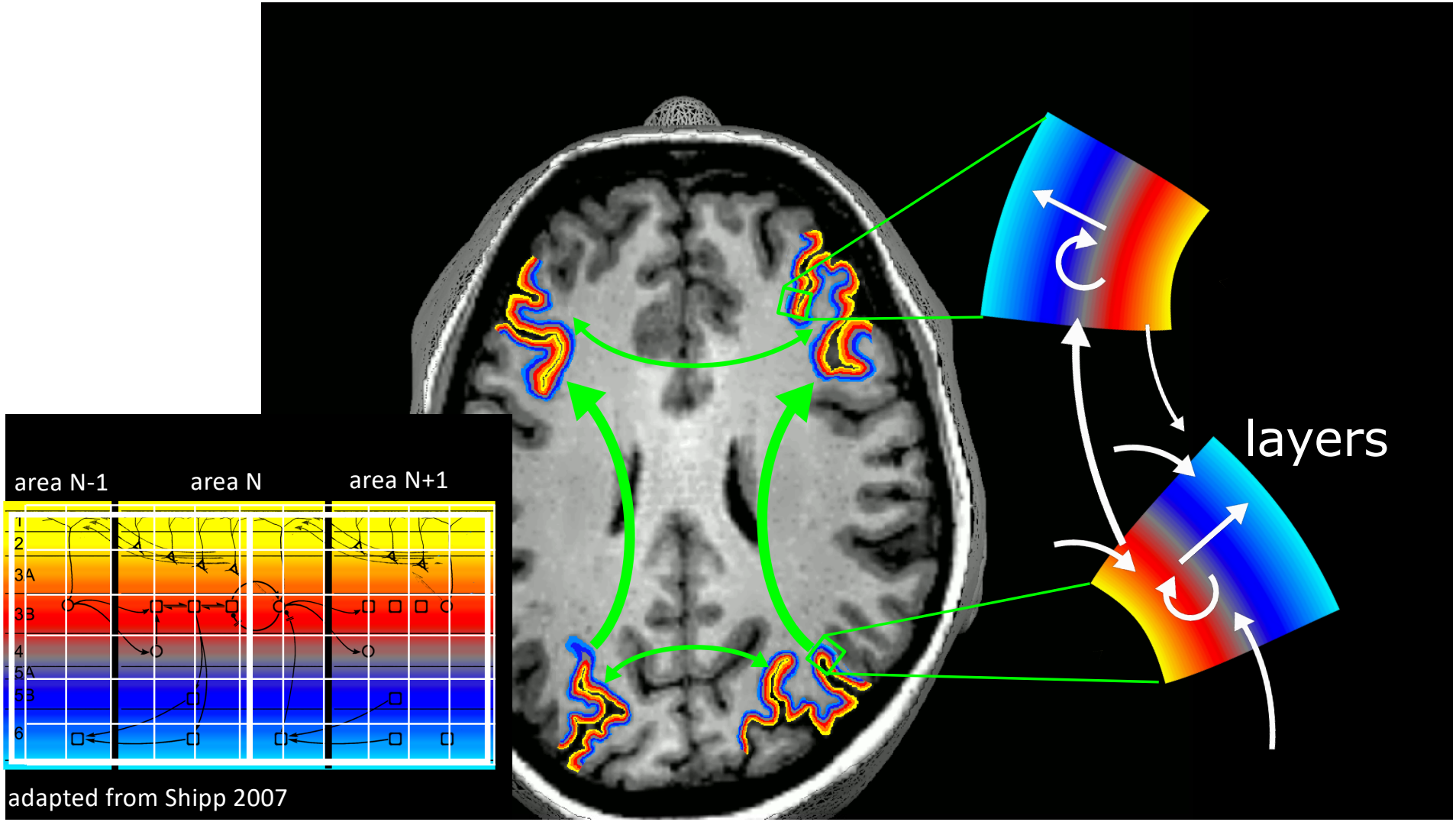


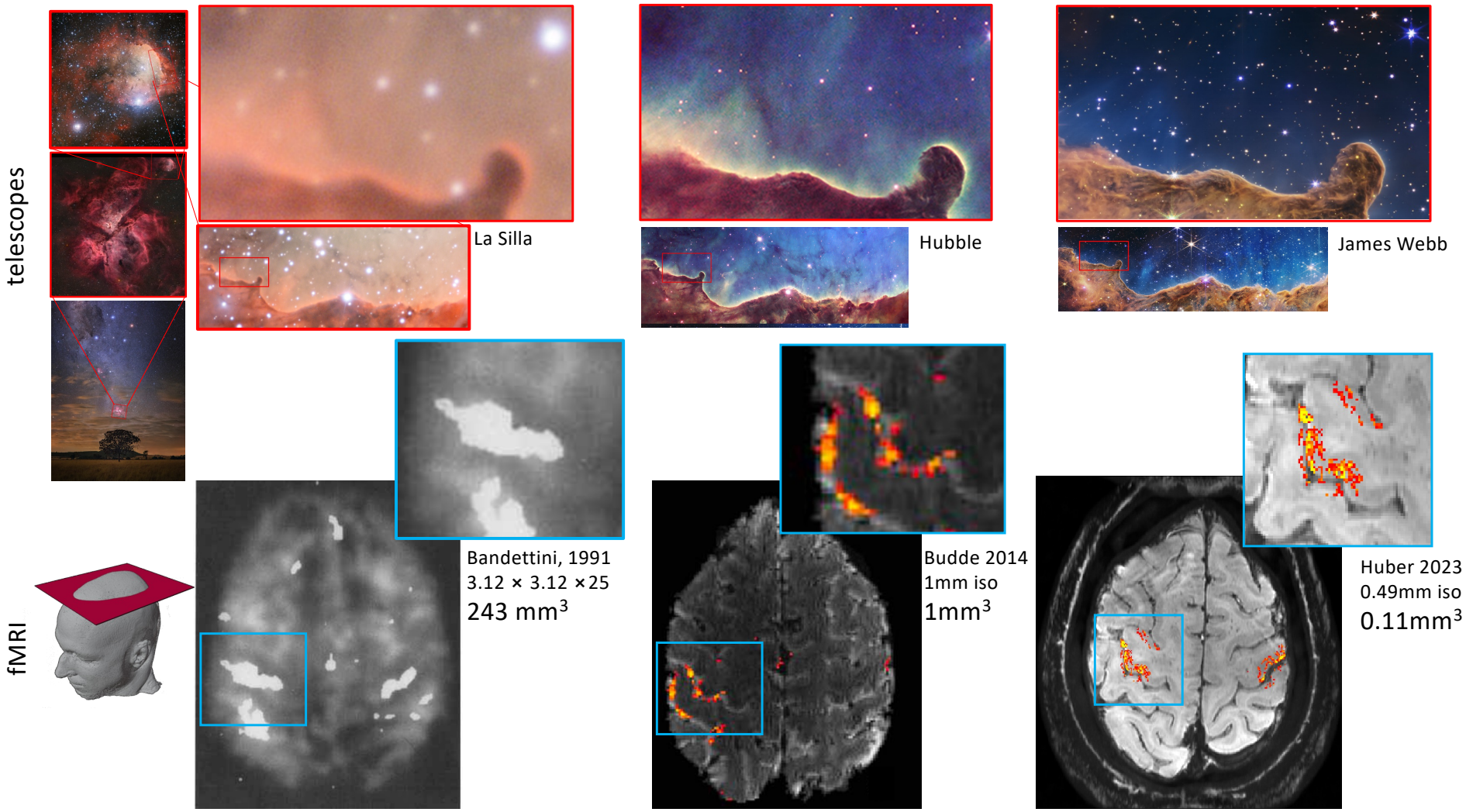
FMRI facility (FMRIF) at the NIMH/NINDS of the National Institutes of health (NIH)


sensorimotor cortex
speech areas
visual cortex
auditory cortex

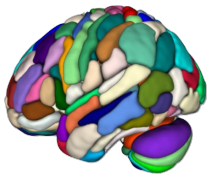





area N-1
area N
area N+1
1
2
3A
3B
4
5A
5B
6
layers
adapted from Shipp 2007

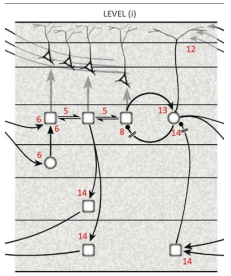

telescopes
La Silla
Hubble
James Webb
fMRI
Bandettini, 1991
3.12 × 3.12 ×25
243 mm3
Budde 2014
1mm iso
1mm3
Huber 2023
0.49mm iso
0.11mm3

brain areas



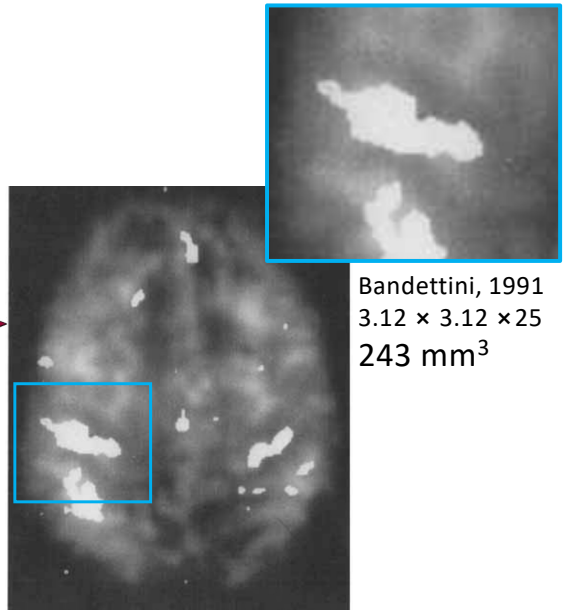
single layer model

three-six layer model

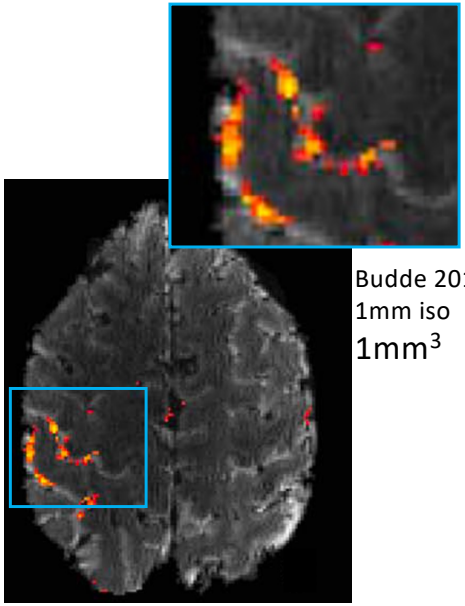


Shipp 2013

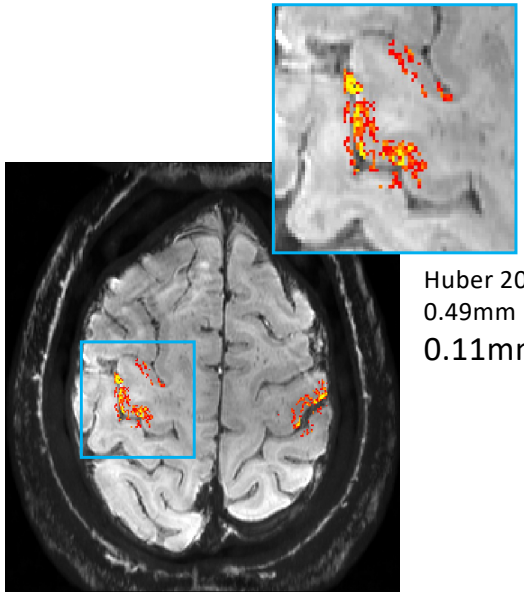
fMRI



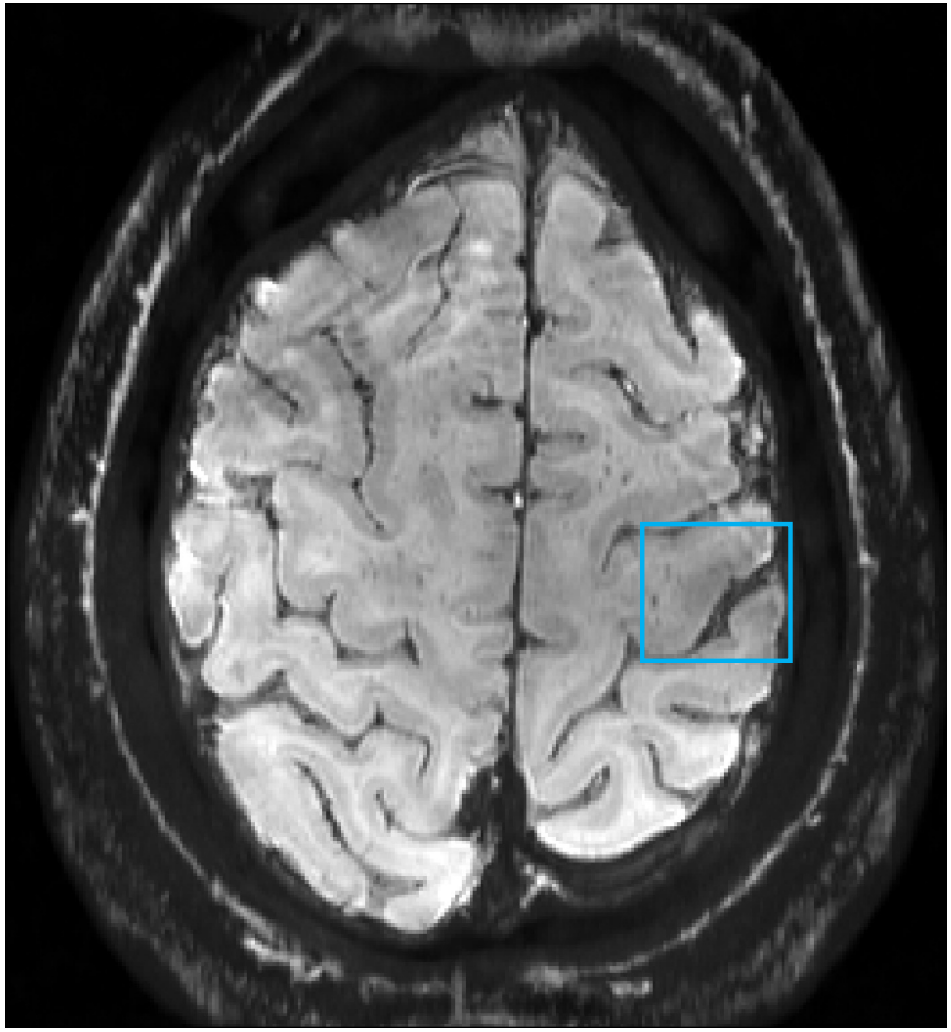
Bandettini, 1991
3.12 × 3.12 ×25
243 mm^3



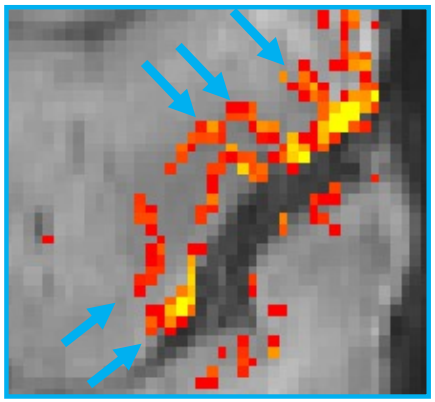
Budde 2014
1mm iso
1mm^3



Huber 2023
0.49mm iso
0.11mm^3



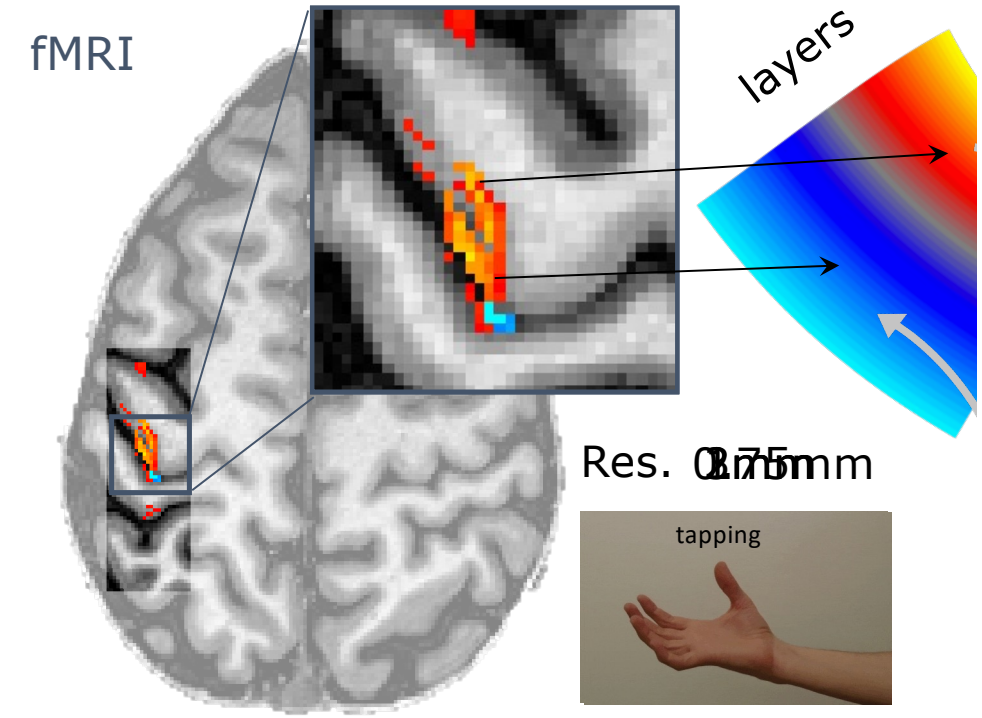
fine scale organization



Neurovascular coupling: make GE-BOLD signal locally misplaced

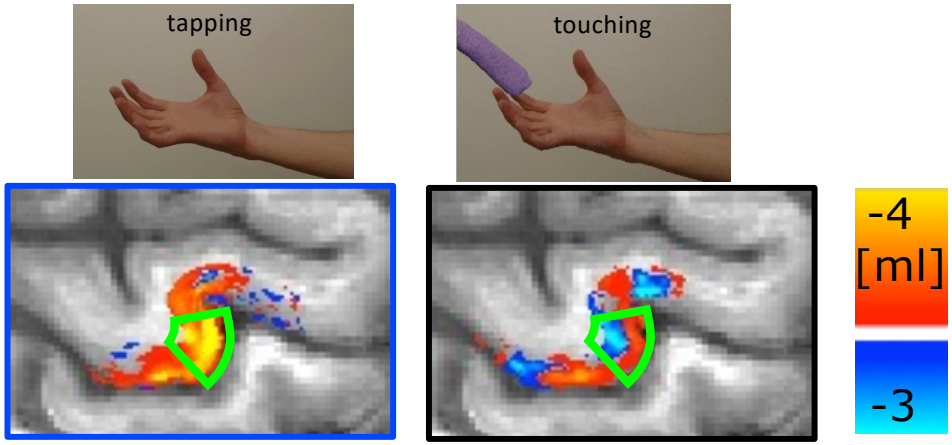
www.neurobureau.org Art competition 2018, fMRI and the BOLD Signal, Jim Stanis, USC, licensed with Creative Commons

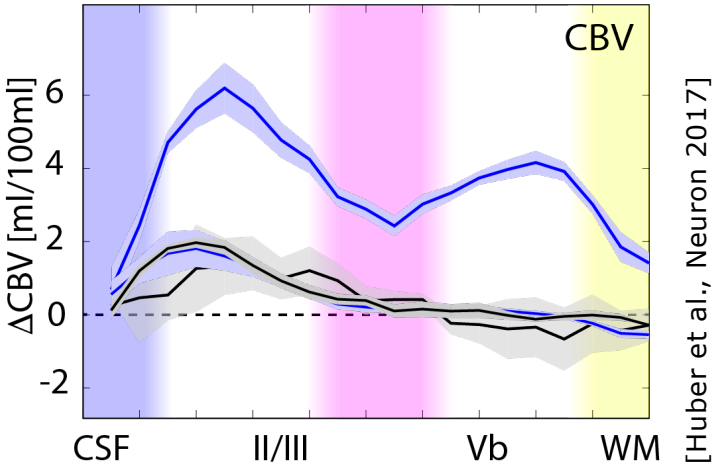
Why should I do high resolution fMRI?

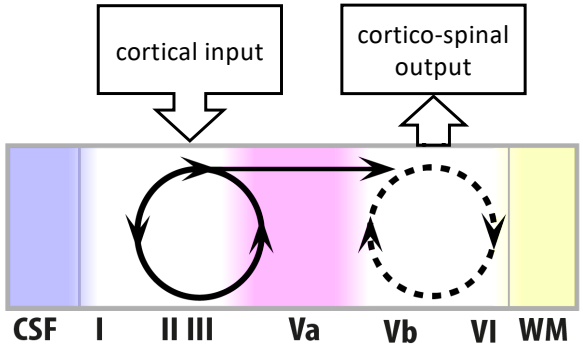


Huber et al., Neuron 2017

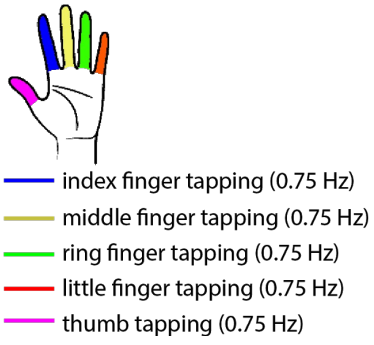
Layers are hard to interpret without
good knowledge about columnar representations

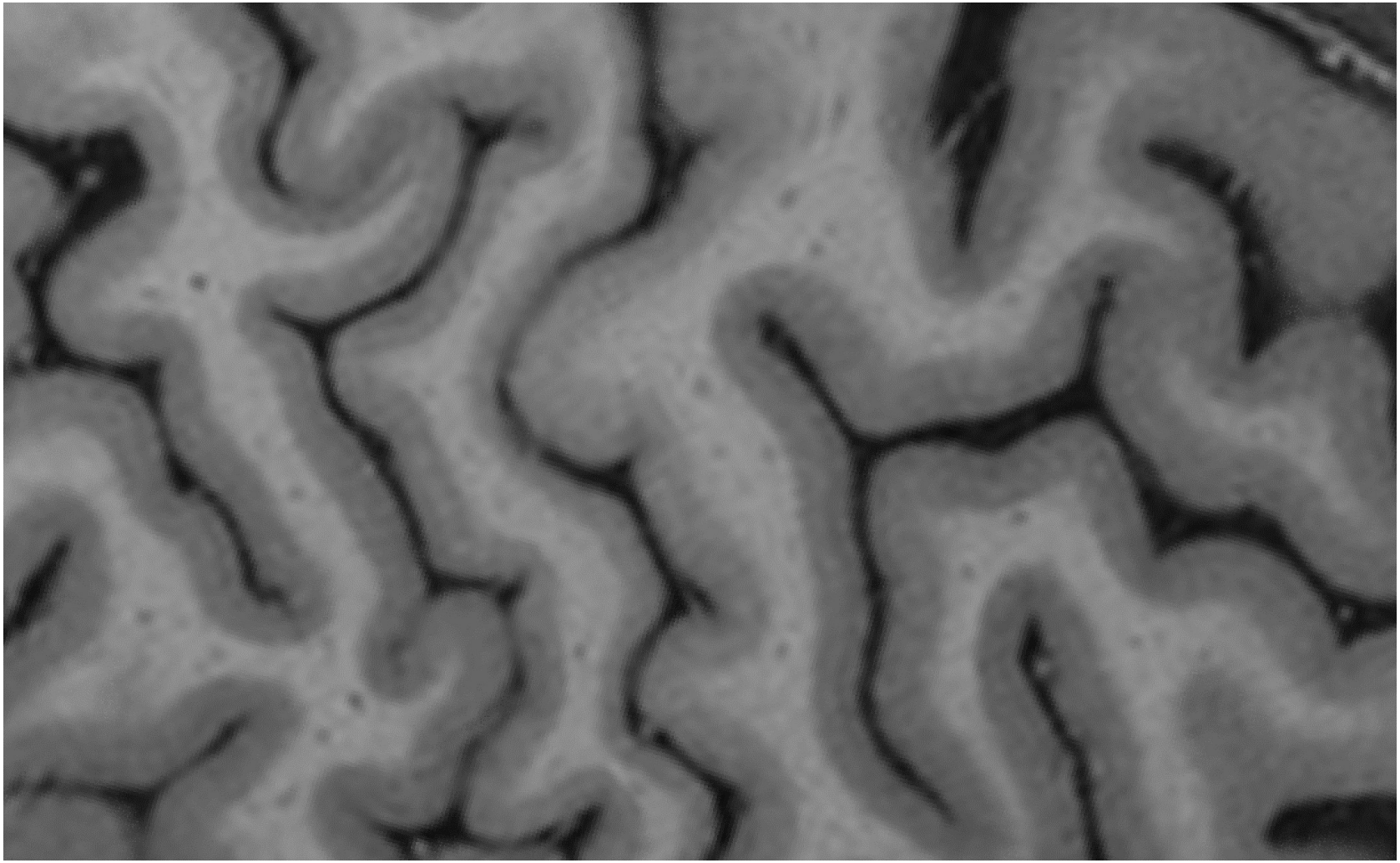


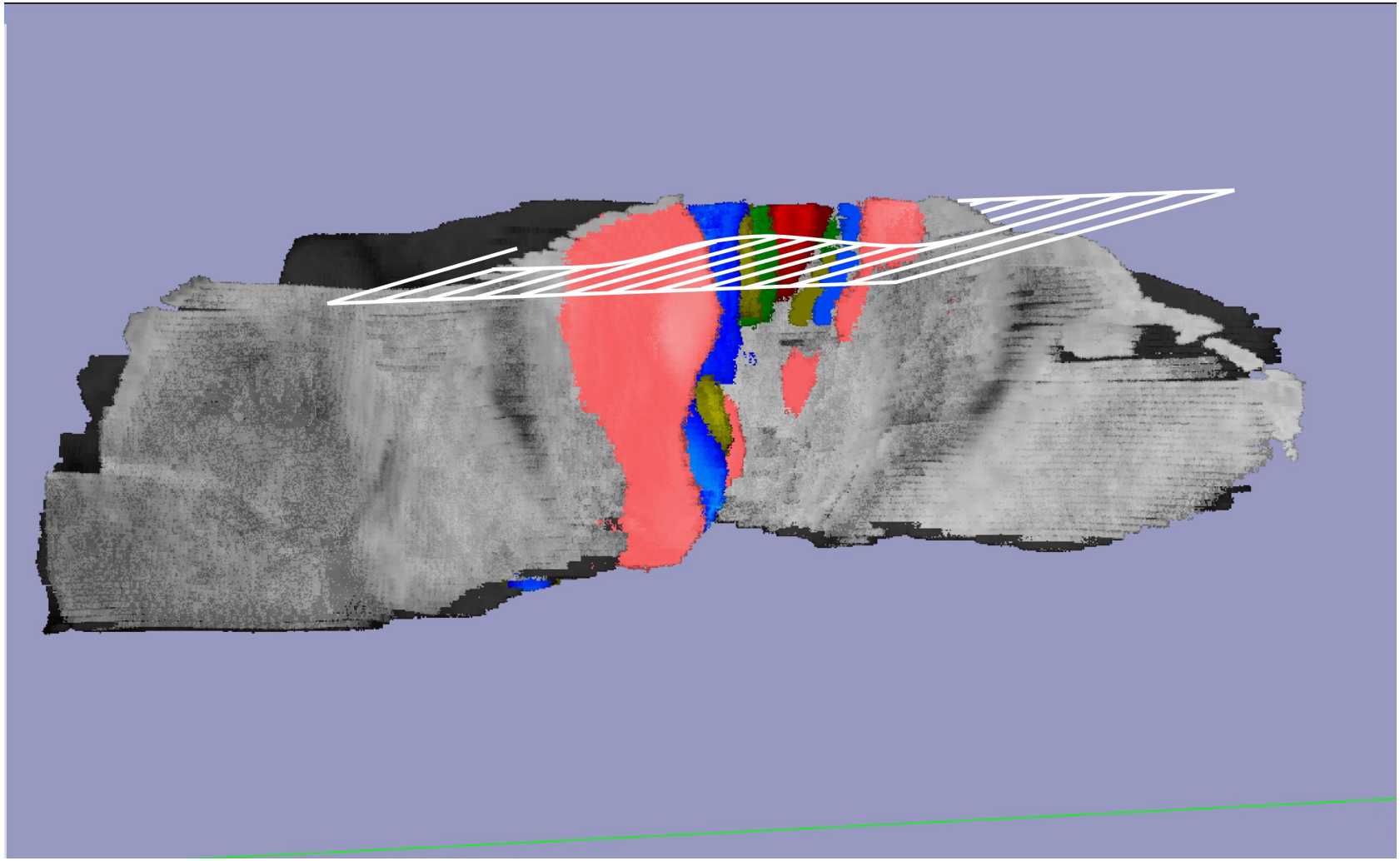




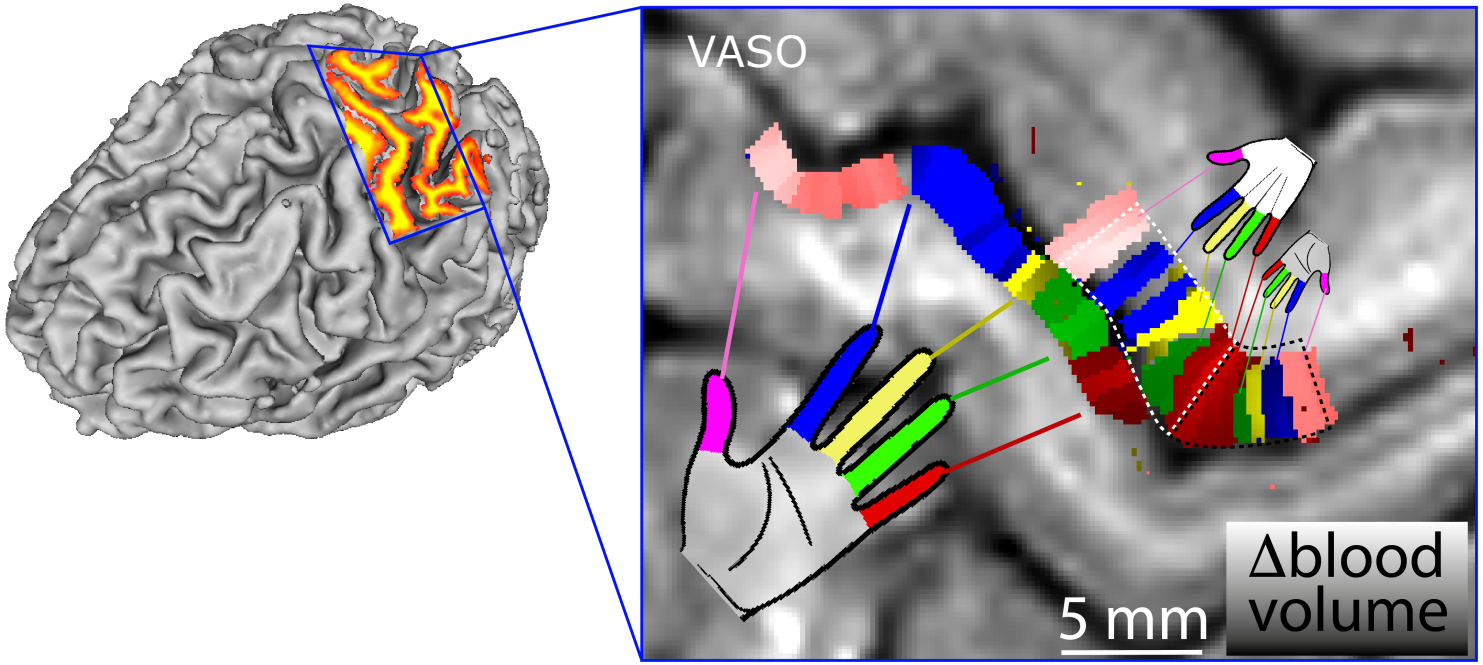
[Weiler, et al., 2008; Papale and Hooks, 2017, Mao, 2011]





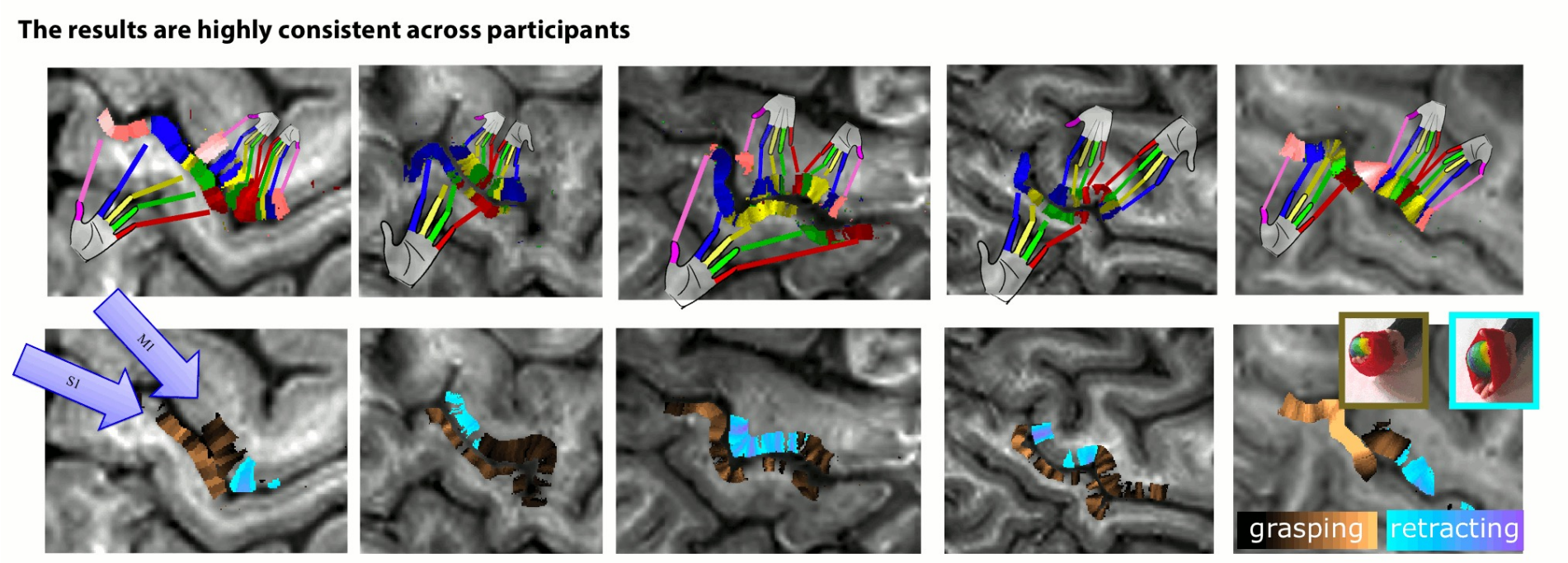


finger representation in M1



Huber, L., Finn, E.S., Handwerker, D.A., Bönstrup, M., Glen, D.R., Kashyap, S., Ivanov, D., Petridou, N., Marrett, S., Goense, J., Poser, B.A., Bandettini, P.A., 2020. Sub-millimeter fMRI reveals multiple topographical digit representations that form action maps in human motor cortex. NeuroImage 208. https://doi.org/10.1016/j.neuroimage.2019.116463

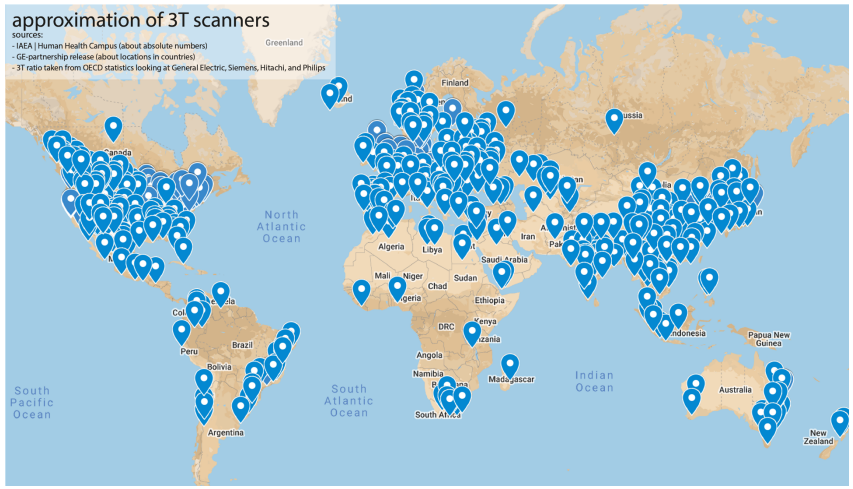
Consistency across people



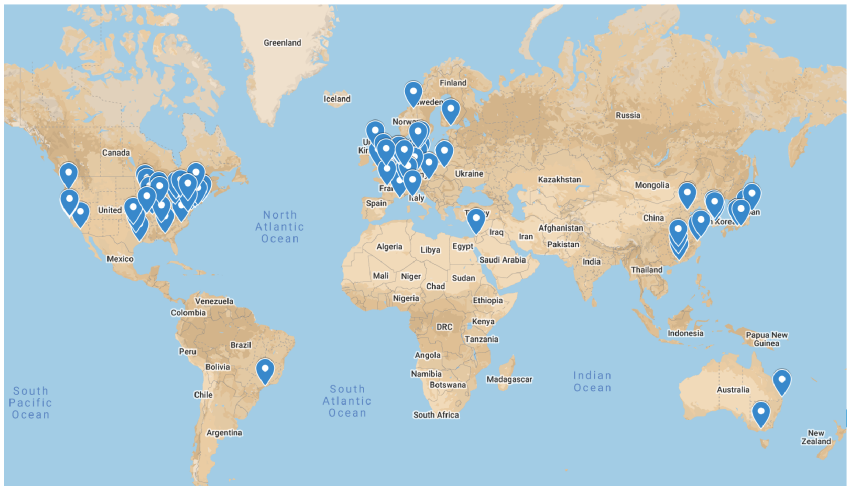
Huber, L., Finn, E.S., Handwerker, D.A., Bönstrup, M., Glen, D.R., Kashyap, S., Ivanov, D., Petridou, N., Marrett
Poser, B.A., Bandettini, P.A., 2020. Sub-millimeter fMRI reveals multiple topographical digit representations t
maps in human motor cortex. NeuroImage 208. https://doi.org/10.1016/j.neuroimage.2019.116463

High resolution is the flagship of ultra high fields

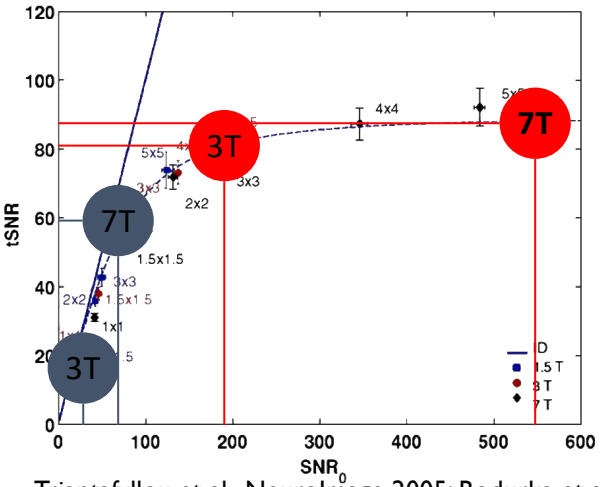
3T scanners



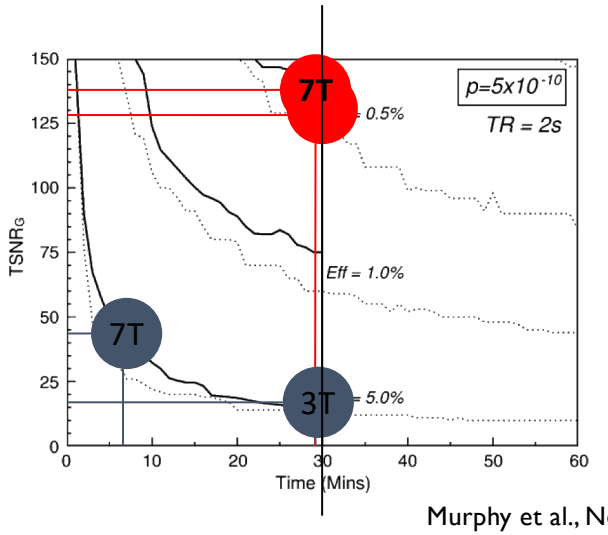
7T scanners



www.layerfmri.com

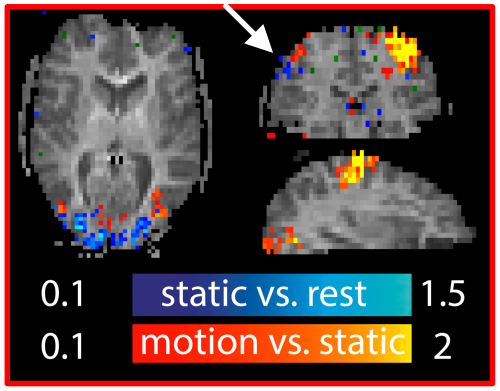


Triantafyllou et al., NeuroImage 2005; Bodurka et al., *NeuroImage,* 2007



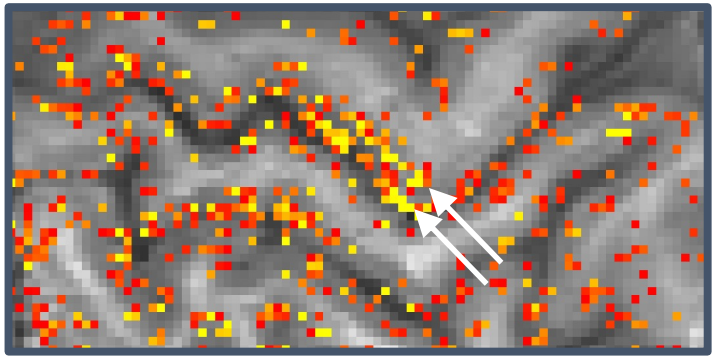
Murphy et al., NeuroImage 2007

negative signal at 3 mm iso. (ΔS = 0.5%)



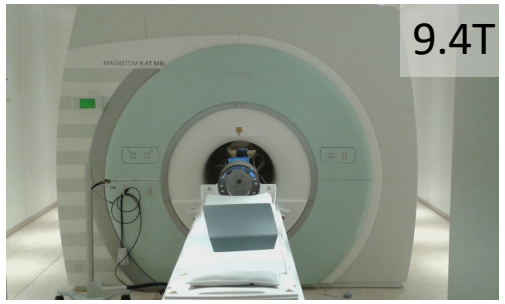
Huber et al., NeuroImage 2015

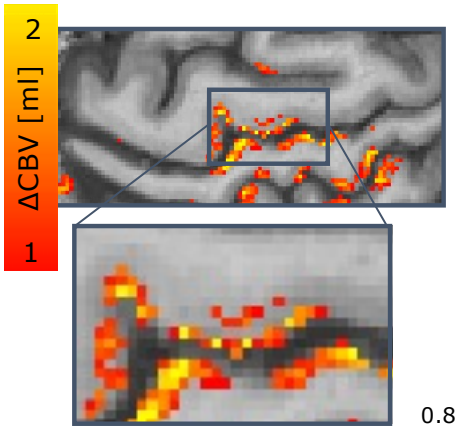
positive layer fMRI at 0.7mm (ΔS = 5%)



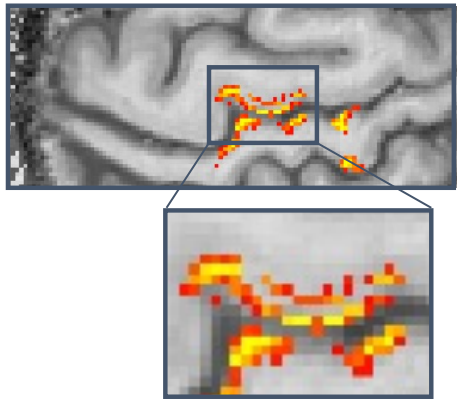
Huber et al., Neuron 2017

field strength

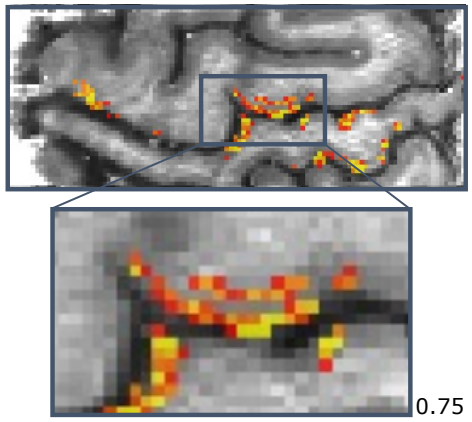




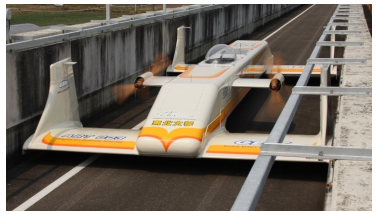
0.8 mm resol.



0.75 mm resol.

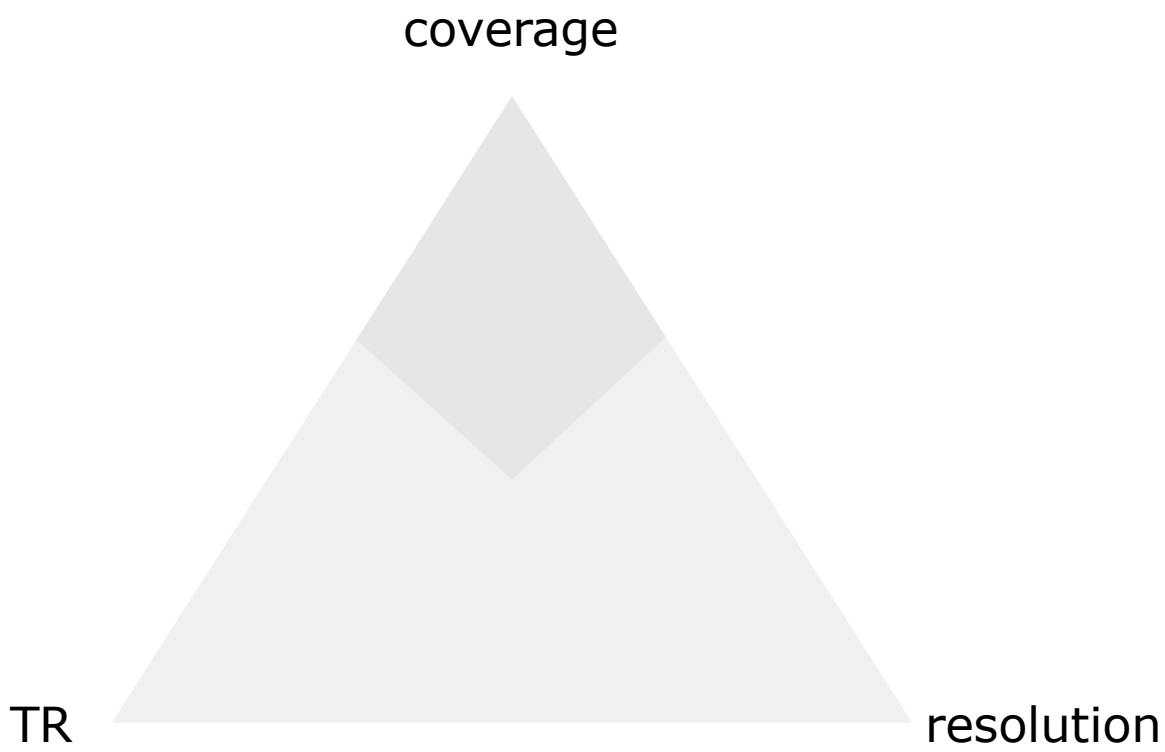


0.75 mm resol.

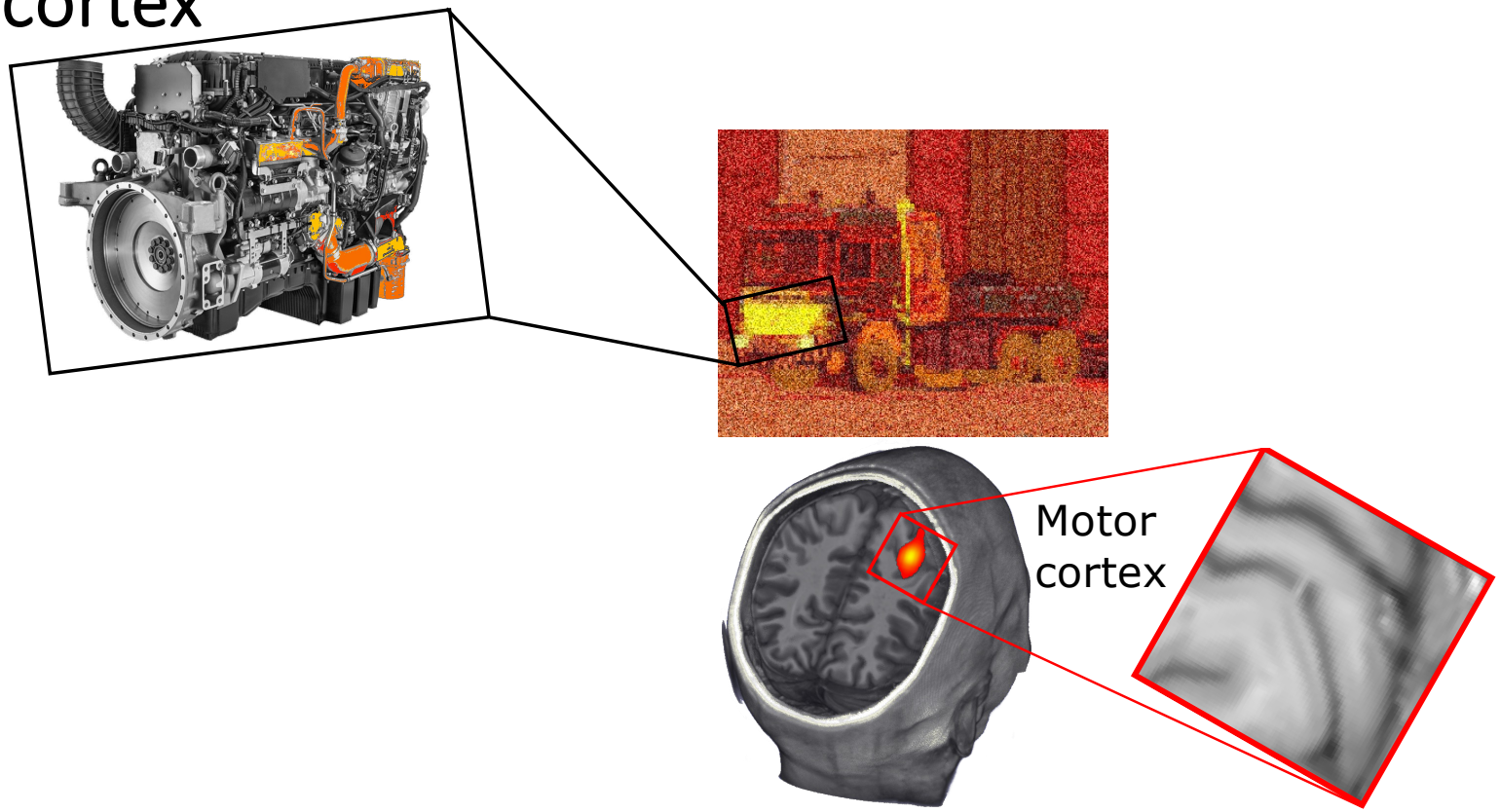


[Huber et al., 2017 NeuroImage]

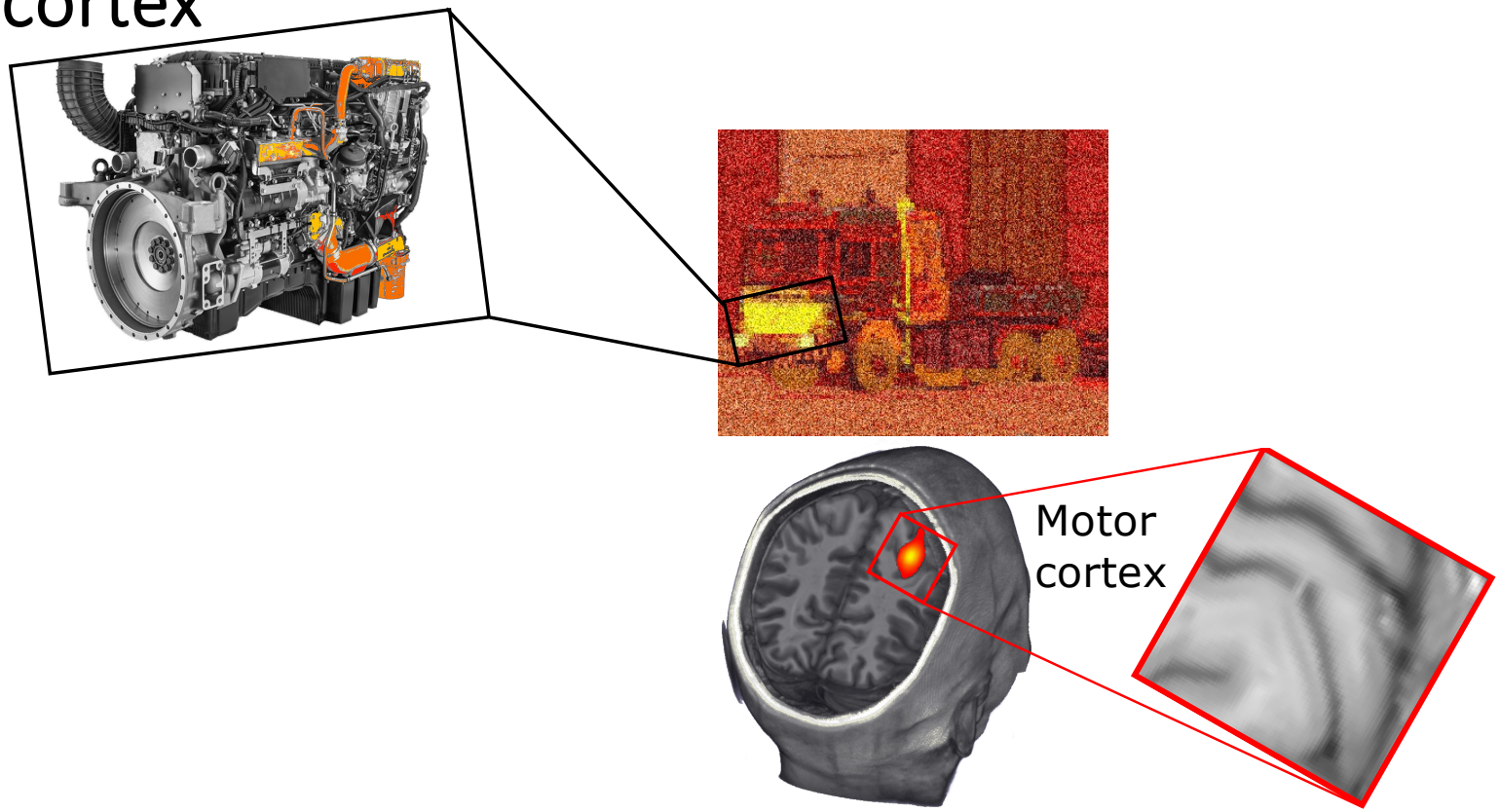
fMRI protocol: pick two out of three



VASO-layer fMRI: beyond the motor cortex

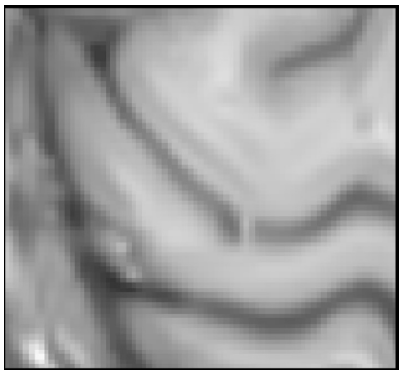


VASO-layer fMRI: beyond the motor cortex



Whole brain layer fMRI

See also
[Pais-Roldán et al., 2020]
[Berman et al., 2020]
[Stirnberg and Soetcker 2021]
[Sharoh et al., 2019]
[Deshpande et al., 2022]



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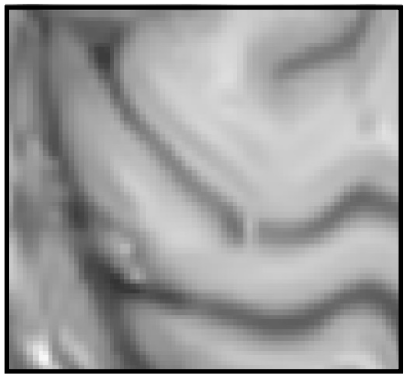

Whole brain layer fMRI

See also
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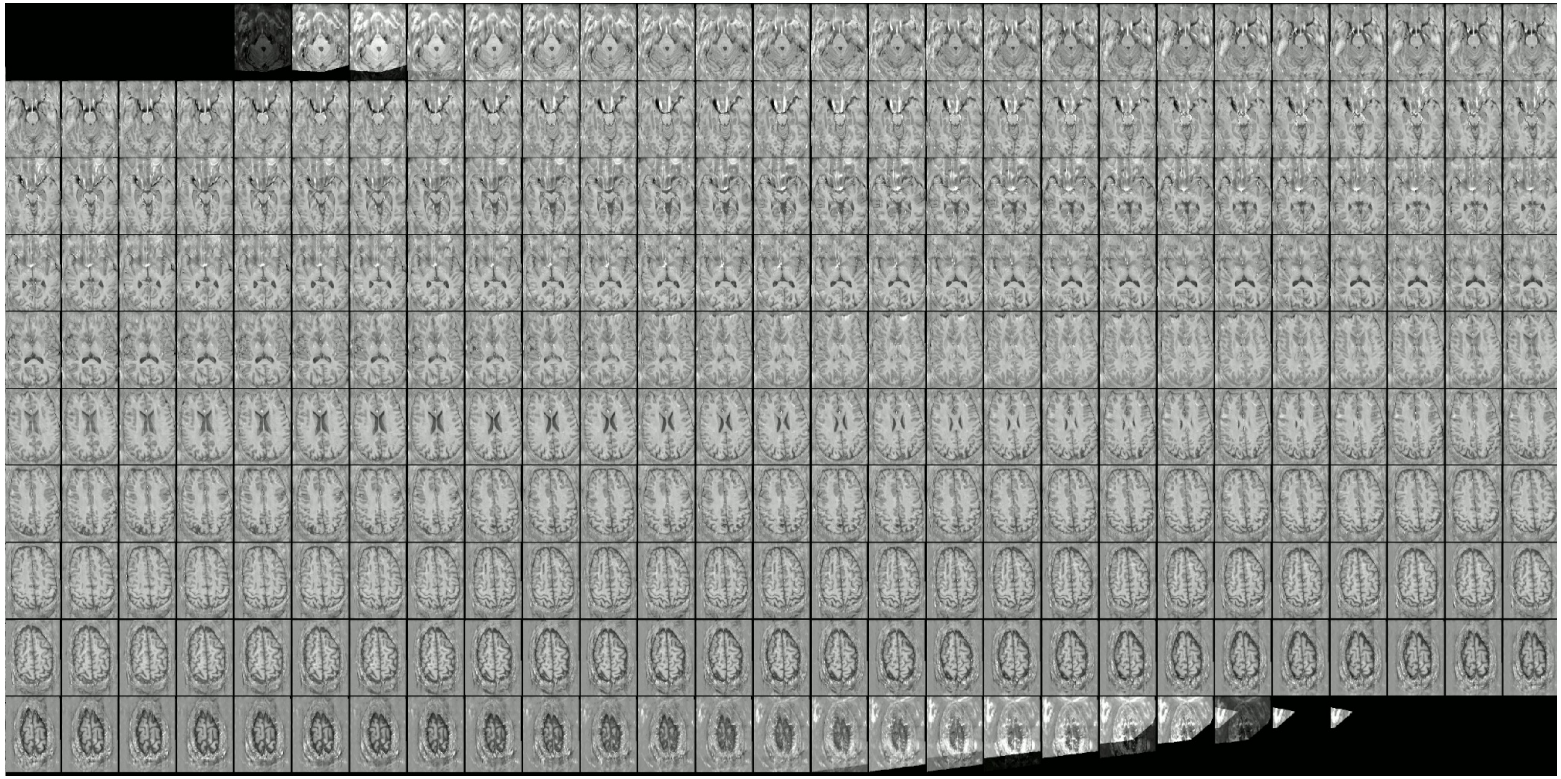
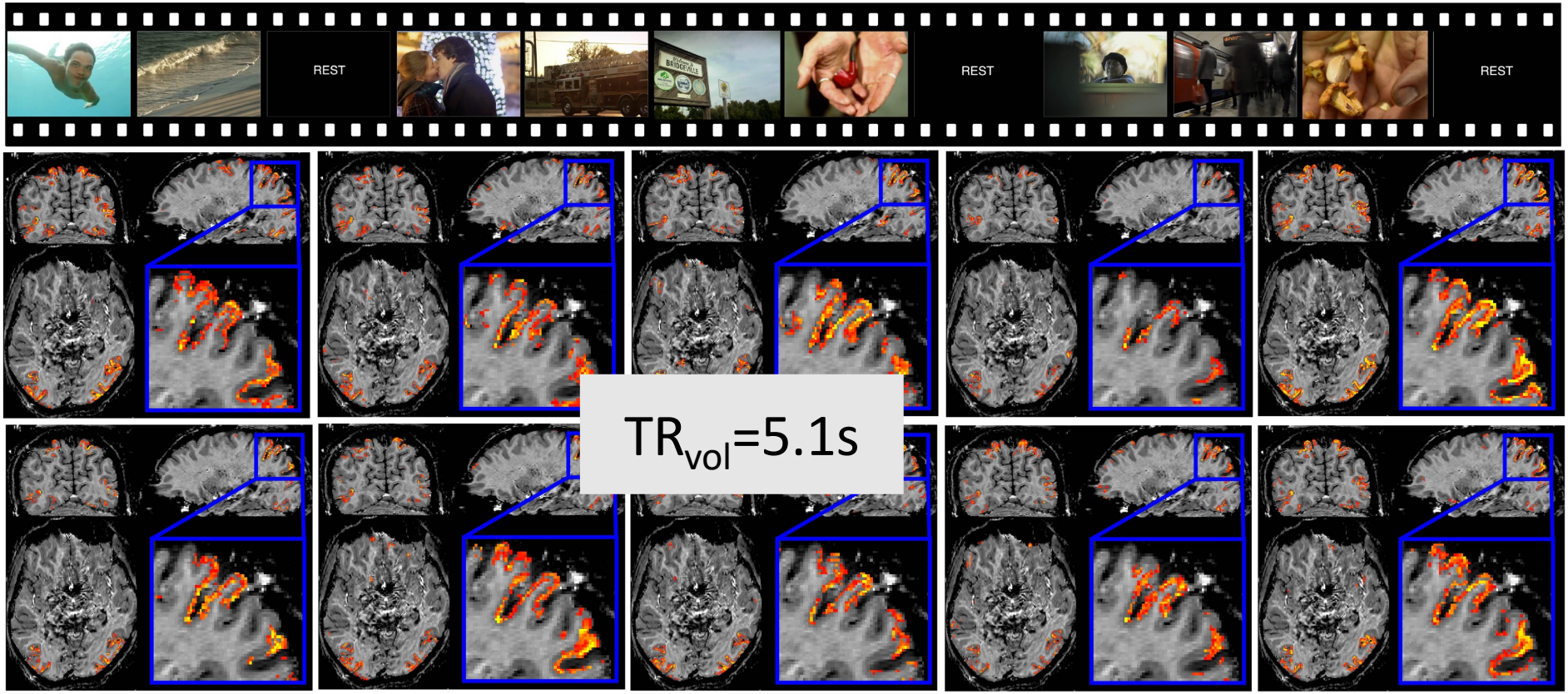
[Berman et al., 2020]
[Stirnberg and Soetcker 2021]
[Sharoh et al., 2019]
[Deshpande et al., 2022]

120 slices
0.8mm iso.
TR = 5.1s
GRAPPA = 6
FLASH ACS

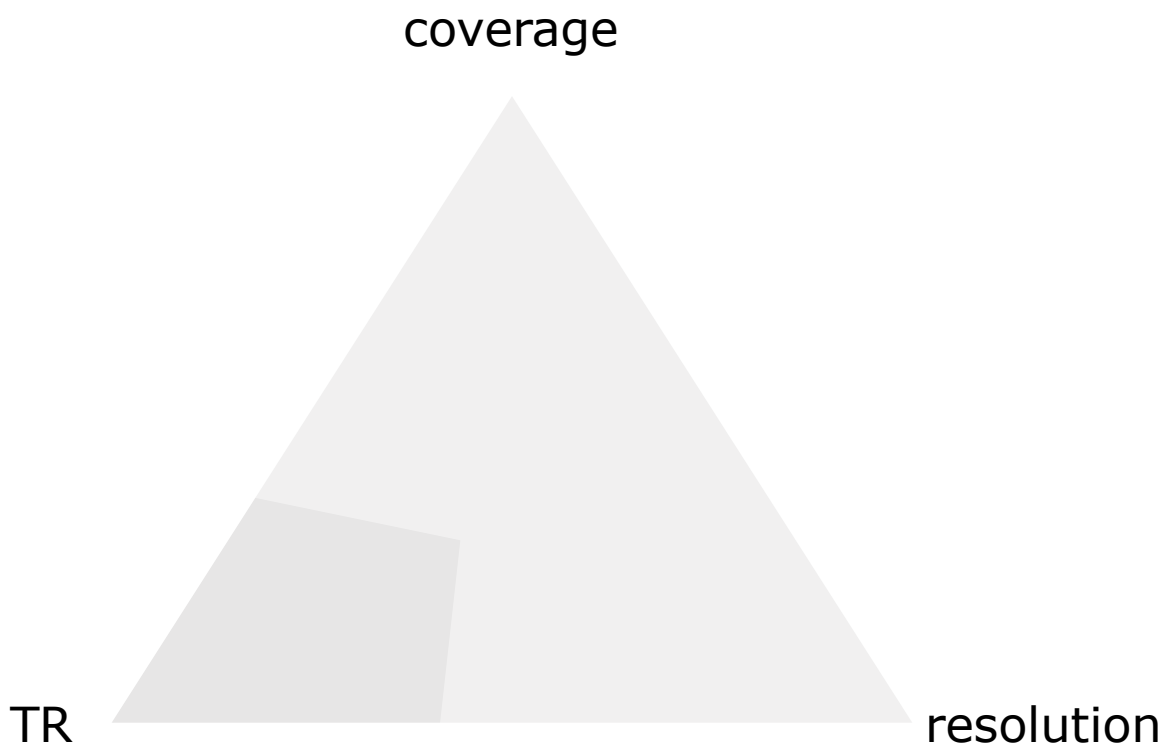


Whole brain layer-fMRI

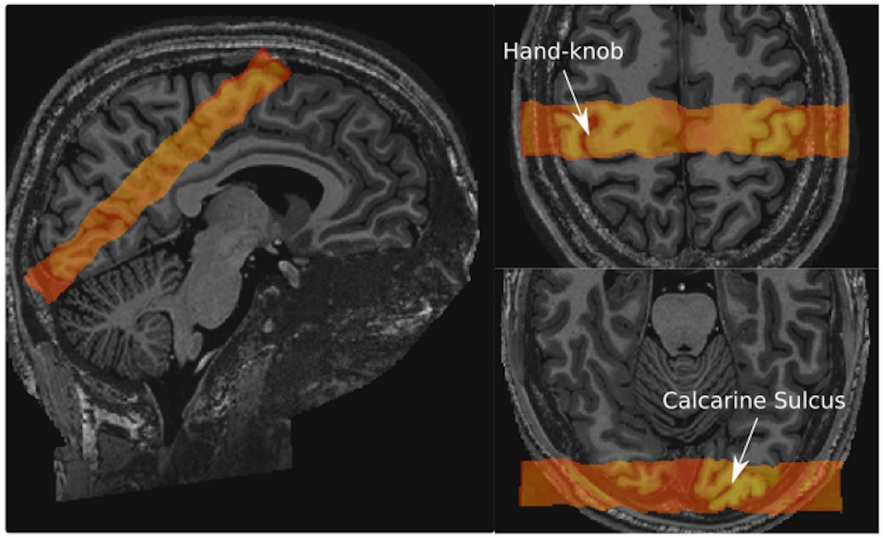
Koiso, K., Müller, A.K., Akamatsu, K., Dresbach, S., Gulban, O.F., Goebel, R., Miyawaki, Y., Poser, B.A., Huber, L. *Acquisition and processing methods of whole-brain layer-fMRI VASO and BOLD: The Kenshu dataset*. ApertureNeuro 2023



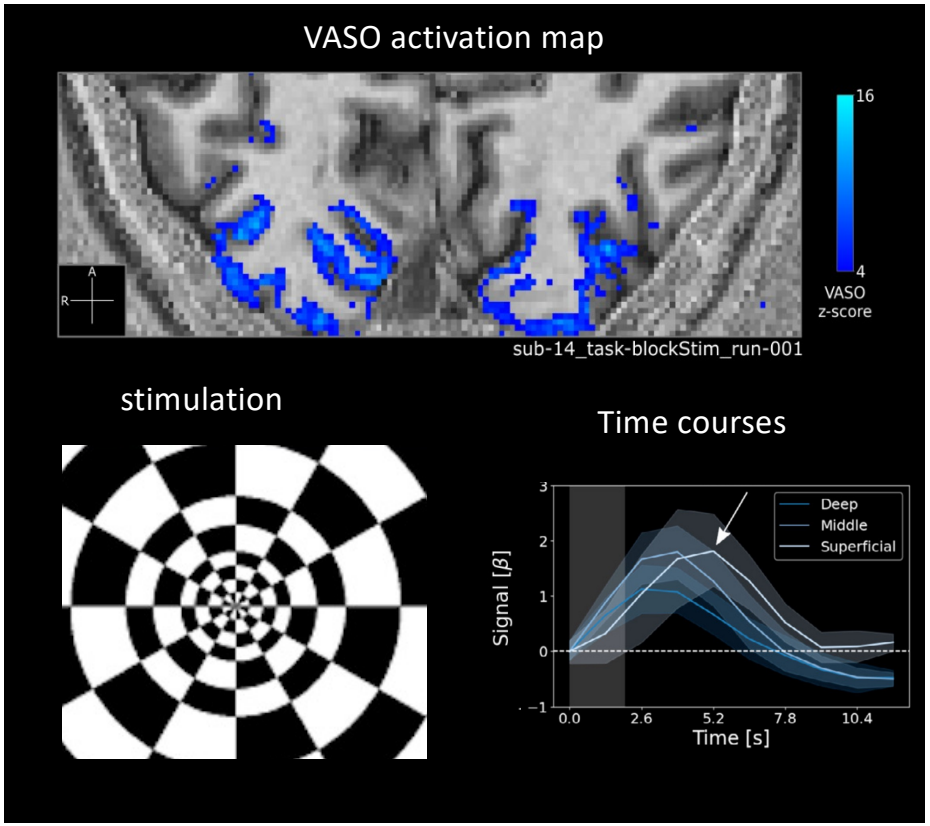
fMRI protocol: pick two out of three



Microvascular CBV responses in deeper layers are faster.

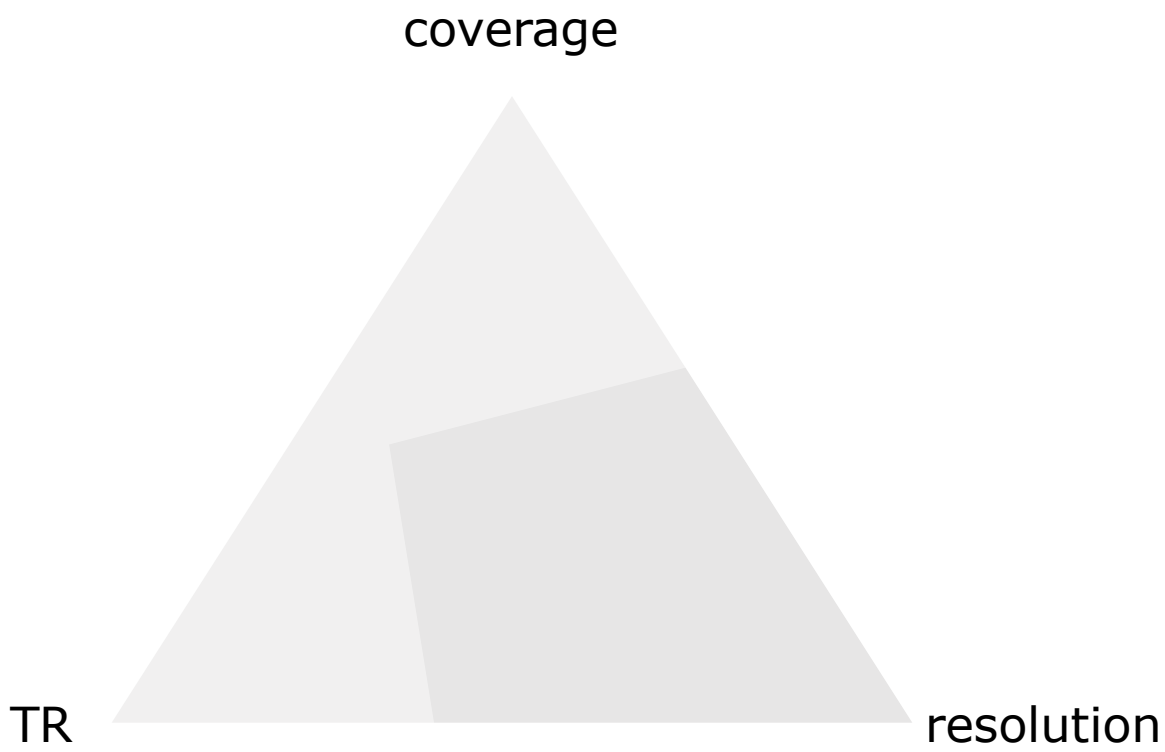


TR_{vol} = 895 ms
16 slices

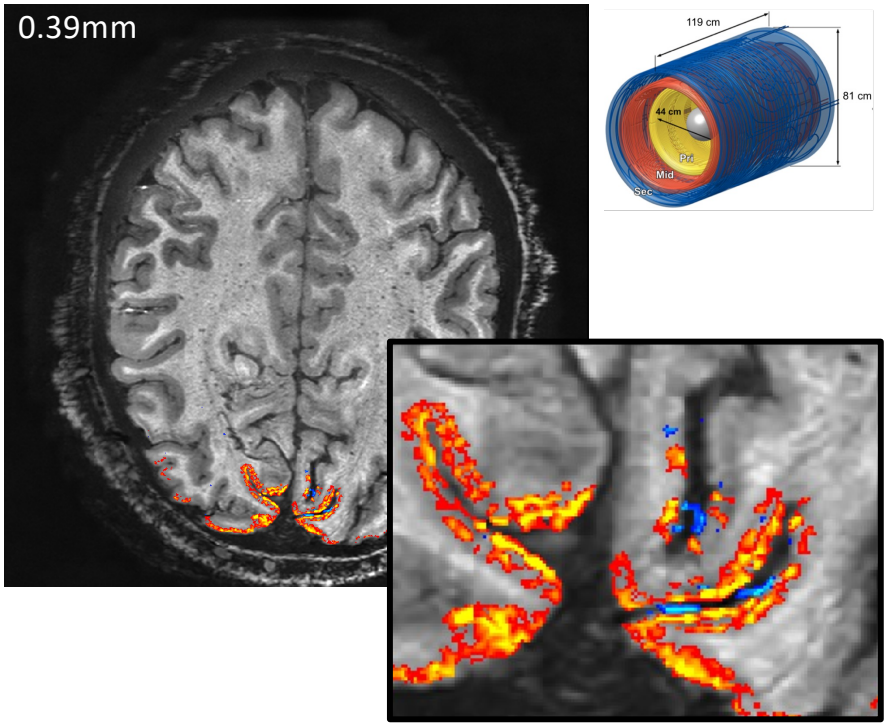


Dresbach, Huber, Gulban, Goebel. Fast layer-fMRI VASO with short stimuli and event-related designs at 7T, NeuroImage 2023

fMRI protocol: pick two out of three

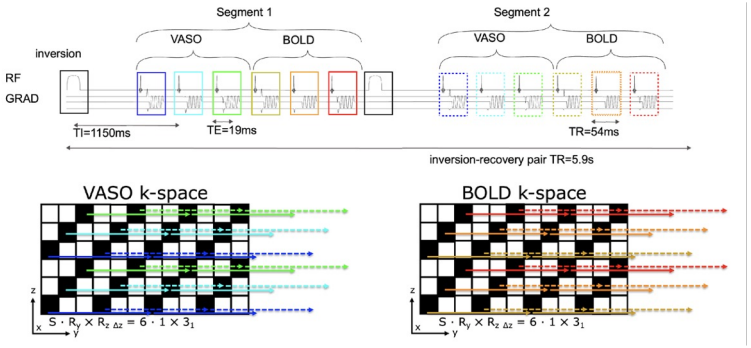


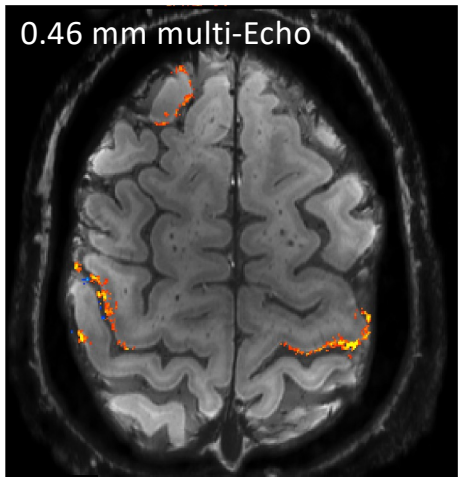
Next Generation 7T

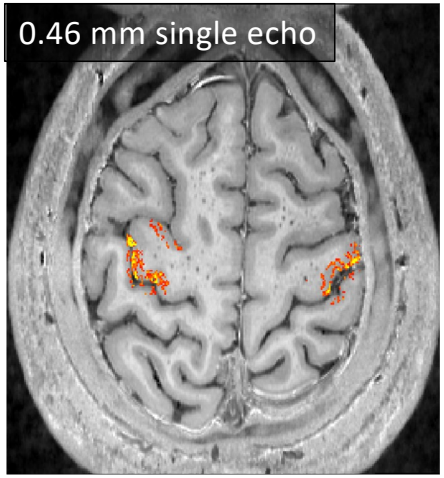


Head gradient designed for layer-fMRI (Feinberg Nat Methods 2023)

7Tb @ FMIRF

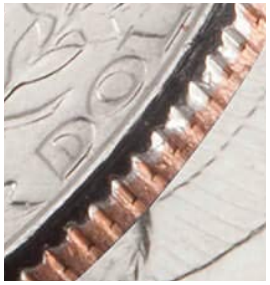


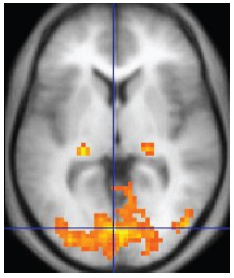




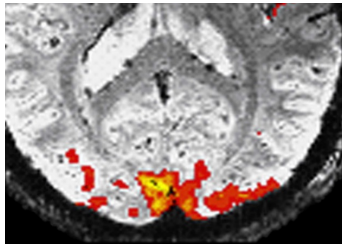
The ultimate limit of fMRI resolution in practice

Res.	3.12mm	0.8mm	0.4mm	0.2mm* non-iso	0.012mm
Vol.	30µl	0.5µl	0.064µl	0.015µl	0.0000017µl

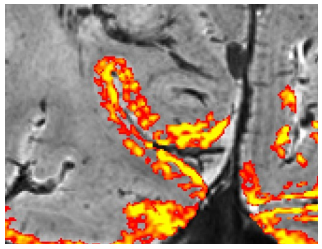




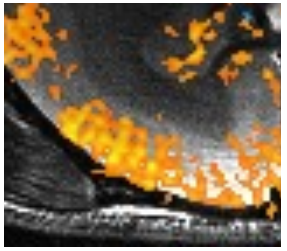
Bollmann 2021



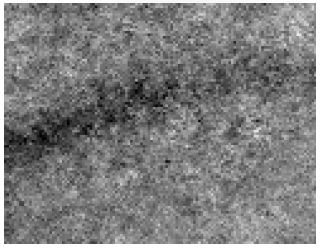
Poser et al. 2010



Feinberg et al. 2021



Silva (NIH) 2013

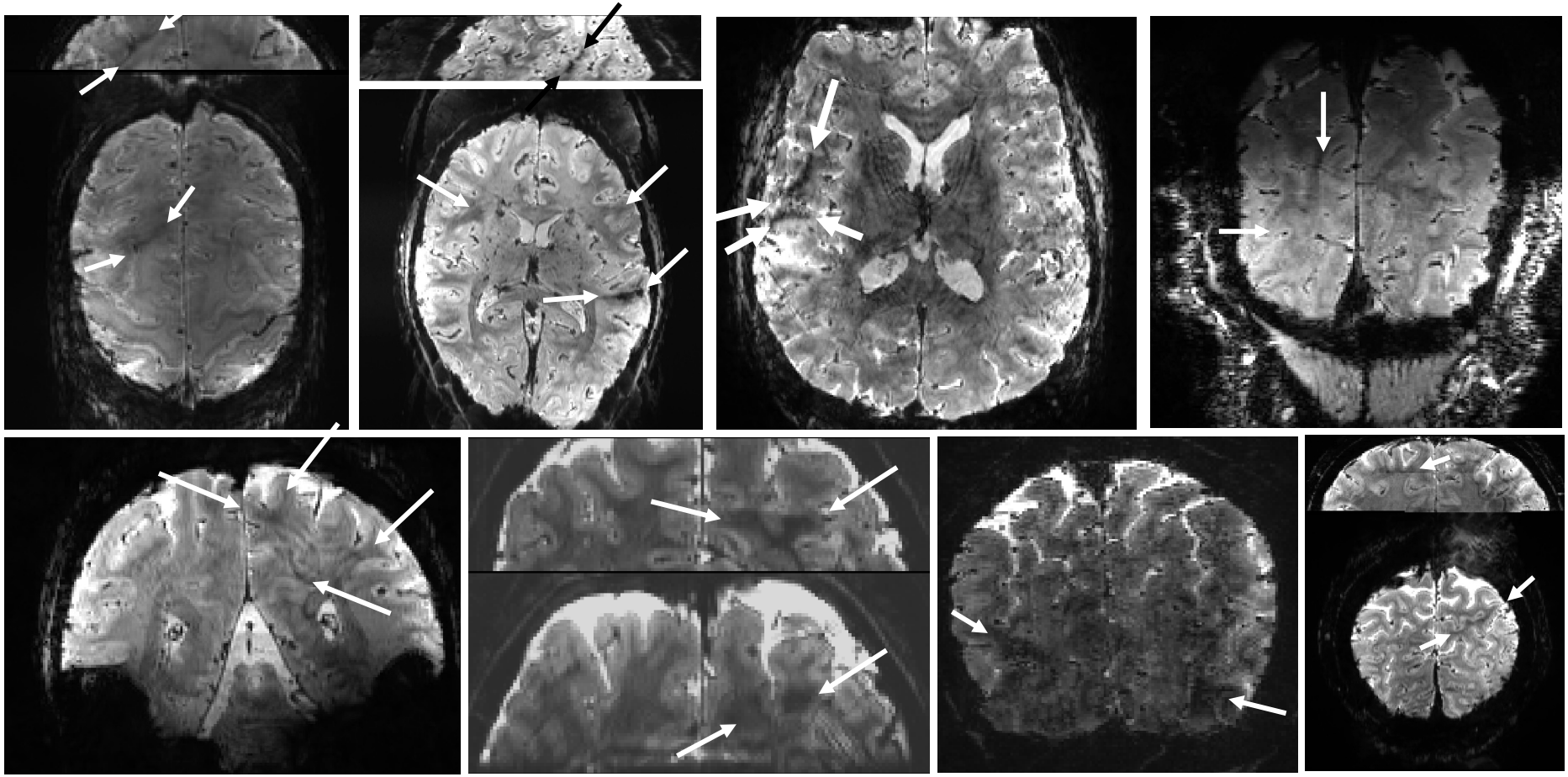


Duyn, Dodd (NIH) 2008

*across different experimental setups

Challenges of high-resolution fMRI: raw data look like this

Challenges of high-resolution fMRI: raw data look like this

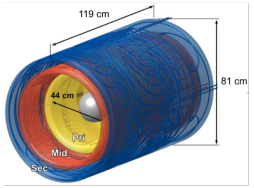


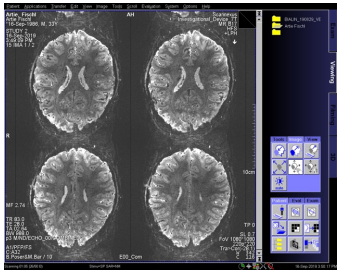
Data from the top labs of layer-fMRI: *Maastricht, Nijmegen/Essen, CMRR, NIH, MGH, Amsterdam, Leipzig, Cambridge.*

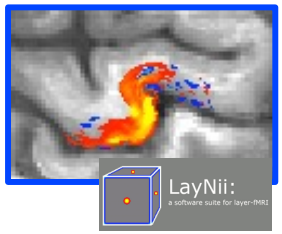
High-resolution fMRI in spectrum of research dependencies.

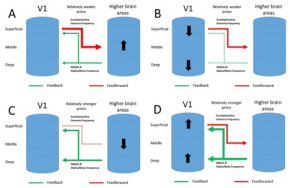
focus (workforce) of intramural NIH

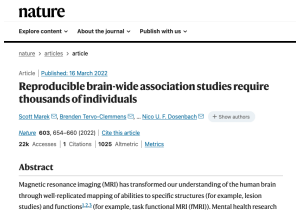
Hardware → imaging → modulation → brain → Behaviour or symptoms → health





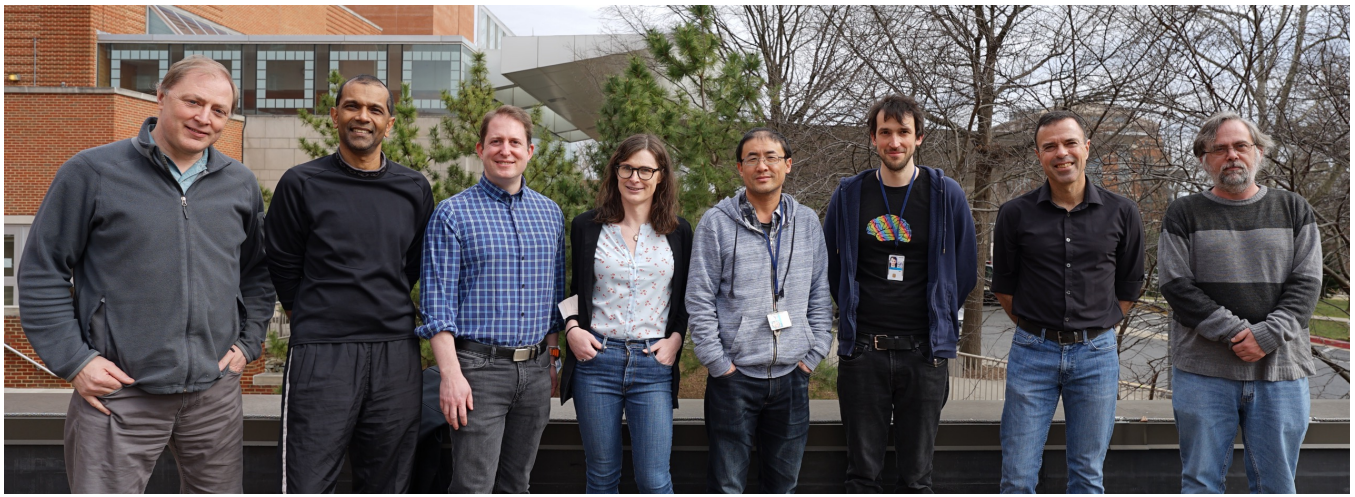






this presentation

Thank You



- Kenshu Koiso (Tokyo)
- Ruediger Stirnberbg (DZNE)
- Philipp Ehses (DZNE)
- Martin Kronbichler (Salzburg)
- David Feinberg (Berkeley)
- Alex Beckett (Berkeley)
- Sean Marrett (NIMH)
- Silvina Horovitz (NIH)
- Benedikt Poser (Maastricht)
- Lonike Faes (Maastricht)
- Federiko De Martino (Maastricht)
- Alessandra Pizzuti (Maastricht)
- Faruk Gulban (Maastricht)
- Sebastian Dresbach (Maastricht)
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- Luca Vizioli (Minnesota)
- Harald Moeller (Leipzig)