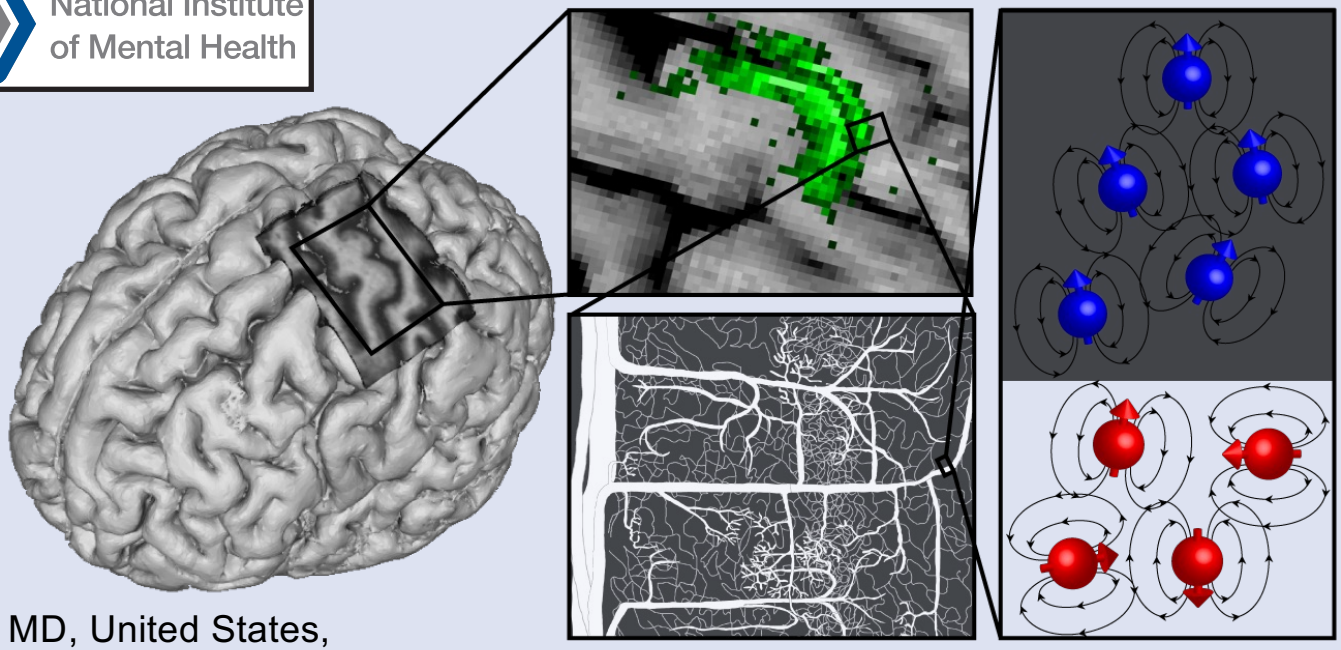
fMRI methods and applications at high field and high resolution

fMRI (methods ∨ applications) ⊗ (high field ∧ high resolution)

Renzo (Laurentius) Huber



[1]NIMH, Bethesda, MD, United States,

Jun 7th 2017

high field and high resolution fMRI educational talks

ISMRM

http://www.ismrm.org/14/14program.htm

PROGRAM

Moderators: Jonathan R. Polimeni, Ph.D. & Kamil Uludag, Ph.D.

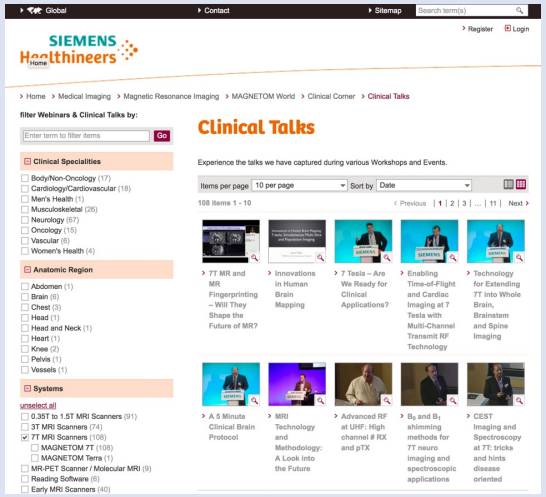
08:30	Neurovascular Coupling, Revisited	Anna Devor, Ph.D.
09:00	fMRI Analysis Methods: Classics & New Trends	Robert W. Cox, Ph.D.
09:25	fMRI Acquisition Strategies	David A. Feinberg, M.D., Ph.D.
09:50	Break - Meet the Teachers	
10:15	Basic Neuroscience: fMRI Studies of Sensory Systems	Federico De Martino, Ph.D.
10:40	High-Resolution fMRI in Humans: What is the Limit?	Robert Turner, Ph.D.
11:05	Clinical Applications of fMRI: From Presurgical Planning to Functional Connectivity	Natalie L. Voets, Ph.D.

study group workshops

http://www.ismrm.org/workshops/UHF16/

SIEMENS

https://www.healthcare.siemens.com/magnetic-resonance-imaging/magnetom-world/clinical-corner/clinical-talks



"layer fMRI" YouTube channel

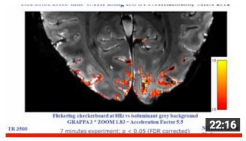
https://www.youtube.com/channel/UCMjtQ3FD41pAh1VJz-UZGJQ

Alan Koretzky shows how layer fMRI reveals feed-forward vs. feedback input in plasticity ...

Layer fMRI
3 months ago • 14 views
This talk was given in June 2014 in Charleston, NC. source: http://www.ismrm.org/workshops/fMRI14/program.htm.

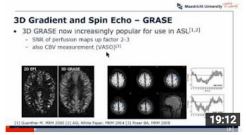
Lars Muckli Predictive encoding using layer-dependent fMRI

Layer fMRI
4 months ago • 52 views
source: https://www.dartmouth.edu/~ccn/workshops/workshop_2016.html.



Robert Turner: layer-dependent fMRI in Leipzig

Layer fMRI
4 months ago • 26 views
Source from ISMRM 2014: http://www.ismrm.org/14/program_files /WK03.htm Sorry about the sound quality.

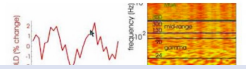


Benedikt Poser Talking about his 3D-EPI with CAIPI

Layer fMRI
4 months ago • 16 views
source: http://www.ismrm.org/workshops/MultiSlice15/

Sriranga Kashyap talks about IR-EPI with TI permutating over slices

Layer fMRI
2 months ago • 11 views
source from http://www.ismrm.org/16/program_files/O33.htm.



Amir Shmuel: resting state laminar activity

Layer fMRI
4 months ago • 6 views

7T scanner worldwide

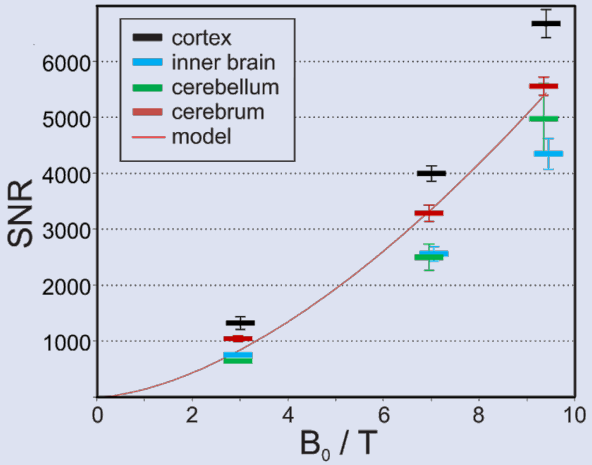
Open Google map (edits and corrections are welcome)
https://drive.google.com/open?id=1dXG84OZIAOxjsqh3x2tGzWL1bNU

65 UHF scanners
59 locations

high field fMRI: prospects and challenges

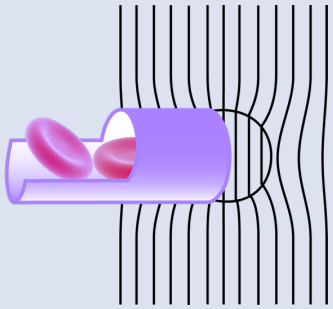
Prospects:

- SNR



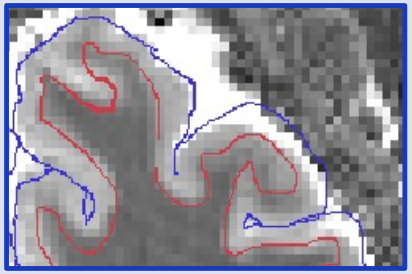
Pohmann, 2016 MRM

- fMRI contrast



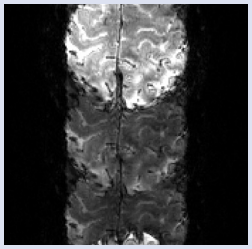
Challenges:

- distortions

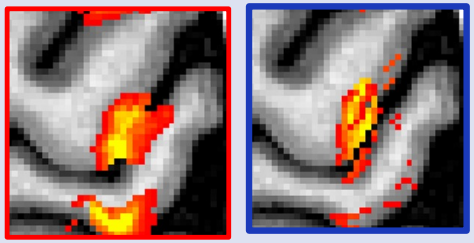


- blurring

- artifacts



- neural specificity

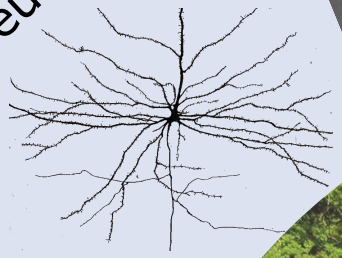


- acquisition speed

spatial scales in neuroscience

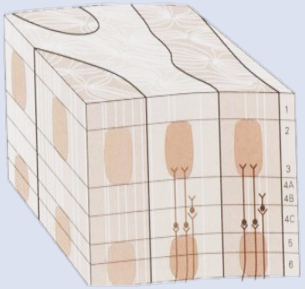
DNA

neuron

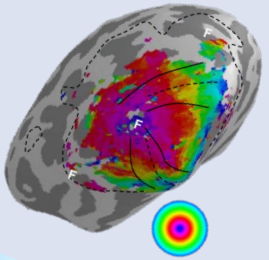


100 neurons

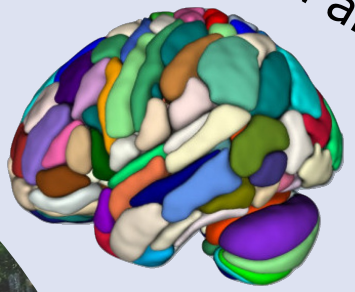
layers & columns



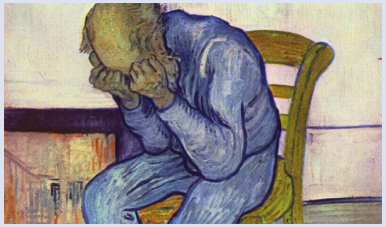
within-areas



brain areas



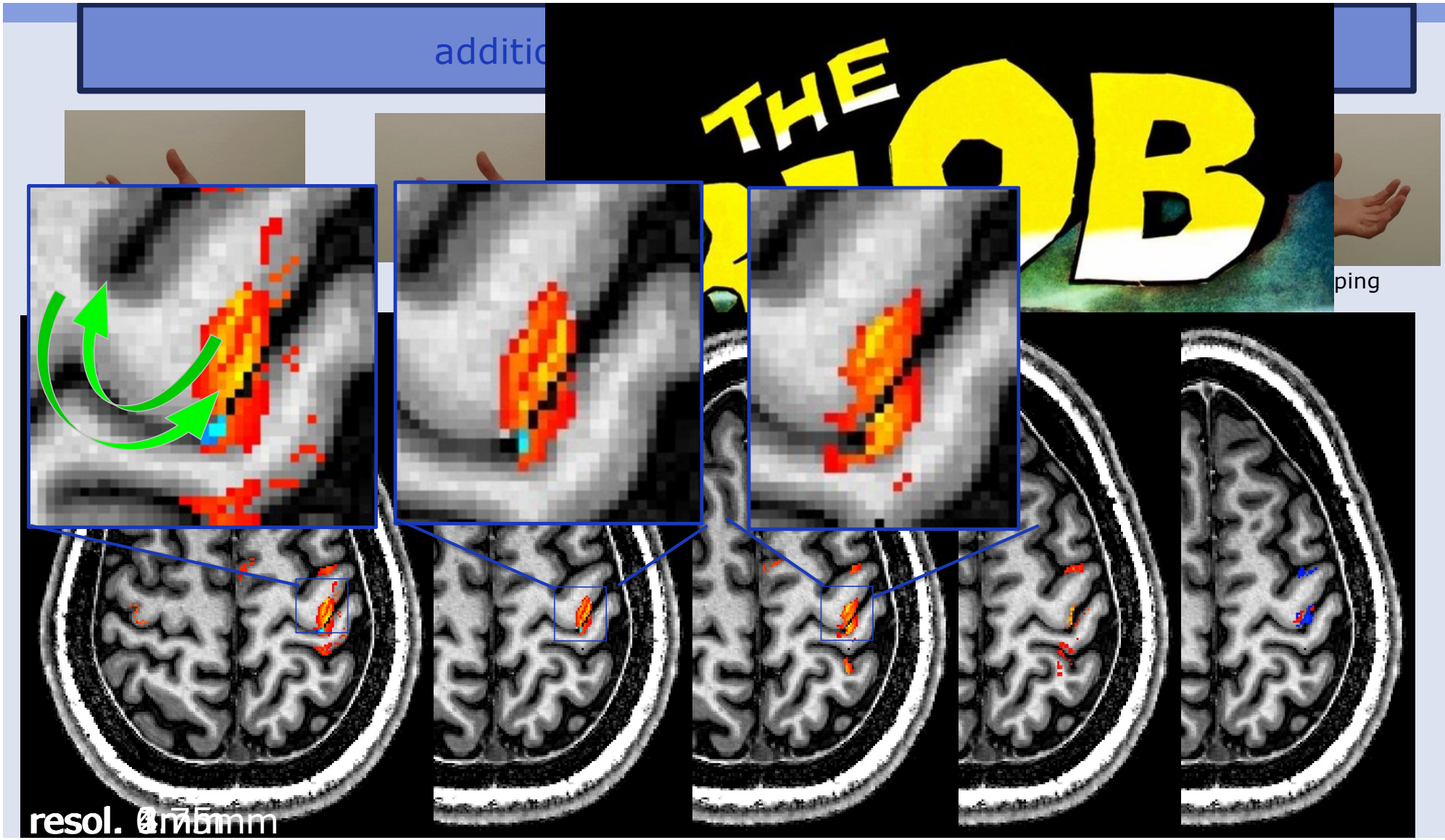
behavior



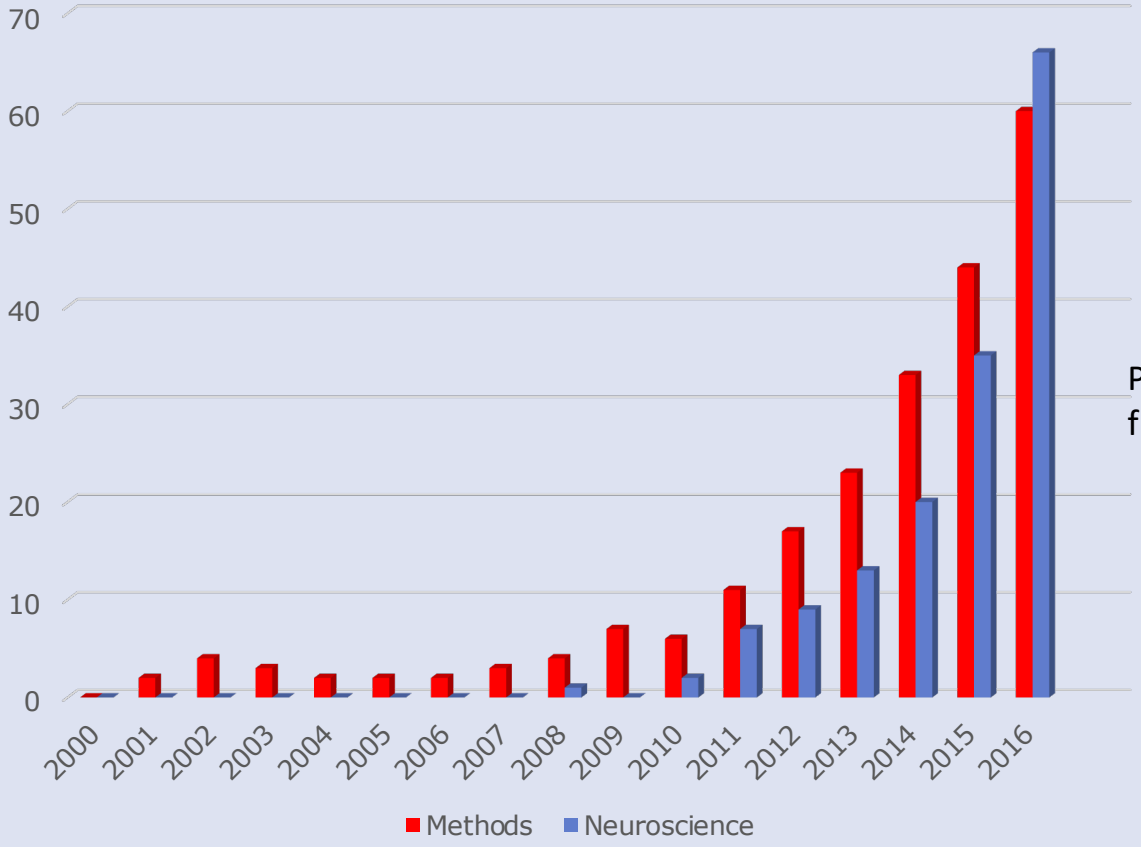
van den Heuvel, Neuron

bridge metaphor idea from
Eric Wong and Bruce Rosen

addition



high-resolution, high-field fMRI publications



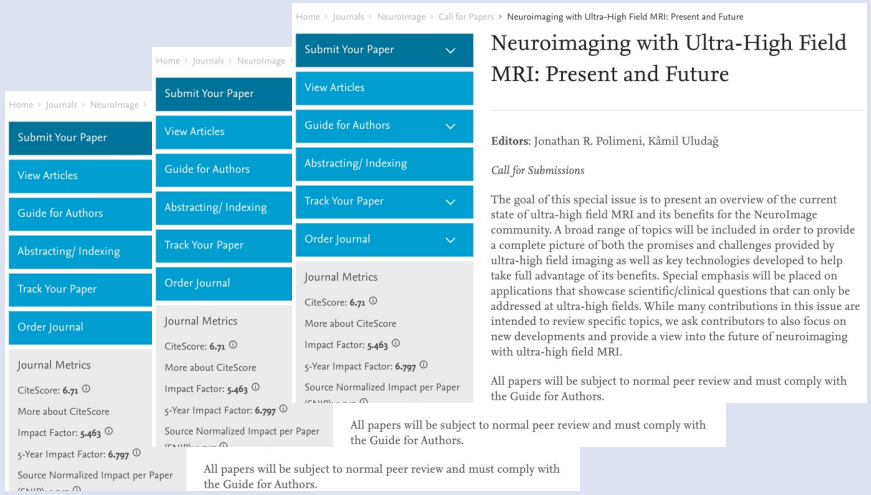
source: PubMed, manually categorized

NeuroImage Special Issues

Neuroimaging with **Ultra-High Field** MRI: Resent and Future

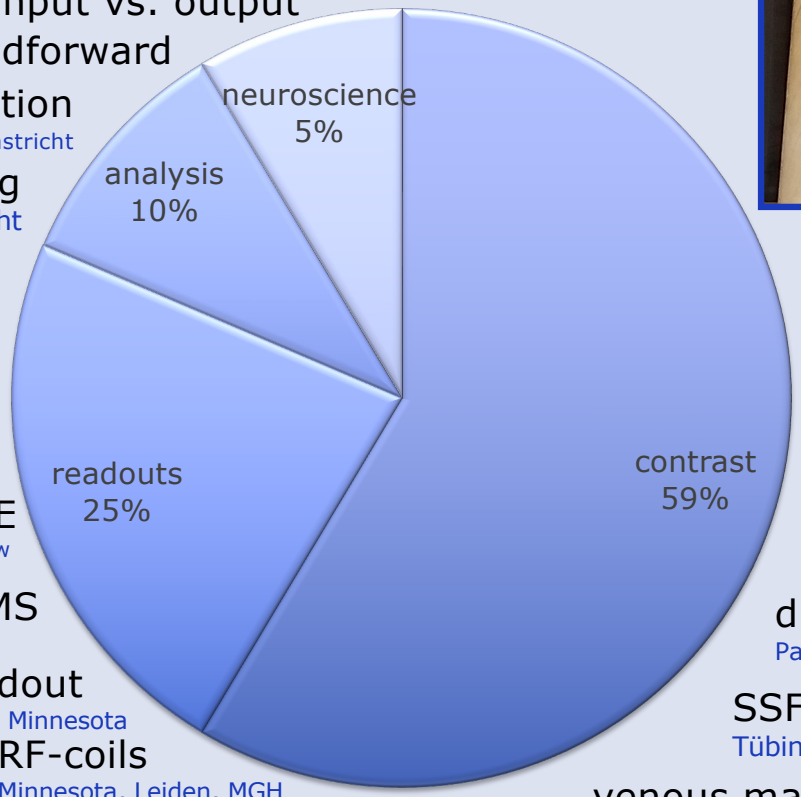
Pushing the **spatio-temporal limits** of MRI and fMRI

Prospects for **cortical laminar MRI** functional and anatomical



columns and layers

50 (of 155) layer-papers in last 6 months



input vs. output

feedback vs. feedforward

segmentation
MGH, Leipzig, NIH, Amsterdam, Maastricht

layering
Leipzig, Maastricht

normalization
Leipzig, MGH, Maastricht, Utrecht, Nijmegen

2D-EPI vs 3D-EPI
NIH, MGH, UCL, Maastricht

3D-GRASE
Minnesota, Maastricht, Glasgow

slider SMS
Berkley, MGH

zoomed readout
Leipzig, Maastricht, Minnesota

RF-coils
Minnesota, Leiden, MGH

National Cemetery

characterization of GE-BOLD
Minnesota, Nijmegen, MGH

SE-BOLD vs. GE-BOLD
Minnesota, Maastricht

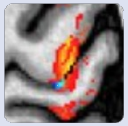
3D-GRASE vs. SE-BOLD
Minnesota, Berkley, Maastricht, Glasgow

VASO vs. GE-BOLD
Pittsburgh, Leipzig, NIH, Johns Hopkins

diffusion vs. GE-BOLD
Paris, Duke

SSFP vs. GE-BOLD
Tübingen, MGH, Korea

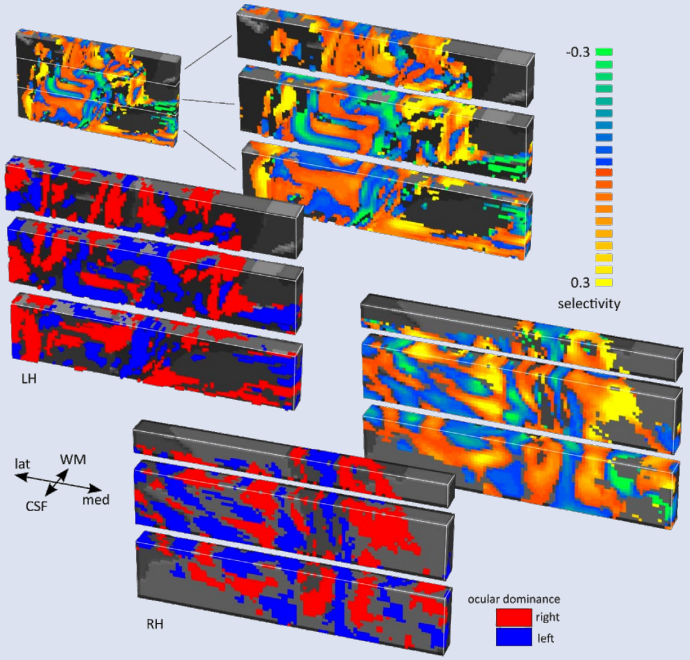
venous masking in GE-BOLD
Minnesota, Nijmegen, Berkley



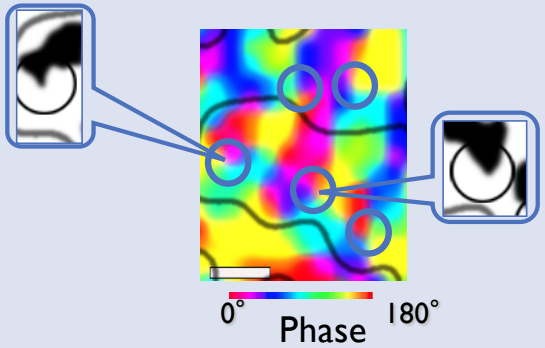
twitter

layerfMRI
@layerfMRI

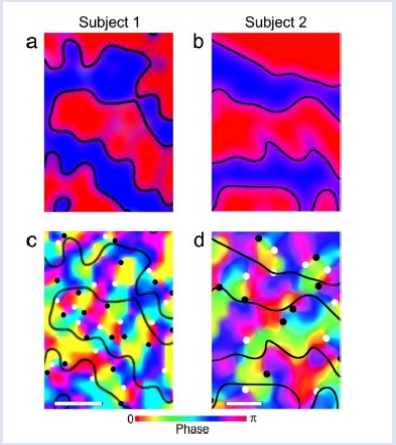
visual cortex

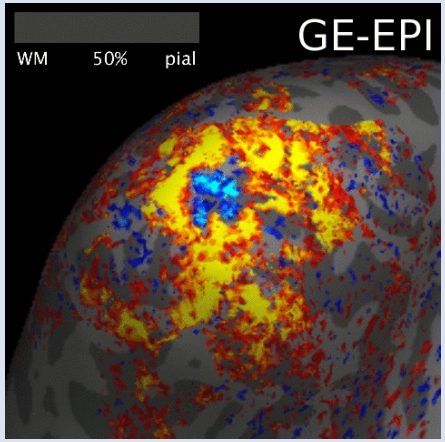


Kemper et al., 2017

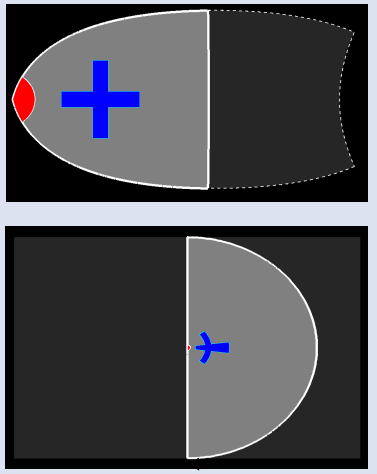


Yacoub et al., 2008



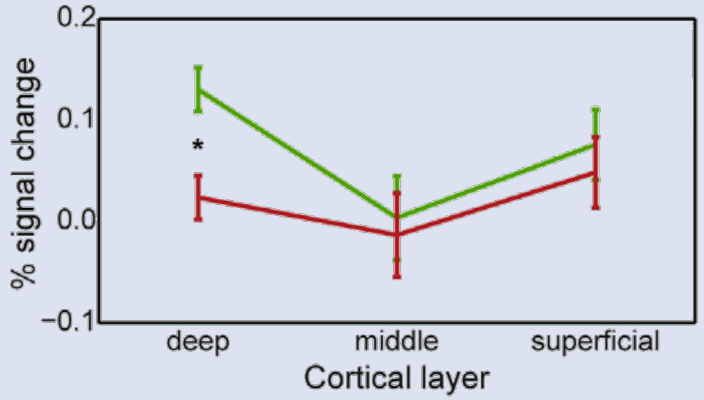


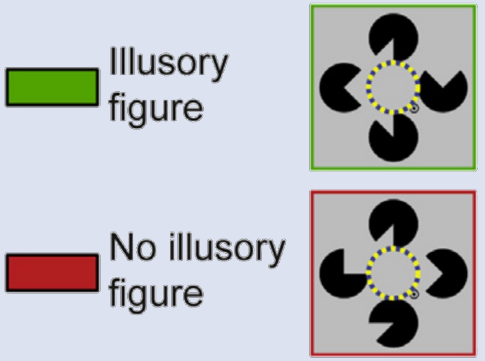
Polimeni et al., 2017



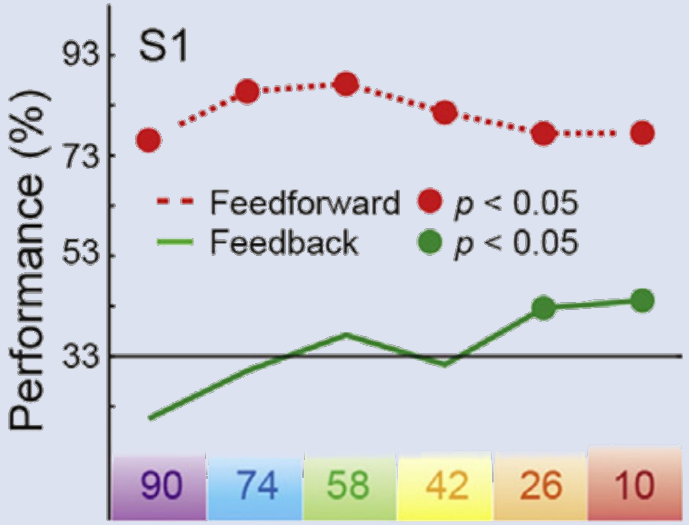
layer fMRI in visual cortex

Kok, Curr Biol, 2015

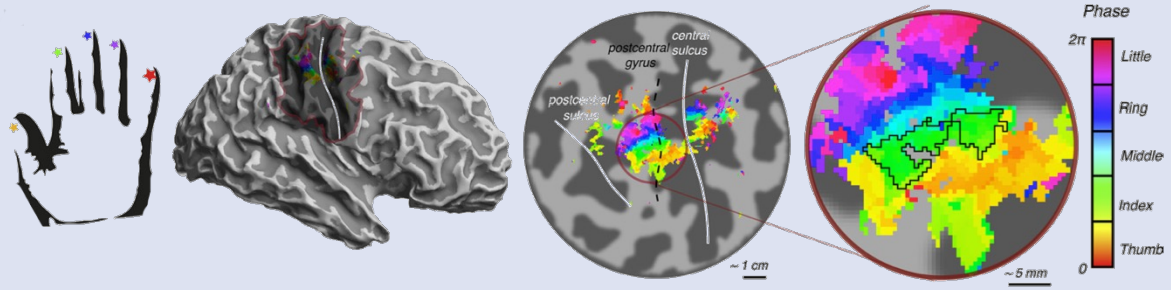


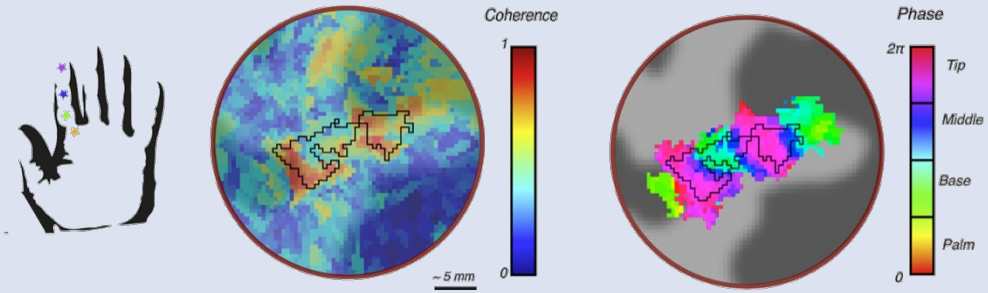


Muckli, Curr Biol, 2015



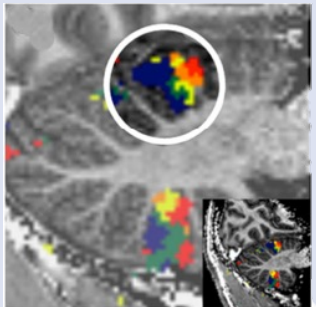
sensory motor cortex

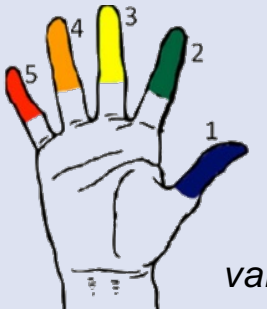




Besle et al., 2010

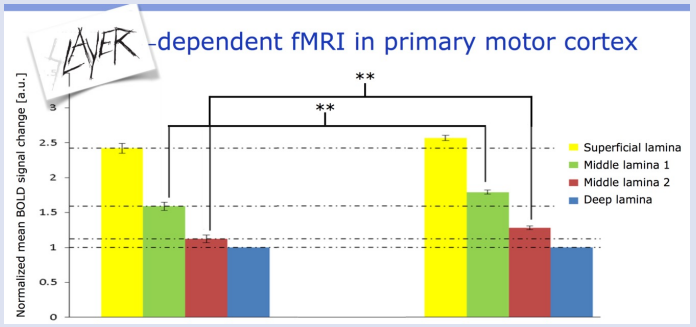
Sanchez-Panchuelo et al., 2012

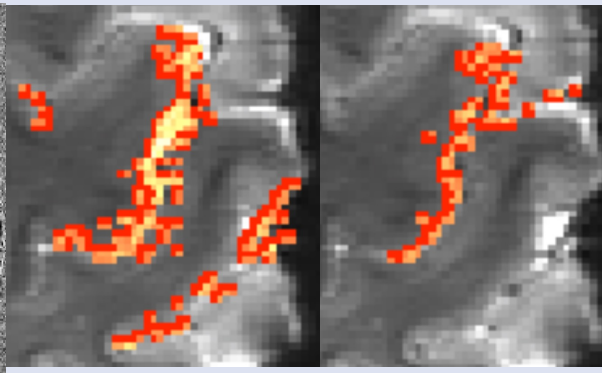




van der Zwaag et al., 2013

LAYER-Robert



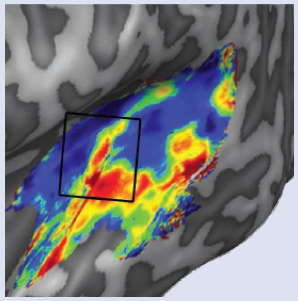


tapping

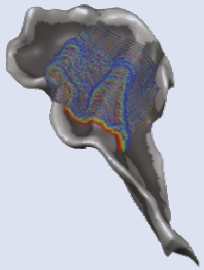
imaginary

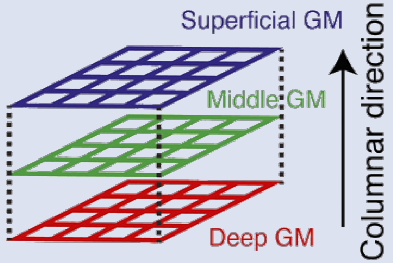
Trampel et al., 2010

auditory cortex



Moerel et al., 2014

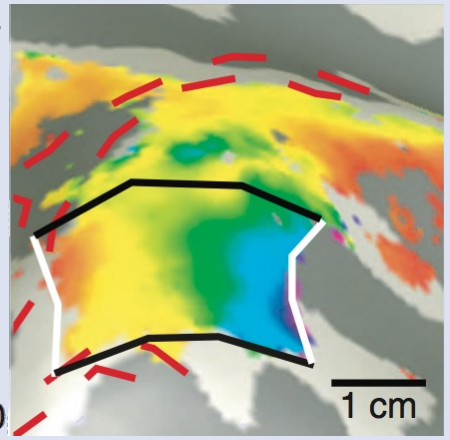


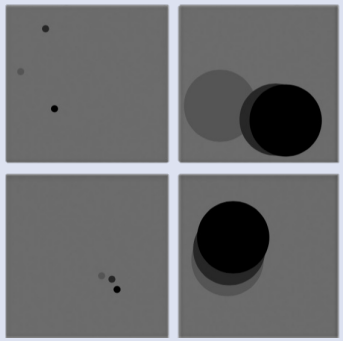


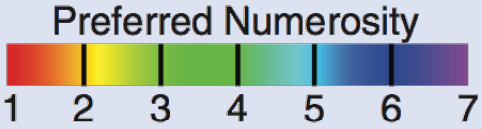
De Martino et al., 2015

the “number sense”

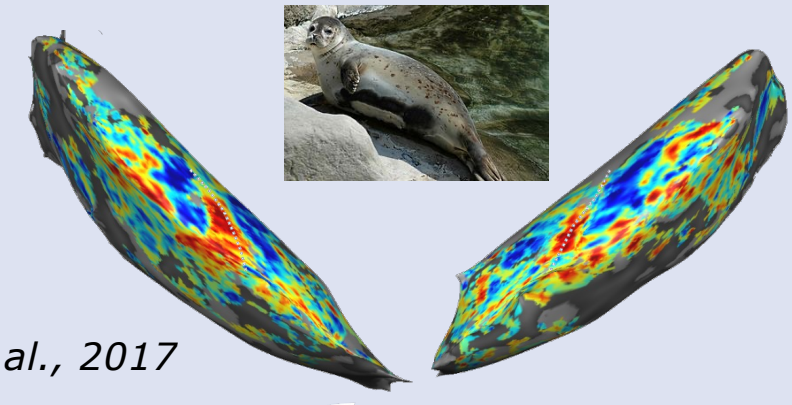
Subject 1: R^2 threshold = 0.30





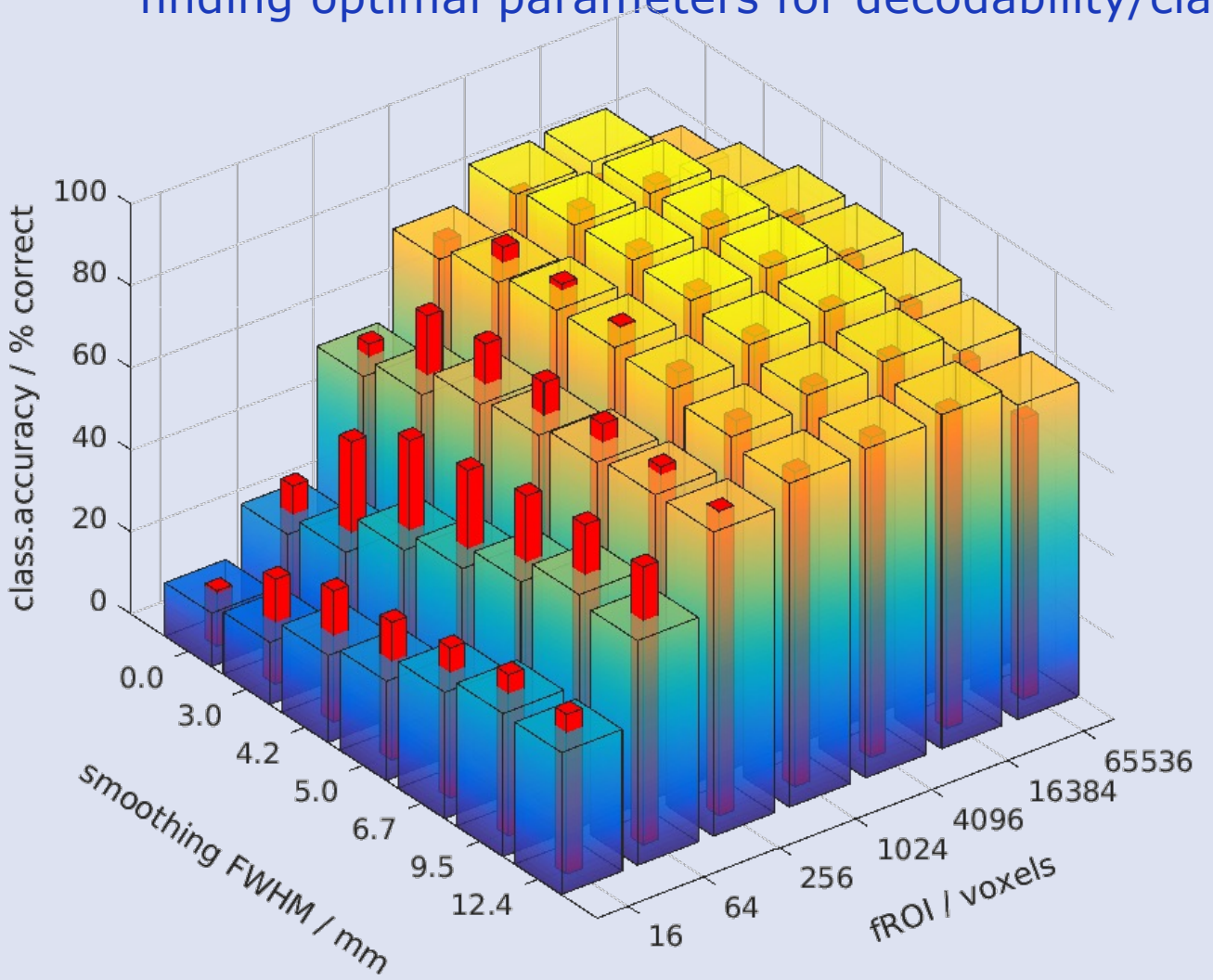


Harvey et al., 2013

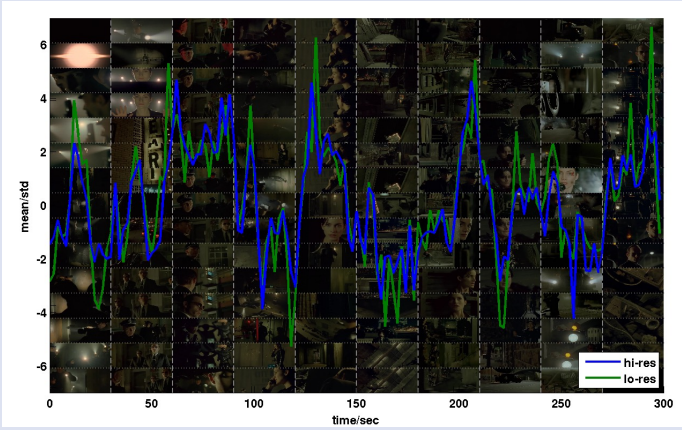


Kemper et al., 2017

finding optimal parameters for decodability/classifiability



Hendrik Mandelkow

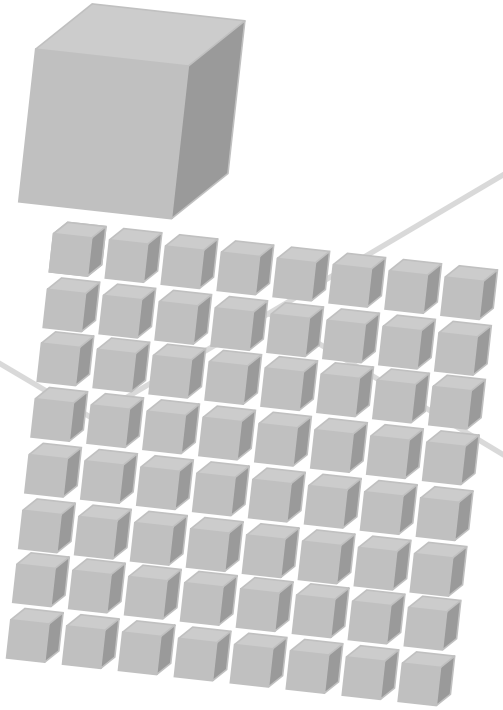


H.Mandelkow et al. 2017, submitted

Challenges of high-res/high-field fMRI and methods to account for them

signal to noise ratio (SNR)~ Δx^3

- going from 3 mm voxels
- to 0.75 mm voxels,
- reduces volume 64 fold.

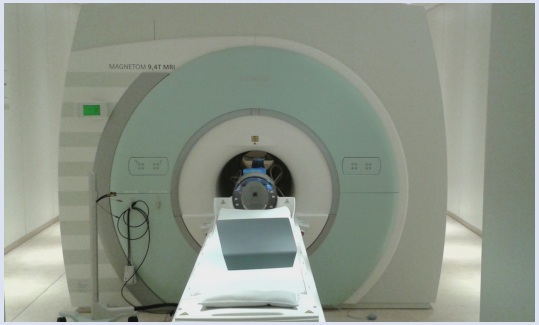


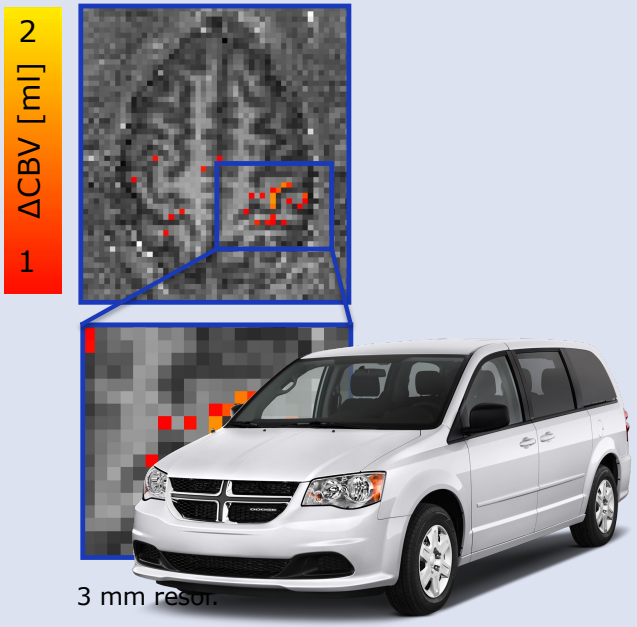
higher fields allow higher resolution

3T

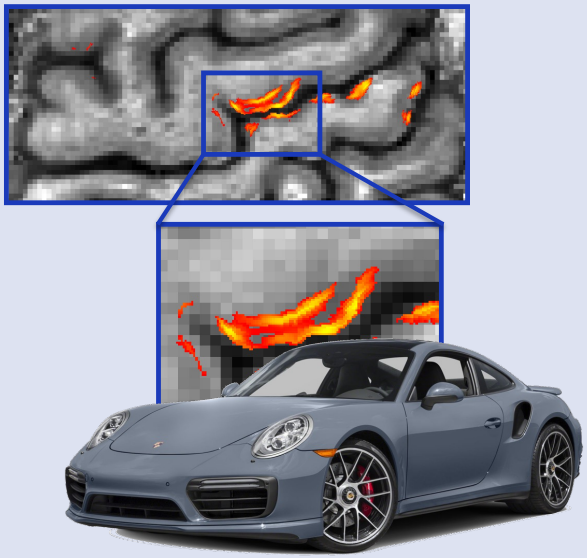
7T

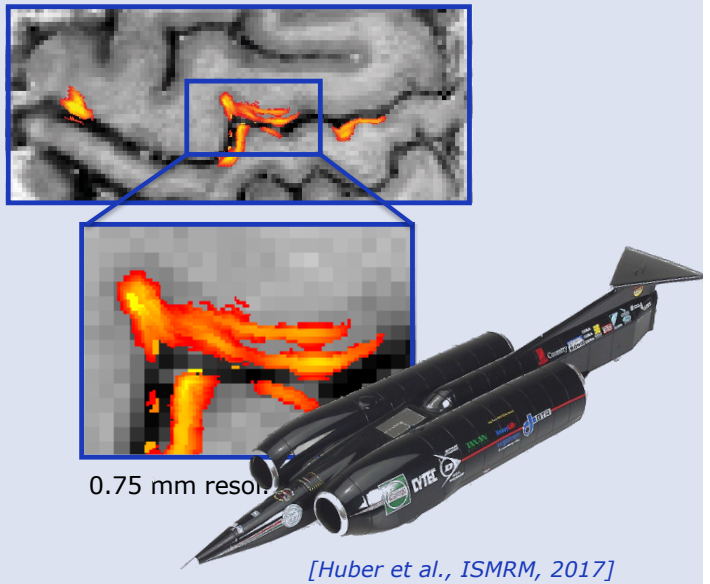
9.4T





3 mm resol.



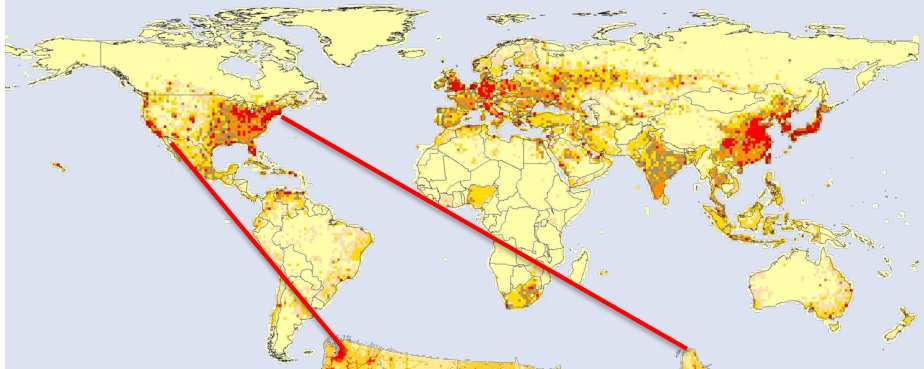


0.75 mm resol.

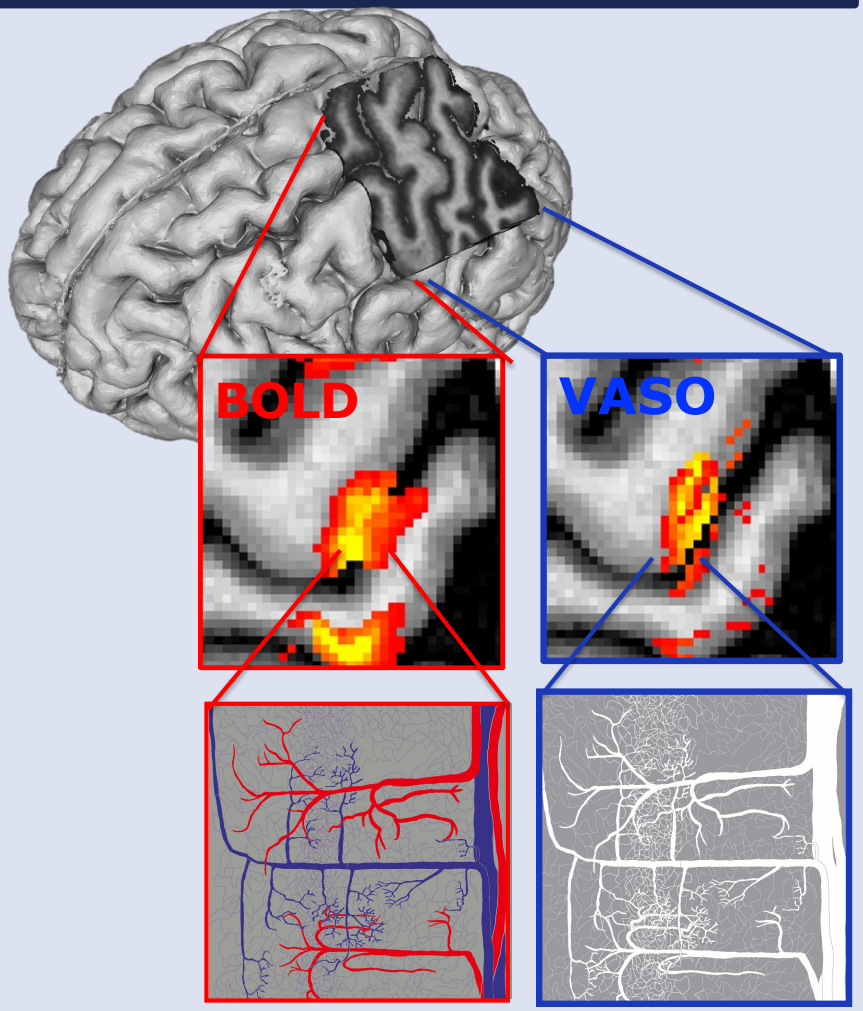
[Huber et al., ISMRM, 2017]

local specificity - highway metaphor

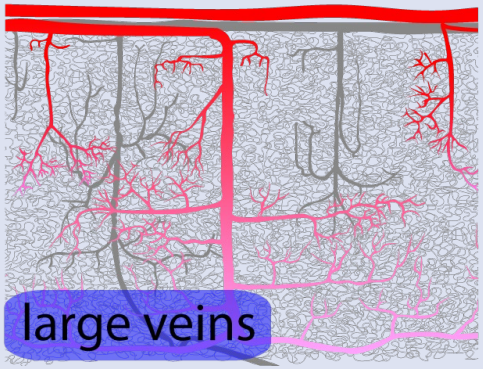
CO_2-emission:

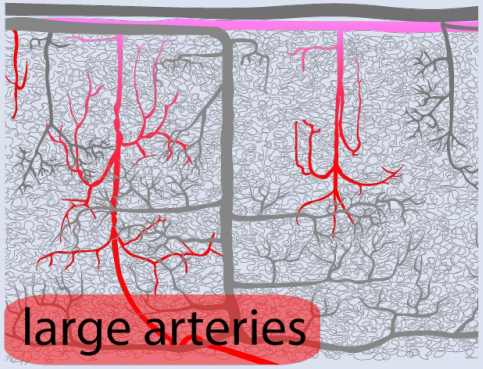


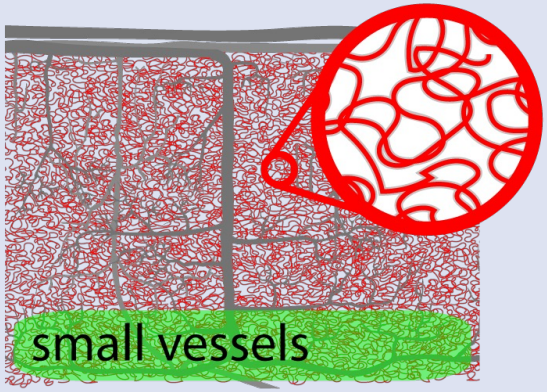
this map is science, not FAKE NEWS

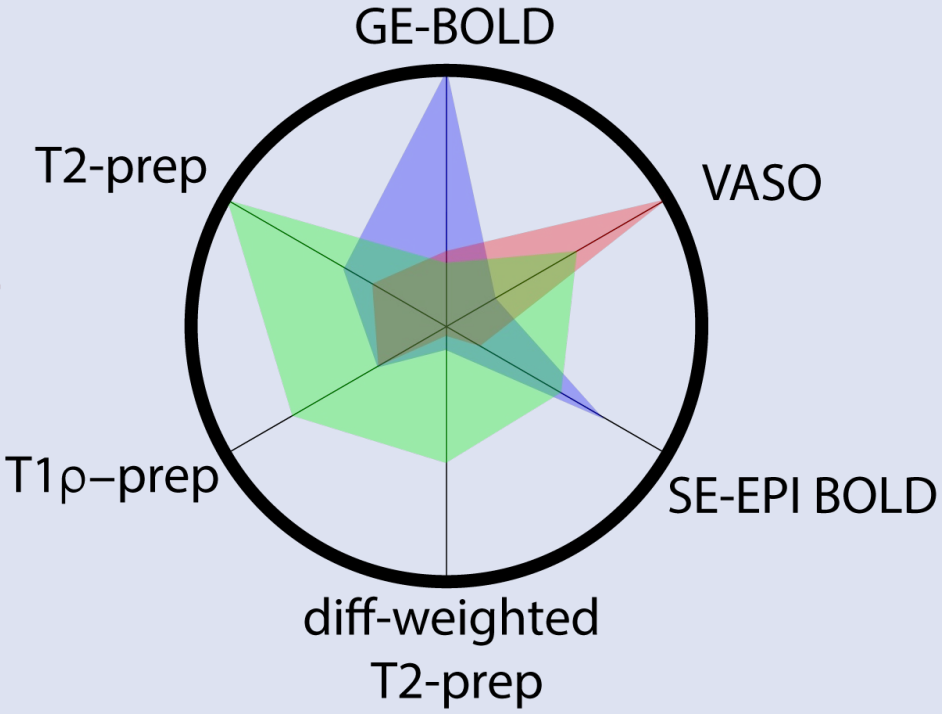


specific contrast candidates



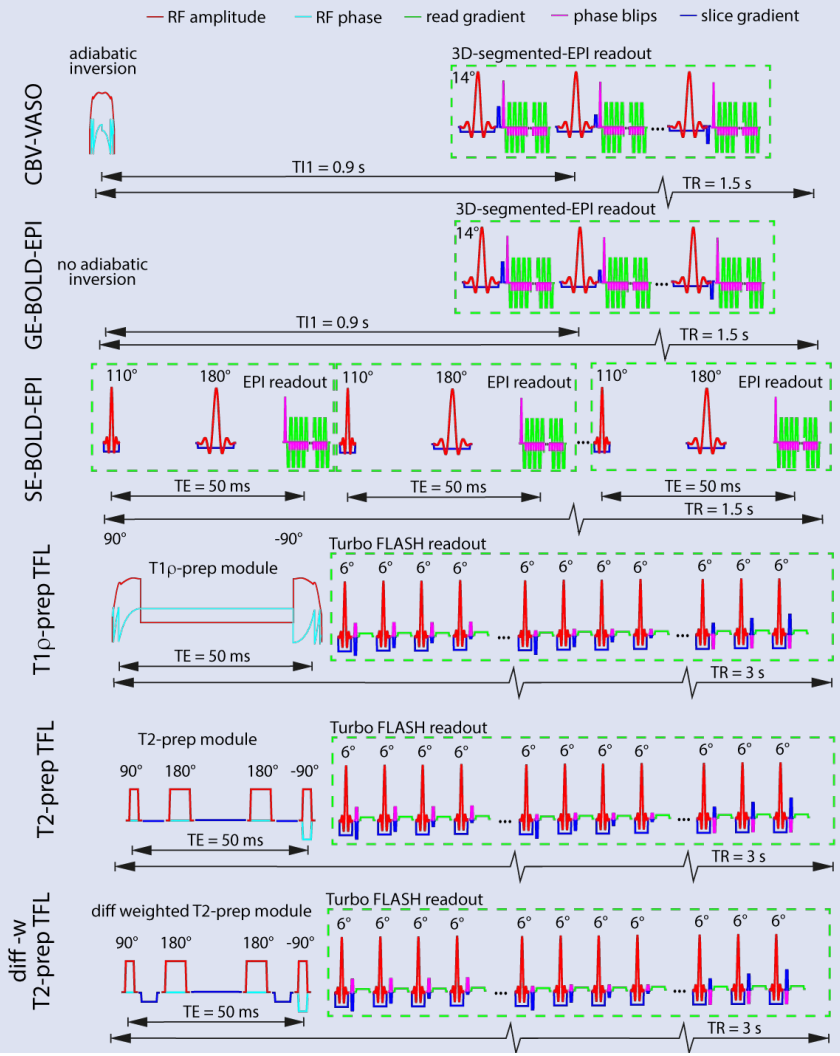






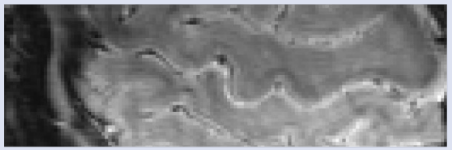
graphical depiction of review articles [Uludağ and Blinder 2017] and [Huber et al., 2017]
drawn based on Duvernoy, 1981 Brain Res

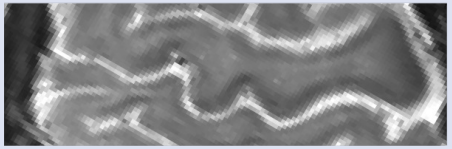
sequence



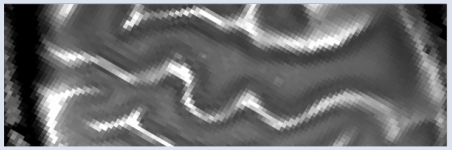
MRI contrast

[Lu, 2003]
[Huber, 2014]





CMRR C2P
[Auerbach, 2013]

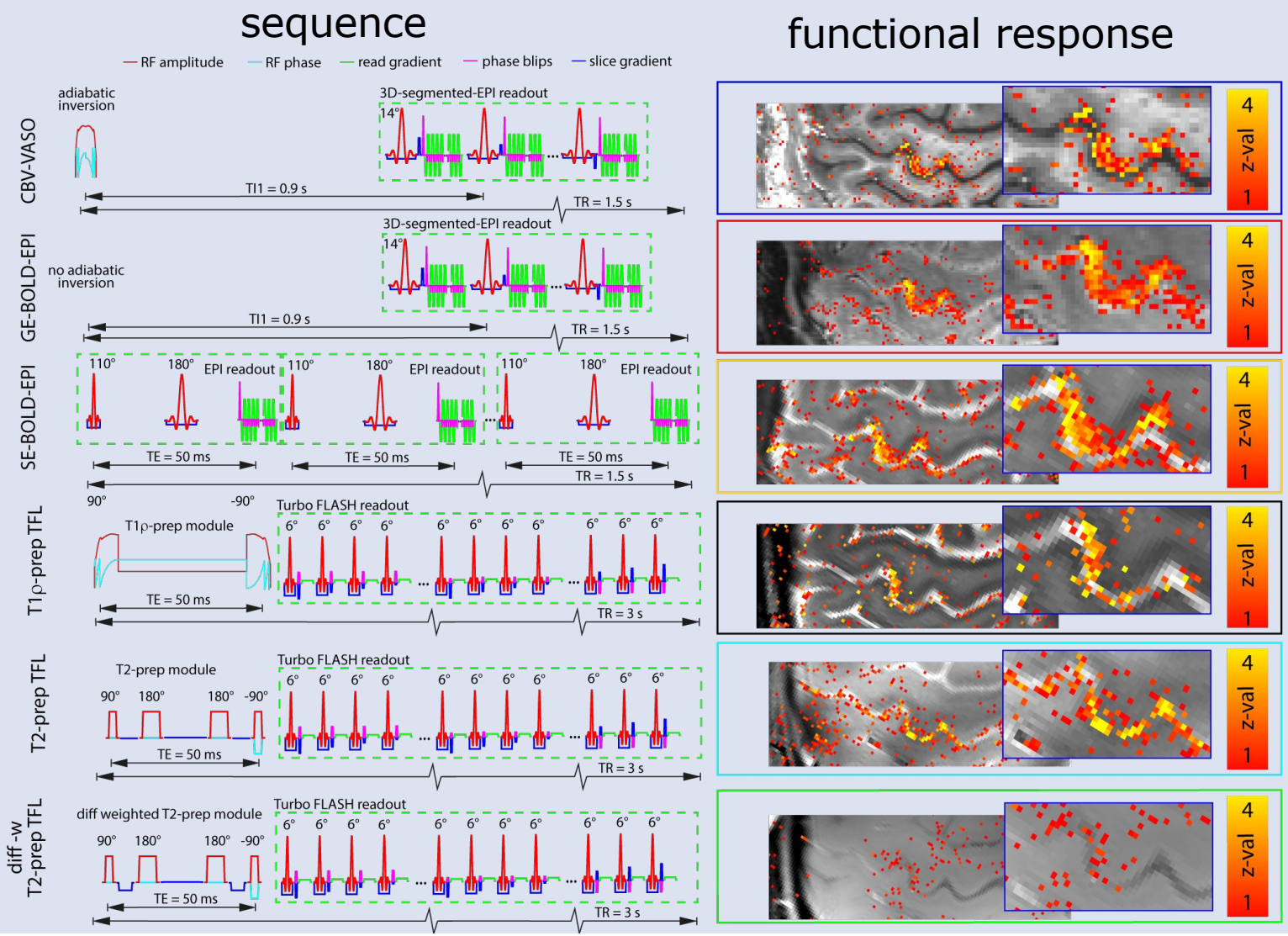


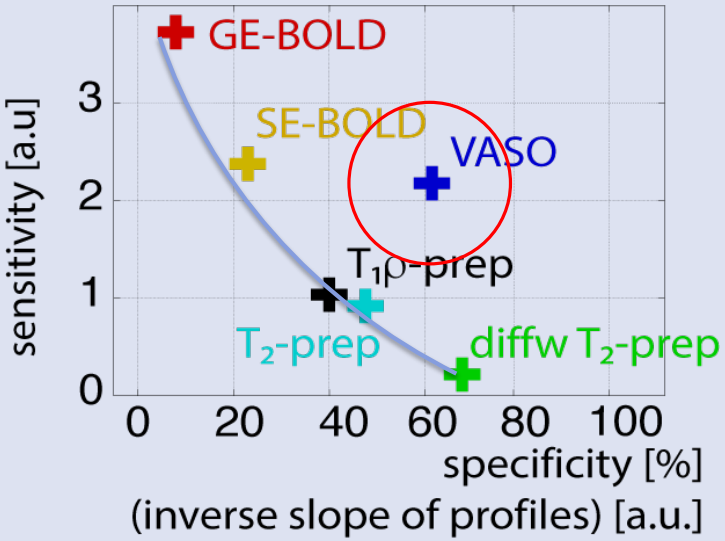
[Rane, 2013]

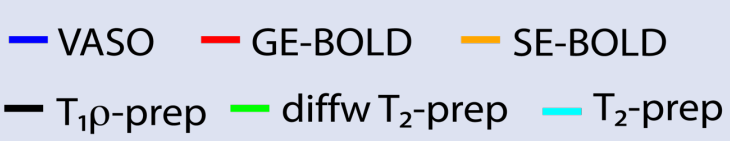
[Hua, 2014]

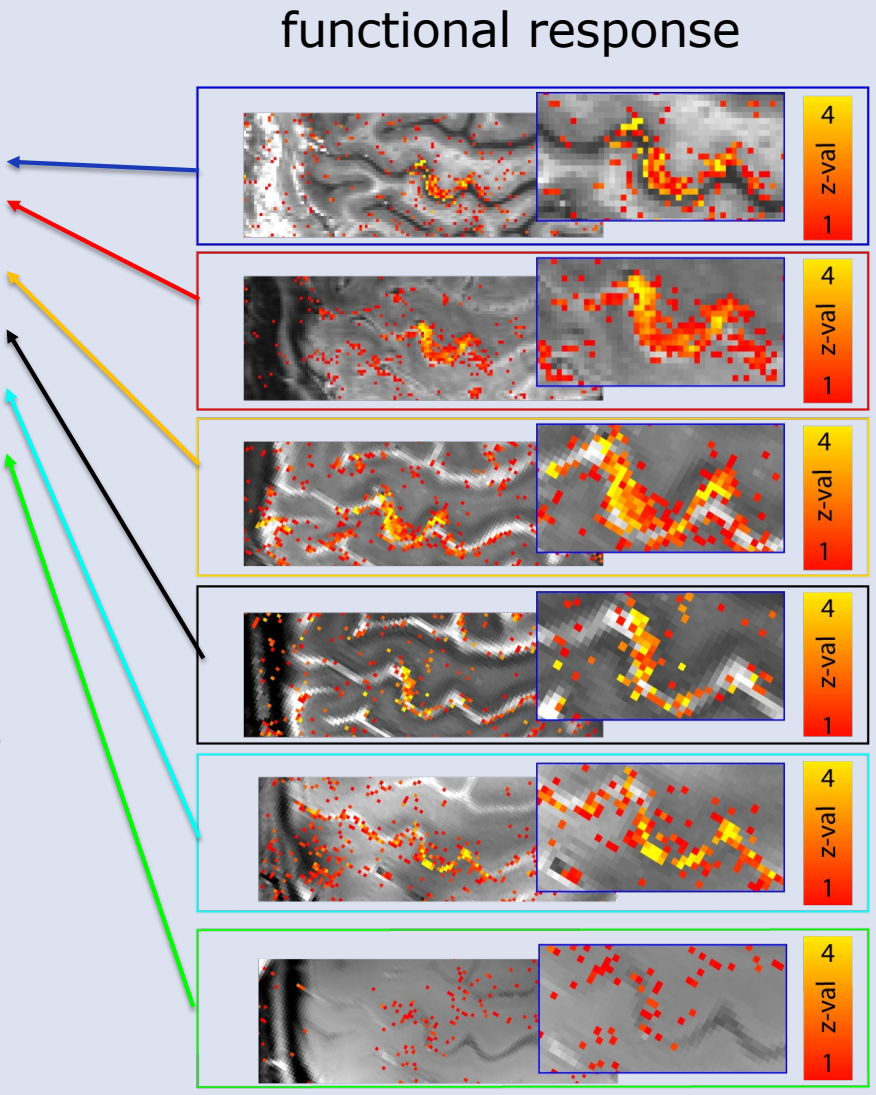
[Duong, 2003]

[Huber et al., ISMRM, 2017]


sequence
functional response
RF amplitude
RF phase
read gradient
phase blips
slice gradient
CBV-VASO
adiabatic inversion
3D-segmented-EPI readout
14°
TI1 = 0.9 s
TR = 1.5 s
GE-BOLD-EPI
no adiabatic inversion
3D-segmented-EPI readout
14°
TI1 = 0.9 s
TR = 1.5 s
SE-BOLD-EPI
110°
180°
EPI readout
TE = 50 ms
TR = 1.5 s
T1ρ-prep TFL
90°
-90°
T1ρ-prep module
Turbo FLASH readout
6°
TE = 50 ms
TR = 3 s
T2-prep TFL
T2-prep module
90°
180°
180°
-90°
Turbo FLASH readout
TE = 50 ms
TR = 3 s
diff -w T2-prep TFL
diff weighted T2-prep module
Turbo FLASH readout
TE = 50 ms
TR = 3 s
4
z-val
1



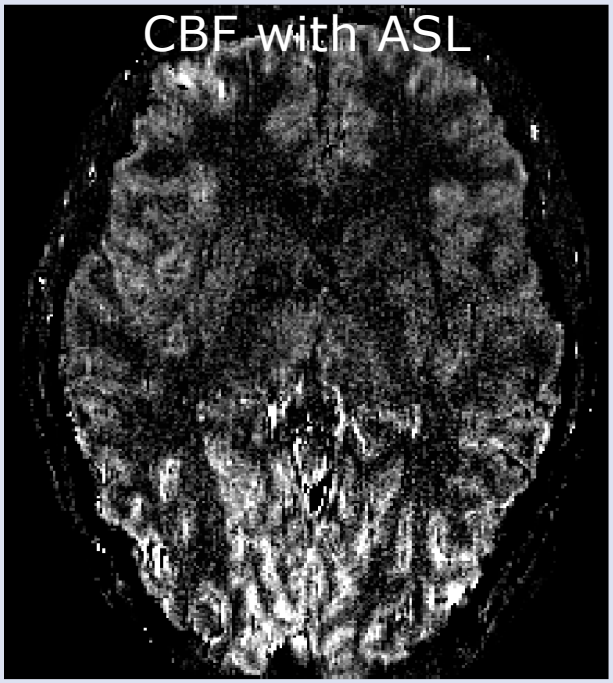


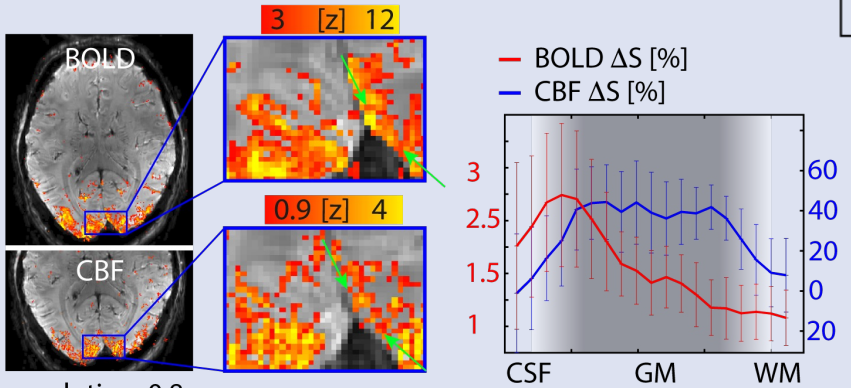


[Huber et al., ISMRM, 2017]

non-BOLD layer-fMRI methods

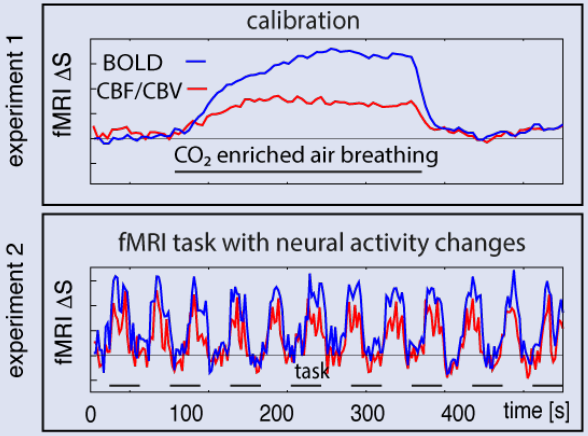
[Huber, Uludağ, Möller, NeuroImage, 2017, in revision]





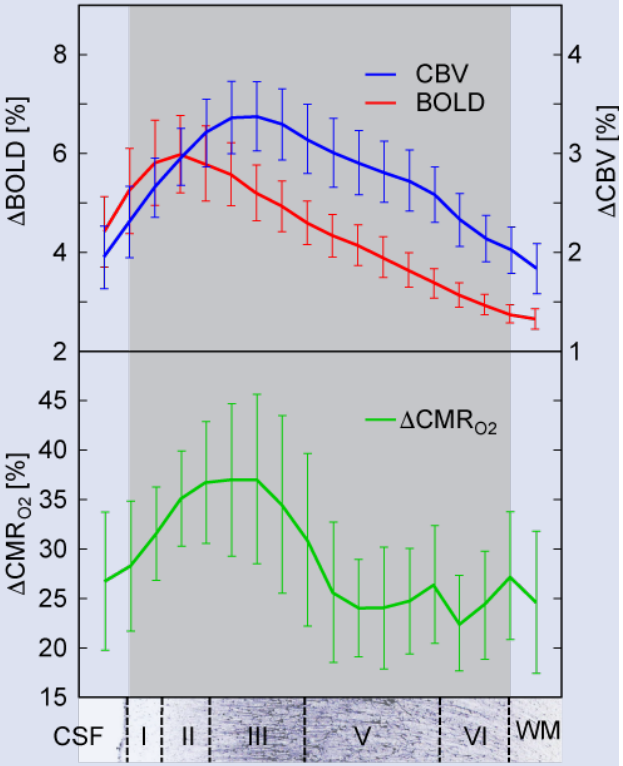
resolution: 0.8 mm Data from Dimo Ivanov, MBIC, Maastricht

$CMRO_2$ with calibrated BOLD

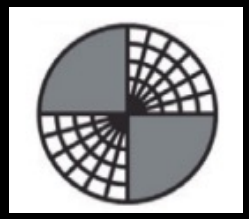


Davis-Model

$$\frac{CMR_{O2}}{CMR_{O2,0}} = \left(1 - \frac{\Delta S_{BOLD}/S_0}{M}\right)^{\frac{1}{\beta}} \cdot \left(\frac{CBF}{CBF_0}\right)^{1-\frac{\alpha_v}{\beta}} = \left(1 - \frac{\Delta S_{BOLD}/S_0}{M}\right)^{\frac{1}{\beta}} \cdot \left(\frac{CBV}{CBV_0}\right)^{\frac{\alpha_v-\beta}{\alpha_t\beta}}$$



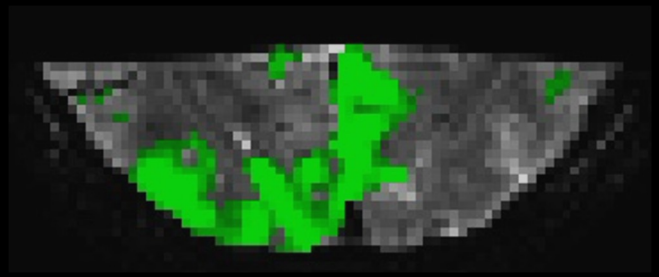
Data from Maria Guidi, MPI, Leipzig



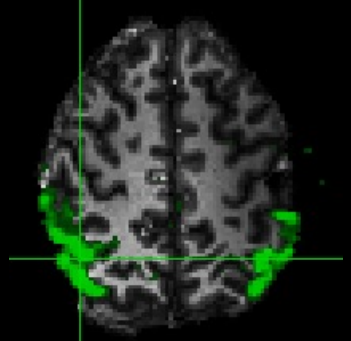
Pinar Özbay

Visual task (block design) – Motor task (event related)

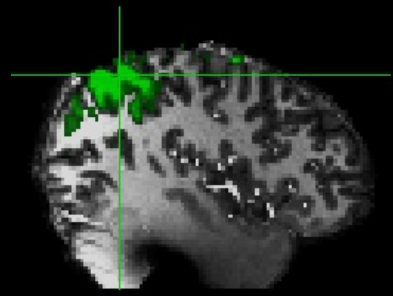
BOLD - fMRI



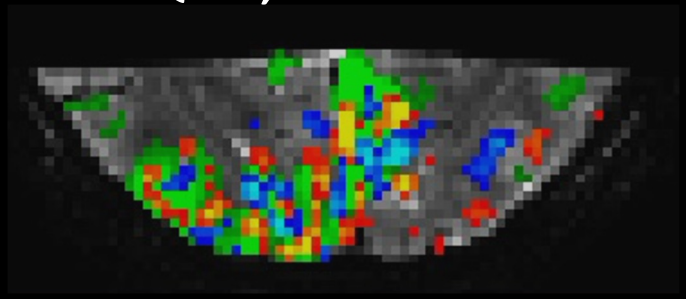
Z>1.2



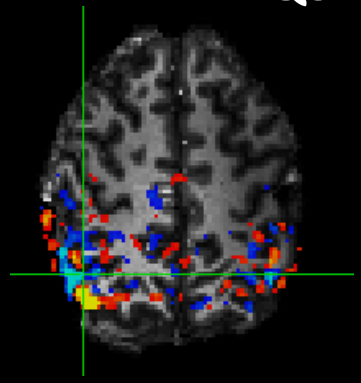
BOLD - fMRI

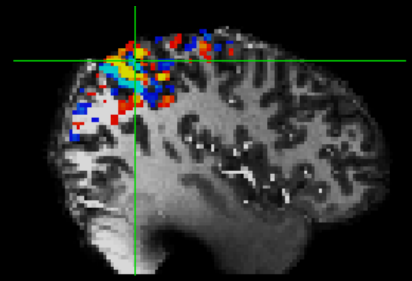


fQSM, Z<-1.2



fQSM, Z<-1.2

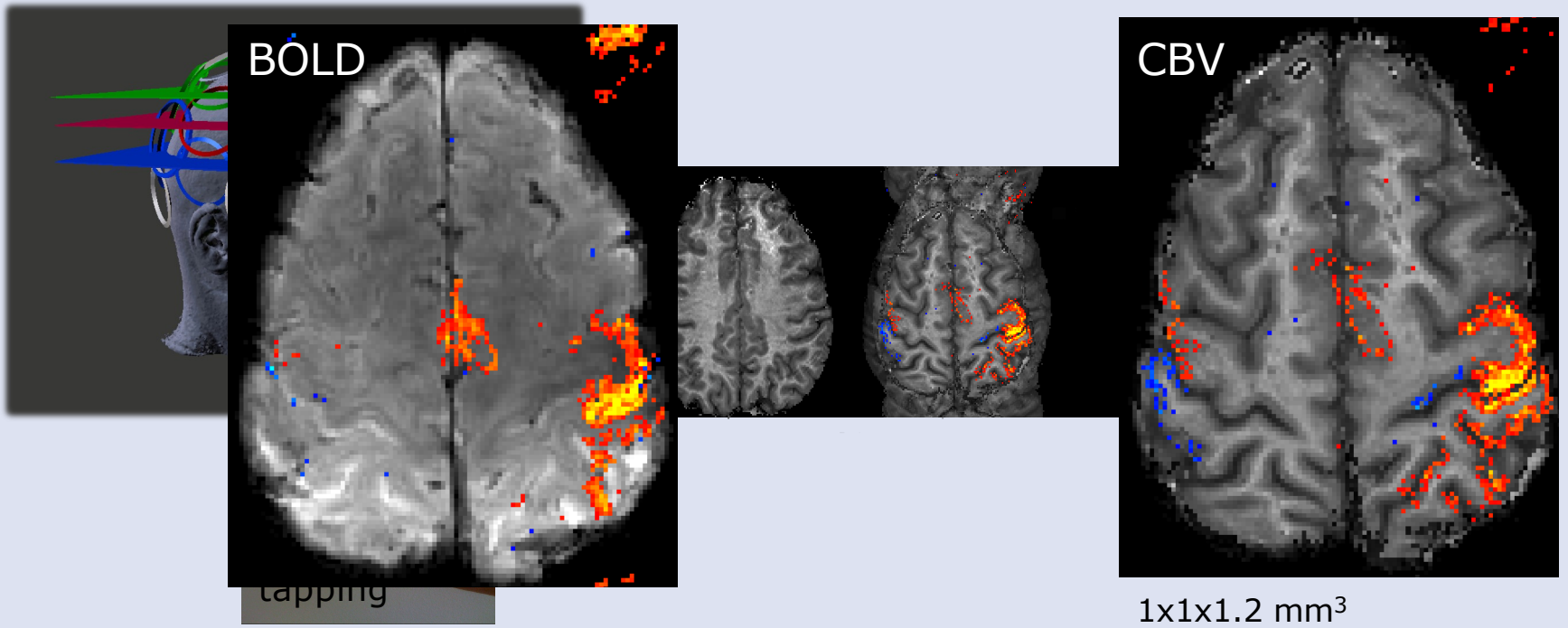




7T Philips (ETH Zurich), 2D Gradient-Echo-EPI
(TE=25ms, TR=3s, FA=85^0,
voxel-dimensions=1.25 x 1.25 x 1.3mm^3, SENSE=3.5)

T1w Anatomical (3D-inversion-recovery gradient-echo, TR=8.2ms, TE=3.79ms, FA=8^0, voxel-dimensions=0.94x0.94x1mm

simultaneous multi-slice (aka multi band)



1x1x1.2 mm^3

z-accelerated 3D-EPI
Poser, 2010
Poser, 2013
Stirnberg, 2017

z-accelerated SMS & MB
Feinberg, 2010
Moeller, 2010
Setsompop, 2012

[Huber et al., NeuroImage, 2016b]

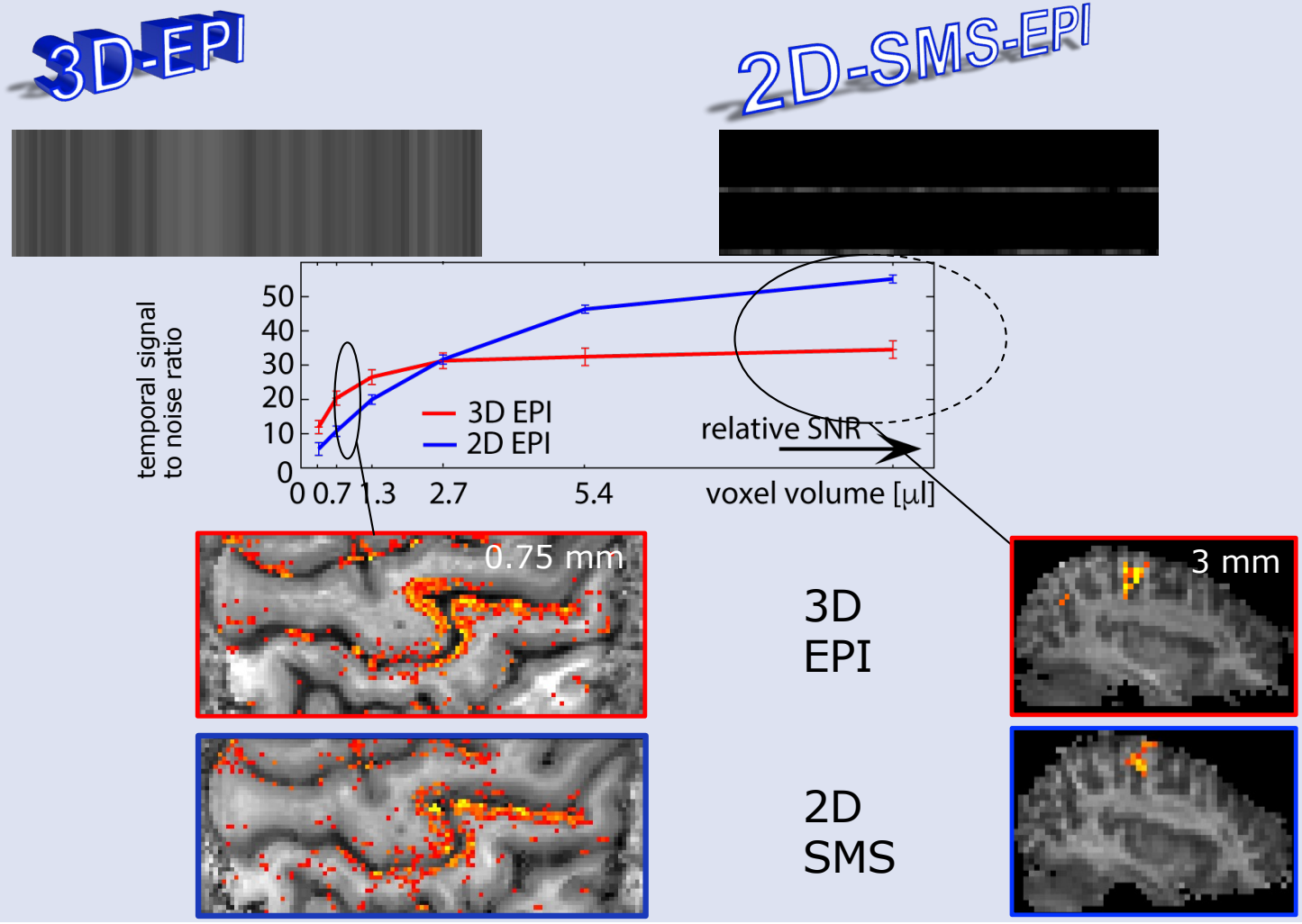
3D-EPI vs. SMS

3D-EPI

2D-SMS-EPI

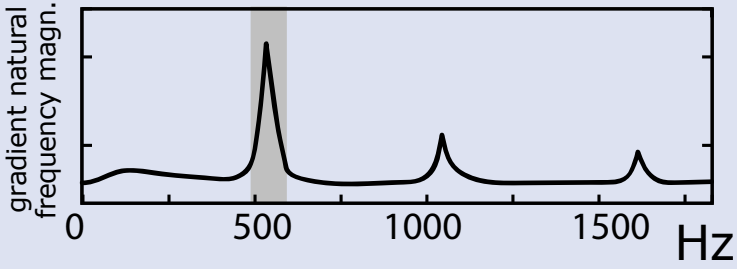
[Huber et al., NeuroImage, 2016]

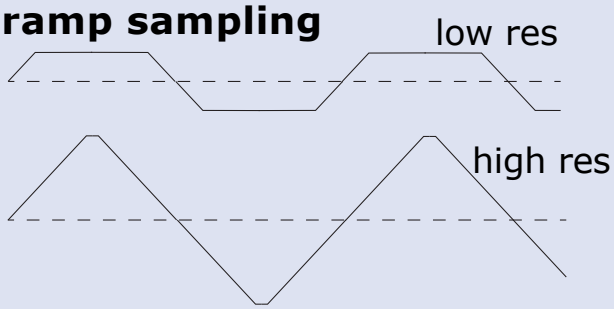
3D-EPI vs. SMS



[Huber et al., NeuroImage, 2016]

High-res EPI-artifacts: ghosts



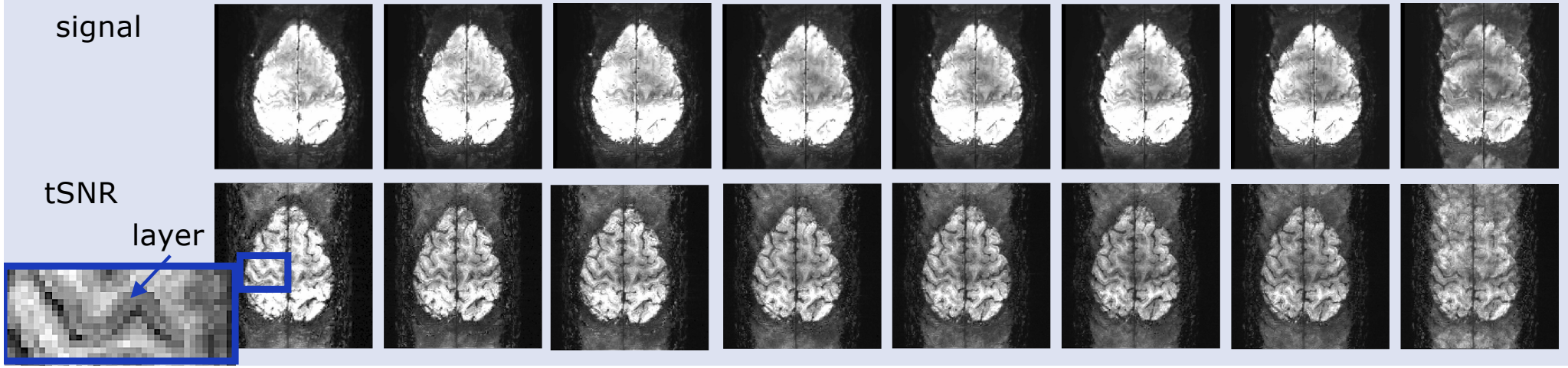


BWDT [Hz/Px]:	960	1010	1112	1234	1388	1516	1754	1960
echo spacing [ms]:	1.2	1.11	1.02	0.92	0.84	0.78	0.83	0.92

signal

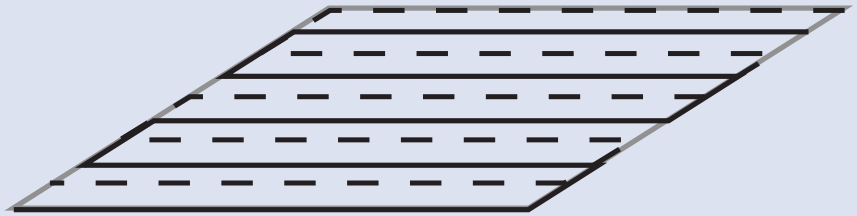
tSNR

layer



GRAPPA calibration data

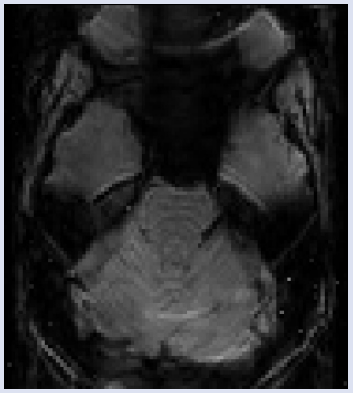
conventional



FLASH

higher SNR

corrupted ACS lines due to eye motion



fixation task helps

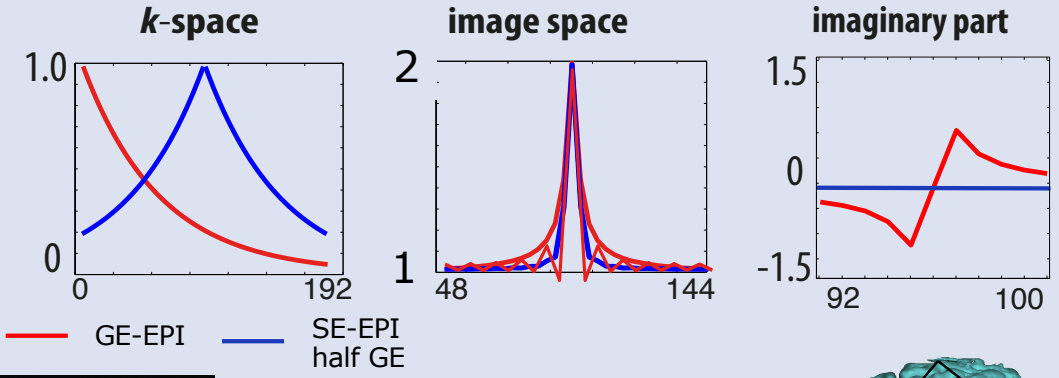
inverting phase encoding direction helps

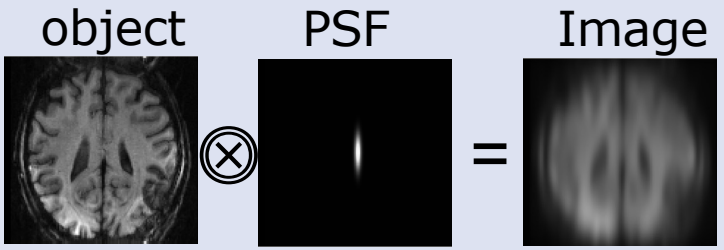
FLASH GRAPPA for fMRI: Talagala et al., 20015 MRM
FLEET GRAPPA for fMRI: Polimeni et al., 2016 MRM
dual polarity GRAPPA for fMRI: Hoge et al., 2016 MRM

T_2*-blurring

Don't trust magnitude PSF

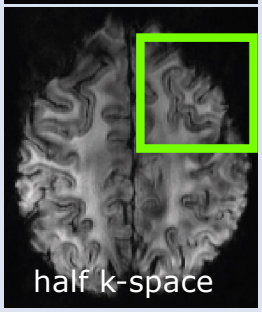
Don't be afraid of long TEs



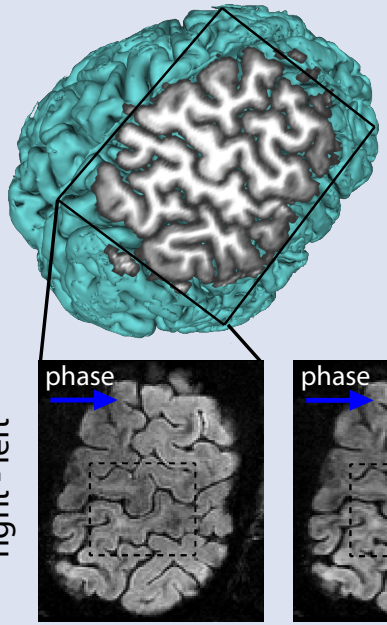


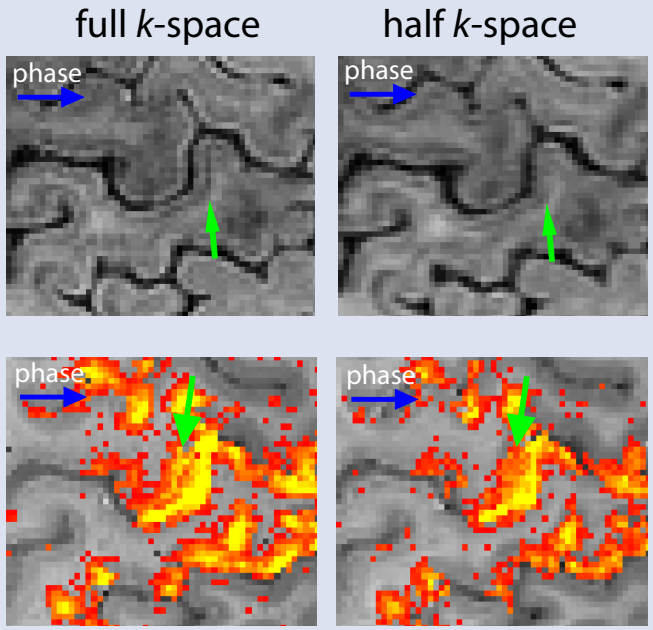
Jesmanowicz, Bandettini, Hyde, 1998 MRM

$$Signal = \sqrt{real^2 + imag^2}$$



TE = 48 ms, 7T, 1.1 mm

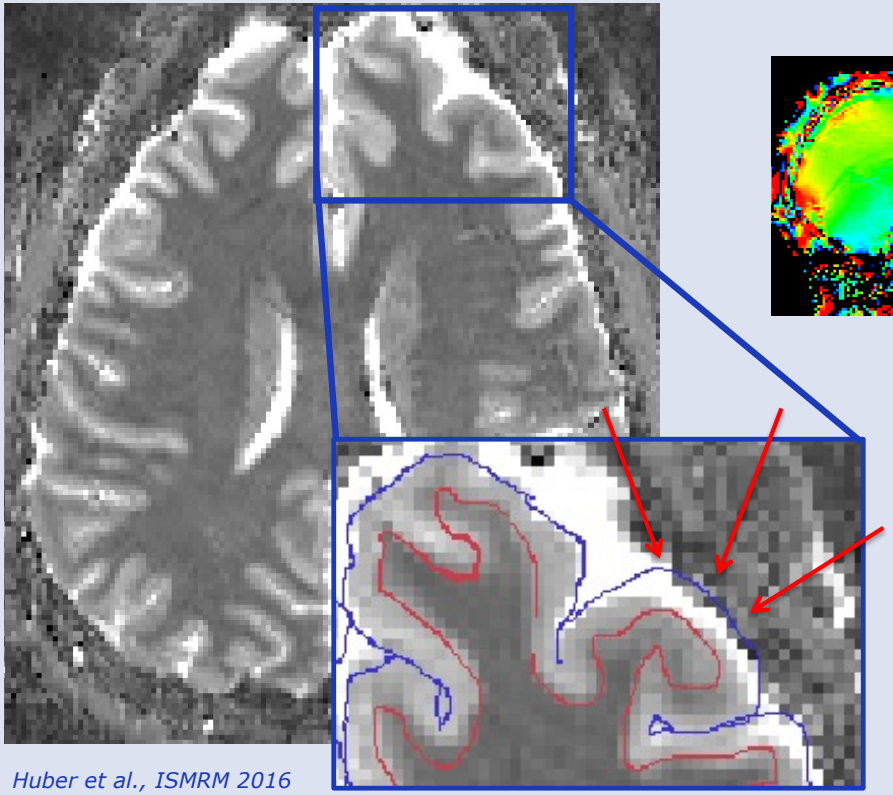


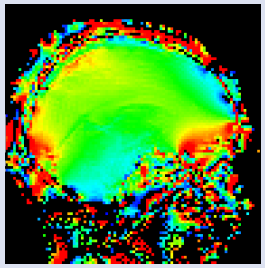


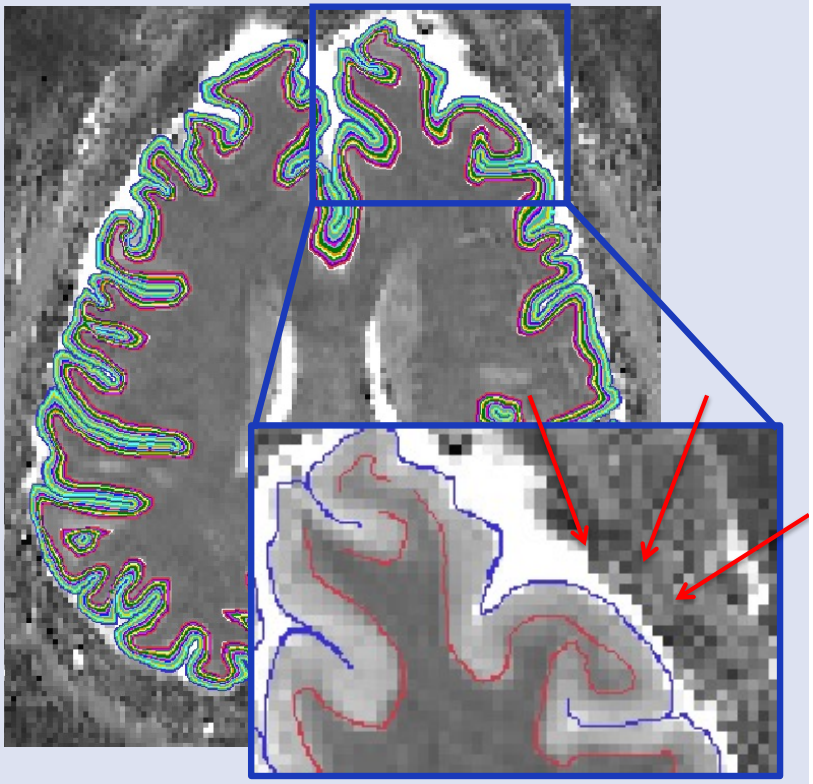
Huber et al., 2014 ISMRM

distortion-matched anatomical reference

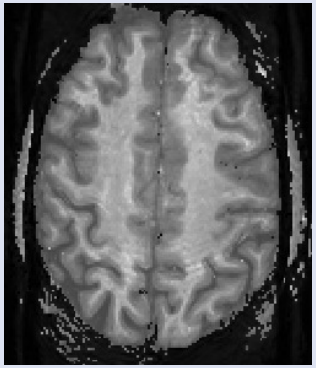
EPI-T_1 and MP2RAGE-T_1

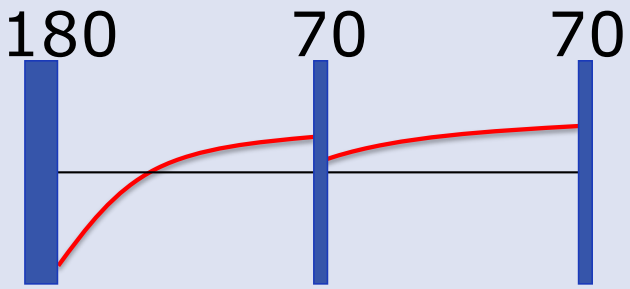




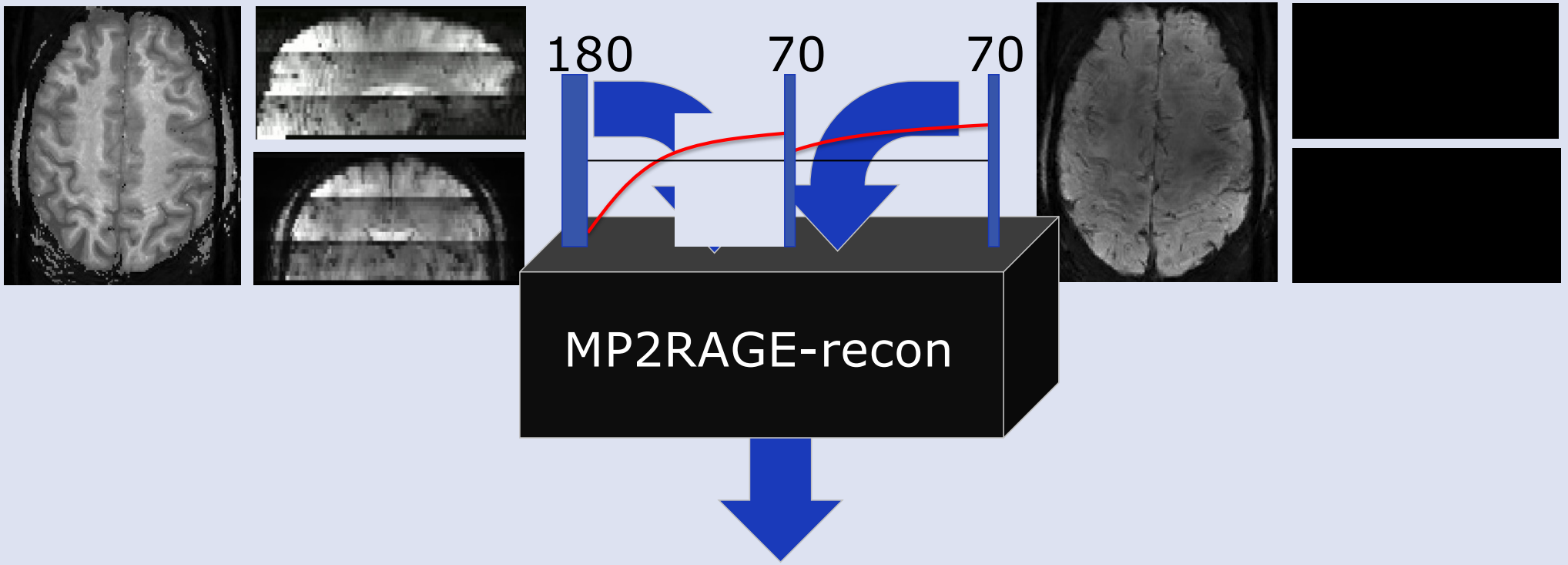


Huber et al., ISMRM 2016

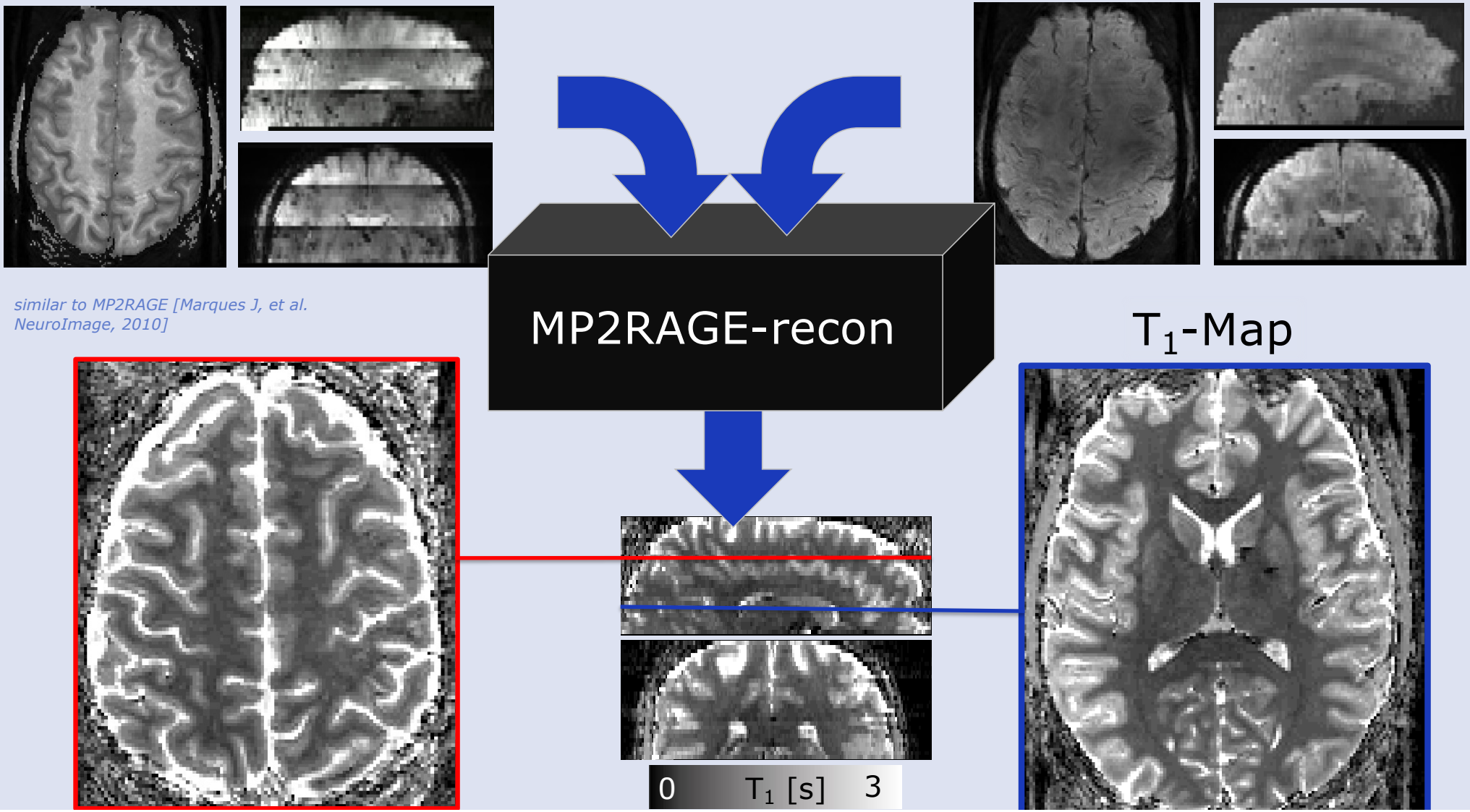




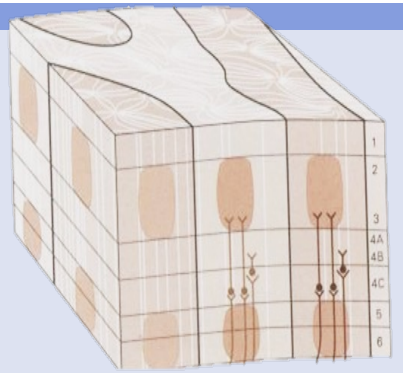
Huber et al., ISMRM 2016: Kashyap et al., 2017: Renvall NeuroImage 2016: van der Zwaag ISMRM 2016



Huber et al., ISMRM 2016


similar to MP2RAGE [Marques J, et al. NeuroImage, 2010]
MP2RAGE-recon
T_1-Map
0
T_1 [s]
3

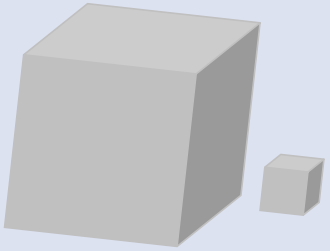
Conclusions



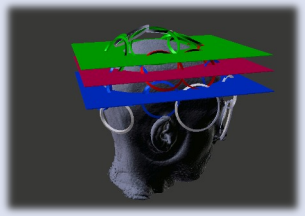
High resolutions provides new information on directionality and circuitry

Many challenges need to be accounted for simultaneously

- SNR

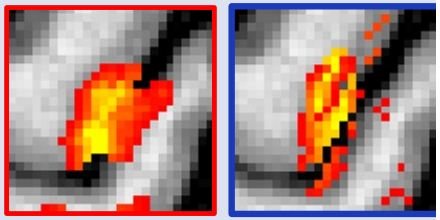


- speed

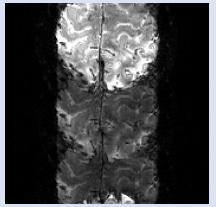


- blurring

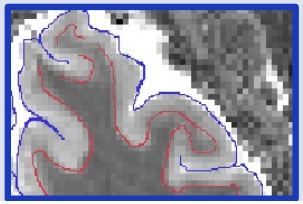
- specificity



- ghosting



- distortion



Thank you

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- **Javier Gonzales**
- **Natasha Topolski**
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