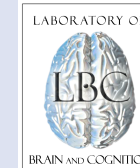
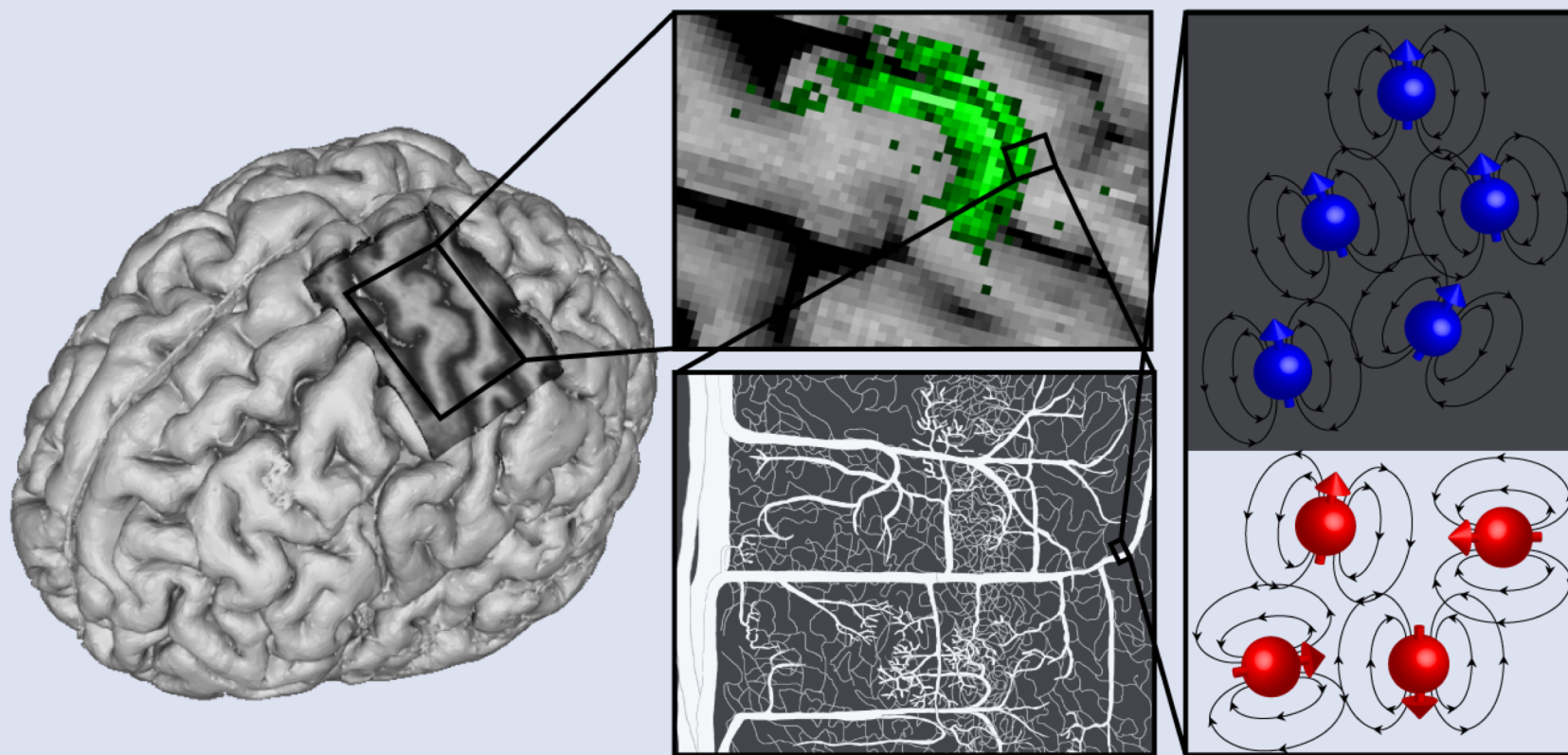


High Field and High Resolution Structural and Functional MRI: Limits that I am dealing with

Renzo (Laurentius) Huber¹



High field and high resolution fMRI educational talks

ISMRRM

<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/>

ISMRRM WORKSHOPS: LEARN, SHARE RESEARCH & NETWORK



Communication Center (Kommunikationszentrum)
German Cancer Research Center (DKFZ)
HEIDELBERG, GERMANY

ISMRRM Workshop on:
**Ultra High Field MRI:
Technological Advances &
Clinical Applications**
06–09 March 2016

Chair: Lawrence L. Wald, Ph.D., Massachusetts General Hospital, Boston, MA, USA
Co-Chair: Mark E. Ladd, Ph.D., German Cancer Research Center (DKFZ), Heidelberg, Germany

* Preliminary credit designation; subject to change

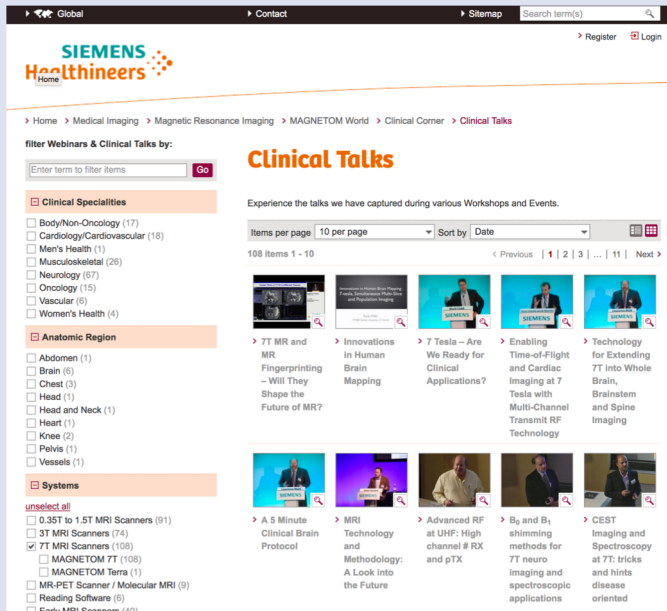
Organizing Committee	Program
Overview	Videos & Syllabi Available to Workshop Registrants Only (password required)
Credit Designation	Syllabus Online Available to Workshop Registrants Only (password required)
Supporters	

For more information, please contact us at info@ismrm.org.

The International Society for Magnetic Resonance in Medicine is accredited by the Accreditation Council for Continuing Medical Education to provide continuing medical education for physicians.

SIEMENS

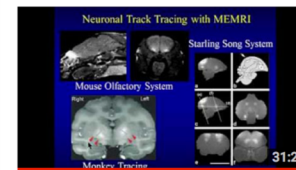
<https://www.healthcare.siemens.com/magnetic-resonance-imaging/magnetom-world/clinical-corner/clinical-talks>



The screenshot shows the Siemens Healthineers website's 'Clinical Talks' section. It features a navigation bar with 'Home', 'Medical Imaging', 'Magnetic Resonance Imaging', 'MAGNETOM World', 'Clinical Corner', and 'Clinical Talks'. Below the navigation, there are filters for 'Clinical Specialties' (Body/Non-Oncology, Cardiology/Cardiovascular, Men's Health, Musculoskeletal, Neurology, Oncology, Vascular, Women's Health) and 'Anatomic Region' (Abdomen, Brain, Chest, Head, Head and Neck, Heart, Knee, Pelvis, Vessels). There are also filters for 'Systems' (0.35T to 1.5T MRI Scanners, 3T MRI Scanners, 7T MRI Scanners, MAGNETOM 7T, MAGNETOM Terra, MR-PET Scanner / Molecular MRI, Reading Software, Early MRI Scanners). The main content area displays a grid of video thumbnails for various talks, including '7T MR and MR Fingerprinting', 'Innovations in Human Brain Mapping', '7 Tesla - Are We Ready for Clinical Applications?', 'Enabling Time-of-Flight and Cardiac Imaging at 7 Tesla with Multi-Channel Transmit RF Technology', 'Technology for Extending T1 into Whole Brain, Brainstem and Spine Imaging', 'A 5 Minute Clinical Brain Protocol', 'MRI Technology and Methodology: A Look into the Future', 'Advanced RF at UHF: High channel # RX and pTX', 'B₀ and B₁ shimming methods for 7T neuro imaging and spectroscopic applications', and 'CEST Imaging and Spectroscopy at 7T: neuro tricks and histis disease oriented'.

"layer fMRI" YouTube channel

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



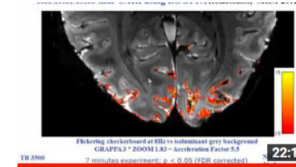
Alan Koretzky shows how layer fMRI reveals feed-forward vs. feedback input in plasticity ...

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>.



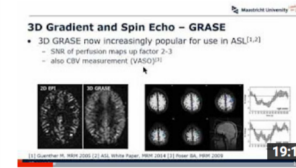
Lars Muckli Predictive encoding using layer-dependent fMRI

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



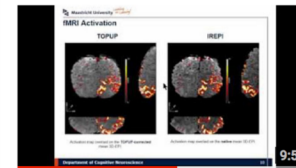
Robert Turner: layer-dependent fMRI in Leipzig

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.



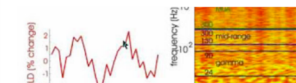
Benedikt Poser Talking about his 3D-EPI with CA1P

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/033.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>

Approx. 80 UHF scanners



High field and high resolution is getting popular

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** function



Home > Journals > NeuroImage > Call for Papers

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- Guide for Authors
- Abstracting/ Indexing
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- Order Journal

Journal Metrics

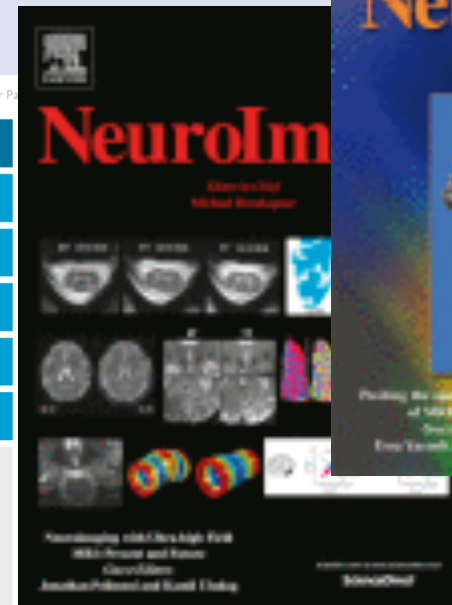
CiteScore: 6.71

More about CiteScore

Impact Factor: 5.463

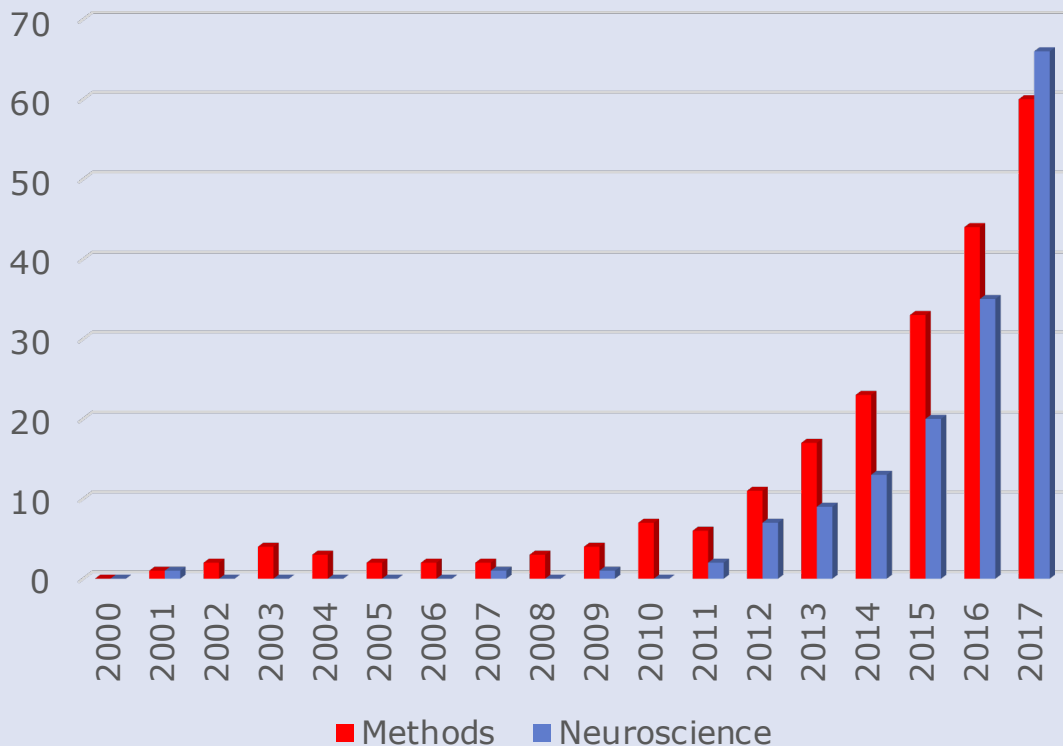
5-Year Impact Factor: 6.797

Source Normalized Impact per Paper (SNIP): 1.11



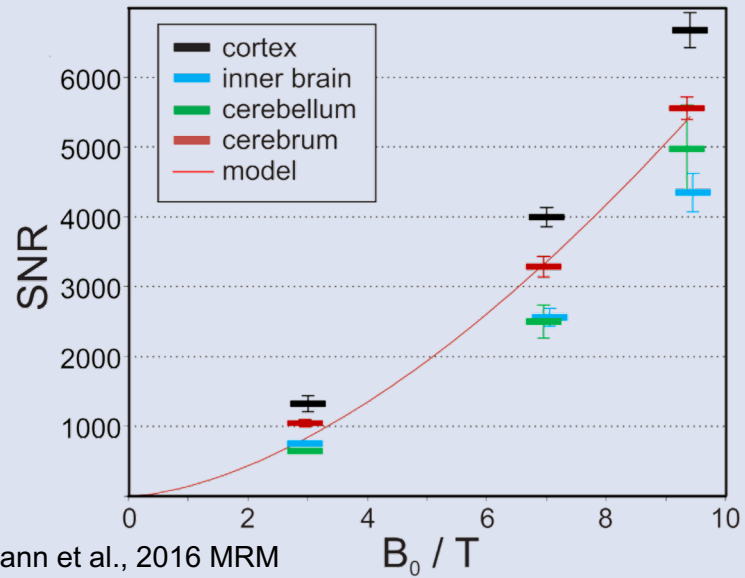
can only be
this issue are
so focus on
neuroimaging

All papers will be subject to normal peer review and must comply with the Guide for Authors.



Advantages of high fields

SNR



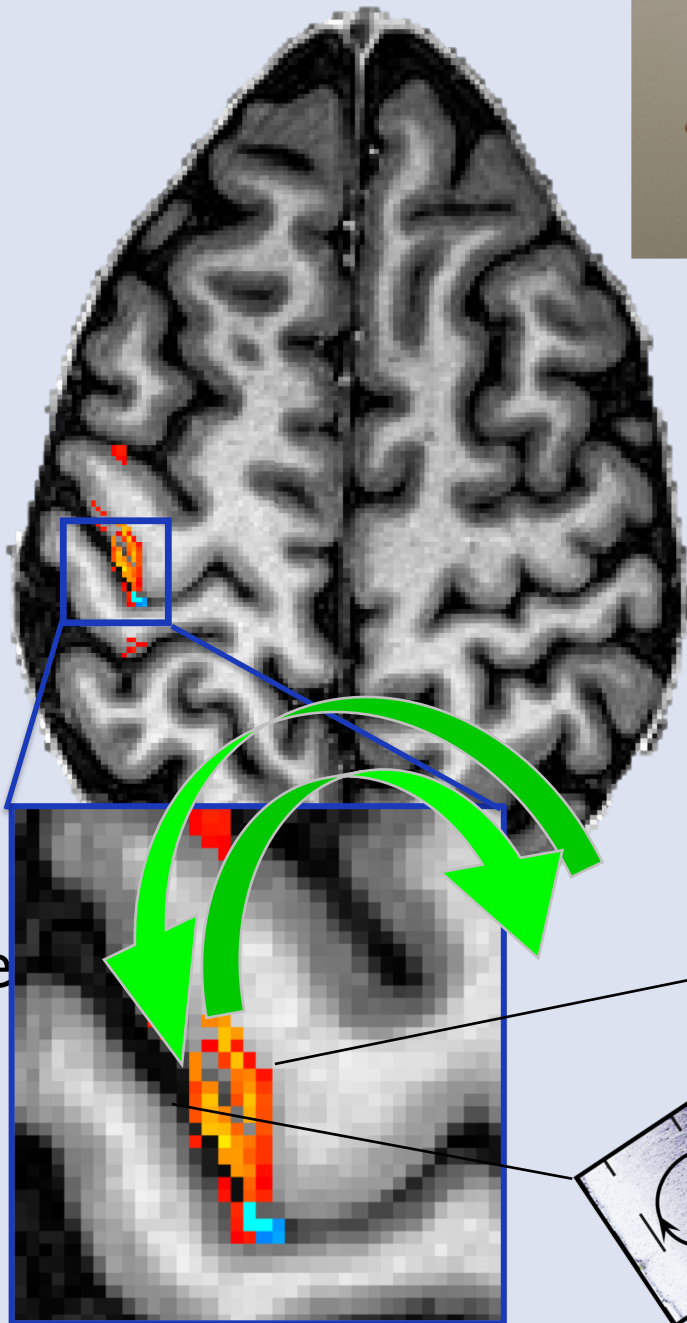
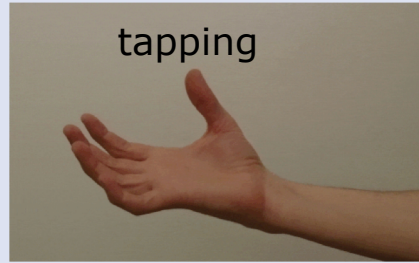
SNR increase 3T \rightarrow 7T is **3.3**

Falk Lüsebrink

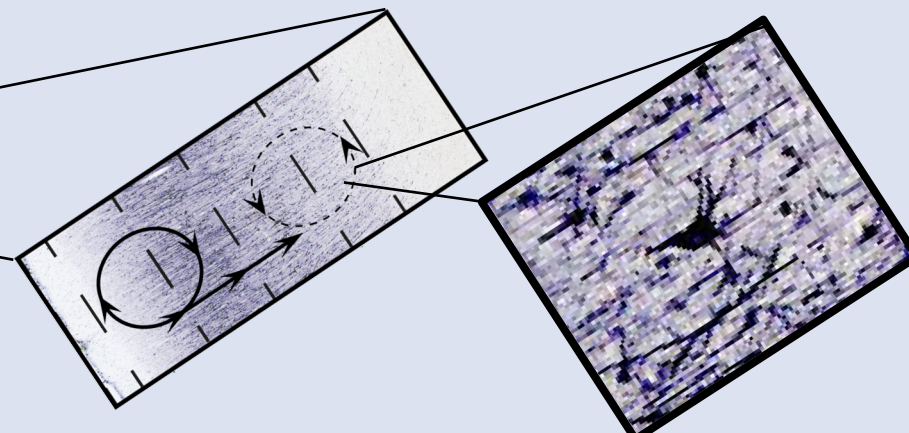
<https://www.nature.com/articles/sdata201732>

Average of 8 MPRAGE datasets of 250 μm

fMRI at 0.75 mm resolution



see layer-fMRI lecture next week
on Friday July 27th



Re

Limits of high field and high resolution fMRI

- Sensitivity limitations
- Physiological noise
- Dealing with complexity
- Inhomogeneity (B1) pTx
- Short T2*
- High-resolution limits with GRAPPA
- 2D vs. 3D limits at high resolutions
- Segmentation
- Motion
- Distortion

Challenge #1: Sensitivity

signal to noise ratio **(SNR) $\sim \Delta x^3$**

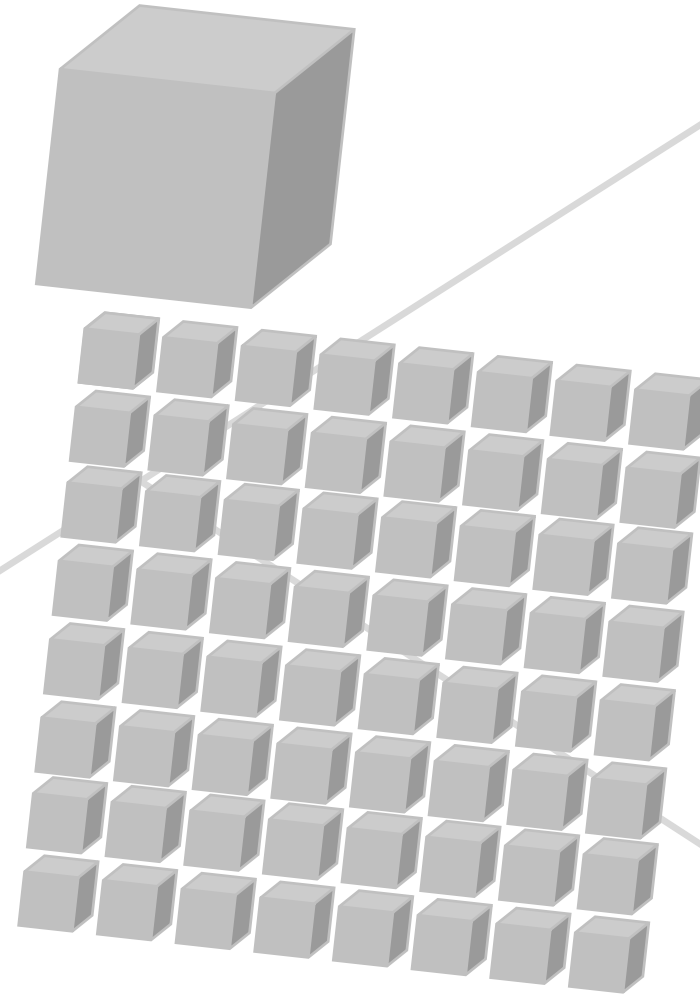
going from 3 mm (fMRI)

going from 1 mm (anatomy)

to 0.75 mm (fMRI)

to 0.25 mm (anatomy)

64 fold reduction



Field strength

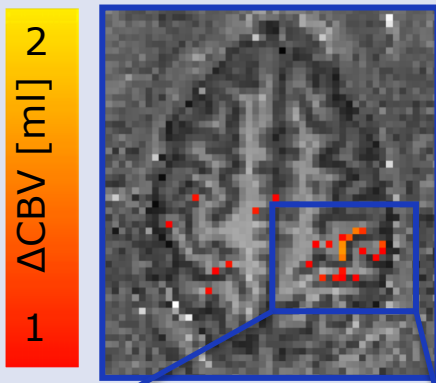
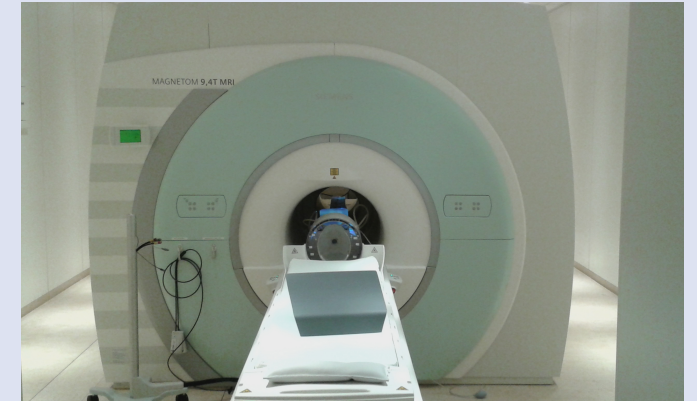
3T



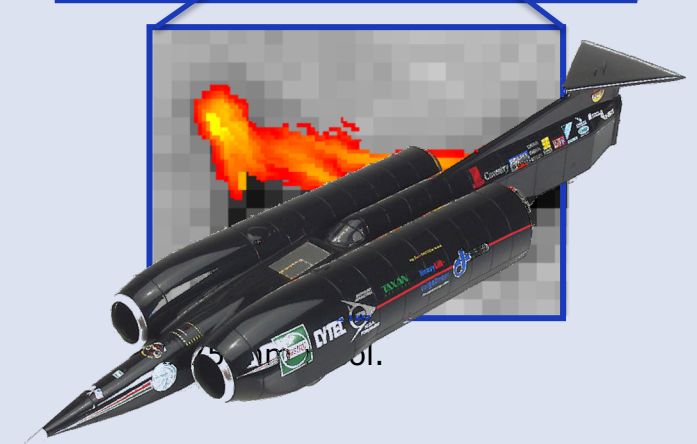
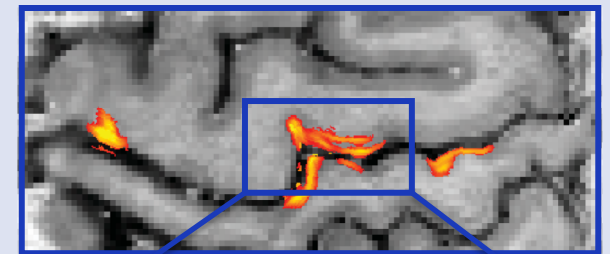
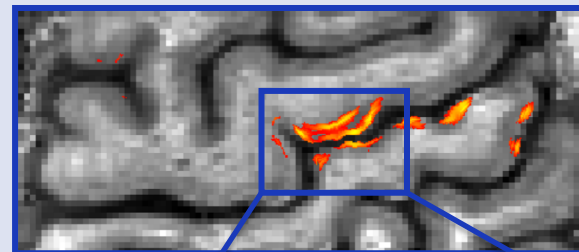
7T



9.4T



3 mm resol.

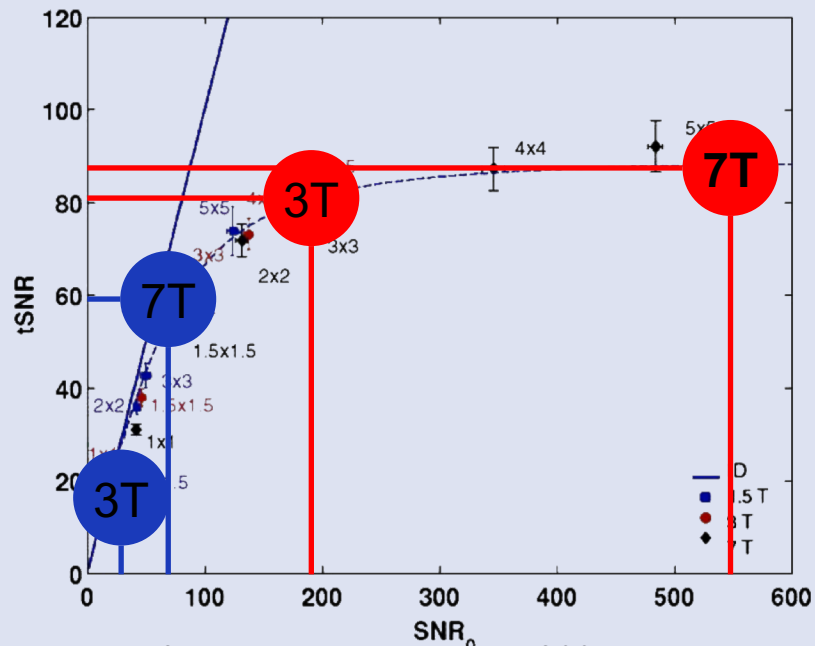


[Huber et al., ISMRM, 2017b]

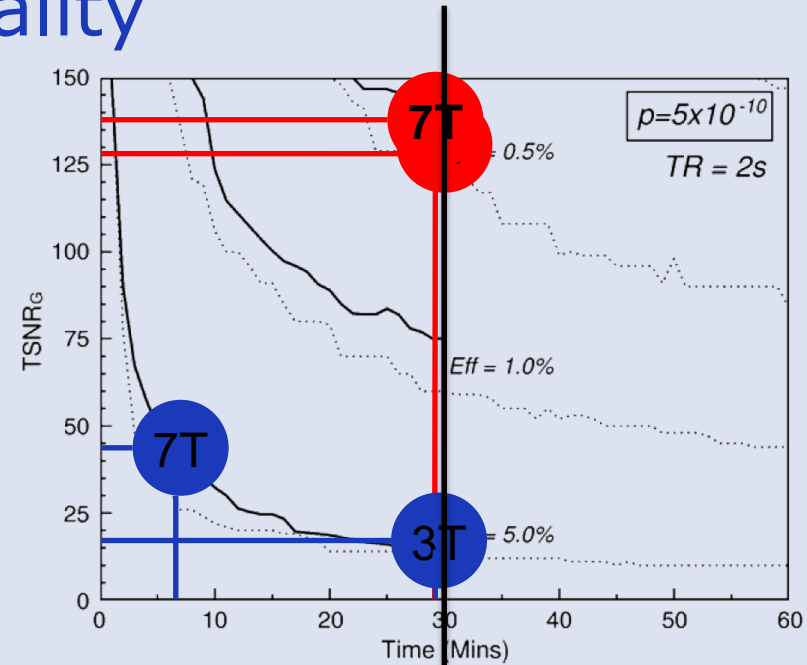
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SNR \neq data quality

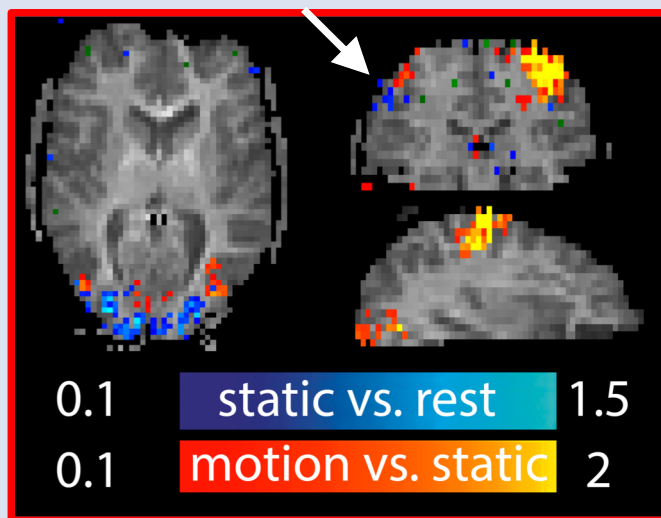


Triantafyllou et al., NeuroImage 2005; Bodurka et al., 2007 *NeuroImage*, 2007



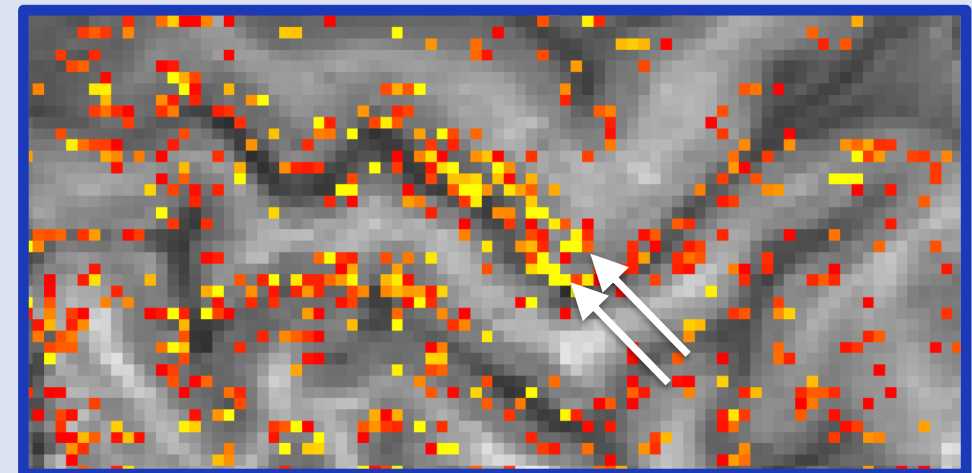
Murphy et al., NeuroImage 2007

negative signal at 3 mm iso. ($\Delta S = 0.5\%$)



Huber et al., NeuroImage 2015

positive layer fMRI at 0.7mm ($\Delta S = 5\%$)



Huber et al., Neuron 2017

Limits of high field and high resolution fMRI

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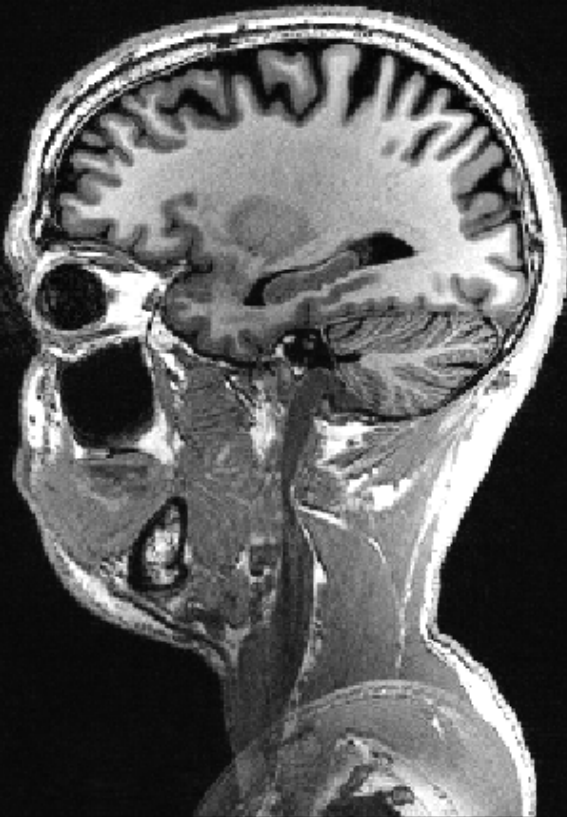
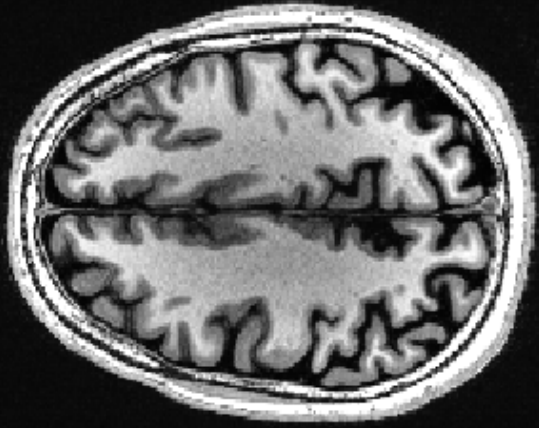
PatPartitions 24 EFFECTIVE TR 120000 ms 20 BWDTH 150 1.00 RF BWTP 5.2
Adjustment Tolerance Auto Matrix Coil Mode Auto (CP) Adjust with body coil MSMA S-C-T
Combined EPI phase correction local Maxwell Correction dummy prep scan time 3
Renzo: Delta TI 100 ms RF duration 2560 us mode Long term Shim mode Gradient use Ernst angle
Ampl 100 EPI factor 64 Phases 1 Concatenations 1 Gain High
1st Signal/Mode Pulse/Trigger RSatRSatSS 1H 243.679 Elliptical filter Position Isoce V32 0.016
Ref. amplitude 1H 0.000 V PasIFSCSatNS 1H 110.205
Frequency 1H 297.180000 MHz at s F >> H 32 mm is 2 Multi-slice mode Interleave Correction factor 1
PasIPre0x21 1H 152.901
Rotation 90.00 deg Jam Auto Coil Select Default m+ 100 Gap 25.0 mm
Average cycle No Signal ms Fourier By Sagittal R >> L 50 R >> L 300 thickness 100 Trigger delay 0 ms
Coil Combine Mode Sum of Squares Acquisition window 5000 ms Trigger pulse 1 Positioning mode REF 2 1100.0
Measurements 2 MotionCorrection 100 TR 5000.00 ms r Spatial Filter
Transversal F >> H Reordering Linear Averaging mode Long term Delay in TR 0
Free echo spacing Dimension 3D Separation mode IPICORE 02T
Bandwidth 752 Hz/Px Contrasts 1 Assume ? Ref. amplitude 1H 0.000
Gradient mode Fast RF pulse type Normal Introduction Echo spacing 1.4 ms
Concatenations 11 z shim 0.00 mT/m*1 Series reordering
RF spoiling Excitation Slab-sel. 32 log physio files 4 Robert (the one) 30

Limits of high field and high resolution fMRI

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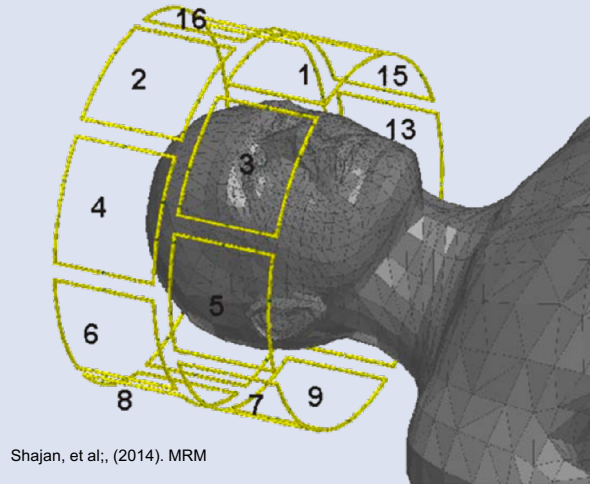
Field inhomogeneities I

7T fMRI is not really straight forward for deep brain structures



3T, 32ch Nova coil, 10 min

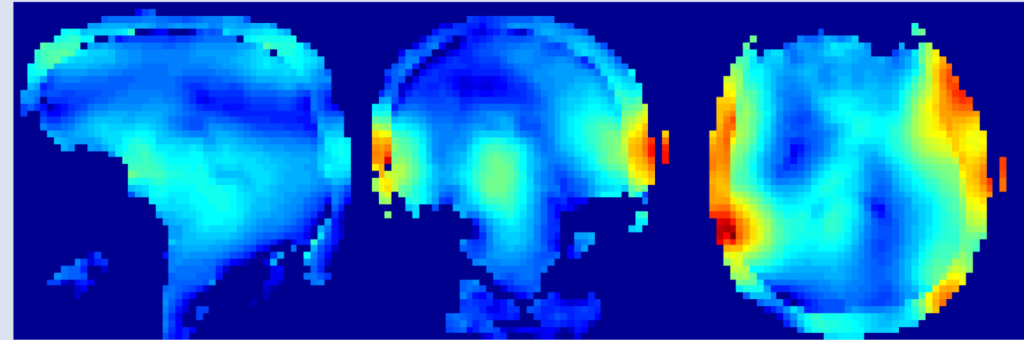
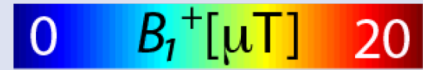
Field inhomogeneities II – SAR - pTX



Shajan, et al., (2014). MRM

9.4T [Huber et al., NeuroImage, 2018] with Desmond Tse, Ben Poser and Dimo Ivanov

no-pTx-shim



Nova Medical Coils



Nova 8TX32RX: SAFETY and Coil Models
 8TX Simulated Fields Hugo Head Model, Remcom XFDTD

Simulated E, J, -> SAR Matrices->
 Virtual Observation Point (VOP) MODEL

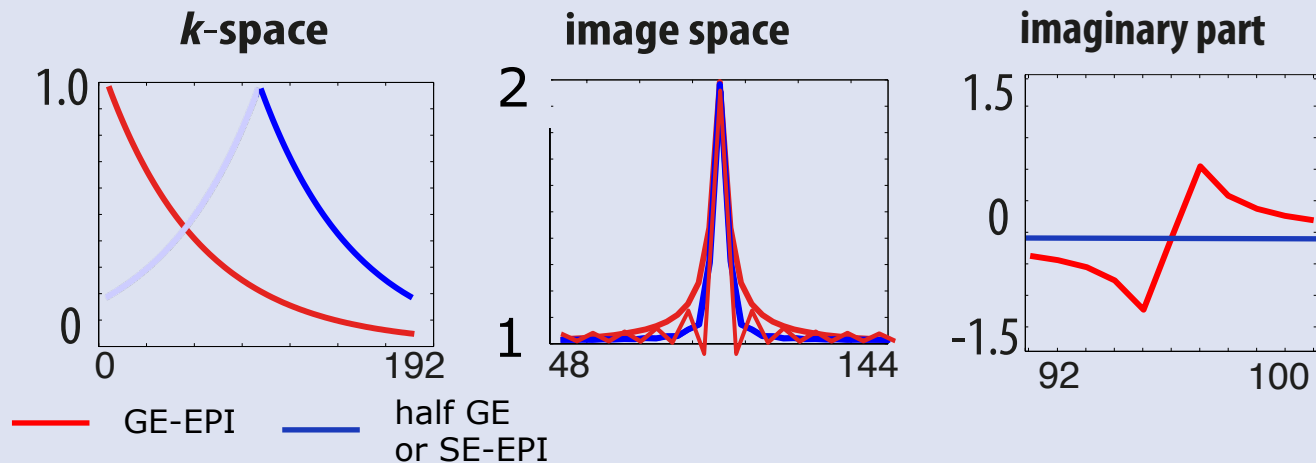
Accurate FDTD coil models – Simulated and Measured Cap values within 2-3%
 Long chain from simulation to actual produced E fields
 VOP MODEL NEEDS VALIDATION with IEC type Temperature Measurements
 Coil provided with recommended and validated VOP MODEL
 If coil used outside recommended limits, customer is responsible for results

Patrick Ledden
 Nova Medical Boston, USA

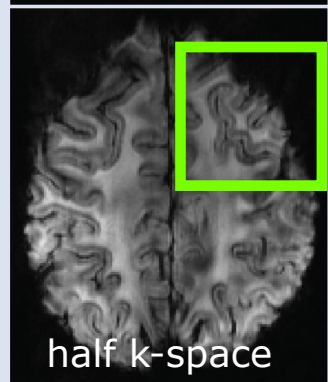
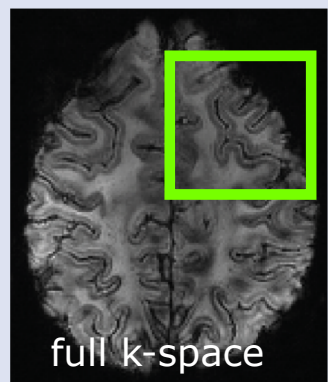
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T₂*-blurring

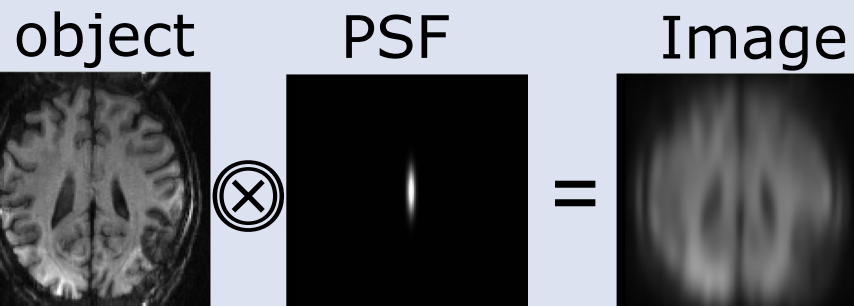
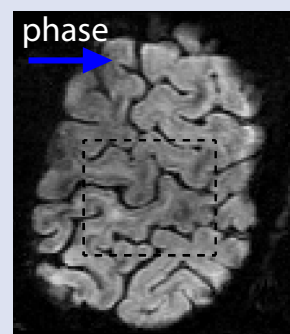
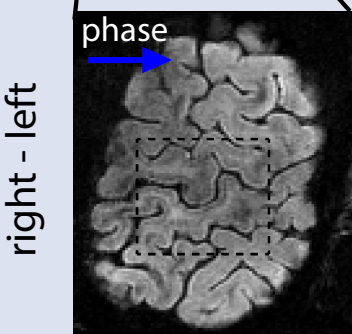
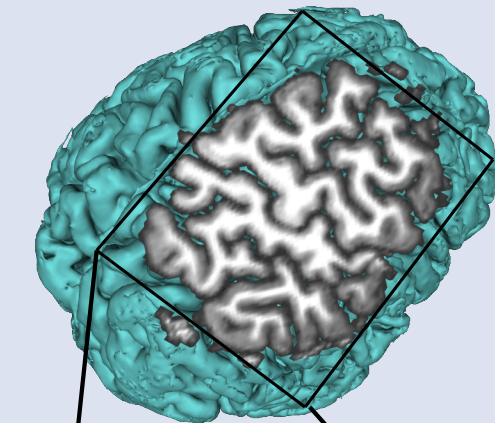
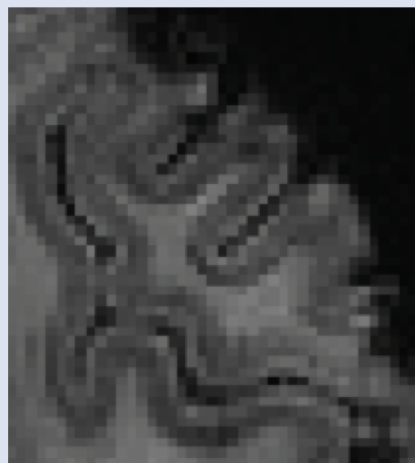


[Feinberg et al., Radiology, 1986]



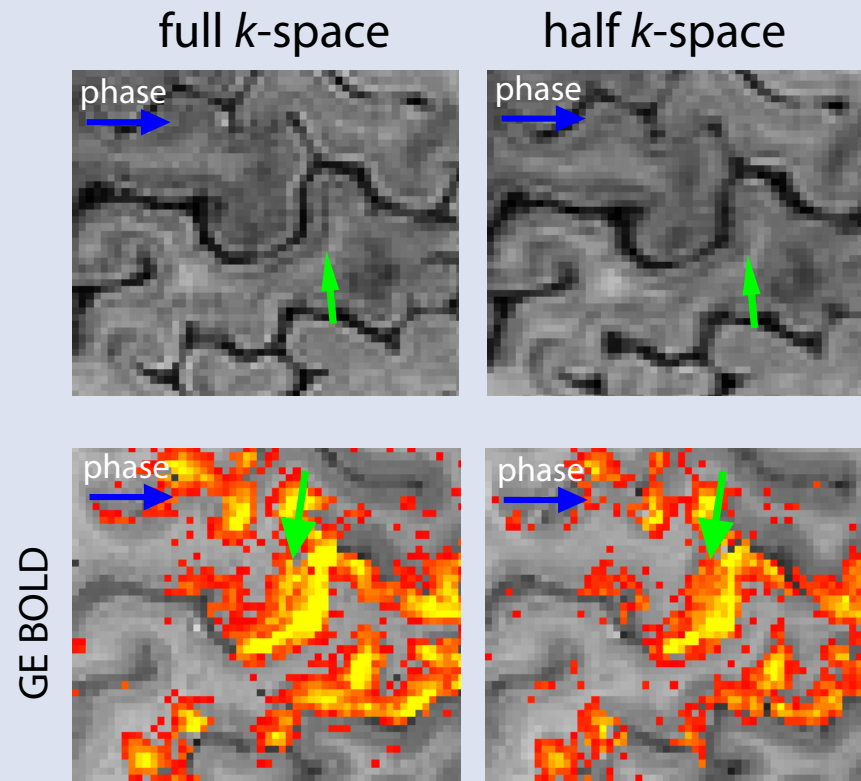
↑
phase

TE = 48 ms, 7T, 1.1 mm
Readout duration = 90ms



Jesmanowicz et al., 1998 MRM

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



[Huber et al., ISMRM, 2015]

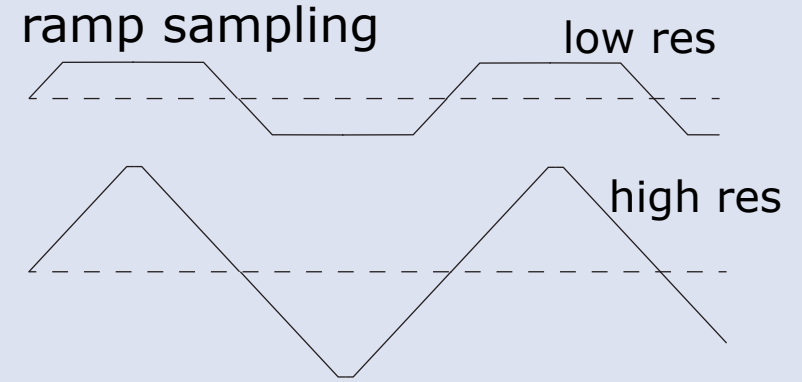
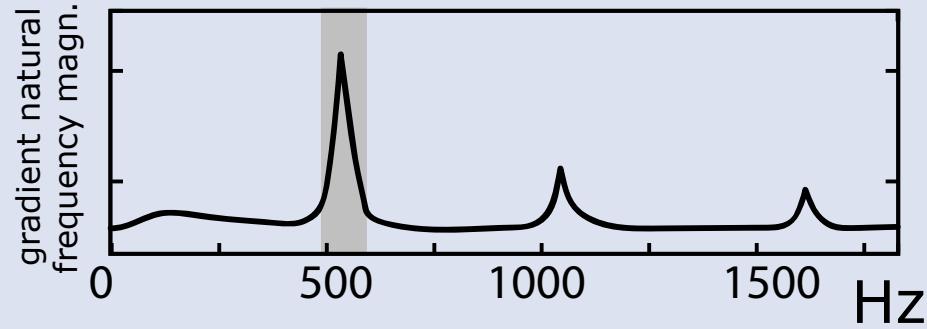
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High-res EPI-artifacts: ghosts

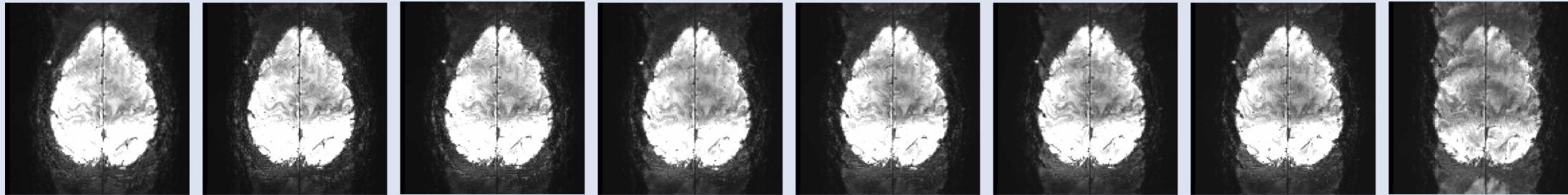


acoustic resonances



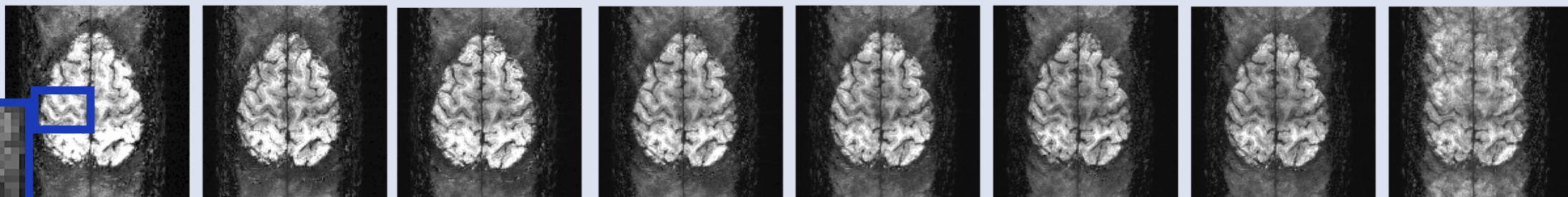
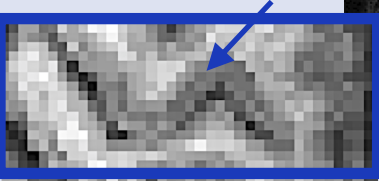
BWDT [Hz/Px]:	960	1010	1112	1234	1388	1516	1754	1960
echo spacing [ms]:	1.2	1.11	1.02	0.92	0.84	0.78	0.83	0.92

signal



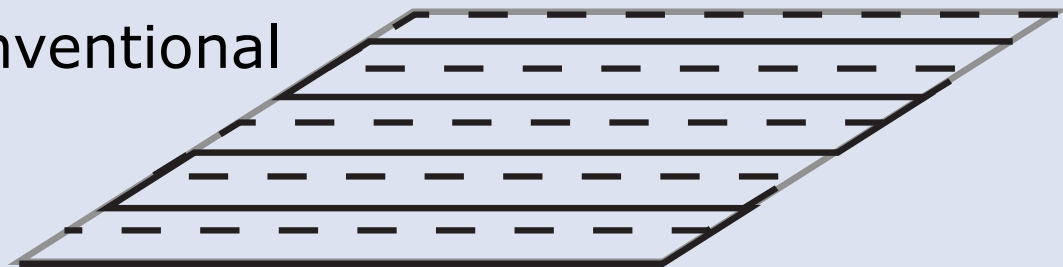
tSNR

layer

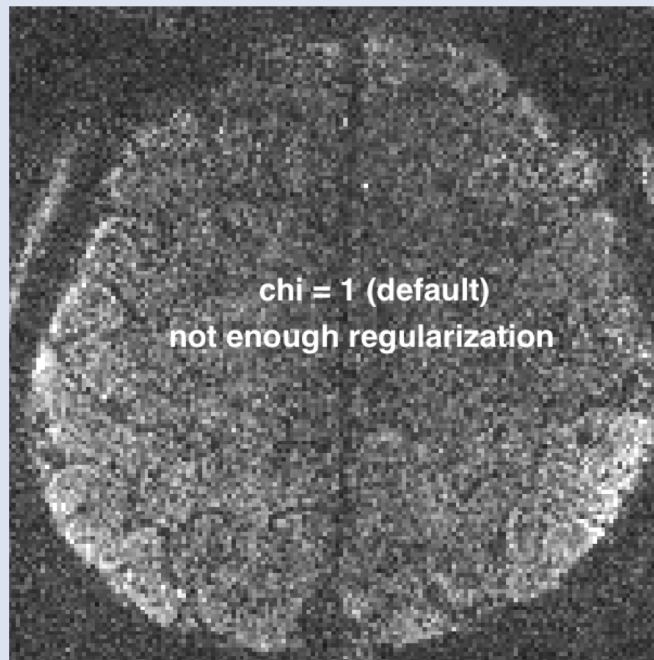


GRAPPA at high field and high resolutions

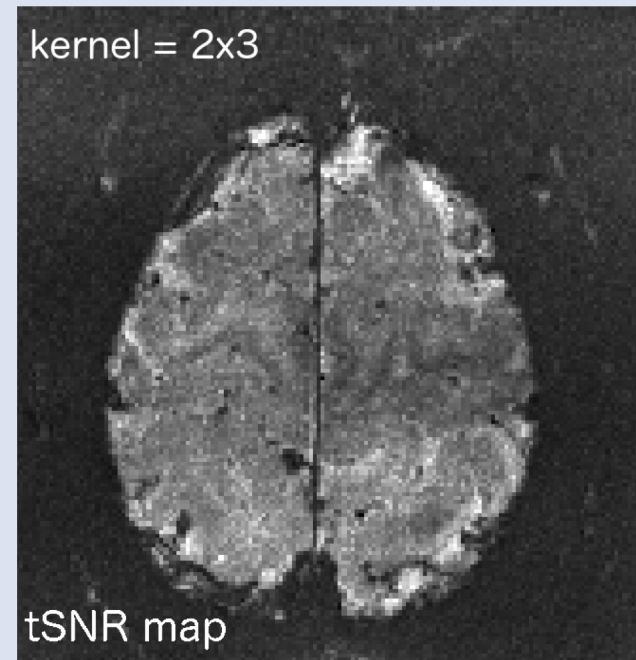
conventional



regularization matters

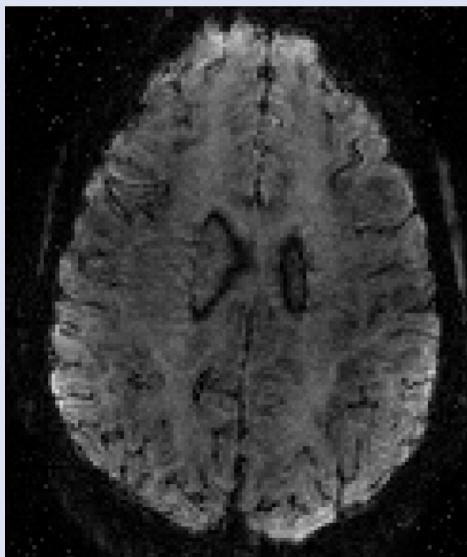
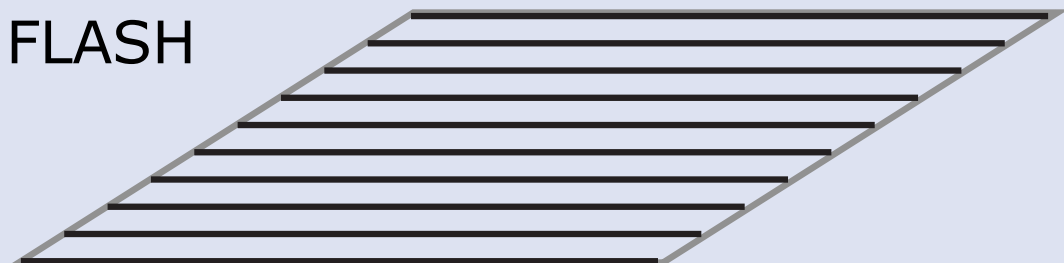


kernel size matters



reference data scheme matters

FLASH

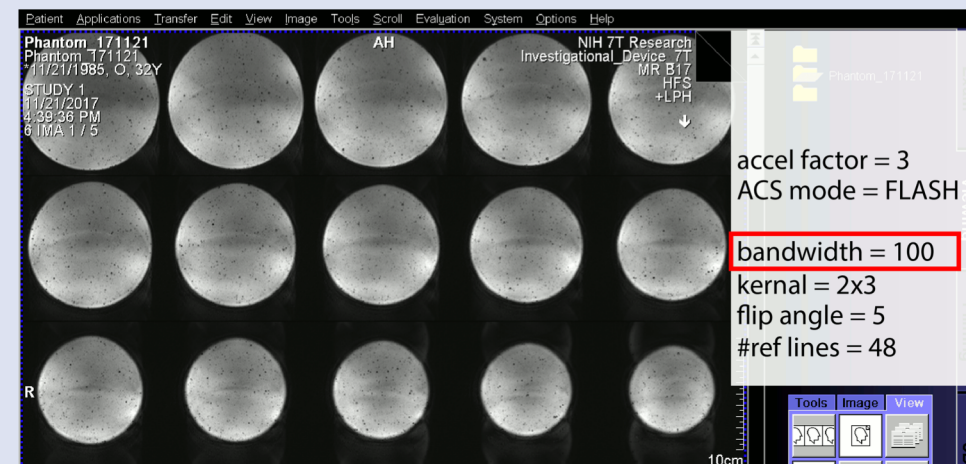


FLASH GRAPPA for fMRI: Talagala et al., 2015 MRM

FLEET GRAPPA for fMRI: Polimeni et al., 2016 MRM

dual polarity GRAPPA for fMRI: Hoge et al., 2016 MRM

everything matters



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readout

2D-SMS-EPI

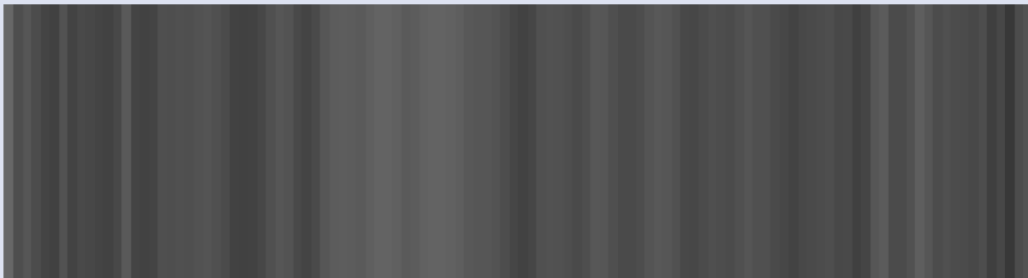


[Setsompop, 2012]

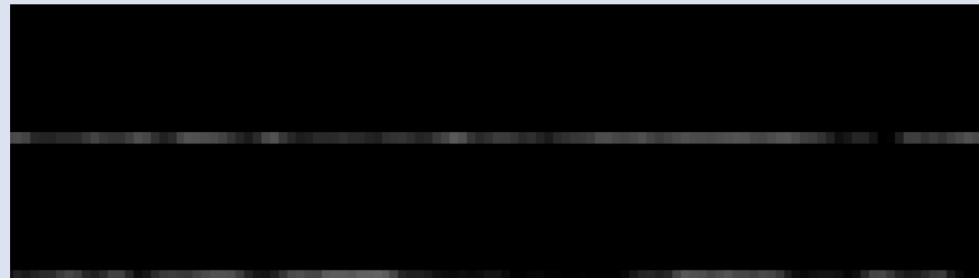
3D-EPI

readout

2D-SMS-EPI

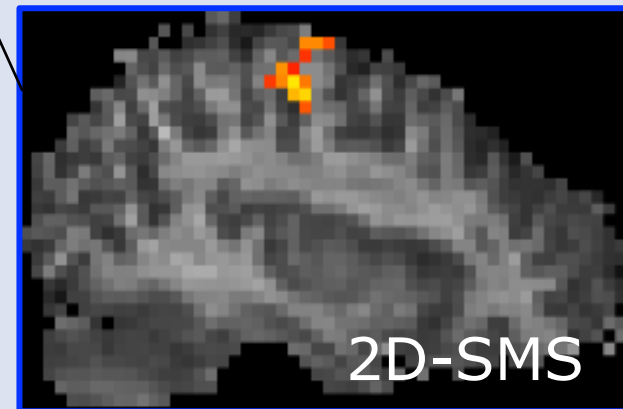
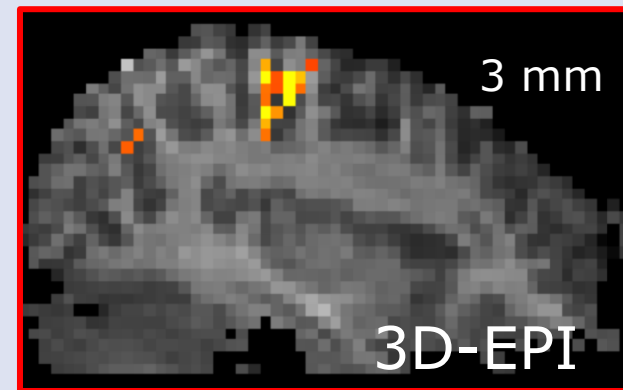
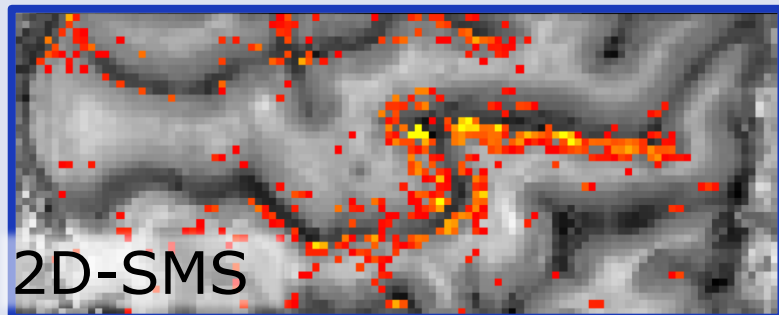
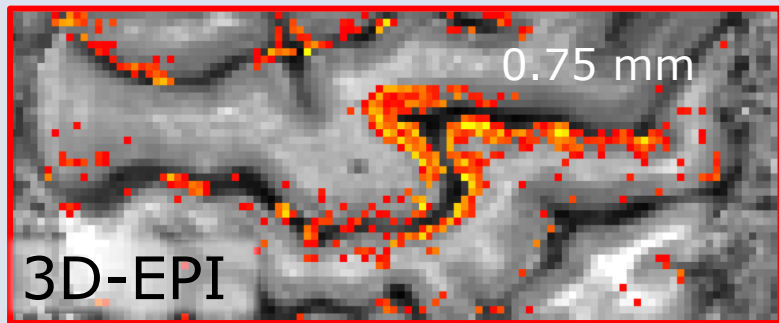
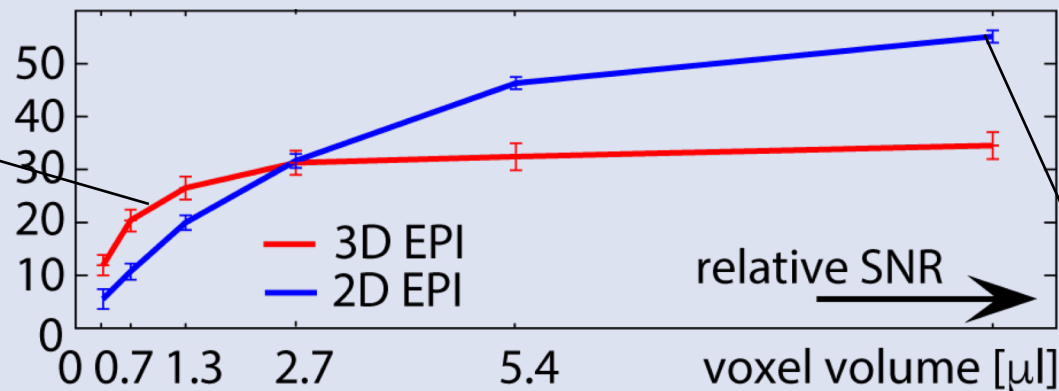


[Poser, 2010, 2013]



[Setsompop, 2012]

temporal signal to noise ratio in N=4 participants



[Huber et al., NeuroImage, 2018]

Limits of high field and high resolution fMRI

- Sensitivity limitations
 - Physiological noise
 - Dealing with complexity
 - Inhomogeneity (B1) pTx
 - Short T2*
 - High-resolution limits with GRAPPA
 - 2D vs. 3D limits at high resolutions
- Segmentation
 - Motion
 - Distortion
 - (statistical) activation analysis

ISMRM study group survey

← high-resolution fMRI biggest challenges ☆

SEND

QUESTIONS

Section 1 of 2

Biggest challenges of high-resolution fMRI

The ISMRM study group "Current Issues in Brain Function" would like to hear your opinion about the challenges in high-resolution fMRI.
The results of this survey will be presented at the study-group business meeting at the 26th ISMRM meeting 2018 in Paris: Thursday, June 21st, 15:30-16:30 pm, room W07
Based on the results of this survey and its discussion at the meeting in Paris, the study group will organize a study-group virtual meeting in the fall of 2018.

Here the term "high-resolution" refers to spatial resolution of voxel sizes below 1.1 mm.

Changes to responses can be made after submitting it.
A google account is not necessary to fill out this form.
A membership to the study group is not necessary to fill out this form.
If you have technical questions about this form, please contact Laurentius.Huber@nih.gov

Name

Short answer text

+

Tt

📷

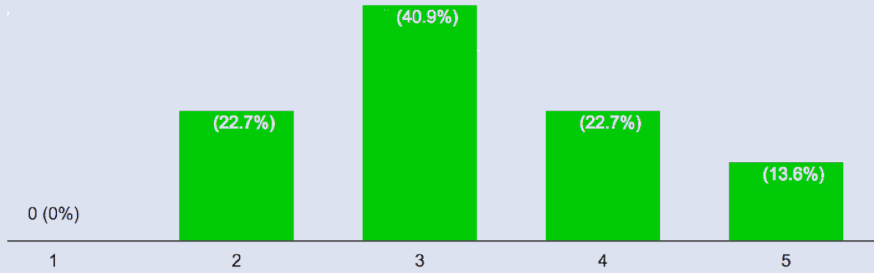
📺

☰

Most limiting factors: 0 (not limited) - 5 (very limited)

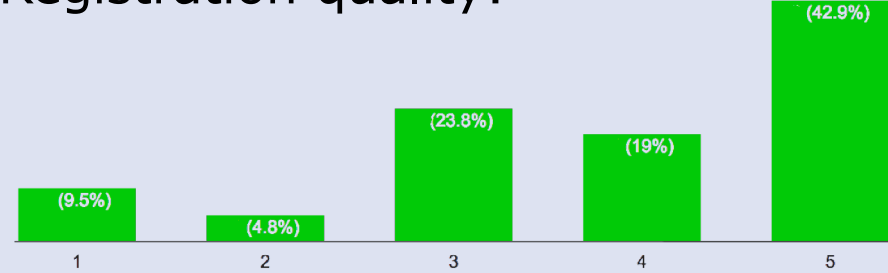
People are least limited by SNR!

Sensitivity: mean=3.27

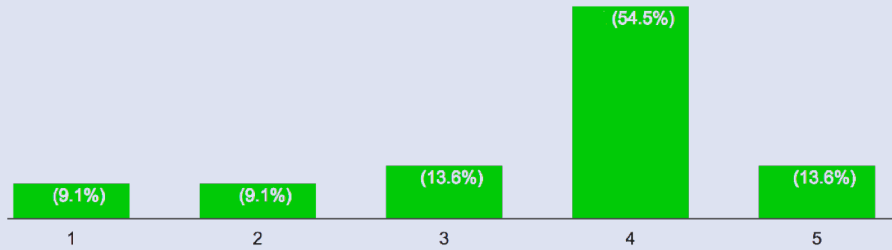


People are most limited by registration

Registration quality: mean=3.8



Localization specificity: mean=3.54



Segmentation quality: mean=3.3

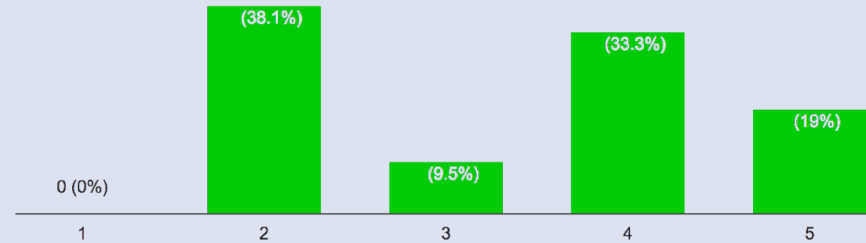
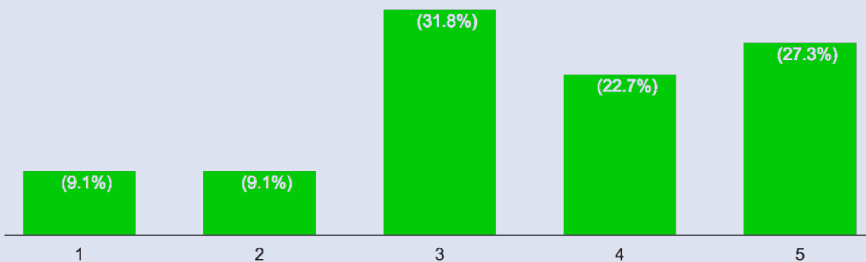
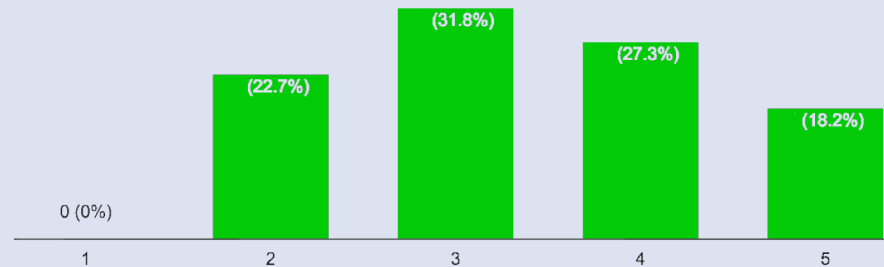


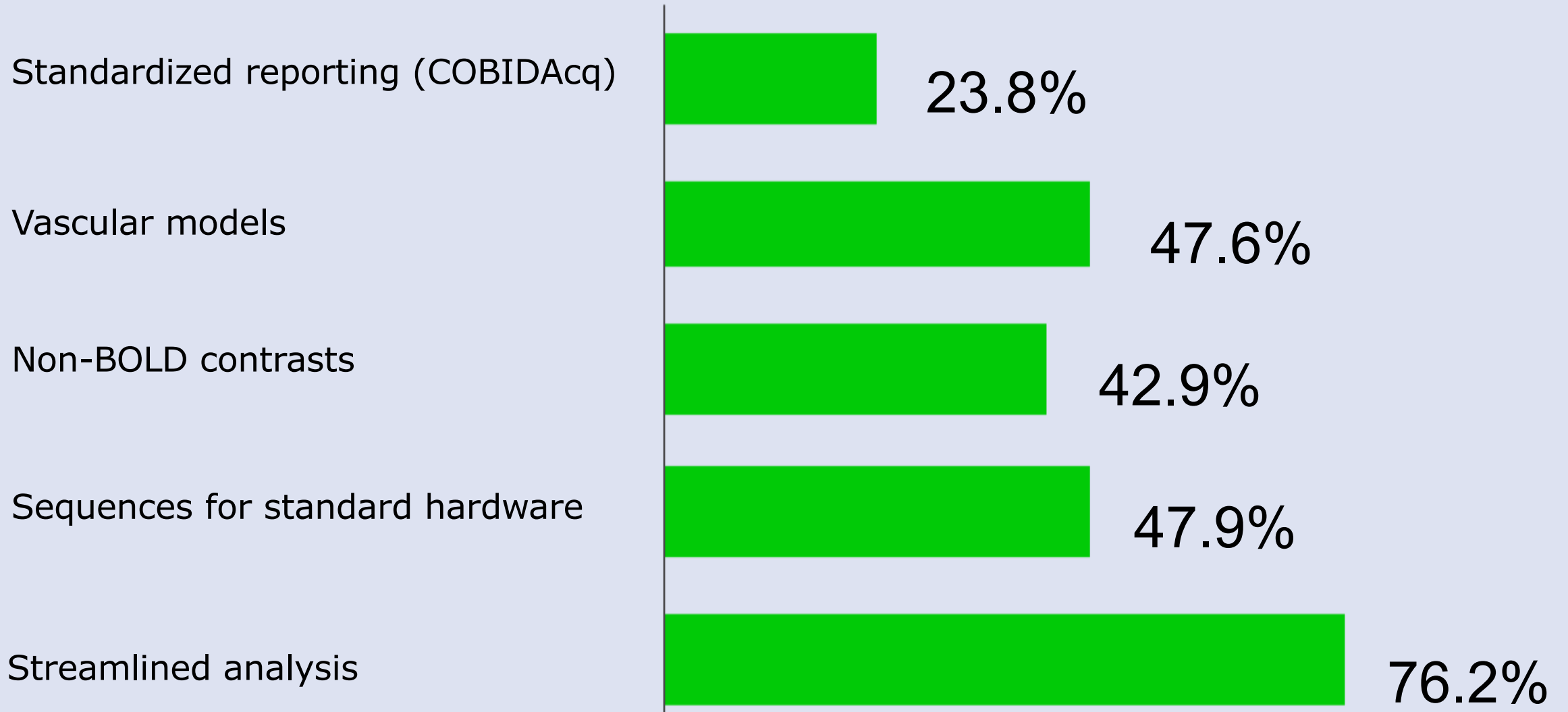
Image distortions: mean=3.5



Head motion: mean=3.4



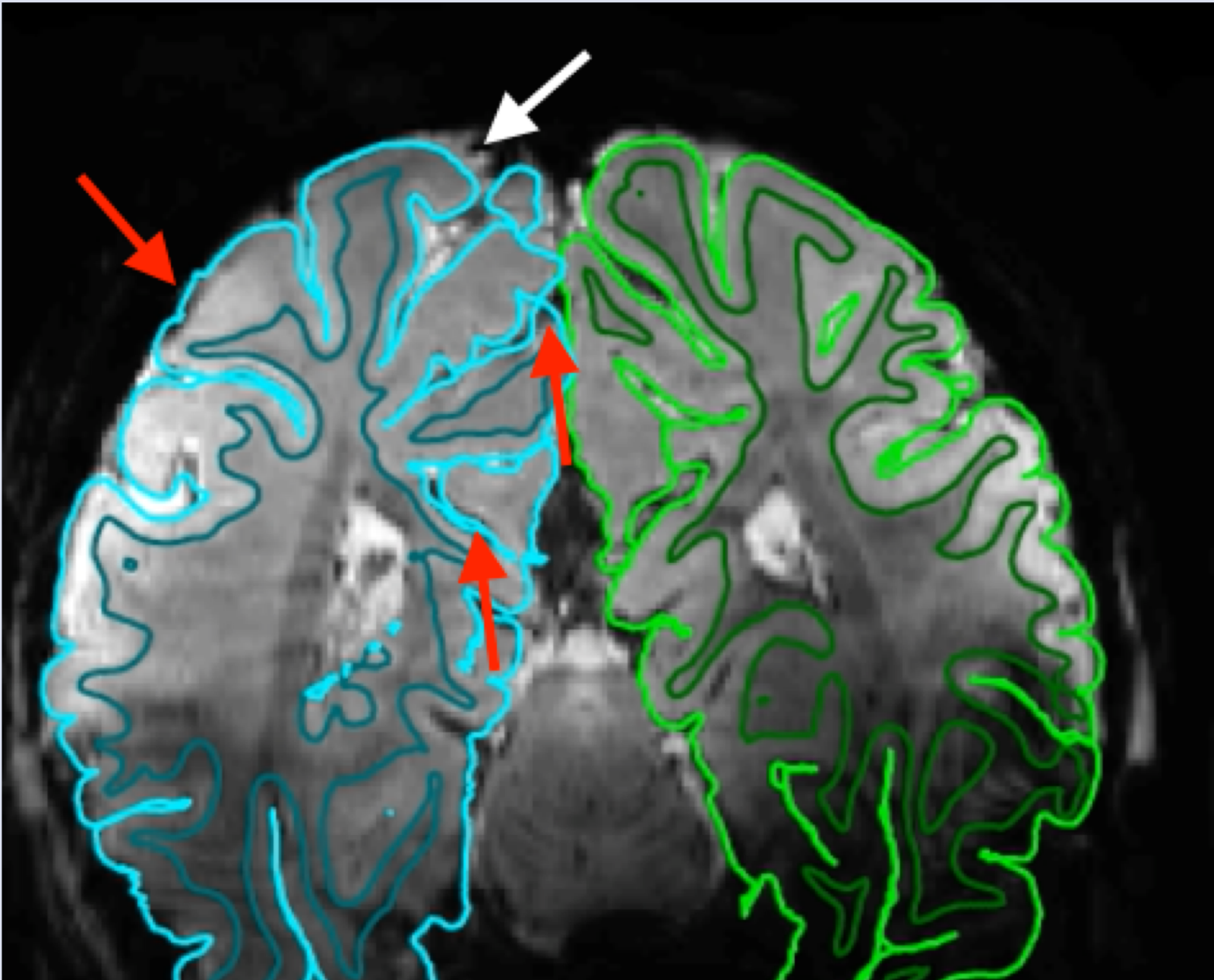
Which directions should future efforts go to?



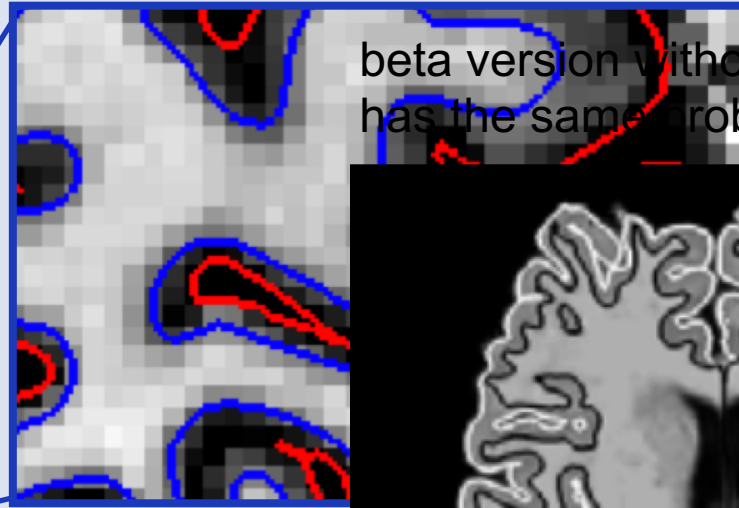
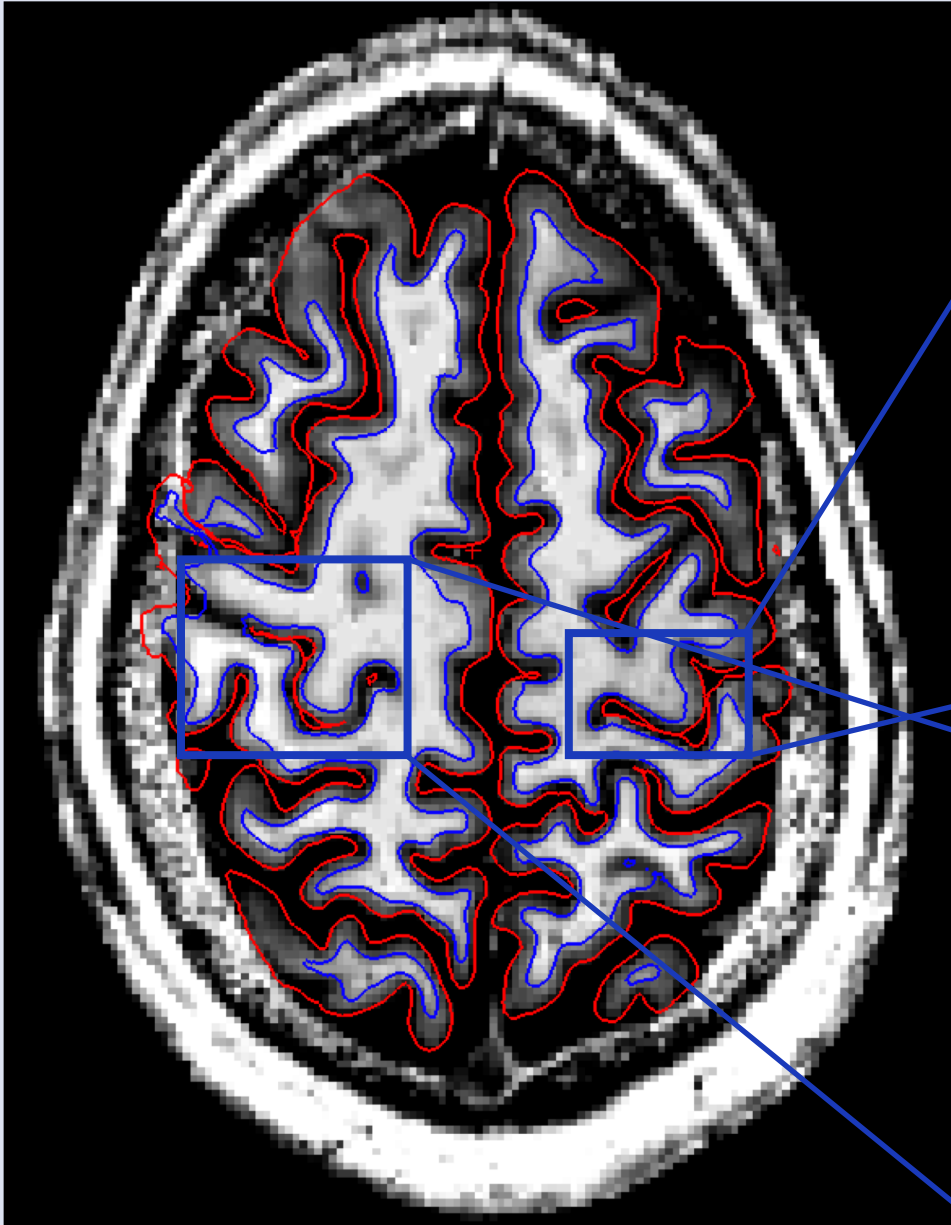
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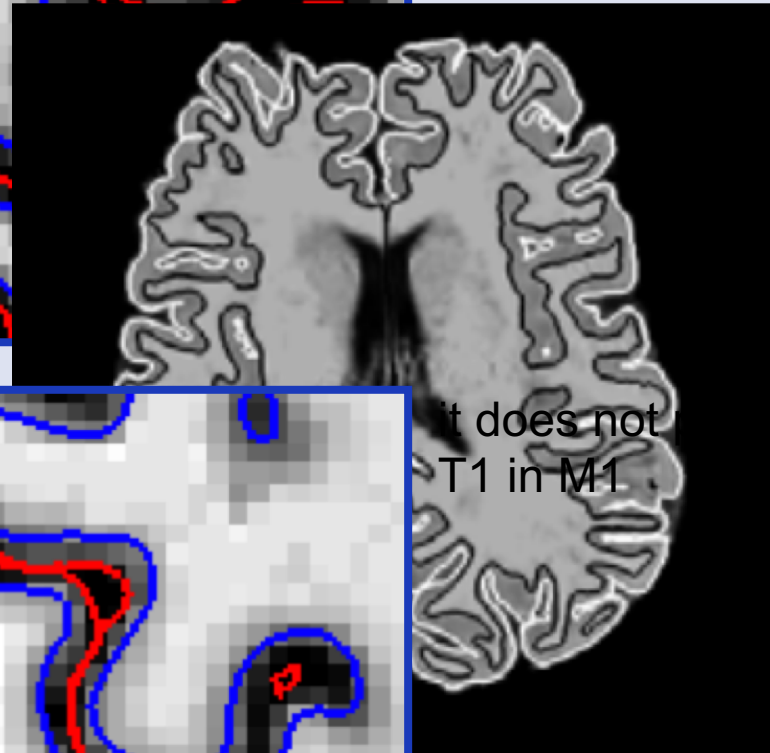
Segmentation in EPI space (Data taken from Kendrick Kay et al.)



Automatic segmentation is challenging in sub-millimeter regime



beta version without resampling
has the same problem
It misses CSF when partial
voluming is small



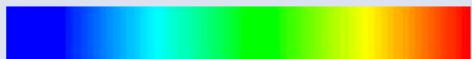
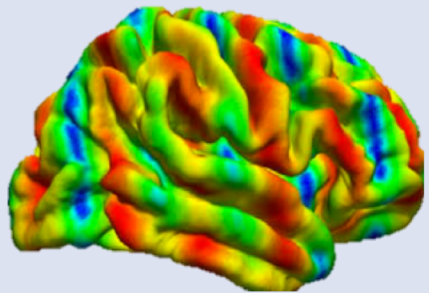
It does not
T1 in M1
rm well with short

Limits of high field and high resolution fMRI

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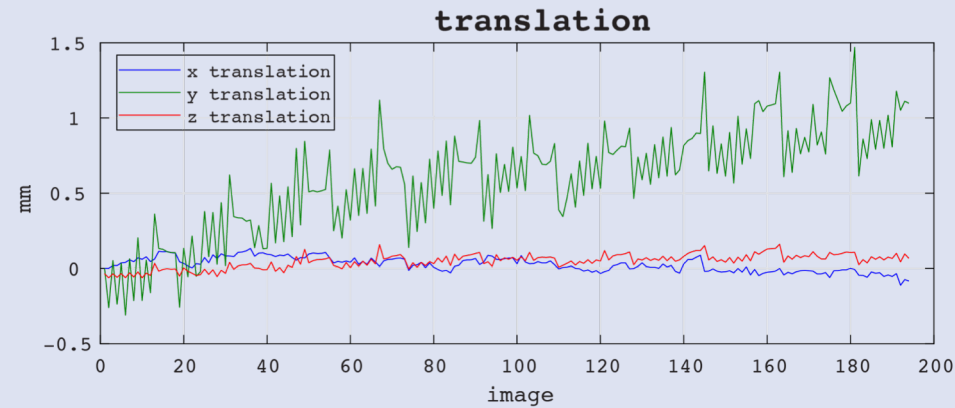
Motion limits

Resolution loss due to resampling



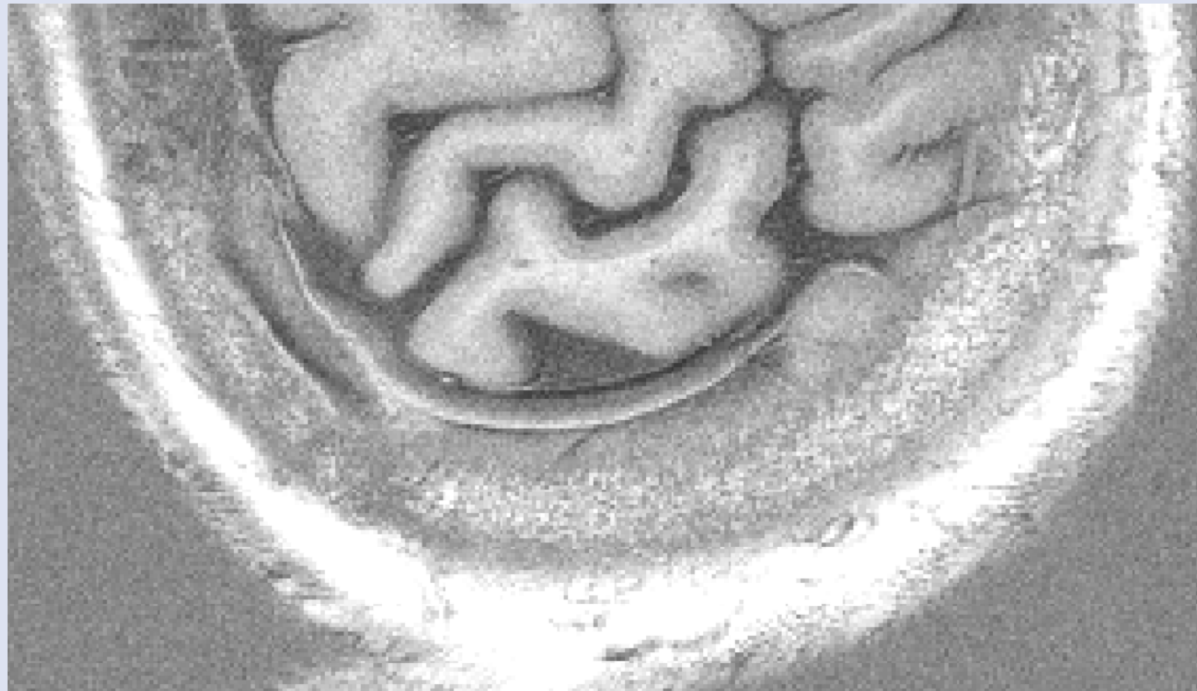
0.53 FWHM [mm] 1.05
Polimeni et al., 2018

field motion is the biggest motion

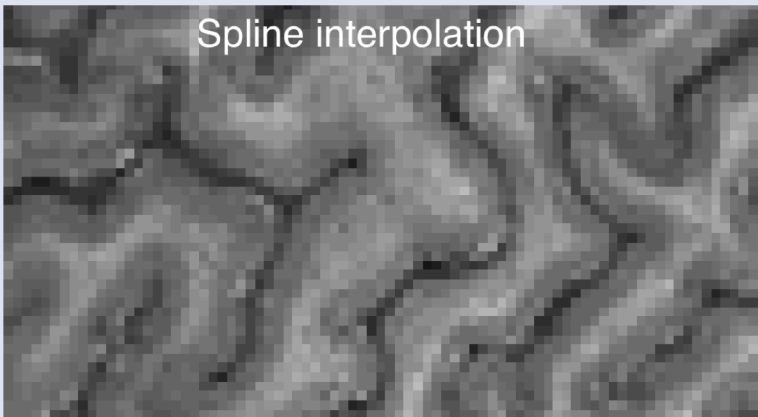


Valsalva breath holding respiration task acquired with Dan Handwerker

local motion correction



Spline interpolation

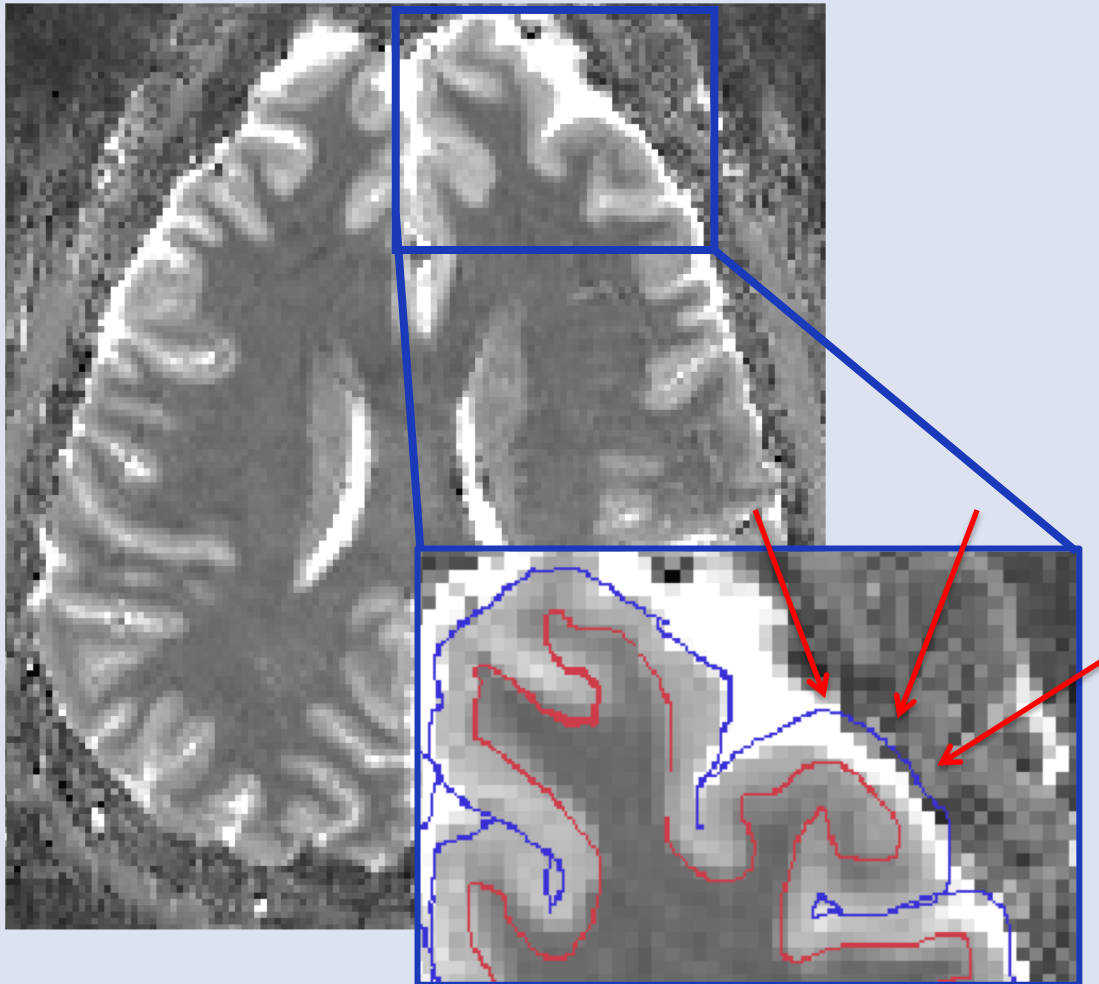


Limits of high field and high resolution fMRI

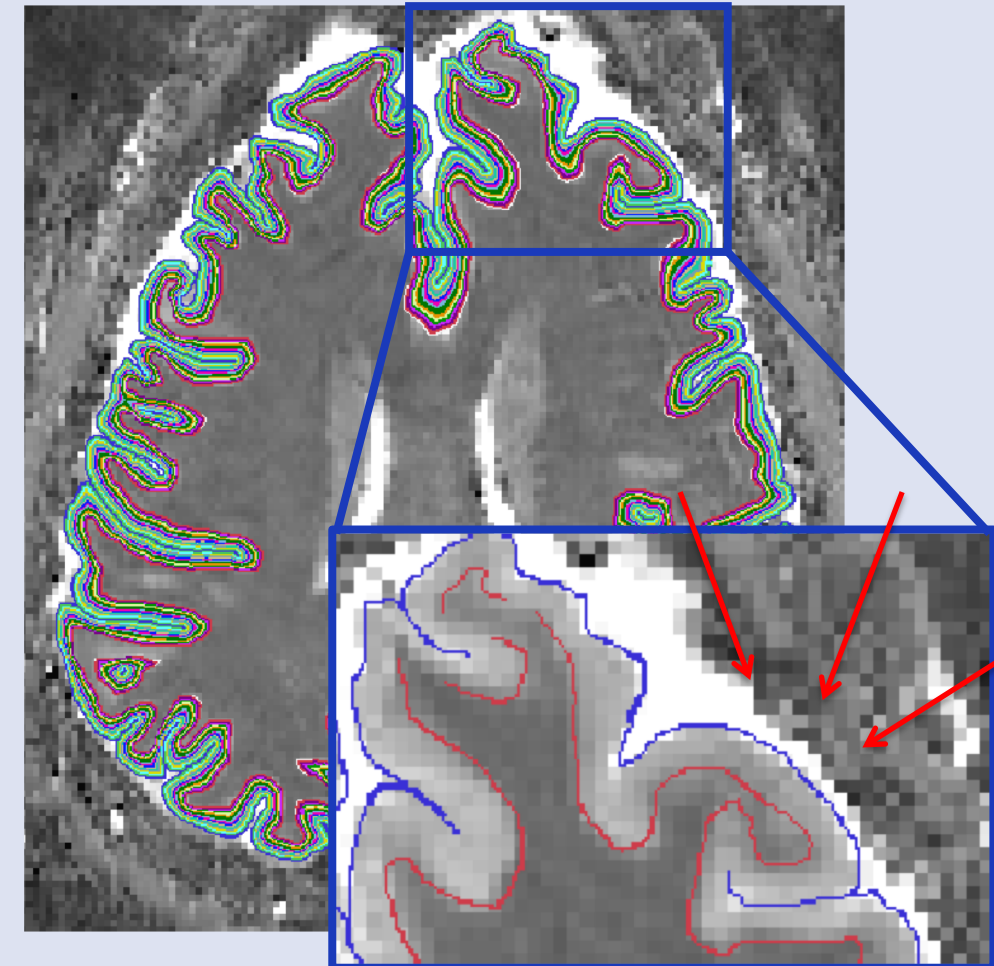
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Distortion limits

Anatomy vs. EPI



EPI-function vs. EPI anatomy



Thank you

NIMH:

- Daniel Handwerker
- Emily Finn
- Yuhui Chai
- Dave Jangraw
- Arman Khojandi
- Sean Marrett
- Vinai Roopchansingh
- Andy Derbyshire
- Kenny Chung
- Javier Gonzales
- Adam Thomas
- Peter Bandettini

comments and questions are appreciated:

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- Bob Turner
- Robert Trampel
- Maria Guidi

University of Glasgow:

- Jozien Goense

University of Sheffield:

- Aneurin Kennerley

Cornell University Hospital

- Carsten Stüber

University of Maastricht:

- **Benedikt Poser**
- Dimo Ivanov



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