HUMAN Connectome PROJECT

Using 7T Multimodal Data

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HCP OT 1-3: UMN (CMRR), Oxford, and WU

https://dl.dropboxusercontent.com/u/23744124/HCP7T.pdf

Learning objectives

- Advantages and challenges of 7T neuroimaging
- MR techniques developed at CMRR, UMN to meet the challenges
- BOLD contrast mechanism and its field dependence
- HCP 7T protocol
- HCP 7T data preliminary analysis results

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WU-Minn Human Connectome Project

- 3T Phase 2: Aug 2012 - 2015

1,200 participants, 300 twin pairs

- 7T Pilot: Aug 2012 - late 2013
- 7T Phase 2: late 2013 – 2015

a subset of 200 HCP subjects scanned at CMRR, UMN

Siemens 7T AS 90/60 cm bore
SC72CD gradients

G_{max} = 70 mT/m (for diffusion)
G_{max} = 42 mT/m (for imaging)
Slew rate = 200 T/m/s (for imaging)
32ch Nova head coil

https://dl.dropboxusercontent.com/u/23744124/HCP7T.pdf

Advantages of 7T MRI

- Increased SNR traded for spatial resolution
- Increased intrinsic BOLD sensitivity
- Increased BOLD specificity (in certain regions)

MR sensitivity ~ field strength

$$S/N \sim B_0^{3/2}$$

system noise dominant

SNR gain $_{7T/3T}$: 3.75!

7T (297 MHz)
3T (123 MHz)

$$S/N \sim B_0$$

sample noise dominant

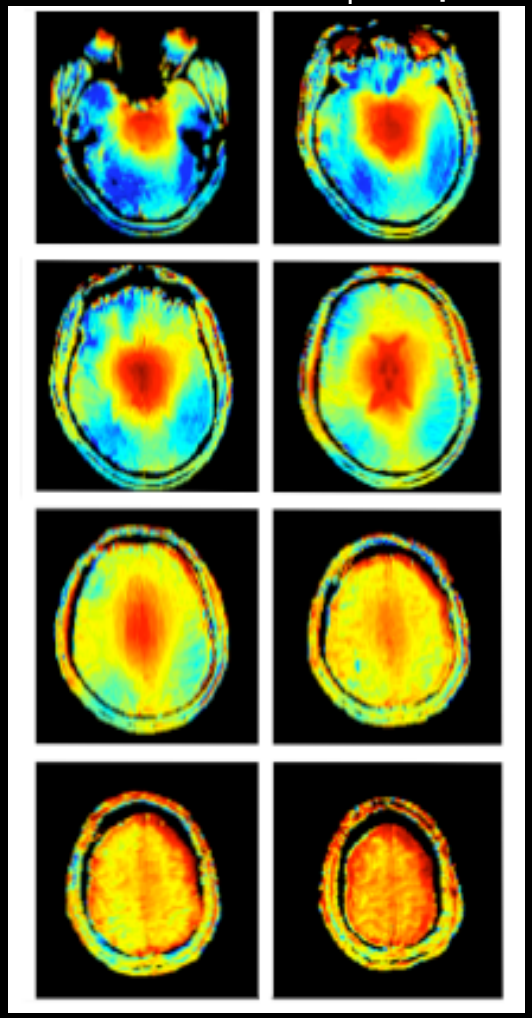
SNR gain $_{7T/3T}$: 2.4

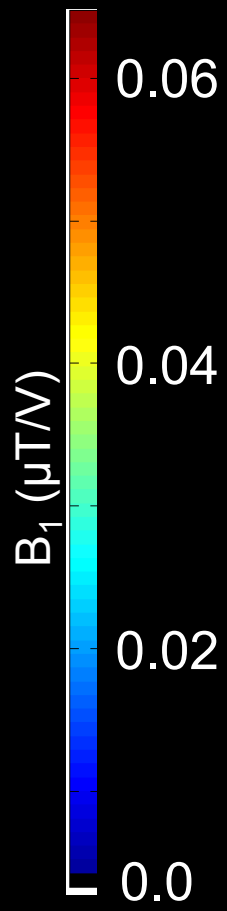
Challenges of 7T MRI

- Relaxation: longer T1 and shorter T2/T2*
- Transmit: inhomogeneous B_1^+ field
  peak power limit
  specific absorption rate (SAR)
- Main field: inhomogeneous B_0
- Motion: increased sensitivity (bulk or physiological)

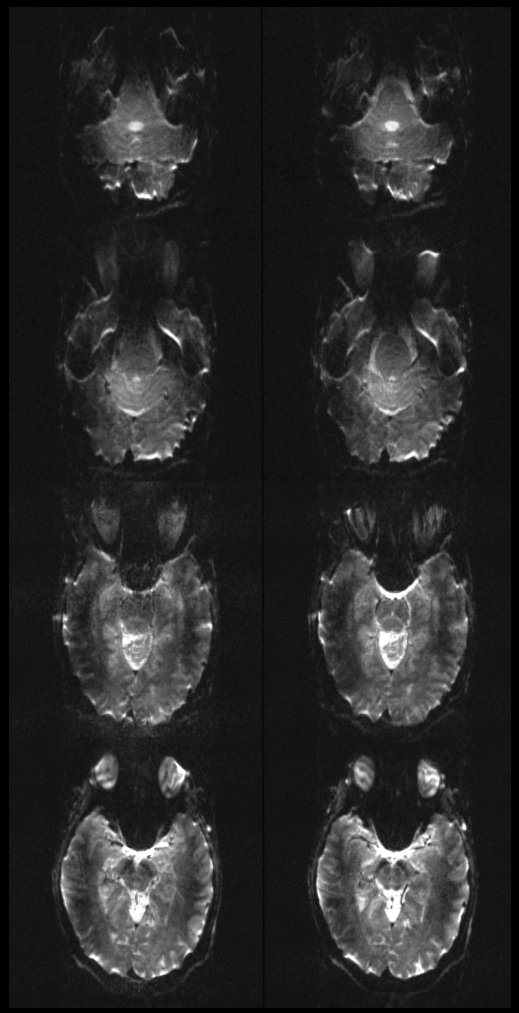
Importance of Improving B_1^+ Homogeneity at 7T

7T Transmit B_1 Maps



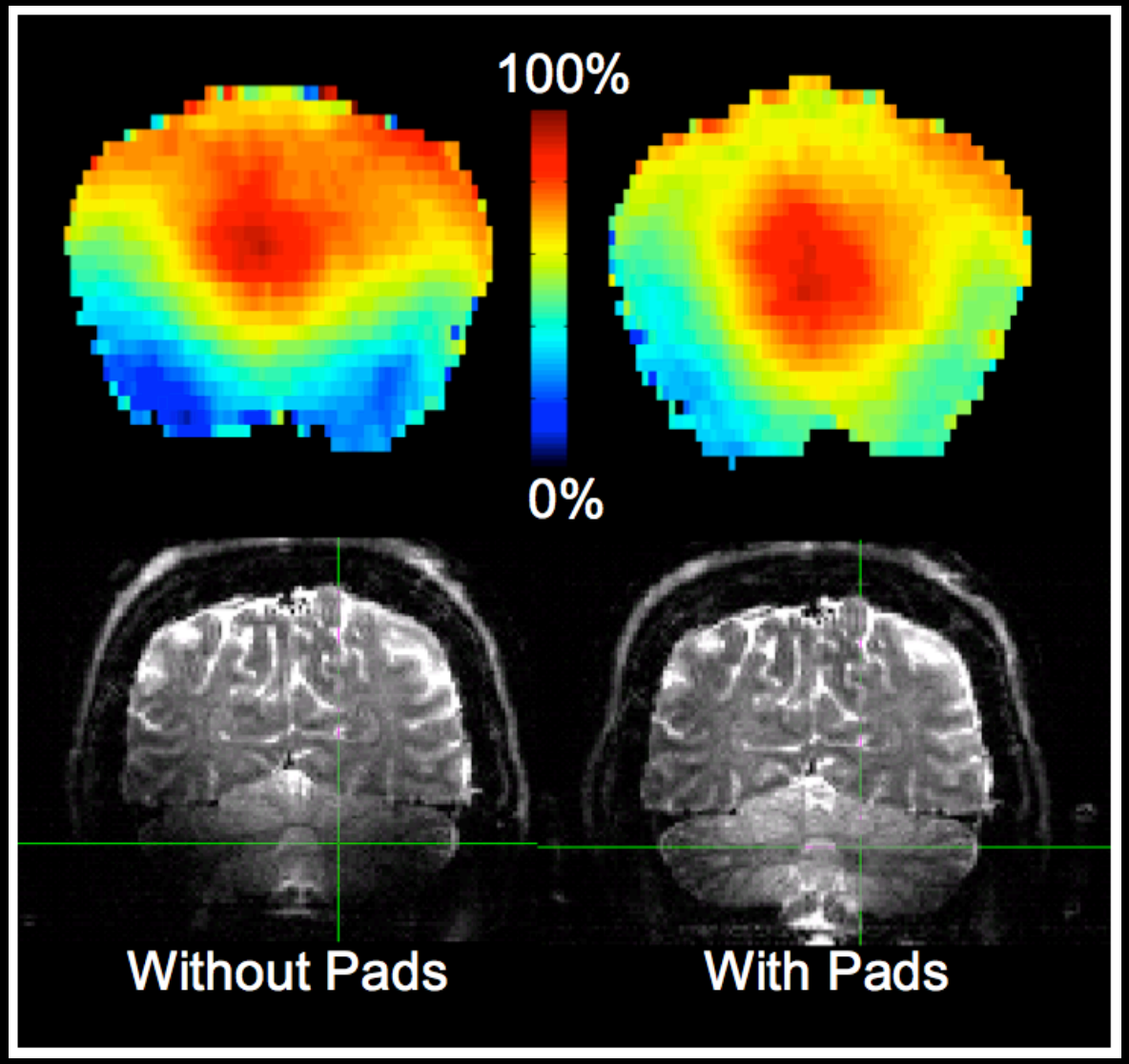


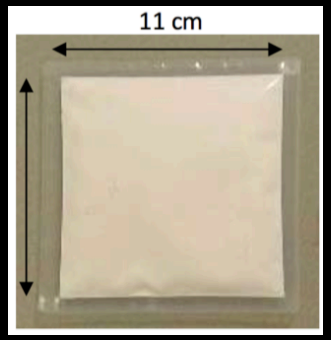
7T Spin Echo EPI



- Over flipping in the center of the brain
- Low flip angle at lower part of the brain (temporal lobe, cerebellum, brain stem)

Dielectric material to improve B_1^+



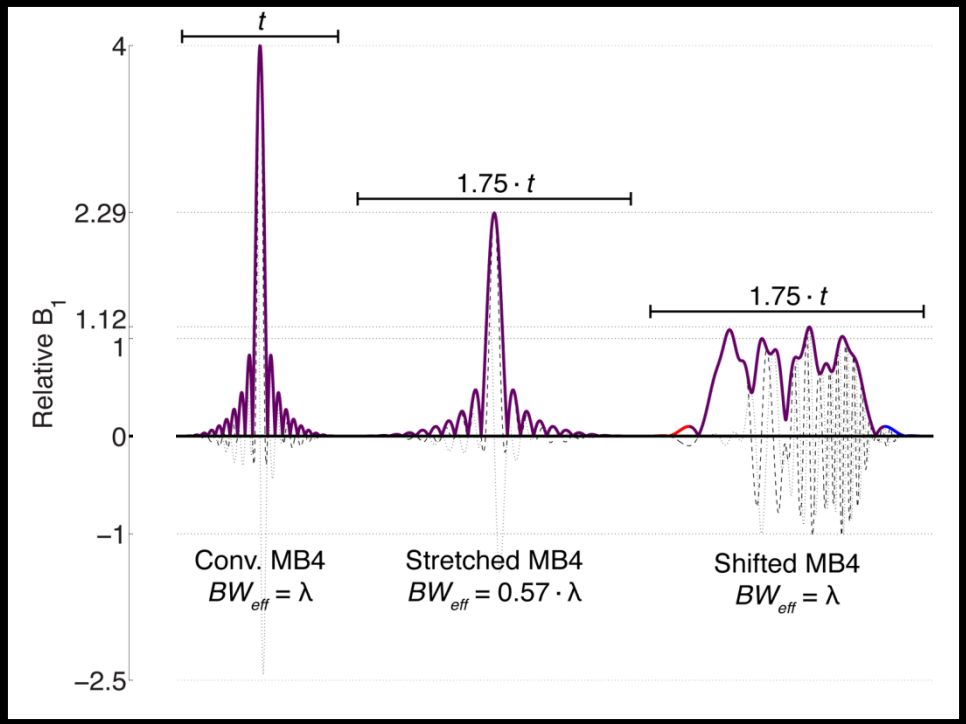


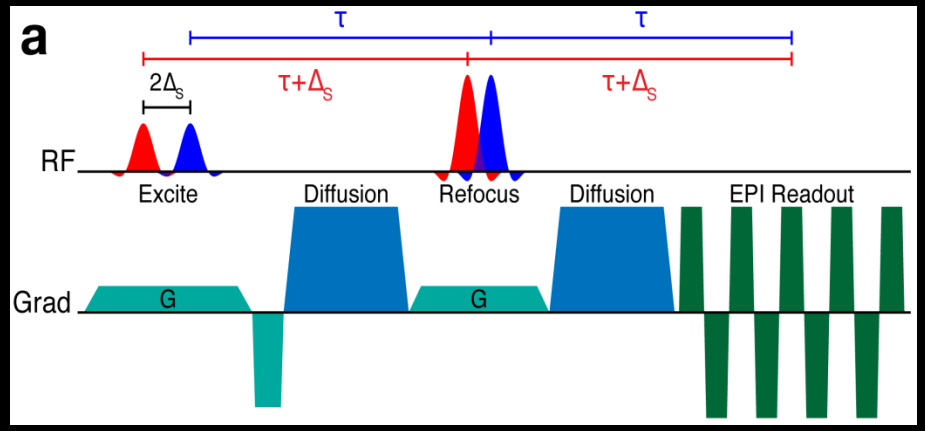
Dielectric pads
(CaTiO3)

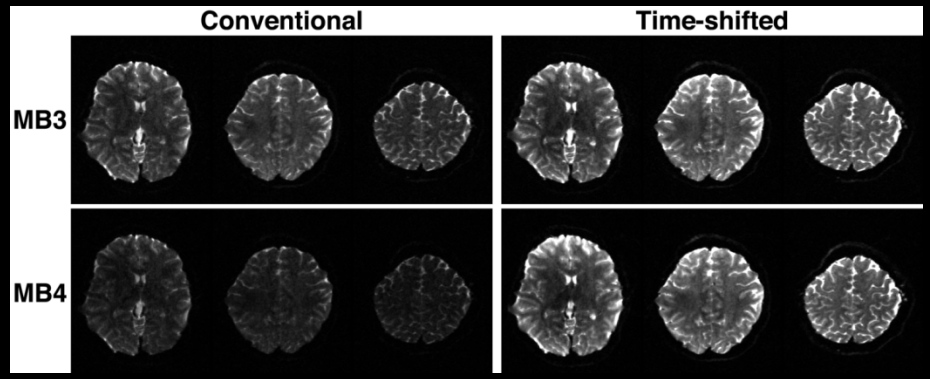
Over flipping in the center of the brain remains

Time and Phase shifted MB pulses to reduce peak power and specific absorption rate (SAR)

Peak Power and BW with 25% temporal shift between bands



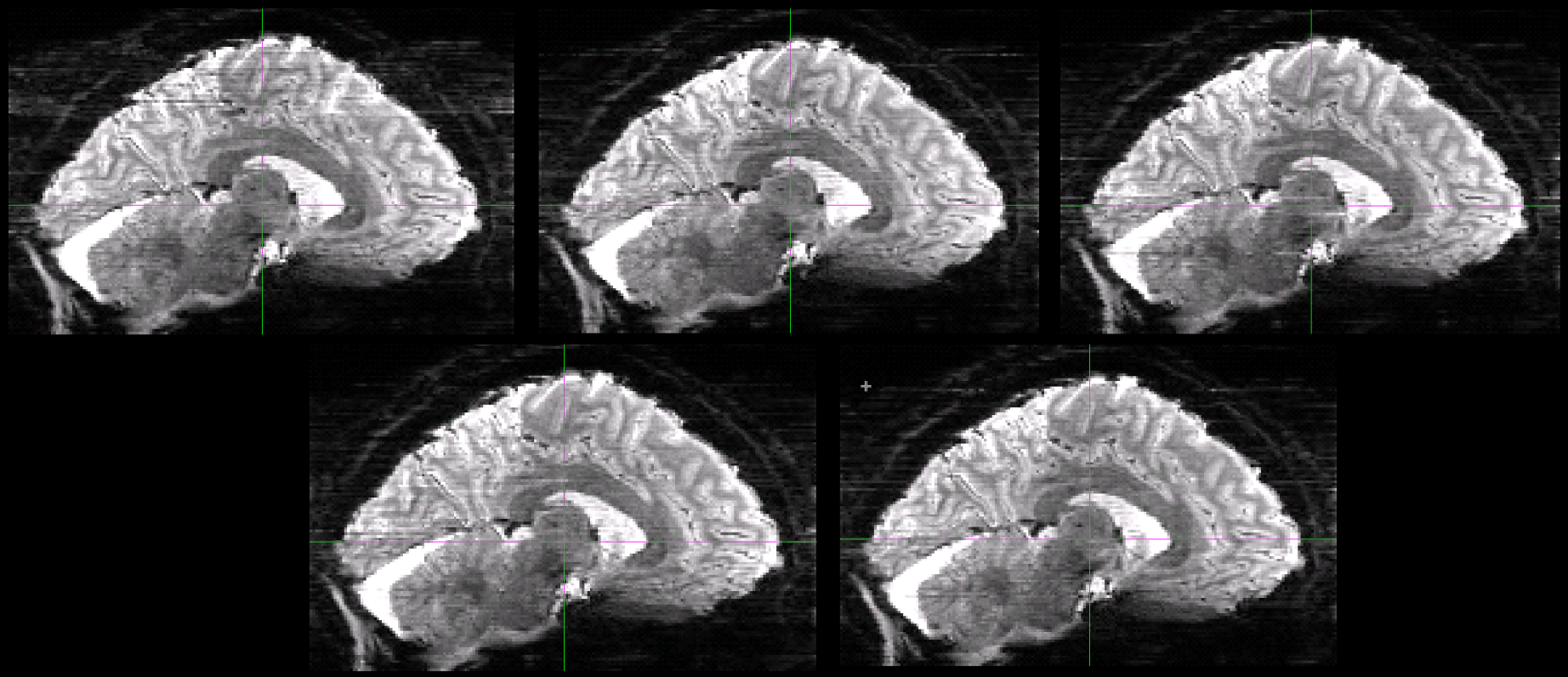




Auerbach et al MRM 2013, (Goelman 97 MRM, Yao SMRM 93, Henning 92 MRM, Wong 2012 ISMRM)

Motion during the reference/calibration scans
(higher resolutions + MB+IPAT)

standard EPI Reference, <u>5 different scans</u>

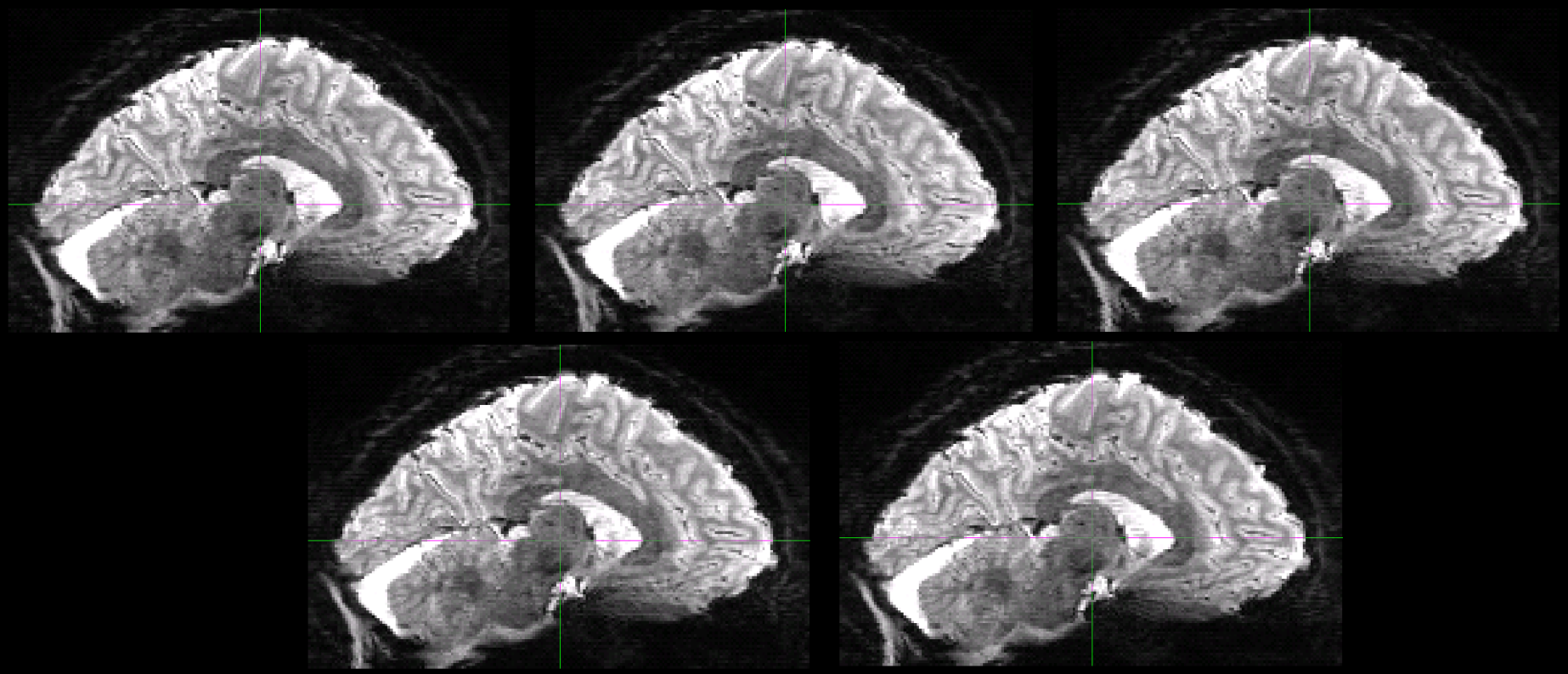


Moeller (CMRR)

MB=3, IPAT=3, 1.25 mm, 7T

GRE Reference acquired once at the beginning

GRE reference



Moeller (CMRR)

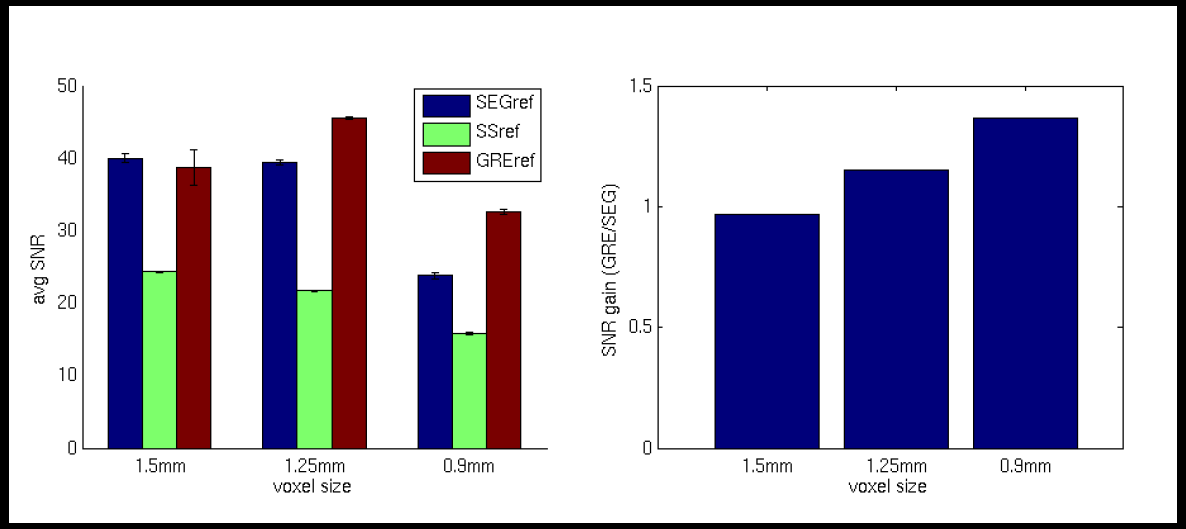
MB=3, IPAT=3, 1.25 mm, 7T

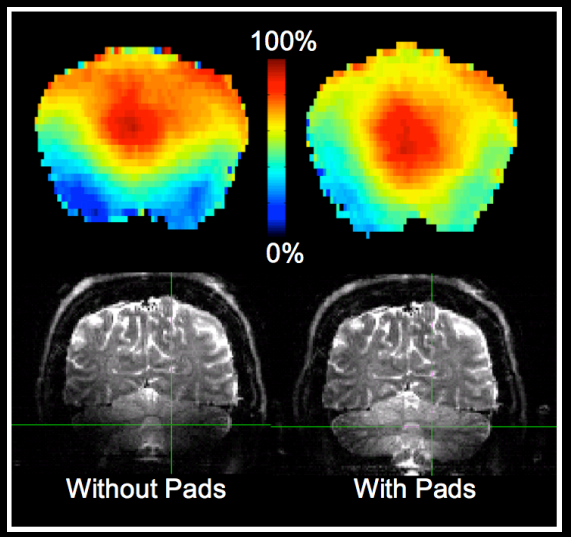
Advances in HCP 7T MRI acquisition

128 slice limit eliminated

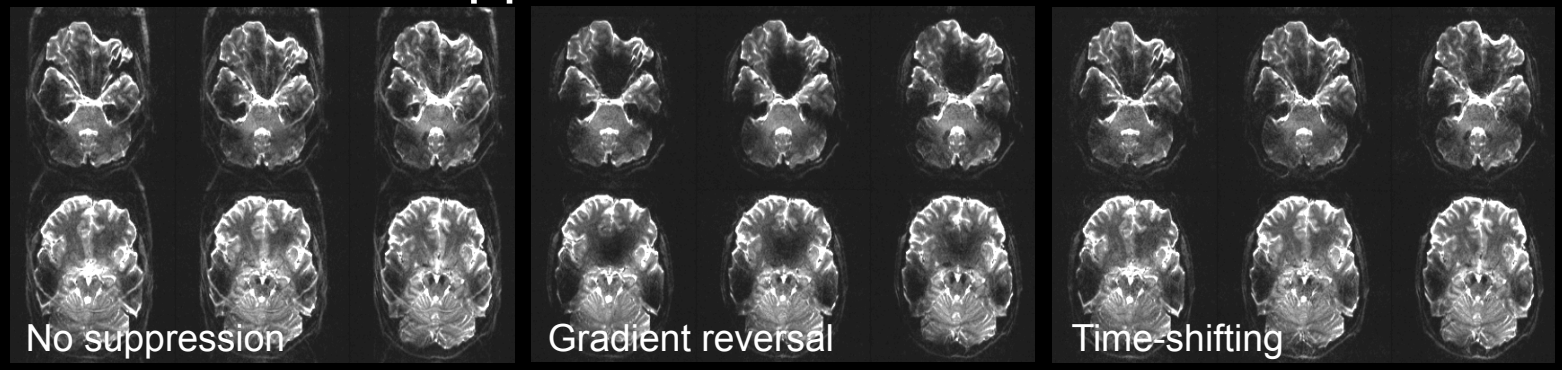
Dielectric pads (CaTiO3)

Motion robust GRE reference scan





Low SAR fat suppression



Vu et al 2015

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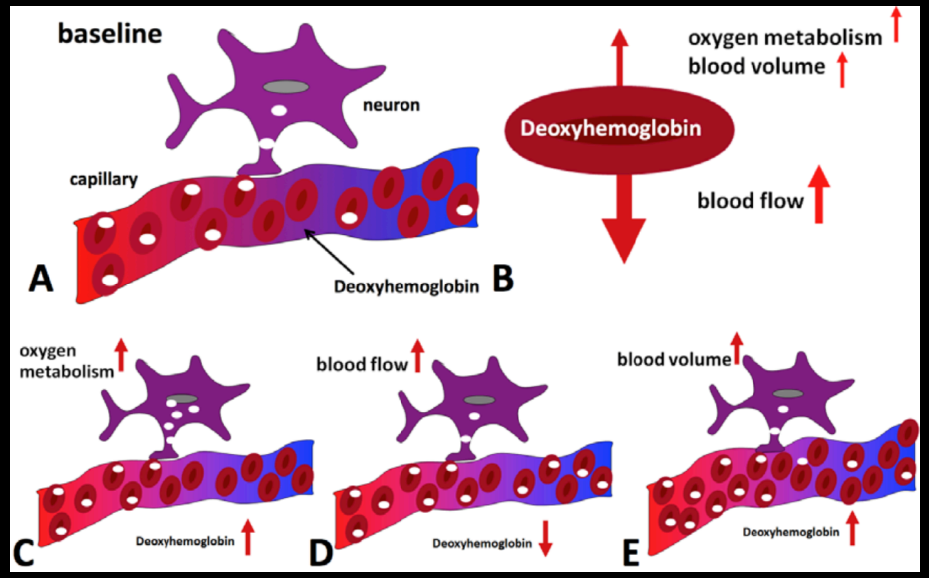
Questions?

BOLD contrast mechanism

- deoxy-Hb (paramagnetic)
- oxygen metabolism
- cerebral blood flow (CBF)
- cerebral blood volume (CBV)

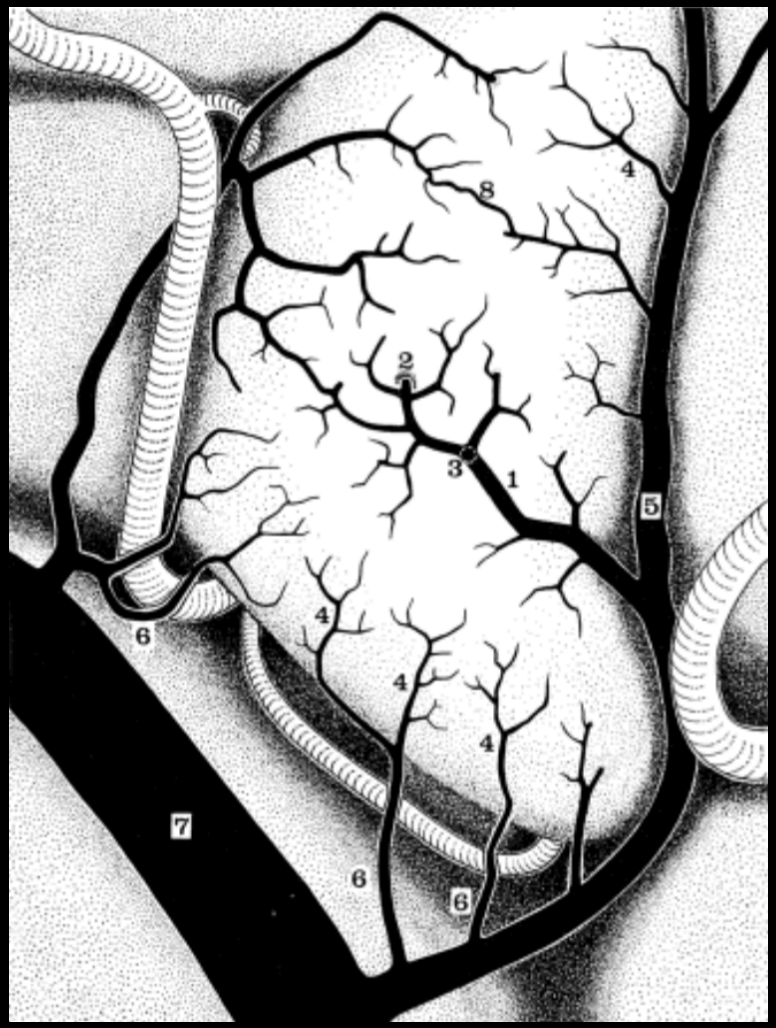


Barth and Poser, 2011

BOLD signal contribution

- Intravascular (IV)
- Extravascular (EV)

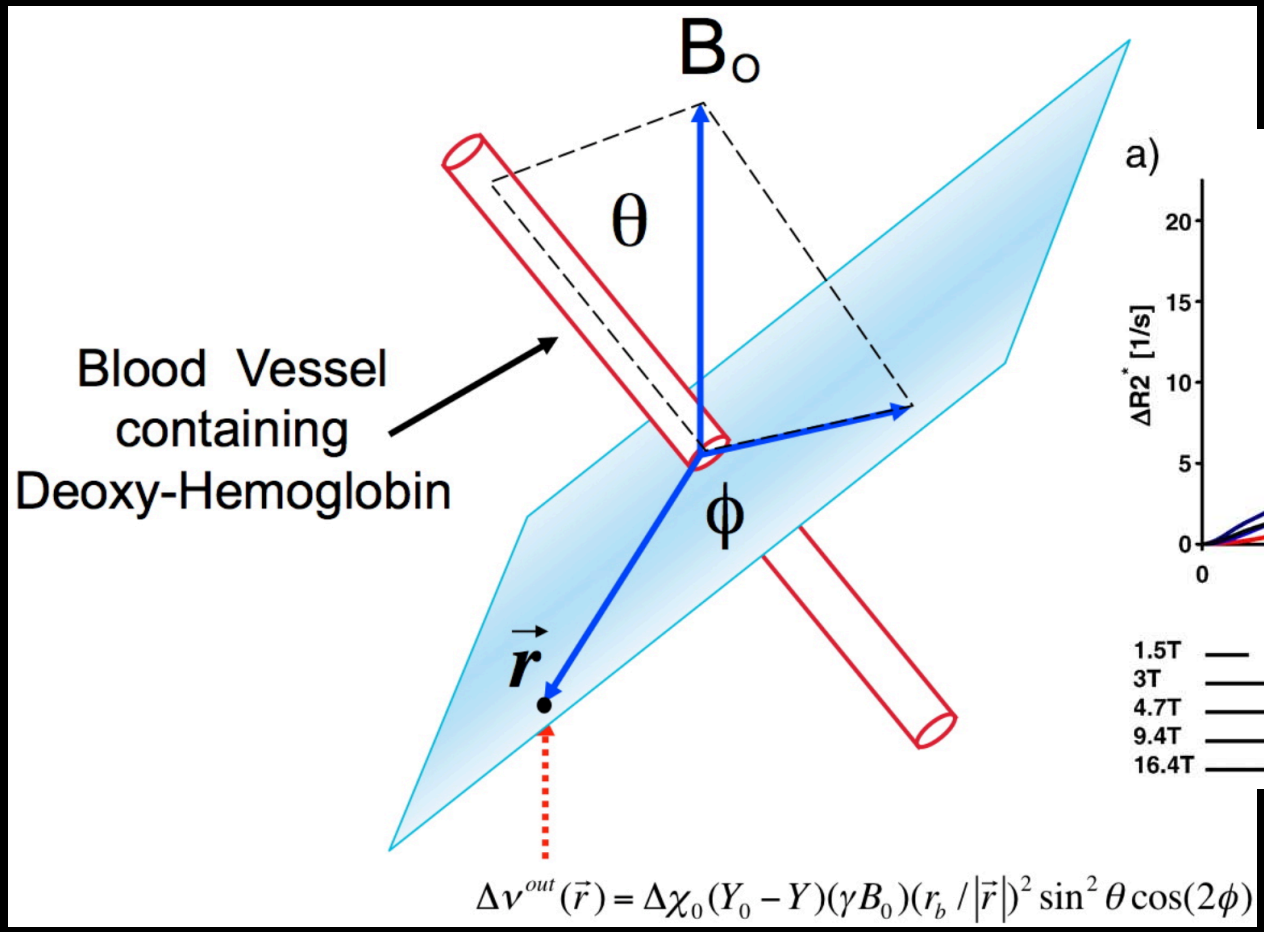
Arrangement of pial veins

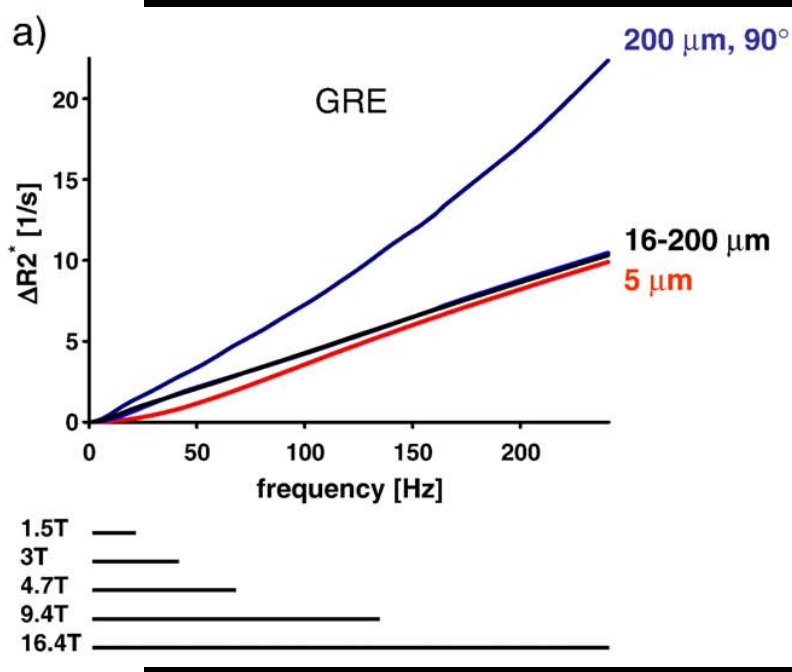


Auer and Loew, 1983

capillary ~ 5 um
venule
vein ~ 500 um - mm

Extravascular (EV) contribution

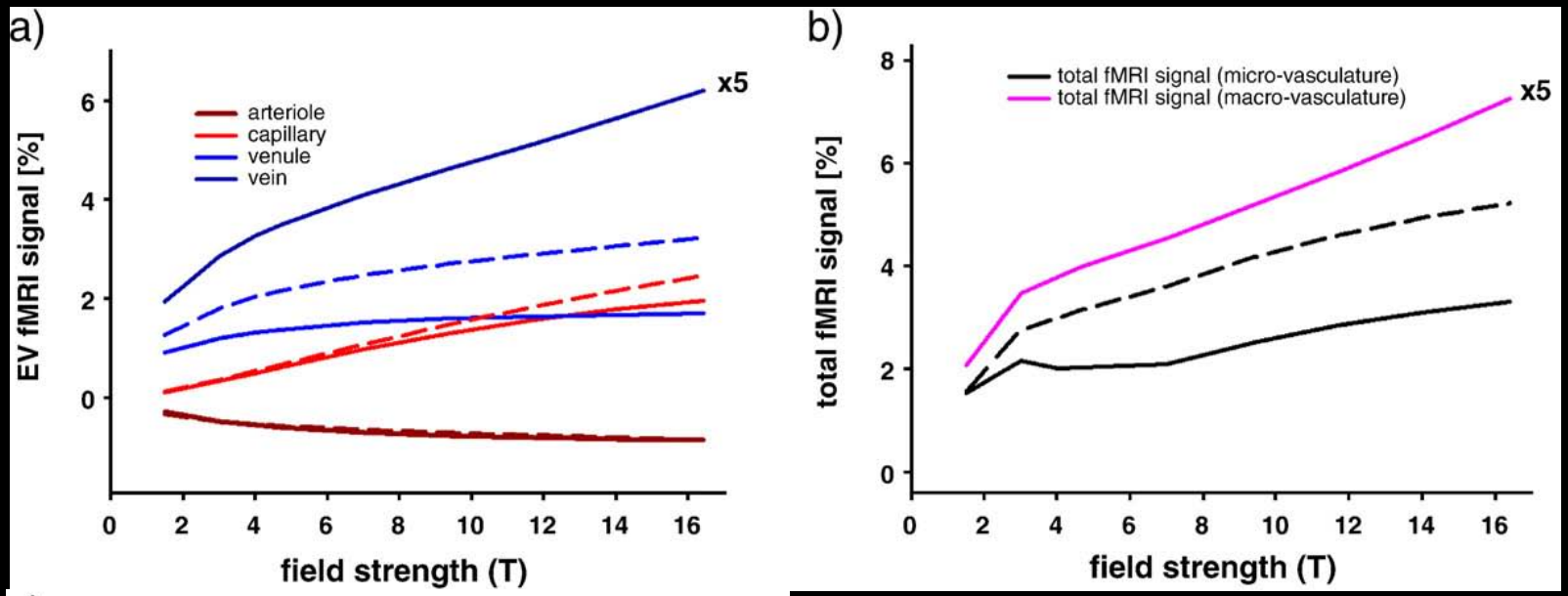


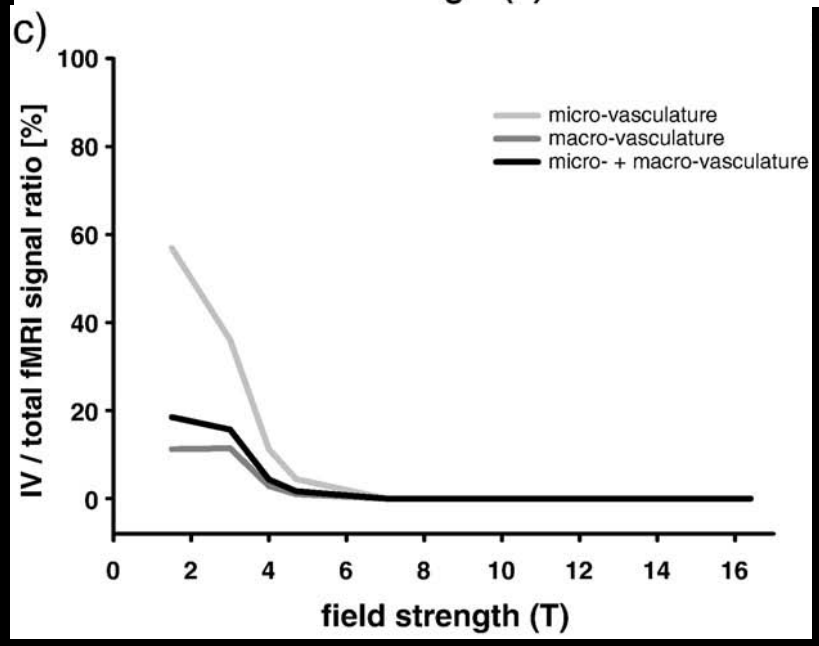


Ugurbil, 2011

Uludag et al. *Neuroimage* 2009

Superlinear field dependence of BOLD sensitivity

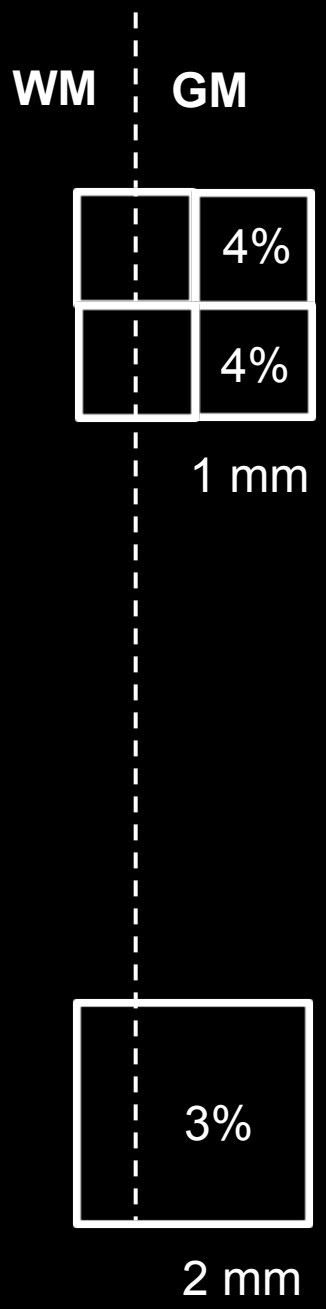


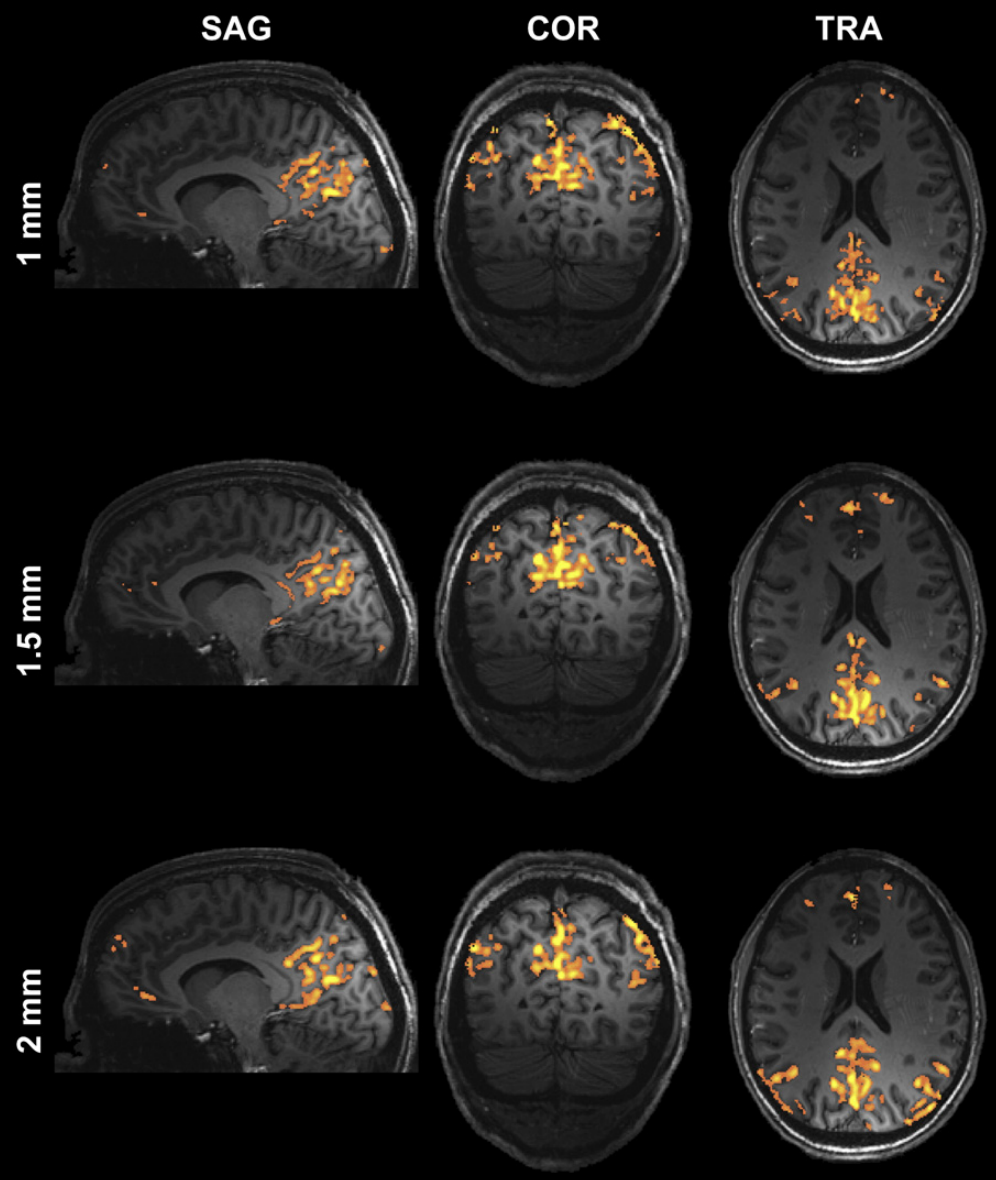


- Extravascular (EV) contributions all increase as field increases
- % intravascular (IV) contribution (esp. large vein) decrease as field increases
- % contribution from microvasculature increases as filed increases

Uludag et al. *Neuroimage* 2009

Reduced partial volume increases BOLD sensitivity



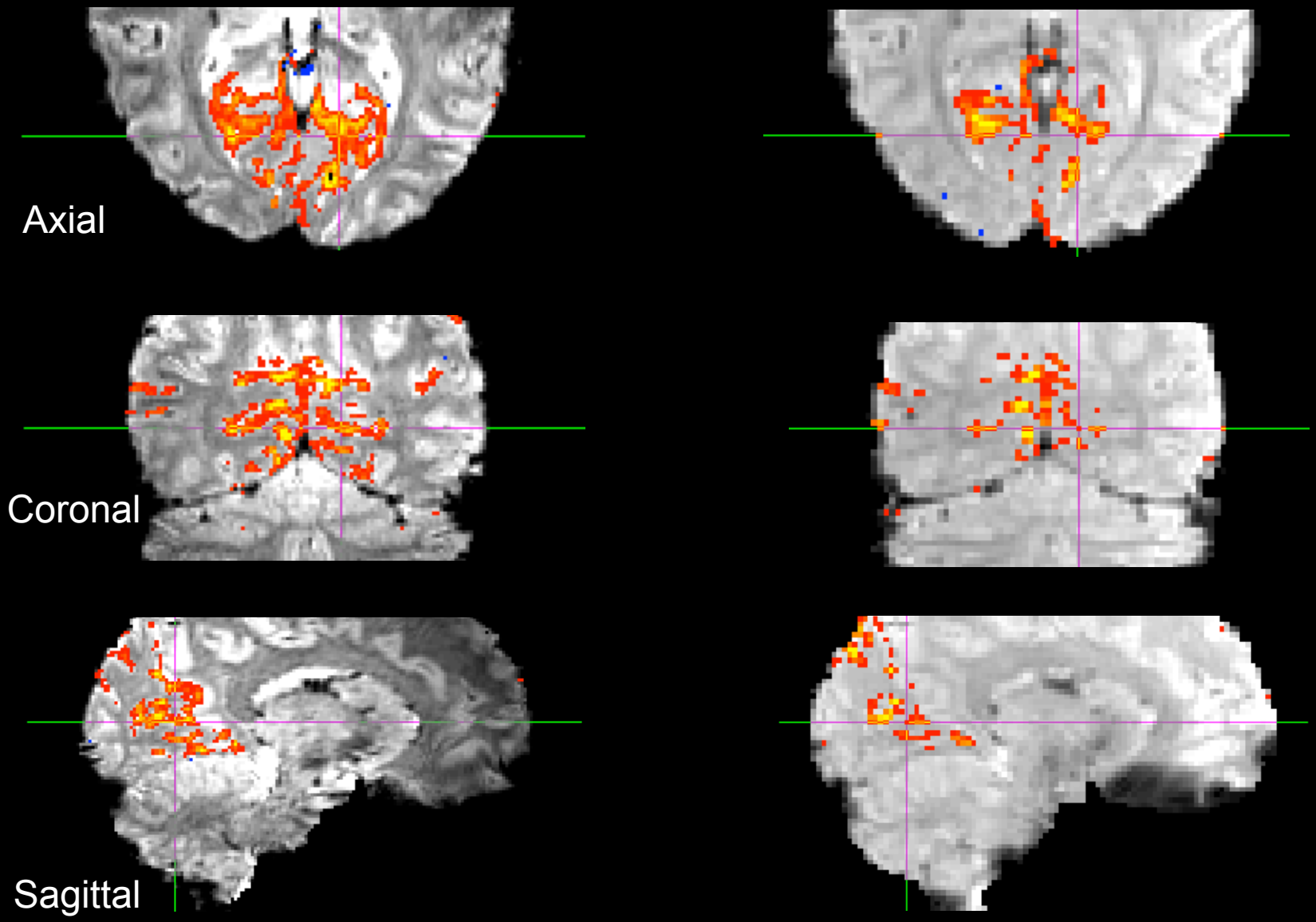


De Martino, *Neuroimage* 2011

Resting State Networks at 7T vs 3T Connectcome

7 Tesla, 1.25 mm Isotropic Res.
MB=3, IPAT=3, TR=2 s

3 Tesla, 2 mm Isotropic Res.
MB=8, IPAT=0, TR=0.7 s



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Questions?

Criteria for HCP 7T Acquisition

- whole brain coverage
- acquisition & image reconstruction stability
- relative scalability (200 subjects)
- spatial resolution
- temporal resolution (fMRI)

HCP 7T session structure

- Session 1 (15 min rfMRI, 30 min movie)
- Session 2 (15 min rfMRI, 40 min dMRI)
- Session 3 (15 min rfMRI, 30 min retinotopy)
- Session 4 (15 min rfMRI, 30 min movie)

fMRI (total): 1hr resting, 1hr movie, 0.5hr retinotopy

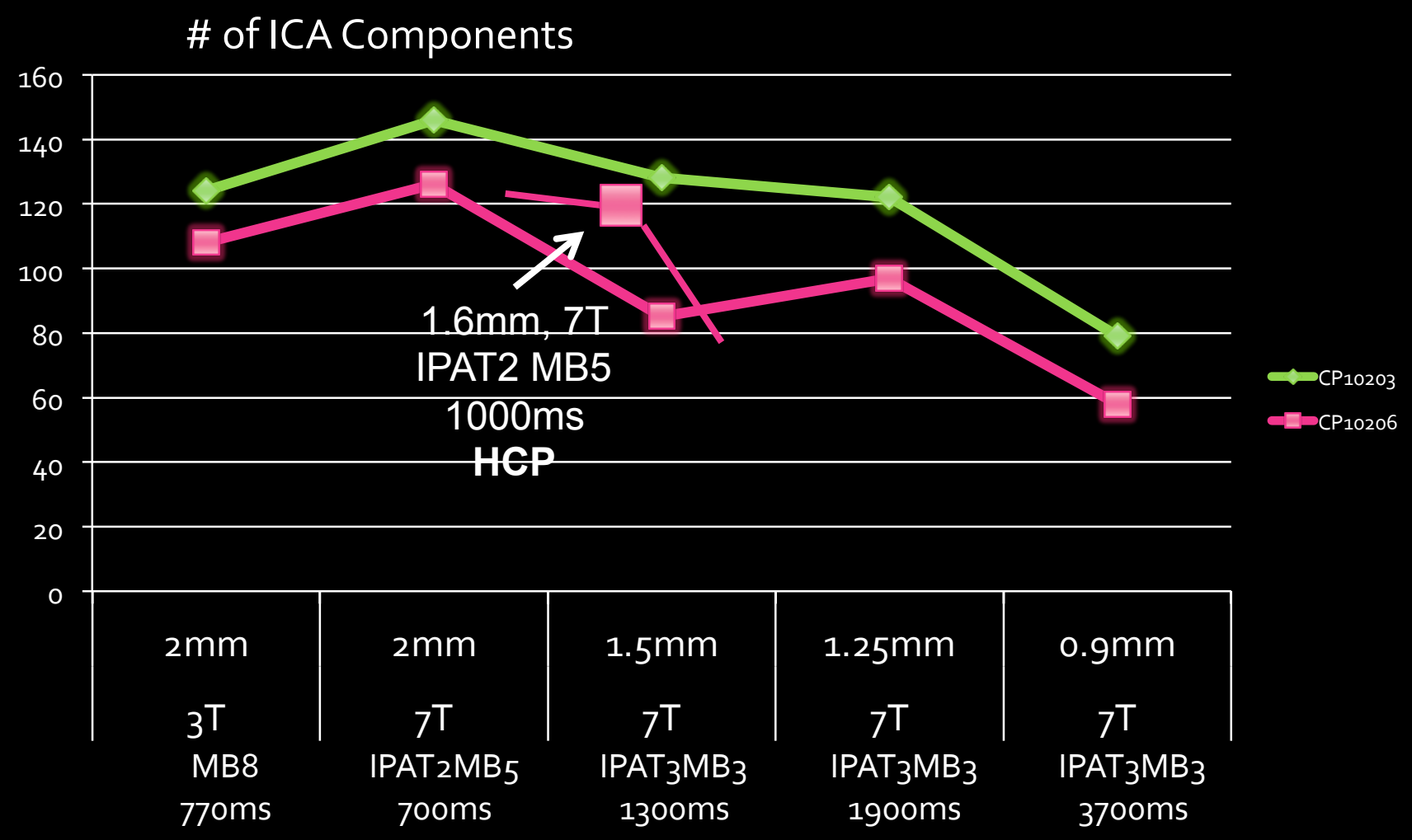
No anatomical MRI at 7T

HCP fMRI Protocols

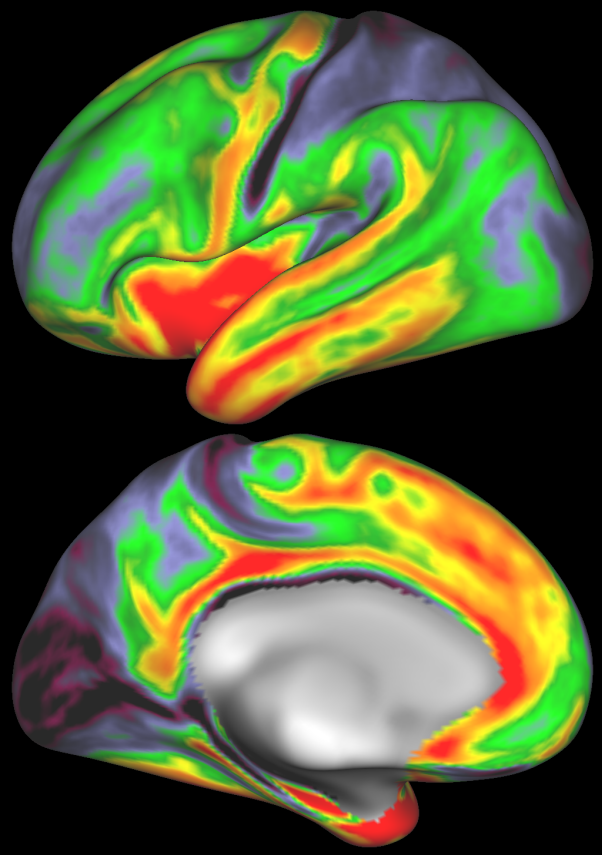
HCP 3T	HCP 7T
2 mm iso	1.6 mm iso
72 slices / MB8	85 slices / MB5
iPAT = 0	iPAT = 2, 7/8 partial Fourier
PE = LR/RL	PE = AP/PA
TE/TR = 33/720 ms	TE/TR=22/1000 ms

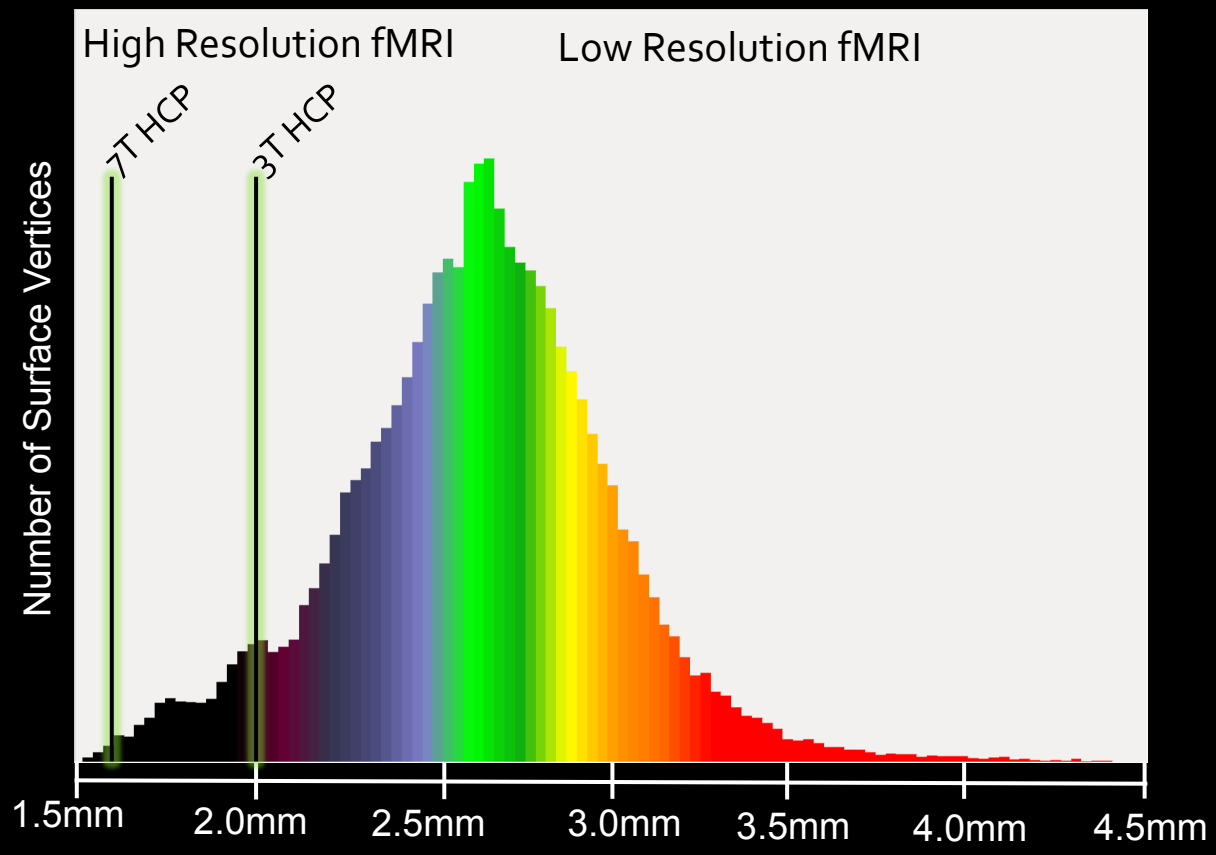
Ugurbil, Neuroimage 2013; Vu, In Preparation

Number of ICA components *reduced* at higher spatial resolutions



Cerebral Cortical Thickness vs Imaging Resolution



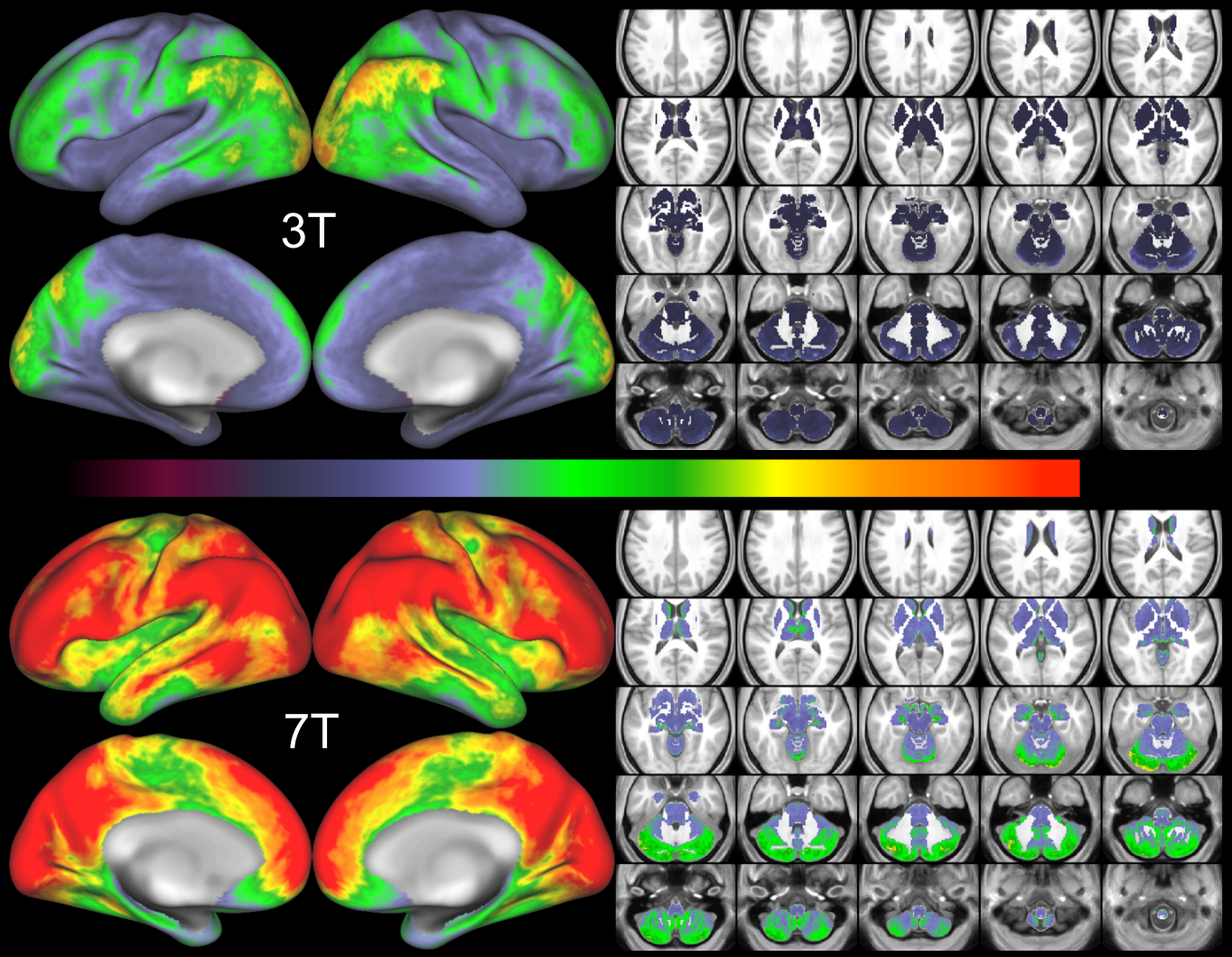


- 3T: 2.0mm resolution, 1 frame / 0.72s
- 7T: 1.6mm resolution, 1 frame / 1.0s
  - 7T fMRI goal was to somewhat increase spatial resolution while gaining a substantial amount of CNR

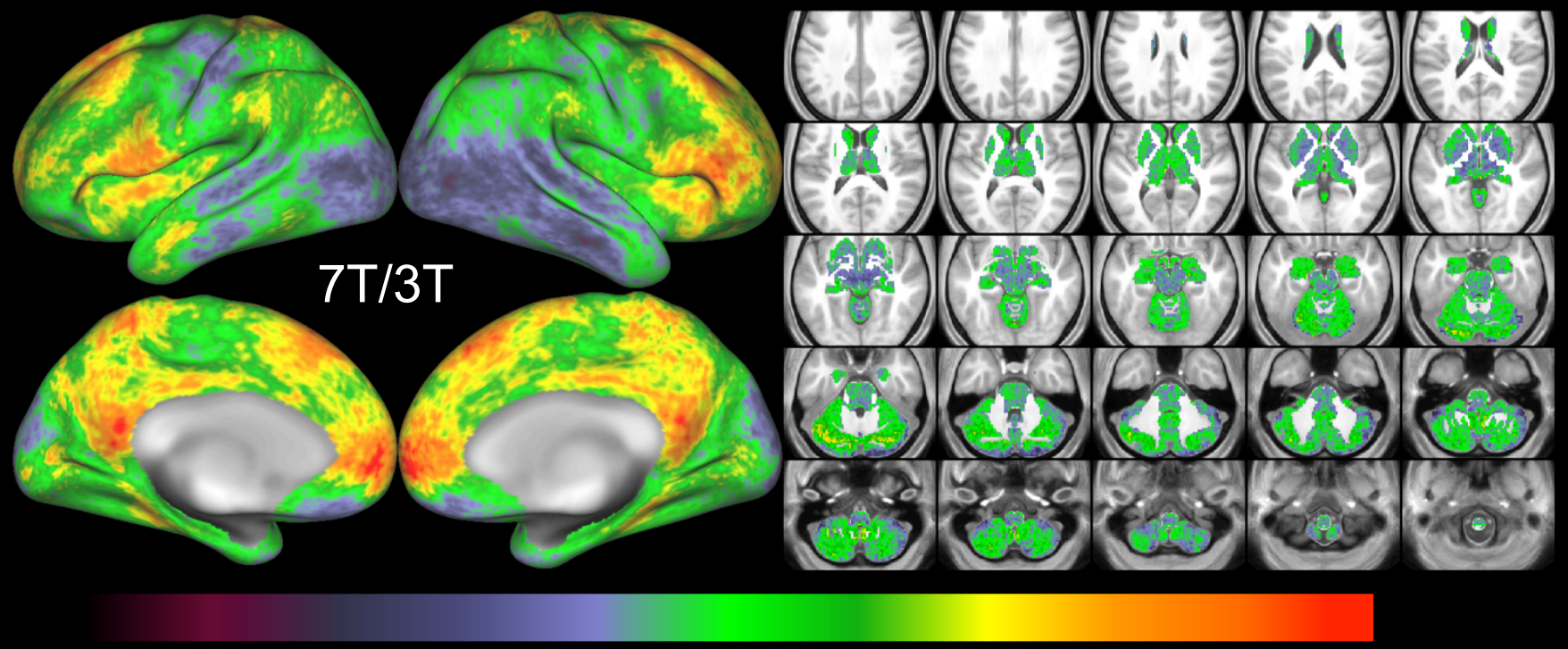
Resting State Denoising

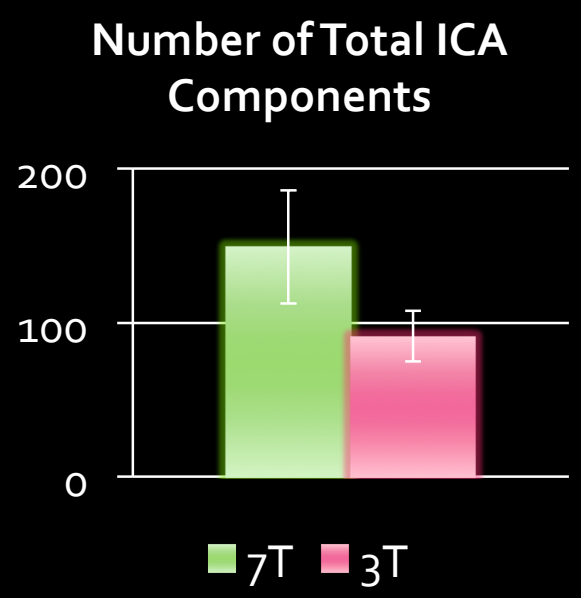
- Very gentle highpass filter removes largely linear trends
  - sigma of 1000s, runs are 900s in length
- ICA with up to 250 components
  - automatically determined (in general higher SNR or more structured signals will lead to higher dimensionality)
- FIX classifies ICA components into signal and noise categories
  - In this case, because FIX was being retrained for 7T data, all components were hand classified
- 24 motion parameters and noise component timeseries are regressed out of the data

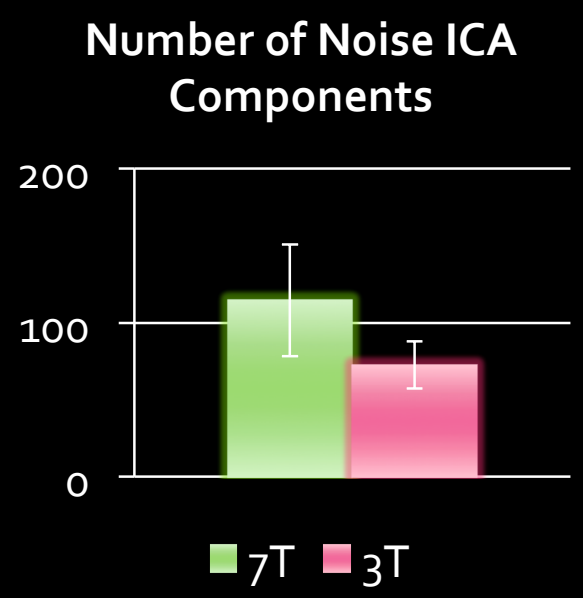
3T vs 7T: rfMRI CNR

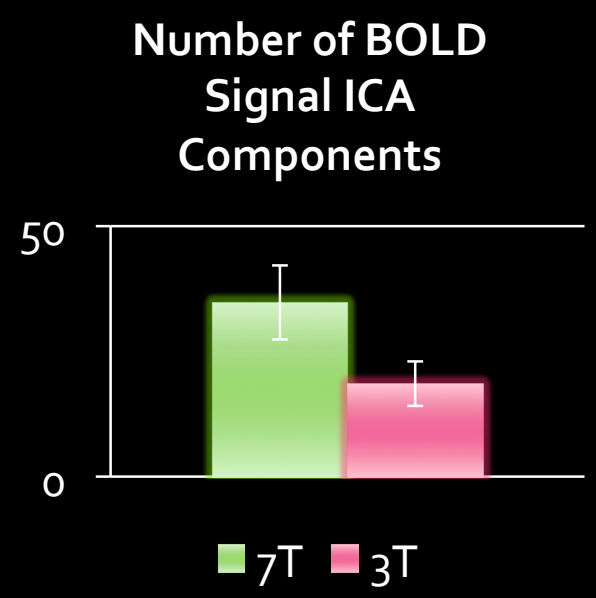


N=24

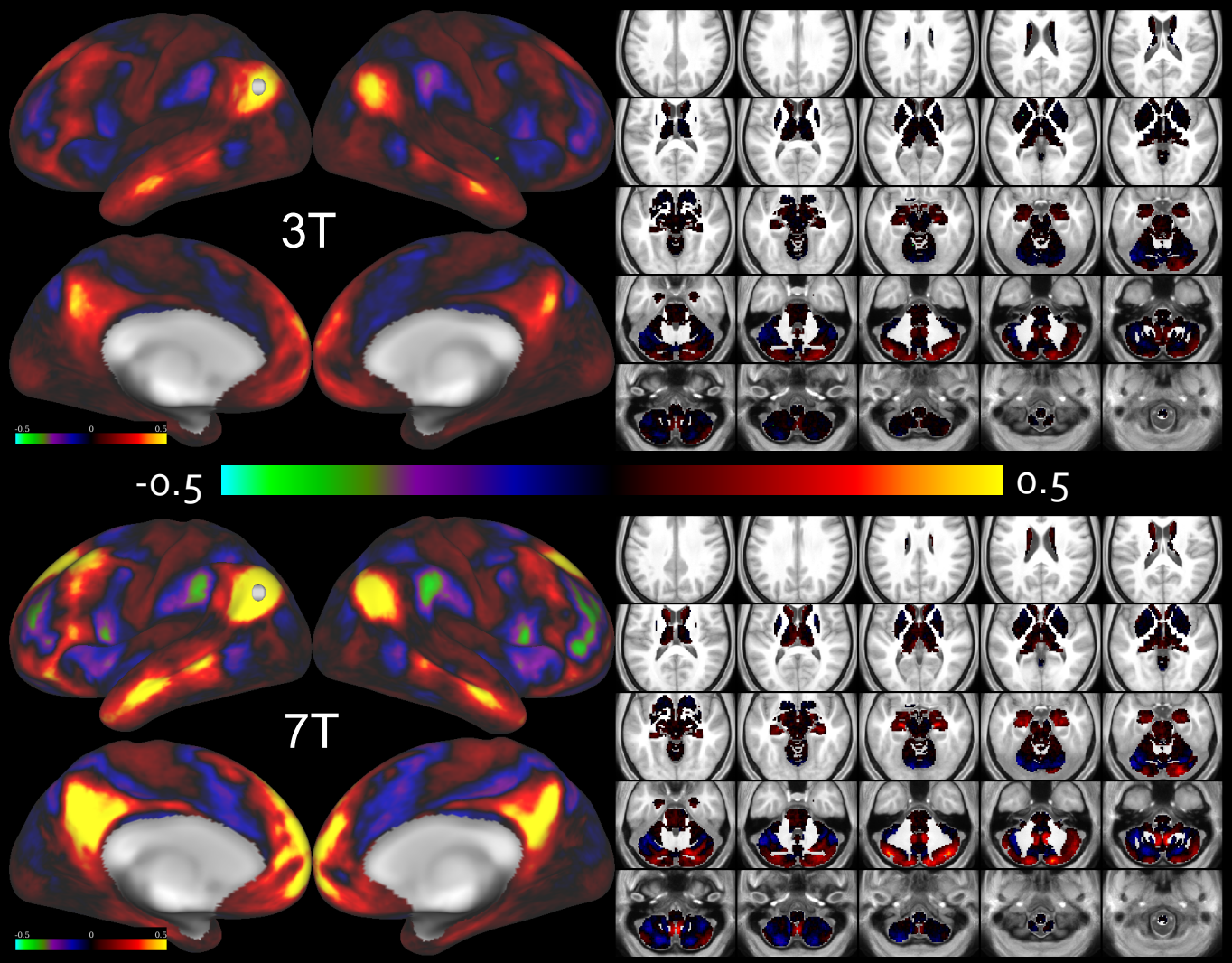

7T/3T


Number of Total ICA Components
200
100
0
7T
3T

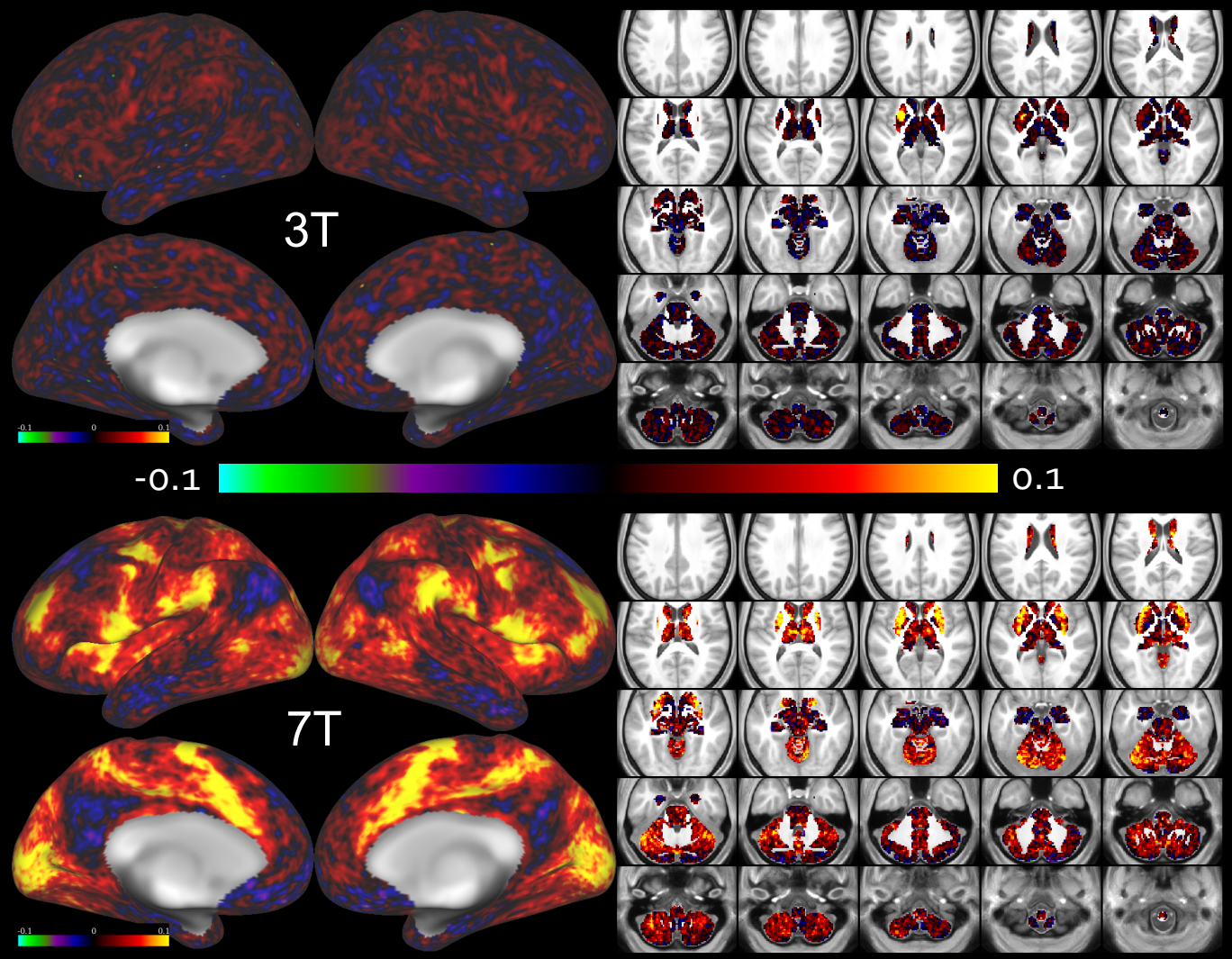

Number of Noise ICA Components
200
100
0
7T
3T


Number of BOLD Signal ICA Components
50
0
7T
3T

3T vs 7T: Dense Connectivity



3T vs 7T: Dense Connectivity



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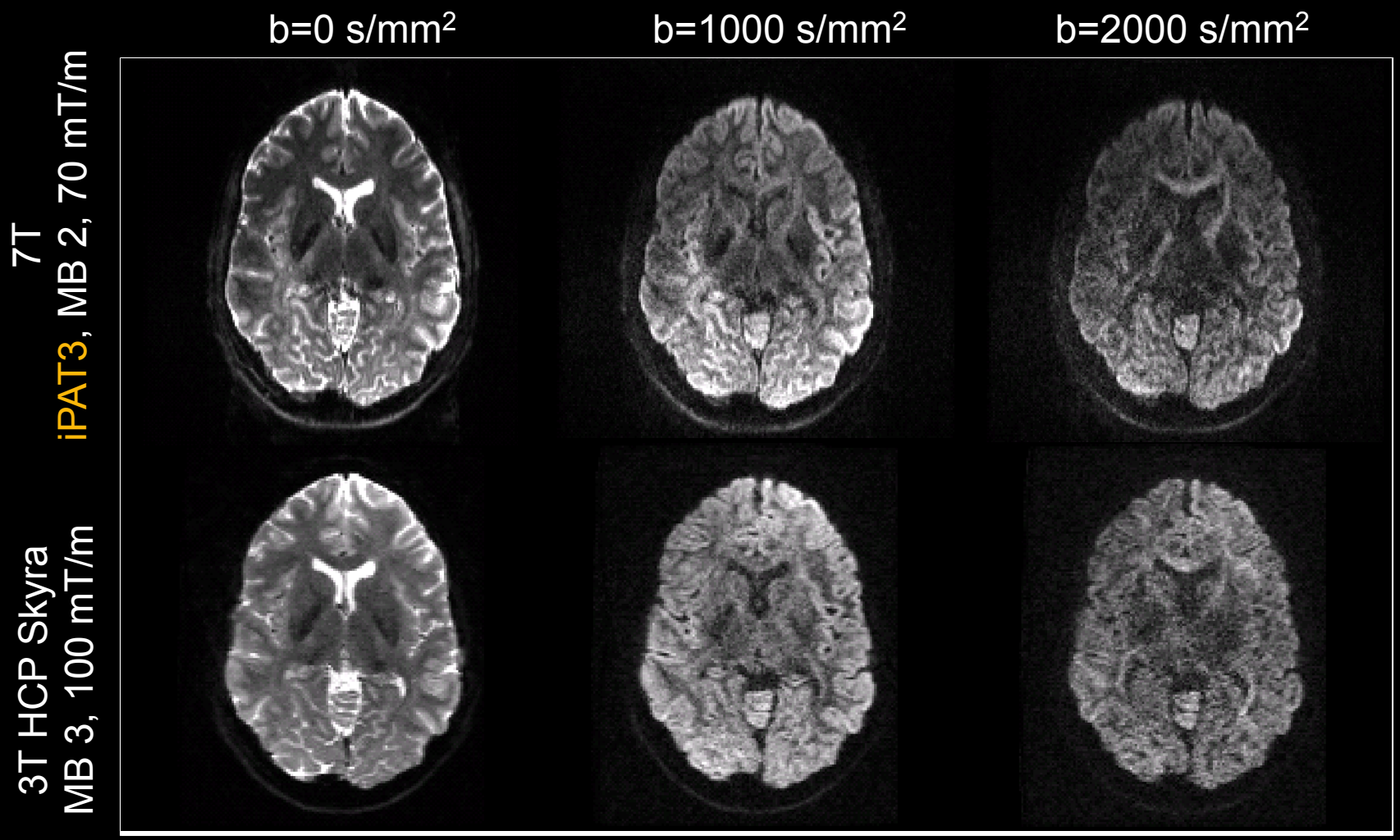
Questions?

HCP dMRI Protocols

HCP 3T	HCP 7T
1.25 mm iso	1.05 mm iso
111 slices / MB3	132 slices / MB2
iPAT = 0, 6/8 partial Fourier	iPAT = 3, 6/8 partial Fourier
PE = LR/RL	PE = AP/PA
TE/TR=89/5500 ms	TE/TR=71/7000 ms
b = 1, 2, 3k HARDI	b = 1 & 2k HARDI

Ugurbil et al. , Sotiropoulos et al. *Neuroimage* 2013

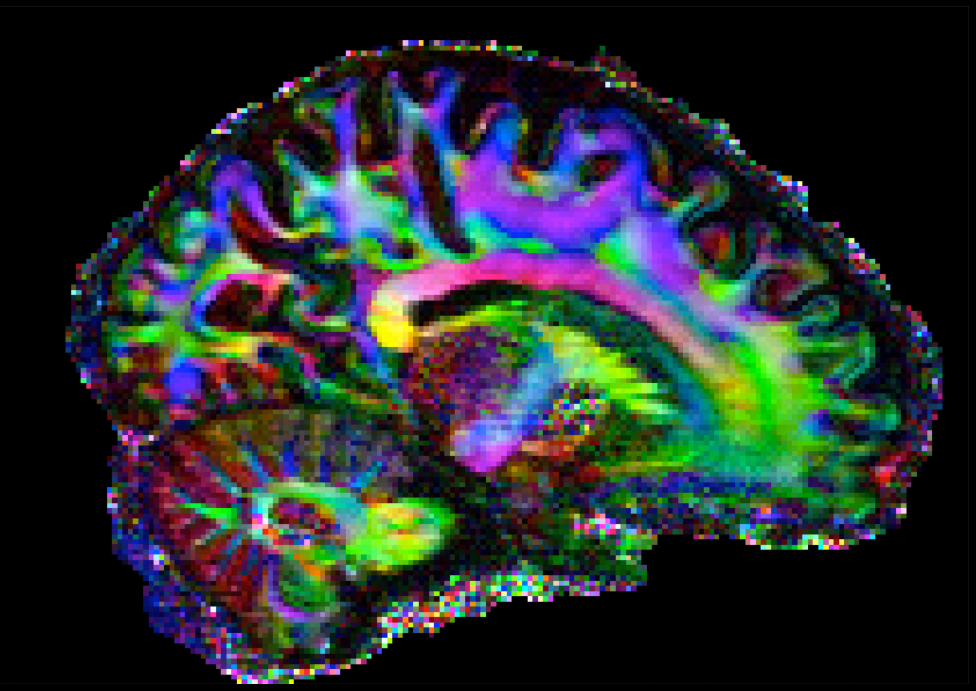
7T improved spatial resolution with less blurring

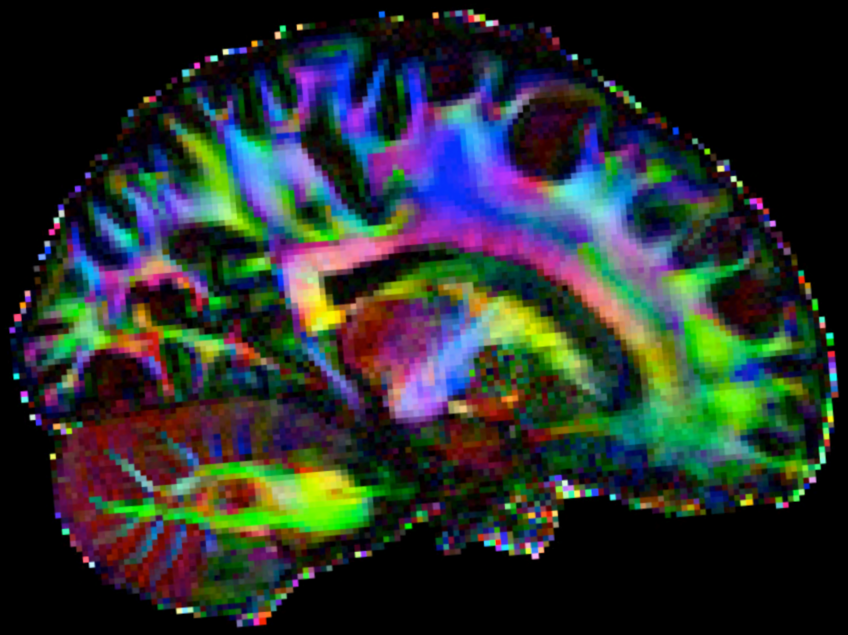


DTI Maps at 7T vs 3T Connectome

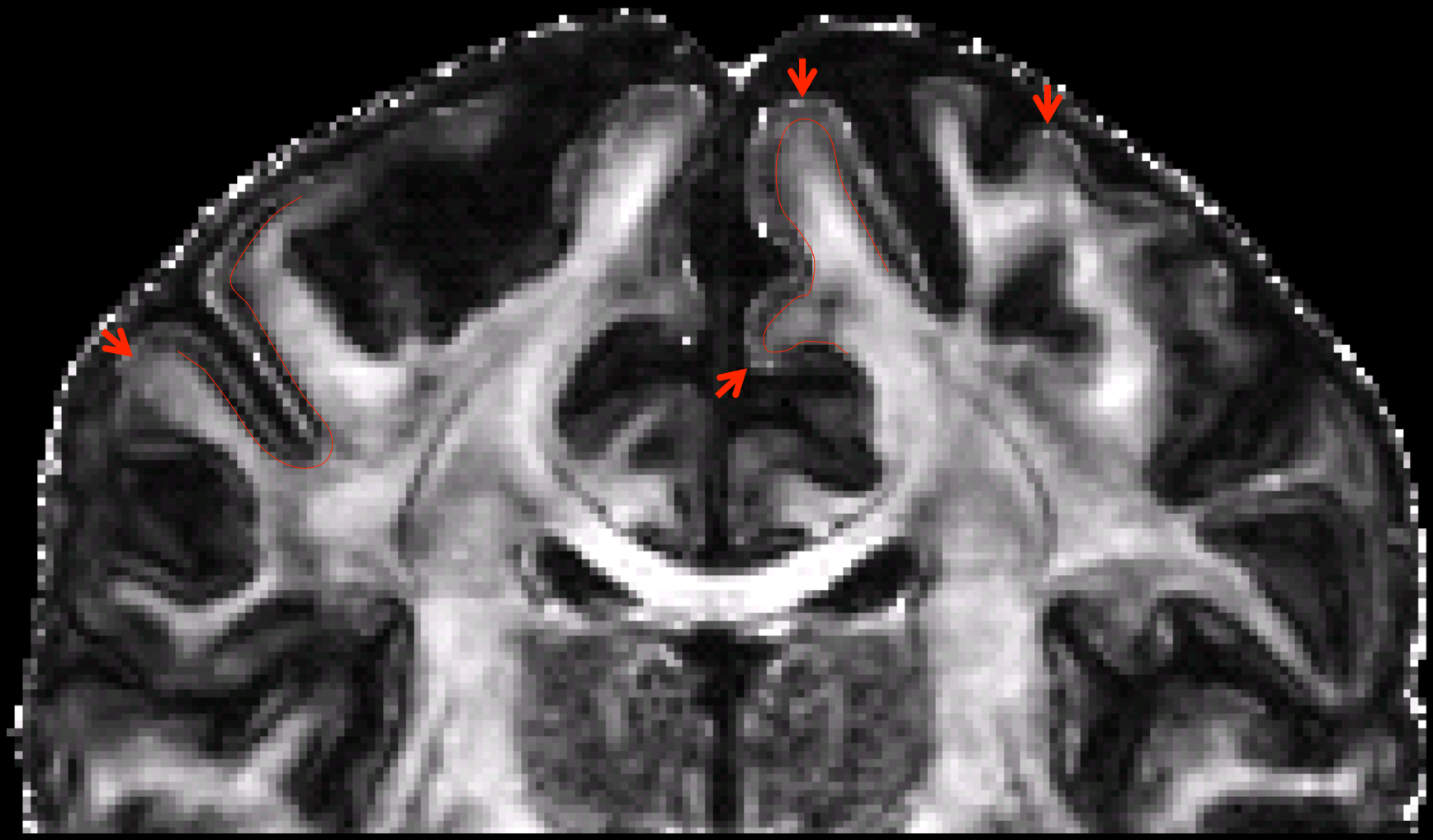
7T, 1.05 mm iso, MB2, IPAT3, 143 dirs
TR = 7000ms, PF 6/8, TA: 38mins
b = 1 & 2k s/mm^2, G = 70 mT/m
time shift = 1920μs, dielectric pads

3T, 1.25mm iso, MB3, IPAT1, 288 dirs
TR = 5500ms, PF 6/8, TA: 60mins
b = 1k, 2k, & 3k s/mm^2, G = 100 mT/m



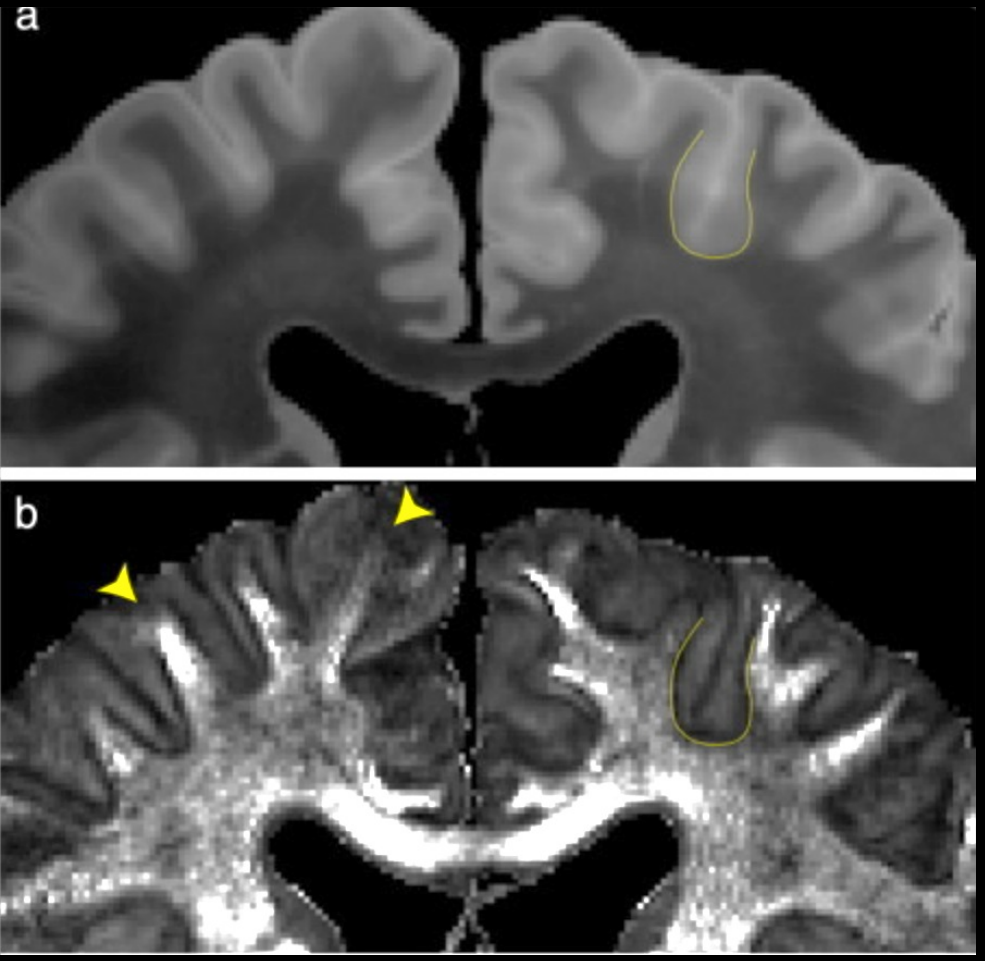


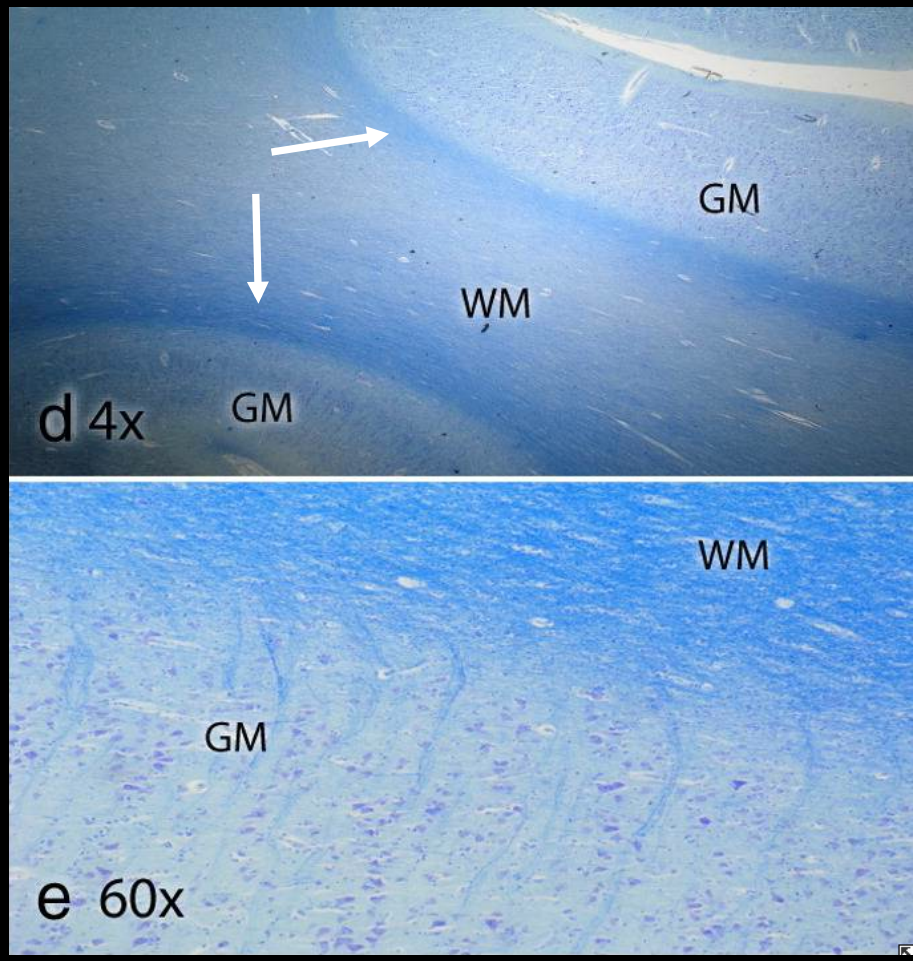
7T HCP Fractional Anisotropy Map



Vu et al 2015

Superficial dense white matter fibers (Postmortem human brain)

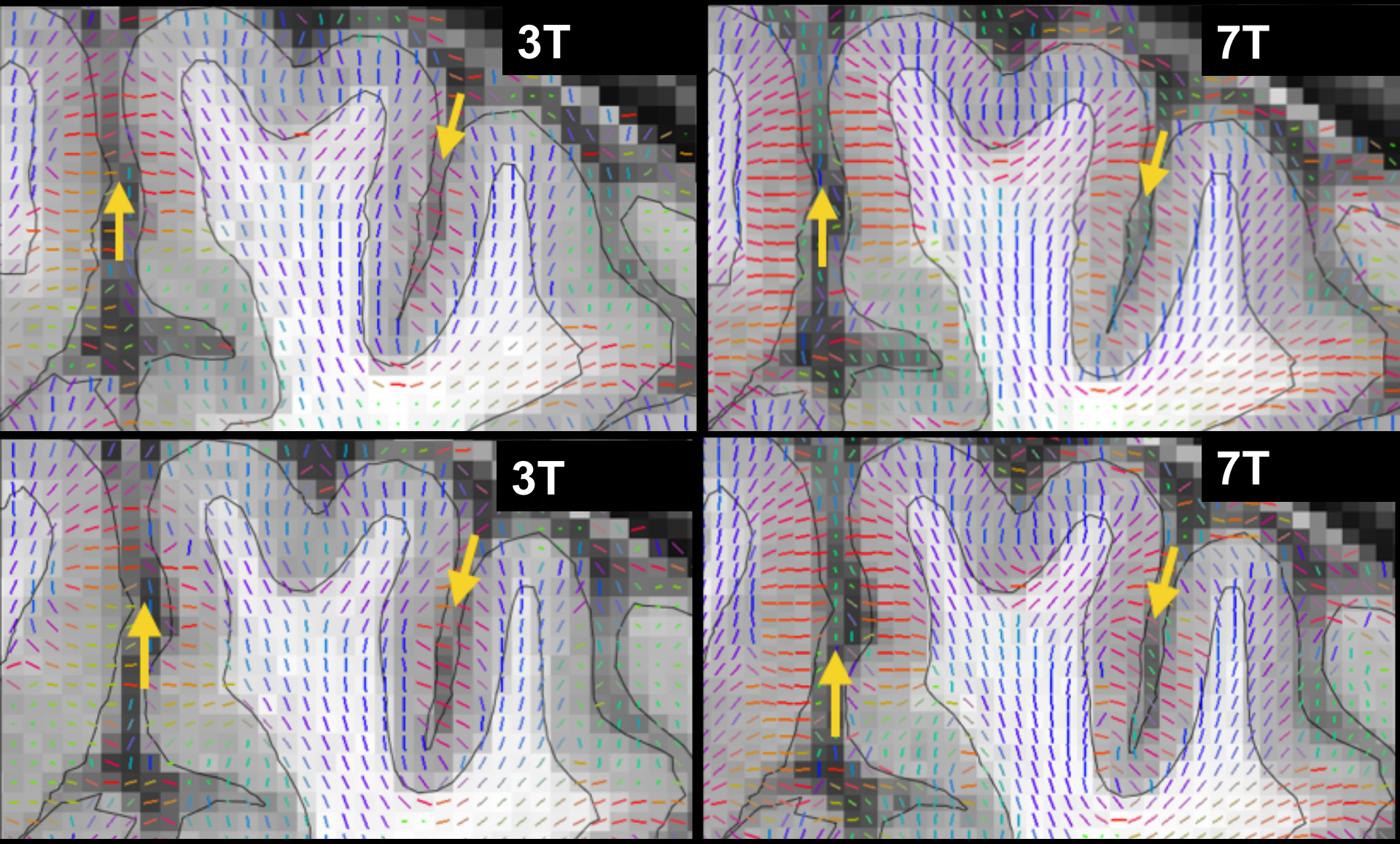




Miller et al., 2011; Leuze et al., 2012

Reveley, PNAS 2015

3T vs 7T HCP dMRI Bedpost

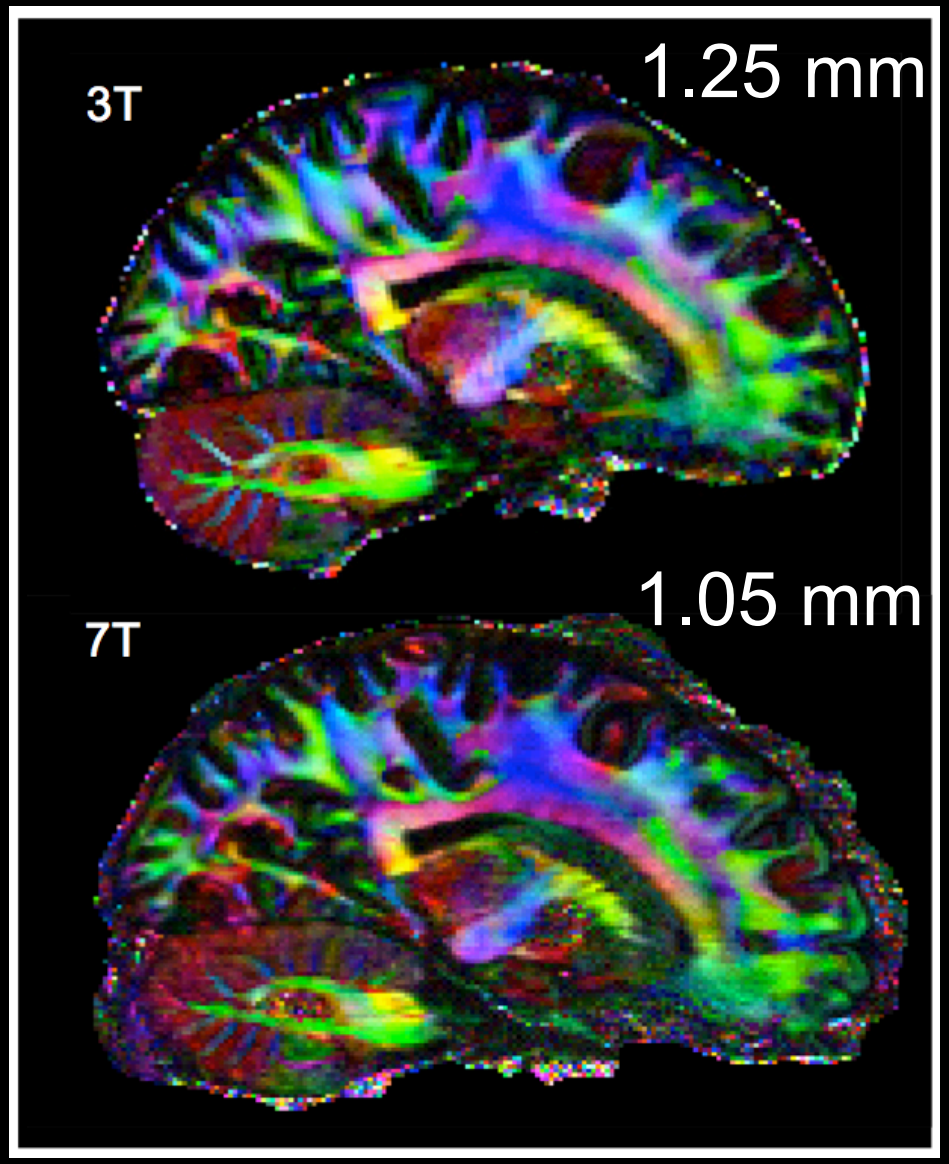


Can we analyze the datasets jointly & retain features from both?

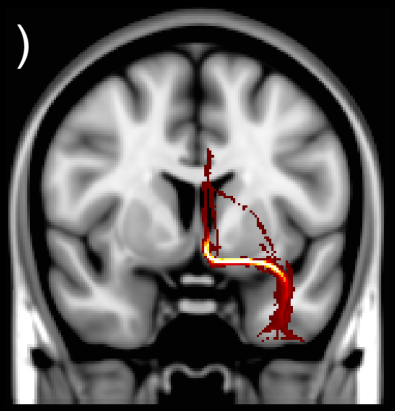
(Sotiropoulos et al ISMRM # 562)

HCP 7T and 3T Diffusion

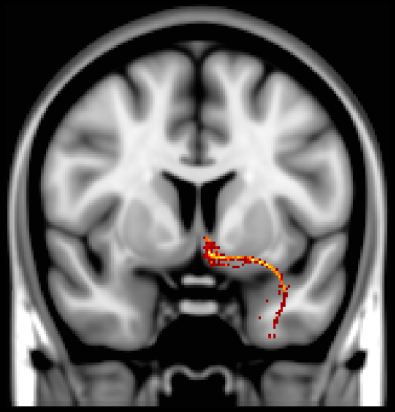
(Sotiropoulos, Vu et al)



3T



7T



7T+3T
(RubiX)

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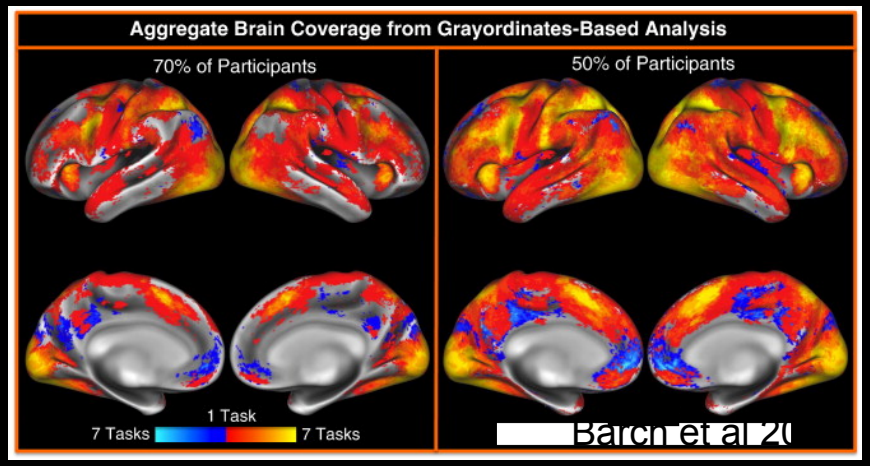
Questions?

fMRI tasks 3T

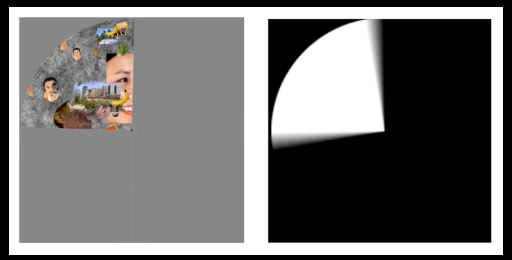
- Working memory
- Gambling
- Motor
- Language
- Social Cognition
- Relational Processing
- Emotion Processing



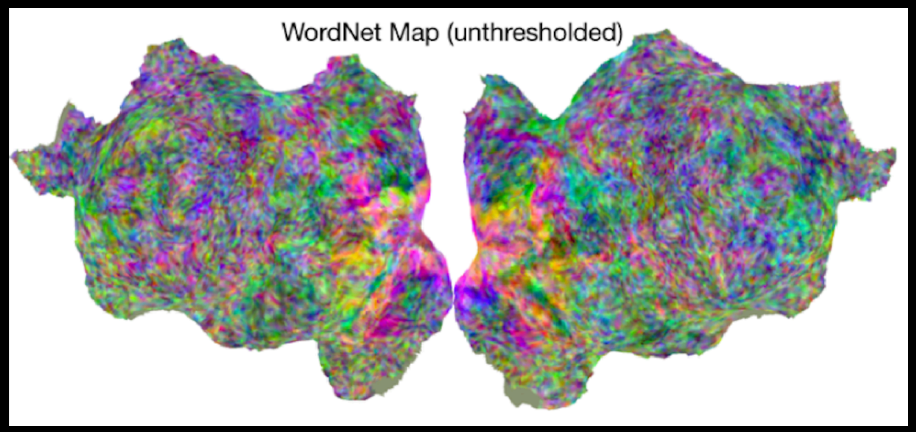
Barch et al. *Neuroimage* 2013

fMRI tasks 7T

- Retinotopy



- Natural movies w/ sound



Movie Clips 4 x 15 min runs

Hollywood (Cutting 2012)

Run 1

- Inception
- The Social Network
- Ocean's Eleven

Run 3

- Home Alone
- Erin Brockovich
- Star Wars Episode V

Creative Commons (vimeo.com)

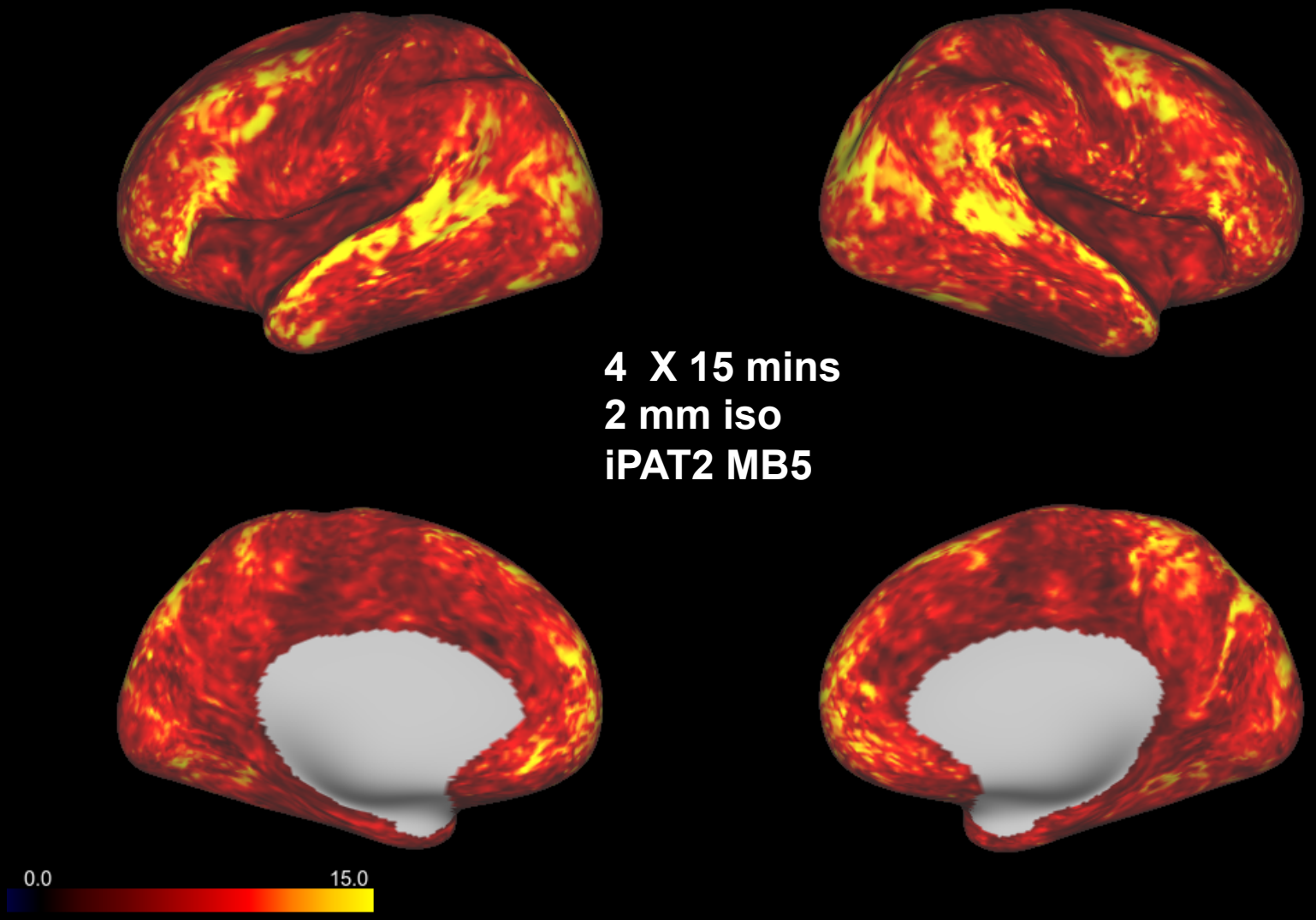
Run 2

- Two Men
- Welcome to Bridgeville
- Pockets – Short Film
- Inside the Human Body

Run 4

- Off the Shelf
- 1212
- Mrs. Meyer's Clean Day
- Northwest Passage (montage)

Movies elicit broad and robust brain activations



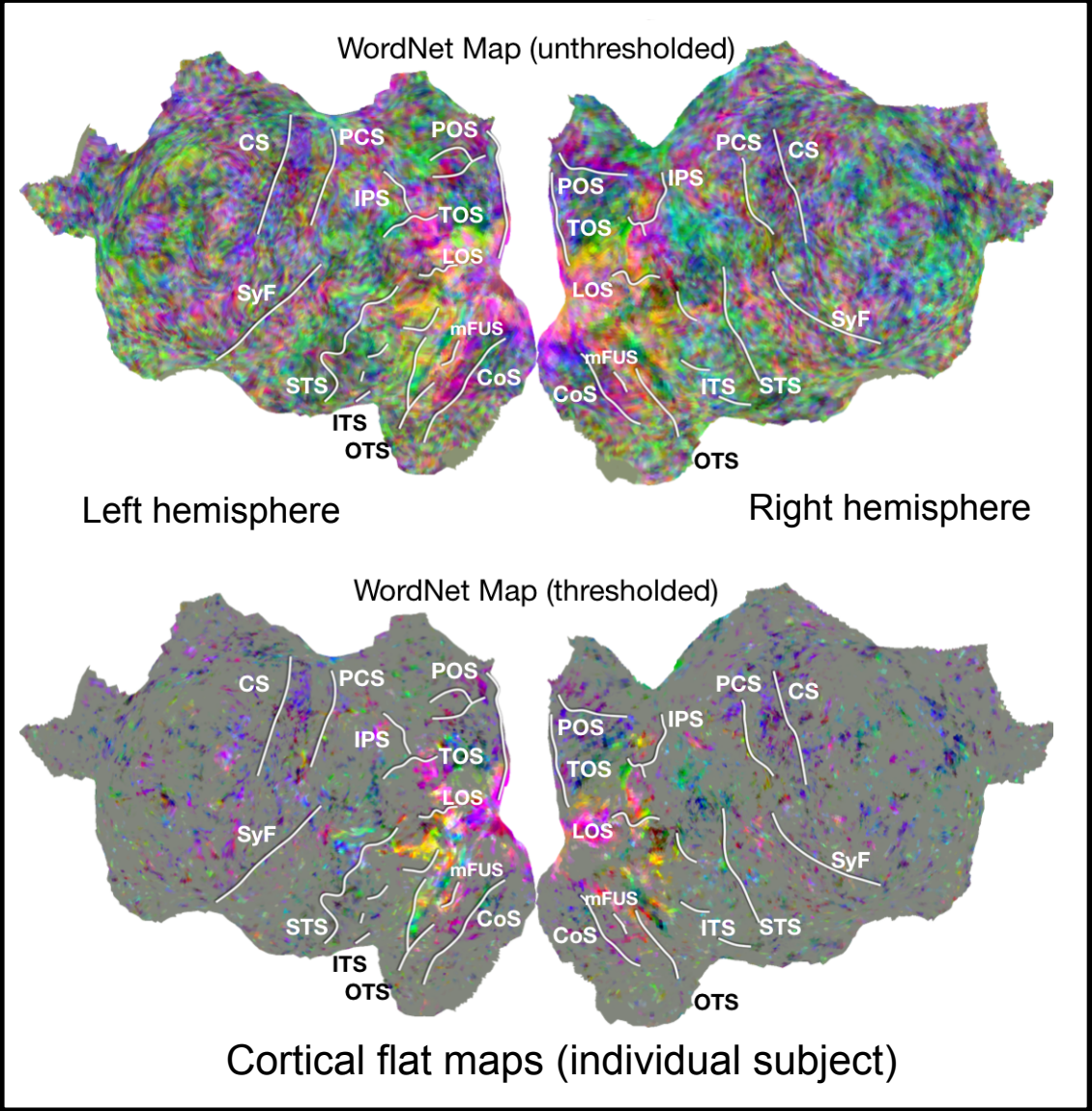
Decoding the neural coding

Movie stimuli:

- 14 movie clips
- 55 min total

First 3 Semantic Principal Components in

- purple (buildings and vehicles),
- green (faces),
- yellow (animals).



Cortical flat maps (individual subject)

J. Gallant, A. Huth, A. Nunez-Elizalde, M. Lescroart (UCB) + HCP consortium

Learning objectives

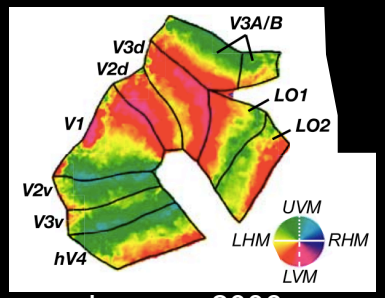
- Challenges and advantages of 7T Imaging
- BOLD contrast mechanism and its field dependence
- MR techniques developed during HCP 7T at CMRR
- HCP 7T protocol
- HCP 7T preliminary analysis results

Questions?

Retinotopy Introduction

- Visual cortex can be divided into distinct areas based on mapping out the representation of the visual field
- Use fMRI to determine retinotopy; use 7T for higher SNR

- What is the goal?
  - Find the visual areas (so you can use them as ROIs?)
  - Discover new ones?
  - Use the large subject pool (*n* = 200) to get population statistics?

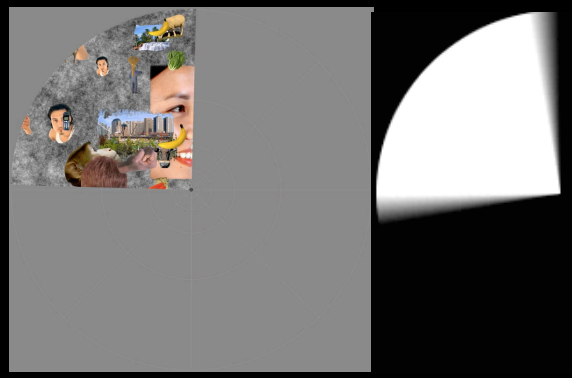


Larsson 2006

- A little history / background:
  - First set of pilots played with experimental design
  - Second set of pilots settled on a particular design
  - Experiment is run using MATLAB + Psychtoolbox on Mac OS X

Retinotopy Experiment

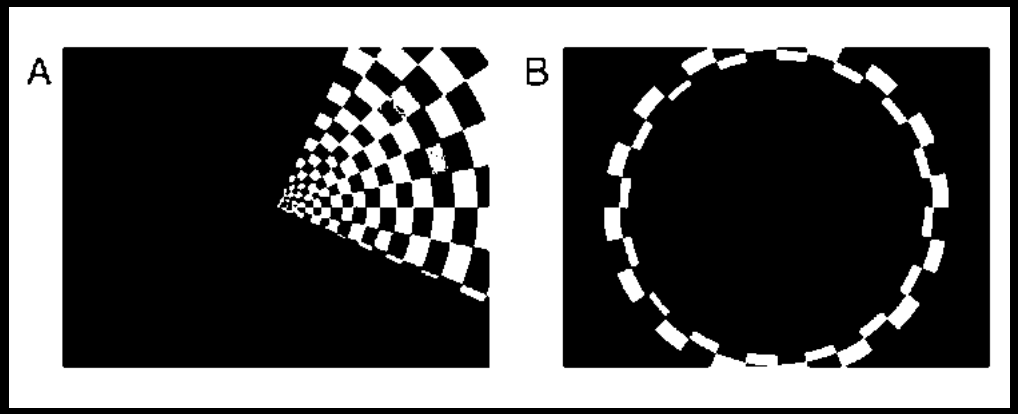
- Stimulus type
  - “mashfast” (multiscale objects on pink-noise background, 15-Hz)
  - Evokes larger responses, improves reliability of phase estimates
- Aperture and run design (each run is 300 s)
  1. CCW. 22 s; 8 cycles * 32 s; 22 s
  2. CW. "
  3. EXPAND. 22 s; 8 cycles * (28 s + 4 s); 22 s
  4. CONTRACT. "
  5. BARS. 16 s;
     R, U, L, D (each 28 s + 4 s); 12 s;
     UR, UL, LL, LR (each 28 s + 4 s); 16 s
  6. BARS. "

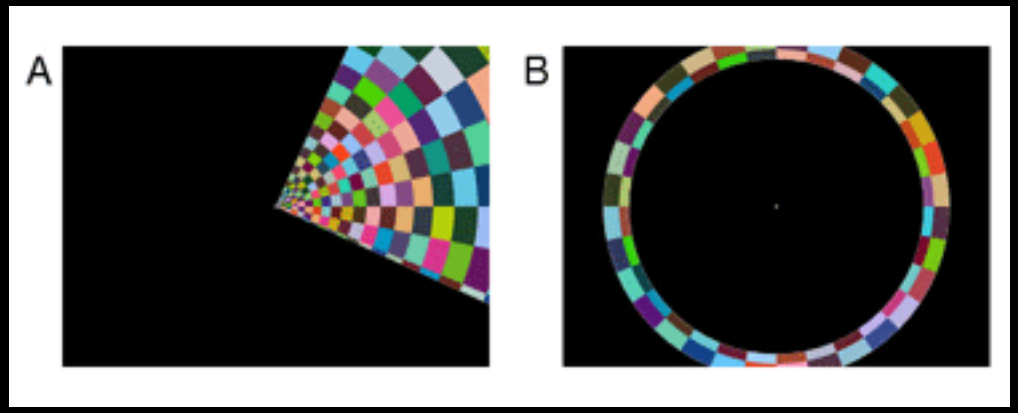


- Task: detect change in color of fixation dot (every 1–5 s)
- Eye-tracking
- Field-of-view: ~15° stimulus diameter
- fMRI: 1.6 mm, 1 s

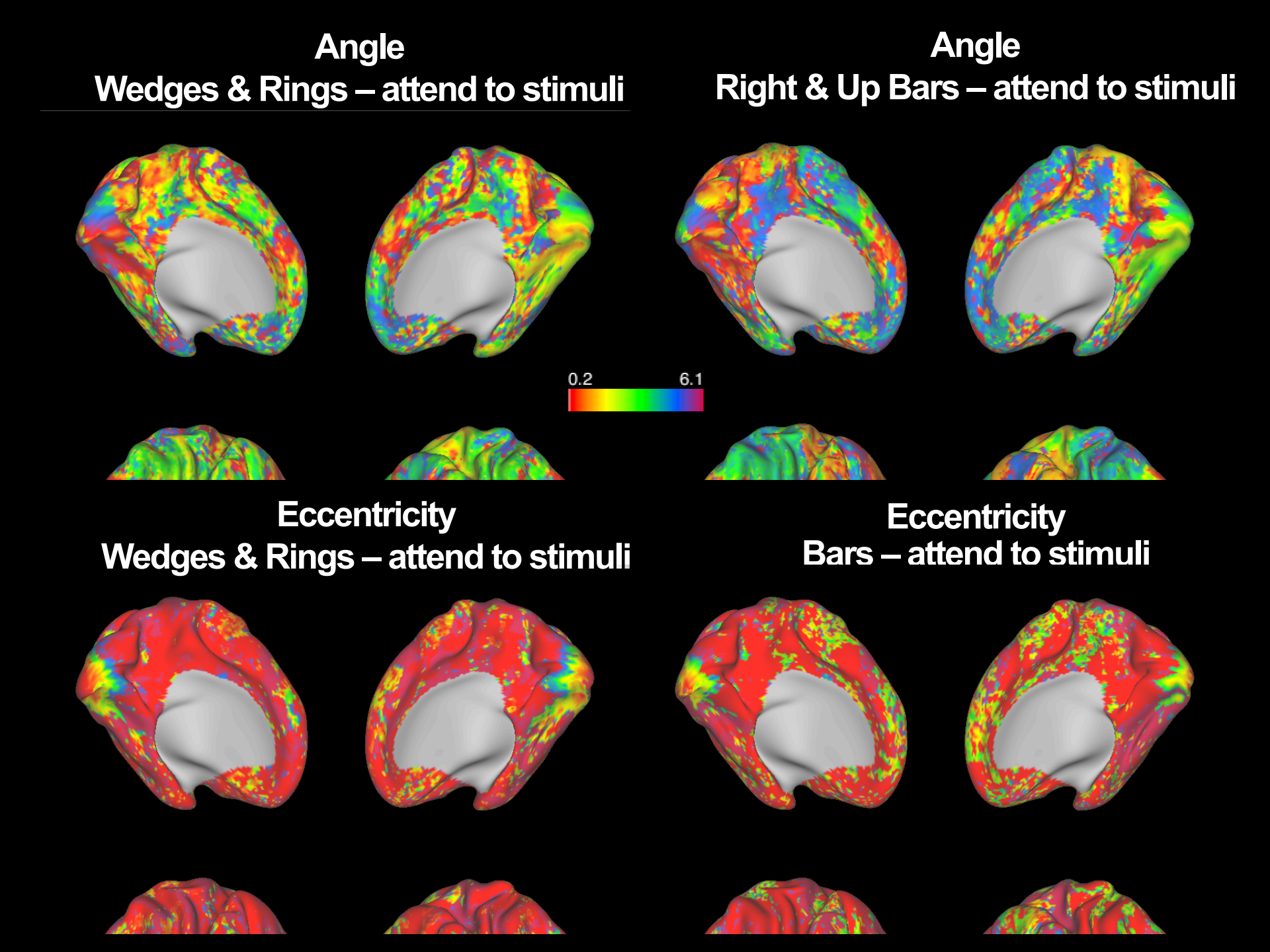
Kendrick Kay, Washington Univ. in St. Louis

Retinotopy Stimuli





Kendrick Kay, Washington Univ. in St. Louis


Angle
Wedges & Rings – attend to stimuli
Angle
Right & Up Bars – attend to stimuli
0.2
6.1
Eccentricity
Wedges & Rings – attend to stimuli
Eccentricity
Bars – attend to stimuli

Learning objectives

- Advantages and challenges of 7T neuroimaging
- MR techniques developed at CMRR, UMN to meet the challenges
- BOLD contrast mechanism and its field dependence
- HCP 7T protocol
- HCP 7T data preliminary analysis results

Questions?

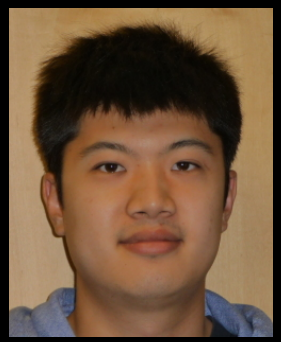
HCP Minimal Preprocessing Pipeline for 7T data

- Pipeline code: upcoming 3.6.0 release
- Requires 3T structural (T1w/T2w)
- Siemens SC72CD unwarp file (gradient non-linearity correction)
- ICA-FIX retrained for 7T (fMRI)
- Latest FSL/eddy version (dMRI)

More details in the upcoming HCP 7T data release documents

Acknowledgments

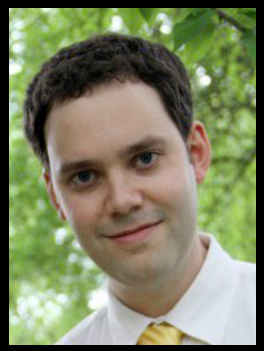
An (Joseph) Vu



Essa Yacoub

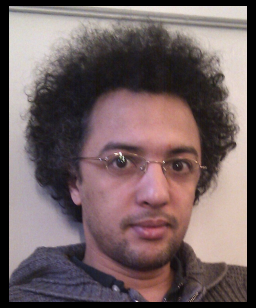
Kendrick Kay

Mathew Glasser



Tim Behrens

Stam Sotiropoulos



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