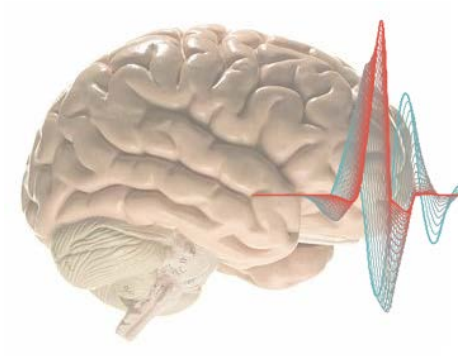

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UNIVERSITÉ DE GENÈVE

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

The human brain in action:

Resting-state neuroimaging unravels functional organization in the brain

Dimitri Van De Ville

Medical Image Processing Laboratory (MIP:lab)
Institute of Bioengineering/Center for Neuroprosthetics
Ecole polytechnique fédérale de Lausanne

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Rennes / September 7, 2017

Center for Neuroprosthetics

EPFL Schools of Life Sciences & Engineering

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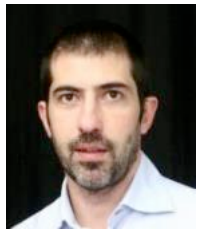
Foundation IRP Chair in Spinal Cord Repair — *Grégoire Courtine*

Medtronic Chair in Neuroengineering — *Diego Ghezzi*



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Defitech Foundation Chair in Non-Invasive Brain-Machine Interface — *José del R. Millán*

Medical Image Processing Lab — *Dimitri Van De Ville*

New member: Friedhelm Hummel

Defitech Foundation Chair (Clinical Neuroengineering) Sion-Geneva

fondation bertarelli

Medtronic

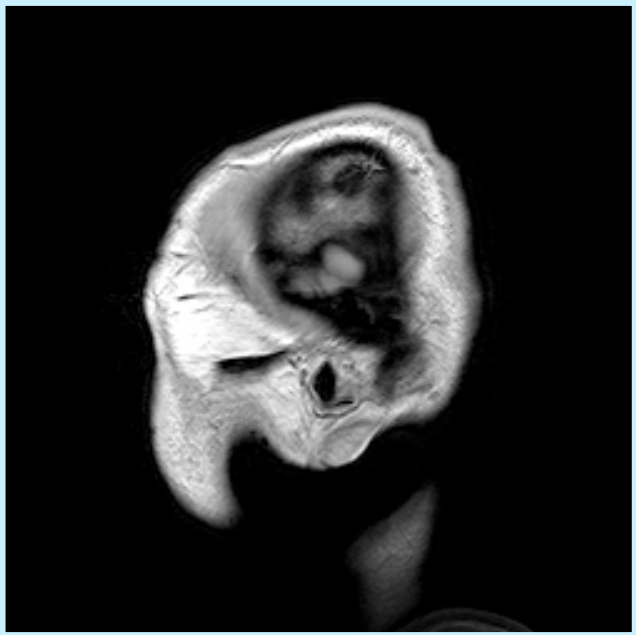
defitech fondation

I R P

Magnetic resonance imaging (MRI)

- Widely deployed in hospitals and research centers
- Endogenous contrast mechanism
- Non-invasive imaging tool to study human brain anatomy and function

Structural MRI



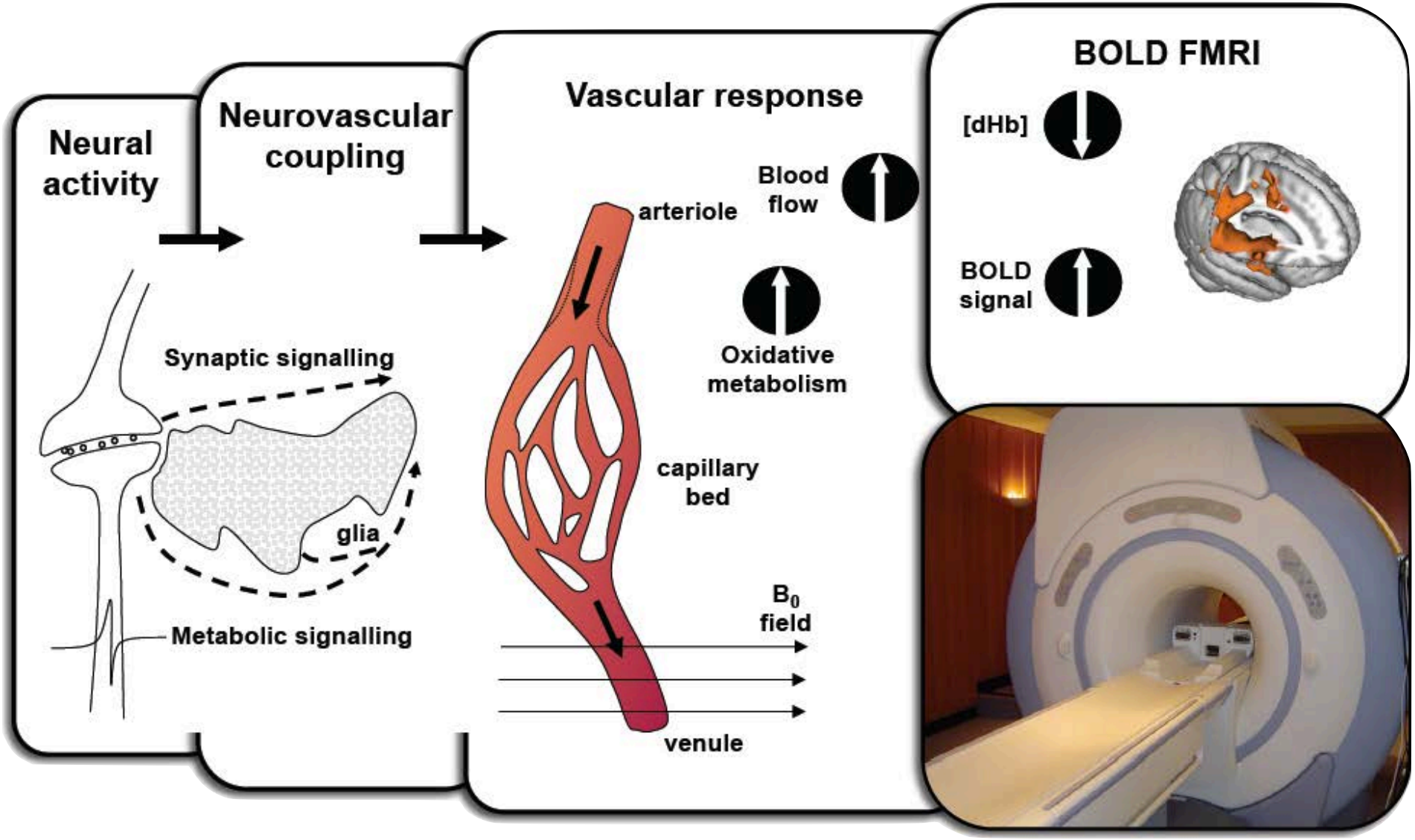
- Single 3D volume
  - 1x1x1 mm^3
  - takes couple of minutes

Functional MRI

- Series of 3D volumes
  - 2x2x2 mm^3
  - 30-60 slices
  - every 1-3 sec
  - during 5-10 minutes

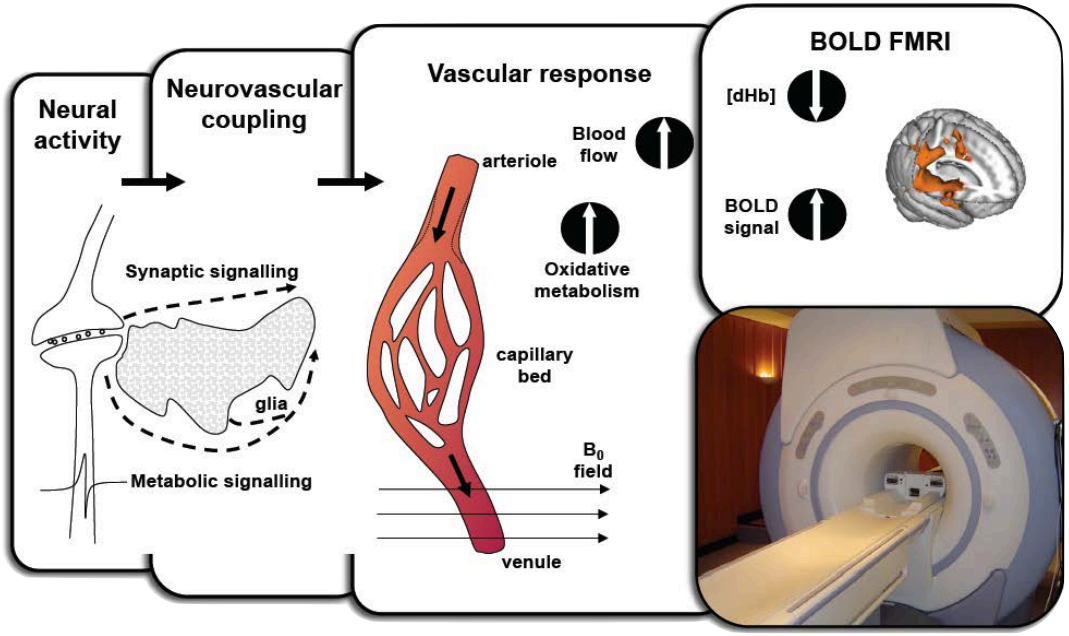
Siemens 3T Prisma MRI scanner @ Campus Biotech / picture (c) EPFL/Alban Kakulya

FMRI blood-oxygenation-level-dependent (BOLD) signals are slow proxy for neuronal activity

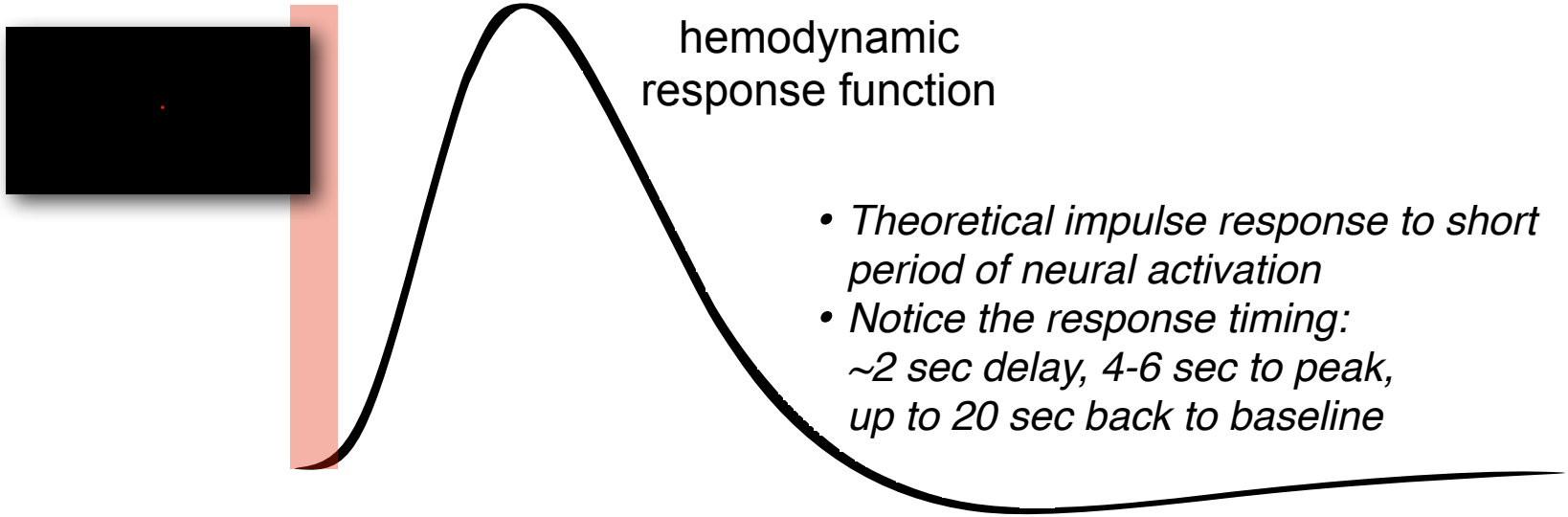


[Buxton et al 1997; Friston et al. 1998, 2000; Iannetti & Wise, 2007]

FMRI blood-oxygenation-level-dependent (BOLD) signals are slow proxy for neuronal activity



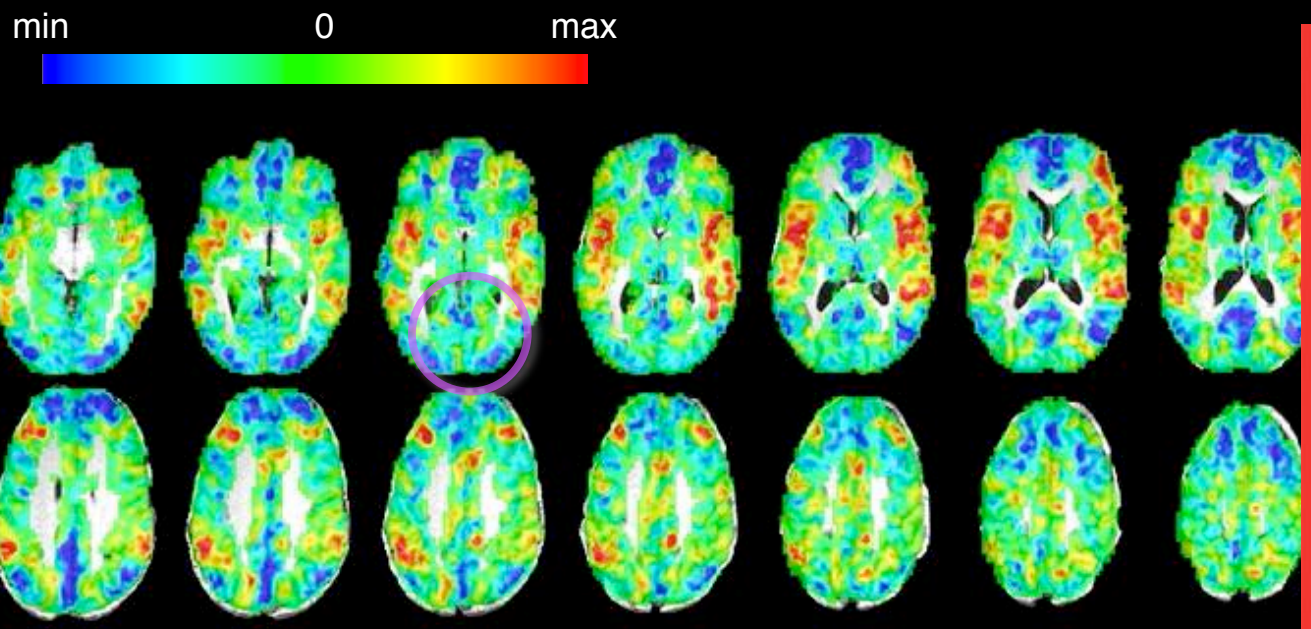
20 sec

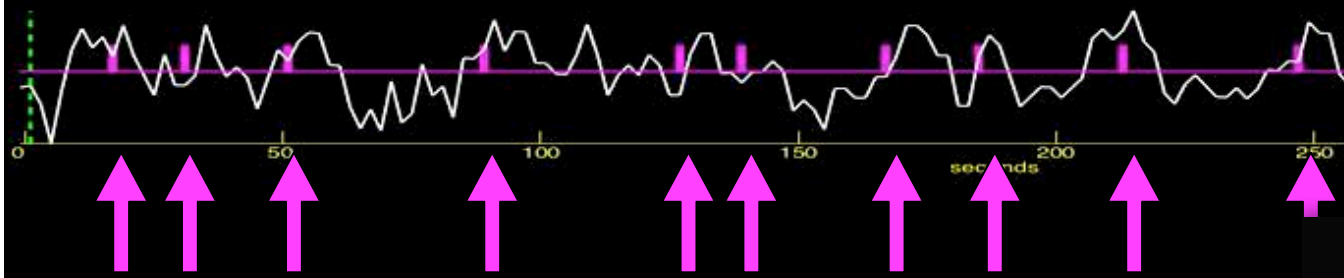


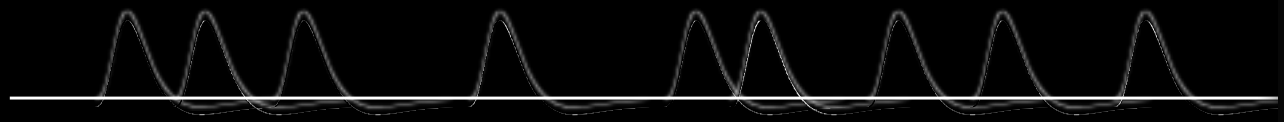
- *Theoretical impulse response to short period of neural activation*
- *Notice the response timing: ~2 sec delay, 4-6 sec to peak, up to 20 sec back to baseline*

[Buxton et al 1997; Friston et al. 1998, 2000; Iannetti & Wise, 2007]

fMRI of evoked activity

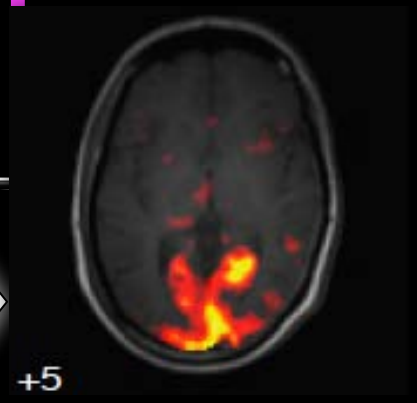


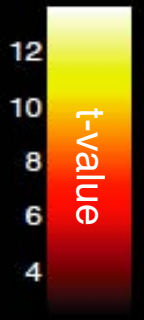




movie accelerated 4 times

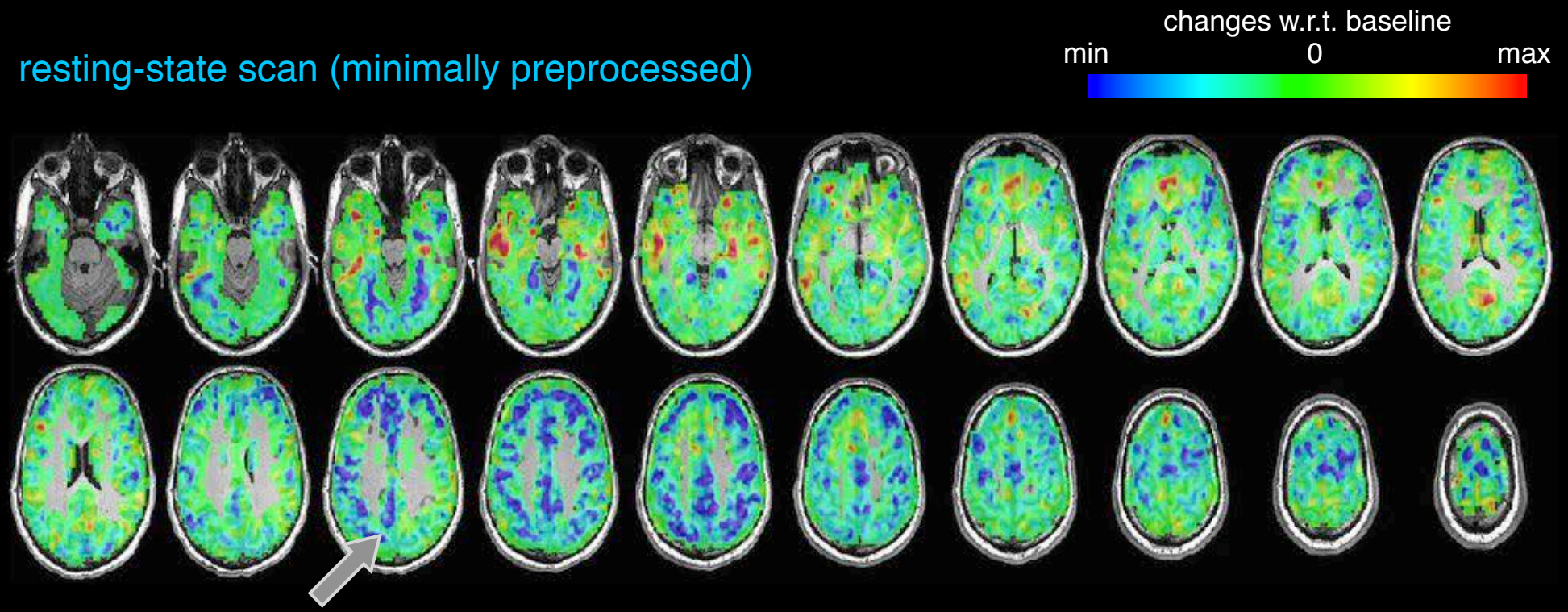
statistical processing





fMRI of spontaneous activity

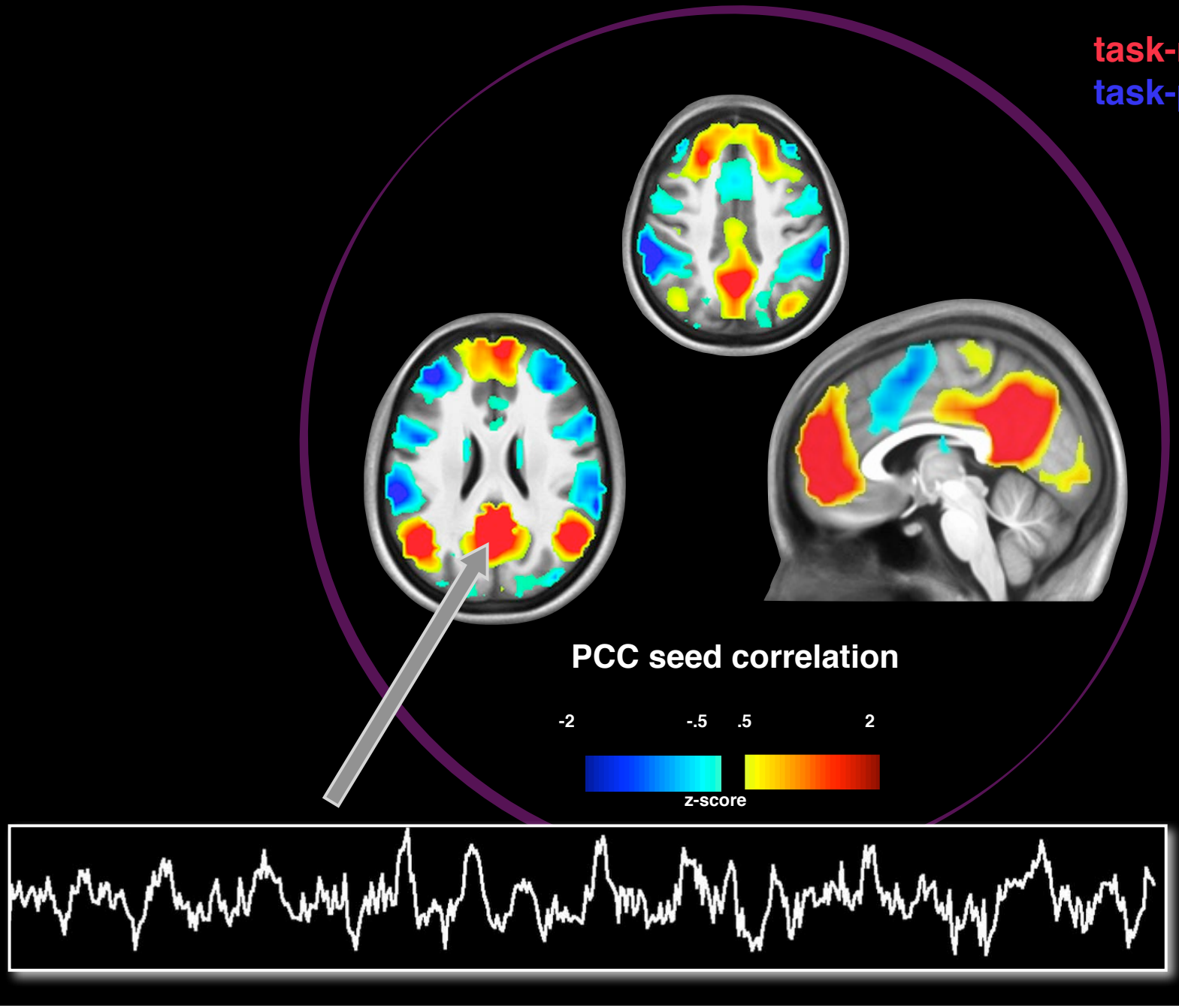
resting-state scan (minimally preprocessed)



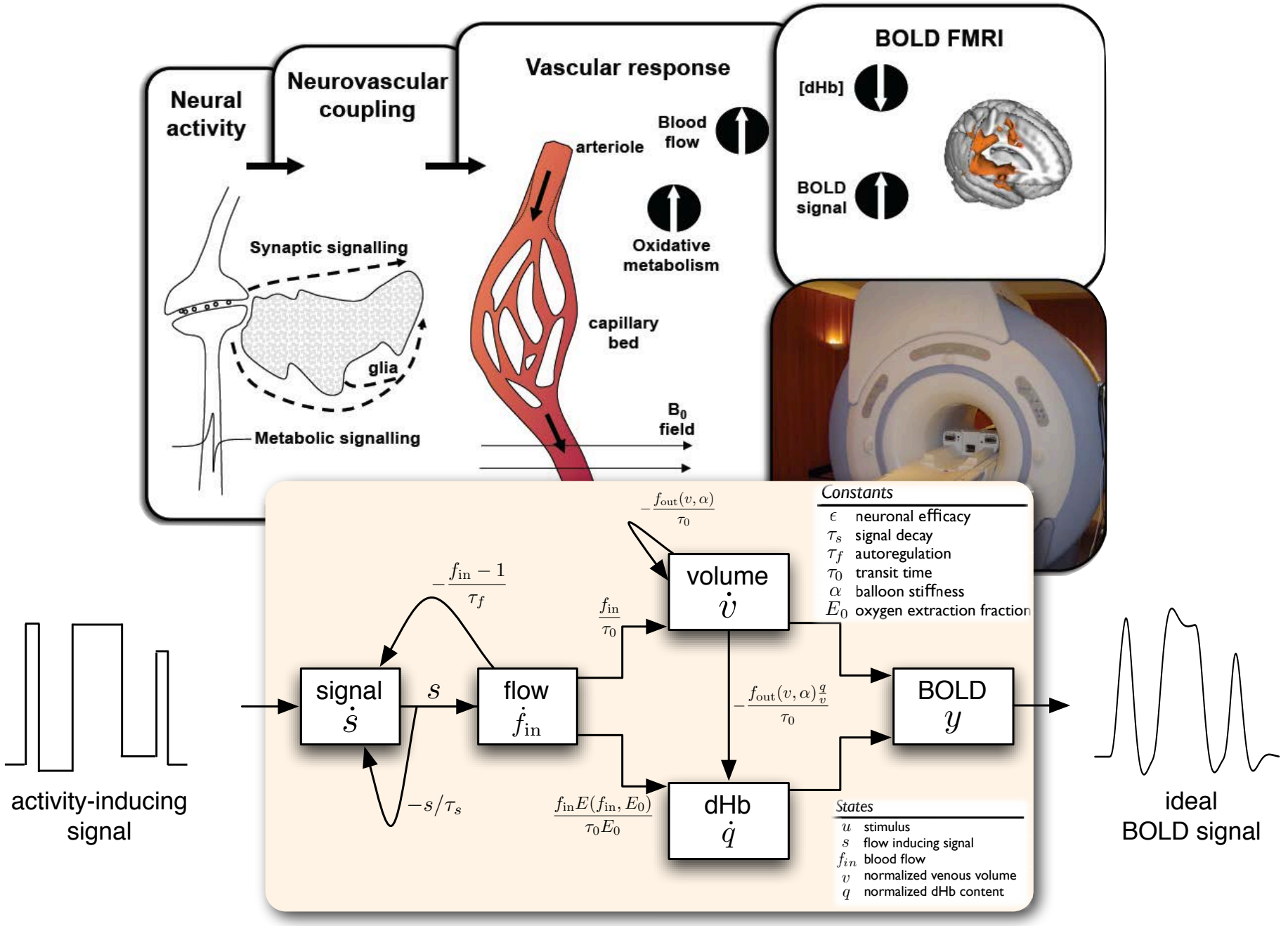
movie accelerated 4 times

minimal compliance for patient studies!

PCC connectivity: task-positive and task-negative networks

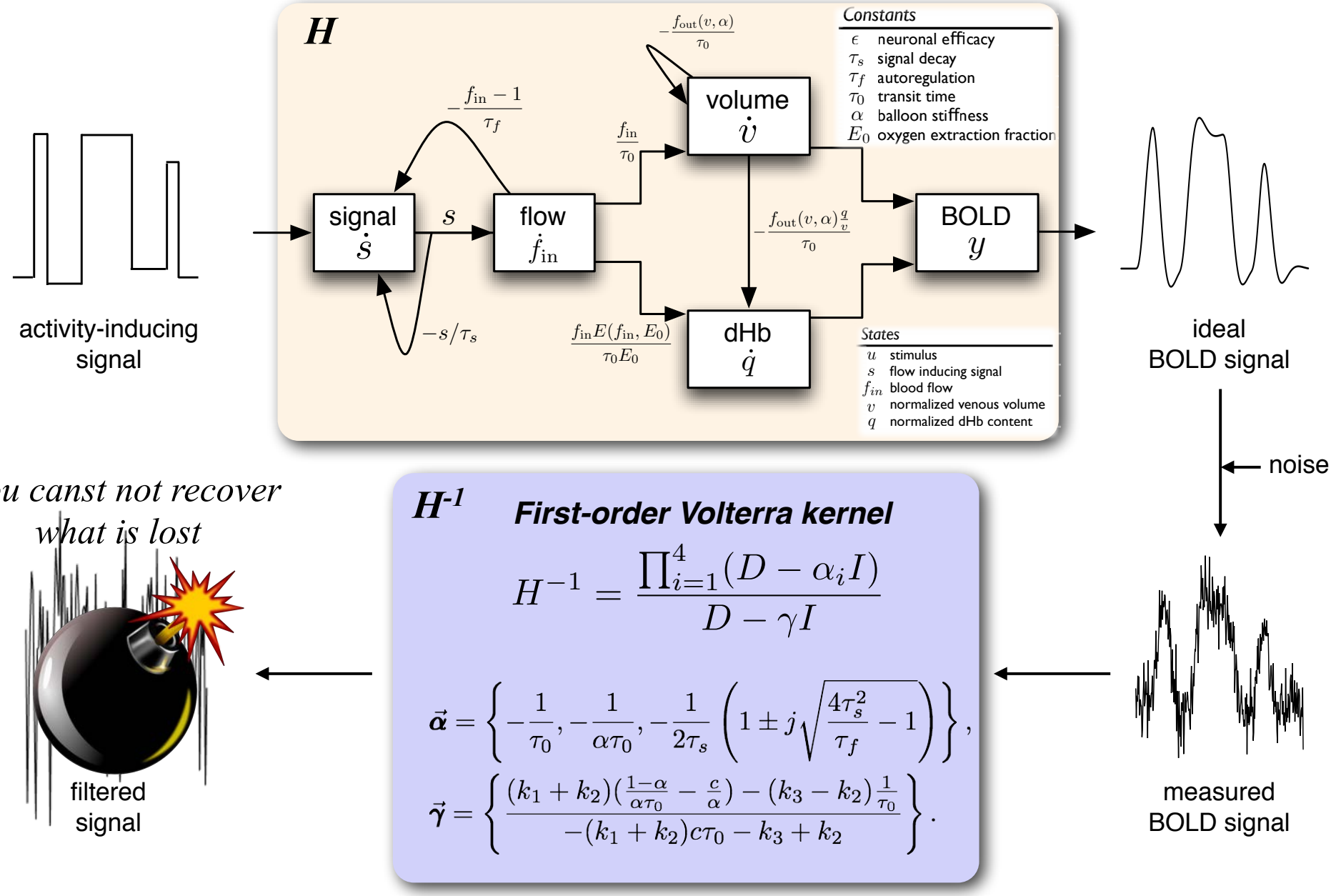


FMRI blood-oxygenation-level-dependent (BOLD) signals are slow proxy for neuronal activity



[Buxton et al 1997; Friston et al. 1998, 2000; Iannetti & Wise, 2007]

FMRI blood-oxygenation-level-dependent (BOLD) signals are slow proxy for neuronal activity



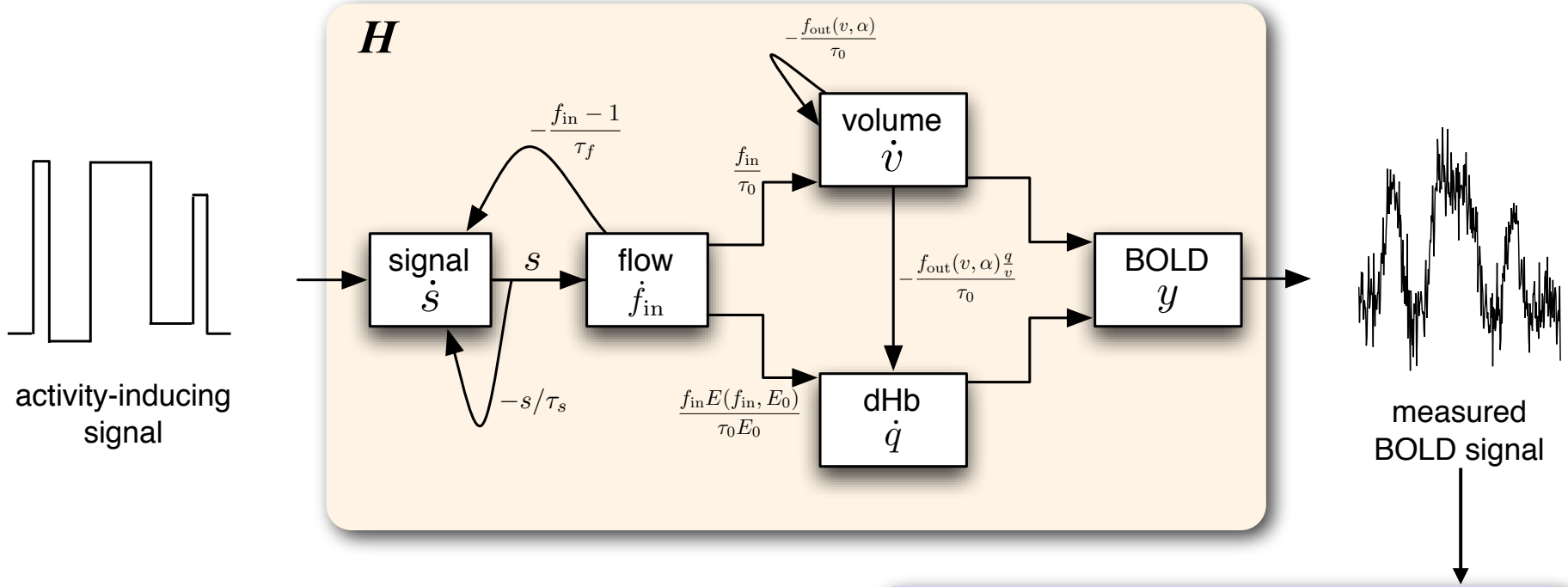
$$H^{-1} = \frac{\prod_{i=1}^{4}(D - \alpha_i I)}{D - \gamma I}$$

$$\vec{\alpha} = \left\{ -\frac{1}{\tau_0}, -\frac{1}{\alpha\tau_0}, -\frac{1}{2\tau_s}\left(1 \pm j\sqrt{\frac{4\tau_s^2}{\tau_f} - 1}\right) \right\},$$

$$\vec{\gamma} = \left\{ \frac{(k_1 + k_2)(\frac{1-\alpha}{\alpha\tau_0} - \frac{c}{\alpha}) - (k_3 - k_2)\frac{1}{\tau_0}}{-(k_1 + k_2)c\tau_0 - k_3 + k_2} \right\}.$$

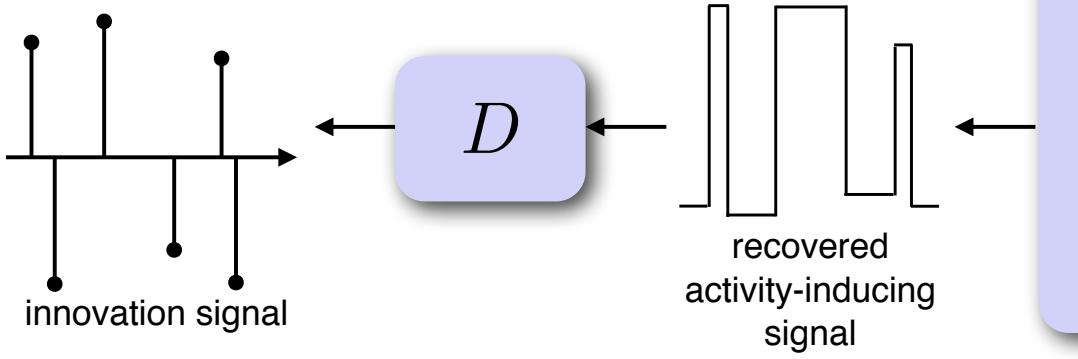
[Khalidov, VDV et al, *IEEE Transactions on SP*, 2011; Karahanoglu, VDV et al, *NeuroImage*, 2013]

FMRI blood-oxygenation-level-dependent (BOLD) signals are slow proxy for neuronal activity



- Total activation regularization:

$$\tilde{\boldsymbol{x}} = \arg\min_{\mathbf{x}} \underbrace{\frac{1}{2}\left\|\boldsymbol{y}-\boldsymbol{x}\right\|_2^2}_{\text{data fitness}} + \lambda \underbrace{\left\|DH^{-1}\{\boldsymbol{x}\}\right\|_1}_{\text{regularization}}$$



H^{-1} ***First-order Volterra kernel***

$$H^{-1} = \frac{\prod_{i=1}^{4}(D-\alpha_i I)}{D-\gamma I}$$

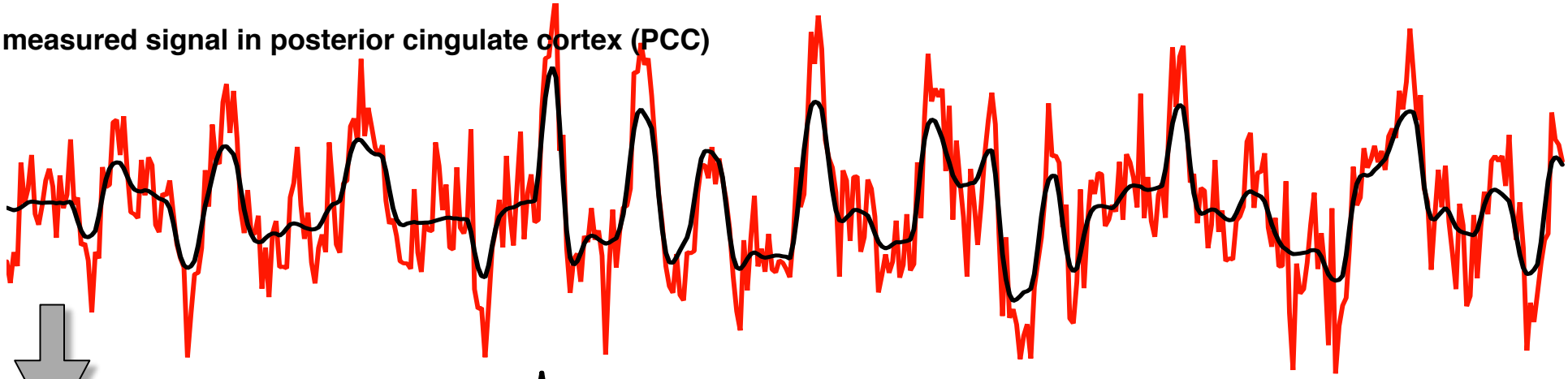
$$\vec{\boldsymbol{\alpha}} = \left\{-\frac{1}{\tau_0}, -\frac{1}{\alpha\tau_0}, -\frac{1}{2\tau_s}\left(1 \pm j\sqrt{\frac{4\tau_s^2}{\tau_f}-1}\right)\right\},$$

$$\vec{\boldsymbol{\gamma}} = \left\{\frac{(k_1+k_2)(\frac{1-\alpha}{\alpha\tau_0}-\frac{c}{\alpha})-(k_3-k_2)\frac{1}{\tau_0}}{-(k_1+k_2)c\tau_0-k_3+k_2}\right\}.$$

[Khalidov, VDV et al, *IEEE Transactions on SP*, 2011; Karahanoglu, VDV et al, *NeuroImage*, 2013]

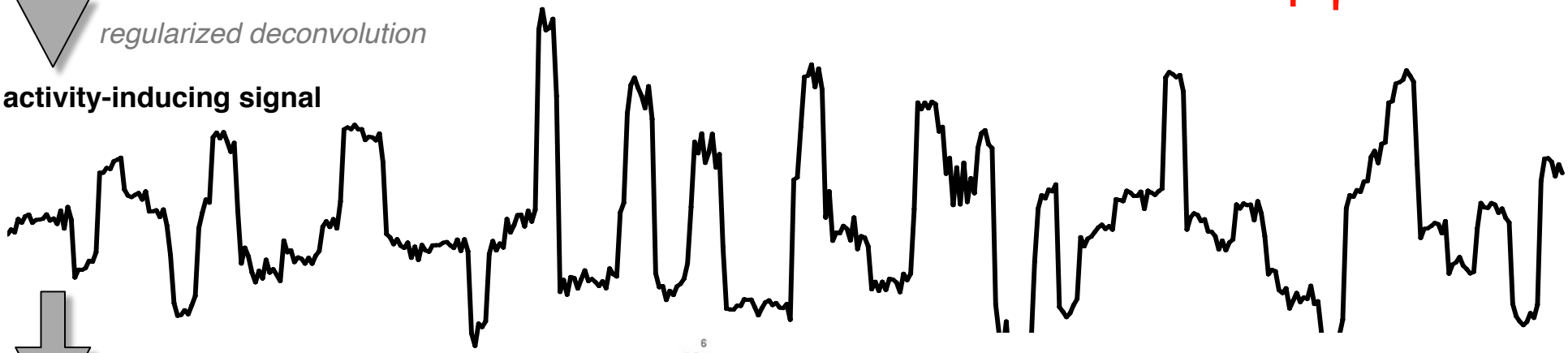
BOLD is full of innovation

measured signal in posterior cingulate cortex (PCC)



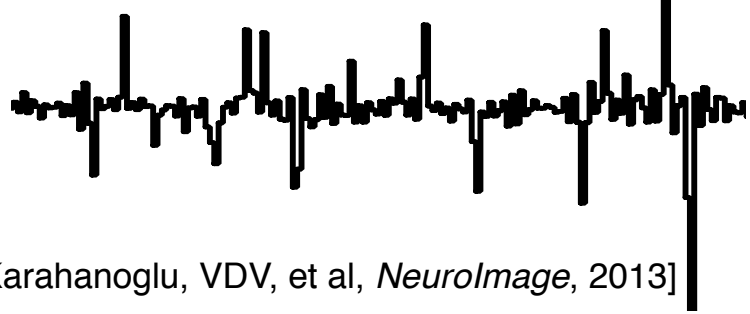
regularized deconvolution

activity-inducing signal

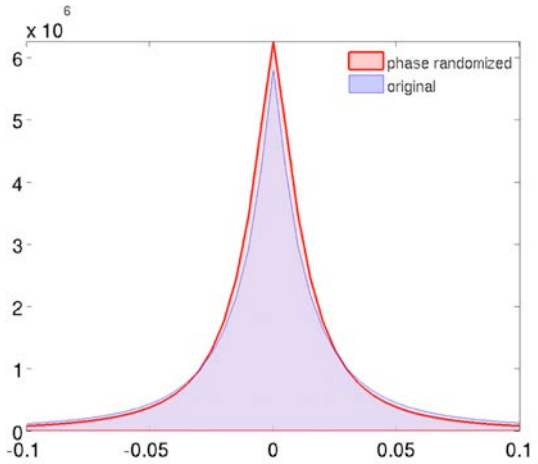


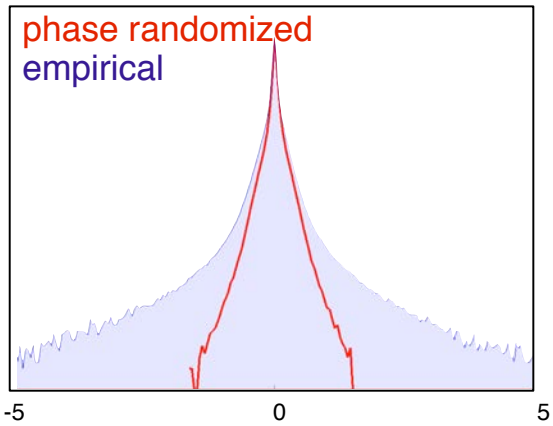
derivative

innovation signal

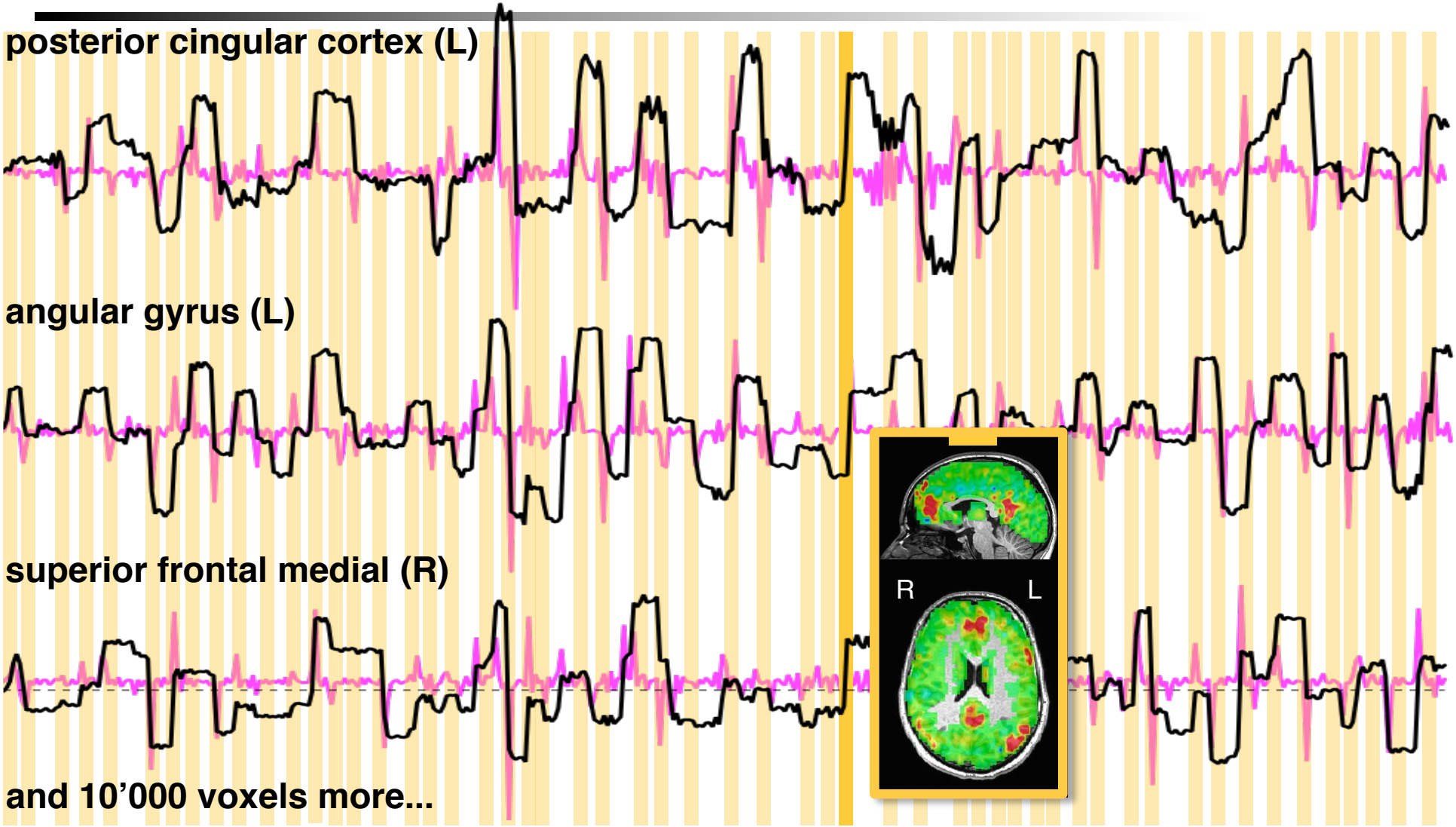


[Karahanoglu, VDV, et al, *NeuroImage*, 2013]



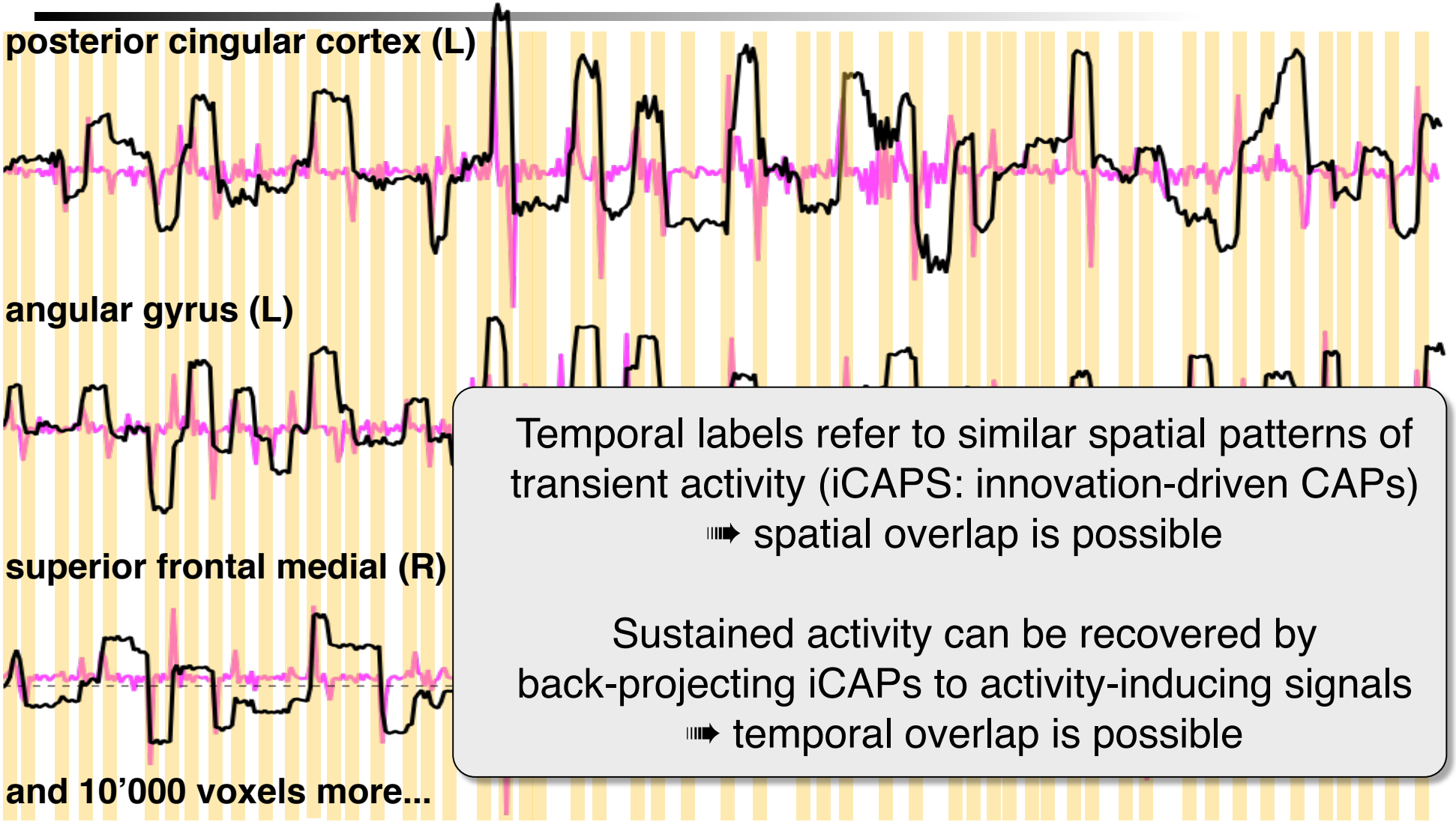


Innovation never comes alone



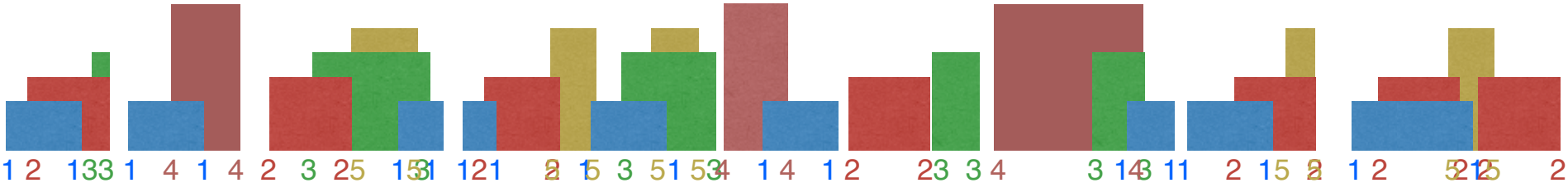
[Karahanoglu and VDV, *Nature Communications*, 2015]

Innovation never comes alone



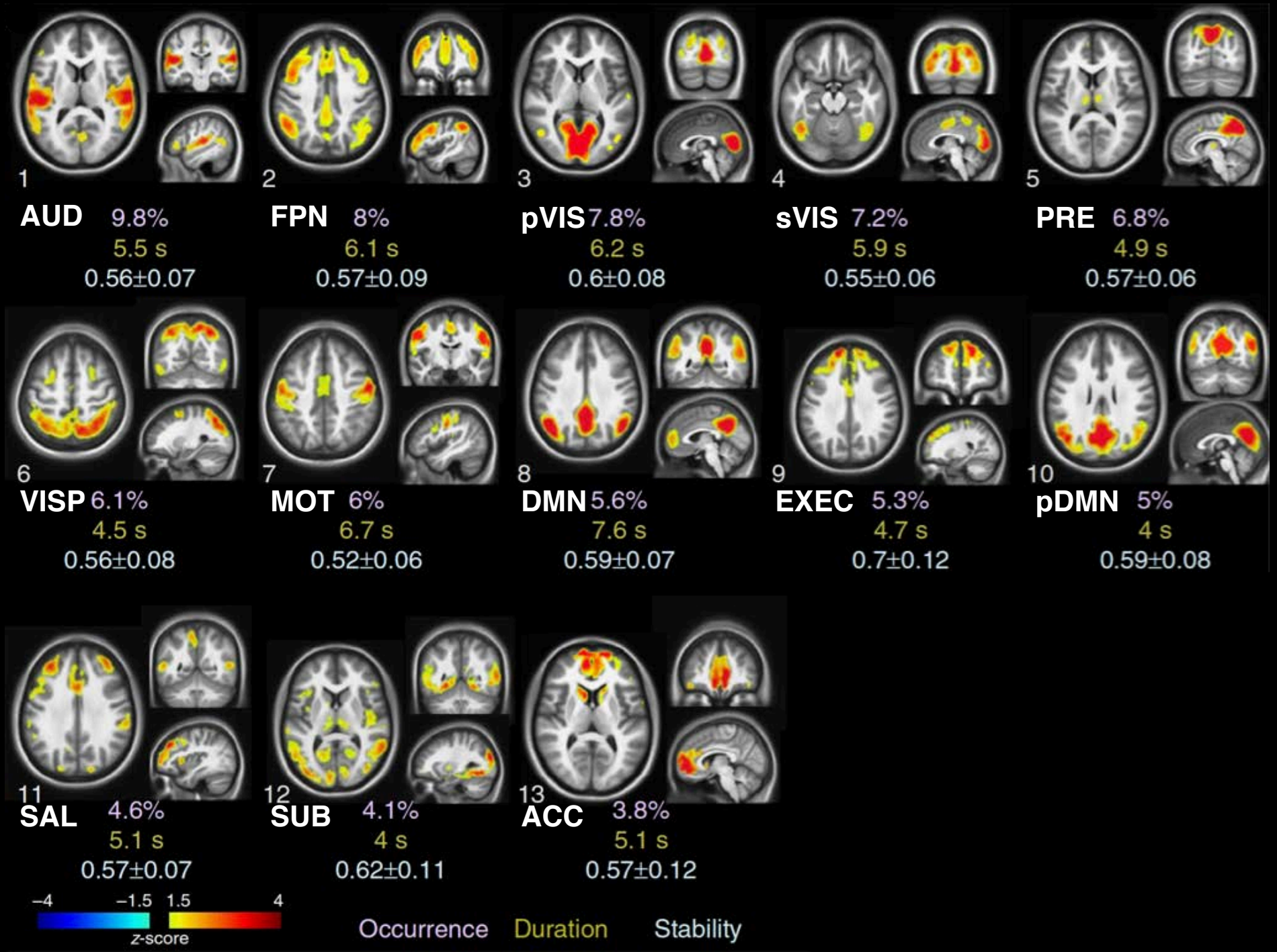
Temporal labels refer to similar spatial patterns of transient activity (iCAPS: innovation-driven CAPs)
➠ spatial overlap is possible

Sustained activity can be recovered by back-projecting iCAPs to activity-inducing signals
➠ temporal overlap is possible

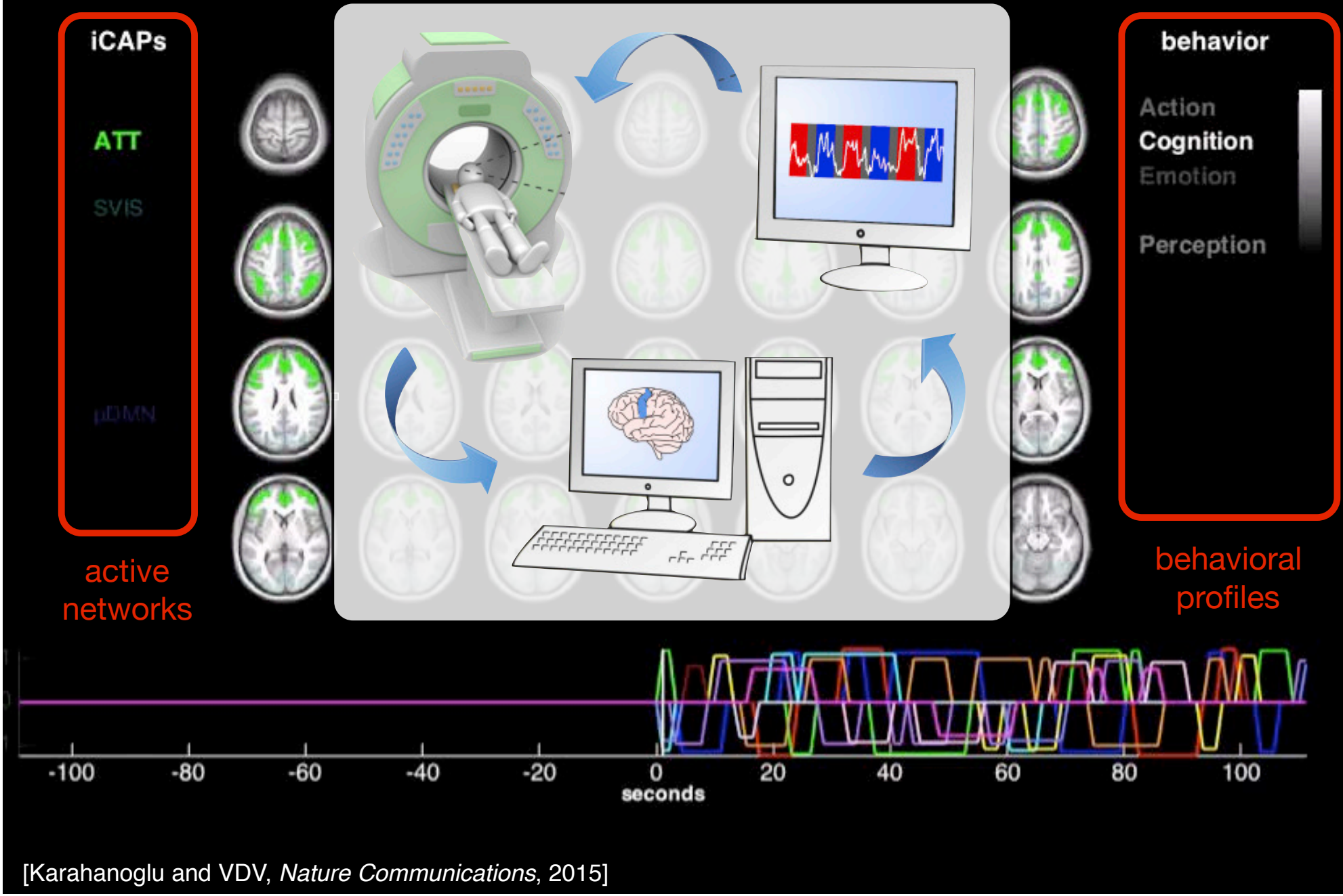


[Karahanoglu and VDV, *Nature Communications*, 2015]

iCAPS: innovation-driven co-activation patterns



Deciphering moment-to-moment activity

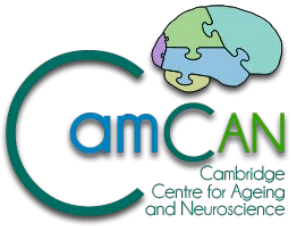


[Karahanoglu and VDV, *Nature Communications*, 2015]

Feed the models: *Big data* in human MRI

- ... is a fact!

International Neuroimaging
Data-Sharing Initiative



Autism Brain Imaging
Data Exchange

Big data in human MRI already arrived

Resource	Sites	Subjects	Size	Population	sMRI	DWI	tfMRI	rfMRI
1000 func connectomes	35	1.355	~240GB	HC	x			x
ABIDE	20	1.112	~200GB	HC, ASD	x			x
ABIDE II NEW Jun 2016	17	1.144	~200GB	HC ASD	x			x
ADHD-200	8	776	~160GB	HC, ADHD	x			x
ADNI	59	758	~100GB	HC,MCI,AD	x			
ADNI 2	63	850	~800GB	HC,MCI,AD	x	x		x
BIRN	10	285	~30GB	HC, SZ	x			
Cam-CAN NEW Nov 2016	1	653	~1TB	HC	x	x	x	x
HCP	2	900	52TB	HC	x	x	x	x
Other INDI retrospective	8	568	~1TB	HC,EP,SZ,COC	x	x	x	x
Other INDI prospective	8	467	~500GB	HC	x	x		x
NKI-RS	1	921	1.2TB	HC	x	x	x	x
OASIS	2	566	70GB	HC,AD	x			
OpenfMRI	55	1.941	~2TB	HC,SZ	x	x	x	
ABCD Project	21	10.000		HC (9-10y)	x	x	x	x
UK Biobank		10.000		HC	x	x	x	x

- Open data of thousands of subjects!...

Adapted and updated from [Poldrack and Gorgolewski, Nature Neuroscience, 2014]

Take home message

- Dynamics of resting-state fMRI
  - Is *not* about oscillations, but about *transients*!
    - basically a “broadband” feature...
      notice that a transient has a “deterministic” 1/f spectrum!
  - Clear transient behavior is recovered
  - Massive spatial and temporal overlap
  - “The human association cortex consists of multiple, interdigitated large-scale networks, that, while partially overlapping, possess predominantly parallel organization. ... Our (essential) correlational analyses will miss vital details of dynamics of network interactions.”
    -- B.T. Thomas Yeo et al, NeuroImage, 2014
- Perspectives
  - Tracking of brain states
    - Naturalistic stimuli/tasks; neurofeedback
  - Towards new markers for brain function and dysfunction
    - Benefit from “big MRI data” in health and disease

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