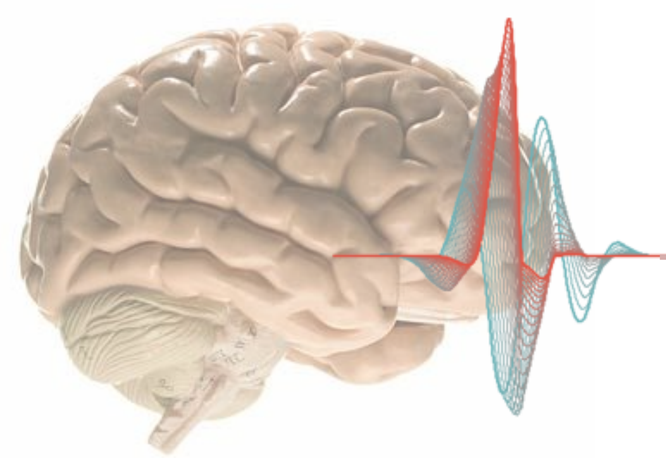


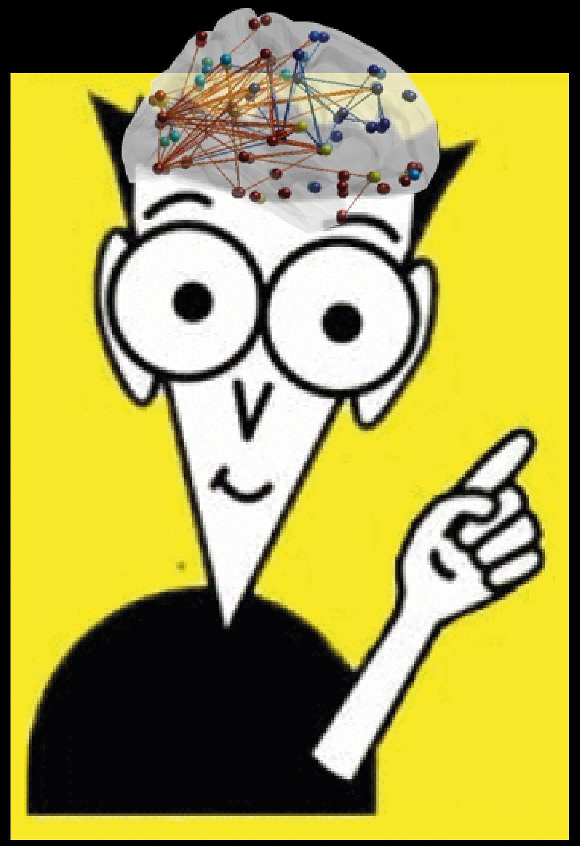
campus biotech

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

UNIVERSITÉ DE GENÈVE

Dynamic functional connectivity

FOR DUMMIES



Anjali Tarun, Younes Farouj and Thomas Bolton

Medical Image Processing Laboratory (MIP:Lab)

http://miplab.epfl.ch

Institute of Bioengineering, Ecole Polytechnique Fédérale de Lausanne

Department of Radiology and Medical Informatics, University of Geneva

BrainHack Zürich, 03.03.2017

Outline

- From stationary to dynamic functional connectivity

Outline

- From stationary to dynamic functional connectivity

- Probing the dynamic functional connectivity landscape

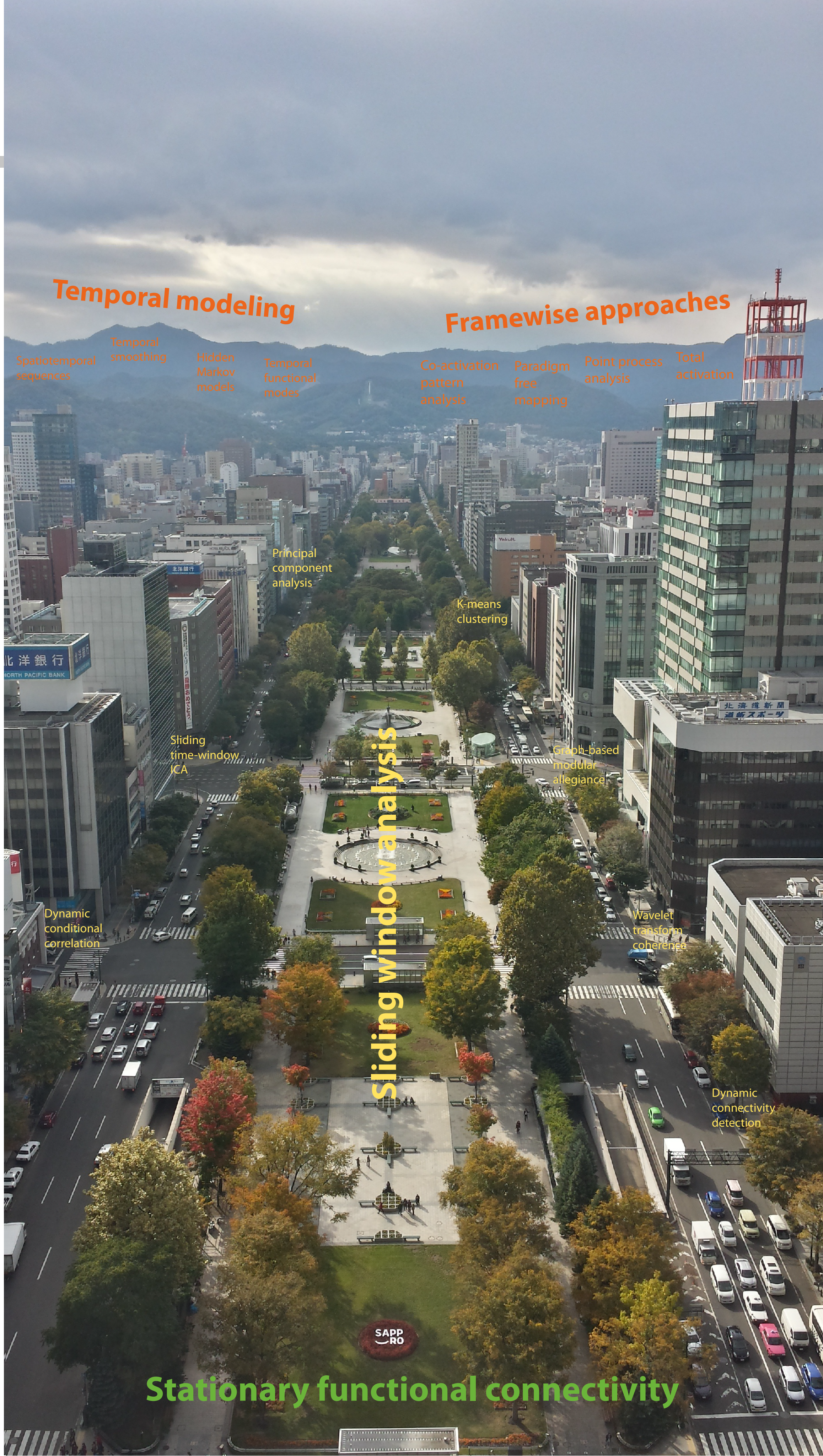
Outline

- From stationary to dynamic functional connectivity

- Probing the dynamic functional connectivity landscape
  - *Traditional* sliding window framework

Outline

- From stationary to dynamic functional connectivity
- Probing the dynamic functional connectivity landscape
  - *Traditional* sliding window framework
  - Conceptually innovative directions

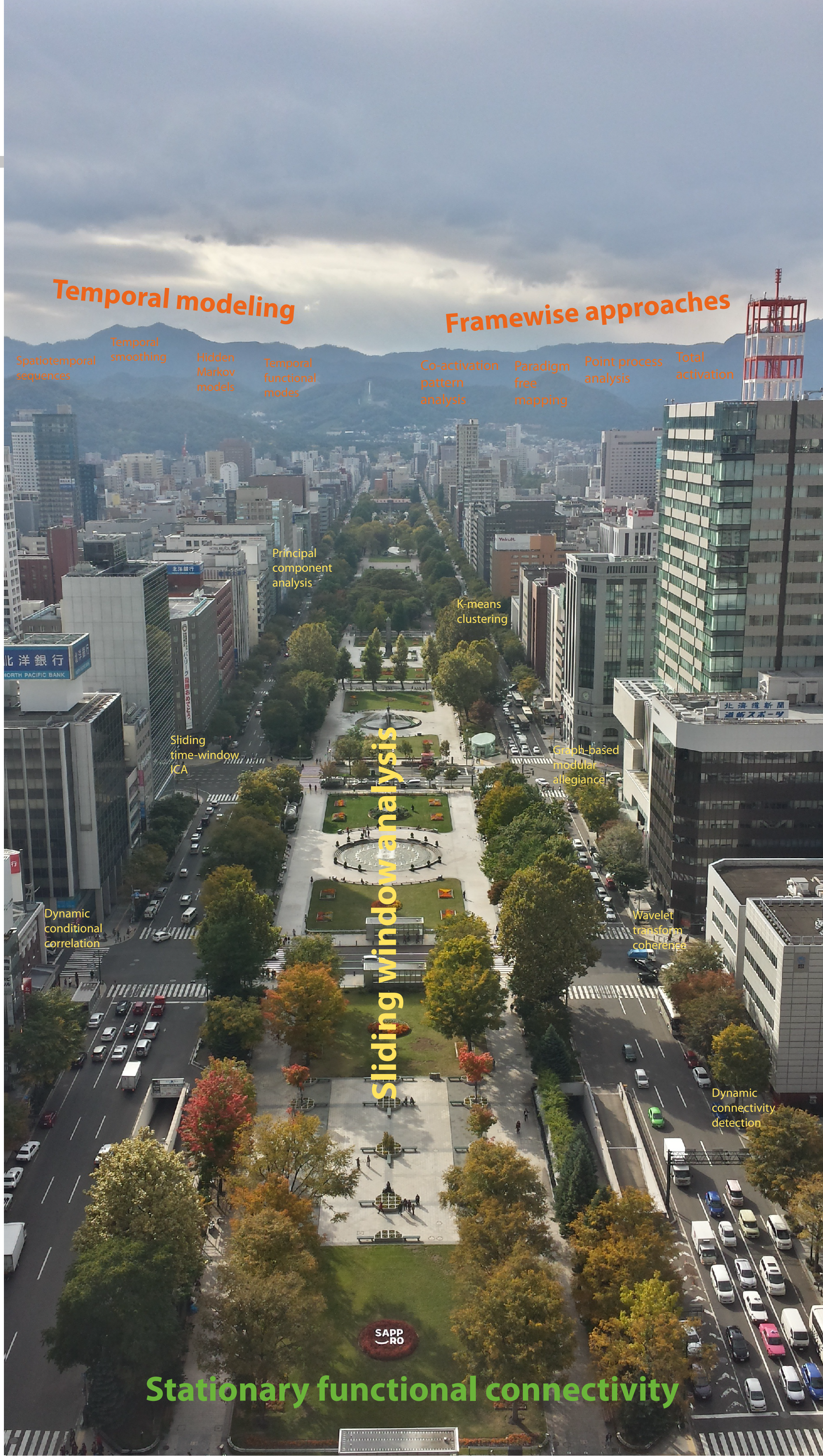


Outline

- From stationary to dynamic functional connectivity

- Probing the dynamic functional connectivity landscape
  - *Traditional* sliding window framework
  - Conceptually innovative directions

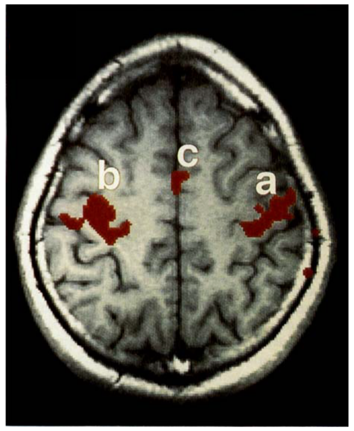
- Origins and relevance of dynamic functional connectivity



A stationary understanding of brain function

- A bilateral finger tapping experiment started it all…

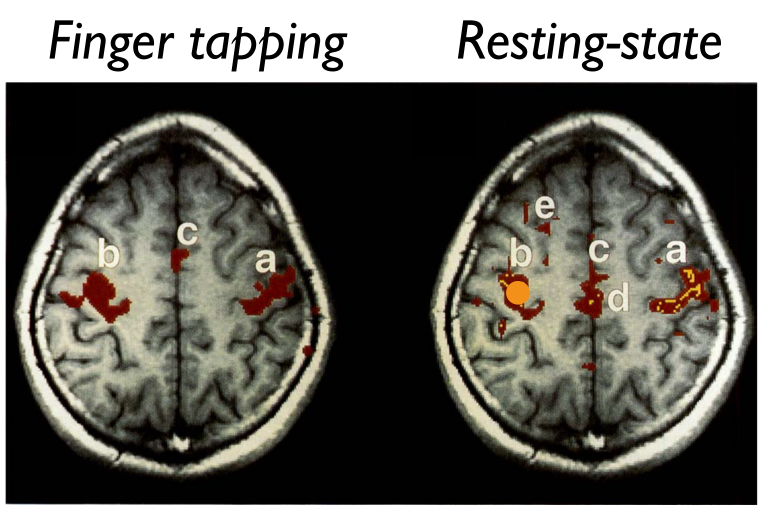
Finger tapping



(Biswal et al., 1995)

A stationary understanding of brain function

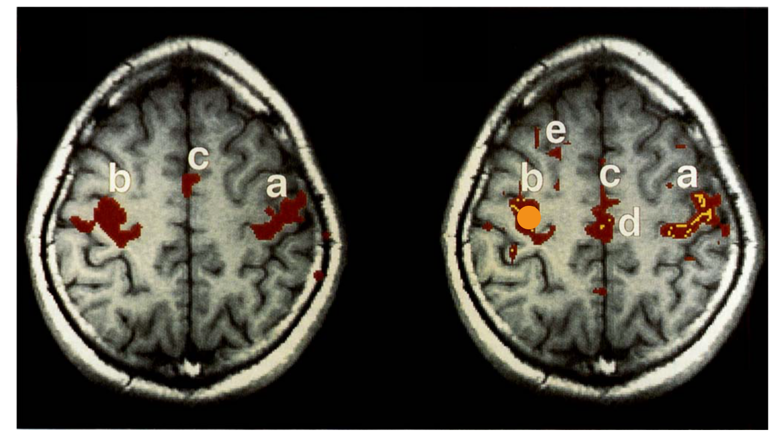
- A bilateral finger tapping experiment started it all…
  - Probing *resting-state* voxel-wise synchrony with a seed region
  - Bilateral, symmetric foci with strong seed correlation



(Biswal et al., 1995)

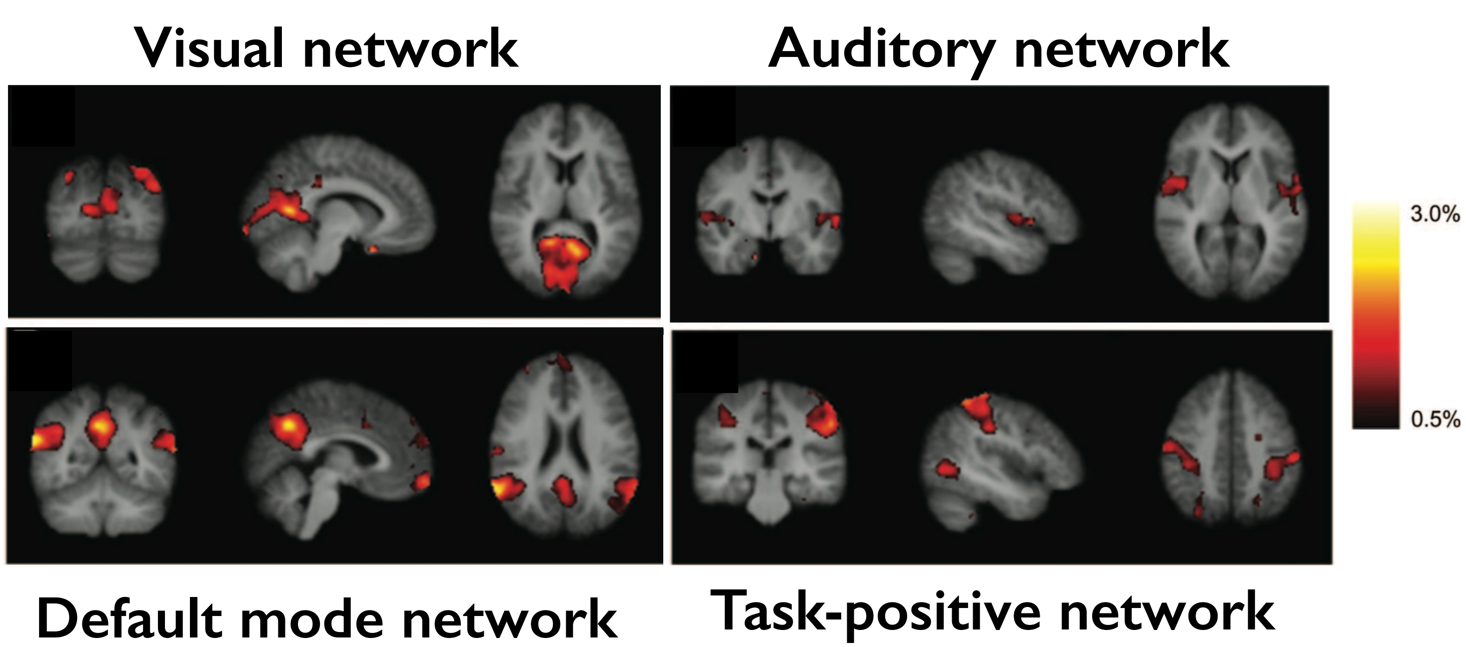
A stationary understanding of brain function

- A bilateral finger tapping experiment started it all…
  - Probing *resting-state* voxel-wise synchrony with a seed region
  - Bilateral, symmetric foci with strong seed correlation

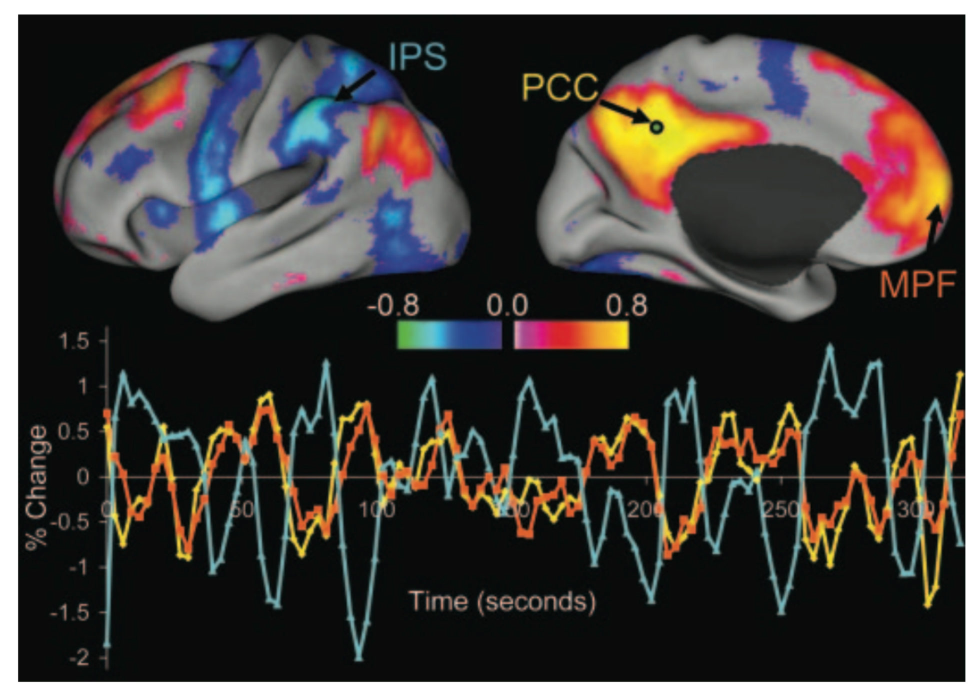


(Biswal et al., 1995)

- Functionally relevant *resting-state networks* co-exist and interact



(Damoiseaux et al. 2006)

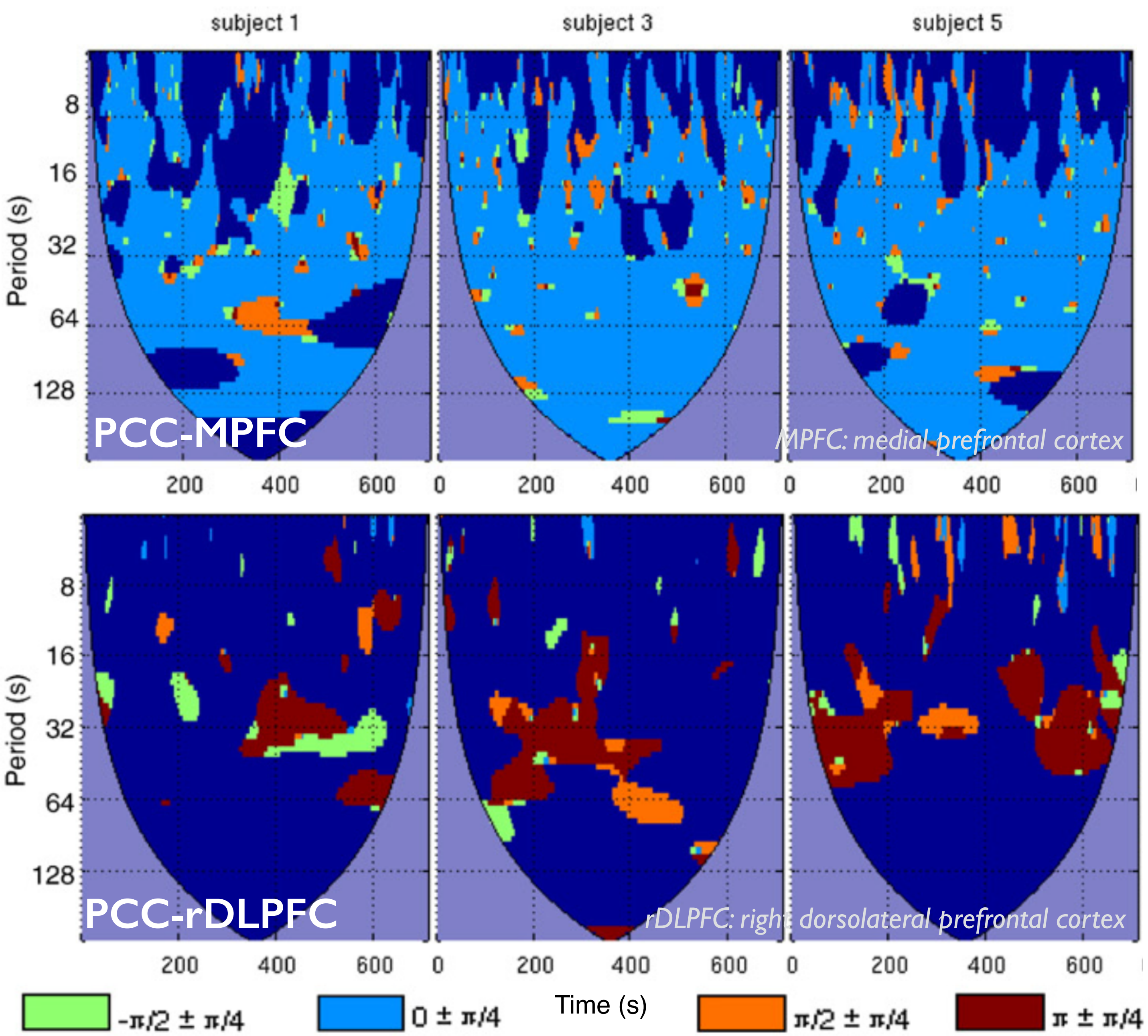


PCC: posterior cingulate cortex
IPS: inferior parietal sulcus
MPF: medial prefrontal cortex

(Fox et al. 2005)

Brain dynamics unraveled

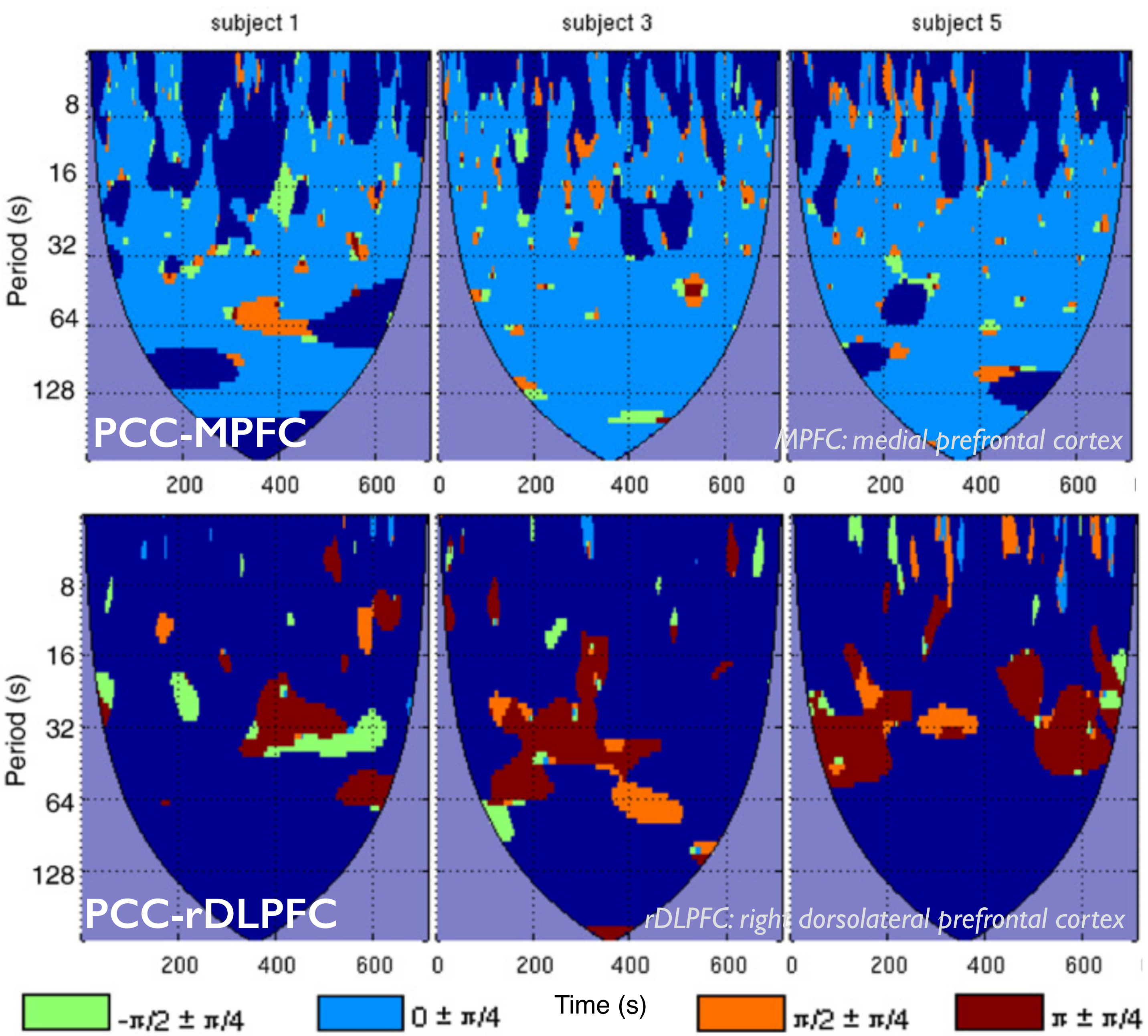
- Within- and cross-network interactions reconfigure over time



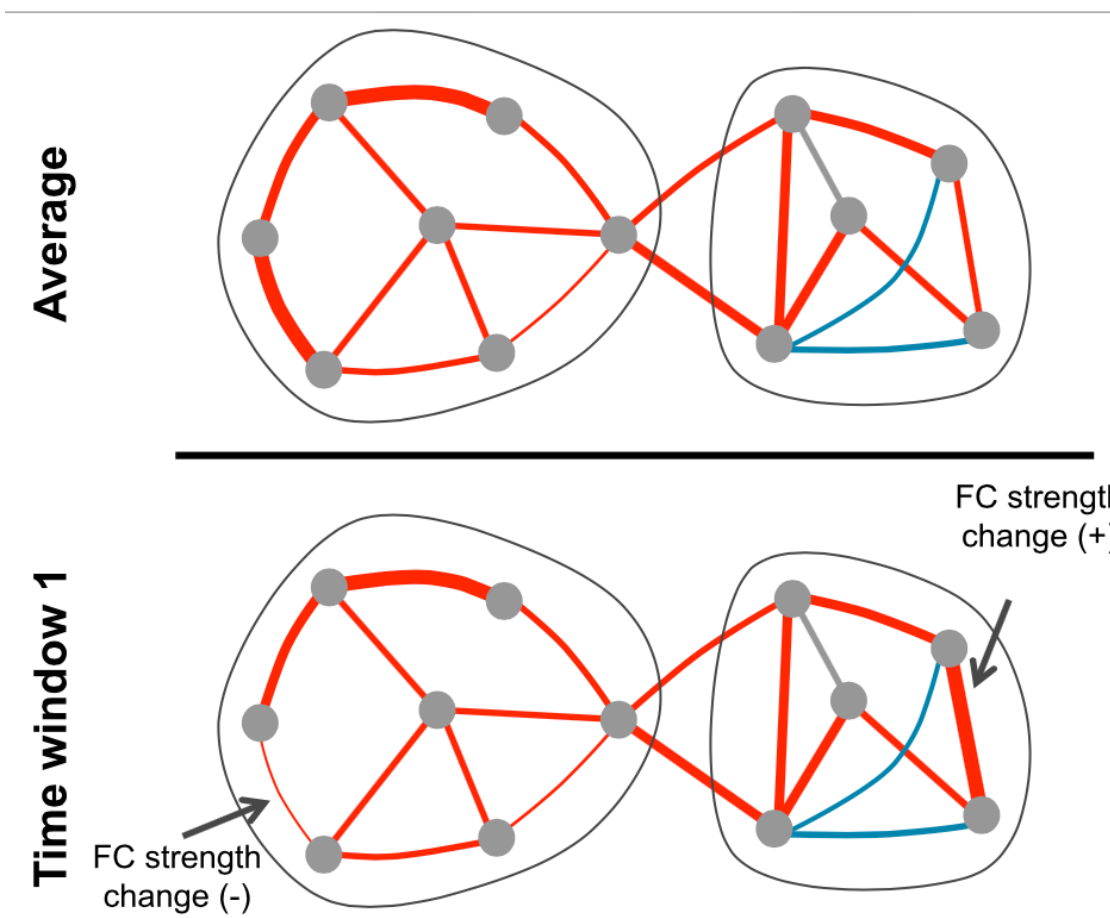
(Chang and Glover, 2010)

Brain dynamics unraveled

- Within- and cross-network interactions reconfigure over time
- Birth of the *dynamic functional connectivity* (dFC) field



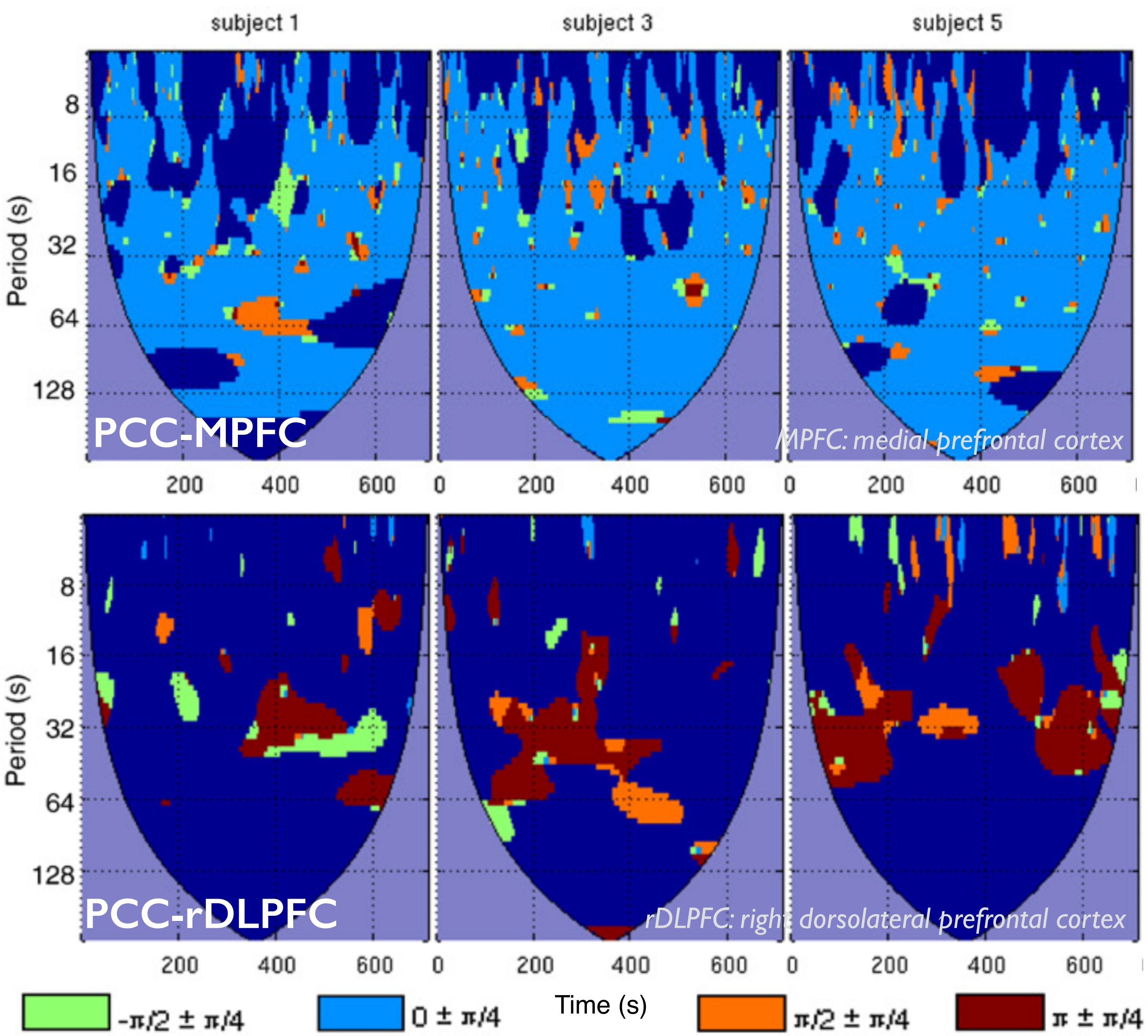
(Chang and Glover, 2010)



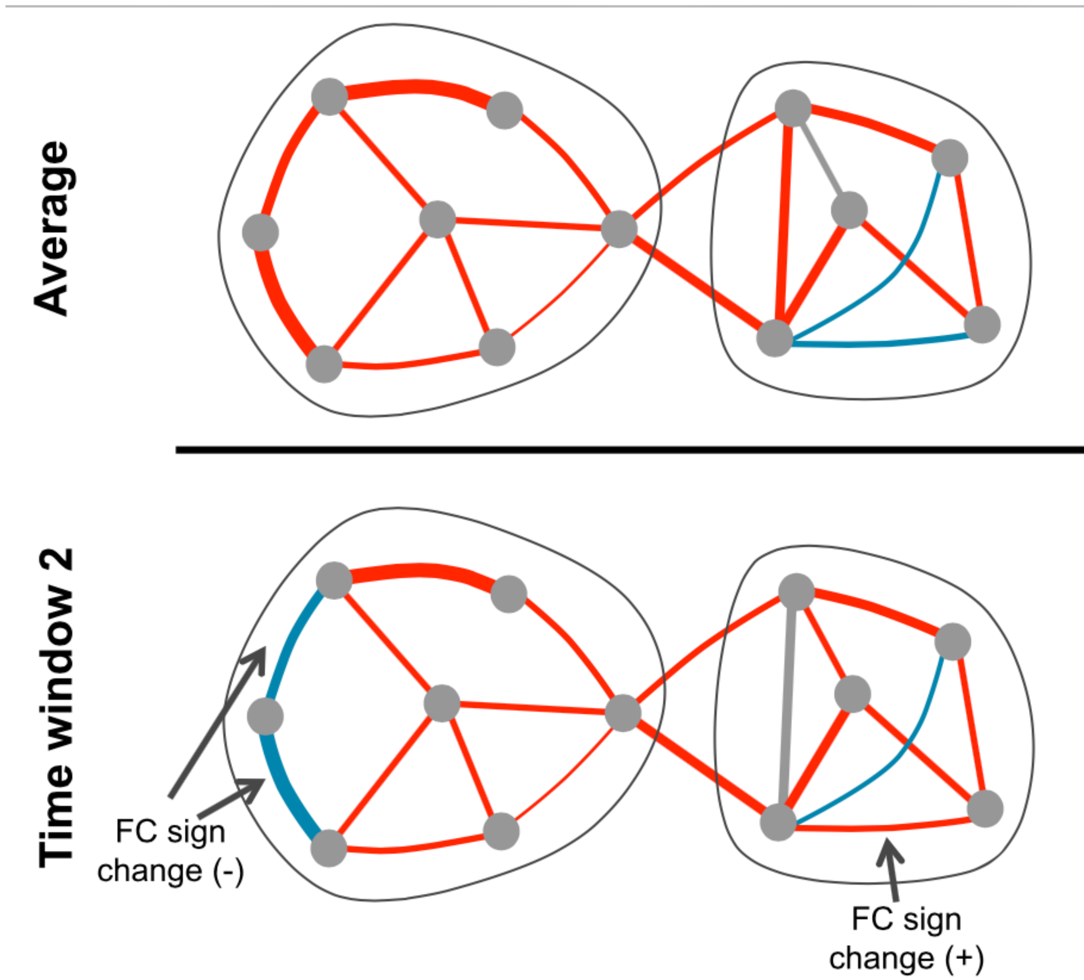
(Hutchison et al. 2013)

Brain dynamics unraveled

- Within- and cross-network interactions reconfigure over time
- Birth of the *dynamic functional connectivity* (dFC) field



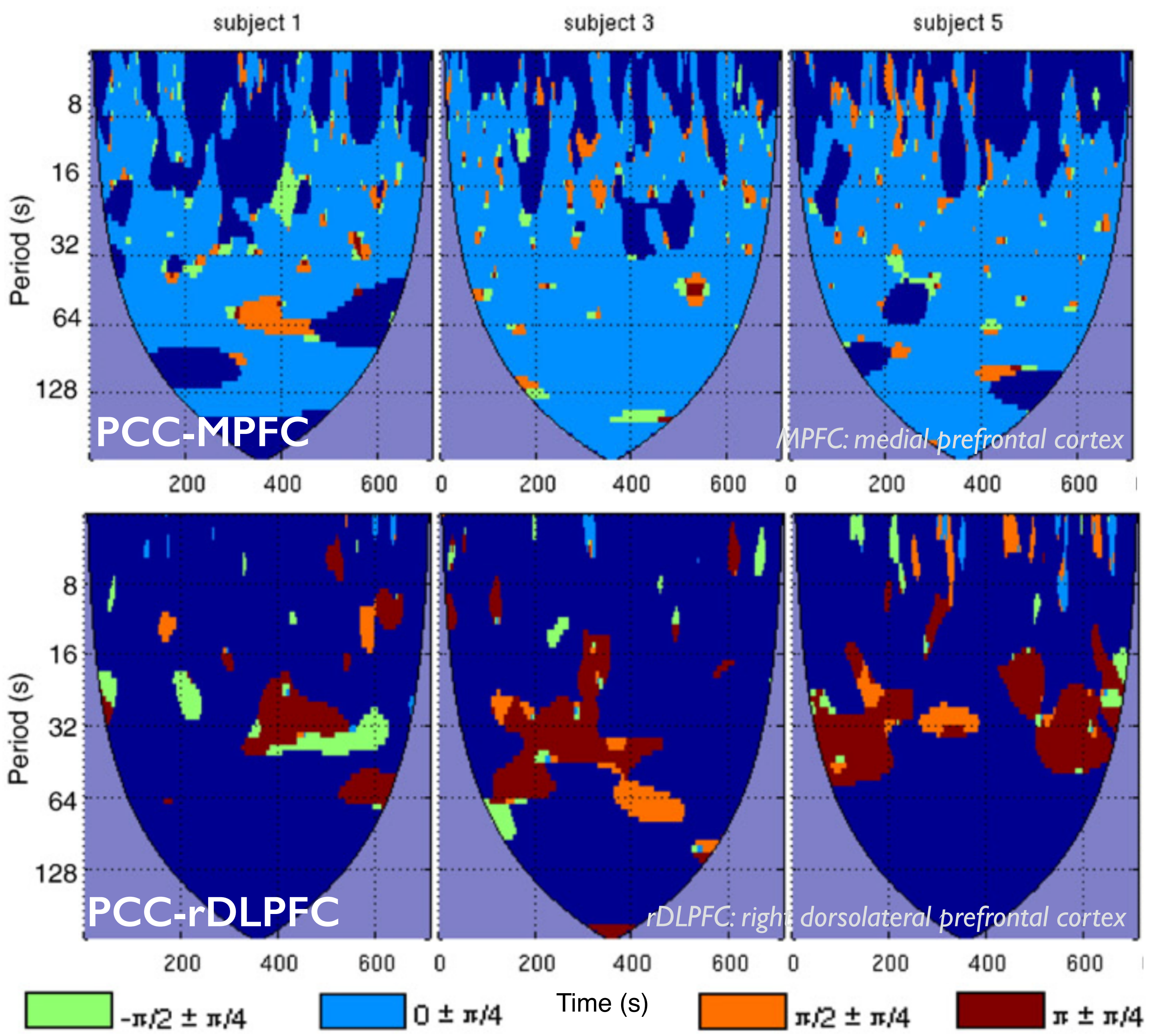
(Chang and Glover, 2010)



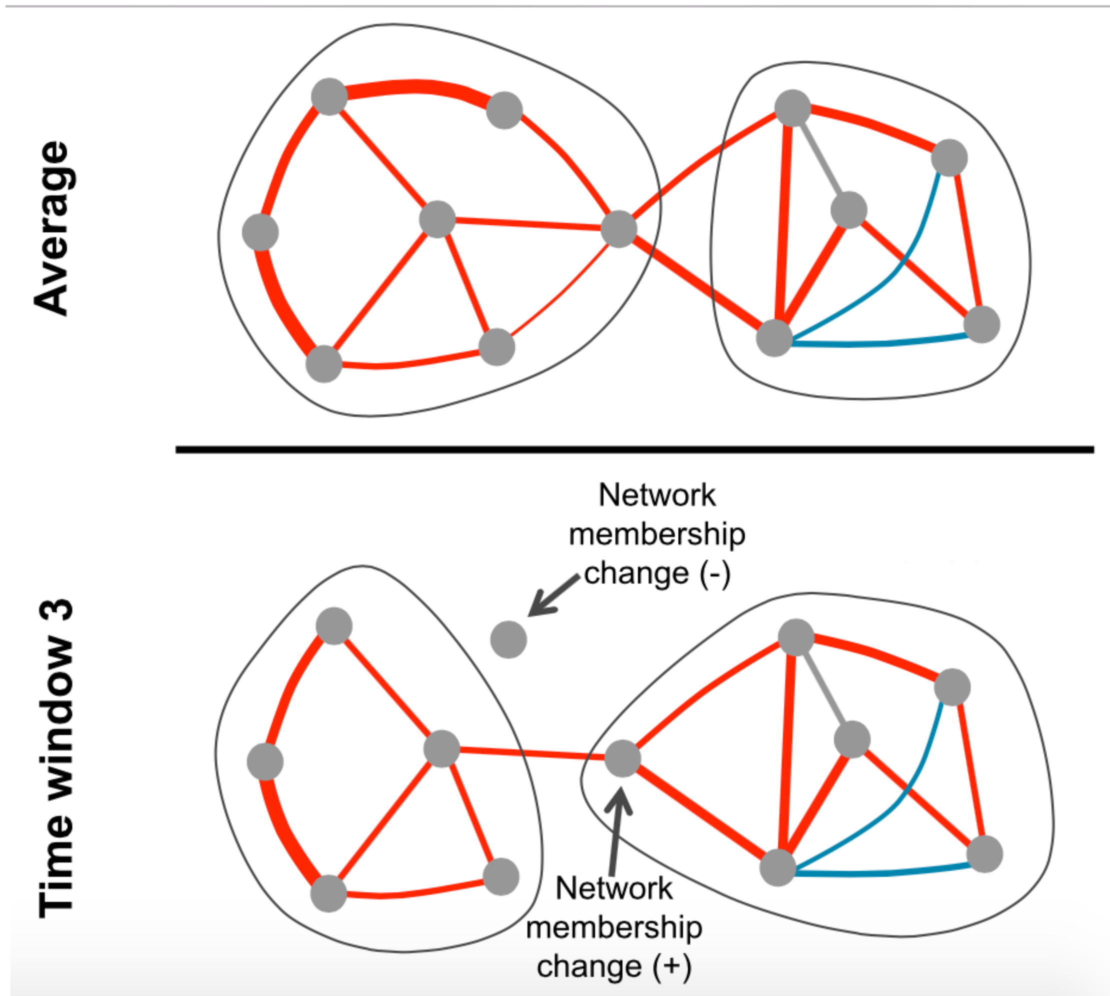
(Hutchison et al. 2013)

Brain dynamics unraveled

- Within- and cross-network interactions reconfigure over time
- Birth of the *dynamic functional connectivity* (dFC) field

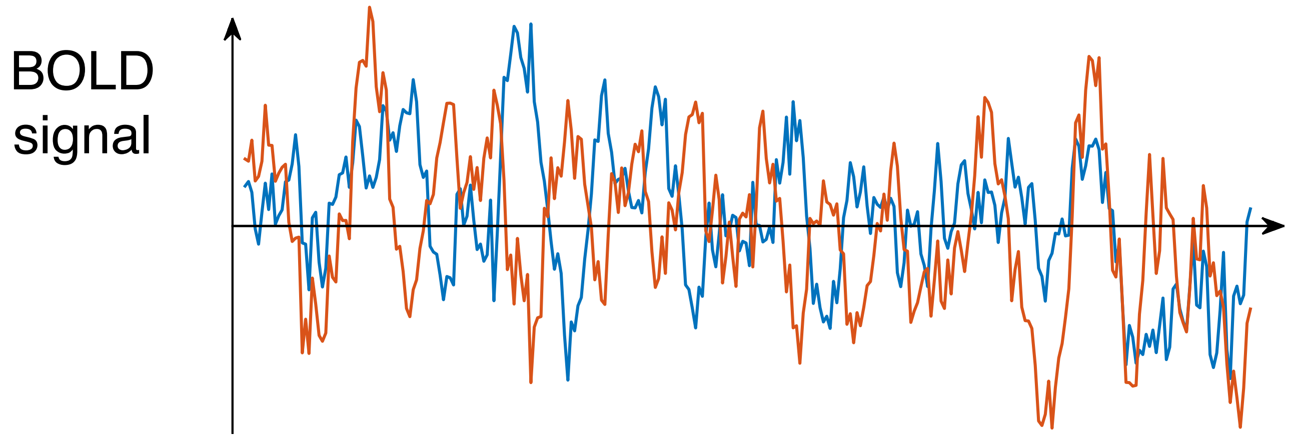


(Chang and Glover, 2010)

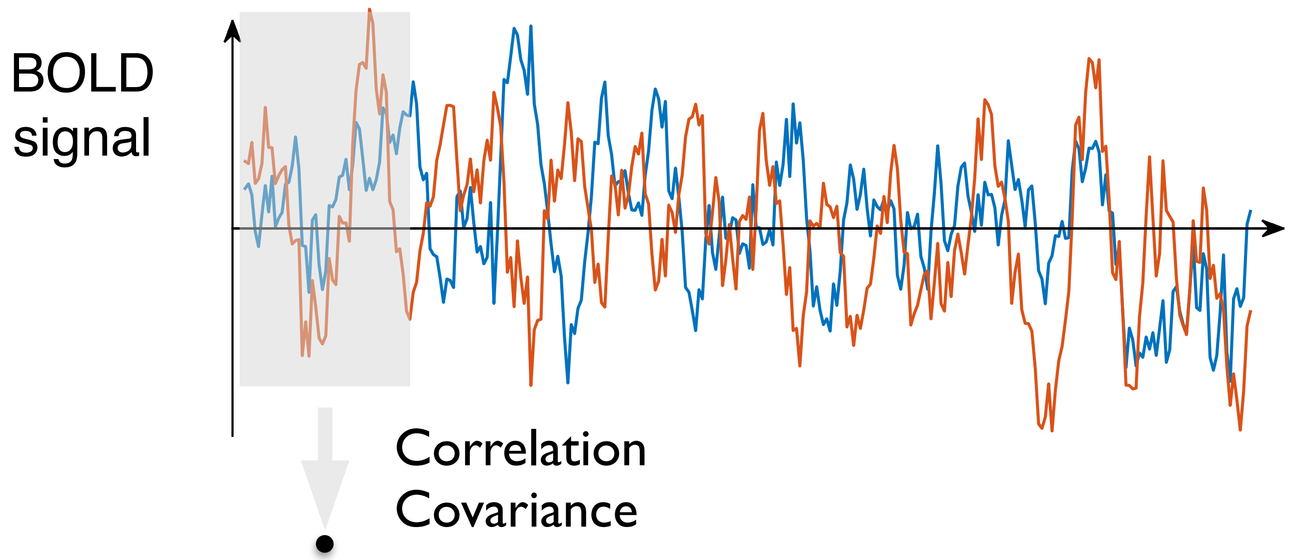


(Hutchison et al. 2013)

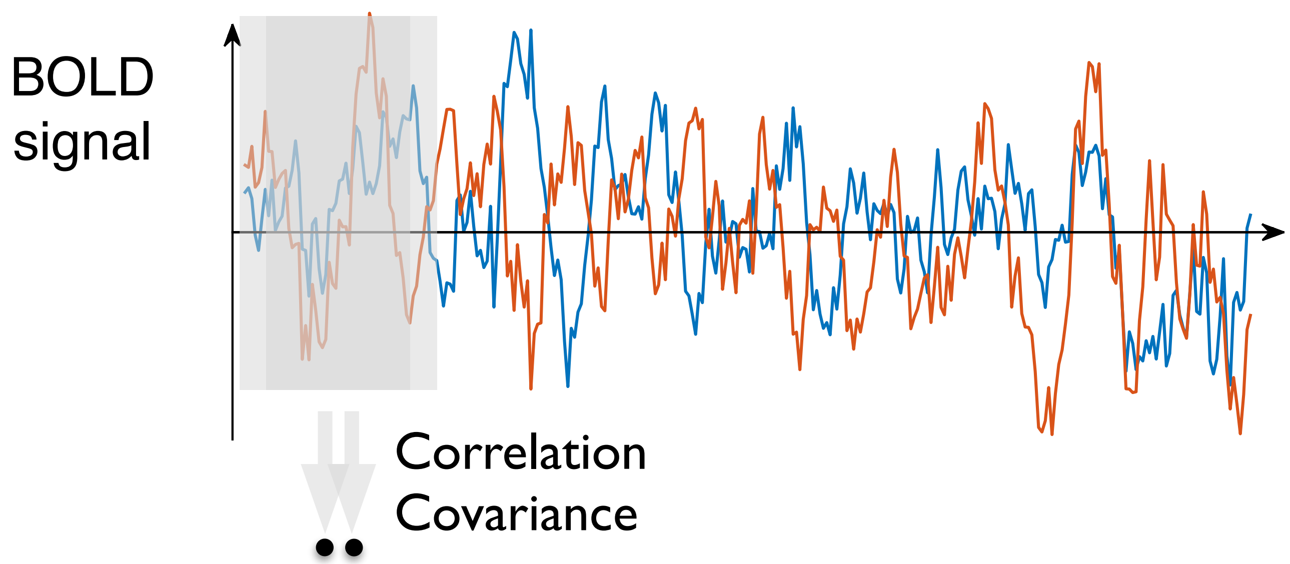
Sliding window analysis: the simplest dFC tool



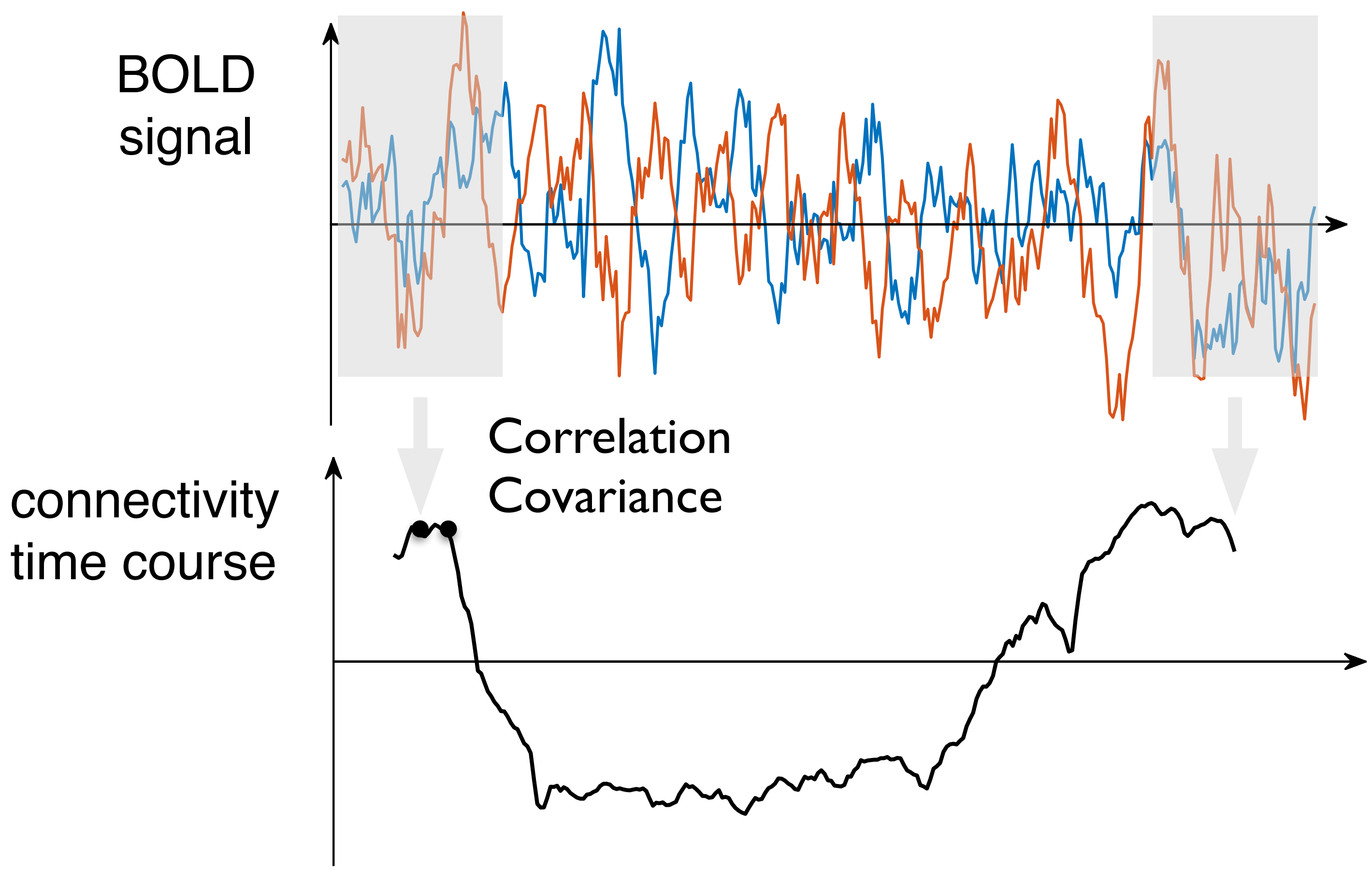
Sliding window analysis: the simplest dFC tool



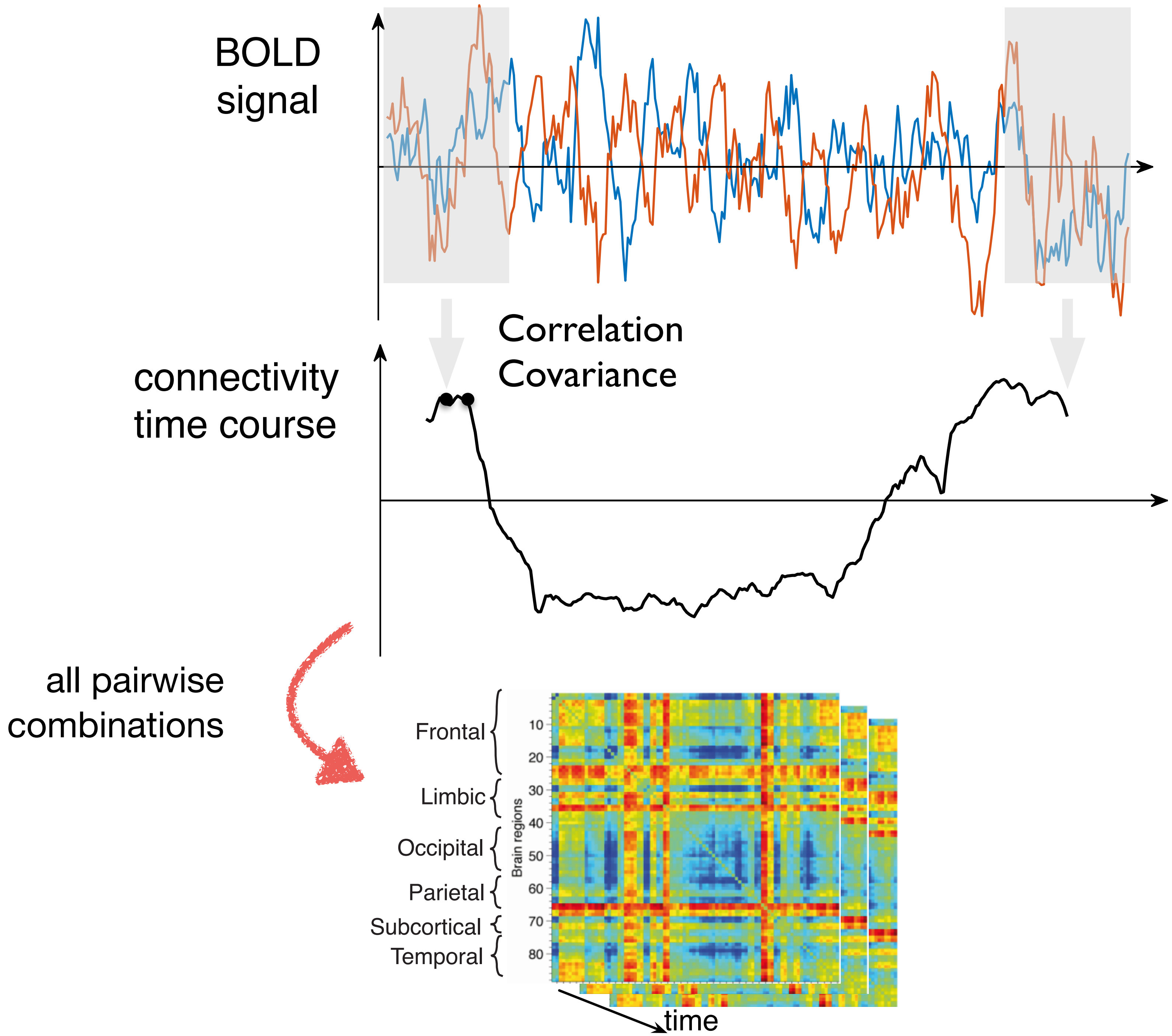
Sliding window analysis: the simplest dFC tool



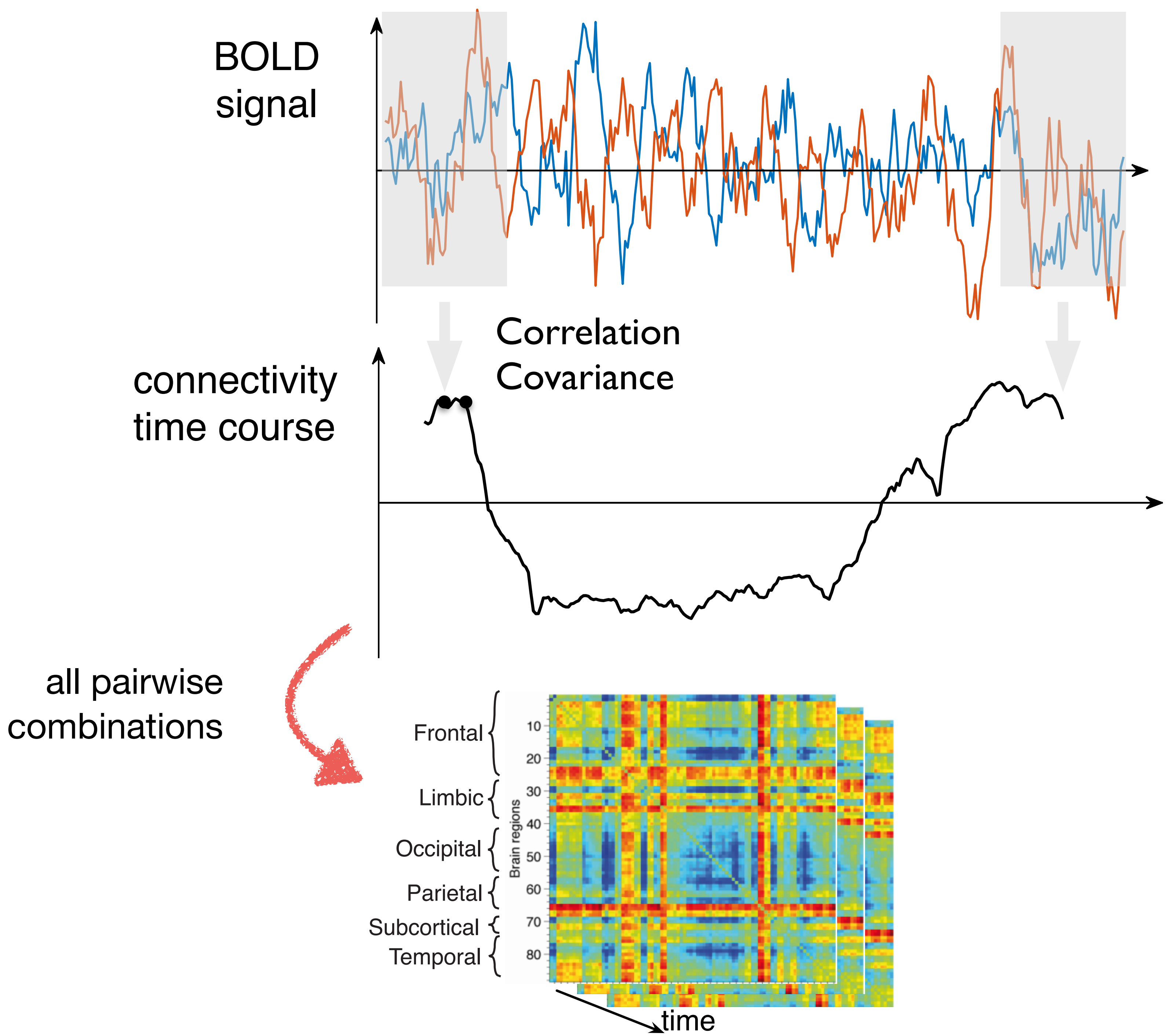
Sliding window analysis: the simplest dFC tool

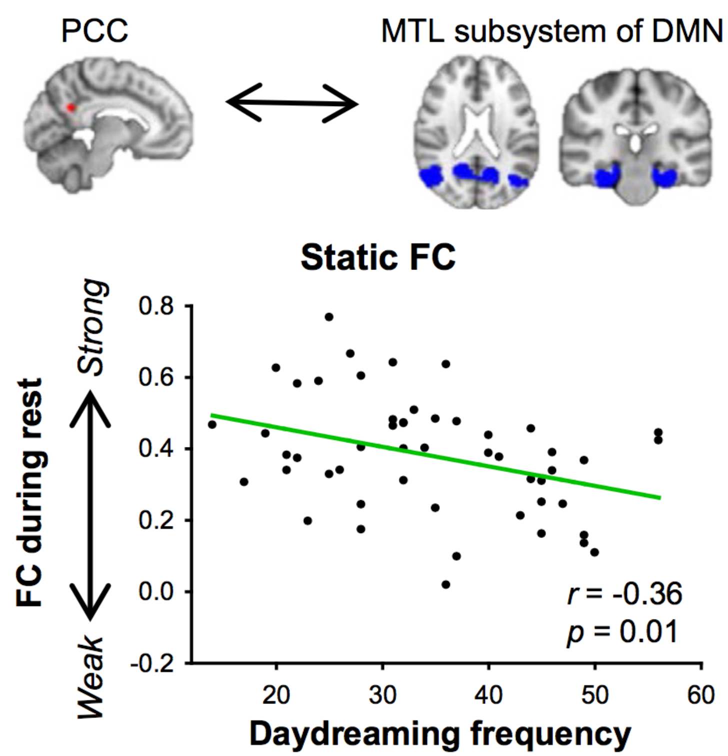


Sliding window analysis: the simplest dFC tool



Sliding window analysis: the simplest dFC tool

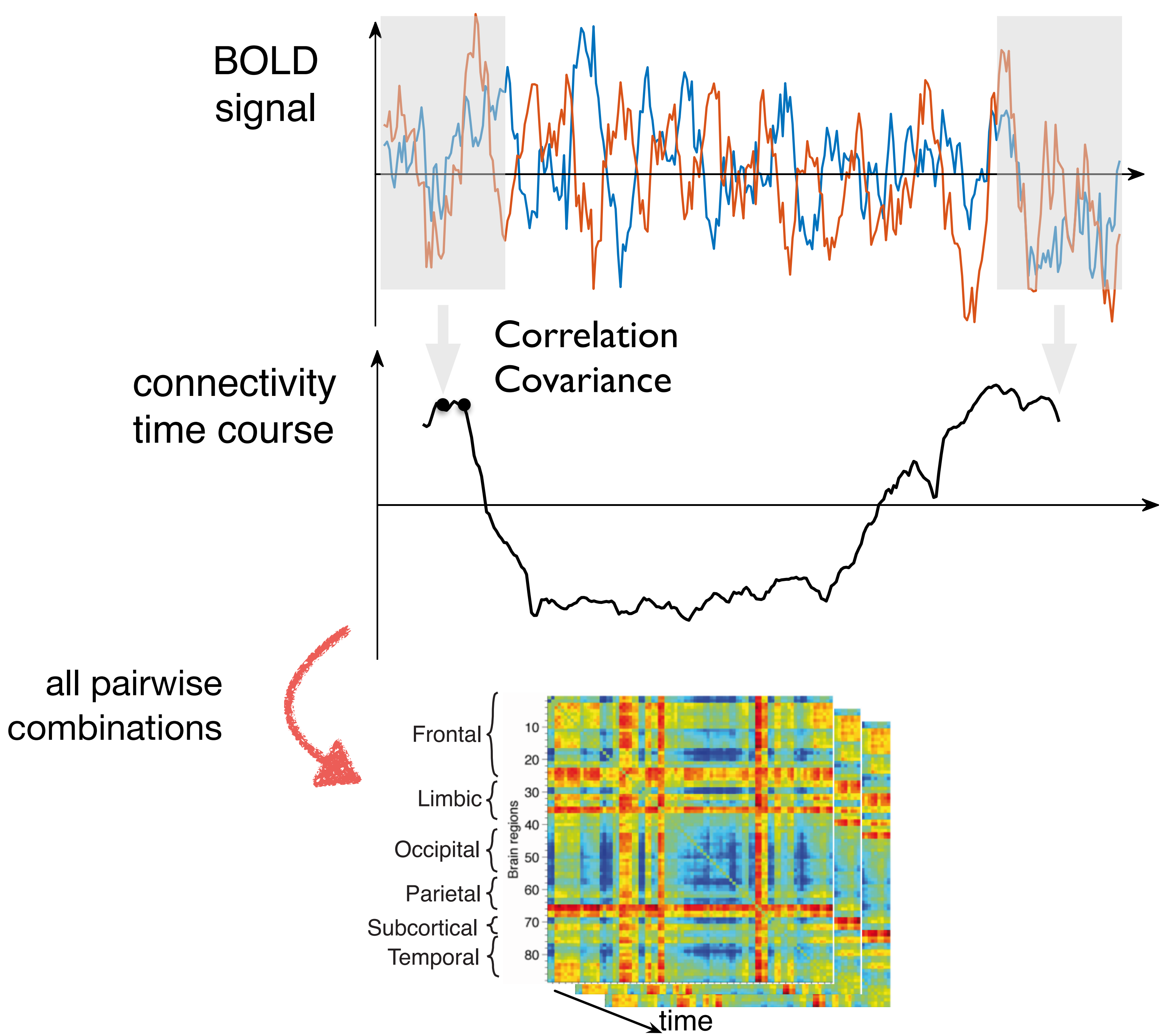


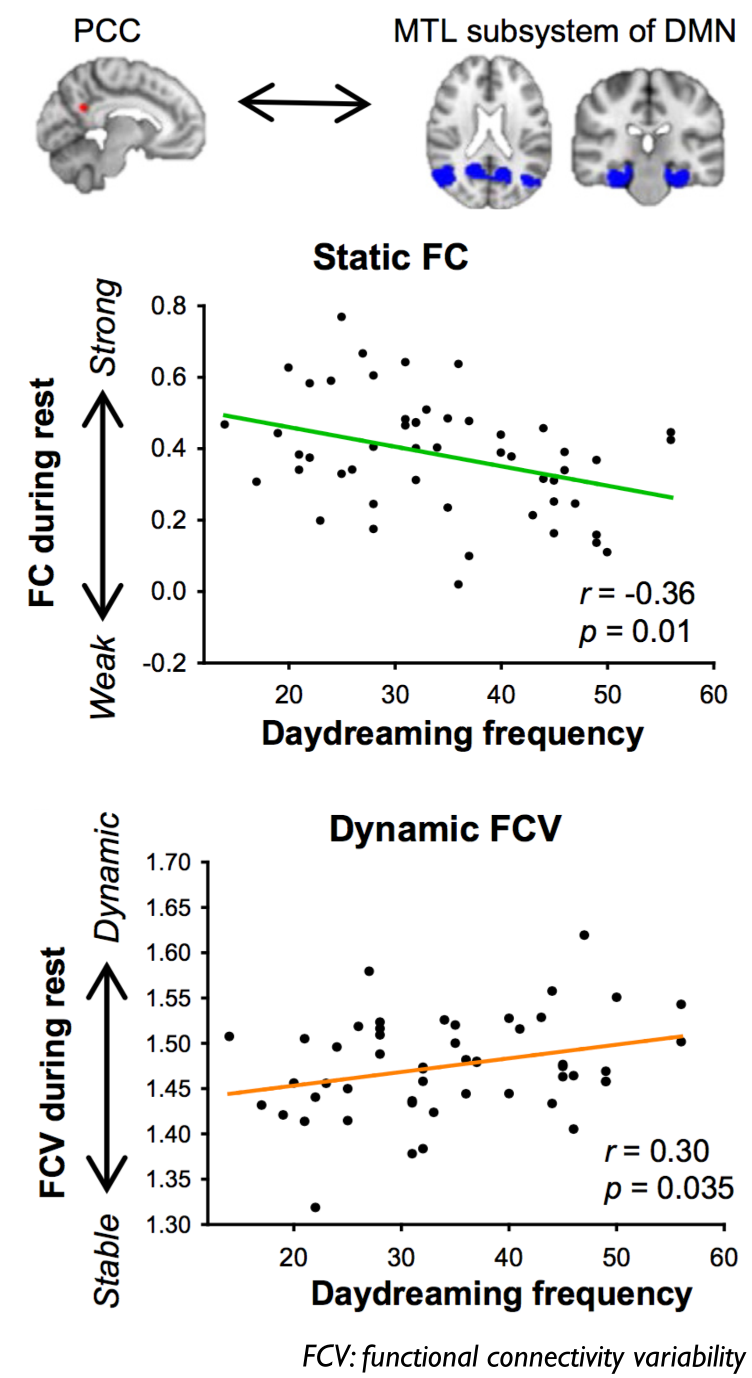


(Kucyi et al. 2014)

Sliding window analysis: the simplest dFC tool

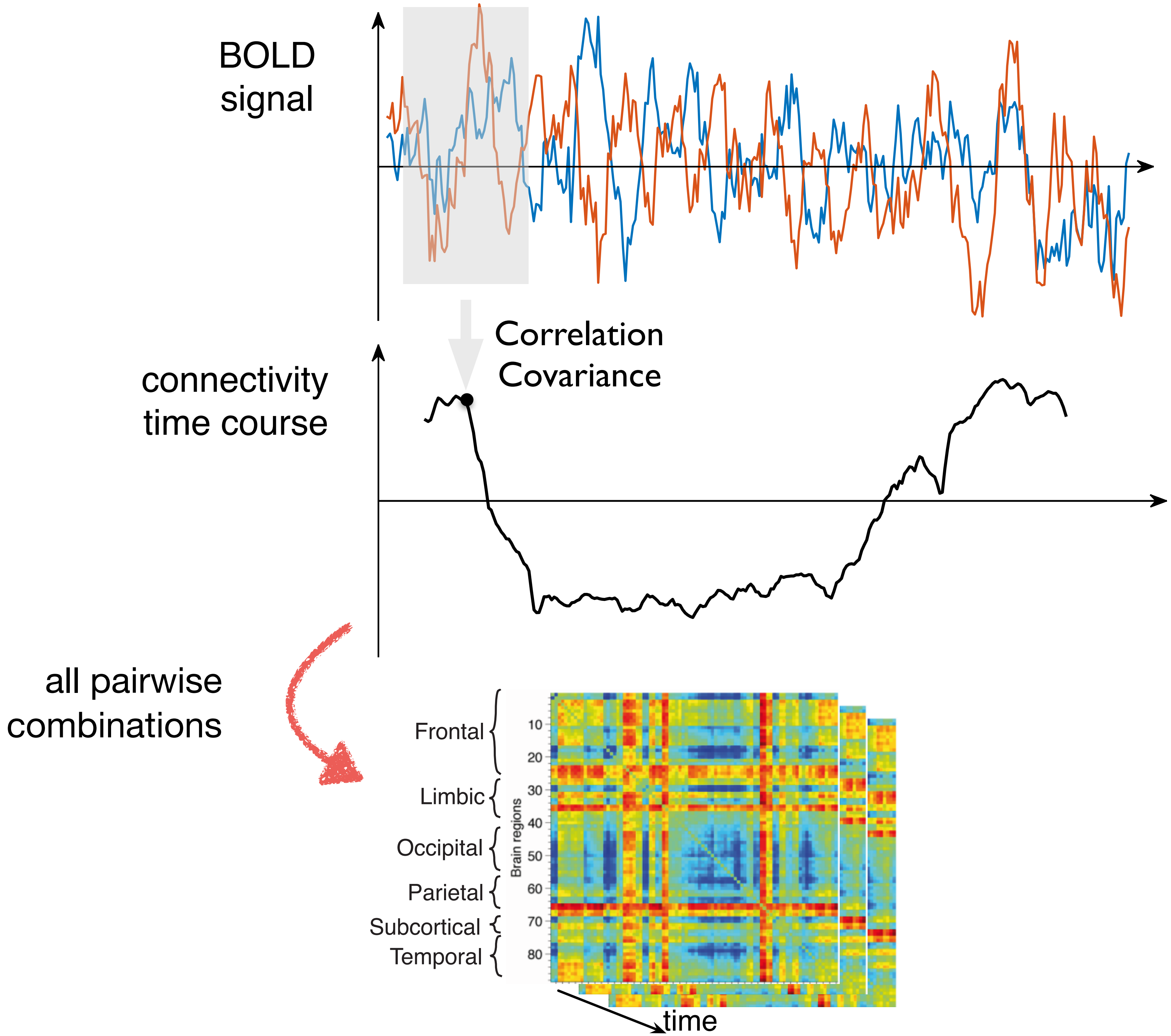
- More daydreaming = increased FC fluctuations between posterior cingulate cortex and other default mode network regions





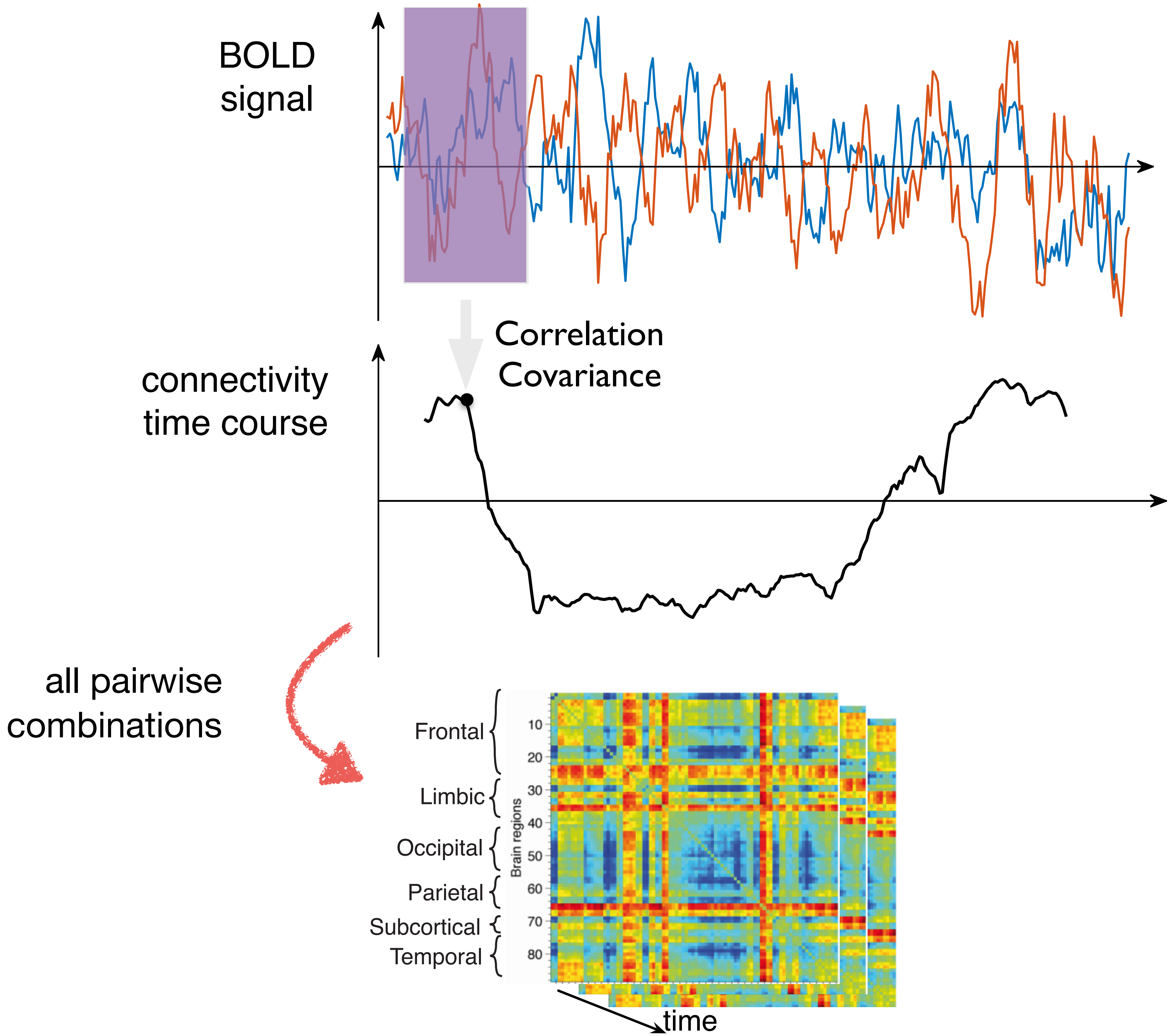
(Kucyi et al. 2014)

Sliding window analysis: the simplest dFC tool



Sliding window analysis: the simplest dFC tool

overcoming window limitations

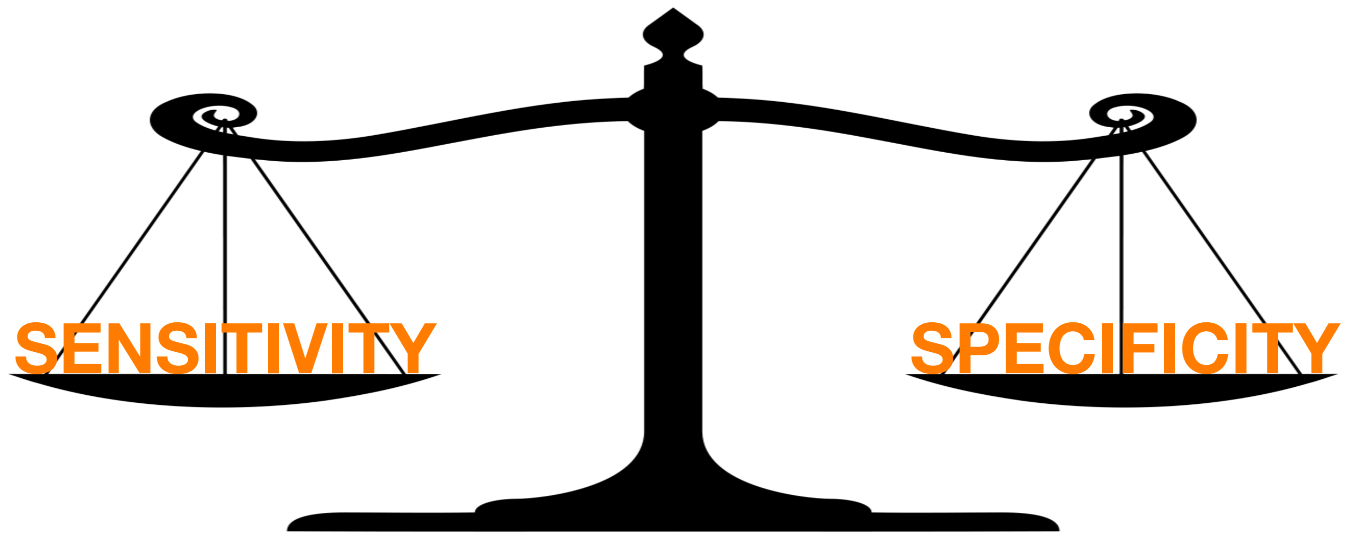


Overcoming window limitations

- Optimal window length (W) and window step (S)

Overcoming window limitations

- Optimal window length (W) and window step (S)
  - W short enough not to miss real dFC fluctuations
  - W long enough to detect only real dFC fluctuations

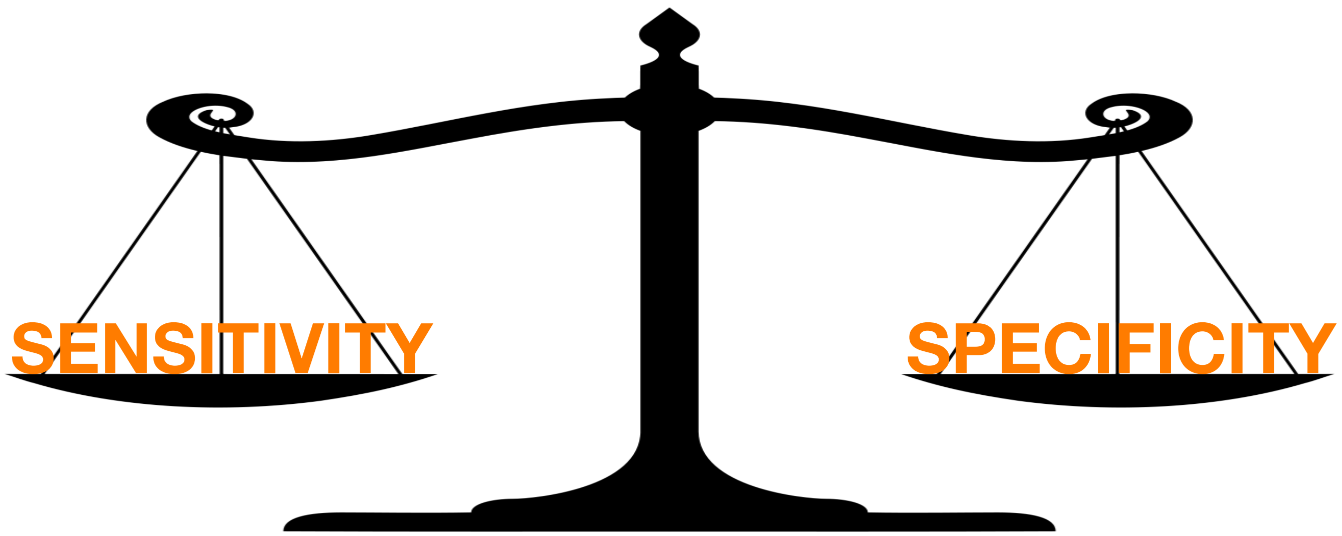


Overcoming window limitations

- Optimal window length (W) and window step (S)
  - W short enough not to miss real dFC fluctuations
  - W long enough to detect only real dFC fluctuations

$$\mathbf{W} > \frac{\mathbf{1}}{\mathbf{f_{min}}}$$

(Leonardi and Van De Ville 2015)

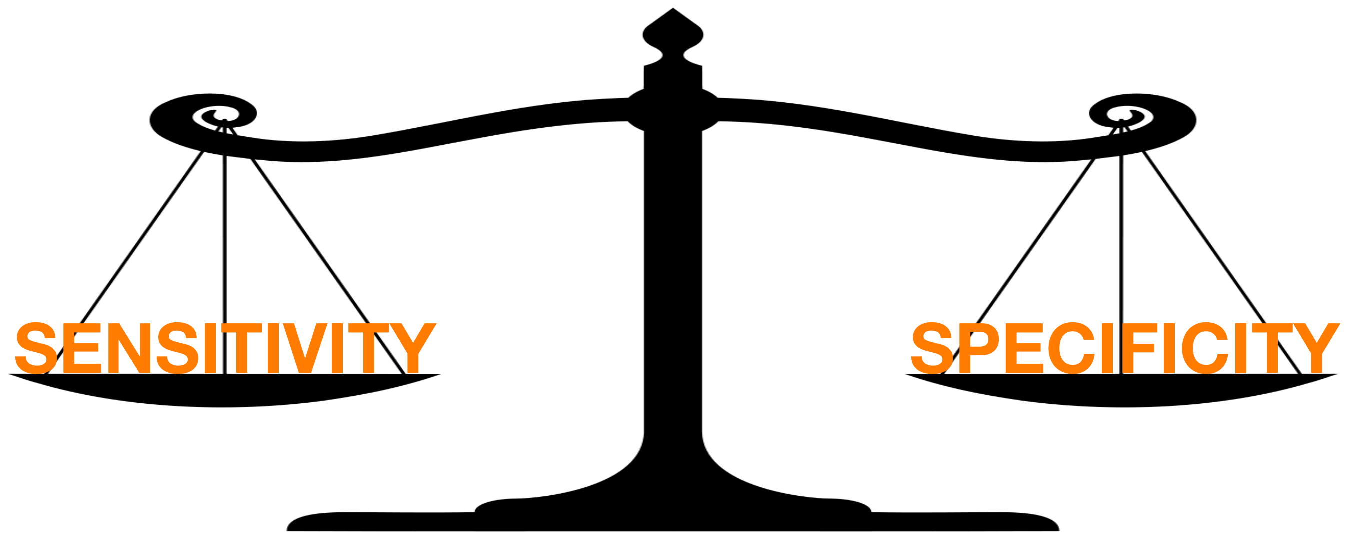


Overcoming window limitations

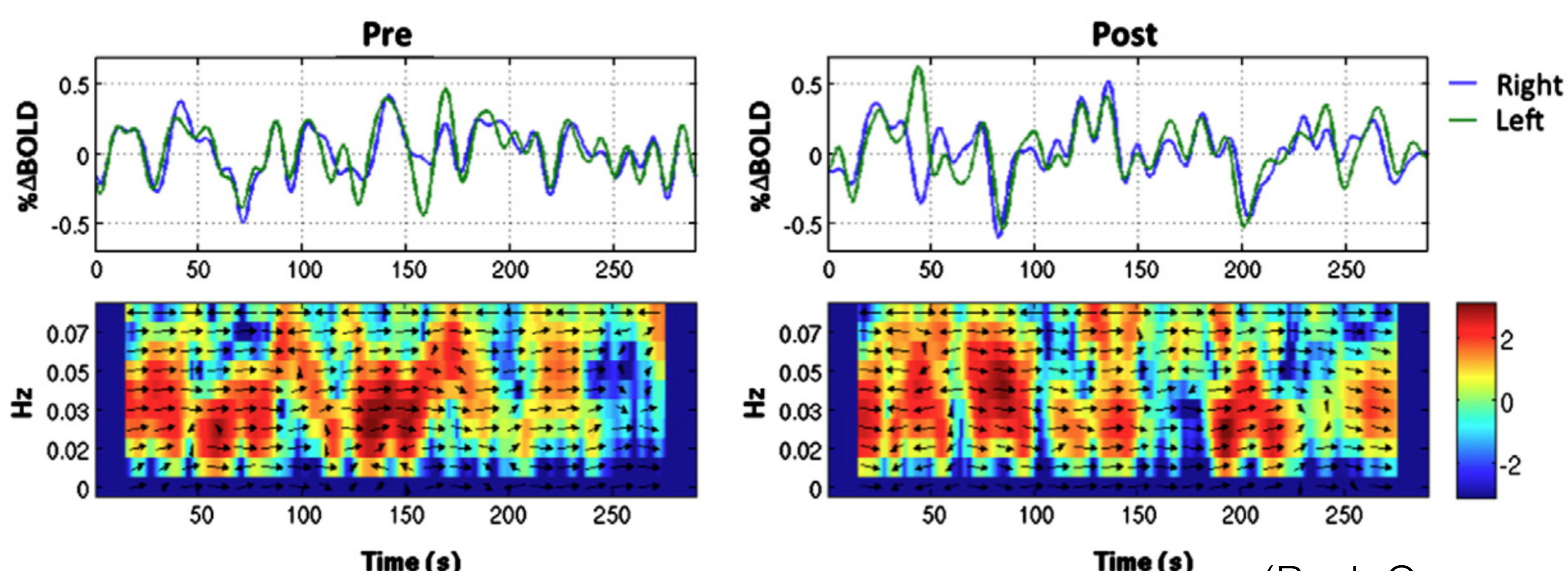
- Optimal window length (W) and window step (S)
  - W short enough not to miss real dFC fluctuations
  - W long enough to detect only real dFC fluctuations

$$W > \frac{1}{f_{min}}$$

(Leonardi and Van De Ville 2015)



- Going for more than one window type with a time-frequency analysis



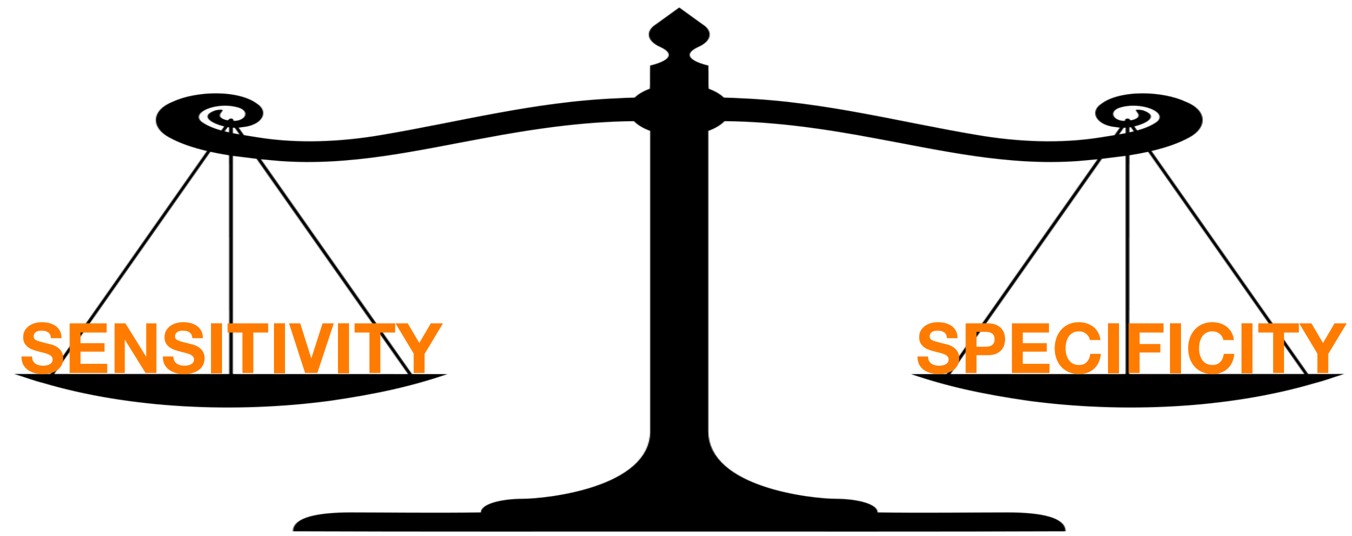
(Rack-Gomer and Liu 2012)

Overcoming window limitations

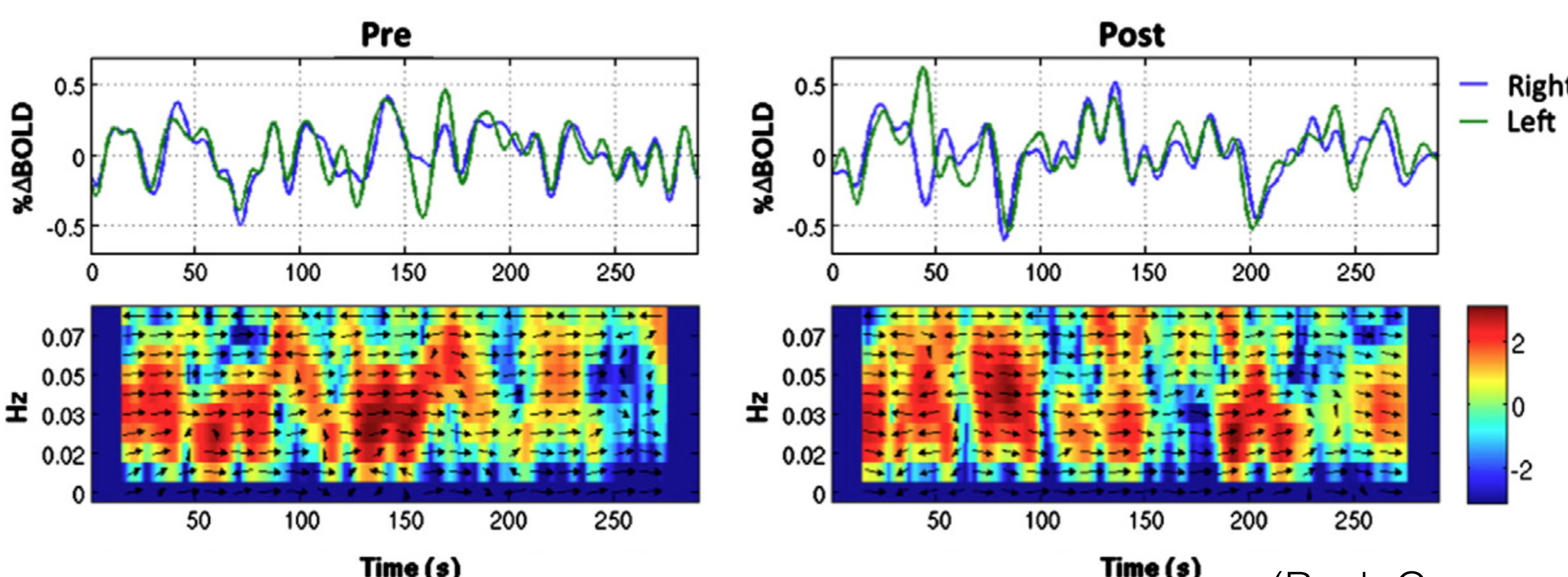
- Optimal window length (W) and window step (S)
  - W short enough not to miss real dFC fluctuations
  - W long enough to detect only real dFC fluctuations

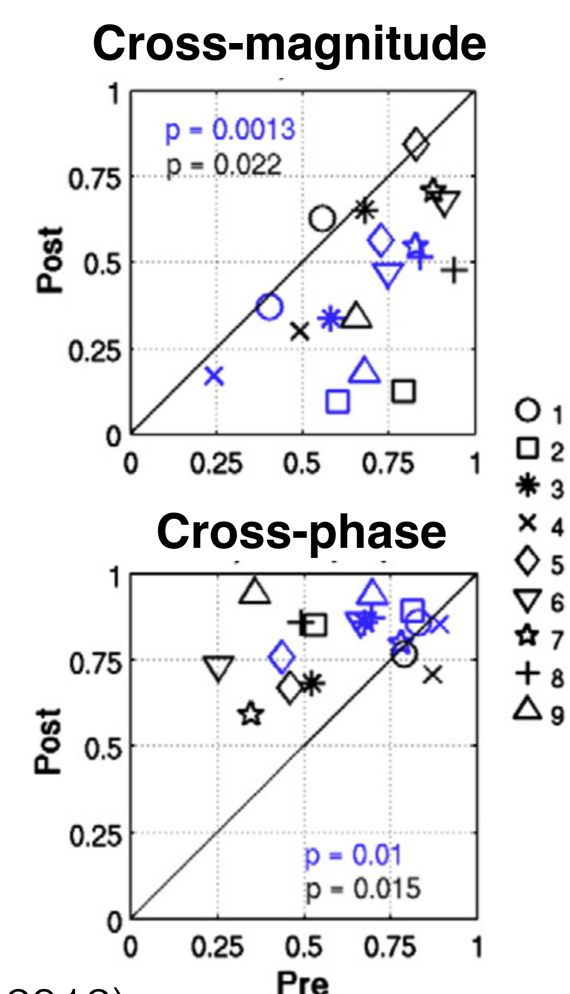
$$W > \frac{1}{f_{min}}$$

(Leonardi and Van De Ville 2015)



- Going for more than one window type with a time-frequency analysis
  - Two facets: cross-magnitude *vs* cross-phase





(Rack-Gomer and Liu 2012)

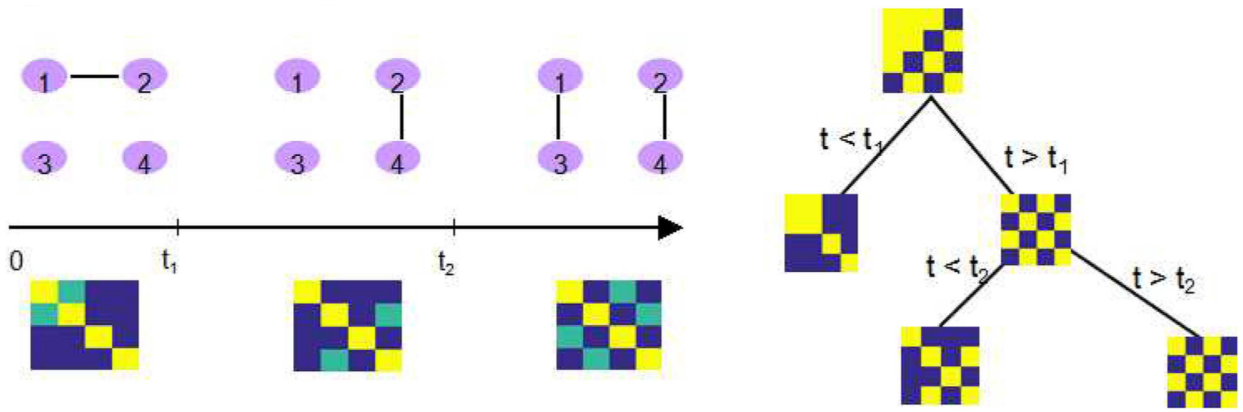
Overcoming window limitations

- Playing with the window shape

Overcoming window limitations

- Playing with the window shape

- Data-driven window definition
  - Detect significant connectivity change points: dynamic connectivity detection (DCD)

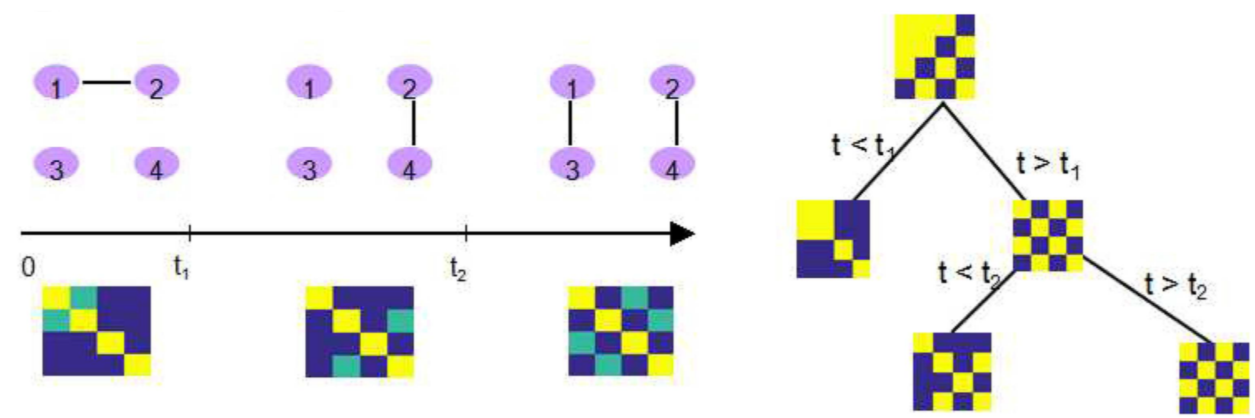


(Xu and Lindquist 2015)

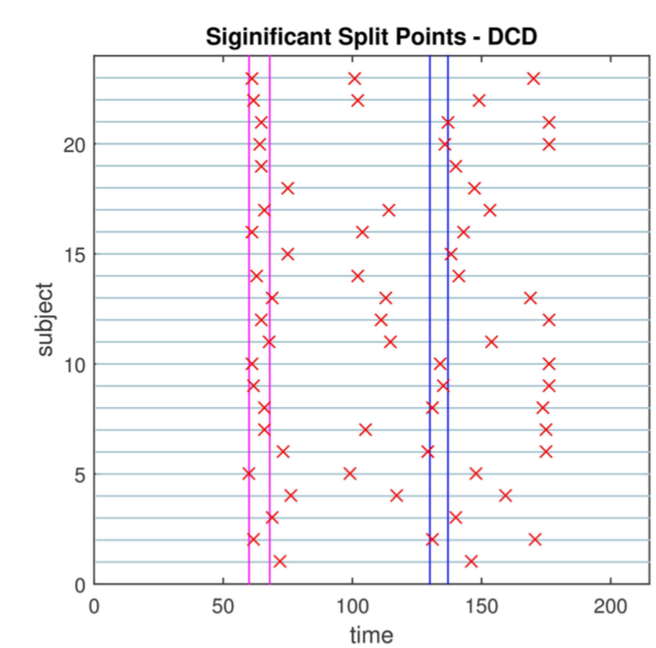
Overcoming window limitations

- Playing with the window shape

- Data-driven window definition
  - Detect significant connectivity change points: dynamic connectivity detection (DCD)



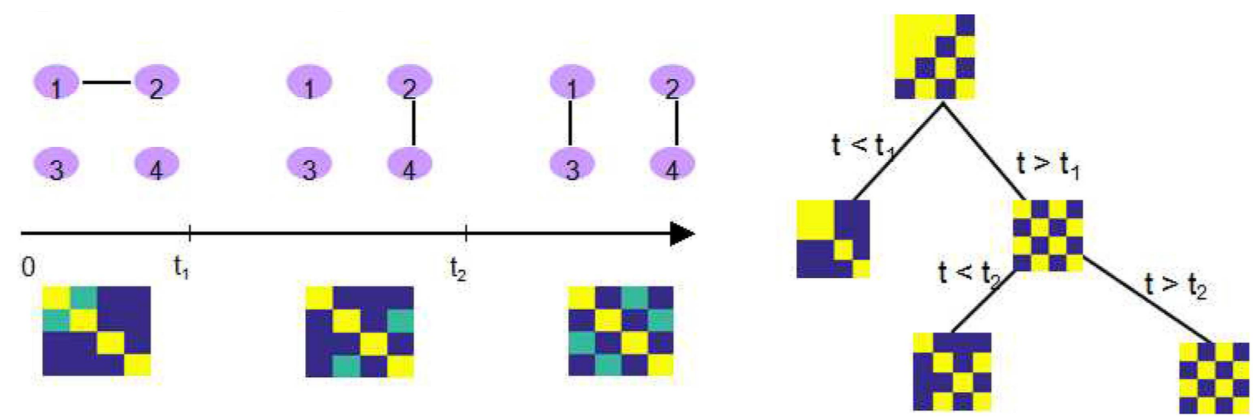
(Xu and Lindquist 2015)



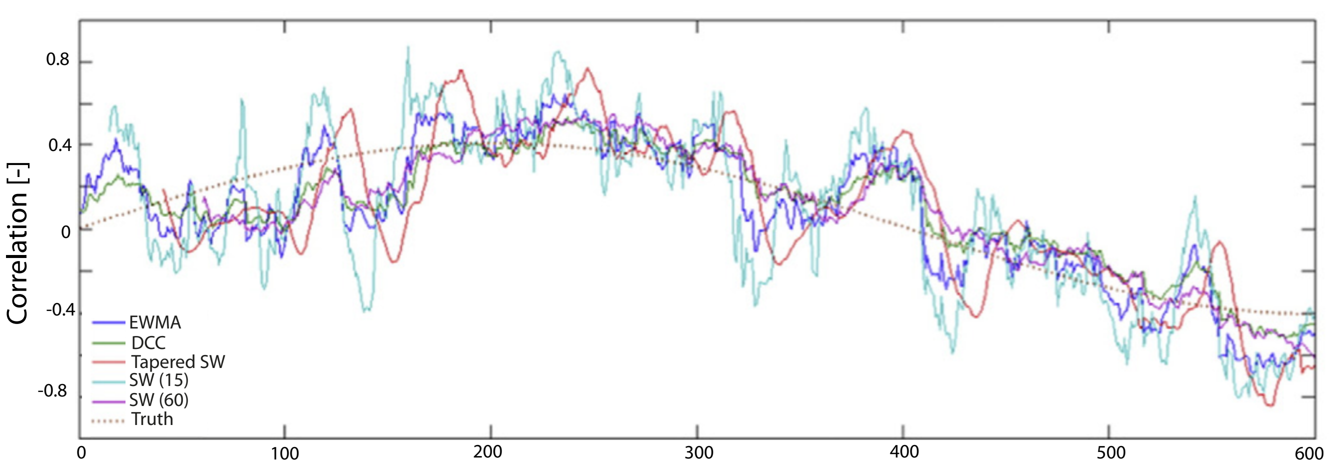
Overcoming window limitations

- Playing with the window shape

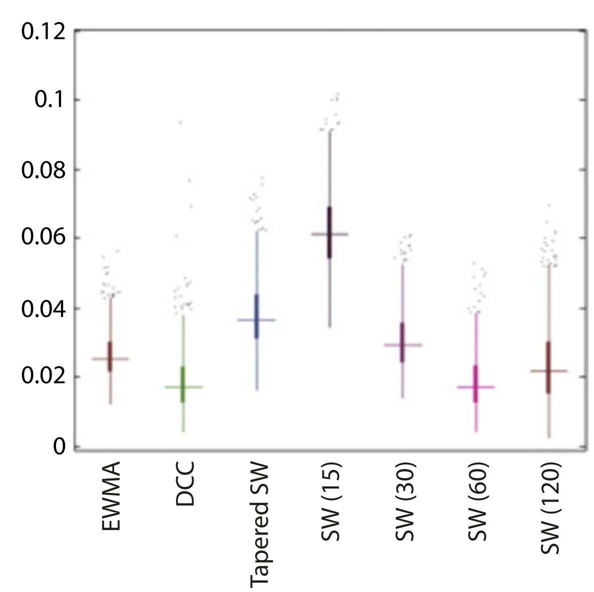
- Data-driven window definition
  - Detect significant connectivity change points: dynamic connectivity detection (DCD)
  - Gradually refine pre-built connectivity estimate: dynamic conditional correlation (DCC)

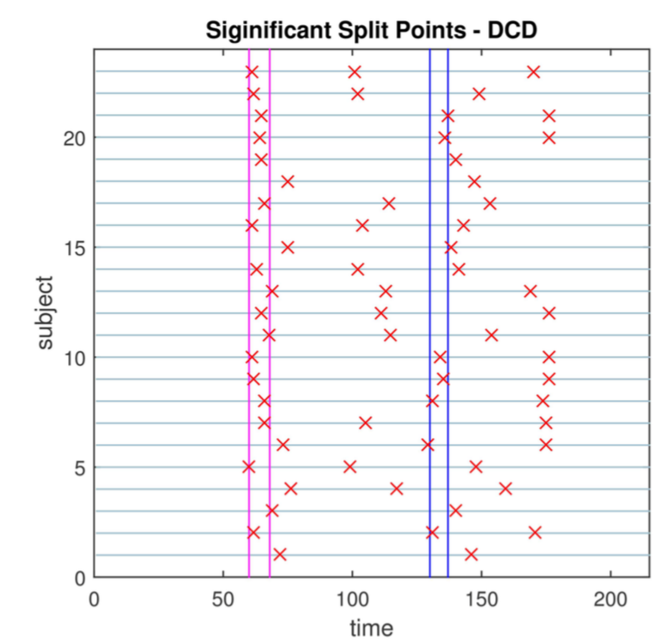


(Xu and Lindquist 2015)



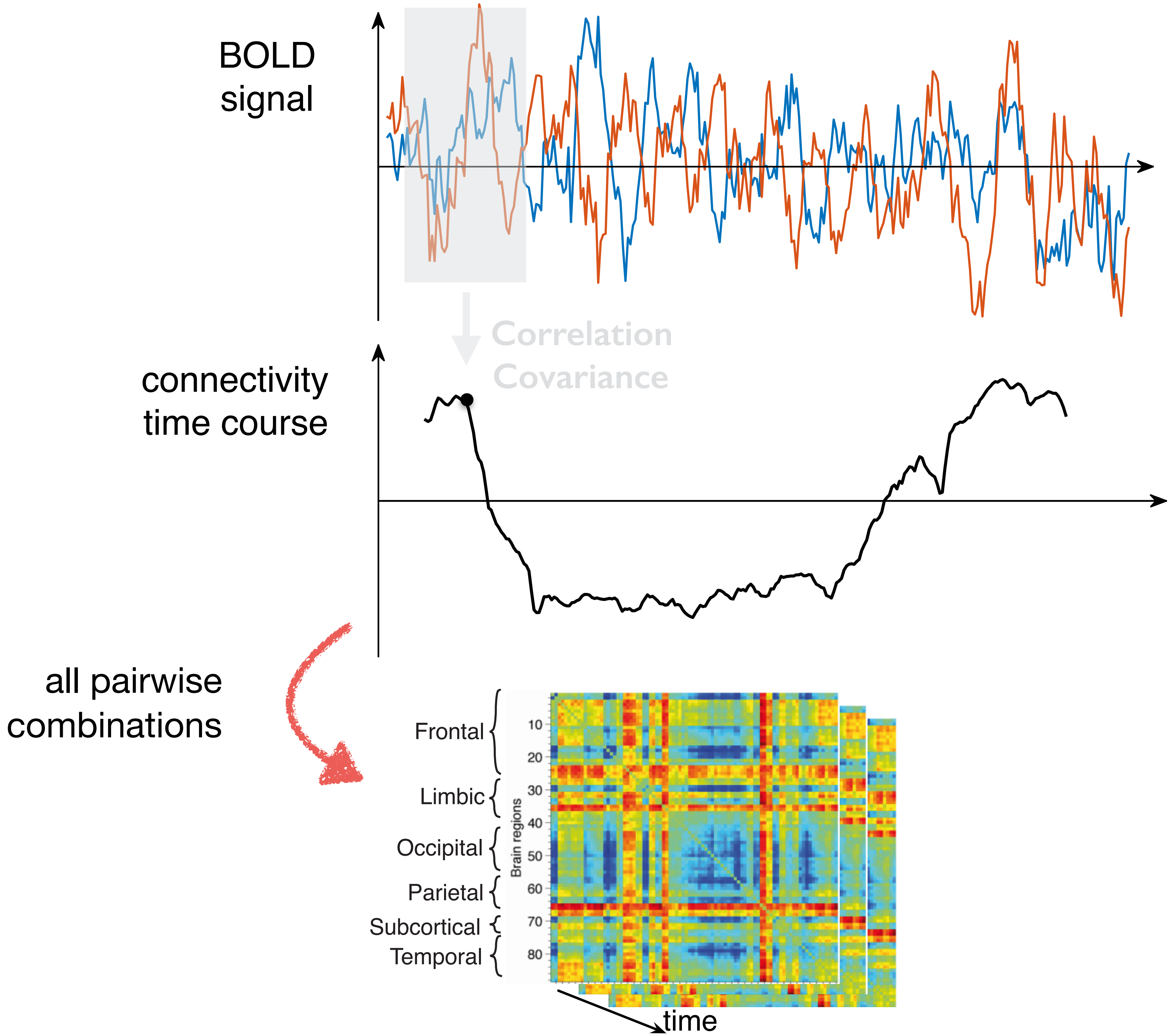
SW: sliding window
EWMA: exponentially weighted moving average



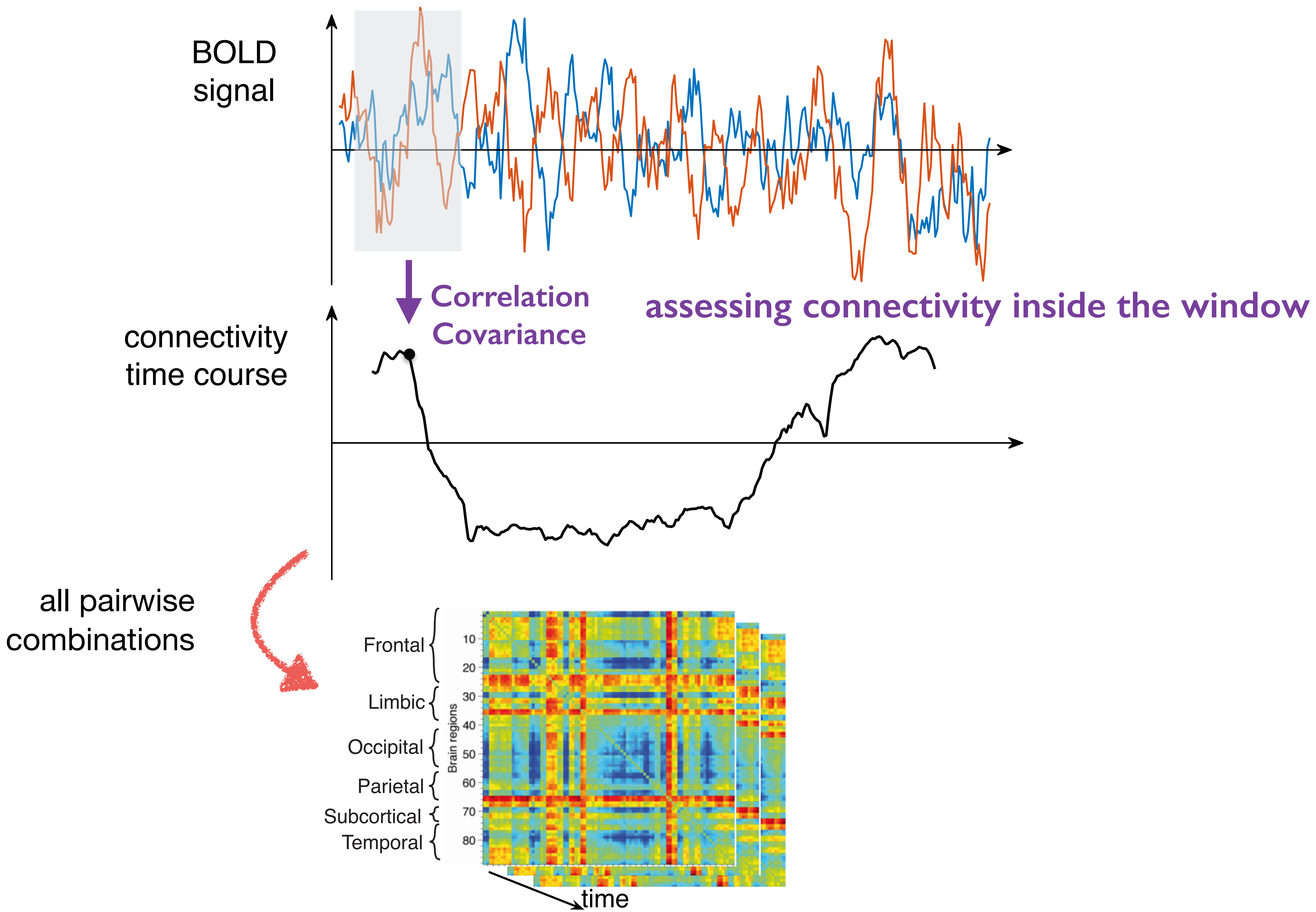


(Lindquist et al. 2014)

Sliding window analysis: the simplest dFC tool

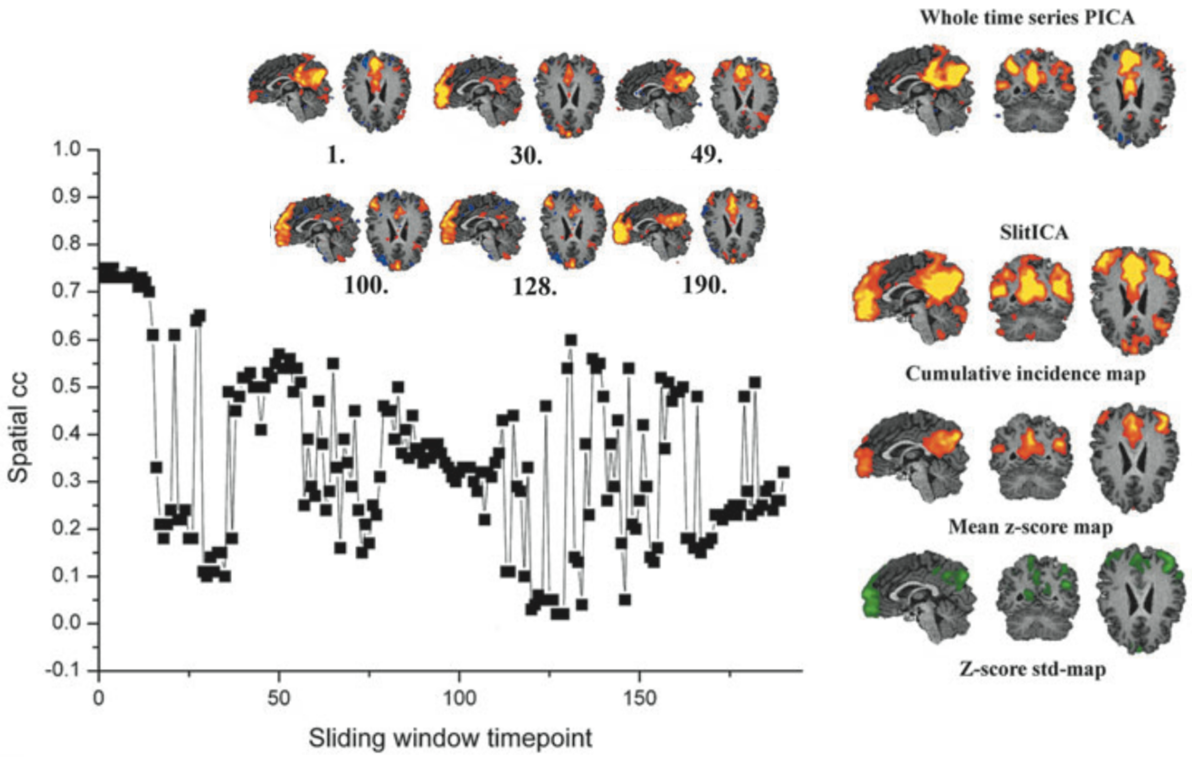


Sliding window analysis: the simplest dFC tool



Assessing connectivity inside the window

- Using more elaborate measures to assess connectivity
  - *Sliding time-window ICA* (SlitICA): spatial independence across components

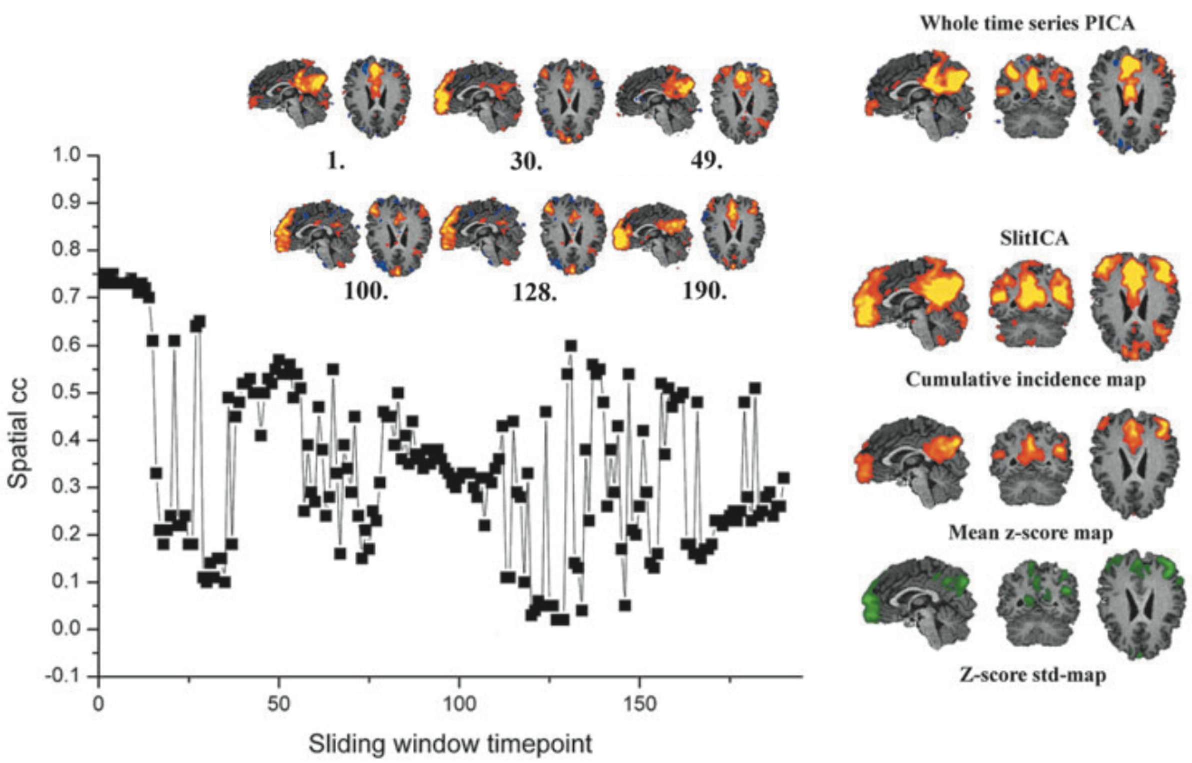


PICA: probabilistic independent component analysis

(Kiviniemi et al. 2011)

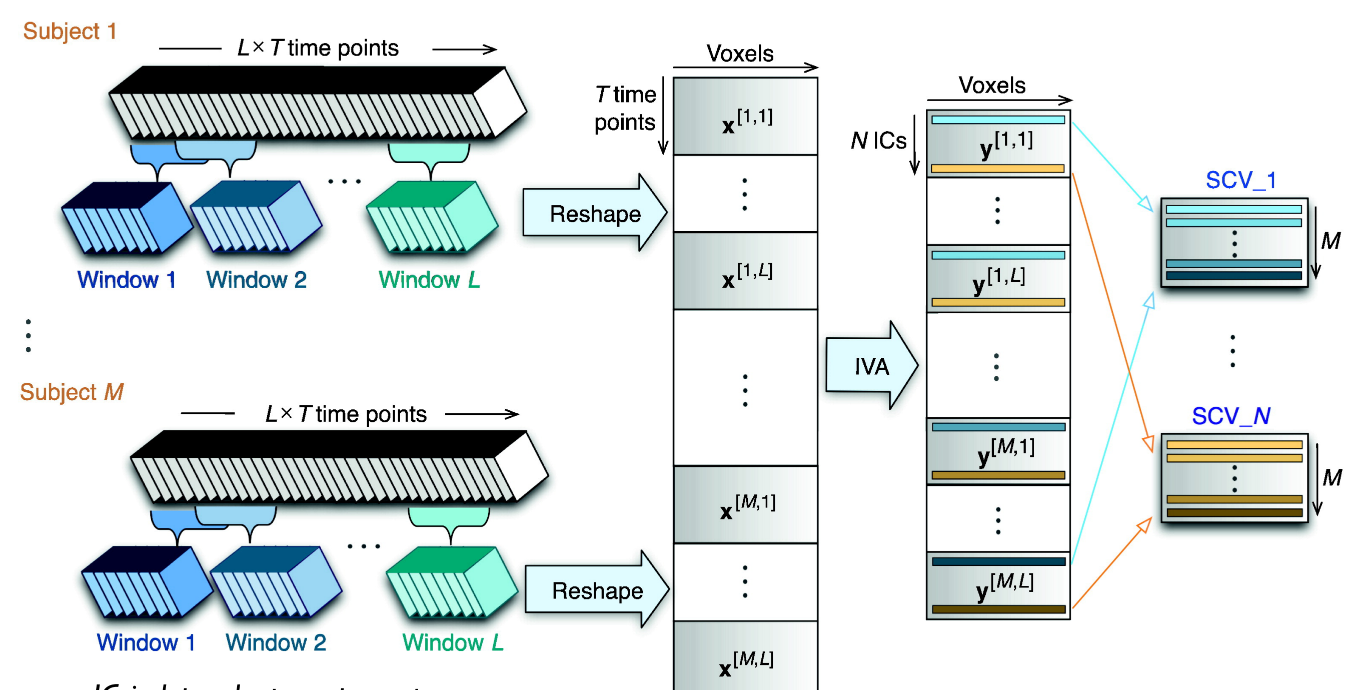
Assessing connectivity inside the window

- Using more elaborate measures to assess connectivity
  - *Sliding time-window ICA* (SlitICA): spatial independence across components
  - *Independent vector analysis* (IVA): spatial independence across components + matching between components from different windows



PICA: probabilistic independent component analysis

(Kiviniemi et al. 2011)



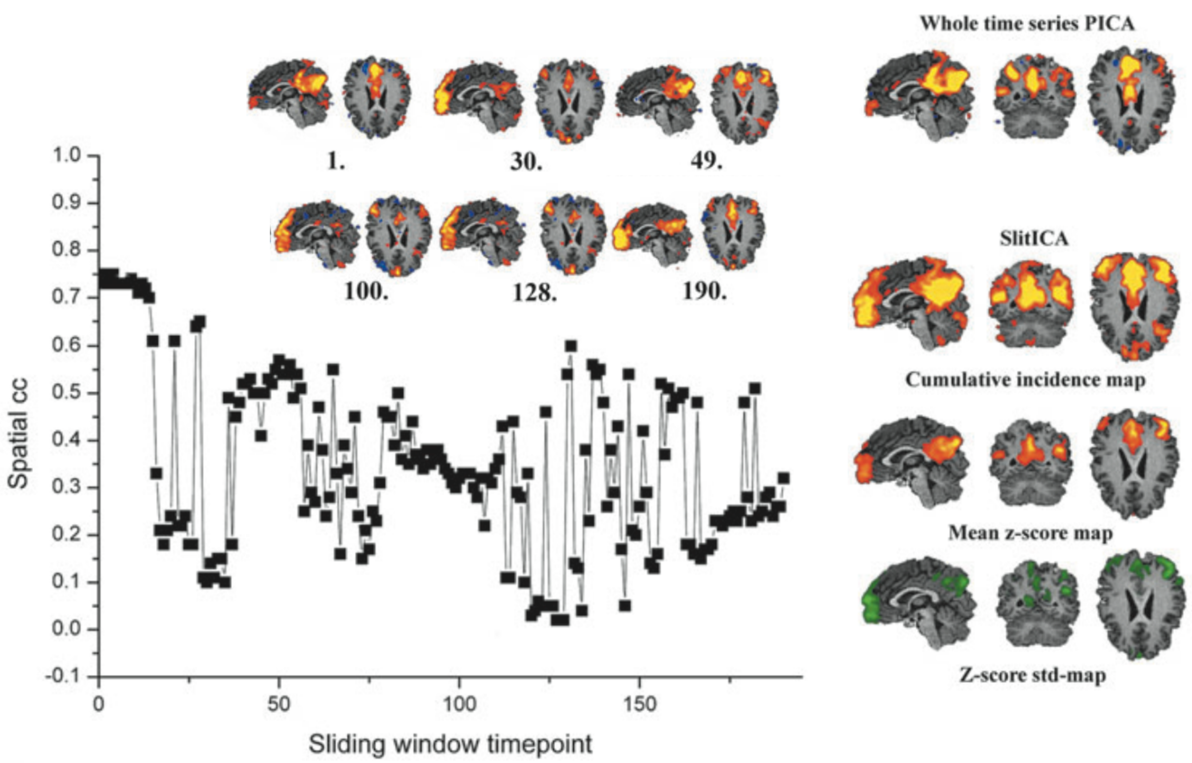
IC: independent component

SCV: source component vector

(Ma et al. 2014)

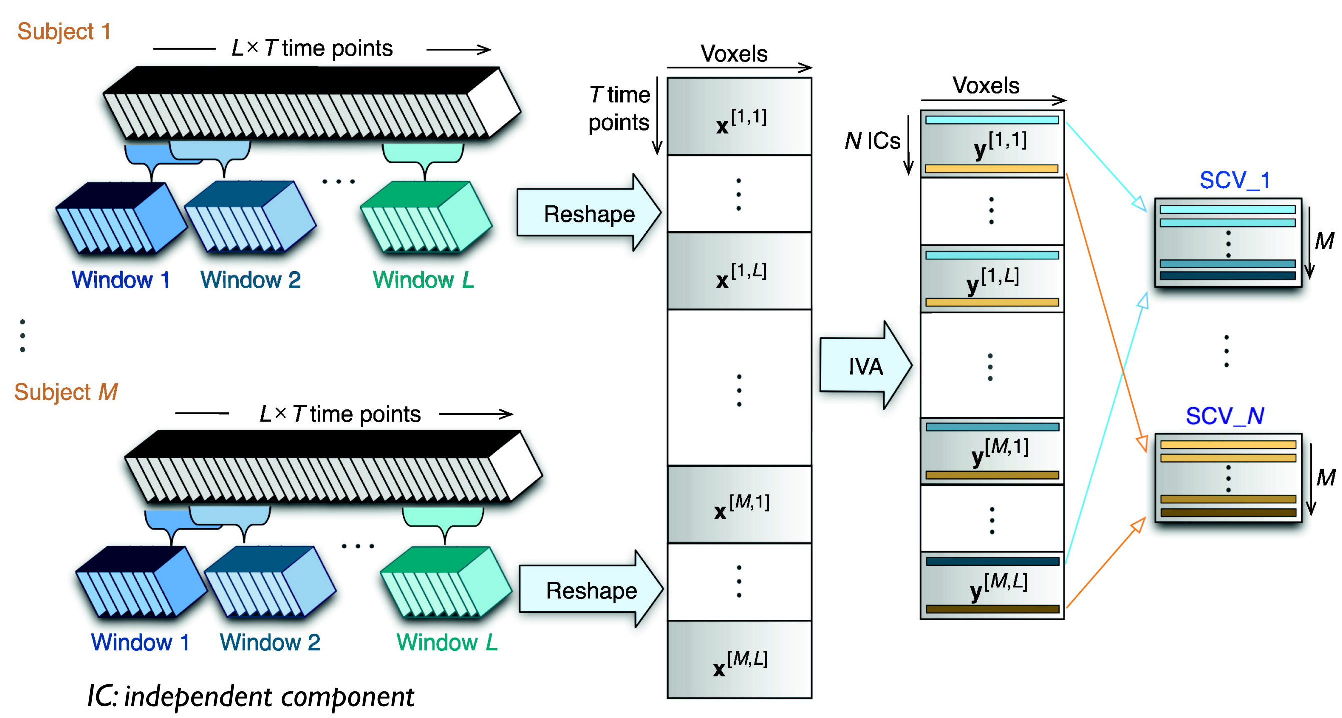
Assessing connectivity inside the window

- Using more elaborate measures to assess connectivity
  - *Sliding time-window ICA* (SlitICA): spatial independence across components
  - *Independent vector analysis* (IVA): spatial independence across components + matching between components from different windows



PICA: probabilistic independent component analysis

(Kiviniemi et al. 2011)



IC: independent component

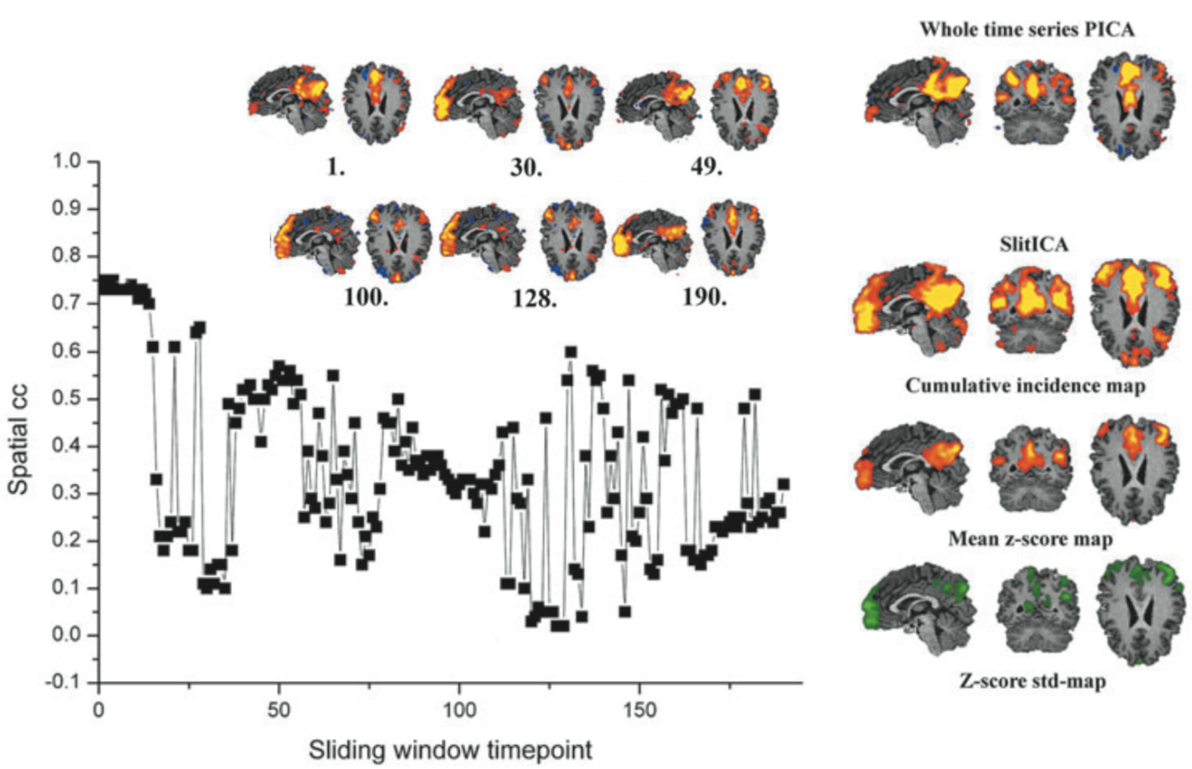
SCV: source component vector

(Ma et al. 2014)

- Casting sparsity on the set of functional connections (Friedman et al. 2008)

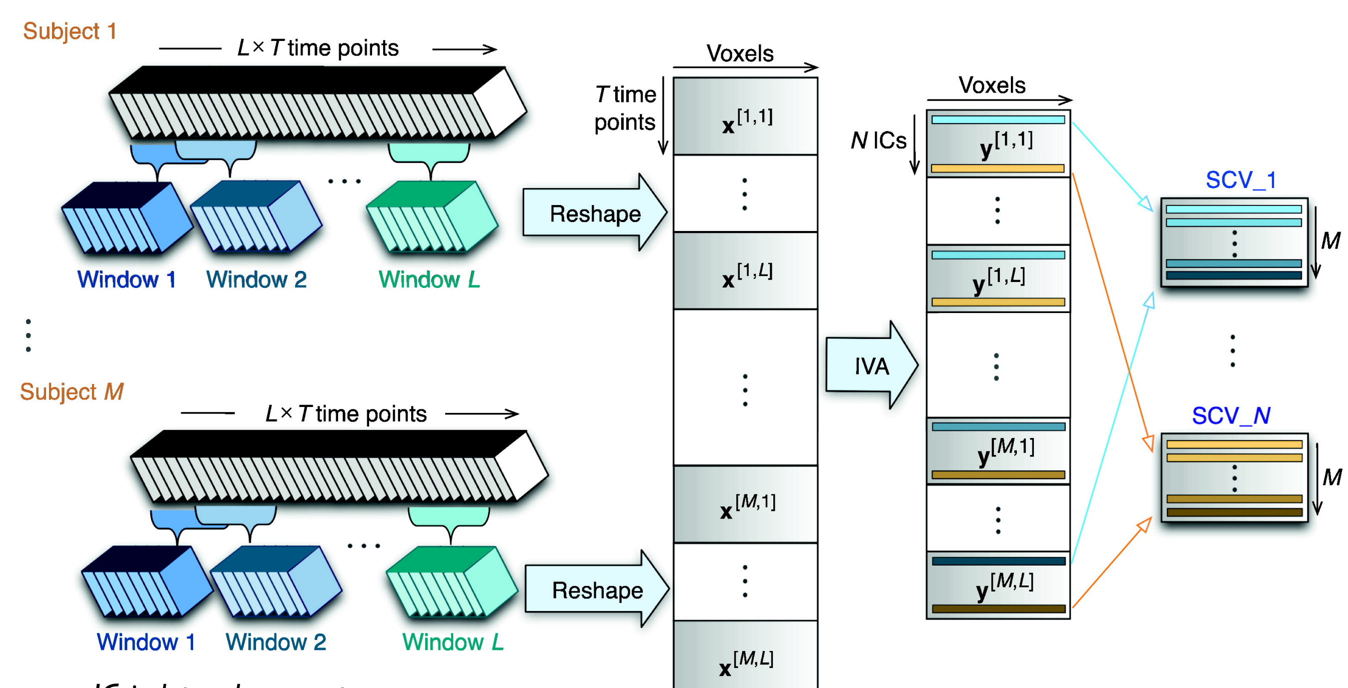
Assessing connectivity inside the window

- Using more elaborate measures to assess connectivity
  - *Sliding time-window ICA* (SlitICA): spatial independence across components
  - *Independent vector analysis* (IVA): spatial independence across components + matching between components from different windows



PICA: probabilistic independent component analysis

(Kiviniemi et al. 2011)



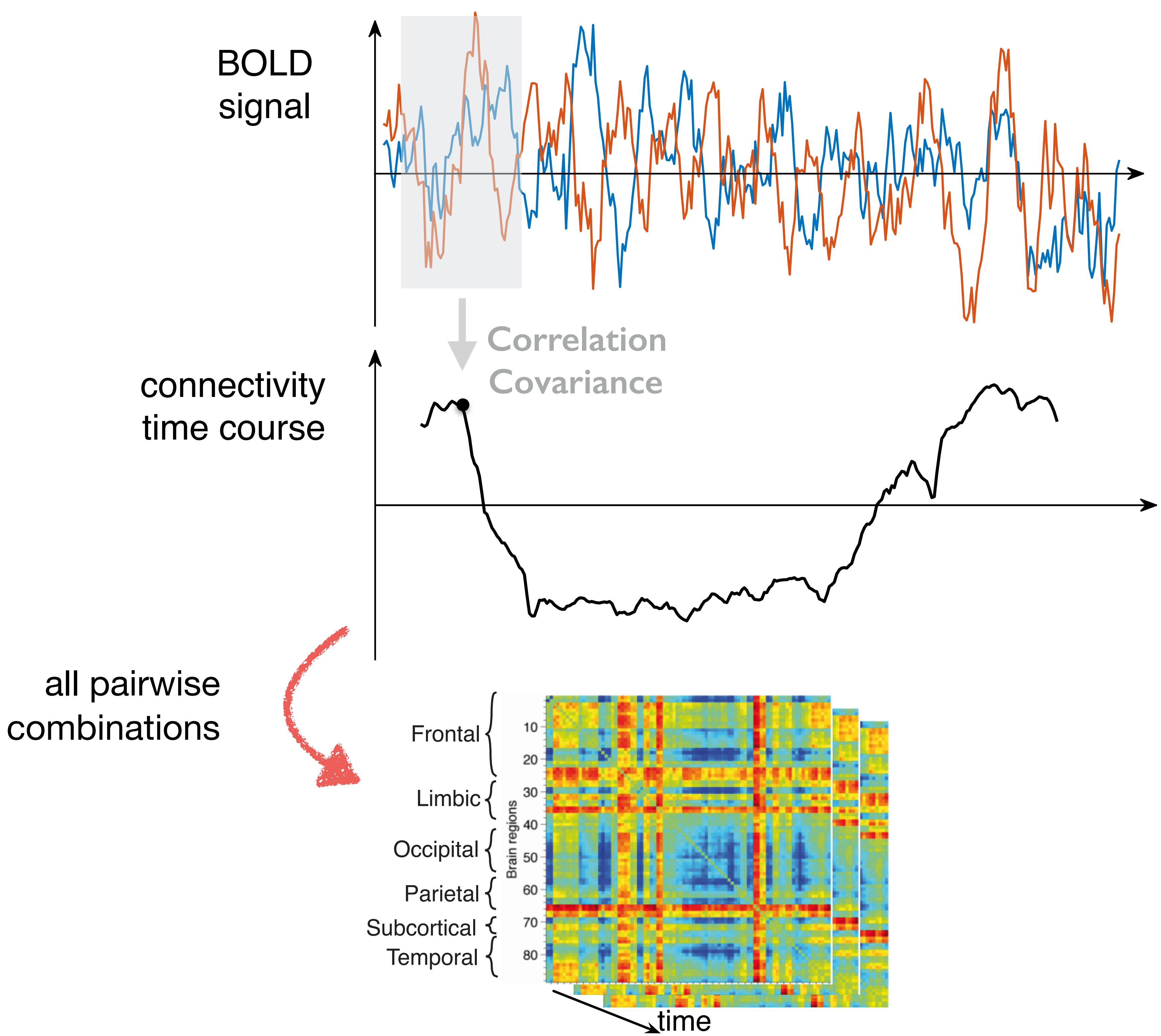
IC: independent component

SCV: source component vector

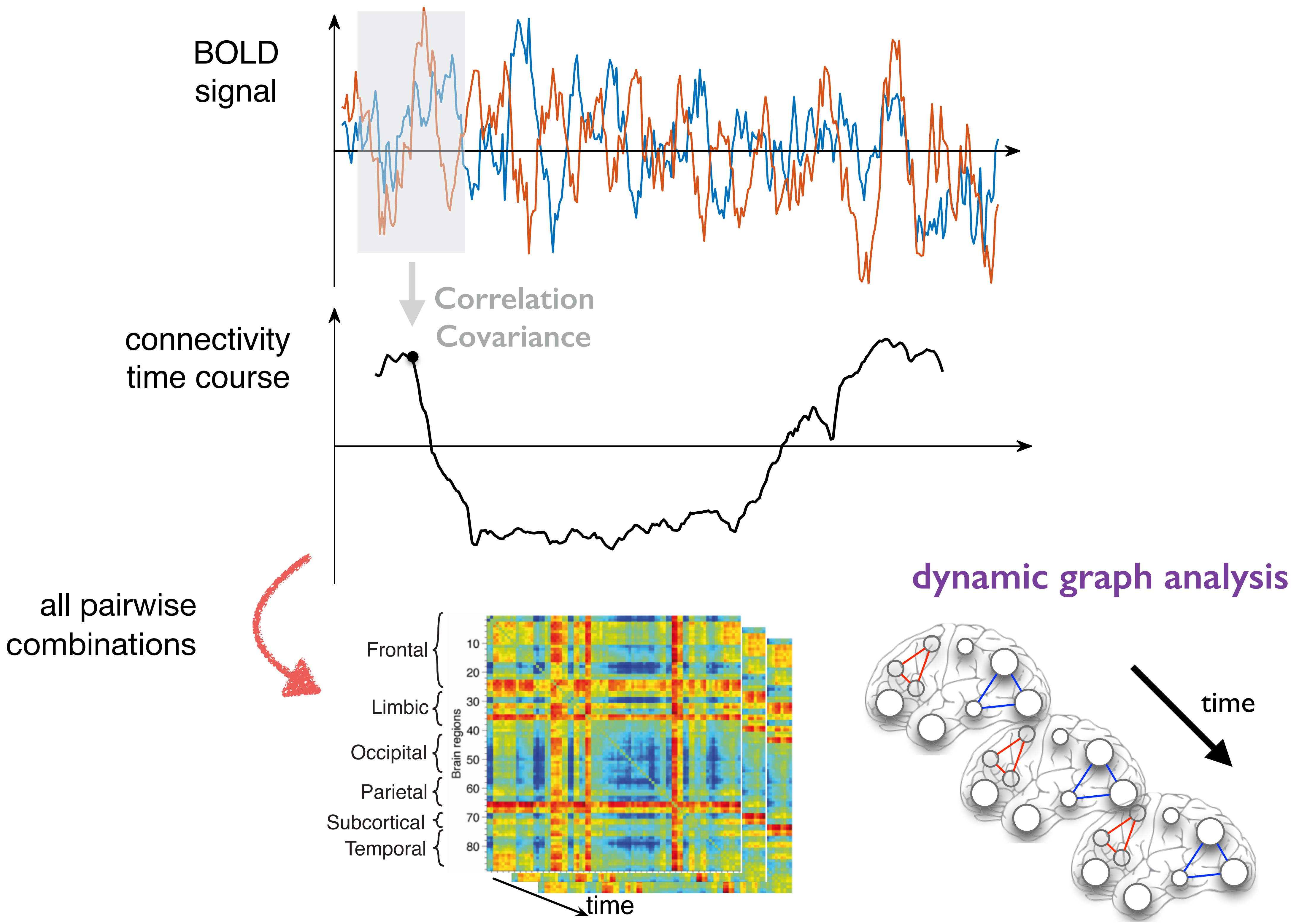
(Ma et al. 2014)

- Casting sparsity on the set of functional connections (Friedman et al. 2008)
- Using window-less assessments of synchrony: *multiplication of temporal derivatives* (MTD) (Shine et al. 2015)

Sliding window analysis: the simplest dFC tool

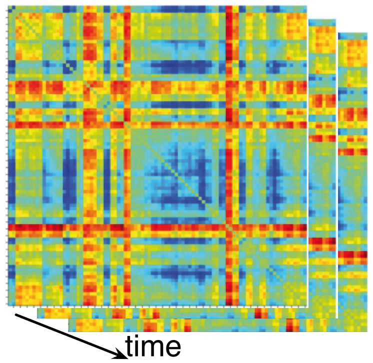


Sliding window analysis: the simplest dFC tool



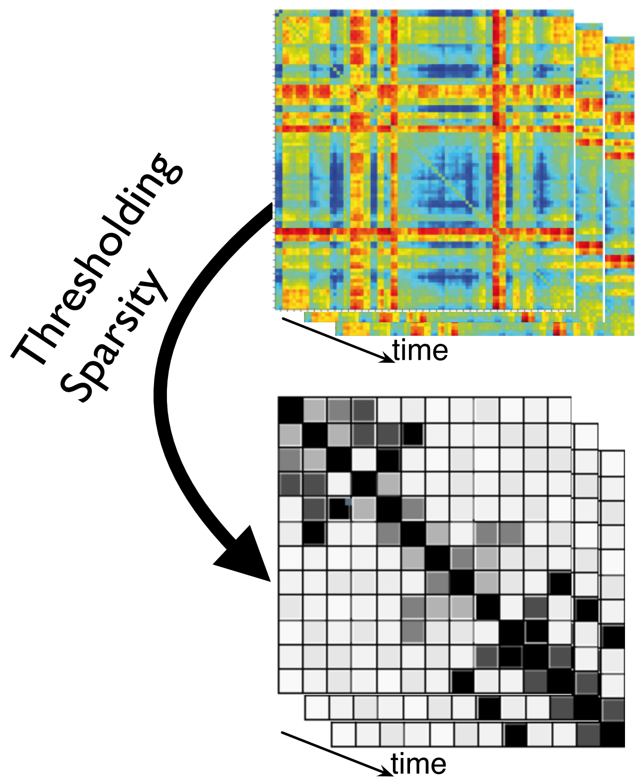
Dynamic graph analysis

- Many graph measures enable network-level analysis



Dynamic graph analysis

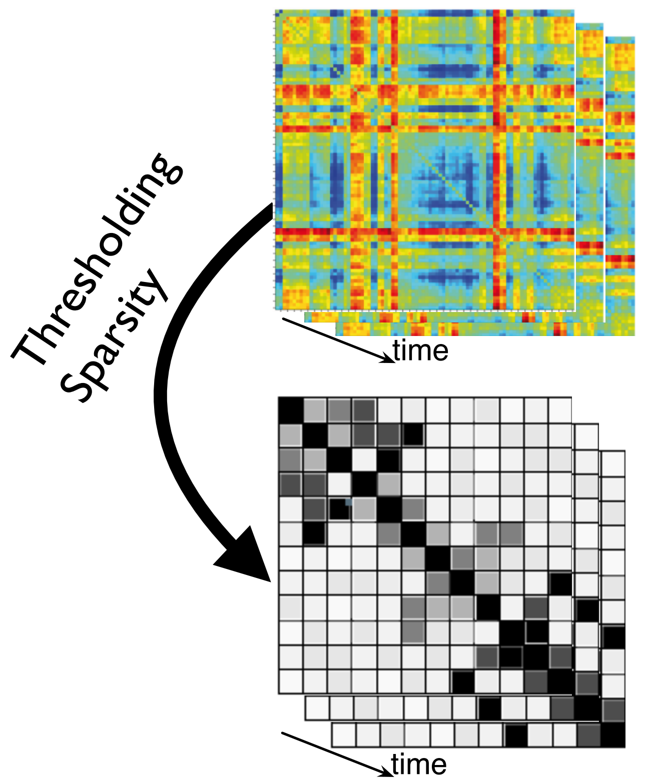
- Many graph measures enable network-level analysis



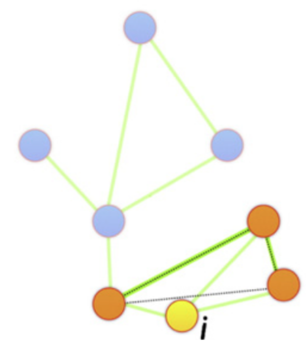
(Rubinov and Sporns 2010)

Dynamic graph analysis

- Many graph measures enable network-level analysis



Clustering coefficient (CC)

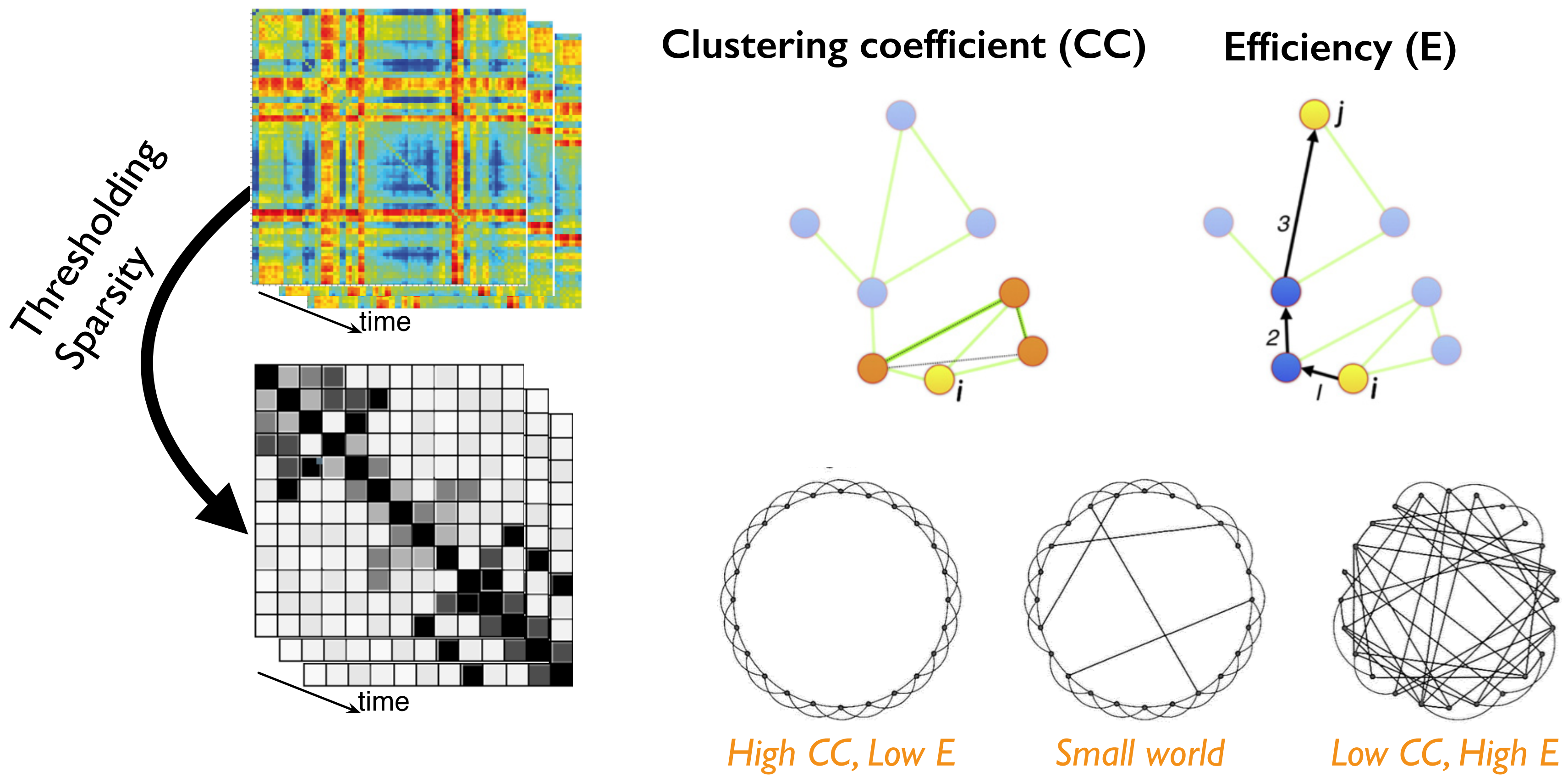


(Van den Heuvel and Pol 2010)

(Rubinov and Sporns 2010)

Dynamic graph analysis

- Many graph measures enable network-level analysis

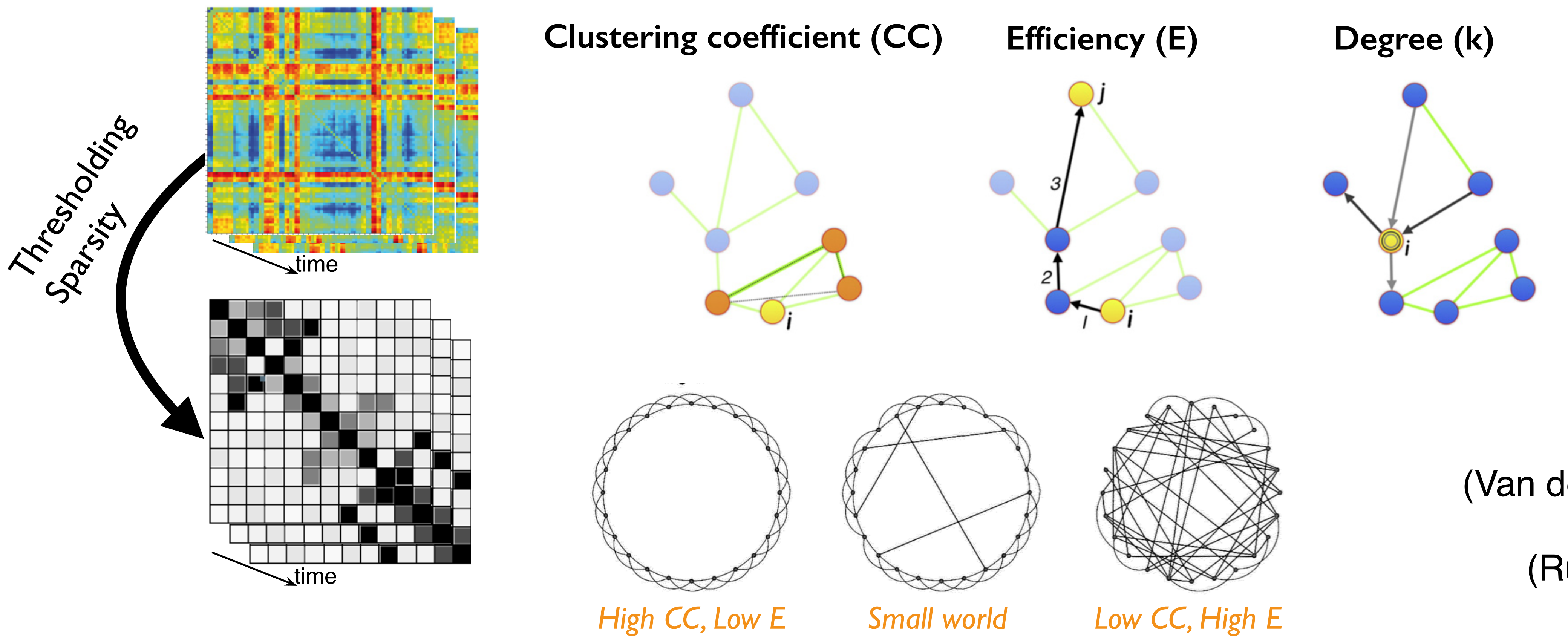


(Van den Heuvel and Pol 2010)

(Rubinov and Sporns 2010)

Dynamic graph analysis

- Many graph measures enable network-level analysis

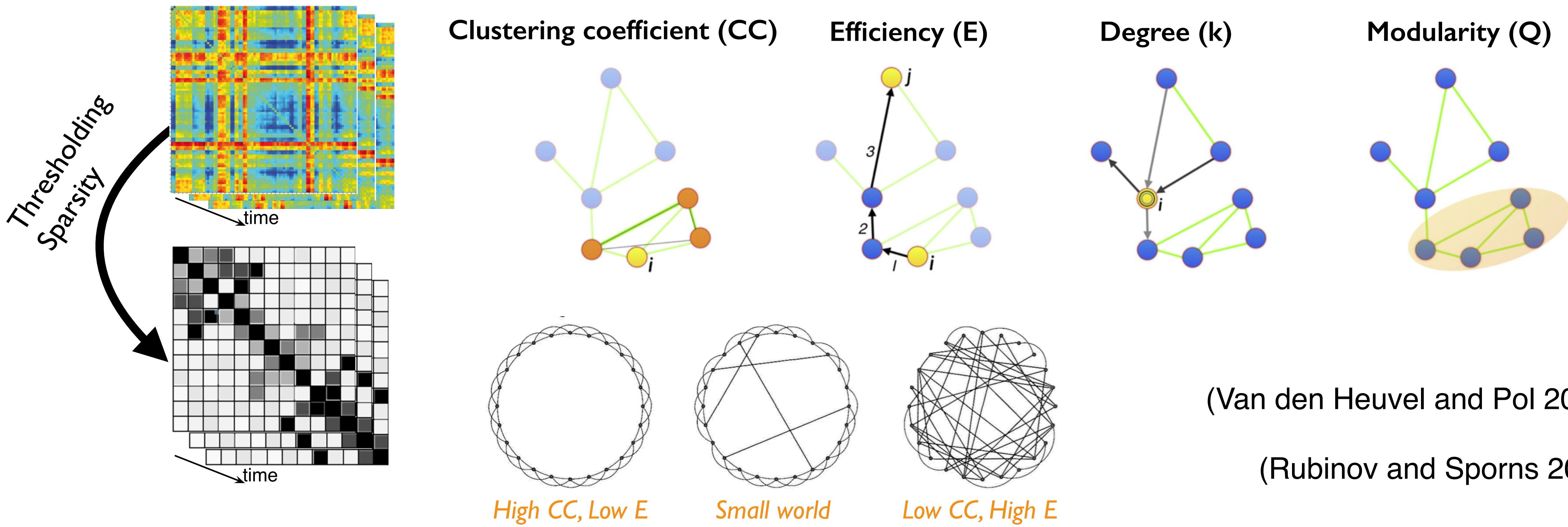


(Van den Heuvel and Pol 2010)

(Rubinov and Sporns 2010)

Dynamic graph analysis

- Many graph measures enable network-level analysis

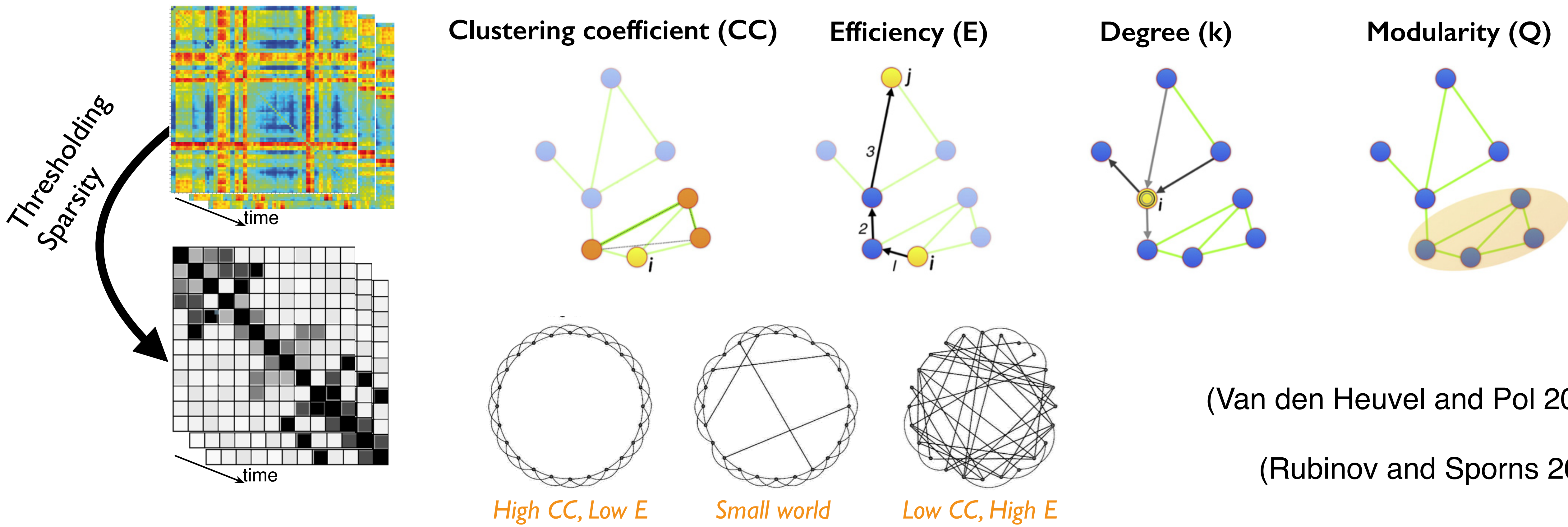


(Van den Heuvel and Pol 2010)

(Rubinov and Sporns 2010)

Dynamic graph analysis

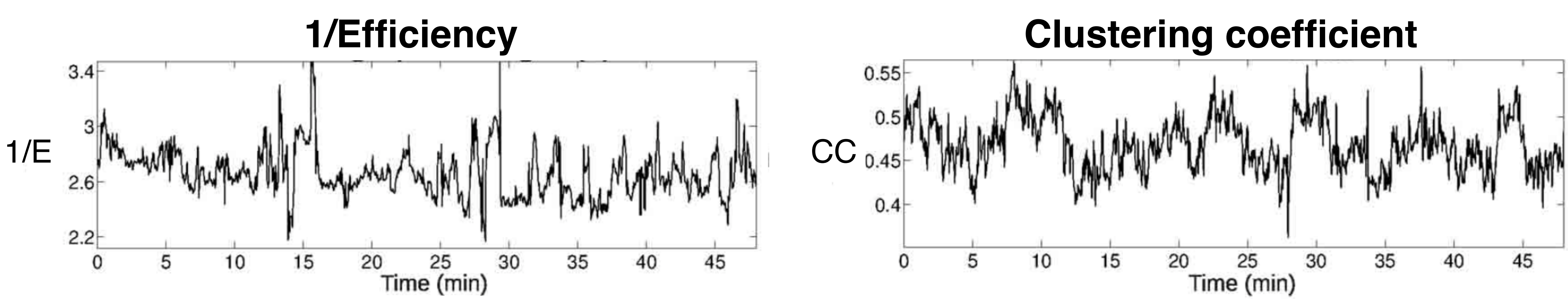
- Many graph measures enable network-level analysis



(Van den Heuvel and Pol 2010)

(Rubinov and Sporns 2010)

- Those measures fluctuate dynamically over time

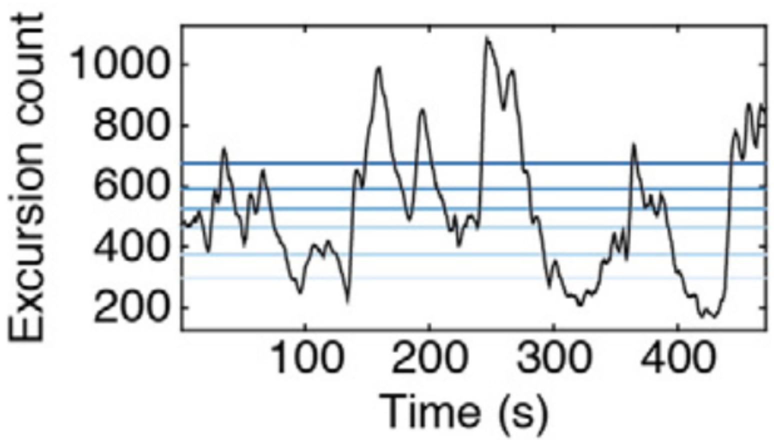


(Tagliazucchi et al. 2012)

Dynamic graph analysis

- Time points of high modularity and low efficiency *vs* low modularity and high efficiency

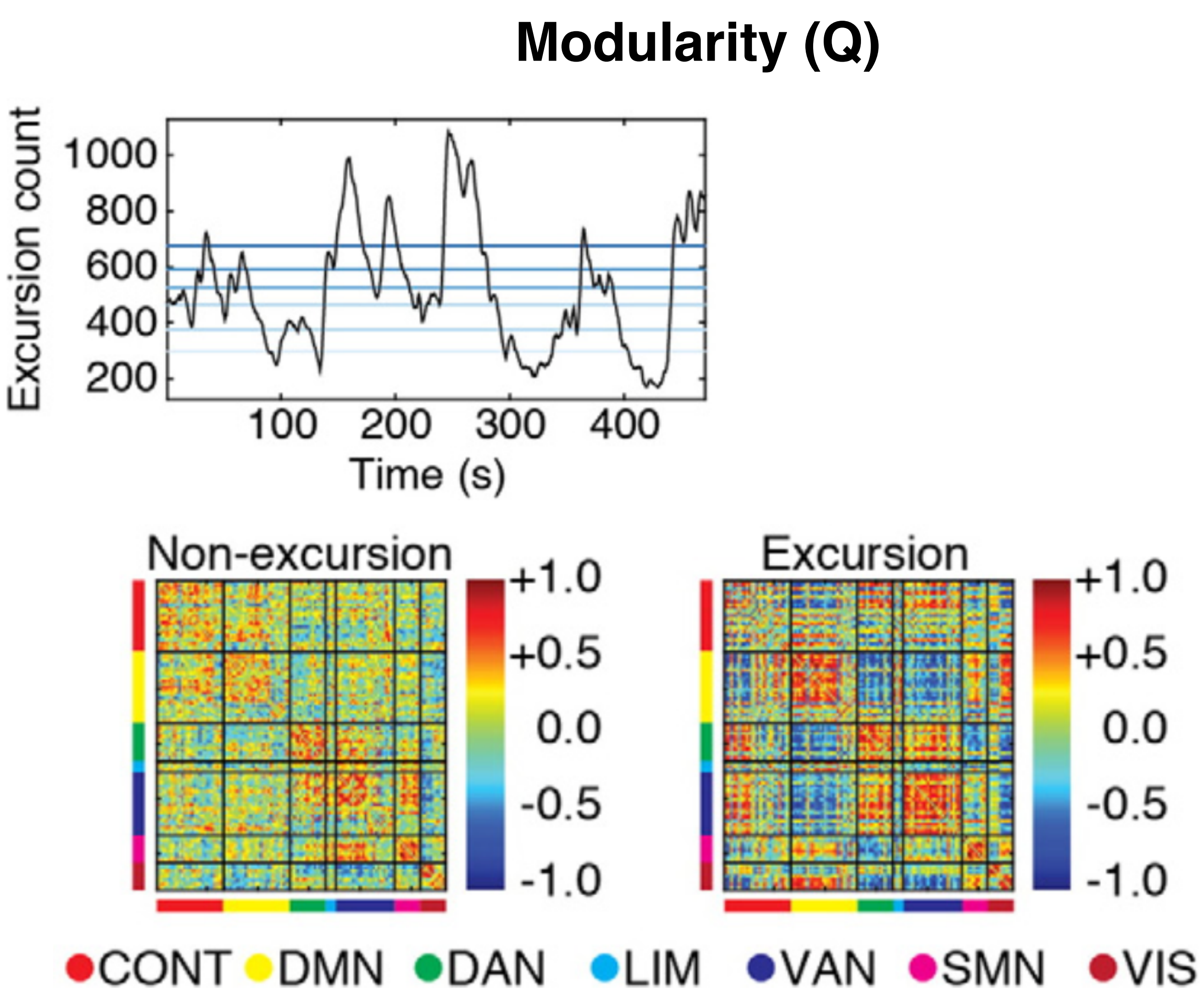
Modularity (Q)



(Betzel et al. 2016)

Dynamic graph analysis

- Time points of high modularity and low efficiency *vs* low modularity and high efficiency

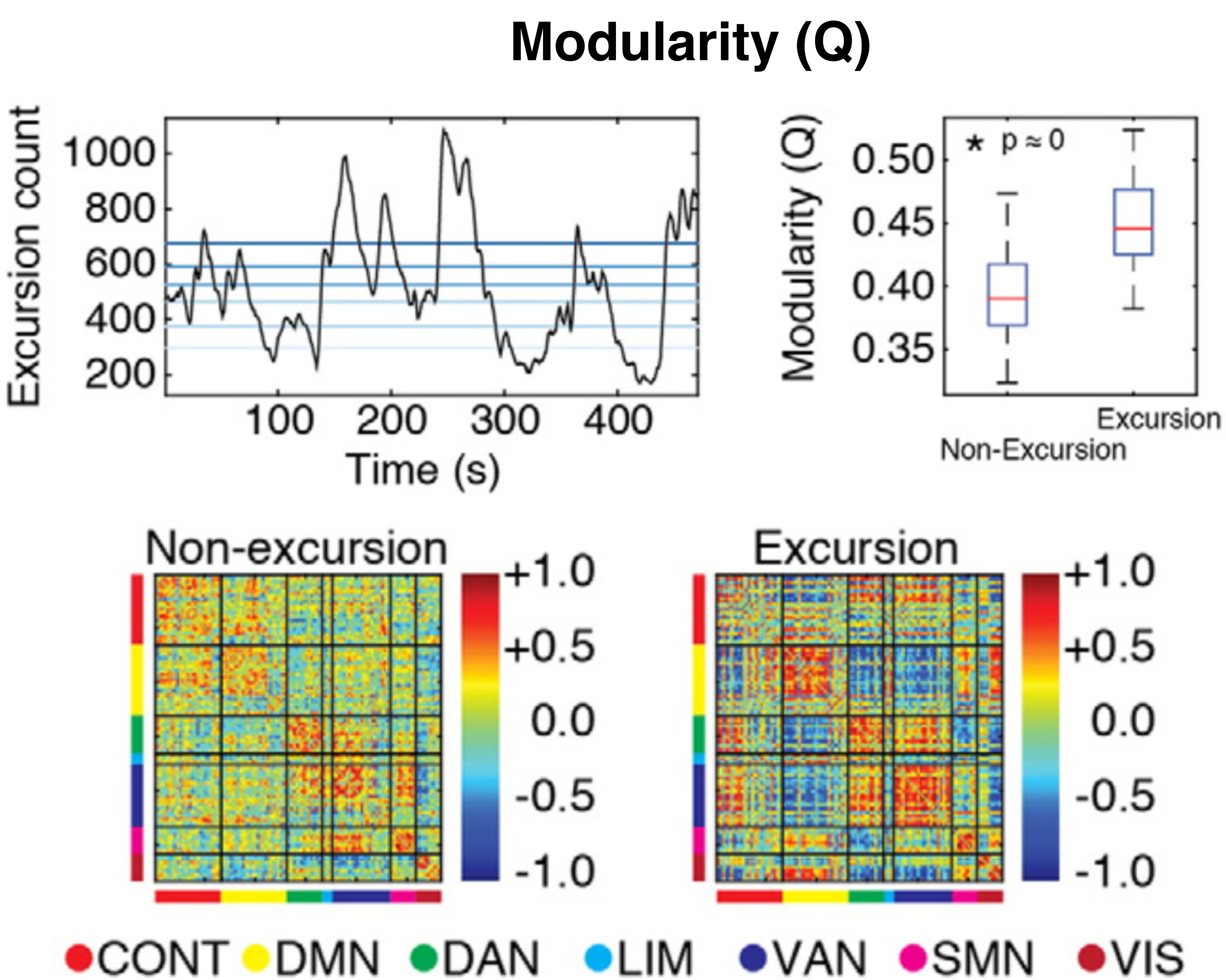


CONT: control *DMN: default mode* *DAN: dorsal attention* *LIM: limbic*
SMN: somatomotor *VAN: ventral attention* *VIS: visual*

(Betzel et al. 2016)

Dynamic graph analysis

- Time points of high modularity and low efficiency *vs* low modularity and high efficiency



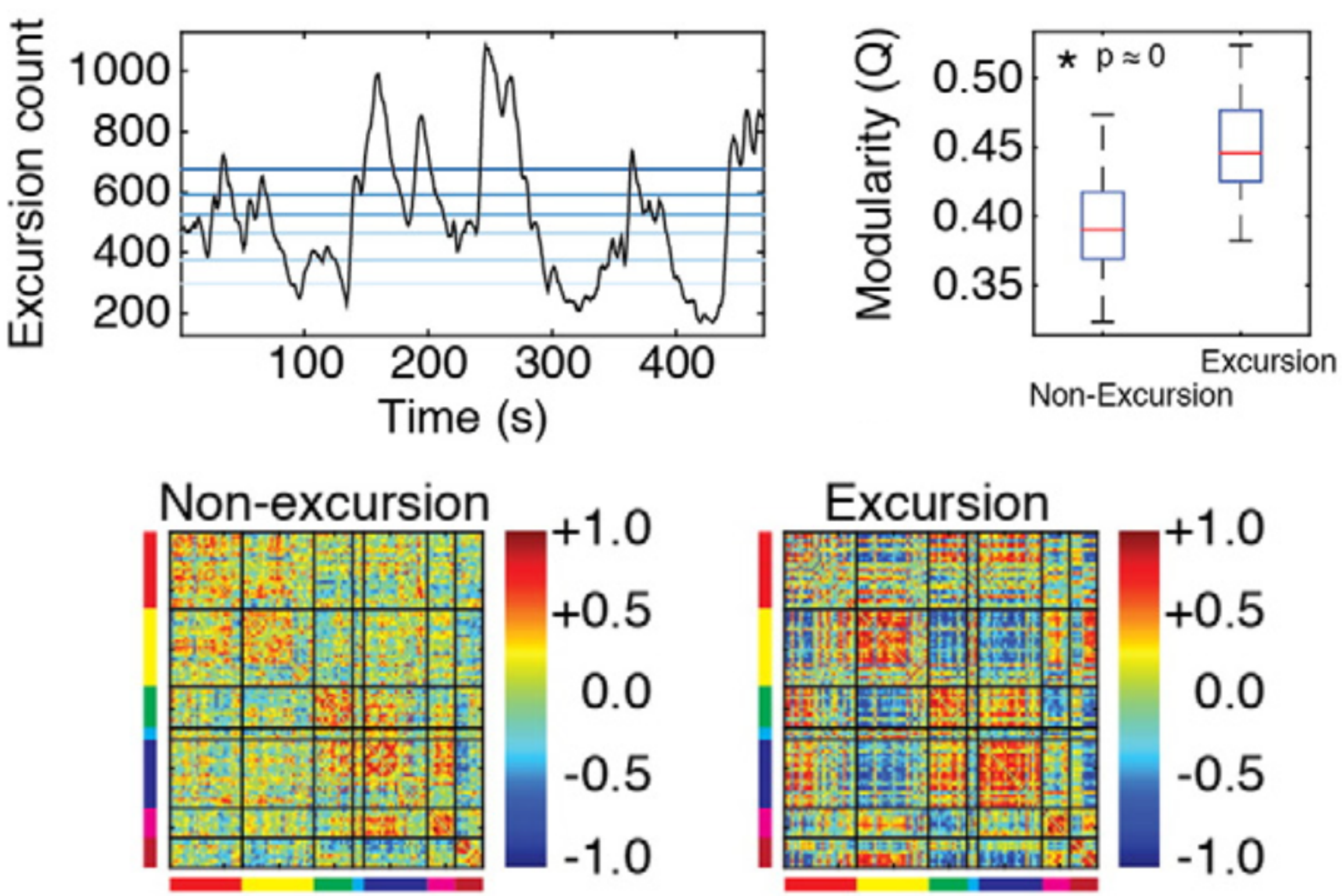
CONT: control *DMN: default mode* *DAN: dorsal attention* *LIM: limbic*
SMN: somatomotor *VAN: ventral attention* *VIS: visual*

(Betzel et al. 2016)

Dynamic graph analysis

- Time points of high modularity and low efficiency *vs* low modularity and high efficiency

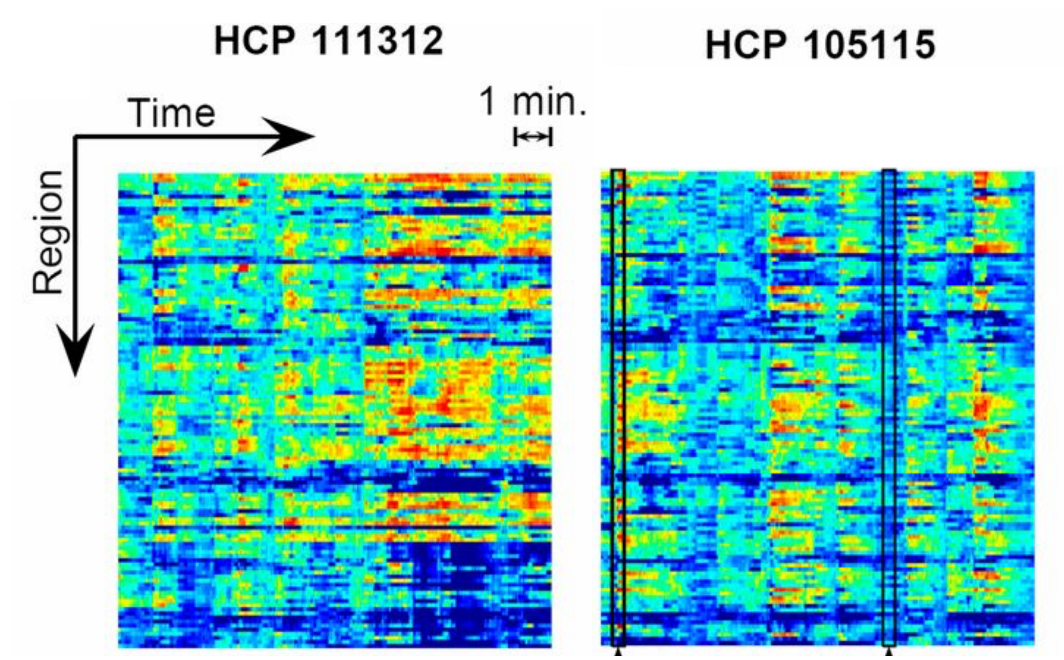
Modularity (Q)



CONT: control *DMN: default mode* *DAN: dorsal attention* *LIM: limbic*
SMN: somatomotor *VAN: ventral attention* *VIS: visual*

(Betzel et al. 2016)

Efficiency (E)

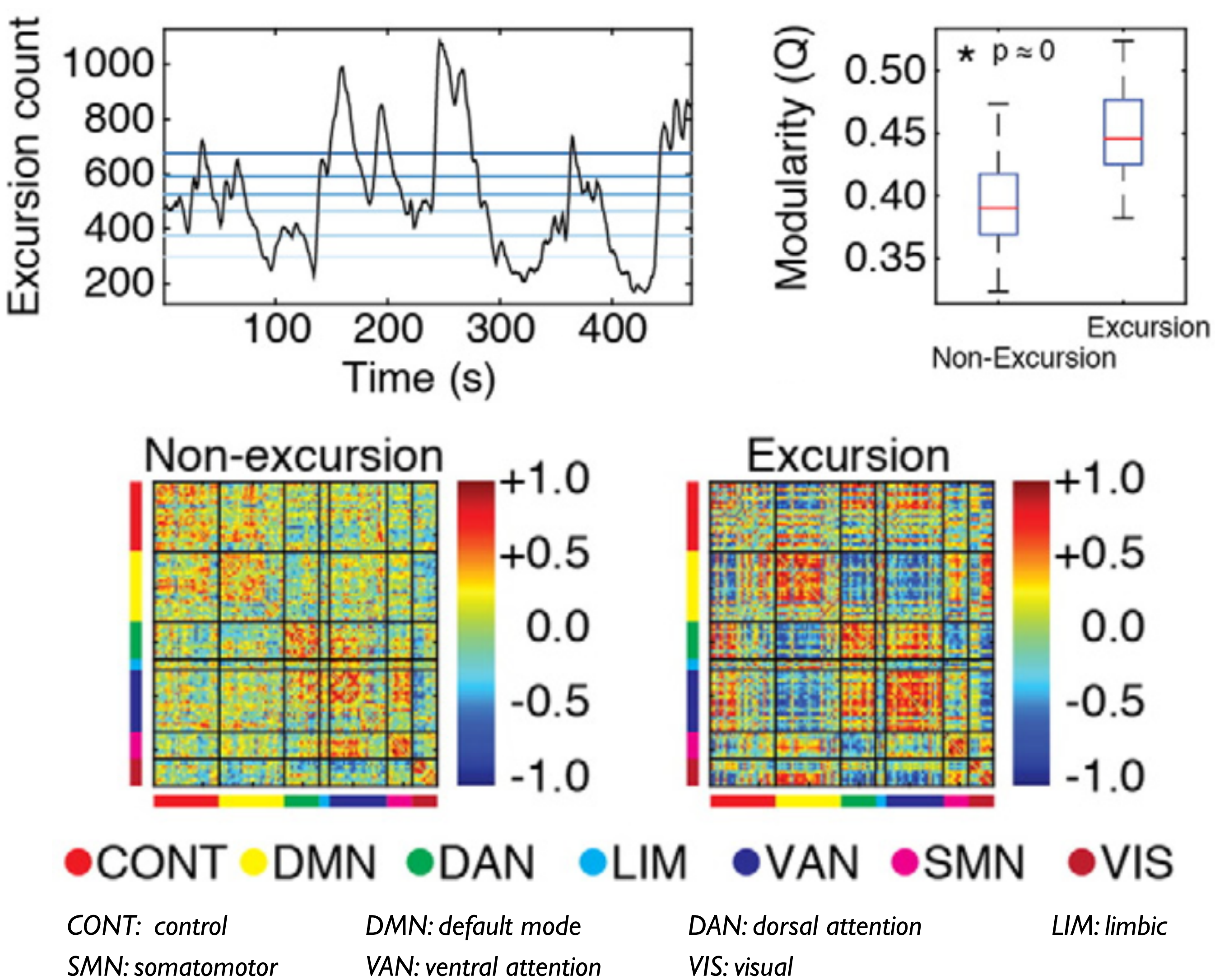


(Zalesky et al. 2014)

Dynamic graph analysis

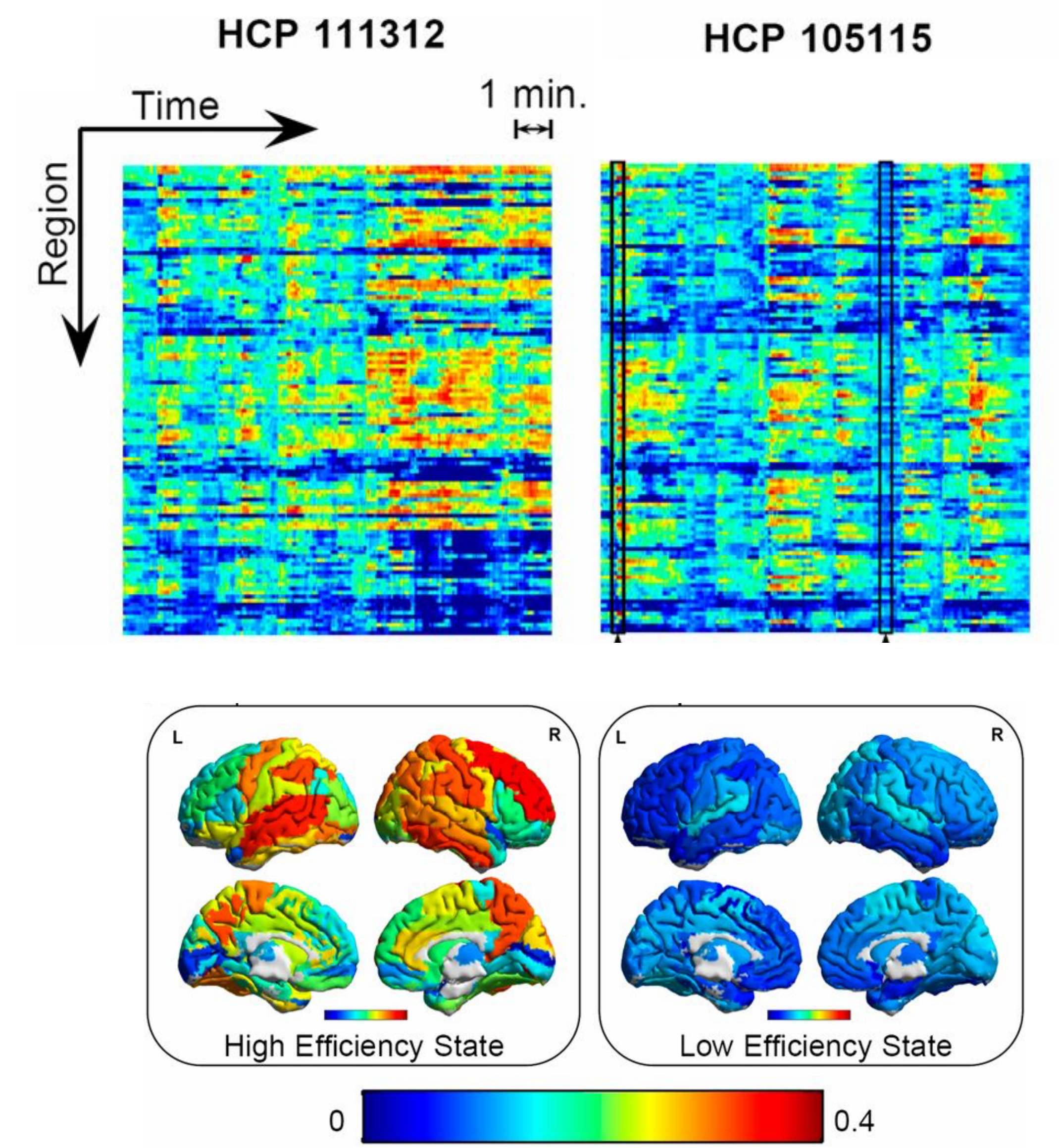
- Time points of high modularity and low efficiency *vs* low modularity and high efficiency

Modularity (Q)



(Betzel et al. 2016)

Efficiency (E)

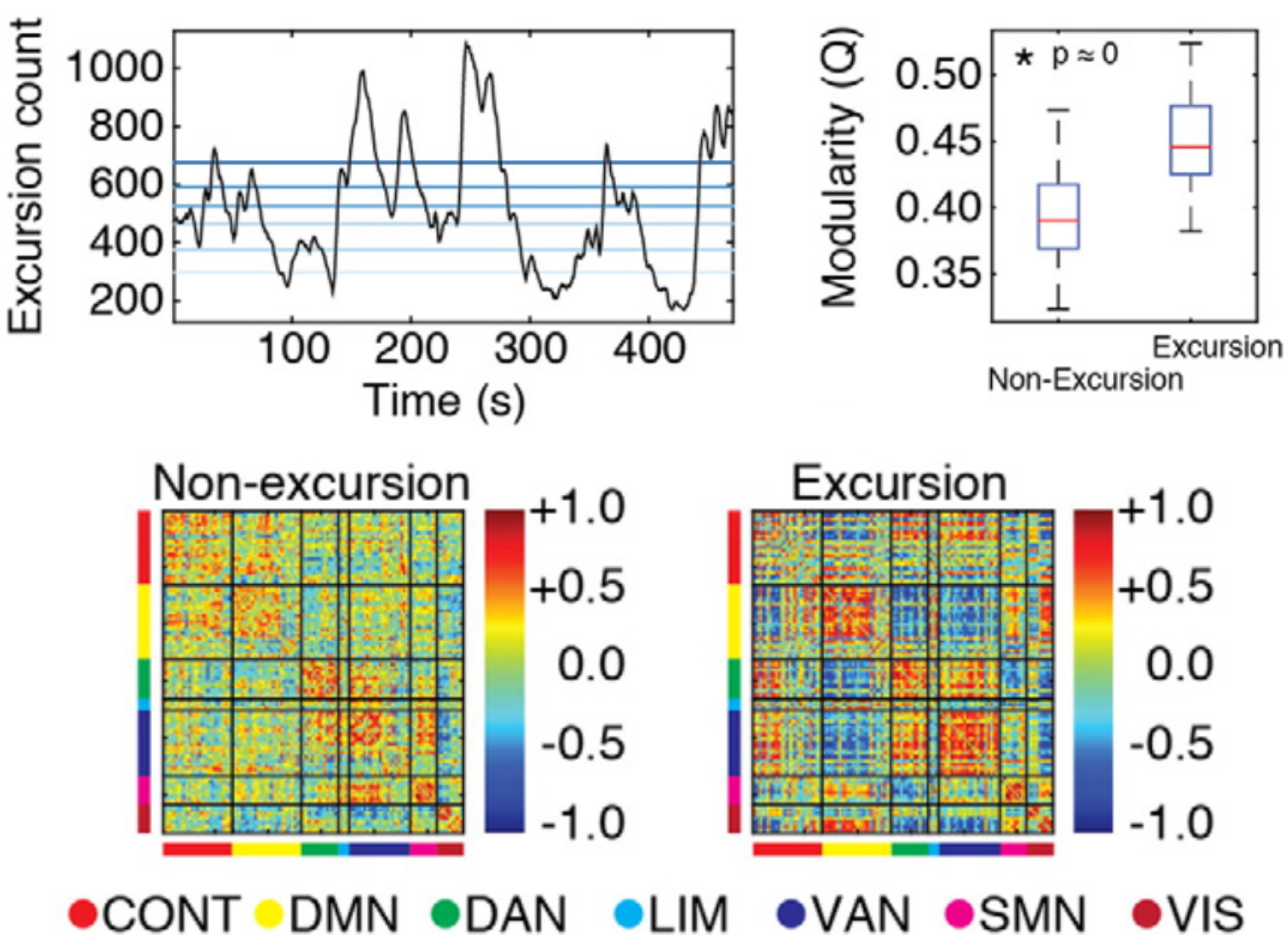


(Zalesky et al. 2014)

Dynamic graph analysis

- Time points of high modularity and low efficiency *vs* low modularity and high efficiency
  - Independently active networks *vs* Interacting modules

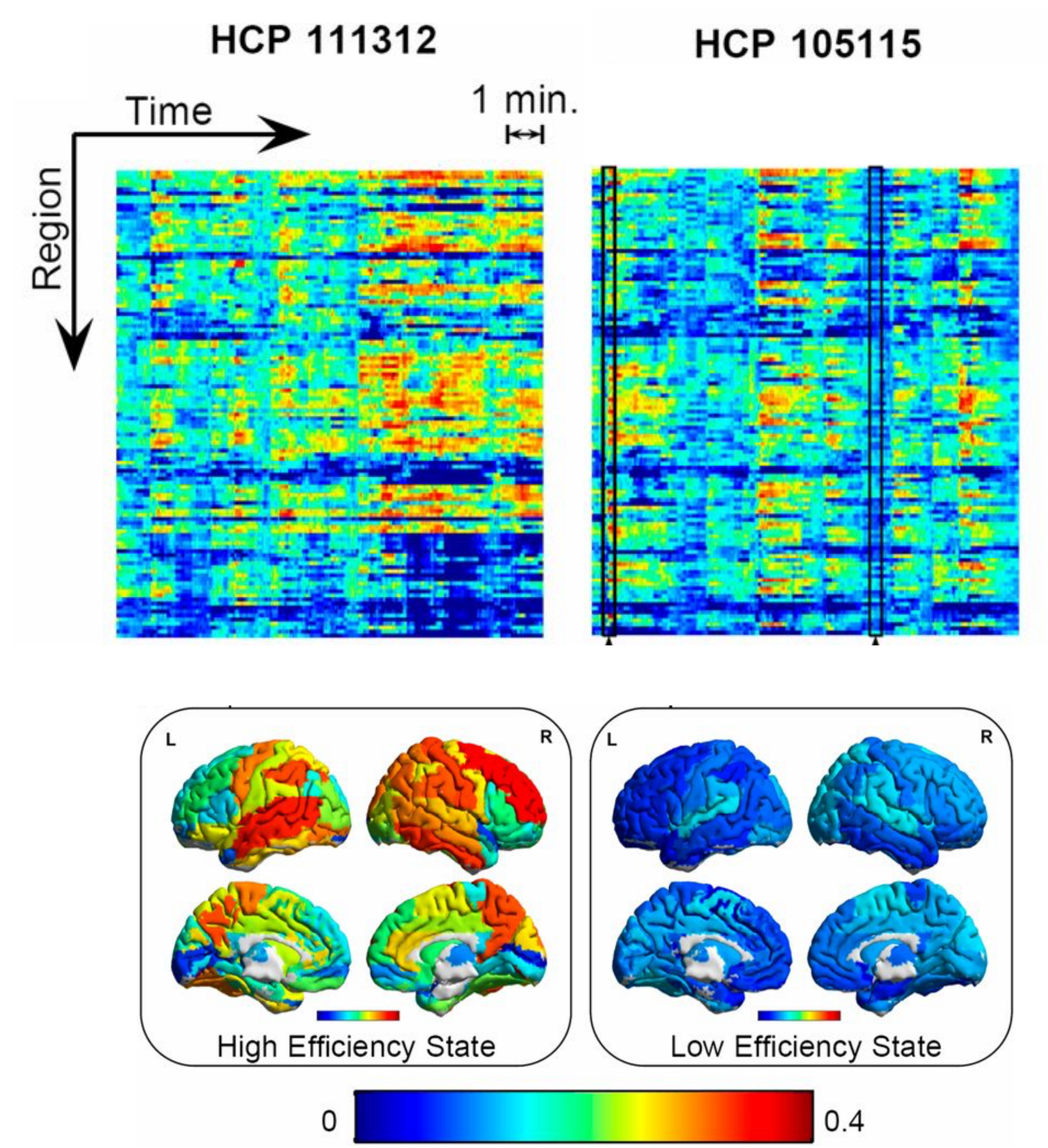
Modularity (Q)



CONT: control *DMN: default mode* *DAN: dorsal attention* *LIM: limbic*
SMN: somatomotor *VAN: ventral attention* *VIS: visual*

(Betzel et al. 2016)

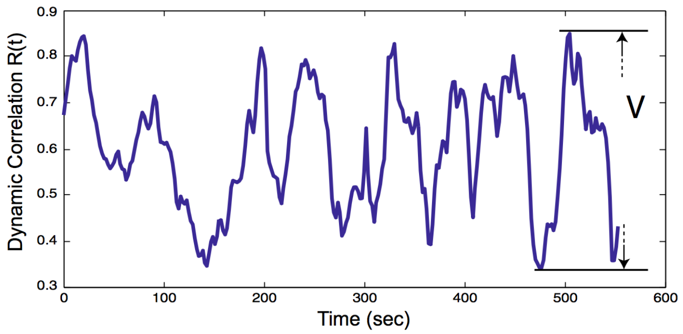
Efficiency (E)



(Zalesky et al. 2014)

Dynamic graph analysis

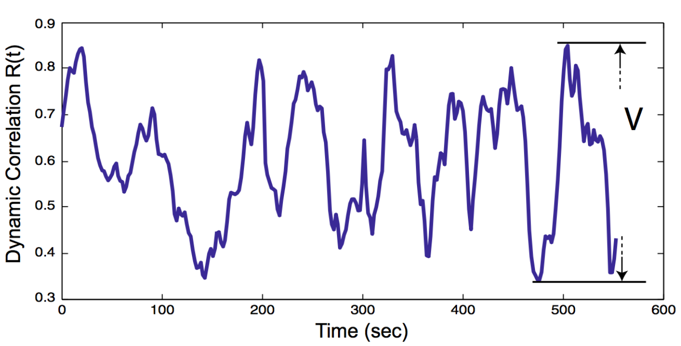
- Brain structure constrains strong functional modularity

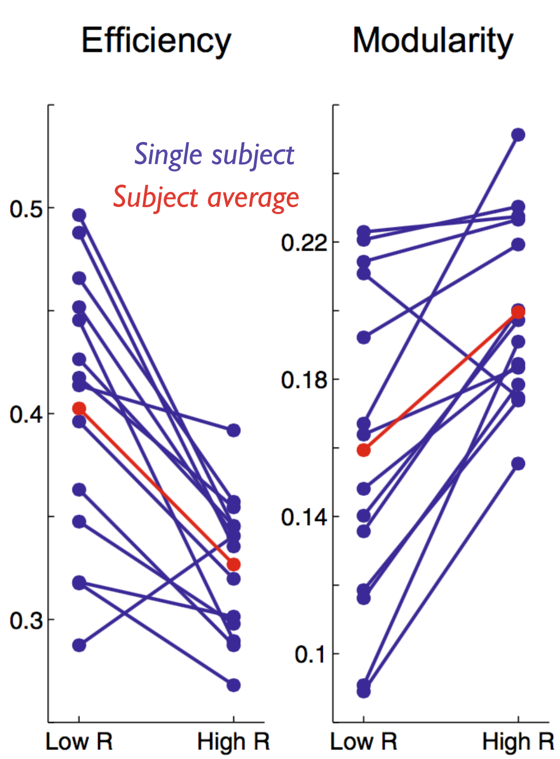


(Liégeois et al. 2015)

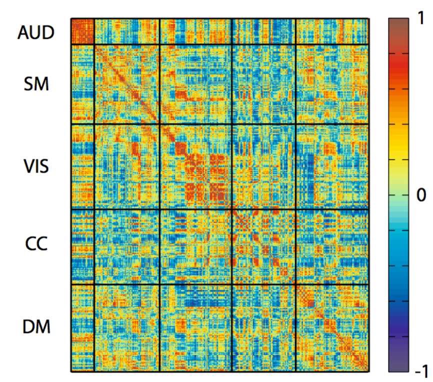
Dynamic graph analysis

- Brain structure constrains strong functional modularity

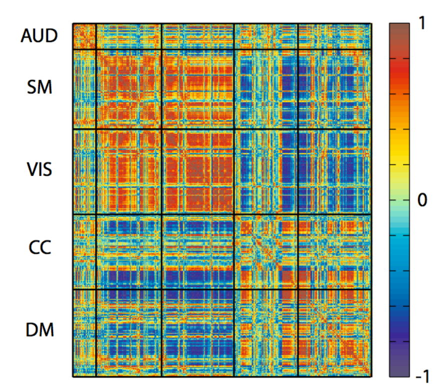




R: correlation to brain structure



Average FC during phases of highest FC-SC correlation



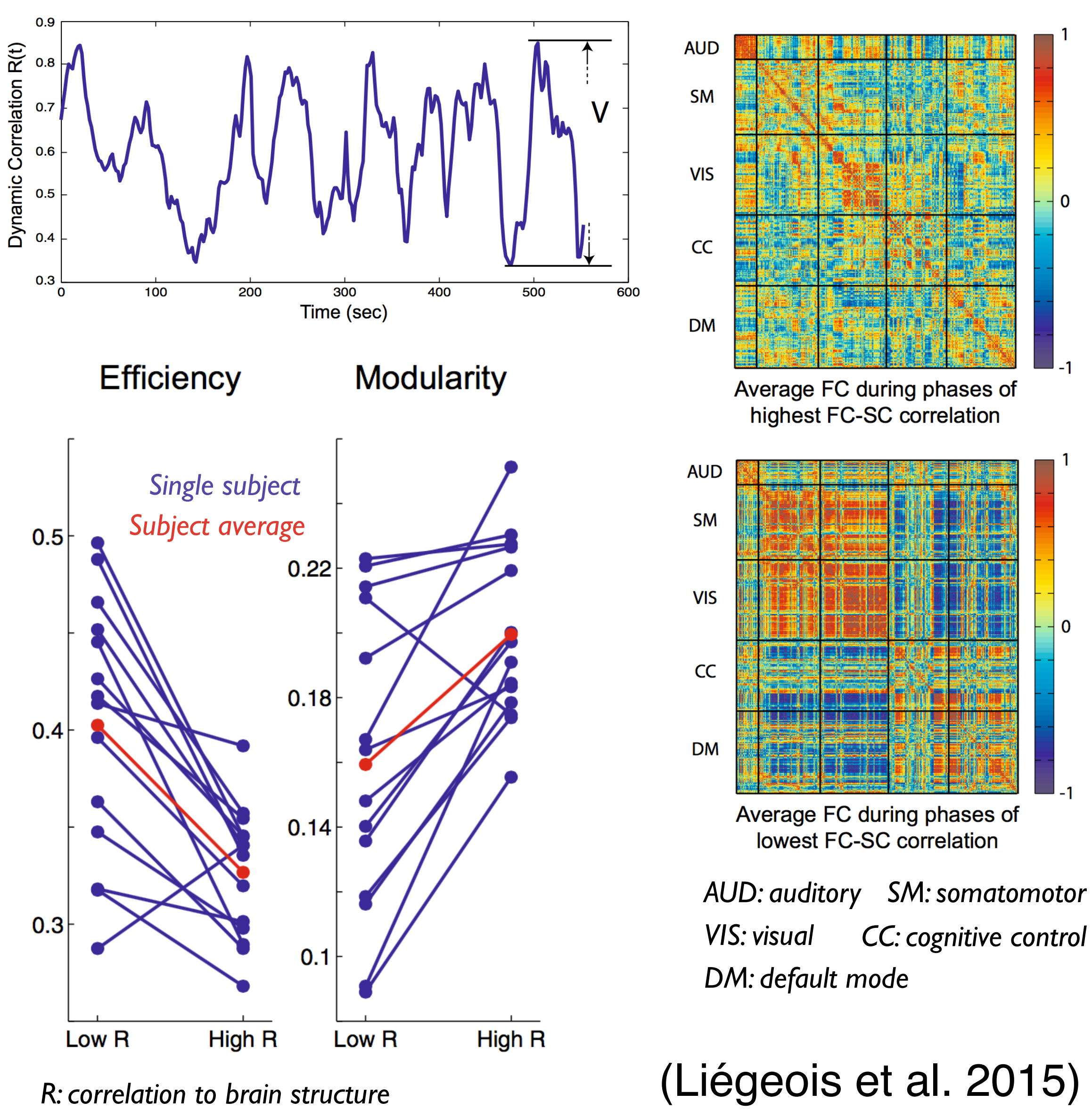
Average FC during phases of lowest FC-SC correlation

AUD: auditory SM: somatomotor
VIS: visual CC: cognitive control
DM: default mode

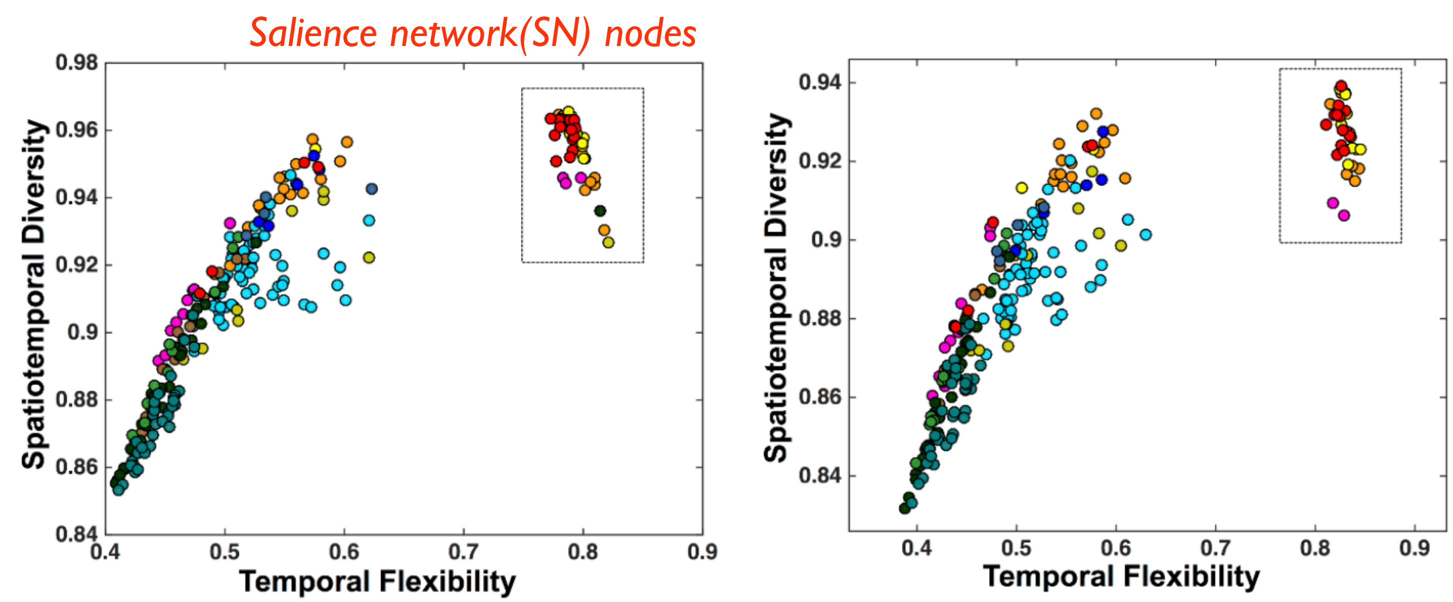
(Liégeois et al. 2015)

Dynamic graph analysis

- Brain structure constrains strong functional modularity
- Flexibility in escaping this constraint relates to cognition



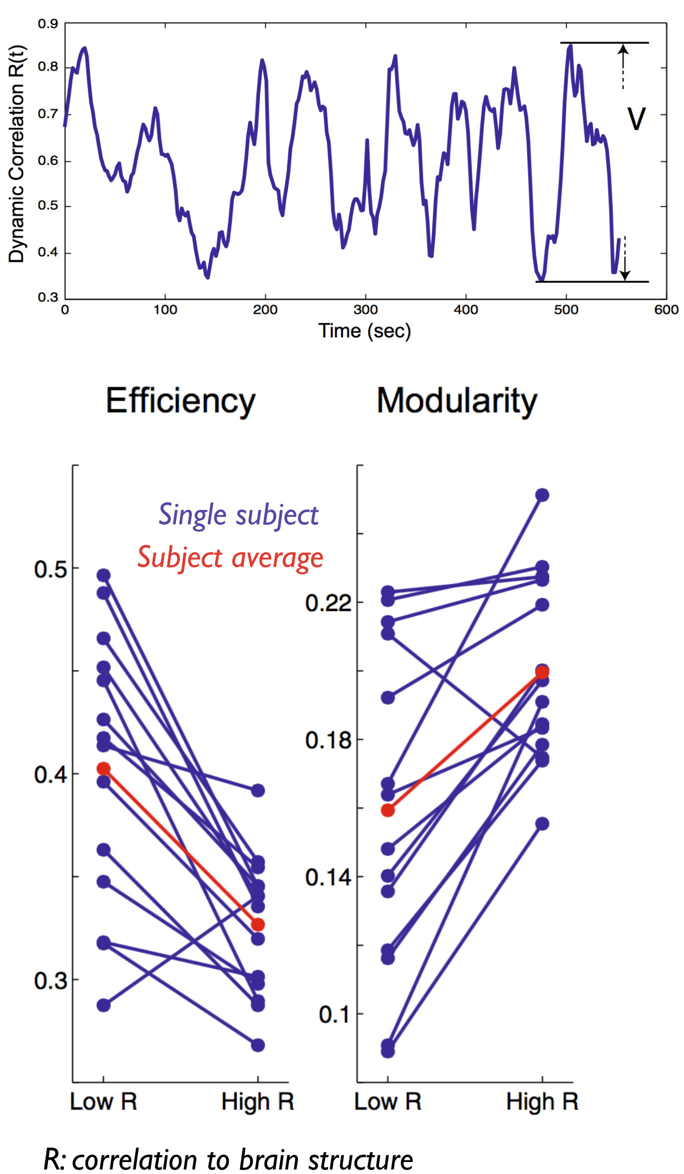
(Liégeois et al. 2015)

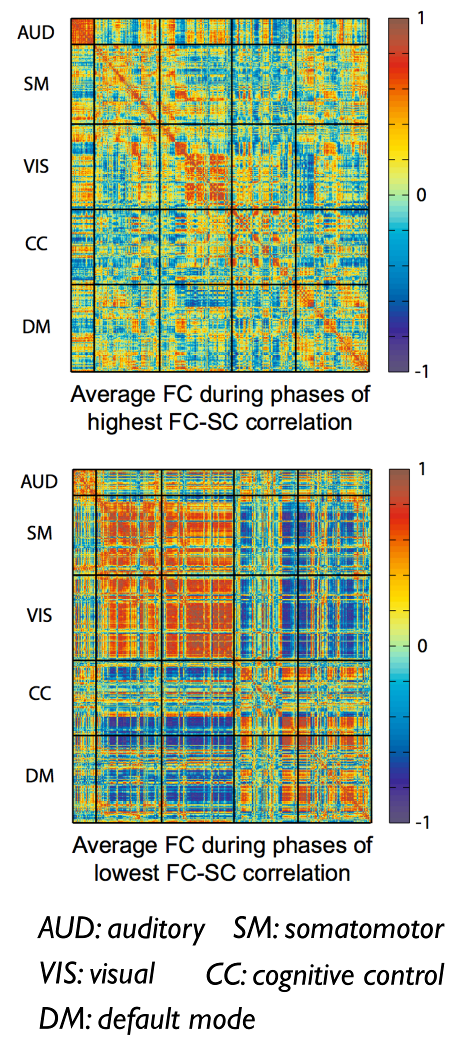


(Chen et al. 2016)

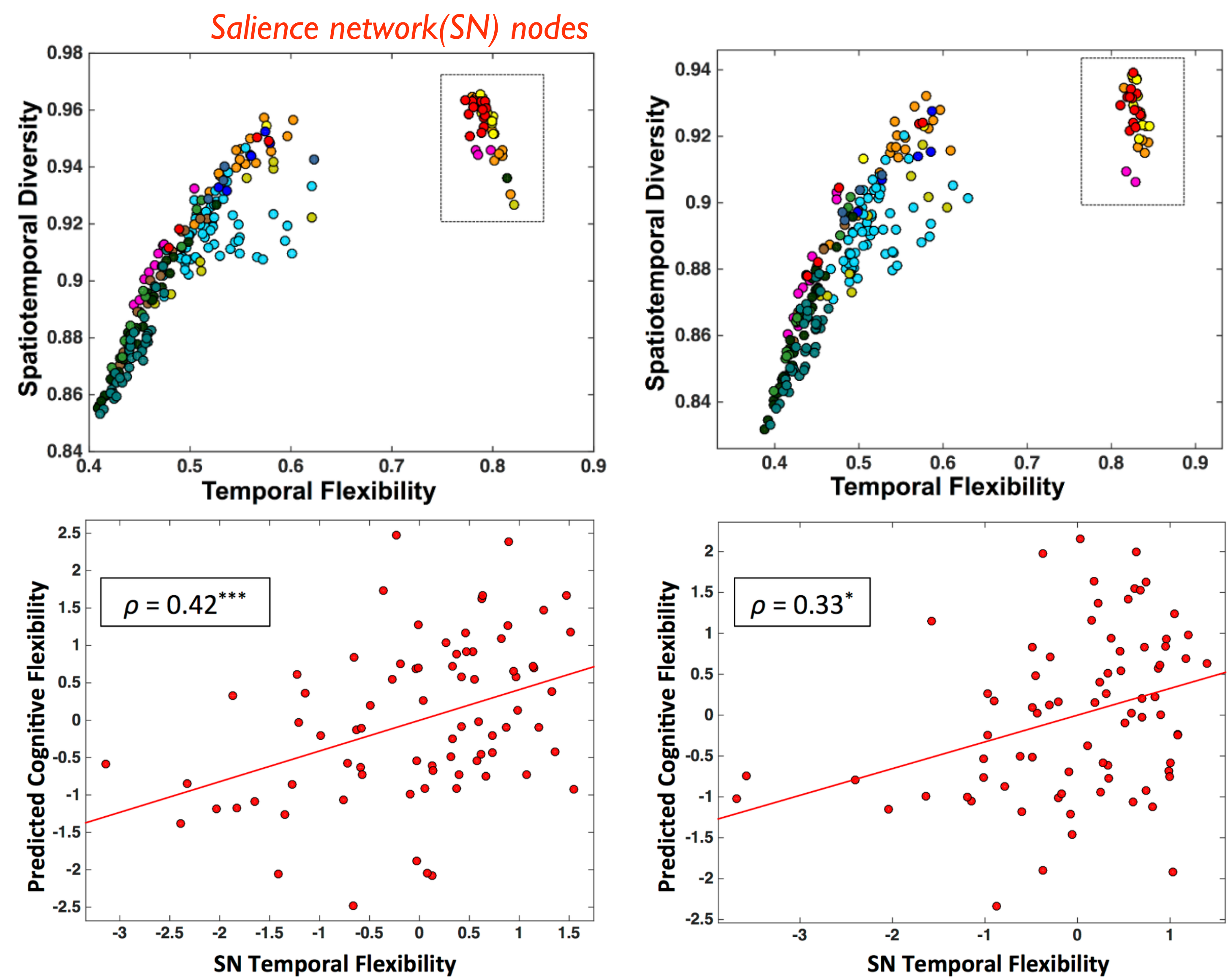
Dynamic graph analysis

- Brain structure constrains strong functional modularity
- Flexibility in escaping this constraint relates to cognition
  - Salience network nodes shift their modular allegiance more in cognitively flexible individuals



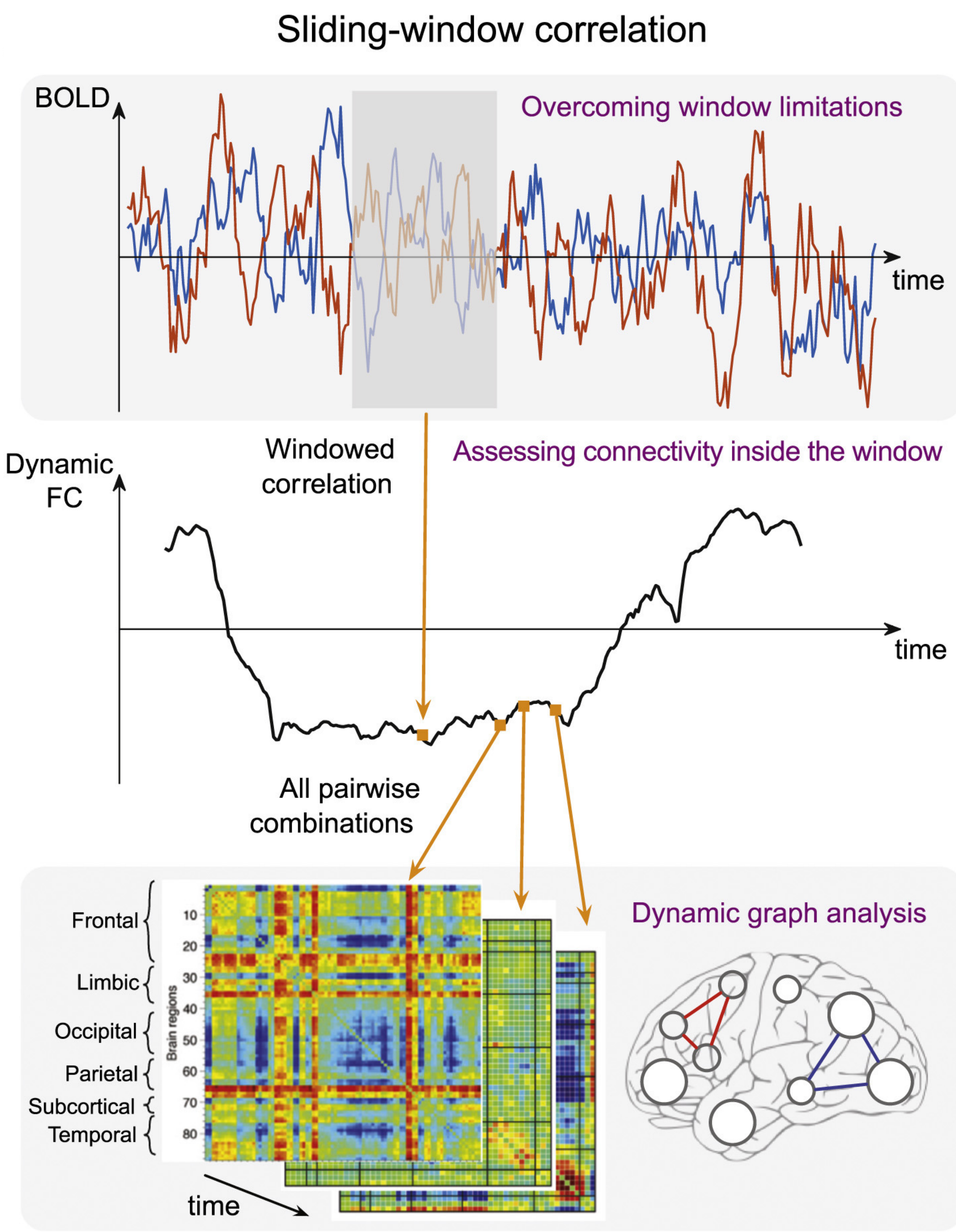


(Liégeois et al. 2015)

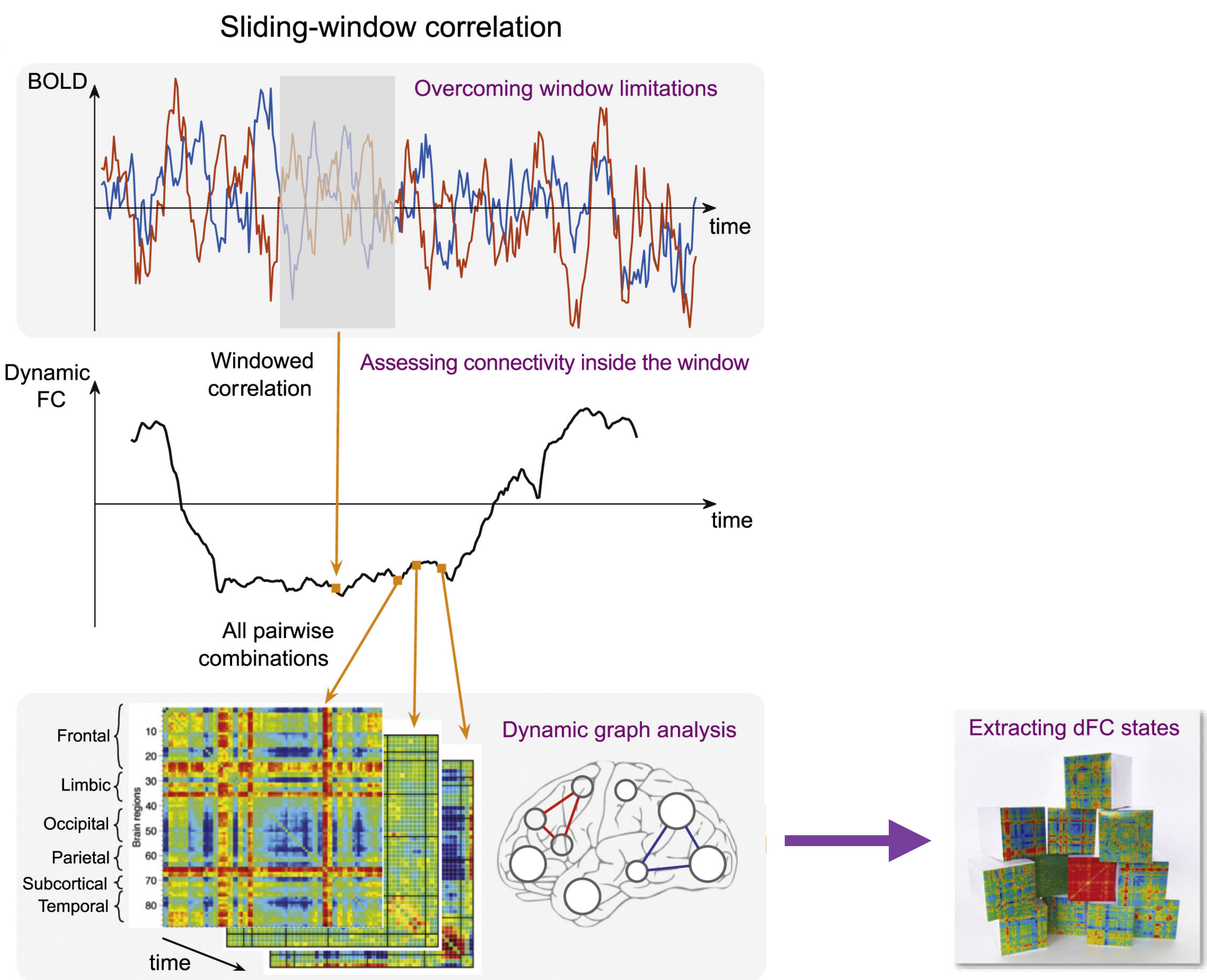


(Chen et al. 2016)

Sliding window analysis: the simplest dFC tool

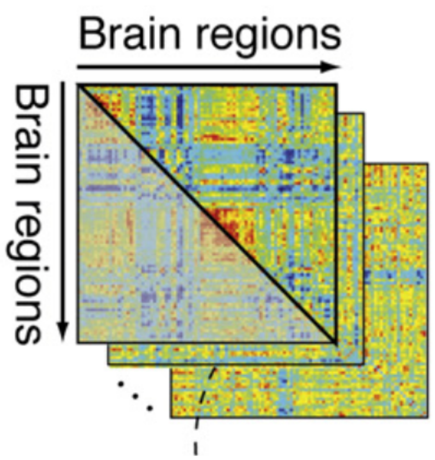


Sliding window analysis: the simplest dFC tool



Extracting dFC states

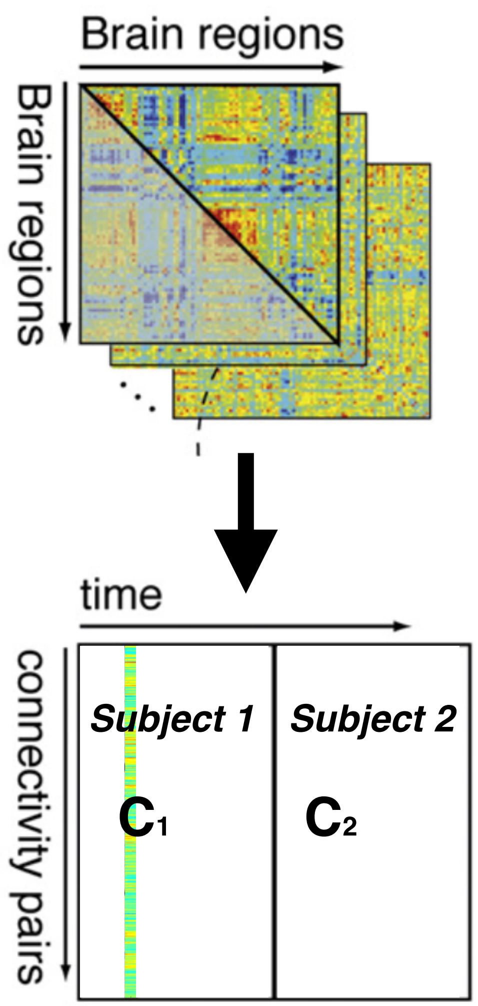
- Concatenated data yield building blocks for the whole population



(Leonardi et al. 2013)

Extracting dFC states

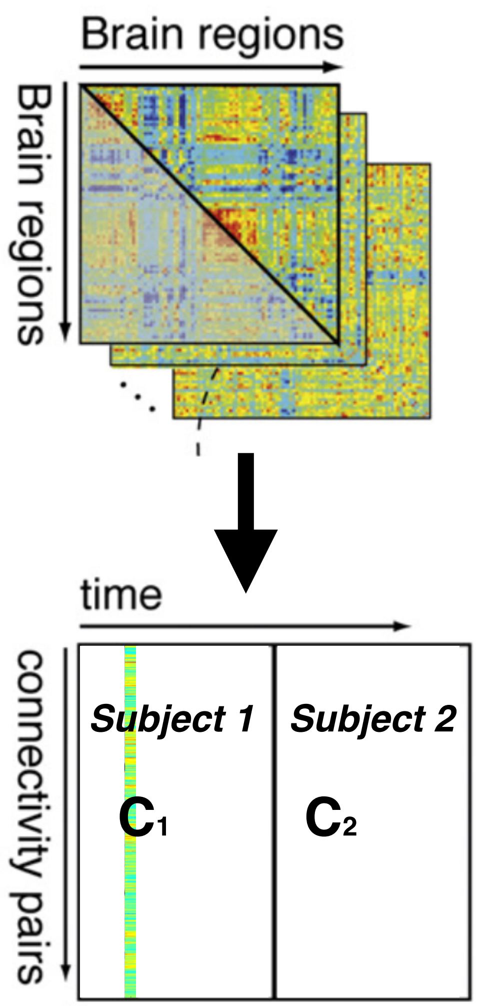
- Concatenated data yield building blocks for the whole population



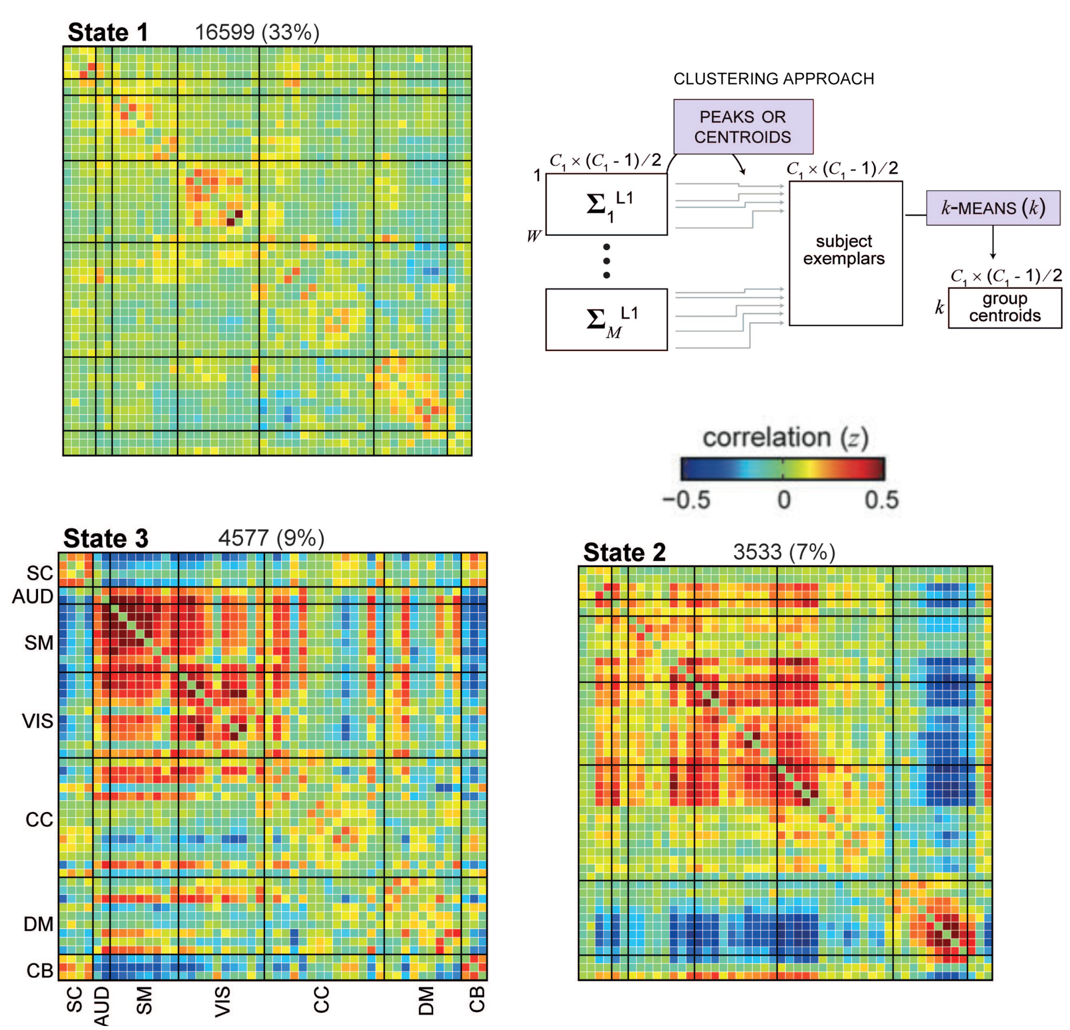
(Leonardi et al. 2013)

Extracting dFC states

- Concatenated data yield building blocks for the whole population
  - Resting-state view: mutually exclusive states



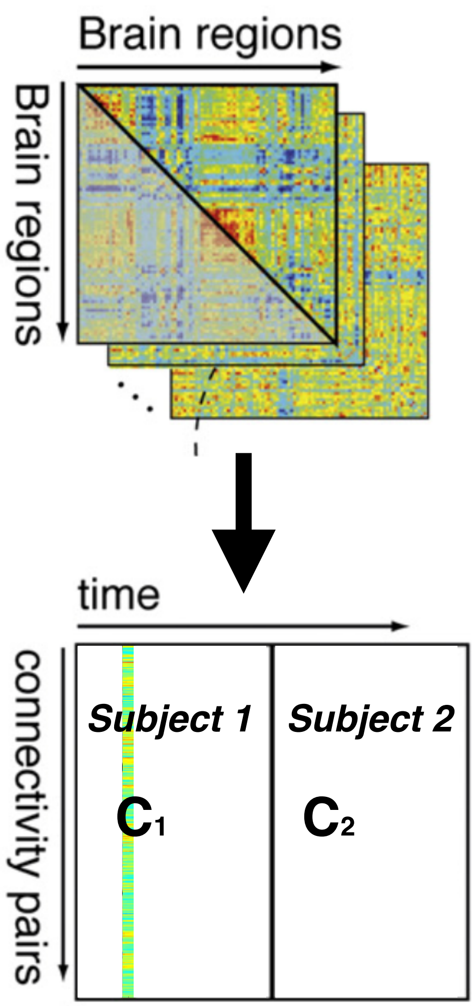
(Leonardi et al. 2013)



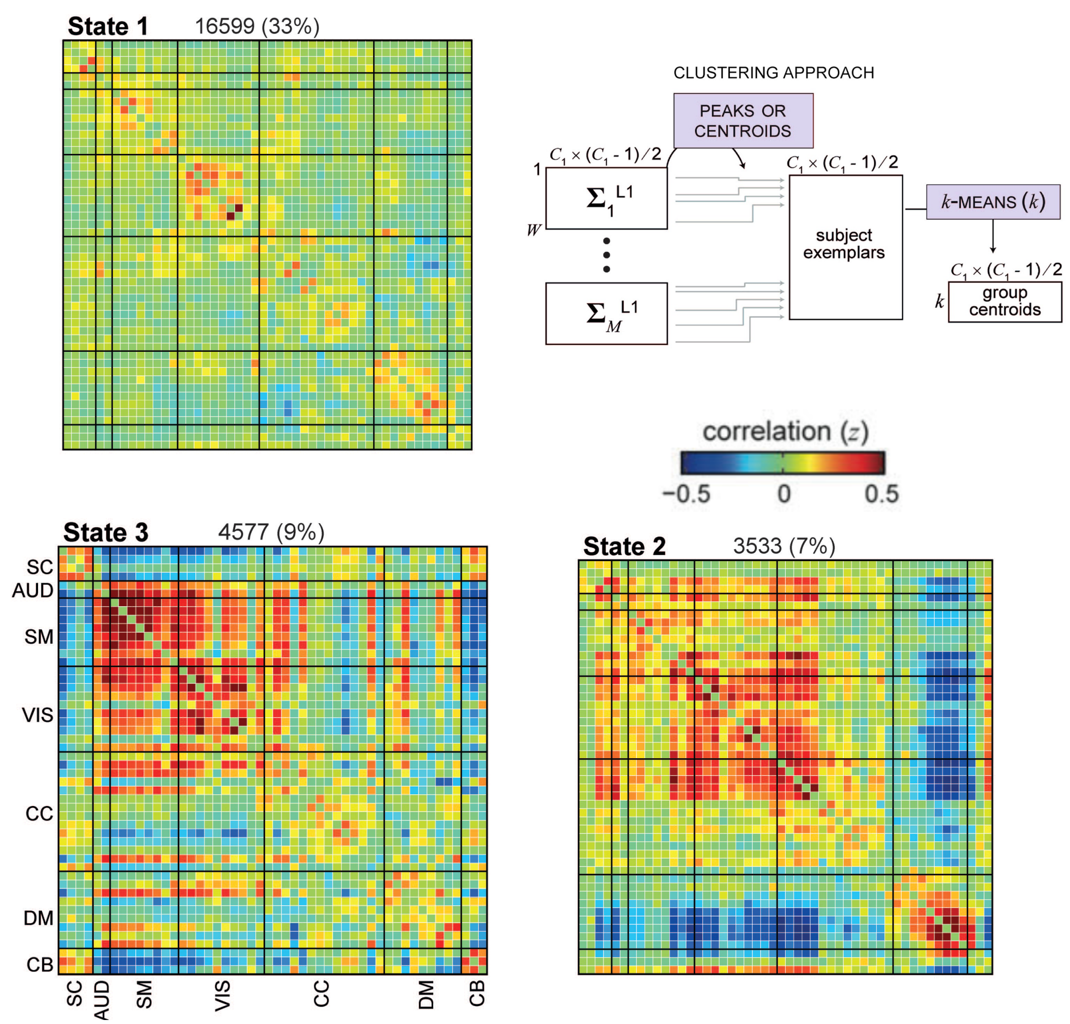
(Allen et al. 2014)

Extracting dFC states

- Concatenated data yield building blocks for the whole population
  - Resting-state view: mutually exclusive states
  - *Cleaning* recipes: selection of subject exemplars



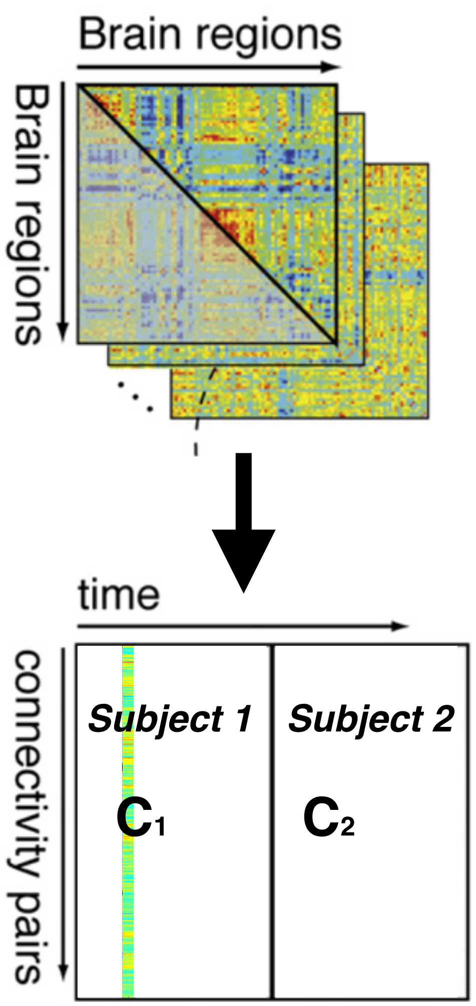
(Leonardi et al. 2013)



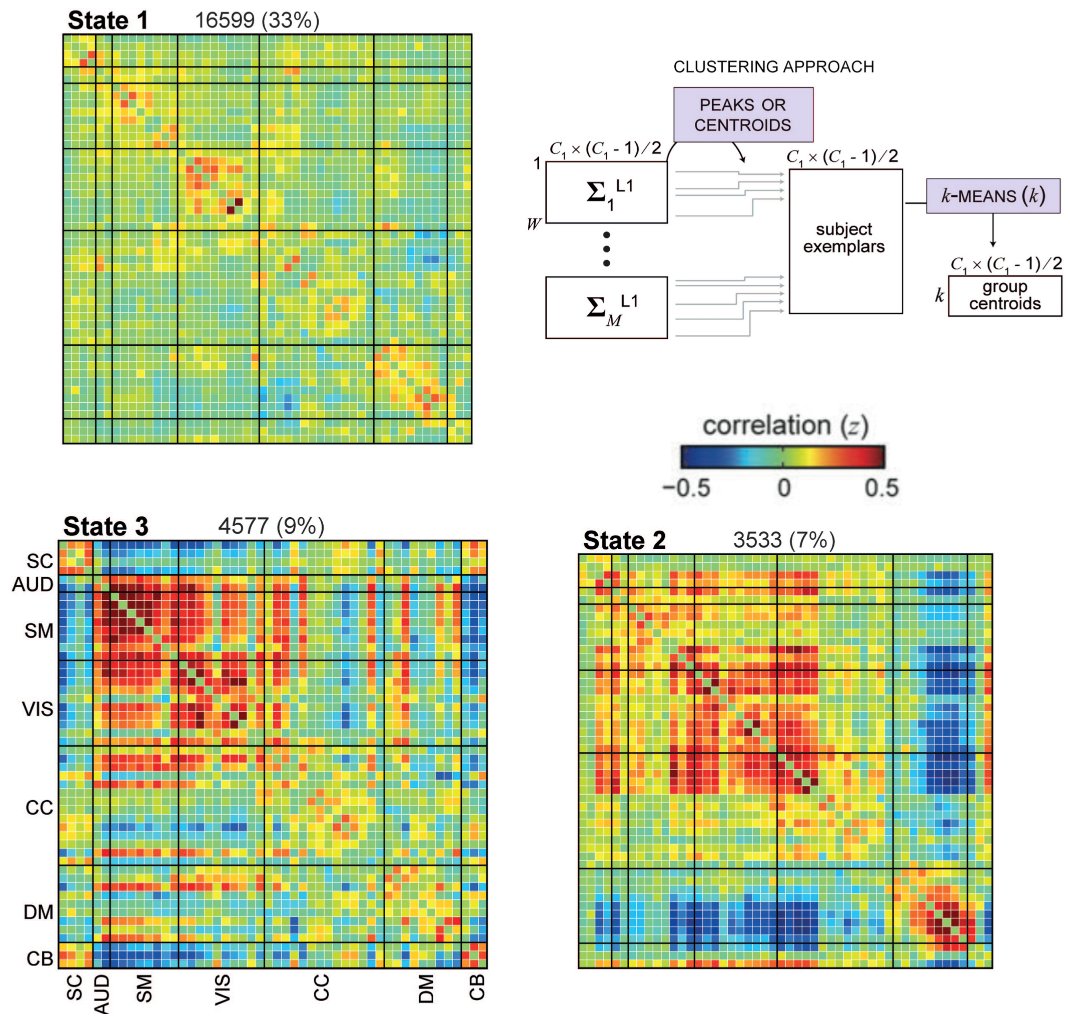
(Allen et al. 2014)

Extracting dFC states

- Concatenated data yield building blocks for the whole population
  - Resting-state view: mutually exclusive states
  - *Cleaning* recipes: selection of subject exemplars
  - Interpretation: state reflective of connectivity value



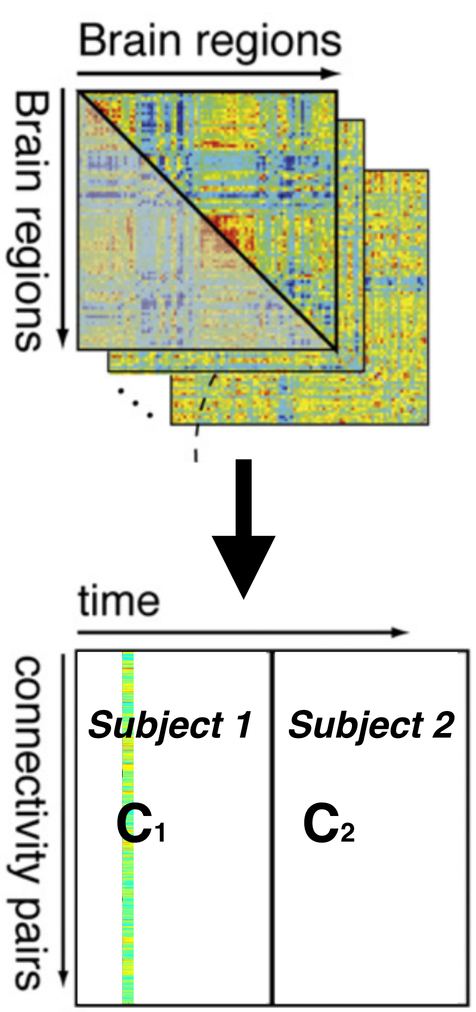
(Leonardi et al. 2013)



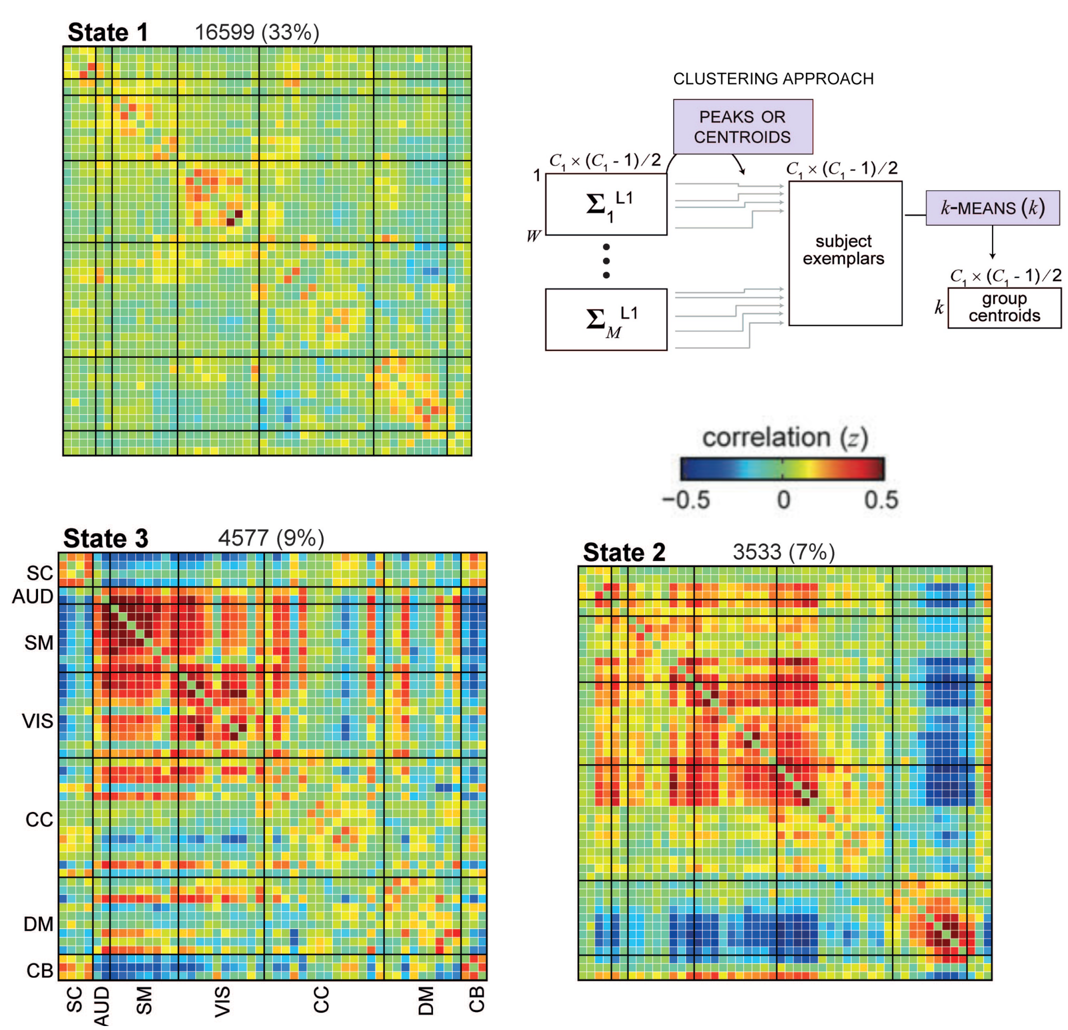
(Allen et al. 2014)

Extracting dFC states

- Concatenated data yield building blocks for the whole population
  - Resting-state view: mutually exclusive states
  - *Cleaning* recipes: selection of subject exemplars
  - Interpretation: state reflective of connectivity value
  - Informative metrics: counts, dwell time



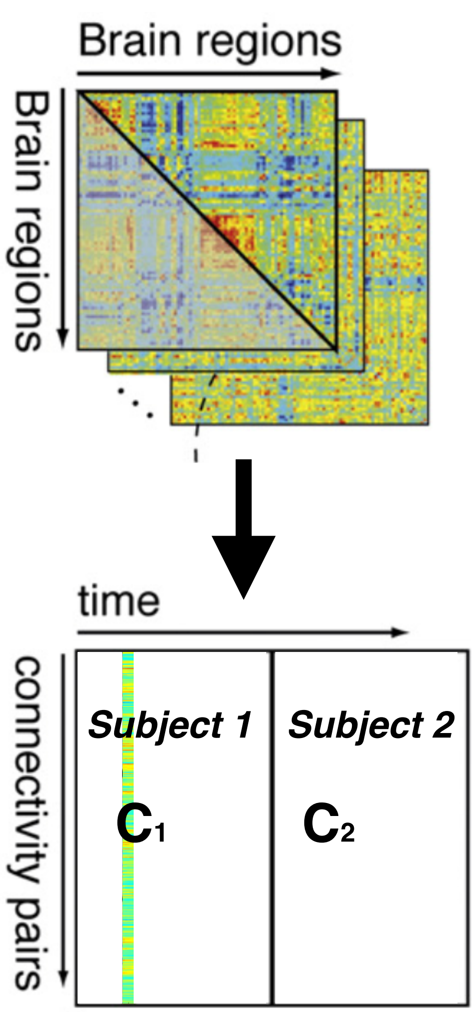
(Leonardi et al. 2013)



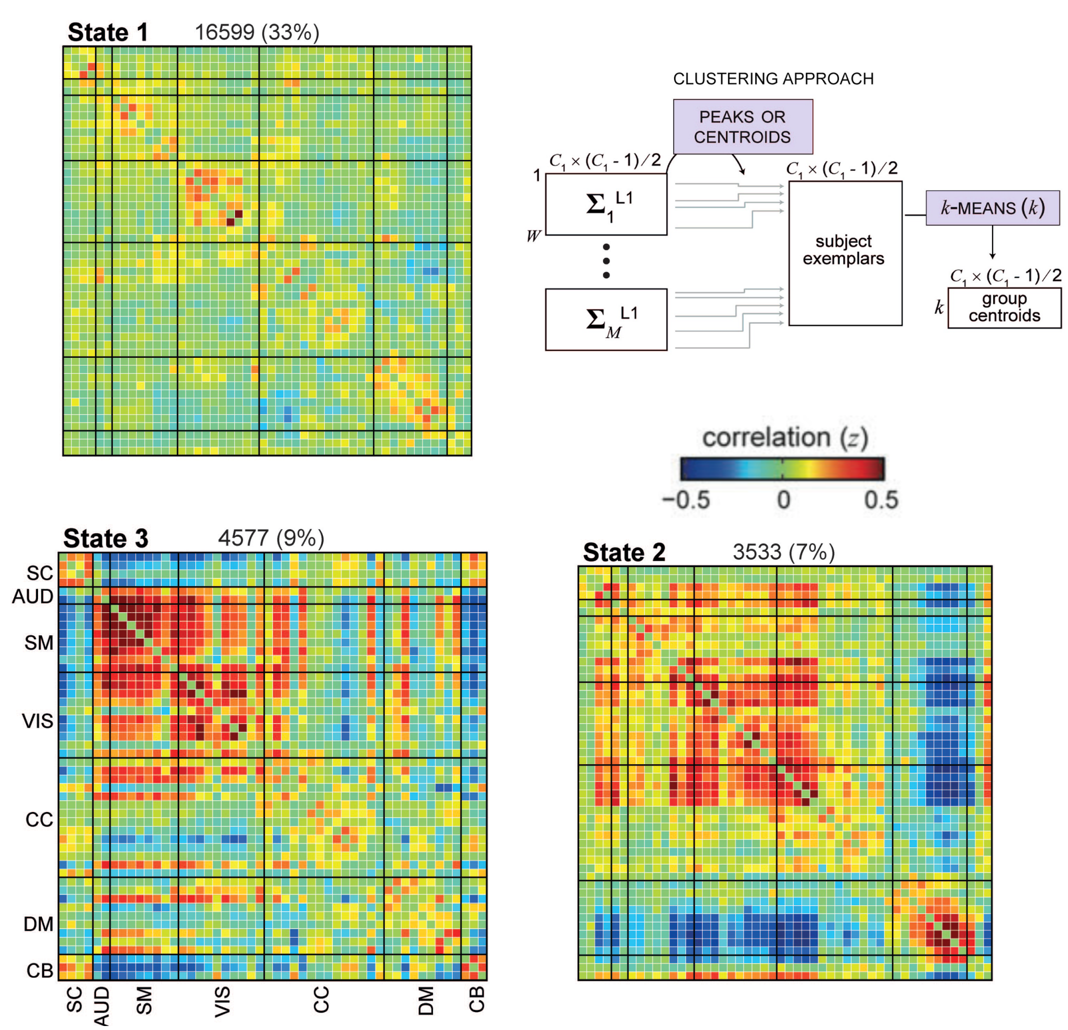
(Allen et al. 2014)

Extracting dFC states

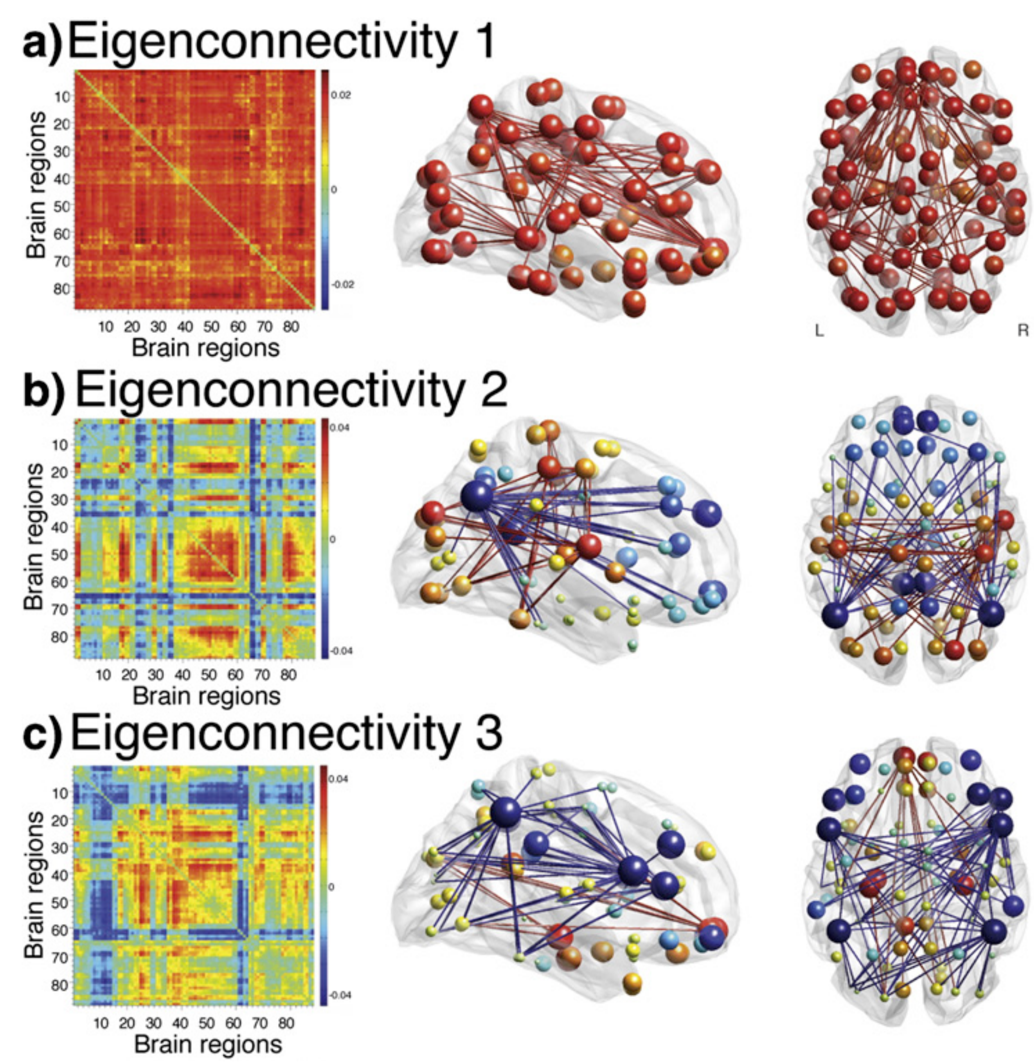
- Concatenated data yield building blocks for the whole population
  - Resting-state view: mutually exclusive states *vs* linear combination of states
  - *Cleaning* recipes: selection of subject exemplars
  - Interpretation: state reflective of connectivity value
  - Informative metrics: counts, dwell time



(Leonardi et al. 2013)



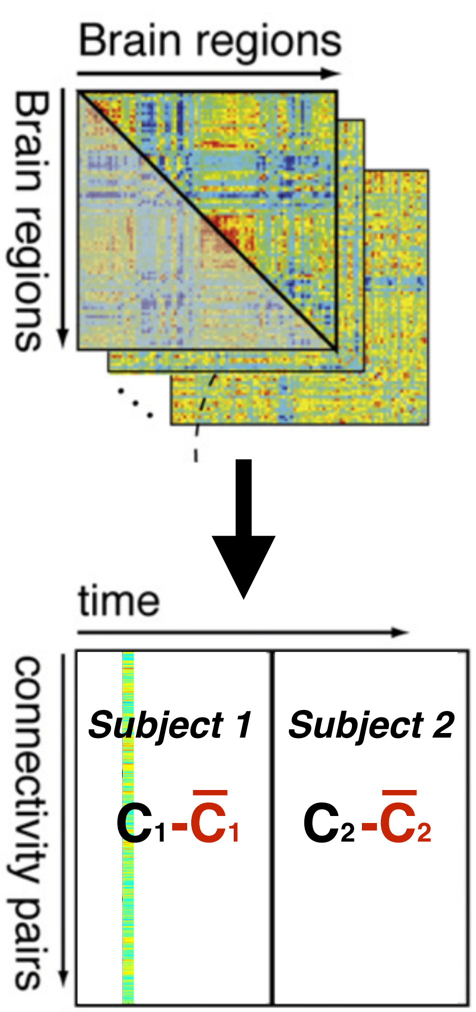
(Allen et al. 2014)



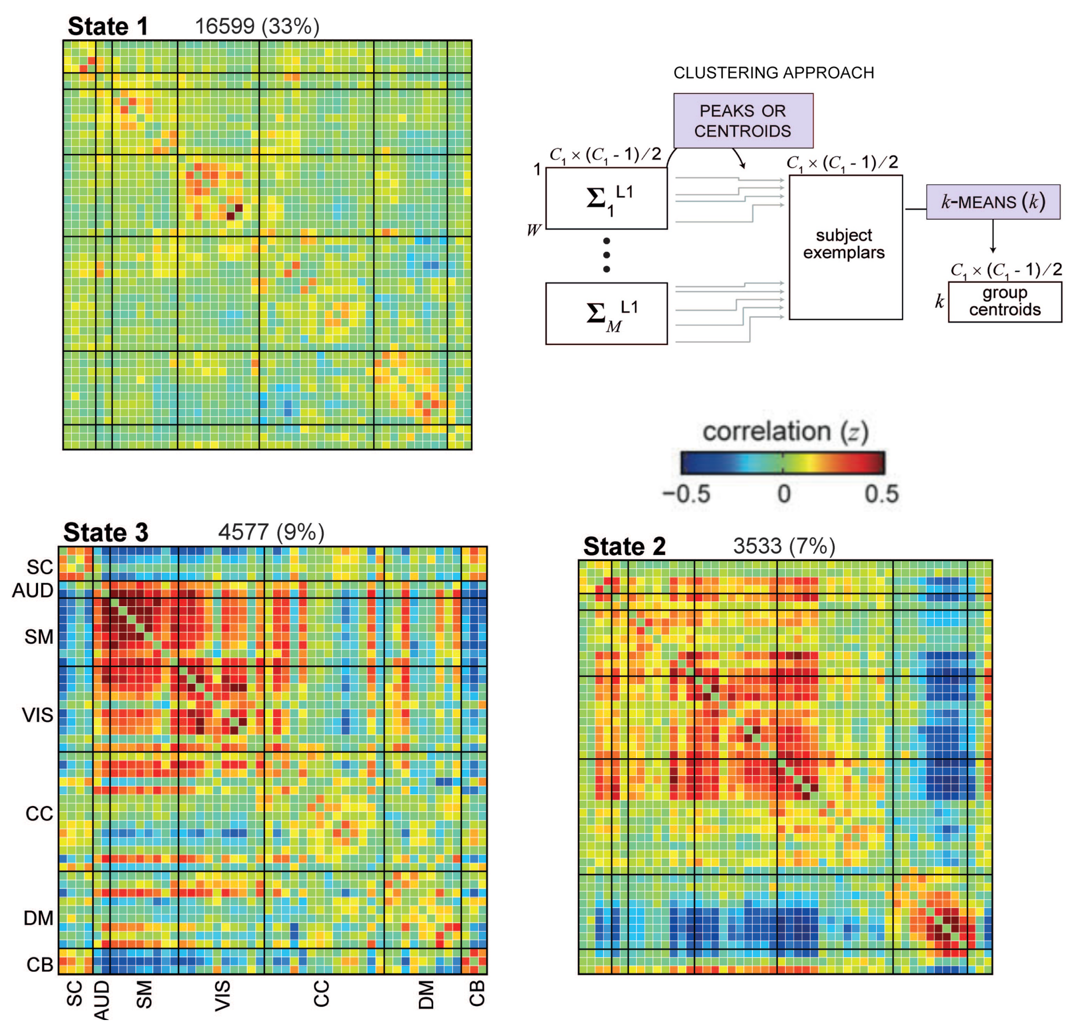
(Leonardi et al. 2013)

Extracting dFC states

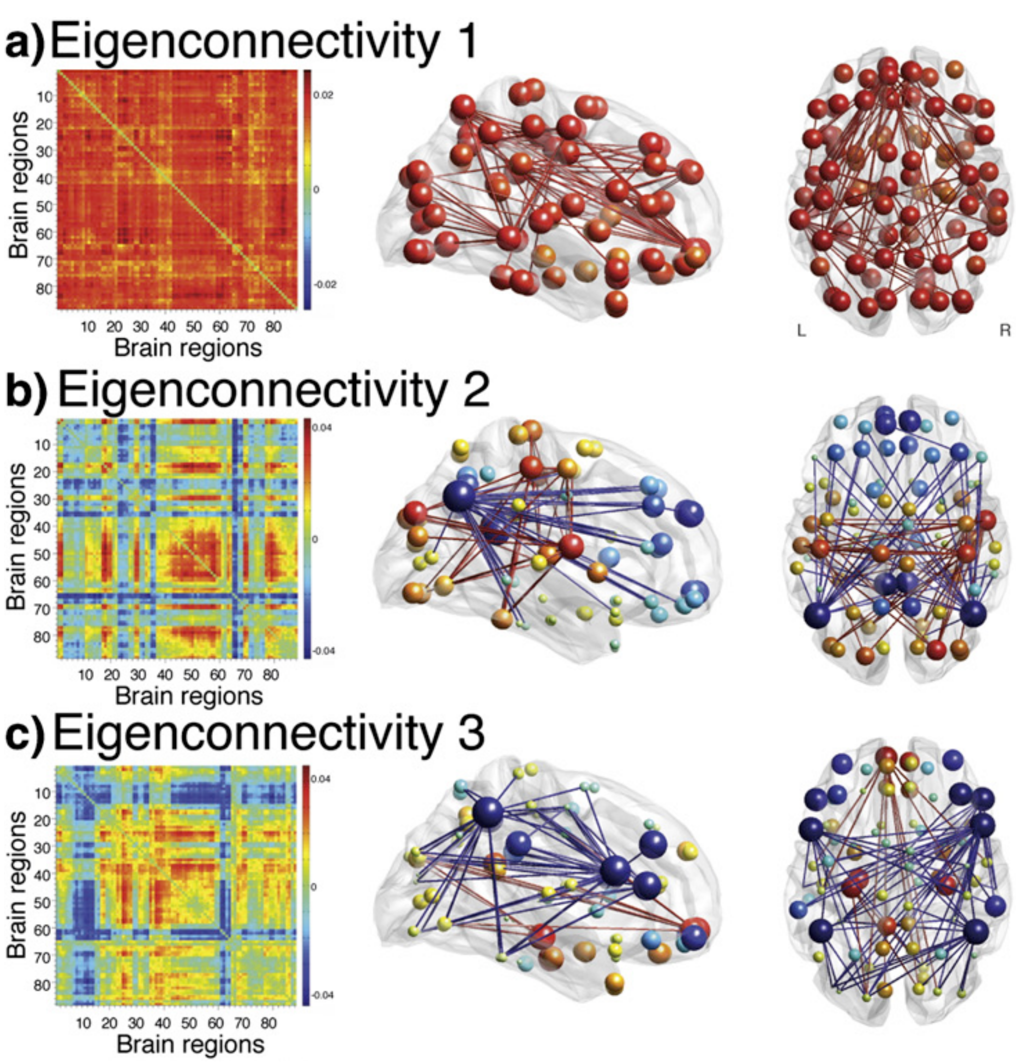
- Concatenated data yield building blocks for the whole population
  - Resting-state view: mutually exclusive states *vs* linear combination of states
  - *Cleaning* recipes: selection of subject exemplars *vs* demeaning
  - Interpretation: state reflective of connectivity value *vs* change from mean
  - Informative metrics: counts, dwell time



(Leonardi et al. 2013)



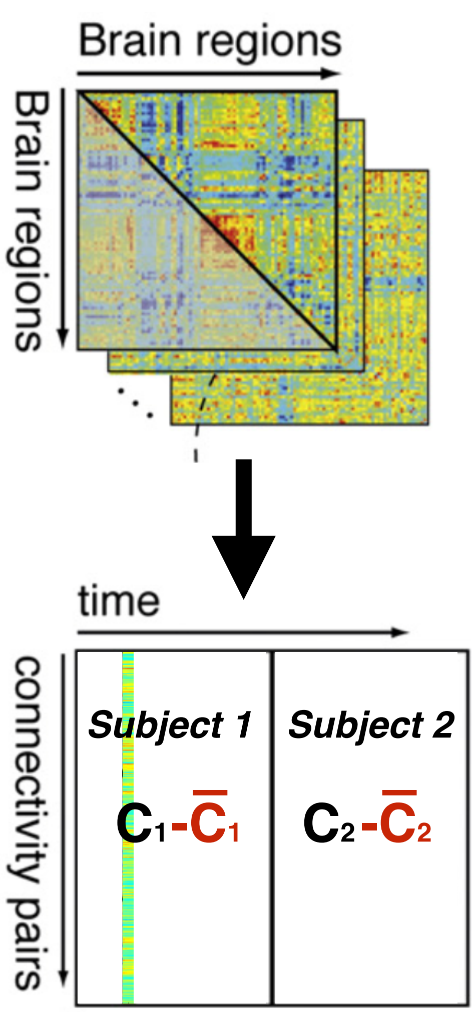
(Allen et al. 2014)



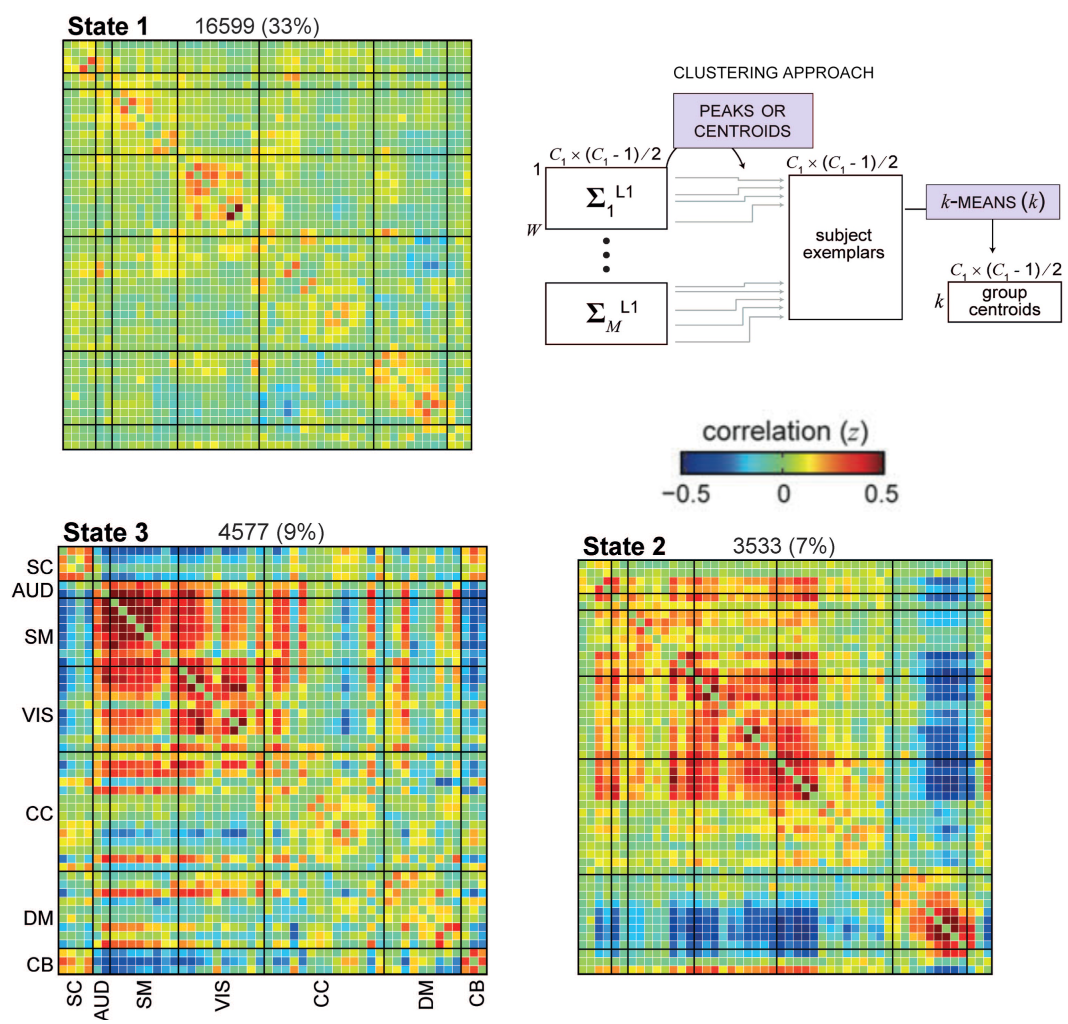
(Leonardi et al. 2013)

Extracting dFC states

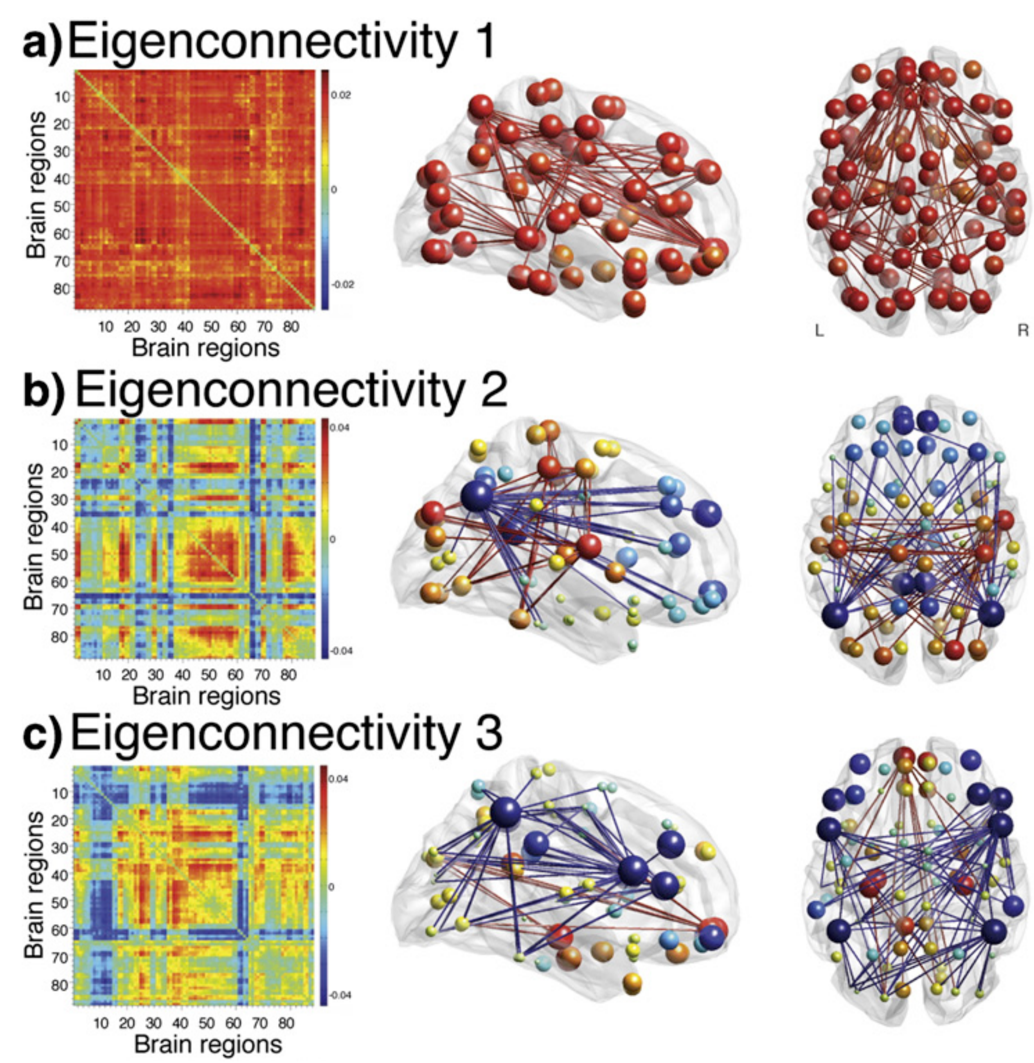
- Concatenated data yield building blocks for the whole population
  - Resting-state view: mutually exclusive states *vs* linear combination of states
  - *Cleaning* recipes: selection of subject exemplars *vs* demeaning
  - Interpretation: state reflective of connectivity value *vs* change from mean
  - Informative metrics: counts, dwell time *vs* *weights, meta-states*



(Leonardi et al. 2013)

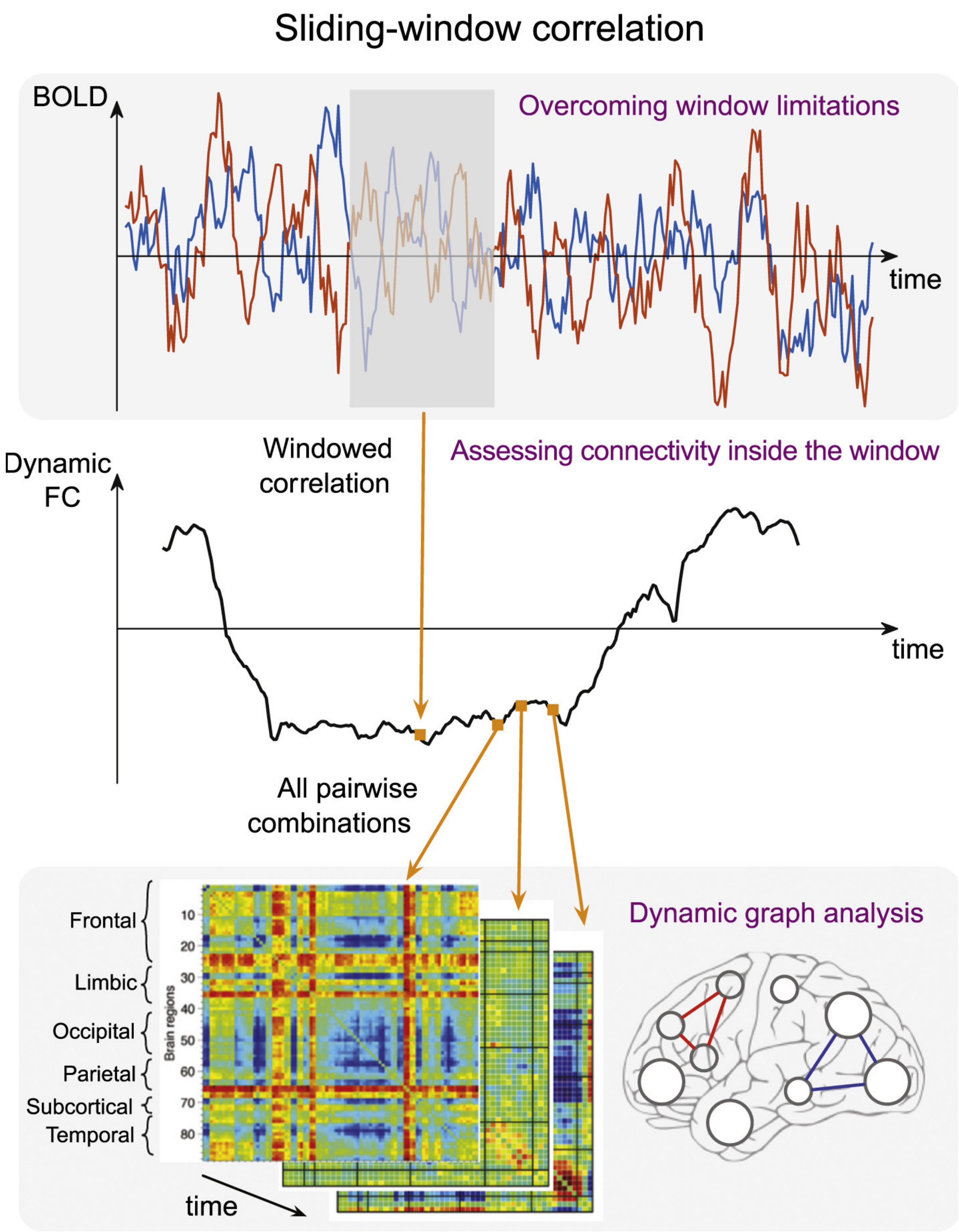


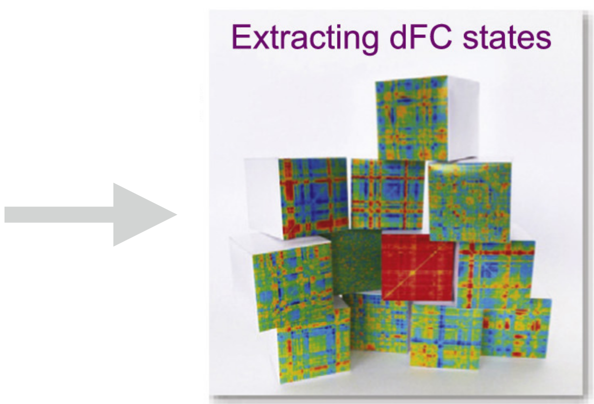
(Allen et al. 2014)



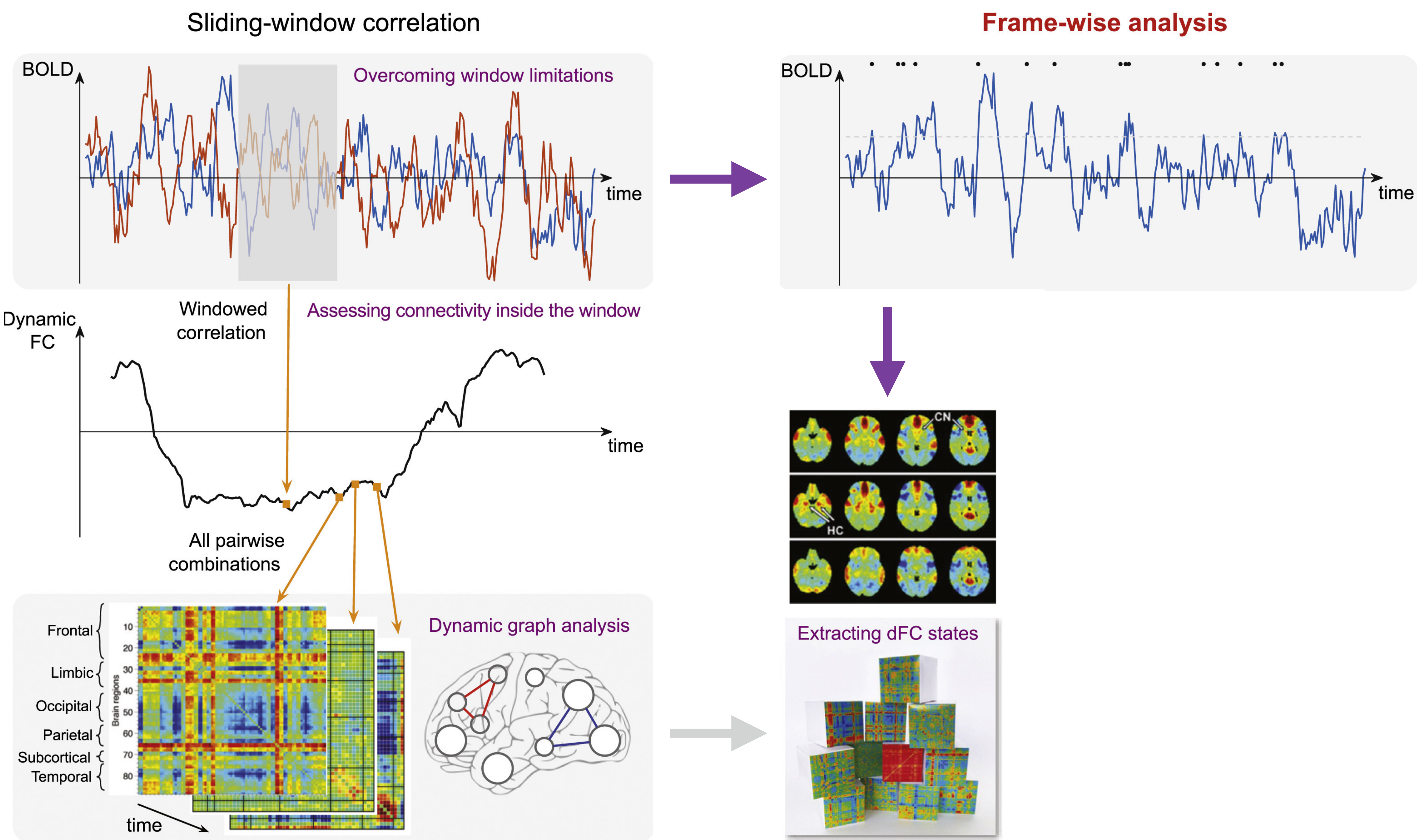
(Leonardi et al. 2013)

Towards novel dFC analytical tools



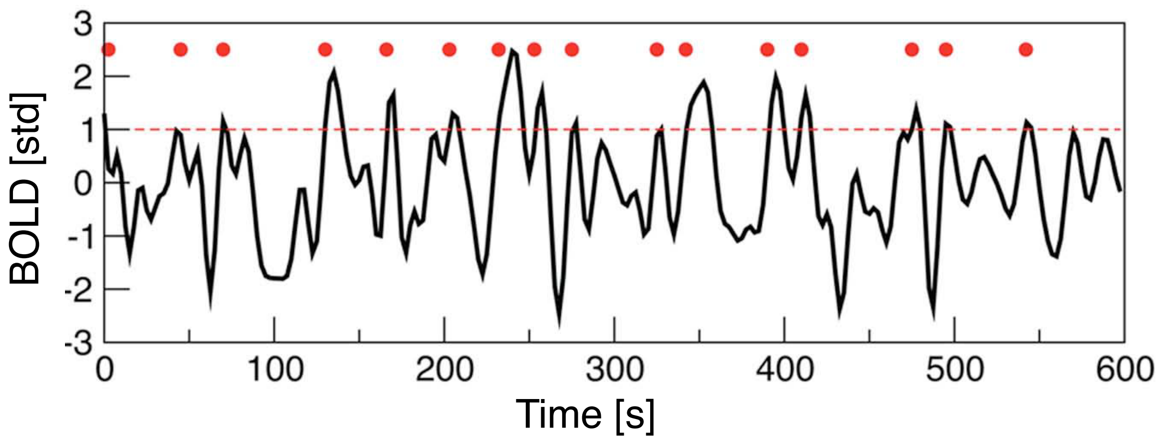


Towards novel dFC analytical tools



From sliding window to single frames

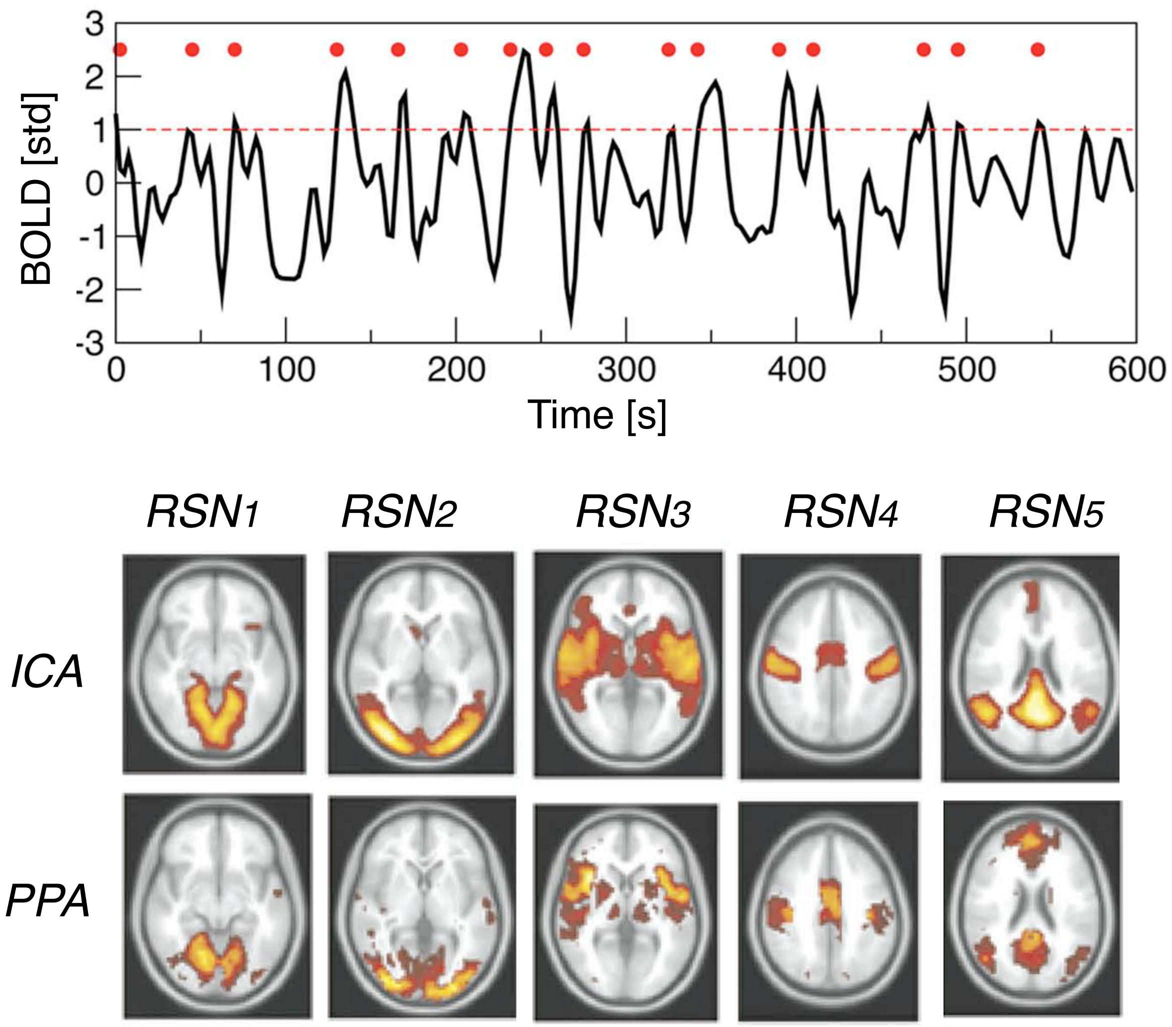
- Point process analysis (PPA)
  - From second-order (connectivity) to first-order (activation) information



(Tagliazucchi et al. 2012)

From sliding window to single frames

- Point process analysis (PPA)
  - From second-order (connectivity) to first-order (activation) information

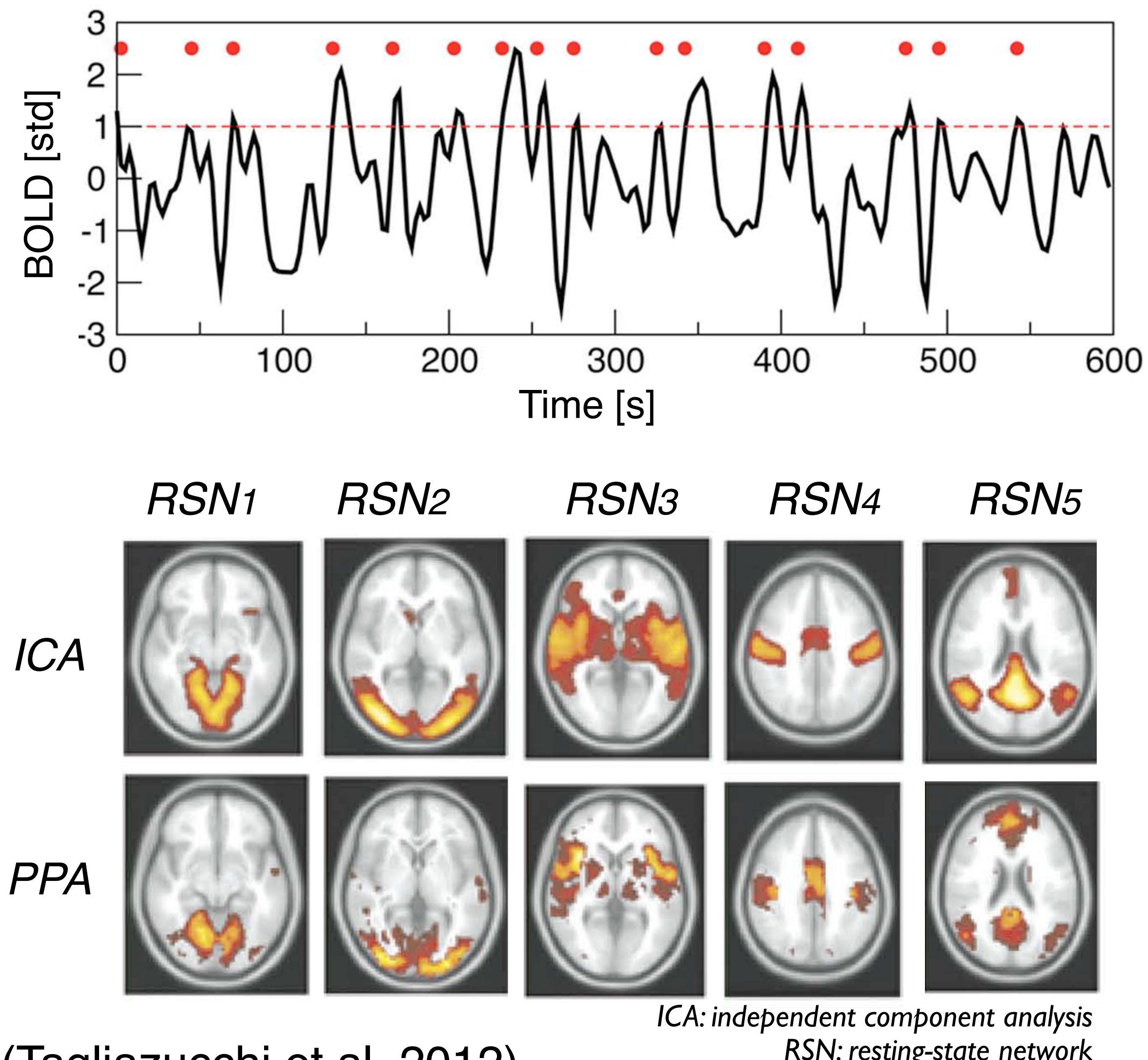


ICA: independent component analysis
RSN: resting-state network

(Tagliazucchi et al. 2012)

From sliding window to single frames

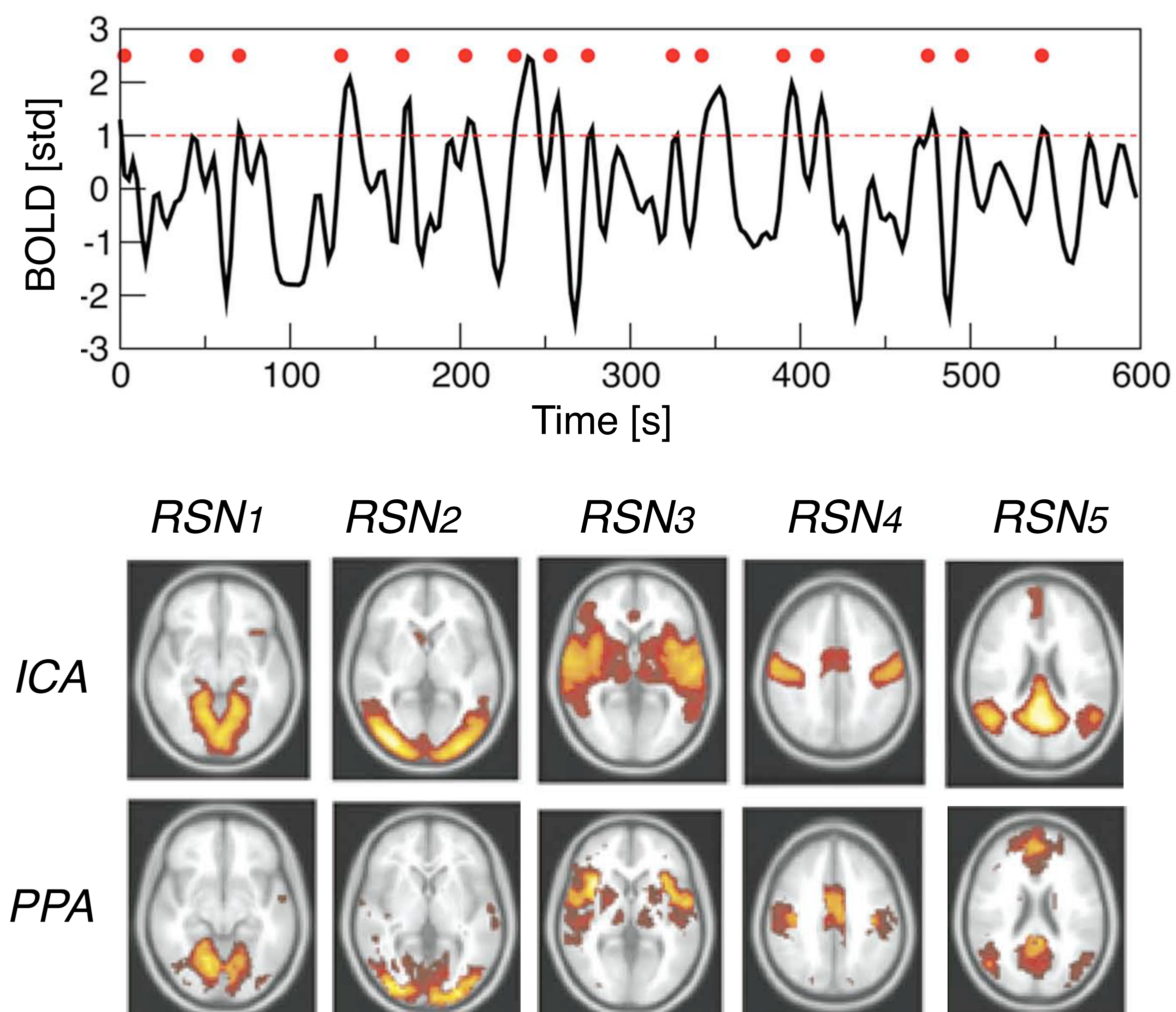
- Point process analysis (PPA)
  - From second-order (connectivity) to first-order (activation) information
  - Less data needed in computations, but arbitrary threshold to select

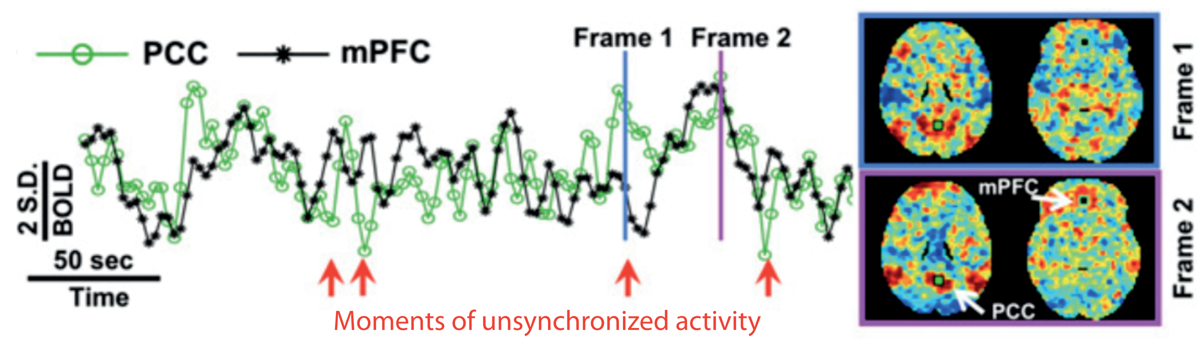


(Tagliazucchi et al. 2012)

From sliding window to single frames

- Point process analysis (PPA)
  - From second-order (connectivity) to first-order (activation) information
  - Less data needed in computations, but arbitrary threshold to select
- Co-activation pattern (CAP) analysis





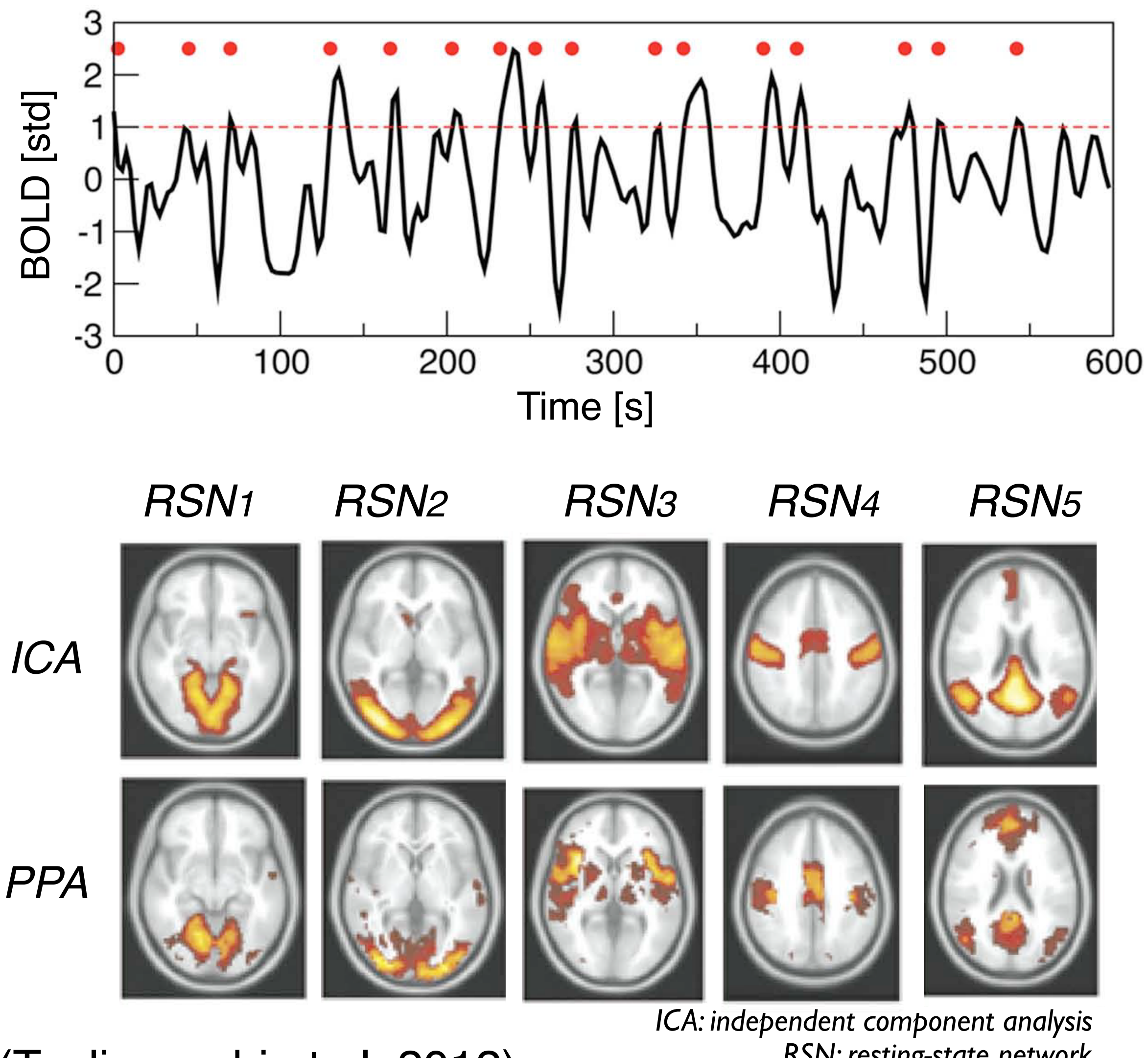
ICA: independent component analysis
RSN: resting-state network

(Tagliazucchi et al. 2012)

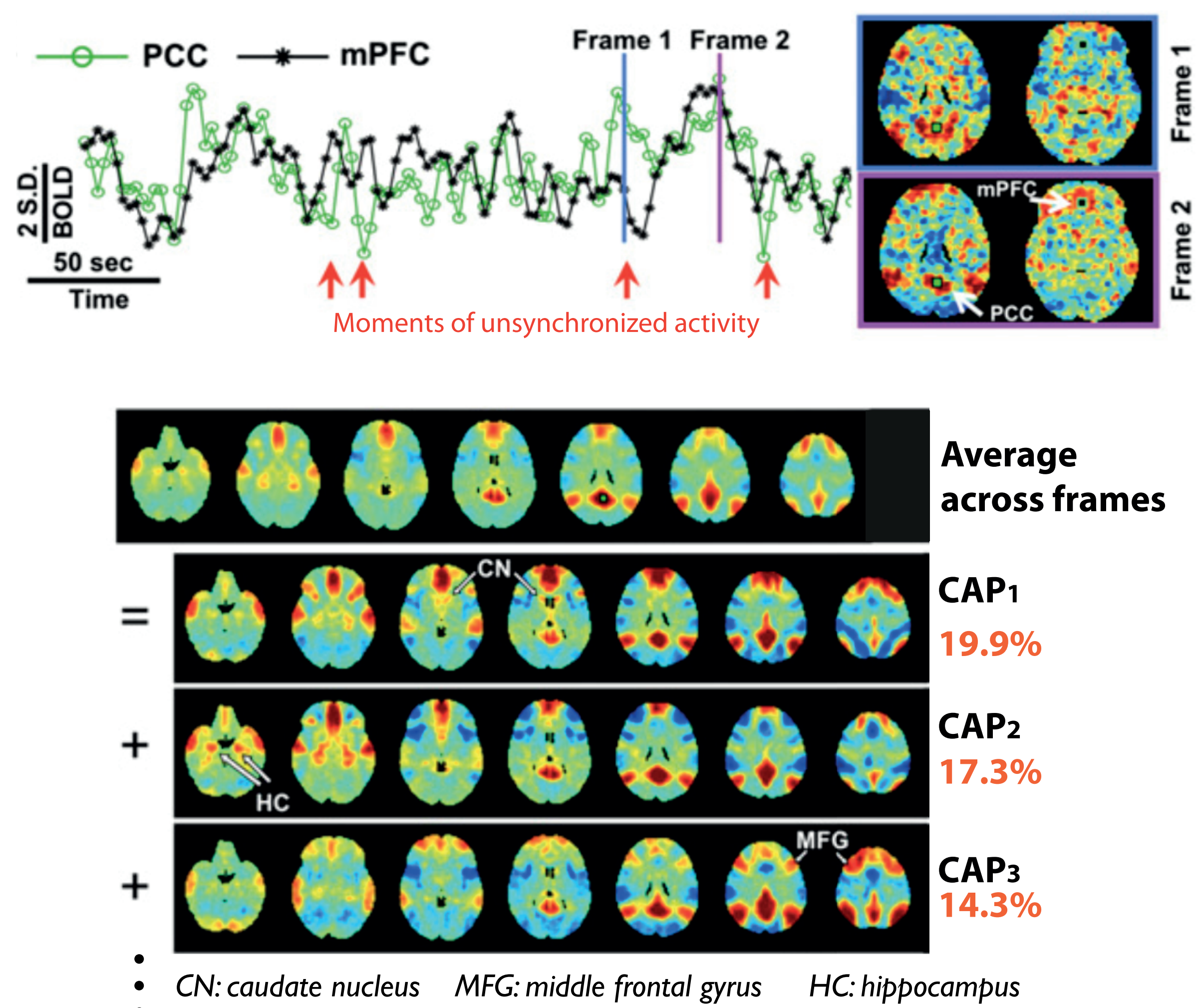
(Liu and Duyn 2013)

From sliding window to single frames

- Point process analysis (PPA)
  - From second-order (connectivity) to first-order (activation) information
  - Less data needed in computations, but arbitrary threshold to select
- Co-activation pattern (CAP) analysis
  - Disentanglement of separate networks co-(de)activating with a seed



(Tagliazucchi et al. 2012)

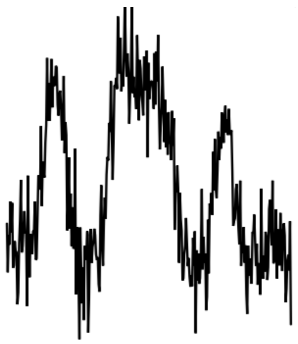


(Liu and Duyn 2013)

From sliding window to single frames

- Hemodynamic effect undone by paradigm-free mapping (PFM)

(Karahanoglu et al. 2013)

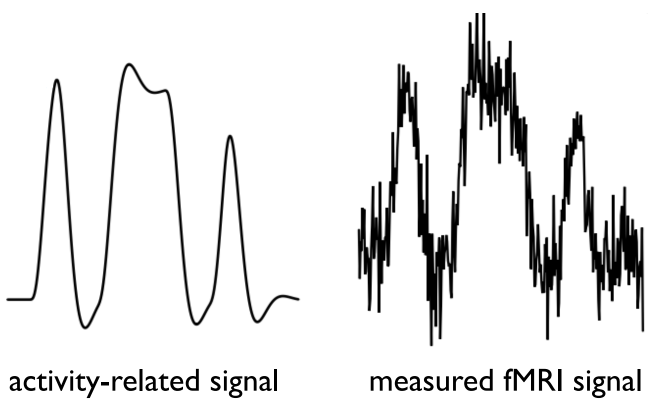


measured fMRI signal

From sliding window to single frames

- Hemodynamic effect undone by paradigm-free mapping (PFM)

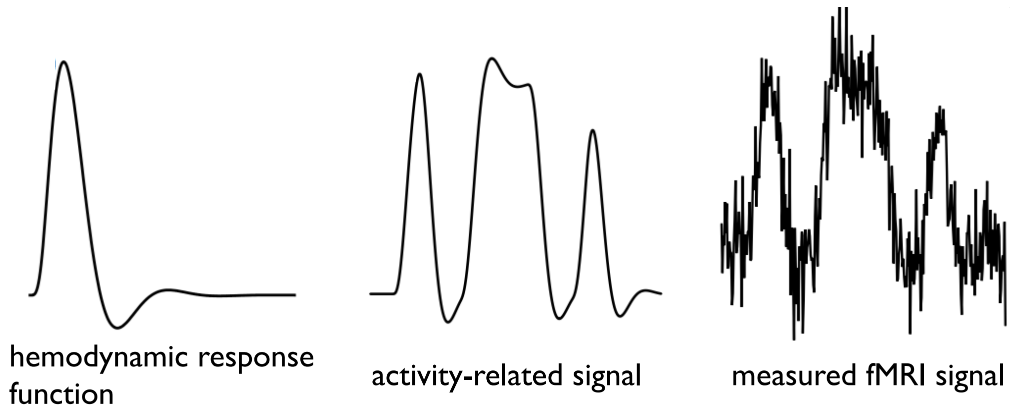
(Karahanoglu et al. 2013)



From sliding window to single frames

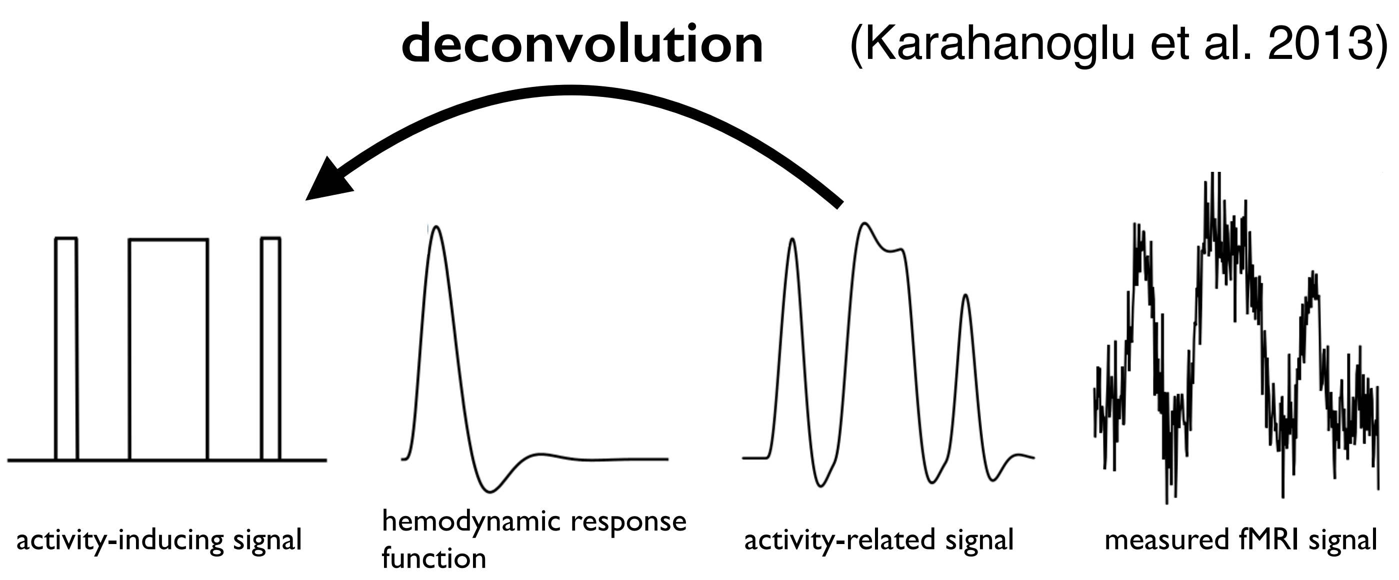
- Hemodynamic effect undone by paradigm-free mapping (PFM)
  - Requires a hemodynamic response function estimate

(Karahanoglu et al. 2013)



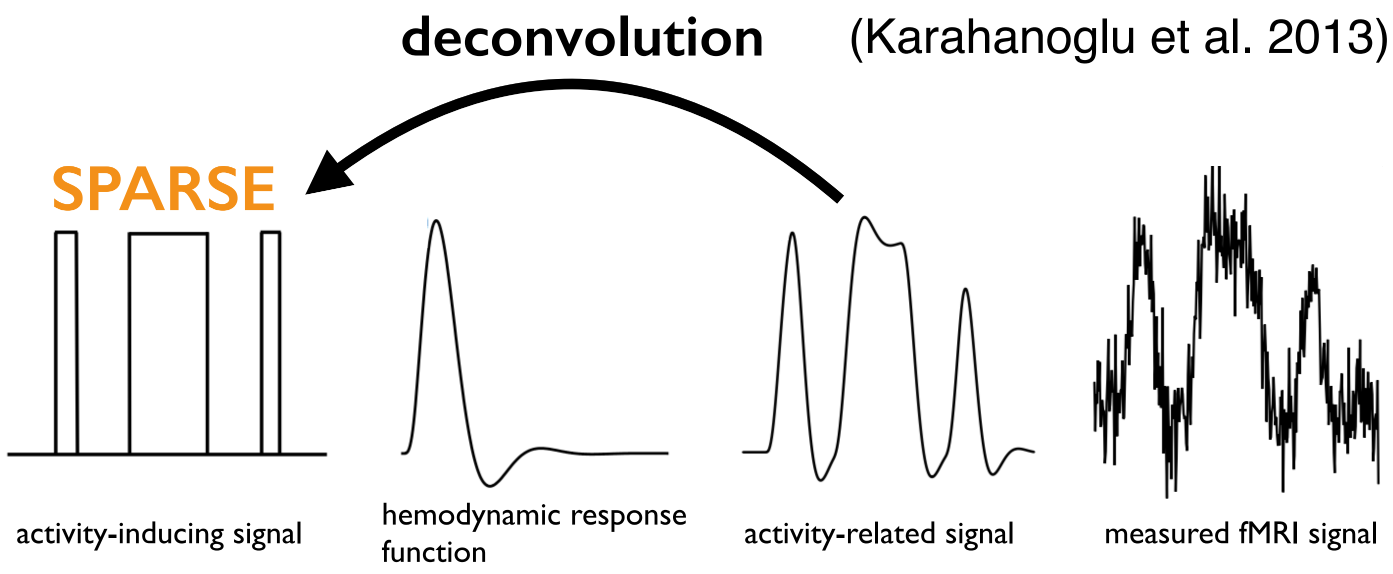
From sliding window to single frames

- Hemodynamic effect undone by paradigm-free mapping (PFM)
  - Requires a hemodynamic response function estimate



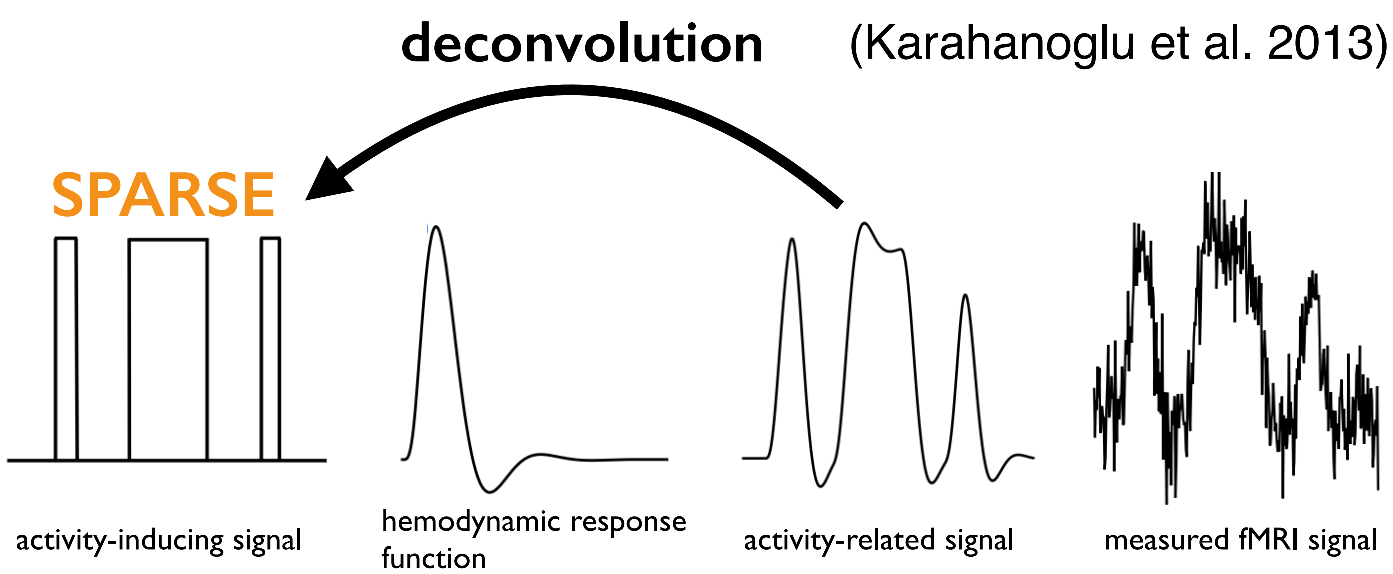
From sliding window to single frames

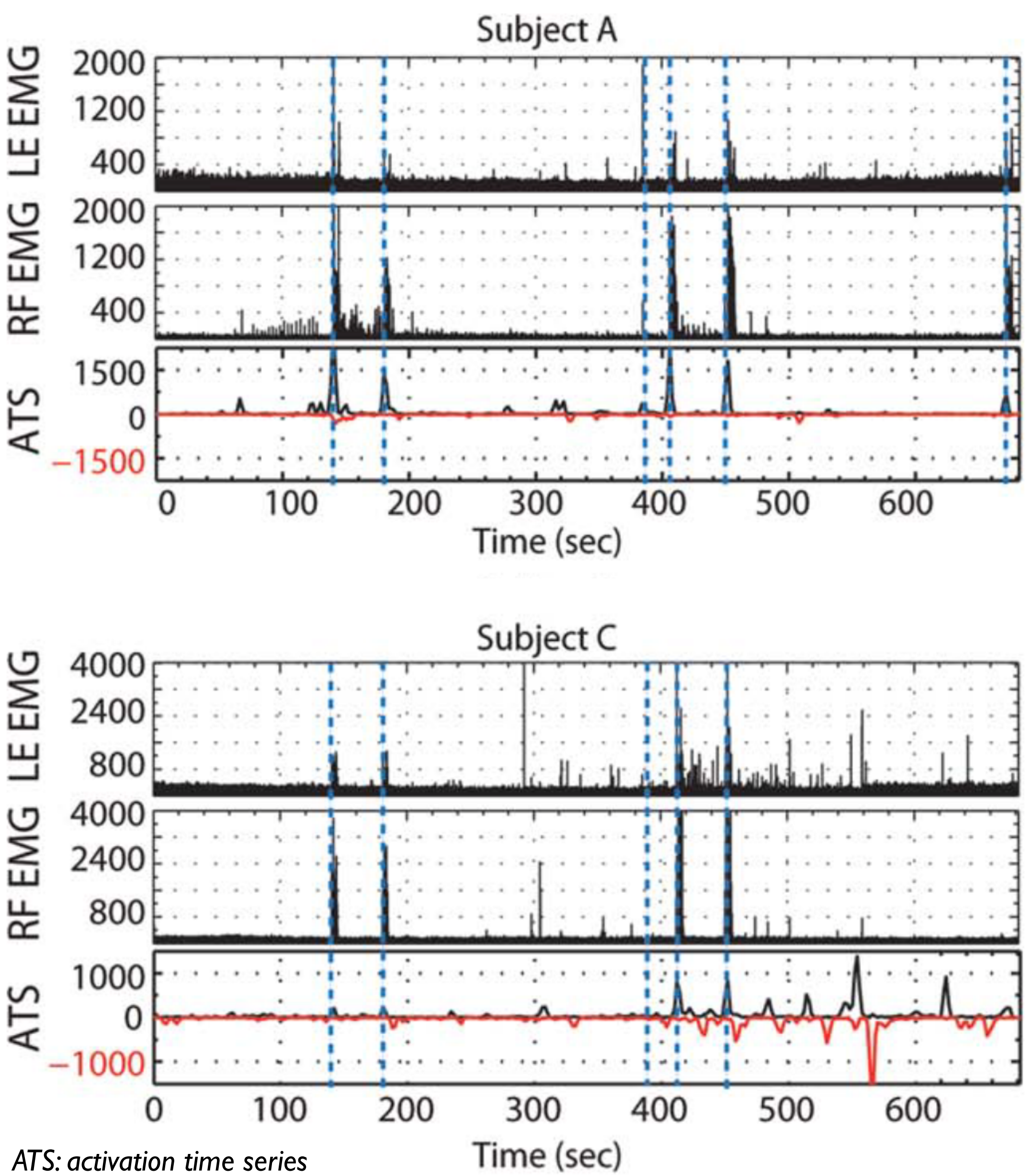
- Hemodynamic effect undone by paradigm-free mapping (PFM)
  - Requires a hemodynamic response function estimate
  - Hypothesises sparsity of the underlying neuronal (*activity-inducing*) signal



From sliding window to single frames

- Hemodynamic effect undone by paradigm-free mapping (PFM)
  - Requires a hemodynamic response function estimate
  - Hypothesises sparsity of the underlying neuronal (*activity-inducing*) signal

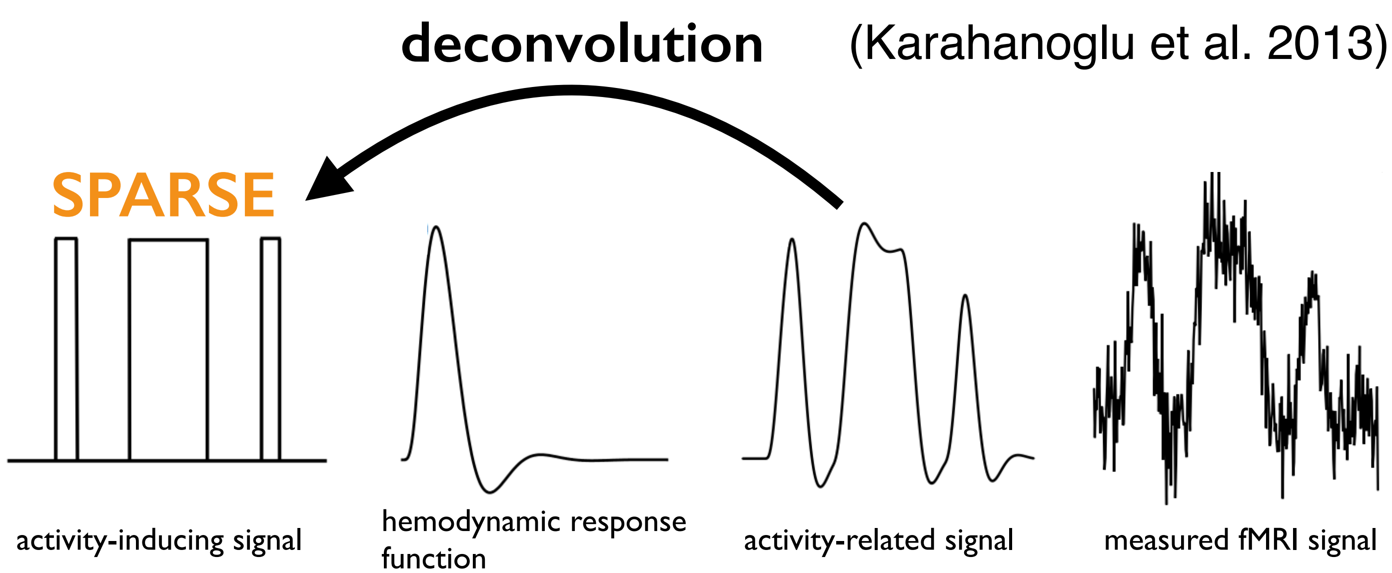




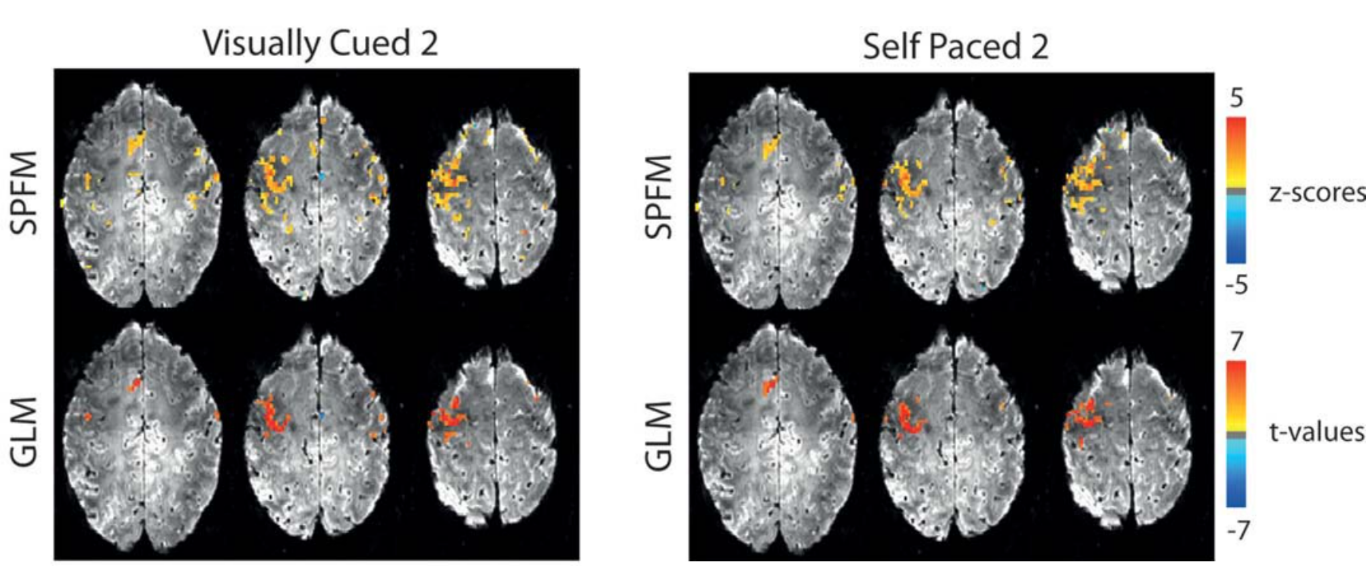
(Caballero Gaudes et al. 2013)

From sliding window to single frames

- Hemodynamic effect undone by paradigm-free mapping (PFM)
  - Requires a hemodynamic response function estimate
  - Hypothesises sparsity of the underlying neuronal (*activity-inducing*) signal

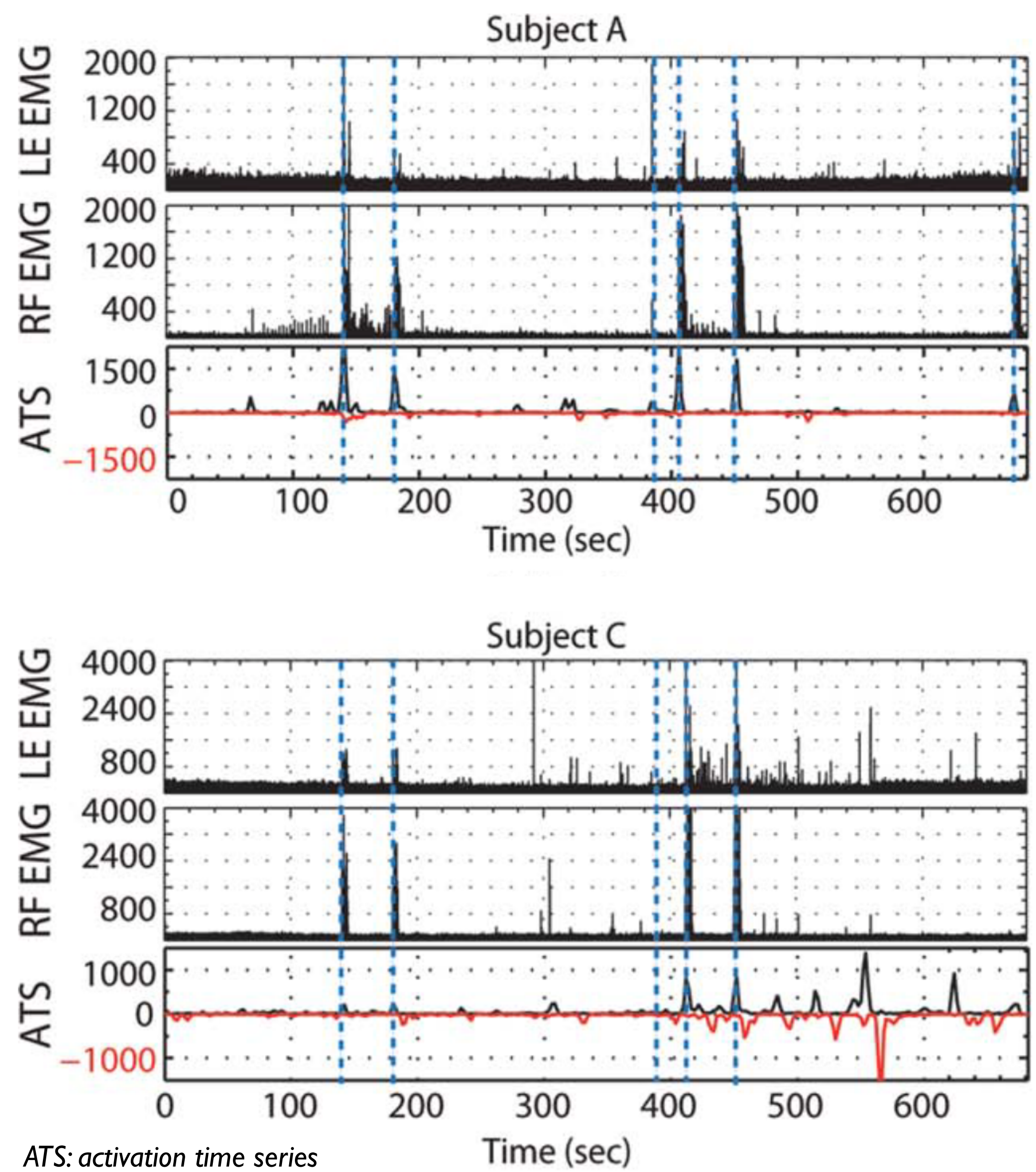


(Karahanoglu et al. 2013)



SPFM: sparse paradigm free mapping

GLM: general linear model



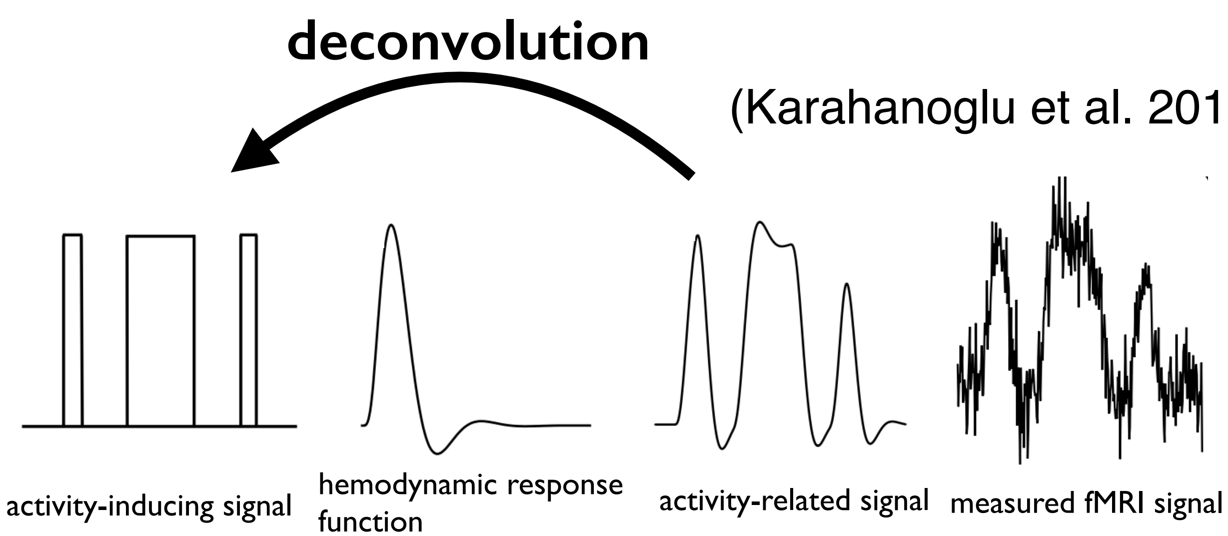
ATS: activation time series

(Caballero Gaudes et al. 2013)

From sliding window to single frames

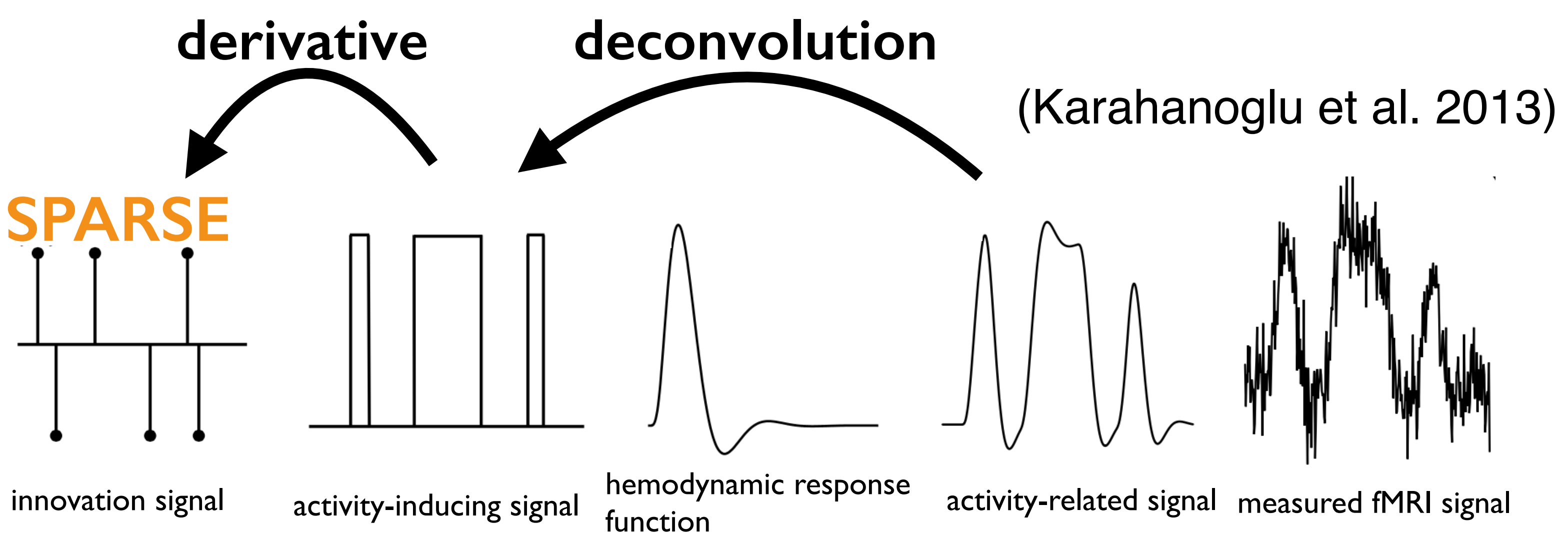
- Total activation (TA) hypothesises sparsity of *changes* in activity and constrains neighbouring voxels to show similar activity profiles

(Karahanoglu et al. 2013)



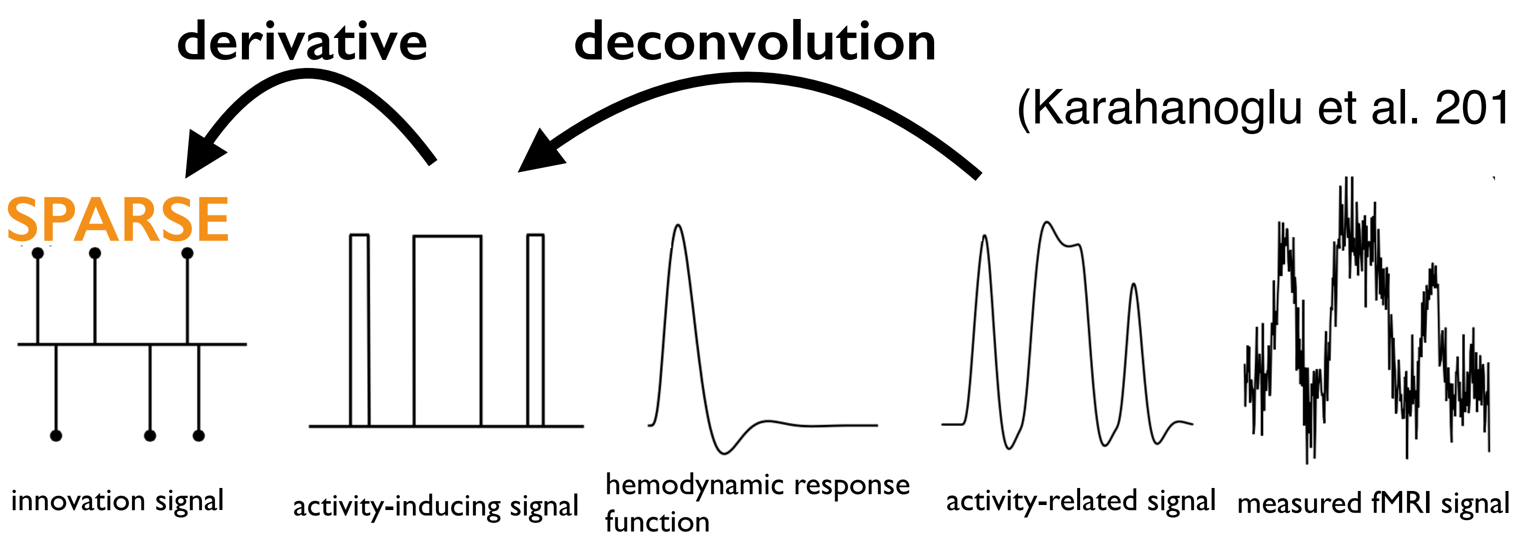
From sliding window to single frames

- Total activation (TA) hypothesises sparsity of *changes* in activity and constrains neighbouring voxels to show similar activity profiles

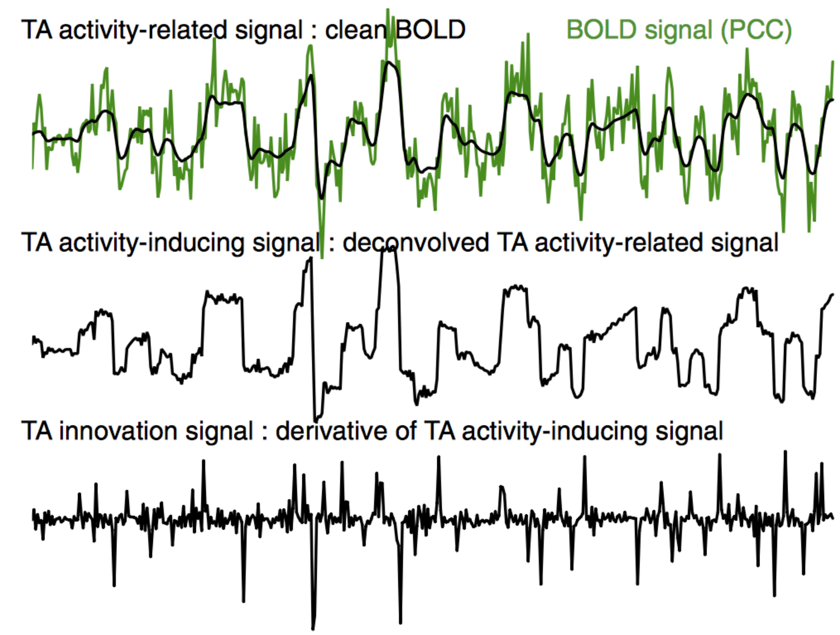


From sliding window to single frames

- Total activation (TA) hypothesises sparsity of *changes* in activity and constrains neighbouring voxels to show similar activity profiles



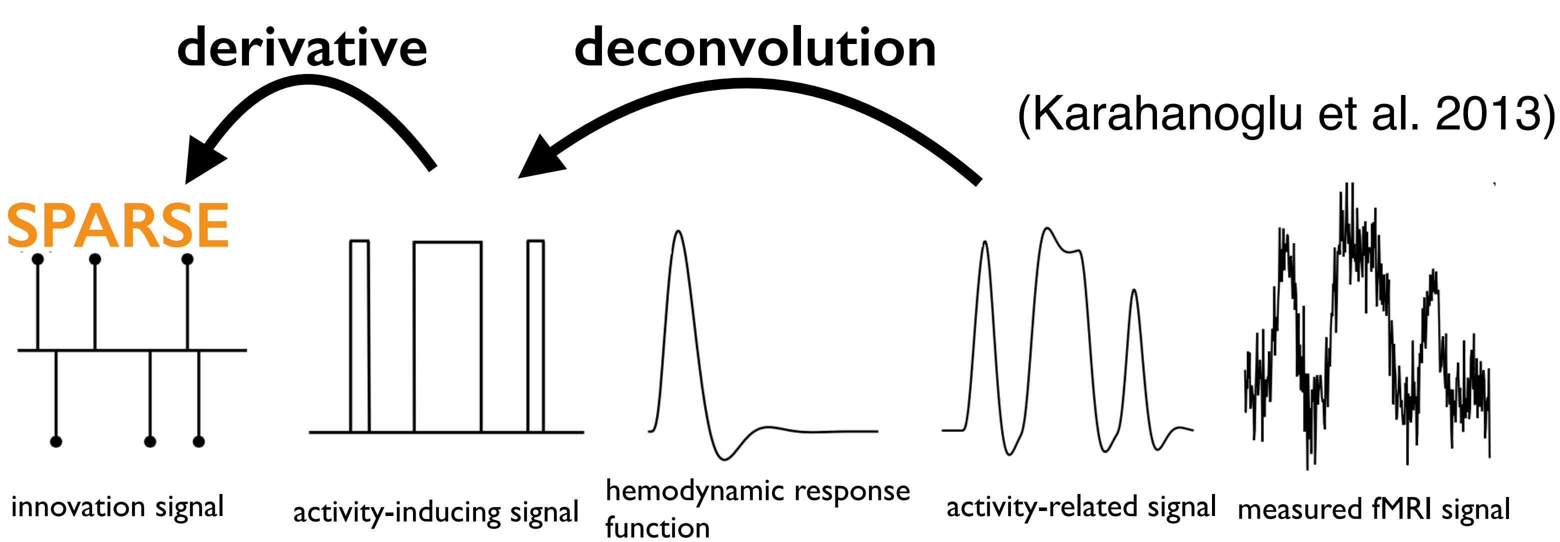
(Karahanoglu et al. 2013)

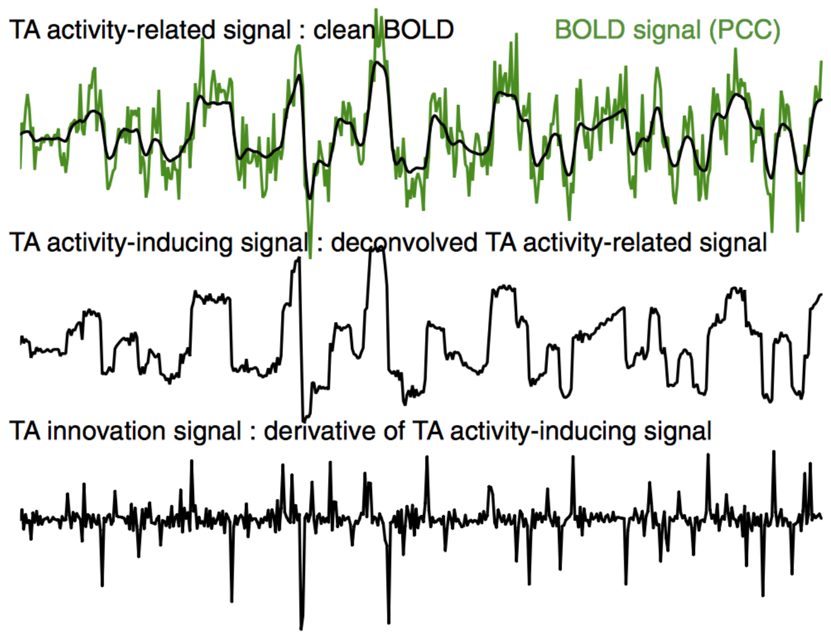


(Karahanoglu and Van De Ville 2015)

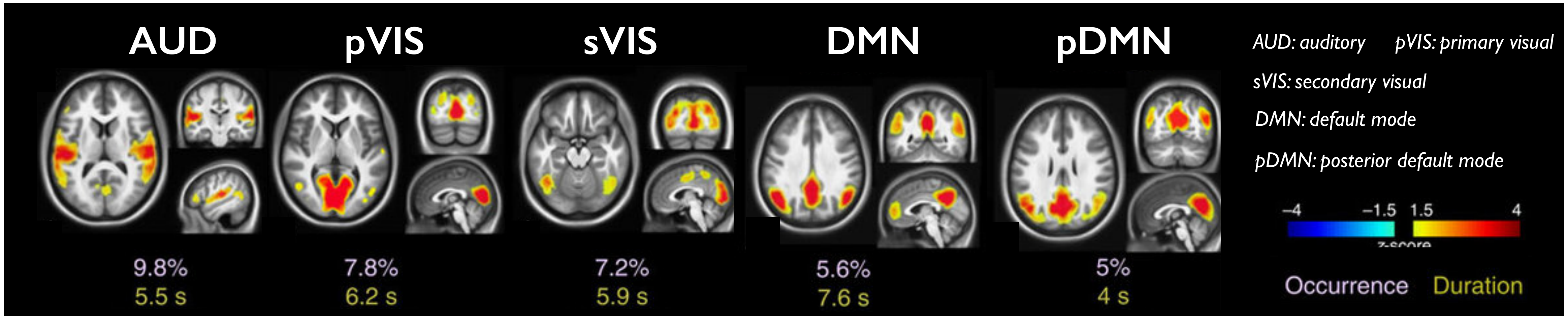
From sliding window to single frames

- Total activation (TA) hypothesises sparsity of *changes* in activity and constrains neighbouring voxels to show similar activity profiles





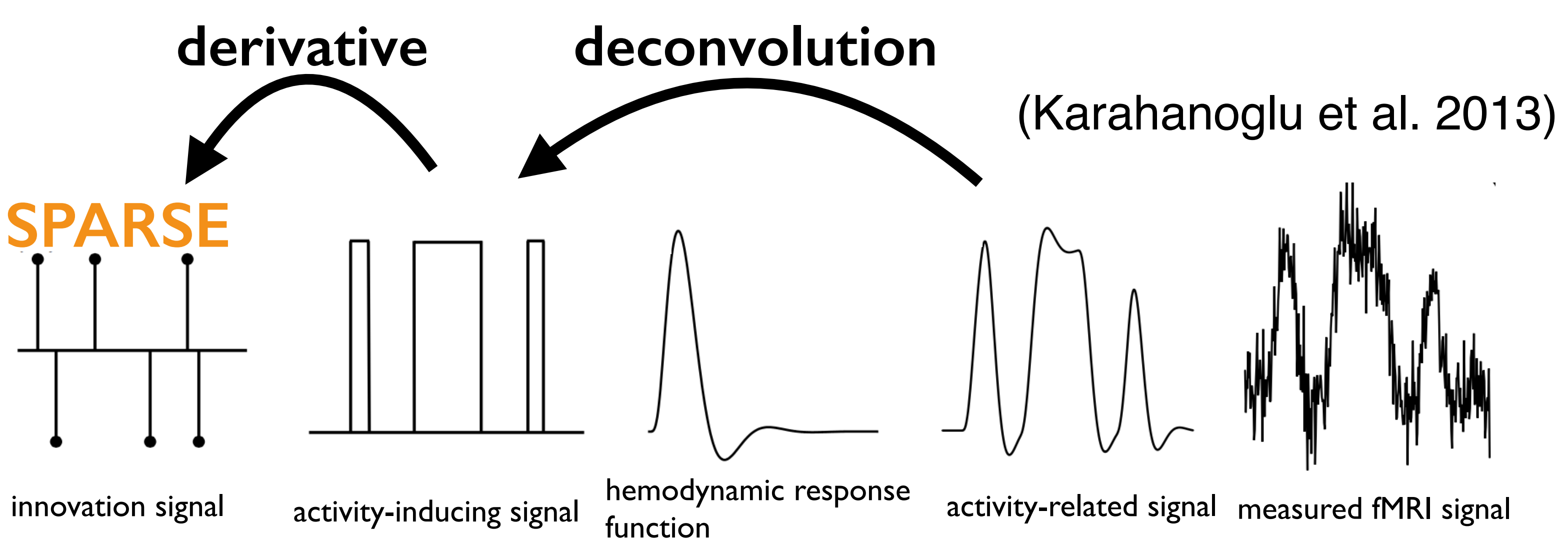
- Generation of *innovation-driven co-activation patterns*
  - Selection and clustering of whole-brain significant innovations

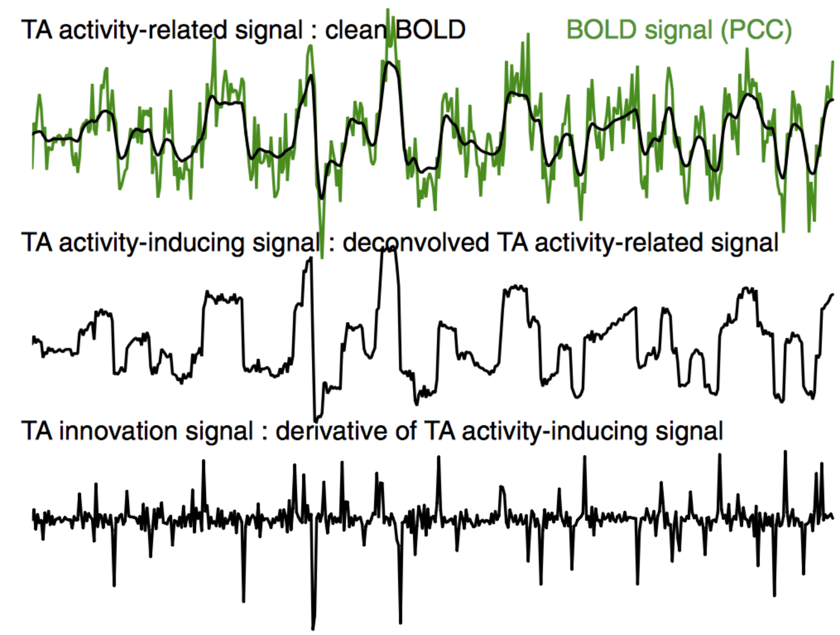


(Karahanoglu and Van De Ville 2015)

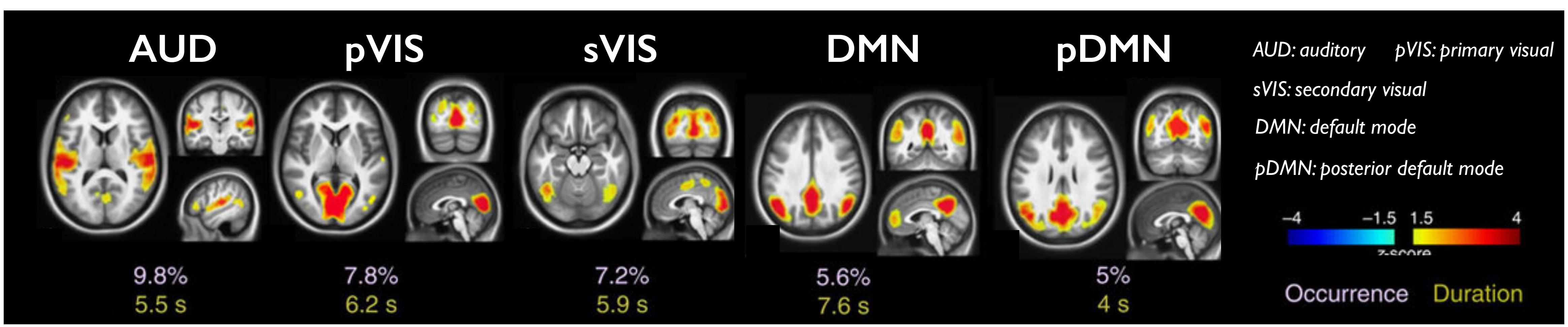
From sliding window to single frames

- Total activation (TA) hypothesises sparsity of *changes* in activity and constrains neighbouring voxels to show similar activity profiles



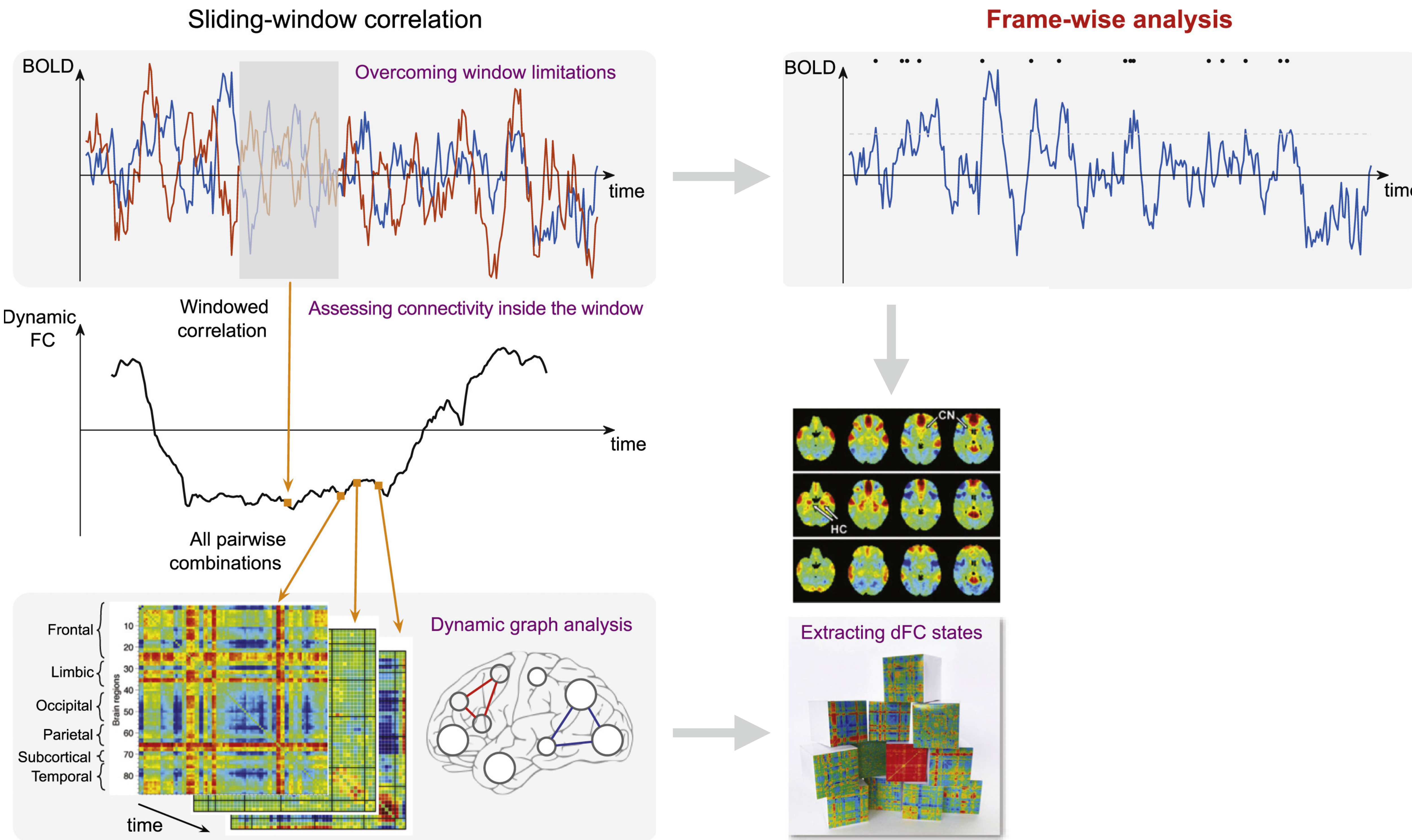


- Generation of *innovation-driven co-activation patterns*
  - Selection and clustering of whole-brain significant innovations
  - Spatially and temporally overlapping network maps

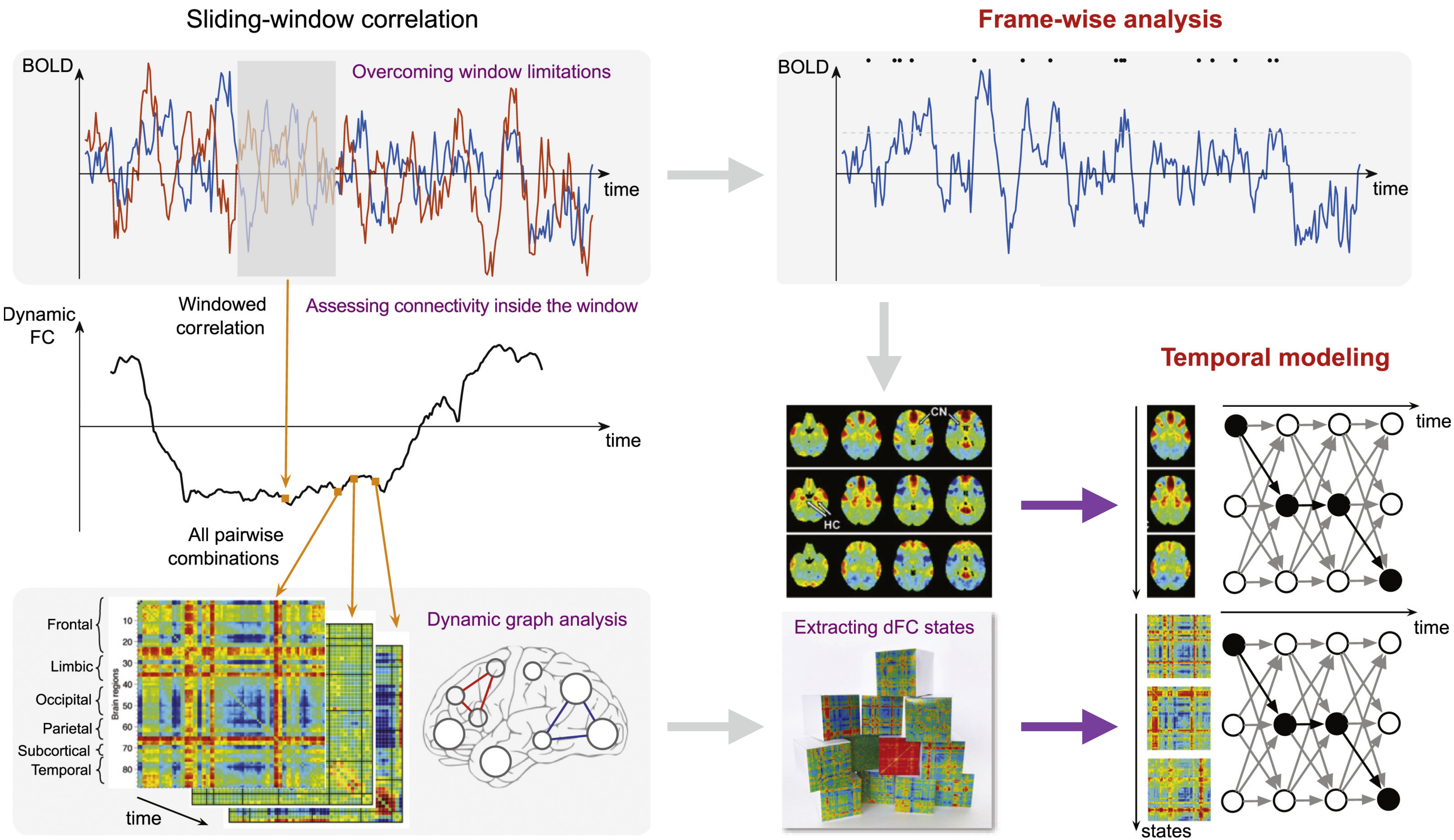


(Karahanoglu and Van De Ville 2015

Towards novel dFC analytical tools

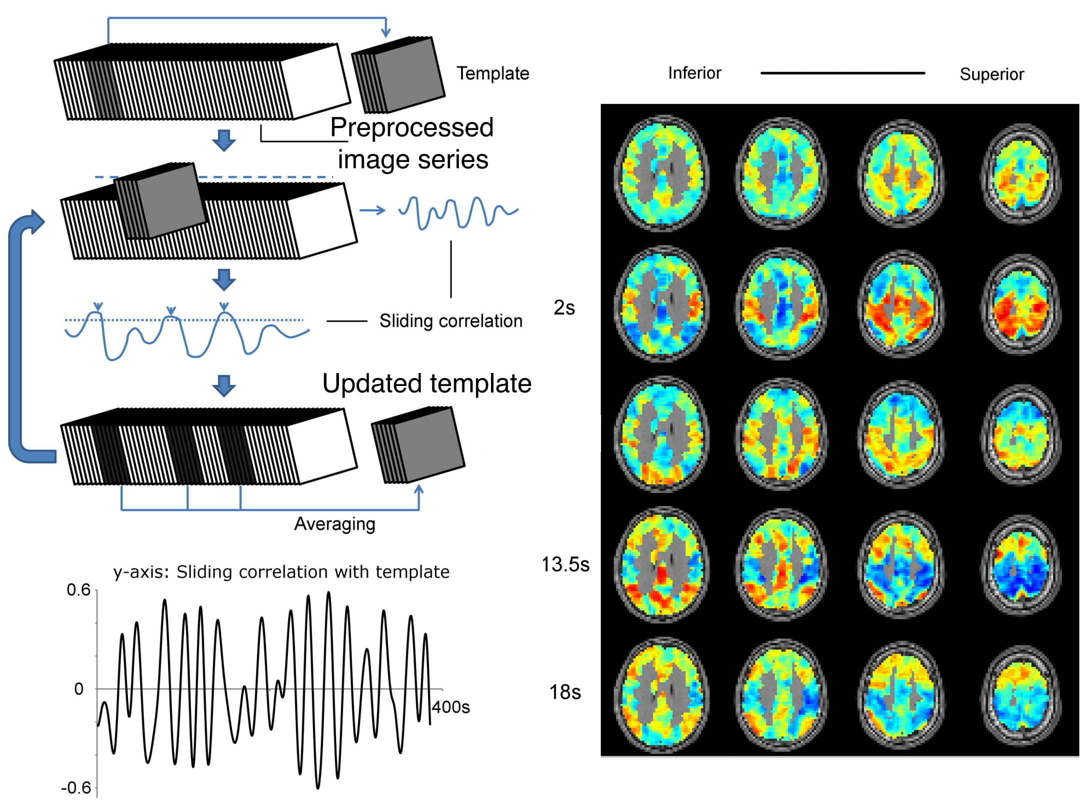


Towards novel dFC analytical tools



Temporal modeling

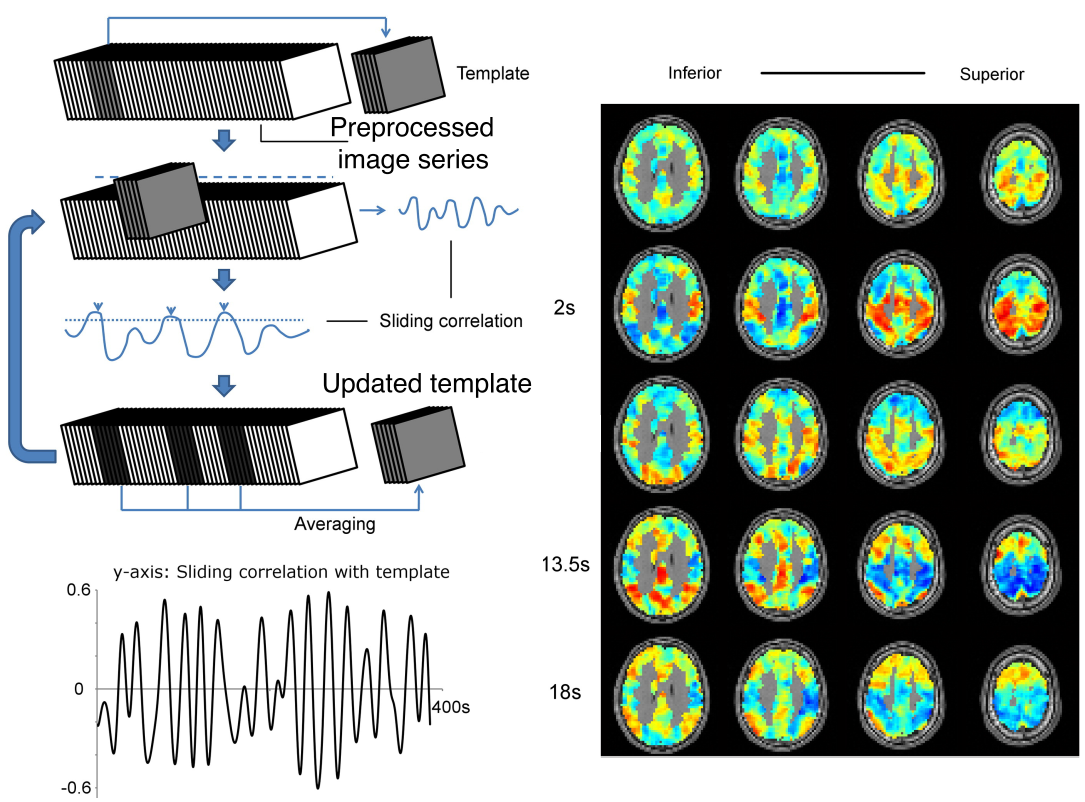
- Brain activity can be seen as a *spatiotemporal sequence*



(Majeed et al. 2011)

Temporal modeling

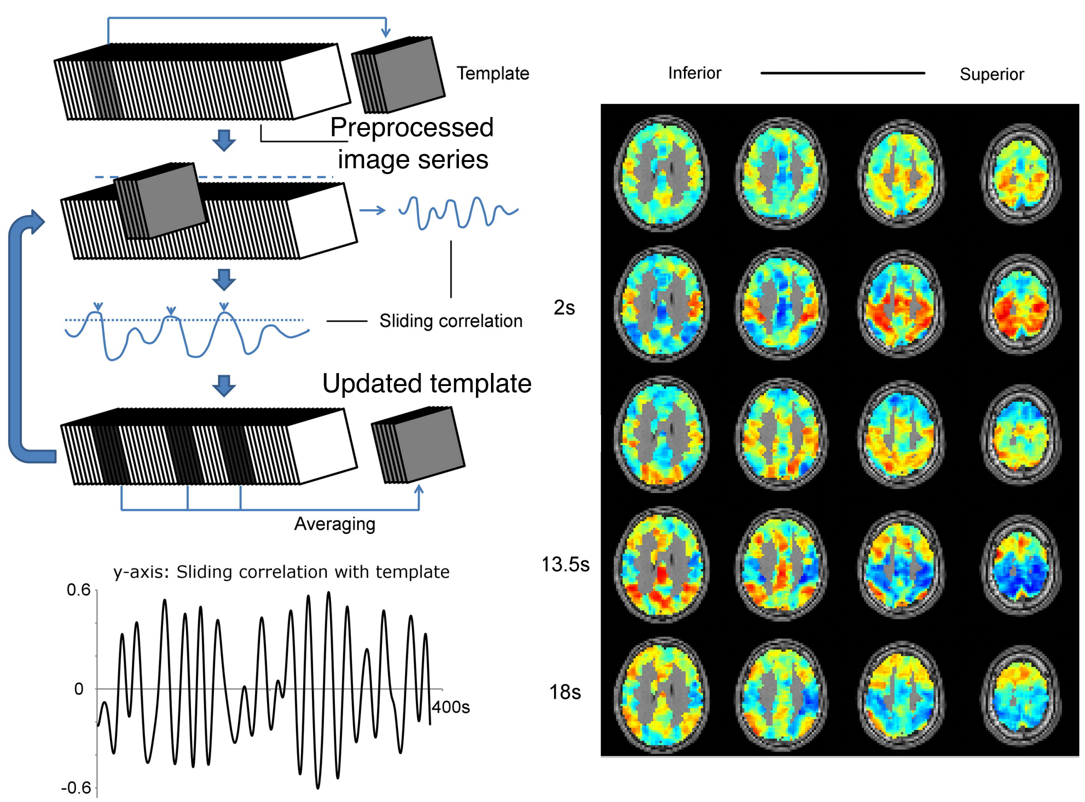
- Brain activity can be seen as a *spatiotemporal sequence*
- Smoothening up activity or connectivity estimates (Monti et al. 2014)
  - Cannot capture abrupt changes of the system



(Majeed et al. 2011)

Temporal modeling

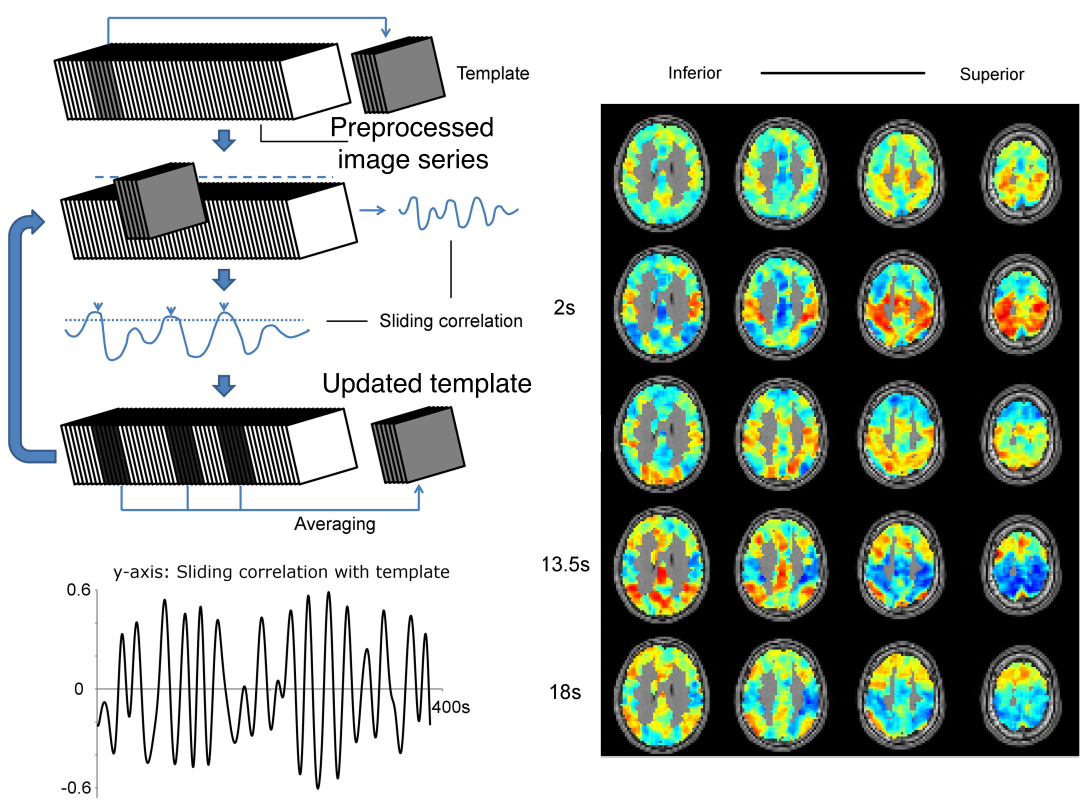
- Brain activity can be seen as a *spatiotemporal sequence*
- Smoothening up activity or connectivity estimates (Monti et al. 2014)
  - Cannot capture abrupt changes of the system
- Assuming temporally independent systems (Smith et al. 2012)
  - Physiologically implausible



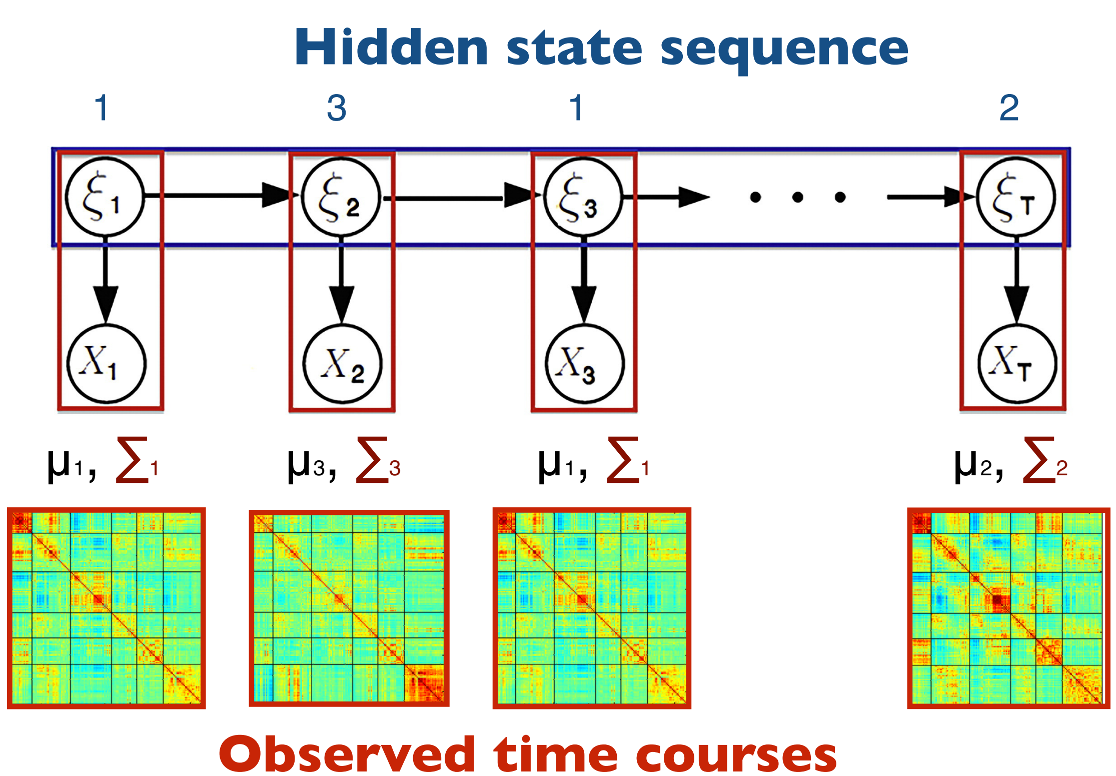
(Majeed et al. 2011)

Temporal modeling

- Brain activity can be seen as a *spatiotemporal sequence*
- Smoothening up activity or connectivity estimates (Monti et al. 2014)
  - Cannot capture abrupt changes of the system
- Assuming temporally independent systems (Smith et al. 2012)
  - Physiologically implausible
- Explicitly model the spatiotemporal sequence of brain states
  - Requires a lot of data and good hypotheses, but generative and flexible



(Majeed et al. 2011)

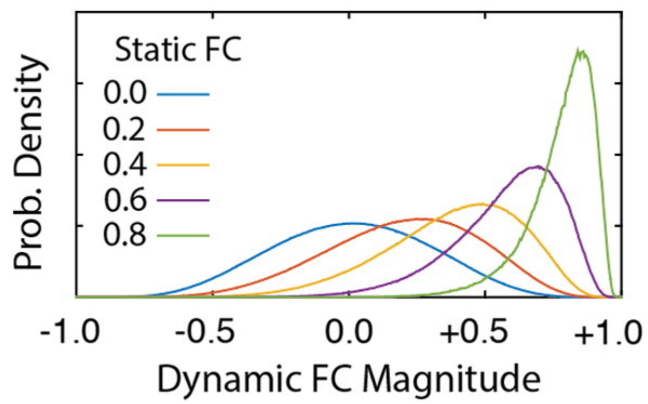


(Eavani et al. 2013, Chiang et al. 2016)

Origin & relevance of dFC

- part of dFC fluctuations survive rigorous statistical testing
  - Cross-session shuffling, (amplitude-adjusted) phase randomisation…

(Betzel et al. 2016, Zalesky et al. 2014, Keilholz et al. 2013)

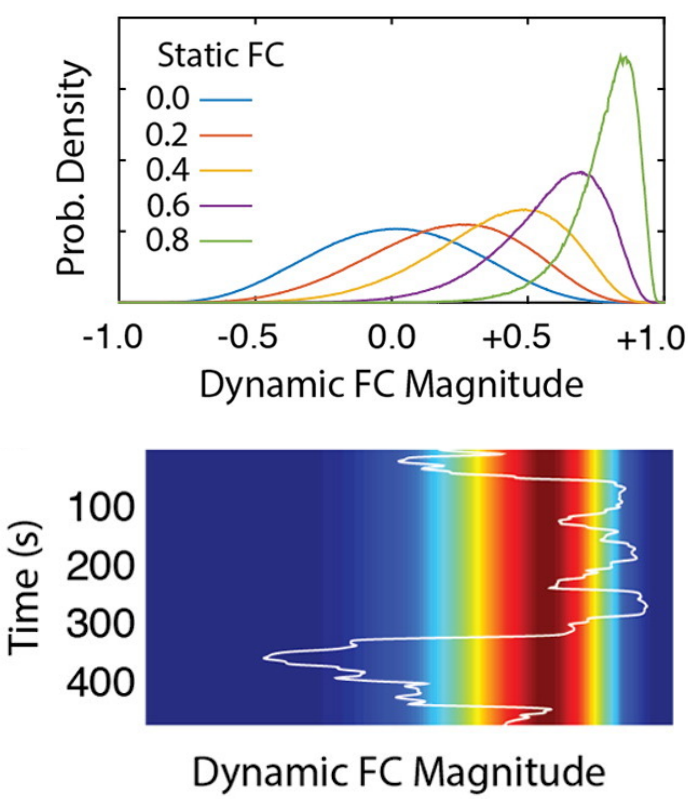


(Betzel et al. 2016)

Origin & relevance of dFC

- part of dFC fluctuations survive rigorous statistical testing
  - Cross-session shuffling, (amplitude-adjusted) phase randomisation…

(Betzel et al. 2016, Zalesky et al. 2014, Keilholz et al. 2013)

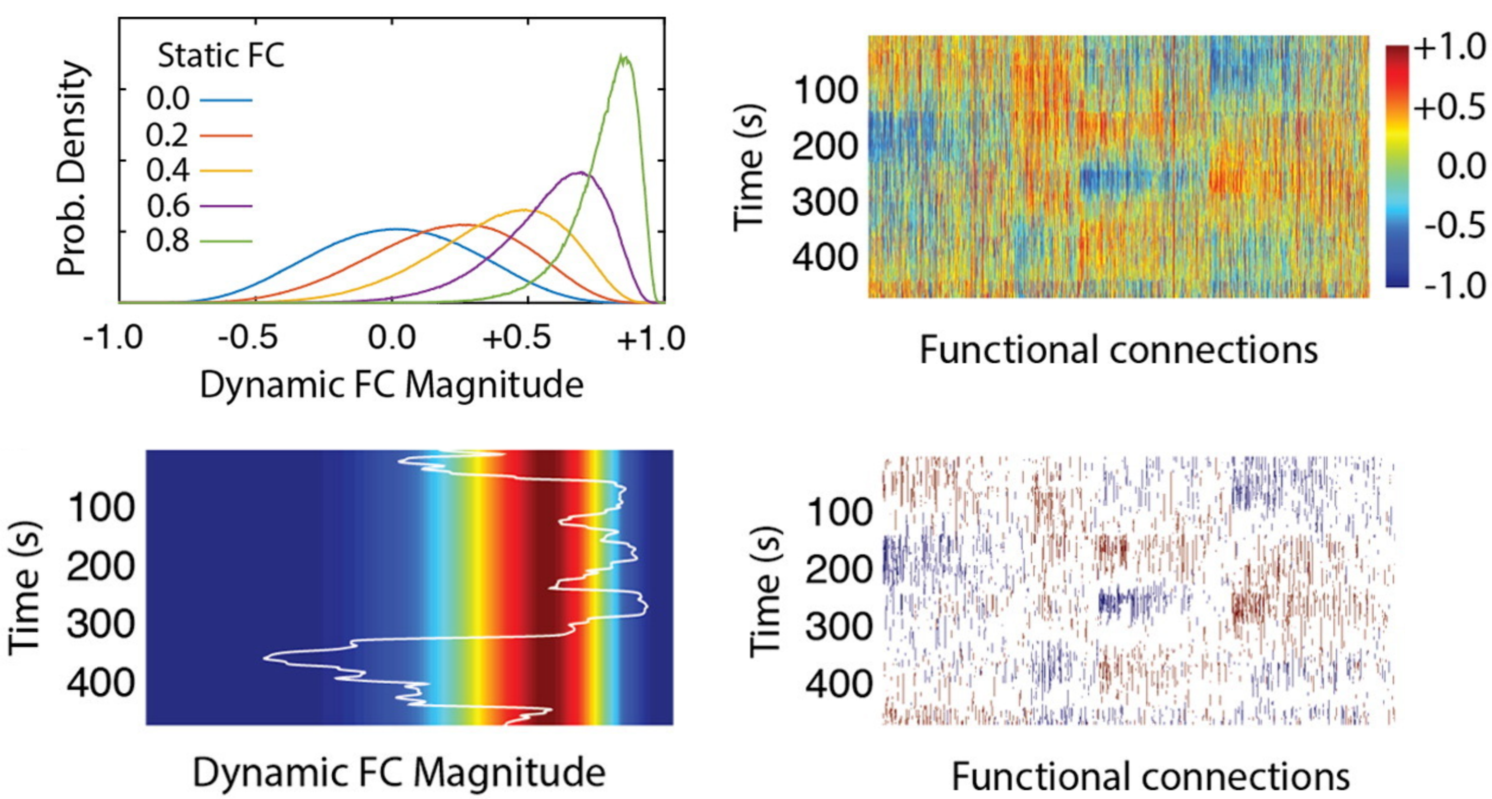


(Betzel et al. 2016)

Origin & relevance of dFC

- part of dFC fluctuations survive rigorous statistical testing
  - Cross-session shuffling, (amplitude-adjusted) phase randomisation…

(Betzel et al. 2016, Zalesky et al. 2014, Keilholz et al. 2013)



(Betzel et al. 2016)

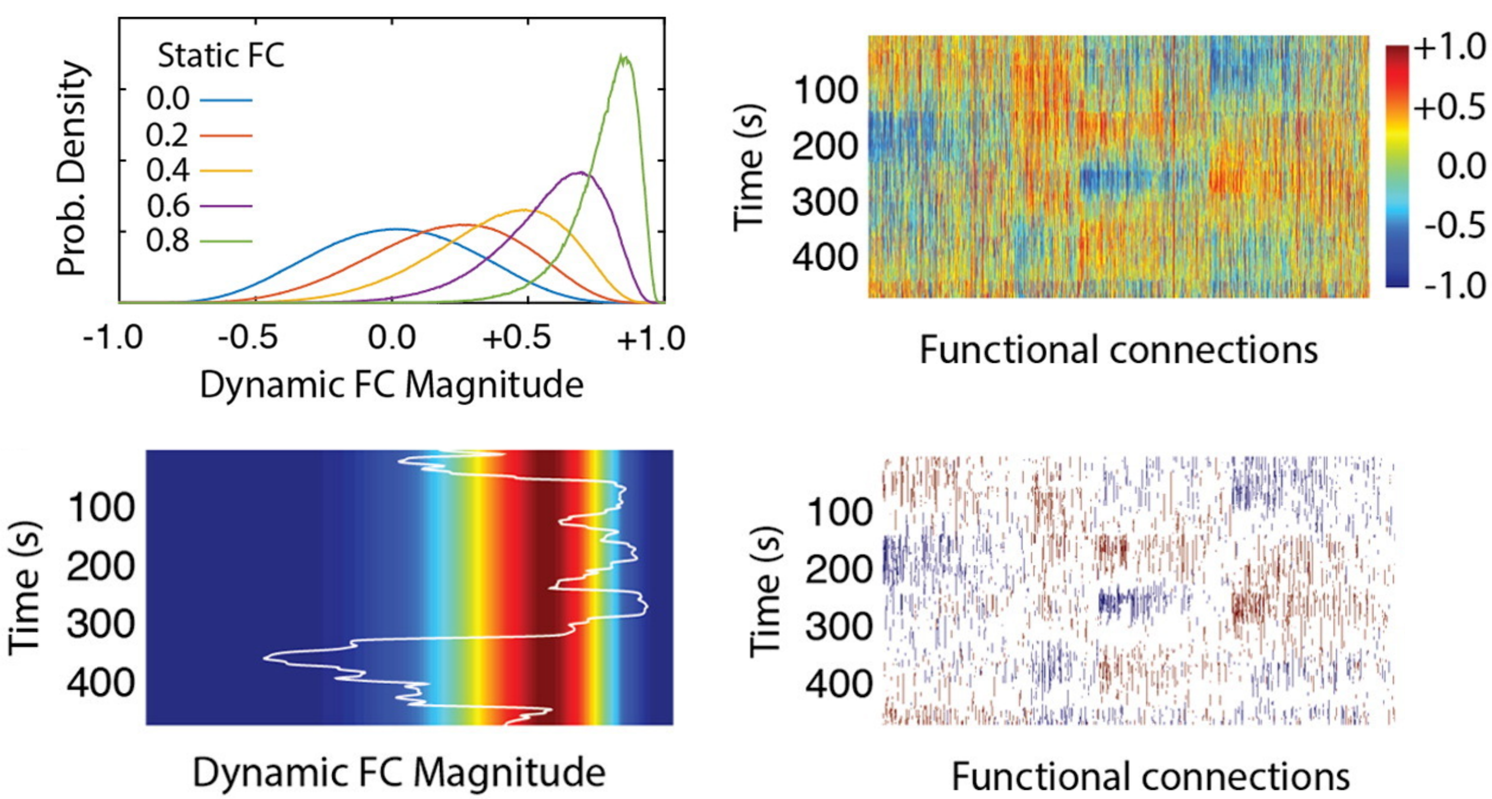
Origin & relevance of dFC

- part of dFC fluctuations survive rigorous statistical testing
  - Cross-session shuffling, (amplitude-adjusted) phase randomisation…

(Betzel et al. 2016, Zalesky et al. 2014, Keilholz et al. 2013)

- dFC correlates with brain electrical activity

(Thompson et al. 2013, Tagliazucchi et al. 2012, Chang et al. 2013)



(Betzel et al. 2016)

Origin & relevance of dFC

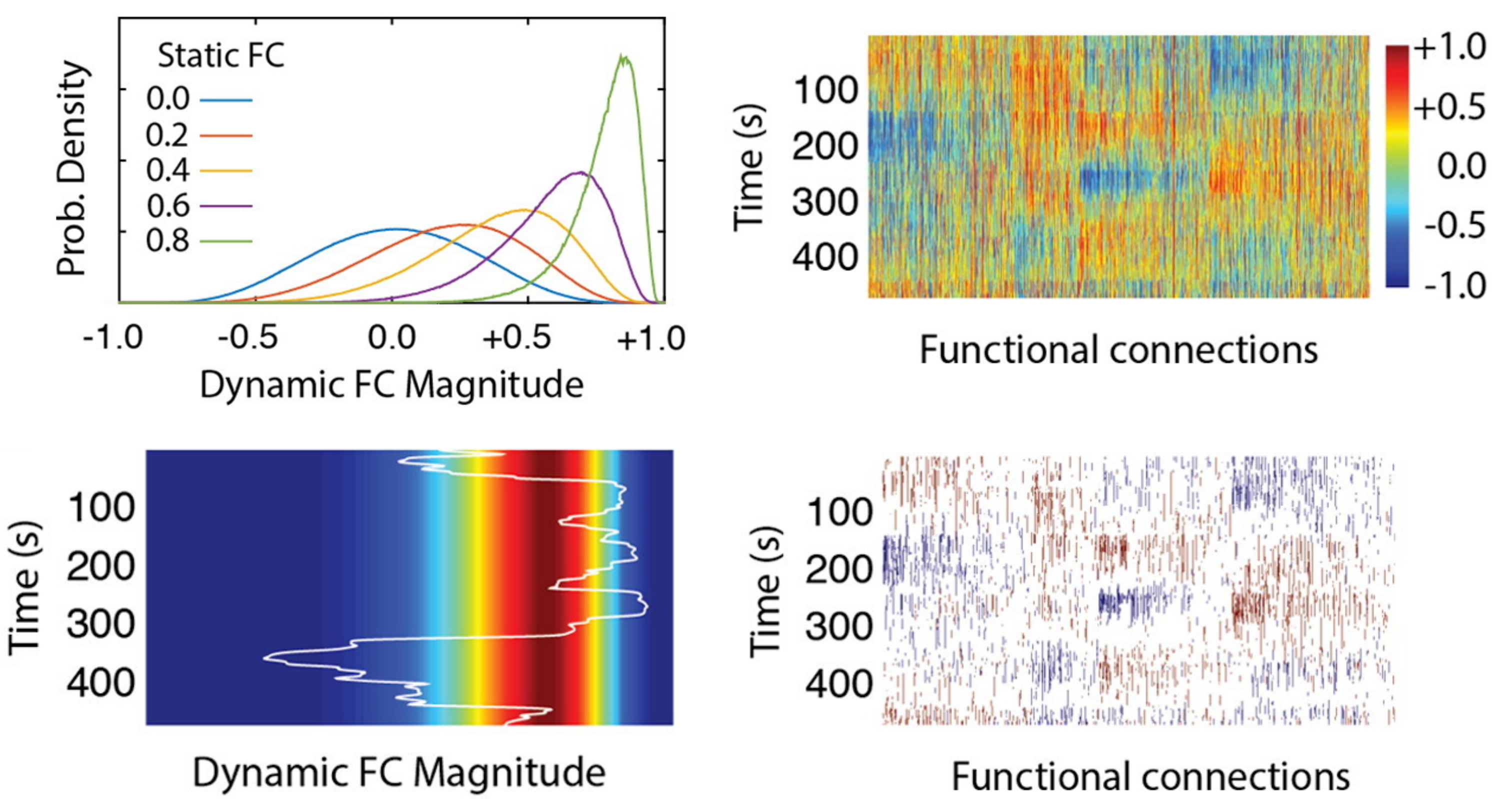
- part of dFC fluctuations survive rigorous statistical testing
  - Cross-session shuffling, (amplitude-adjusted) phase randomisation…

(Betzel et al. 2016, Zalesky et al. 2014, Keilholz et al. 2013)

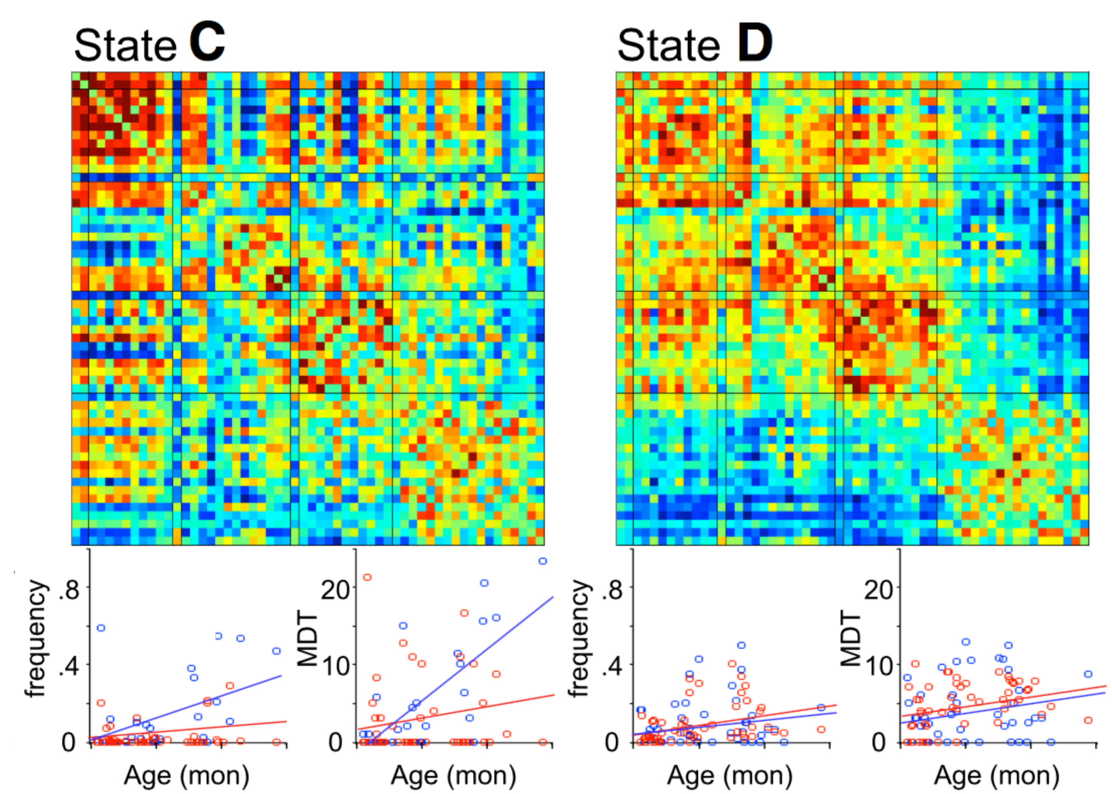
- dFC correlates with brain electrical activity

(Thompson et al. 2013, Tagliazucchi et al. 2012, Chang et al. 2013)

- dFC varies along demographic variables
  - Age, gender…   (Hutchison and Morton 2015, Yaesoubi et al. 2015)



(Betzel et al. 2016)



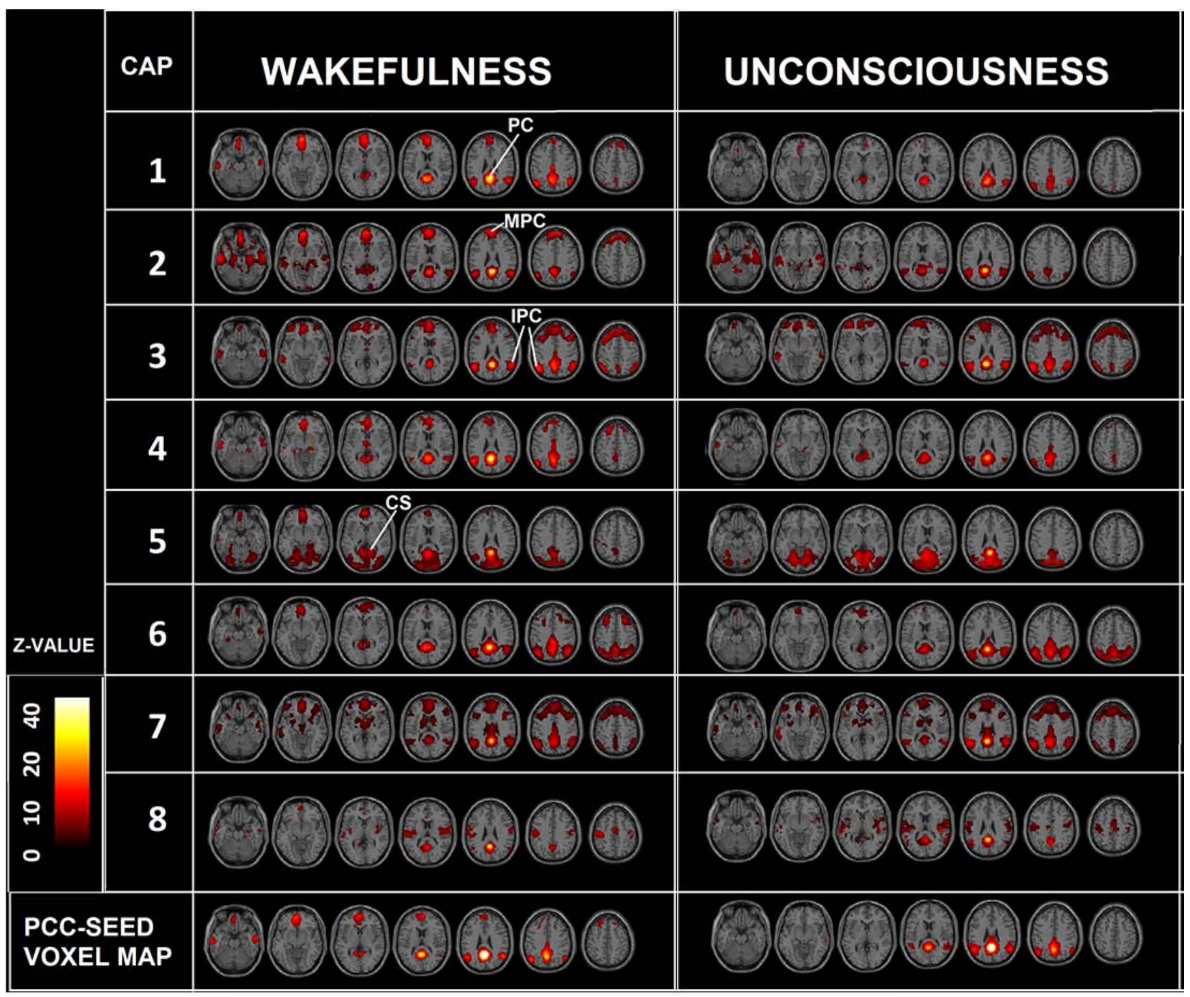
MDT: Mean Dwell Time

(Hutchison and Morton 2015)

Origin & relevance of dFC

- dFC is modulated by changes in arousal level
  - Caffeine, anesthesia…

(Rack-Gomer and Liu 2012, Barttfeld et al. 2015, Tagliazucchi et al. 2014)



(Amico et al. 2014)

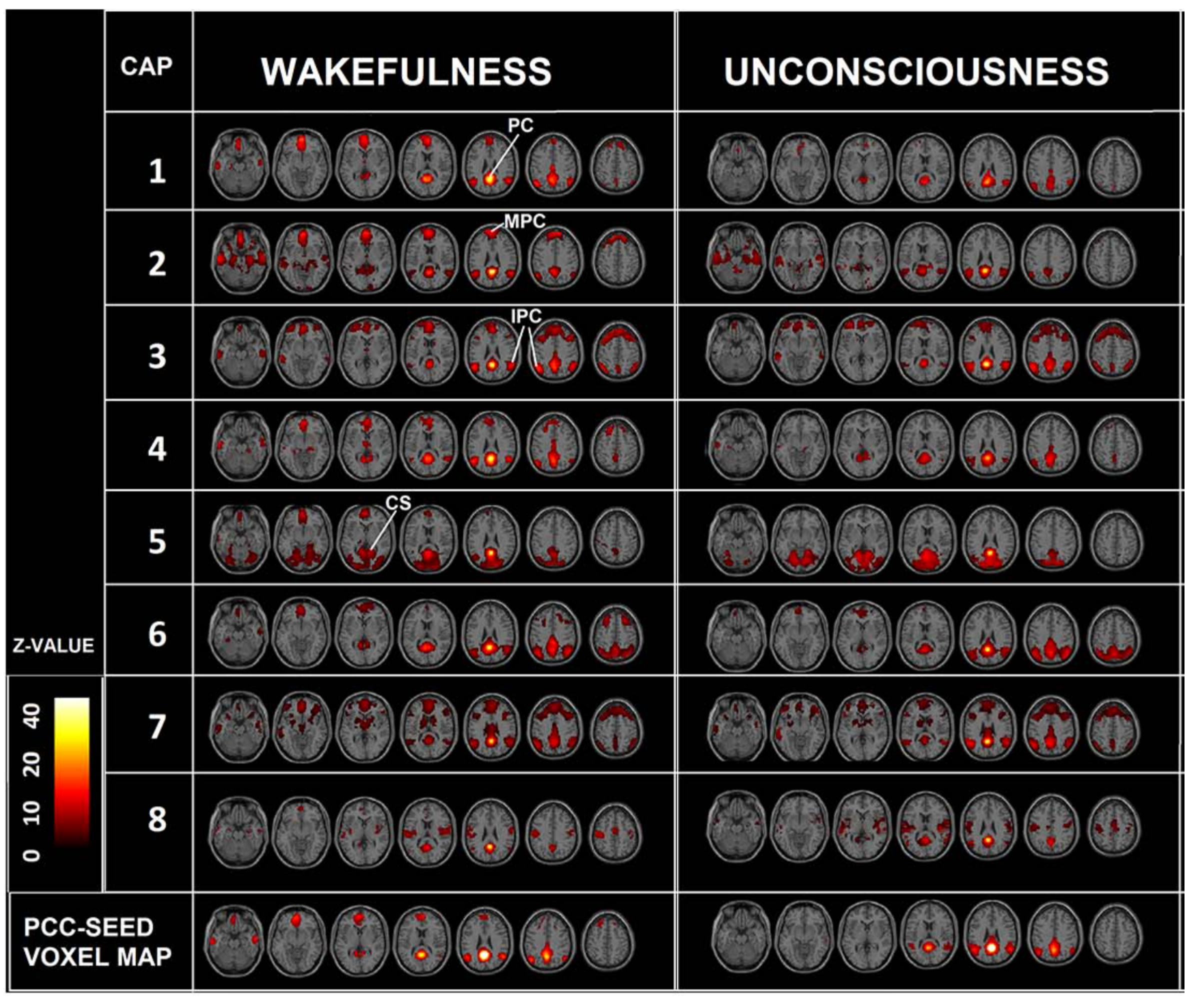
Origin & relevance of dFC

- dFC is modulated by changes in arousal level
  - Caffeine, anesthesia…

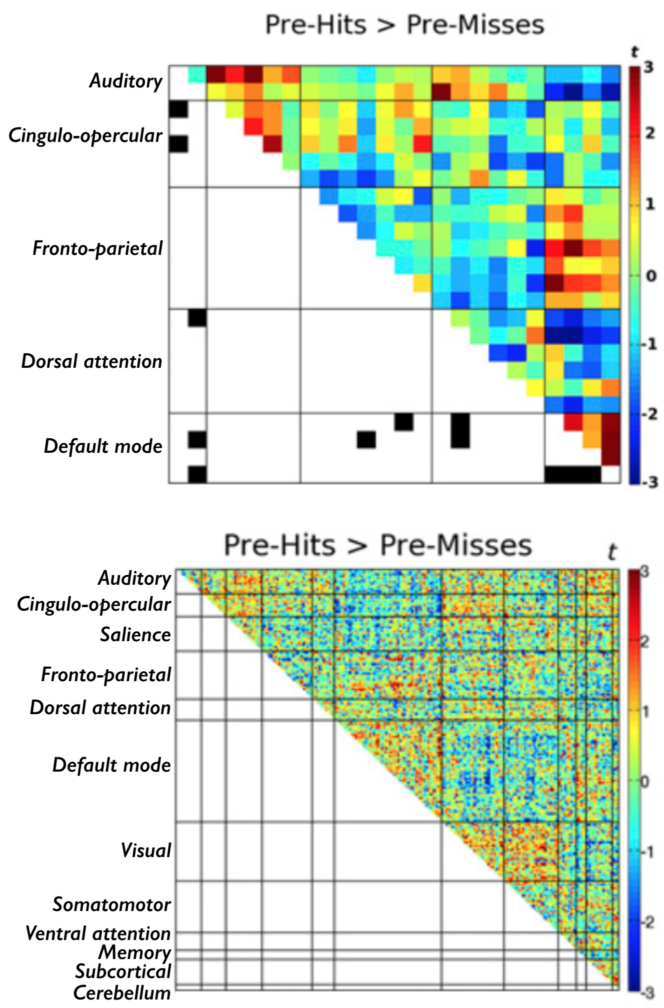
(Rack-Gomer and Liu 2012, Barttfeld et al. 2015, Tagliazucchi et al. 2014)

- dFC correlates with cognition
  - Daydreaming, cognitive flexibility, attentional ressources…

(Kucyi and Davis 2013, Yang et al. 2014, Chen et al. 2016,)



(Amico et al. 2014)



(Sadaghiani et al. 2015)

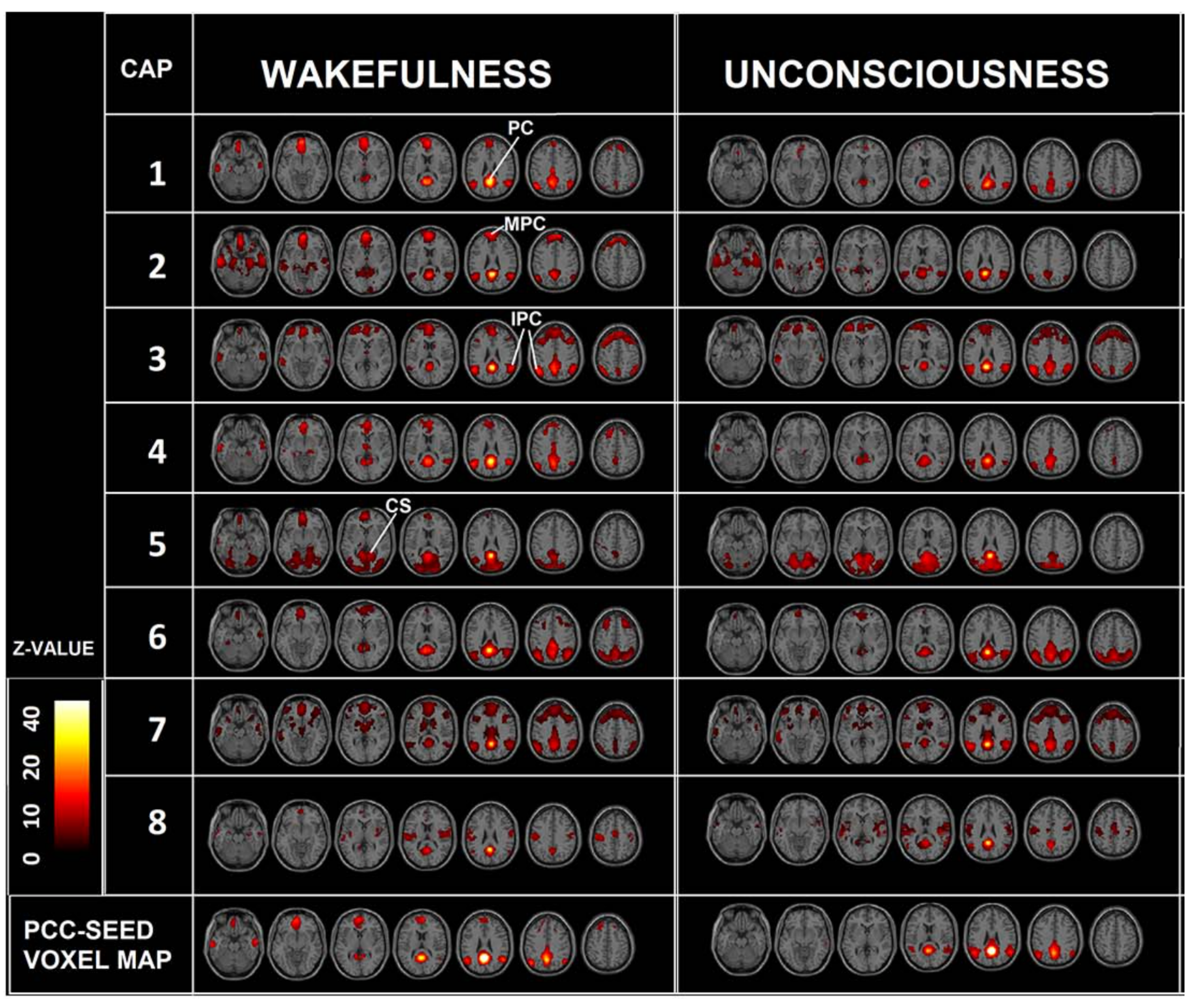
Origin & relevance of dFC

- dFC is modulated by changes in arousal level
  - Caffeine, anesthesia…

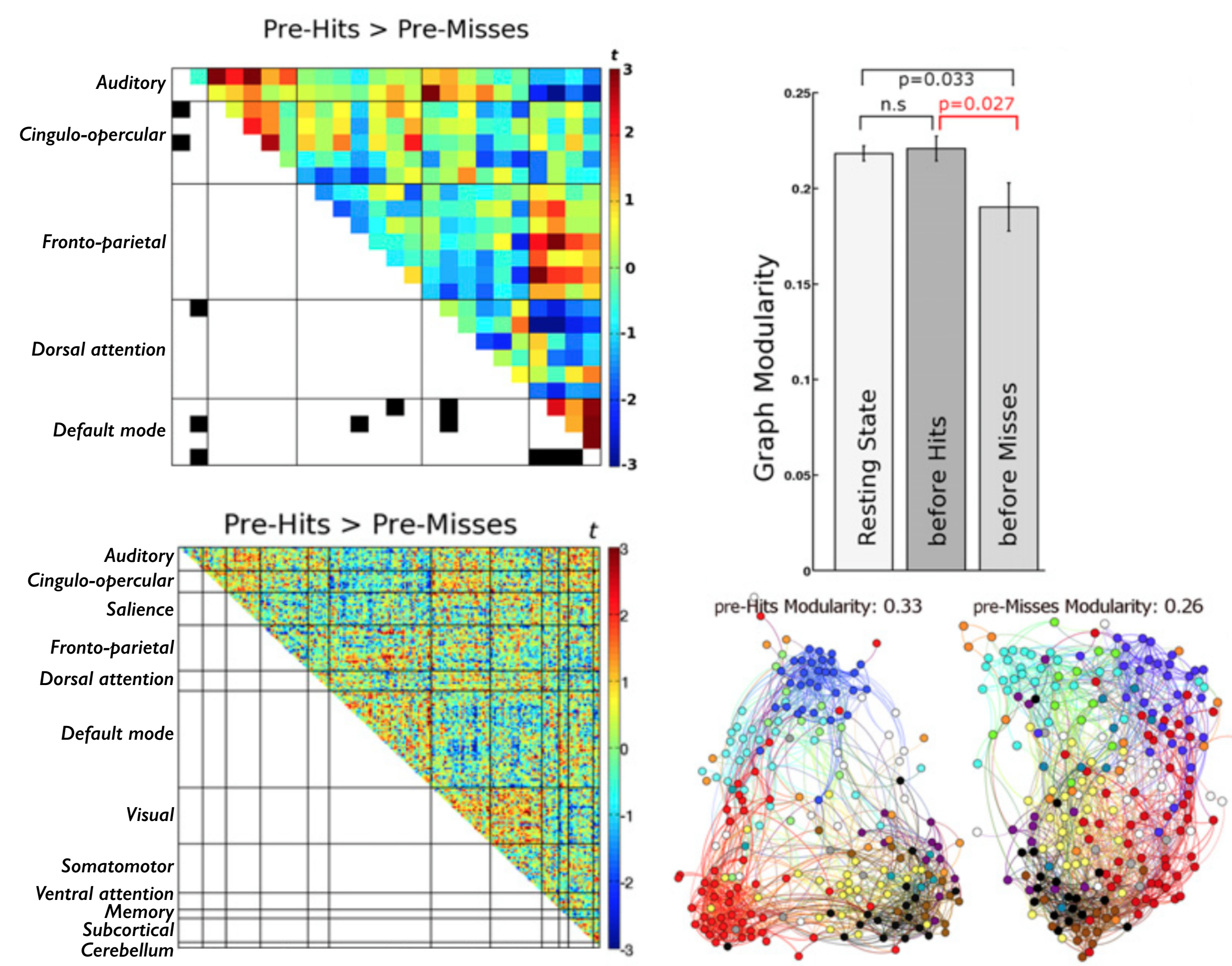
(Rack-Gomer and Liu 2012, Barttfeld et al. 2015, Tagliazucchi et al. 2014)

- dFC correlates with cognition
  - Daydreaming, cognitive flexibility, attentional ressources…

(Kucyi and Davis 2013, Yang et al. 2014, Chen et al. 2016,)



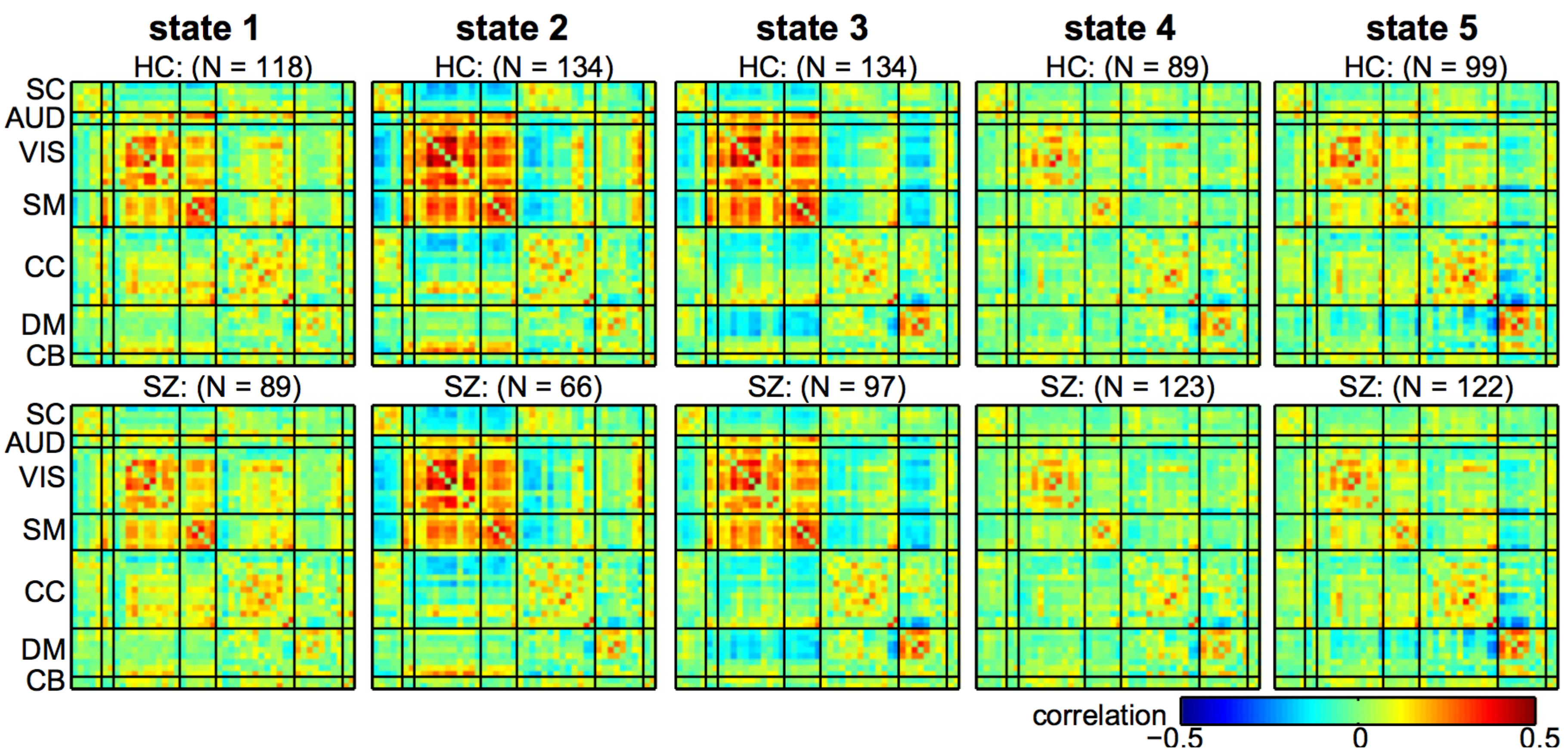
(Amico et al. 2014)



(Sadaghiani et al. 2015)

Origin & relevance of dFC

- dFC is altered in many brain disorders
  - Schizophrenia, autism, major depressive disorder…



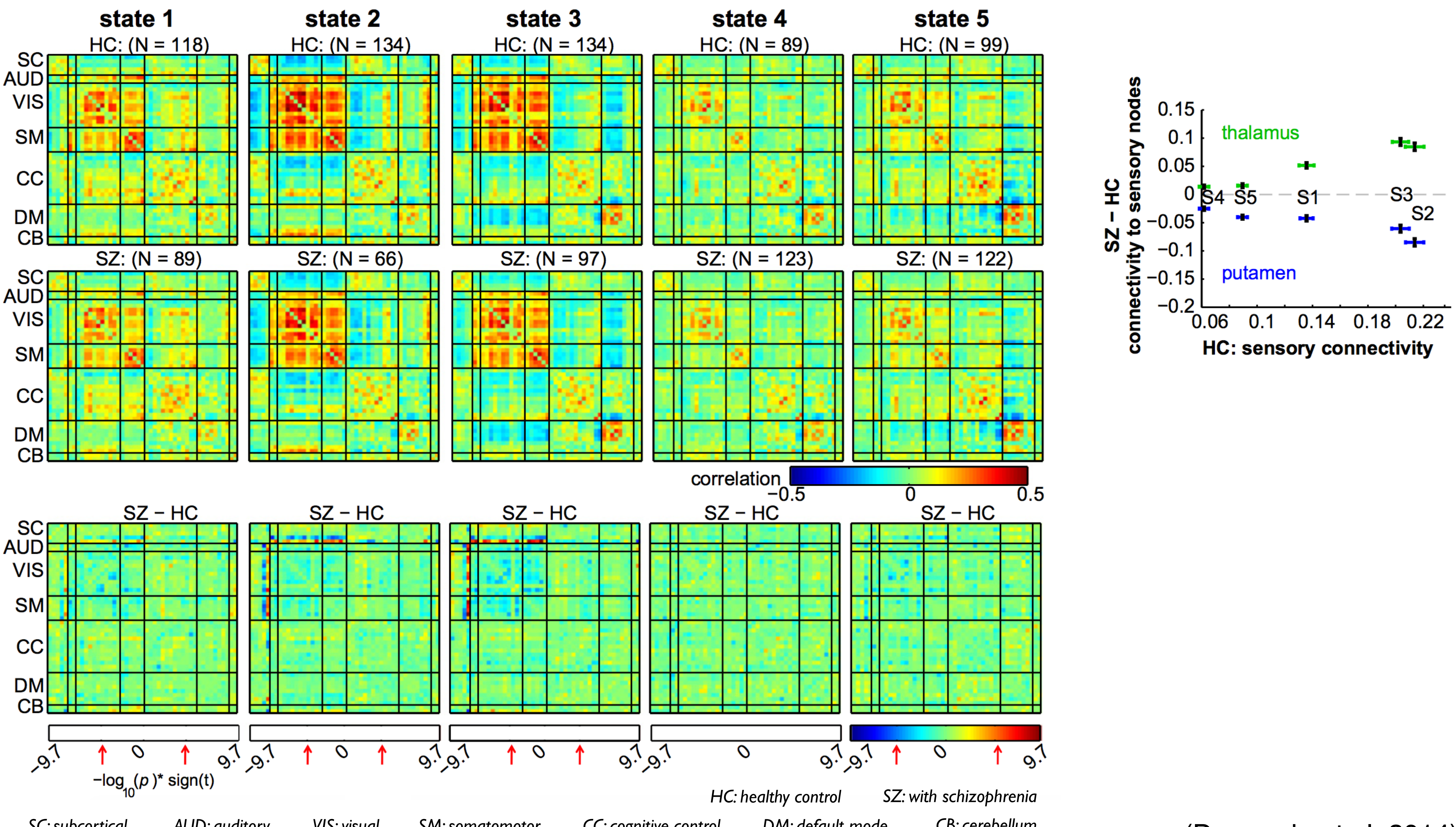
HC: healthy control *SZ: with schizophrenia*

SC: subcortical *AUD: auditory* *VIS: visual* *SM: somatomotor* *CC: cognitive control* *DM: default mode* *CB: cerebellum*

(Damaraju et al. 2014)

Origin & relevance of dFC

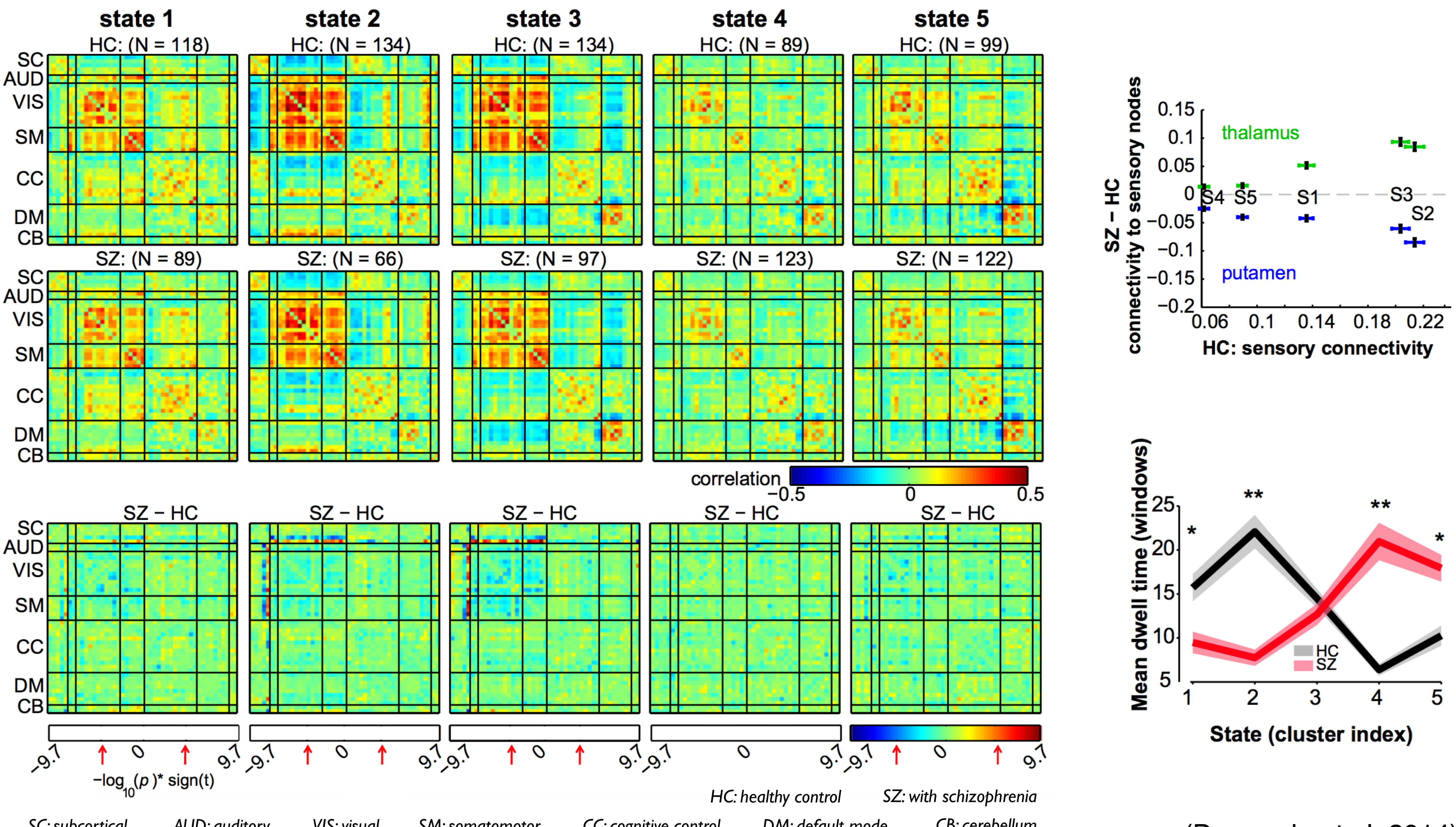
- dFC is altered in many brain disorders
  - Schizophrenia, autism, major depressive disorder…



(Damaraju et al. 2014)

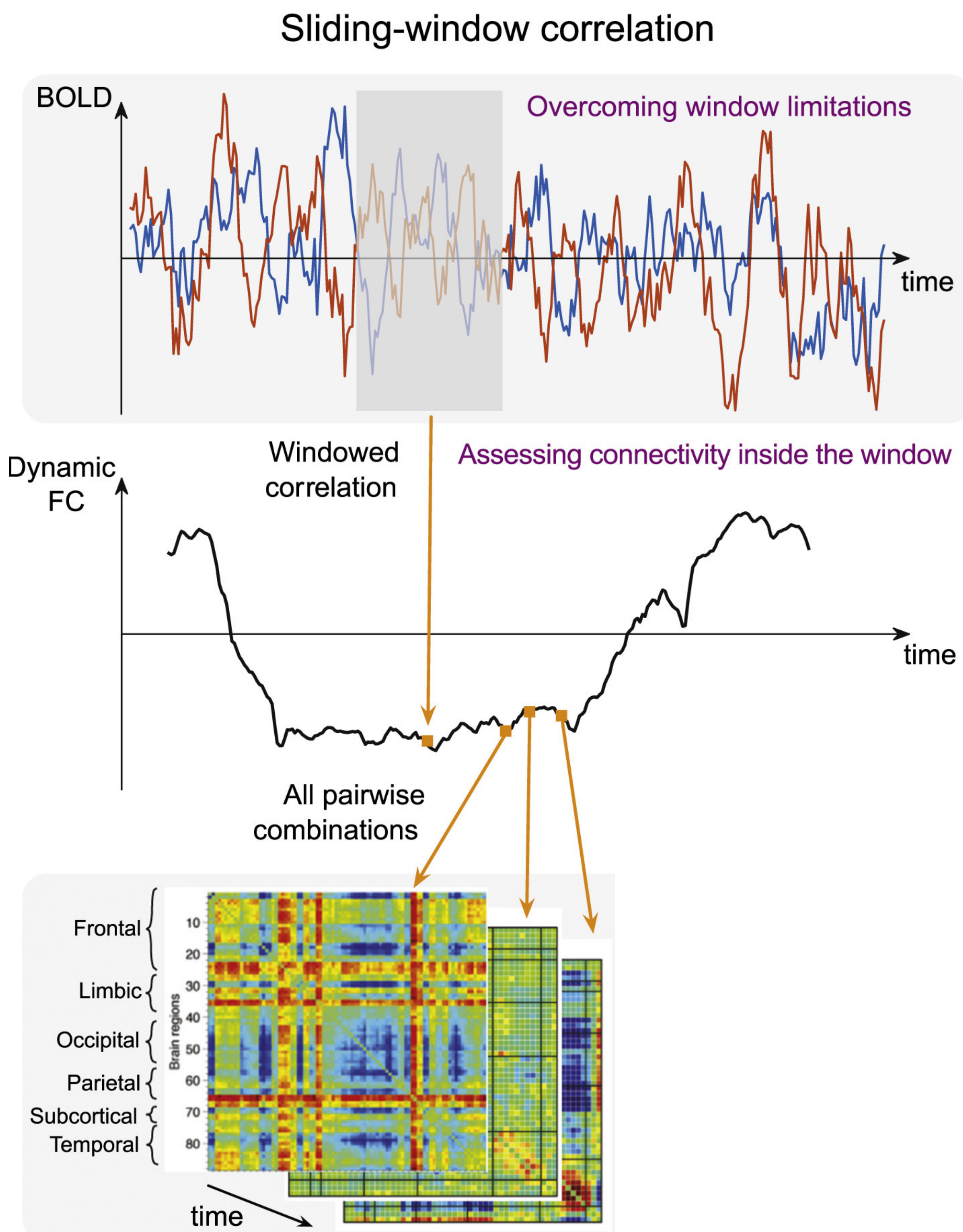
Origin & relevance of dFC

- dFC is altered in many brain disorders
  - Schizophrenia, autism, major depressive disorder…

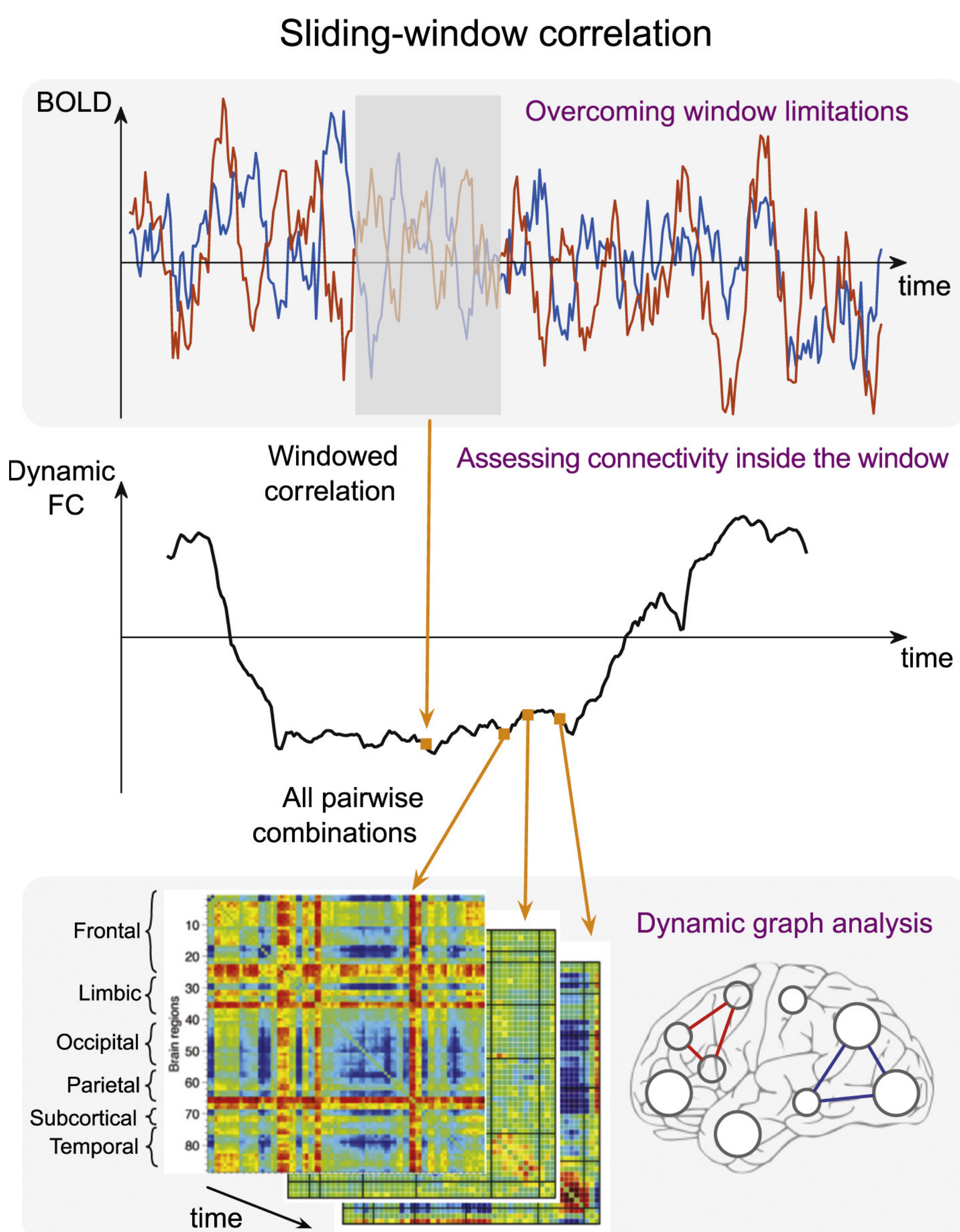


(Damaraju et al. 2014)

Summary


Sliding-window correlation
BOLD
Overcoming window limitations
time
Dynamic FC
Windowed correlation
Assessing connectivity inside the window
time
All pairwise combinations
Frontal
Limbic
Occipital
Parietal
Subcortical
Temporal
Brain regions
10
20
30
40
50
60
70
80
time

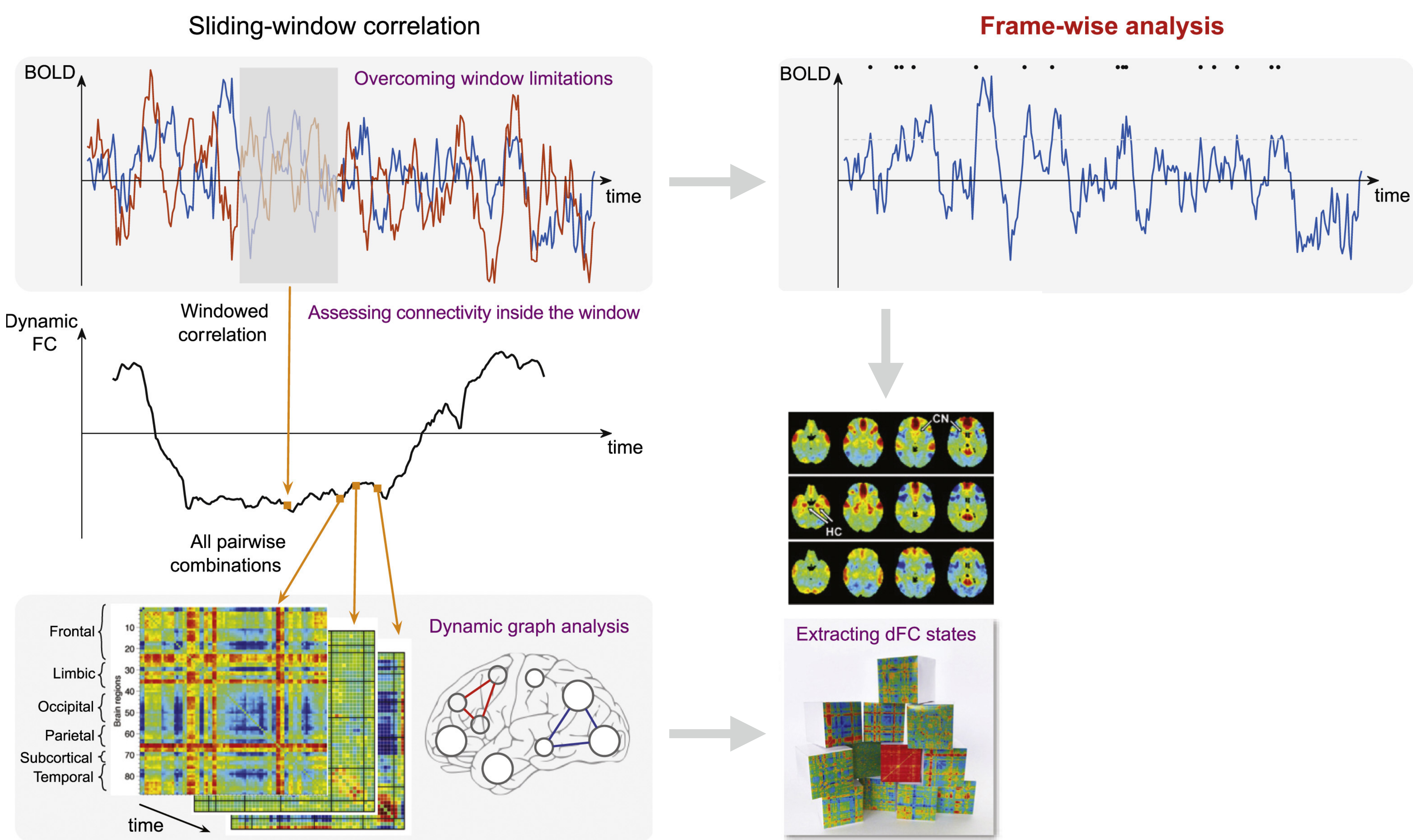
Summary



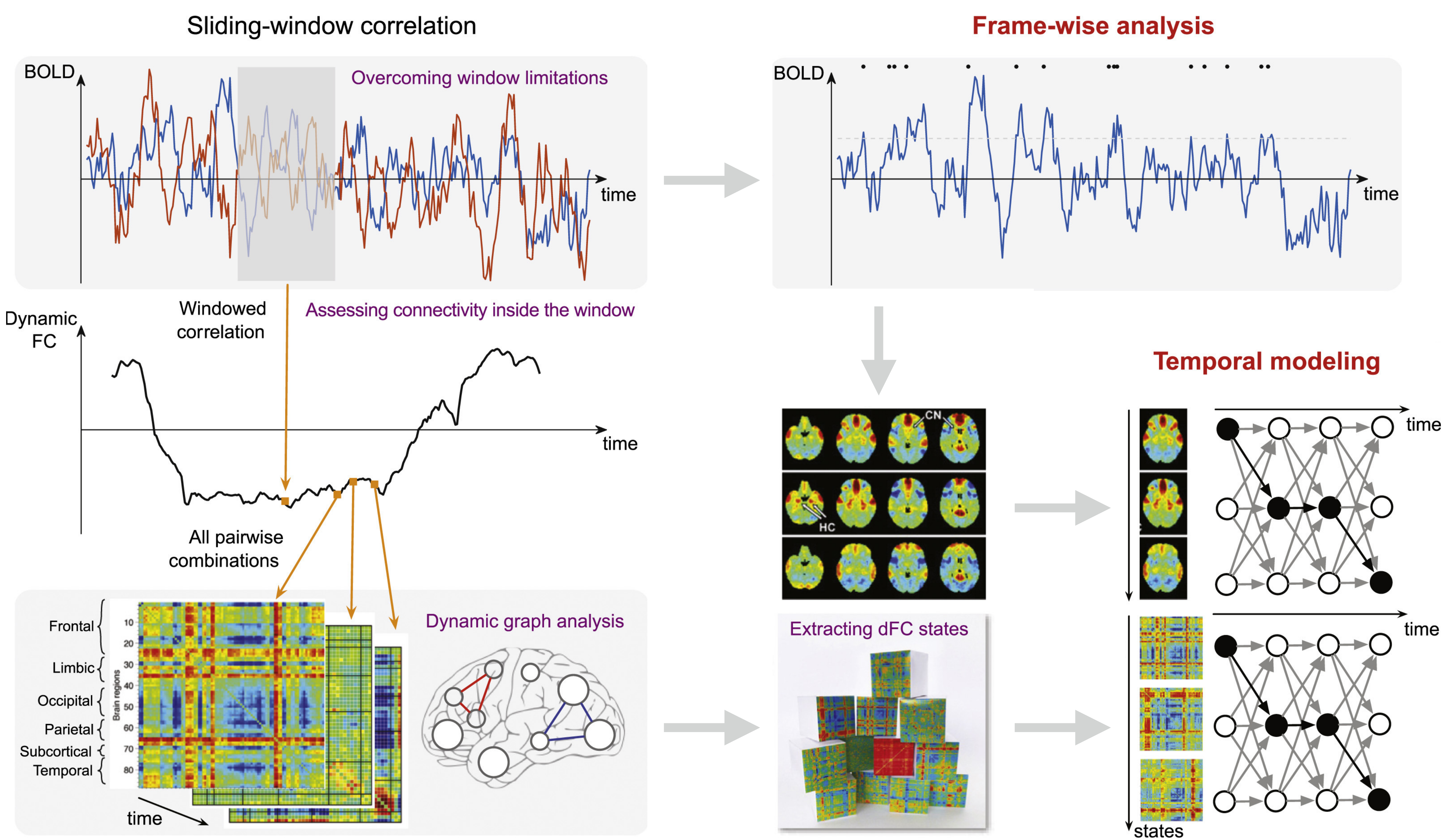
Sliding-window correlation
BOLD
Overcoming window limitations
time
Dynamic FC
Windowed correlation
Assessing connectivity inside the window
time
All pairwise combinations
Frontal
Limbic
Occipital
Parietal
Subcortical
Temporal
Brain regions
10
20
30
40
50
60
70
80
time
Dynamic graph analysis

Extracting dFC states

Summary


Sliding-window correlation
Frame-wise analysis
BOLD
Overcoming window limitations
time
BOLD
time
Dynamic FC
Windowed correlation
Assessing connectivity inside the window
time
All pairwise combinations
CN
HC
Frontal
Limbic
Occipital
Parietal
Subcortical
Temporal
Brain regions
10
20
30
40
50
60
70
80
time
Dynamic graph analysis
Extracting dFC states

Summary


Sliding-window correlation
BOLD
Overcoming window limitations
time
Dynamic FC
Windowed correlation
Assessing connectivity inside the window
time
All pairwise combinations
Frontal
Limbic
Occipital
Parietal
Subcortical
Temporal
Brain regions
time
Dynamic graph analysis
Frame-wise analysis
BOLD
time
CN
HC
Extracting dFC states
Temporal modeling
time
time
states