9th meeting of
European
Study
Group on
Cardiovascular
Oscillations

ADVANCED TIME-VARIANT, NON-LINEAR APPROACHES FOR ANALYSING BRAIN DYNAMICS

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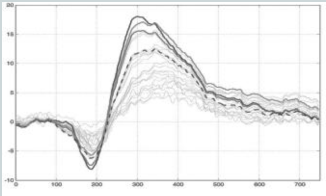
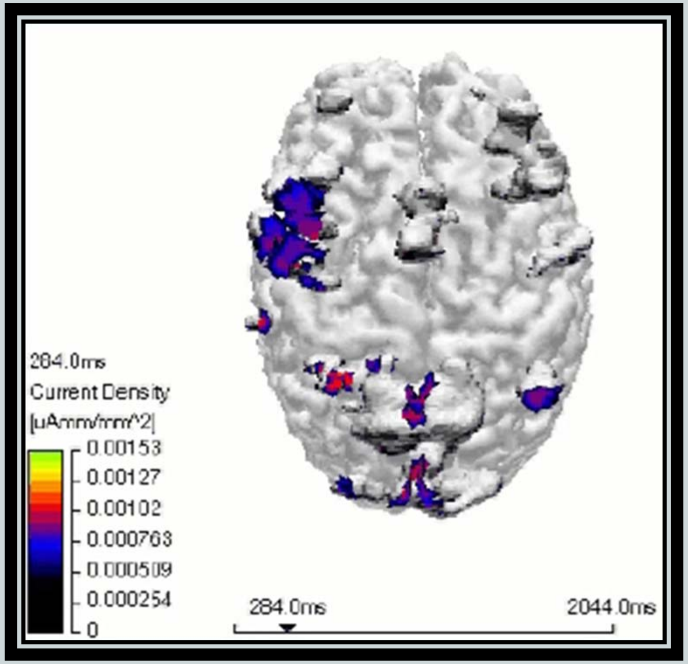
Brain Dynamics

MRI (head model)

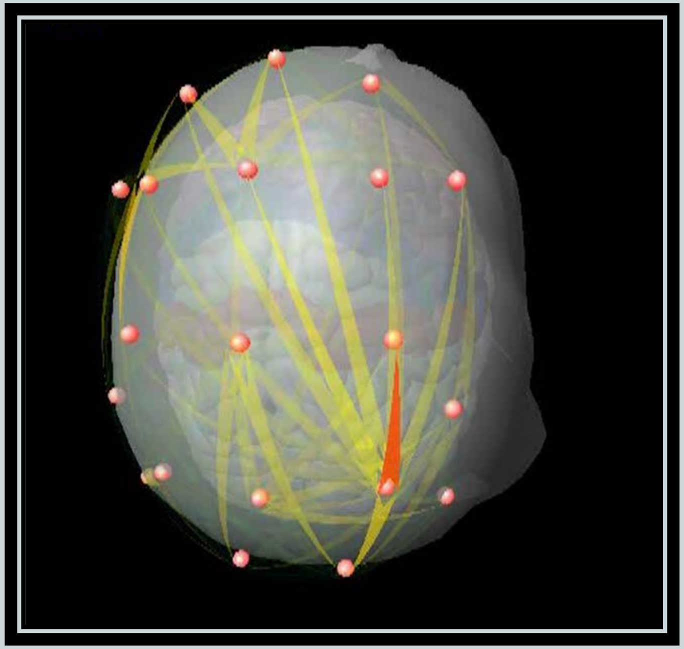
EEG / MEG



source model (e.g. CDR)



system and/or process models



A. Brzezicka et al.: *Brain Topography* 24(2011)

neural mass activity, sensor space

source space activity

connectivity, sensor and source space

Connectivity

Multivariate

Time-variant

Frequency-selective

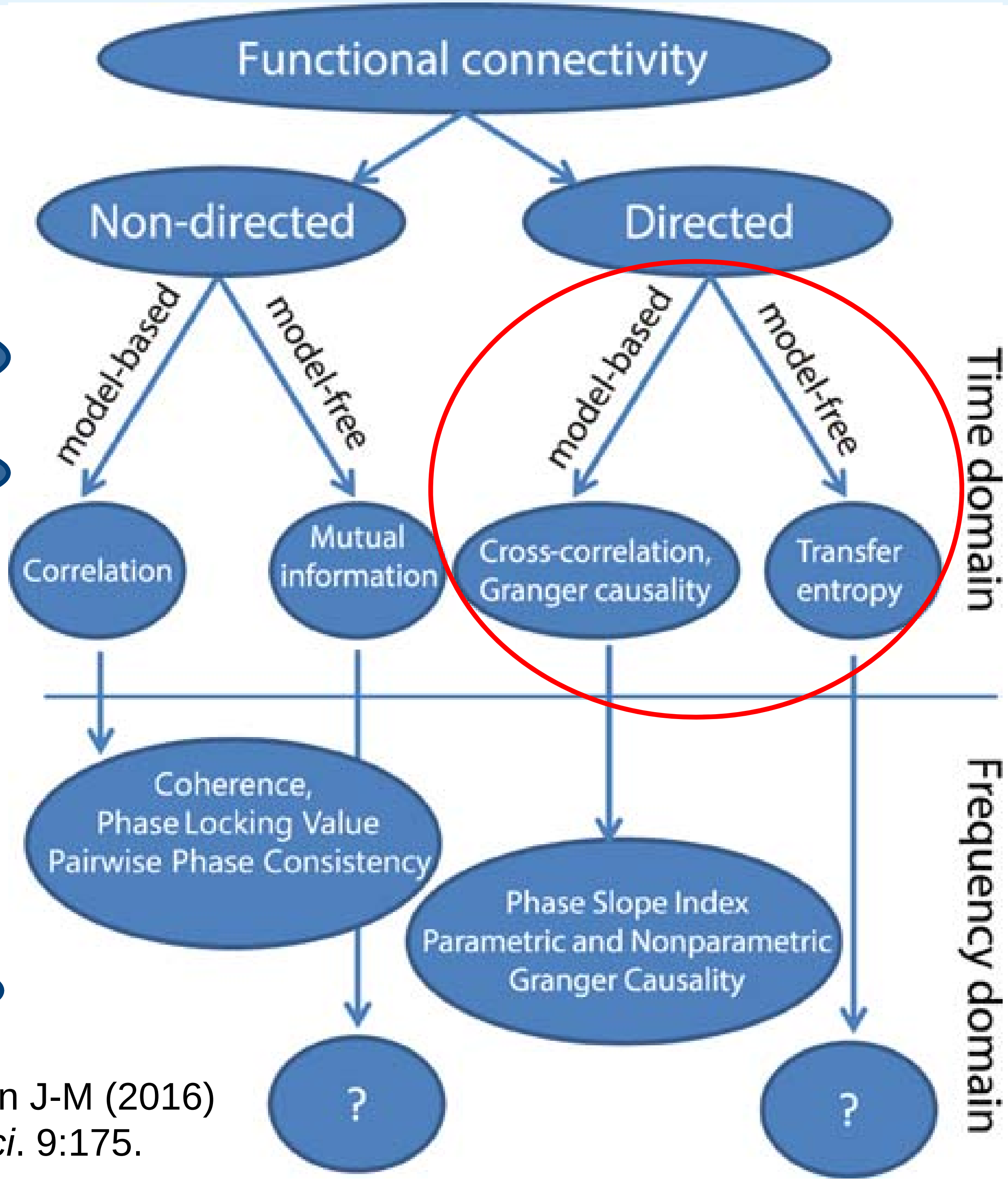
…

Representation and Inter-pretation of Results:

Tensor Decomposition

Network Analysis

…



Bastos AM and Schoffelen J-M (2016) *Front. Syst. Neurosci*. 9:175.

Real Data: Children with TLE

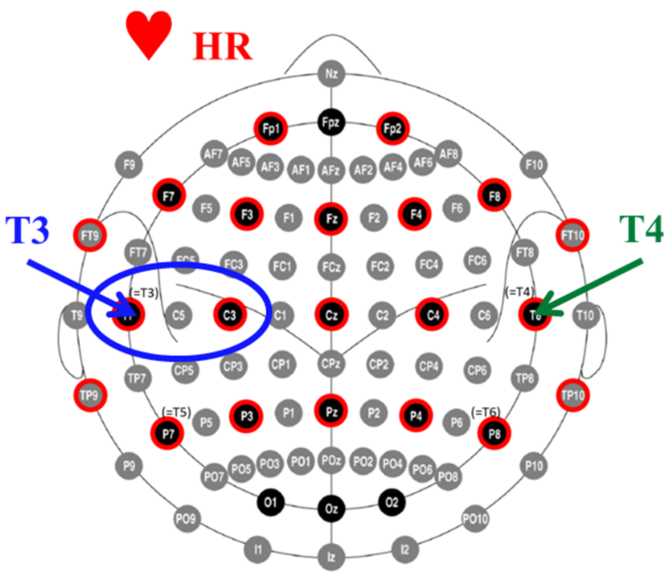
Epilepsy Monitoring Unit Vienna: temporal lobe epilepsy (TLE); 18 children, 9 left-sided, 9 right-sided seizures; video monitoring, 21 channels EEG, ECG; 1 seizure per child, 10 min recordings (f_s=256 Hz), seizure onset at 5 min;

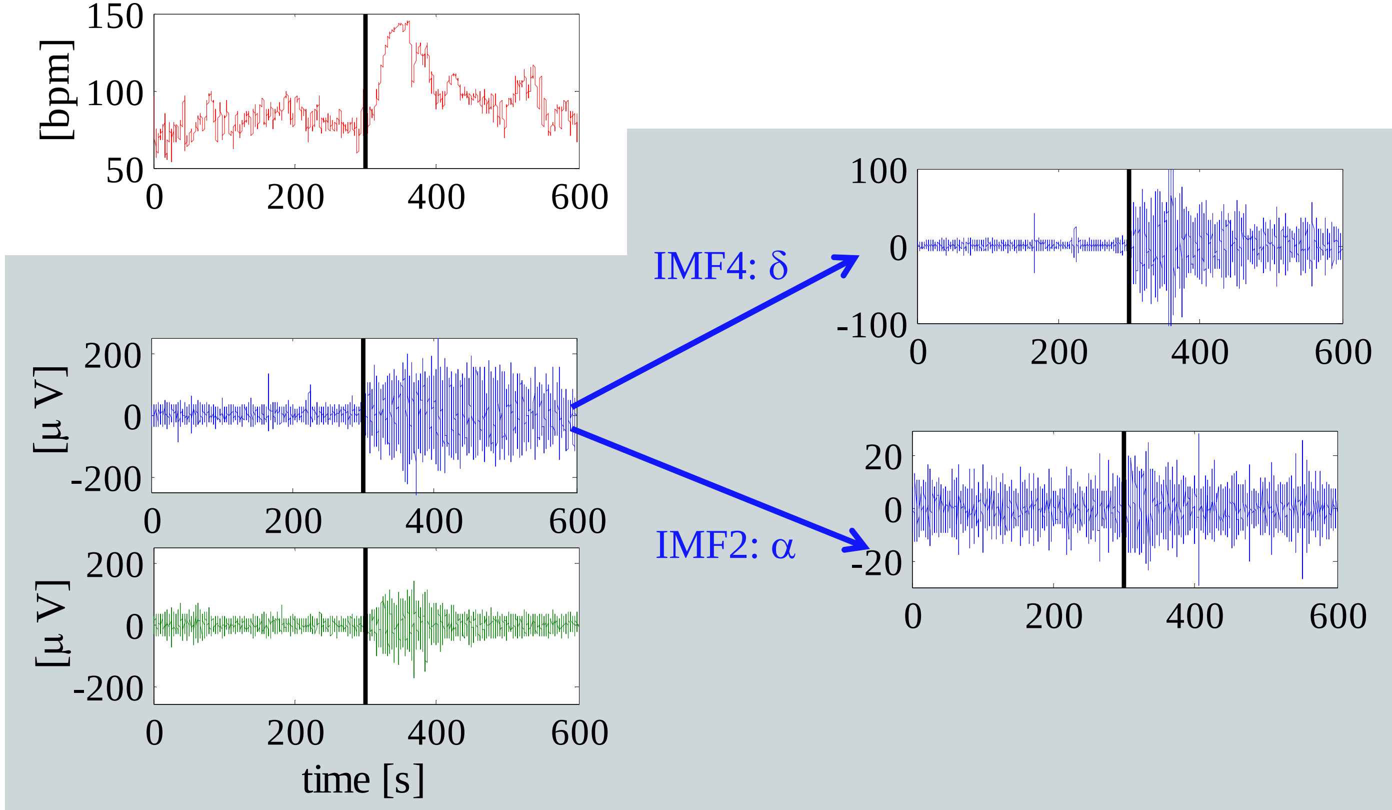
EEG

⇓

MEMD: $\mathbf{EEG_{IMF4}}$ and $\mathbf{EEG_{IMF2}}$

example (focus left):

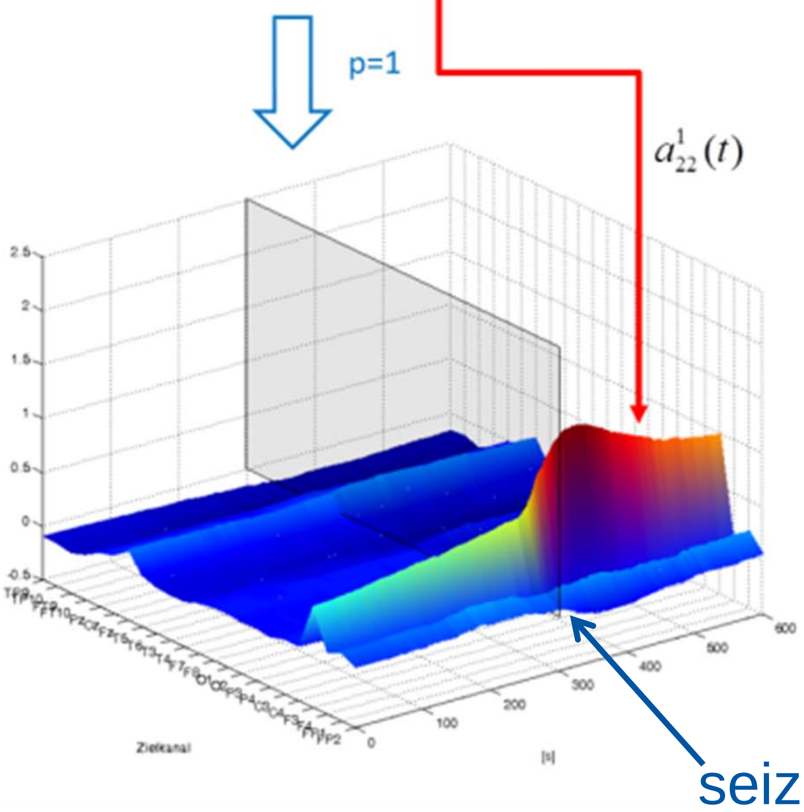




GC-based: AR modeling

≙F3

$$\begin{bmatrix} x_1(t)\\ \vdots \\ x_N(t)\end{bmatrix} = \sum_{p=1}^{P} \begin{bmatrix} a^p_{11}(t) & a^p_{12}(t) & \cdots & \cdots & a^p_{1N}(t)\\ \vdots & a^p_{22}(t) & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & a^p_{ij}(t) & \vdots\\ \vdots&\vdots&\vdots&\vdots&\vdots\\ a^p_{N1}(t) & a^p_{N2}(t) & \cdots & \cdots & a^p_{NN}(t)\end{bmatrix} \begin{bmatrix} x_1(t-p)\\ \vdots\\ x_N(t-p)\end{bmatrix} + \begin{bmatrix} w_1(t-p)\\ \vdots \\ w_N(t-p)\end{bmatrix}$$

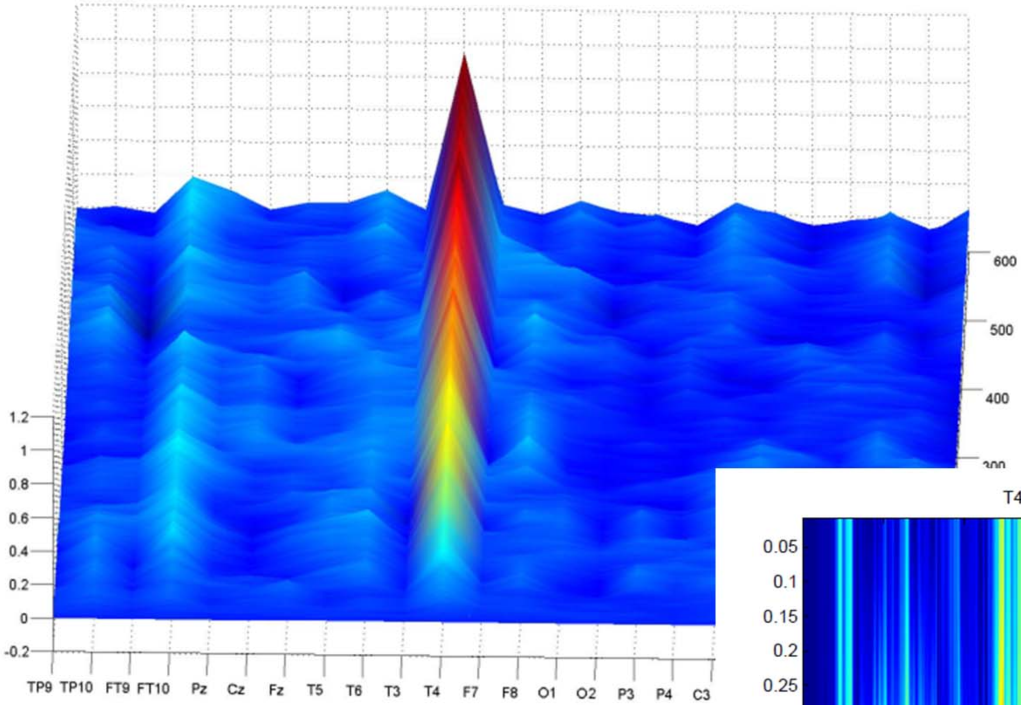


example 1:
EEG during TLE
F3-related column of AR coefficients for p=1 (time-variant, multivariate approach)

⇓

each channel / electrode is best explainable by itself !!!

GC-based: AR modeling

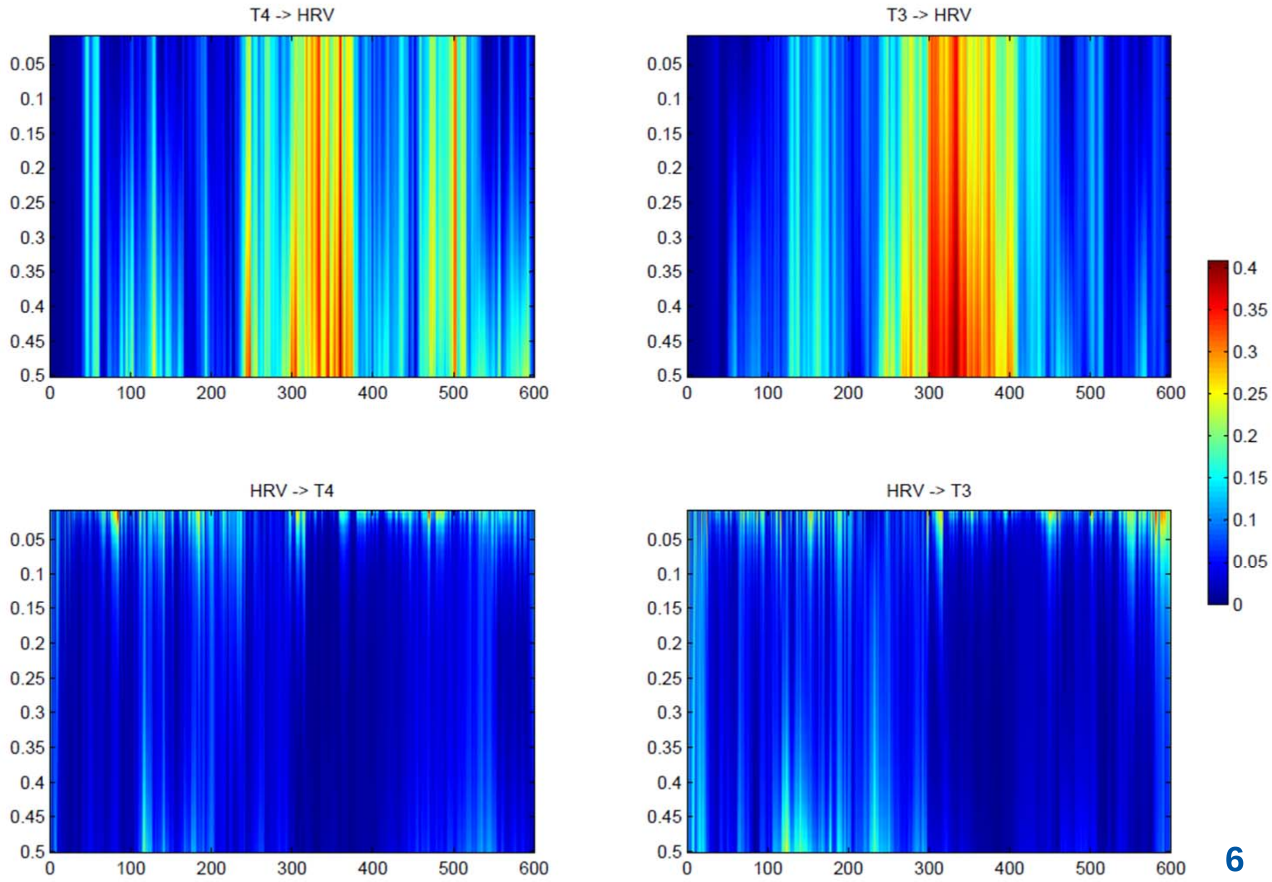


Example 2:
EEG-component-envelope / HRV during TLE
T4-related column of AR coefficients for p=1 (time-variant, multivariate approach)

Example 2:
EEG-component-envelope / HRV during TLE
resulting time-variant, multivariate estimation of PDC

⇓

no interpretable / meaningfull results!!!



Motivation

interaction / coupling between EEG components, EEG and HR …: adaptation of (TVMVAR) GC-based approaches

TLE data: AR-based models fail !

nonlinear, non-AR-based alternatives

- ✓ directed causation
- ✓ time-variant
- ✓ frequency-selective
- ✓ multivariate
- ✓ robust concerning noise
- ✓ statistically quantifiable

Convergent Cross Mapping ?

General Concept CCM

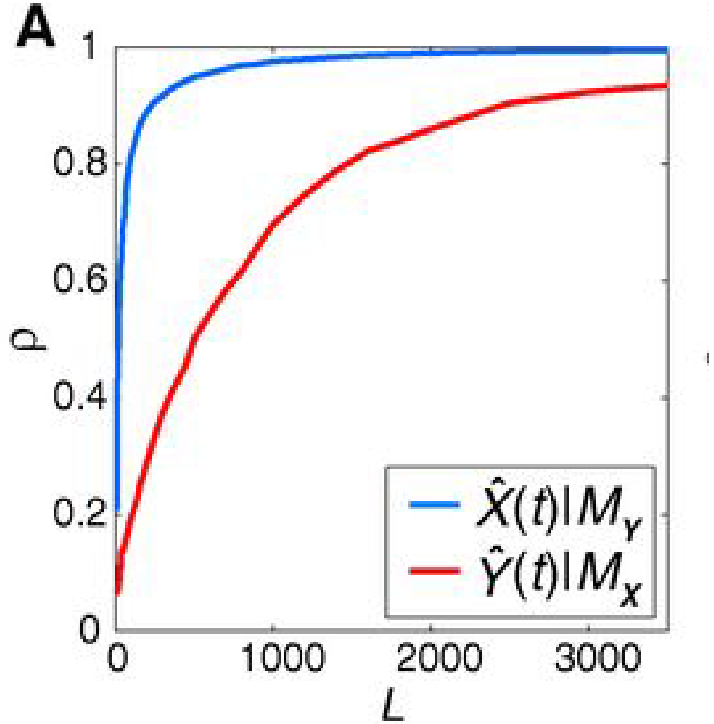
Convergent Cross Mapping (CCM) [Sugihara et al. 2012] **:**

- **correspondence between "shadow manifolds" M_X and M_Y (nonlinear state space reconstruction by lagged coordinates) of time series *X* and *Y***
- **measures to which extent historical record of *Y* values can estimate states of *X* or vice versa**
- **cross mapping: *X* by M_Y (X/M_Y) and Y by M_X (Y/M_X)**
- ***X* drives *Y* $\Rightarrow$ possible estimation of *X* from *Y*, but not of *Y* from *X* (contrary to intuition and Granger causality!)**

Practical Procedure

estimation of CCM:

- **correlation coefficient ρ between X and X/M_Y or Y and Y/M_X (or other error metrics) by using basic algorithm**
- **use of increasing data length („library length L“)**
- **X drives Y stronger than vice versa $\Rightarrow$ ρ between X and X/M_Y converge faster/reach a higher plateau than ρ between Y and Y/M_X**



G Sugihara et al. Science 2012;338:496-500

performance of CCM:

- **embedding dimension**
- **time lag**
- **library length**
- **used error metrics**
- **system noise**

Simulation

- **2-species logistic model:**

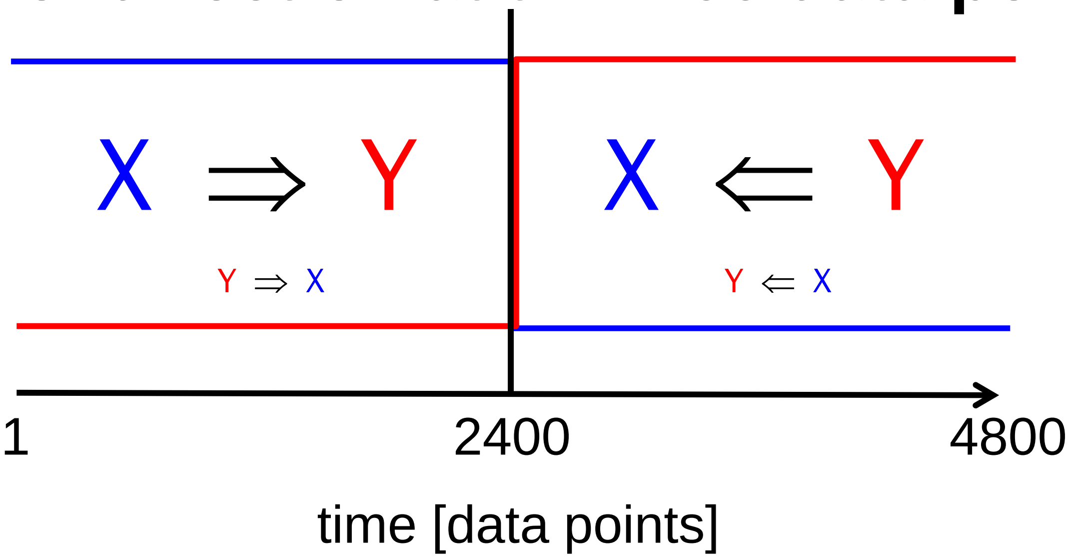
$$x(t+1) = x(t)[3.8 - 3.8\,x(t) - 0.02\,y(t)]$$
$$y(t+1) = y(t)[3.5 - 3.5\,y(t) - 0.1\,x(t)],$$

(„X drives Y stronger than vice versa“)

X ⇒ Y

Y ⇒ X

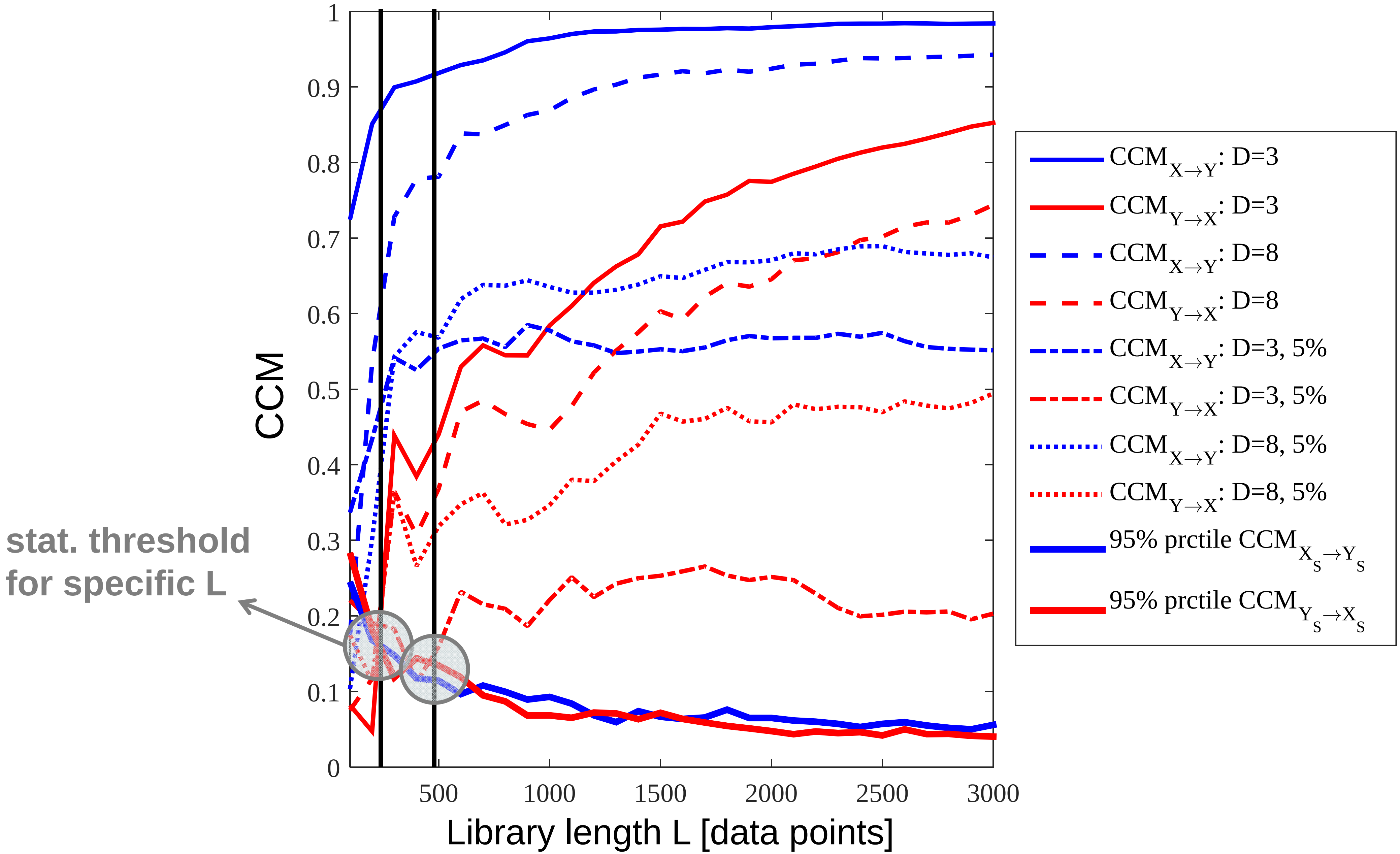
- **change of direction at t = 2400 data points:**



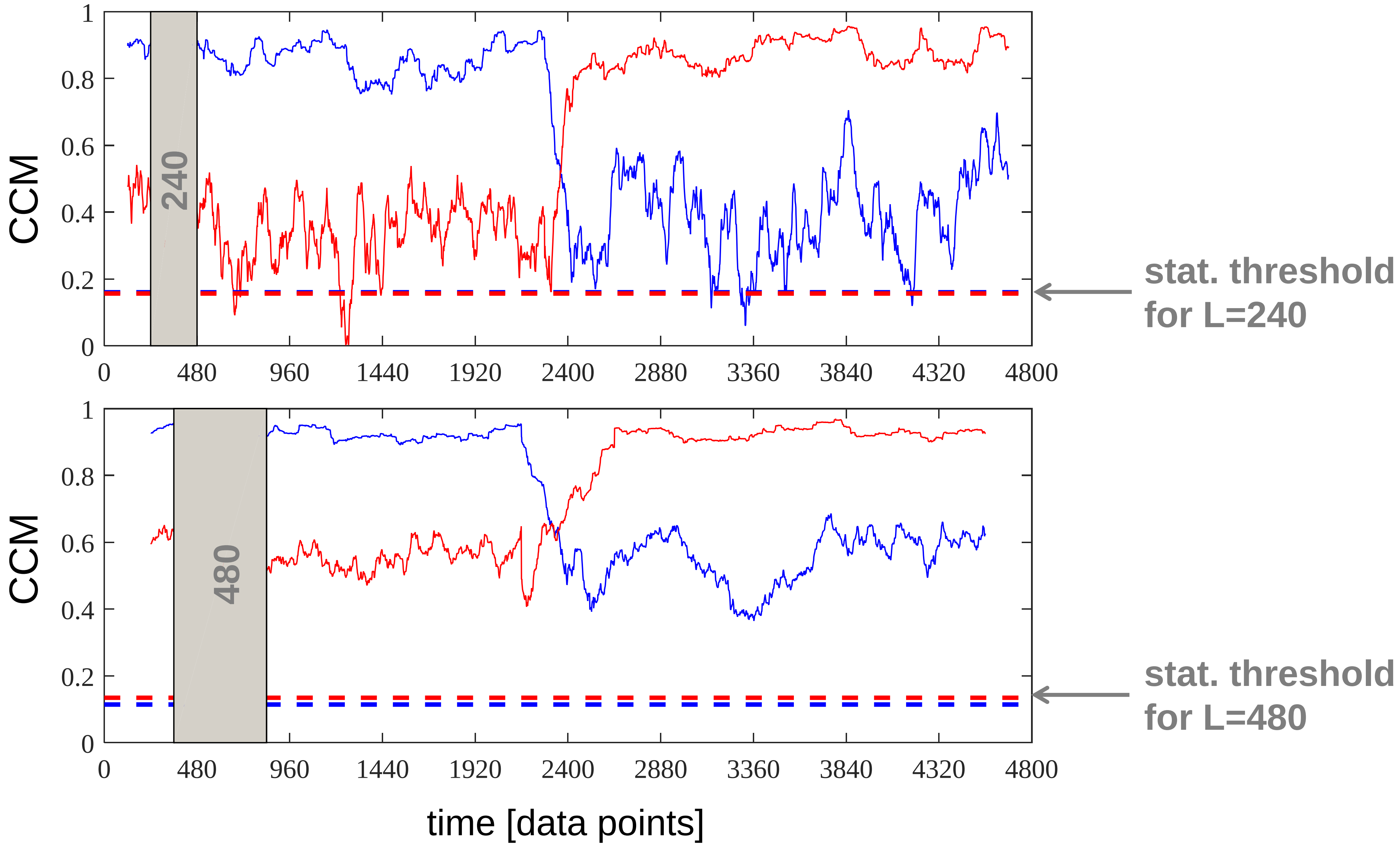
Simulation: Investigated Parameters

- **influence of different levels of additive noise (% of STD of original signals)**
- **influence of embedding dimension**
- **surrogate data test for statistical validation**
- **influence of window-length on interval-based performance**

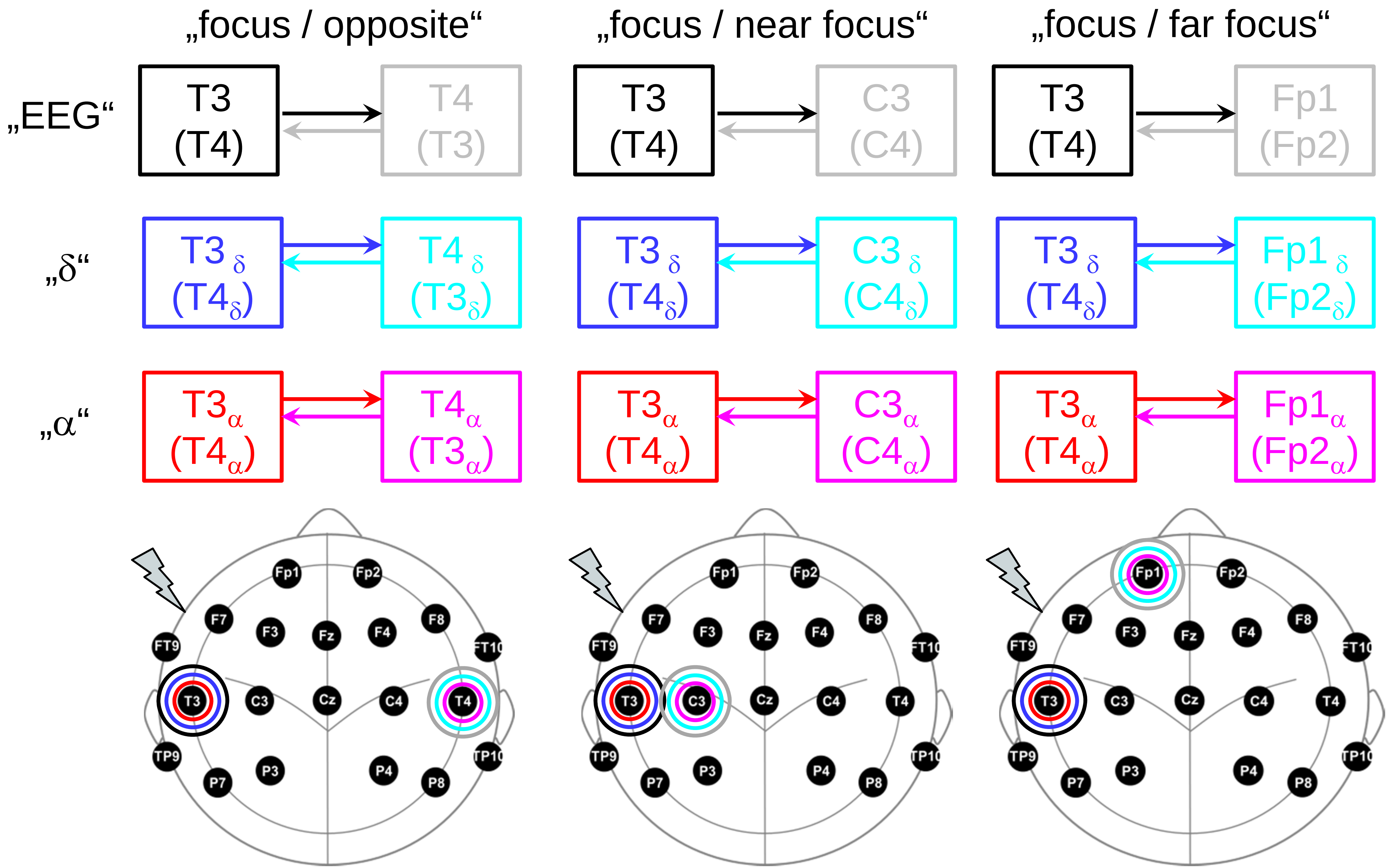
Simulation: D, Noise, Surrogates



Simulation: Interval-based

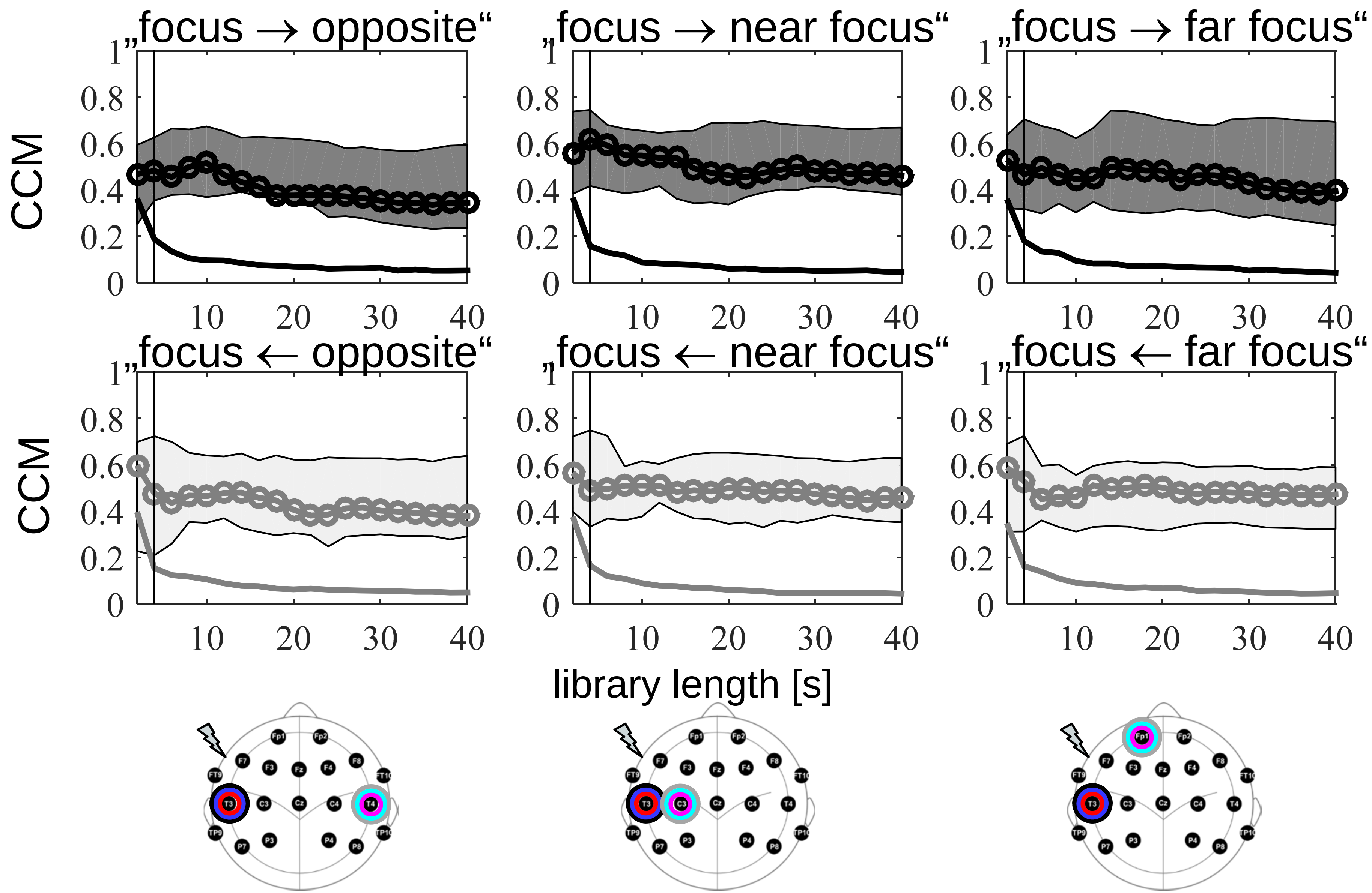


Real Data: Schemes of Coupling



Real Data: Library Length EEG

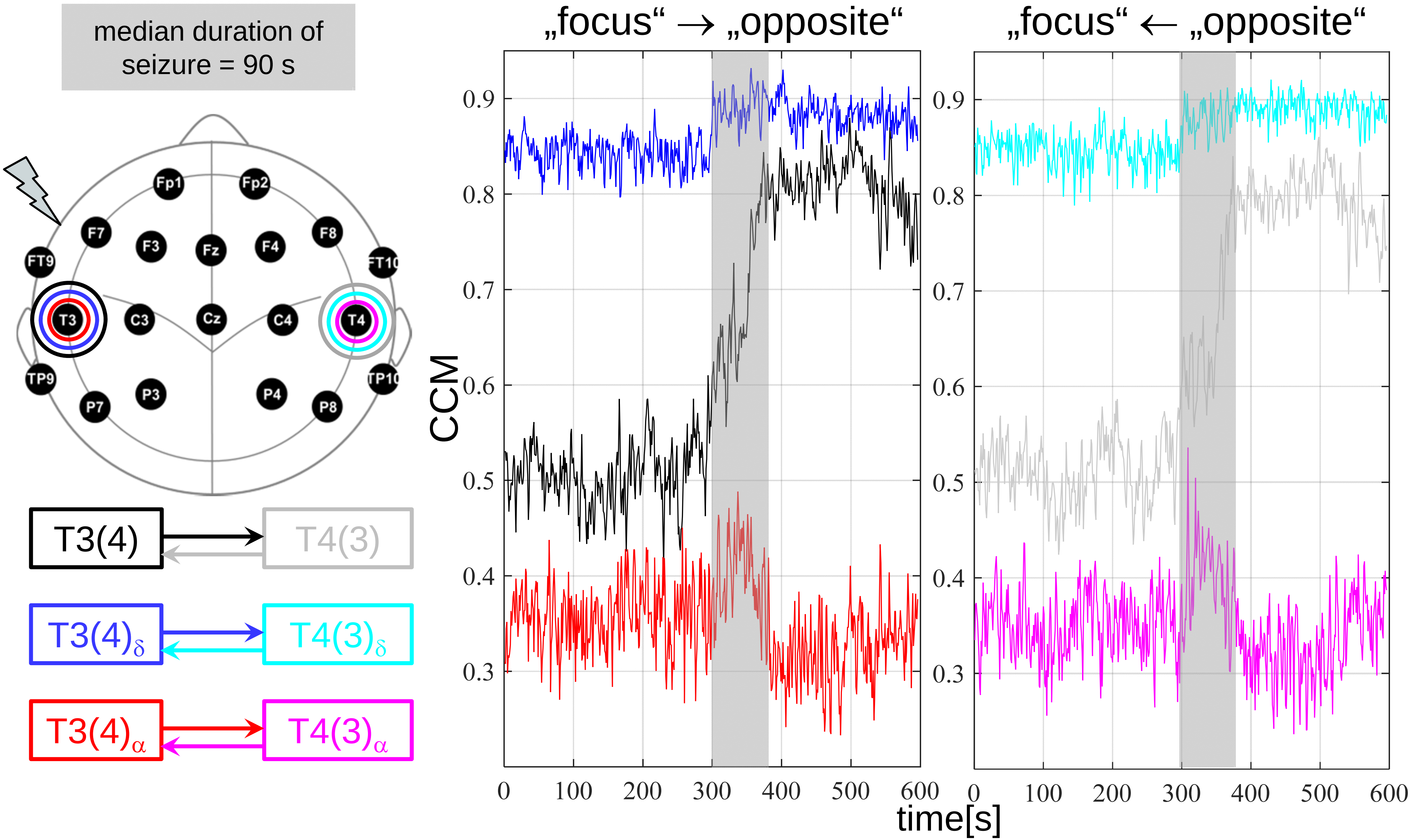
„EEG"



18 children, median and 95% CI-tube (bootstrap), stat. threshold (surrogates), data: [200 - 240 s], L=128, 256,…, 2560, (2 s, 4 s,…, 40 s)

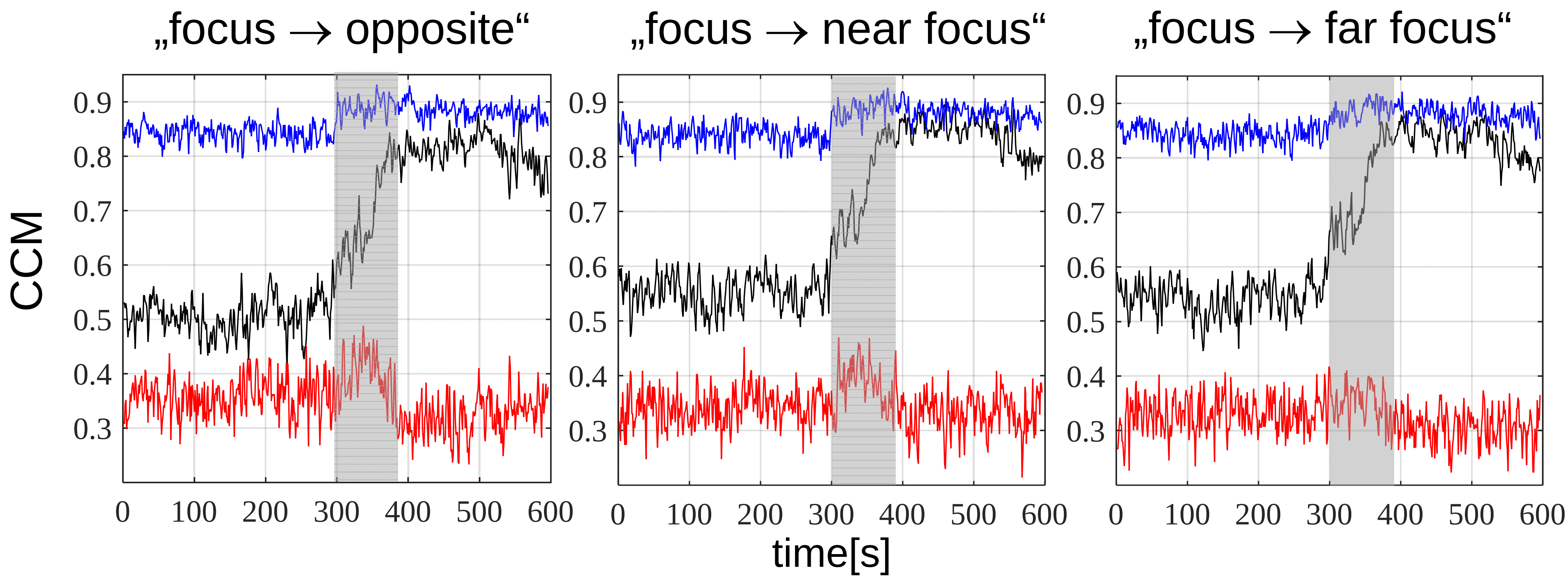
Real Data: Interval-based CCM

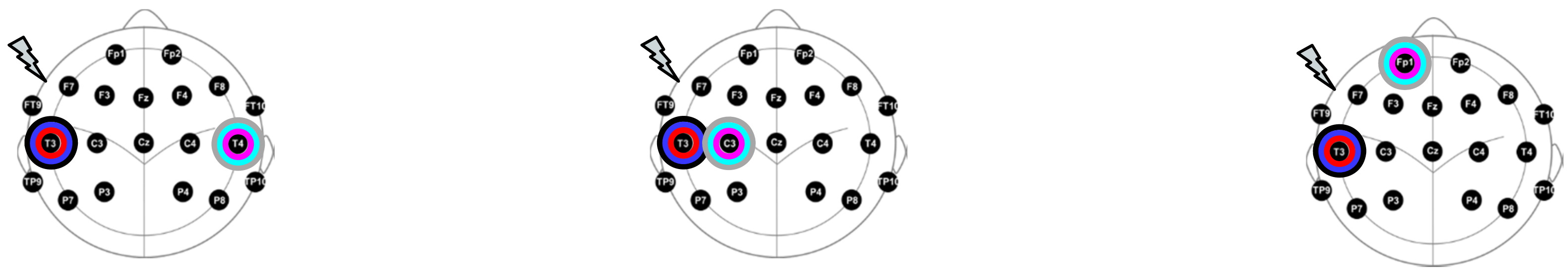
median duration of seizure = 90 s

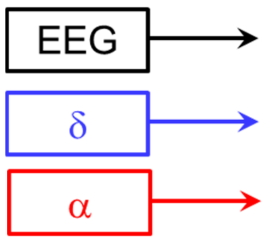


mean of 18 children, moving window: 4 s (256 data points)

Real Data: Interval-based



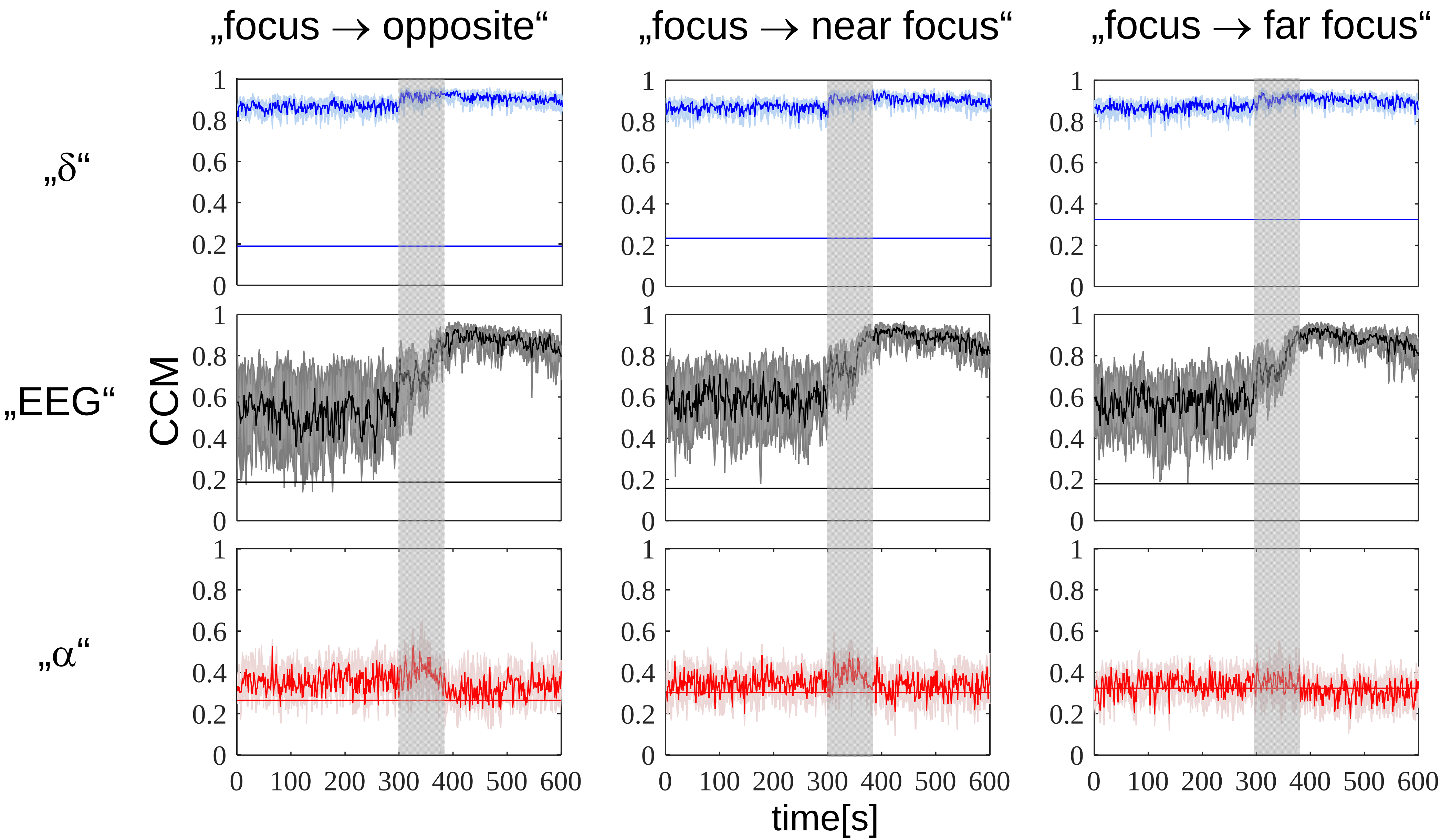




median duration of seizure = 90 s

mean over 18 children
moving window: 4 s (256 data points)

Real Data: Statistics



18 children, median and 95% CI-tube (bootstrap), stat. threshold (surrogates) , moving window: 4 s (256 data points)

Conclusion

CCM:

- nonlinear ✓
- directed causation ✓
- time-variant (✓)
- frequency-selective ✓
- multivariate ?
- noise ✓
- statistical measures ✓

- considerable nonlinear alter-native to (TVMVAR) GC-based approaches
- needs further improvements (bivariate! error metrics?)
- comparison to other nonlinear (model-free) approaches (TE)

EEG during TLE:

- direction and strength of interactions vs. time-varying changes of (frequency-selective) network measures?
- concept epileptic focus vs. epileptic network?
- other models (DDEs and derived meta-parameters)?

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THANK YOU FOR YOUR ATTENTION!

Die menschliche Größe

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Dr. Franz Benninger

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