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# INFORMATION OPTIMIZED MULTILAYER NETWORK REPRESENTATION OF HIGH DENSITY ELECTROENCEPHALOGRAM RECORDINGS

29 07 2022
*Lake Como School*

DEPARTMENT OF
PHYSICS
"ALDO PONTREMOLI"

DEPARTMENT OF
ENVIRONMENTAL
SCIENCE AND POLICY

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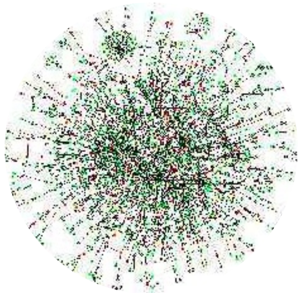
COMPLEXDATA

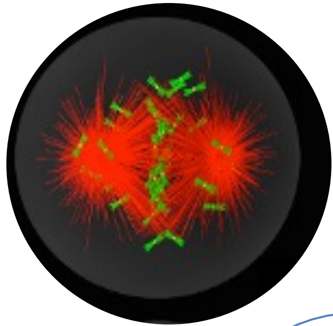
# CC&B RESEARCH

Neurodegenerative diseases

Network Medicine

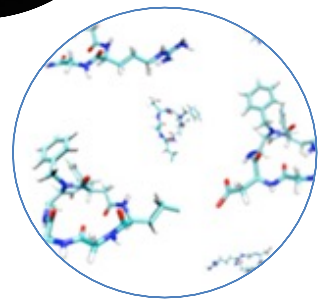


Cancer



Data science

Protein simulations



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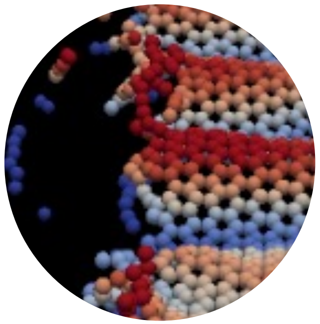
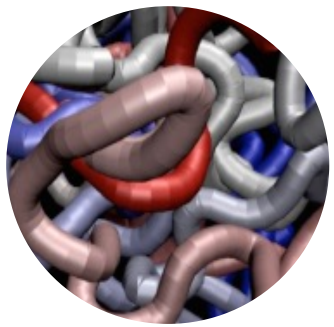
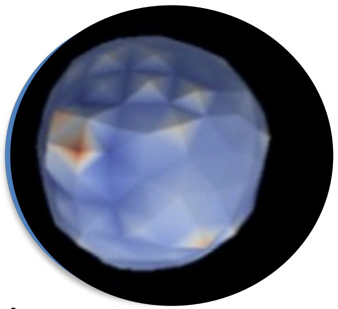
Disordered Systems

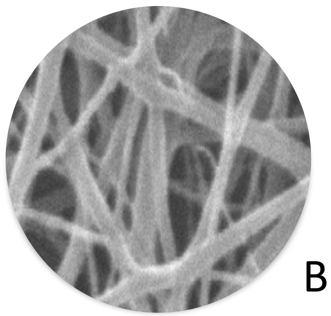


Chromatin conformations





Cell biomechanics



Bio-inspired materials

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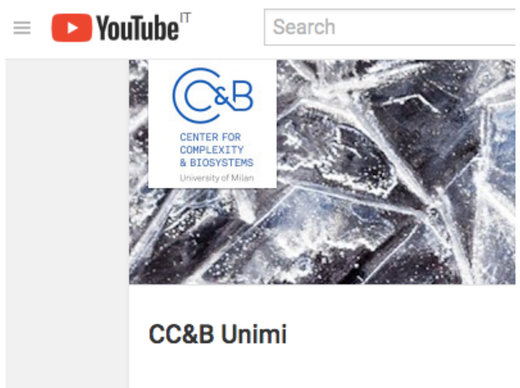
# OUTREACH

## Newsletters


## WEB: www.complexitybiosystems.it


## Social media (Youtube, twitter)





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# VIRTUAL SEMINARS ON COMPLEXITY

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https://sites.google.com/view/virtualseminarsoncomplexity

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# SUMMER SCHOOL SERIES: Advances in Complex Systems



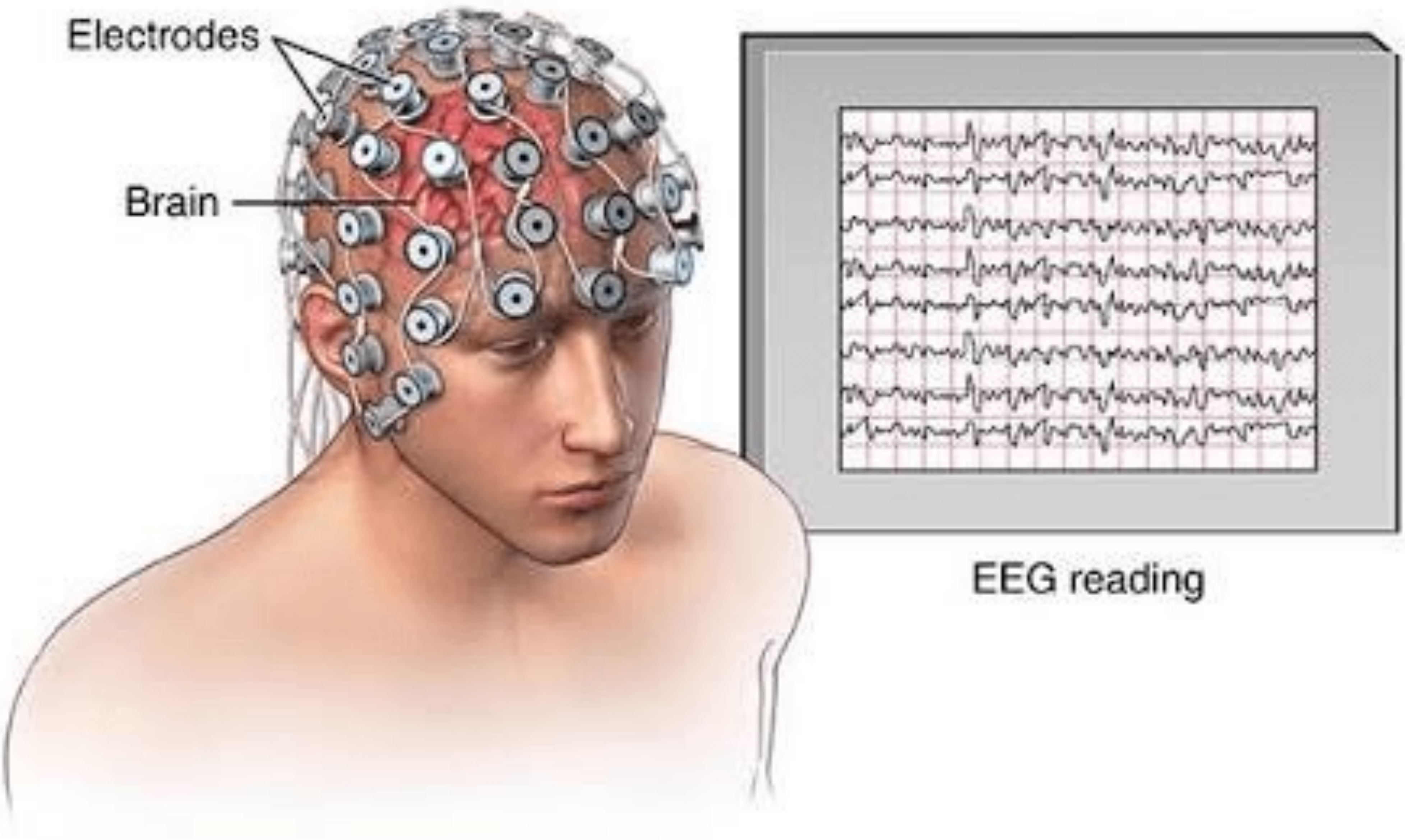
The school takes place every two years in July:

2015: http://acss.lakecomoschool.org
2017: http://acst.lakecomoschool.org
2019: http://acse.lakecomoschool.org

Topics: complex networks, chromatin, regeneration, morphogenesis, bioinspired materials….

**NEXT SCHOOL July 2024**

# ELECTROENCEPHALOGRAM (EEG)

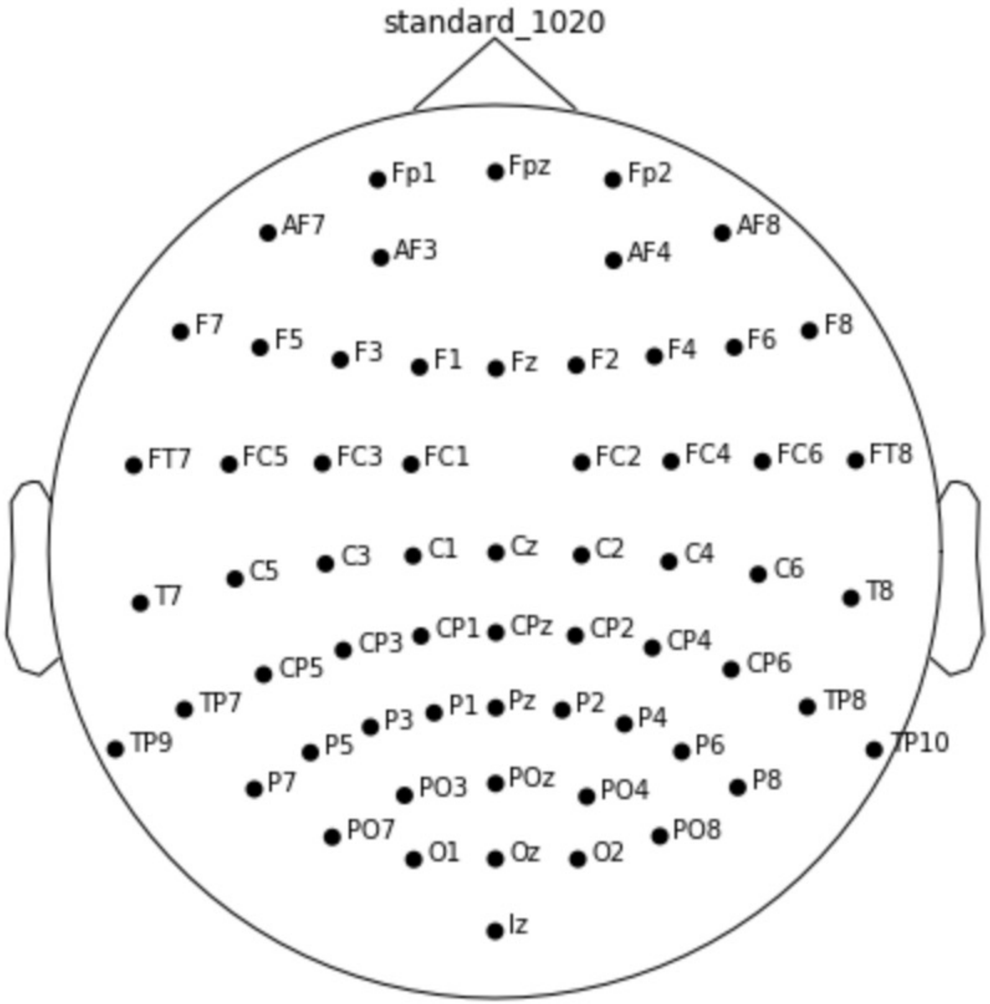


CAN WE USE EEG SIGNALS
TO DETECT CLINICAL CONDITIONS
IN PATIENTS?

e.g. Patients with mental health issues

# EXPERIMENTAL DATA

64 electrodes
500 Hz frequency
8 hours recording during sleep




## 32 PATIENTS:

7 Bipolar Disorder (BD)
12 First Episode Psychosis (FEP)
13 Control subjects

Sistema Socio Sanitario
Regione Lombardia
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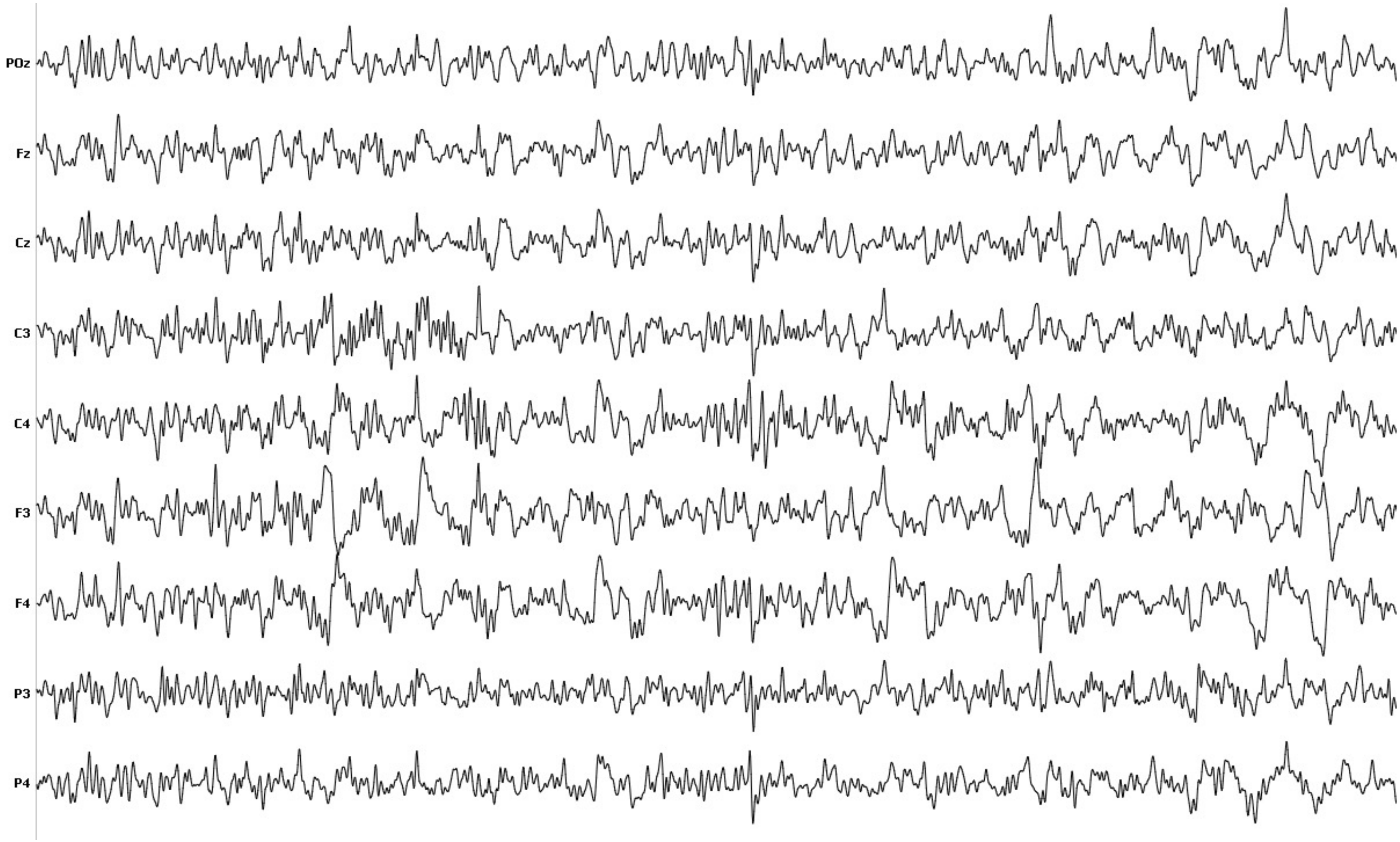
# RAW EEG SIGNALS

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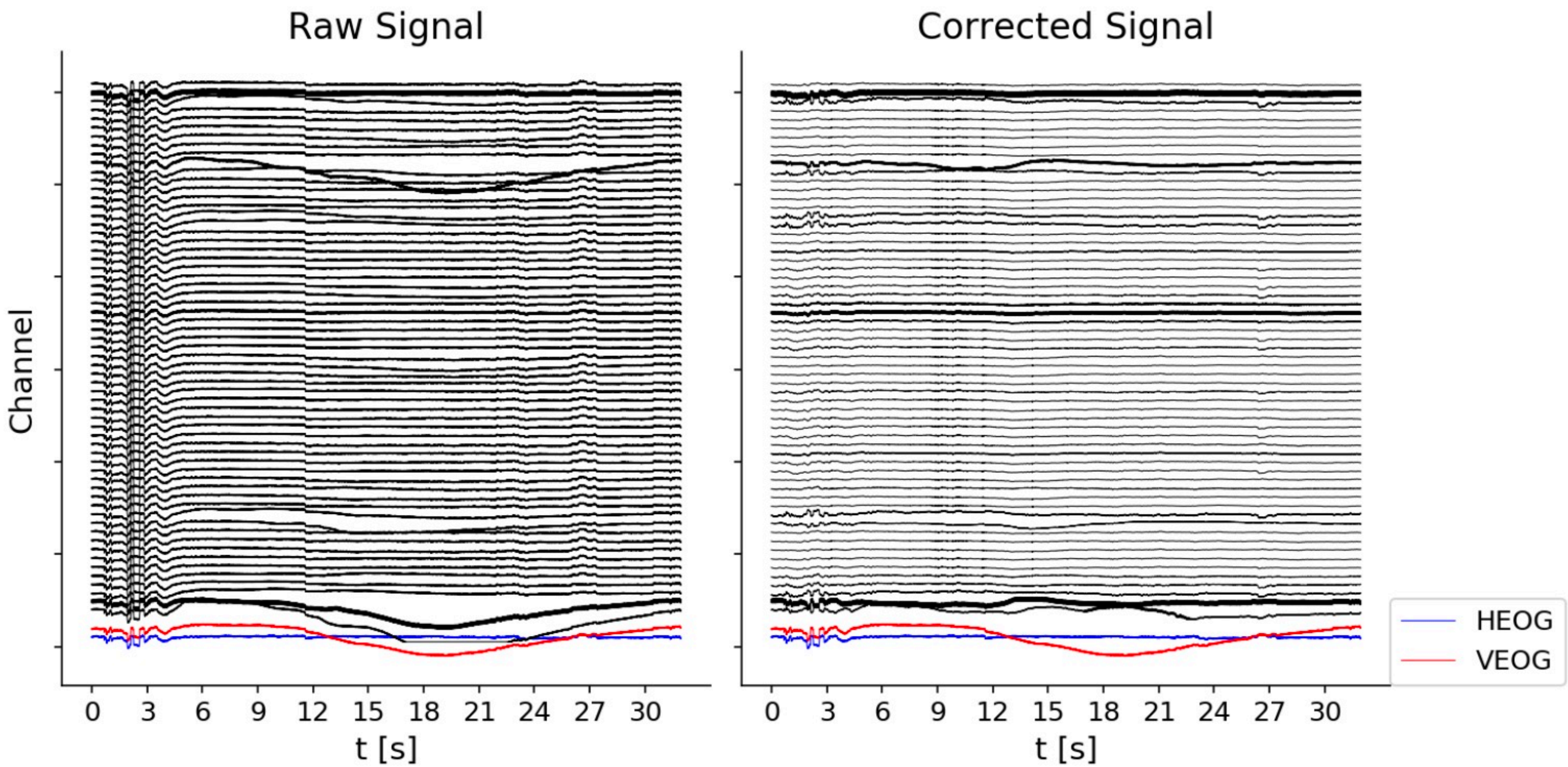
# DATA PREPROCESSING

## Eye Movement Correction

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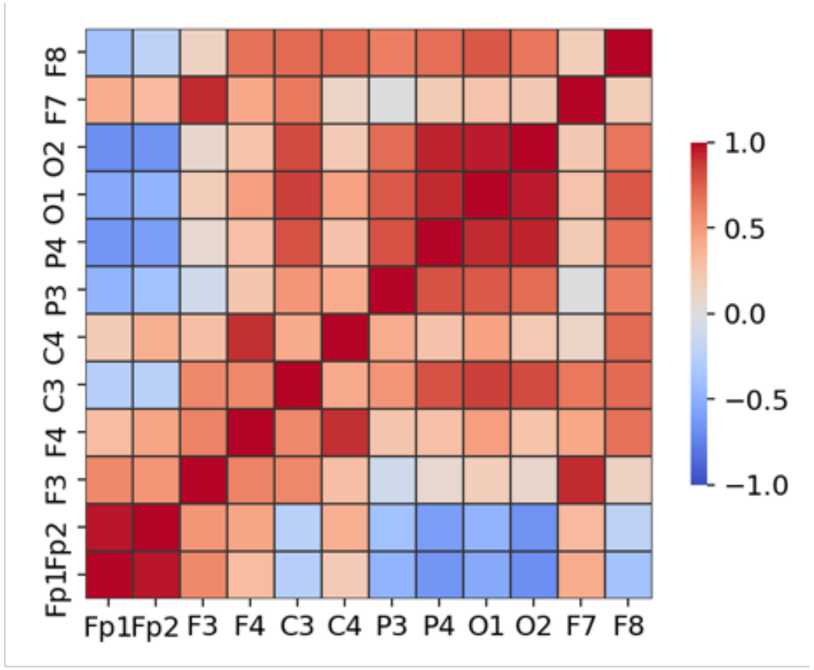
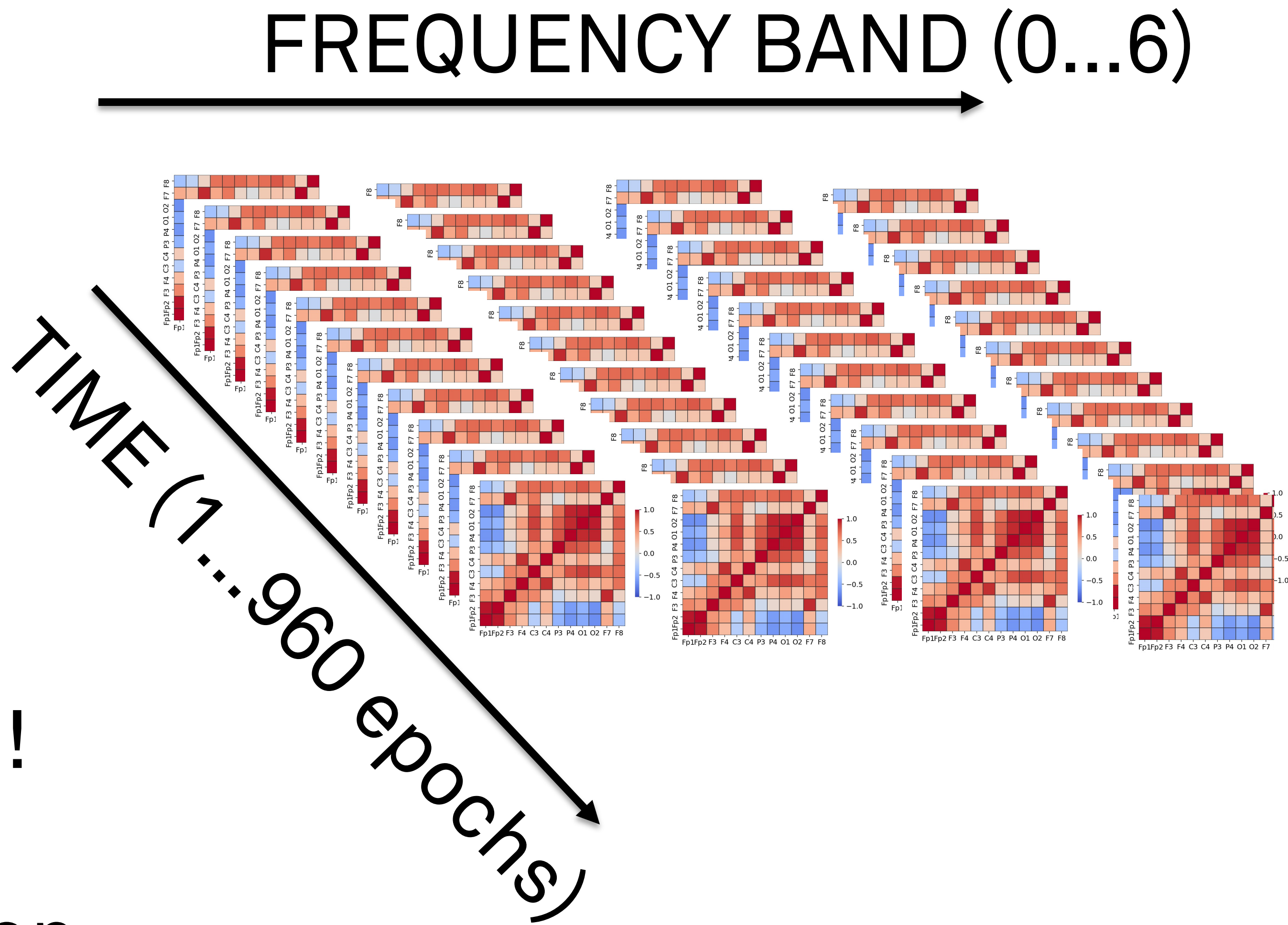
# SIGNAL COVARIANCE MATRICES

$$C_{ij} = \frac{\mathrm{cov}(x_i, x_j)}{\sigma_{x_i}\sigma_{x_j}}.$$

30 seconds timesteps

7 bands: [0.5-1],[1-2],[2-4],[4-8],[8-16], [16-32], [32-64] Hz




6720 62x62 matrices!

Dimensional reduction

by network representation

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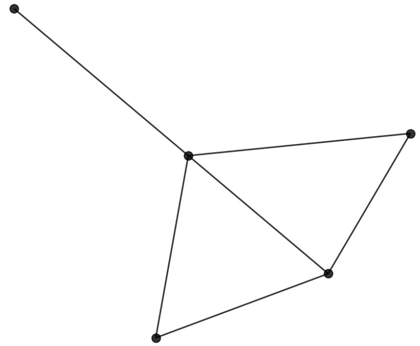
# SIMPLE NETWORK CONSTRUCTION (EXAMPLE)

$$A = \begin{pmatrix} 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 \\ 1 & 1 & 1 & 1 & 0 \end{pmatrix}$$

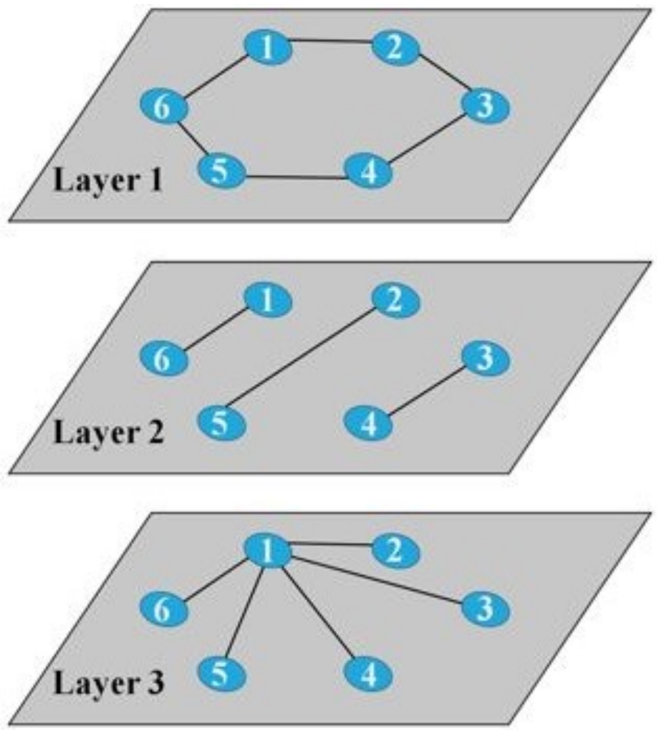


# MULTILAYER NETWORK (EXAMPLE)

$$A^1 = \begin{pmatrix} 0 & 1 & 0 & 0 & 0 & 1 \\ 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 \\ 1 & 0 & 0 & 0 & 1 & 0 \end{pmatrix}$$

$$A^2 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

$$A^3 = \begin{pmatrix} 0 & 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

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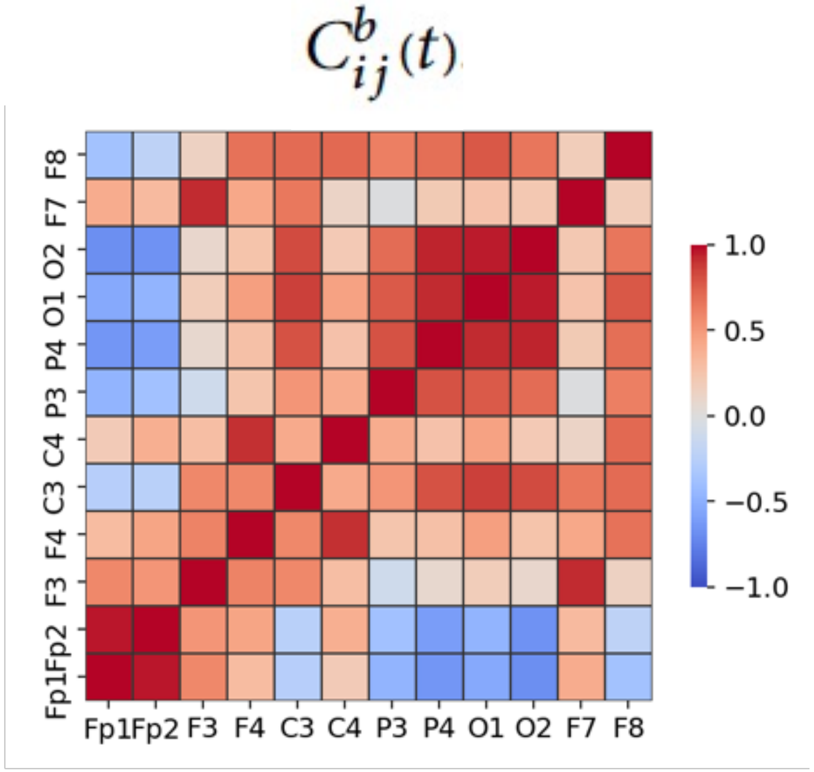
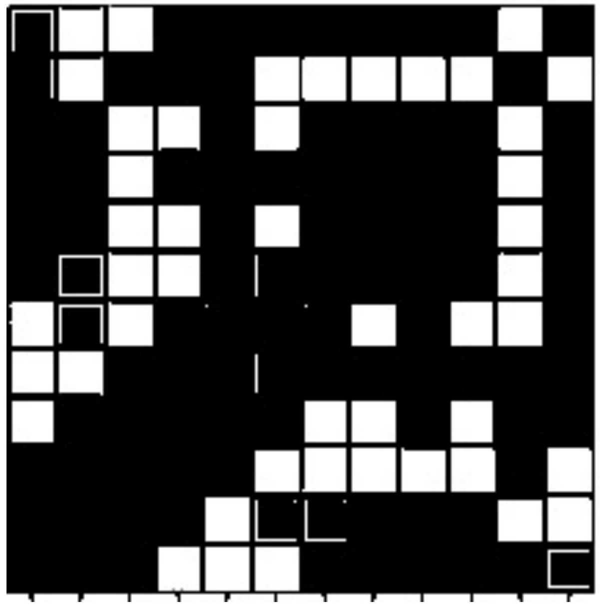
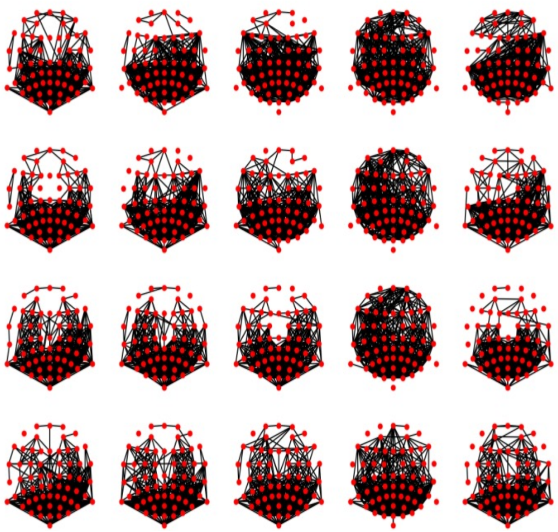
# FROM COVARIANCE MATRIX TO NETWORK




$$A^b_{ij}(t) = \begin{cases} 1 & \text{if } |C^b_{ij}(t)| \geq \theta^* \\ 0 & \text{else} \end{cases}$$

θ*





How to chose θ* ?

# NETWORK JENSEN-SHANNON DIVERGENCE

De Domenico & Biamonte 2016

$$\rho = \frac{e^{-\tau L}}{Z}$$ NETWORK “DENSITY MATRIX”

$$Z = \mathrm{Tr}[e^{-\tau L}]$$ DIFFUSION PROPAGATOR AT TIME $\tau$

$$S(\rho) = \log_2 Z + \frac{\tau}{\ln 2}\mathrm{Tr}[L\rho]$$ NETWORK “ENTROPY”

$$J(\rho|\sigma) = S\left(\frac{\rho+\sigma}{2}\right) - \frac{1}{2}(\rho+\sigma)$$ J-S DIVERGENCE

$$\mathcal{I}(\theta) = \sum_{t=1}^{T} J(\rho_t(\theta)|\rho_{t-1}(\theta))$$ INTEGRATED J-S DIVERGENCE

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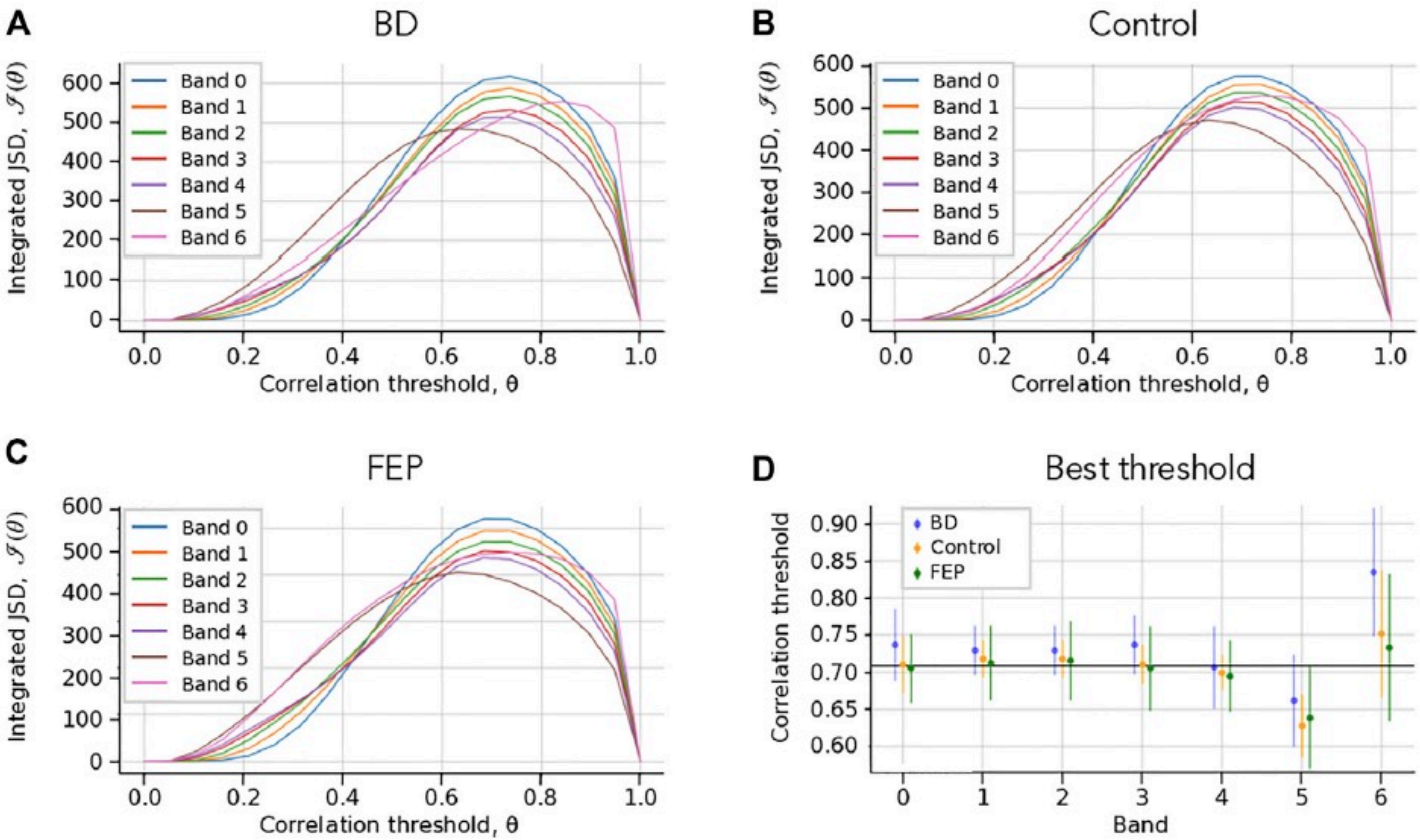
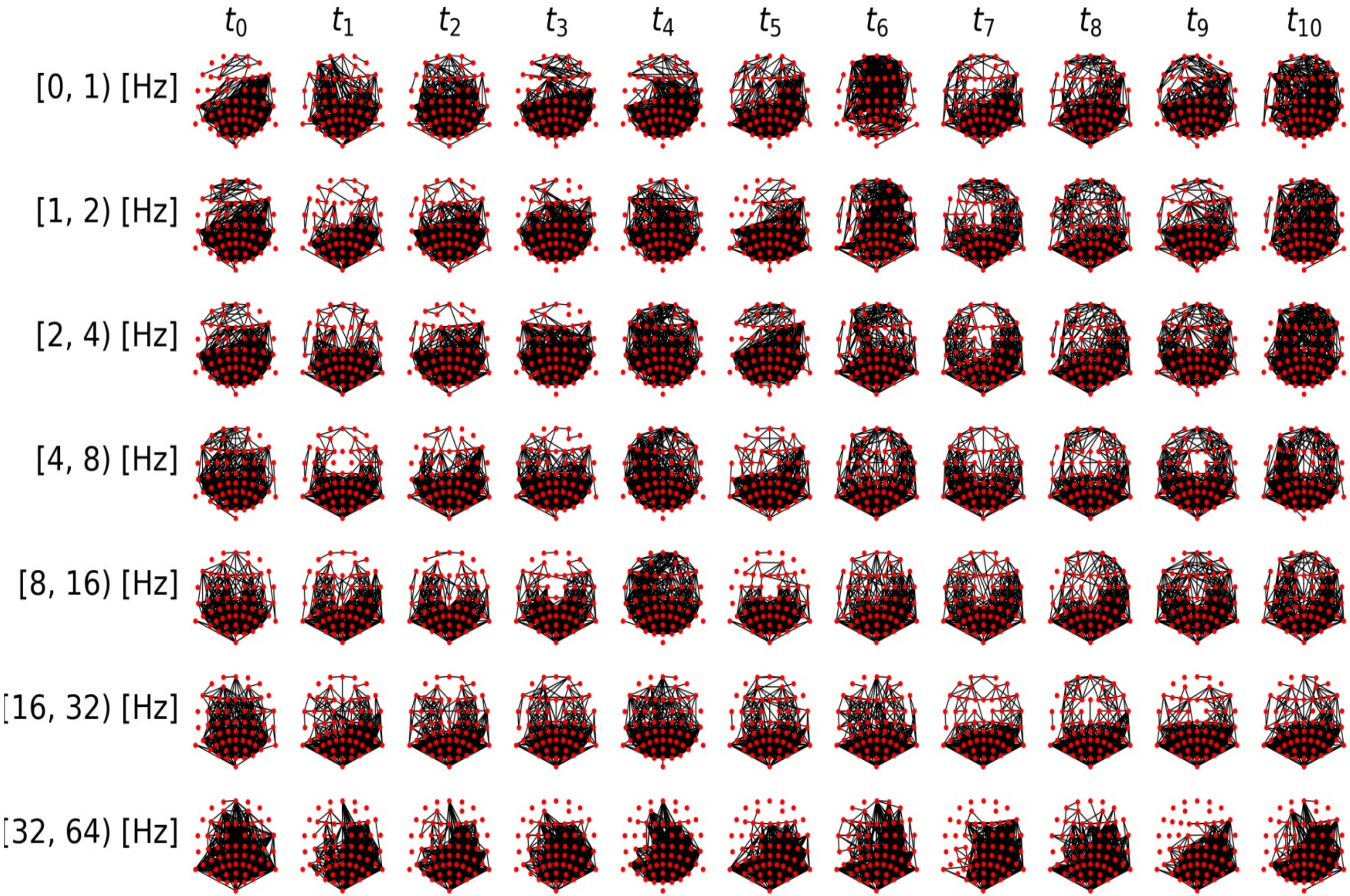
# MAXIMIZE INTEGRATED J-S DIVERGENCE

$$\theta^*_{b,p} = \mathrm{argmax}_{\theta\in[0,1]}\mathcal{I}_{b,p}(\theta) \qquad \theta^* = \langle\theta^*_{b,p}\rangle_{b,p}$$



# EEG MULTILAYER NETWORKS

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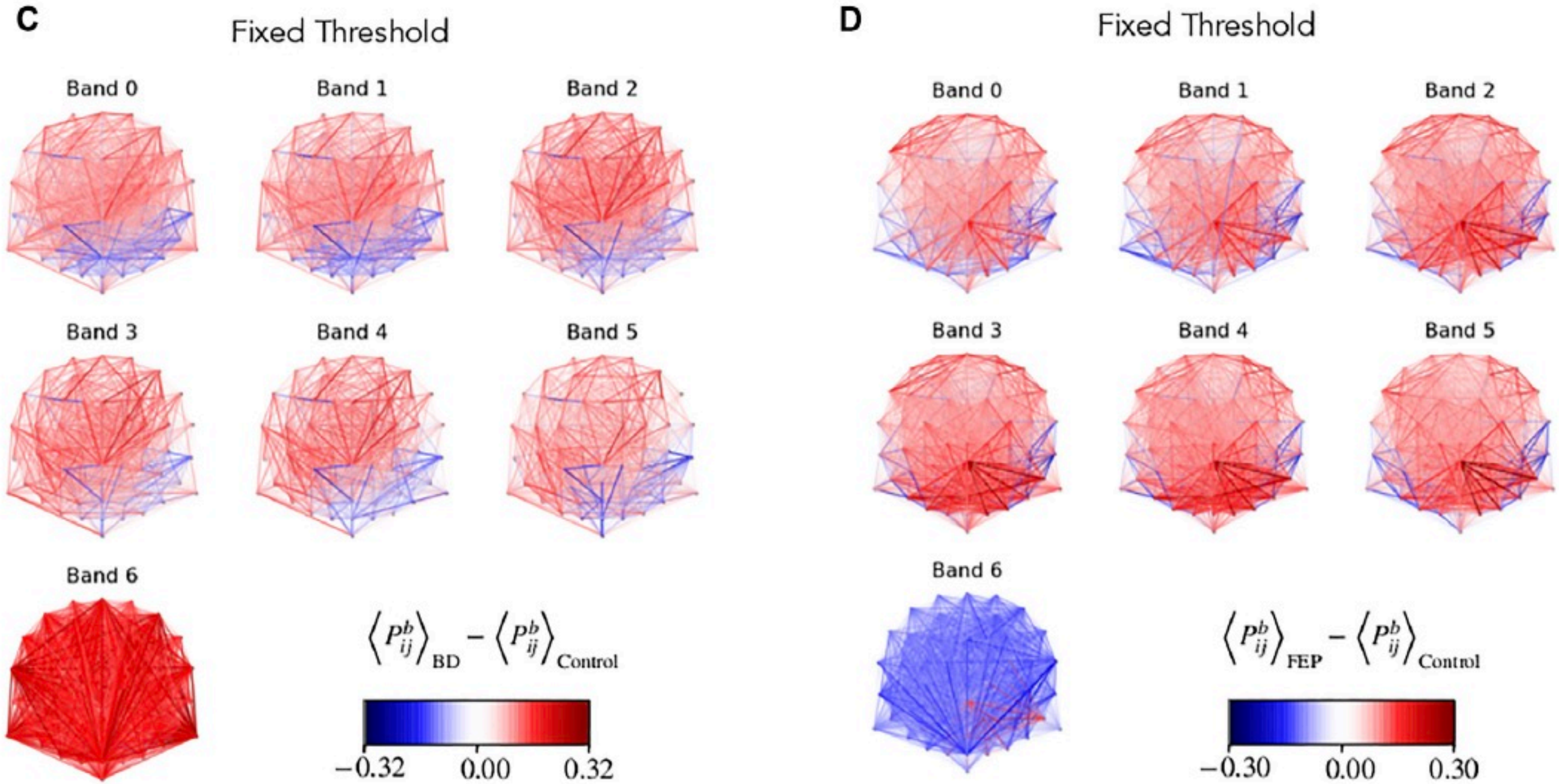
# NETWORK EDGE PRESENCE

$$P_{ij}^{b} = \langle A_{ij}^{b}(t) \rangle_t$$



# NETWORK MEASURES

## Betweennes Centrality:

$$\mathrm{BC} = \frac{1}{N}\sum_{i=1}^{N} c_B(i)$$

$$c_B(i) = \frac{2}{(N-1)(N-2)} \sum_{j,k \in V} \frac{\sigma(j,k|i)}{\sigma(j,k)}$$

passing from node i

Number of shortest paths between j and k

## Clustering Coefficient:

$$c = \frac{1}{N}\sum_{i=1}^{N} c_i$$

$$c_i = \frac{2 \cdot t_i}{k_i \cdot (k_i - 1)}$$

Number of triangles involving node i

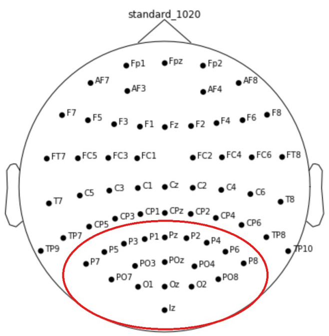
Degree of node i

## Average Path Length:

$$a_G = \frac{1}{N \cdot (N-1)} \sum_{i \neq j} d(i,j).$$

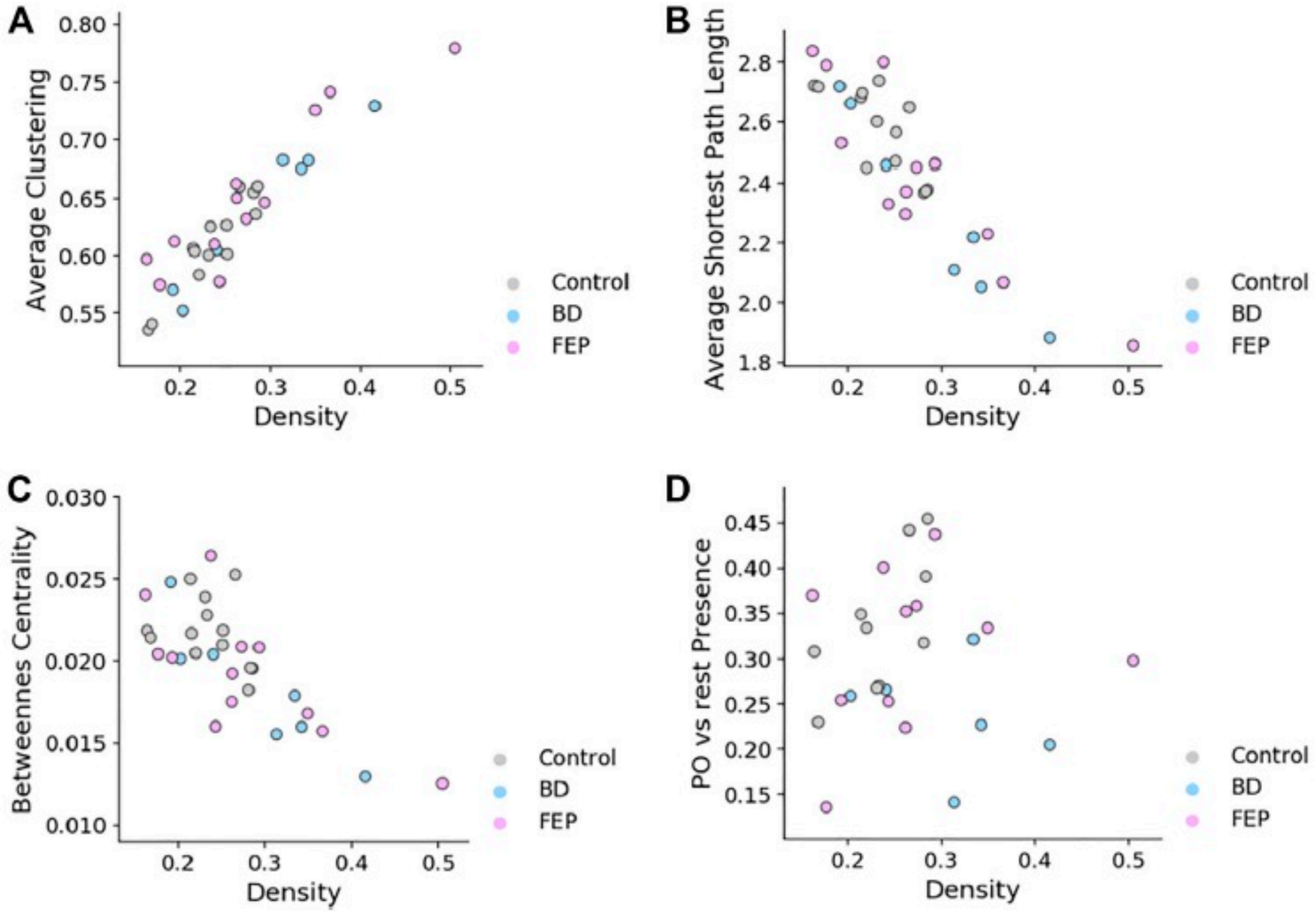
Length of shortest path between i and j

## Parieto-Occipital Edge Presence:



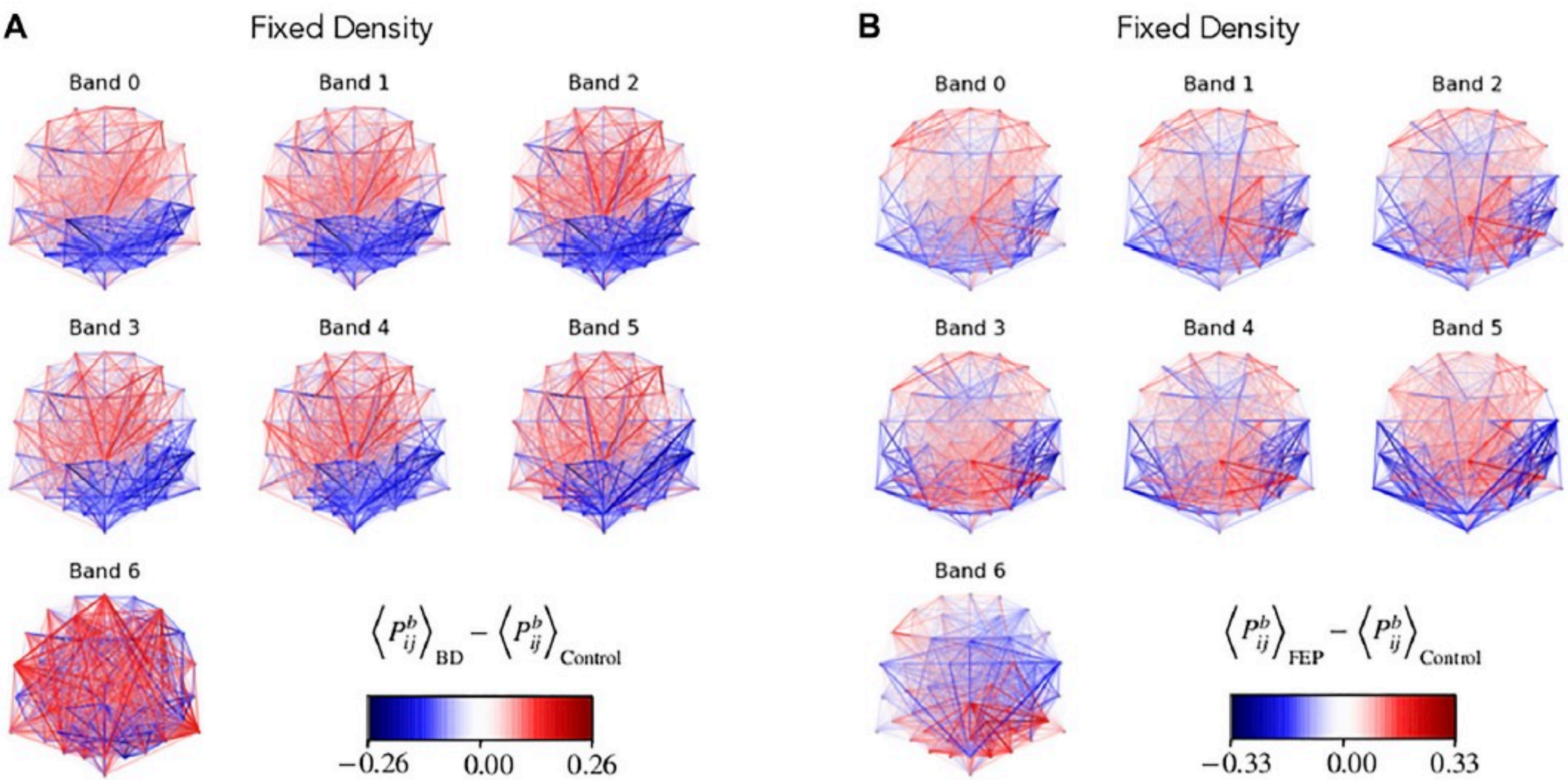

$$P_{\mathrm{PO}} = \langle P_{ij}^{b} \rangle_{(ij) \in \mathrm{PO}} - \langle P_{ij}^{b} \rangle_{(ij) \notin \mathrm{PO}} \qquad P_{ij}^{b} = \langle A_{ij}^{b}(t) \rangle_t$$

# DENSITY DEPENDENCE OF NETWORK MEASURES

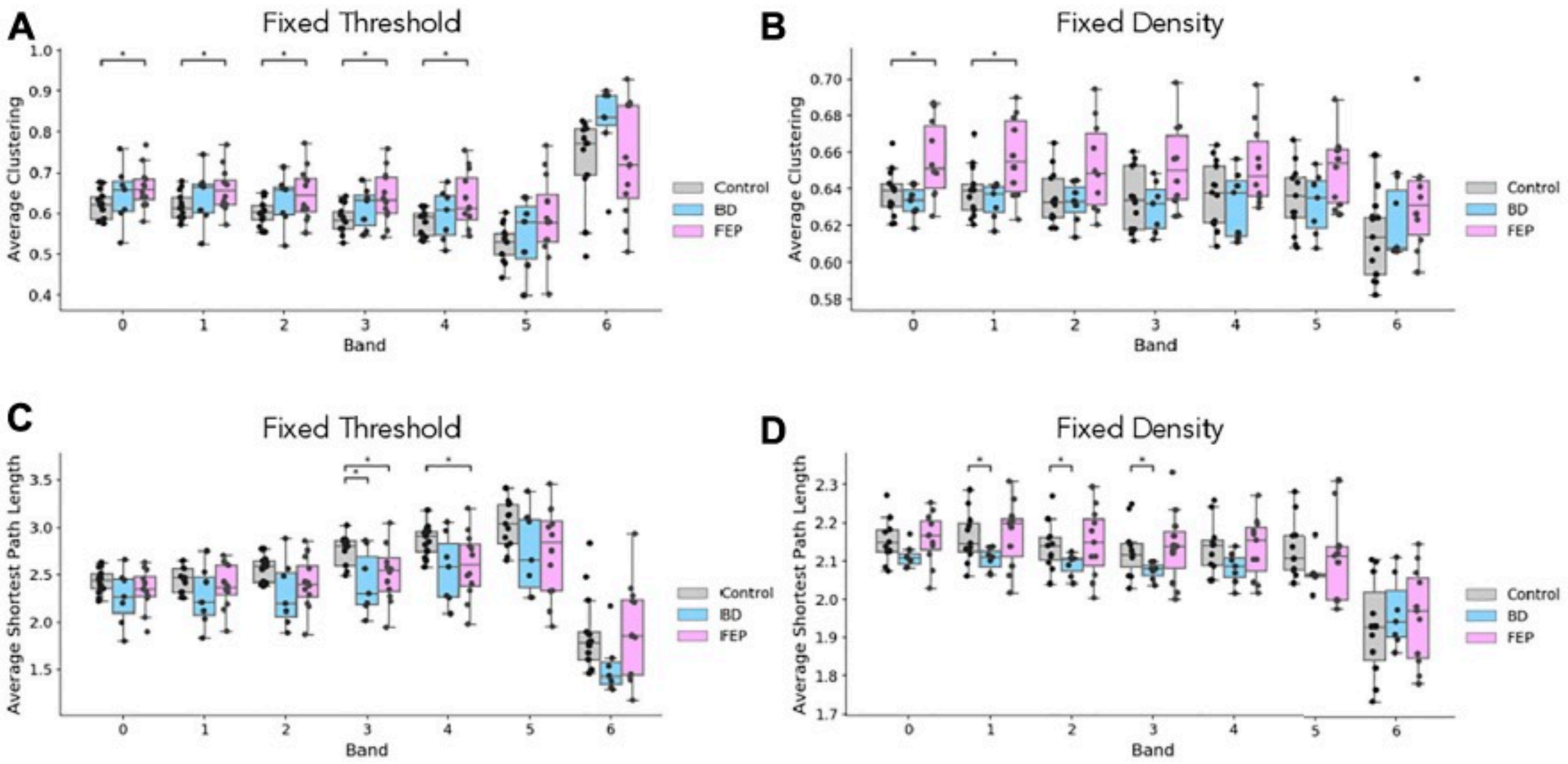


# NETWORK EDGE PRESENCE (FIXED DENSITY)

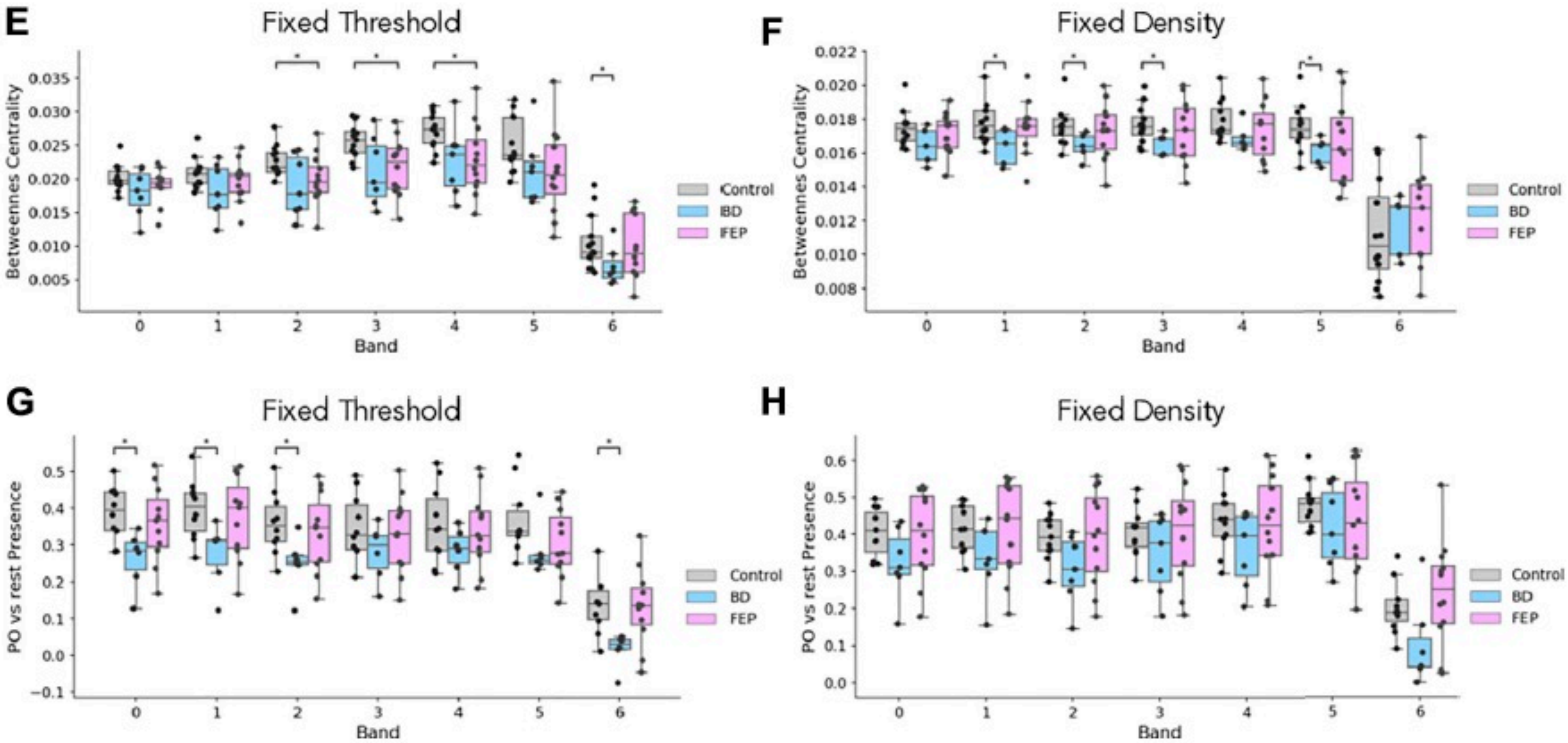
DENSITY IS CONSTANT AND CORRESPONDS TO THE AVERAGE DENSITY OF FIXED THRESHOLD NETWORKS



# NETWORK MEASURES



# NETWORK MEASURES



# SUMMARY

EEG network representation
Network measures
Patients stratification

# COWORKERS:

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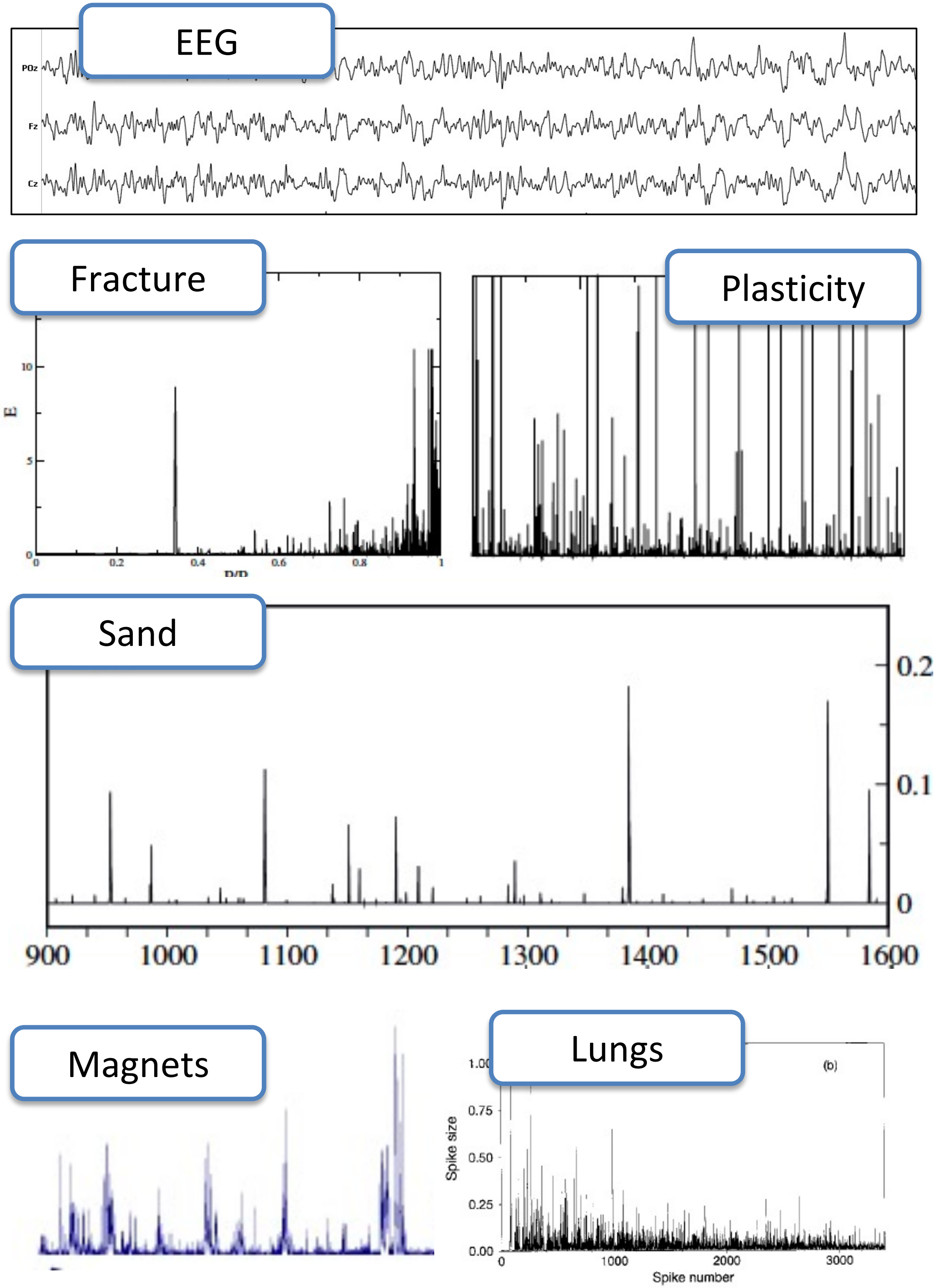
Sistema Socio Sanitario
Regione Lombardia
ASST Santi Paolo e Carlo

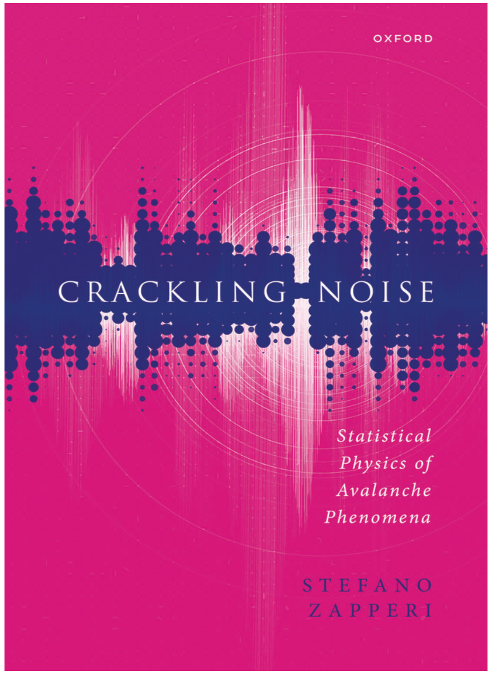
# PAPER:

Font-Clos, F., Spelta, B., D'Agostino, A., Donati, F., Sarasso, S., Canevini, M.P., Zapperi, S. and La Porta, C.A., 2021. Information optimized multilayer network representation of high density electroencephalogram recordings. *Frontiers in Network Physiology*, p.8.




# Crackling Noise

## Statistical Physics of Avalanche Phenomena




The response of materials and the functioning of devices is often associated with noise. In this book, Stefano Zapperi concentrates on a particular type of noise, known as crackling noise, which is characterized by an intermittent series of broadly distributed pulses. While representing a nuisance in many practical applications, crackling noise can also tell us something useful about the microscopic processes ruling a material's behavior.

Features

- Provides a comprehensive overview of key concepts and theoretical models
- Explores the many applications of the theory of crackling noise in materials science
- Includes expansive discussions considering implications for the life sciences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Stefano Zapperi is Professor of Theoretical Condensed Matter Physics and Coordinator of the Center for Complexity and Biosystems at the University of Milan.





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