

# On how network connections determine the dominant patterns of spontaneous neural activity

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Department of Neurosciences

# Understanding the functional role of coordinated neural activity

- A major challenge in current neuroscience is to understand the emergence of coherent complex activity from the interactions between neurons...
- ...and its role in normal and pathological brain function

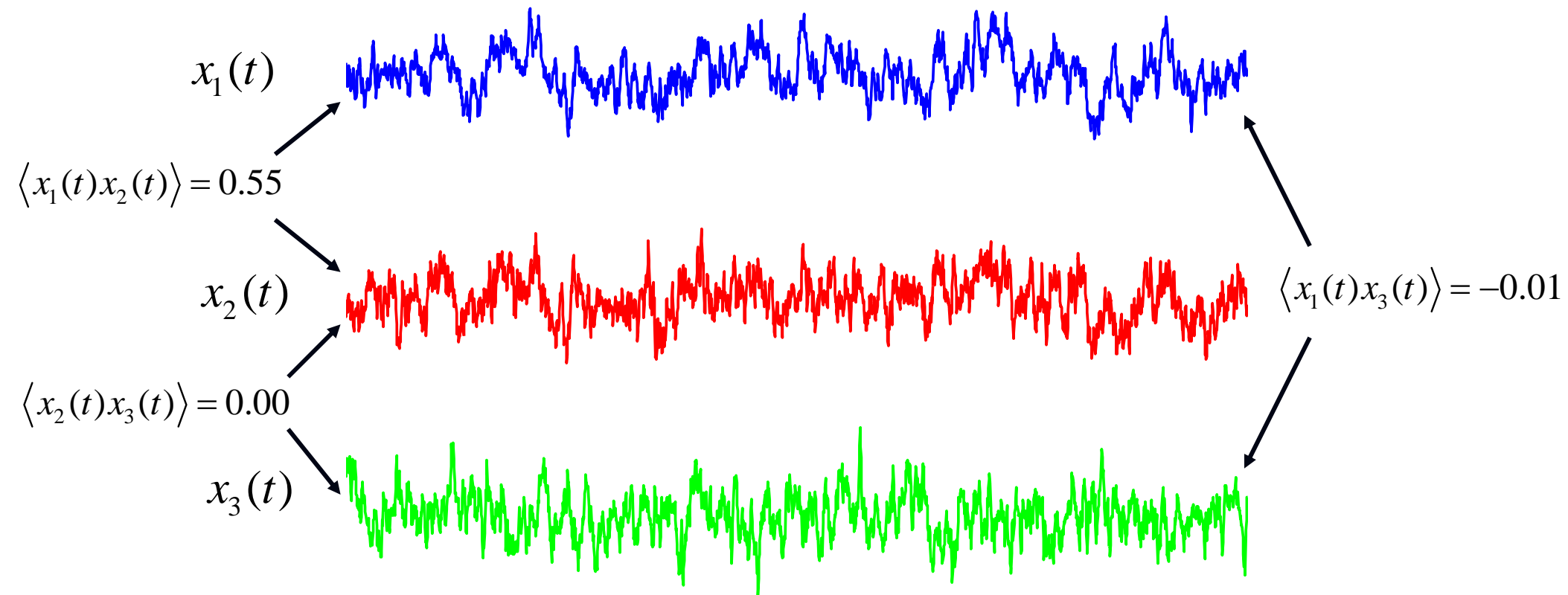
# Complex activity and network structure

The complex spatiotemporal patterns of brain dynamics must reflect the complexity of the underlying network structure, but HOW?

# Coherent activity and network structure

$$A_{ij} = \begin{bmatrix} -10 & 10 & 0 \\ 5 & -15 & 0 \\ 0 & 0 & -12 \end{bmatrix}$$

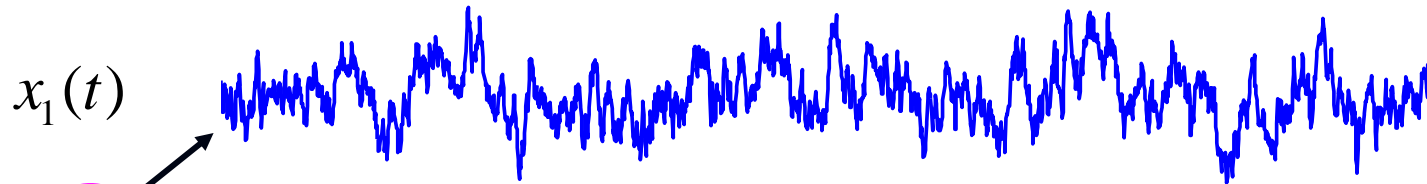
$$C_{ij} = \begin{bmatrix} 1 & 0.55 & -0.01 \\ 0.55 & 1 & 0.00 \\ -0.01 & 0.00 & 1 \end{bmatrix}$$



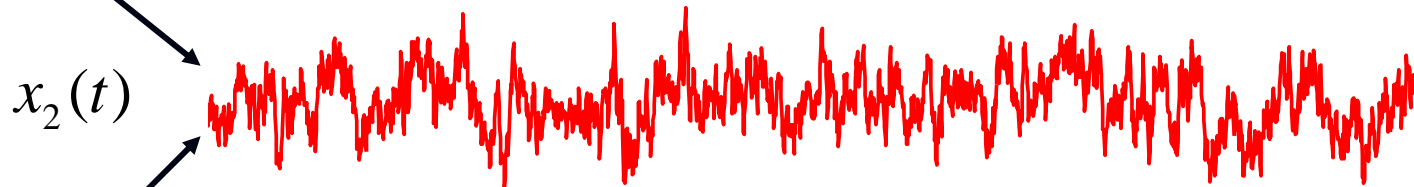
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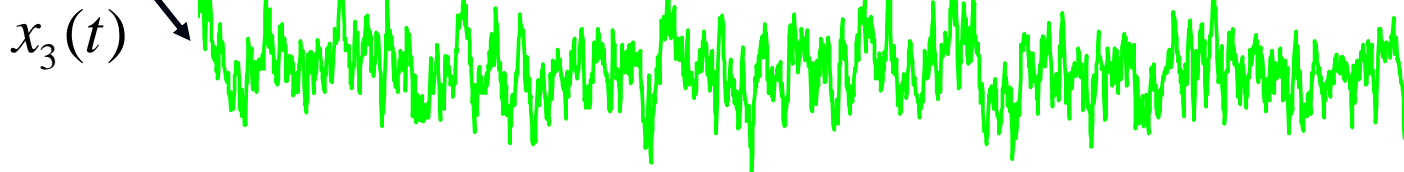


$$\langle x_1(t)x_2(t) \rangle = 0.55$$



$$\langle x_1(t)x_3(t) \rangle = -0.01$$

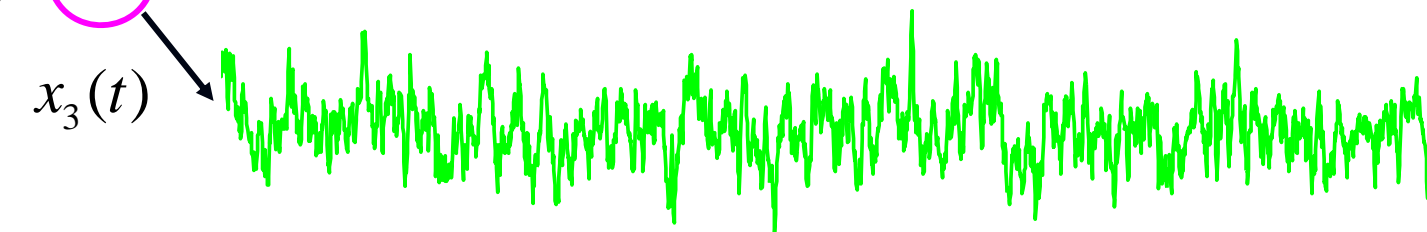
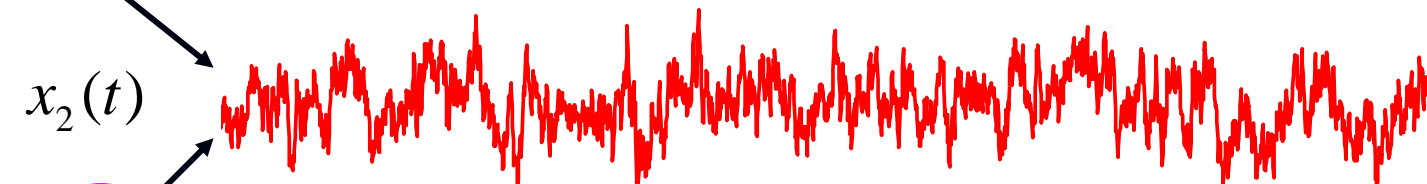
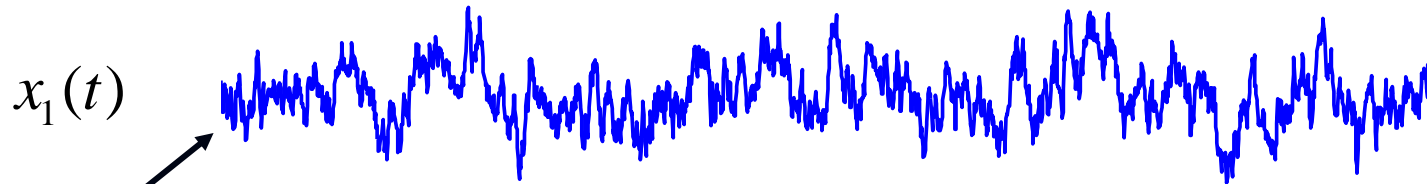
$$\langle x_2(t)x_3(t) \rangle = 0.00$$



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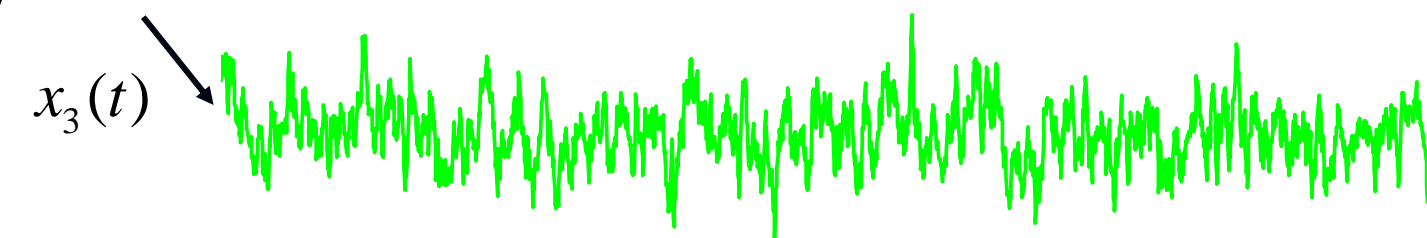
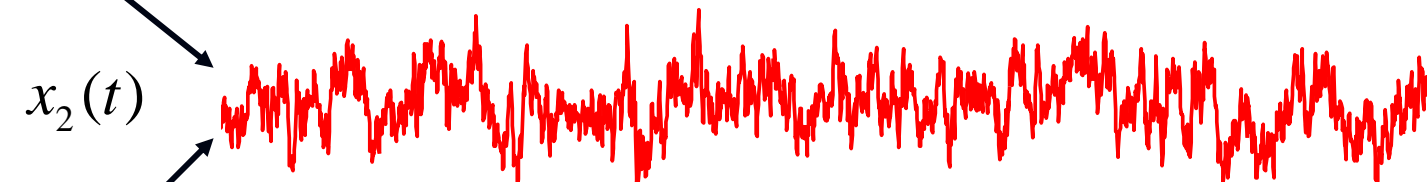
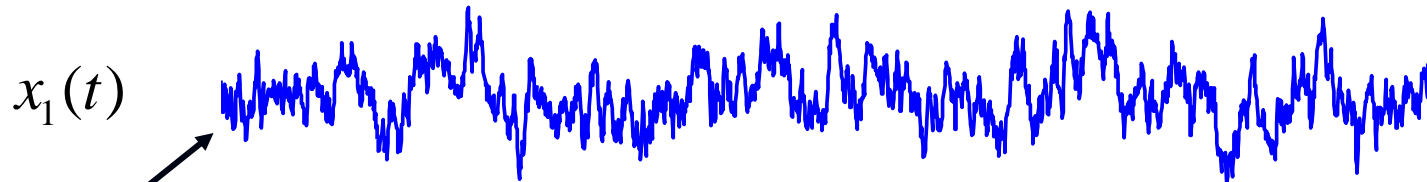
$$\langle x_2(t)x_3(t) \rangle = 0.00$$

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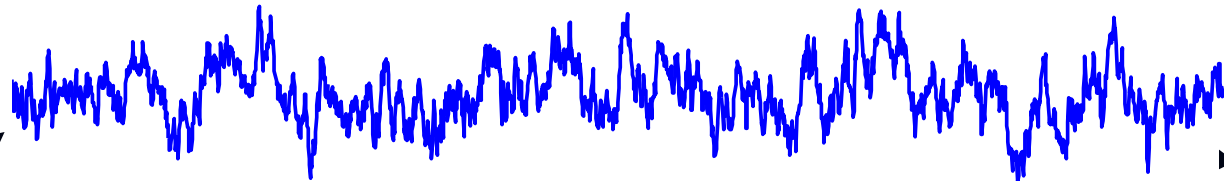
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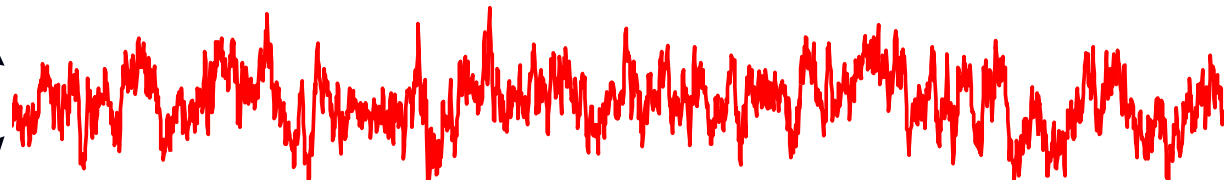


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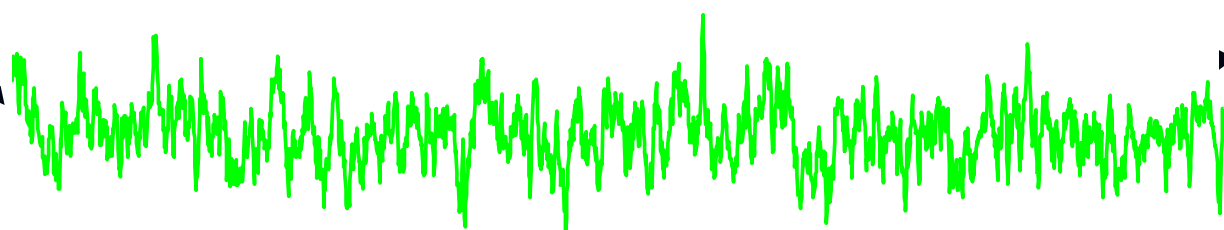
$x_1(t)$



$x_2(t)$



$x_3(t)$



$$\langle x_1(t)x_2(t) \rangle = 0.55$$

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# Complex activity and network structure

In analogy with the quantitative description of other complex systems (climate, stock market,...), the spontaneous activity of the brain can be conceived as a multivariate stochastic process.

$$\frac{d\vec{x}(t)}{dt} = A\vec{x}(t) + \vec{\eta}(t)$$

# Coherent activity and network structure

This model allows us to relate the connectivity matrix to the covariance matrix of the network, whose eigenvectors are the dominant spatial patterns of the spontaneous activity:

$$\underbrace{\langle \vec{x}(t) \vec{x}^T(t) \rangle}_C = A \underbrace{\langle \vec{x}(t) \vec{x}^T(t) \rangle}_C A^T + \underbrace{\langle \vec{\eta}(t) \vec{\eta}^T(t) \rangle}_{\sigma^2 I}$$

# Coherent activity and network structure

This model allows us to relate the connectivity matrix to the covariance matrix of the network, whose eigenvectors are the dominant spatial patterns of the spontaneous activity:

$$C = ACA^T + \sigma^2 I$$

# Connectivity determines activity patterns in cortical networks

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## On How Network Architecture Determines the Dominant Patterns of Spontaneous Neural Activity

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connectivity



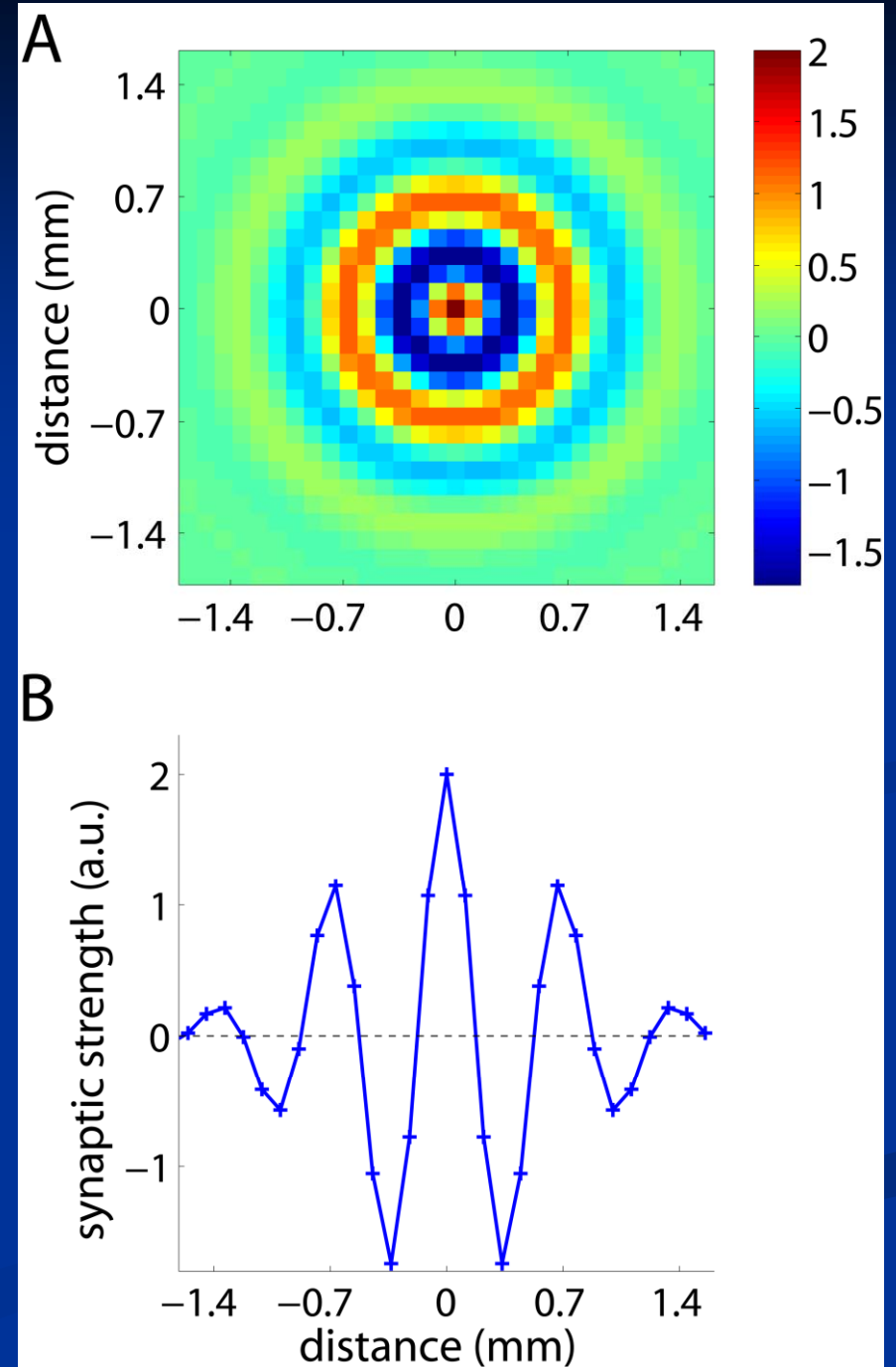
covariance



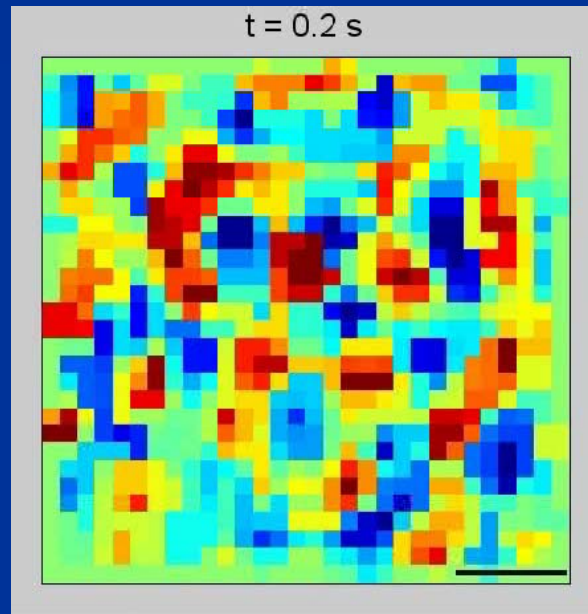
dominant patterns

# Connectivity kernel of the cortex:

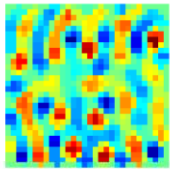
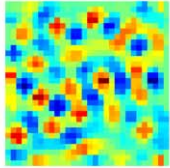
Interleaved domains of  
excitation and inhibition as  
an example of center-  
surround inhibition



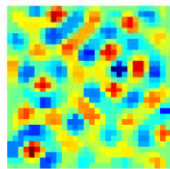
# Simulated spontaneous activity in cortical networks



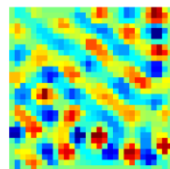
predicted  
patterns



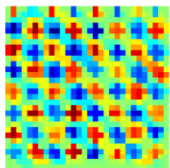
...



...

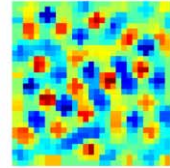


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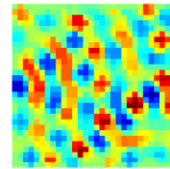


0.7 mm

observed  
patterns

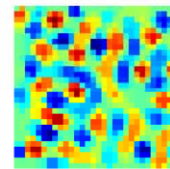


+



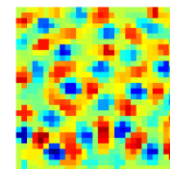
+

...



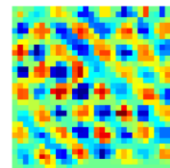
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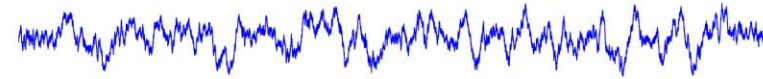
...



temporal modulation of the patterns

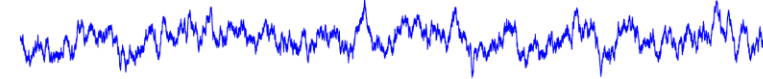
$$\lambda_1 = 4.85 \text{ (3.20 \%)}$$

×



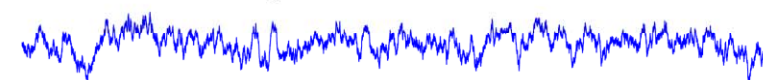
$$\lambda_2 = 4.04 \text{ (2.66 \%)}$$

×



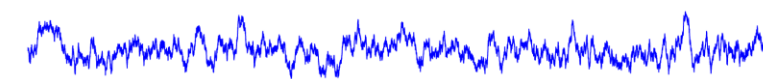
$$\lambda_5 = 3.06 \text{ (2.01 \%)}$$

×



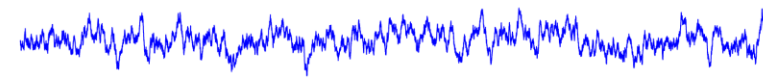
$$\lambda_{15} = 1.40 \text{ (0.92 \%)}$$

×



$$\lambda_{29} = 0.52 \text{ (0.34 \%)}$$

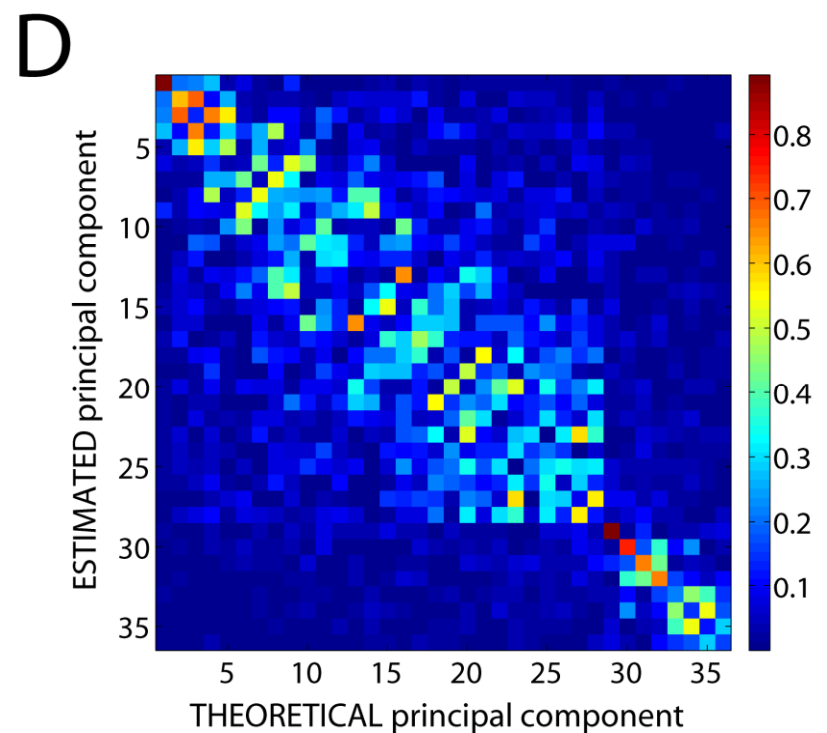
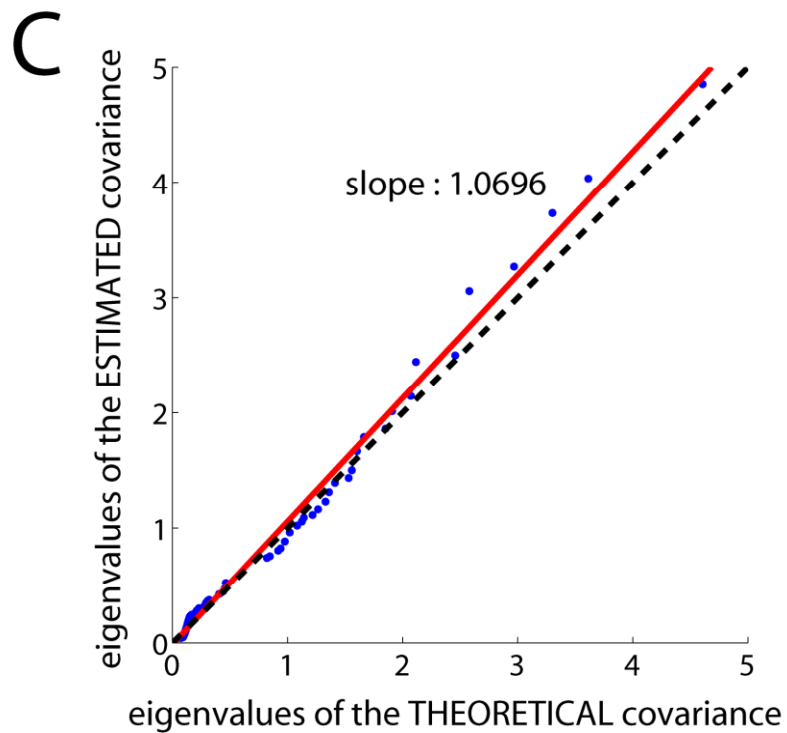
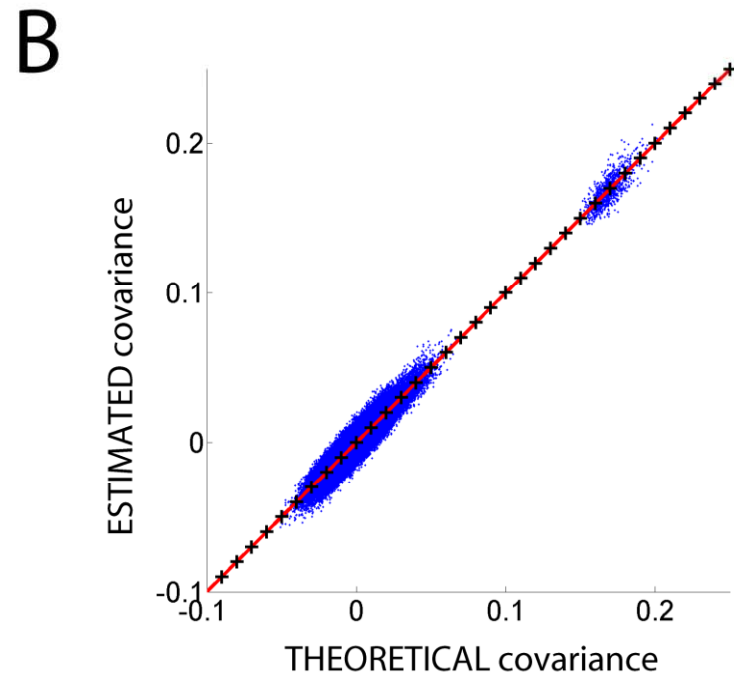
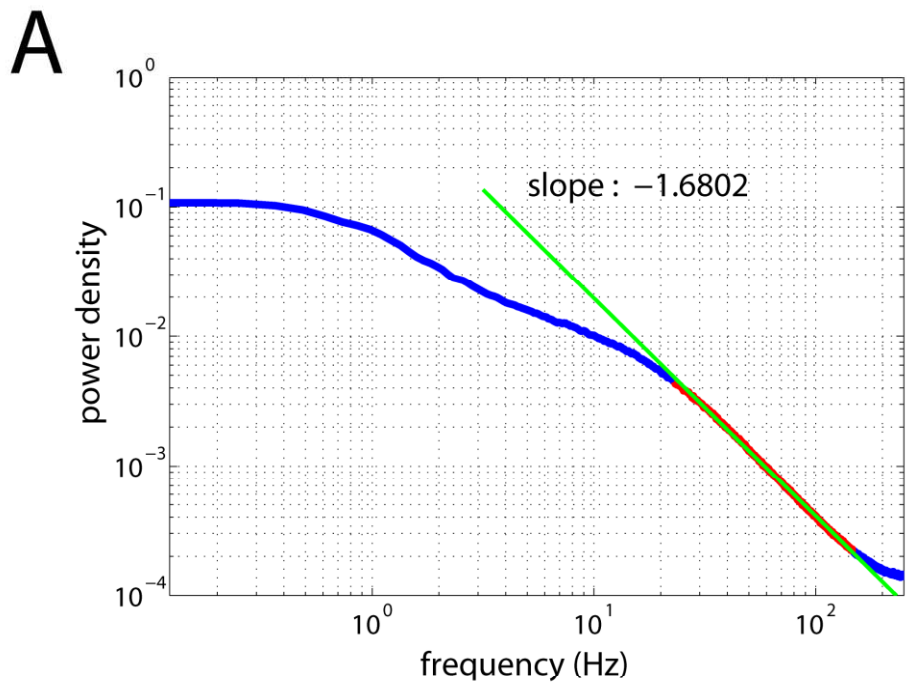
×



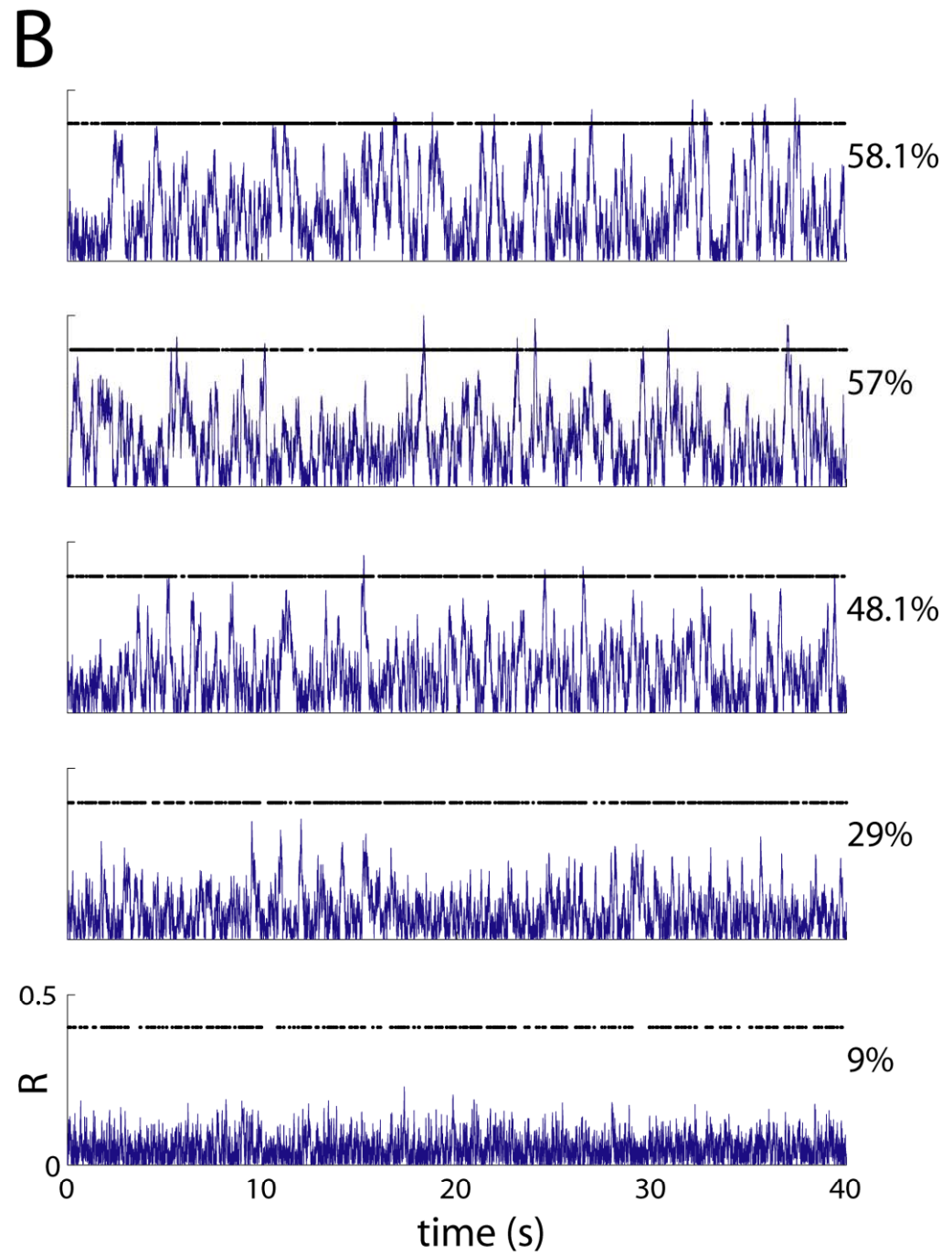
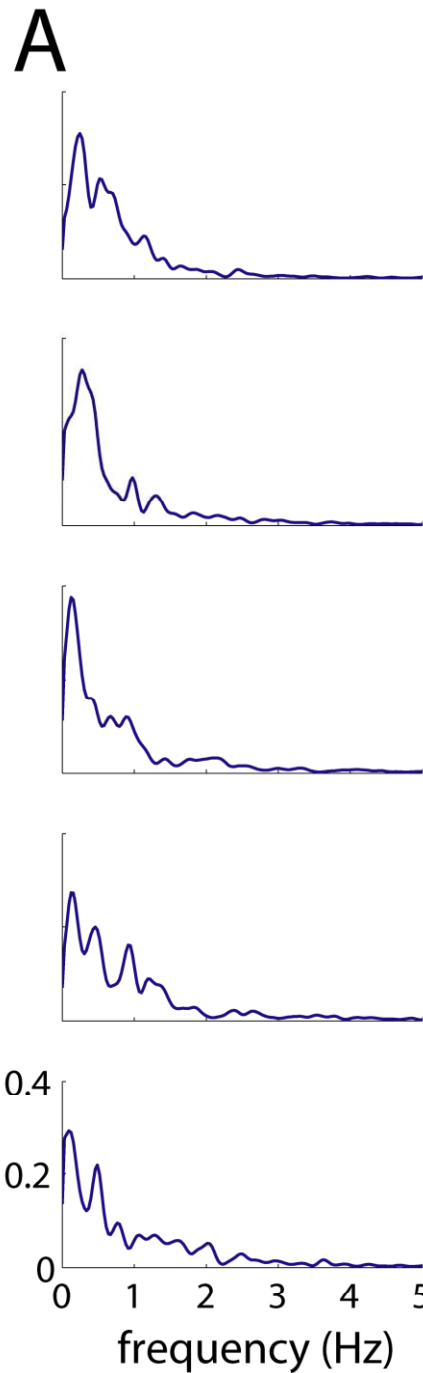
5 a.u.

2 s

spontaneous activity movie



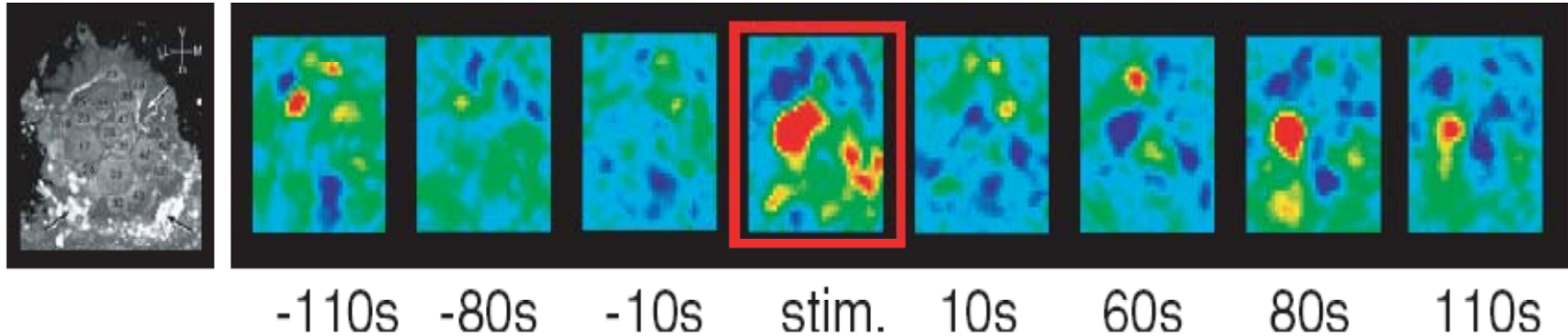
The dominant patterns represent attractors of the network dynamics



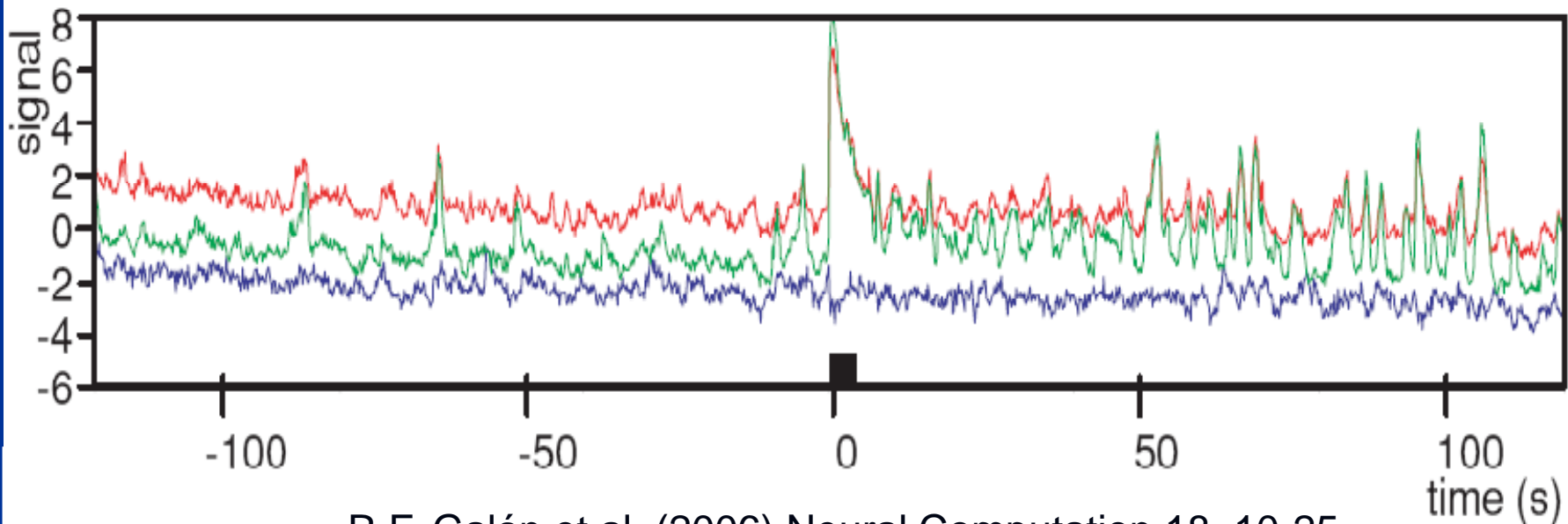
*An example from the real world*

# Coherent activity stores a memory of the last stimulus

## A

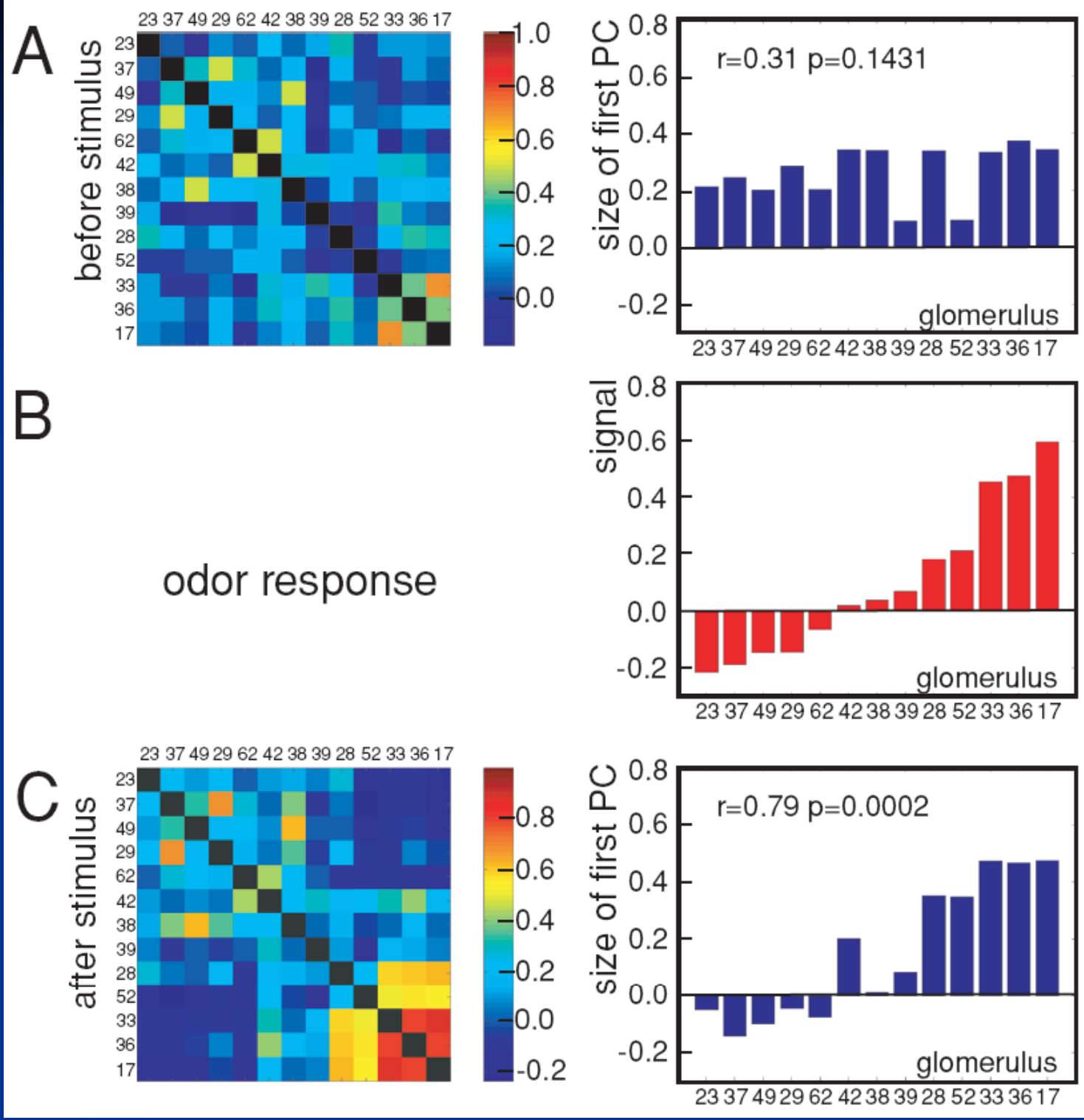


## B



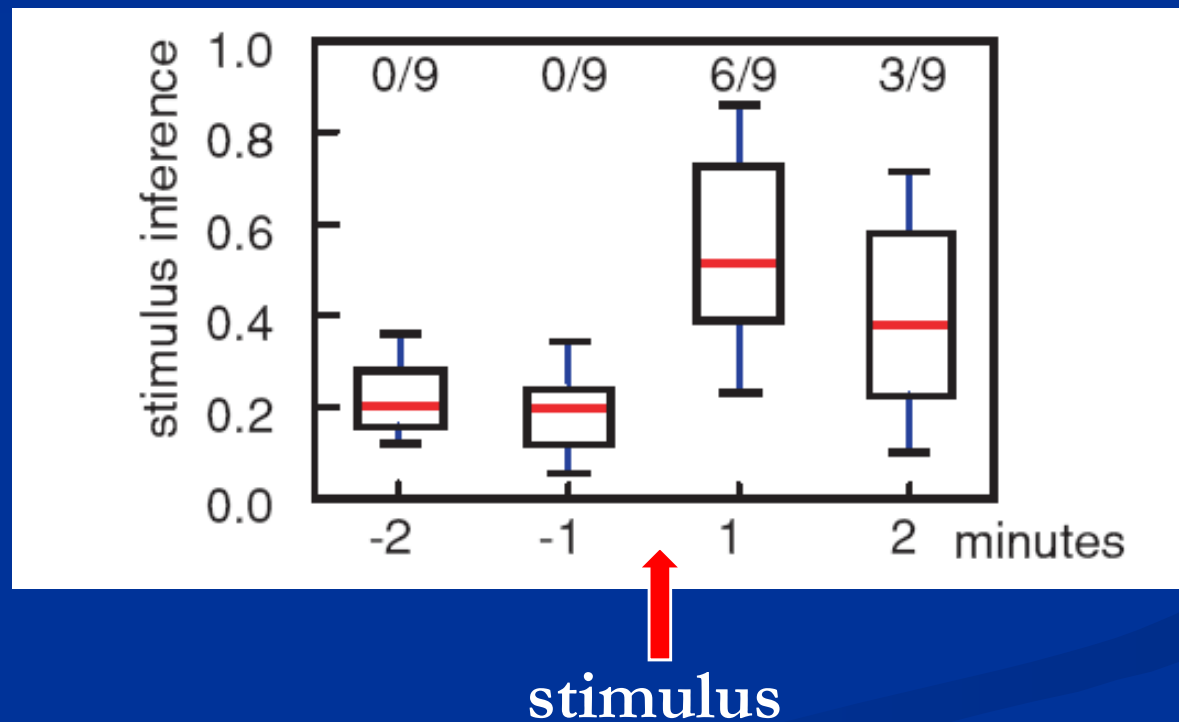
R.F. Galán et al. (2006) *Neural Computation* 18, 10-25

The dominant pattern of the spontaneous activity retrieves the last odor response



# Population data

The memory trace in the spontaneous activity fades out within a few minutes



# Summary

- The synaptic connections between neurons determine the emergent patterns of spontaneous network activity.
- The dominant patterns of the spontaneous activity represent attractors of the stochastic network dynamics.
- Attractor, principal component and dominant pattern are therefore completely equivalent concepts in this context.
- At least in some neuronal networks, these attractors represent a memory trace of recently experienced stimuli.

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# Acknowledgments

Krishnan Padmanabhan  
(Carnegie Mellon University)



THE MT. SINAI HEALTH CARE FOUNDATION