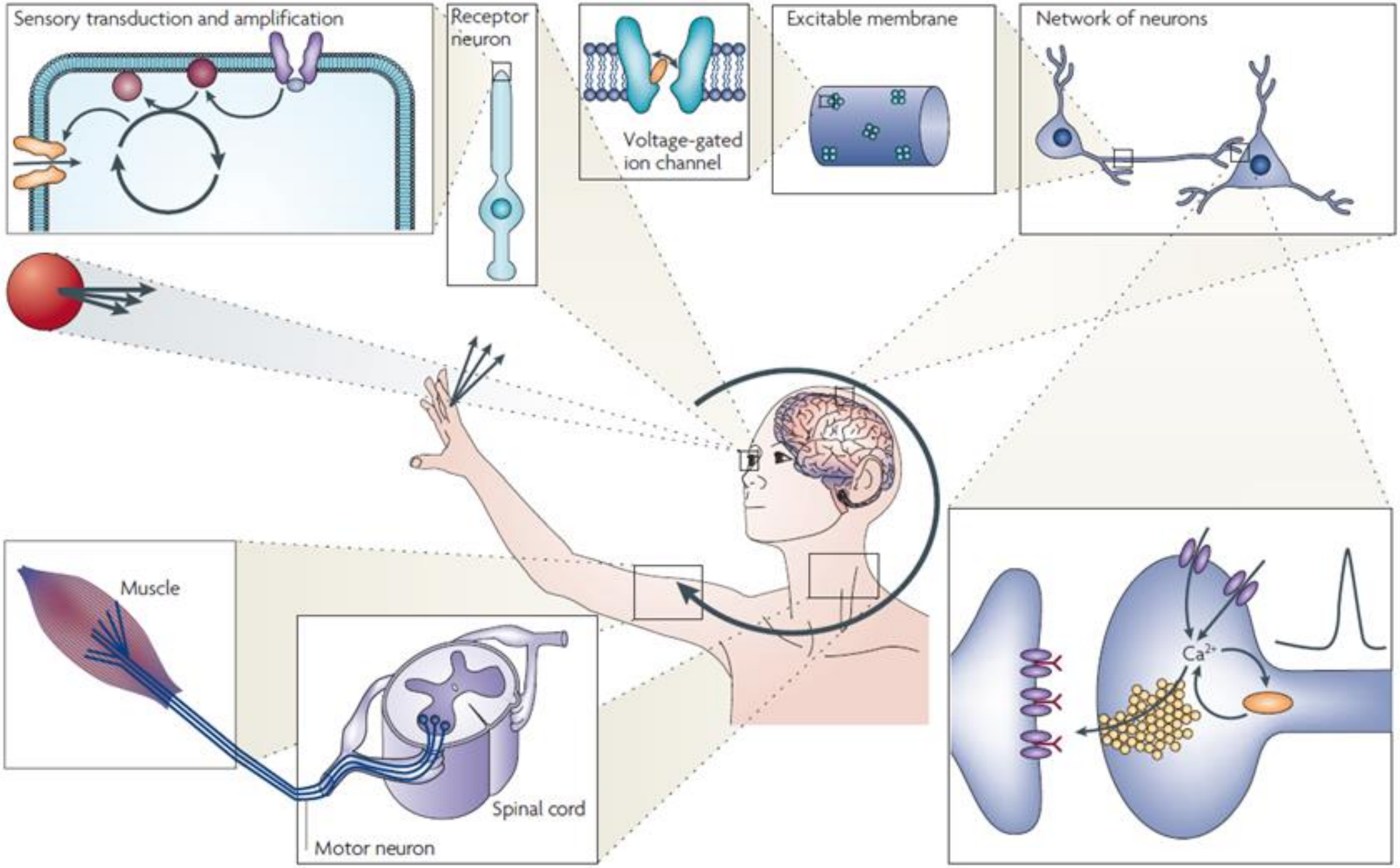
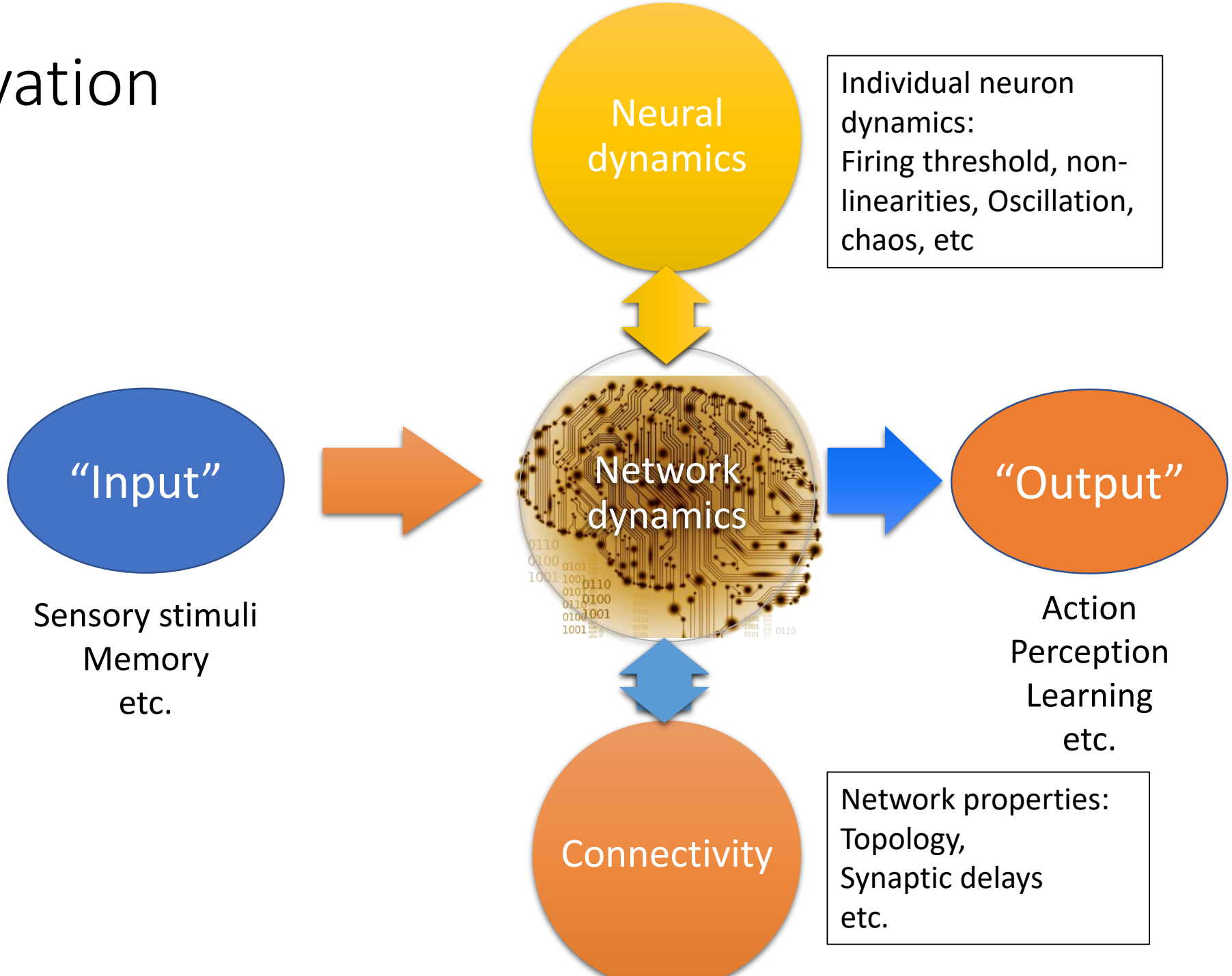
Midiendo la multiestabilidad en Redes Neuronales



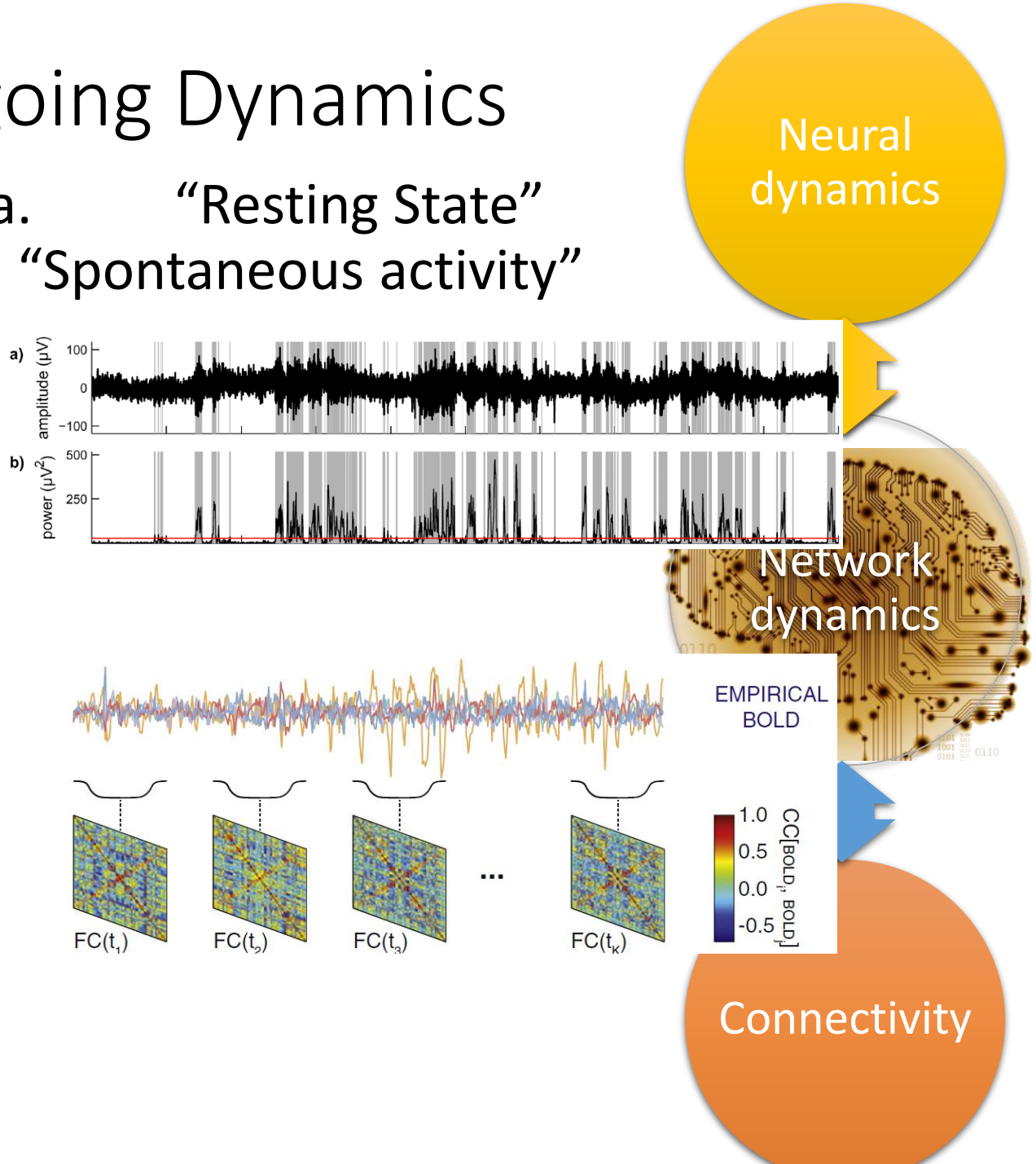
Adaptado de: Faisal A.A., Selen L. & Wolpert D.M.(2008). Noise in the nervous system. *Nat Rev Neurosci* **9**:292-303

Motivation

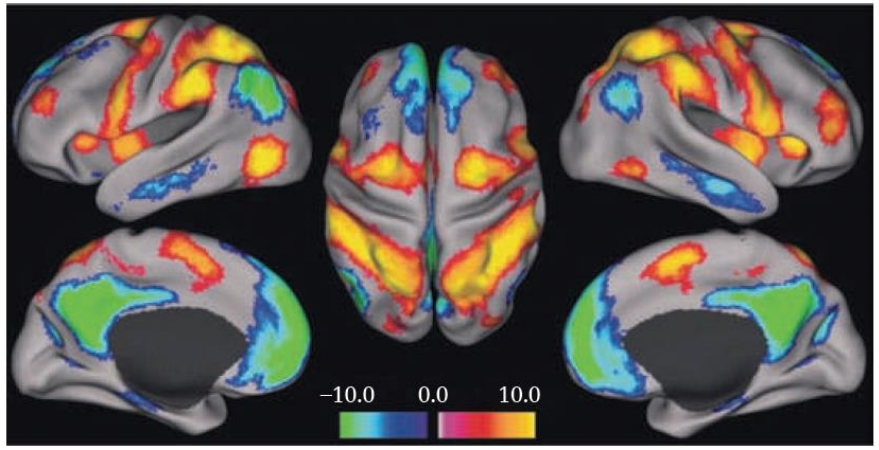

Neural dynamics
Individual neuron dynamics:
Firing threshold, non-linearities, Oscillation, chaos, etc
"Input"
Network dynamics
"Output"
Sensory stimuli
Memory
etc.
Action
Perception
Learning
etc.
Connectivity
Network properties:
Topology,
Synaptic delays
etc.

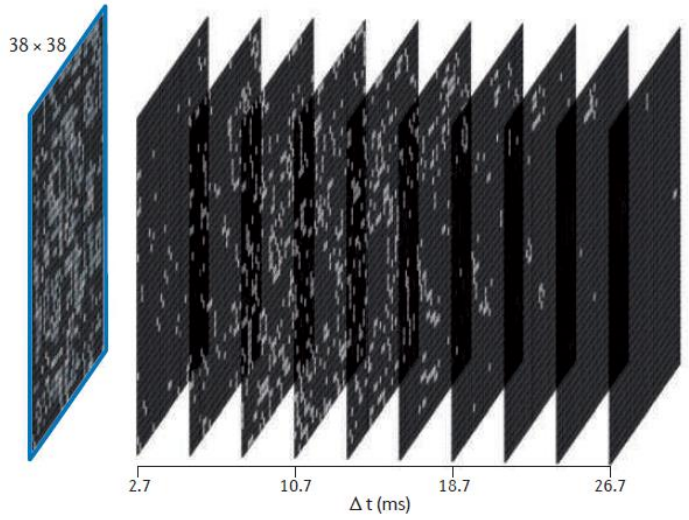
Ongoing Dynamics

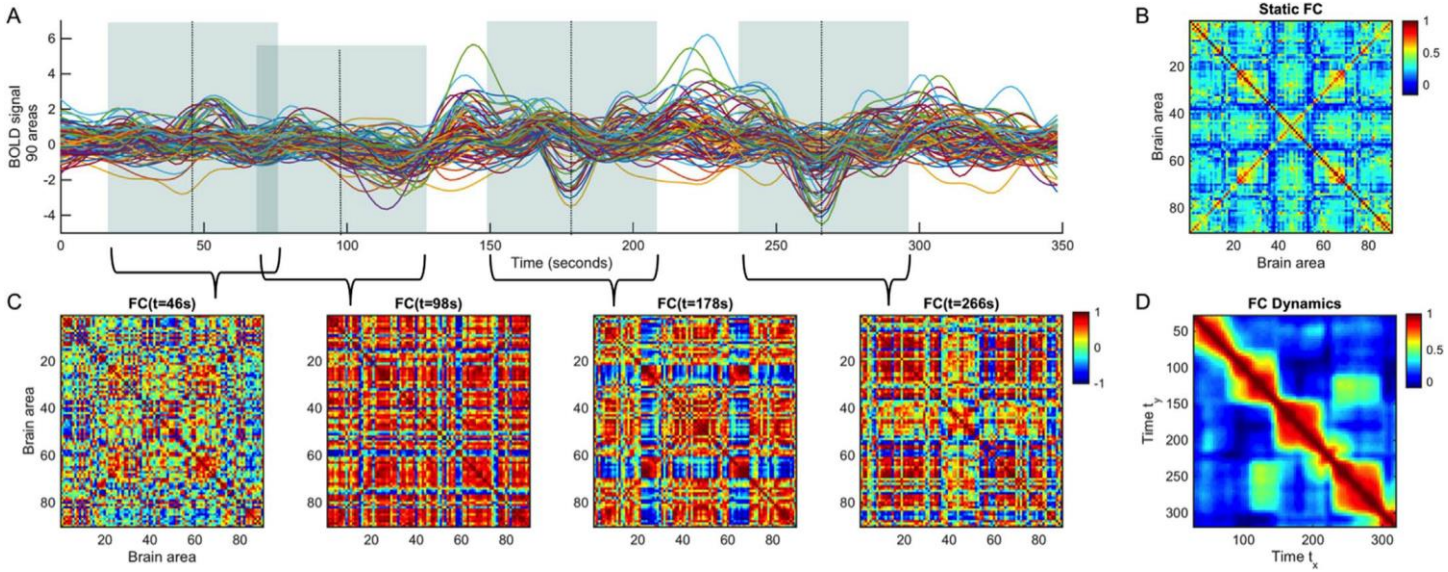
- a.k.a. "Resting State"
  "Spontaneous activity"



Multistability in Neural Networks





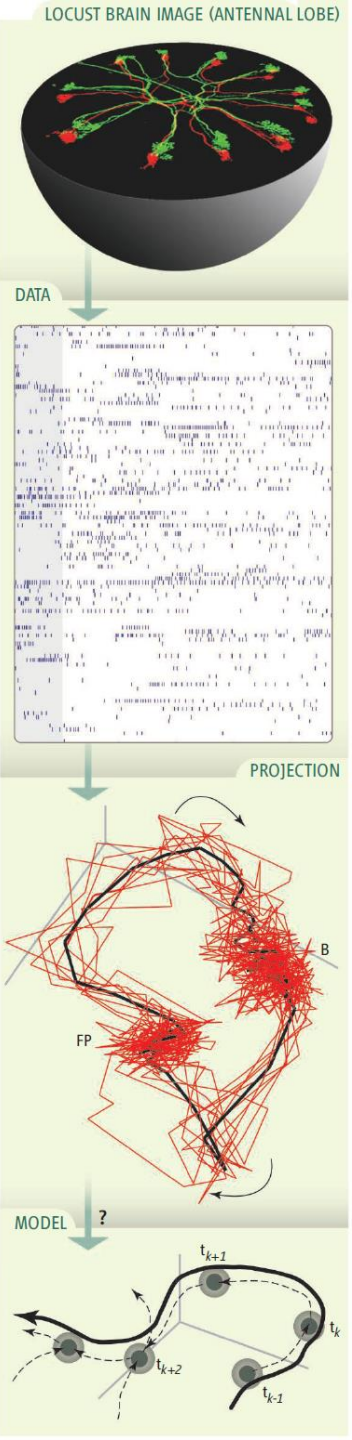


Observed in EEG/MEG and fMRI (diverse time scales)

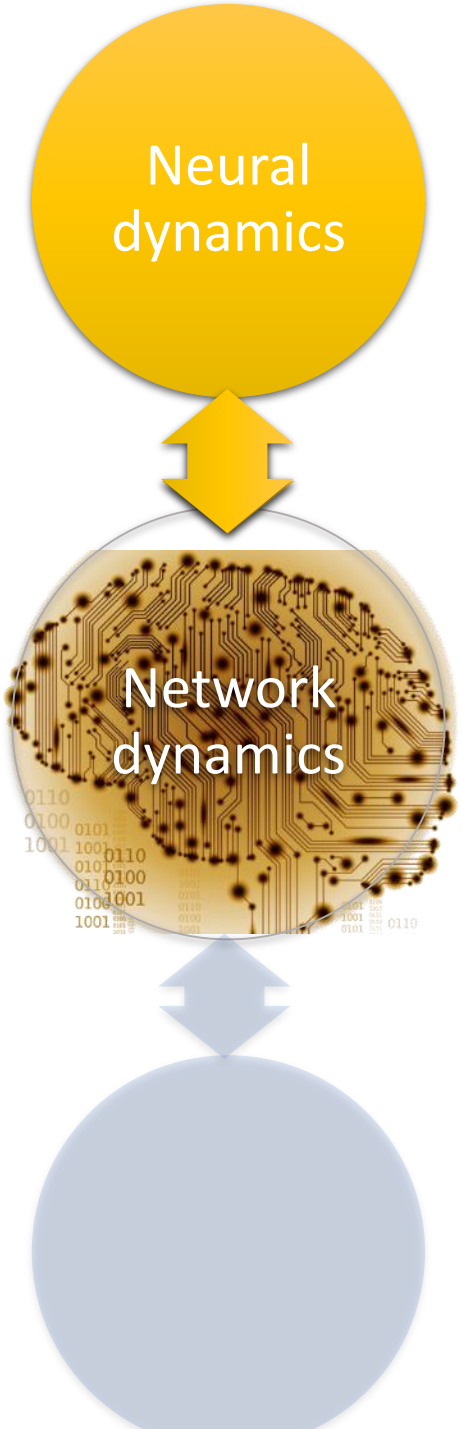
“Resting” (no task) activity.

Multistability in Neural Networks

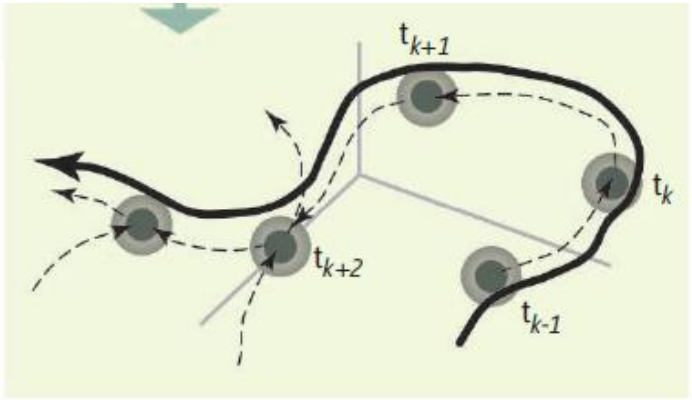
- It has been interpreted as different subnetworks transiently engaging with phase synchrony or coherence in one or more oscillatory bandwidths.
- Growing evidence suggests that this multi-stability allows the system to explore a large number of state configurations enabling an efficient coding of the ever-changing surrounding environment (Friston et al., 2012; Heitmann et al., 2012; Palmigiano et al., 2017).
- The importance of this ‘itinerancy’ has been expressed many times as a mechanism to deal with sensory novelty and allow for learning (Skarda and Freeman, 1987; Nara, 2003; Rabinovich et al., 2008; Breakspear, 2017).
- **What is the origin of the dynamical diversity observed in neural systems?**

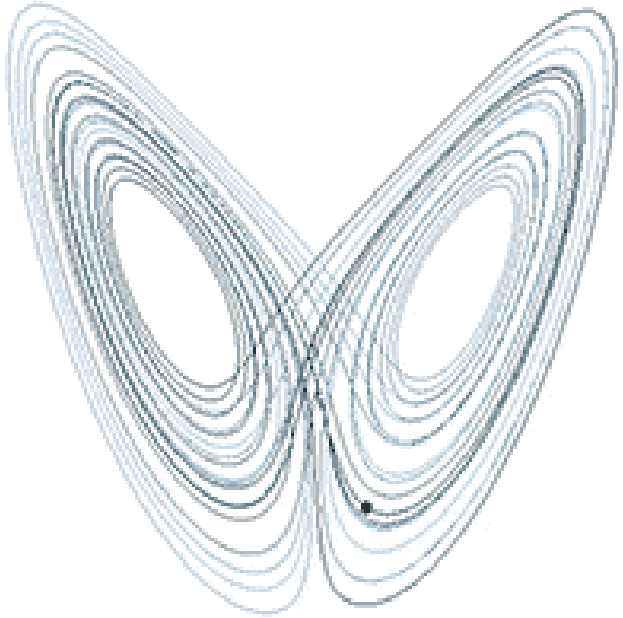


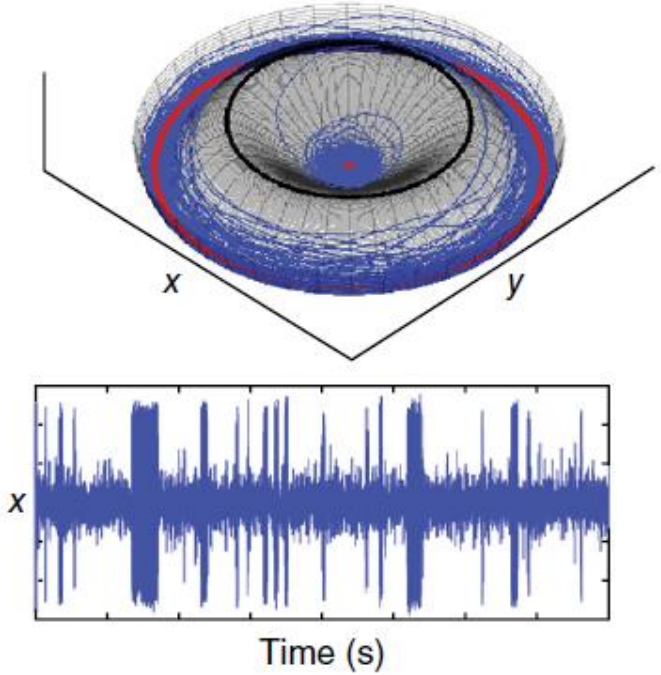
- Multistability has been associated to:
- - delays in synaptic communication (Ghosh et al., 2008; Deco et al., 2009; Cabral et al., 2014; Lea-Carnall et al., 2016)
- - multiple attractors can be found only within a certain range of the global coupling strength (Deco et al., 2009; Deco and Jirsa, 2012).
- - network topology: multi-stability is lost when the connections are randomized (Cabral et al., 2014) and role of the ‘rich club’ nodes (Gollo et al., 2015).
- - What about dynamics?



Dynamical mechanisms for Multistability







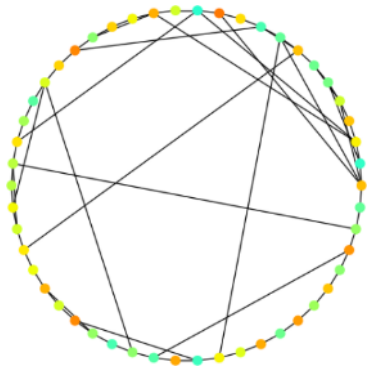
Heteroclinic cycling

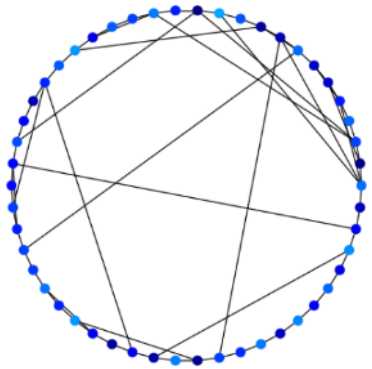
Chaotic itinerancy

Multi-stable switching

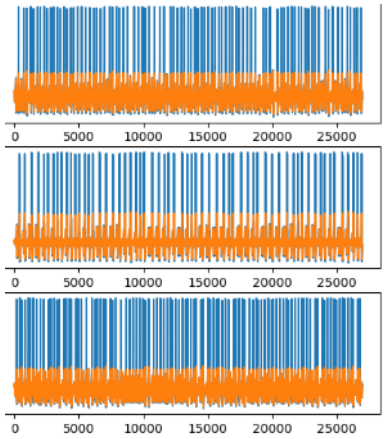
Deterministic system

Stochastic system
("noise")

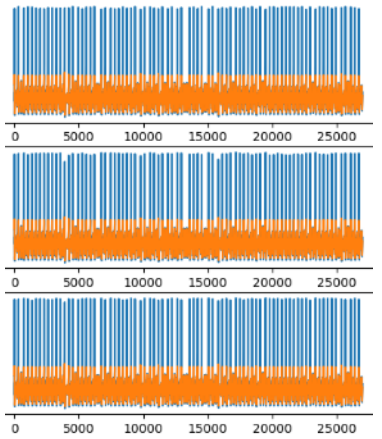




Uncoupled asynchronous

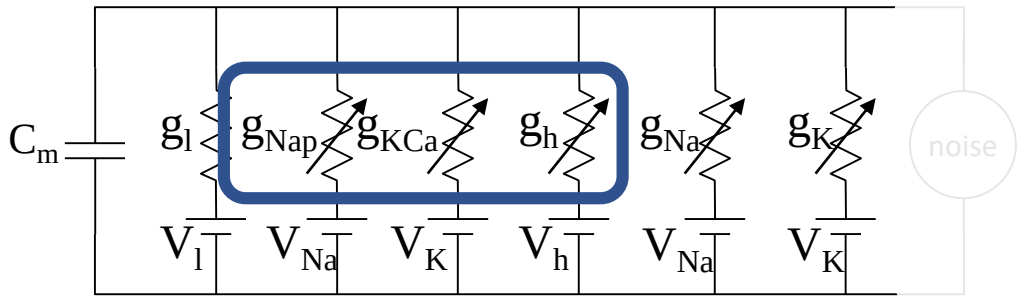


Increase coupling G

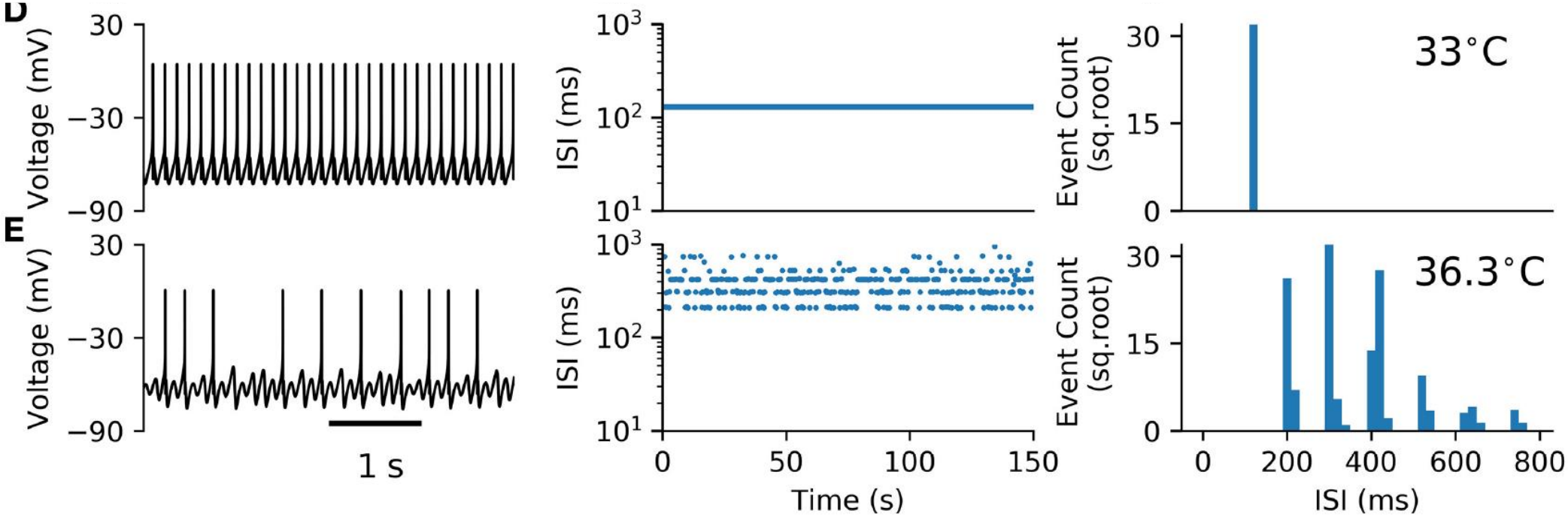


synchronous

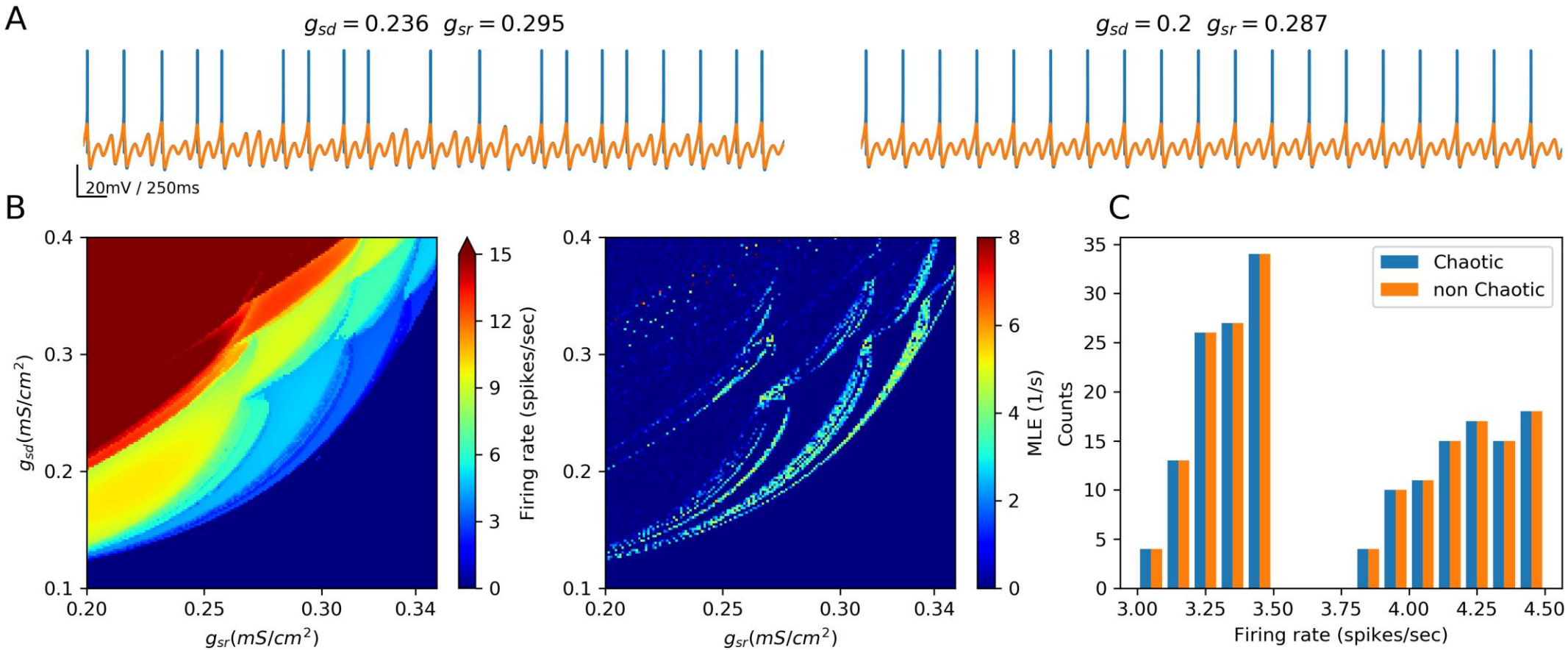
Huber-Braun + Ih model

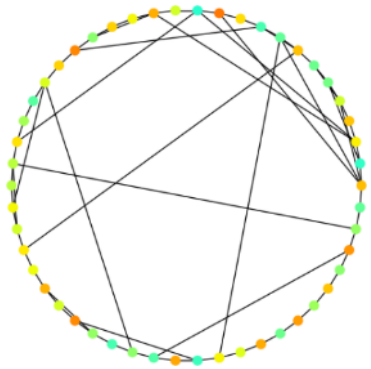


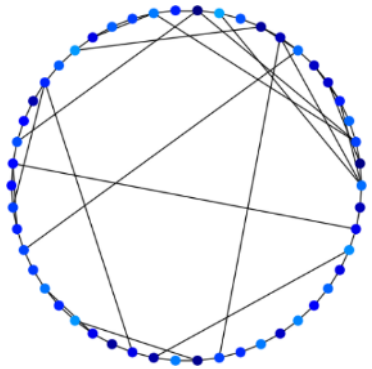
$Na_p + K_{ca} + I_h$



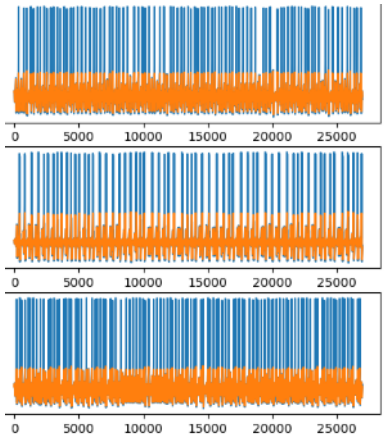
Orio et al., *J Neurophys* 2012; Xu et al., *Front Comp Neurosci* 2017


A
$g_{sd} = 0.236$ $g_{sr} = 0.295$
$g_{sd} = 0.2$ $g_{sr} = 0.287$
20mV / 250ms
B
$g_{sd}(mS/cm^2)$
$g_{sr}(mS/cm^2)$
Firing rate (spikes/sec)
MLE (1/s)
C
Chaotic
non Chaotic
Counts
Firing rate (spikes/sec)

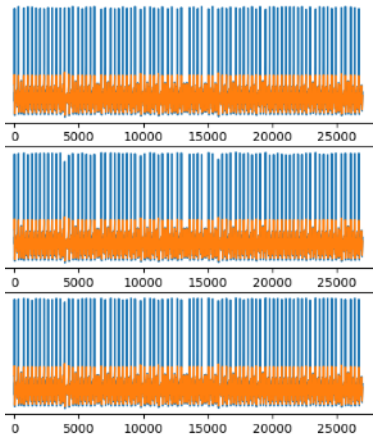




Uncoupled asynchronous

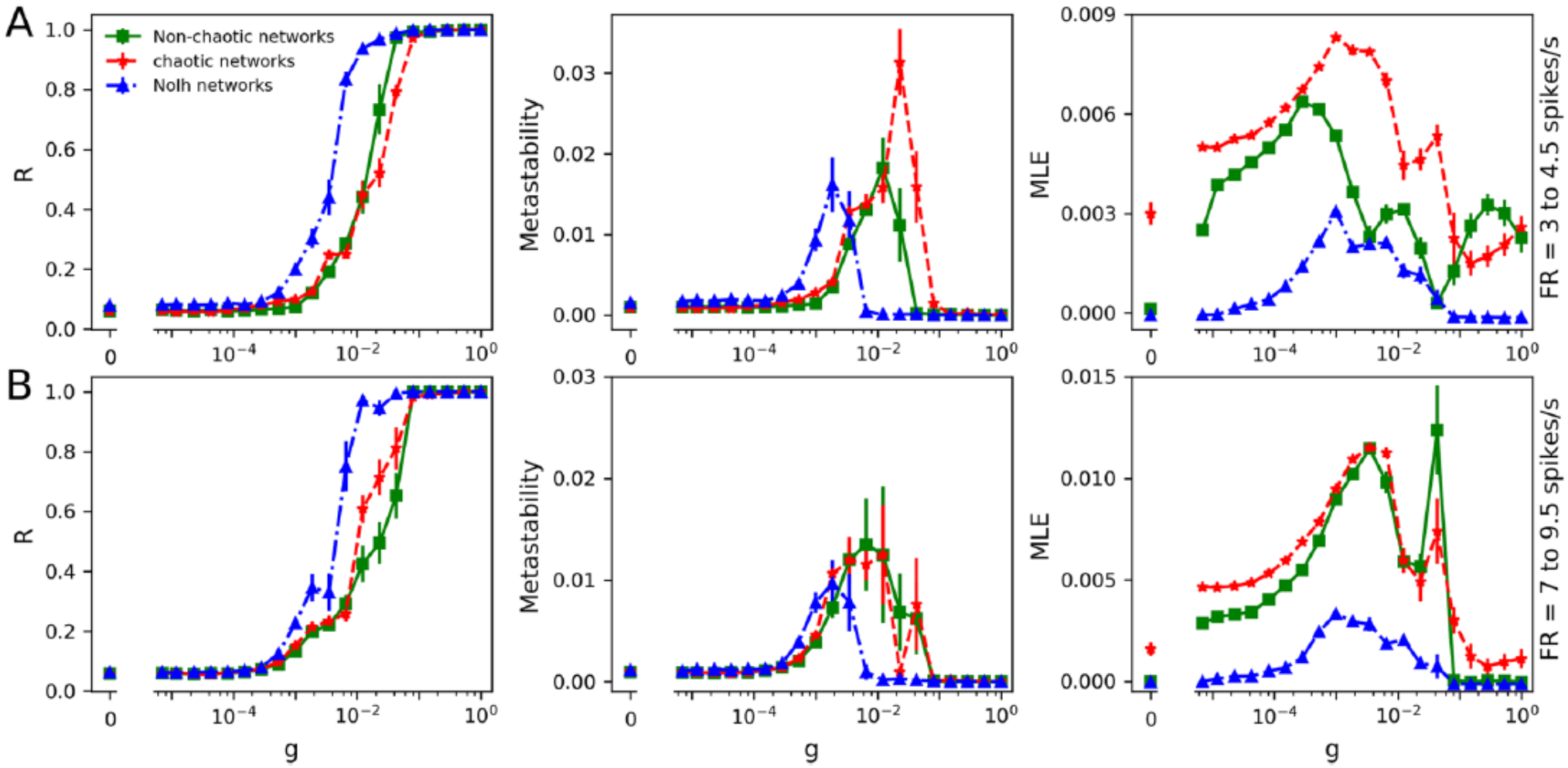


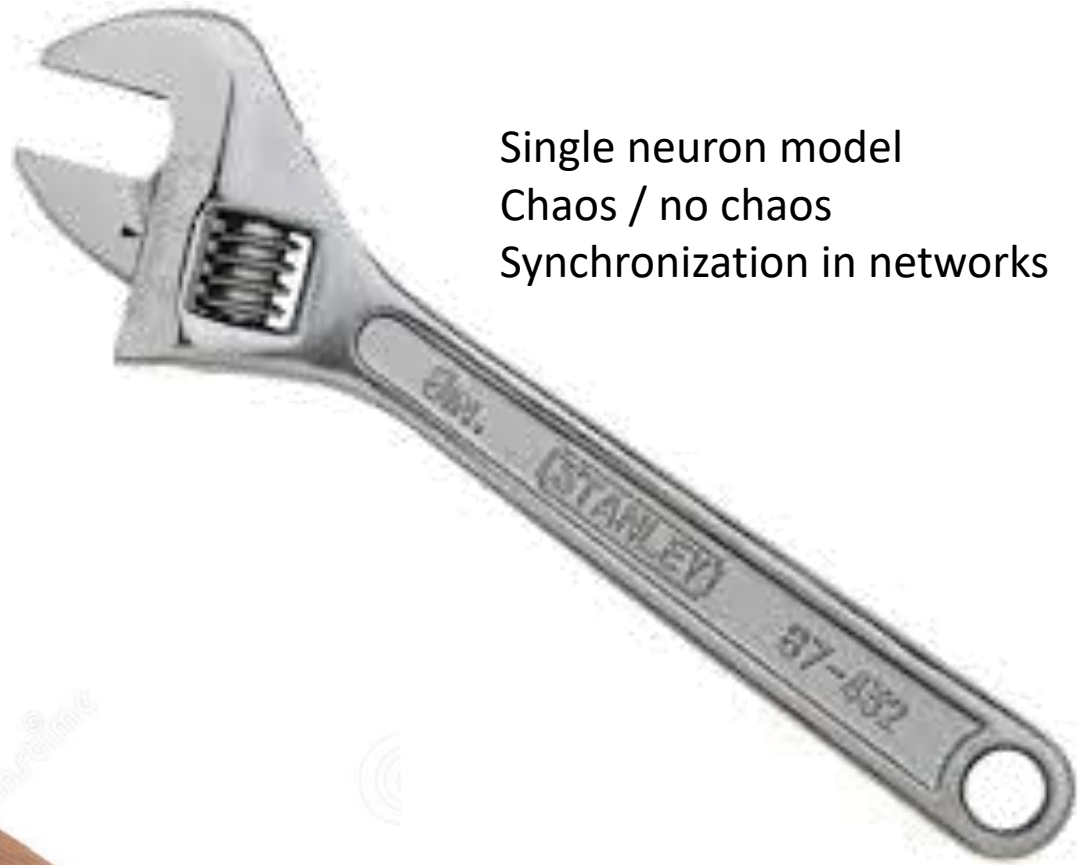
Increase coupling G



synchronous

Synchronization behavior

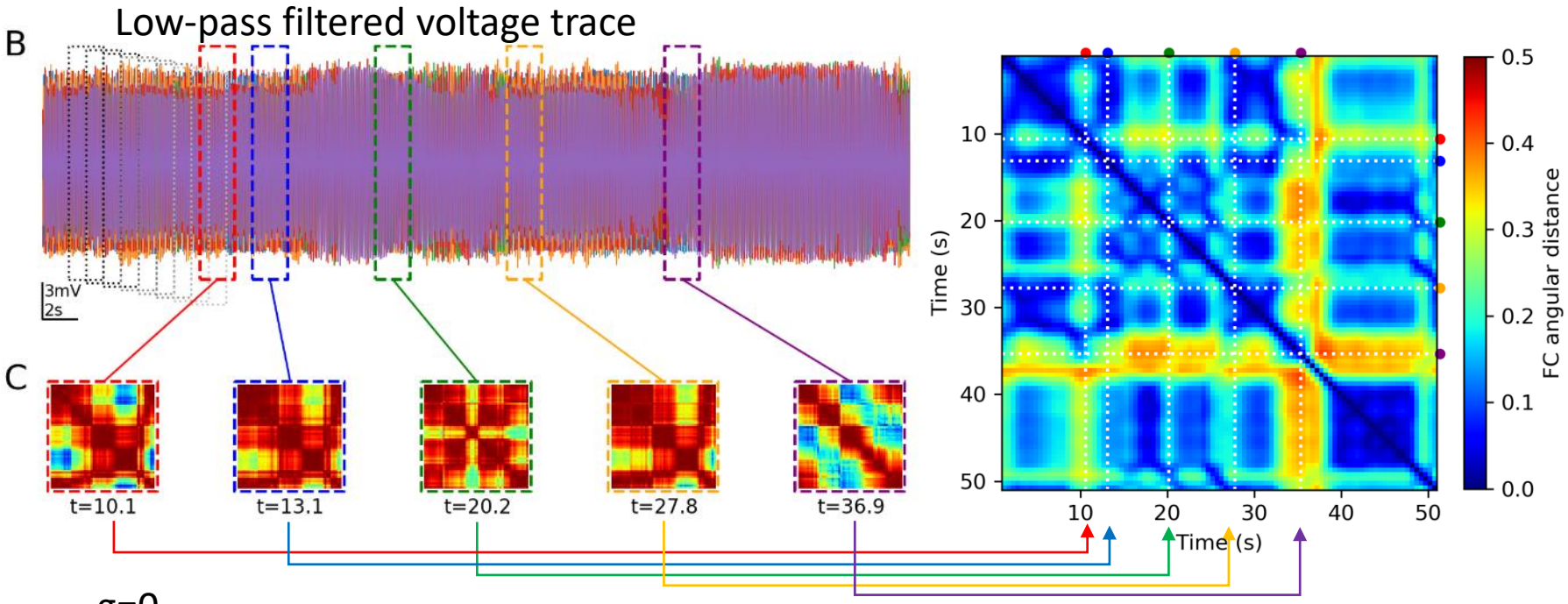




Single neuron model
Chaos / no chaos
Synchronization in networks

Large scale brain dynamics

Functional connectivity dynamics



g=0

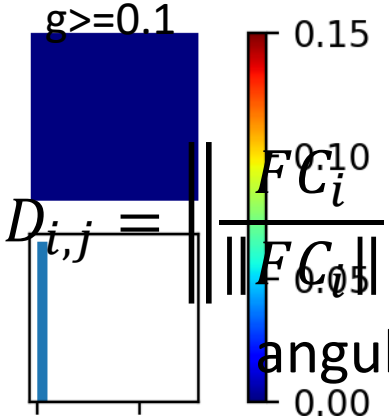
g>=0.1

$$FC_{k,l} = R_{k,l} = \left| \frac{1}{2} \left(e^{i\varphi_k(t)} + e^{i\varphi_l(t)} \right) \right|_T$$

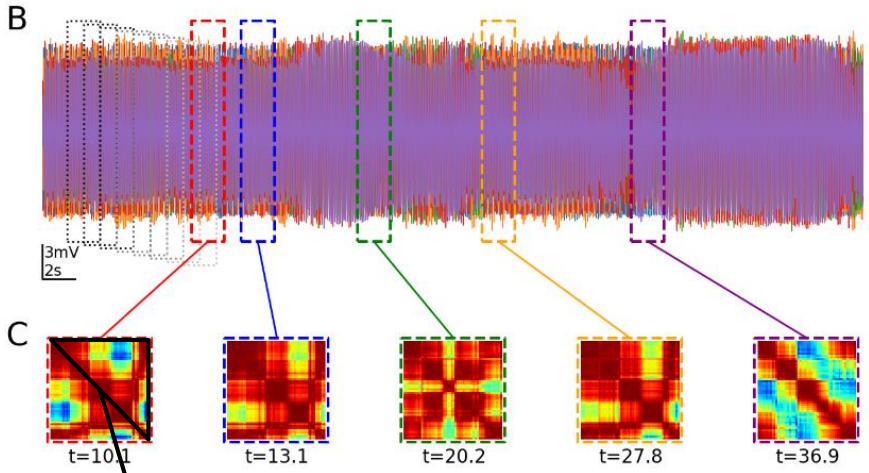
Kuramoto order parameter
(Phase synchrony)

$$FCD_{i,j} = \left\| \frac{FC_i}{\|FC_i\|} - \frac{FC_j}{\|FC_j\|} \right\|$$

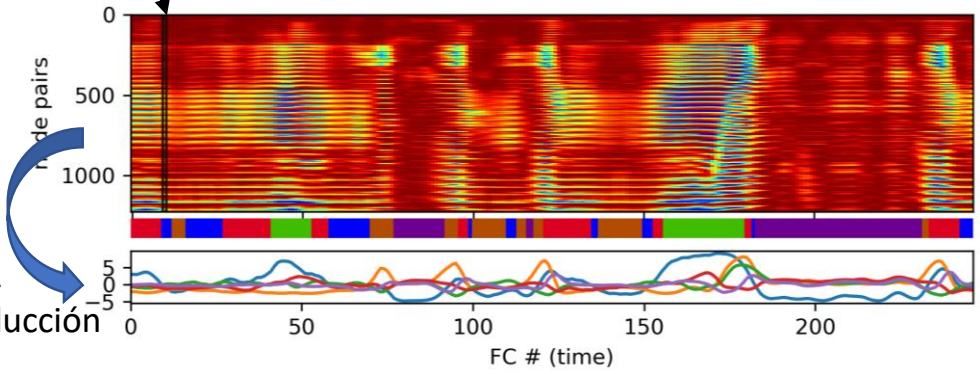
angular distance



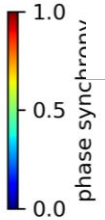
FC clustering

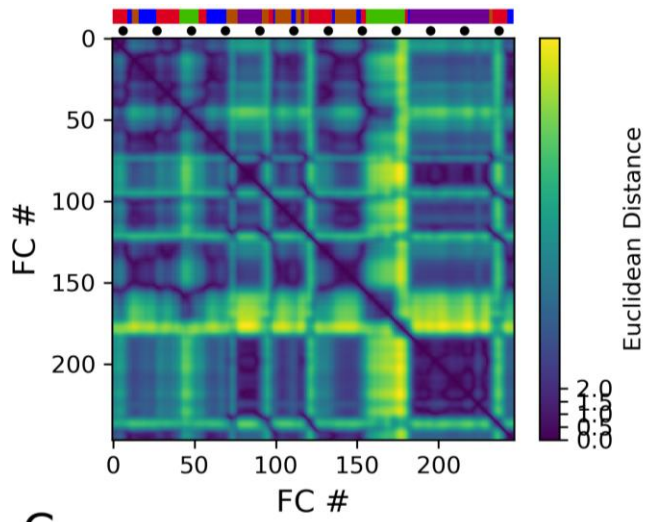


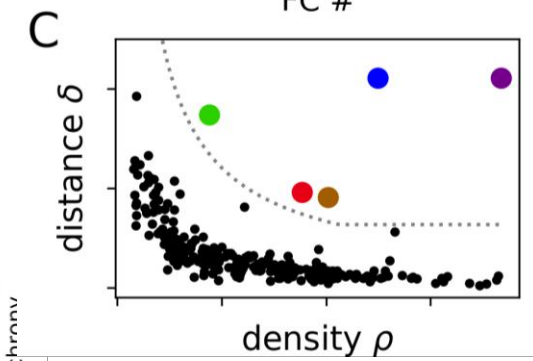
"unfolding"

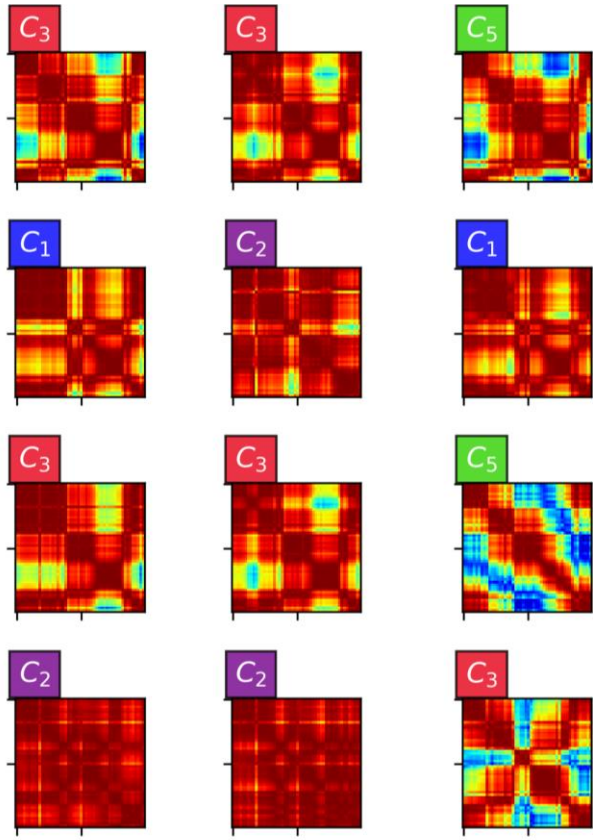


PCA (reducción de dimensionalidad)

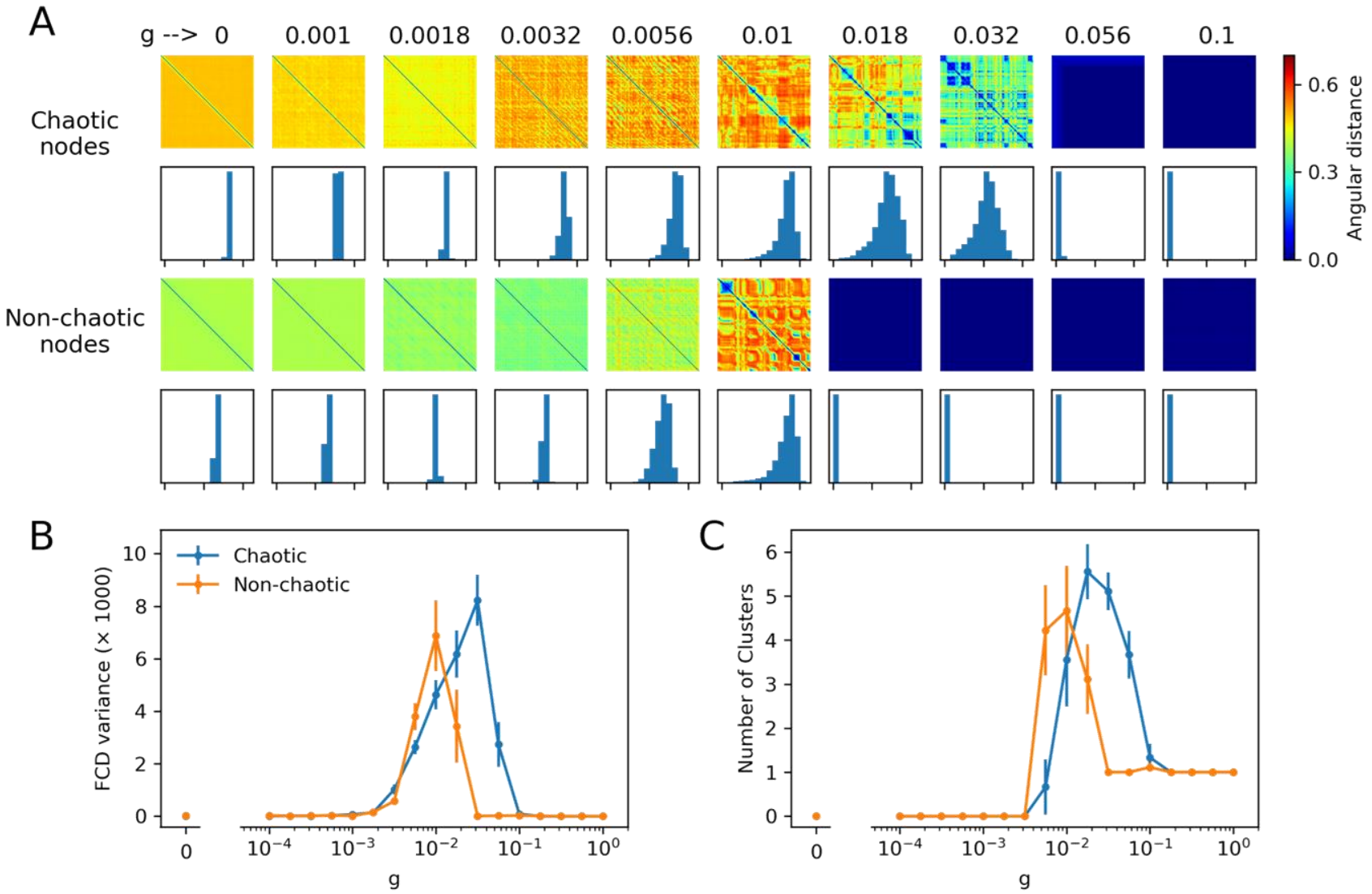


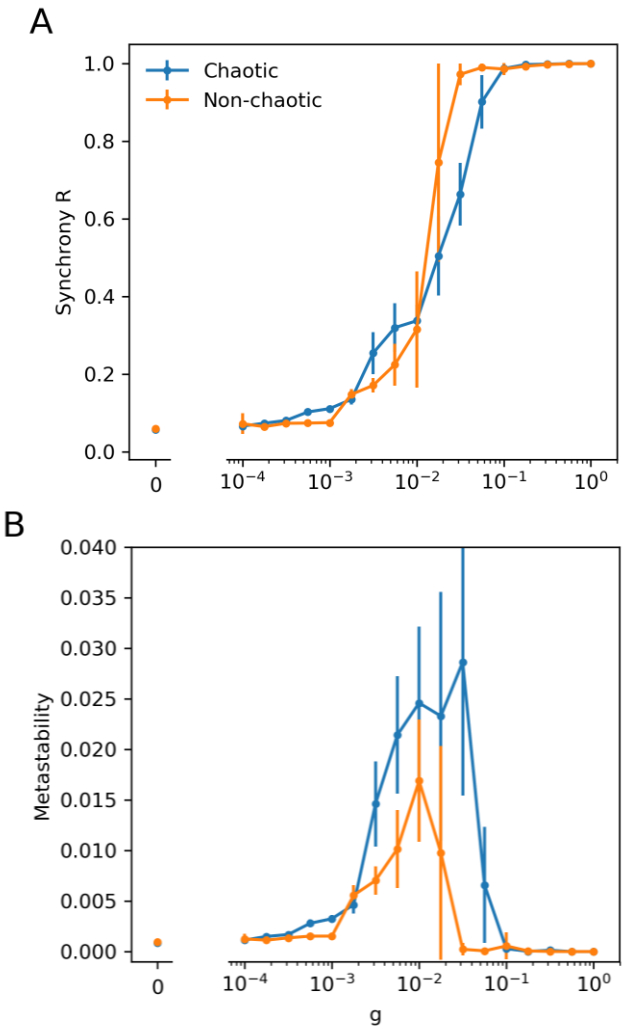






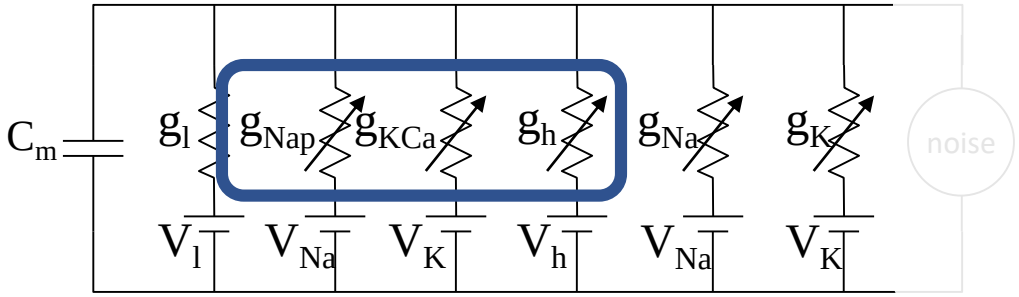
FCD in deterministic simulations





Orio et al., *Chaos*, 2018

Stochastic model – channel noise



$$da_i = \phi \frac{a_i^{\infty} - a_i}{\tau_i} dt + \sqrt{\phi \frac{|a_i|\left(1 - a_i^{\infty}\right) + a_i^{\infty}(1 - |a_i|)}{N_i \tau_i}} dW_t \quad i = Nap, h$$

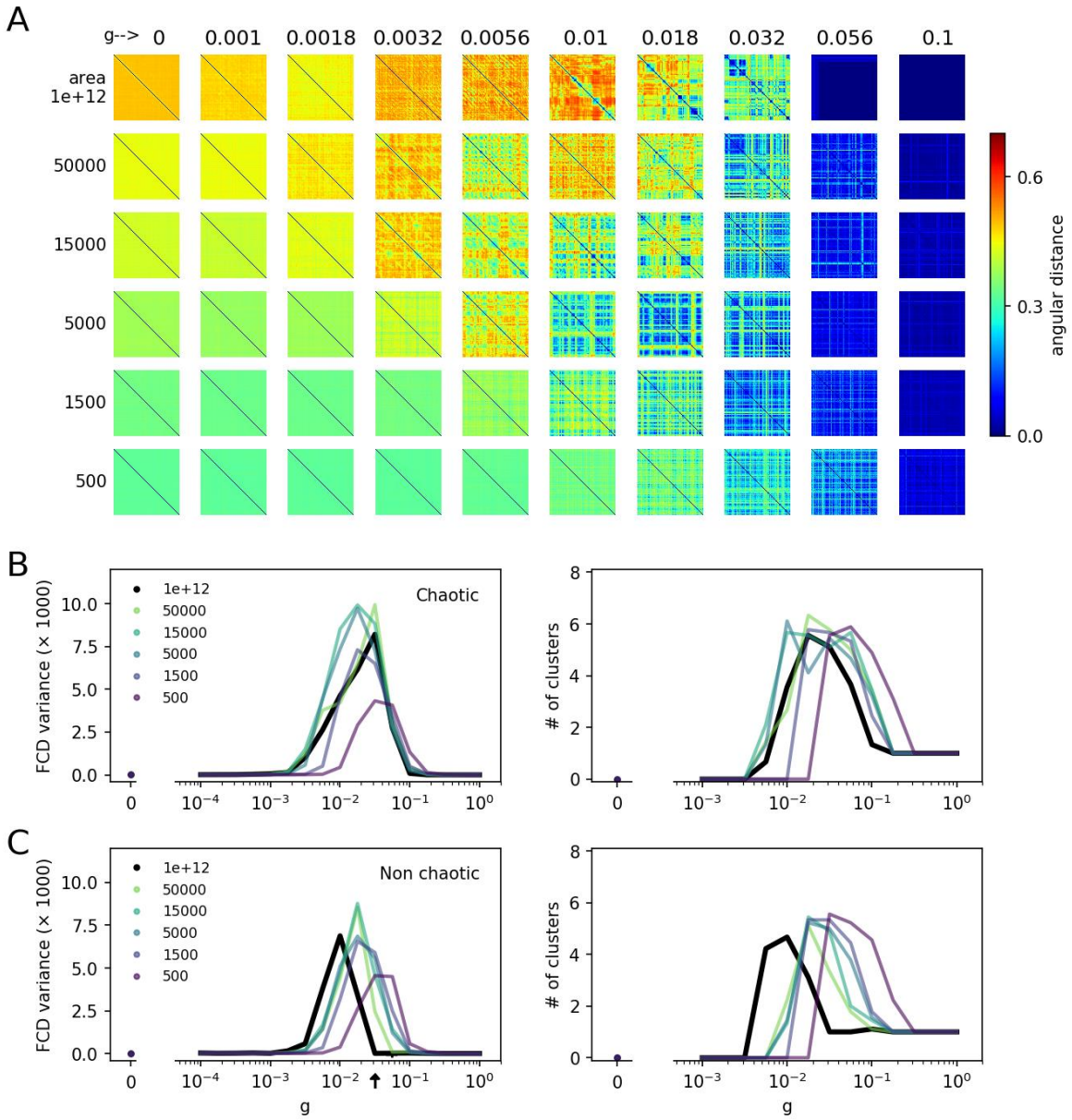
$$I_{K_{Ca}} = \rho g_{K_{Ca}} (V - E_K) \left(p + \sqrt{\frac{p(1-p)}{N_{sr}}} \xi(t) \right)$$

$$N_i = 10 \frac{g_i \times A}{g_i^u}$$

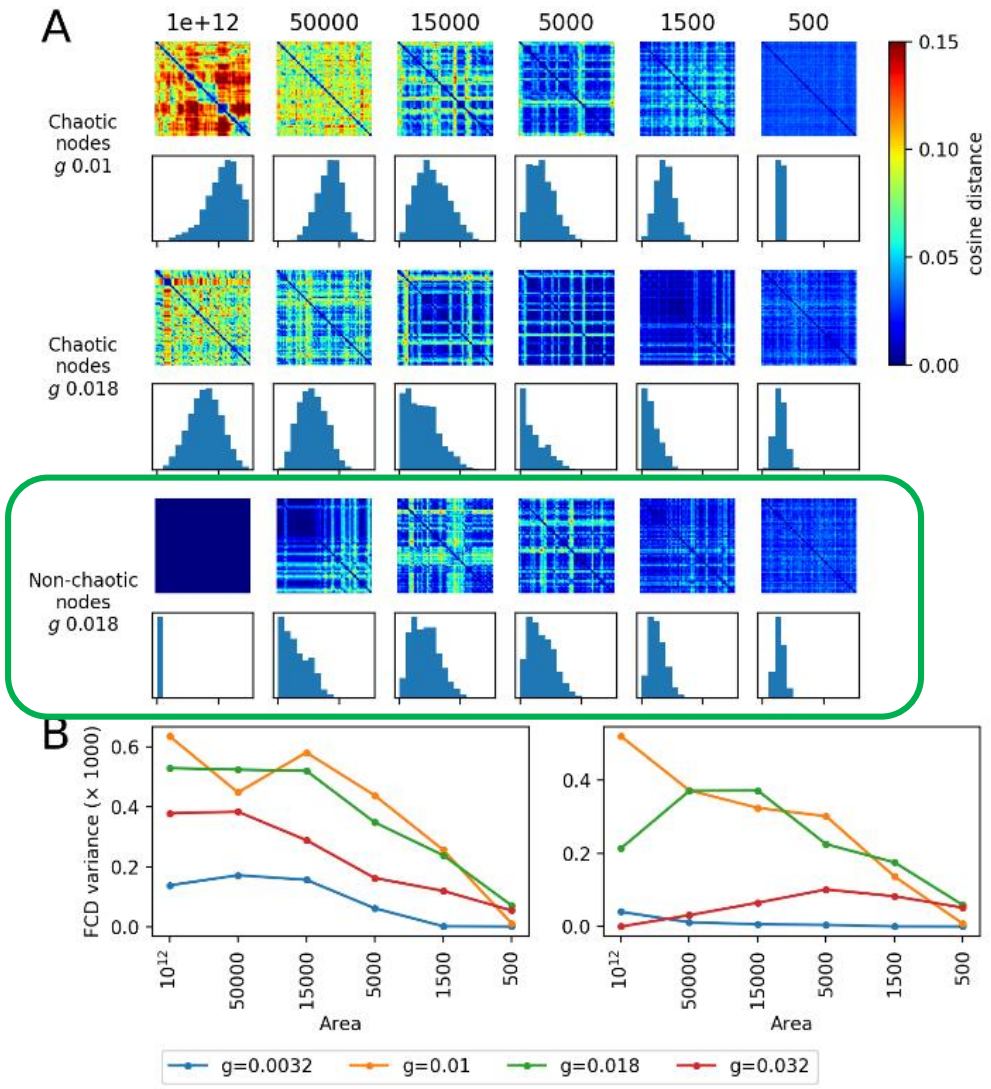
Membrane area controls the intensity of noise

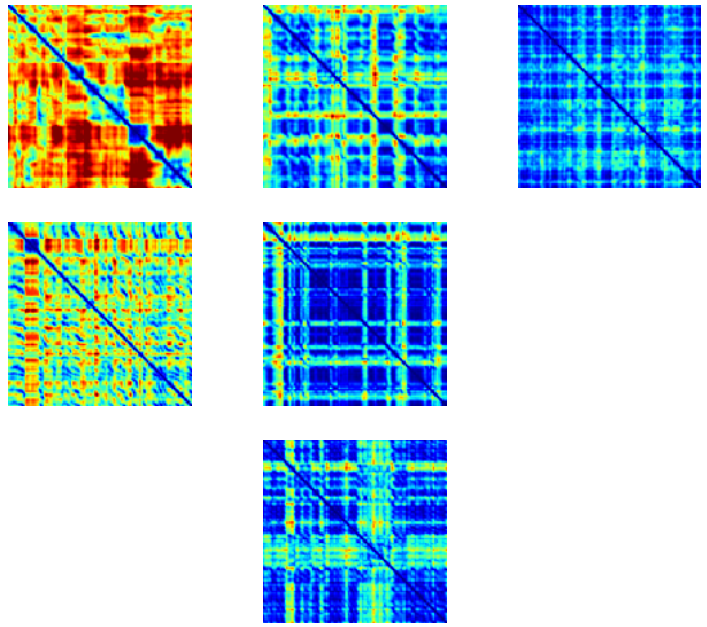
Orio et al., 2012, Pezo et al., 2014

Noise abolishes chaos-induced multi-stability



Orio et al., *Chaos*, 2018

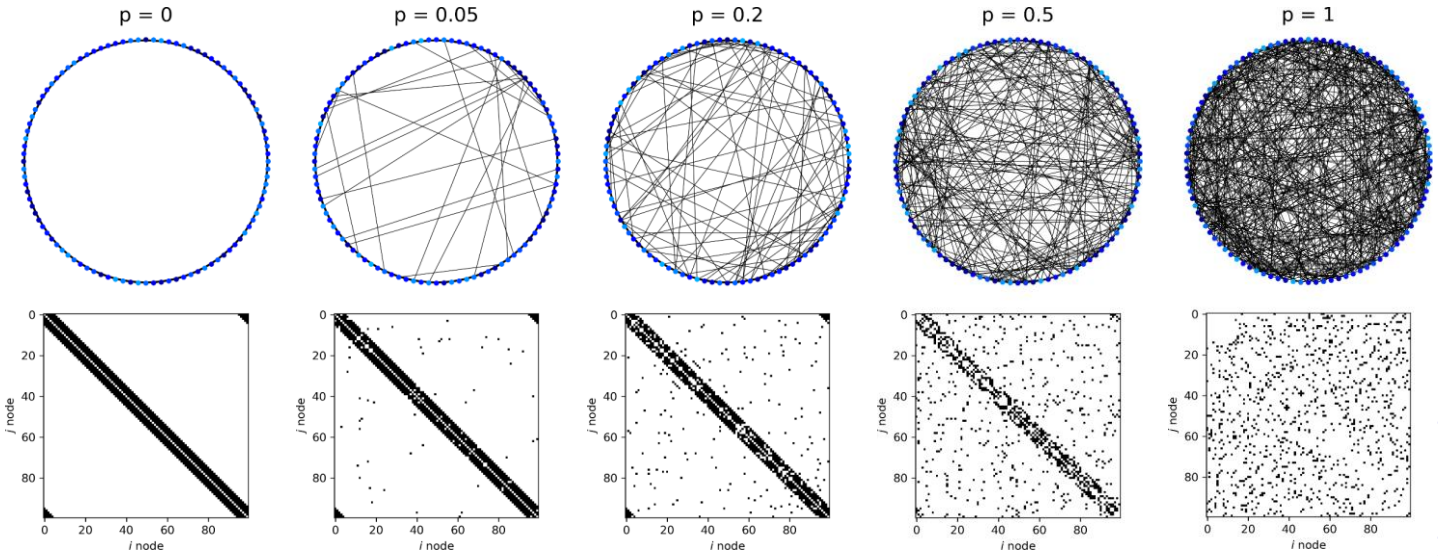




Noise can *induce* multi-stability in networks of non-chaotic oscillators

Orio et al., *Chaos*, 2018

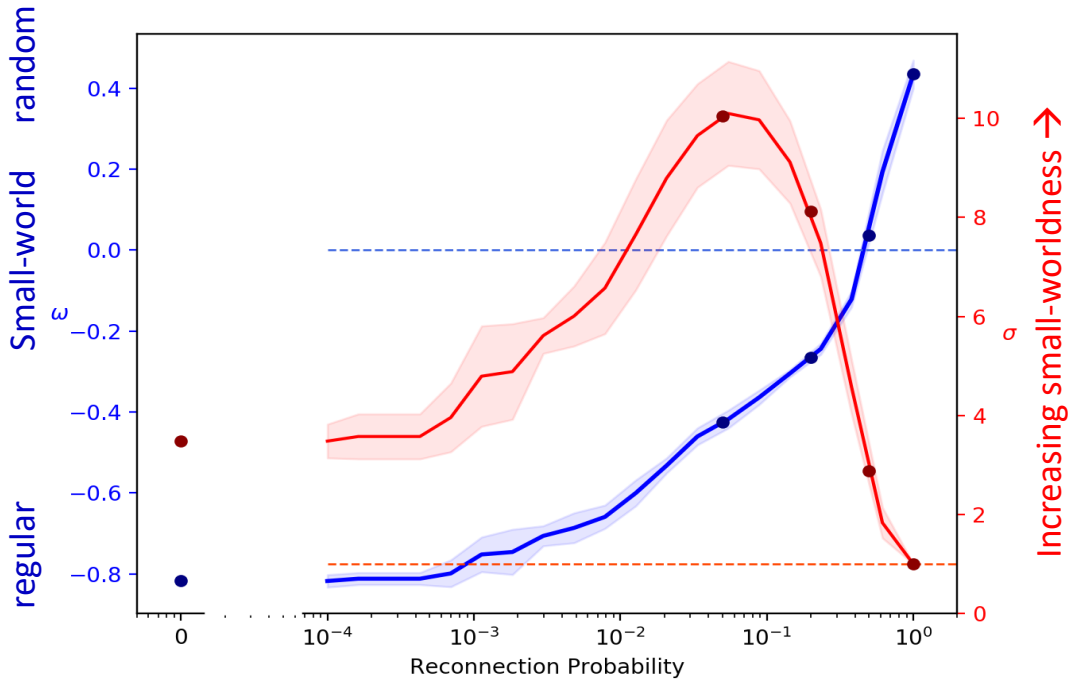
From regular to random



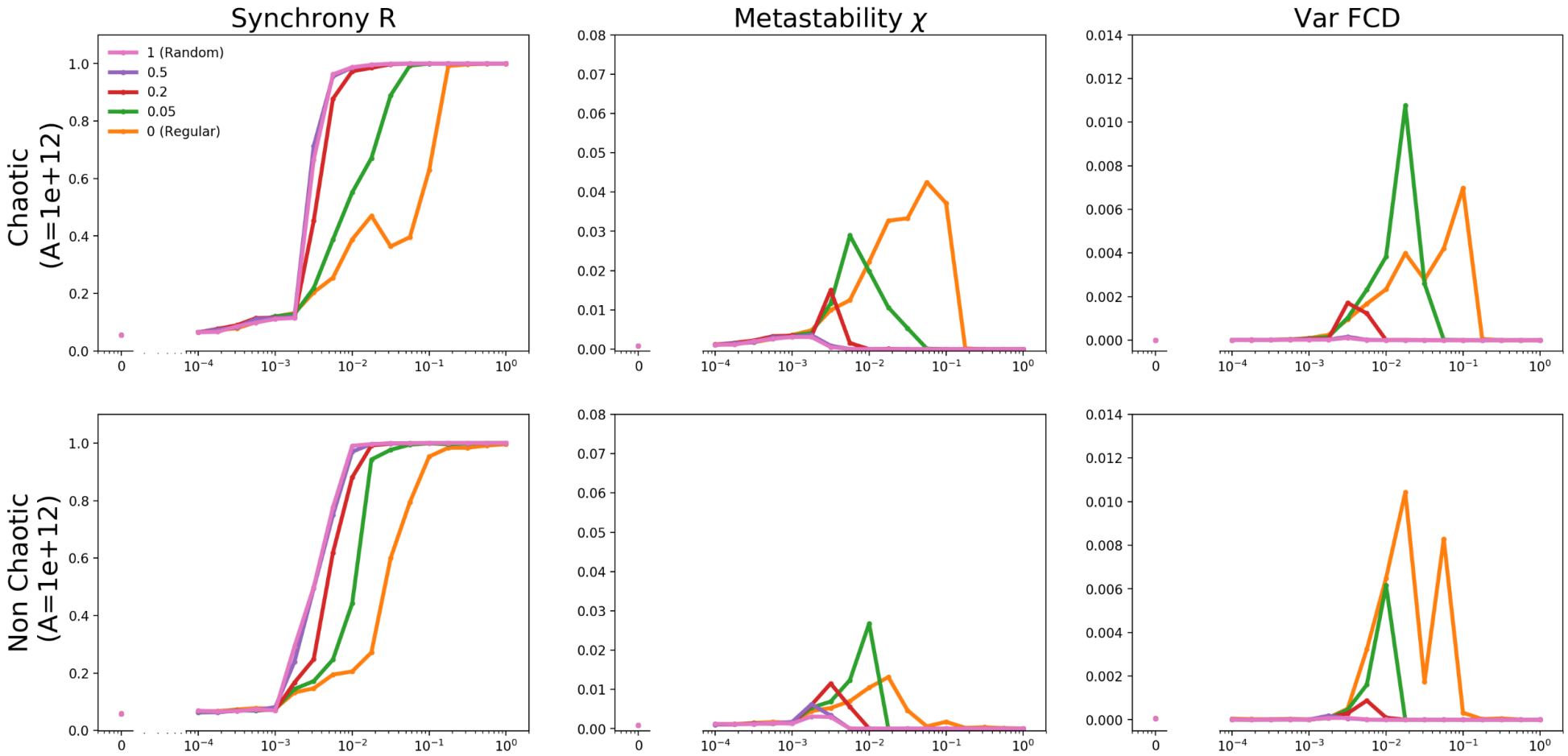
Small world indices:

σ (Humphries) and ω (Telesford):

$$\sigma = \frac{C/C_r}{L/L_r} \qquad \omega = \frac{L_r}{L} - \frac{C}{C_0}$$



Long-range connections abolish multistability



Además

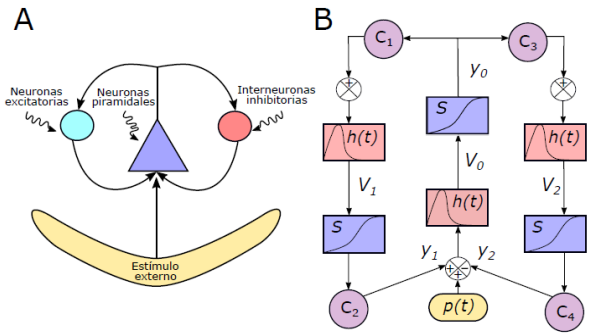
- Análisis de la FCD en datos experimentales
  - Registros de EEG en nivel del mar y en altura (hipoxia)
  - Registros de fMRI

Propuestas de proyectos

- Revisitar o revisar el algoritmo de *clustering*.
  - ¿Utilizar análisis topológico?

- Estudiar el comportamiento de la FCD en modelos de *masas neuronales*.
  - HB+Ih → *neurona oscilatoria*.
  - Electrical synapses → naturally synchronizing

Jansen & Rit



Wilson Cowan