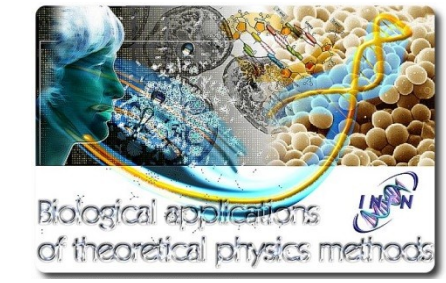

Phase transition & the role of topology in a neural network with spatio-temporal attractors

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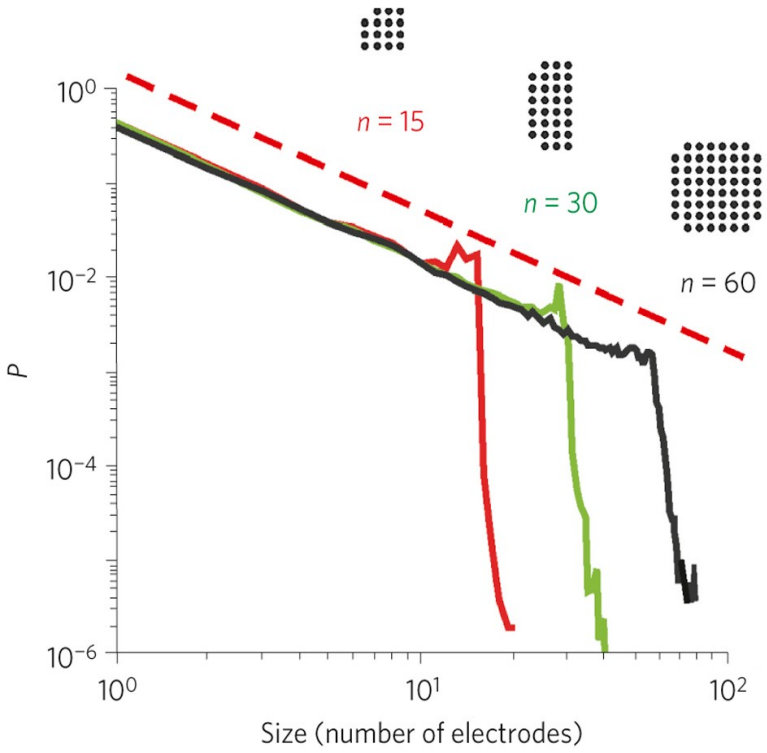
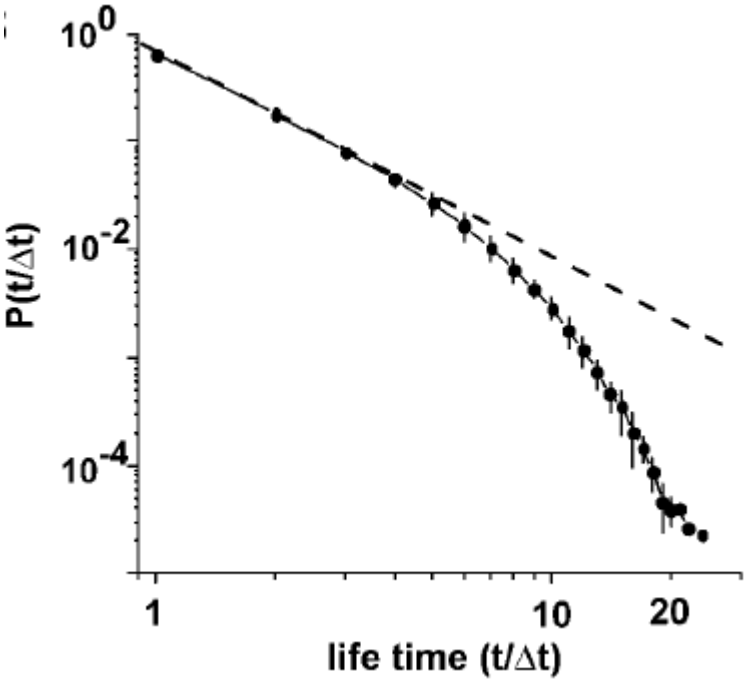
ANACAPRI WORKSHOP Complex Collective Dynamics: Brains and beyond
Aug 31-Sep 4, 2015

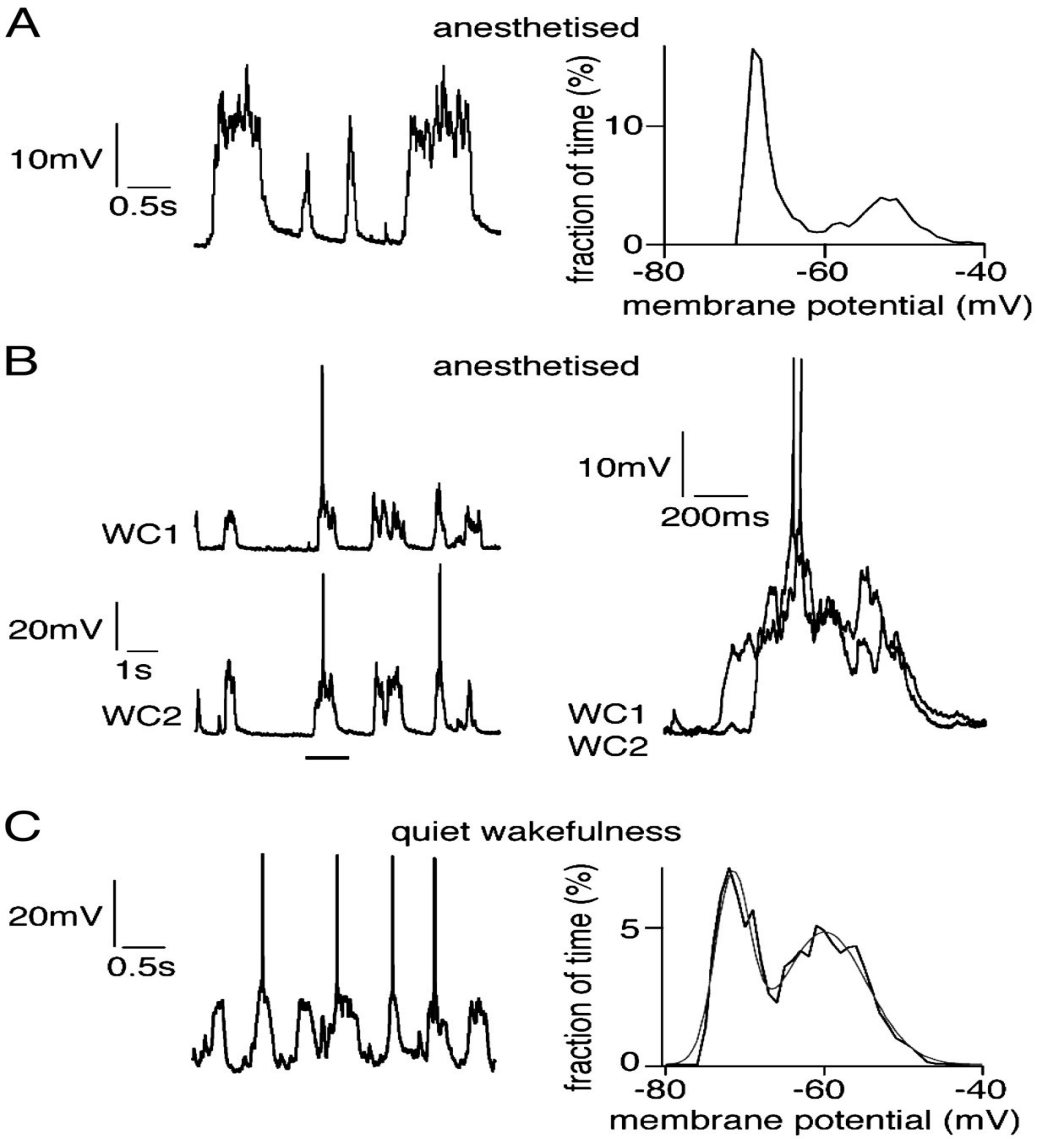
Power law distributions





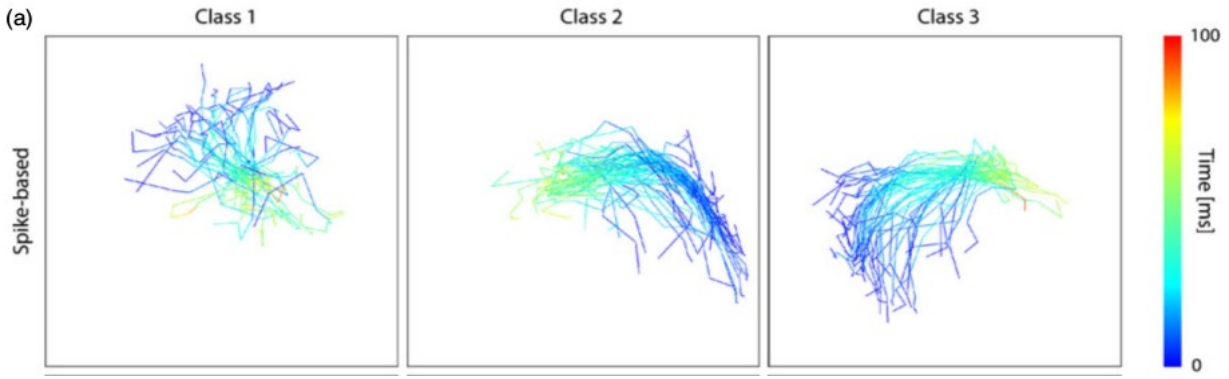
Beggs & Plenz, J. Neurosci. 23, 11167 (2003).

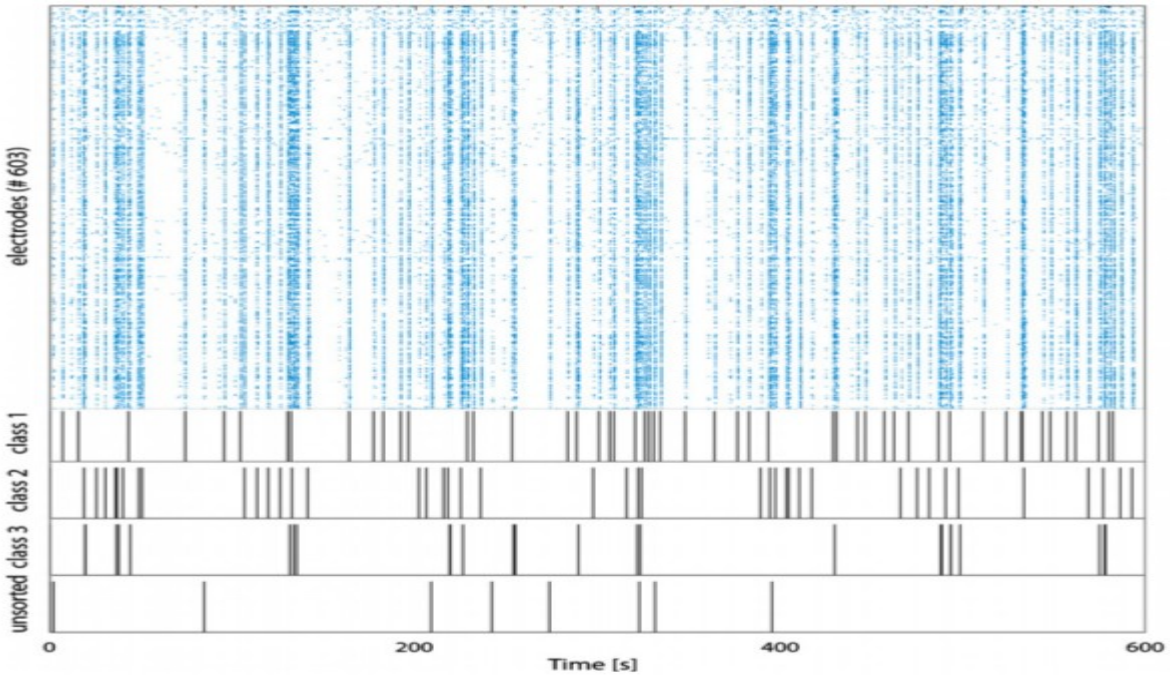
UP and DOWN states during anesthesia and quiet wakefulness.

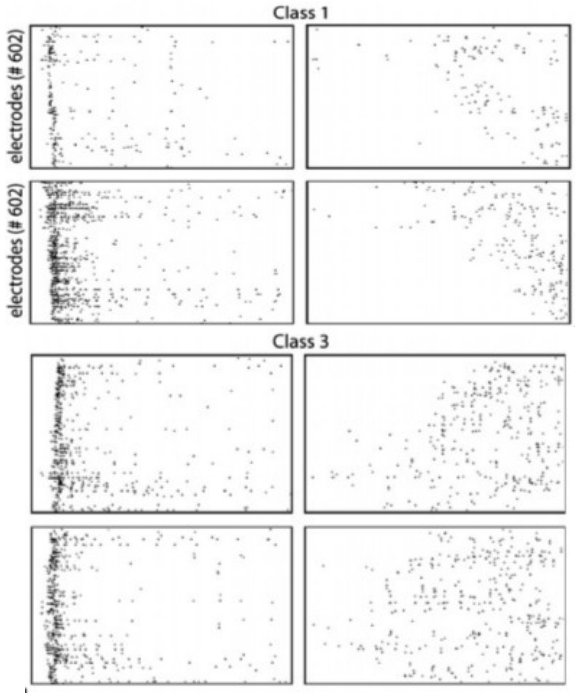


Carl C. H. Petersen et al. PNAS 2003;100:13638-13643

Repeatability of network bursts in hippocampal cultures



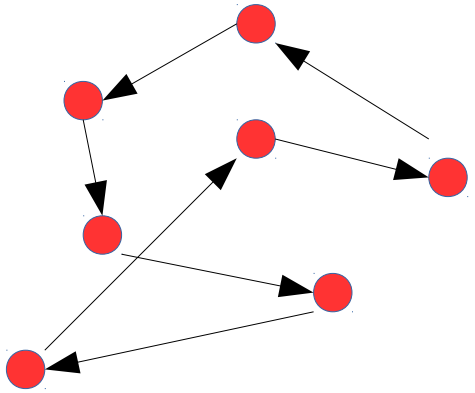




M. Gandolfo et al., J. Neural Eng. 7 (2010) 056001

A model with spatio-temporal attractors

network is forced to replay patterns and connections are shaped by STDP

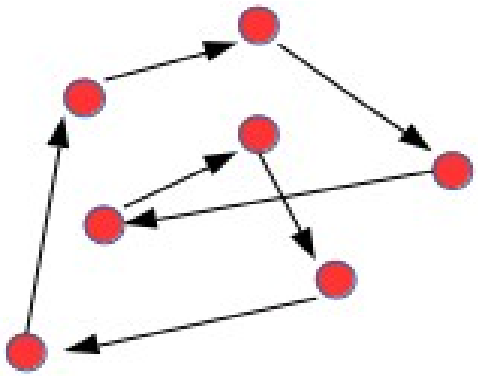


$$\text{neuron activity: } x_i(t) = \sum_n \delta(t - t_i^\mu)$$

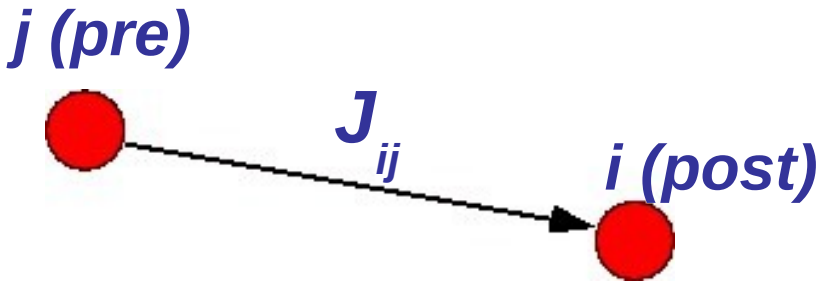
$$\Delta J_{ij}^\mu \propto \int dt\, dt' x_i(t) A(t - t') x_j(t')$$

$$\propto \sum_n A\left(t_i^\mu - t_j^\mu + \frac{n}{f^\mu}\right)$$

$$J_{ij} = \sum_\mu \Delta J_{ij}^\mu \qquad \sum_{ij} J_{ij} \simeq 0$$

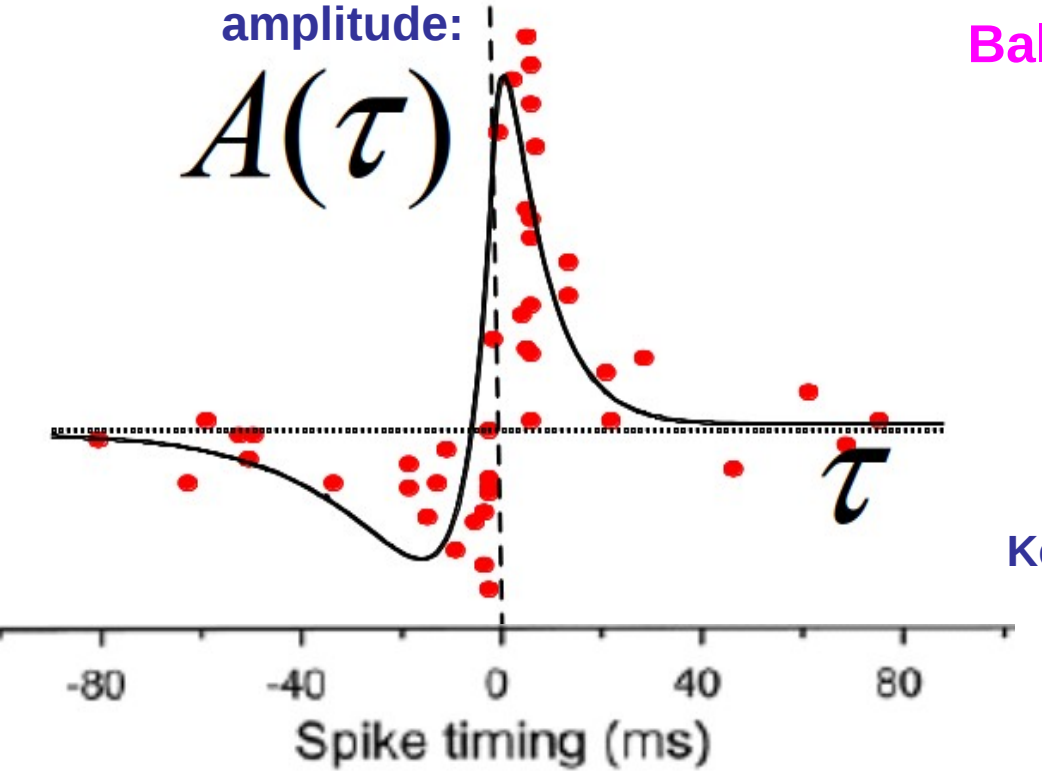


Spike-timing dependent plasticity



Change in EPSC amplitude:

$A(\tau)$



$$\Delta J_{ij} \propto A\left(t_i^{(\mathrm{post})} - t_j^{(\mathrm{pre})}\right)$$

Balance between excitation and inhibition

$$\int_{-\infty}^{\infty} A(\tau)\, d\tau = 0$$

Theoretical prediction:
Kempter, Gerstner & van Hemmen, PRE 199

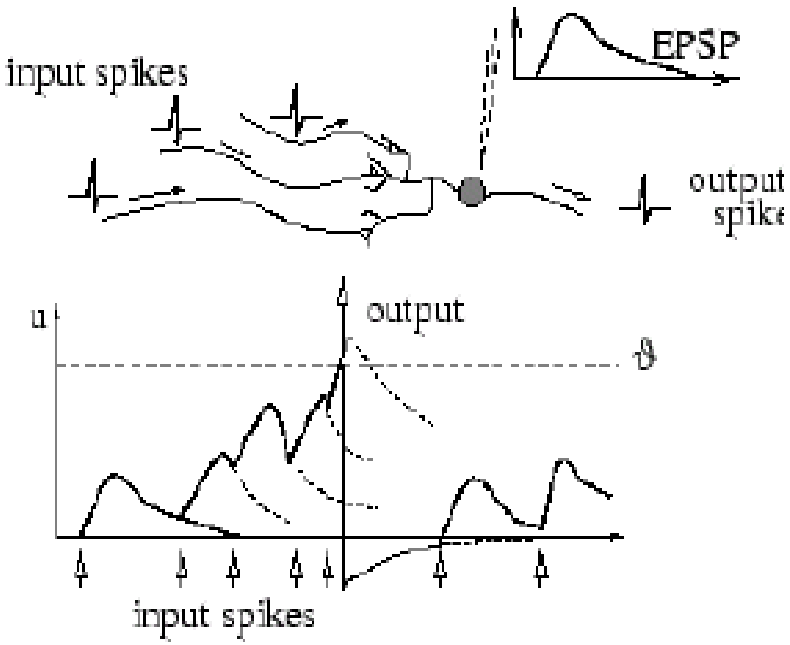
Experiments:
Markram et al., Nature 1997
Bi & Poo, J. Neuroscience 1998

Hub (leader) neurons & pruning

- Leader neurons: 3% of the neurons have a three times larger amplitude of the incoming connections.

- Pruning of the connections: only the 30% largest connections survive, the others are set to zero.

The dynamics:
Leaky Integrate-and-Fire neurons

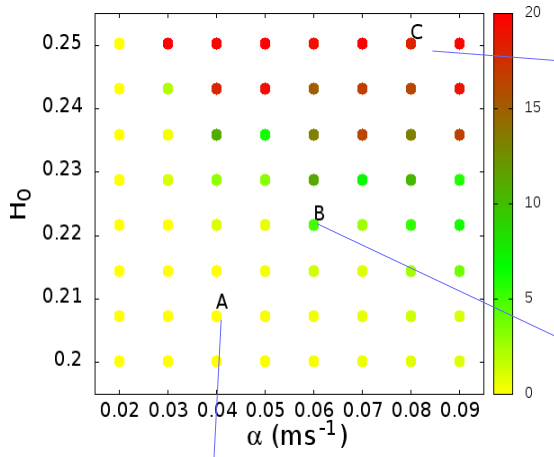


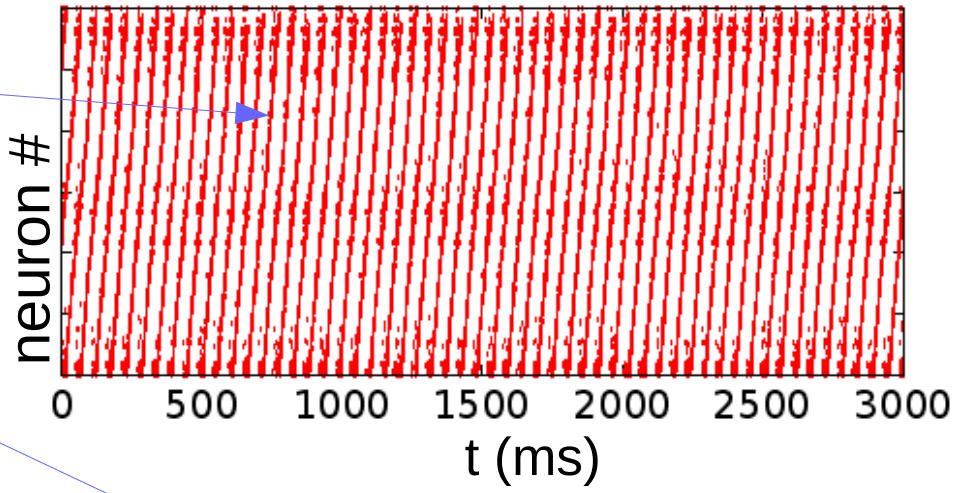
$$\frac{dV_i(t)}{dt} = -\frac{V_i(t)}{\tau_m} + I_i(t)$$

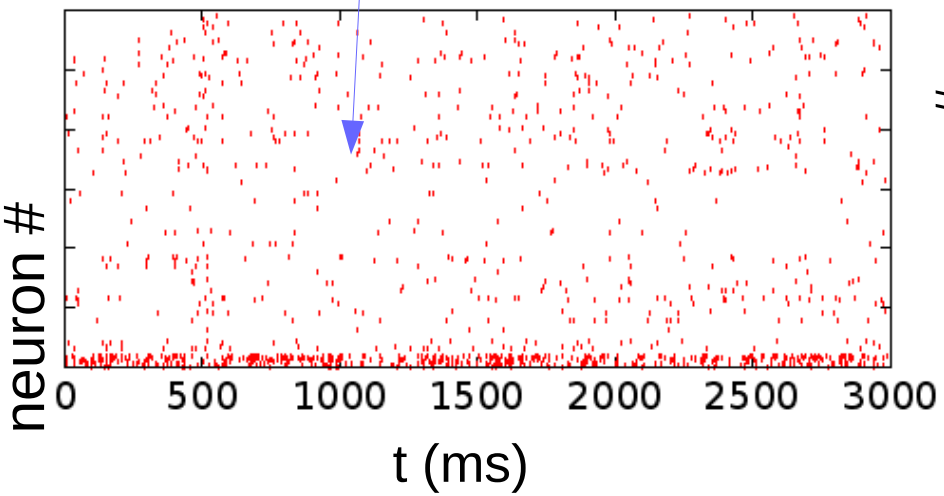
$$I_i(t) = \sum_j \sum_{t_i < t_j < t} \frac{J_{ij}}{\tau_s} e^{-(t-t_j)/\tau_s} + \sum_{t_i < \hat{t}_i < t} \frac{\hat{h}_i}{\tau_s} e^{-(t-\hat{t}_i)/\tau_s}$$

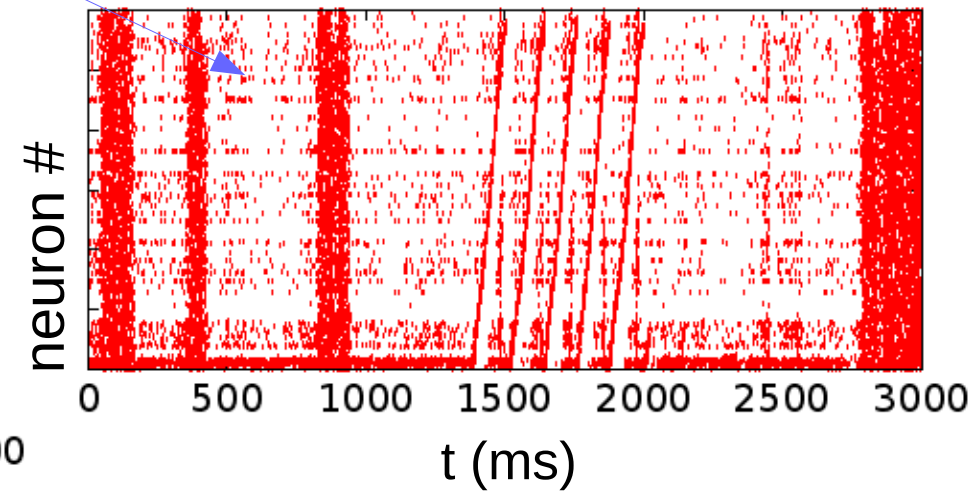
$\tau_m = 10\,\text{ms},\ \tau_s = 5\,\text{ms}$

Phase diagram: transition between replay and non-replay of patterns



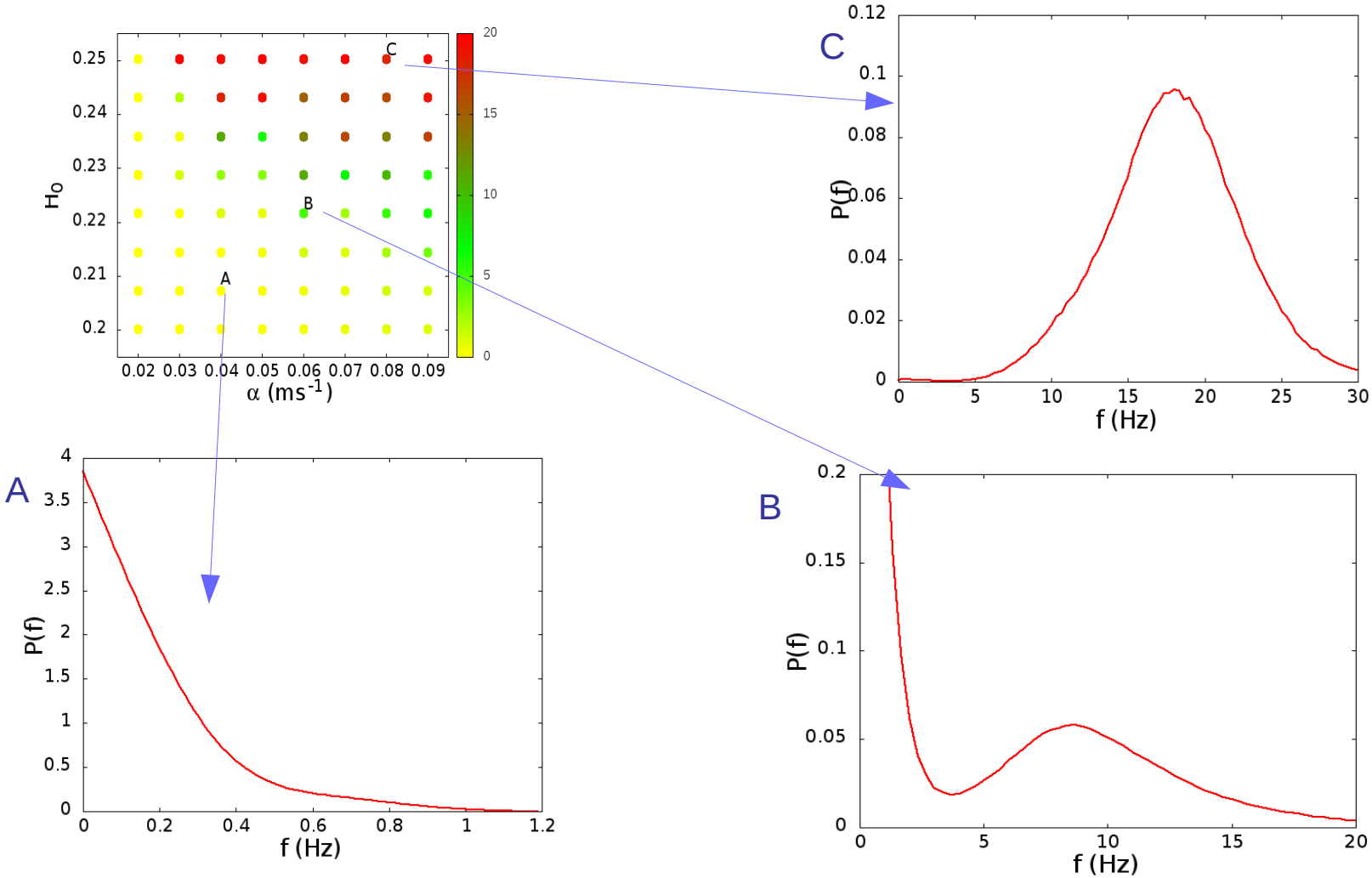






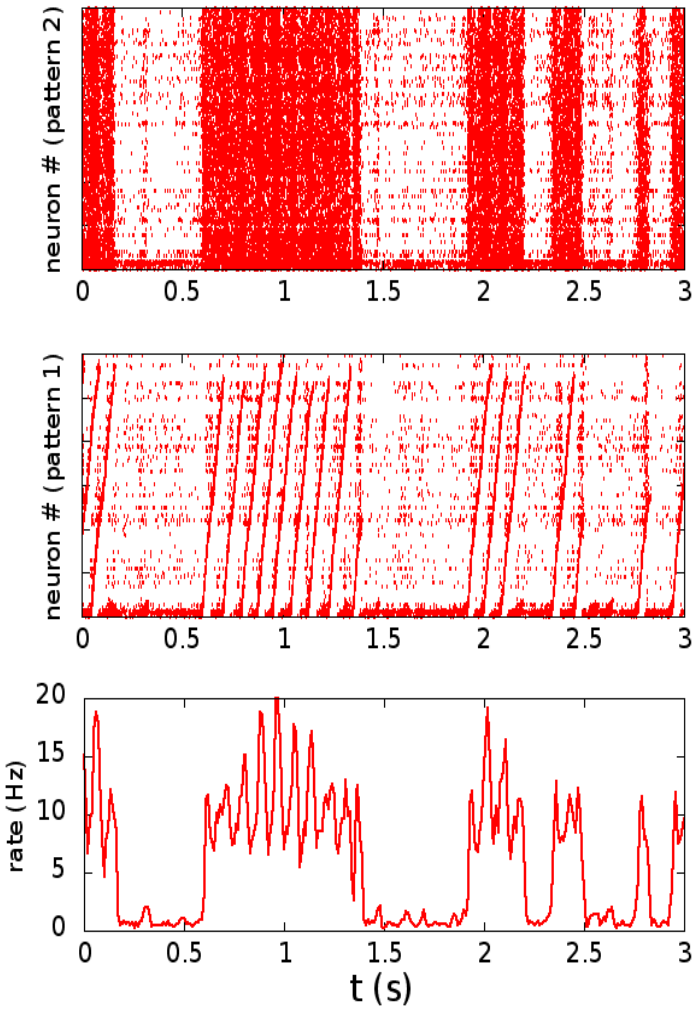
Scarpetta, de Candia, PloS One 8, e64162 (2013)

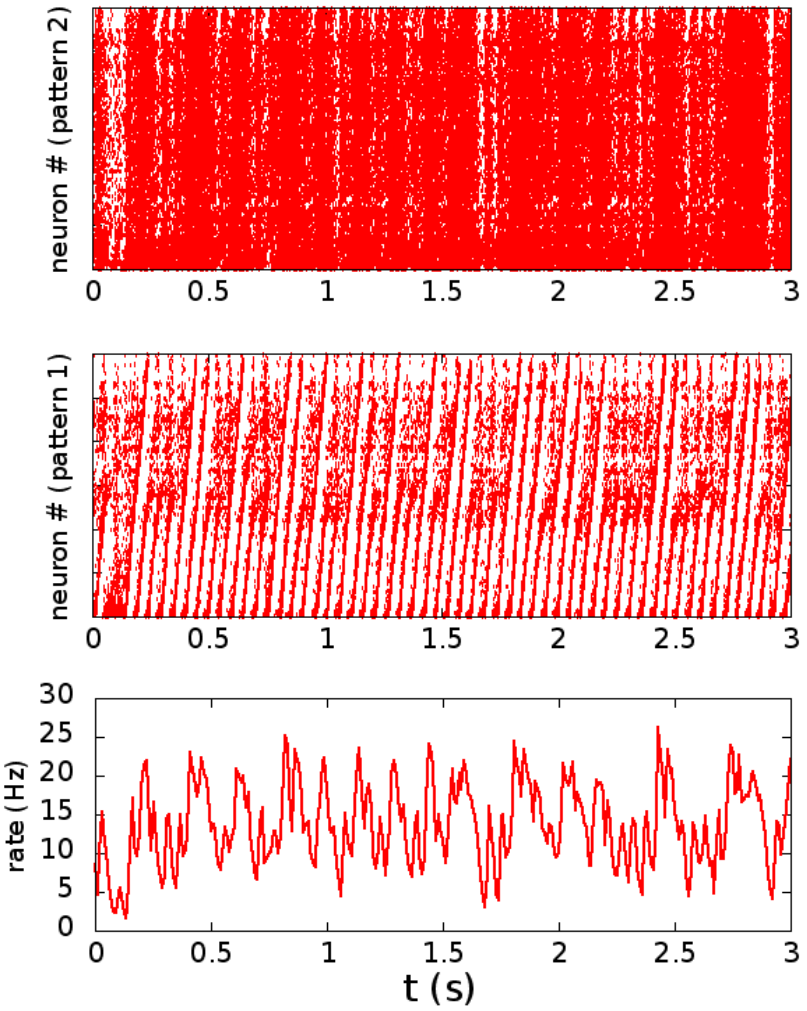
Distribution of rates



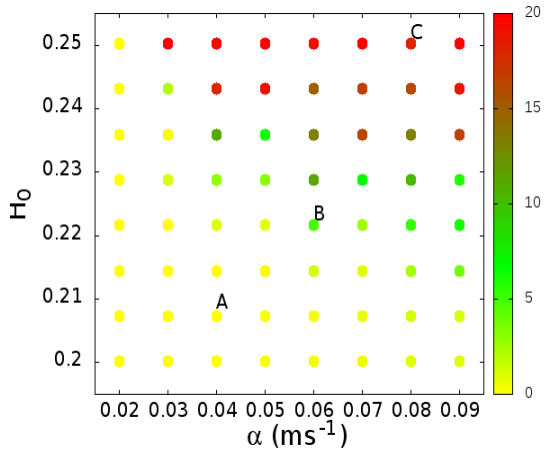
Scarpetta, de Candia, Front. Syst. Neurosci. 8, 88 (2014)

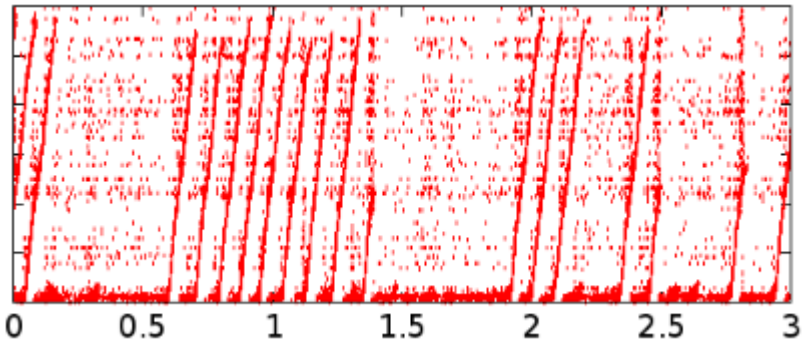
Rate and raster plots



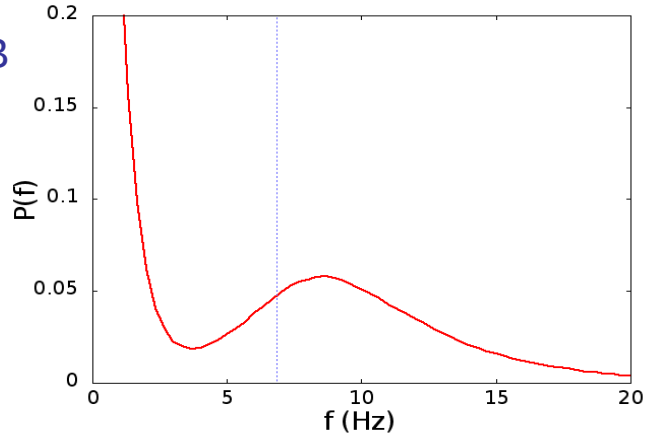


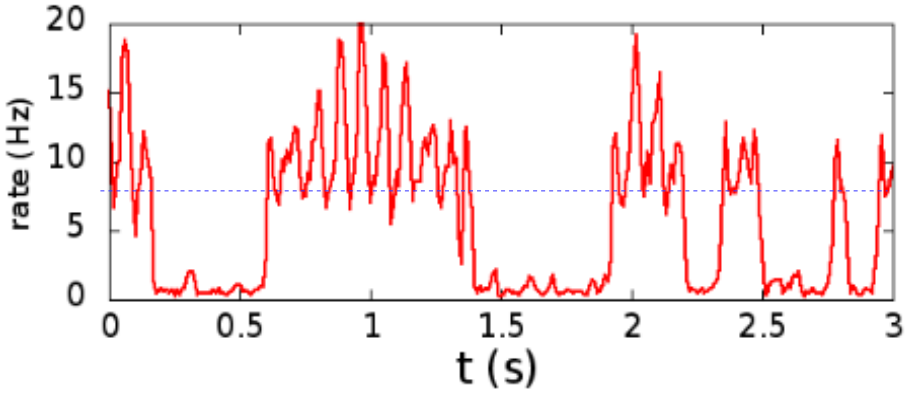
Avalanches at the transition



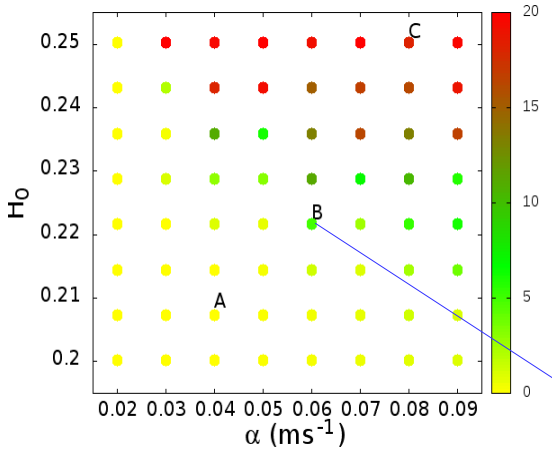


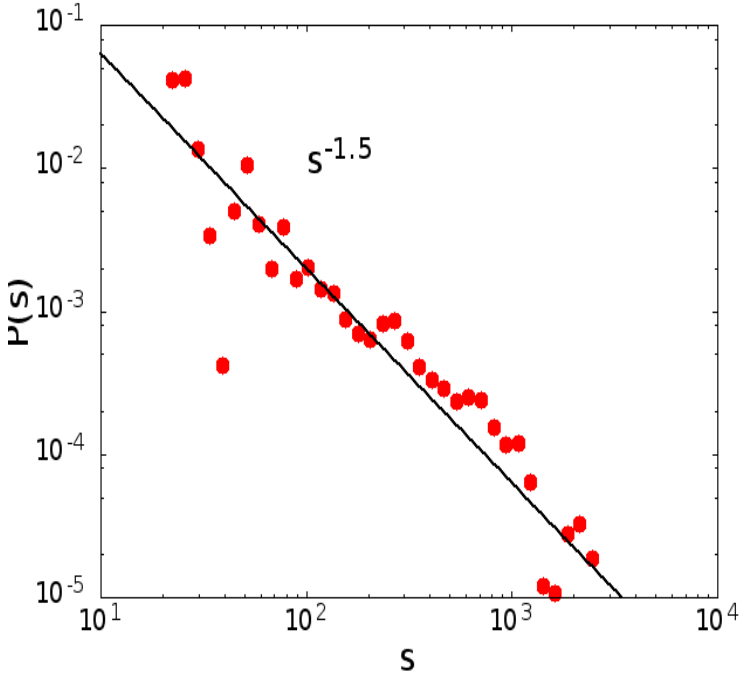
B

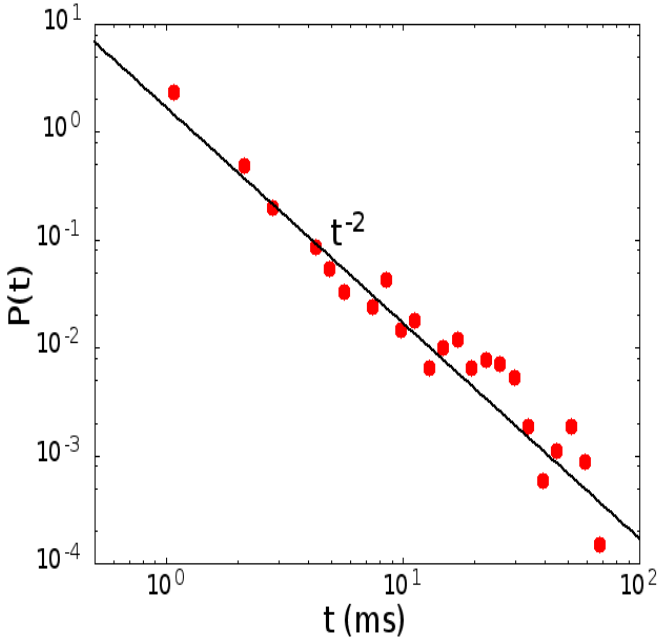




Size and duration distribution of avalanches



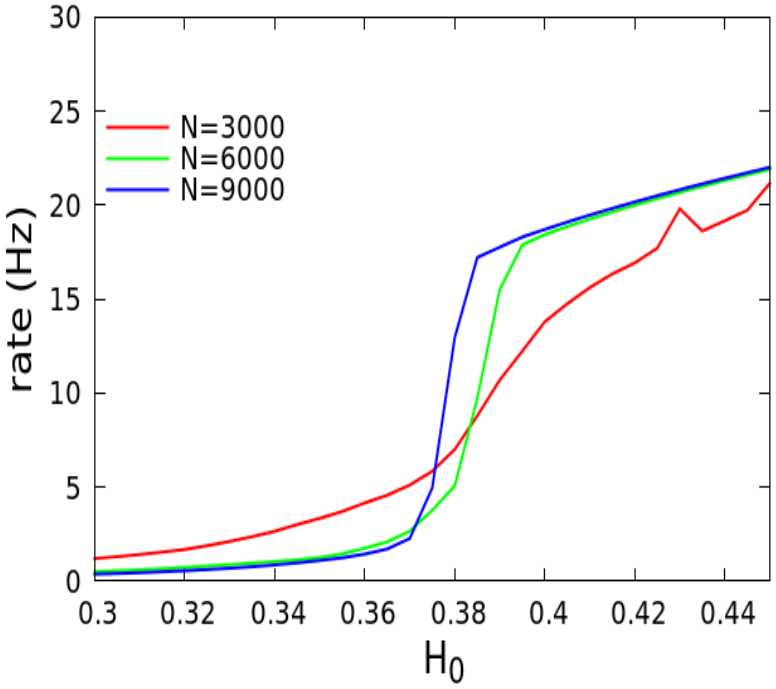


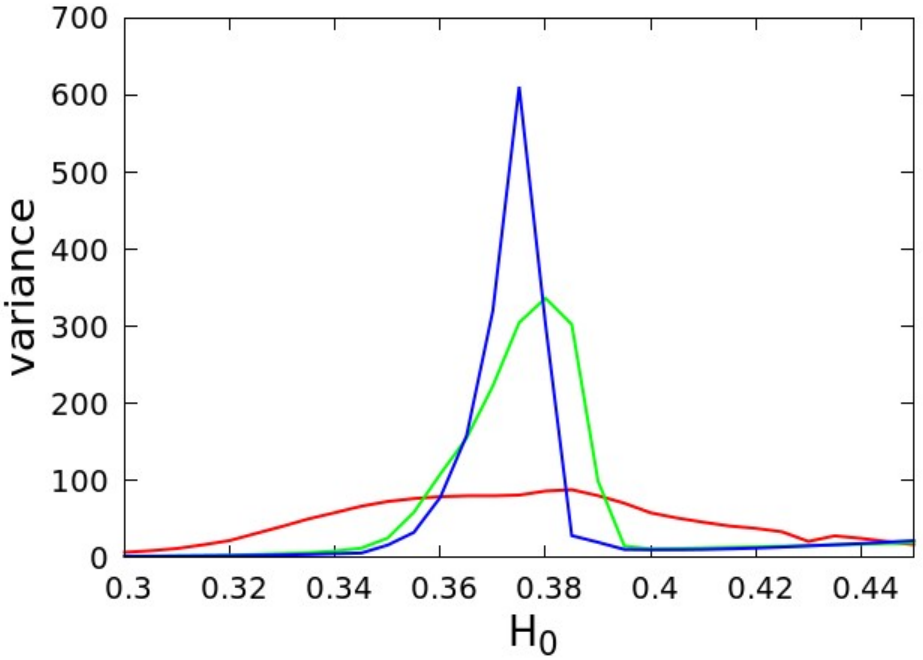


What is the order of the transition?

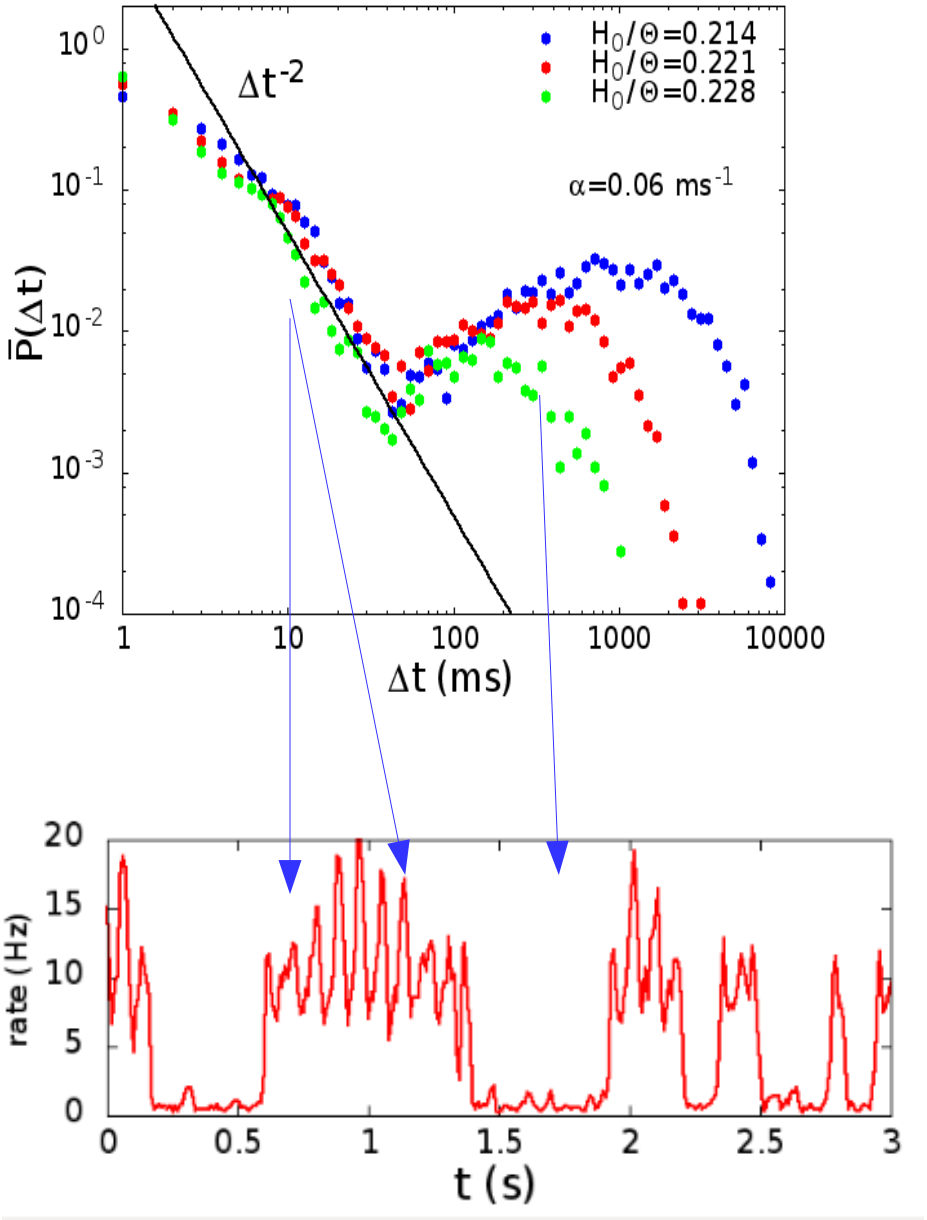
$\langle r \rangle$

$$N\Delta \frac{\langle r^2 \rangle - \langle r \rangle^2}{\langle r \rangle}$$

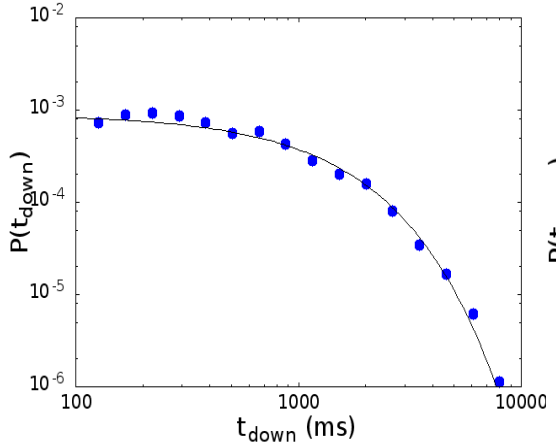


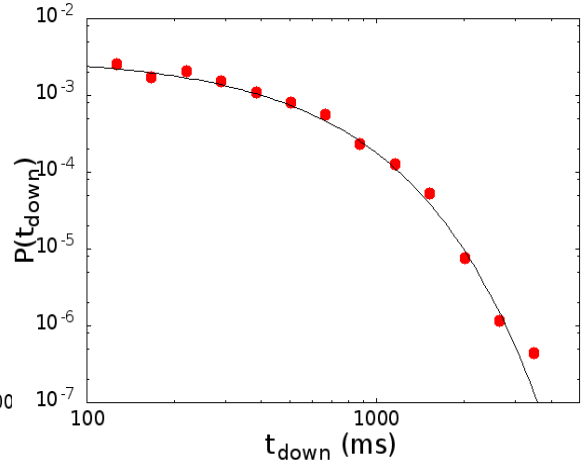


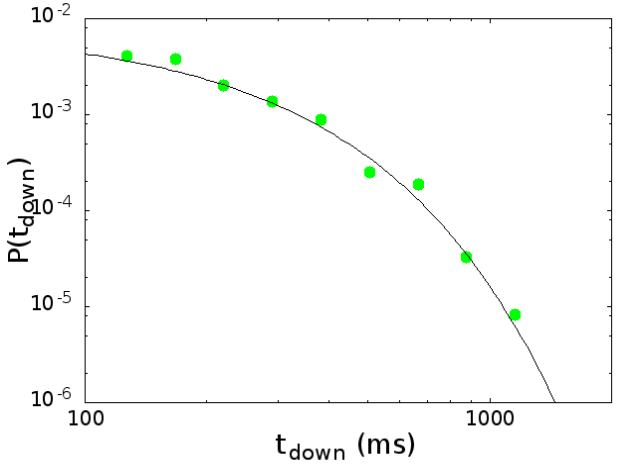
Waiting times between avalanches

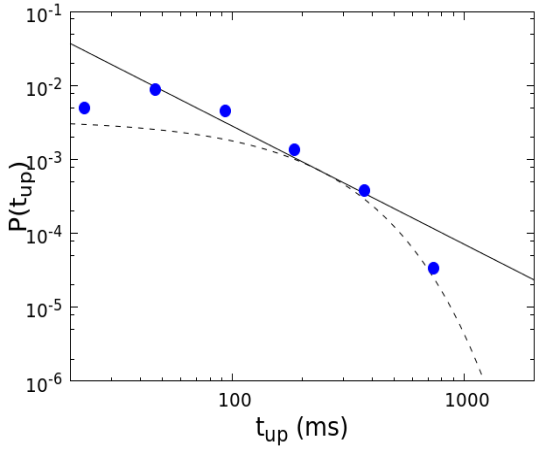


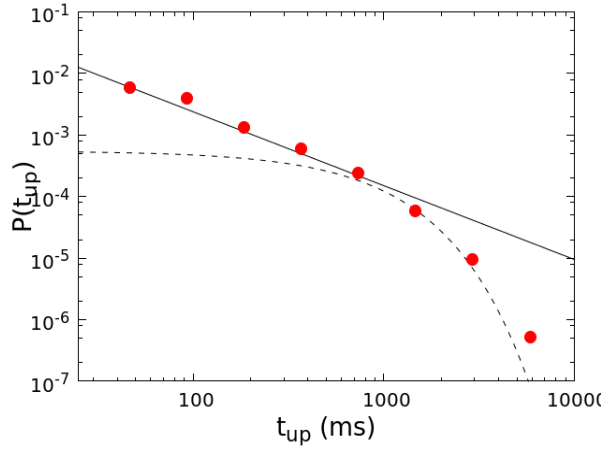
Durations of up and down states

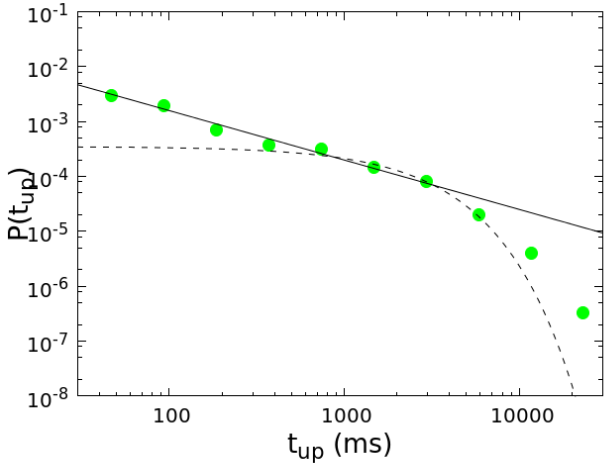






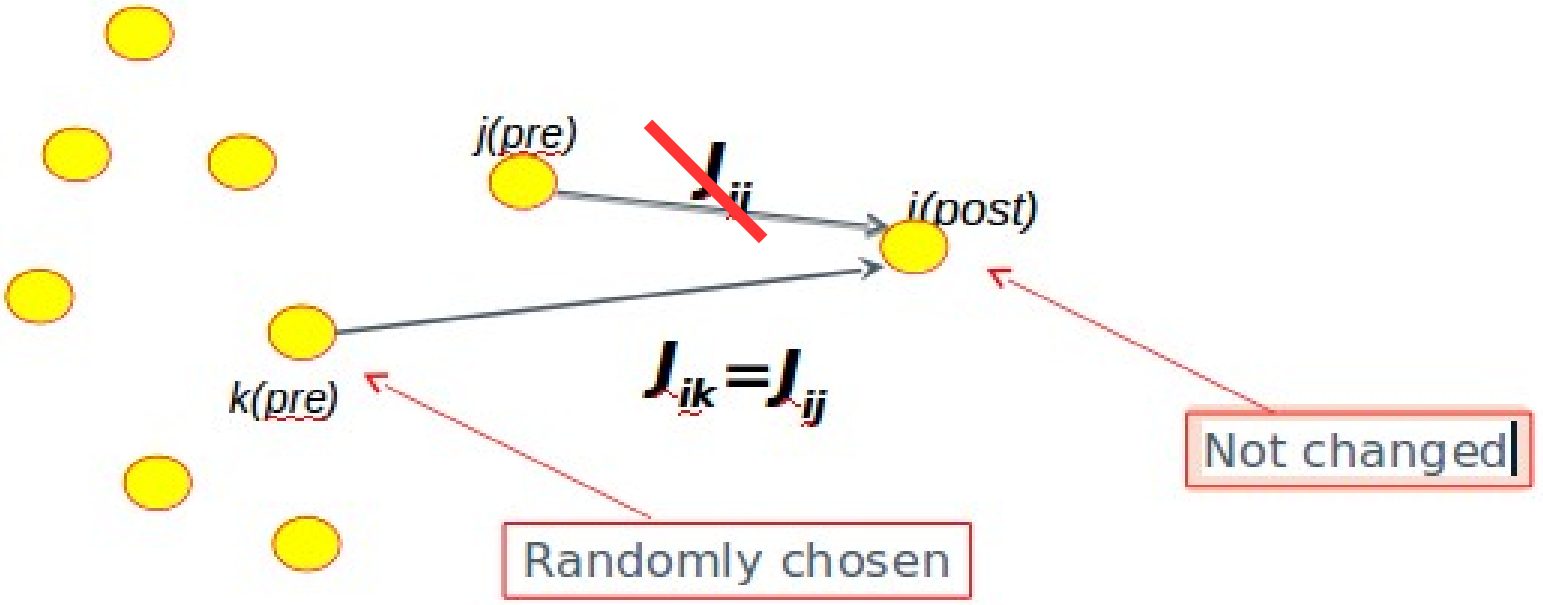






Role of topology: shuffling the connections

- We keep the number and value of the connections, but change the neurons they connect. Namely, the presynaptic neuron of a connections is changed with a randomly chosen one.

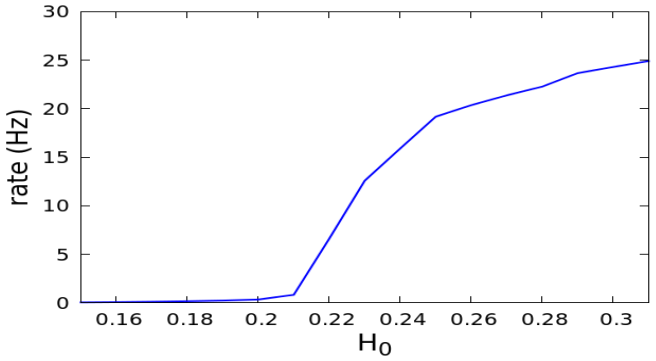


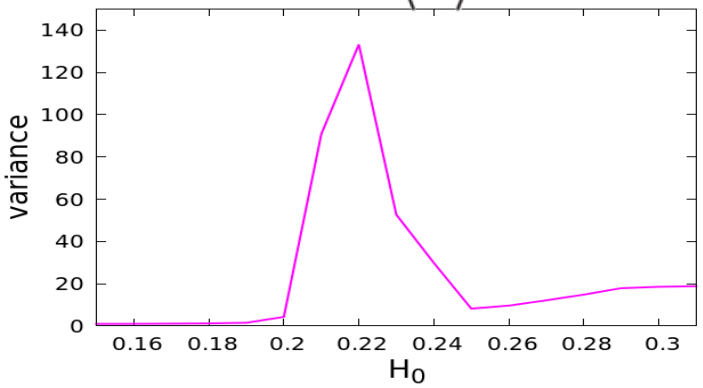
Rate and normalized variance

$\langle r \rangle$

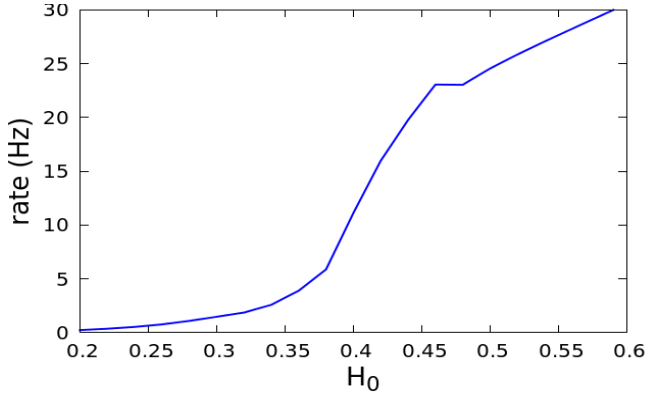
$N\Delta \dfrac{\langle r^2 \rangle - \langle r \rangle^2}{\langle r \rangle}$

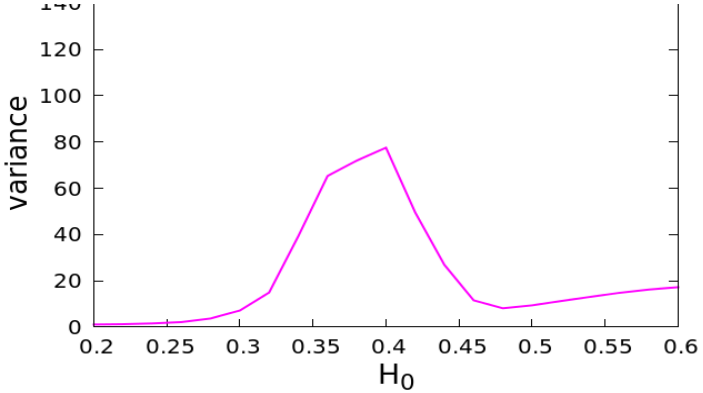
Not shuffled



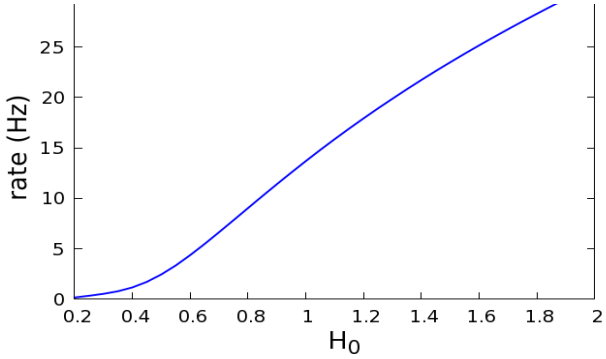


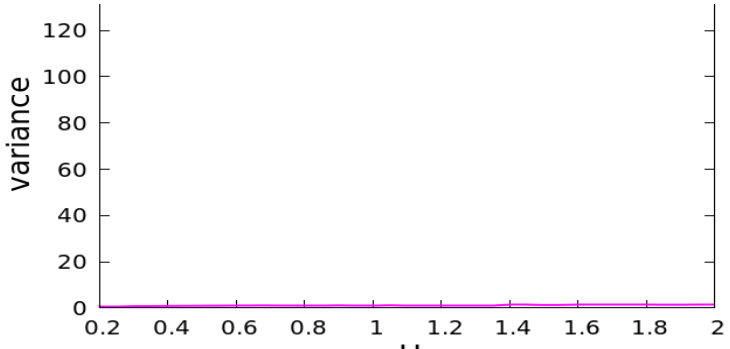
39% shuffled



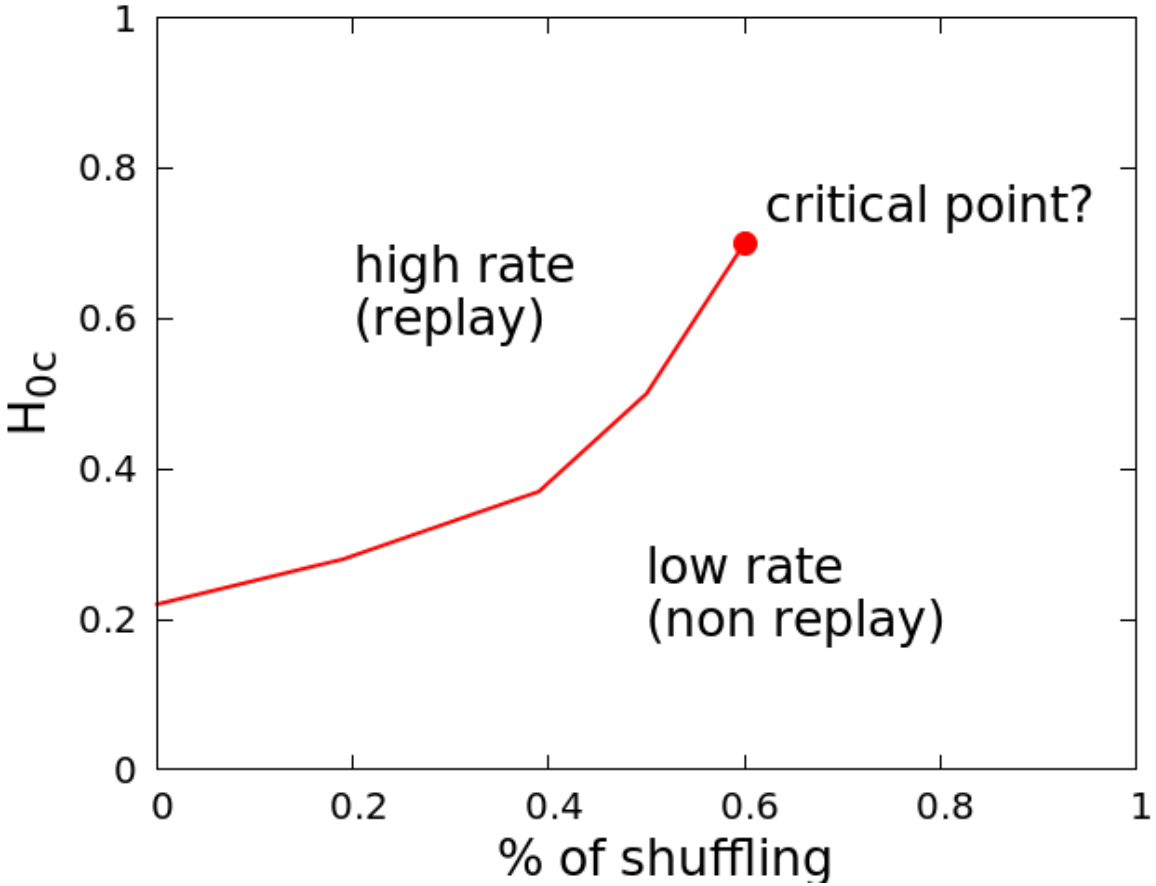


100% shuffled





How the mixed order line ends?



Conclusions

- The model displays a mixed order line (?) of transitions between a state of replay of patterns and one of non-replay
- Near the transition, intermittence between two states in observed, with one of the states (the UP state) characterized by power law correlations
- Shuffling the connections destroys the transition, and the line ends (with a critical point?)

Thank you for your attention !