Too much noise to sleep: Noise-induced transition from sleep to awake-like state in a spiking network model

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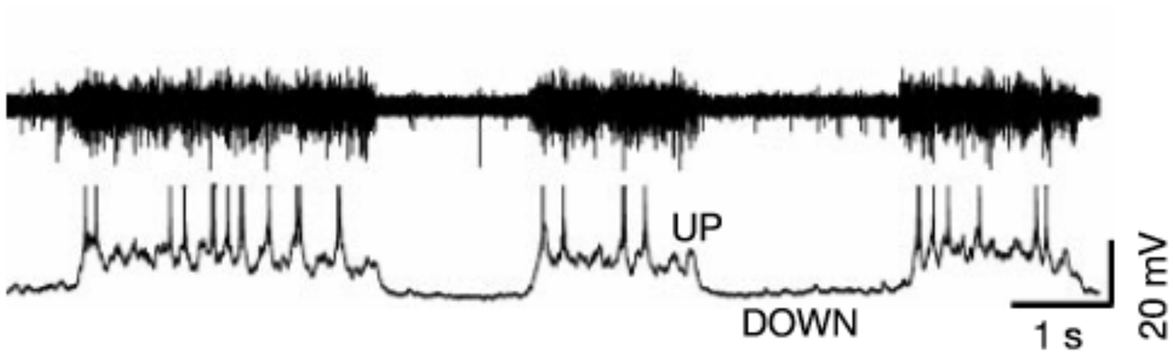
Different brains states

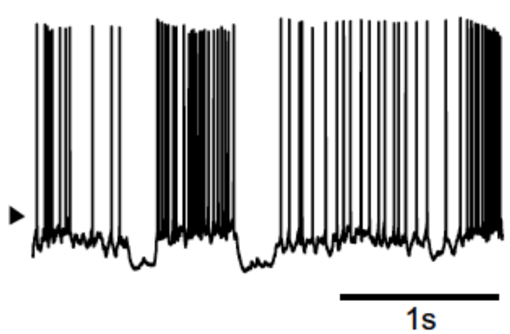
Sleep
SWS or anesthesia

Cortical slice *in vitro*



Shu et al., Nature 423:288-293, 2003

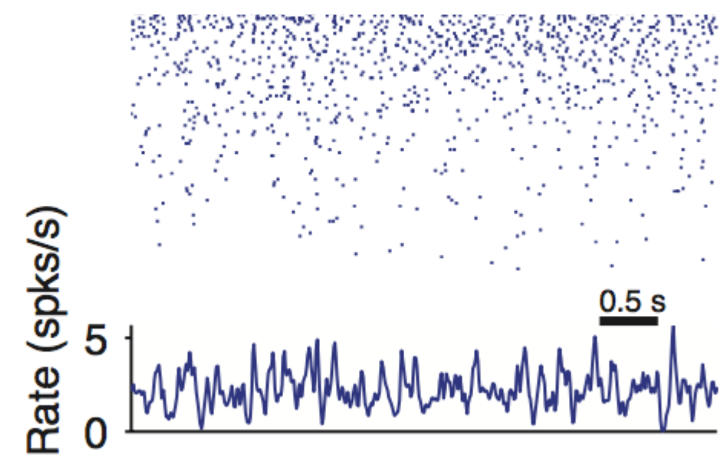
In vivo recordings



Boustani et al., J Physiol (Paris) 101:99-109, 2007

Awake

Weak correlations - asynchronous - irregular



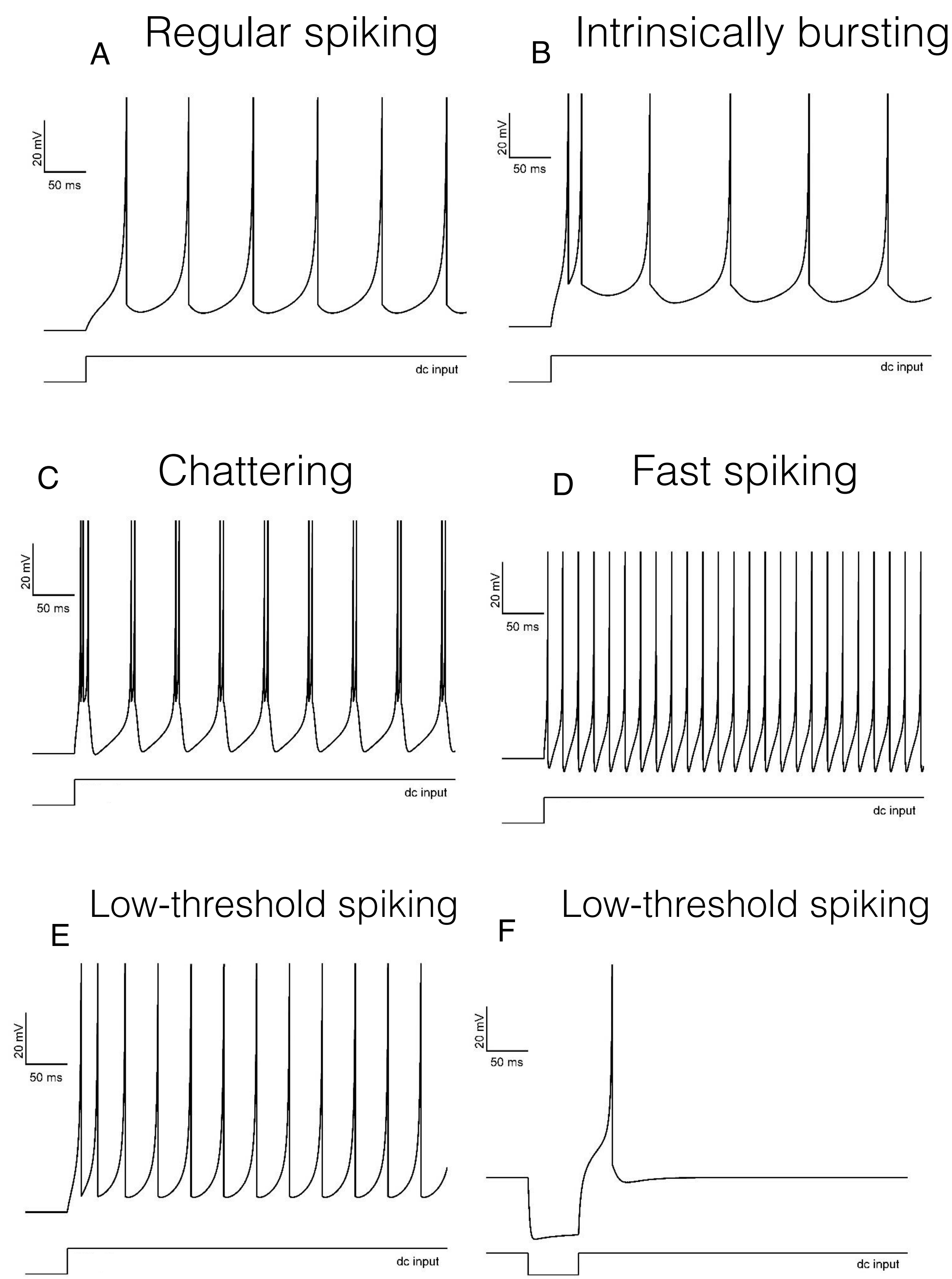
Renart et al., Science **327**, 587; 2010

Randomly connected 2^{10} neurons Izhikevich's formalism

$$\dot{v} = f(v) - u + I(t) \quad \text{(voltage)}$$
$$\dot{u} = a(bv - u) \quad \text{(recovery)}$$

$$v(t) = v_{peak}$$
Then $v(t) \rightarrow c, u(t) \rightarrow u(t) + d.$

Izhikevich, I*EEE Transactions on neural networks,* 2003

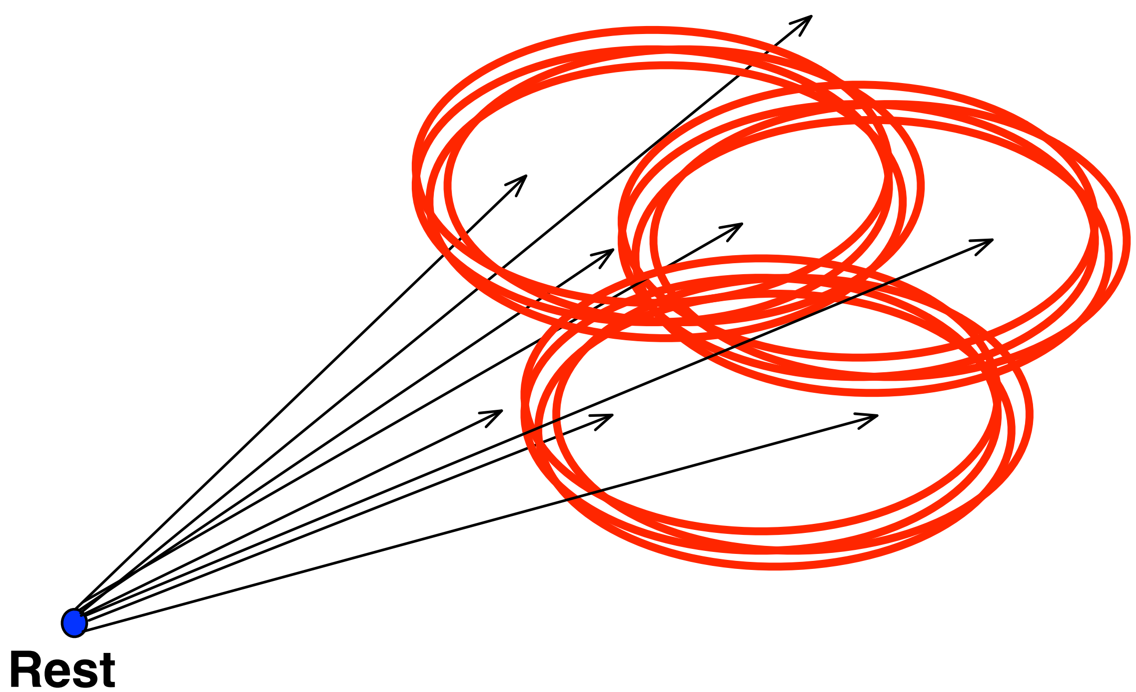


Conductance-based synapses

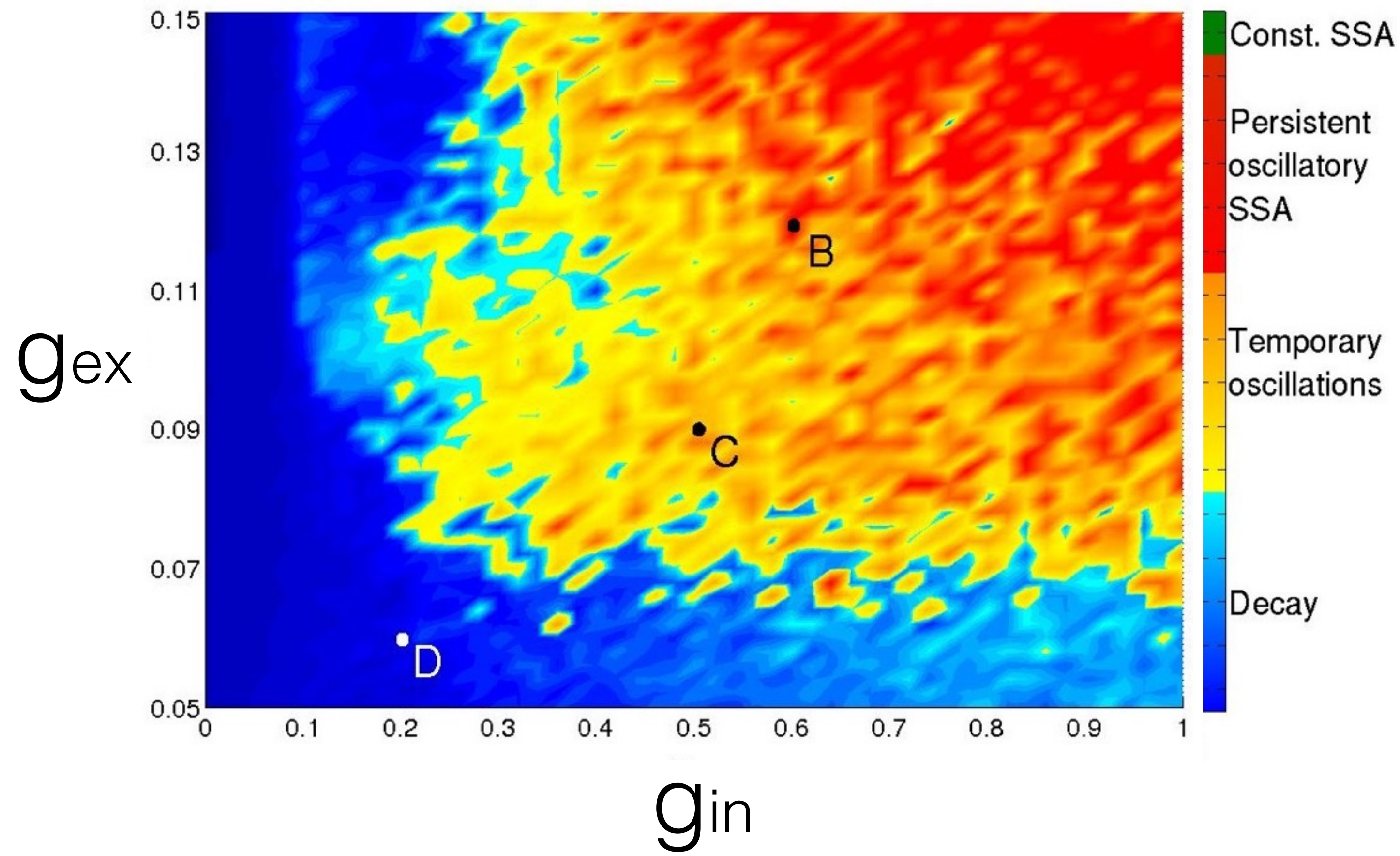
$$I_{syn,i}(t) = \sum_{j \epsilon Presyn} G^{ex/in}_{i/j}(t)(E^{ex/in} - v_i)$$

$$\frac{dG^{ex/in}_{i/j}(t)}{dt} = -\frac{G^{ex/in}_{i/j}(\mathrm{t})}{\tau_{ex/in}} + g_{ex/in}\sum_{t^f_j}\delta(t - t^f_j)$$

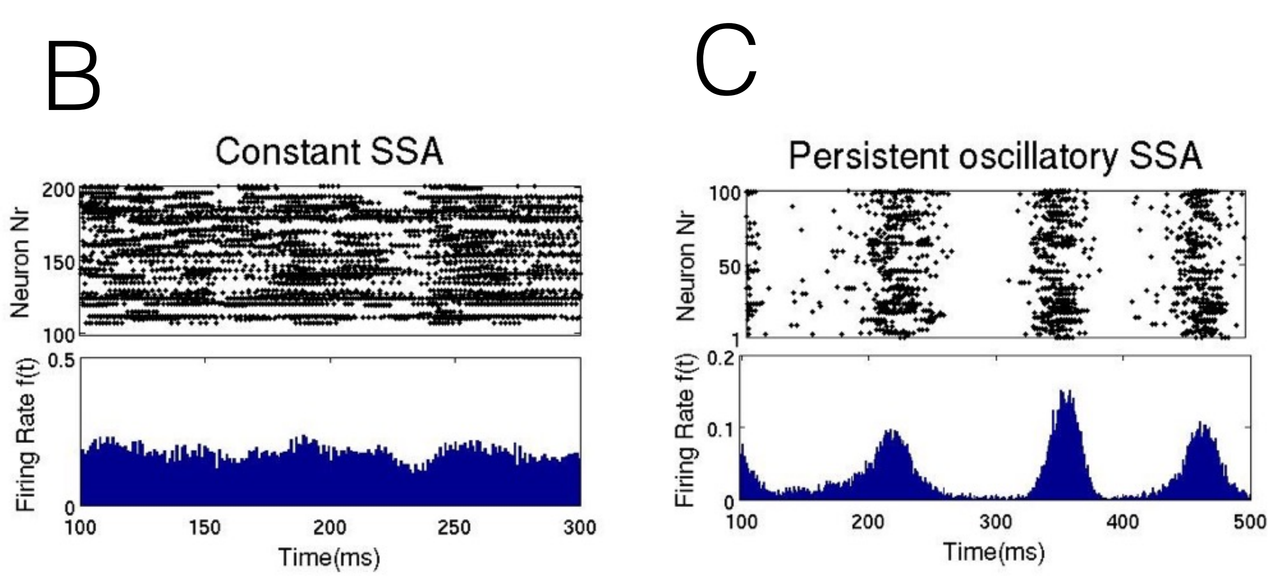
Ensemble of trajectories that leave to SSA



Lifetime; network with LTS as inhibitory, 80%RS and 20%CH;



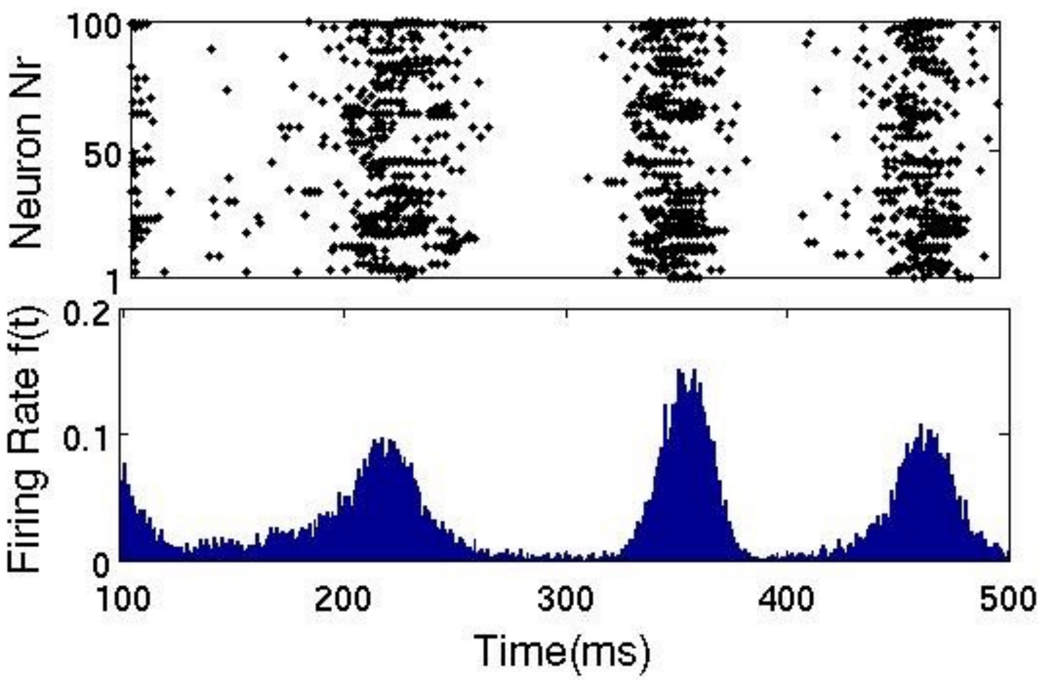
- If network correctly tuned, inhibitory conductance **exceeds** excitatory one: SSA;

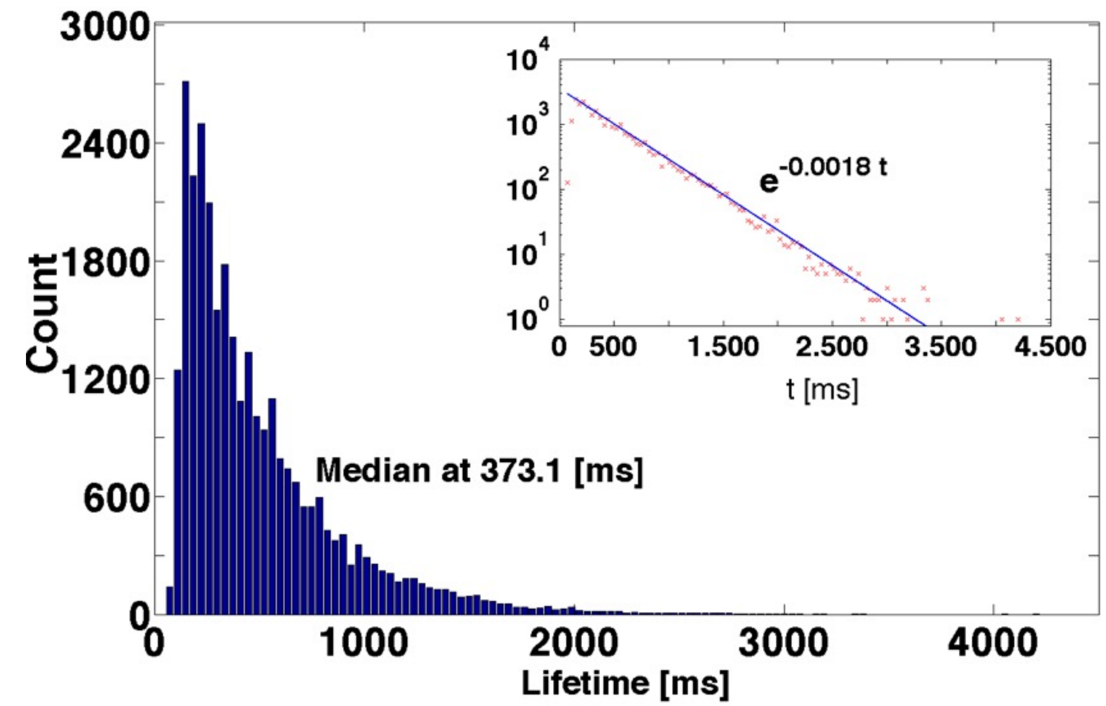


Work published at Tomov, P., Pena, R. F., Zaks, M. A., & Roque, A. C. (2014). Sustained oscillations, irregular firing, and chaotic dynamics in hierarchical modular networks with mixtures of electrophysiological cell types. ***Frontiers in computational neuroscience***, *8*.

- Activity is *transiently self-sustained;*
- Sensitive dependence of individual trajectories on initial conditions;
- Exponential distribution of lifetimes in the large ensemble of trajectories:

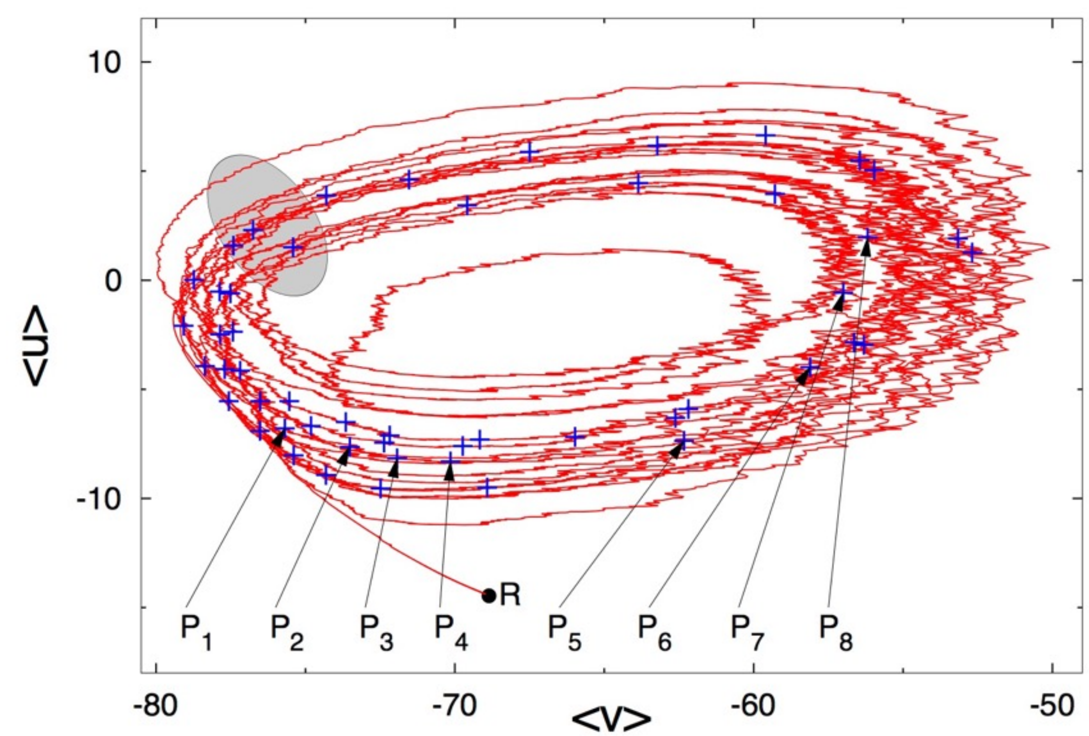
Typical raster plot





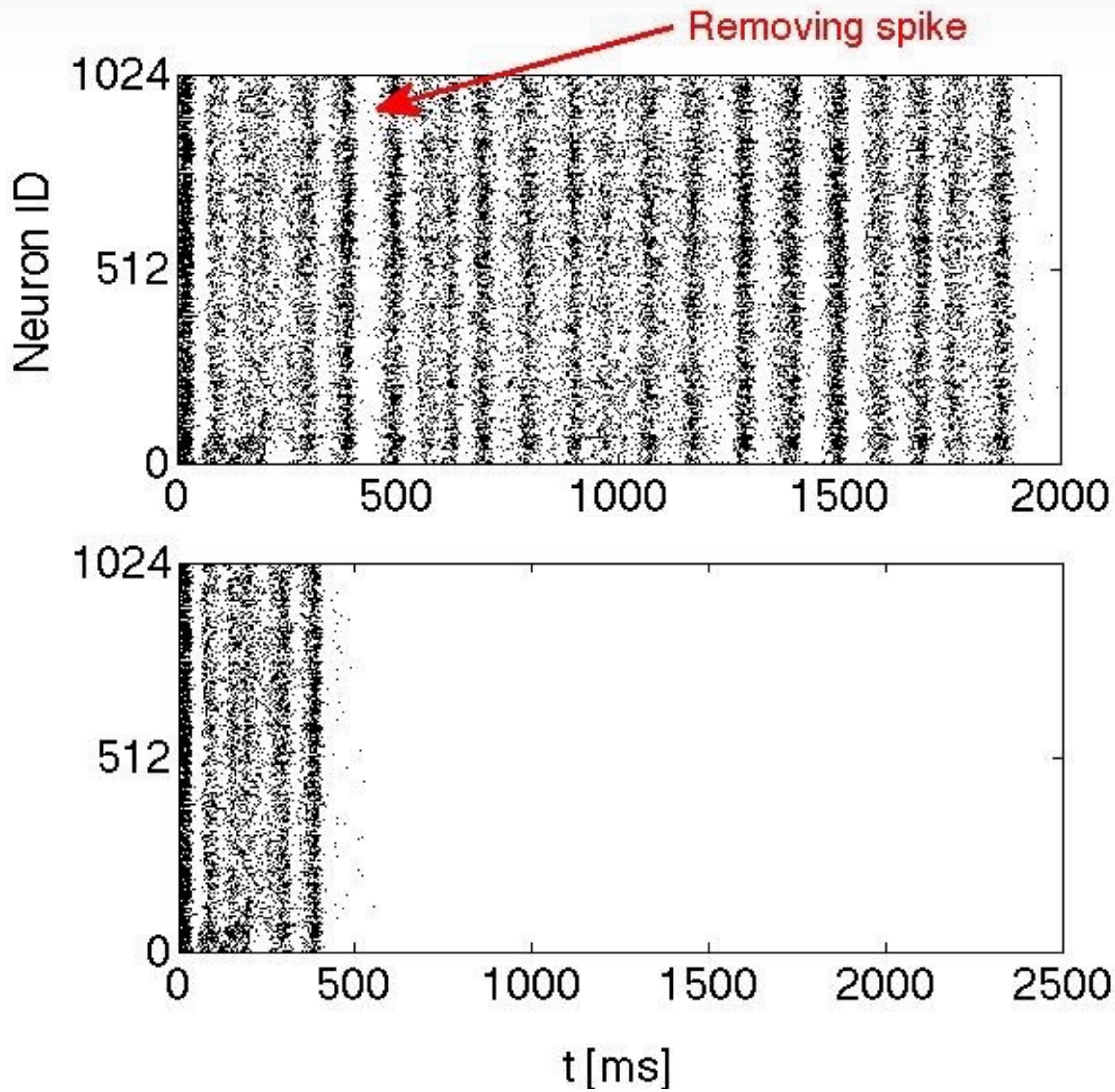
Attributes of **transient chaos**

Lai, Y. C., & Tél, T., *Transient chaos: complex dynamics on finite time scales*, 2011

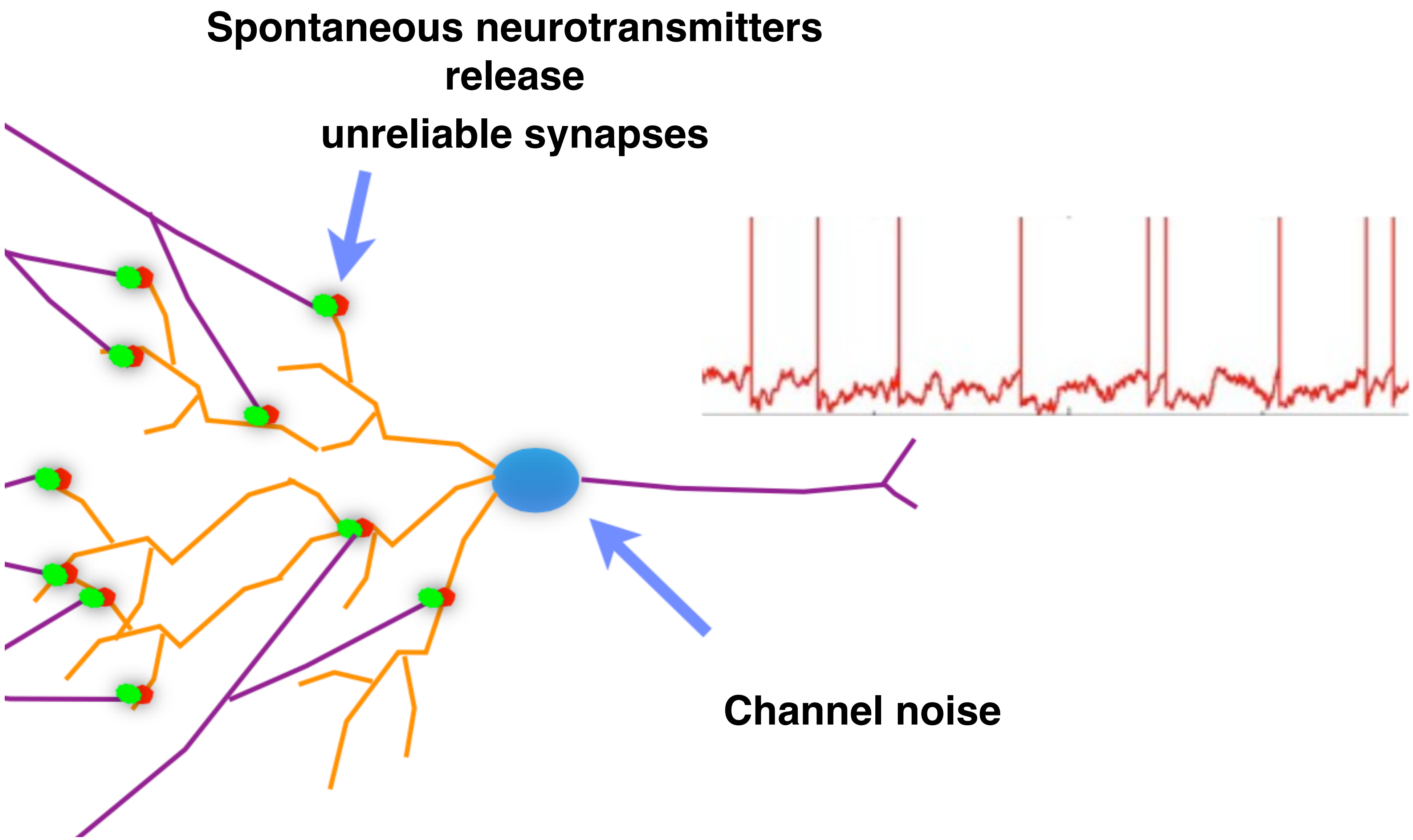


Work published at Tomov, P., Pena, R. F., Zaks, M. A., & Roque, A. C. (2016). Mechanisms of self-sustained oscillatory states in hierarchical modular networks with mixtures of electrophysiological cell types. ***Frontiers in computational neuroscience***, *10*.

Transient Chaos



Neurons are stochastic



Lindner, B. (2016)

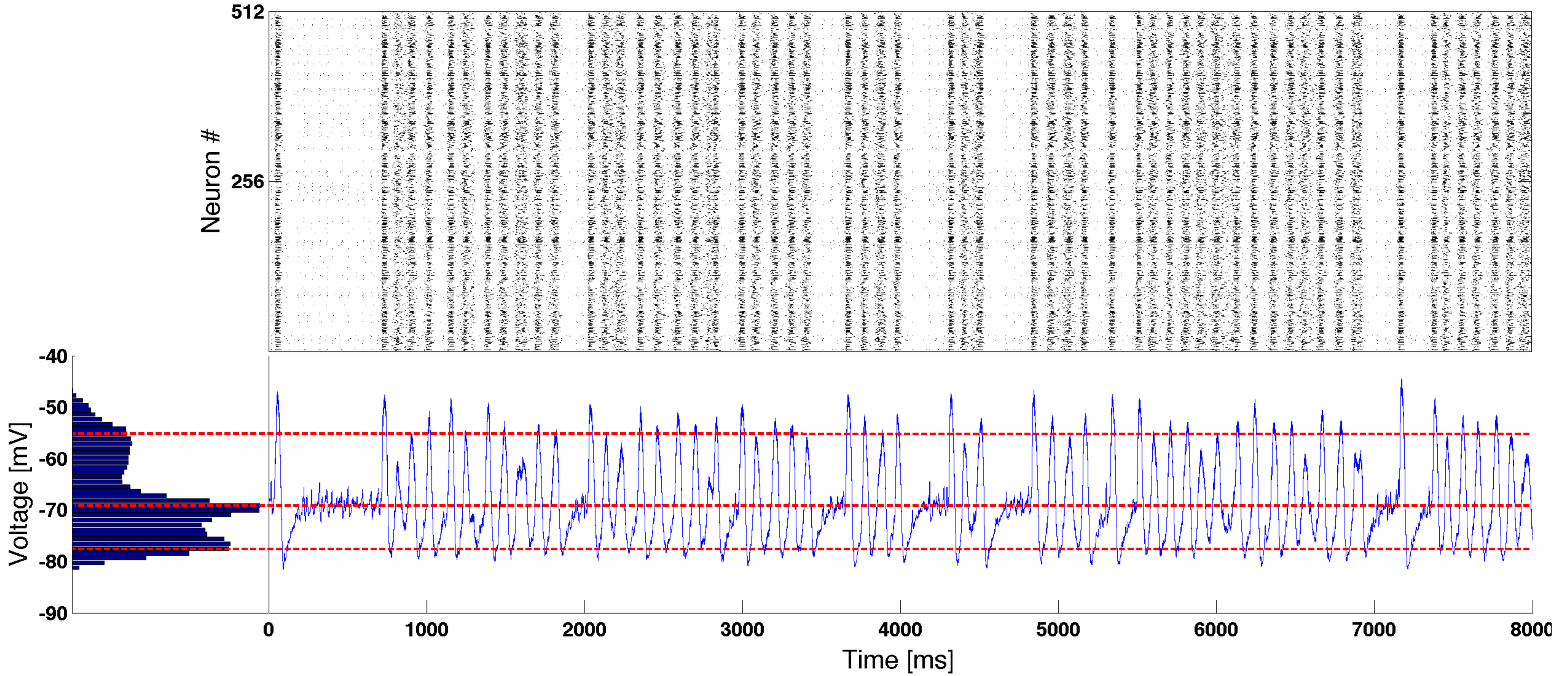
Neurons are stochastic: synaptic noise

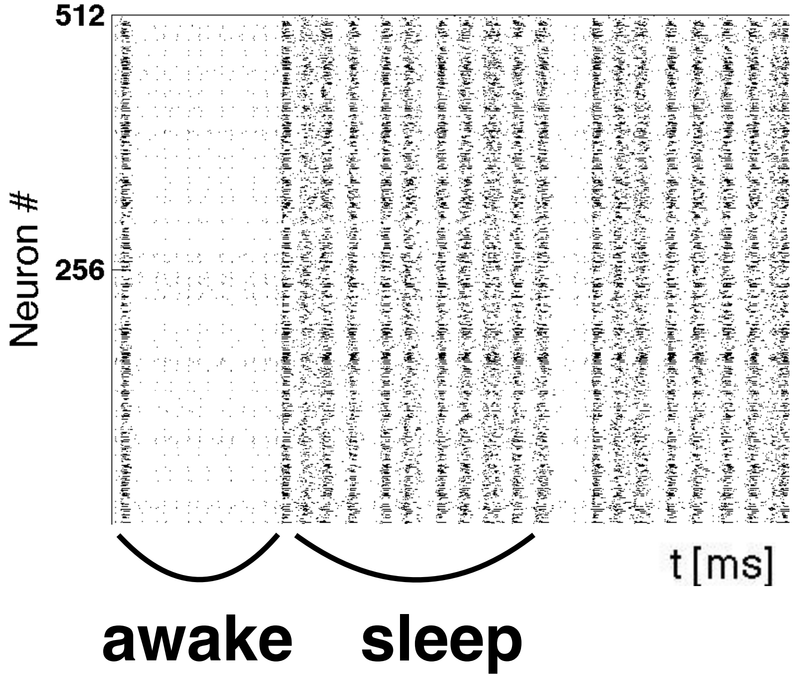
$$I_{syn}(t) = G_{ex}(t)(E_{ex} - v) + G_{in}(t)(E_{in} - v)$$

$$\dot{G}_{ex/in}(t) = -\frac{G_{ex/in}(t)}{\tau_{ex/in}} + \sqrt{2D}\xi(t)$$

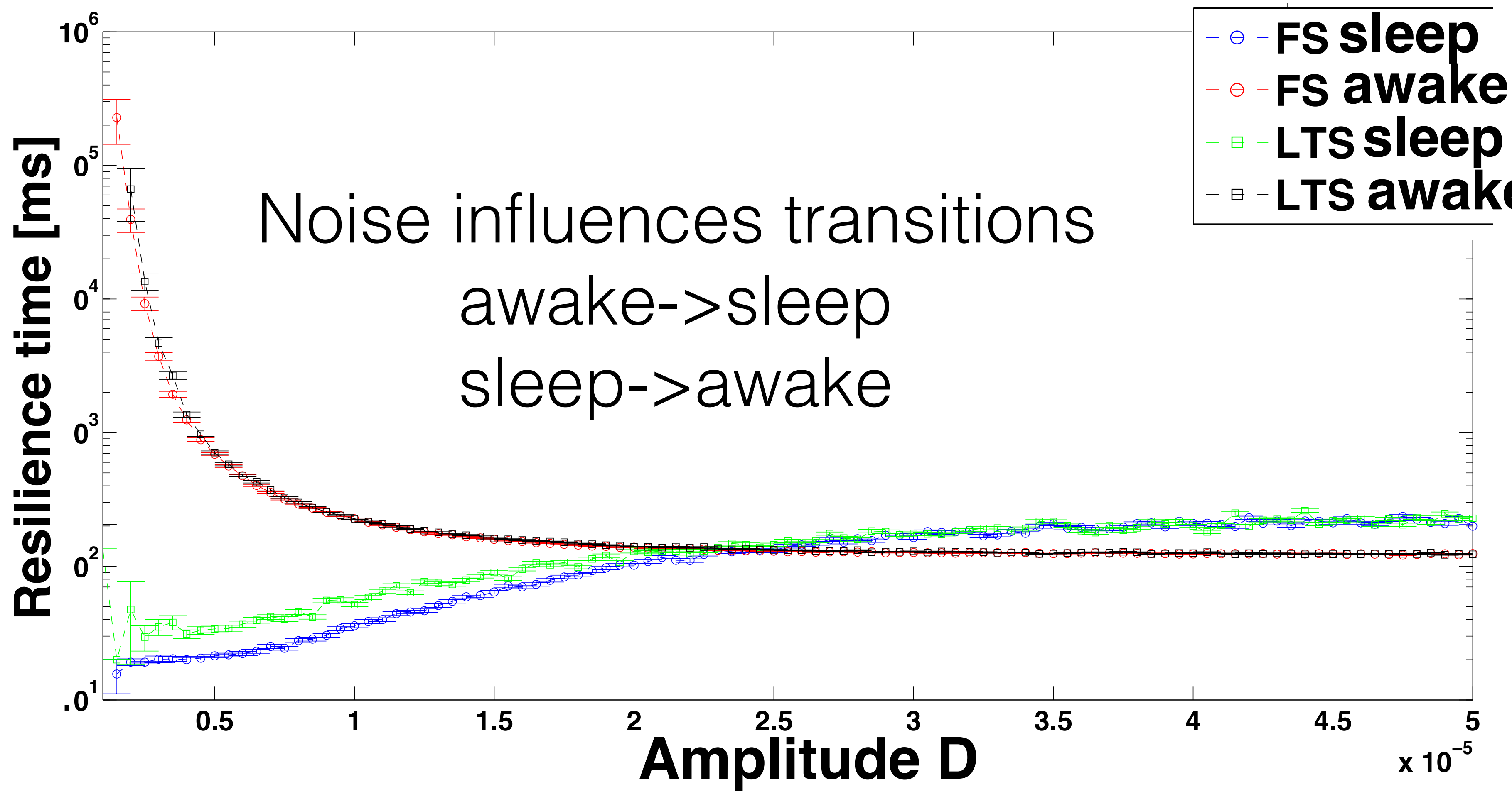
Point-conductance model described by Destexhe et. al., (2001).

where we assume that the stochastic process ξ is Gaussian with $\langle \xi(t) \rangle = 0$ and $\langle \xi(t)\xi(s) \rangle = \delta(t - s)$.





Noise influences transitions
awake->sleep
sleep->awake

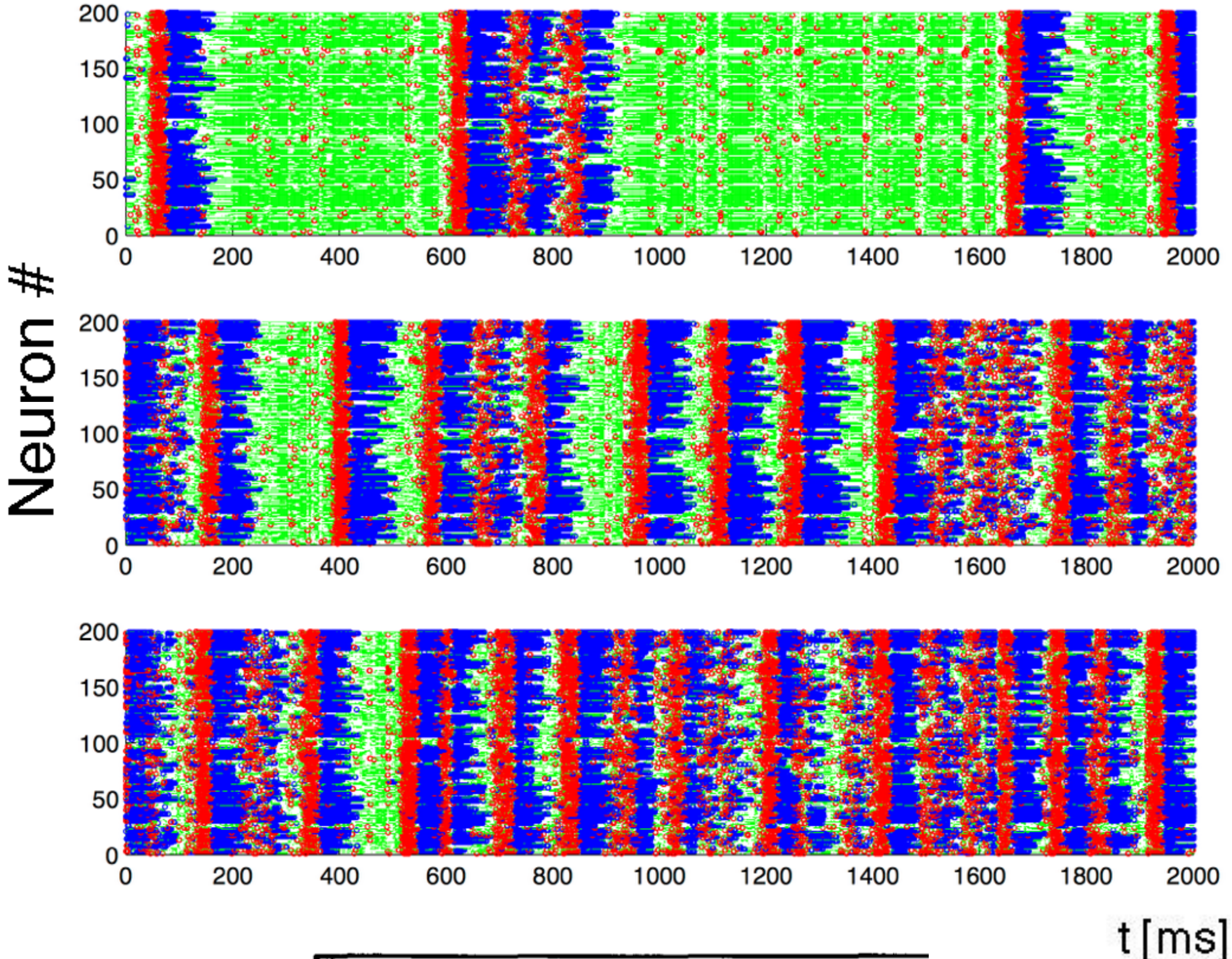


Experiments measuring amplitude and frequency of mEPSC in the cerebral cortex of mice and rats show that these are:

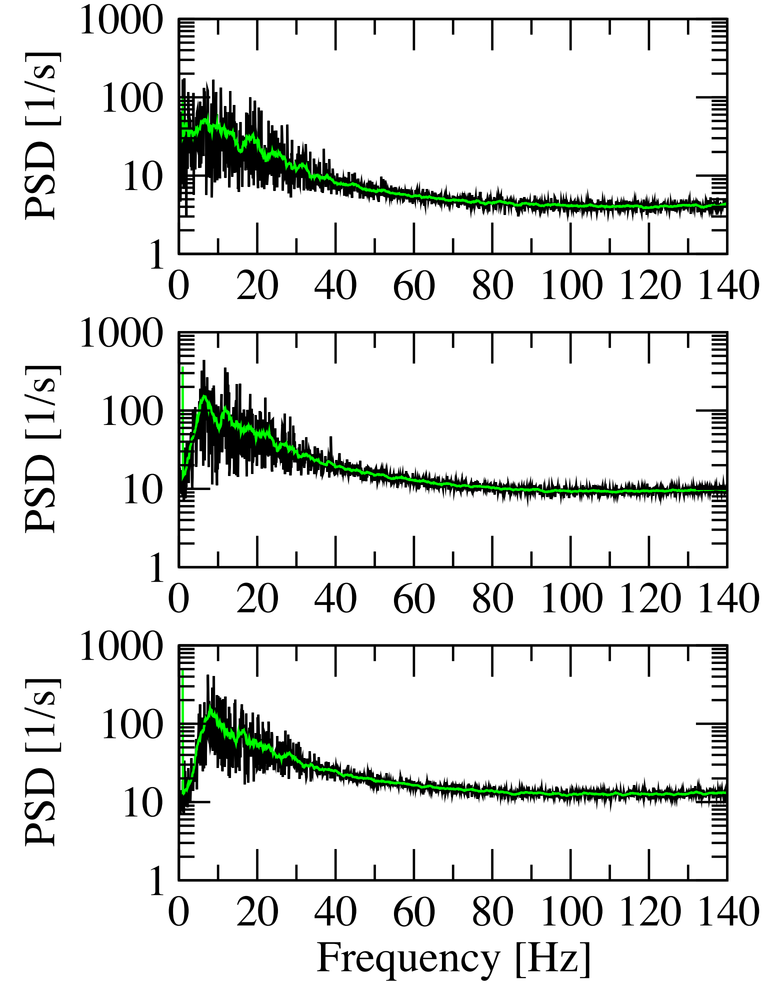
- **lower after a few hours of sleep,**
- **higher after a few hours of wake,**
- **higher after sleep deprivation.**

Rao et al., (2007), Liu et al., (2010)

up down awake



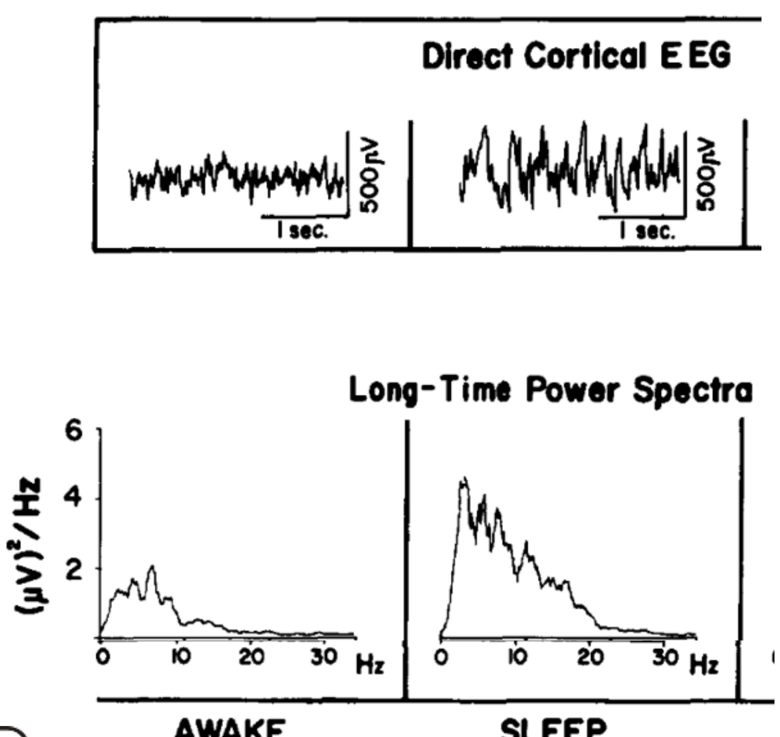
Power spectrum



$D=0.5\times10^{-5}$

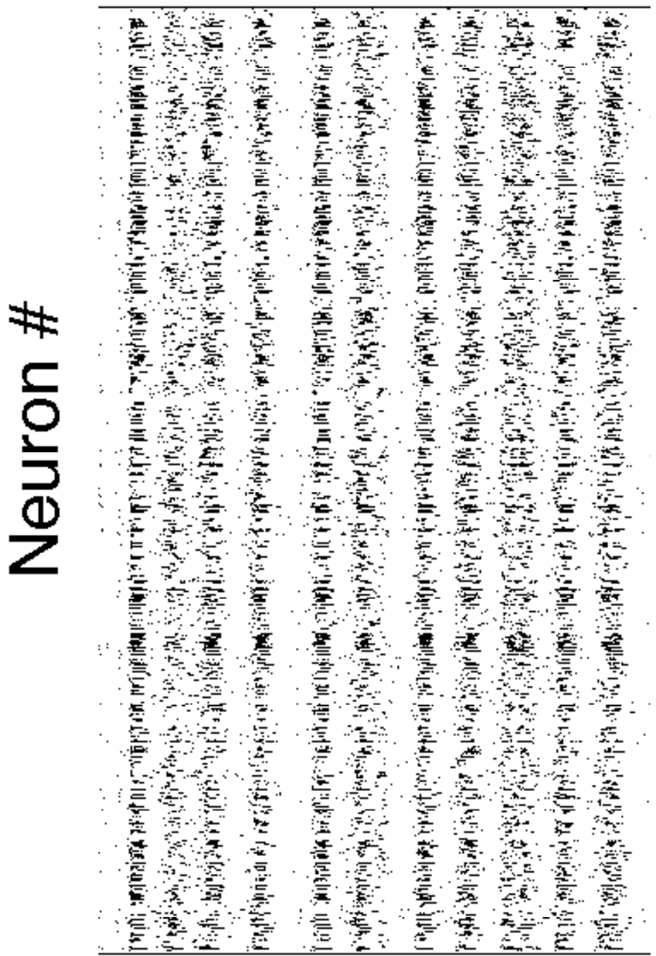
$D=1.5\times10^{-5}$

$D=4.5\times10^{-5}$

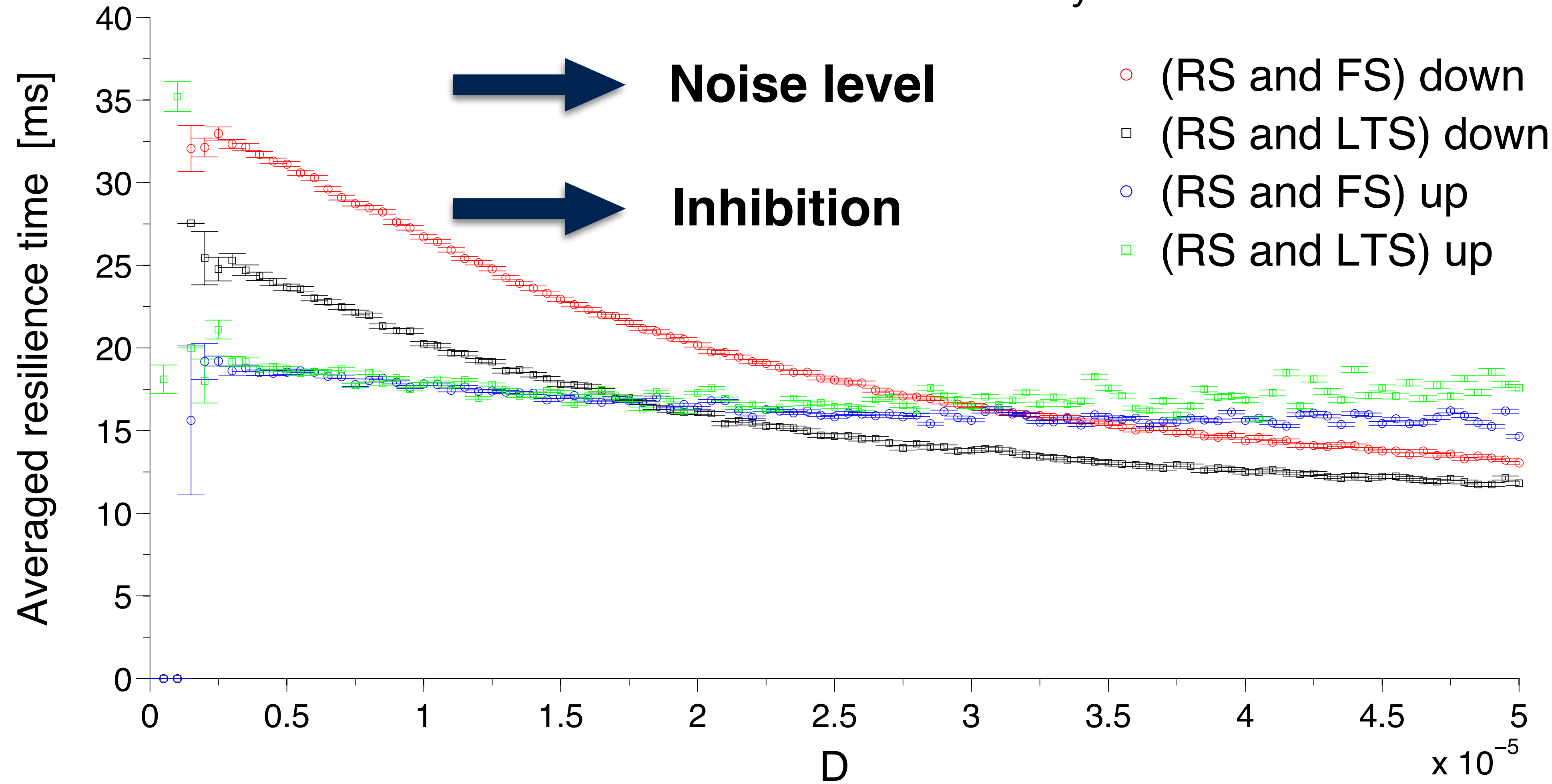


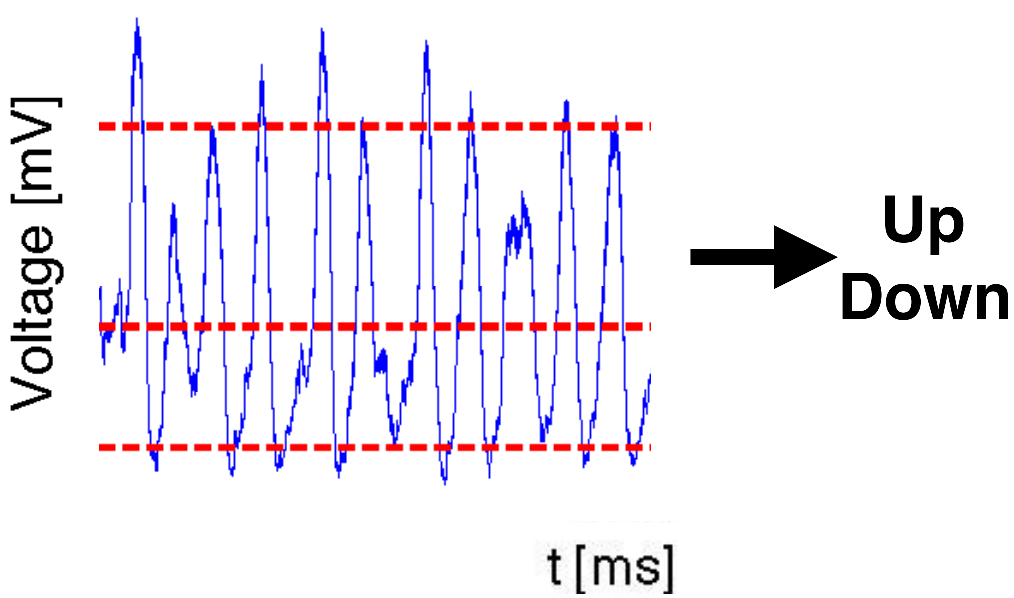
Spectra agree with the literature;

Young, Gerald A., et al. (1978): 89-91.



Down state is influenced by:





Experiments where inhibitory neurons are progressively blocked showed that inhibition influences up down transitions.

Sanchez-Vives, M. V, Journal of Neurophysiology (2010)

Evidences showing that noise regulates up down transitions.

Holcman, D. and Tsodyks, M. PLoS Comput Biol, (2006)

Thanks for your attention

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