PRE-STIMULUS PHASE AND AMPLITUDE REGULATION OF PHASE-LOCKED RESPONSES ARE MAXIMIZED IN THE CRITICAL STATE,

Avramiea et al., 2020, eLife

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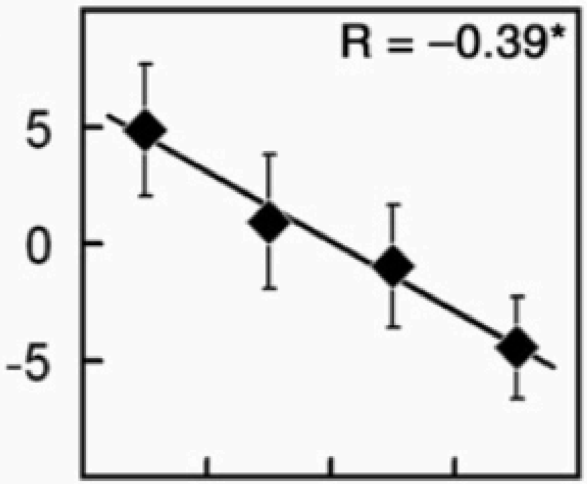
Journal Club 19/11/2020

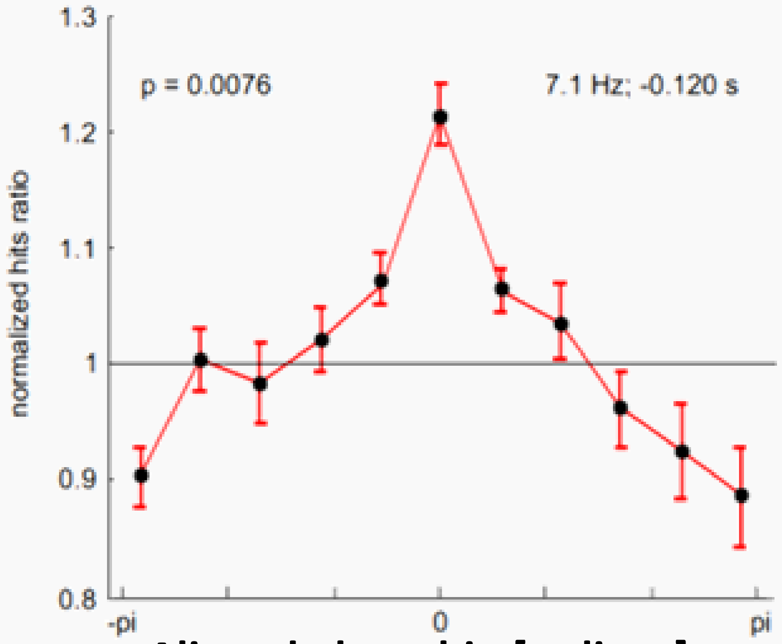
Background I

Detection rate change (%)



Alpha band amplitude [quartile]

(Capilla et al, 2014)



Aligned phase bin [radians]

(Busch et al, 2009)

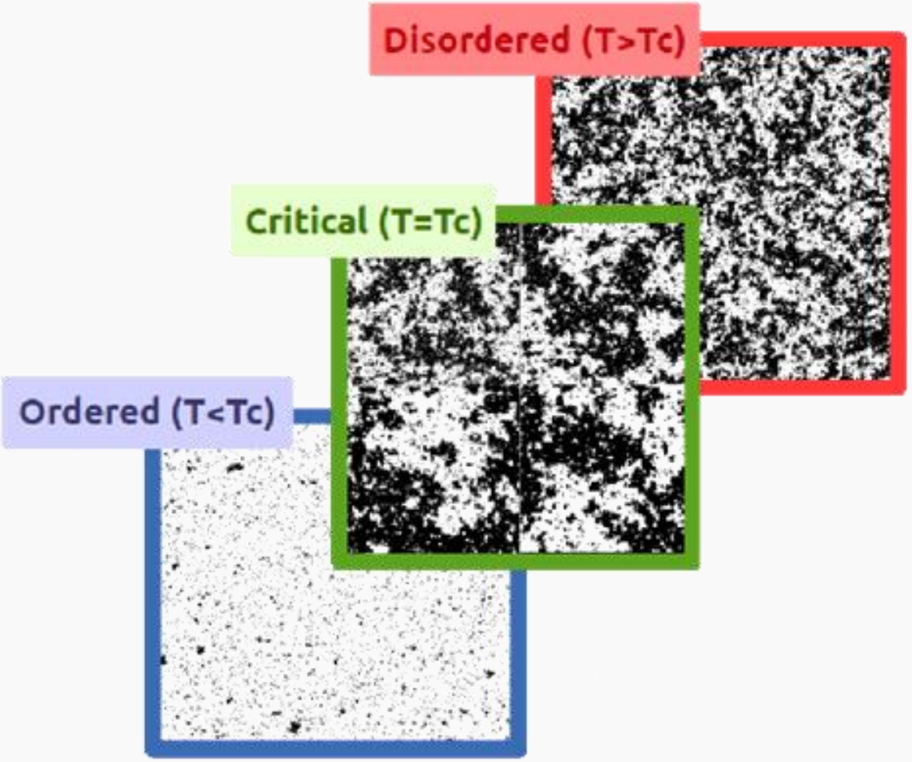
Does the long term state of the network influence state-dependent processing of stimuli?

Does pre stimulus regulation depend on a critical state?

Background II

Critical brain hypothesis

- Optimized dynamic range
- High sensitivity to stimuli

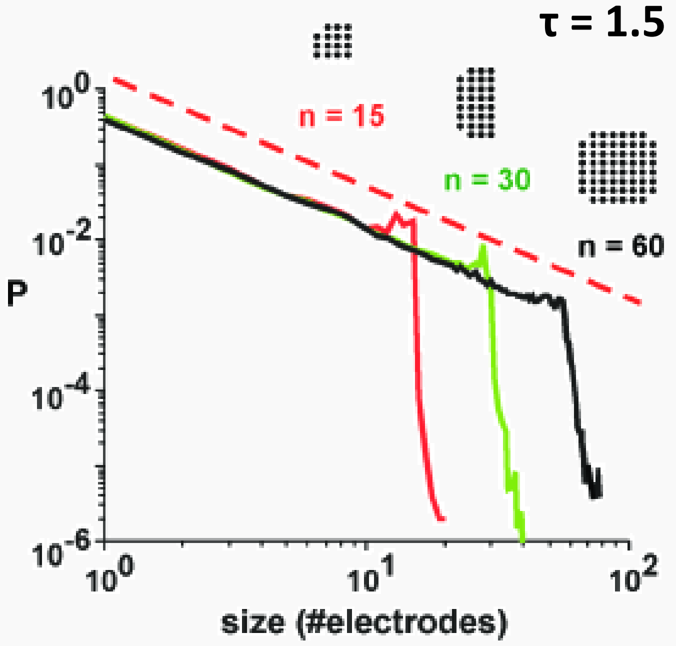


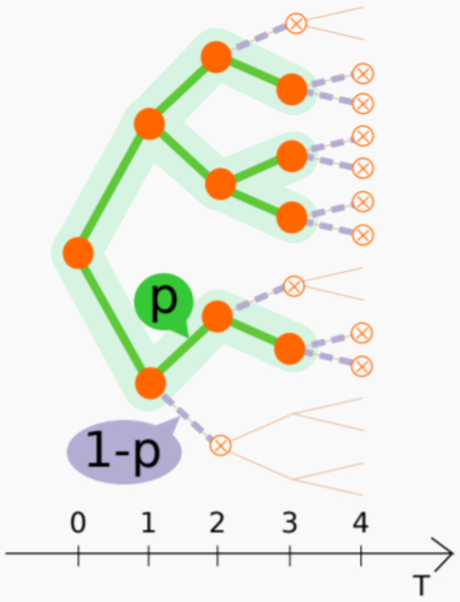
Experimental signatures of criticality:

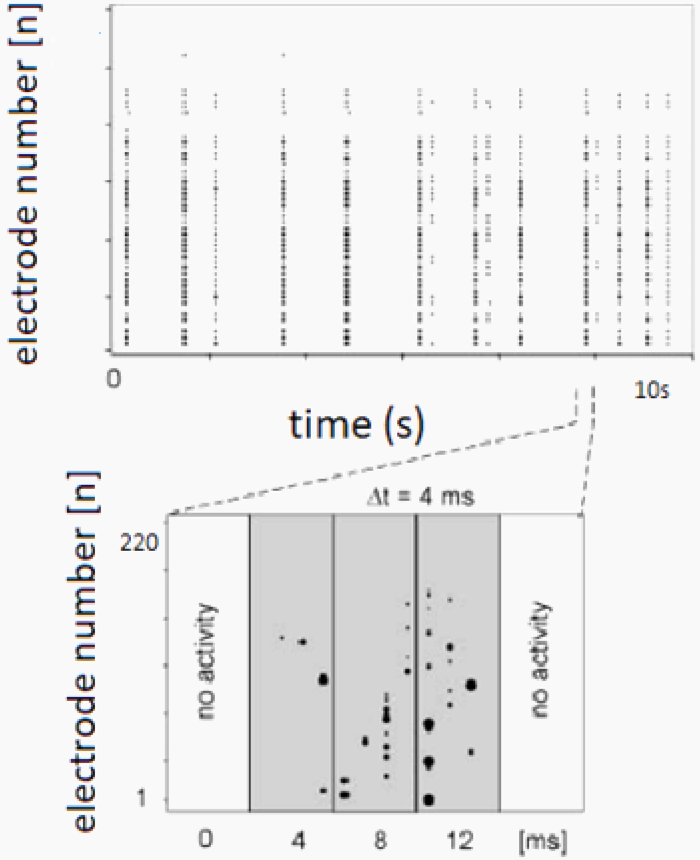
Power law distributions of cascades of activity **VS** long range correlations in time

Background II

J. M. Beggs and D. Plenz (2003): **power law neuronal avalanches, branching process** predictions





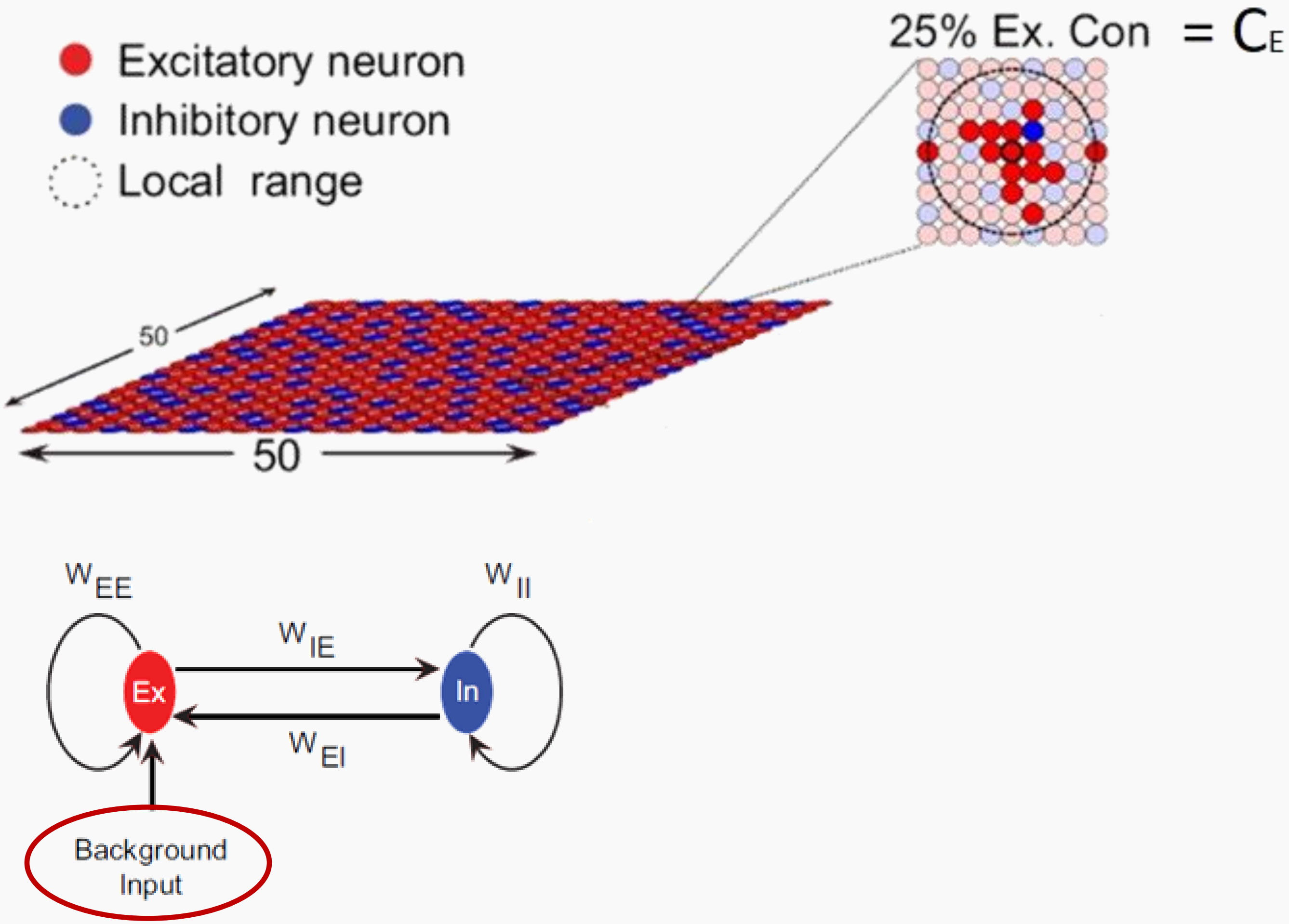


Outline

- **Unstimulated network** → «Multi-level» criticality

- **Stimulated network** → Phase-locked responses and prestimulus regulation

CRITICAL OSCILLATIONS (CROS) MODEL



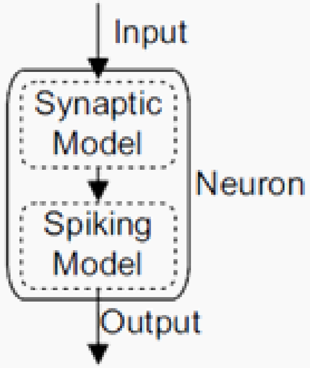
Poil et al., 2012

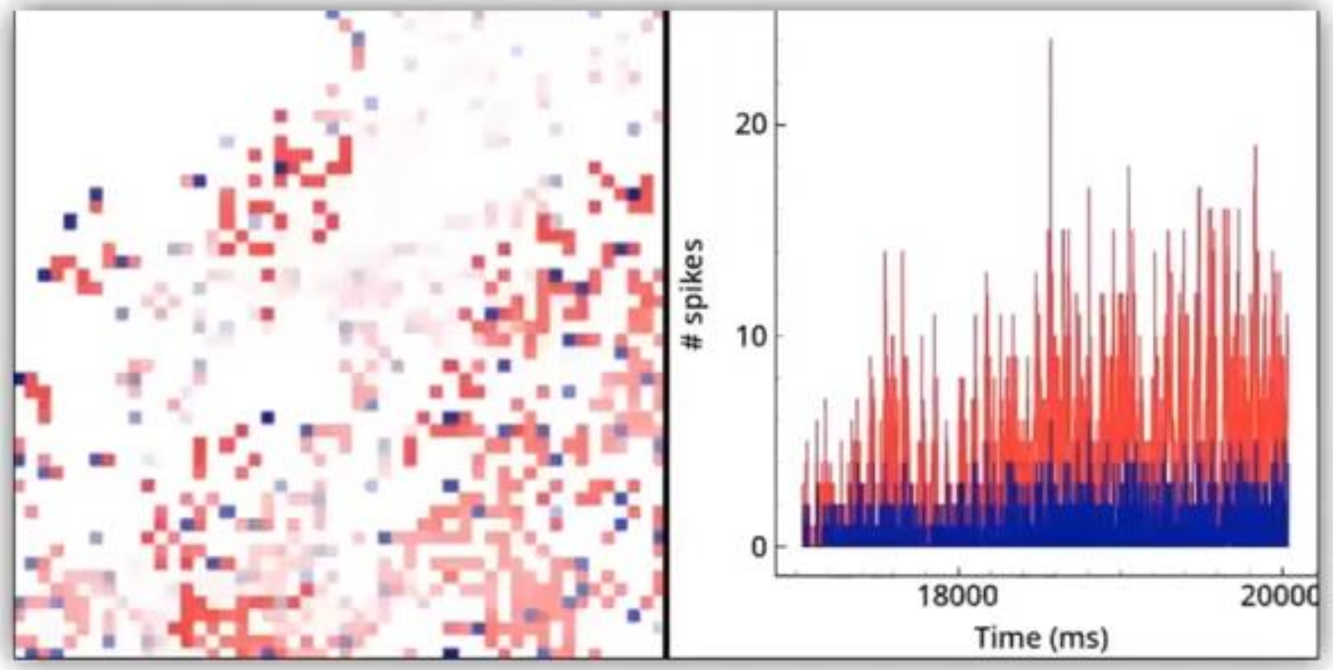
Excitatory neurons (E): **75** %
Inhibitory neurons (I) : **25** %

Free parameters: C_E and C_I, excitatory and inhibitory **local** connectivity (%)

W_{EE}, W_{II}, W_{IE} and W_{EI} **fixed**

Critical Oscillations (CROS) model



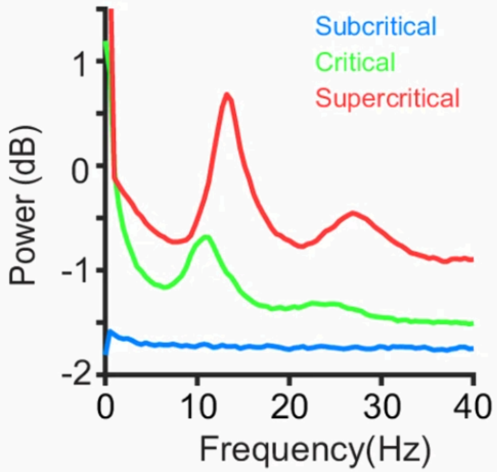


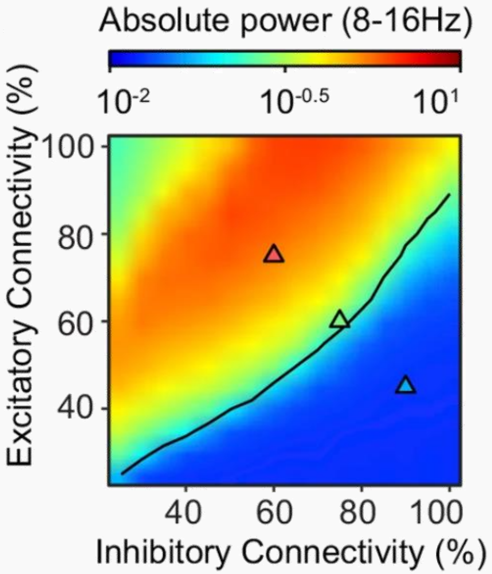
$$I_i(t+dt) = \left(I_i(t) + \sum_{j}^{J_i} W_{ij} S_j(\mathrm{t})\right)\left(1 - \frac{dt}{\tau_I}\right)$$

$$A_i(t+dt) = (A_i(t) + I_i(t))\left(1 - \frac{dt}{\tau_P}\right) + A_0 \frac{dt}{\tau_P}$$

$$P_i^s(t) = \begin{cases} 0, & A_i(t)<0 \\ A_i(t), & 0 \le A_i(t) \le 1 \\ 1, & A_i(t)>1 \end{cases}$$

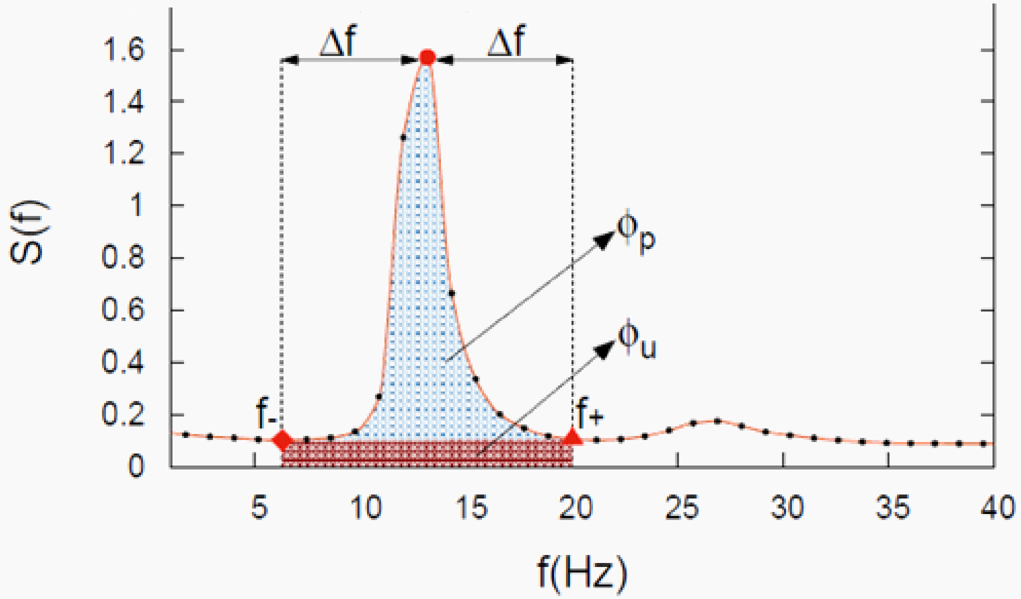
Phase transition at the onset of collective oscillation (alpha band)



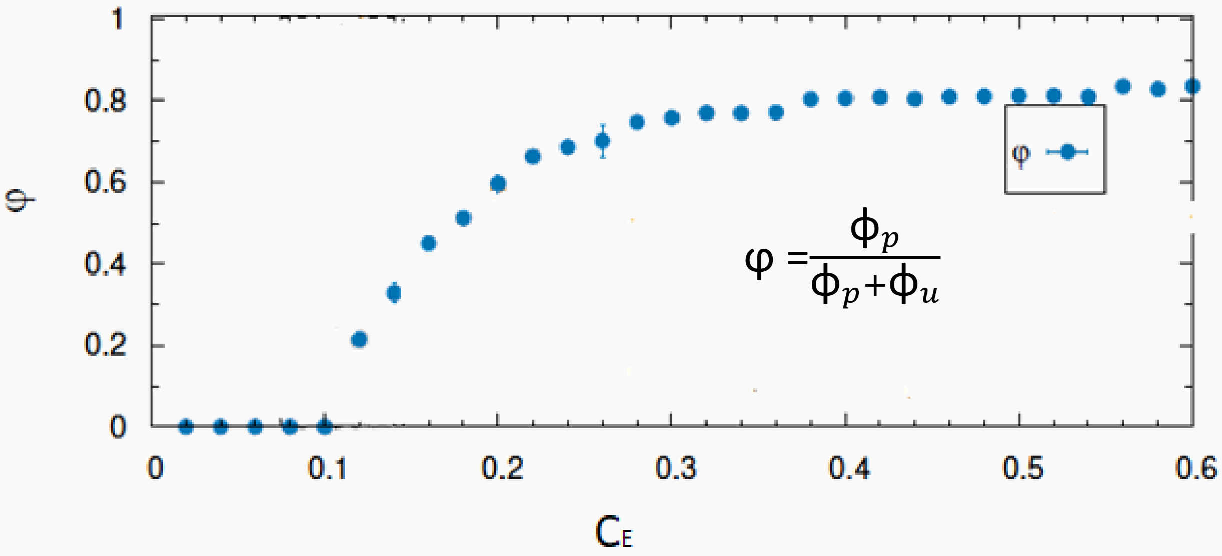


8-16 Hz

Order parameter:



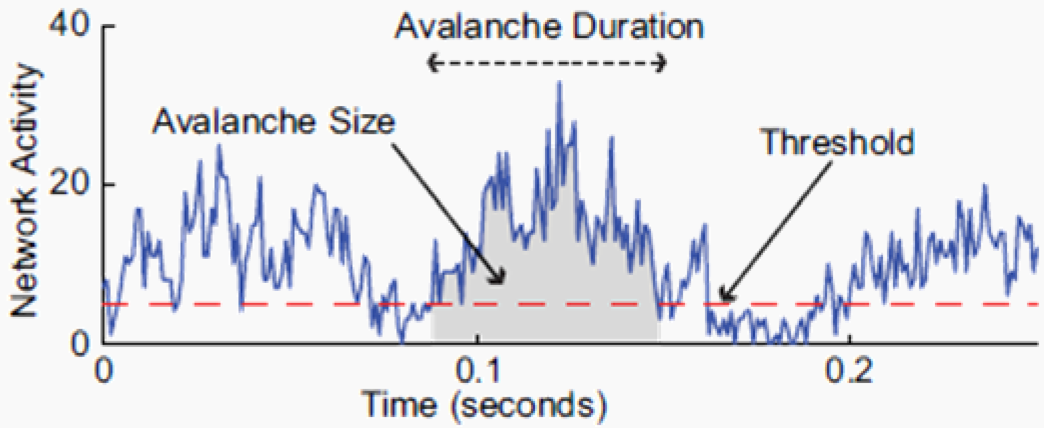
(Dalla Porta, Copelli, 2019)



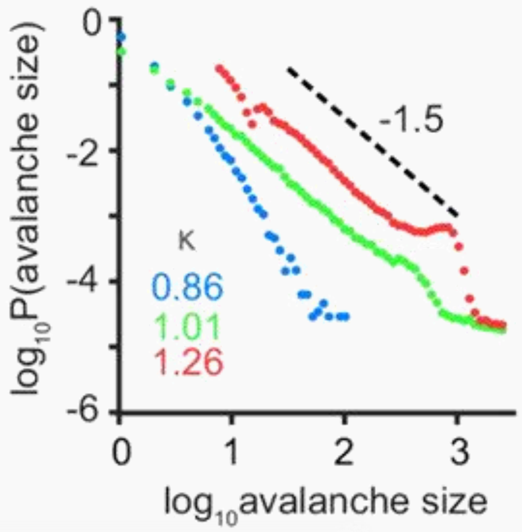
UNSTIMULATED NETWORK PRODUCES MULTI-LEVEL CRITICALITY

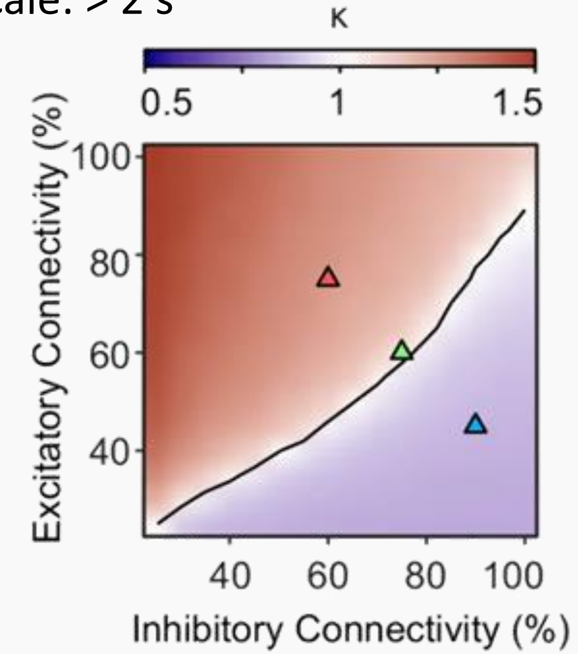
Power law neuronal avalanches + ***long range time correlations (LRTC)***

Time scale: < 120 ms



Time scale: > 2 s



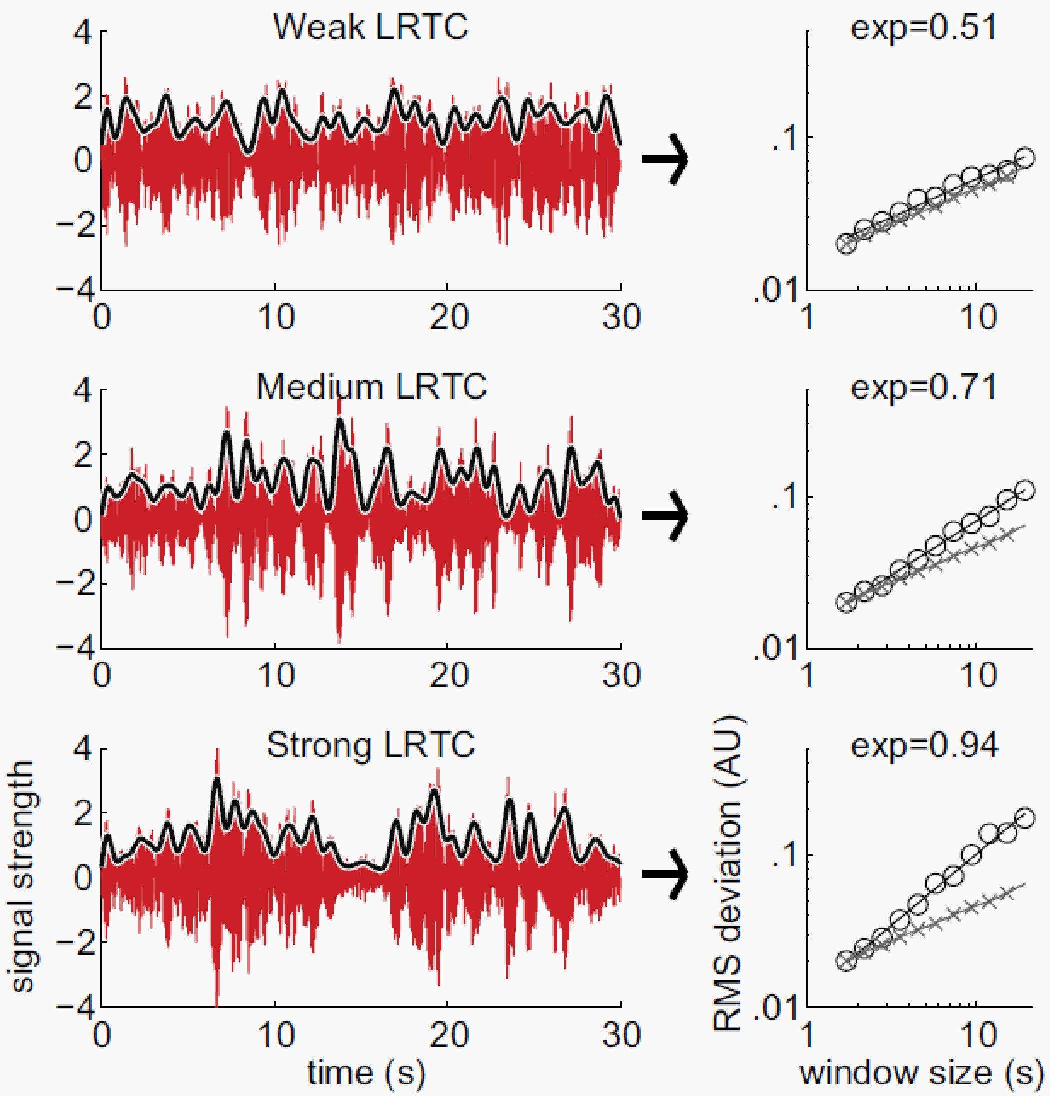


$$\kappa = \frac{1}{10}\sum_{i=1}^{10}(P(\beta_i) - A(\beta_i)) + 1$$

Cumulative distribution of a power-law with exponent 1.5

Cumulative distribution of data

Detrended fluctuation analysis



On the amplitude **envelope** of the **alpha band** filtered signal

$$F(n) = \sqrt{\sum_{k=1}^{N} [y(k) - y_n(k)]^2}$$

if $F(n) \sim n^{\alpha}$ then

Autocorrelation function:

$C(\tau) \sim \tau^{-\gamma}$ with $\gamma = 2 - 2\alpha$

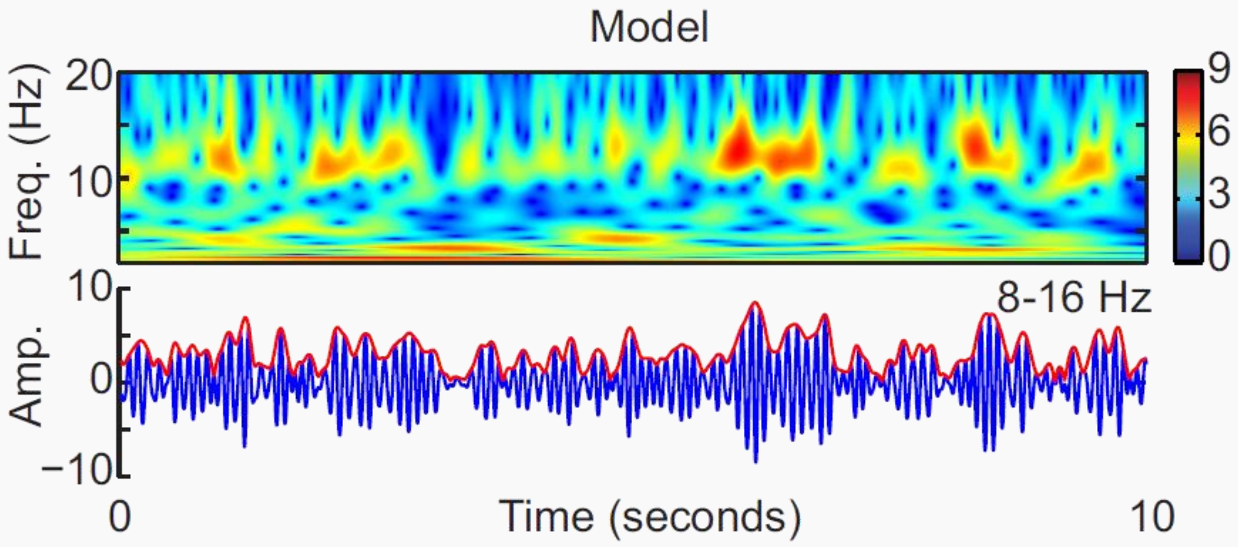
Power spectrum:

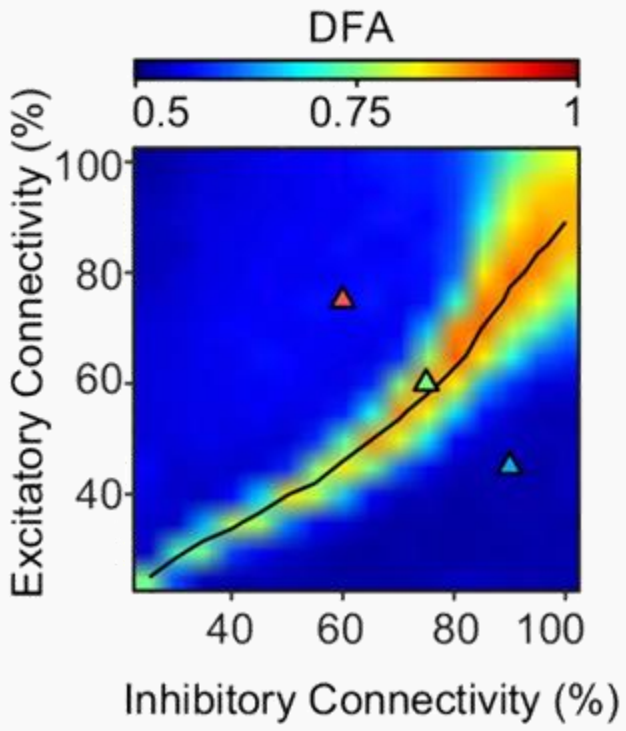
$S(f) \sim f^{\beta}$ with $\beta = 1 - \gamma = 2\alpha - 1$

- $0 < \alpha < 0.5 \rightarrow$ anticorrelations
- $\alpha = 0.5 \rightarrow$ white noise
- $0.5 < \alpha < 1 \rightarrow$ correlations
- $\alpha = 1 \rightarrow 1/f$ noise

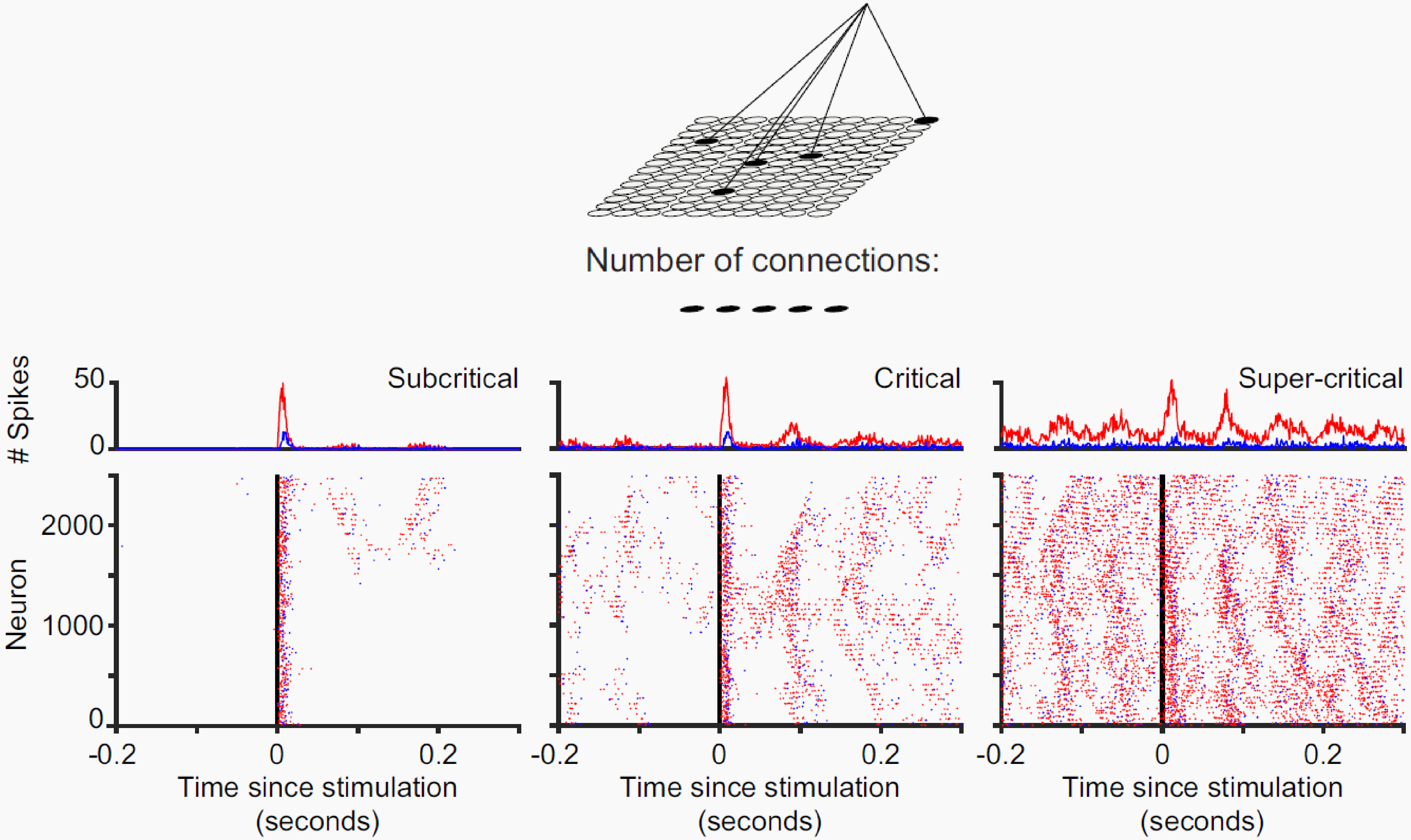
UNSTIMULATED NETWORK PRODUCES MULTI-LEVEL CRITICALITY

Power law neuronal avalanches + *long range time correlations (LRTC)*

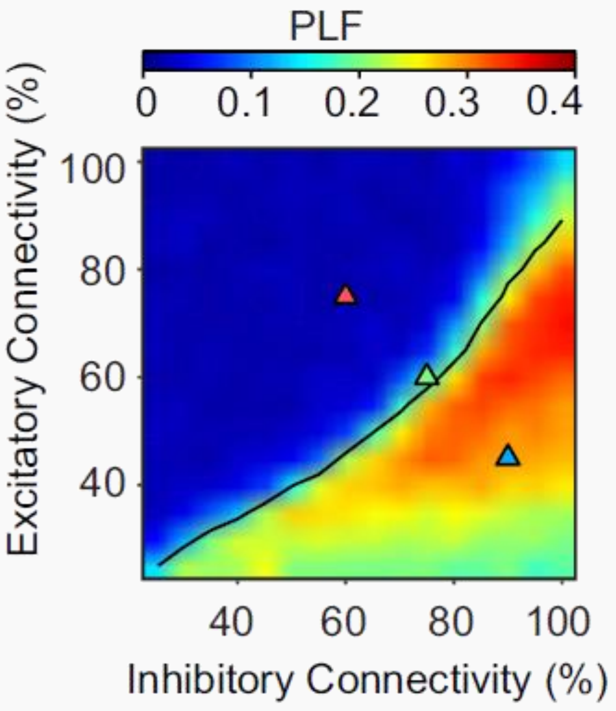


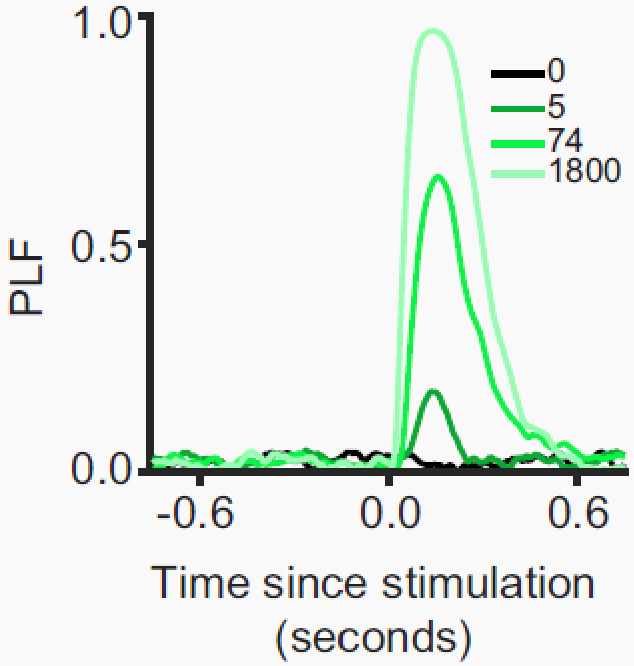


STIMULATED NETWORK



Phase-locking response



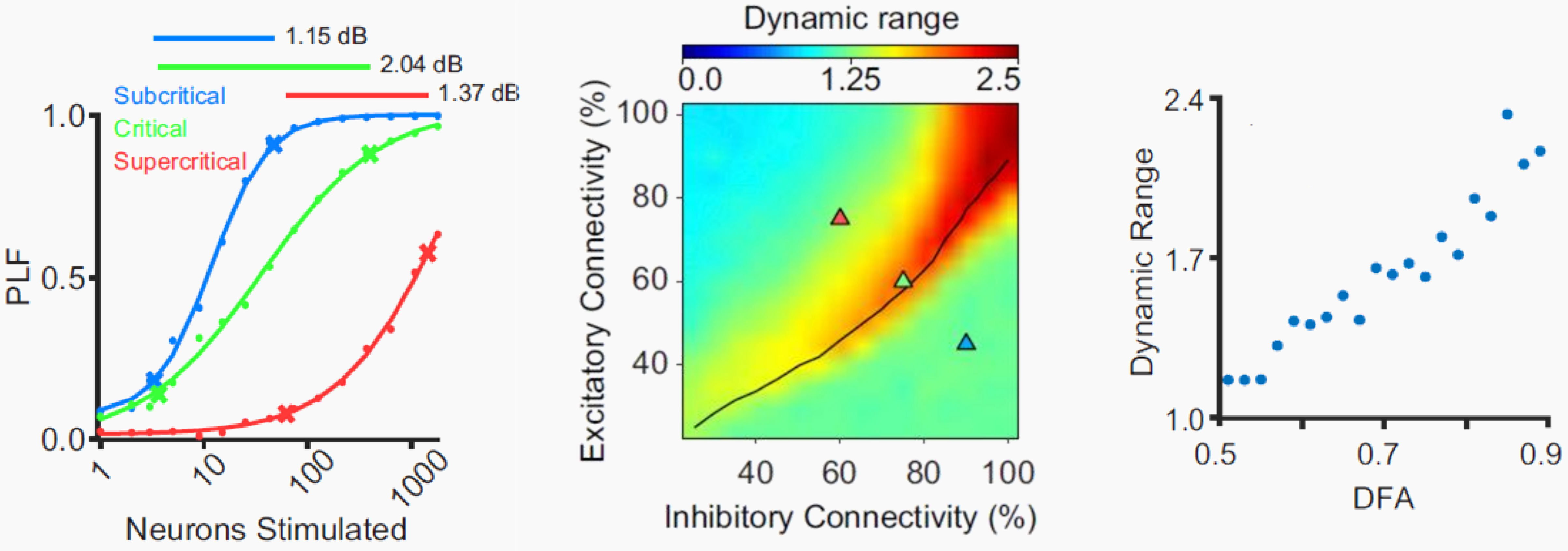


Phase locking factor

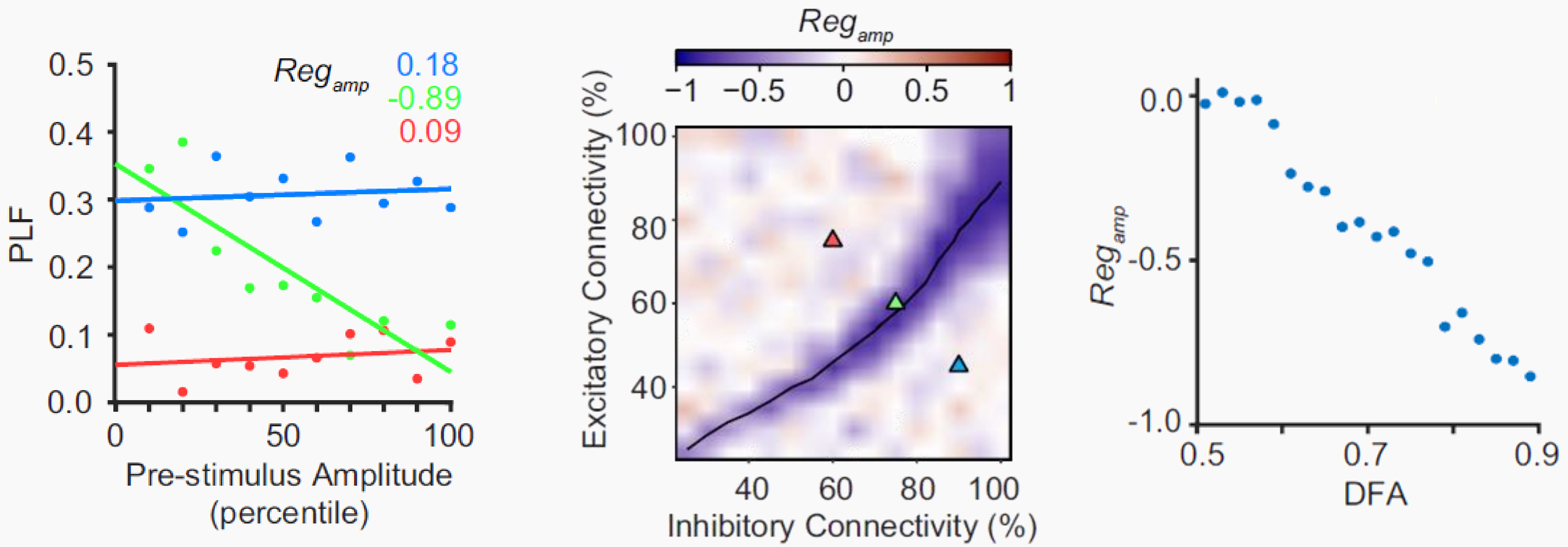
Measures the uniformity of phases across trials at a time-point post-stimulus (150 ms post stim)

$$\mathrm{PLF} = \left| \frac{\sum_{i=1}^{N} z_i}{N} \right| \text{ where } z_i = e^{i\phi_i}$$

Dynamic range of phase-locking response is strongest for critical networks

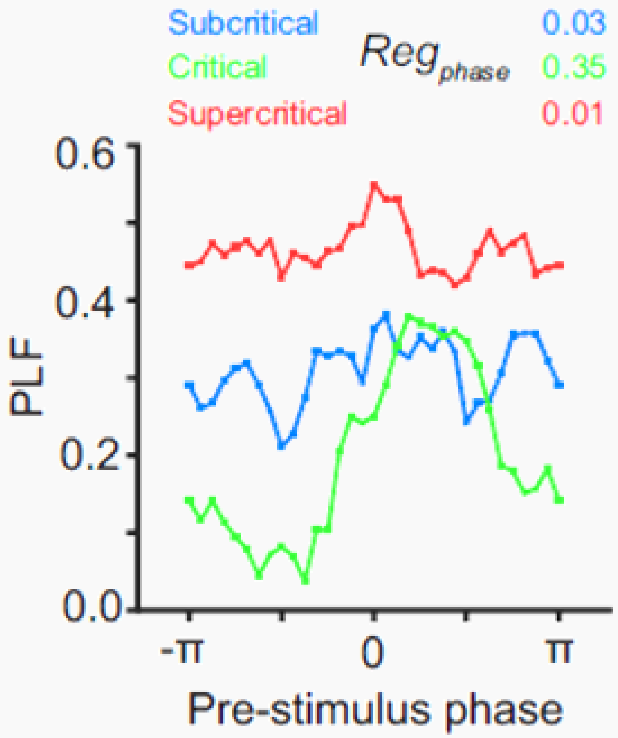


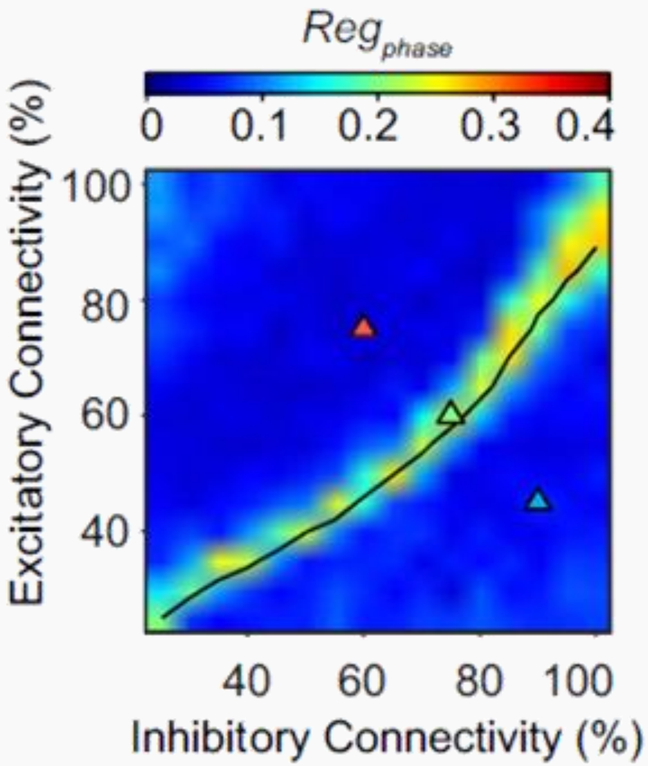
PRE-STIMULATION AMPLITUDE INFLUENCE ON PHASE-LOCKING REQUIRES CRITICAL DYNAMICS

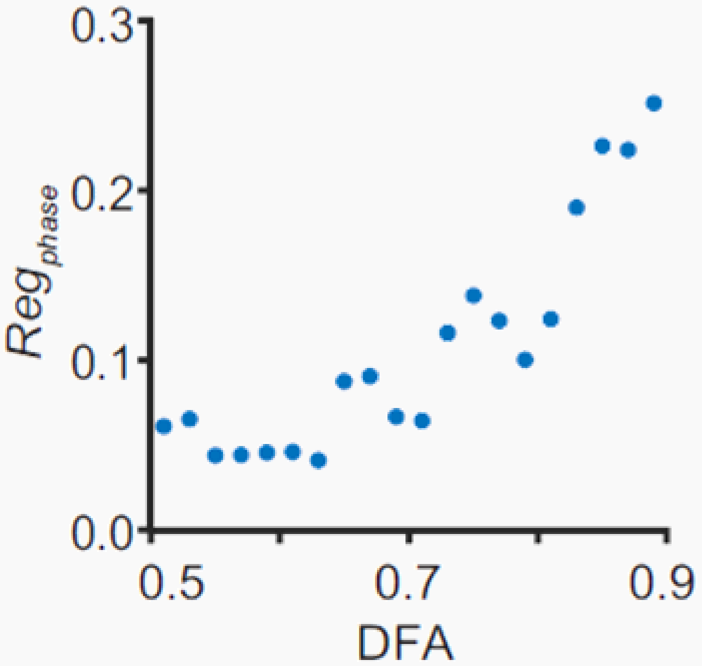


Pre-stimulation PHASE influence on phase-locking requires critical dynamics

$$Reg_{phase} = \left| \frac{\sum_{i=1}^{P} PLF_i z_i}{\sum_{i=1}^{P} PLF_i} \right| \text{ where } z_i = e^{i\phi_i}$$







Conclusions

- Alpha **oscillations**, long-range temporal **correlations**, and **avalanches** emerge at a specific balance of excitation and inhibition

- **Oscillatory** neural networks have **optimal dynamic range** at criticality

- Pre-stimulus phase and amplitude **regulation** of phase locked responses is only possible at the **critical** state

Conclusions - Discussion

- Spontaneous amplitude fluctuations may have a **functional role**

- If versatility is not required for a particular task, the network may shift in the subcritical/supercritical phase