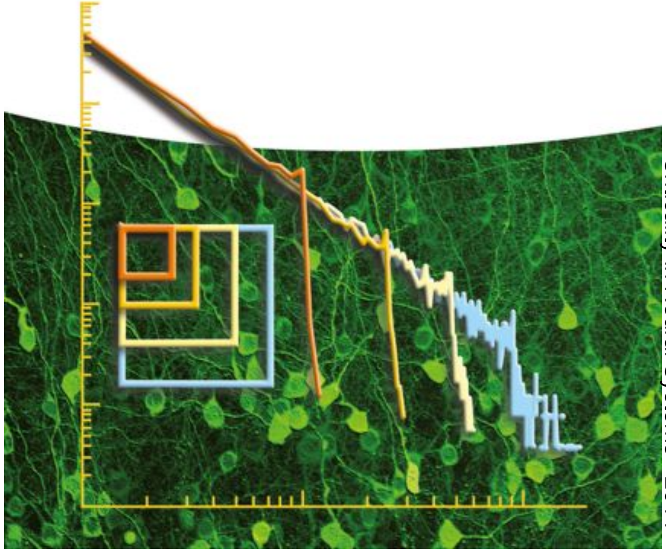
Hipótese do cérebro crítico:

assinaturas de criticalidade no córtex cerebral



Criticality in Neural Systems - 2014

Renata B. Biazzi

Tópicos de Mecânica Estatística - Transições de Fase

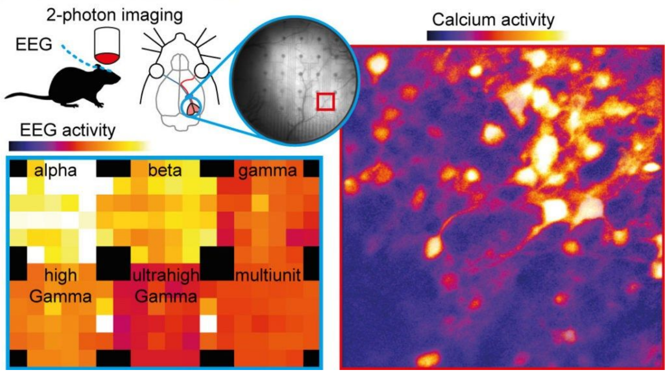
IFUSP 2020 - Prof. Silvio Salinas

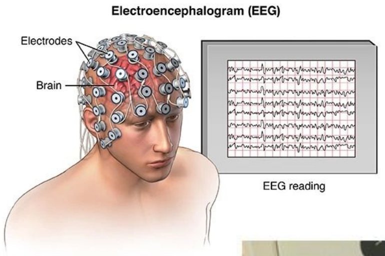
Organização do seminário

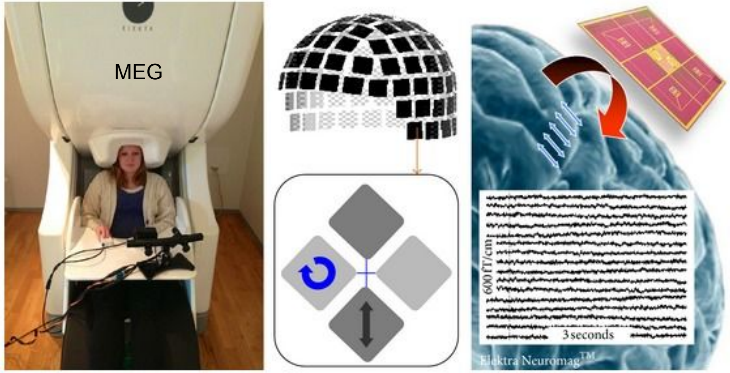
- Critical Brain Hypothesis
- Debate: controvérsia na área
- Respondendo a controvérsia: resultados do artigo “Criticality between Cortical States” PRL, 2019.
- Conclusões e perspectivas na área

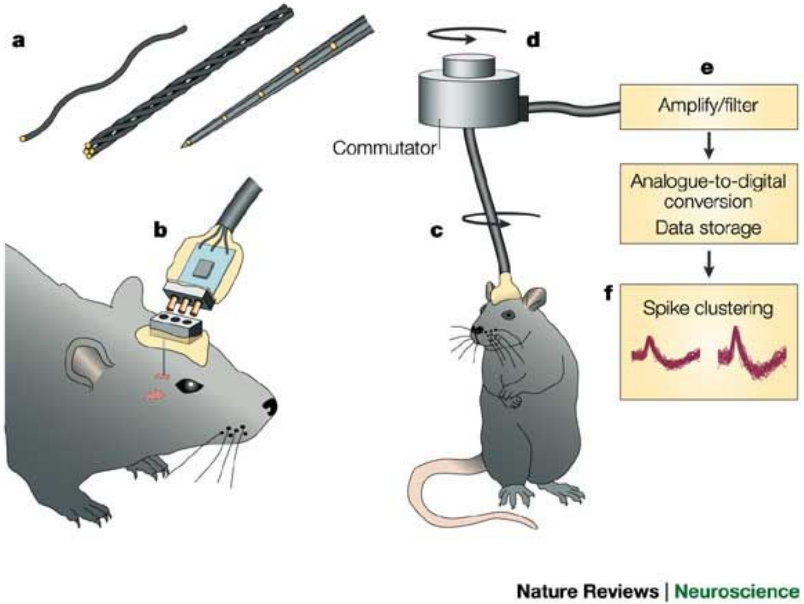
Neurociência: contexto

- Revolução dos equipamentos de medição
- "Neuronal Avalanches"
  National Institute of Mental Health, 2001



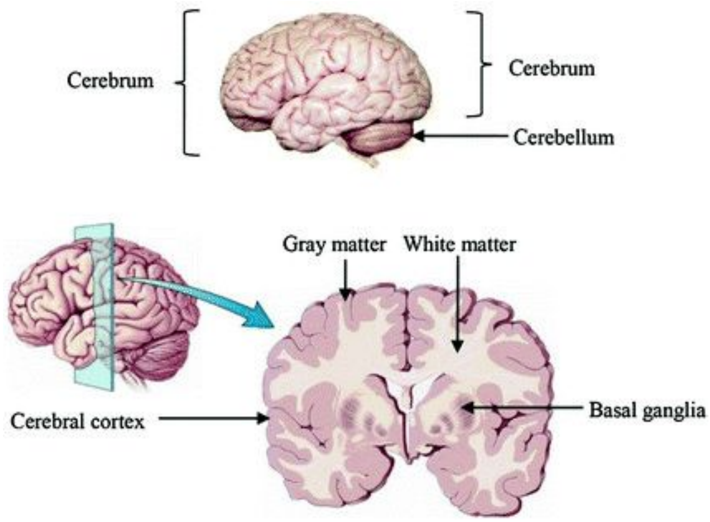






Critical Brain Hypothesis

- Algumas áreas operam na transição de fase: “entre ordem e caos”
- Otimizações, regime saudável
- Área em debate



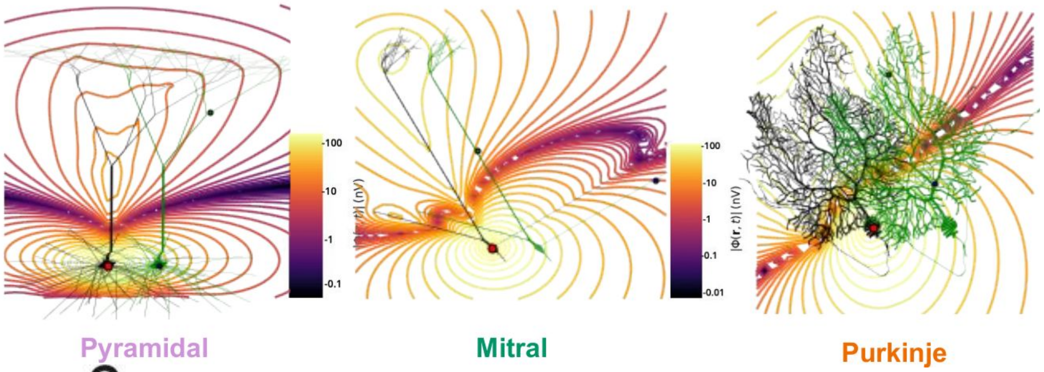
Self-organized criticality (SOC)

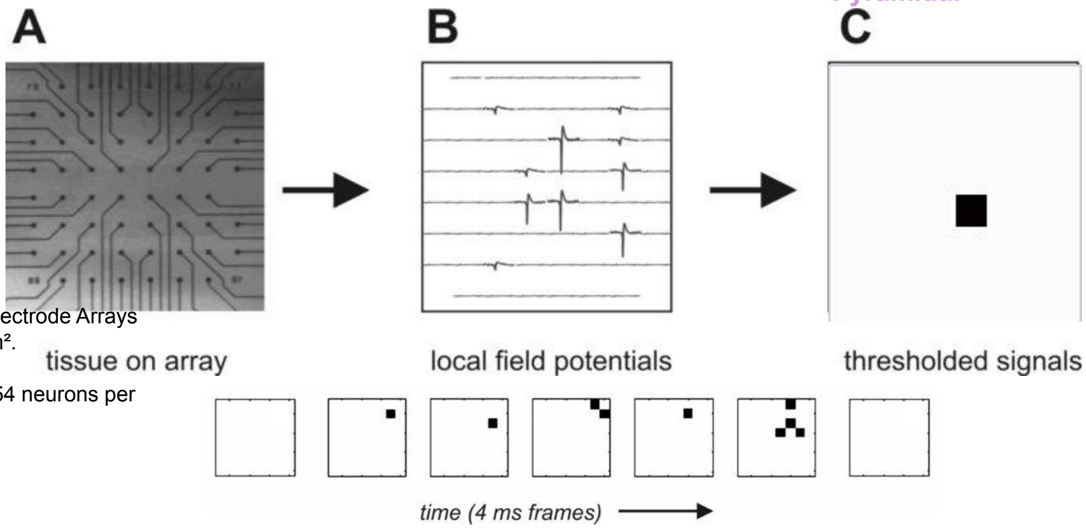
Gross - 2017

Ex: terremotos, incêndios florestais, panes em redes elétricas e redes neuronais

Critical Brain Hypothesis

- Avalanches Neuronais
- Local Field Potential (LFP)





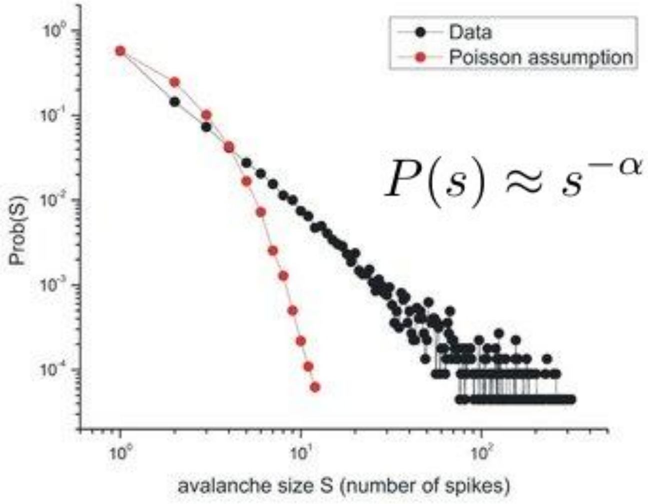
MEA - Multielectrode Arrays $7.8mm^2$.

158,554 neurons per $mm2^2$

http://www.scholarpedia.org/article/Neuronal_avalanche

Critical Brain Hypothesis

- Avalanches Neuronais
- Leis de Potência



http://www.scholarpedia.org/article/Neuronal_avalanche

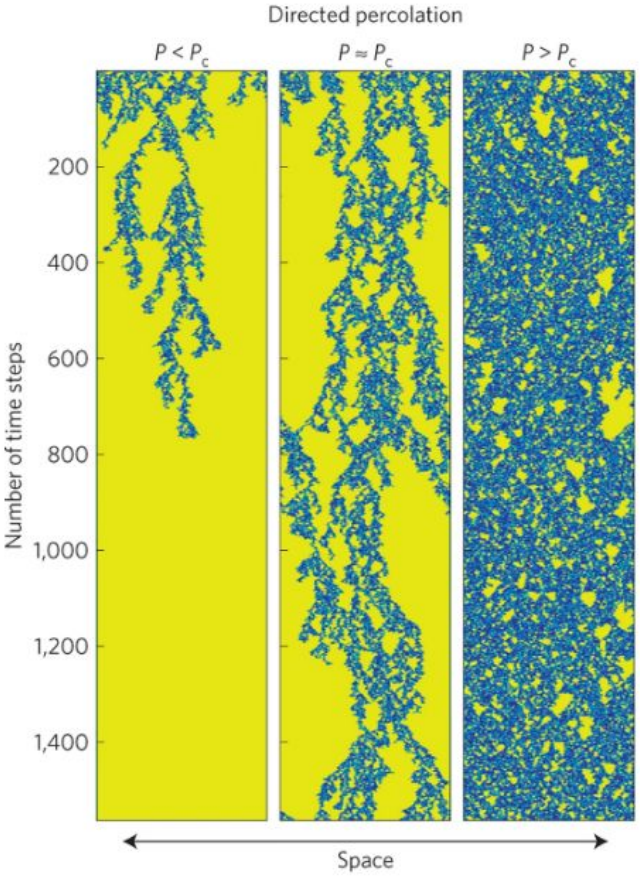
Expoentes conforme classe de universalidade

MF-Directed Percolation com d = 4

$$P(s) \approx s^{-\alpha} \qquad \alpha = 3/2$$

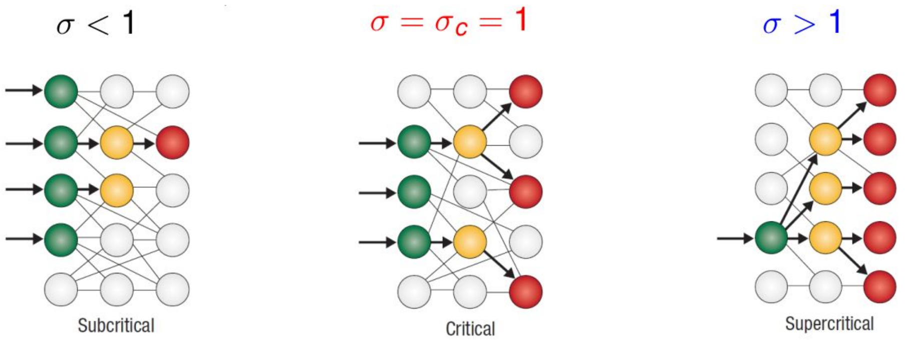
$$P(T) \sim T^{-\tau_T} \qquad \tau_t = 2.0$$

Critical Brain Hypothesis

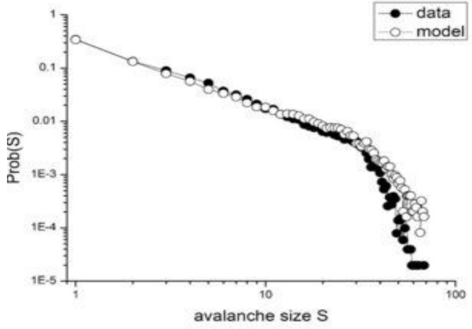


https://www.nature.com/articles/nphys3675/figures/1

Branching process (Galton-Watson model, 1874):



D. Chialvo, Nat. Phys. 2, 301 (2006)



http://www.scholarpedia.org/article/Neuronal_avalanche

Control parameter: σ =branching ratio
Order parameter: $F = \langle \rho \rangle \sim$ firing rate

DP phase transition: between absorbing and active (but otherwise unstructured) phases

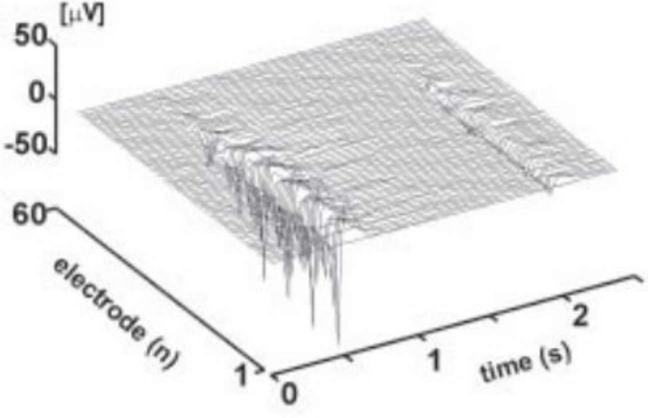
Mauro Copelli, School on Fundamentals of Complex Networks and Applications to Neuroscience, ICTP- SAIFR, 2015

Critical Brain Hypothesis

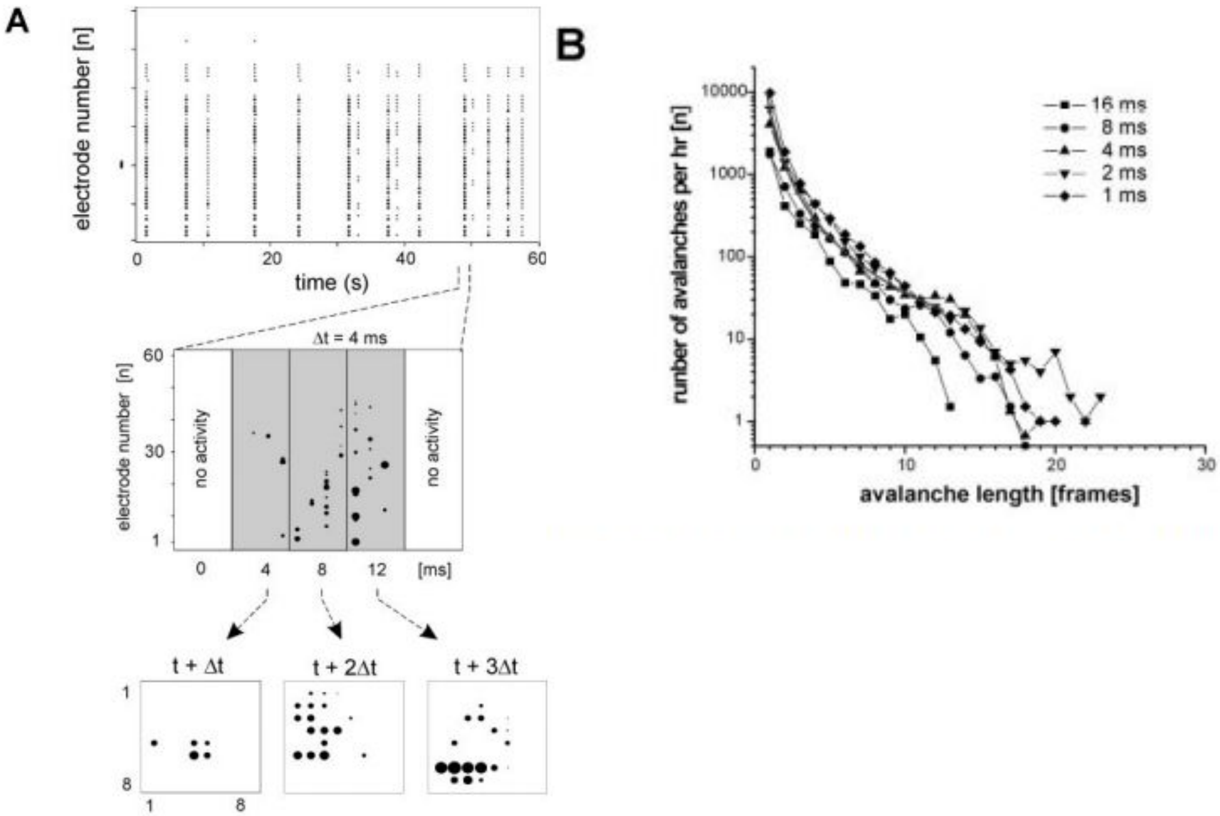
Beggs and Plenz, 2003

atividade sincronizada

culturas de células corticais



Beggs and Plenz • Power Laws in Cortical Networks

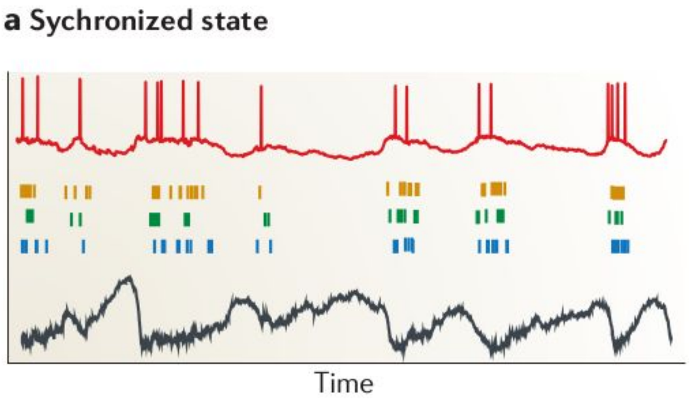


Sincronicidade dos disparos

Oscilações lentas do LFP com anestesia

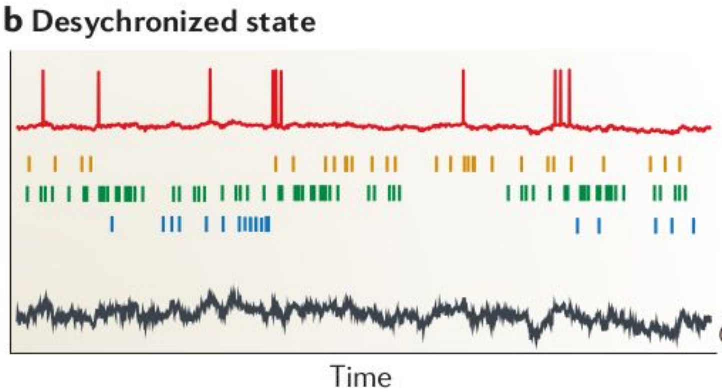
Power-law size distributions

Córtex de ratos, gatos e macacos anestesiados



Oscilações rápidas do LFP em ratos se movendo

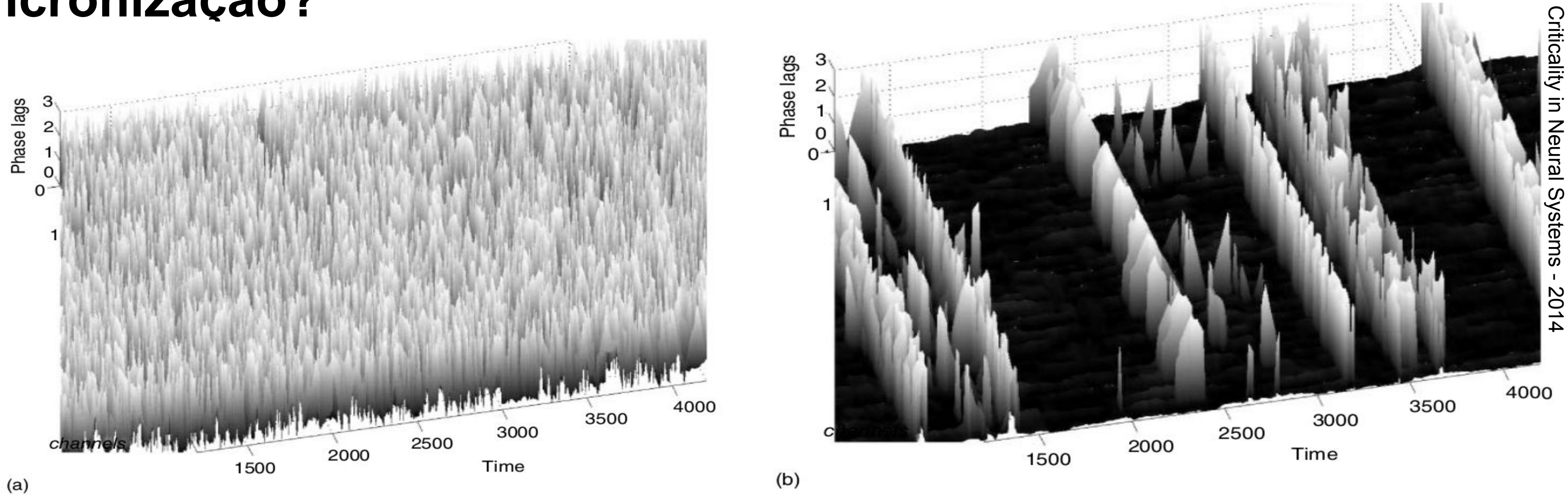
Correlações temporais de longo alcance (só em ratos sem anestesia)



Harris and Thiele, 2011. Nature reviews

Controvérsia

Assinaturas de criticalidade dependem do nível de sincronização?



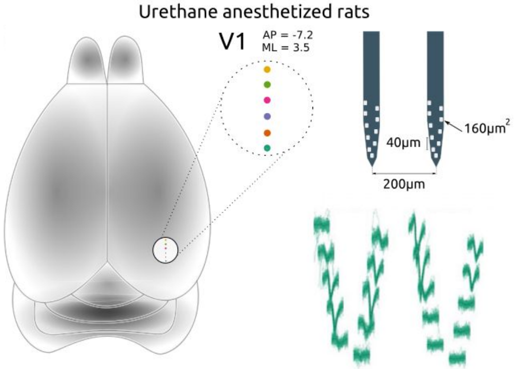
Criticality in Neural Systems - 2014

Oscilações não são previstas na percolação direcionada:

vai de estado absorvente para estado completamente ativado

Criticality between Cortical States

Córtex V1



PHYSICAL REVIEW LETTERS **122**, 208101 (2019)

Featured in Physics

Criticality between Cortical States

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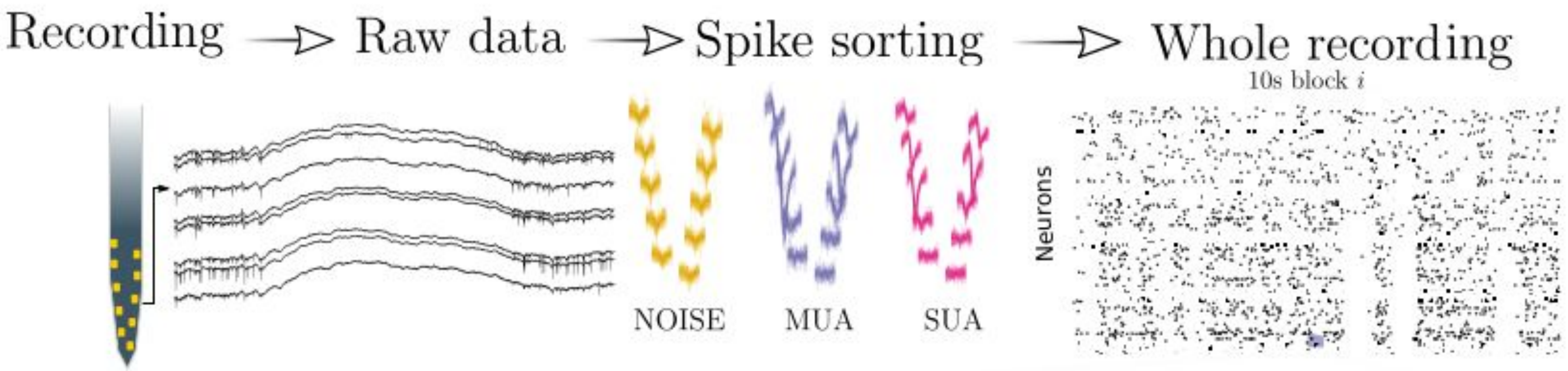


Coeficiente de Variação (CV)

$$r(t) = \frac{1}{\Delta T} \int_t^{t+\Delta T} \rho(\tau) d\tau$$

$\Delta t_i = \langle ISI \rangle_i \sim 2 - 4$ ms

spike count u_{ij}

$\Delta T = 50$ ms

firing rate r_{ik}

➤ $CV_i = \frac{\sigma_i}{\mu_i}$

desvio padrão

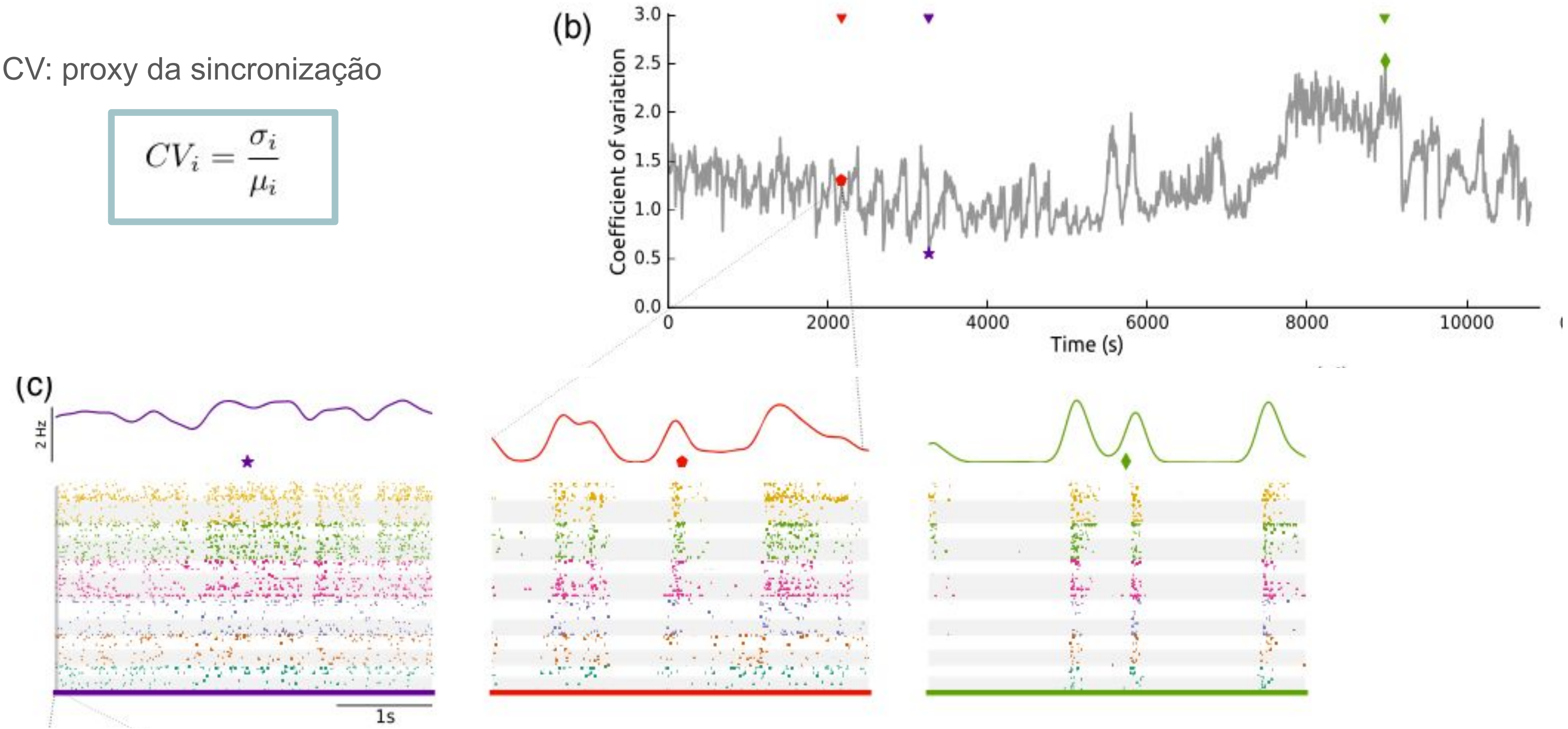
média

$$\begin{cases} \mu_i = \frac{1}{N} \sum_k^N r_{ik} \\ \sigma_i^2 = \frac{1}{N} \sum_k^N (r_{ik} - \mu_i)^2 \end{cases}$$

Resultados do artigo

CV: proxy da sincronização

$$\boxed{CV_i = \frac{\sigma_i}{\mu_i}}$$



Tamanho (S) e vida (T) das avalanches

$\Delta t_i = \langle ISI \rangle_i \sim 2 - 4$ ms

spike count u_{ij}

$\Delta T = 50$ ms

firing rate r_{ik}

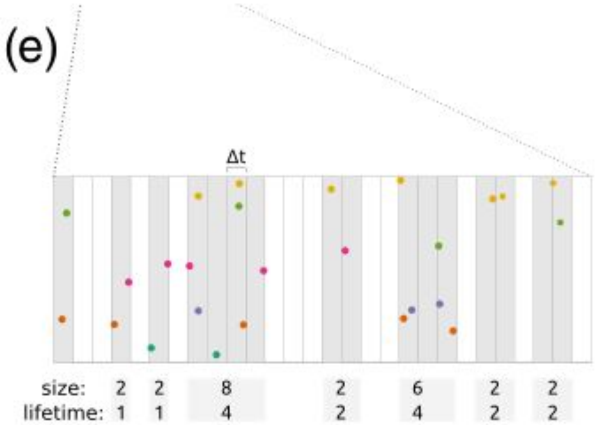
➤ $u_{ij} = 0$ in between avalanches

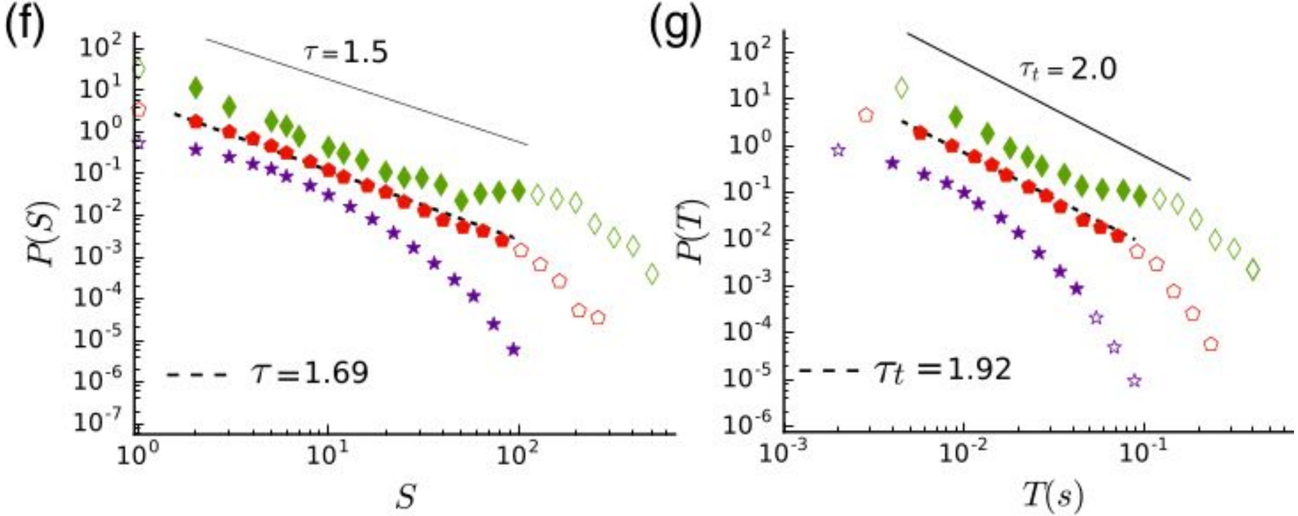
Count

$\{S_{i1}, ..., S_{in_i}\} \equiv S_i$ *tamanho*

$\{T_{i1}, ..., T_{in_i}\} \equiv T_i$ *tempo de vida*

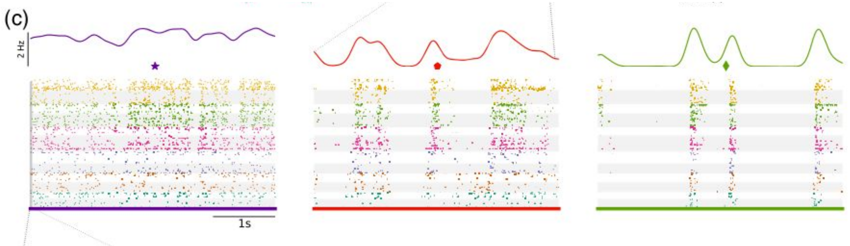
Resultados do artigo





$$P(S) \sim S^{-\tau}$$

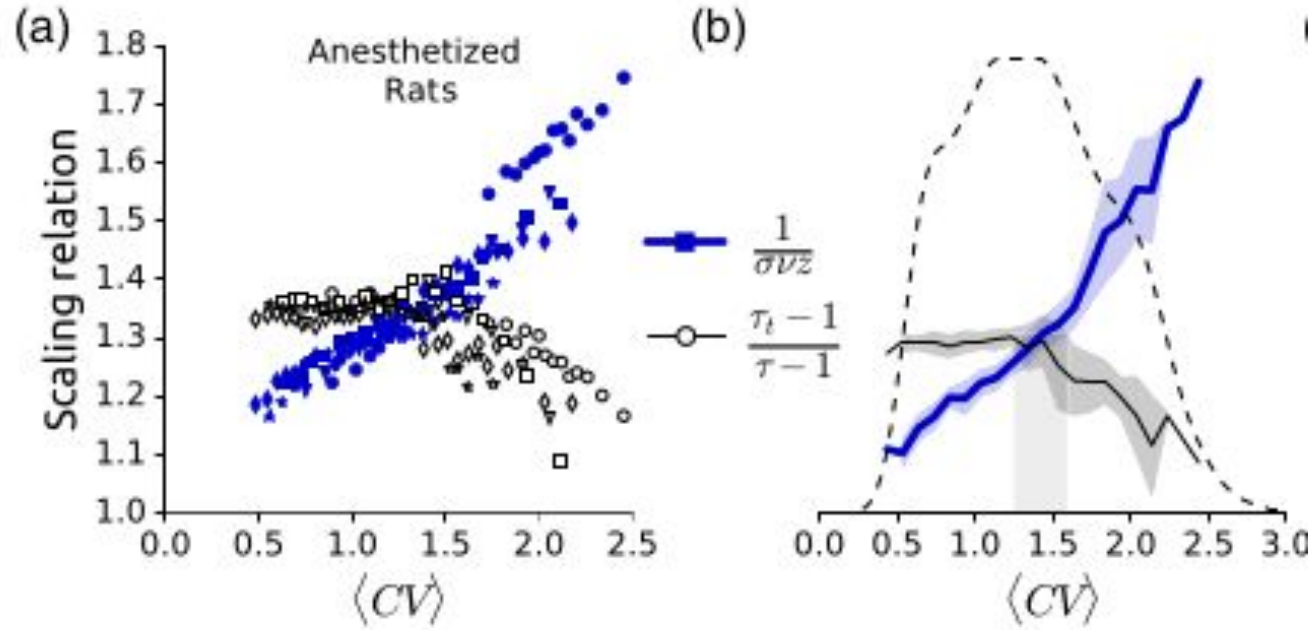
$$P(T) \sim T^{-\tau_T}$$



Resultados do artigo

Relação que deve valer somente na região crítica:

$$\boxed{\frac{\tau_t - 1}{\tau - 1} = \frac{1}{\sigma \nu z}}$$



$$\langle S \rangle (T) \sim T^{\frac{1}{\sigma \nu z}}$$

Resultados do artigo

DFA (detrended fluctuation analysis) -> mede auto-afinidade das séries temporais em diferentes escalas de tempo

Correlações temporais de longo alcance ($\alpha = 1$)

Memória

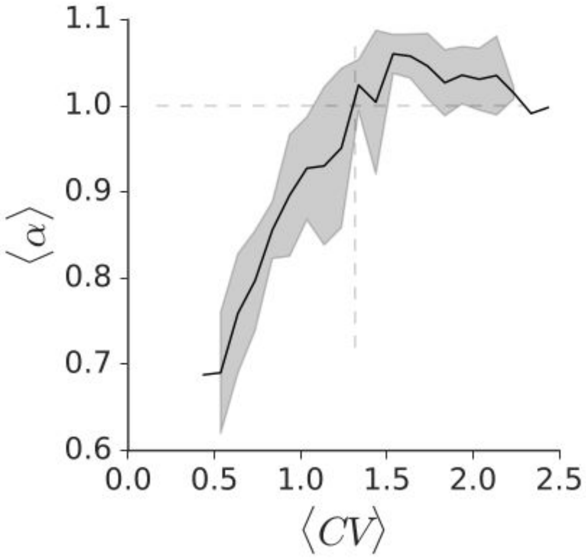
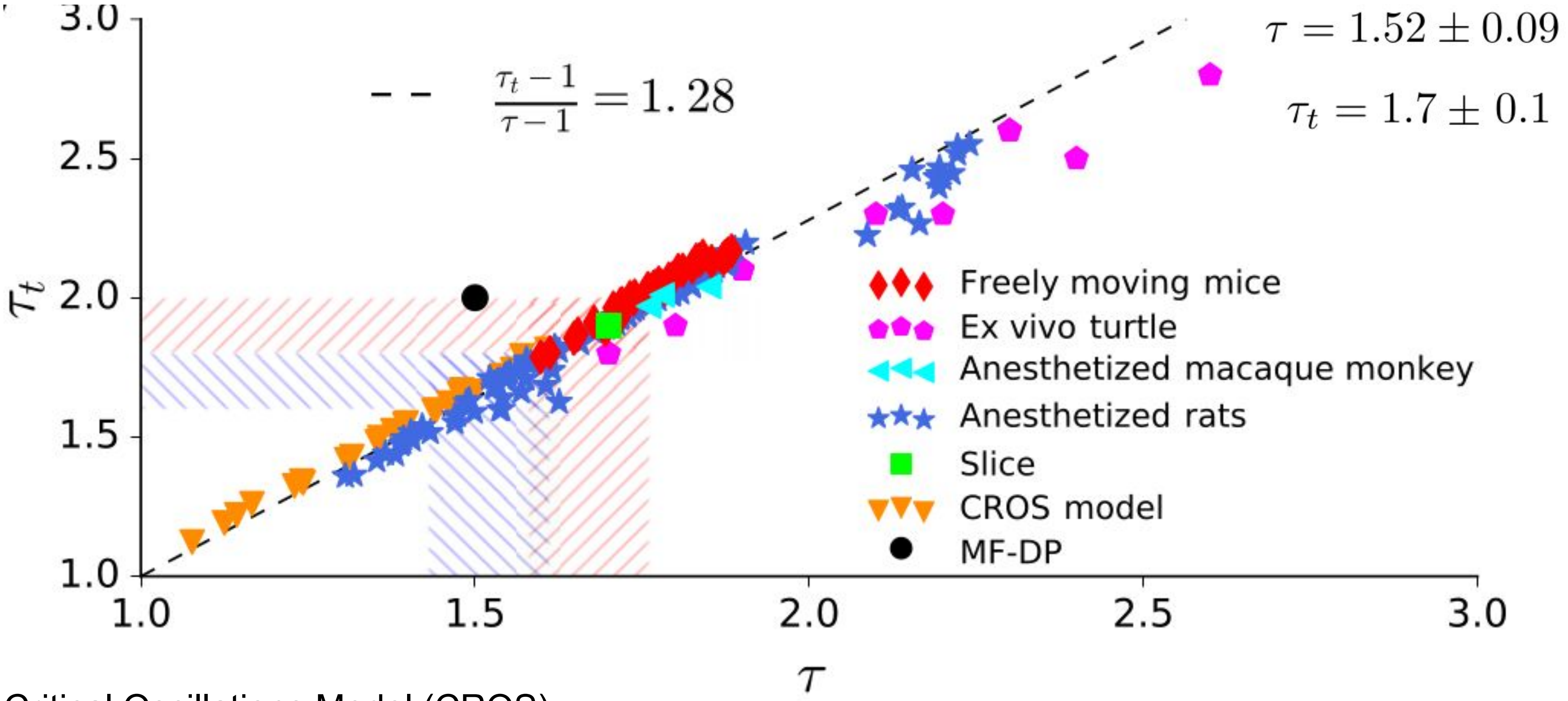


FIG. S13. **Long-range time correlations across different levels of spiking variability**. DFA exponent α versus $\langle CV \rangle$ for Group data B.

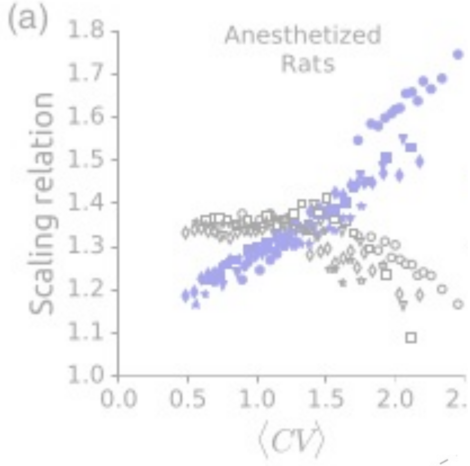
Resultados do artigo



Critical Oscillations Model (CROS)

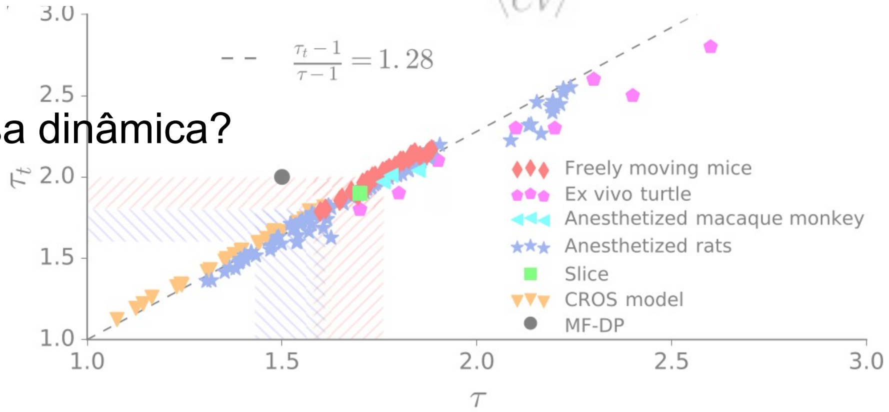
Conclusões

- Assinaturas de criticalidade consistentes em animais anestesiados e se movendo livremente
- Ponto crítico está em uma valor intermediário de <CV>
- Incompatibilidade com MF-DP (paradigma da área)
- Relação linear entre τ e τ_t reprodutível pelo CROS model



Questões em aberto

- Que modelo mínimo explica esses resultados?
- Quais são os mecanismos responsáveis por essa dinâmica?
- Ponto crítico como bioindicador?



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