Workshop on Dynamical Processes on Complex Networks

Self-sustained activity and intermittent synchronization in balanced networks

Fernando da Silva Borges

SUNY The State University of New York
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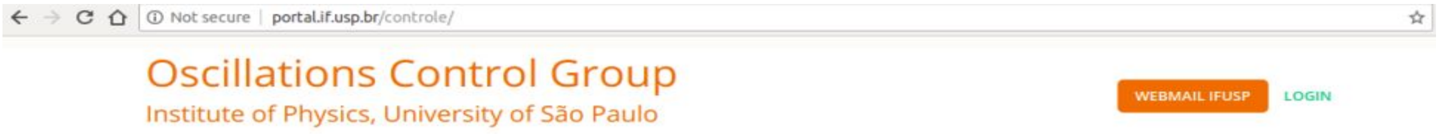

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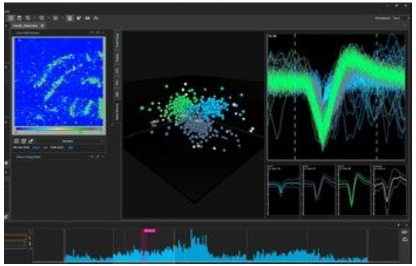
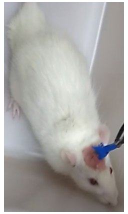
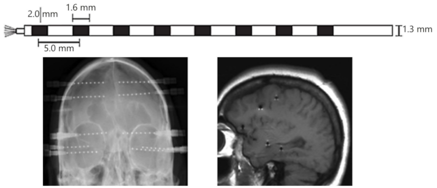
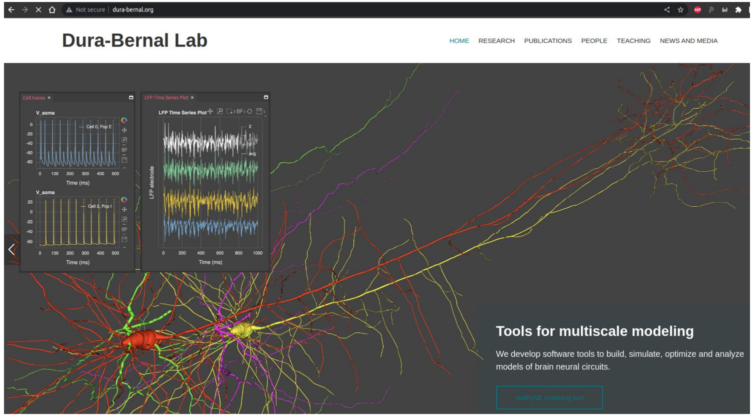
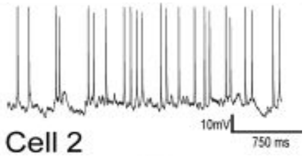
http://netpyne.org/

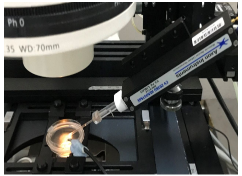


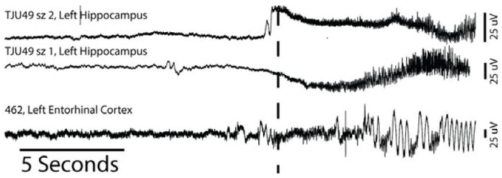












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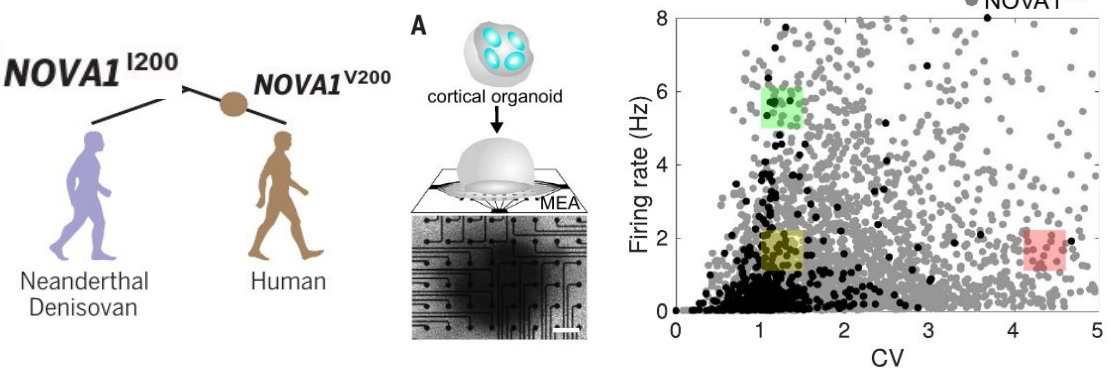
Recent works

Experimental Networks and Chimera States

Science **371**, 694 (2021)

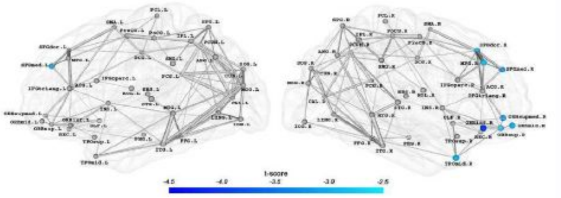


Chaos 34, 023107 (2024)

J. Phys. Complex. **5** (2024) 025010

Chaos **33**, 033131 (2023)

Front. Physiol. 11:1053 (2020)

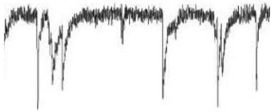


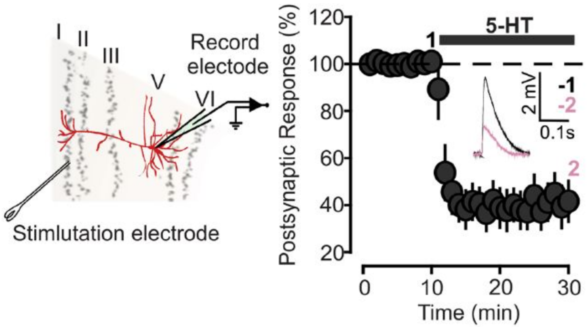
Scientific Reports | (2022) 12:21015

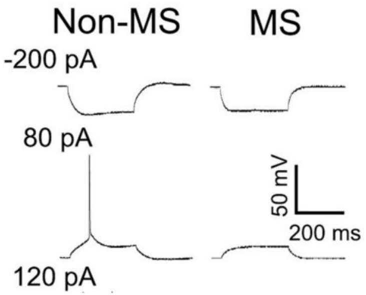
Experimental Neurology 373 (2024) 114652

Int. J. Mol. Sci. **2024**, *25*, 519.

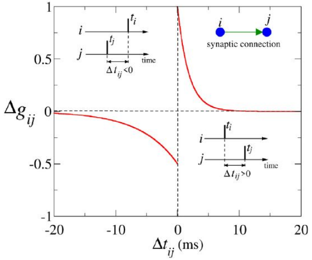
5-HT

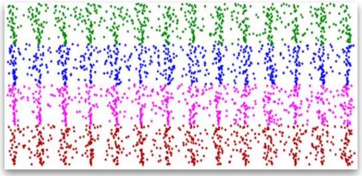


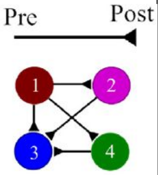




Chaos, Solitons and Fractals 171 (2023) 113480

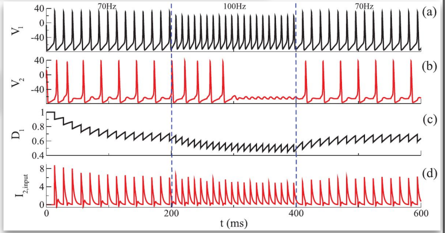






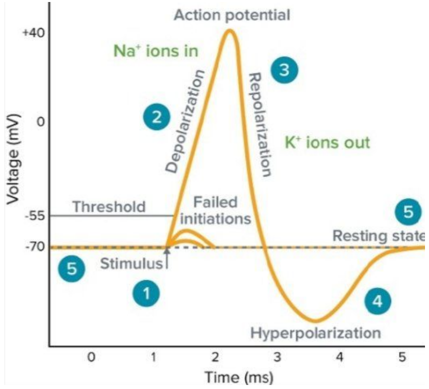
Eur. Phys. J. Spec. Top. **231**, 4049–4056 (2022).

Commun Nonlinear Sci Numer Simulat 96 (2021) 105689

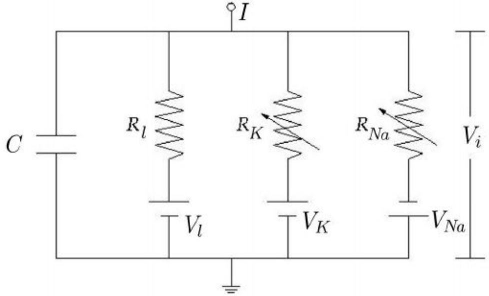


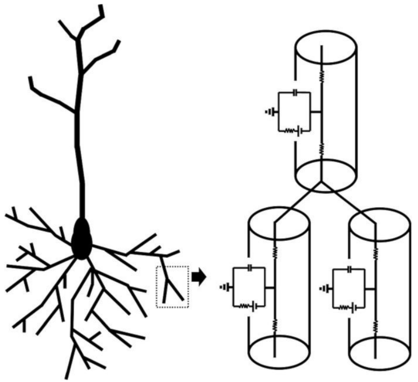
Computational modeling

- Hodgkin-Huxley model or conductance-based model (Nobel 1963):



$$C_m \frac{dV_i}{dt} = I - \bar{g}_K n^4 (V_i - V_K) - \bar{g}_{Na} m^3 h (V_i - V_{Na}) - \bar{g}_l (V_i - V_l)$$



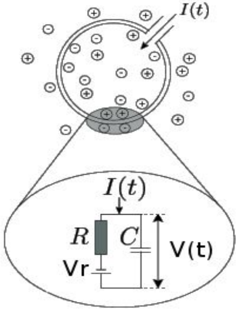


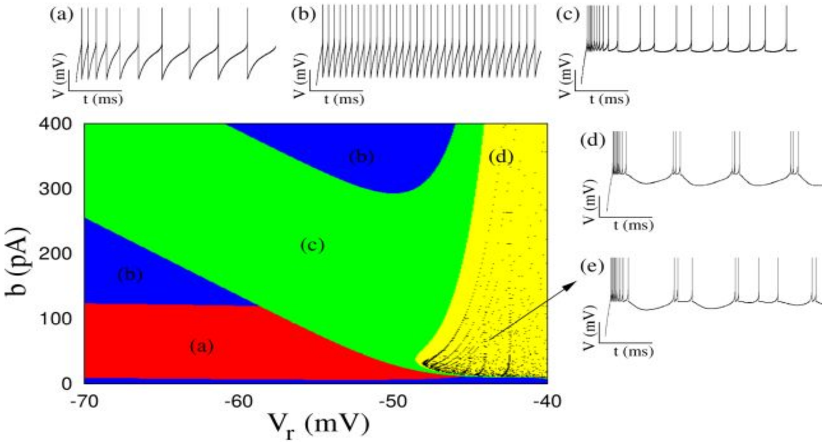
- Adaptive exponential integrate-and-fire model:

$$C \frac{dV}{dt} = -g_L (V - E_L) + g_L \Delta_T \exp\left(\frac{V - V_T}{\Delta_T}\right)$$

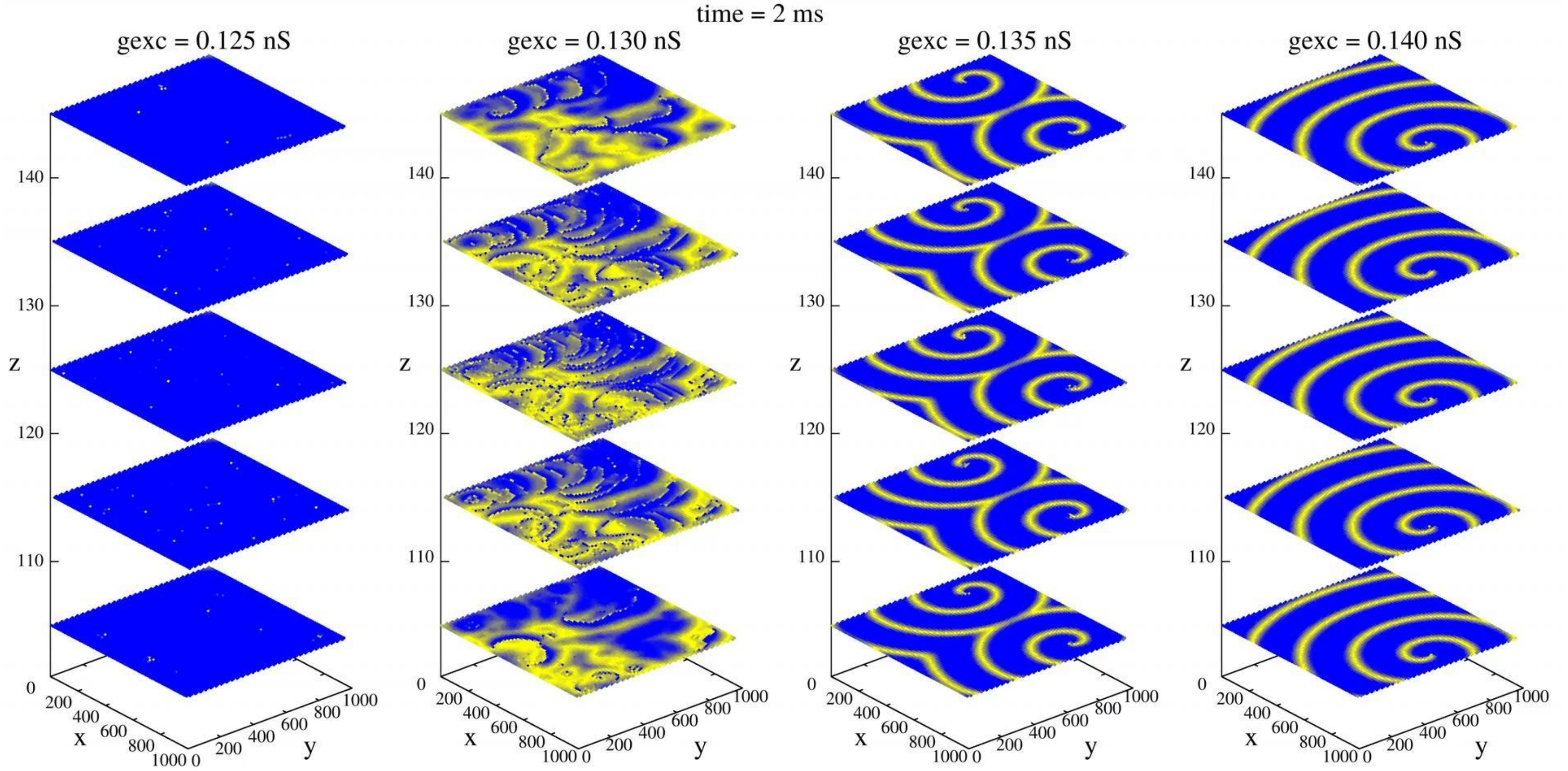
$$\tau_w \frac{dw}{dt} = a(V - E_L) - w$$

➢ Low computational cost
➢ Problems related to neural network
➢ Describes biological patterns (Micro and Macro)

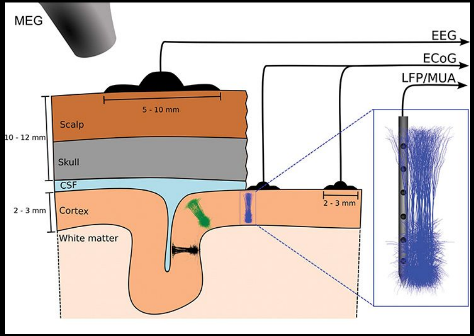




Spiral waves in IF model of CA1



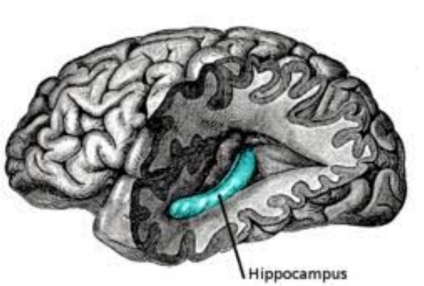
Microcircuit Reconstruction



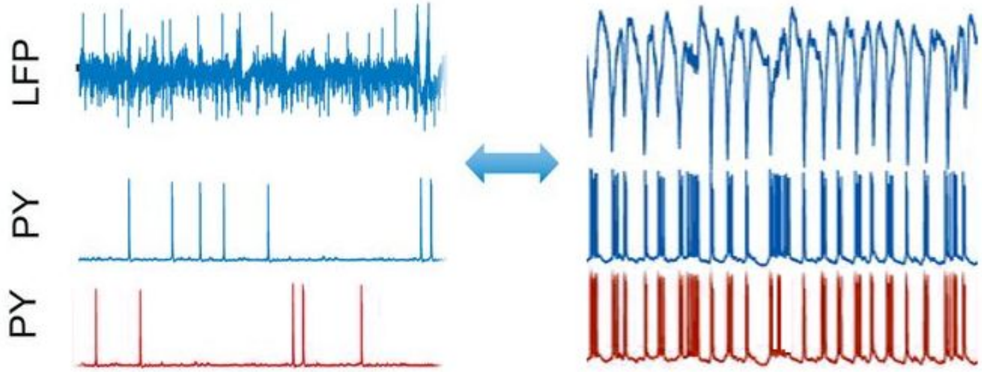
Bulletin of the World Health Organization:

- Over 85 million people suffer from neurological diseases;
- ~ 50 million have epilepsy;
- The most common form is temporal lobe epilepsy (TLE)
- TLE presents high refractoriness to pharmacological treatment (~60%)
- What happens in the brain activity during an epileptic seizure?

Data from human hippocampal slices



Resting state **Seizure**



Buchin et al. ENEURO, 2018.
Reyes-Garcia et al. Scientific Reports, 2018.

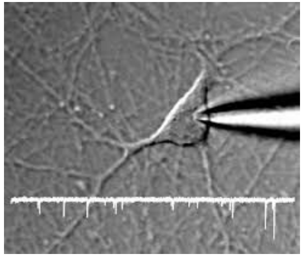
epileptic neurons

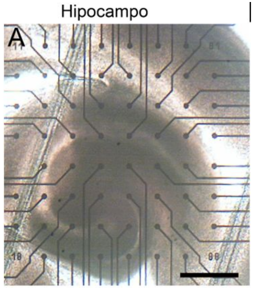
Modelling epileptic seizures

- The pilocarpine model of temporal lobe epilepsy
- Pilocarpine acting through muscarinic receptors, causes an **imbalance between excitatory and inhibitory** transmission resulting in the generation of Status epilepticus

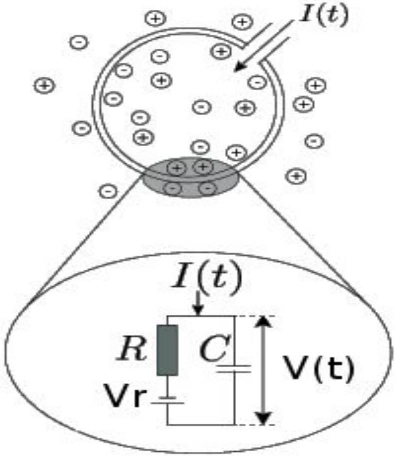
In vivo

In vitro





In silico

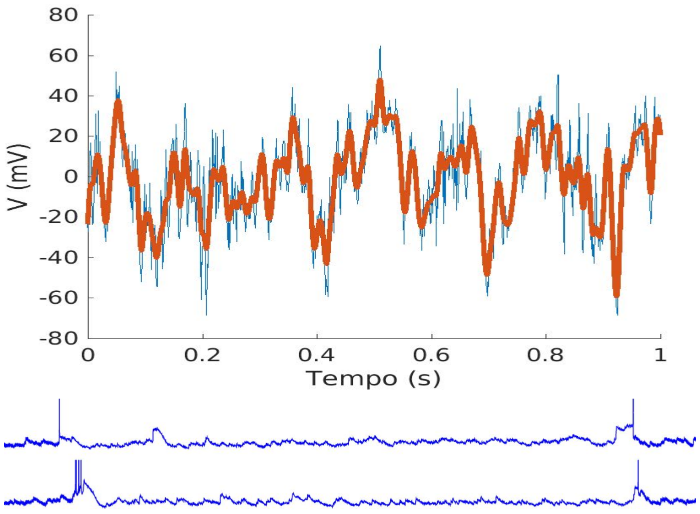


- Epileptic seizure ⟷ normal neuronal activity
- How neuronal systems transit between these regimes?
- **Bistate firing patterns**

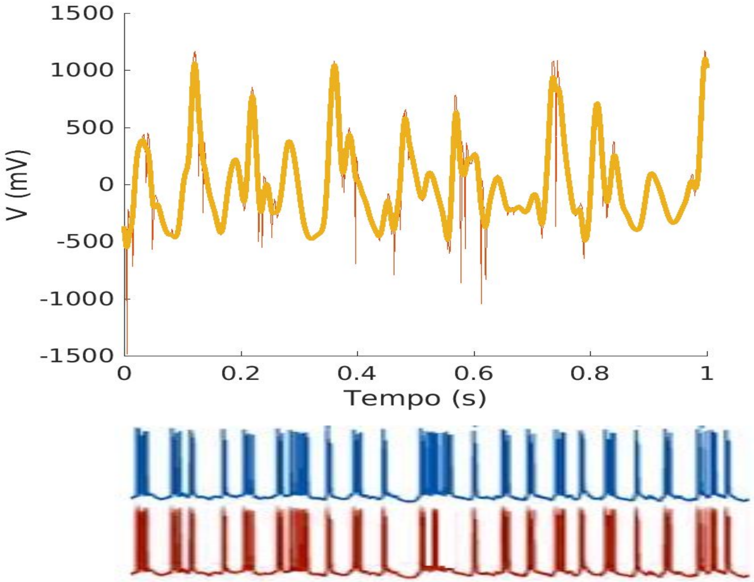
I. Asynchronous firing (spikes)

II. High synchronous firing (bursts)

Resting state

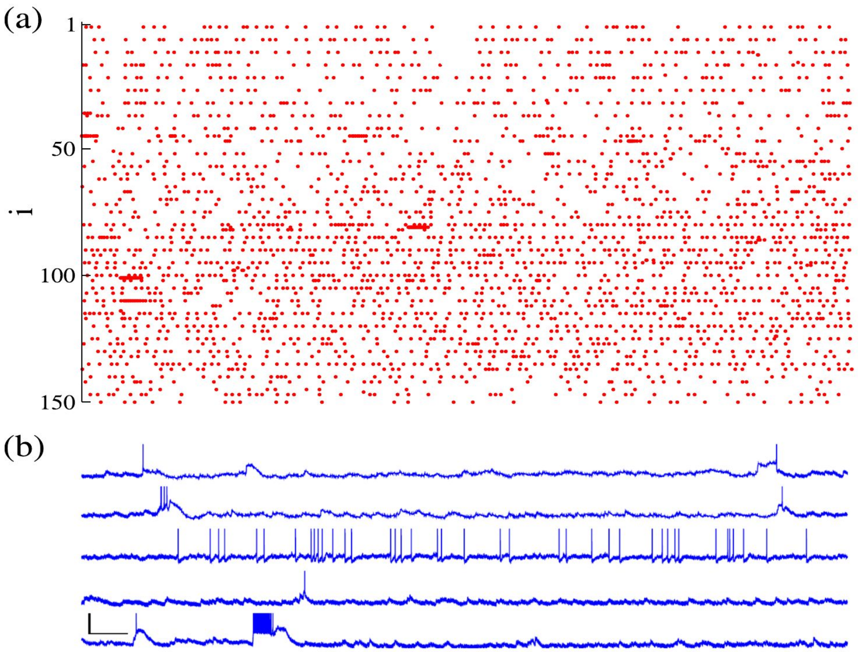


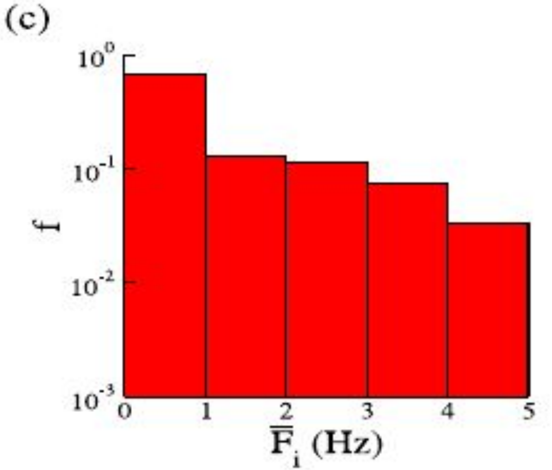
Seizure (Pilo)

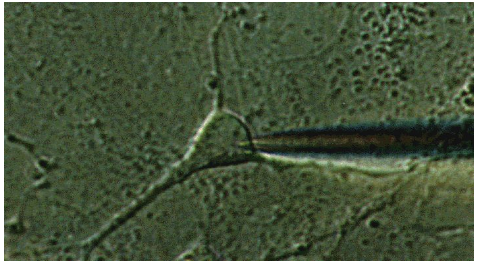


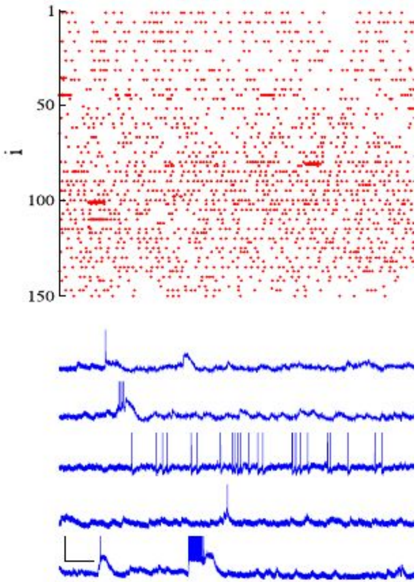
Asynchronous firing in Rat

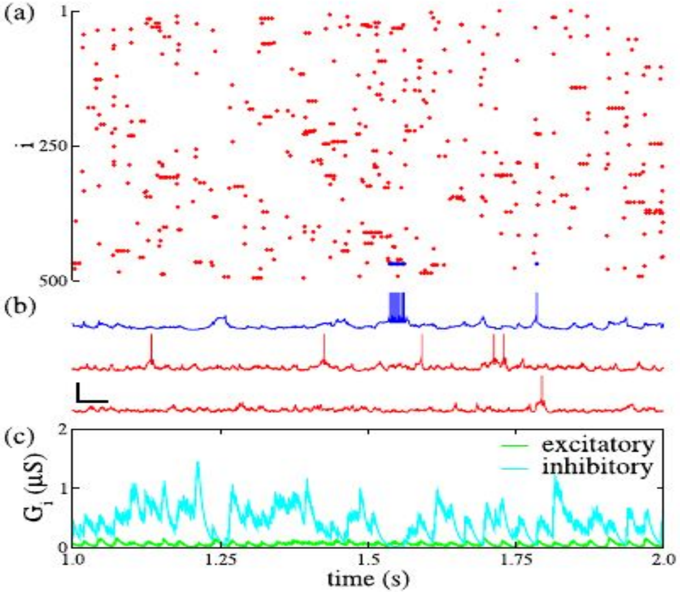
- Mean Fire Rate ~ 1 Hz
- No External Noise
- Self-Sustained Activity (SSA)

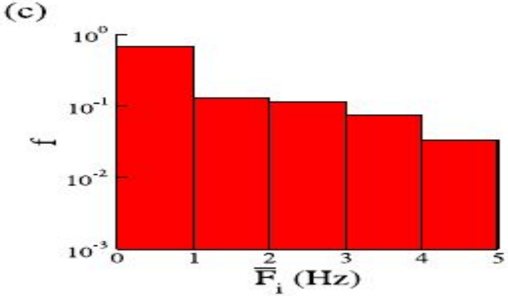


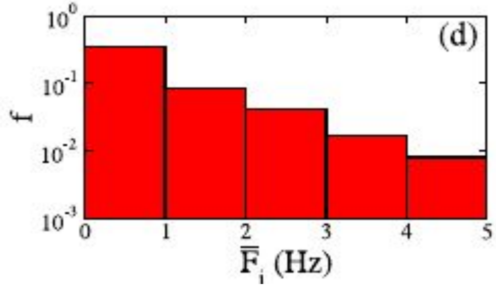












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Physica A

journal homepage: www.elsevier.com/locate/physa

Self-sustained activity of low firing rate in balanced networks

F.S. Borges [a,*], P.R. Protachevicz [b], R.F.O. Pena [c], E.L. Lameu [d,e], G.S.V. Higa [a], A.H. Kihara [a], F.S. Matias [f,g], C.G. Antonopoulos [h], R. de Pasquale [i], A.C. Roque [c], K.C. Iarosz [j], P. Ji [k,l], A.M. Batista [b,m]

From Asynchronous firing (spikes) to High synchronous firing (bursts)

Neural Networks 90 (2017) 1–7

Contents lists available at ScienceDirect

Neural Networks

journal homepage: www.elsevier.com/locate/neunet

Synchronised firing patterns in a random network of adaptive exponential integrate-and-fire neuron model

F.S. Borges[a], P.R. Protachevicz[b], E.L. Lameu[b], R.C. Bonetti[b], K.C. Iarosz[a,c,*], I.L. Caldas[a], M.S. Baptista[c], A.M. Batista[a,b,c,d,*]

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IOP Publishing Physiol. Meas. 39 (2018) 074006 (9pp) https://doi.org/10.1088/1361-6579/aace91

Physiological Measurement

IPEM Institute of Physics and Engineering in Medicine

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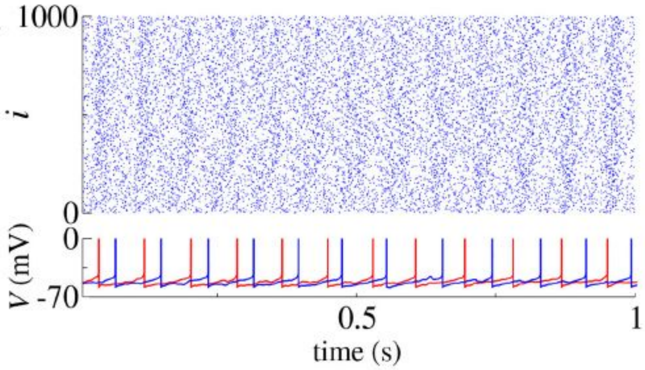
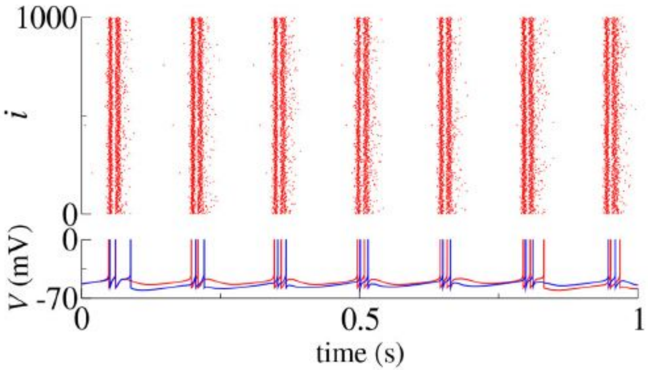
PAPER

Synchronous behaviour in network model based on human cortico-cortical connections

P R Protachevicz[1], R R Borges[2], A S Reis[3], F S Borges[4], K C Iarosz[5,6,7], I L Caldas[5], E L Lameu[7,8], E E N Macau[8,9], R L Viana[3], I M Sokolov[7], F A S Ferrari[10], J Kurths[6,7], A M Batista[1,6,11], C-Y Lo[12], Y He[13,14,15] and C-P Lin[16]

Increase the excitatory connection probability and synaptic conductance





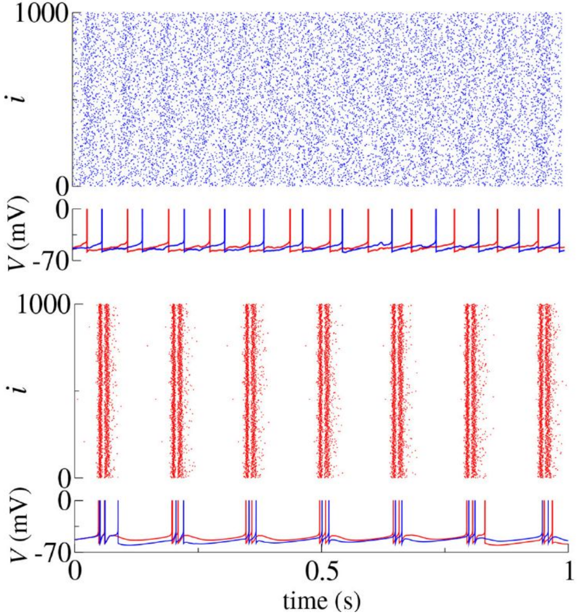
Modelling Epileptic Networks

- Traub and Wong have proposed which epileptic synchronized burst are possible due three reasons:
- (i) the capability of neurons to firing in burst,
- (ii) the strong synaptic excitation, and
- (iii) the **relative disinhibition**

- Epileptic and normal neuronal activity are support by the **same physiological structure**
- How neuronal systems transit between these regimes?

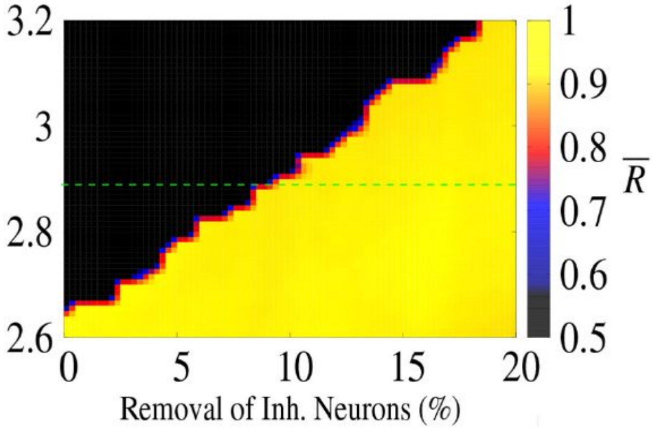
Inhibitory Effect on Synchronous Behavior

- The unbalance between excitation and inhibition generates synchronized bursts.
- Two types of loss of inhibition:
  - Decrease in synaptic strength (relative inhibitory synaptic conductance);
  - Dead of inhibitory neurons (fraction of inhibitory neurons).

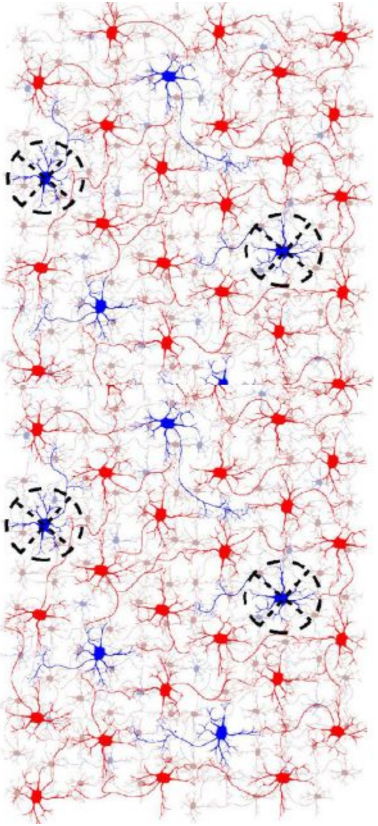


(black region) R < 0.5

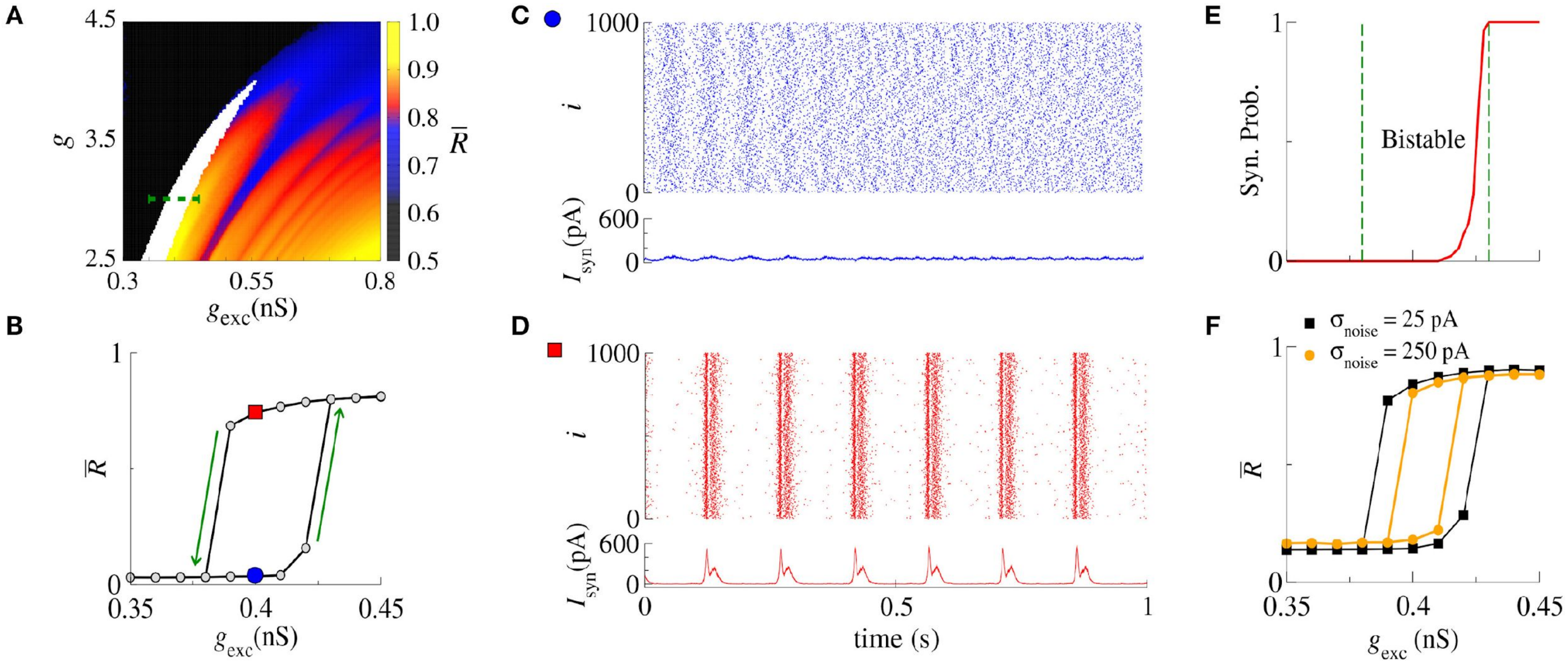
relative inhib/excit synaptic conduct.



(yellow region) R > 0.9

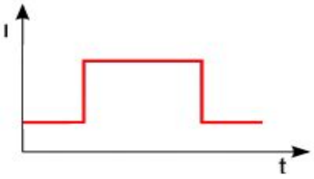


- Synchronization in function of **g** (relative inhibitory synaptic conductance) and **gexc** (excitatory synaptic conductance).
- The transition from desynchronous spikes to synchronous bursts of activity, induced by varying the synaptic coupling, emerges in a hysteresis loop due to bistability where abnormal (excessively high synchronous) regimes exist.



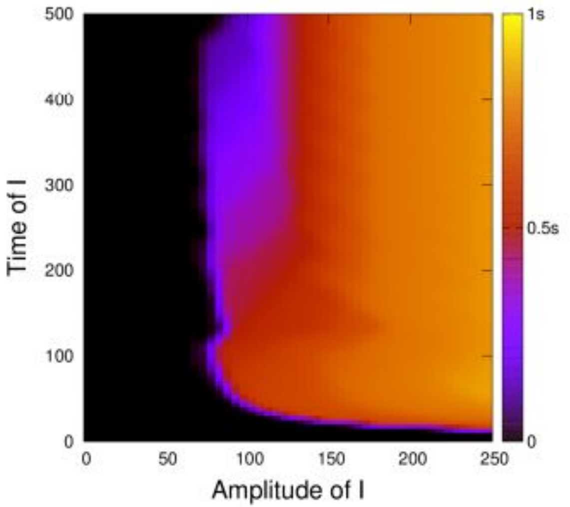
How epileptic seizures are triggered?

Mean Seizure Duration after applying SCP randomly (Asynchronous initial conditions)

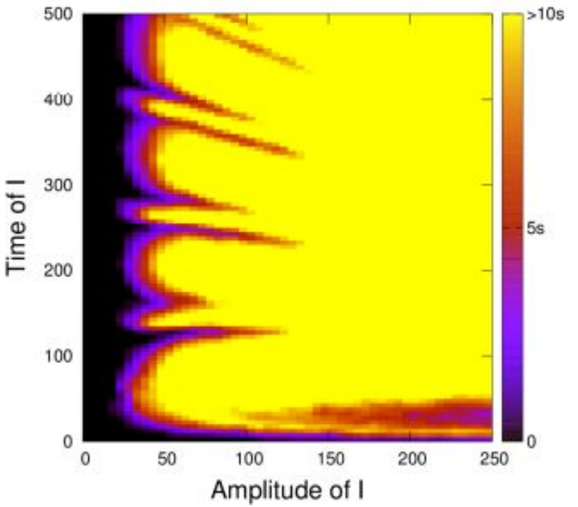


Square Current Pulse

Nonepileptic region



Epilepsy (Bistable region)



frontiers in Computational Neuroscience

ORIGINAL RESEARCH
published: 05 April 2019
doi: 10.3389/fncom.2019.00019

Bistable Firing Pattern in a Neural Network Model

*Paulo R. Protachevicz[1], Fernando S. Borges[2], Ewandson L. Lameu[3], Peng Ji[4,5], Kelly C. Iarosz[6], Alexandre H. Kihara[2], Ibere L. Caldas[6], Jose D. Szezech Jr.[1,7], Murilo S. Baptista[8], Elbert E. N. Macau[3], Chris G. Antonopoulos[9], Antonio M. Batista[1,7] and Jürgen Kurths[10,11]**

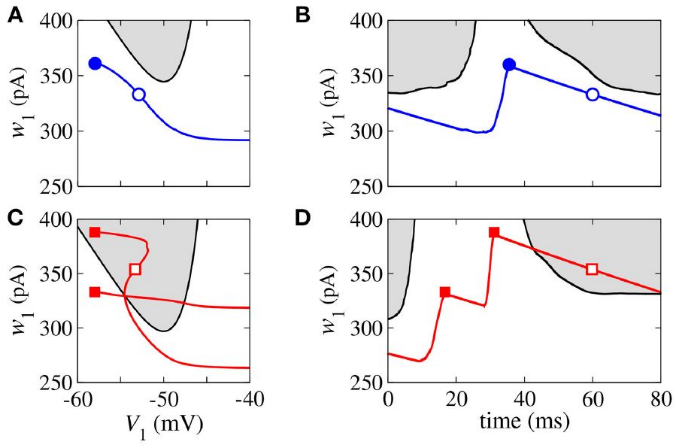


FIGURE 3 | Phase space (w_1, V_1) **(A,C)** and time evolution of w_1 **(B,D)** for spikes (blue) and burst activity (red). The gray regions correspond to $dV_1/dt < 0$ and the black line represents $dV_1/dt = 0$ (V-nullcline).

Epilepsy & Behavior 139 (2023) 109072

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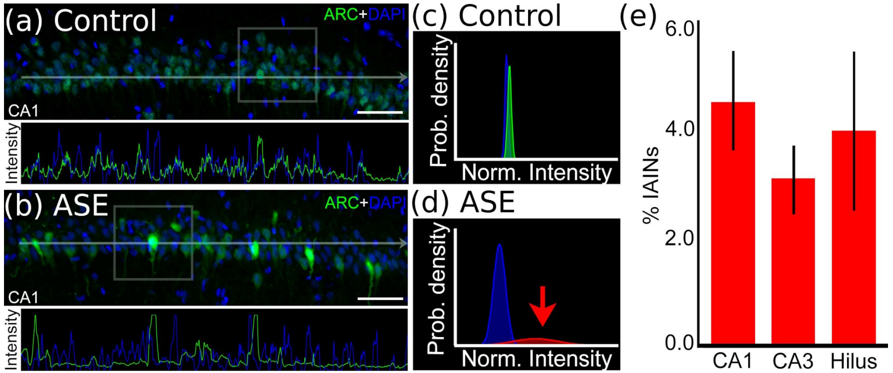
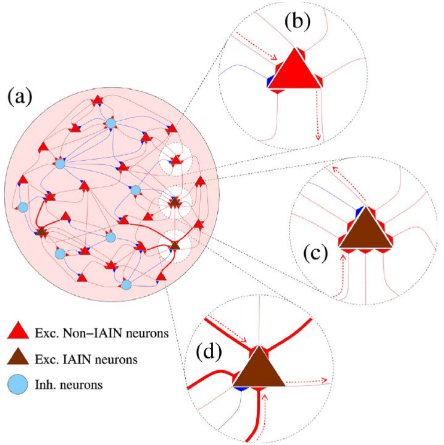
Epilepsy & Behavior

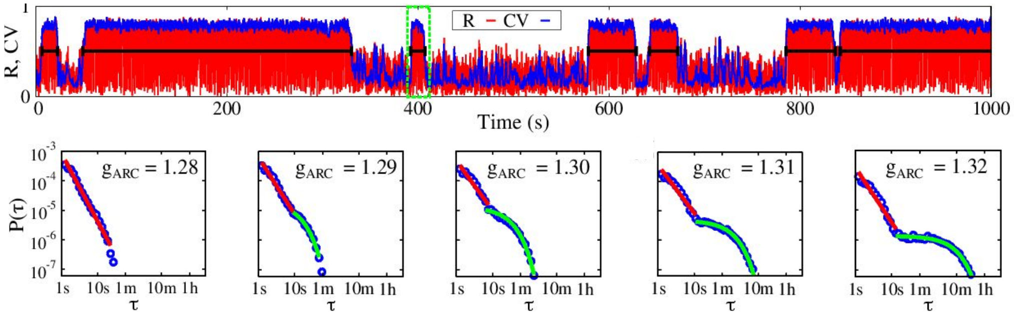
journal homepage: www.elsevier.com/locate/yebeh

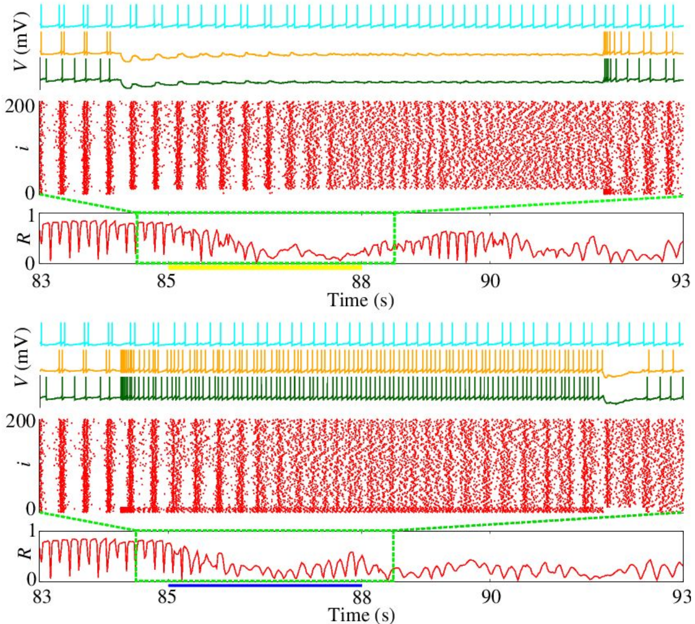
Intermittency properties in a temporal lobe epilepsy model

F.S. Borges [a,b,*], E.C. Gabrick [c], P.R. Protachevicz [d], G.S.V. Higa [b,e], E.L. Lameu [f], P.X.R. Rodriguez [b,g], M.S.A. Ferraz [b], J.D. Szezech Jr. [c,h], A.M. Batista [c,d,h], A.H. Kihara [b,*]









And about Ion Channels?

brain sciences

MDPI

Article

The Roles of Potassium and Calcium Currents in the Bistable Firing Transition

Fernando S. Borges [1,2], Paulo R. Protachevicz [3], Diogo L. M. Souza [4], Conrado F. Bittencourt [4], Enrique C. Gabrick [4], Lucas E. Bentivoglio [4], José D. Szezech, Jr. [4,5], Antonio M. Batista [4,5], Iberê L. Caldas [3], Salvador Dura-Bernal [1,6] and Rodrigo F. O. Pena [7,8,*]

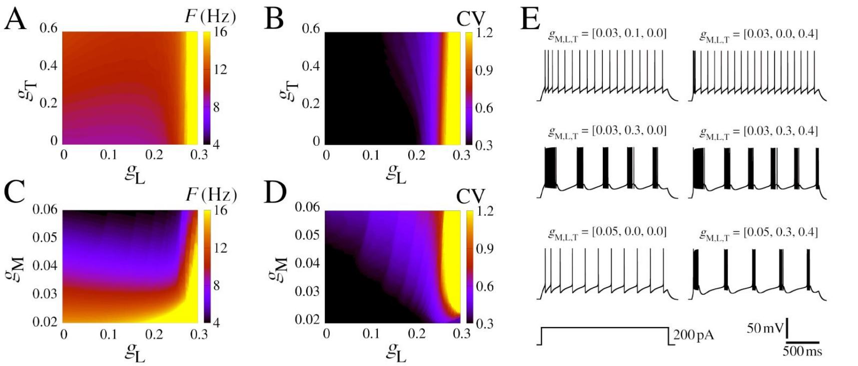
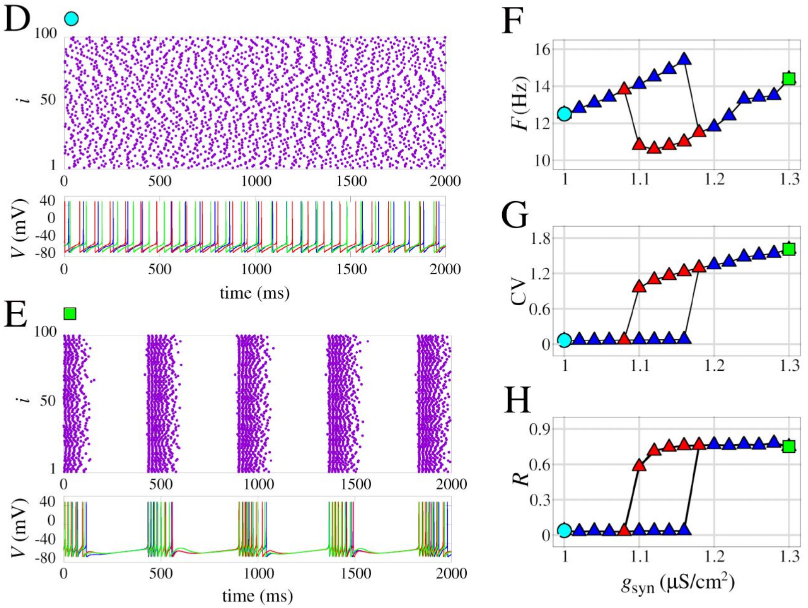
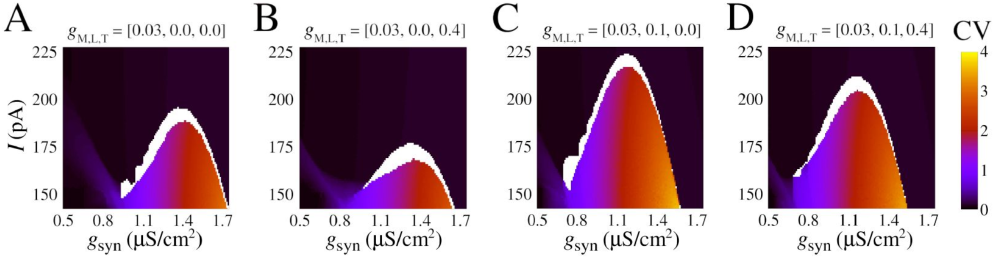
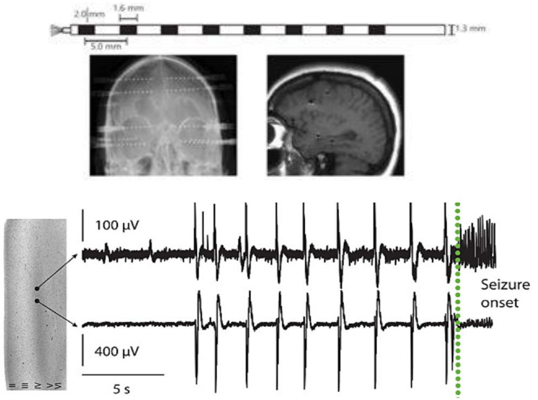


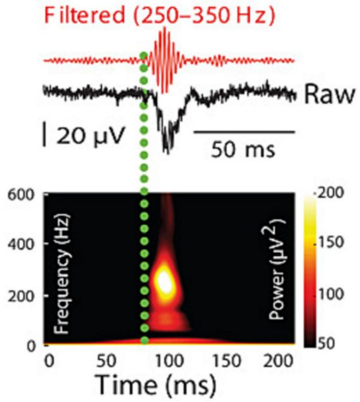
Figure 2. Firing pattern for different I_M, I_T, and I_L conductances. (**A**) Firing rate in colored (g_T, g_L)-diagram for $g_M = 0.03$ mS/cm^2. (**B**) The same as (**A**) for the CV. (**C**) Firing rate in colored (g_M, g_L)-diagram for $g_T = 0.4$ mS/cm^2. (**D**) The same as (**C**) for the CV. (**E**) Exemplar voltage traces considering different values of g_M, g_L, and g_T, where each parameter combination is shown atop and $V = -85$ mV before the depolarizing pulses. Other parameters are the same as Figure 1 with I = 200 pA.

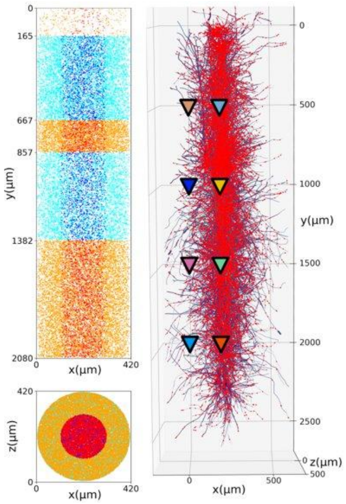


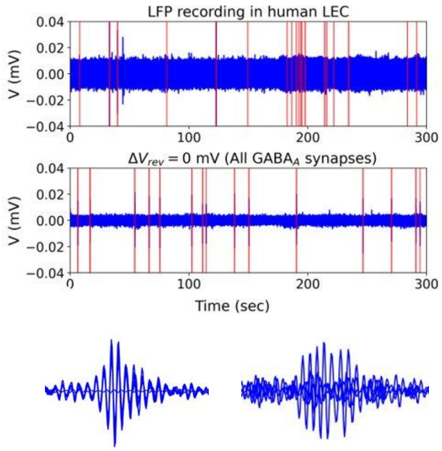


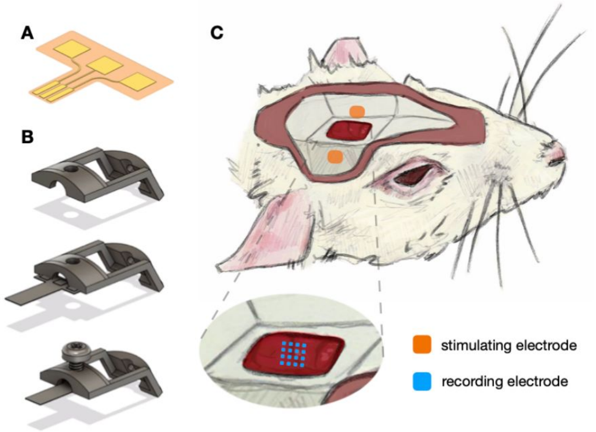
Extracellular recording and stimulation

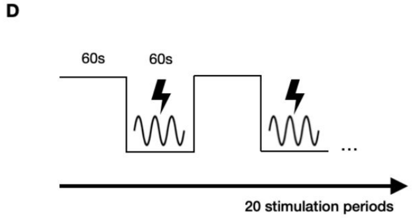




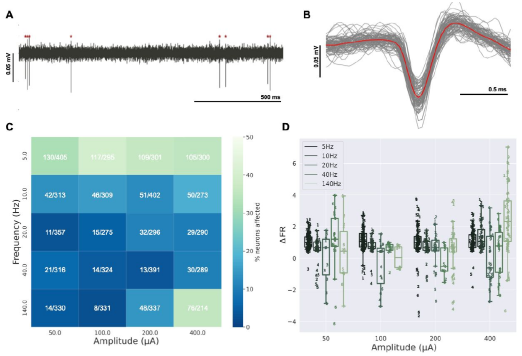








Group	Amplitudes (µA)	Frequencies (Hz)
Training	50, 100, 200, 400	5, 10, 15, 20, 40, 140
Testing	50, 100, 200, 400	1, 7, 15, 30, 90



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Large-scale biophysically detailed model of somatosensory thalamocortical circuits in NetPyNE

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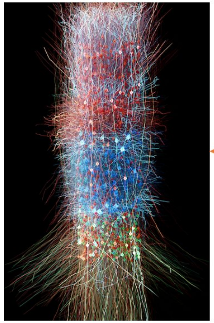
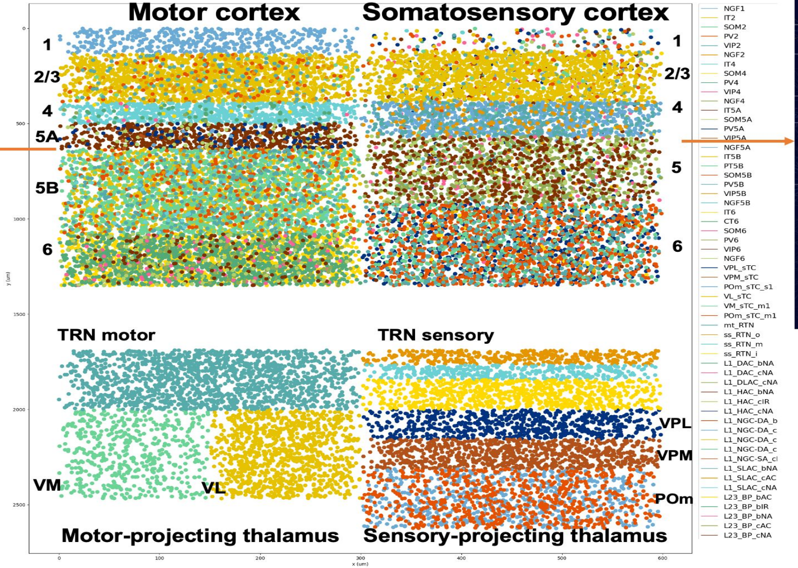
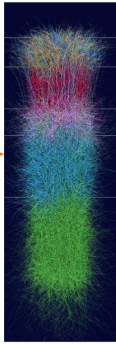
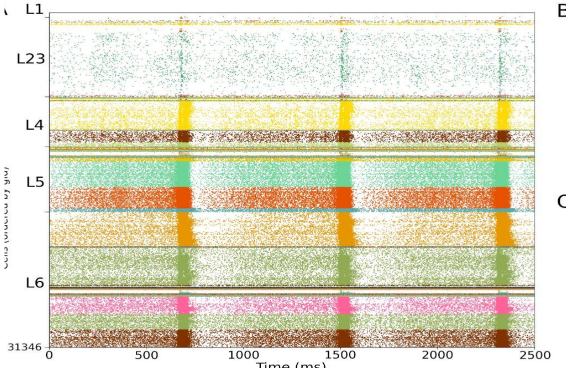
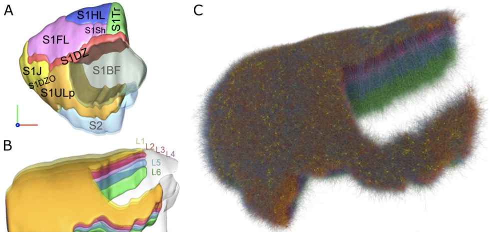


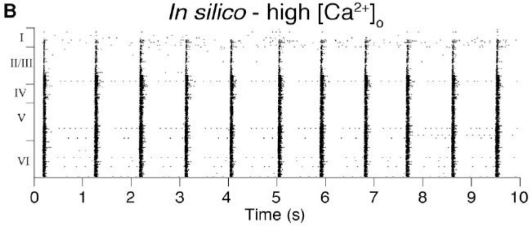


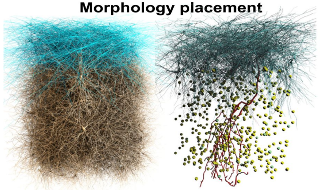


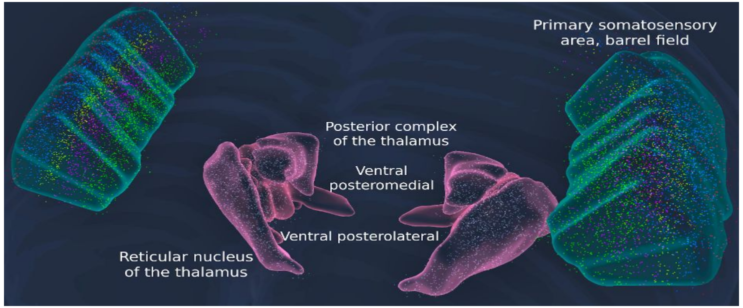


- > 26k neurons
- 249 populations
- > 60M synapses







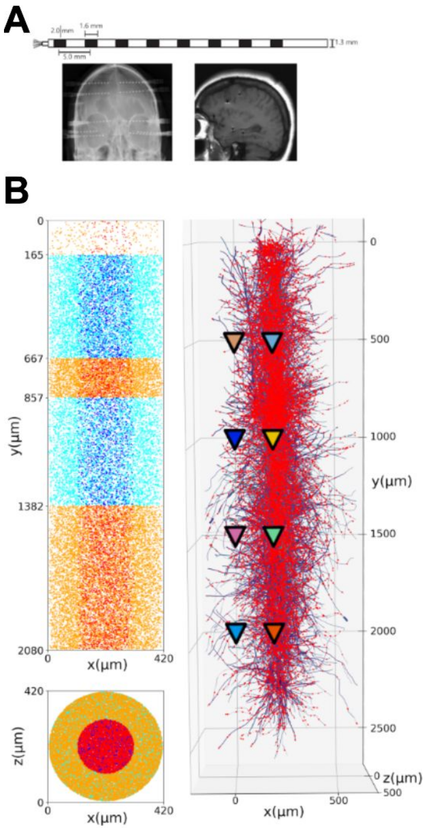


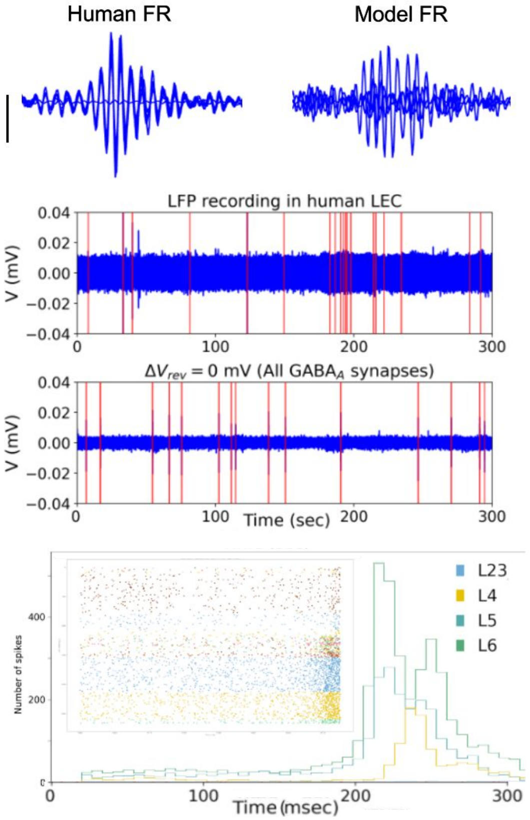
S1 model: LFP of 8k neurons (25%), running 15 sec simulations

Simulations: numprocs=1680, cell connection time = 3830.37 s, run time = 2052.19 s (15 sec), Total time = 7521.19 s

Human data: 64 events in 1200 sec ~ **17 in 300 sec**

S1 model: **15 events in 300 sec**





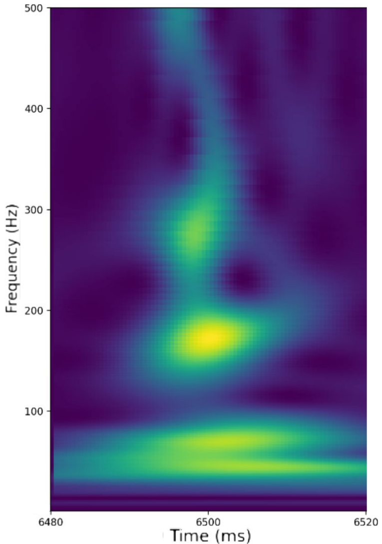

```
In [19]: from ripple_detection import Karlsson_ripple_detector

In [20]: filtered_lfps = filter_ripple_band(lfps2)
         Karlsson_ripple_times = Karlsson_ripple_detector(
             time, filtered_lfps, speed, SAMPLING_FREQUENCY
         )

         display(Karlsson_ripple_times)
```

ripple_number	start_time	end_time
1	2.824026	2.867398
2	14.383954	14.415807
3	40.940166	41.027615
...	...	...
66	1127.799359	1127.849273
67	1153.437522	1153.514558
68	1179.736239	1179.821999

Karlsson, M.P., and Frank, L.M. (2009). **Nature Neuroscience** 12, 913-918.



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NSF

NIH

USP Universidade de São Paulo

UFABC

FAPESP

ICTP

unesp

IFT - UNESP INSTITUTO DE FÍSICA TEÓRICA

105 GROUP

UEPG Universidade Estadual de Ponta Grossa

https://github.com/suny-downstate-medical-center/S1_netpyne

https://github.com/suny-downstate-medical-center/M1_S1_thalamus

https://github.com/FernandoSBorges/CA1_netpyne

https://github.com/FernandoSBorges/adex_netpyne