

# Precise Synchronization of Active and Silent States in El-units using Excitatory-Inhibitory Models

By Martijn S. Brouwer  
6859488



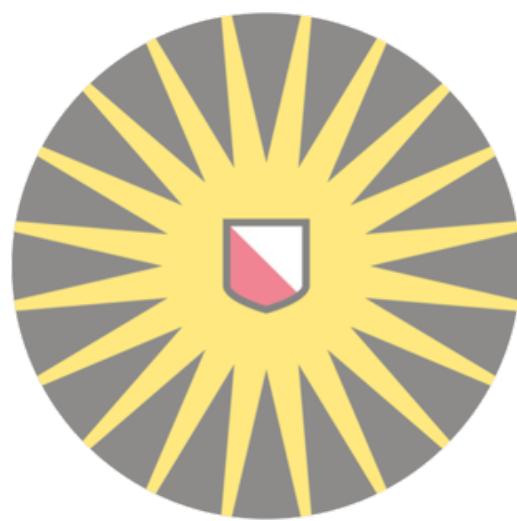
MSc Mathematical Sciences

Mathematical Neuroscience (WISL413)  
Project 11.6.5

**Course coordinators:**  
dr. Daniele Avitabile  
dr. Hil Meijer

June 8th, 2023





# The article by Volgushev et al.

The Journal of Neuroscience, May 24, 2006 • 26(21):5665–5672 • 5665

Behavioral/Systems/Cognitive

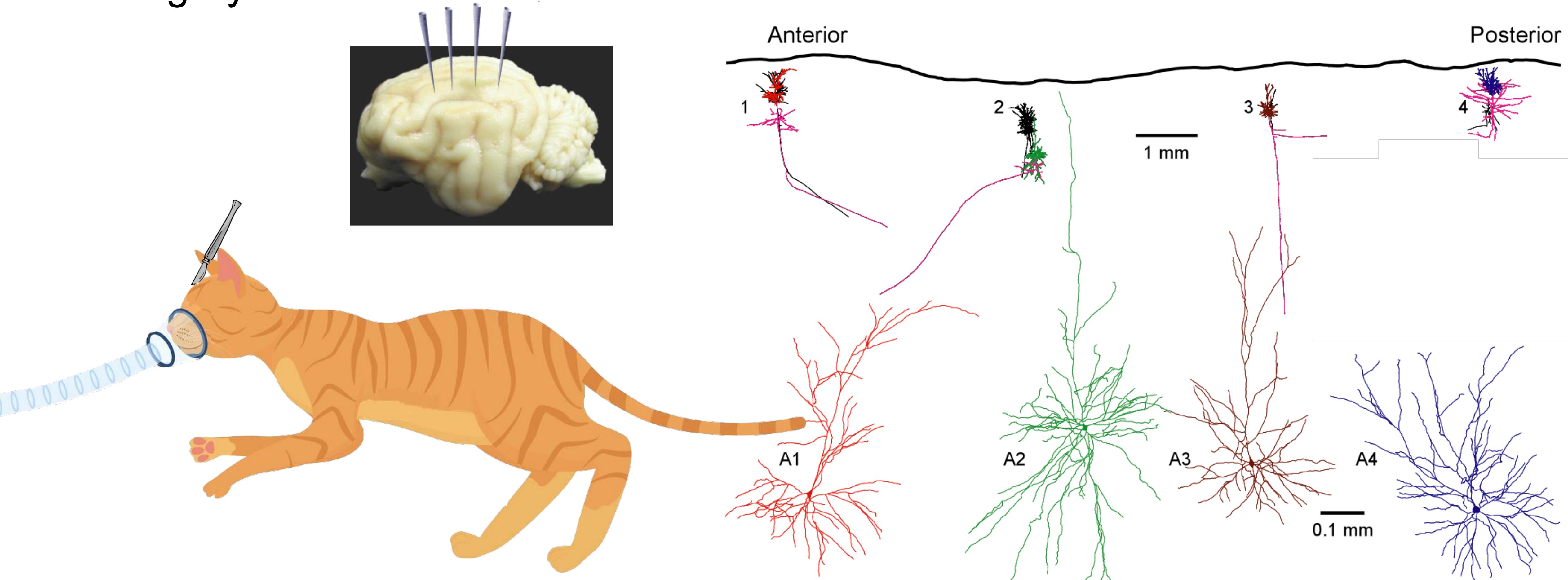
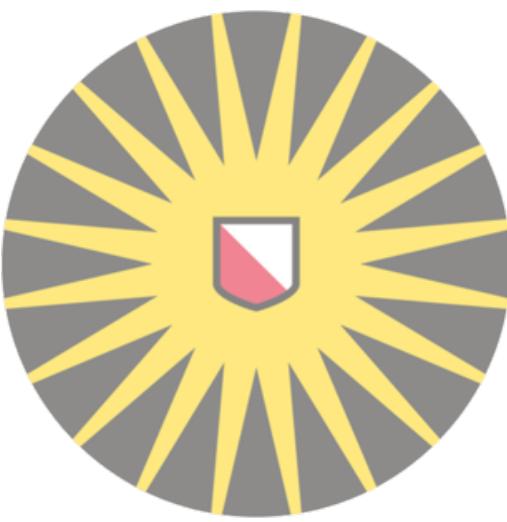
## Precise Long-Range Synchronization of Activity and Silence in Neocortical Neurons during Slow-Wave Sleep

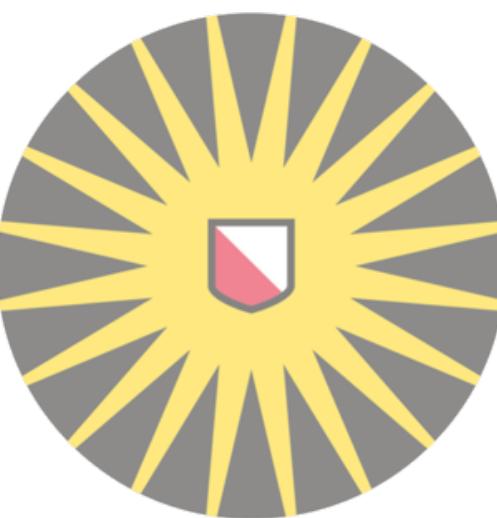
Maxim Volgushev,<sup>1,2</sup> Sylvain Chauvette,<sup>3</sup> Mikhail Mukovski,<sup>1</sup> and Igor Timofeev<sup>3</sup>

<sup>1</sup>Department of Neurophysiology, Ruhr-University Bochum, D-44780 Bochum, Germany, <sup>2</sup>Institute of Higher Nervous Activity and Neurophysiology, Moscow, 117485, Russia, and <sup>3</sup>Department of Anatomy and Physiology, Laval University, Québec, Québec, Canada G1K 7P4

# The article by Volgushev et al.

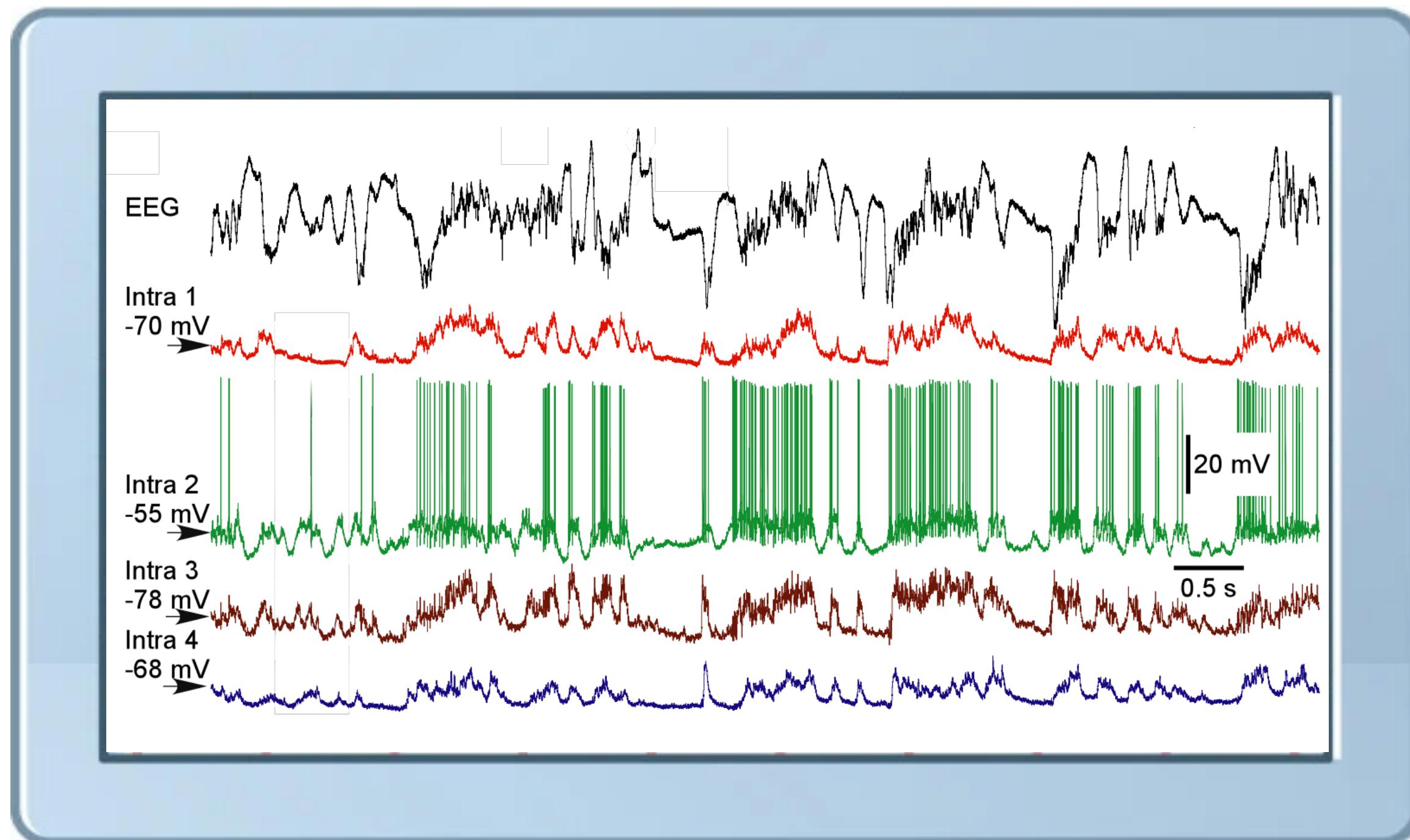
## Surgery



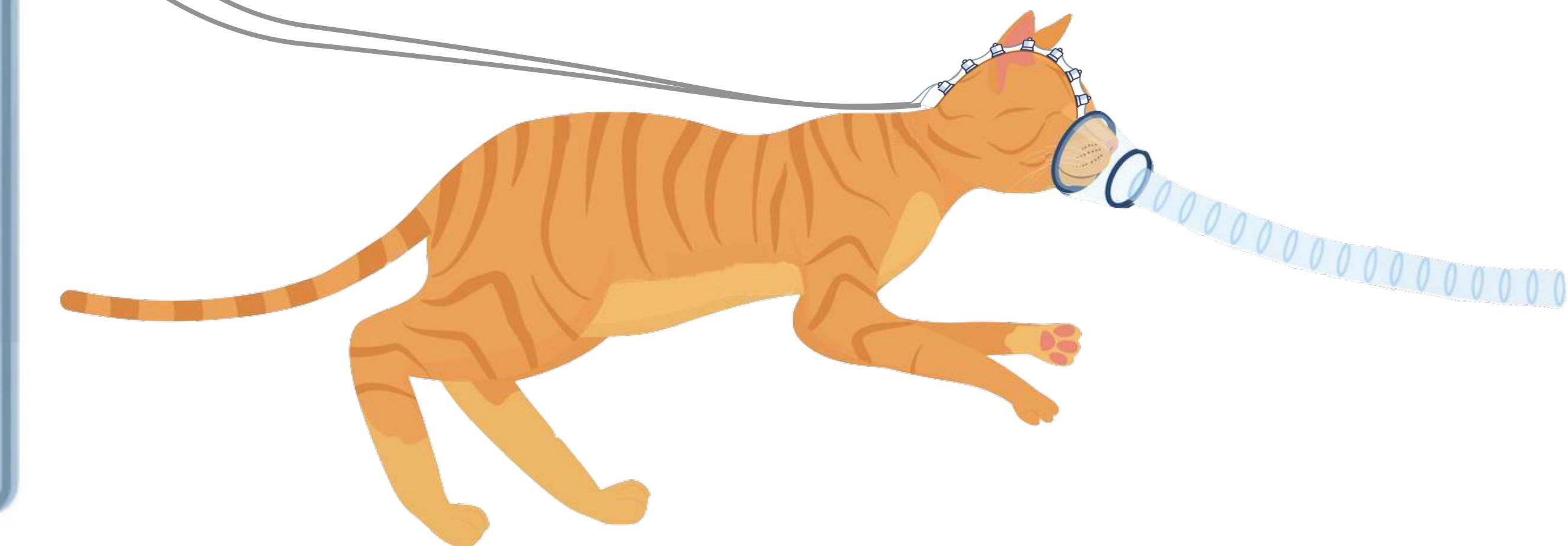


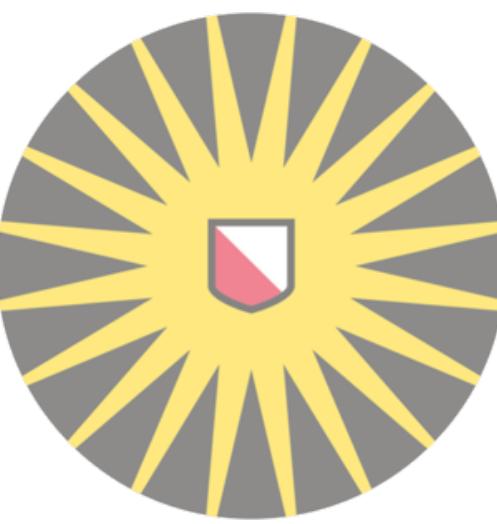
# The article by Volgushev et al.

## Recordings



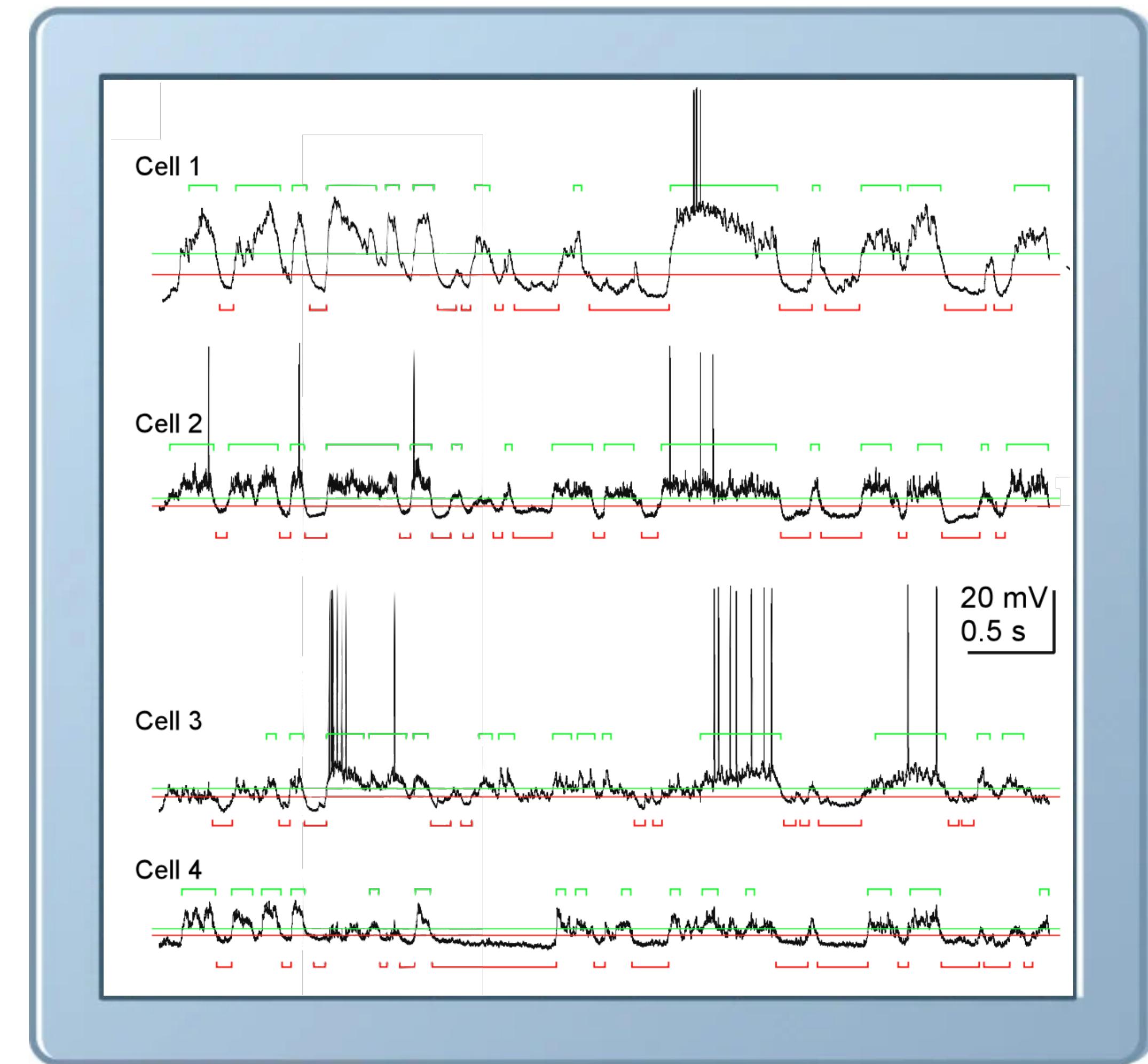
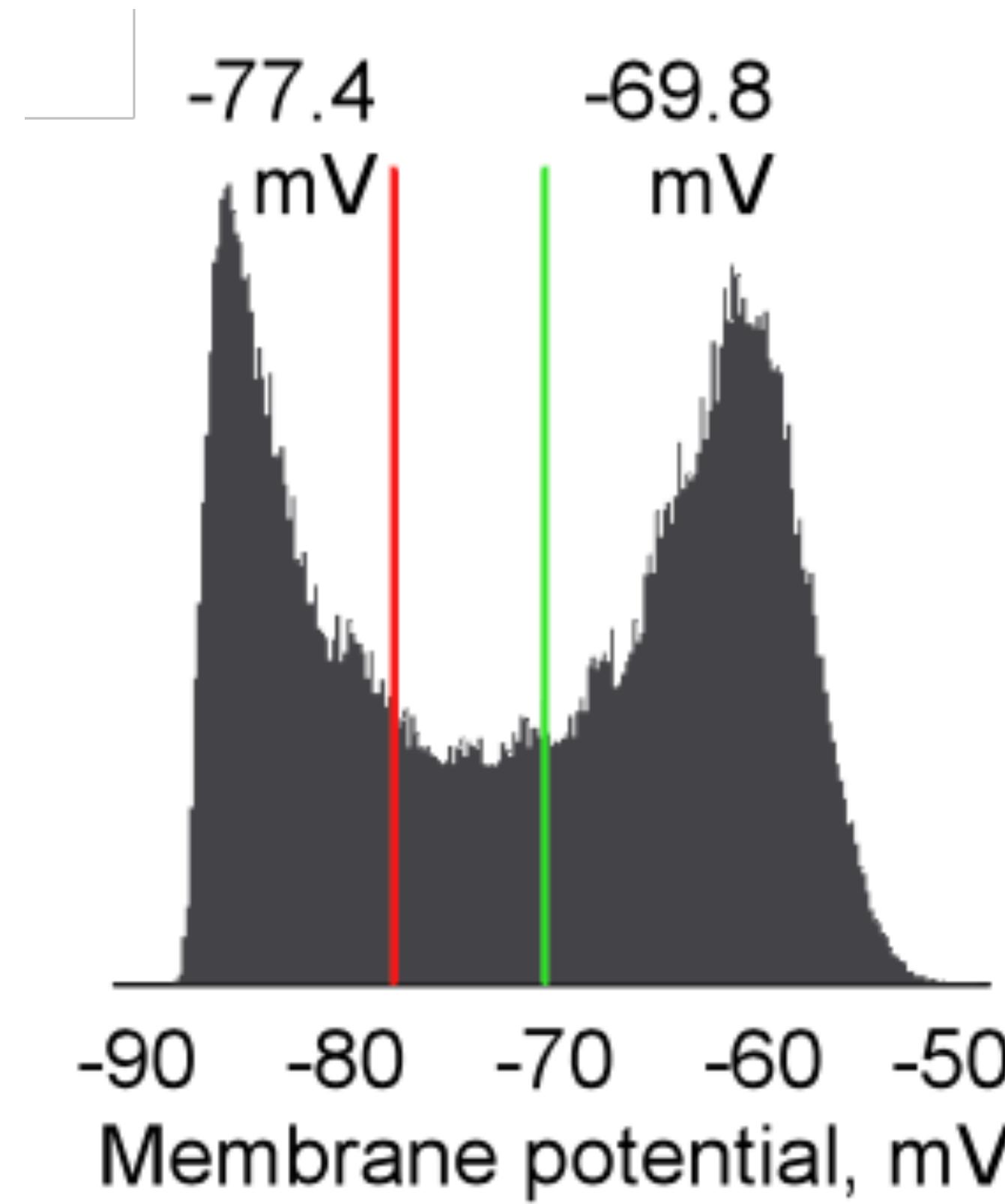
**Recording of**  
Local Field Potentials (LFPs)  
and intracellular activity



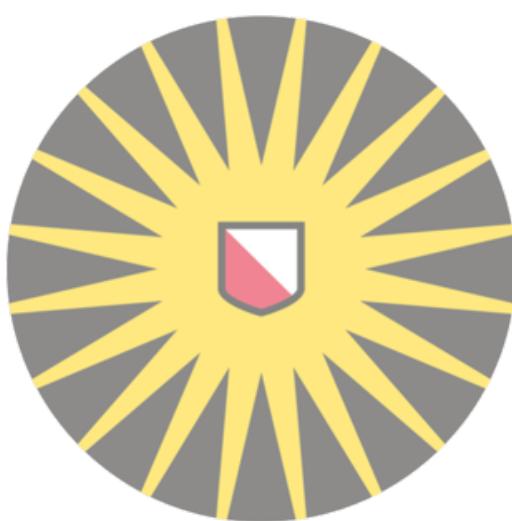


# The article by Volgushev et al.

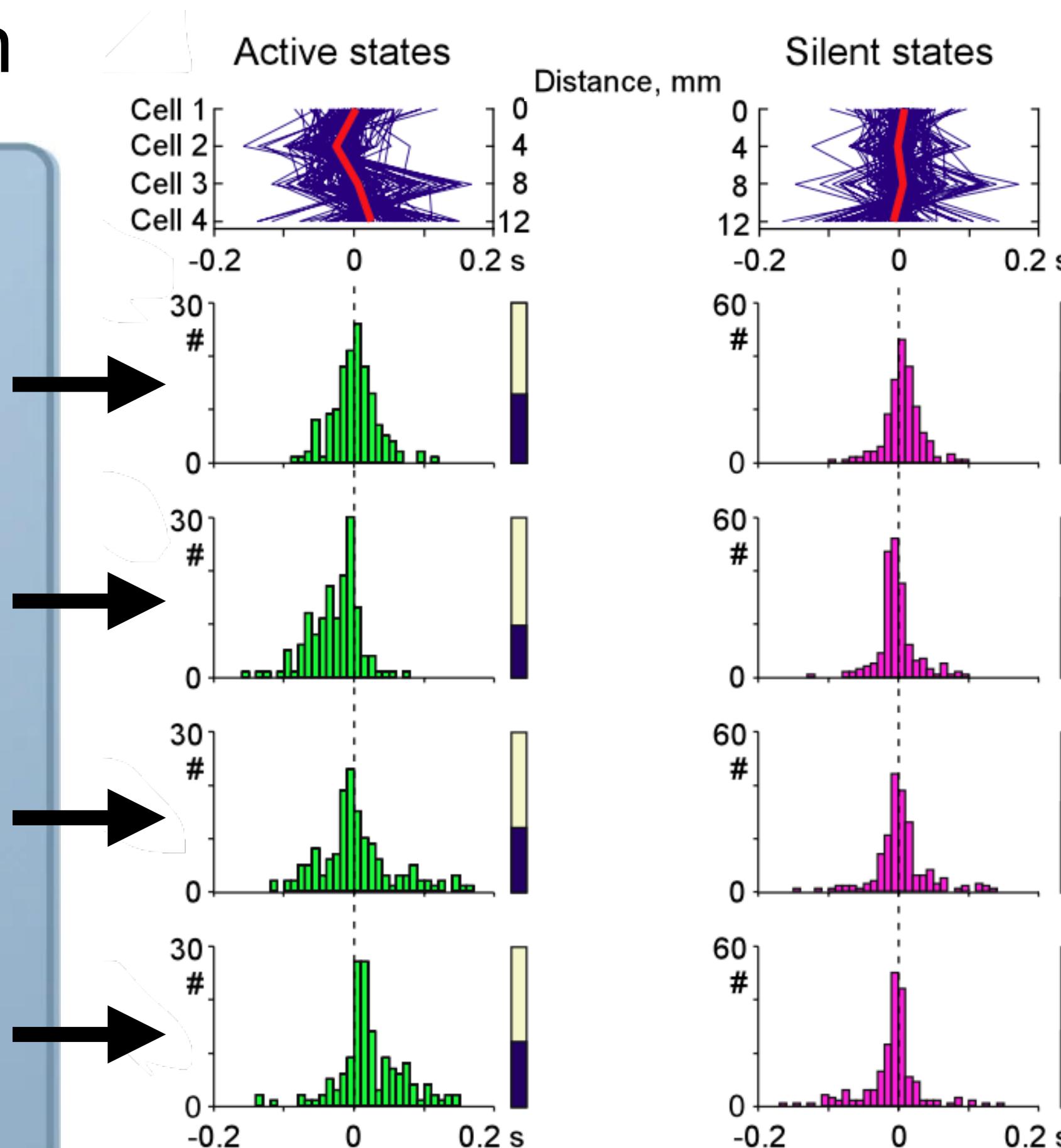
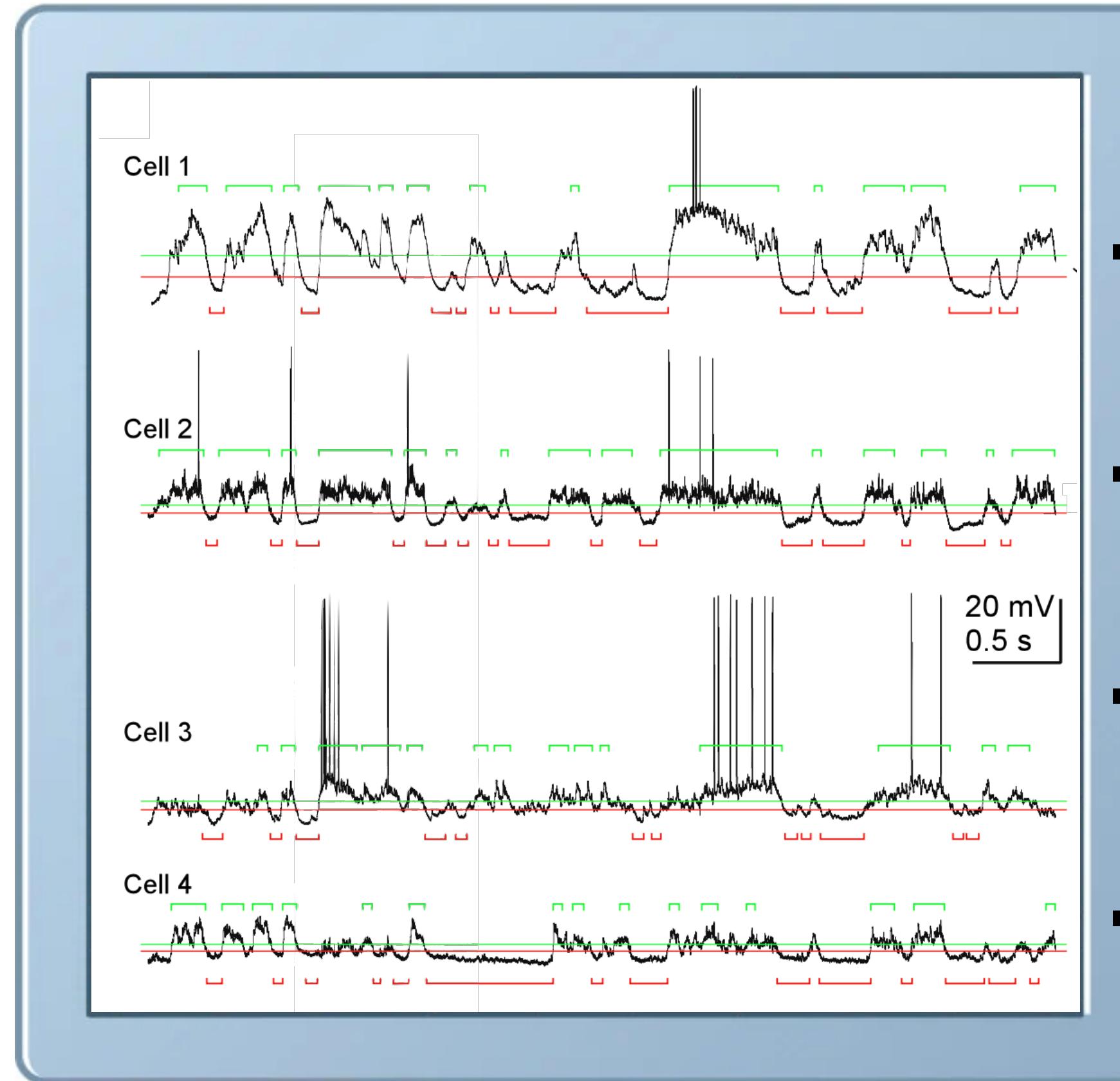
## State detection



# The article by Volgushev et al.

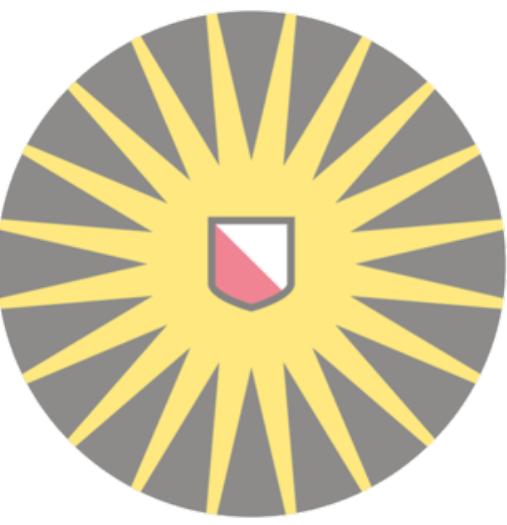


# Quantifying synchronization



# More precise synchronization in the silent state transition!

In state clusters, the SD of the onset delays is:  $39.8 \pm 11.0$  ms v.s.  $34.4 \pm 11.2$  ms



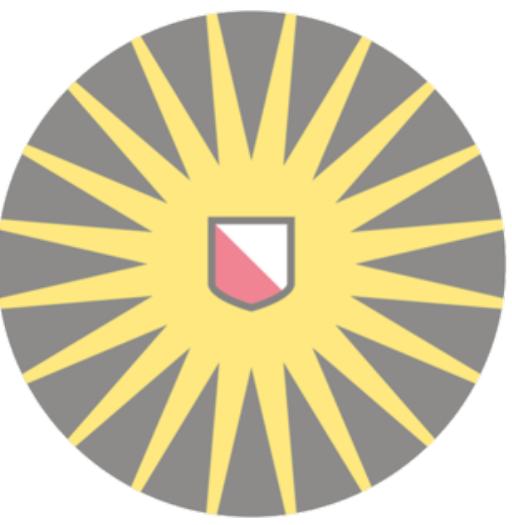
# The article by Volgushev et al.

## Conclusions

- **Goal:** to research of the underlying mechanisms of the alternation between periods of activity and silence in neocortical networks during slow-wave sleep.

## Main results

- Slow-wave oscillations in the membrane potential involves **all** neocortical neurons.
- The spread of states originates from a **local focus**.
- Onsets of **silent** states were **synchronized more precise** than the onsets of **activity** (over a 12-mm spatial area).



# My project

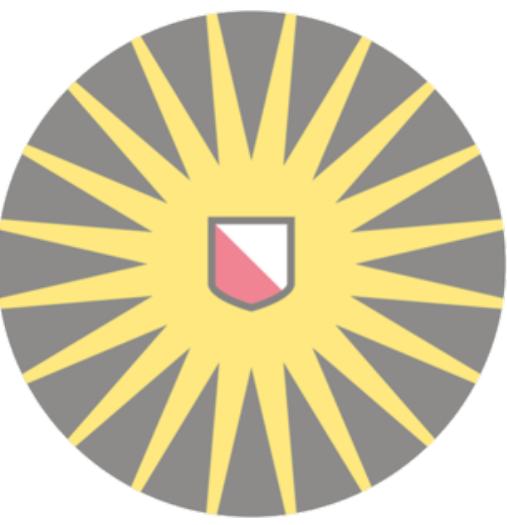
**Goal:** reproducing and confirming the results of the article by Volgushev et al. by performing numerical simulations.

**How:** using the excitatory-inhibitory population models from ‘*Mathematical foundations of neuroscience*’ (section 11.3.3) by Ermentrout, G. Bard, and David H. Terman.

$$\begin{cases} \tau_e \dot{u}_e = -u_e + F(w_{ee}u_e - w_{ei}u_i + I_e) \\ \tau_i \dot{u}_i = -u_i + F(w_{ie}u_i - w_{ii}u_i + I_i) \end{cases}$$

→  $F(x) = \frac{1}{1 + e^{-x}}$

$$\tau_e = 5, \tau_i = 3, w_{ee} = 16, w_{ie} = 24, w_{ei} = 10, w_{ii} = 6, I_e = -3.7 \text{ and } I_i = -6.7$$



# My project

**Goal:** reproducing and confirming the results of the article by Volgushev et al. by performing numerical simulations.

**How:** using the excitatory-inhibitory population models from ‘*Mathematical foundations of neuroscience*’ (section 11.3.3) by Ermentrout, G. Bard, and David H. Terman.

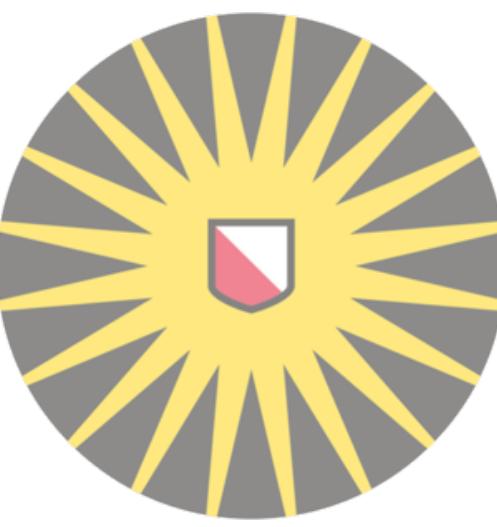
$$\dot{u}_j = \frac{-u_j + F(w_{ee}\bar{u}_j - w_{ie}\bar{v}_j + I_e) + \eta_j}{\tau_e}$$

$$\bar{u}_j = (1 - c_e)u_j + \frac{c_e}{2}(u_{j+1} + u_{j-1})$$

$$\dot{v}_j = \frac{-v_j + F(w_{ei}\bar{u}_j - w_{ii}\bar{v}_j + I_i) + \zeta_j}{\tau_i}$$

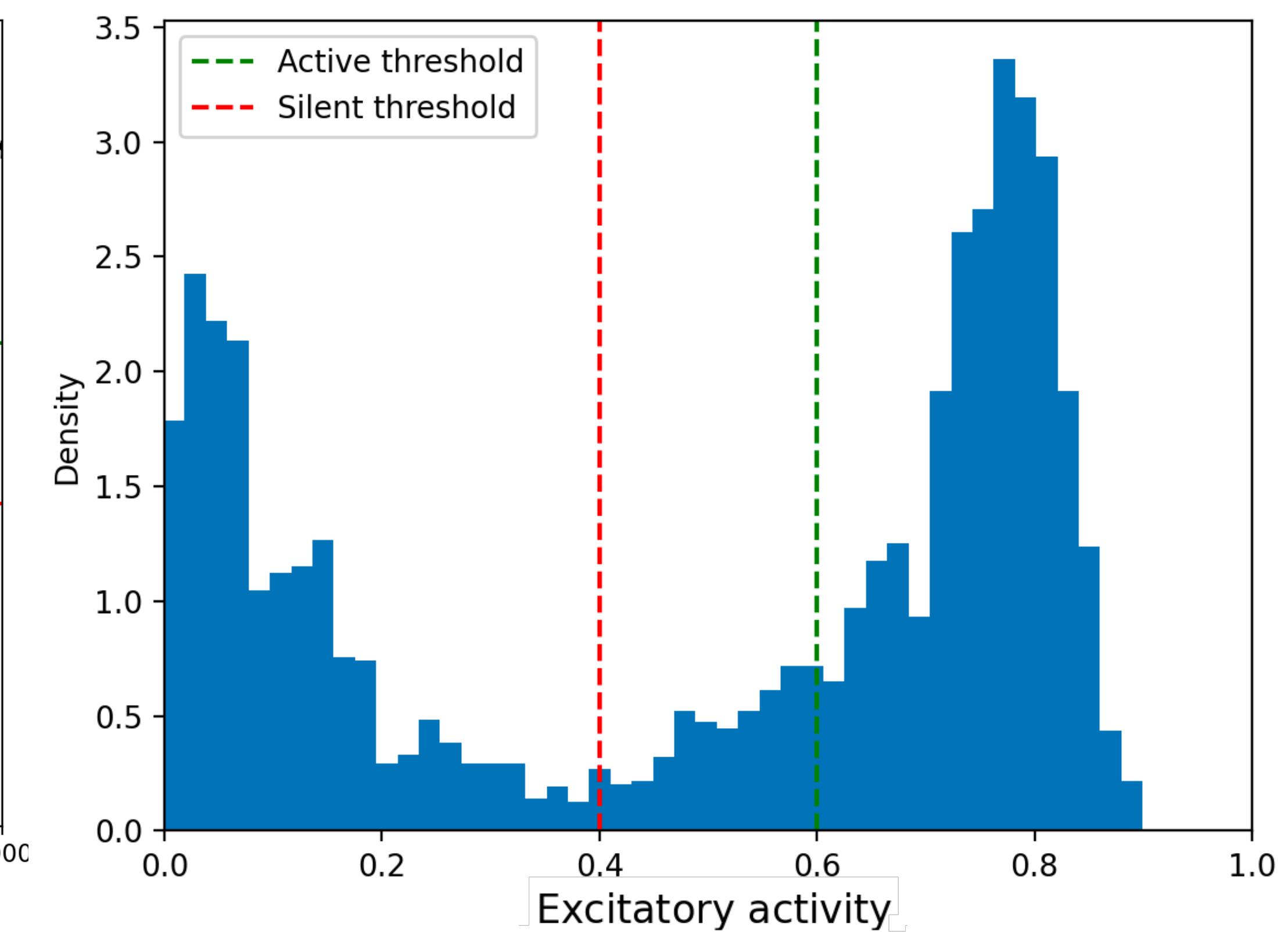
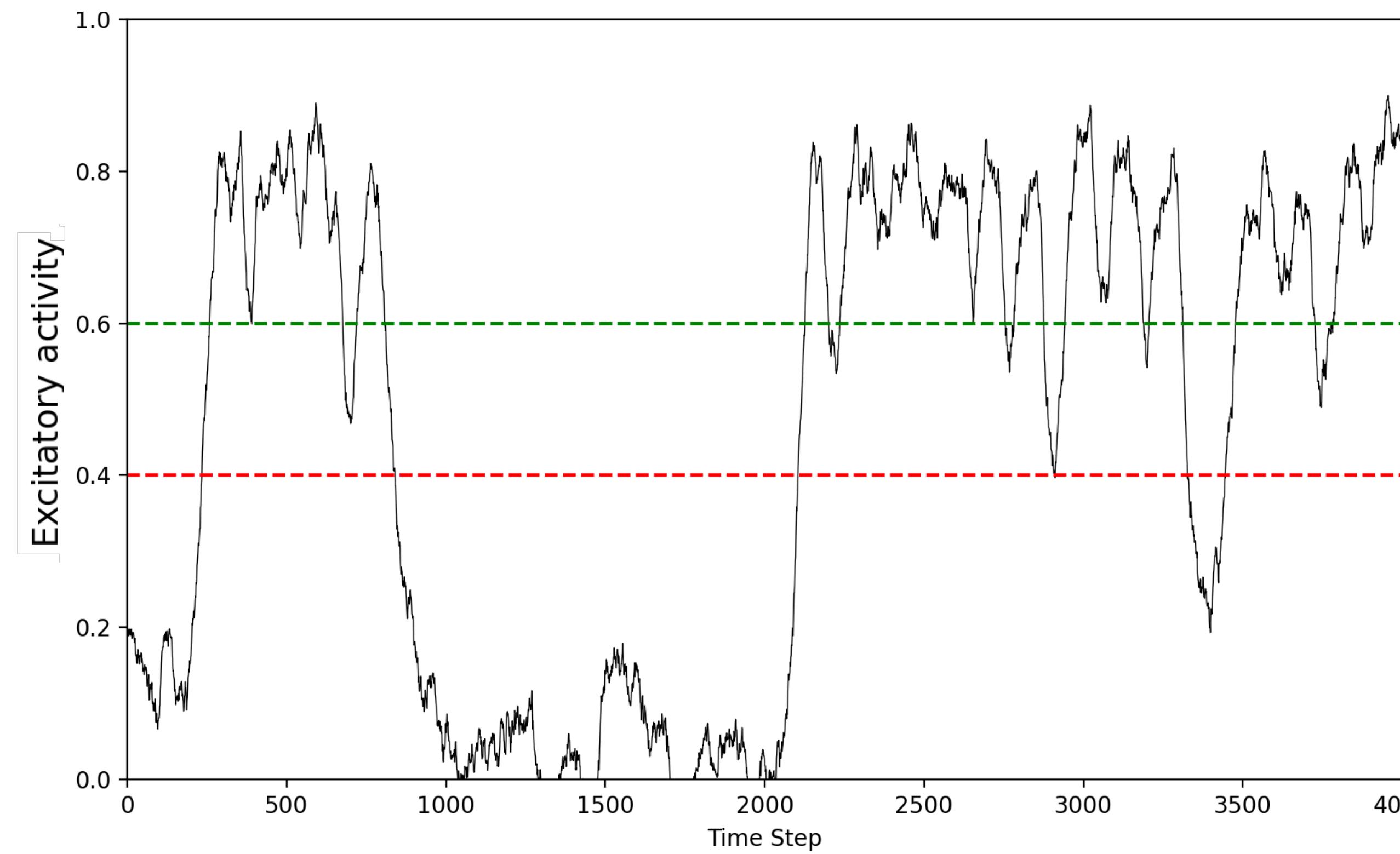
$$\bar{v}_j = (1 - c_i)v_j + \frac{c_i}{2}(v_{j+1} + v_{j-1})$$

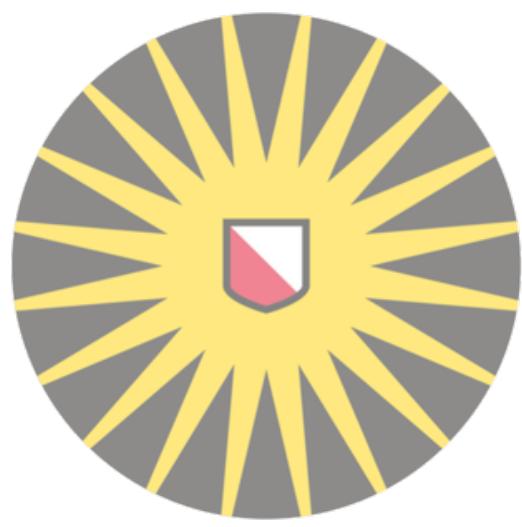
$$\tau_e = 5, \tau_i = 3, w_{ee} = 16, w_{ie} = 24, w_{ei} = 10, w_{ii} = 6, I_e = -3.7 \text{ and } I_i = -6.7$$



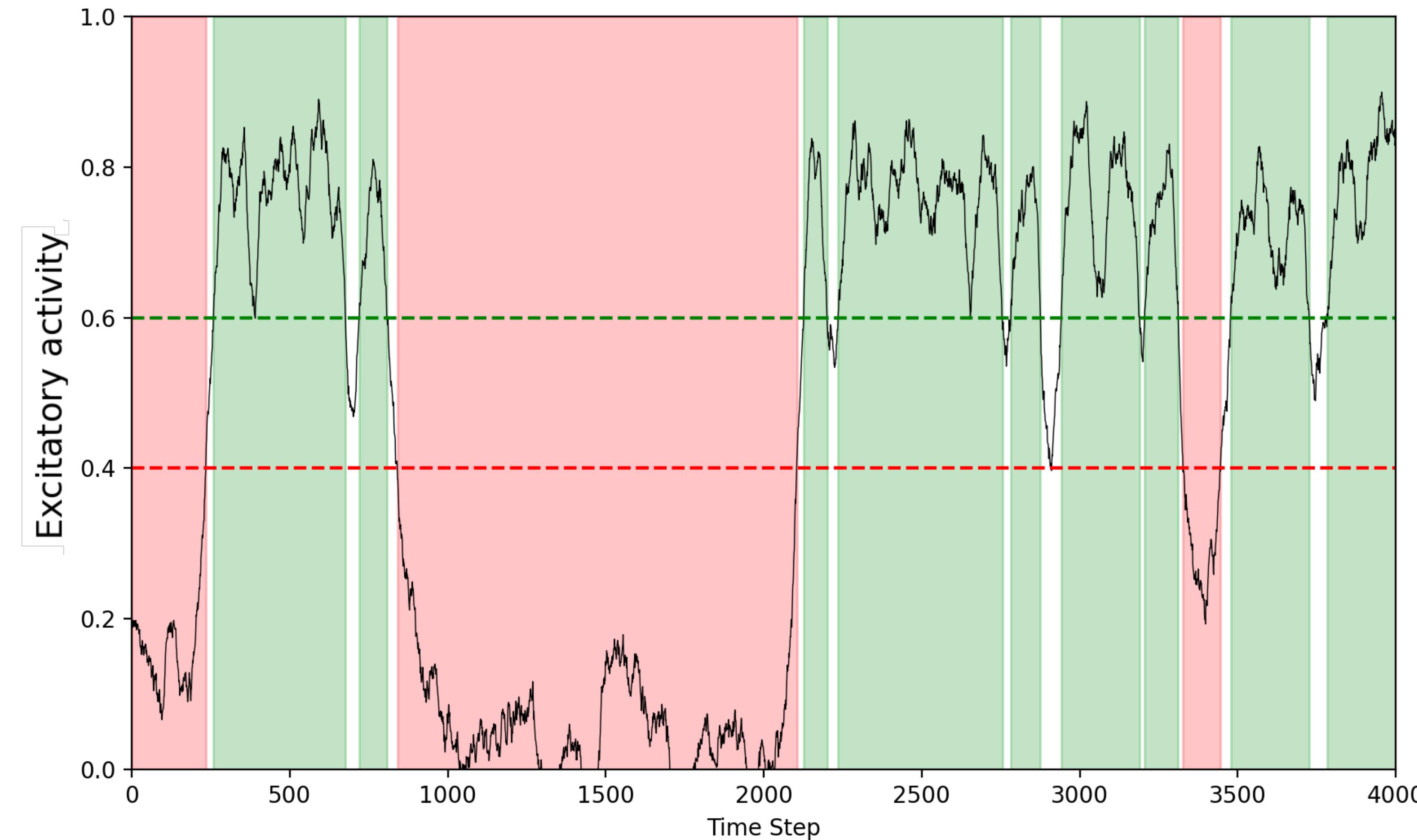
# My project

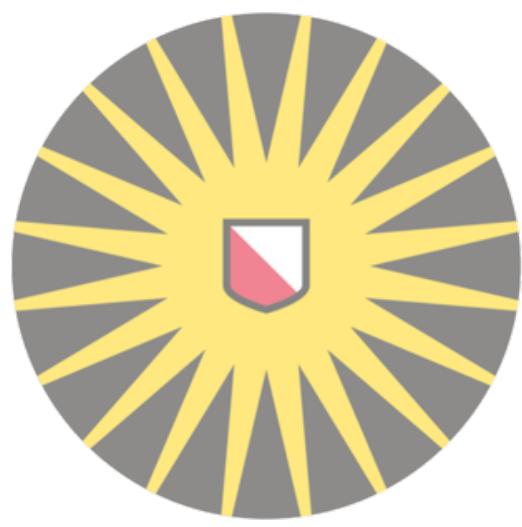
$$c_e = 5, c_i = 5, \text{noise} = 0.4$$



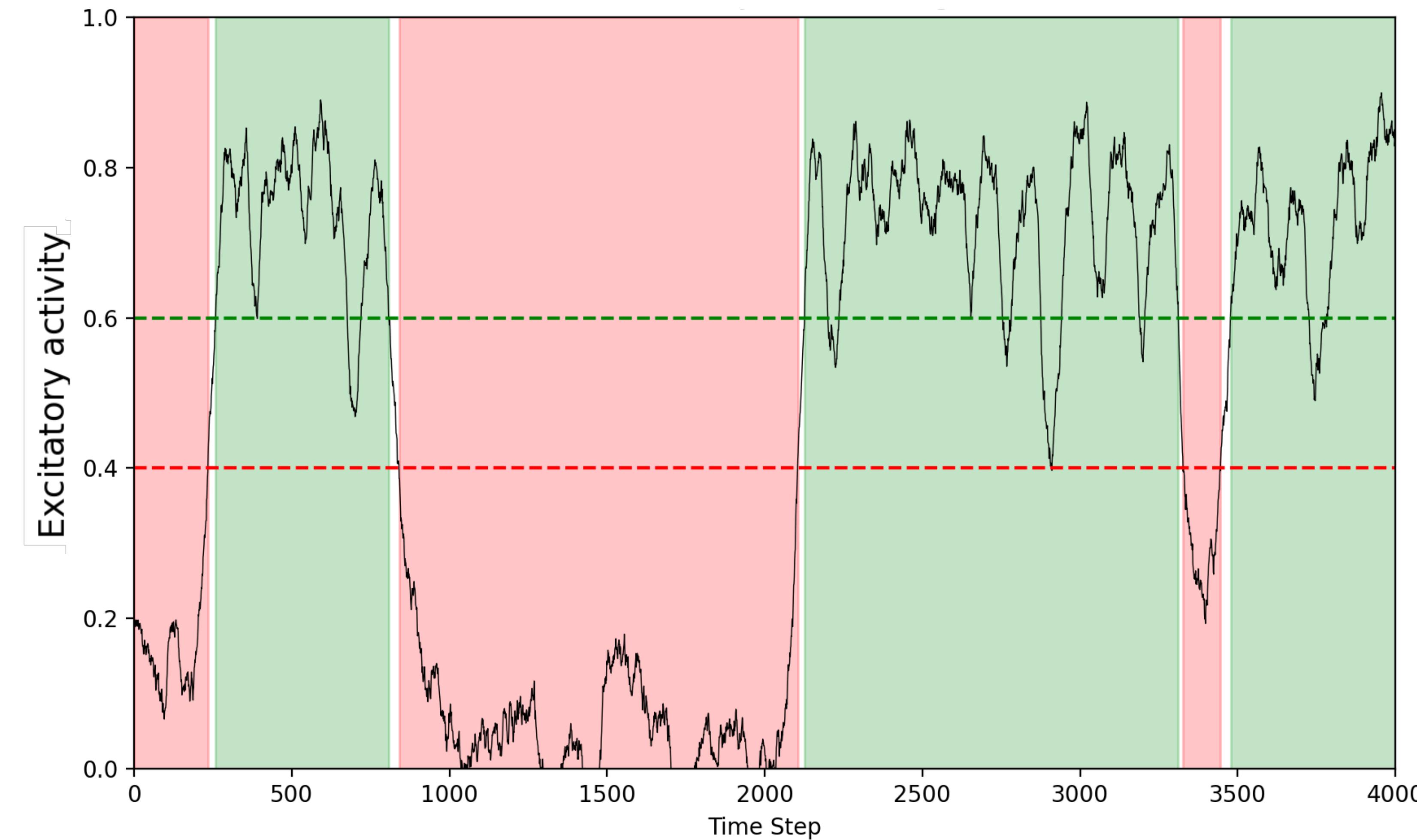


# My project

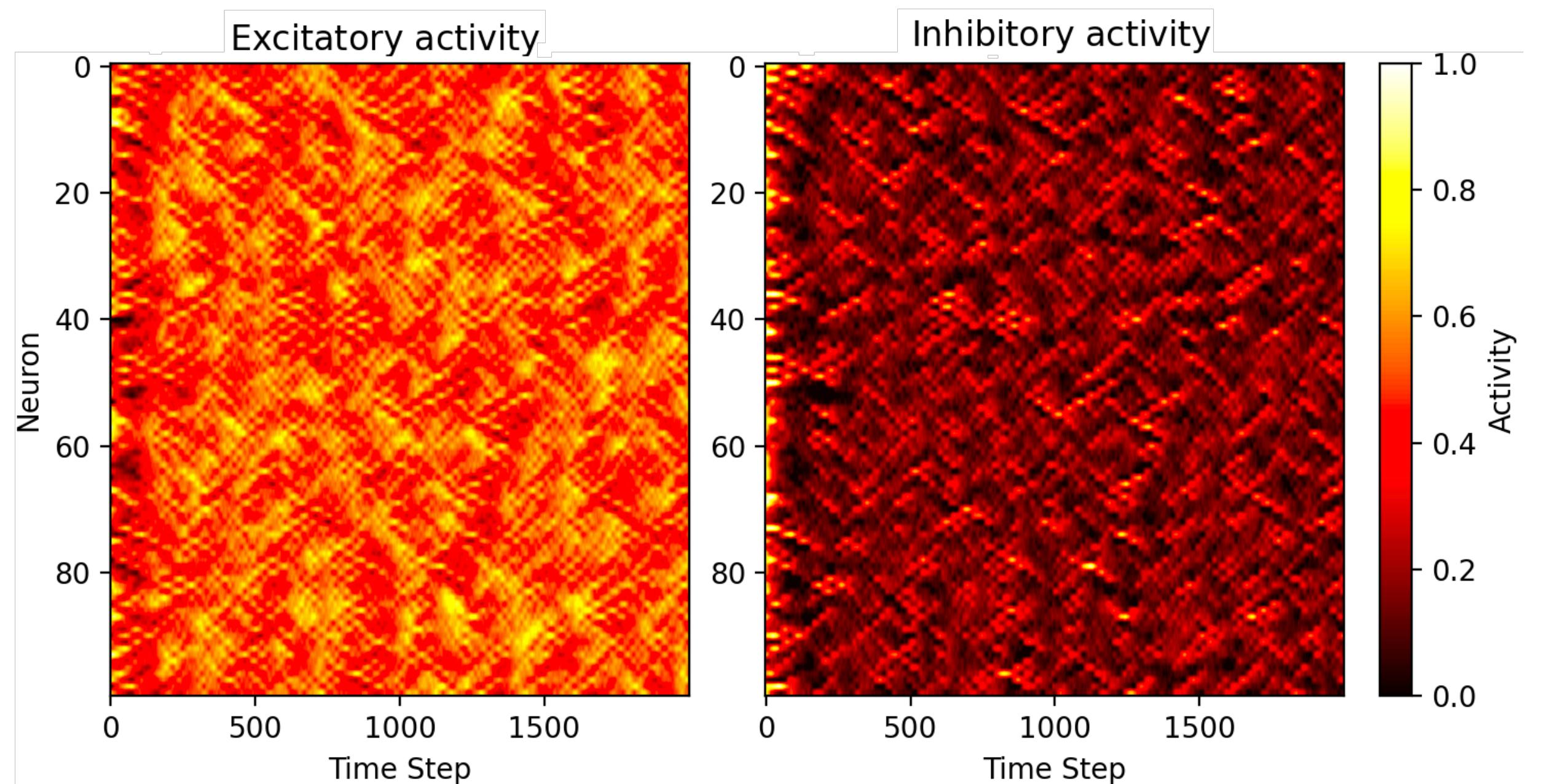
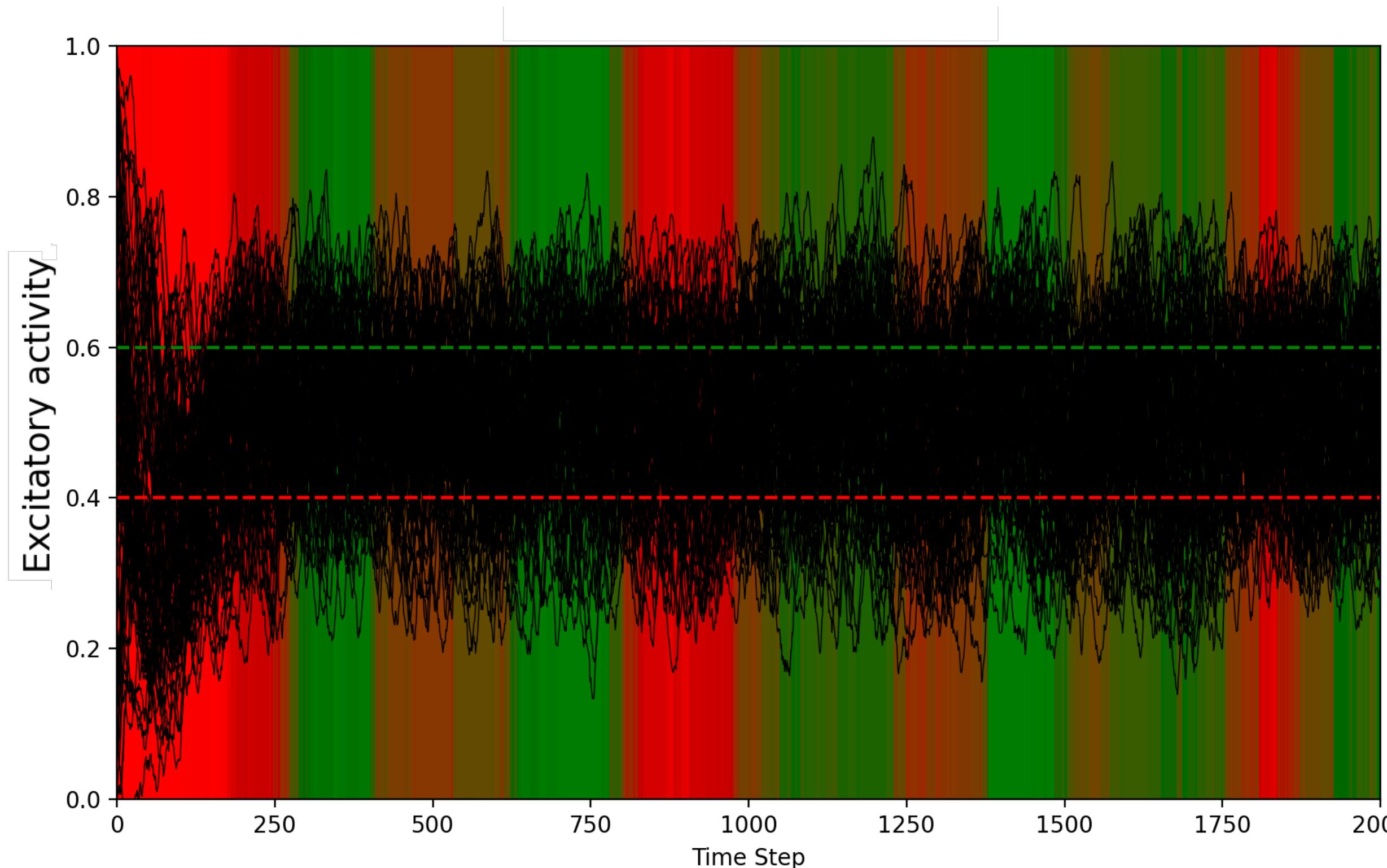
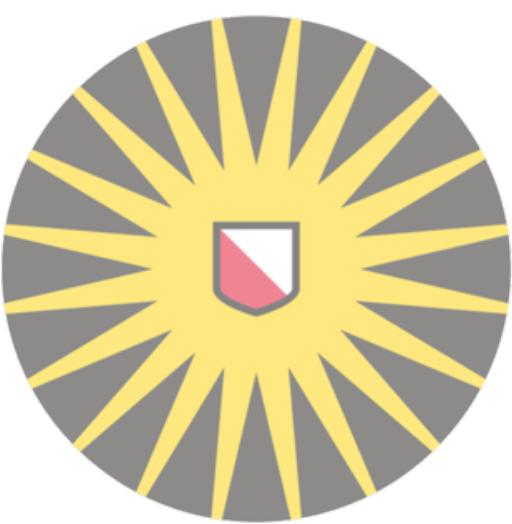




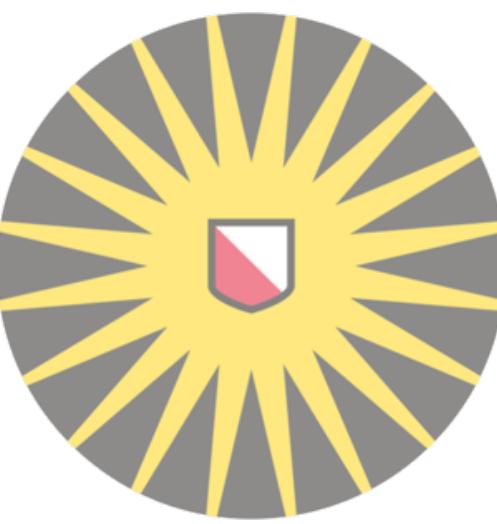
# My project



# My project

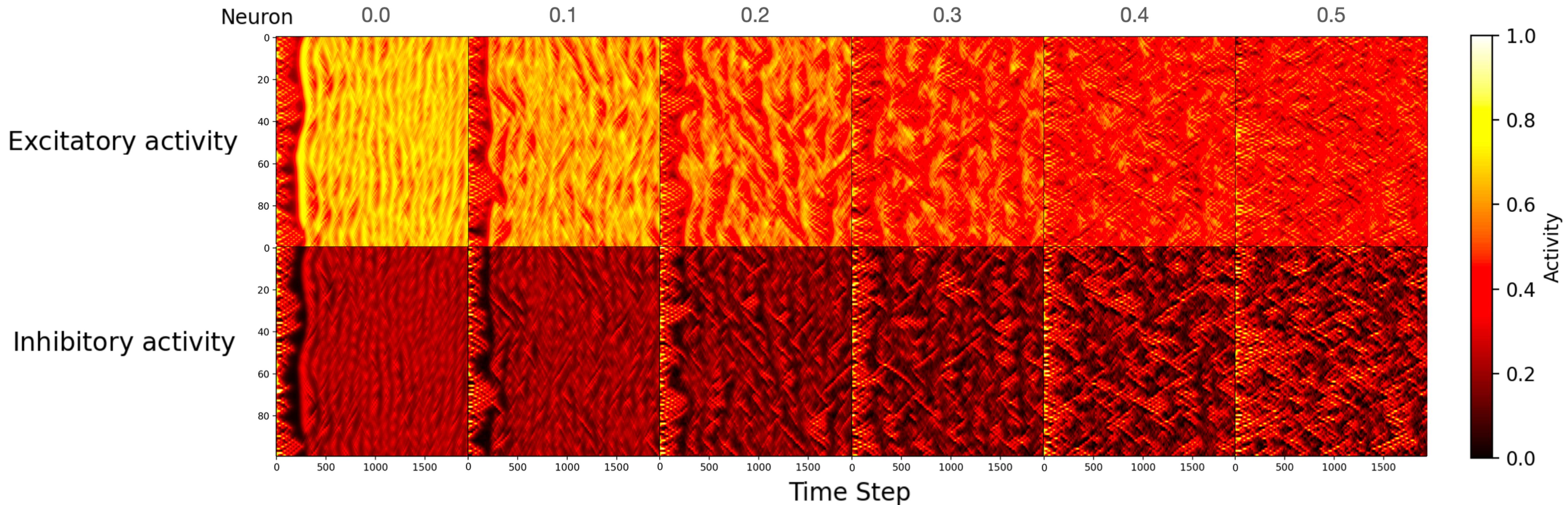


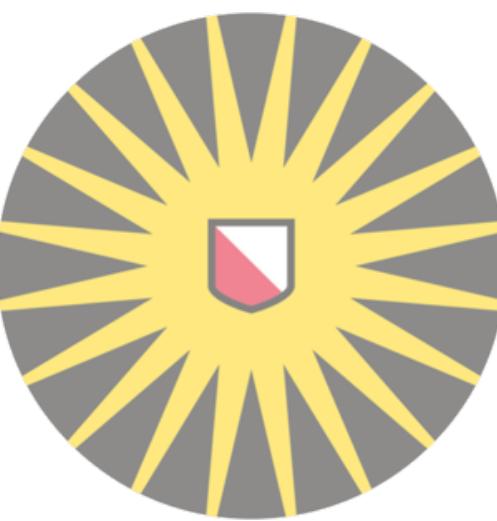
active state SD averaged over 100 seeds: 315.36 time steps  
silent state SD averaged over 100 seeds: 292.93 time steps



# My project

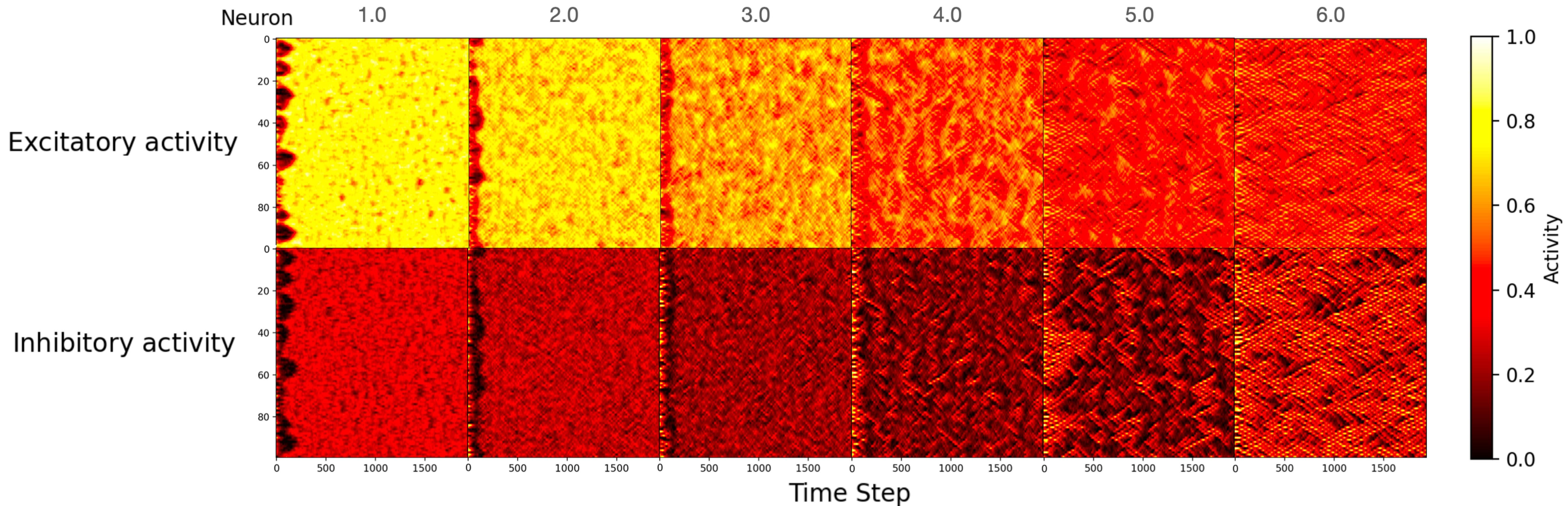
## Varying noise

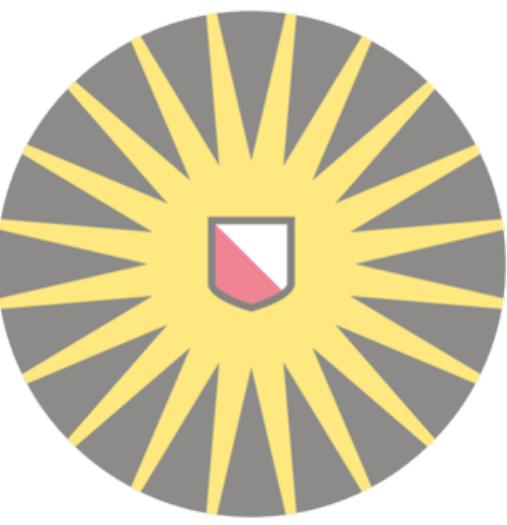




# My project

## Varying coupling





# My project

## Conclusions

- **Goal:** reproducing and confirming the results of the article by Volgushev et al. by using the excitatory-inhibitory model.

## Main results

- The onset of activity laterally propagates to neighboring neurons using EI-population models.
- The smaller standard deviation for onset delays of silent states relative to active states → higher degree of synchronization in the silent state transition.
- Increasing noise induced more spontaneous state switching.
- Stronger coupling elongated the duration of the laterally propagating states.

Questions?