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Large scale modeling of the mouse brain dynamics

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Introduction

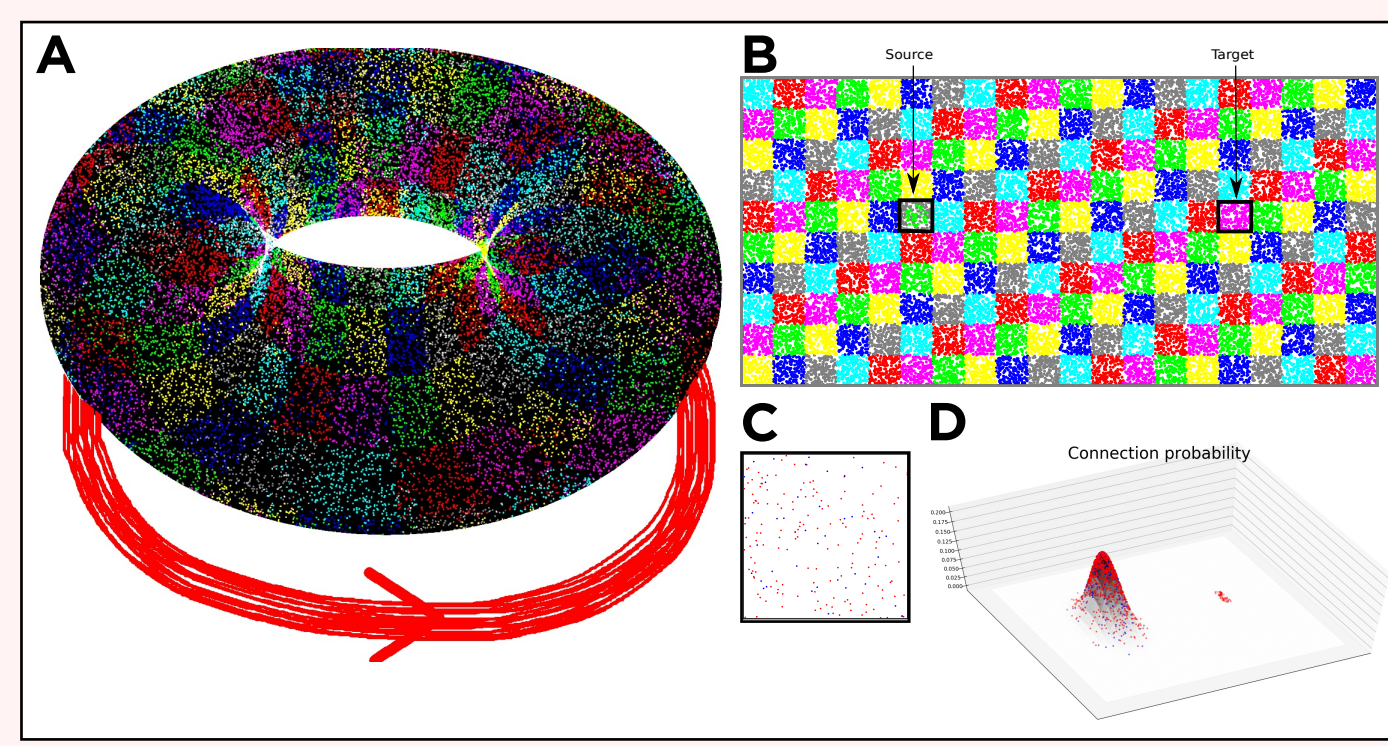
To bridge the large-scale brain modelling to spiking neural network, first we need to characterize the impact of the heterogeneous connectivity for the overall dynamics. In particular, we study how the network synchronization is affected by these connections. This is the first step for understanding the mechanisms behind the large-scale simulation of the connectome.

Model

Spiking neuron :

The model is adaptive exponential leaky integrate and fire with a refractory period of 2.0ms and alpha conductance synapse. The chosen parameters are the default Nest parameters.^{1,5}

Network Tology :



Network topology of the network.² A The network topology is a torus with long range connection. B The same network can be represented by a grid with double periodic boundary conditions. C Each cell of the grid contains 160 excitatory neurons (red) and 40 inhibitory neurons (blue). D How a neuron connects is prescribed by a two-dimensional Gaussian probability function with a standard deviation of $\sigma_e = 0.8$ for the excitatory connectivity and $\sigma_i = 1.2$ for the inhibitory synapses. This neuron is part of the source population, in consequence it also has some connection to the target population.

Metrics :

$$\text{Mean firing rate : } f_{\text{mean}} = \frac{\sum \# \text{spike}}{\# \text{neurons} \cdot t}$$

$$\text{Coefficient of variation : } C_V = \frac{\sigma}{\mu}$$

View spiking neurons has oscillator³ :

$$z(t) = R(t) \exp(i\phi(t))$$

$$\equiv \frac{1}{N} \sum_{j=1}^N \exp(i\psi_j(t))$$

with $\psi_j(t) = 2\pi m + 2\pi \frac{t - t_{j,m}}{t_{j,m+1} - t_{j,m}}$ where $t_{j,m}$ corresponds to the time when a spike m of a neuron j happens.

• Mean phase : $\psi_j(t)$

• Mean phase velocity : $\dot{\psi}_j(t)$

• Phase coherence or Kuramoto parameter: $R(t)$

• Mean phase coherence :

$$\bar{R} = \frac{1}{t_{\text{end}} - t_{\text{init}}} \sum_{t_{\text{init}}}^{t_{\text{end}}} R(t)$$

• Phase locking value complex⁴:

$$PLV c_i(t) = \frac{1}{N} \sum_{j=1}^N \exp(i(\psi_j(t) - \psi_i(t)))$$

• Phase locking value:

$$PLV_i = \frac{1}{t_{\text{end}} - t_{\text{init}}} \sum_{t_{\text{init}}}^{t_{\text{end}}} |PLV c_i(t)|$$

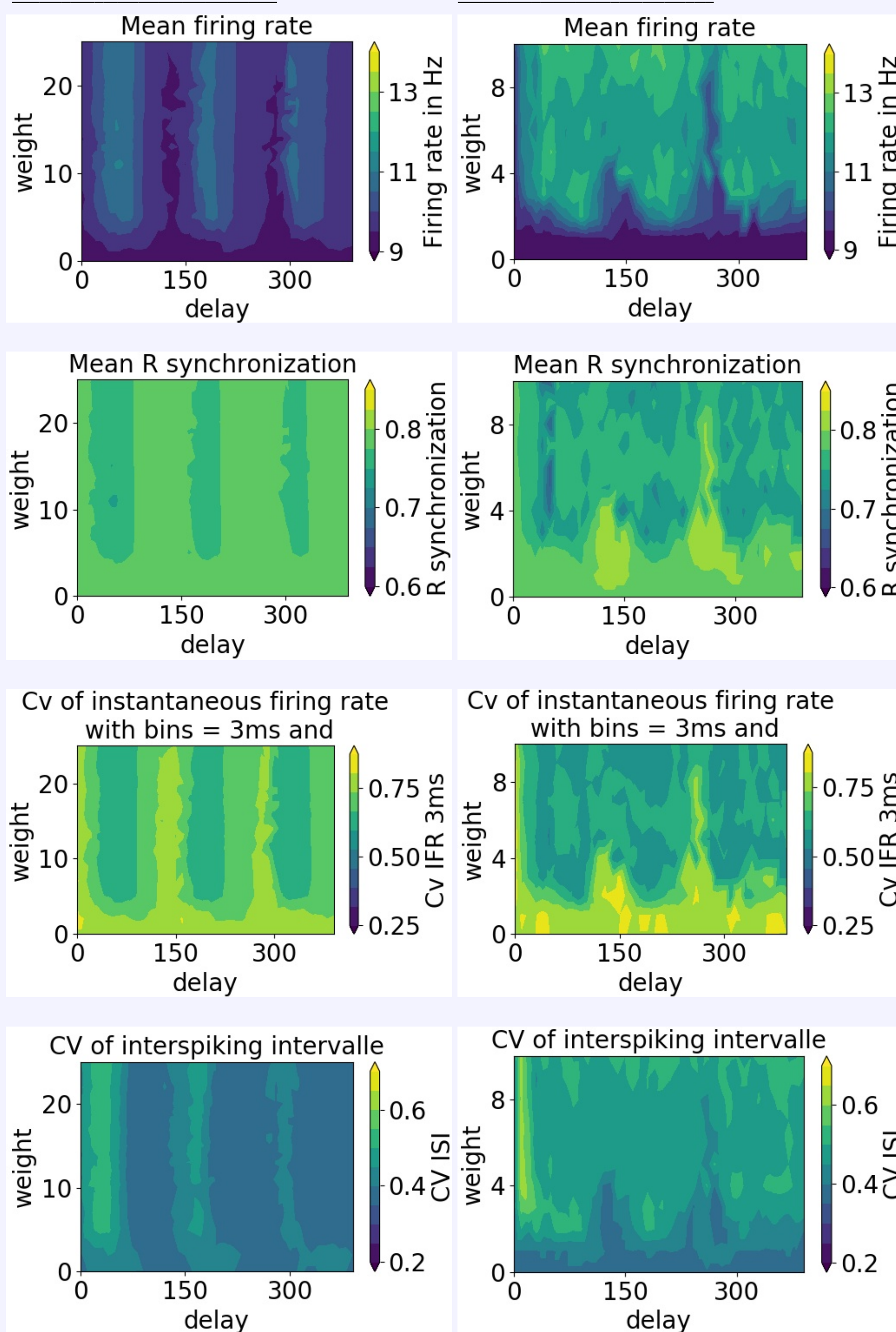
• Mean Phase difference:

$$\Delta\phi_i = \frac{1}{t_{\text{end}} - t_{\text{init}}} \sum_{t_{\text{init}}}^{t_{\text{end}}} \arg(PLV c_i(t))$$

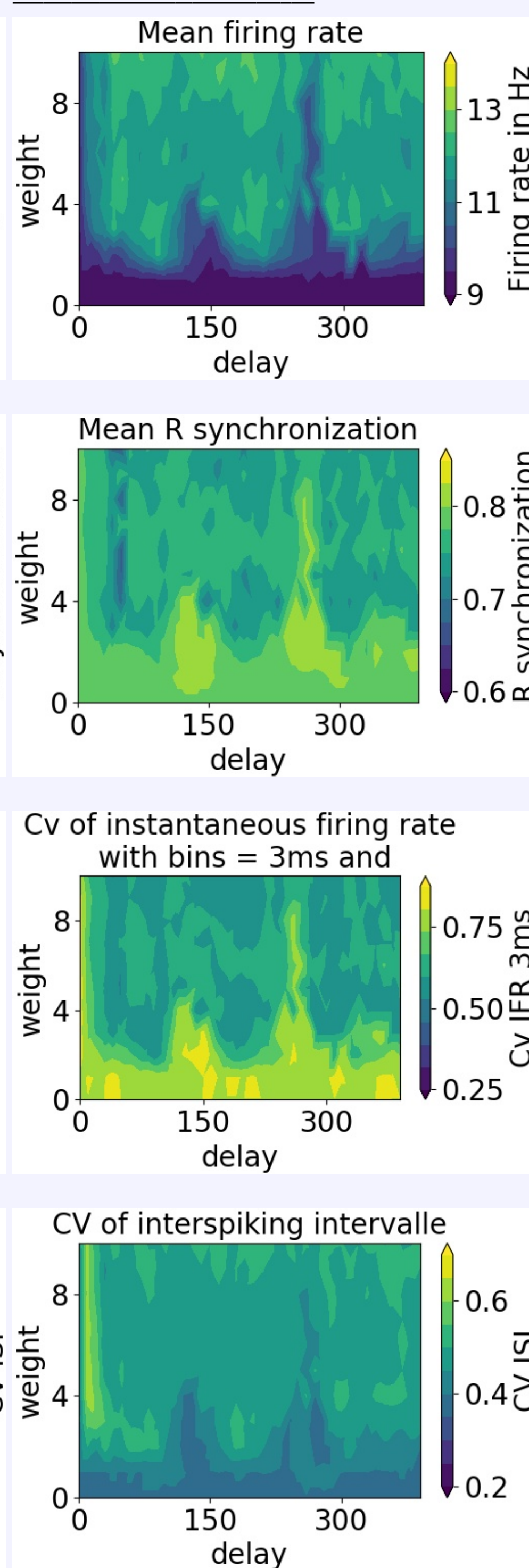
nest:
simulated()

Results

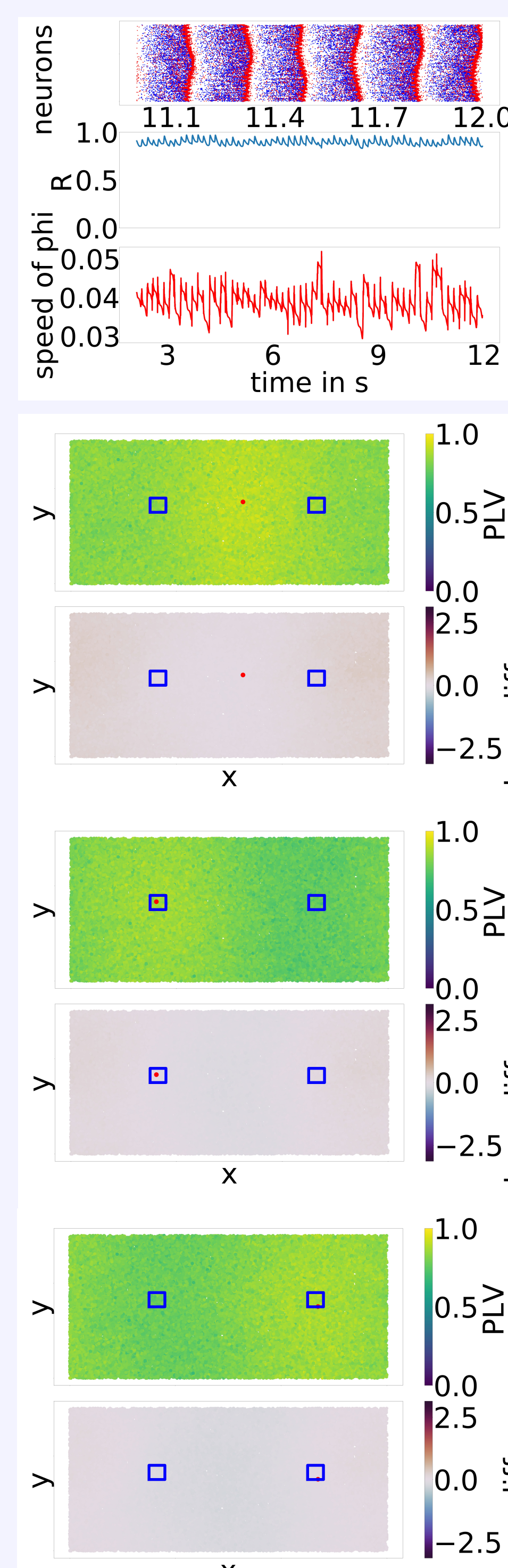
Unidirectional :



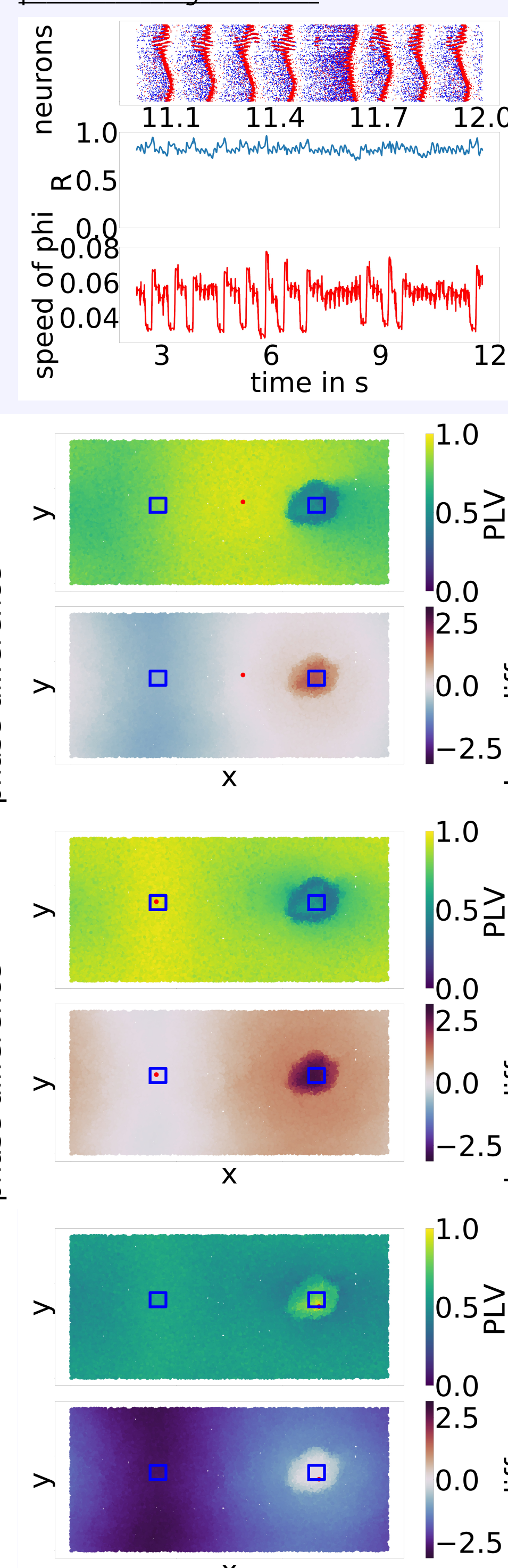
Bi-directional :



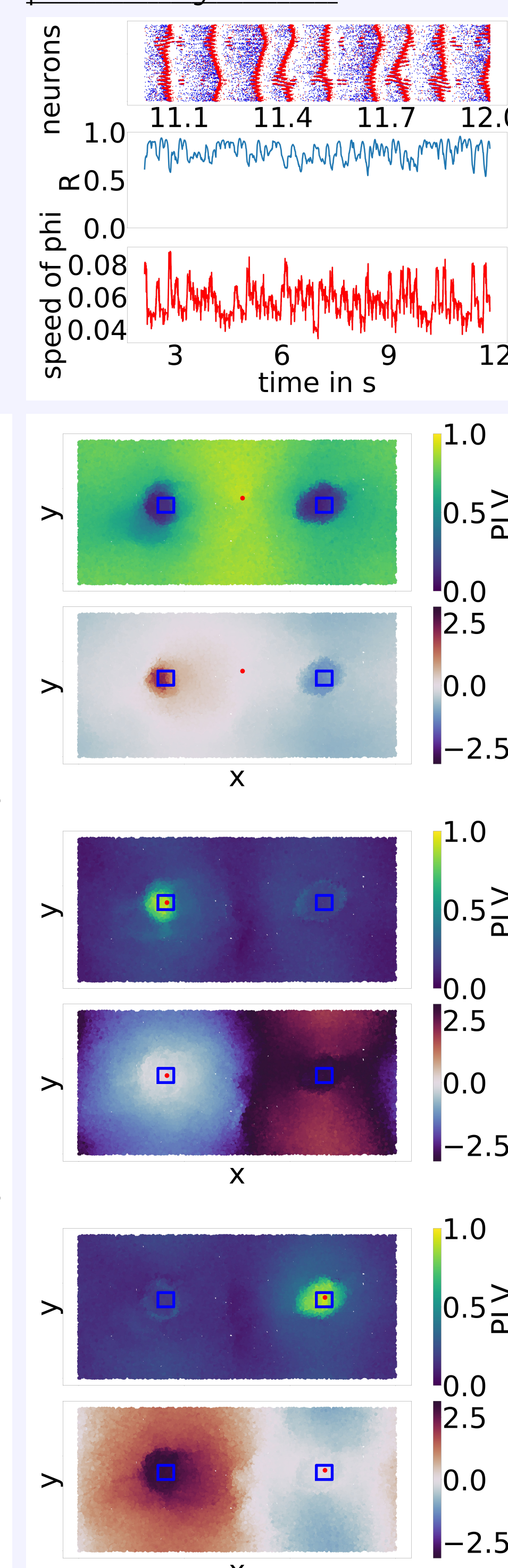
sync. :



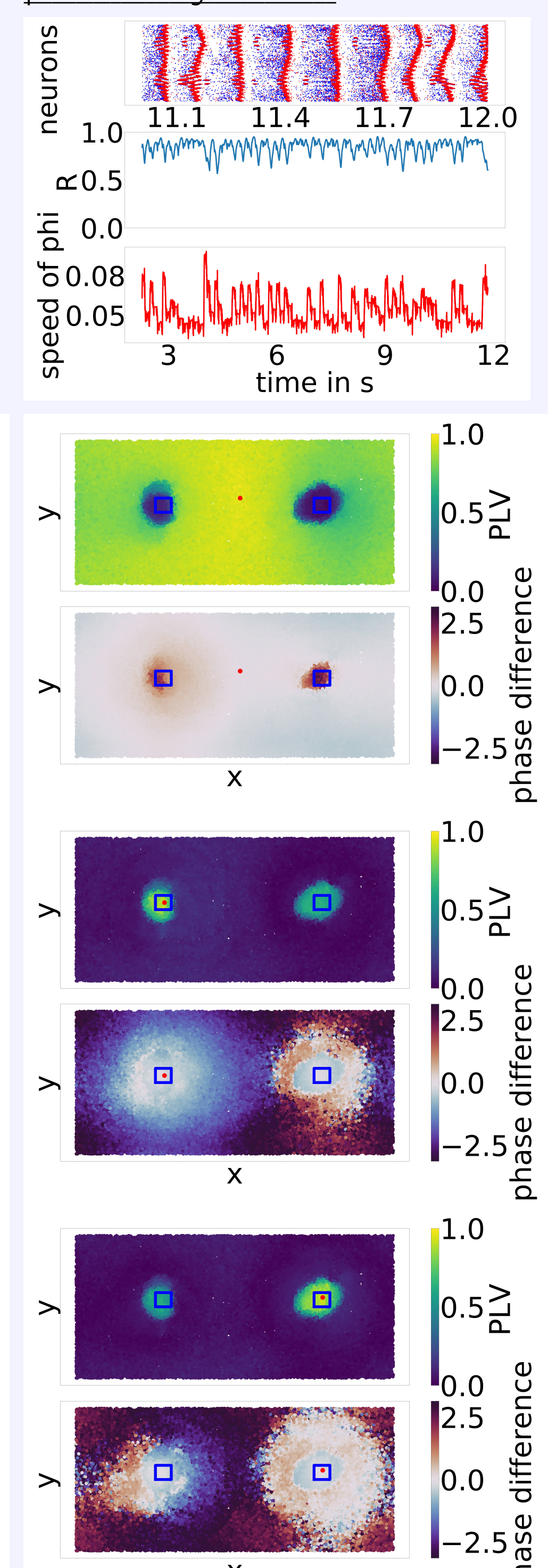
partial sync. 1 :



partial sync. 2 :



partial sync. 3 :



Conclusion:

The long-range connections desynchronize the neurons around receptors of these connections.

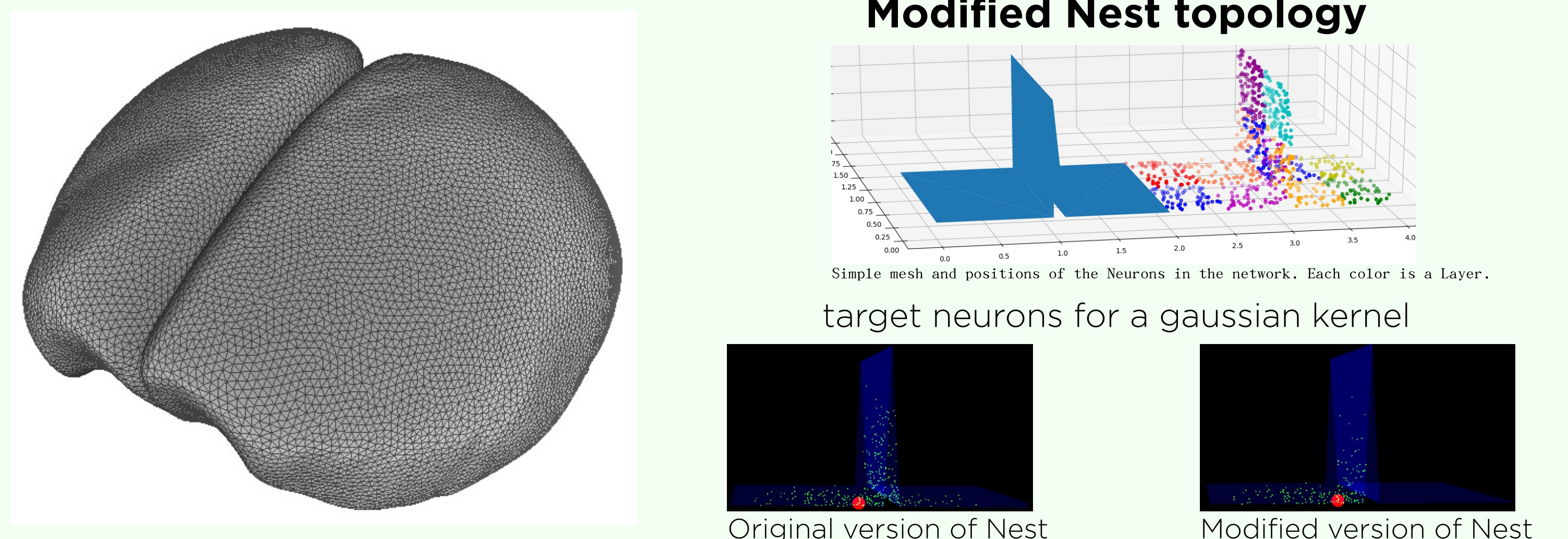
For the unidirectional long-range connection the network is synchronized when the delay along this is at $\sim 1/f_{\text{mean}}$ of the homogeneous network, which is 7.6Hz.

For the bidirectional case, the result is more complex because there are two populations receptors, and hence, three states are possible:

- all neurons are synchronized (sync.)
- the two receptor populations are synchronized between them but not with the rest of the network (partial sync. 1).
- the two receptors population are desynchronized between them and with the rest of the network (partial sync. 2)..

Future perspectives : Mouse brain cortical surface simulation⁷

We have shown the impact of the heterogenous connections on the synchronization of networks of spiking neurons. The results also unveil a possible a working point for the simulation of the mouse whole-brain dynamics that contains the parameters for the neurons and the ratio between the global and local connectivity. This should allow simulation of large scale brain mouse using the particularity of the shape of the iso-cortex⁷ and the structural connectivity⁶. The whole-brain model would require modification of the module Topology in Nest in order to have the connectivity dependent of the mesh.



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