

1. Introduction

High-dimensional datasets recorded via multielectrode arrays are often best understood in terms of low-dimensional representations that highlight those dimensions that account for the greatest amount of variance in the data. In this work, we describe the low-dimensional dynamics of neural activity in rat somatosensory cortex that result from tactile stimulation and compare it to the dynamics of spiking network model of the same system.

2. Methods

Data were recorded from the somatosensory cortices of 14 rats anesthetized with isoflurane, with tactile stimulation of 200 ms duration on their forepaws. The simulation (Fig. 1) consisted of six-layered somatosensory cortex and ventral posterolateral thalamus comprised of 10,000 spiking Izhikevich neurons [1], with connectivities drawn from empirical data; a similar model has previously been shown to produce realistic firing rates and spectra [2].

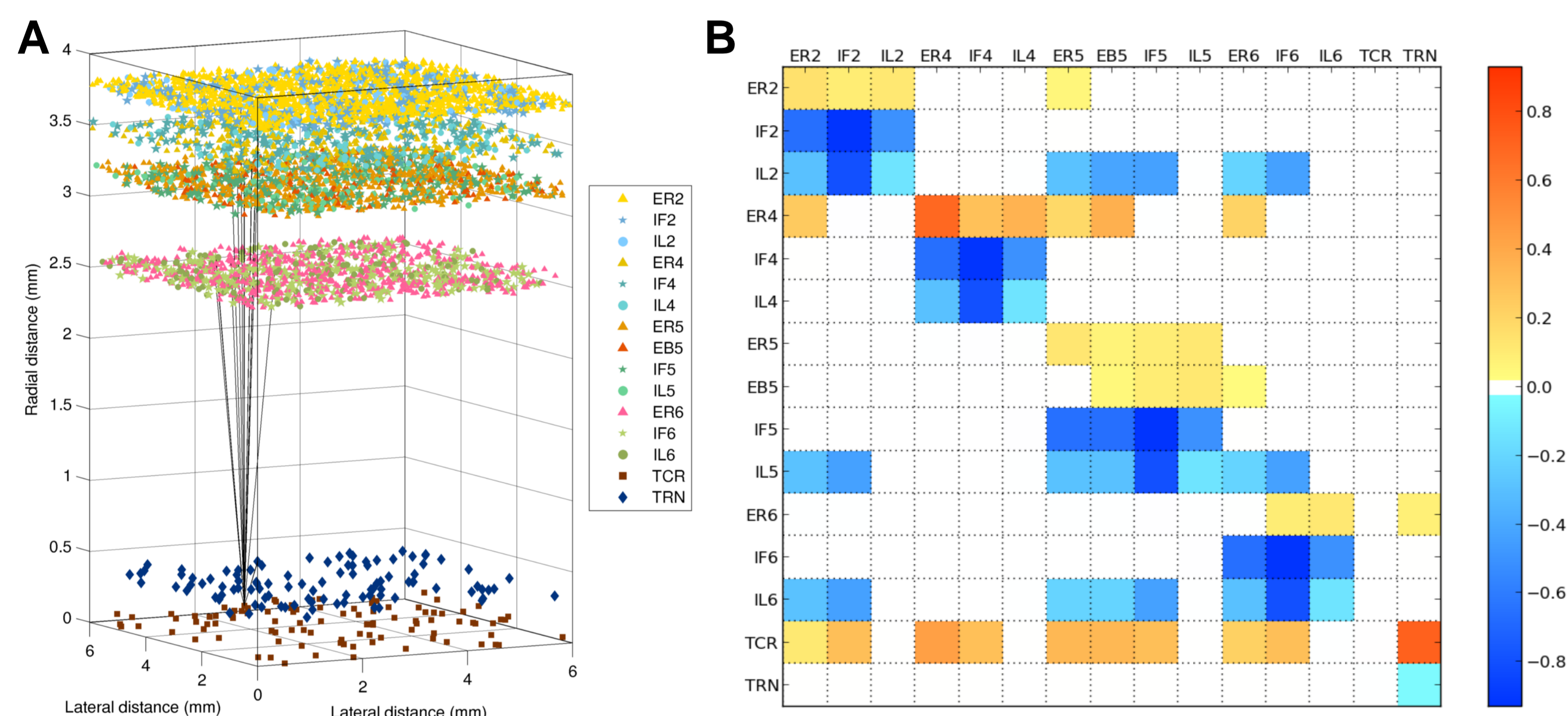


Fig. 1: (A) Layout of the model. The 28 efferent connections from a single thalamocortical relay neuron are shown (black lines). (B) Connectivity of the model. Color shows normalized effective connectivity (probability \times weight) from rows to columns, with red denoting excitation and blue denoting inhibition. E = excitatory pyramidal neuron; I = inhibitory interneuron; R = regular firing; B = bursting; F = fast-spiking; L = low-threshold spiking; TSR = thalamocortical relay; TRN = thalamic reticular nucleus.

Data were analyzed using principal component analysis (PCA) and a recurrent linear model (RLM, Fig. 2), the latter given by [3]:

$$P(\mathbf{y}_{t+1} | \mathbf{y}_1 \dots \mathbf{y}_t) = \text{Poisson}(\mathbf{y}_{t+1} | \hat{\mathbf{y}}_{t+1}), \quad \hat{\mathbf{y}}_{t+1} = f(C\mathbf{x}_t + \boldsymbol{\mu}_t), \quad \mathbf{x}_t = A\mathbf{x}_{t-1} + W(\mathbf{y}_t - \hat{\mathbf{y}}_t)$$

where \mathbf{y}_t is the multivariate neural activity at time t , \mathbf{x}_t is the low-dimensional dynamical state, A is the matrix of internal dynamics, C is a matrix describing the magnitude to which each neuron is influenced by a particular dimension of the dynamics, W is the Kalman gain, and $\boldsymbol{\mu}_t$ is a term that captures each neuron's sensory drive, corresponding to the peristimulus time histogram (PSTH).

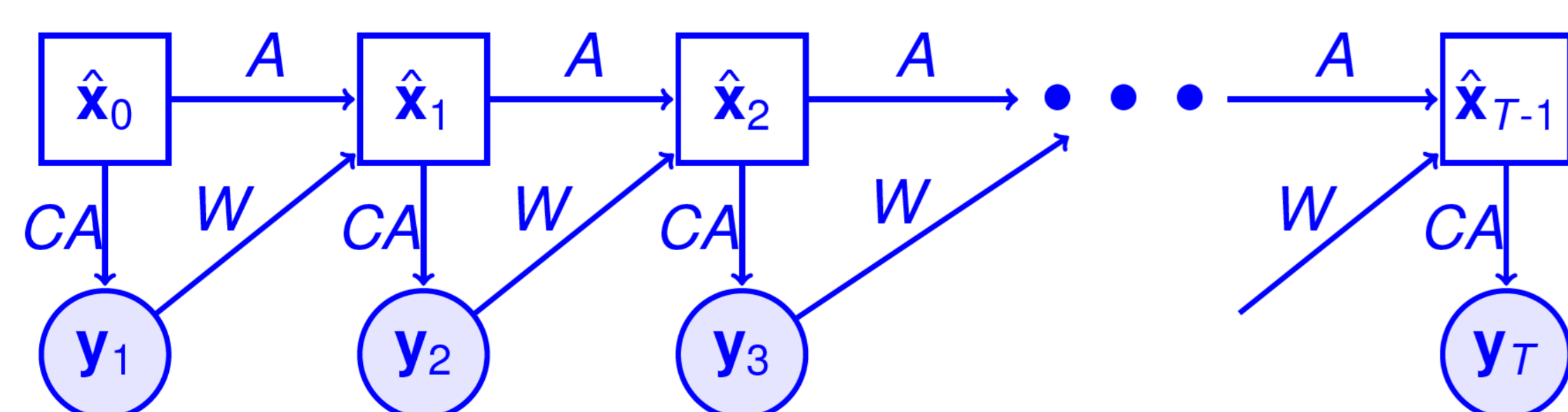


Fig. 2: Schematic of the recurrent linear model, showing how matrices A , C , and W relate to observations \mathbf{y}_t and low-dimensional state \mathbf{x}_t .

3. Results

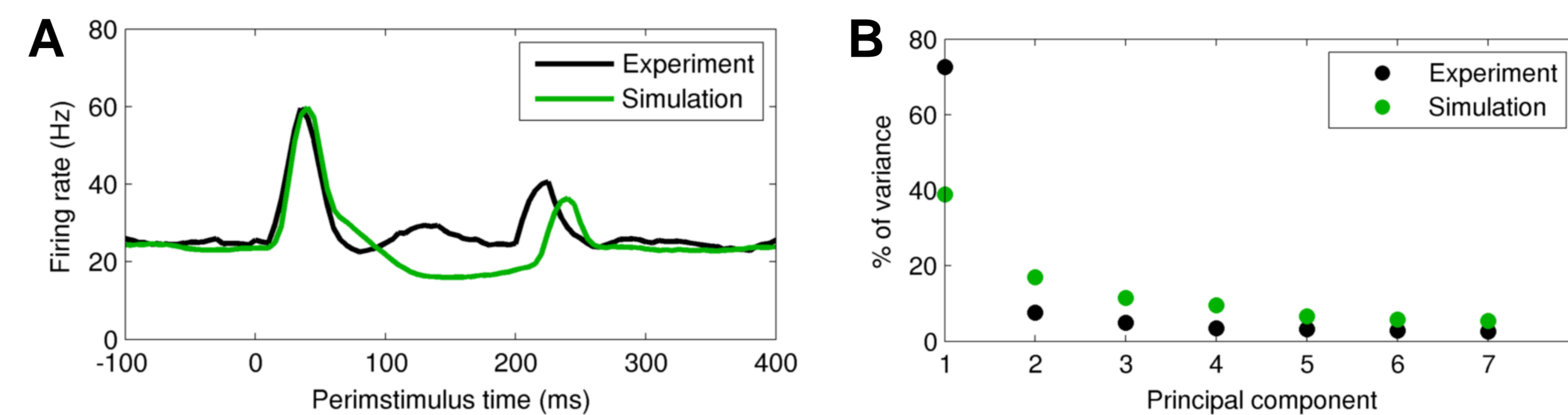


Fig. 3: PSTH (A) and PCA eigenvalue spectrum (B) for experiment and simulation. Both have similar stimulus response dynamics, although much more of the variance is captured by the first principle component (effectively the PSTH) in the experiment than in the simulation.

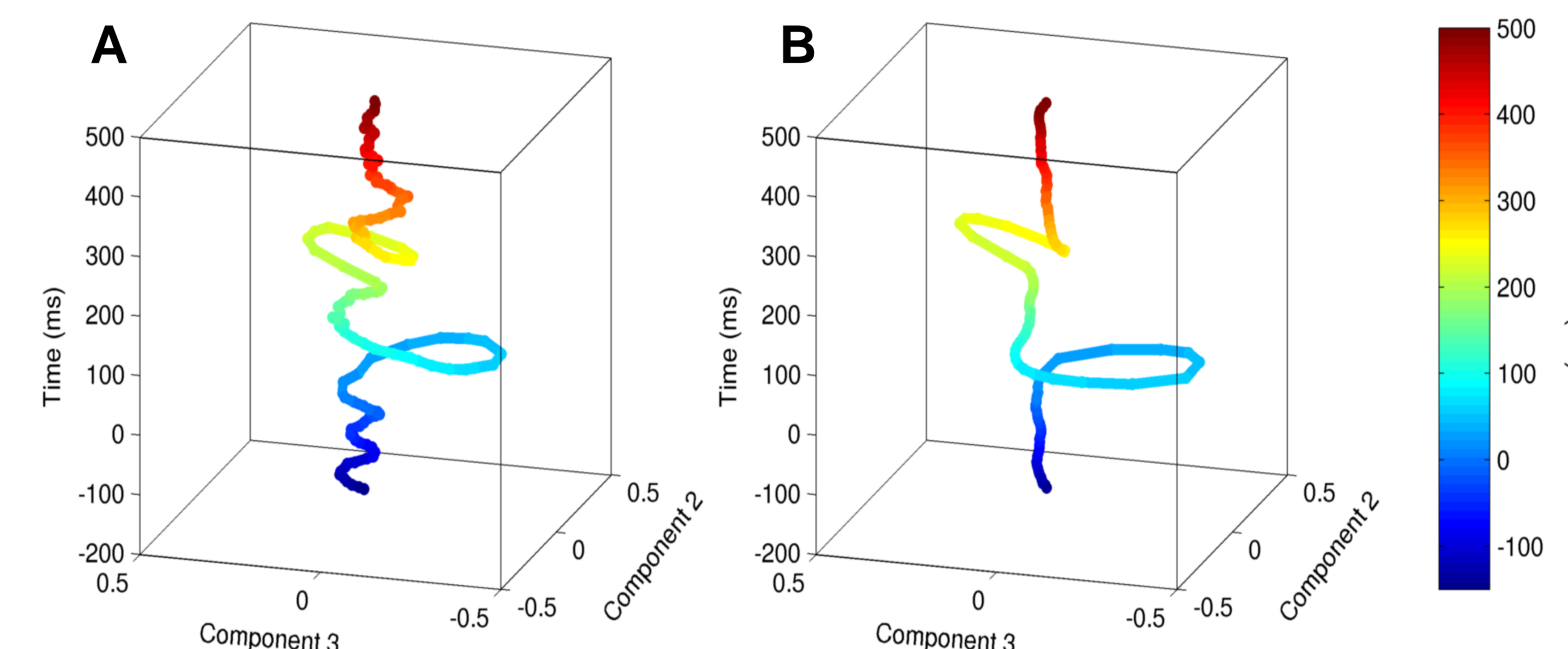


Fig. 4: Neural trajectories in the experiment (A) and simulation (B) for the second and third principal components. The system begins at baseline (dark blue). The stimulus onset response is the semicircular trajectory that occurs between 20 and 100 ms peristimulus time (light blue). The offset response begins at roughly 200 ms, and consists of a smaller, elongated trajectory perpendicular to the onset response (yellow). The system then returns to baseline (red).

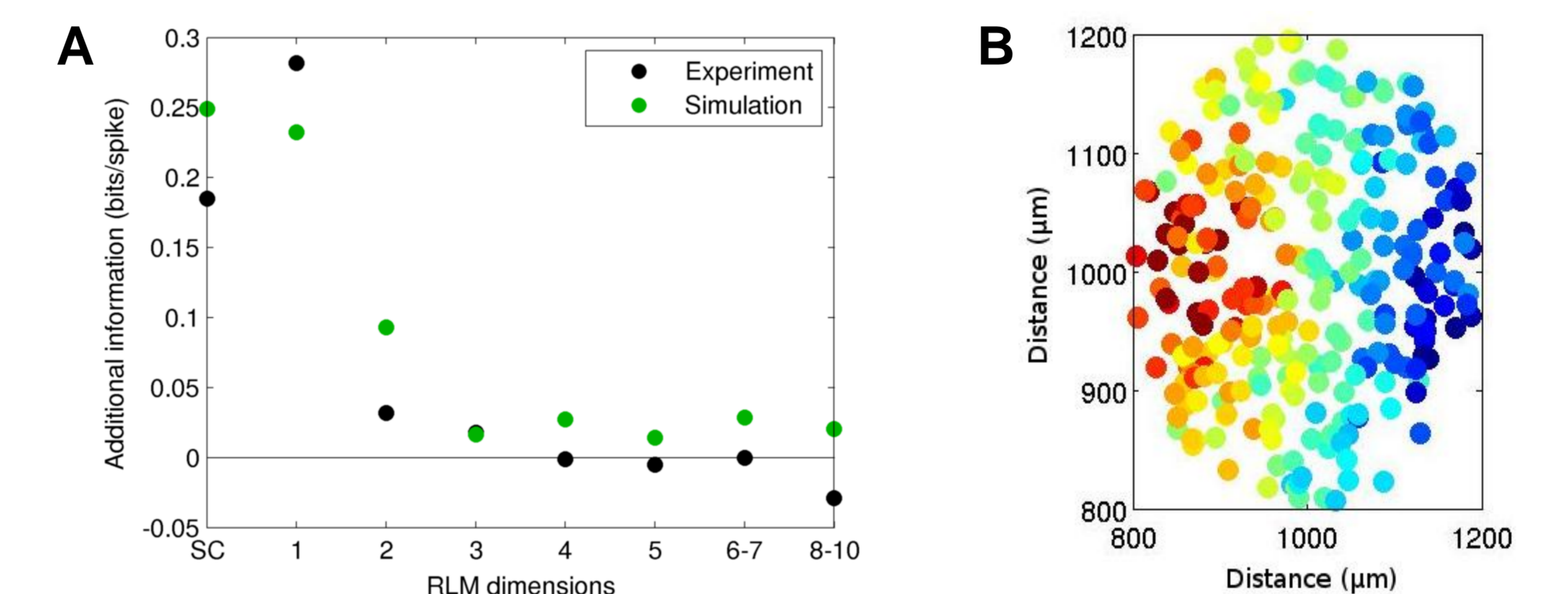


Fig. 5: (A) Predictive information of the RLM beyond the PSTH, measured in bits per spike (SC = self-coupling only). A majority of the predictive information is in the first dimension of the RLM, indicating that most variance is in a single mode. Predictive information increased with the addition of two more dimensions, which corresponded to spatial waves; an example mode is shown in (B). Models with higher dimensionality provided little or no additional predictive power.

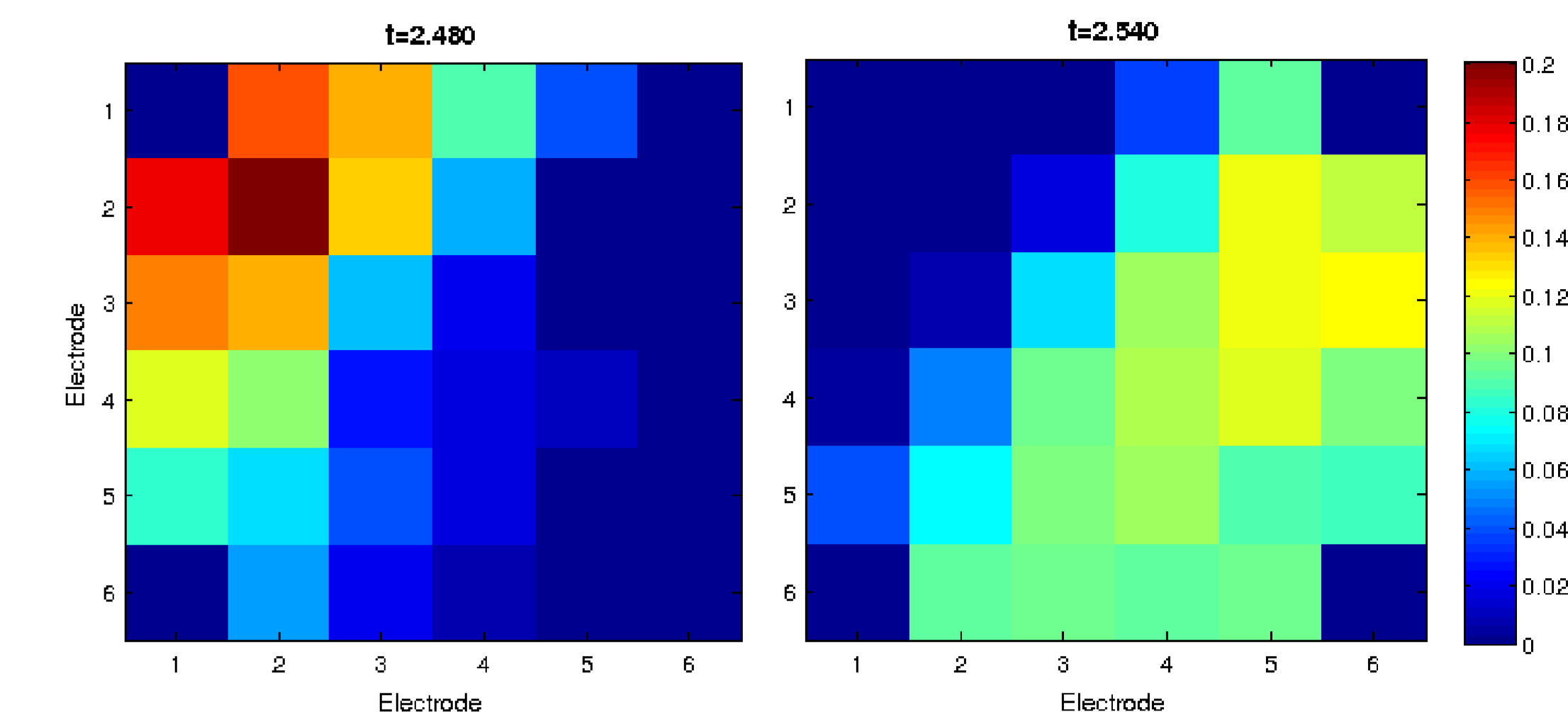


Fig. 6: Traveling waves in the experiment, showing local field potential recordings (color axis: mV) across the 32-channel electrode array. Traveling waves were variable in intensity but showed less variability in either direction of motion (here, from upper left to lower right) or velocity.

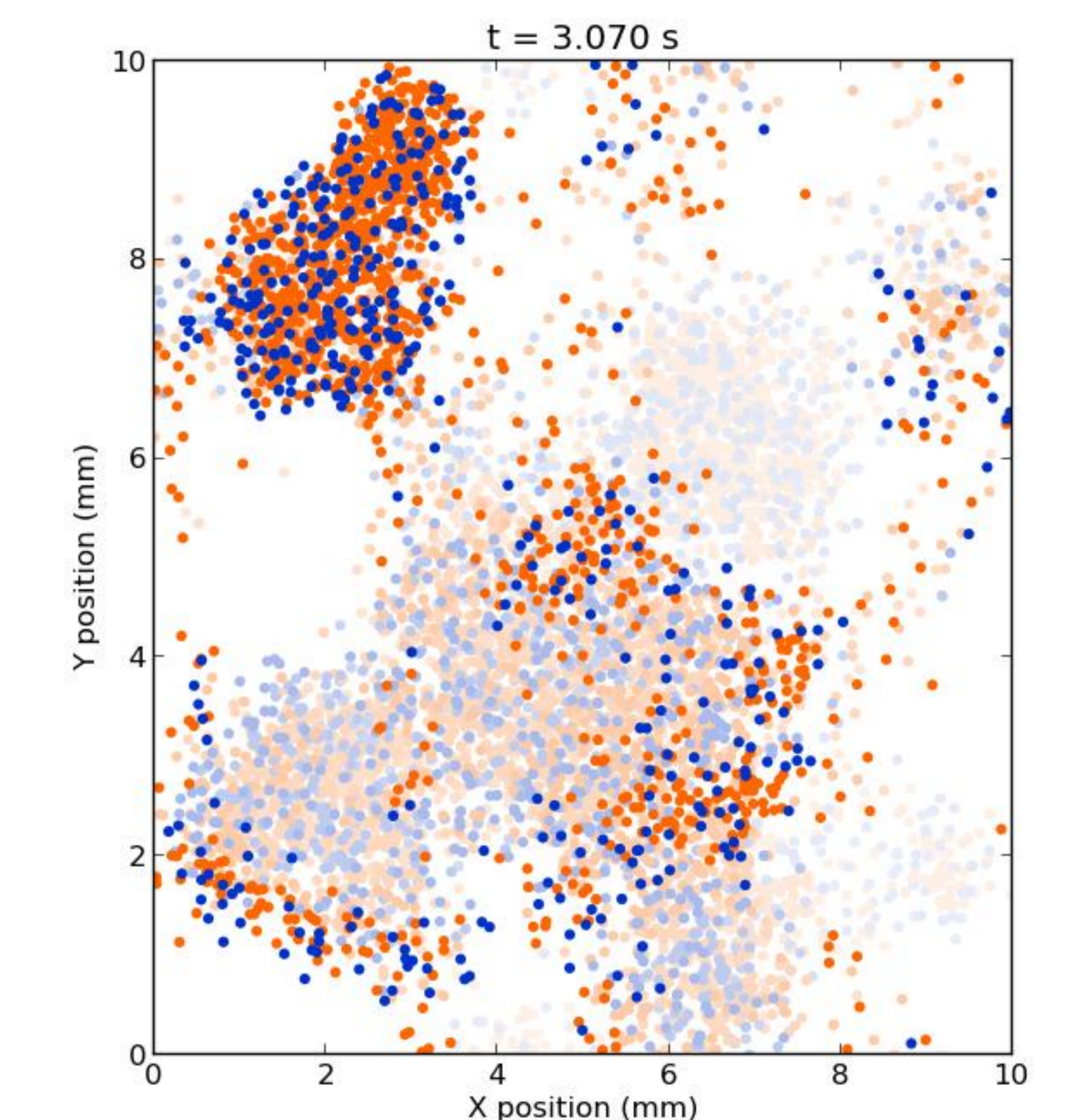


Fig. 7: Traveling waves in the simulation, showing spiking in excitatory (orange) and inhibitory (blue) neurons; saturation shows time since last firing (palest gray: 100 ms ago). A traveling wavefront is visible in the lower left of the plot; a new nucleus of activity is visible in the upper left. These waves are associated with slow dynamics. Thus, the realistically long time scales of noise correlations in the simulation arose due to intrinsically generated traveling waves of spiking activity, not from long time constants.

4. Summary

- To our knowledge, this is the first time low-dimensional dynamics have been described in the somatosensory cortex.
- Onset and offset responses to the tactile stimuli corresponded to approximately semicircular trajectories in state space.
- A majority of predictive information could be captured by a single dimension in the RLM, which corresponded to up/down states.
- Other RLM components corresponded to traveling waves in both experiment and simulation, accounting for long time scales in the latter.

References

- [1] Izhikevich EM, Edelman GM (2008). *Proc Natl Acad USA* 105:3593–8.
- [2] Kerr CC, et al. (2013). *Front Comput Neurosci* 7:1–14.
- [3] Pachitariu M, et al. (2013). *Advances in Neural Information Processing Systems* 26.

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Further information

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