Noise Focusing: the Emergence of Coherent Activity in Neuronal Cultures

Jaume Casademunt [1], *Javier G. Orlandi* [1], *Enrique Alvarez-Lacalle* [2], *Sara Teller* [1], *Jordi Soriano* [1]
[1] Dept. ECM, Facultat de Física, Universitat de Barcelona, Barcelona, Spain
[2] Dept. Física Aplicada, EETAC, Universitat Politècnica de Catalunya, Castelldefels, Spain

Neuronal cultures in vitro provide and interesting model system to search for general organization principles in neuronal systems. In particular, understanding the patterns of spontaneous activity of neuronal networks is recognized to be of chief importance in neuroscience. An intriguing but robust observation is that, at early stages of development, neuronal cultures spontaneously reach a coherent state of collective firing in a pattern of nearly periodic global bursts. The origin and nature of this pulsation has remained elusive. From high-resolution calcium imaging techniques, we first establish that this behavior is mediated by the propagation of fast excitation waves. Nevertheless, according to experimental data, the nucleation mechanism of such waves is very puzzling as it requires an extremely high nucleation rate, and an extremely heterogeneous distribution of the nucleation points. With the help of numerical simulations, we unveil a complex spatio-temporal structure of activity avalanches, as noise is amplified and propagated by the integrate-and-fire dynamics of the neurons in a way that is sensitive to network details. This dynamics eventually gives rise to a strong spatio-temporal localization of the peaks of activity, a phenomenon that we call noise focusing. This explains at the same time the high nucleation rate and the sharp selection of specific nucleation sites as a collective effect of the pattern of noise flow that is induced by the network throughout relatively extended areas around the nucleation points. The emerging scenario challenges previous understanding of spontaneous activity of neuronal cultures while providing a full quantitative explanation of the early stages of network self-organization as a noise-driven phenomenon. Results are relevant to neuronal tissues and generically to complex networks with integrate-and-fire dynamics and metric correlations, for instance in rumor spreading in social networks.