A highly-reduced model of the dopaminergic neuron : mechanisms of oscillations

Alexey Kuznetsov
Department of Mathematical Sciences, Indiana University-Purdue University Indianapolis

Dopamine is a neurotransmitter that has been found to play a role in the motivation of animal and human behavior and psychiatric disorders. The release of dopamine is regulated by the firing patterns of midbrain dopaminergic (DA) neurons. The neurons display two distinct patterns of spiking : low frequency tonic spiking and burst-like episodes of short high-frequency spiking. In vivo, the high-frequency episodes are irregular events that can be observed upon exposure to unpredicted stimuli perceived as rewarding. How the stimuli evoke the bursts is not clear. In order to explore the mechanisms of bursting, we created a model that reproduces the major excitability properties of the DA neuron. First, the high frequency firing cannot be triggered by tonic applied depolarization, which evokes a blockade of oscillations instead. Second, two apparently similar inputs, tonic NMDA and AMPA receptor activation elicit distinct responses – a high frequency for the former, and a block for the latter. We reduce the model to 3-dimentional system of ODEs with a separation onto one fast and two slow variables. Together with classical complex solutions, the calibration of the model yielded new bistability between large- and small-amplitude oscillations, which makes the system interesting for further mathematical analysis. The interaction of each slow variable with the fast one can independently create oscillations, and, thus, the model forms a structure of interlocked oscillatory mechanisms. The structure connects our research of the DA neuron with circadian biology and defines common minimal models for investigation the oscillatory mechanisms.