Mathematical modeling of neuronal connexin-36 channels

R. Jaimes-Reátegui [1,2], L. C. Barrio[3], D. Gonzalez-Nieto[3,4], and A. N. Pisarchik[1,5]

[1] Computational Systems Biology, Center for Biomedical Technology, Technical University of Madrid, Campus Montegancedo, 28223 Pozuelo de Alarcon, Madrid, Spain

[2] Centro Universitario de los Lagos, Universidad de Guadalajara, Enrique Díaz de Leon, Paseos de la Montaña, Lagos de Moreno, Jalisco 47460, Mexico

[3] Unit of Experimental Neurology, Hospital Universitario Ramón y Cajal-IRYCIS, Madrid, Spain. Ctra. de Colmenar Viejo, km. 9,100, 28034 Madrid, Spain

[4] Experimental Neurology Laboratory, Center for Biomedical Technology, Technical University of Madrid, Campus Montegancedo, 28223 Pozuelo de Alarcon, Madrid, Spain.

[5] Centro de Investigaciones en Óptica, Loma del Bosque 115, Lomas del Campestre, 37150 León, Guanajuato, Mexico

Neurotransmission through electrical synapses play an important role in the spike synchrony among neurons and oscillation of neuron networks. Connexin36 (Cx36) is the principal gap junction protein of electrical synapses between inhibitory interneurons in vertebrates. Coupling strength between coupled neurons is modulated, among other factor, by the voltage difference between cell interiors, termed transjunctional voltage (Vj), in a complex manner; with the Vj gradient junctional conductance of Cx36 channels first increases instantaneously (+ 20% for + 100 mV) and then it decreases slowly to half for a similar range of Vj. The significance of this regulation by voltage, a stimulus always presents and changing, in the firing properties of coupled neurons is unknown. We use the Finz-Hung Nagumo neuron model to simulate dynamics of two neurons with bidirectional coupling mediated by Cx36. The model qualitatively well describes physiological experiments with mouse neurons. When harmonic stimulation is applied to the membrane potential of one of the neurons, synaptic plasticity of electrical neurotransmission mediated by Cx36 channels enriches the neuron dynamics leading to chaos in the neuron spikes via a cascade of period-doubling bifurcations as the coupling strength increases. Although constant synaptic conductivity does not result in chaotic spikes, the dynamics is also very complex, exhibiting multistability when two subthreshold limit cycle attractors coexist with two superthreshold spiking attractors for a certain range of the modulation frequency and amplitude.