Dynamics of two-process astrocyte networks

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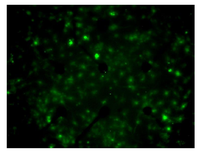
Intro:

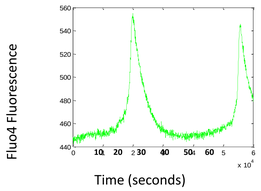
Recent work suggests that astrocytes may play a role alongside neurons in information processing. Astrocytic interaction is known to happen through gap junction coupling as well as through diffusion in extracellular matrix. We examine a simplified model of interacting astrocytes through two distinct processes: fast speed direct gap junction coupling and passive diffusion coupling. Specifically we look for emerging dynamics that result from the interplay between the two excitation pathways. We observe that gap junction and diffusion are competitive processes in primarily global network structures, where as they work together in highly local networks.

Motivation:

Observed astrocytic networks



Fluo 4-AM Calcium Sensitive Dye



Developing astrocytic networks

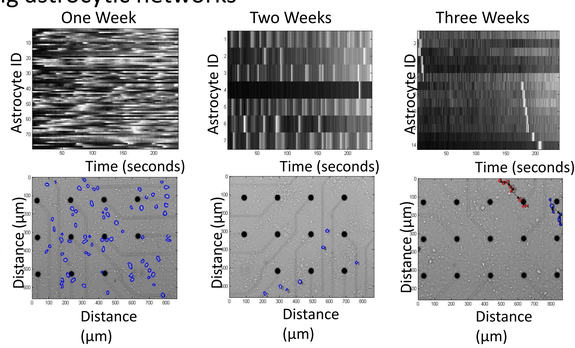


Fig. 2. **(a)** Example raster plot of spontaneous calcium activity of astrocytes in developing co-cultures (1-3 weeks in vitro). **(b)** Spatial location of active astrocyte cells from (a) Cell locations of functional astrocyte clusters. Arrows show the order of propagating activity.

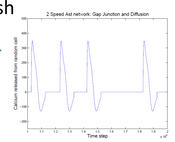
Model: 2D Integrate and Fire with gap junction and diffusion coupling

$$\frac{dC_i}{dt} = -\alpha C + C_{ext,i} + C_{flush} + \gamma_1 * Diff(i,j,t_{ij}) + \sum_{connections} \gamma_2 * (C_j - C_i), \qquad Diff(i,j,t_{ij}) = \frac{N}{4\pi D t_{ij}}\, e^{-\frac{r^2}{4Dt_{ij}}}$$

A)Leak term

B)Noisy external stimulation

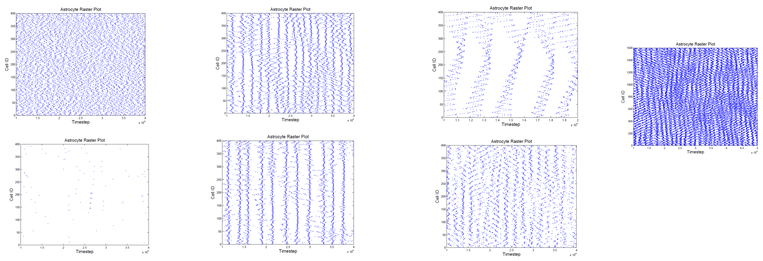
C) Threshold based internal storage flush



D) Gap junction connections

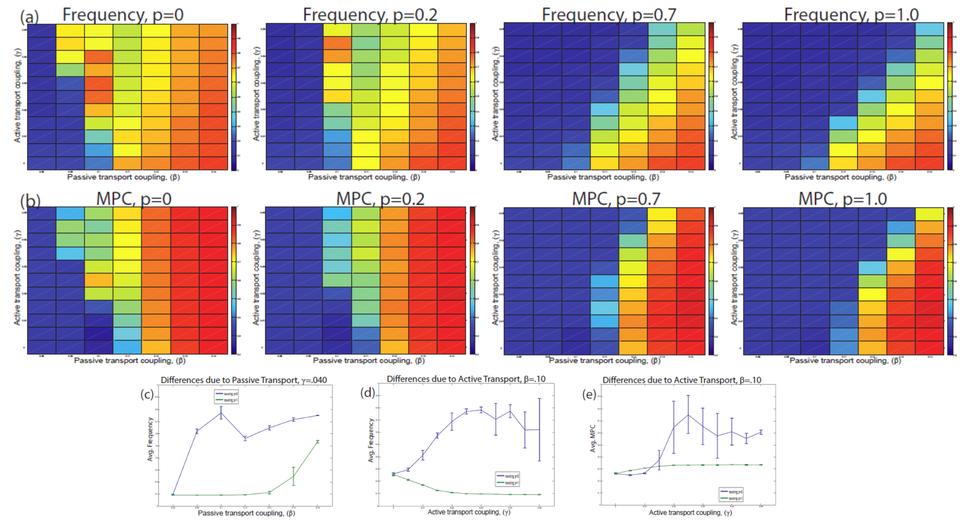
E) Diffusion

Sample raster plots:



Findings:

-The active and passive processes work together to drive activity for locally connected networks, but compete against one another for globally wired networks

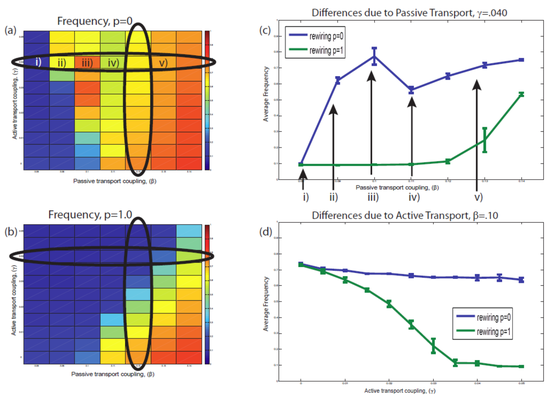


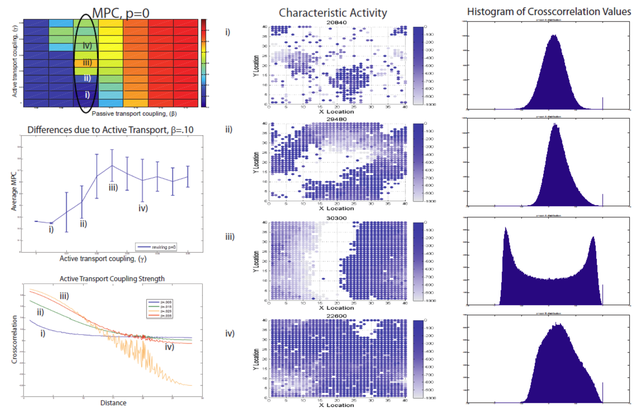
-Diffusion generally acts as a local excitation

-**Gap junction coupling can be both excitatory or inhibitory**

Drives network towards homogeneity

-Certain activity patterns are only present for local network structures: Noise driven waves, phase locked waves, spiraling excitations





Summary and Future Directions:

Astrocyte networks are embedded in the space of the brain. Allowing for a separate process to spread through this space in addition to direct gap junction connections between astrocytes gave rise to cooperative and competitive dynamics depending on the network structure.

In the future we intend to examine inhibitory diffusion processes and also increase the speed of the diffusion process to better understand the role the time difference between the two processes plays.

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