Mathematical Modelling of Temperature Effects on the AFD Neuron of *Caenorhabditis elegans*

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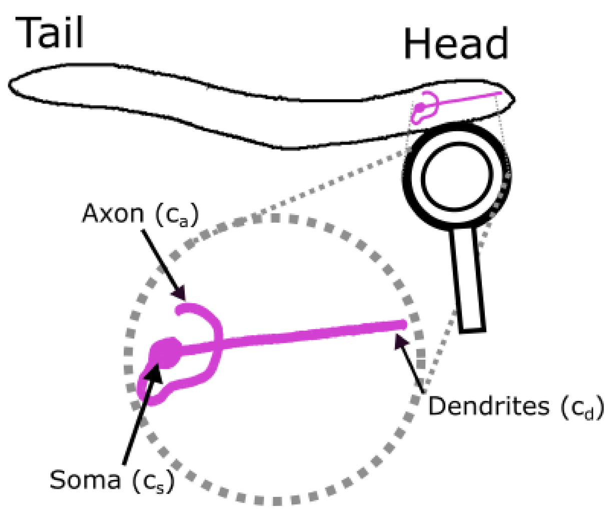
Introduction

The 1-mm free-living nematode *C. elegans* displays an exceptional sensitivity to temperature fluctuations. Laser ablation studies have shown that the amphid finger-like ciliated AFD neurons in the worm are necessary and sufficient for thermotaxis [1]. We build upon a compartmental model for calcium dynamics in the chemosensitive ASER neuron of the worm [2]. Arrhenius temperature-dependent Q10 coefficients have been added, in the spirit of adapting this model to describe the temperature-sensitive dynamics of AFD. The AFD neuron is depicted schematically above and to the right. We find that the pairing of NaCl concentration fluctuations with temperature stimuli is needed for our model neuron to evoke dynamics similar to those observed experimentally.



AFD Neuron Model

Variables c_d, c_s, and c_a represent Ca^{2+} concentration in the dendrite, soma, and axon, respectively. y_i $(i = d, s, a)$ are inactivation variables for each compartment.

$$\frac{dc_d}{dt} = \frac{\rho}{\tau_d}\left[-c_d + Y_d y_d + D(W_d c_s - c_d)\right] + I(t)$$

$$\frac{dc_s}{dt} = \frac{\rho}{\tau_s}\left[-c_s + Y_s y_s + D(c_d + c_a - c_s)\right]$$

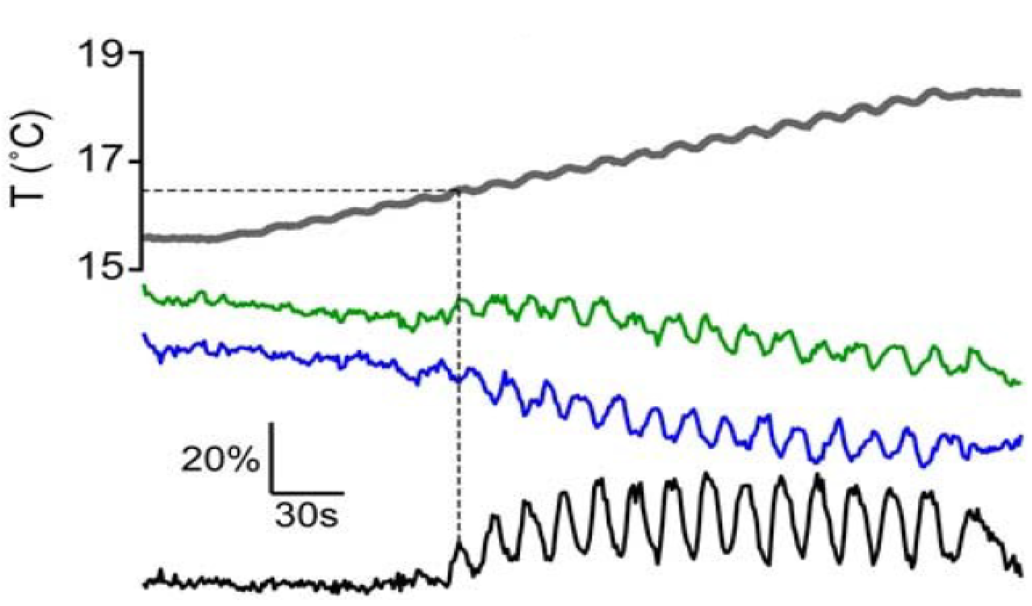
$$\frac{dc_a}{dt} = \frac{\rho}{\tau_a}\left[-c_a + Y_a y_a + D(W_a c_s - c_a)\right]$$

$$\frac{dy_i}{dt} = -\phi A c_i$$

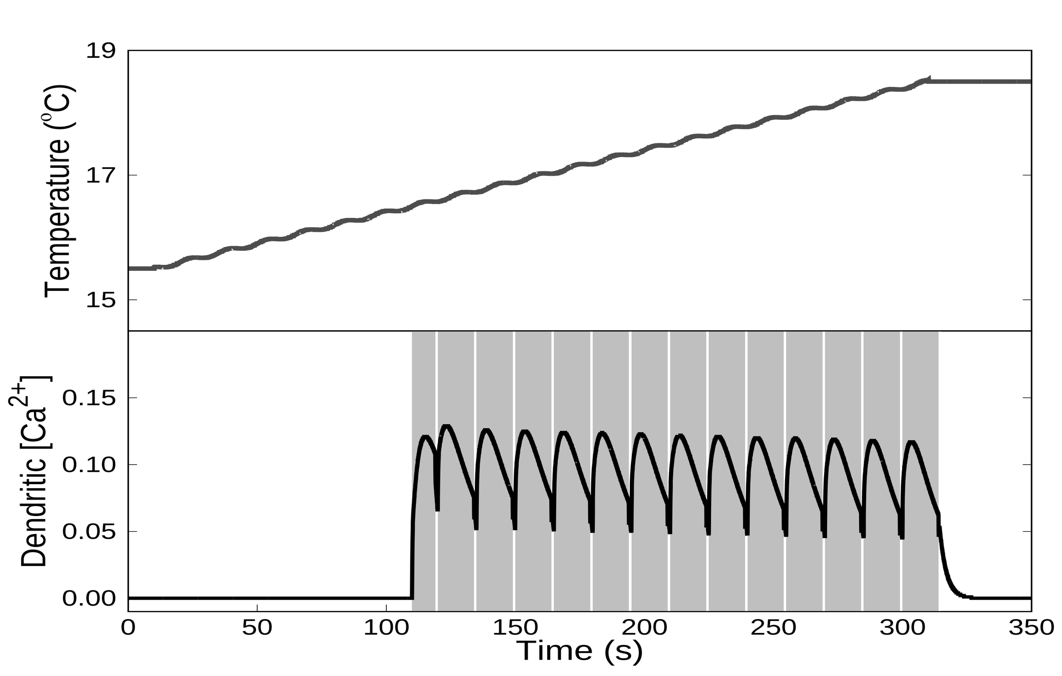
$\rho = \rho_0^{(T-T_C)/10}$ and $\phi = \phi_0^{(T-T_C)/10}$ are temperature-dependent Arrhenius coefficients for activation and inactivation, respectively. T = ambient temperature and T_C = cultivation temperature. $I(t)$ is a time-dependent binary stimulus to the neuron, representing NaCl concentration.

Oscillating temperature ramp below T_C

Experiment [3]



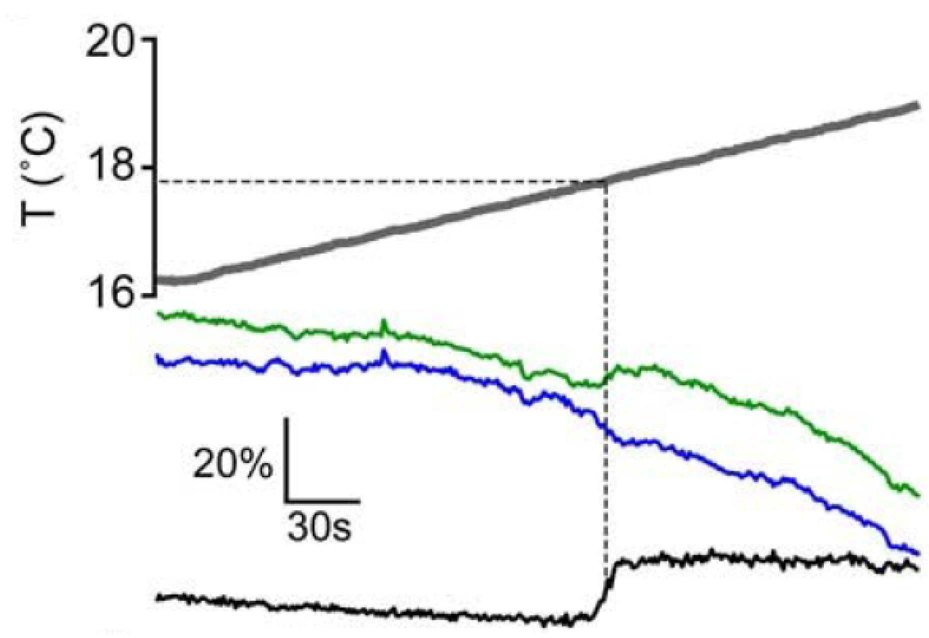
Model



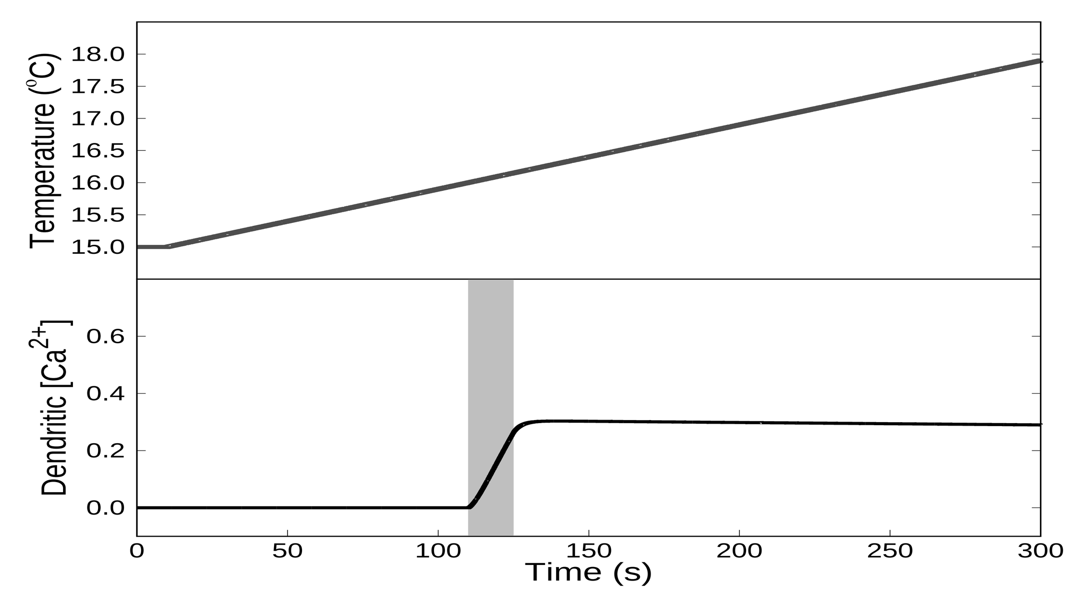
$T_C = 20°C$. Gray regions in the model plot denote where $I(t) \neq 0$, otherwise $I(t) = 0$.

Linear temperature ramp below T_C

Experiment [3]



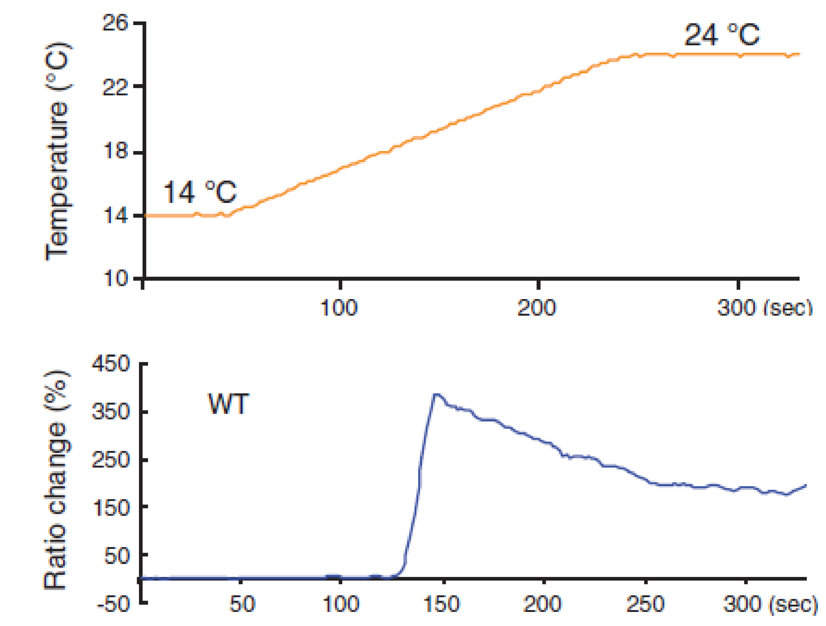
Model



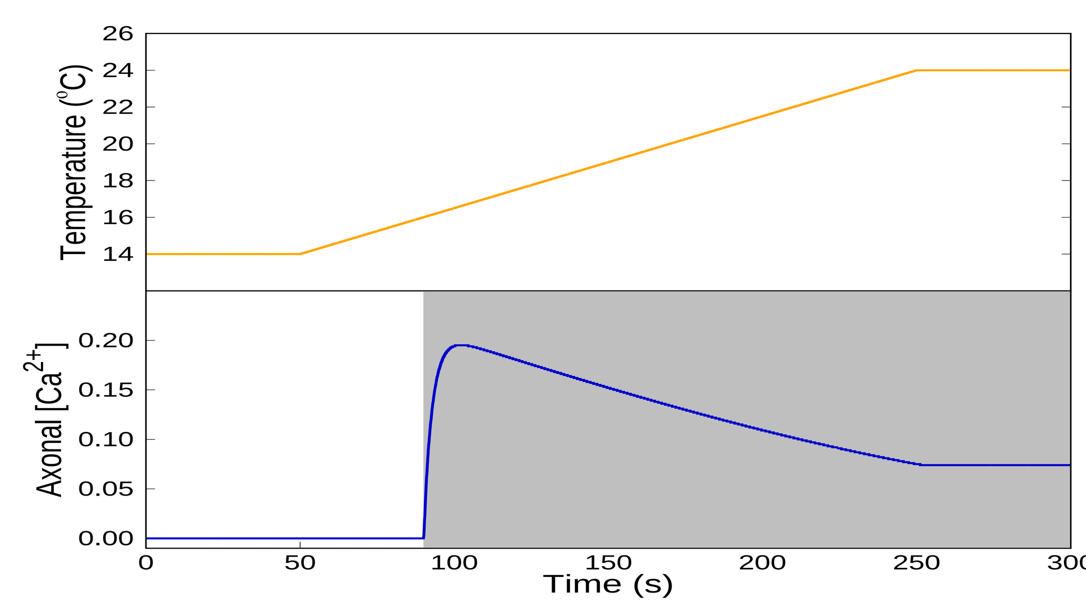
$T_C = 20°C$. Gray regions in the model plot denote where $I(t) \neq 0$, otherwise $I(t) = 0$

Linear temperature ramp above T_C

Experiment [4]

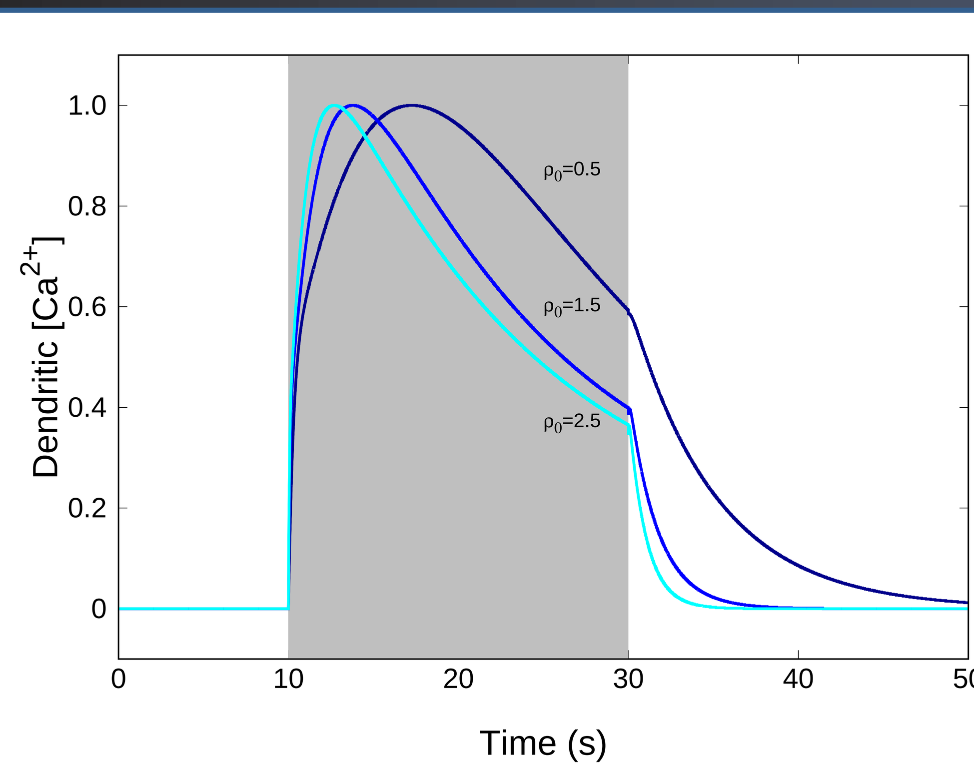


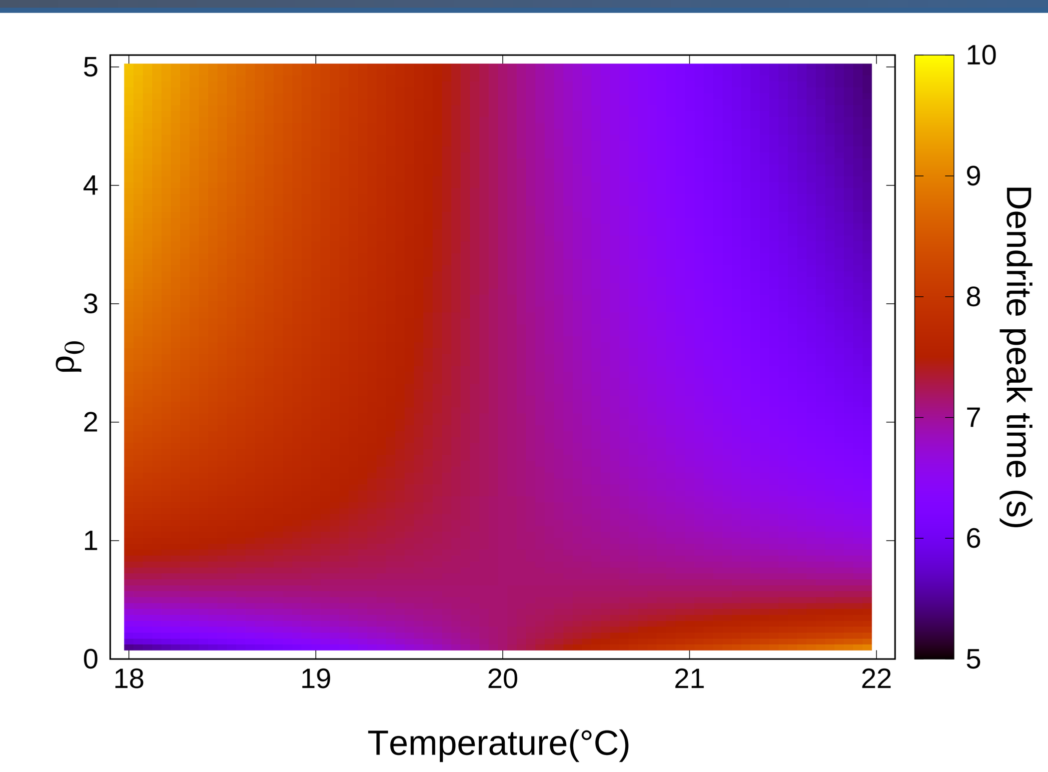
Model

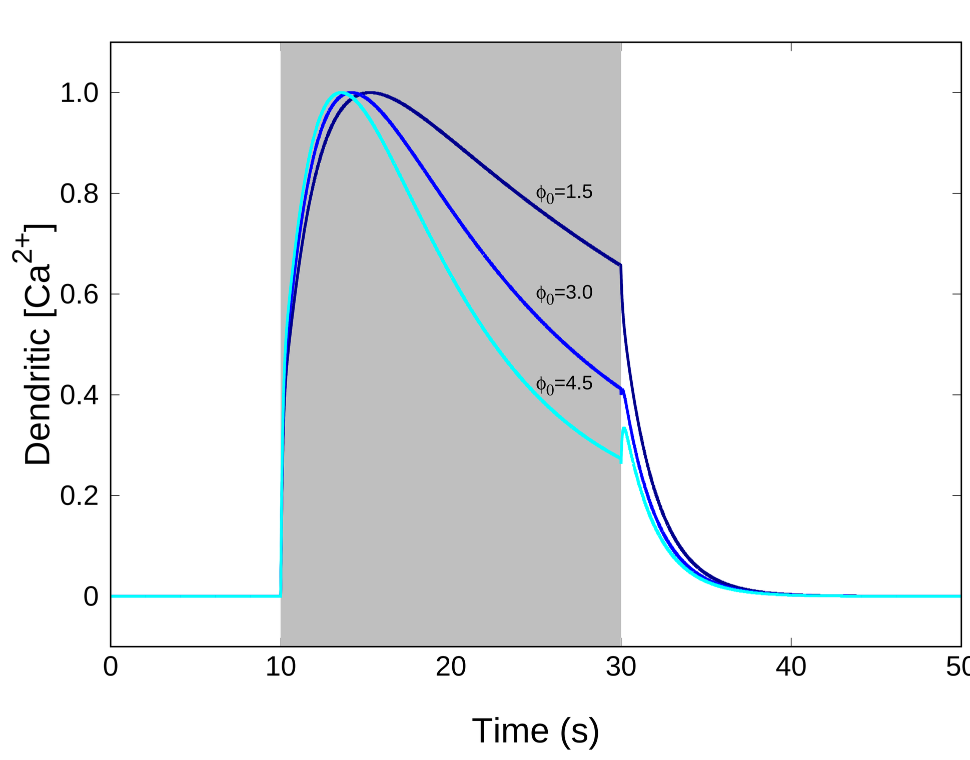


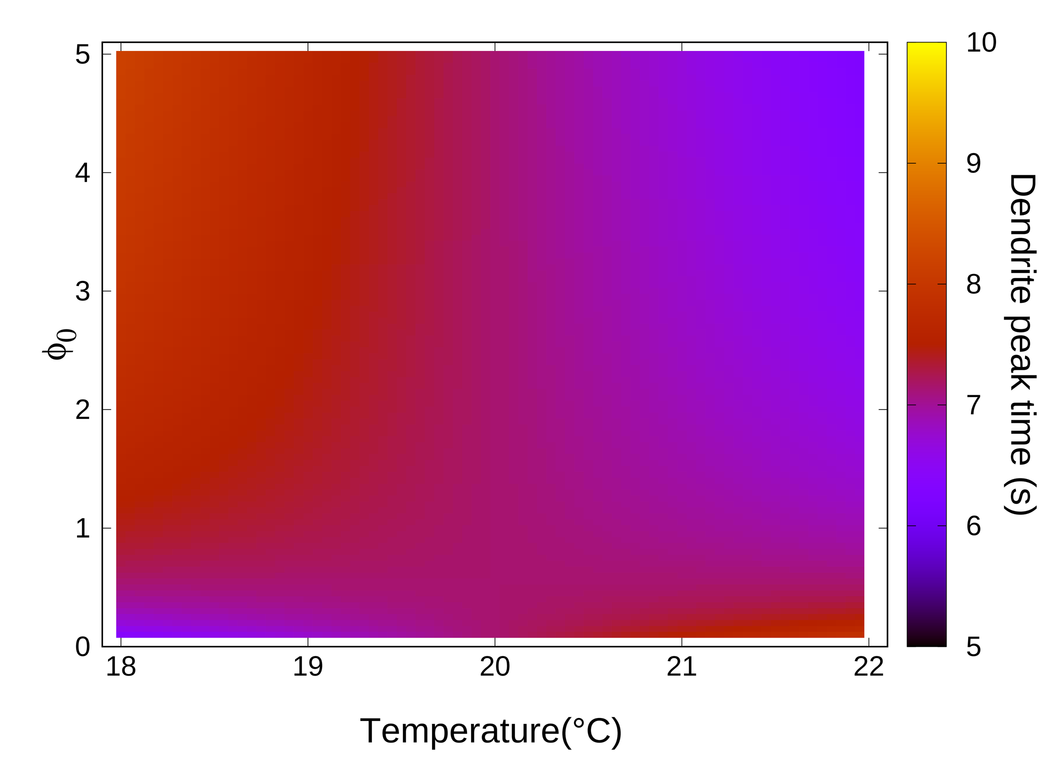
$T_C = 20°C$. Gray regions in the model plot denote where $I(t) \neq 0$, otherwise $I(t) = 0$

ρ_0 and ϕ_0 affect sensitivity of [Ca^{2+}] waveform to temperature









Dendritic responses with $T = 30°C$ & $T_C = 20°C$ for various ρ_0 & ϕ_0.

Top: time of dendritic [Ca^{2+}] peak for various ρ_0. [Ca^{2+}] Bottom: time of dendritic [Ca^{2+}] peak for various ϕ_0.

References and Acknowledgments

[1] I. Mori, and Y. Ohshima. *Nature* **376** (1995).
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[3] D.A. Clark et al. *J. Neurosci.* **26** (2006).
[4] A. Yoshida et al. *Genes, Brain and Behavior* **15** (2016).
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Discussion points

- This phenomenological model can reproduce qualitative dynamics similar to those seen in experiments.
- $I(t)$ is coupled to a temperature threshold of $T \approx T_C - 3.25°C$.
- Model neurons with $\rho_0 > 3$ may poorly represent the AFD neuron, since it is known to detect temperature differences within a 20-second time window [5].
- ρ_0 modulates the [Ca2+] peak time, while ϕ_0 modulates the rate of decay during a chemical stimulus.