Modeling Neural Circuits to Understand Reproductive Isolation and Cryptic Evolution

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Introduction

- Species interactions propel biodiversity and can shape evolutionary trajectories among populations
- Species interactions can promote speciation when unfit hybridization results in the selection of traits that promote divergence of mating behavior to prevent hybridization
- Divergence of mating behaviors leads to reproductive isolation among populations of the same species
- The variation in male acoustic signaling is primarily observed in P. feriarum sympatric populations, which have diverged due to interactions with other species (e.g. P. nigrita). The male acoustic signal varies little in allopatry, where no closely-related species exist

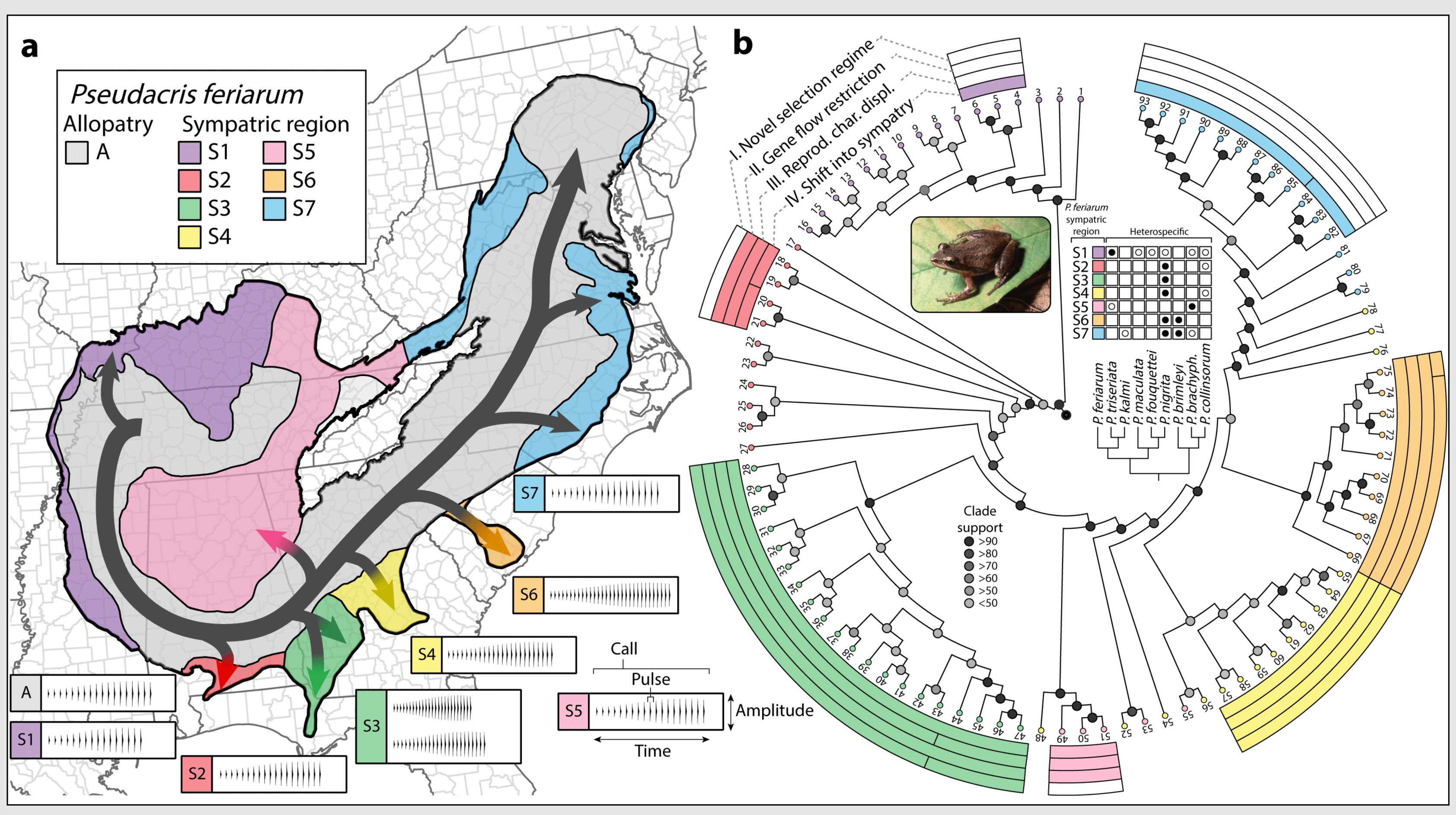

Figure 1. Diversification of mating signals in the upland chorus frog (P. feriarum). (a) The upland chorus frog has expanded from an ancestral region (gray) into the ranges of heterospecifc species (sympatry, colored ranges) multiple independent times. In many of these cases, the male mating call has diverged (see oscillograms representing the calls) in response to selection on females to avoid hybridization. (b) Phylogenetic relationships among P. feriarum sampled across the range, showing the independent expansion into sympatric regions. The inset shows phylogenetic relationships among the chorus frogs and the interactions of P. feriarum with those species.

Behavioral Data

- In a previous study (Lemmon 2009), male calls were recorded across the geographic range of the species. Binary choice experiments were used to assess female preferences for different calls.

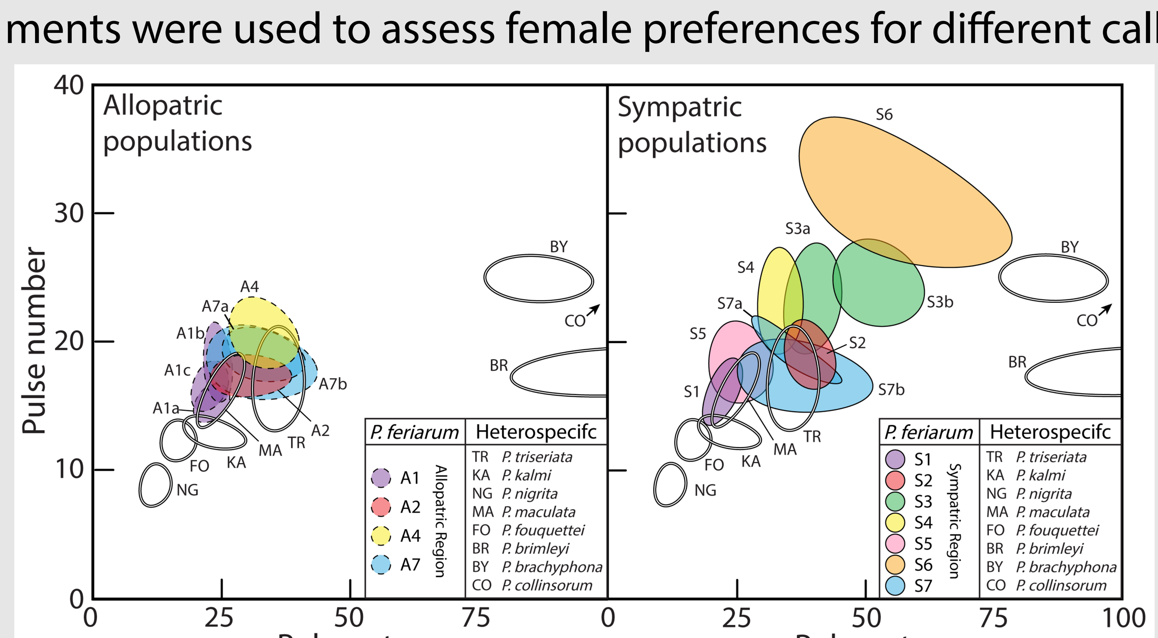

Figure 2. Distributions of male calls recorded in different allopatric (left) and sympatric (right) populations. Distributions are represented by 50% confidence envelopes. Note the increased diversity of calls among sympatric populations, compared to allopatric populations.

Methods

- Optimized likelihood scores to find the peaks in parameter space.
- Selected 5 peaks from the FL and SC data to compare to the ALNC combined population
- Evaluated the likelihood of the FL and SC data separately against the ALNC combined population for each peak
- Plotted in MATLAB values for each peak and compared where the peaks occur in parameter space to determine if there could be evolution from one population to another
- Search for paths through parameter space that connect the peaks without substantial changes to the behavior.
- Used MDS to reduced dimensionality from 8 to 3 dimensions

References

- Alluri et al. 2016. PNAS E1927 - 2935.
- Lemmon 2009. Evolution 63: 1155-1170.
- Naud et al. 2015. J. Neurophysiology 114: 2804 - 2815.

Neural Circuit

- Previous work in neurophysiology (Naud et al. 2015; Aluri et al. 2016) has identified a neural mechanism by which female frogs can distinguish among male calls differing in the number and rate of pulses within the calls
- The neural computational model describing this mechanism incorporates the activities of neurotransmitter receptors, which determine the magnitude and duration of effect that each neuron has on the downstream nueron
- Neurotransmitter receptor activities are controlled by the expression level and structure of protien subunits comprising them
- By comparing (among populations) the neural model parameters that best fit the behavioral data, we hope to identify the genes that have evolved as the female preferences have diversified across populations

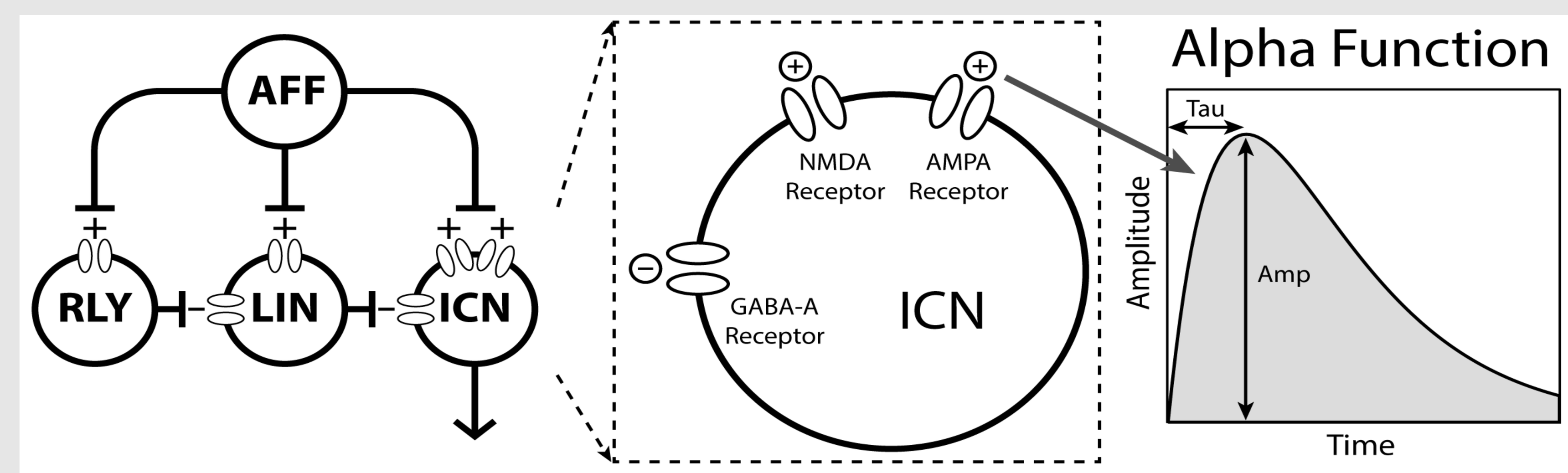

Figure 4. The female preference for male mating signals is modeled using a dis-inhibition circuit involving four neurons, the afferent neuron (which trasmitts a signal from the ear to the mid-brain), a relay neuron (RLY), a long interval neuron (LIN), and an interval counting neuron (ICN). The LIN inhibits the activity of the ICN until a sufficient number of call pulses cause the LIN itself to be inhibited by the relay neuron. At that point, the ICN is released from inhibition and can send a signal downstream. This signal is eventually expressed as a preference of the female for the male producing the call signal. At each synapse, the upstream neuron has either an excitatory (+) or an inhibitory (-) effect on the downstream neuron, controlled through neurotransmitter receptors goverened by an alpha function. This function has two parameters, tau and alpha, reflecting the composition and abundance of the protein that forms the neurotransmitter receptor.

Results

- Similarities between different peaks imply that we can make conclusions about the evolution of neural circuits without knowing exactly how the neural network is parameterized (Fig. 5).
- The relative positions of peaks corresponding to different populations suggest that the FL and SC evolved along different trajectories from their ancestral state (Fig. 5).
- White spaces between peaks indicate the potential for reprod. isolation between pops (Fig. 5).
- Some peaks are connected by paths not requiring substantial behavioral change indicating cryptic evol. is possible (Fig 6).
- Although much of parameter space is connected, there are examples of isolated peaks, implying that reproductive isolation may exist between populations with the same mating behavior (Fig 6).

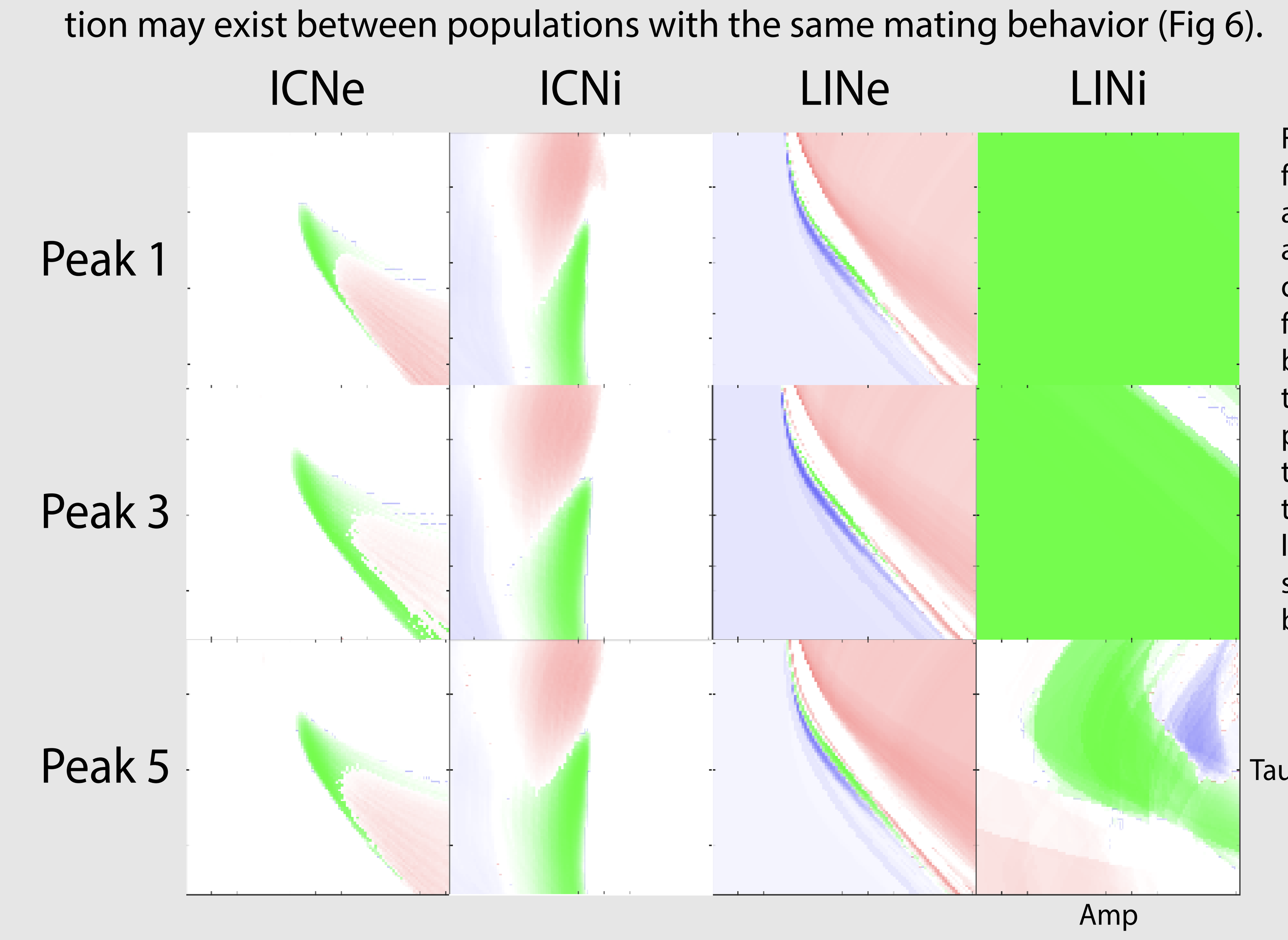

Figure 5. Plots representing peaks in parameter space of different receptor neurons for different populations. The ICNe and LINe correspond to the AMPA receptor while the ICNi and LINi receptors correspond to the GABA-A receptor. The different color of each pixel represents the likelihood score for that combination of parameters, with the bright colors being the best likelihood scores and the pale colors being the worst likelihood scores. The green represents the allopatric ALNC population while the red and blue represent the sympatric SC and FL populations, respectively. Note that since the computational model is optimized for the allopatric populations, all of the graphs have a bright green section but do not necessarily have a bright red or bright blue section.

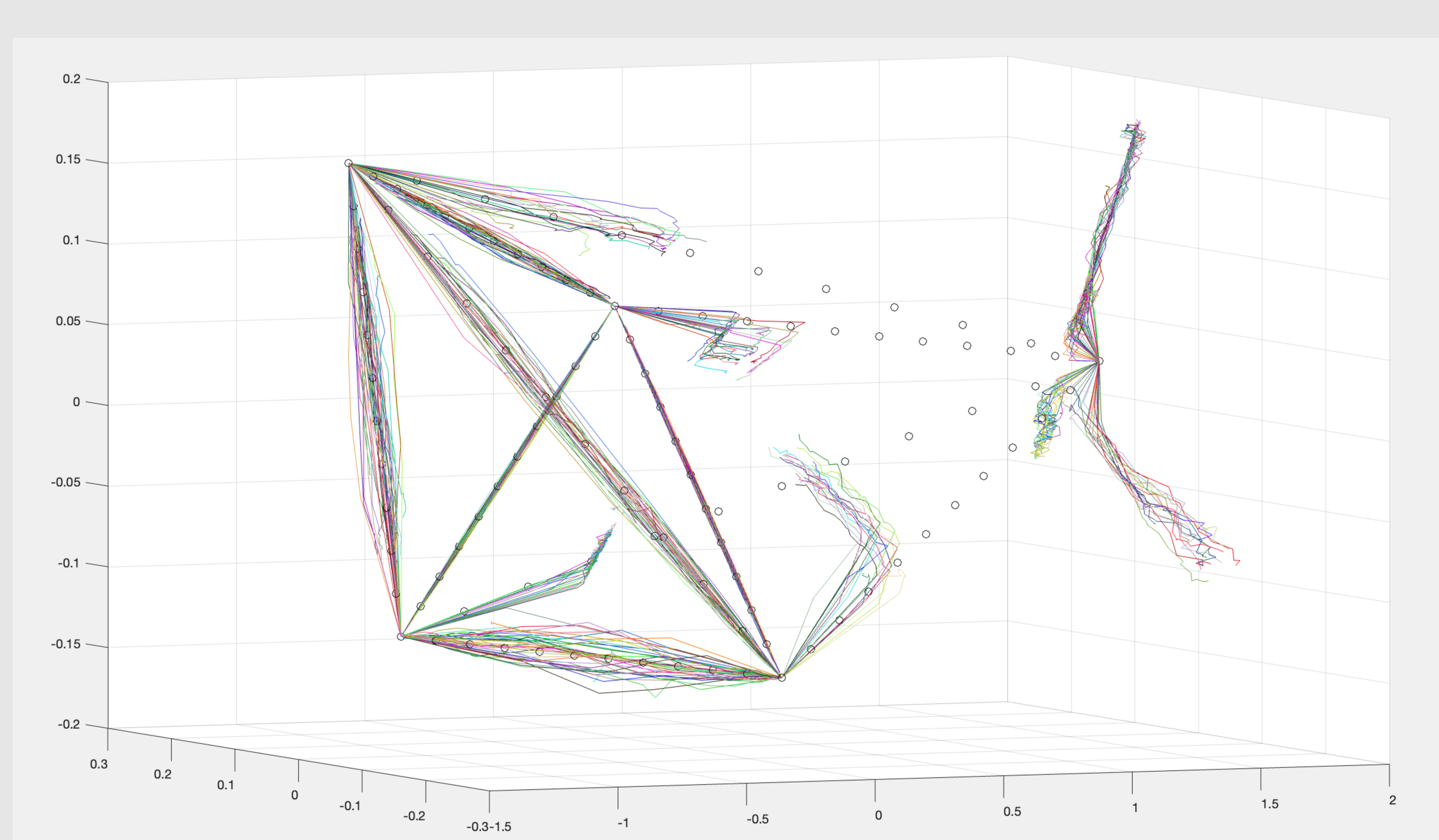

Figure 6. Three dimensional representation of the 8-dimensional parameter space showing five opima (peaks). Here we plot five vertices (labeled 1-5) representing the five best model parameter settings (fit to the behavioral data from the allopatric females). Colored lines represent attempts to connect two vertices by changing one or more model parameter values, while keeping the fit to the behavior data approximately the same. These lines represented possible paths of cryptic evolution: the behavior of the females remains unchanged while the neural circuit underlying the behavior changes. Note that peak 5 is isolated: the neural circuit cannot evolve between peak 5 and other peaks without changing the behavior in the process.