Characterizing diverse neuronal dynamics in sensory circuits

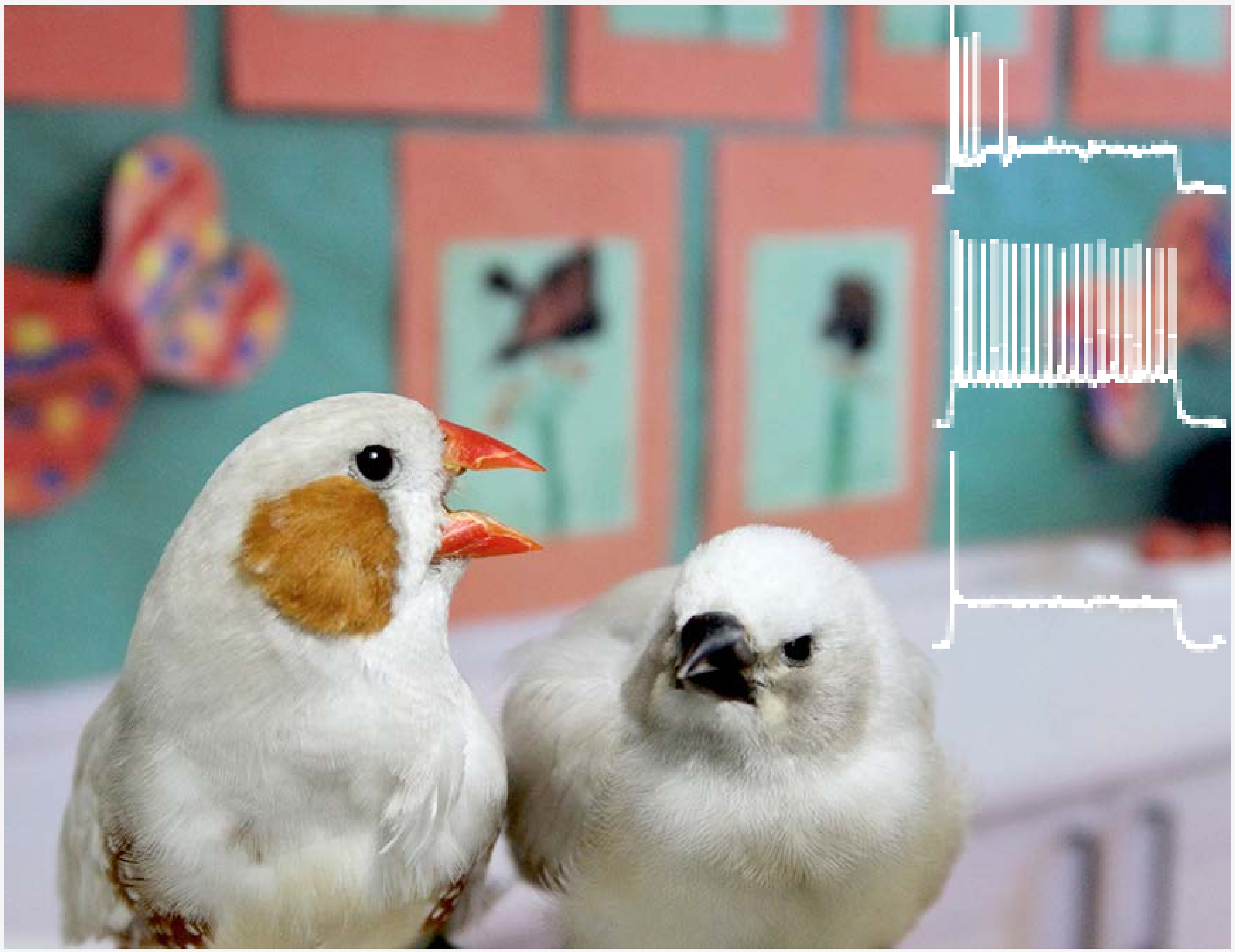
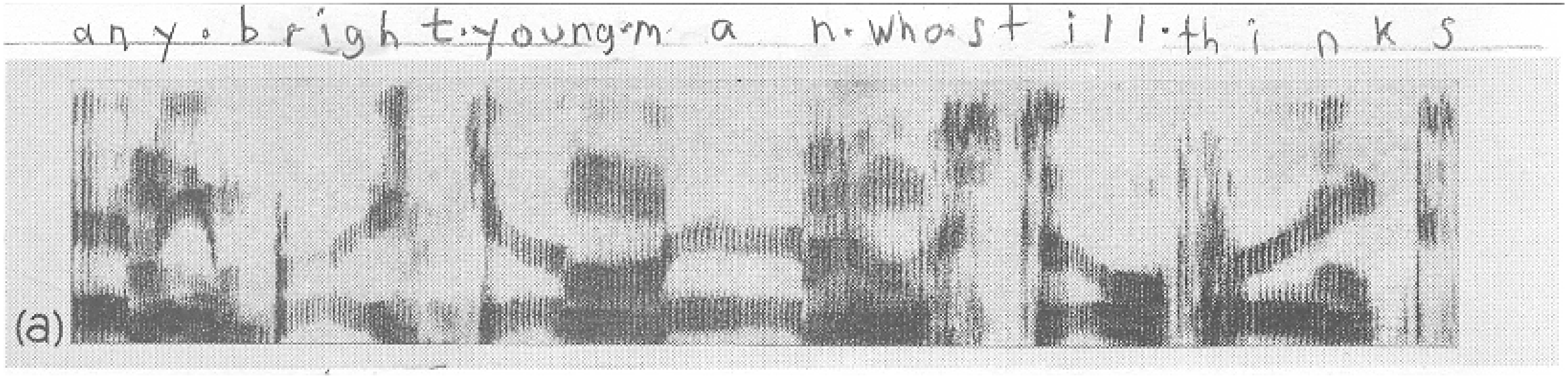


photo: Jon Sakata

Dan Meliza
University of Virginia
Department of Psychology

The sensory decoding problem

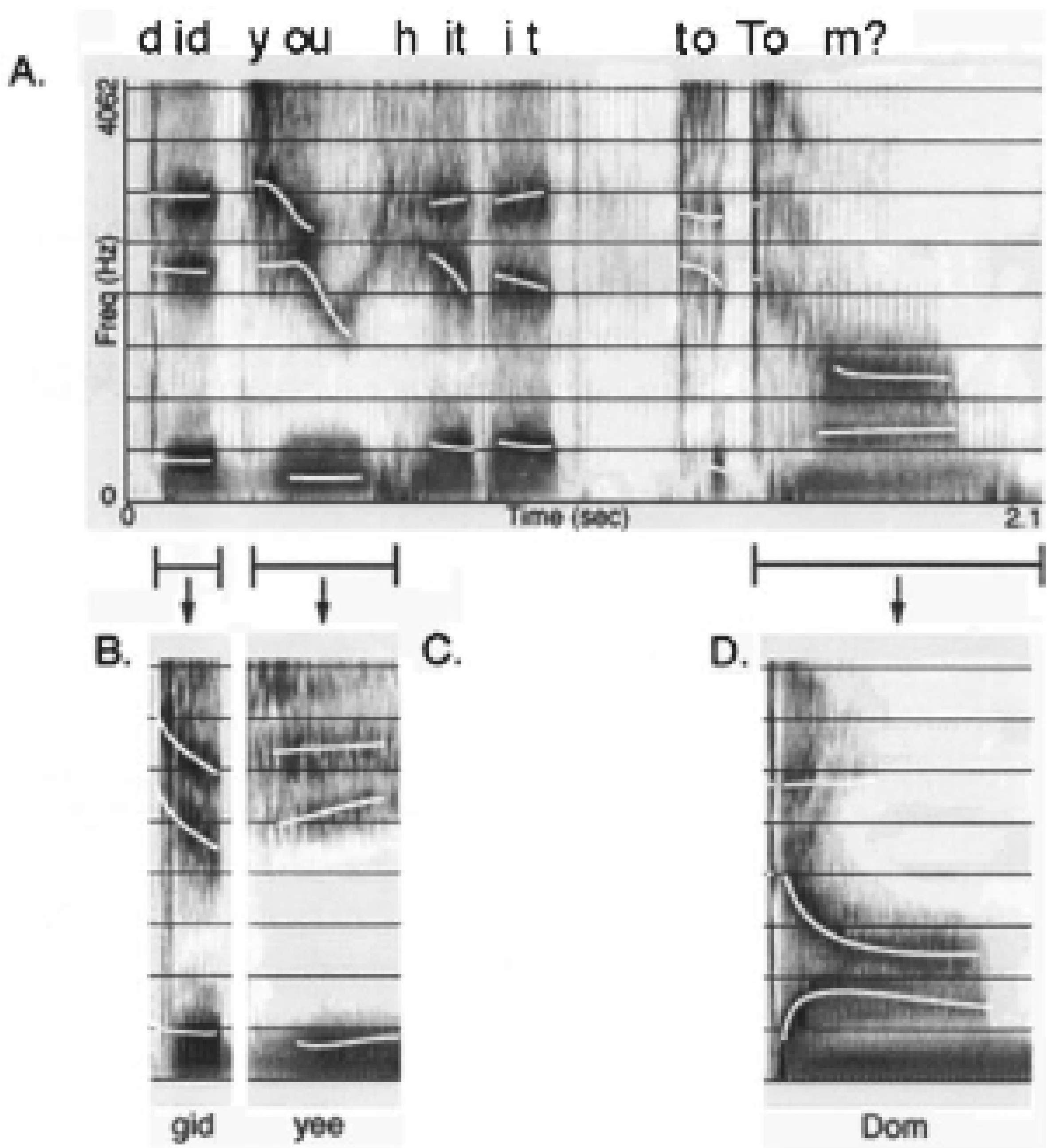
- Same distal object, many proximal representations
- Example: phonetic perception



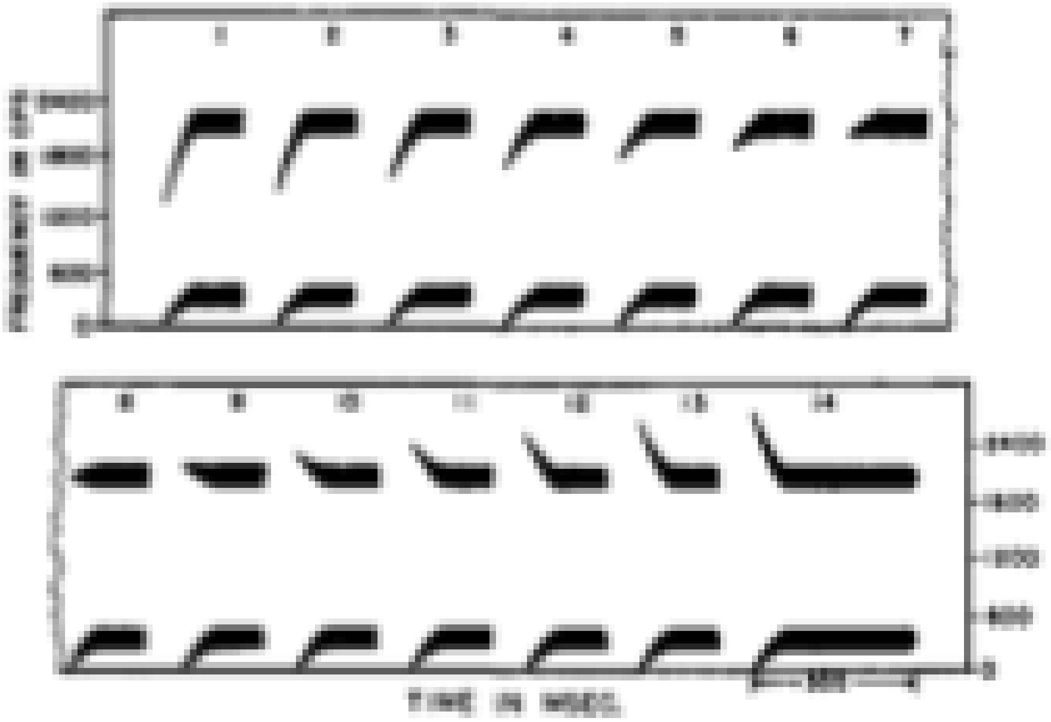
- Misleading or absent segmentation
- Coarticulation: context effects from anticipatory configuration of vocal tract
- Variations in pitch and duration (prosody, different speakers)
- Noise and interference (cocktail party problem)

The sensory decoding problem

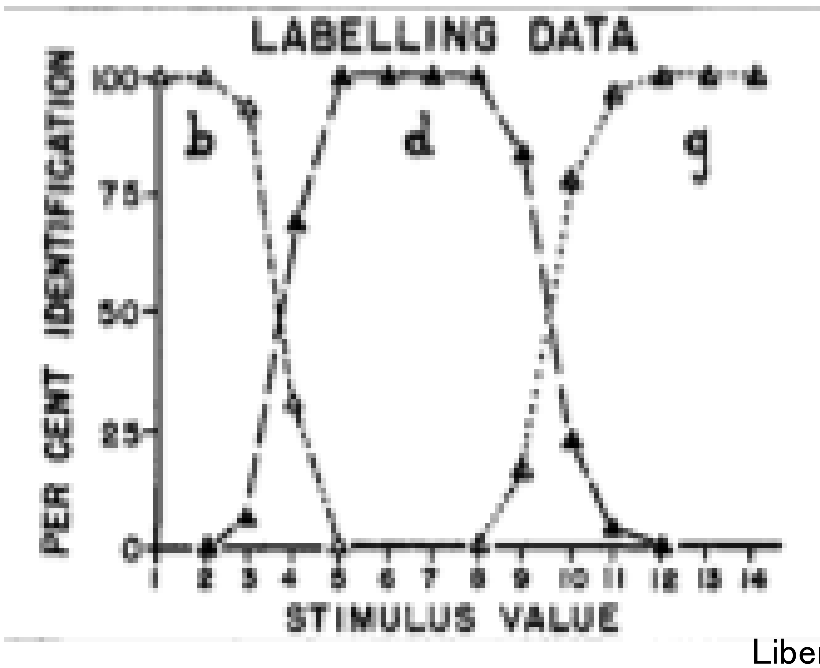
- **Different distal objects, similar proximal representations**



Doupe and Kuhl (1999)



Liberman et al (1957)



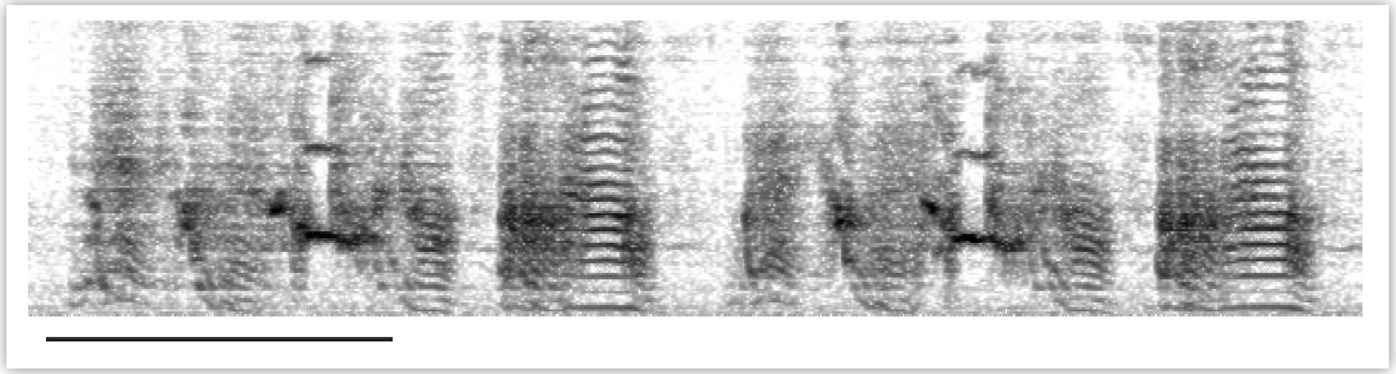
Liberman et al (1961)

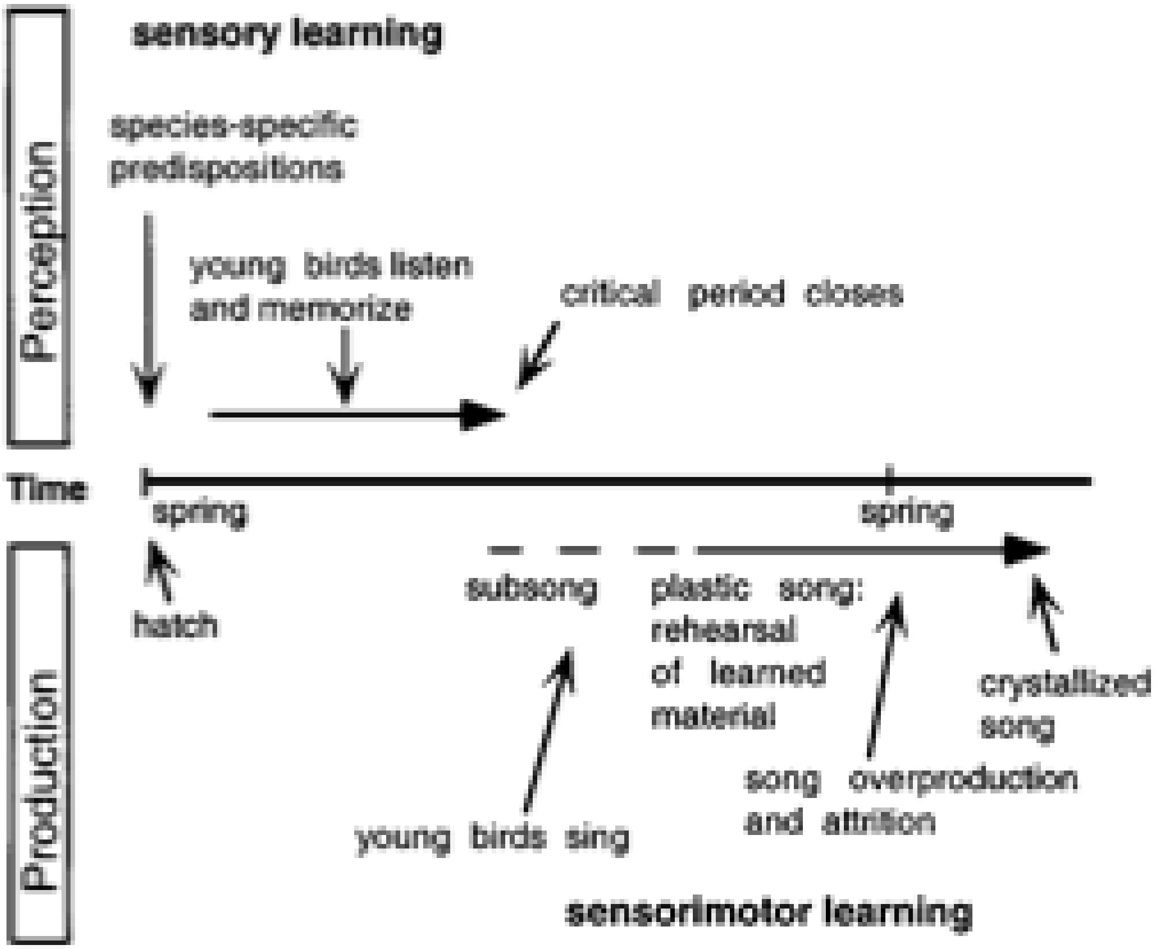
Towards biophysical models of sensory decoding

1. Songbirds as a model for speech decoding
2. Diverse dynamics in auditory circuits
3. Combining sensory response models with dynamical neuron models to understand the function of neuronal diversity

Songbirds as models for auditory and vocal learning

- Songbirds imitate an adult tutor heard in a critical period
- Juveniles refine their imitation of the tutor through sensorimotor learning
- Production and perception are tightly linked

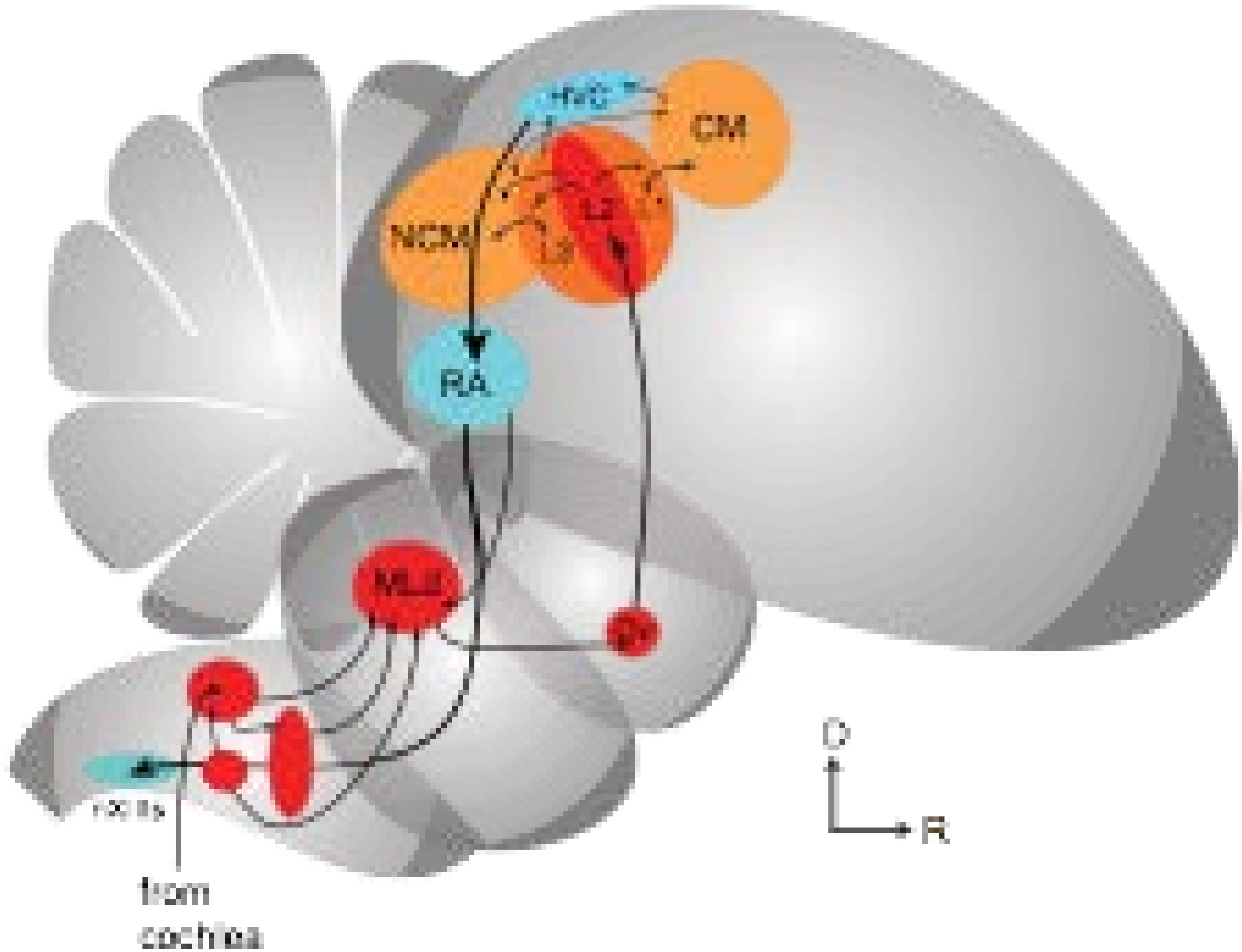




Doupe and Kuhl (1999)

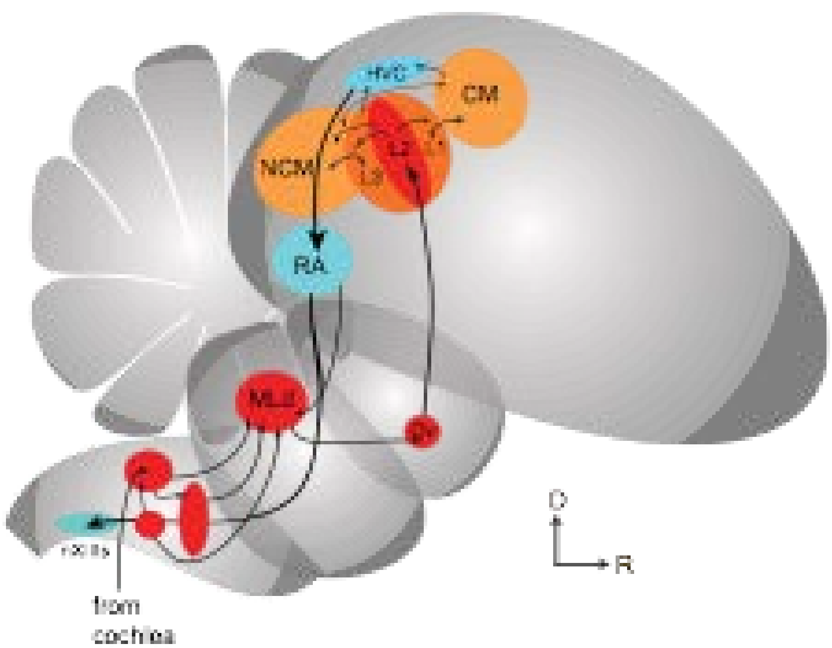
The songbird auditory pathway

- Auditory stimuli are processed hierarchically

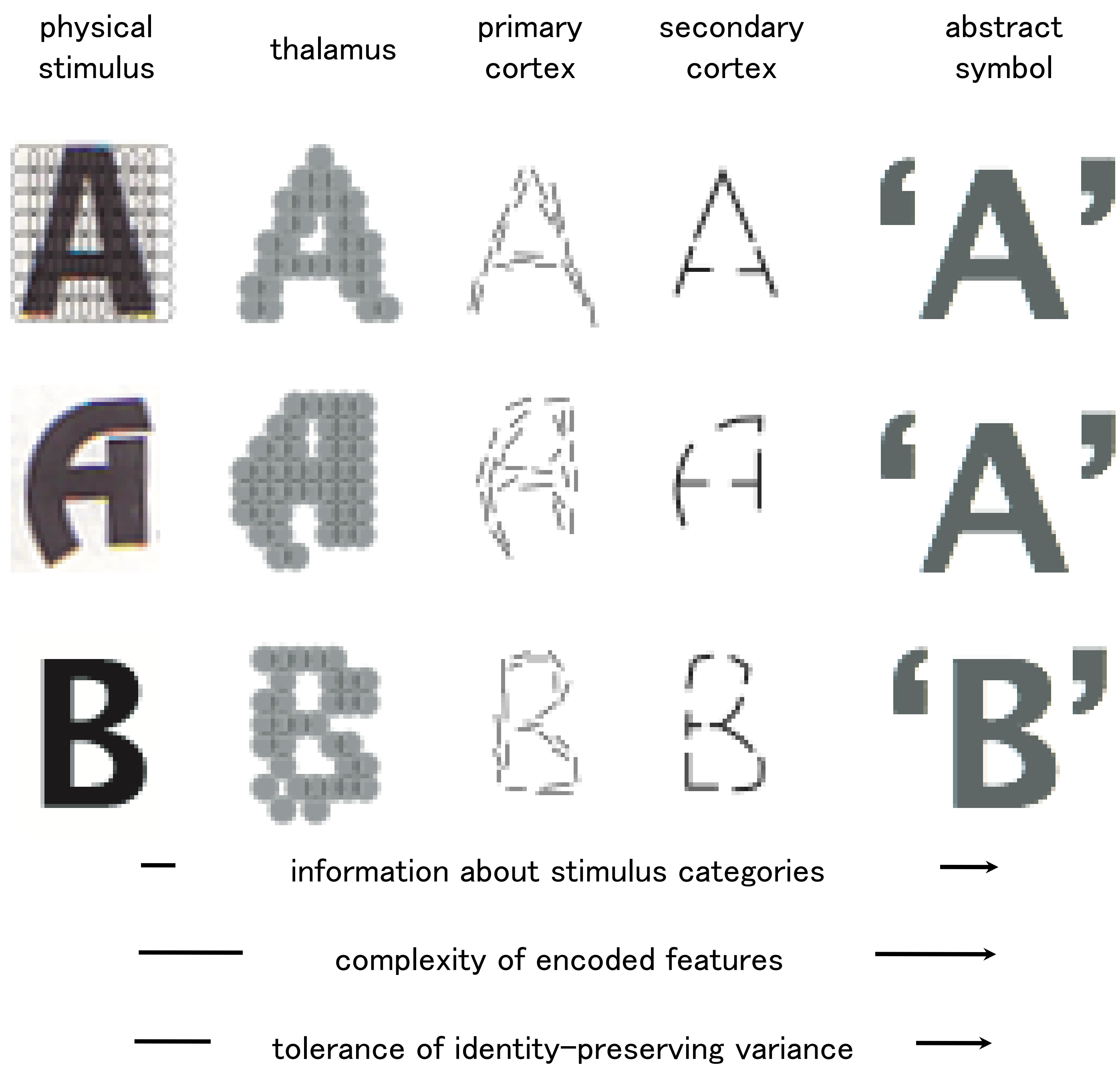


Woolley (2012)

The songbird auditory pathway



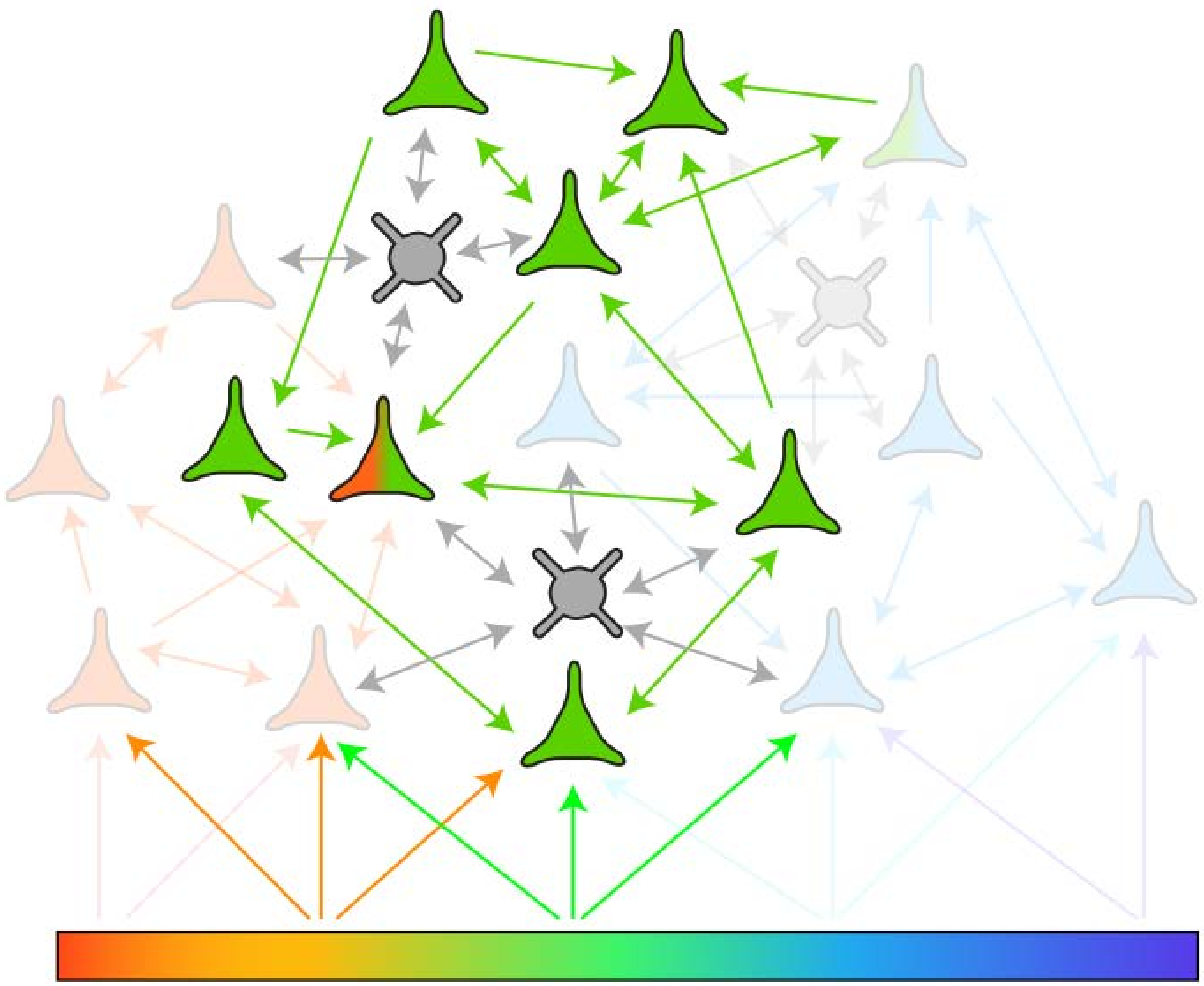
- **Auditory stimuli are processed hierarchically**



Woolley (2012)

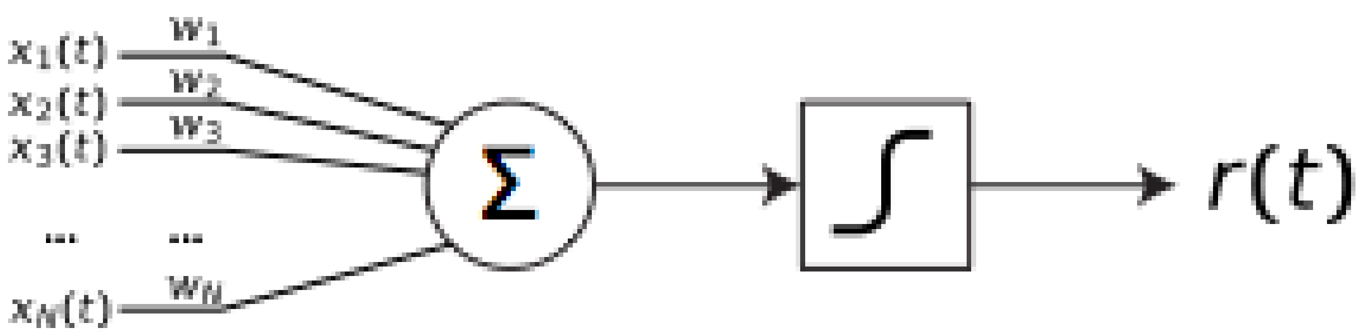
Circuits for sensory decoding

Convergent and recurrent networks

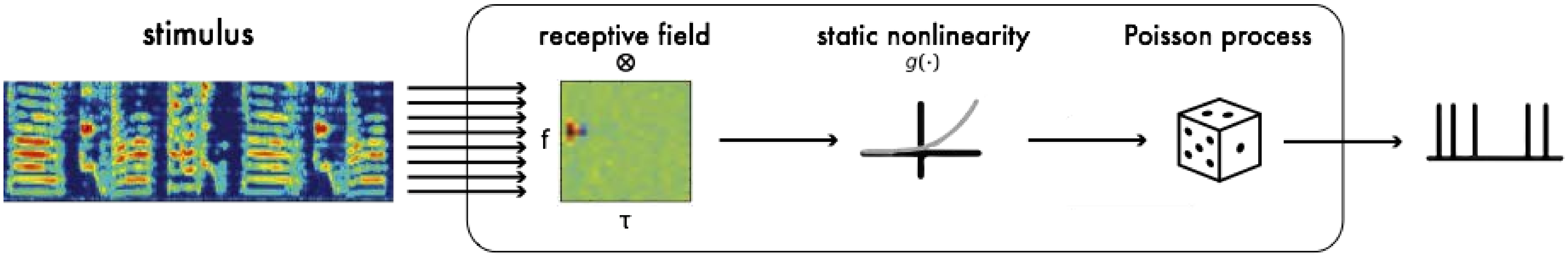


Models for neural computation

A very simple neuron model

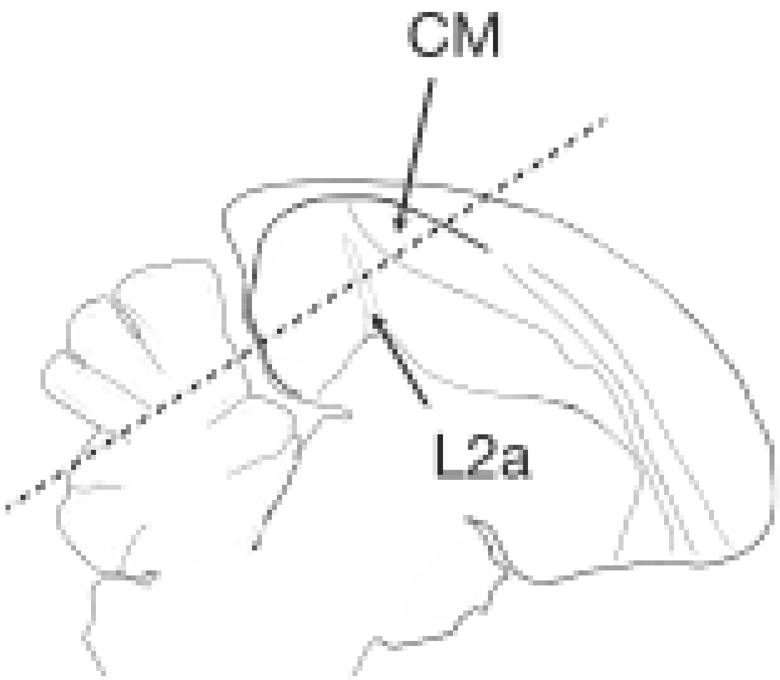


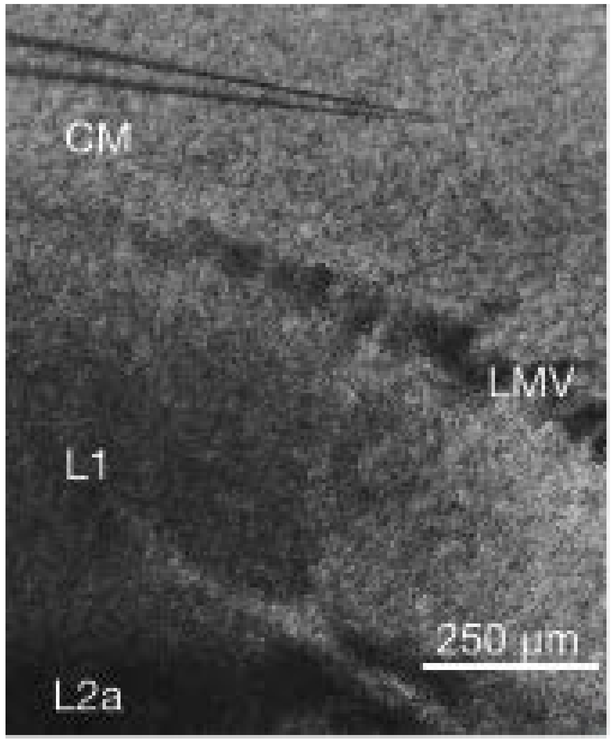
gives the linear-nonlinear-Poisson (LNP) RF model

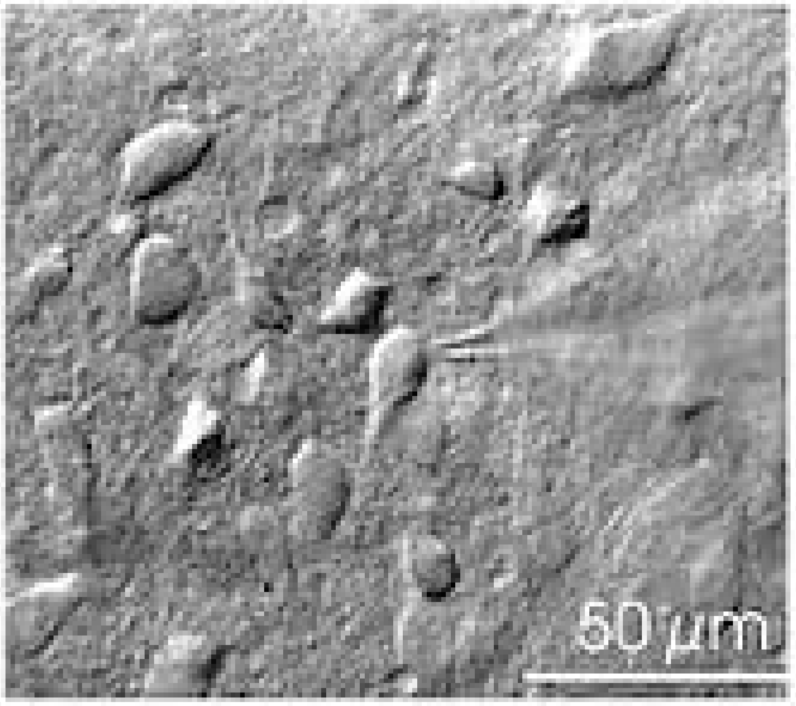


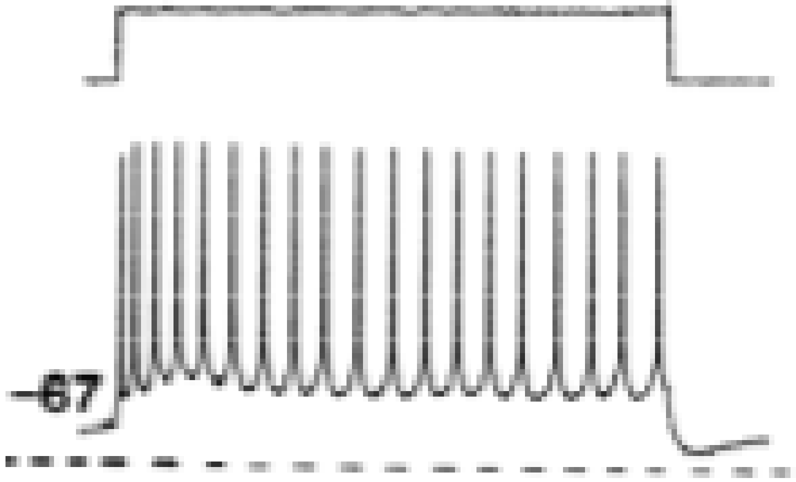
adapted from Desbordes et al. (2010)

Intracellular electrophysiology in CM



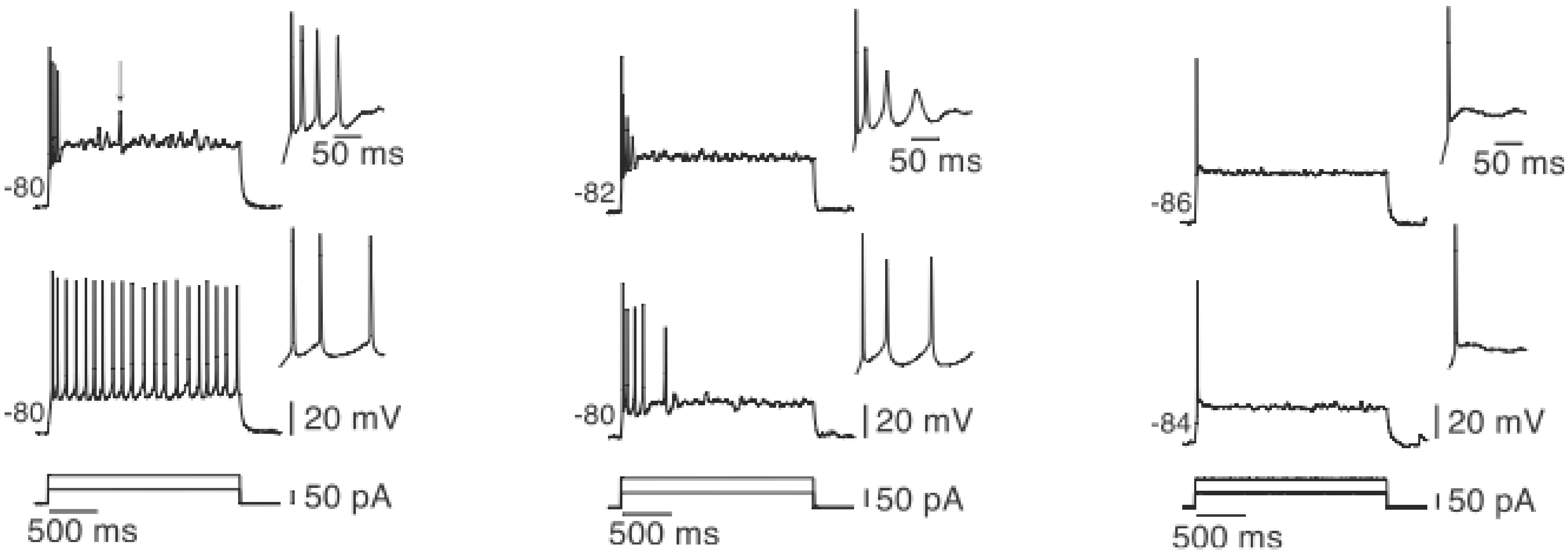


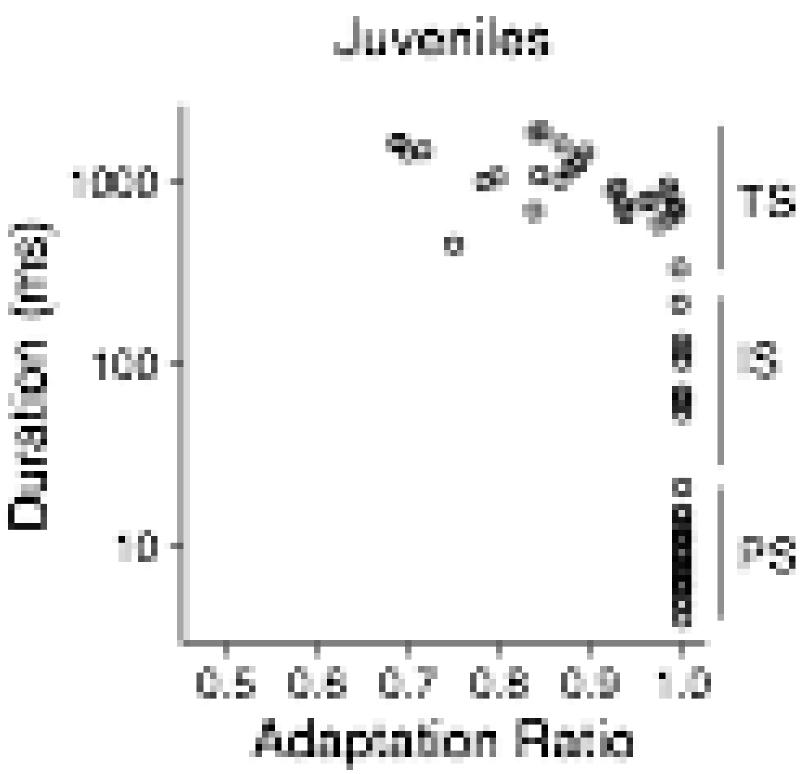




McCormick et al (1985)

Zebra finch CM neurons are phasic

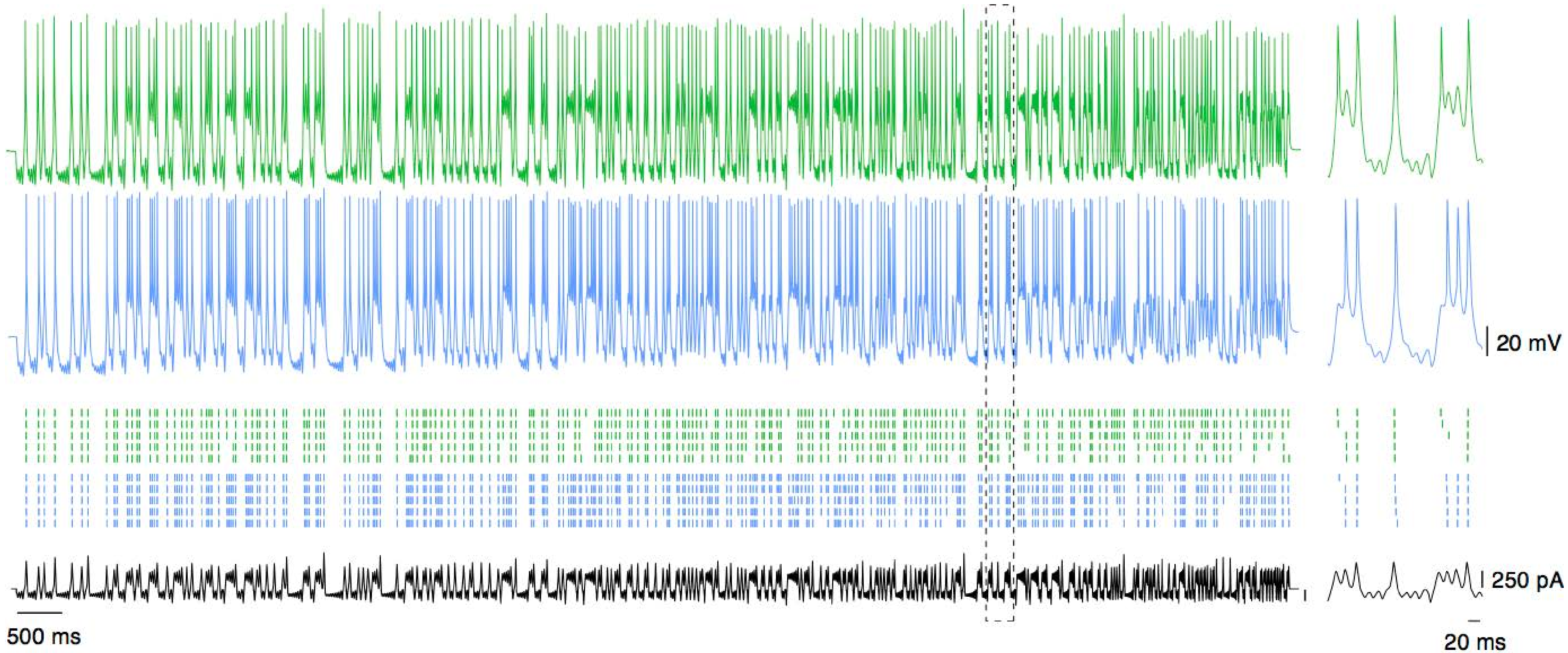


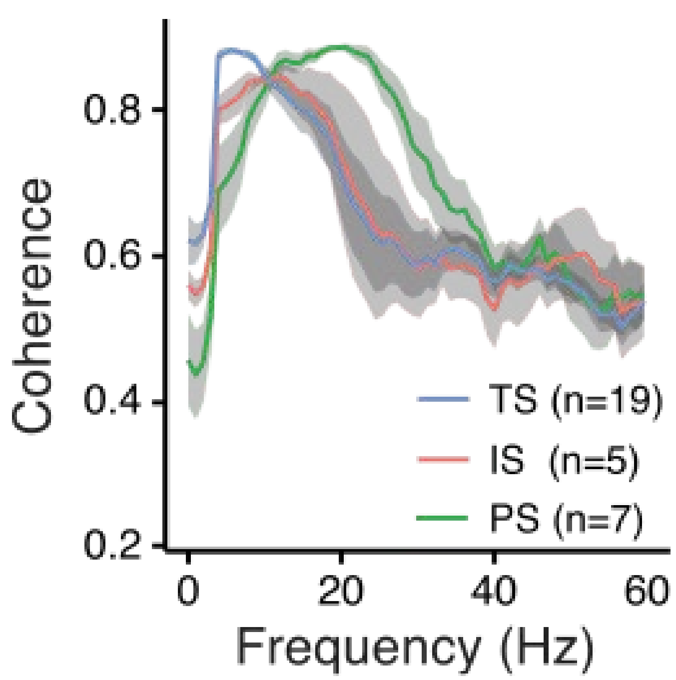


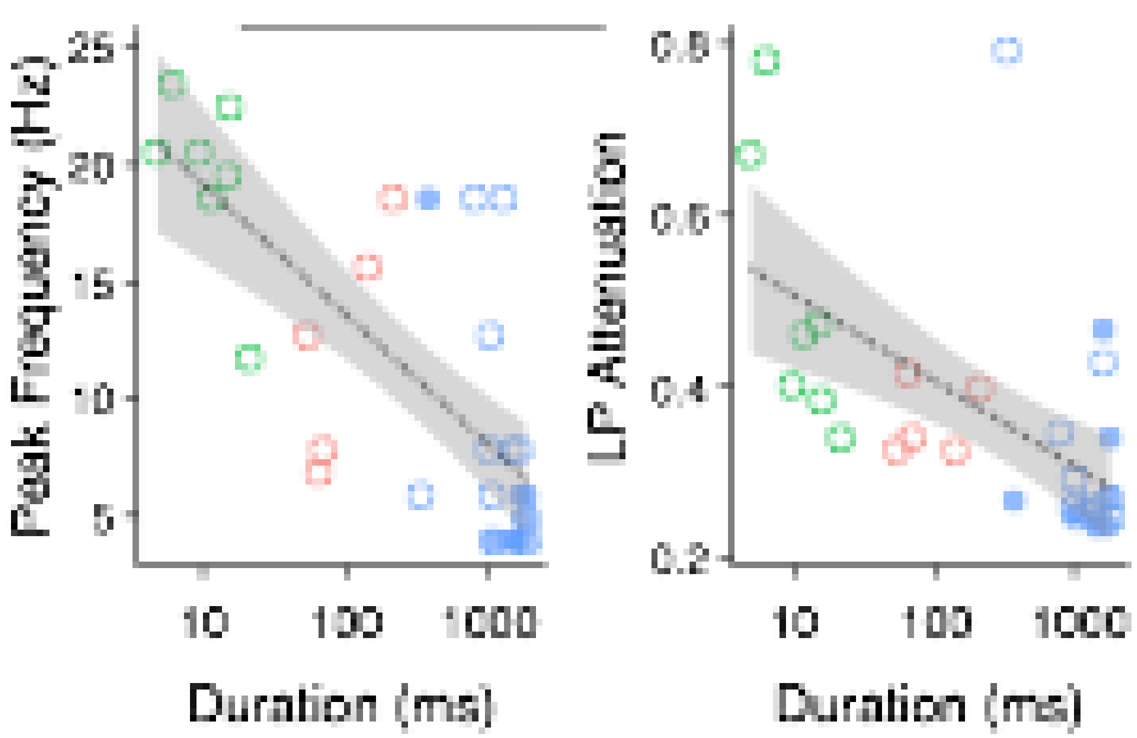
Chen & Meliza (in revision)

Do dynamics matter?

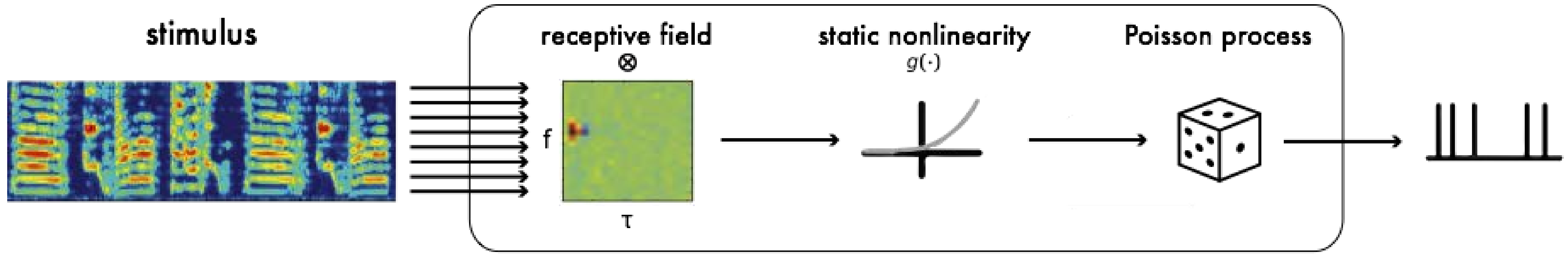
- Phasic neurons are tuned to faster modulations



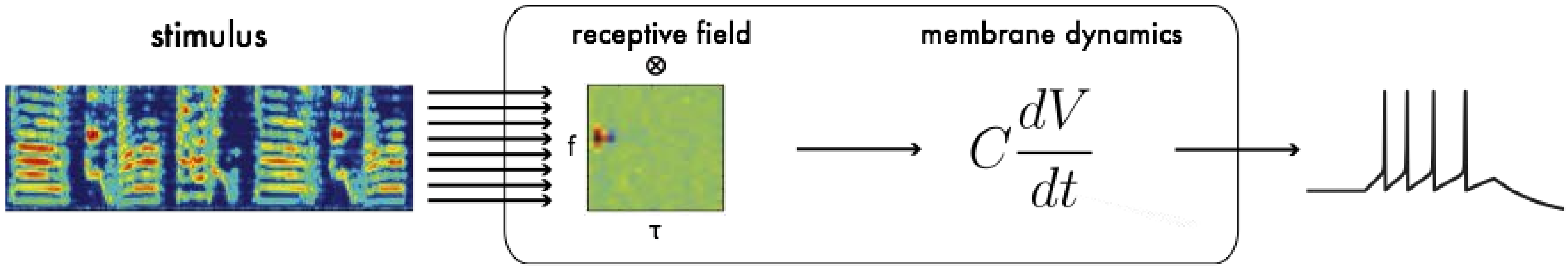




Dynamical receptive field models



adapted from Desbordes et al. (2010)



Stimulus enters the dynamics as a driving current:

$$
\begin{aligned}
C_m \frac{dV}{dt} &= g_L(E_L - V) \\
&\quad + g_{Na}(t)(E_{Na} - V) \\
&\quad + g_K(t)(E_K - V) \\
&\quad + \cdots \\
&\quad + I_{\text{stim}}(t)
\end{aligned}
$$

$$
I_{\text{stim}}(t) = \sum_f \sum_\tau h(f,\tau) \cdot s(f, t-\tau)
$$

Phenomenological neuron models

Multi-timescale Adaptive Threshold (MAT) model

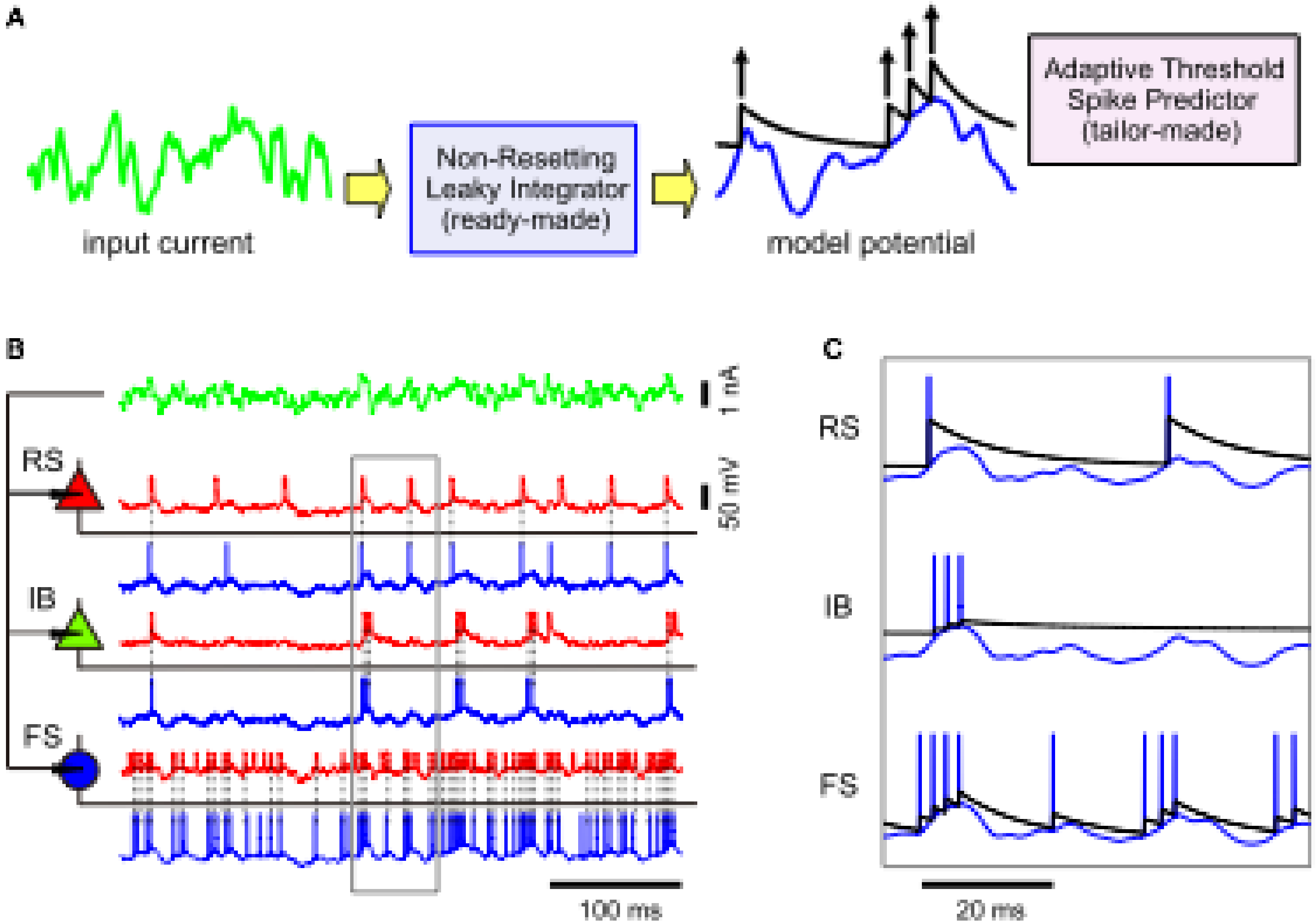
$$\tau_m \frac{dV}{dt} = -V + RI(t)$$

$$\theta(t) = \sum_k H(t - t_k) + \omega$$

$$H(t) = \sum_{j=1}^{L} \alpha_j \exp(-t/\tau_j)$$

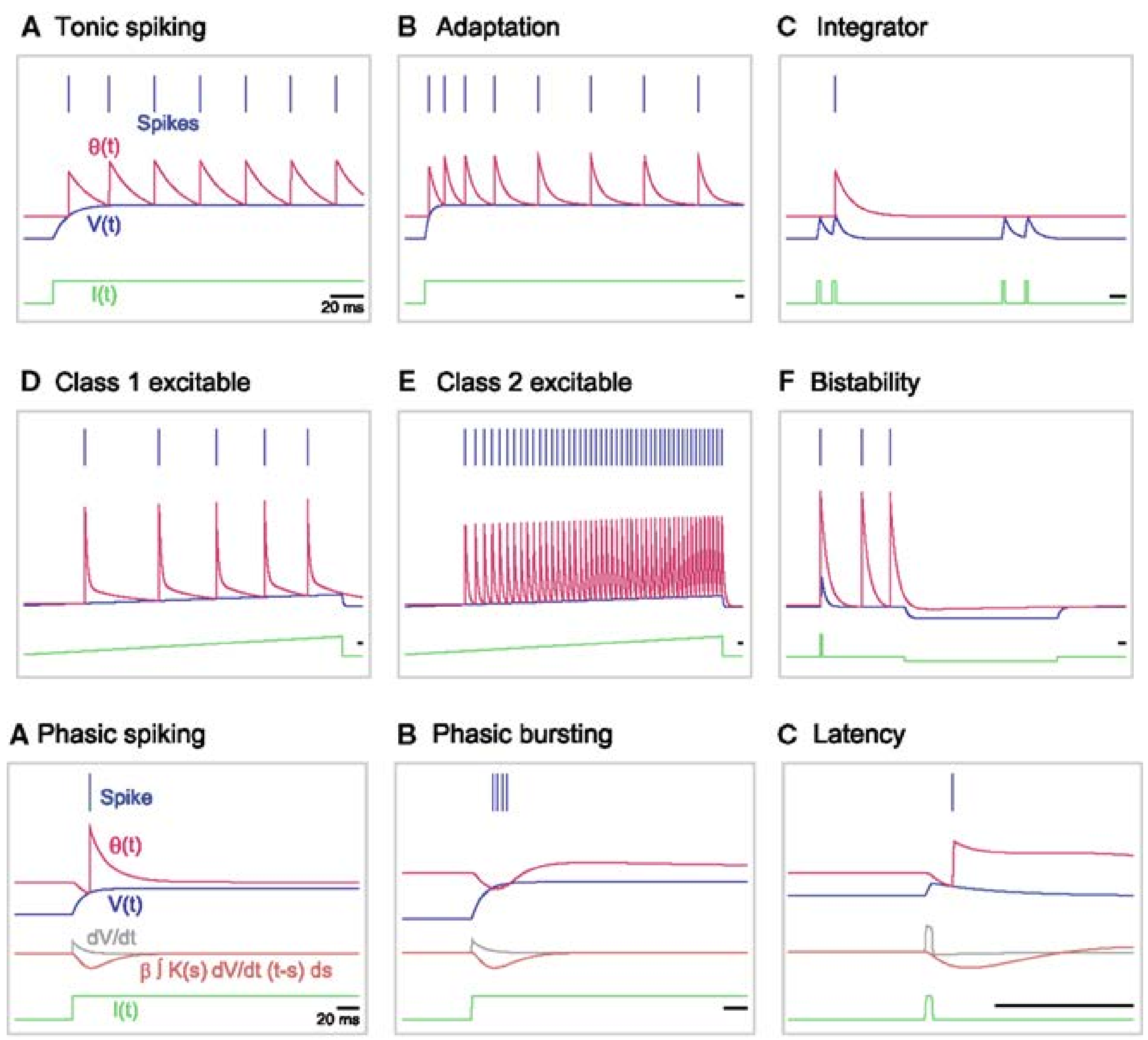
$$\mathbf{x}(t) = (V(t), \theta(t))$$

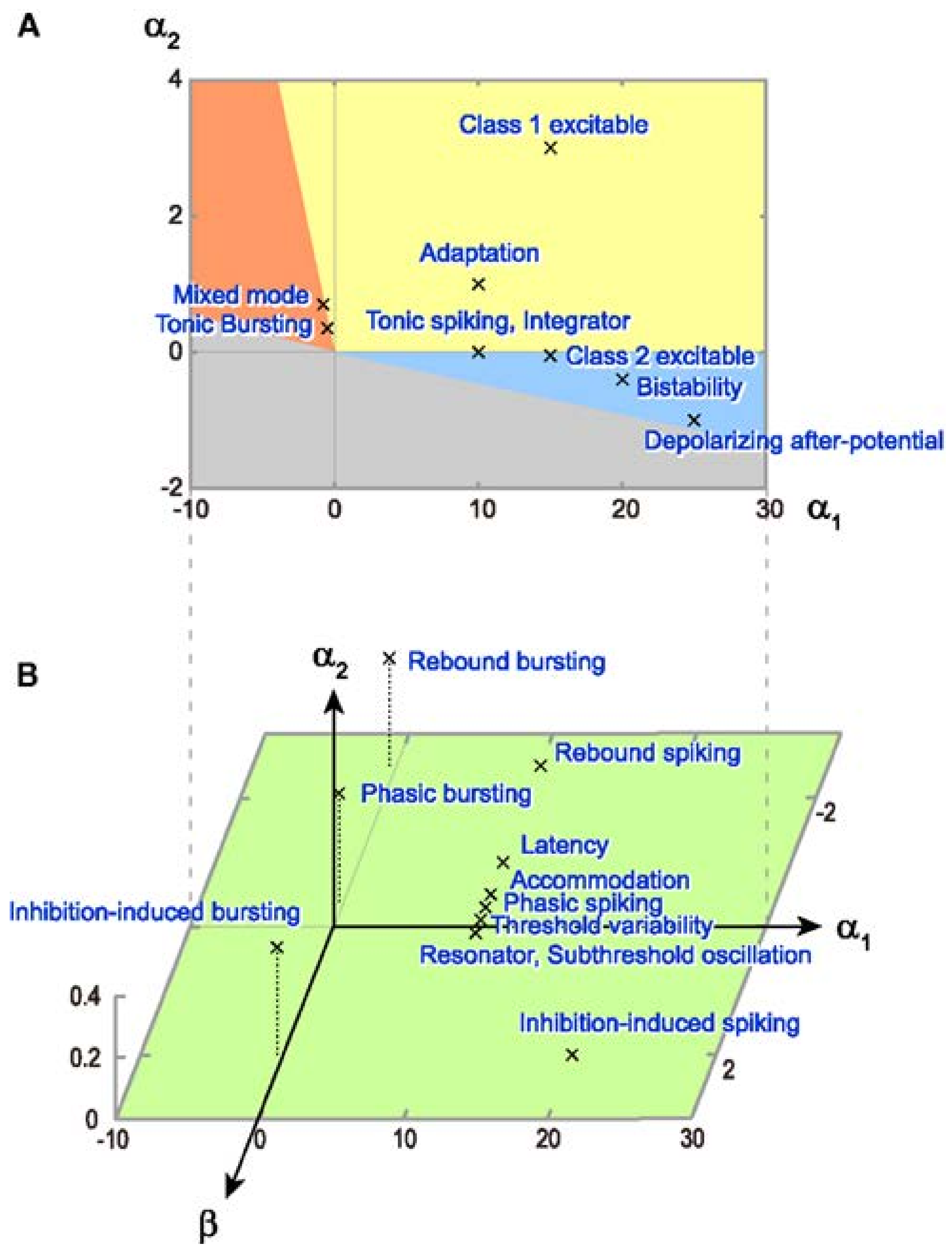
$$\mathbf{p} = (\tau_m, R, \omega, \alpha_1, \tau_1, \ldots, \alpha_L, \tau_L)$$



Kobayahsi et al (Front Comp Neurosci 2009)

MAT model firing patterns and parameters





Kobayahsi et al (Front Comp Neurosci 2009)

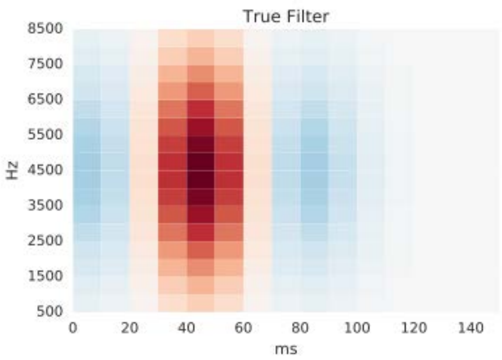
Yamauchi et al (Front Comp Neurosci 2011)

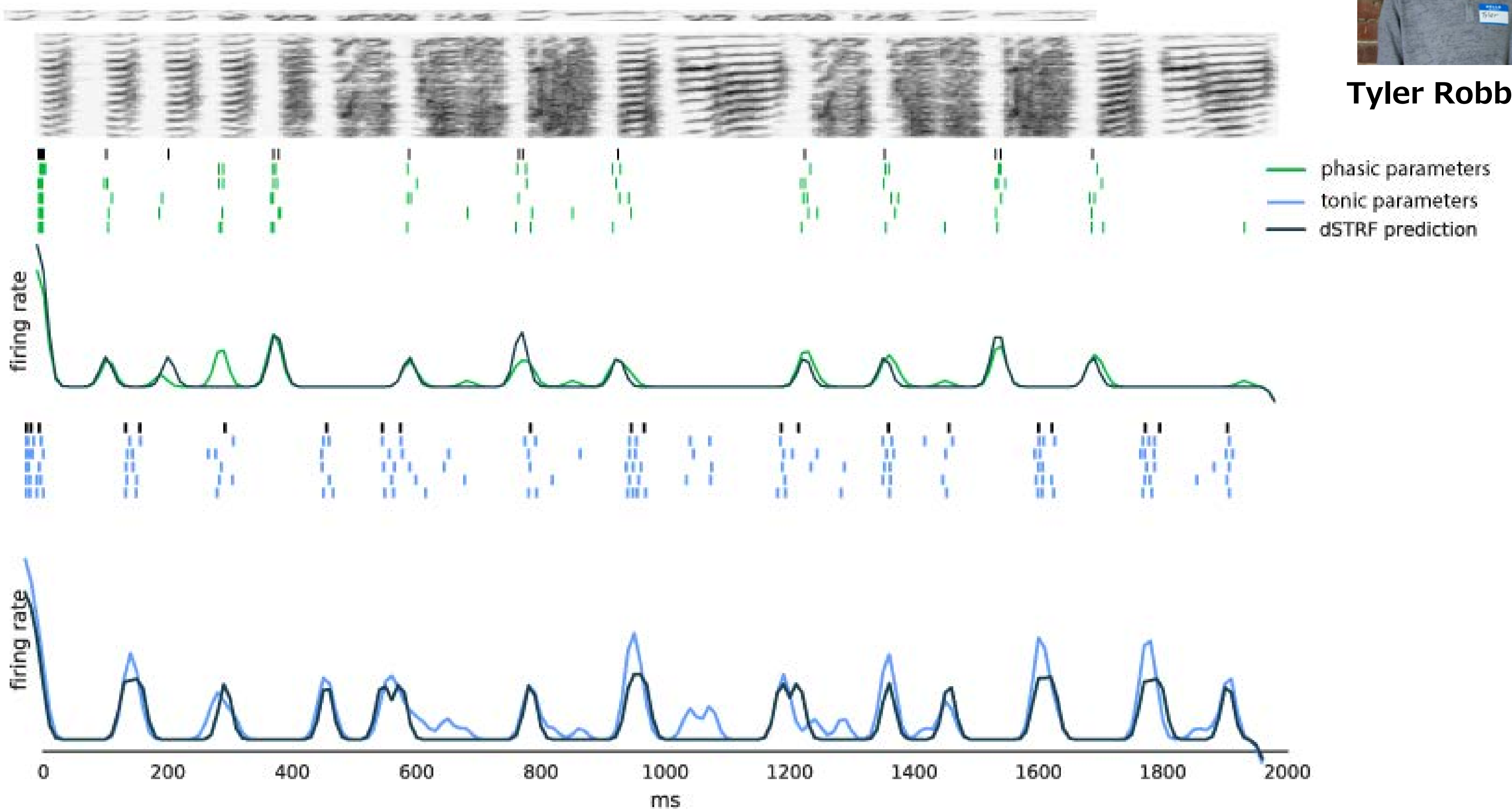
Intrinsic dynamics matter!

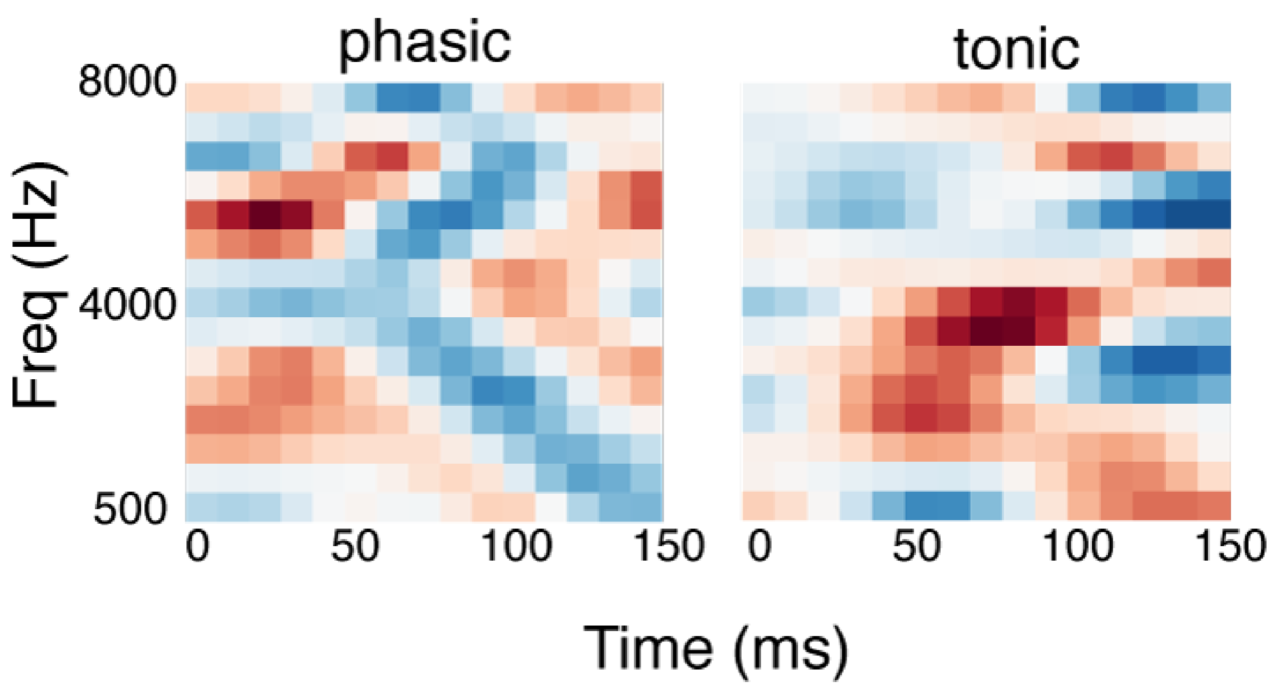
Tyler Robbins

5 stimuli @ 2 s

I_noise → 60% sync

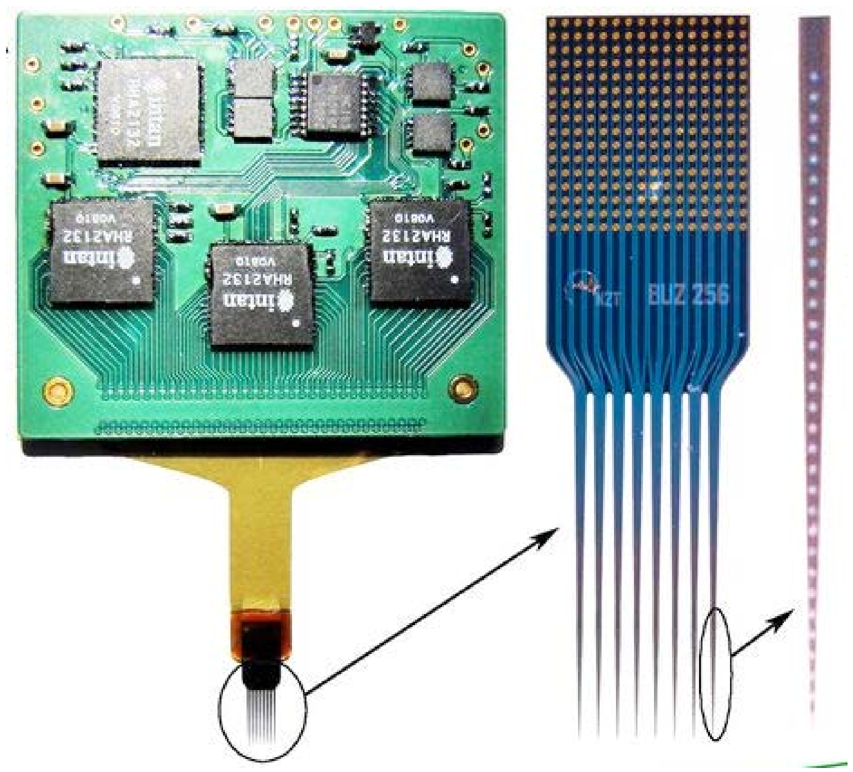


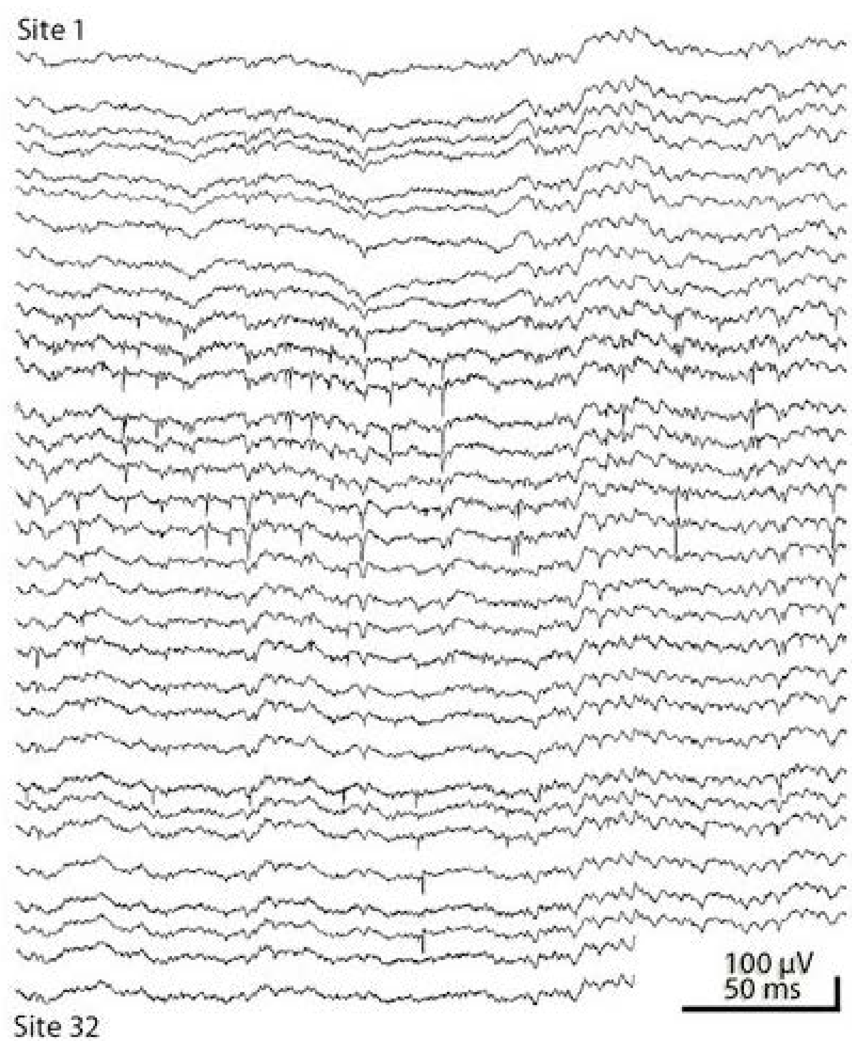


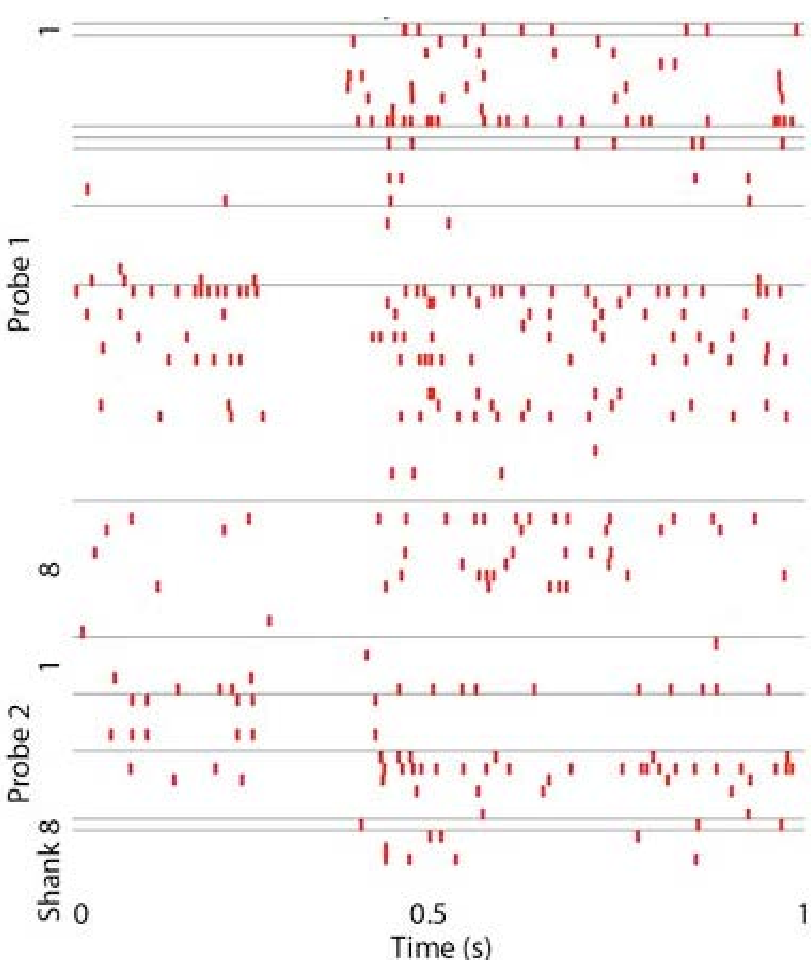


Characterizing neural diversity with DA

- Method: extracellular recordings from living birds

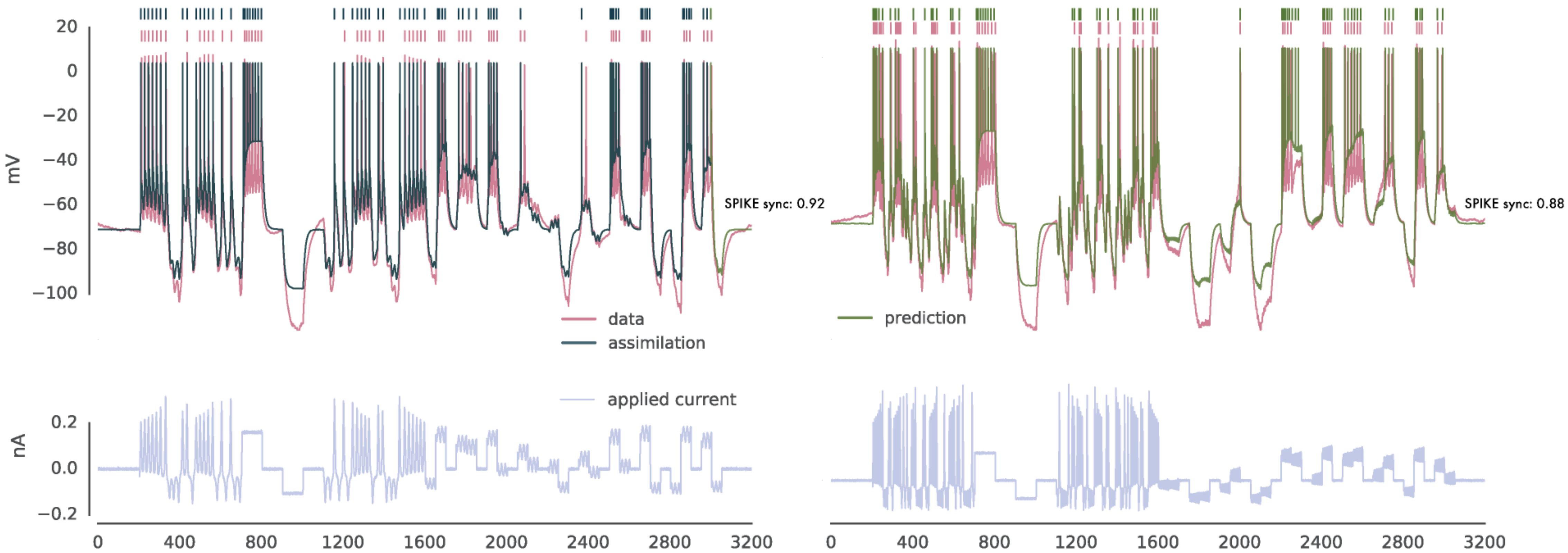


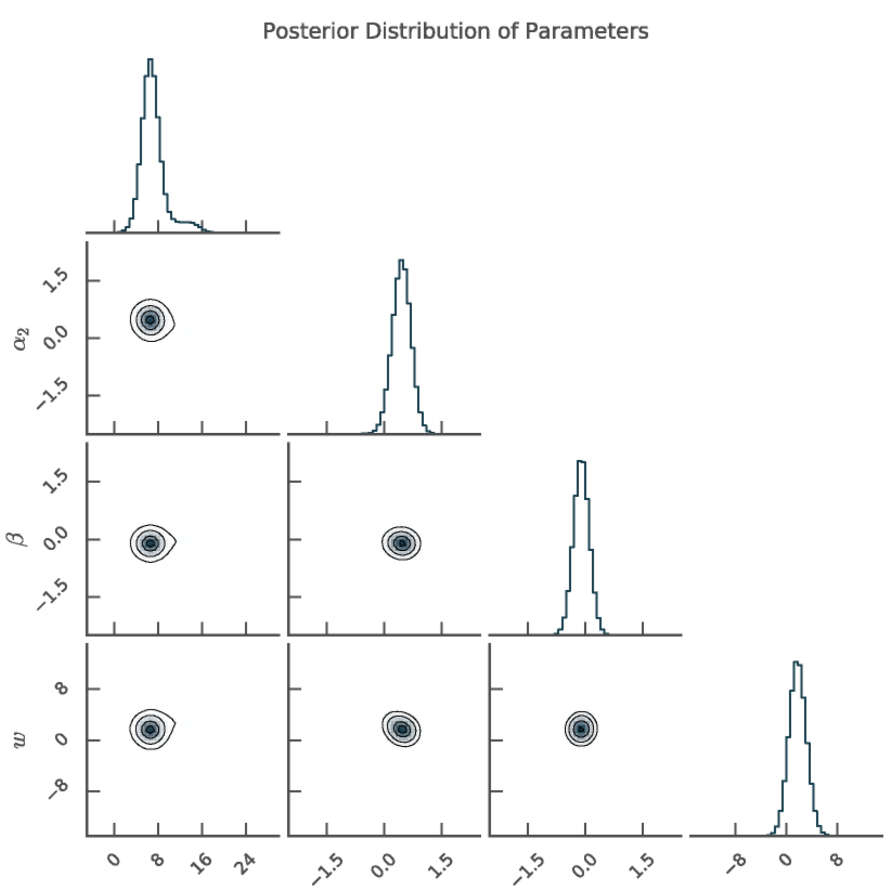


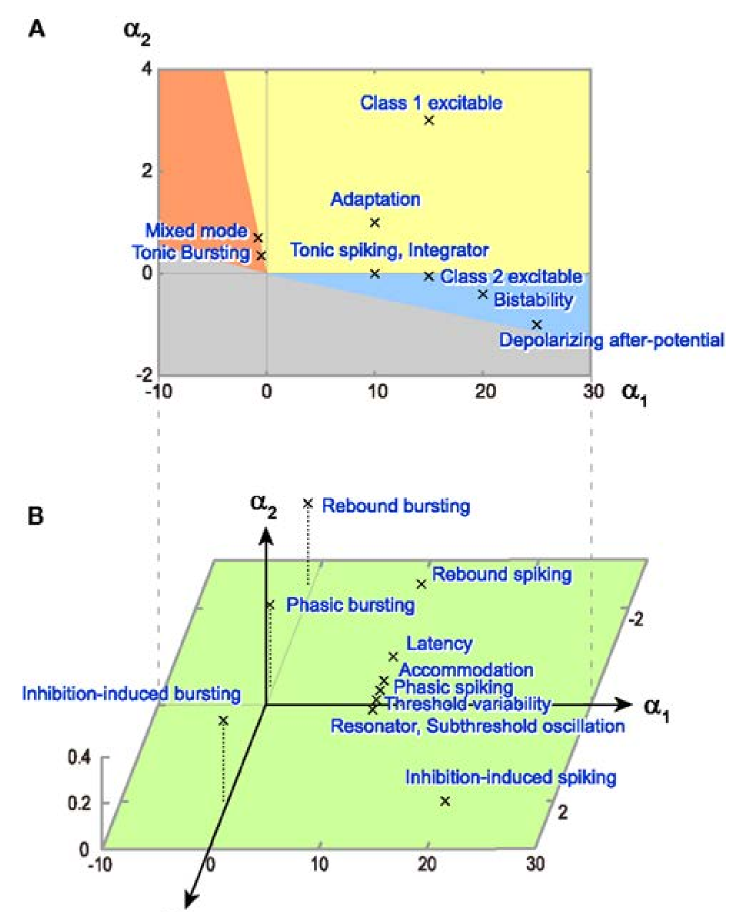


Berényi et al (2013)

MAT model assimilated to spike times





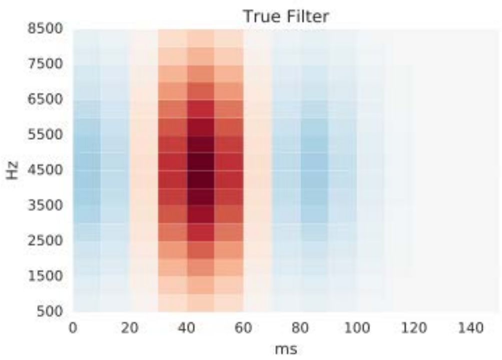


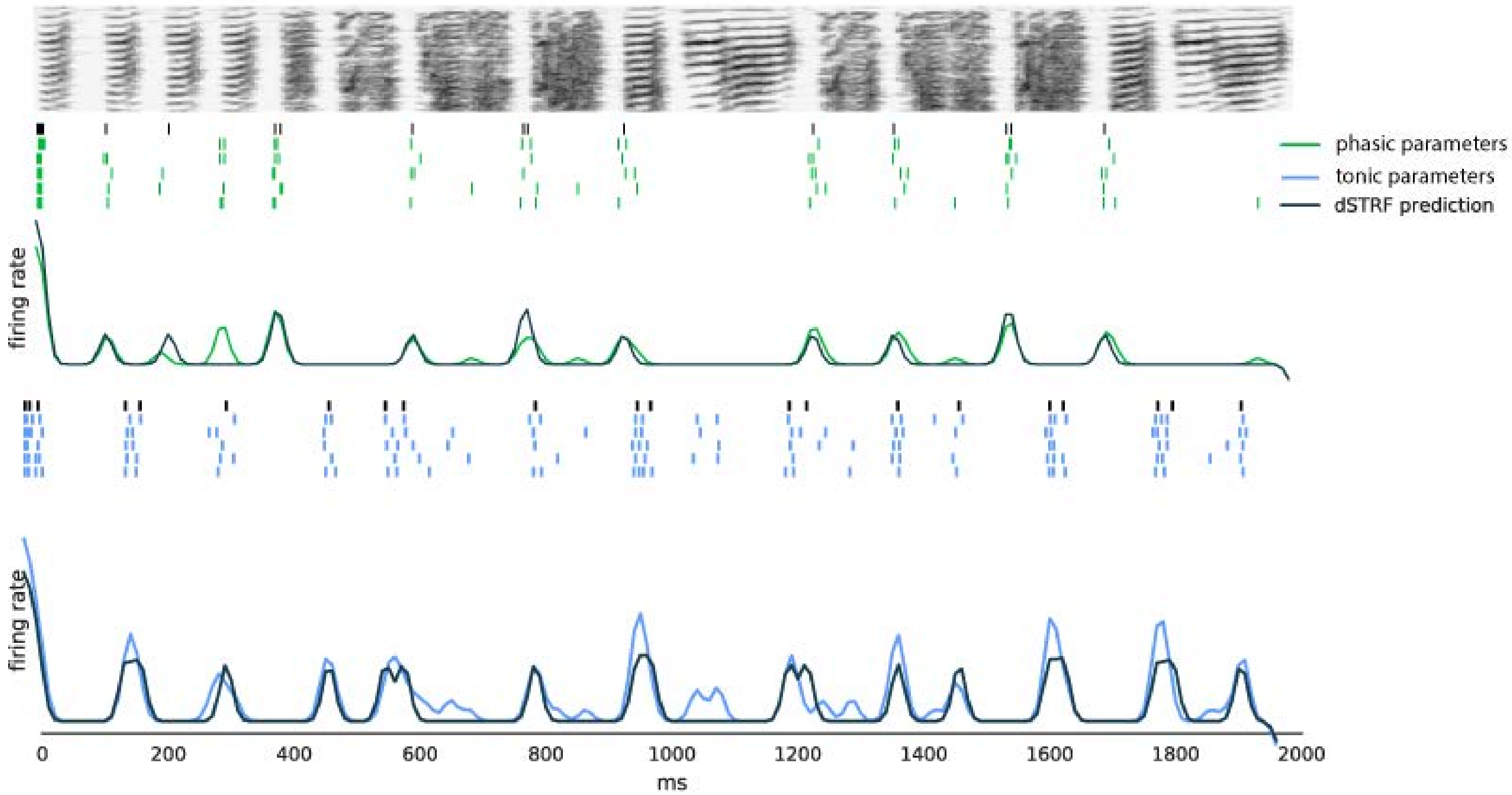
dSTRF twin experiments

Tyler Robbins

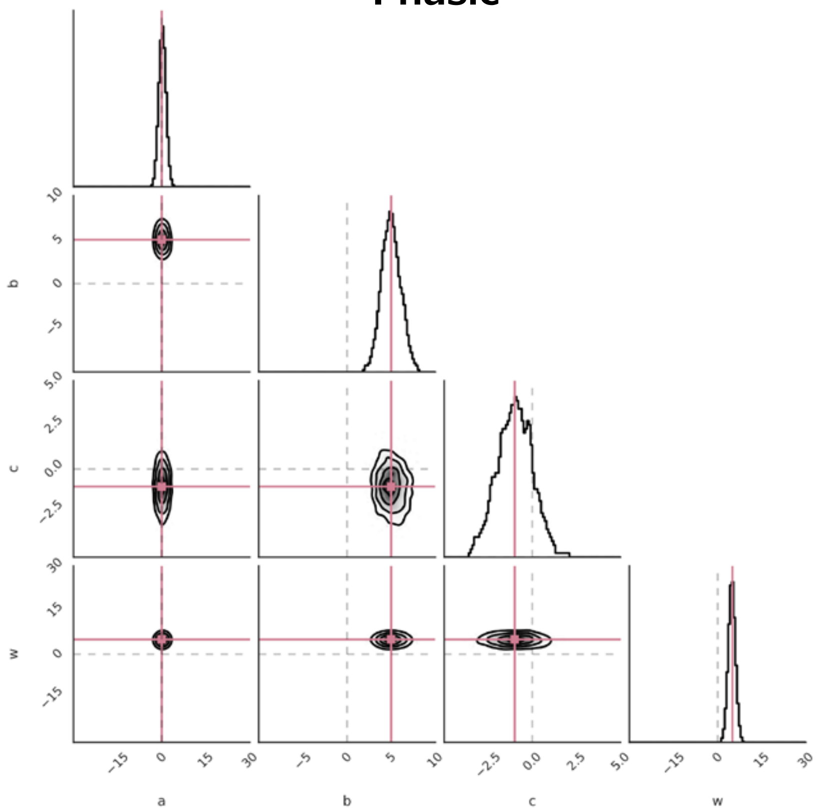
5 stimuli @ 2 s

I_noise ⟶ 60% sync

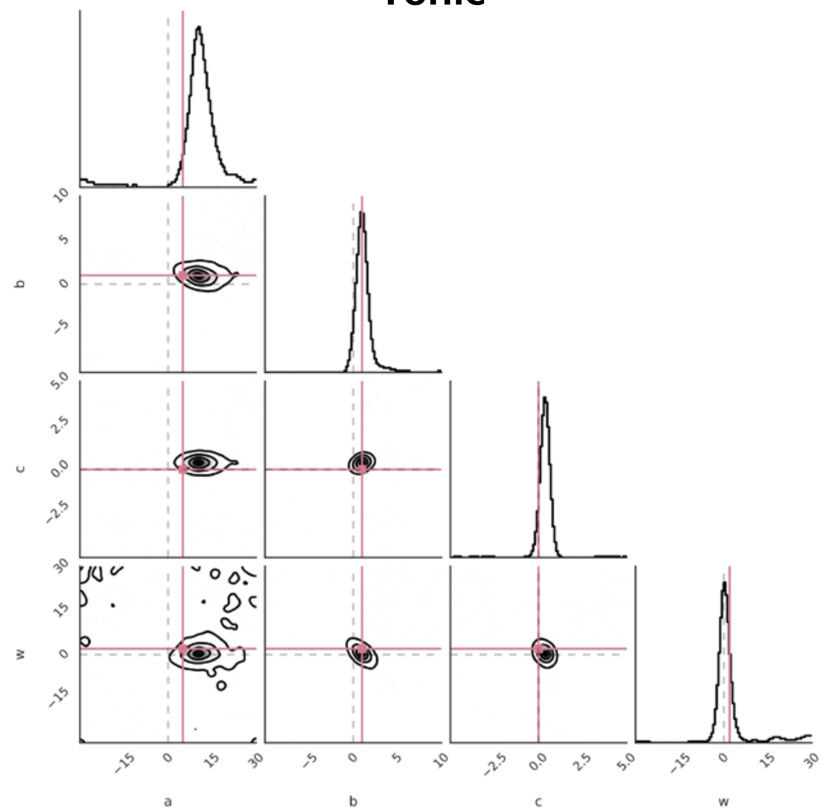




Phasic



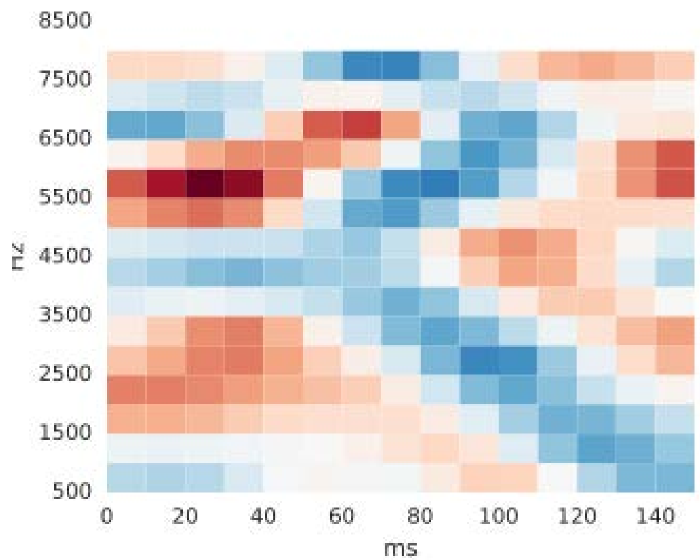
Tonic

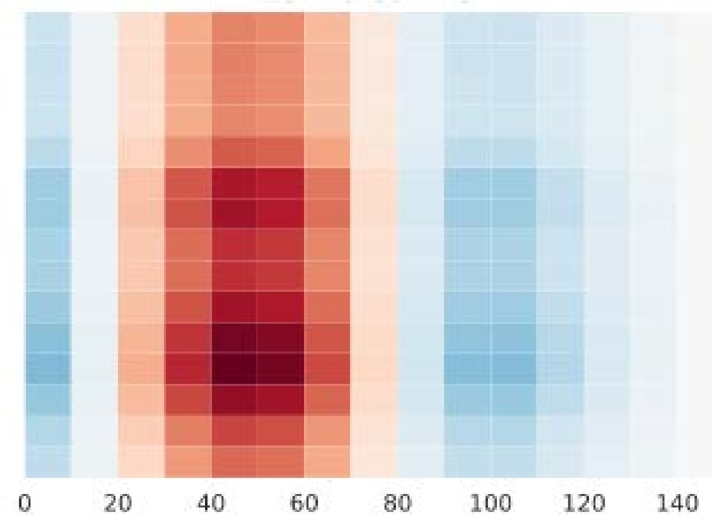


dSTRF twin experiments

STRF

dSTRF

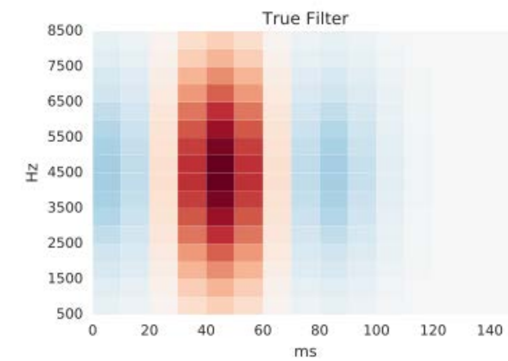


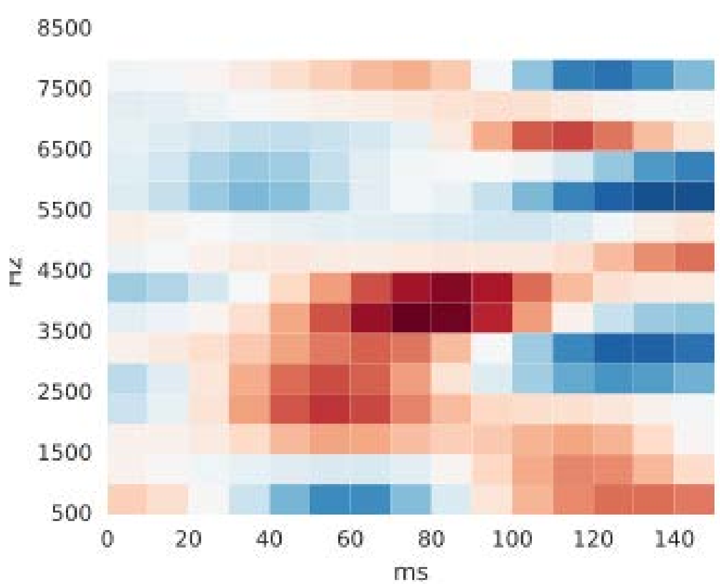


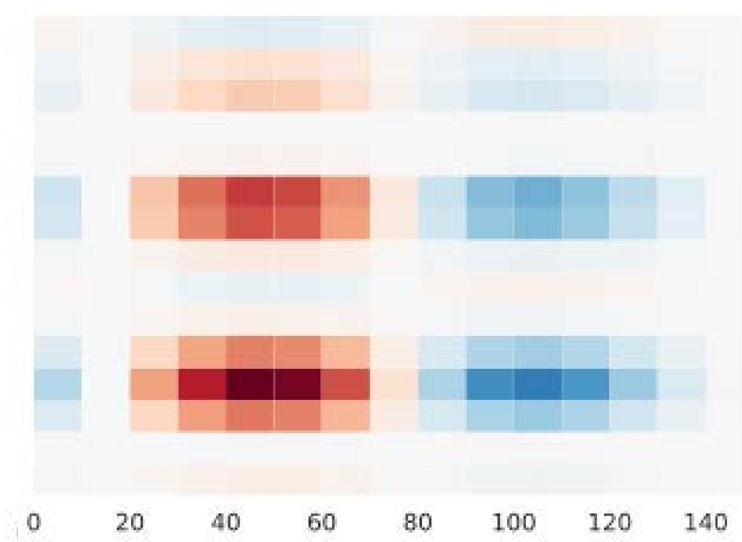
r = 0.65

r = 0.92

Phasic





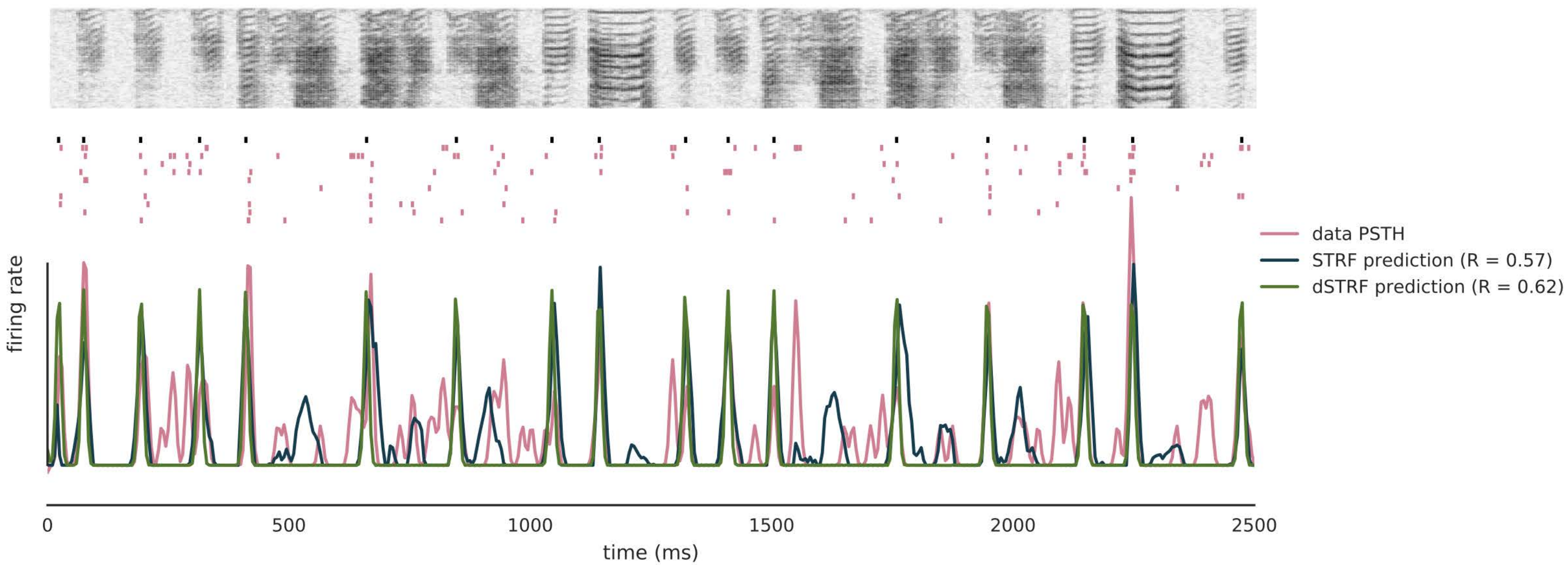


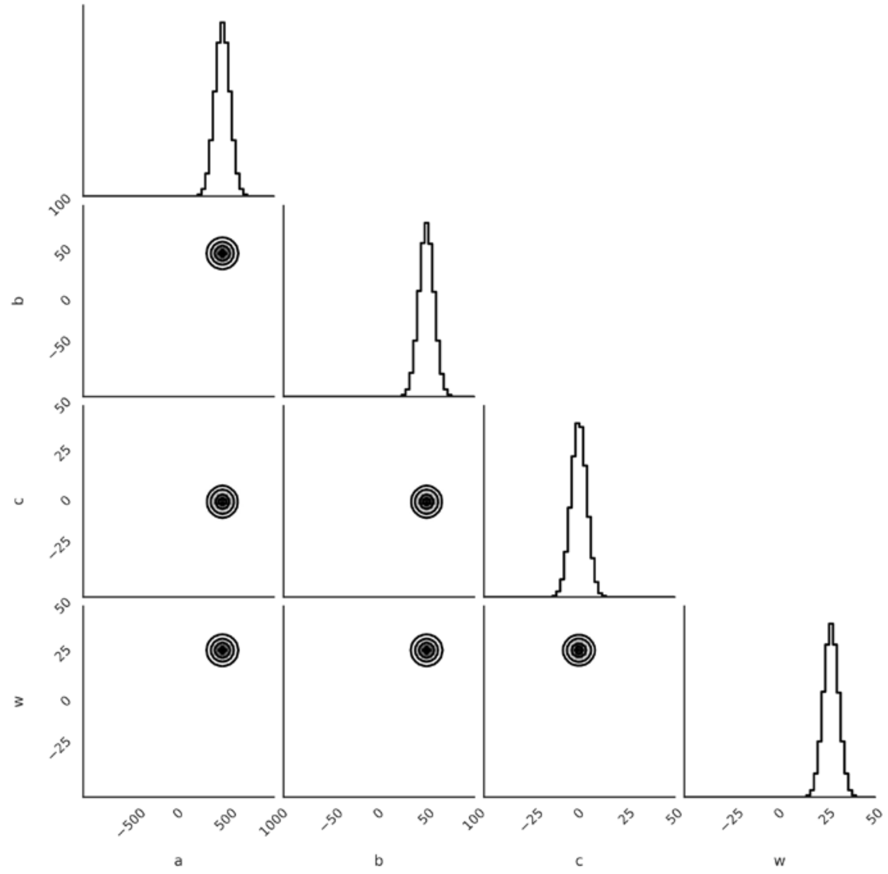
Tonic

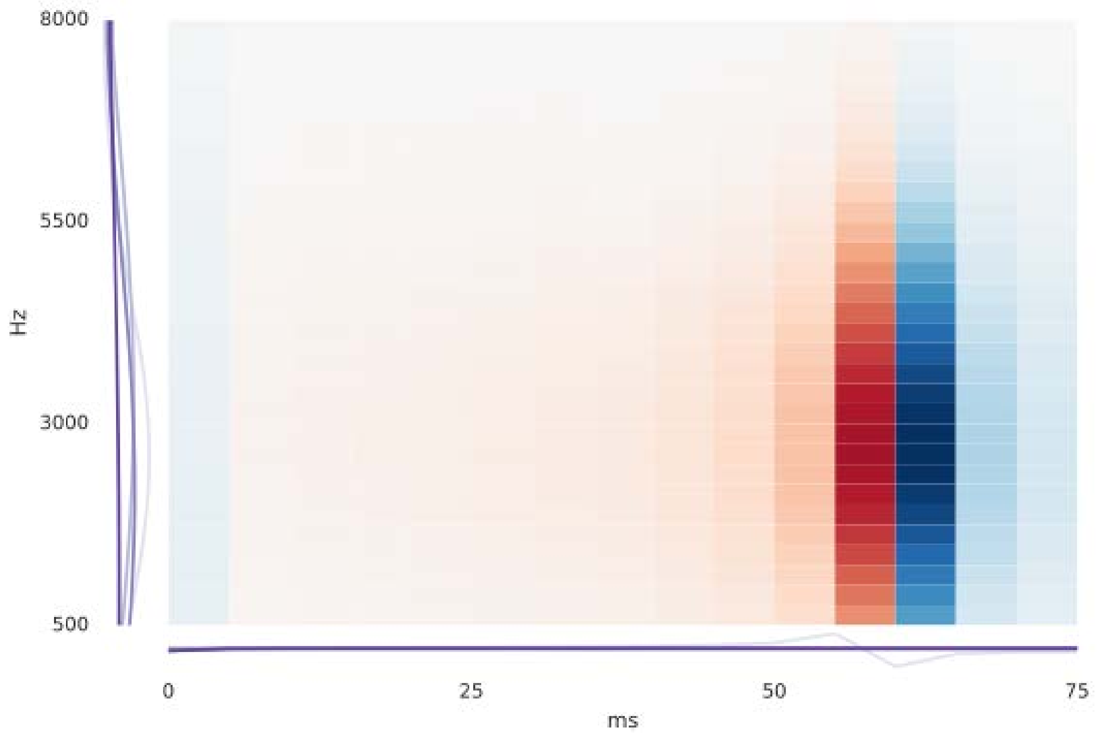
r = 0.79

r = 0.91

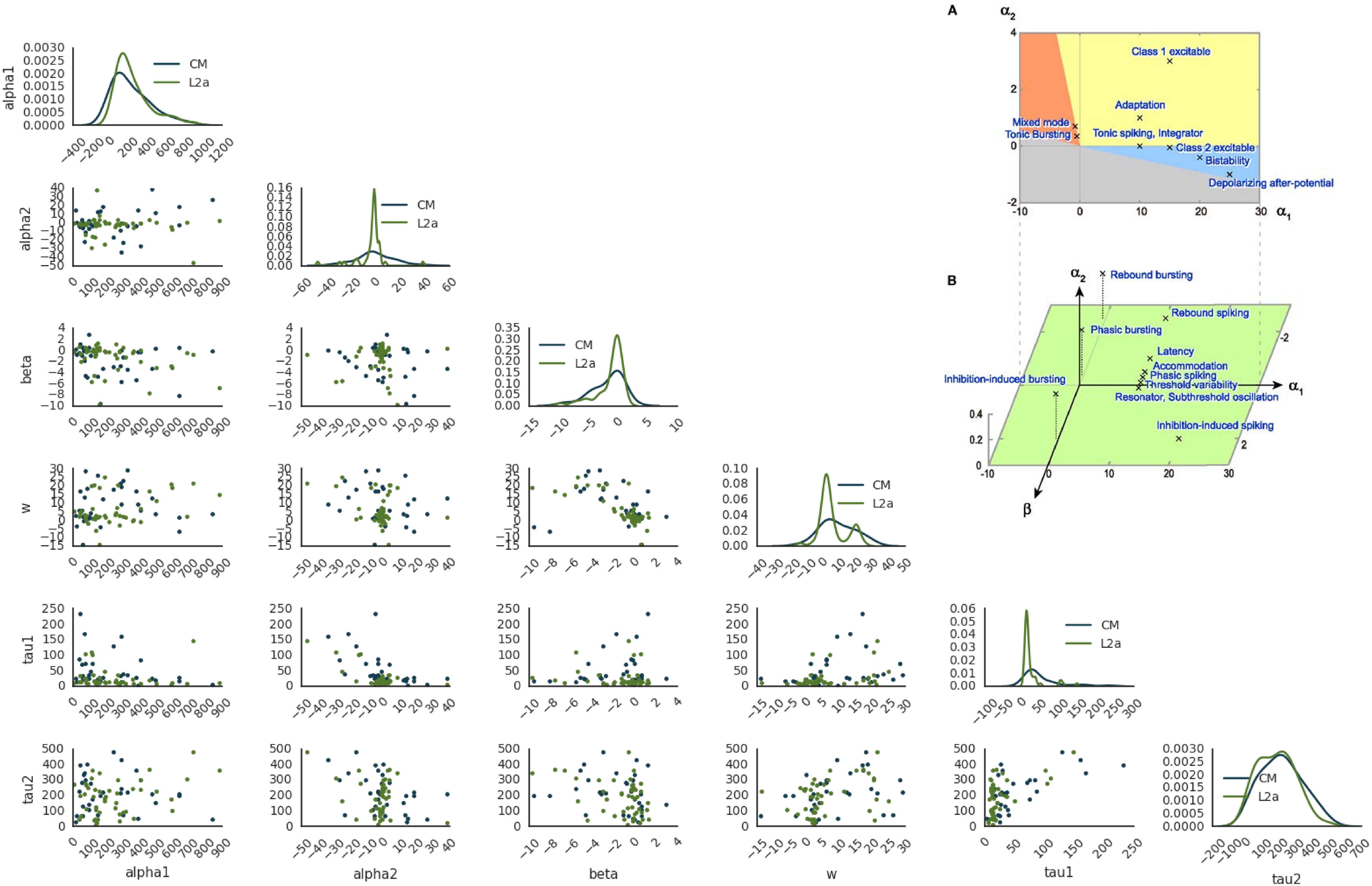
dSTRF of zebra finch neuron







Diverse dynamics from extracellular data



Conclusions

- Data assimilation of dynamical models is a tool for characterizing sensory neural circuits
- Sensory-evoked extracellular responses *alone* convey information about dynamical properties of neurons

and Future directions

- Circuit models
  - inferring network connectivity
  - predicting/interpreting optogenetic manipulations
- Biophysical models
  - predicting/interpreting pharmacological effects

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