Laboratorio de
Sistemas Dinámicos

Lecture 2

Dynamical models, neurons and experimental data.

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& INFINA – CONICET, ARGENTINA

CONICET

School on The Next Era of Network Science

ICTP-SAIFR - São Paulo, Brasil – March 2-6, 2026

Recording neural activity

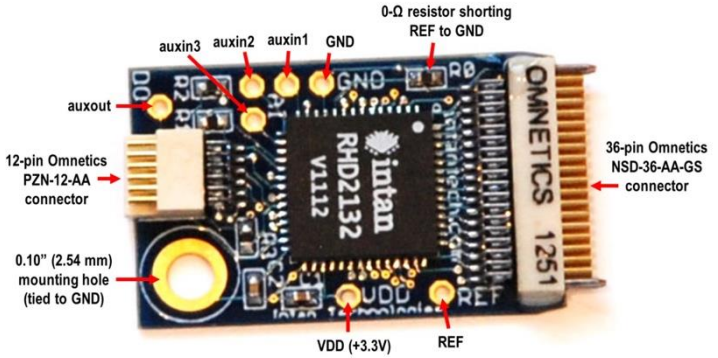
Now that we have a model for spikes,
we want to record real spikes!

Or is it the other way around?

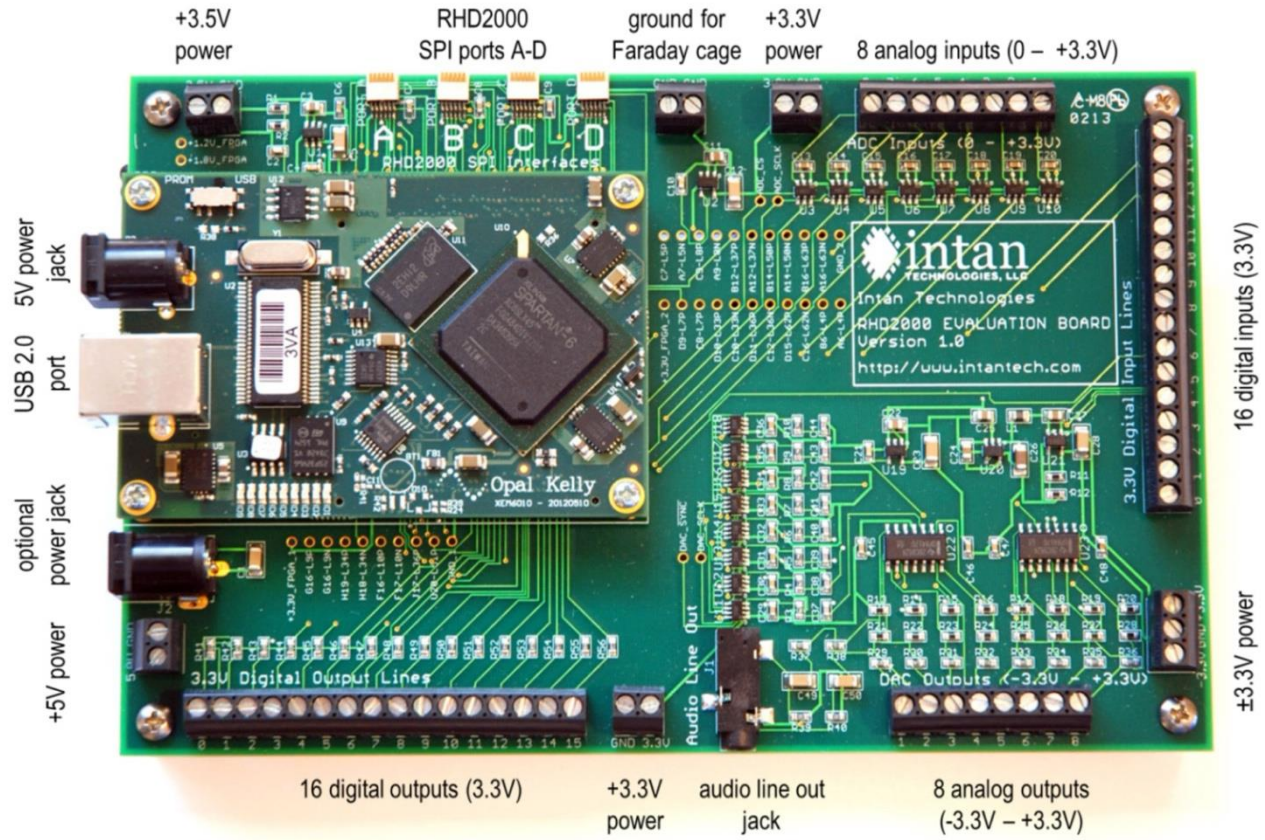
We first make **recording of spikes** and propose to use
dynamical models of spikes
to make sense of our recordings
(we are just measuring few spikes out of many, many more!)

Measuring electrical activity in the brain

intan TECHNOLOGIES, LLC



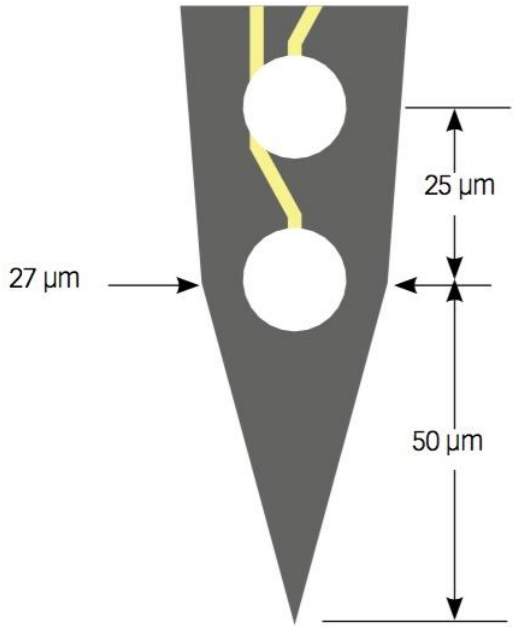
RHD2000 USB Interface Board

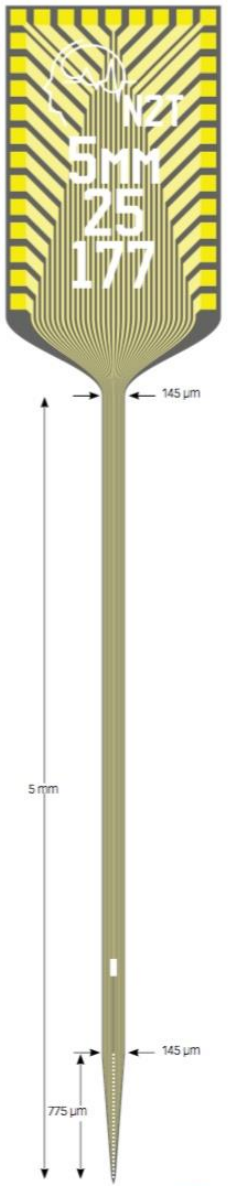


INTAN + Neuronexus

NeuroNexus

32-channel silicon probe





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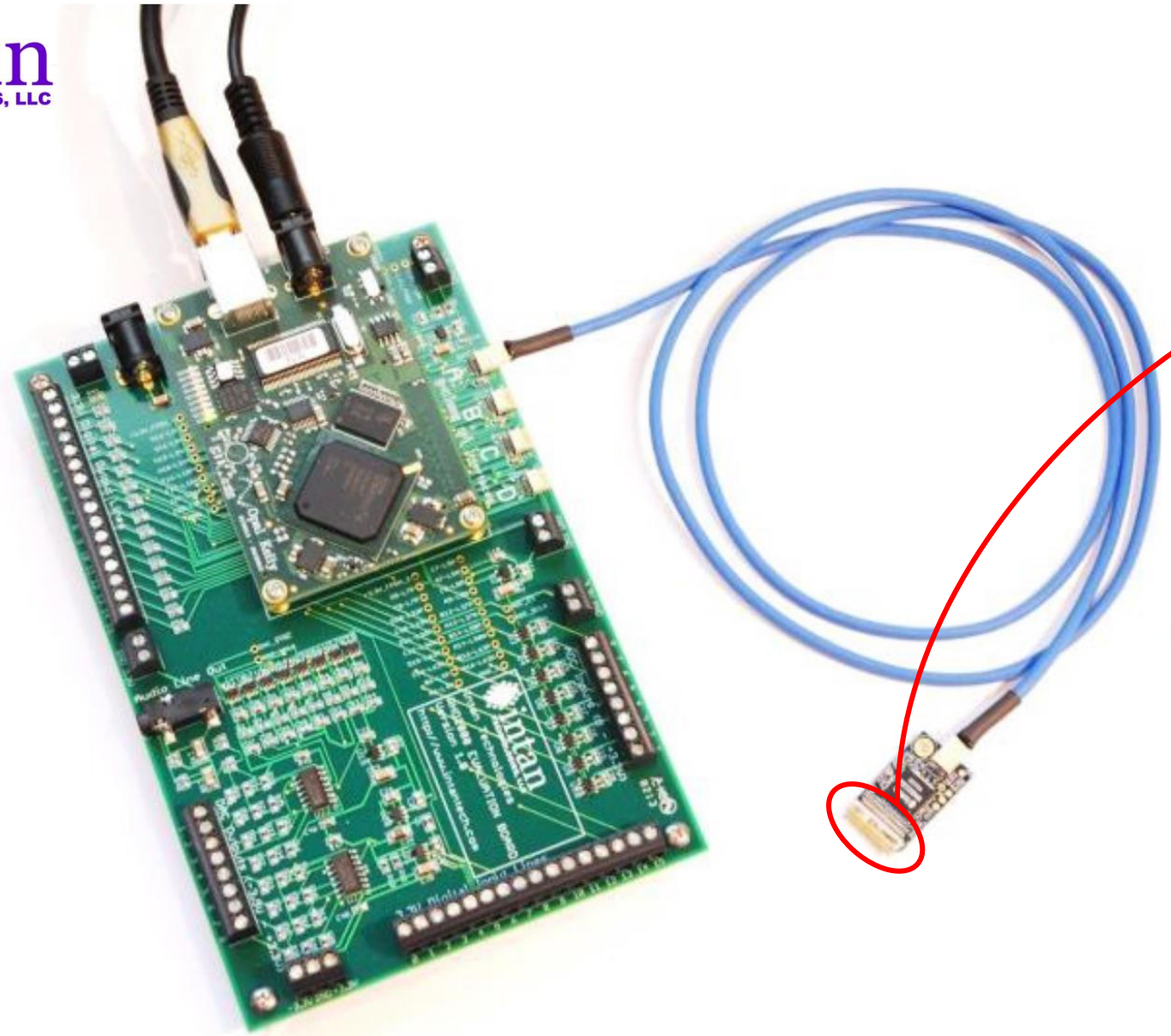

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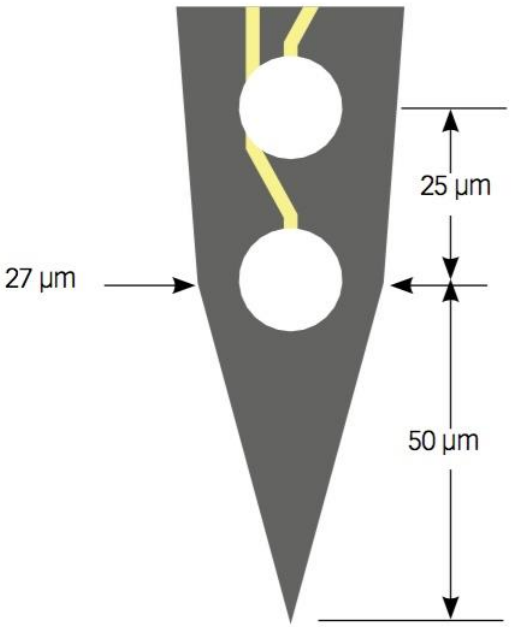
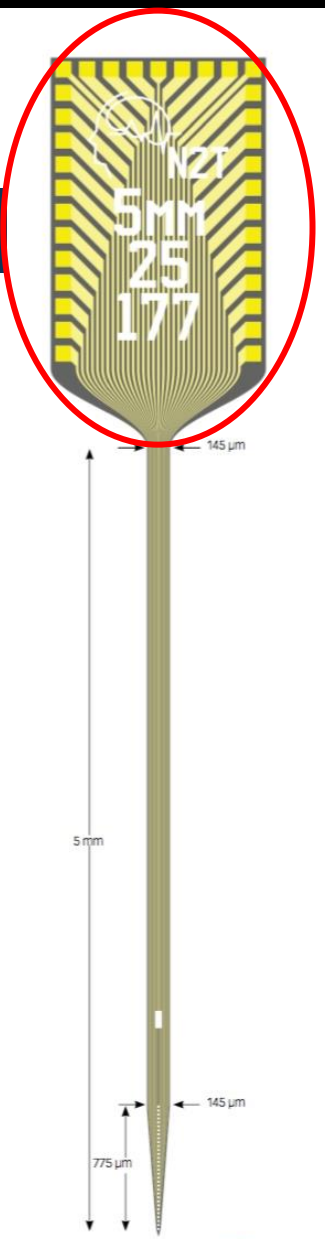
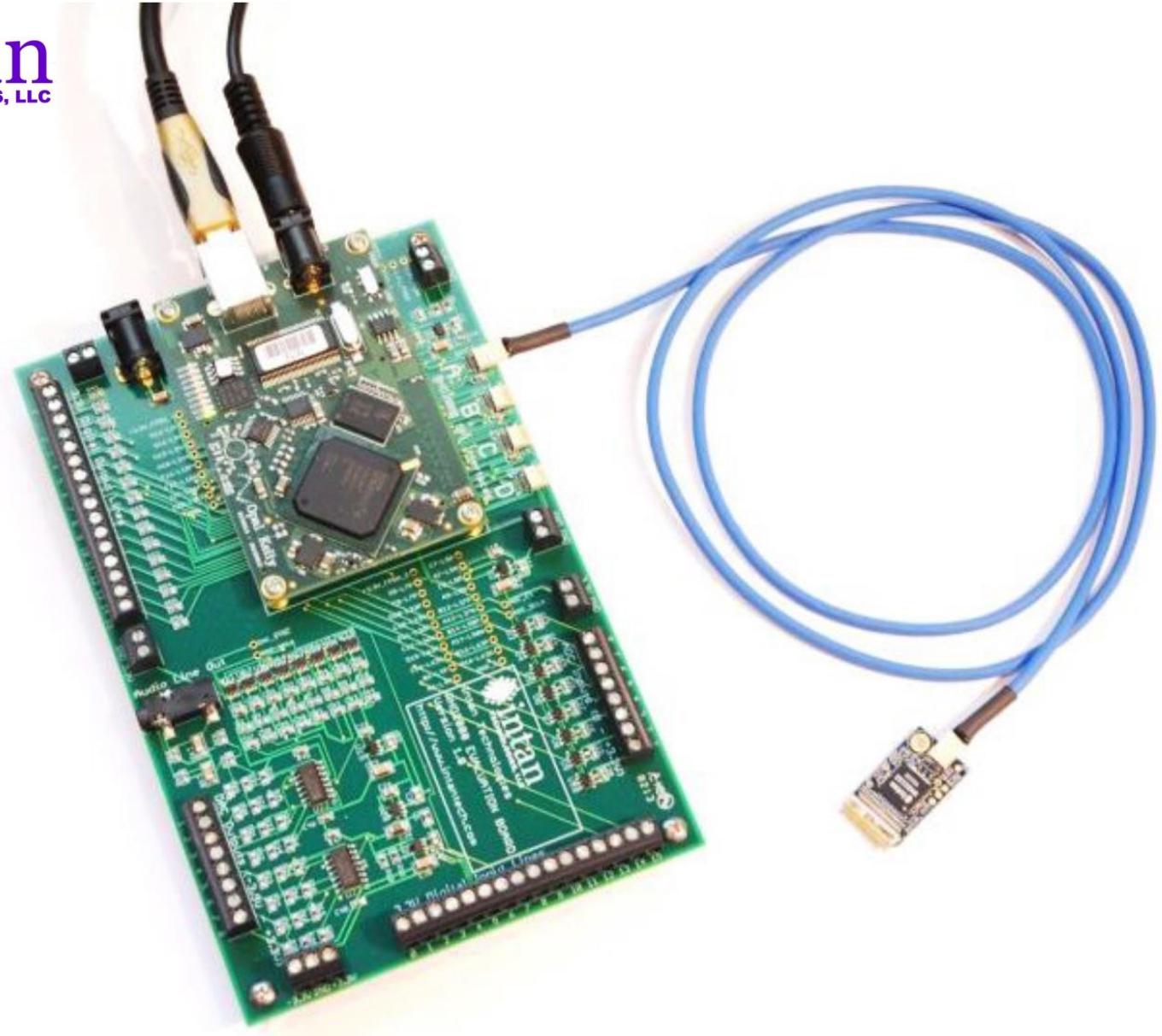
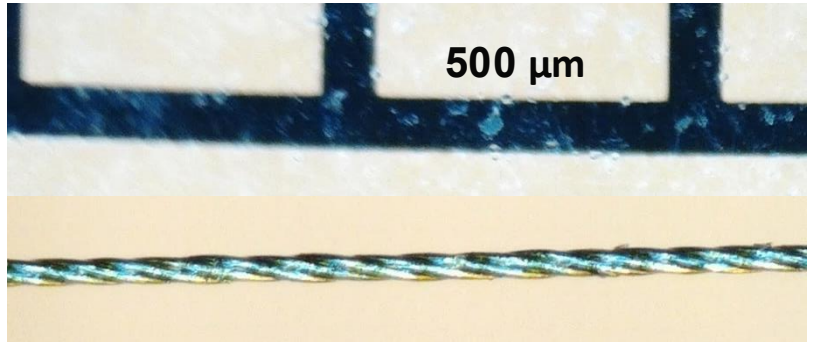




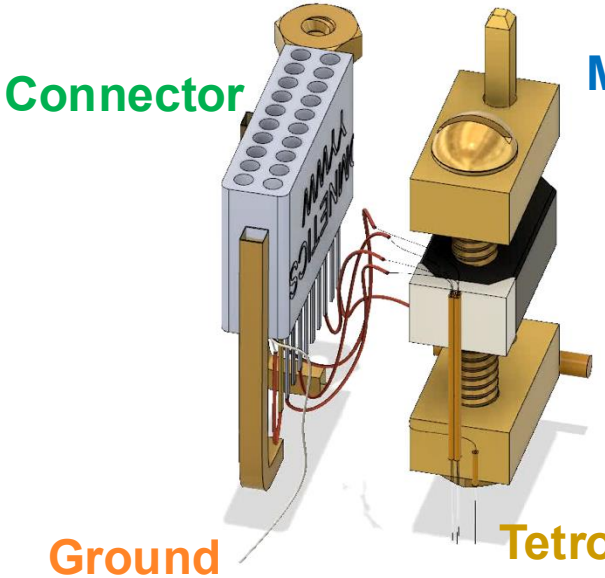
Measuring electrical activity in the brain



In-house manufactured tetrodes



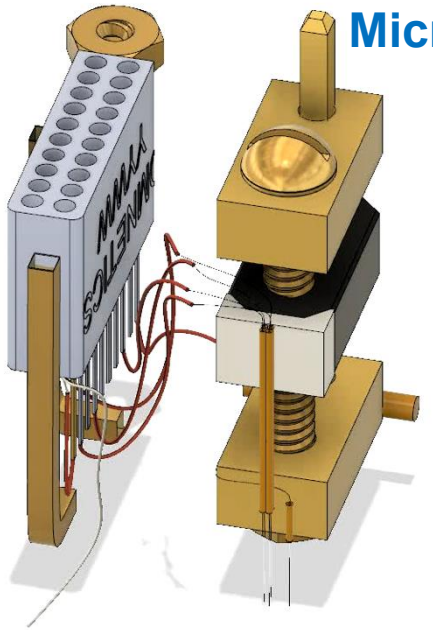
- Diameter 0.0005” (12.7 µm)
- Tungsten, HML coating
- Impedances: 500k to 3 MOhm

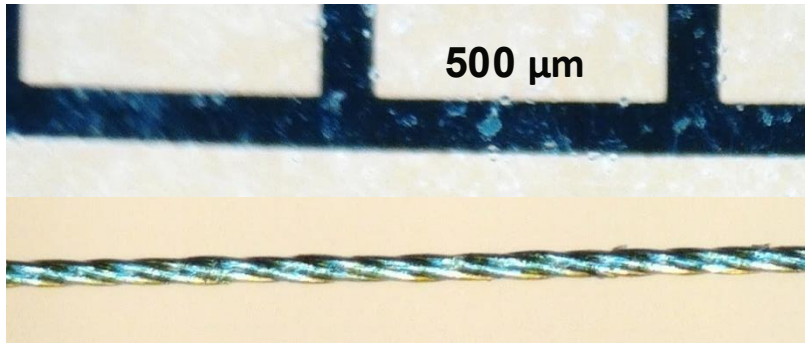


Measuring electrical activity in the brain

- **ultra-lightweight**
- **compact**
- **customizable**
- **low-cost**

Connector





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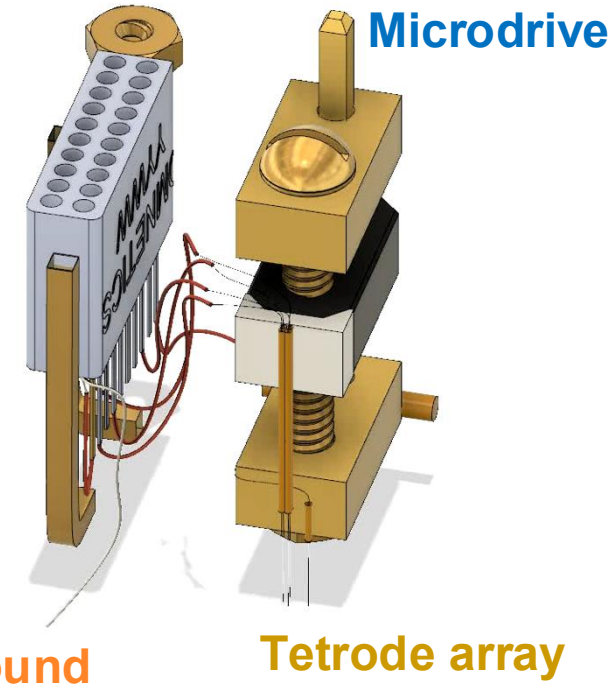
In collaboration with M. Belluscio

Credits: Cecilia T. Herbert

Lightweight recording device

- ultra-lightweight
- compact
- customizable
- low-cost



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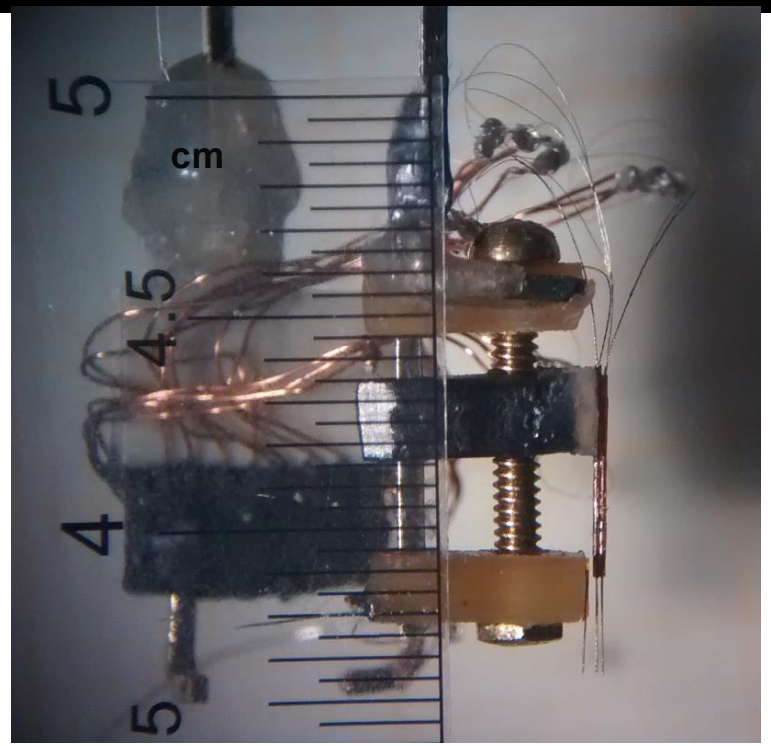
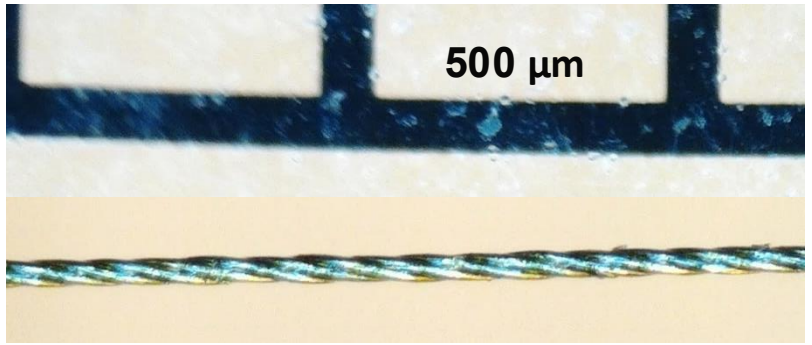


- Pitch 90 TPI = 282 µm/turn
  (manual step ≈25 µm)
- Mass <1g
- 15mm tall, 13mm^2 footprint
- Tetrode geometry easy to modify.



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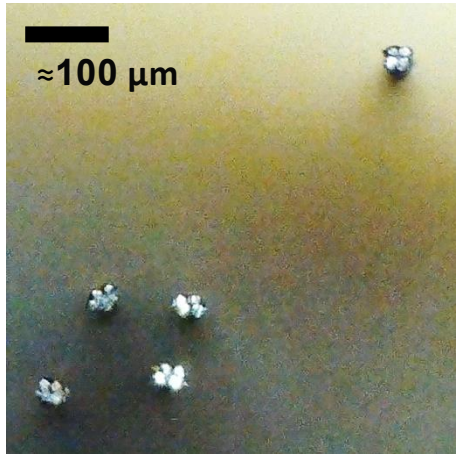


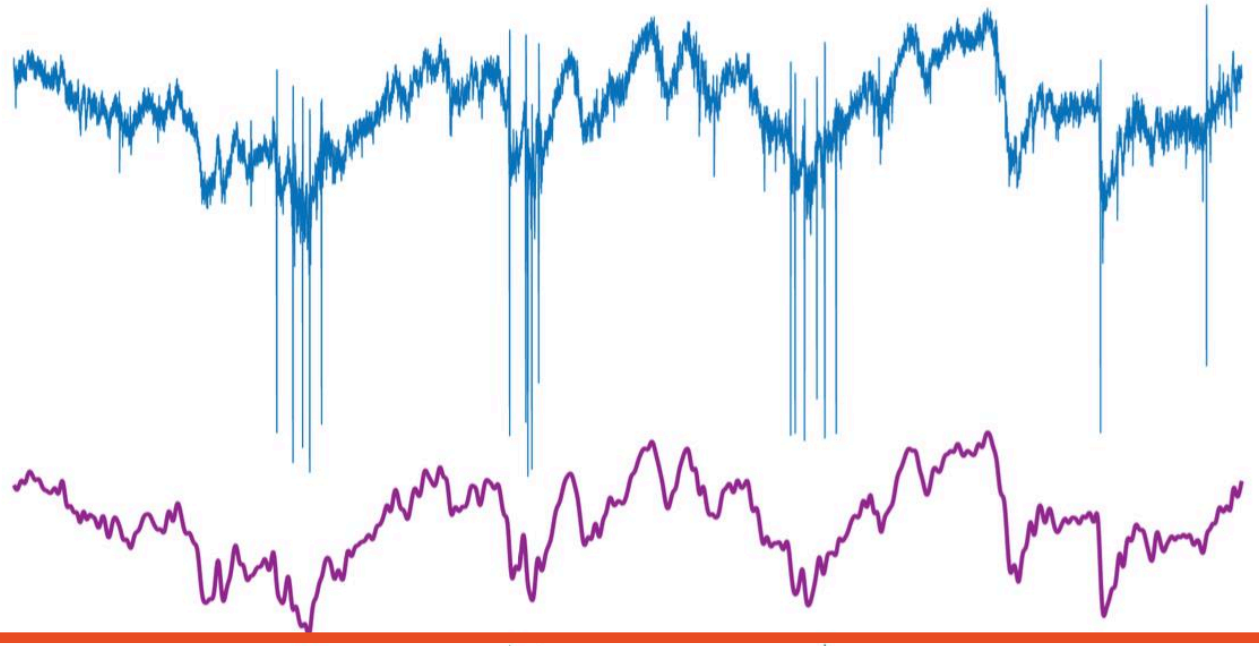
- 4-tetrode array (16ch) + Ref
- 2x2 geometry

Credits: Cecilia T. Herbert

Neural recordings

Credits: Cecilia T. Herbert & Santiago Boari

Neural recordings



Raw data

Low-pass filter

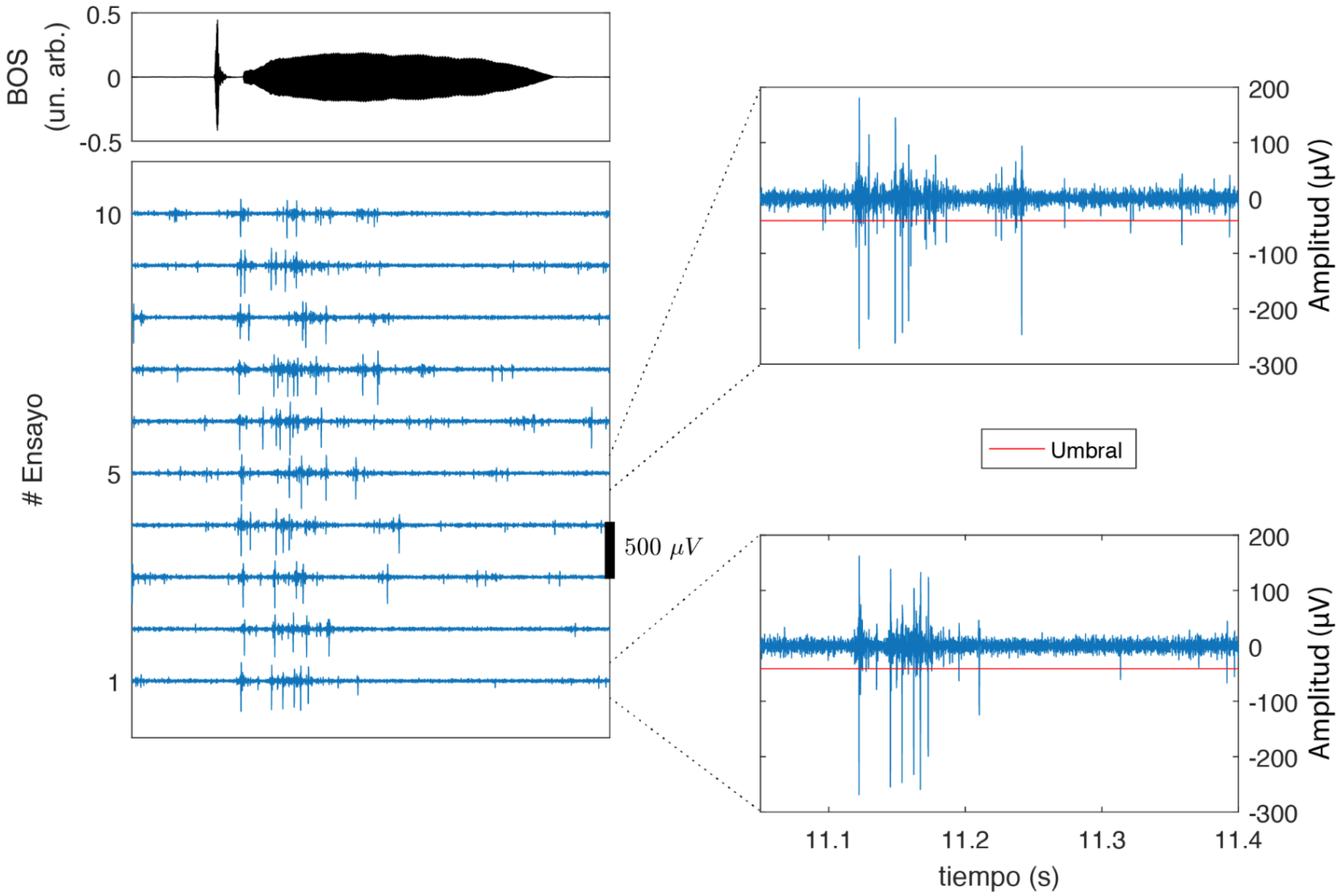
Local Field Potential (LFP)

High-pass filter

Neuronal activity (spikes)

Neural recordings

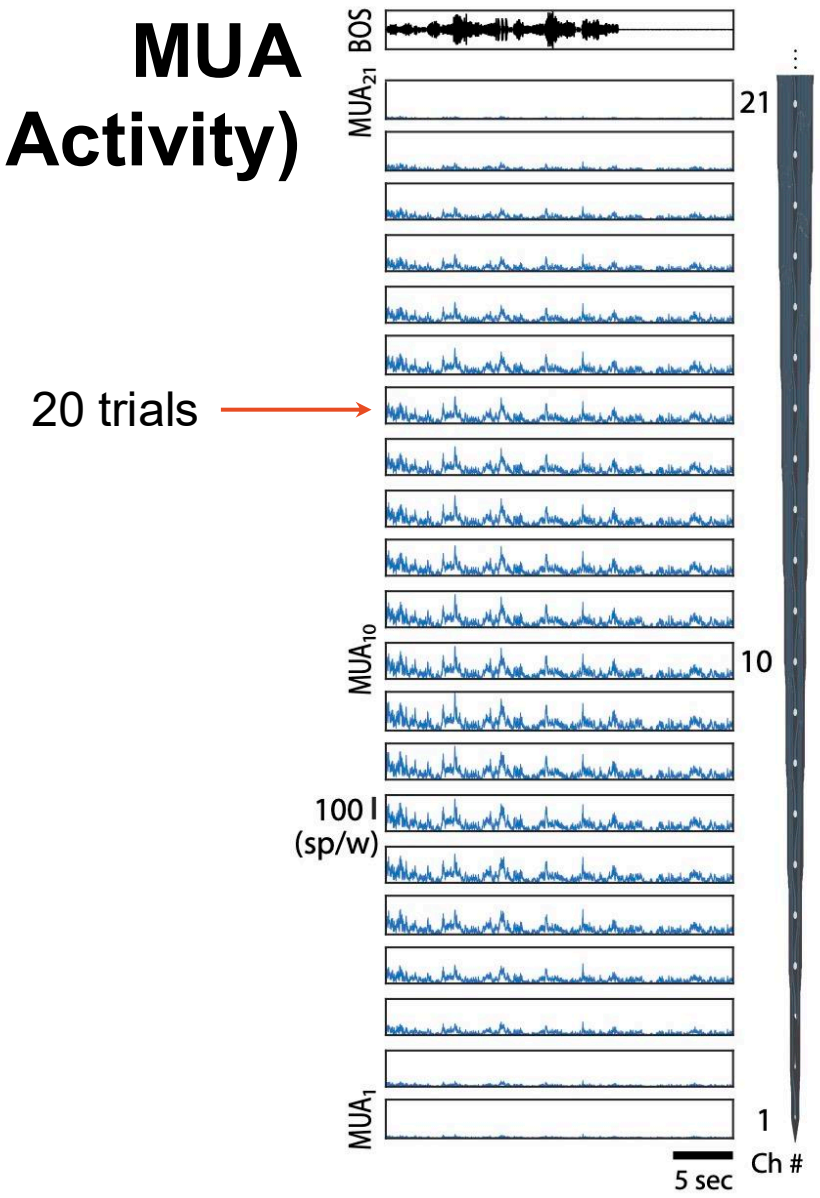
Neural activity in response to the Bird´s Own Song (BOS)



Multi-unit activity →

Neural recordings

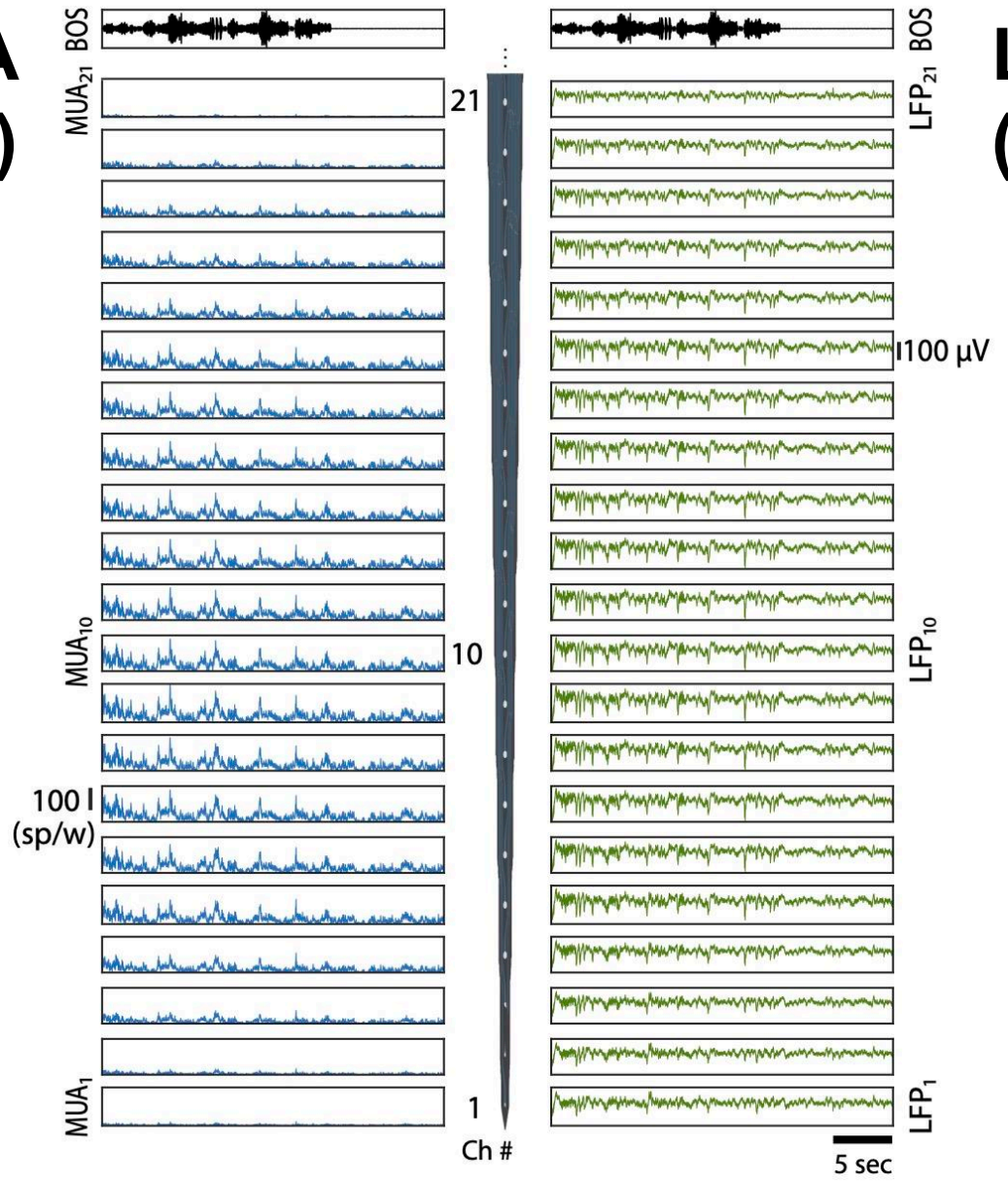
MUA (Multi-Unit Activity)



Boari, Mindlin and Amador, EJN 2021

Neural recordings: LFP and MUA

MUA
(Multi-Unit Activity)

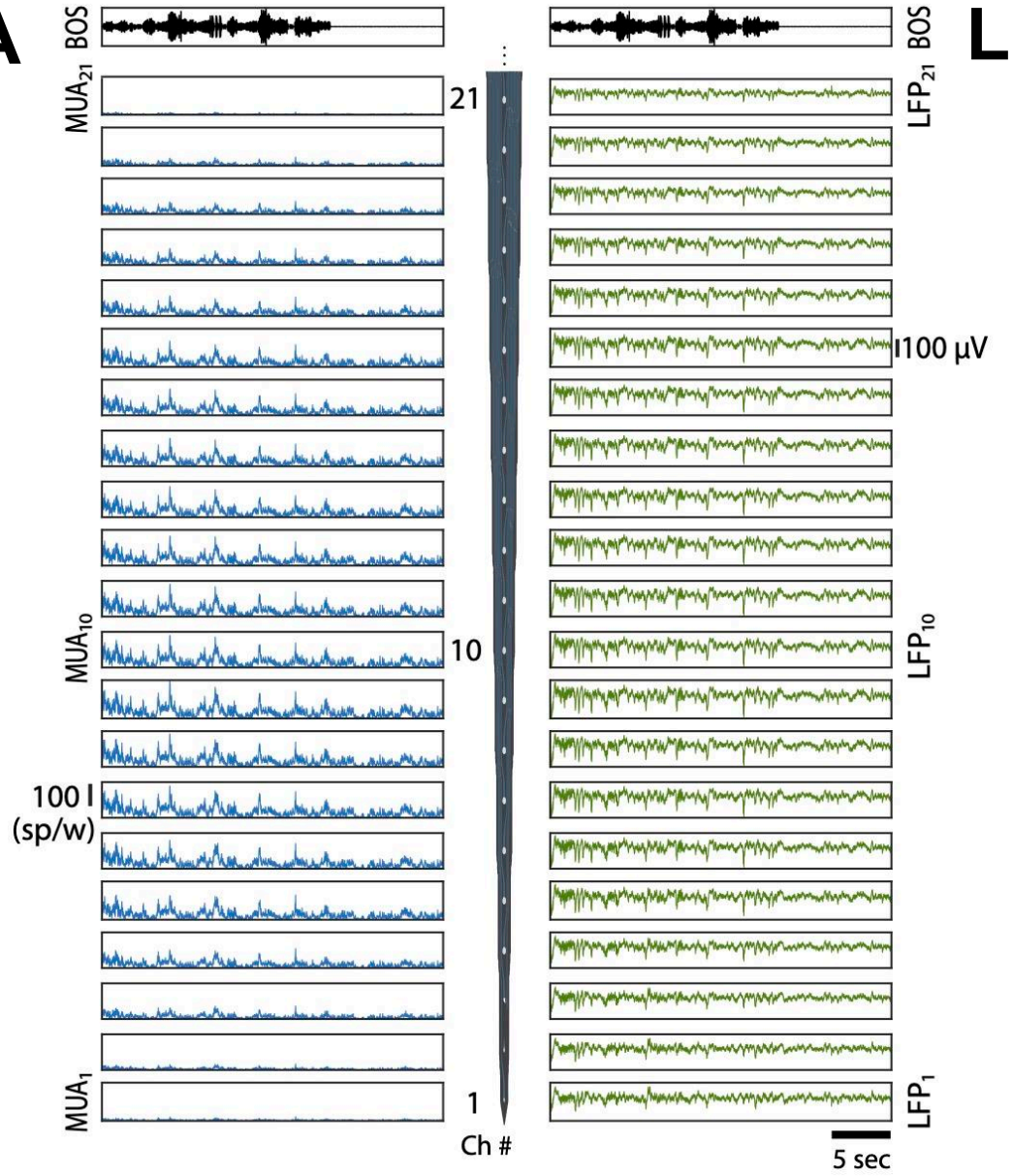


LFP
(Local Field Potential)

Boari, Mindlin and Amador, EJN 2021

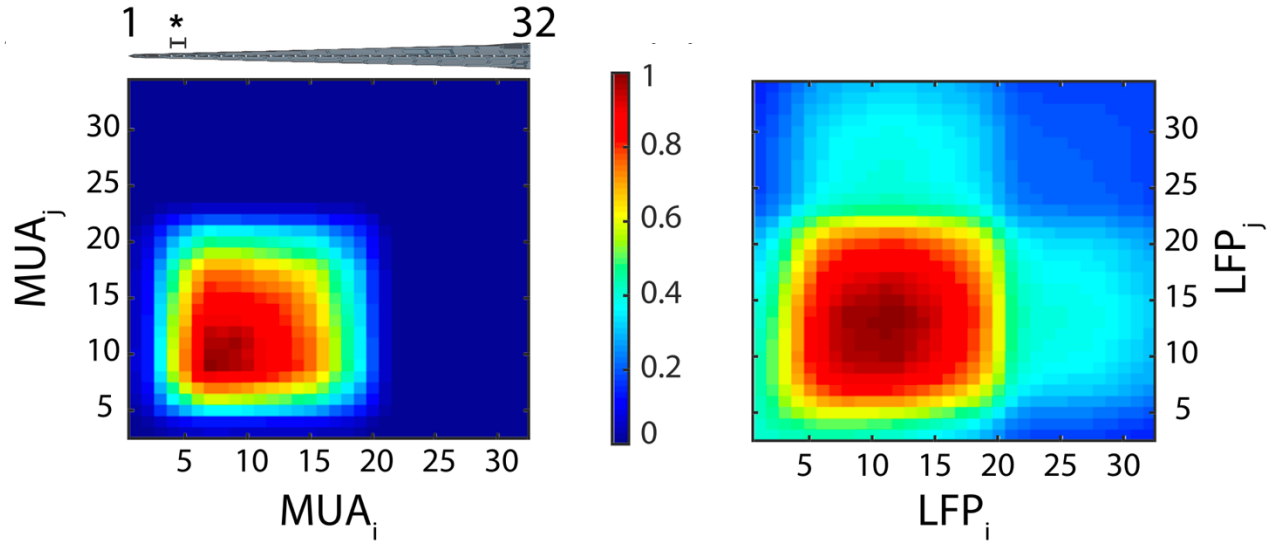
Neural recordings: LFP and MUA

MUA



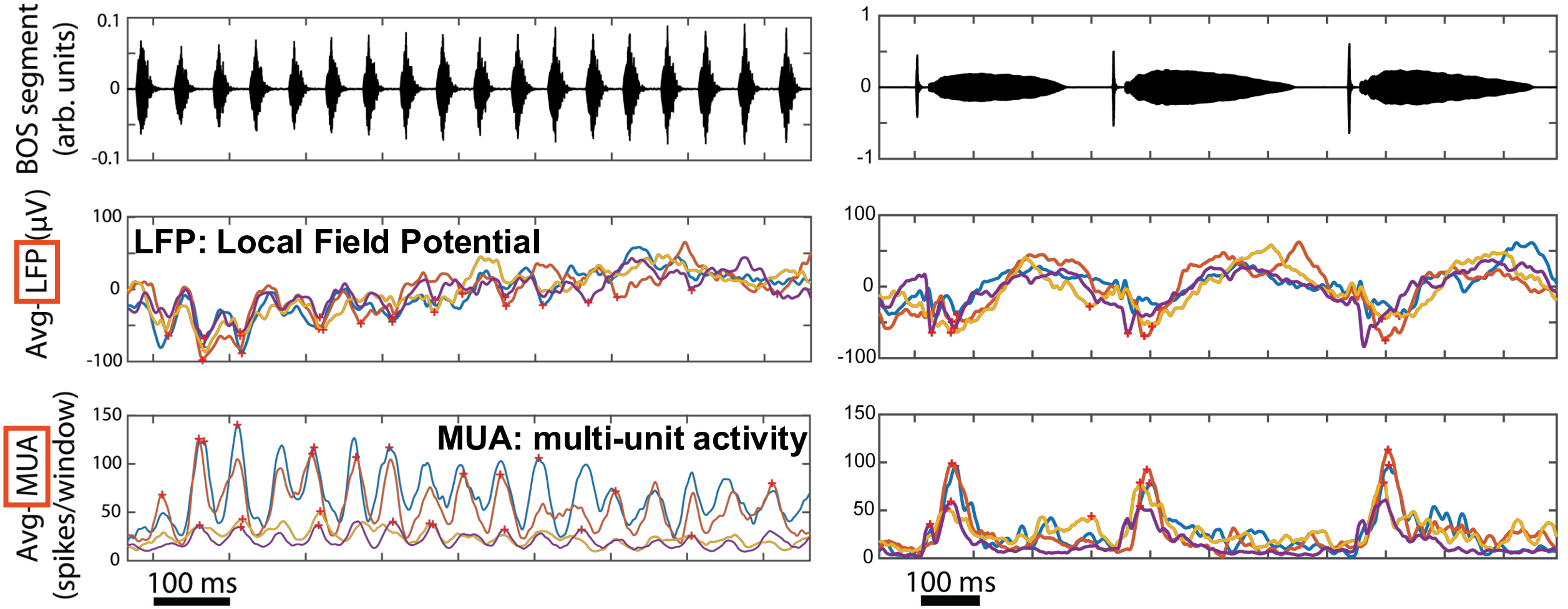
LFP

Spatial correlation
(amplitude weigthed)



Boari, Mindlin and Amador, EJN 2021

Neural recordings: LFP and MUA



Rhythms in the Brain?

Rhythms in the Brain

Speech perception exhibits rhythmicity

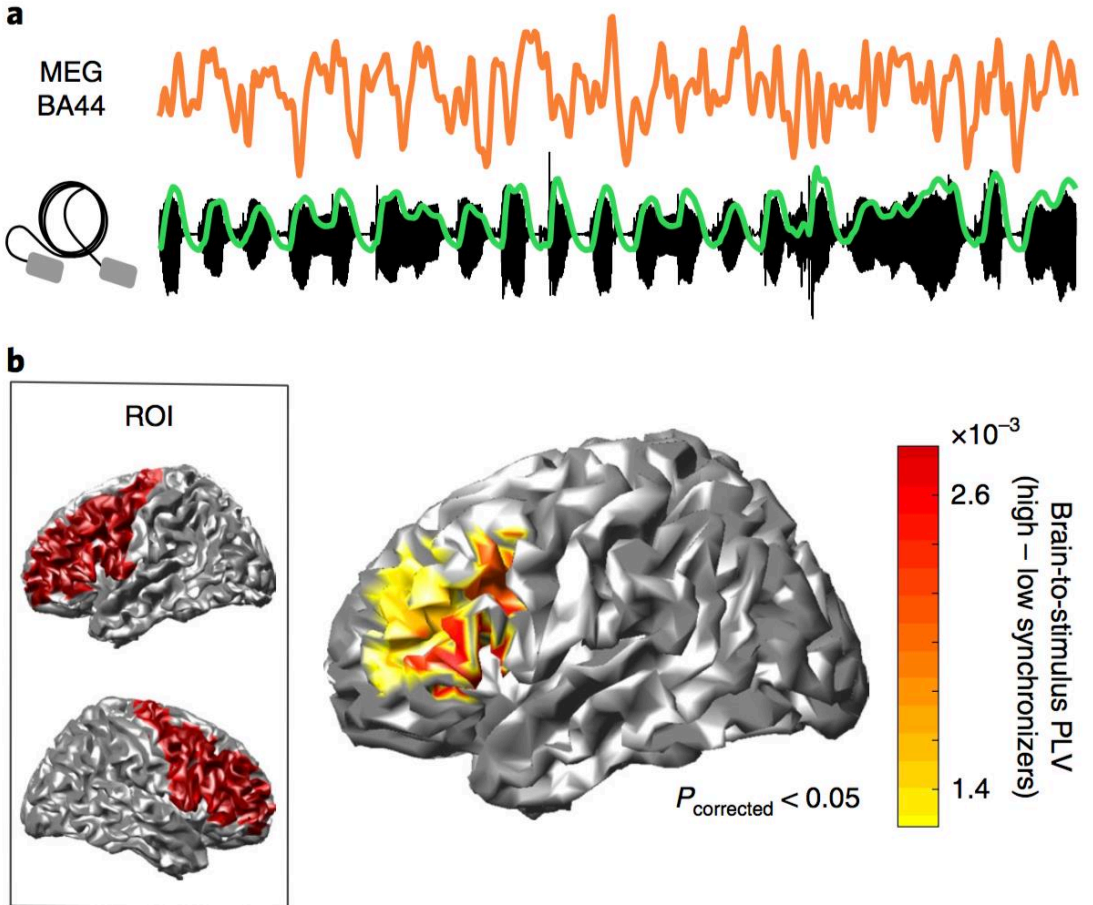
When presented with an **acoustic stimulus** (speech or modulated white noise) the auditory cortex tracks the amplitude modulation of the input.

The speech rhythm enhances perception

nature neuroscience
ARTICLES
https://doi.org/10.1038/s41593-019-0353-z

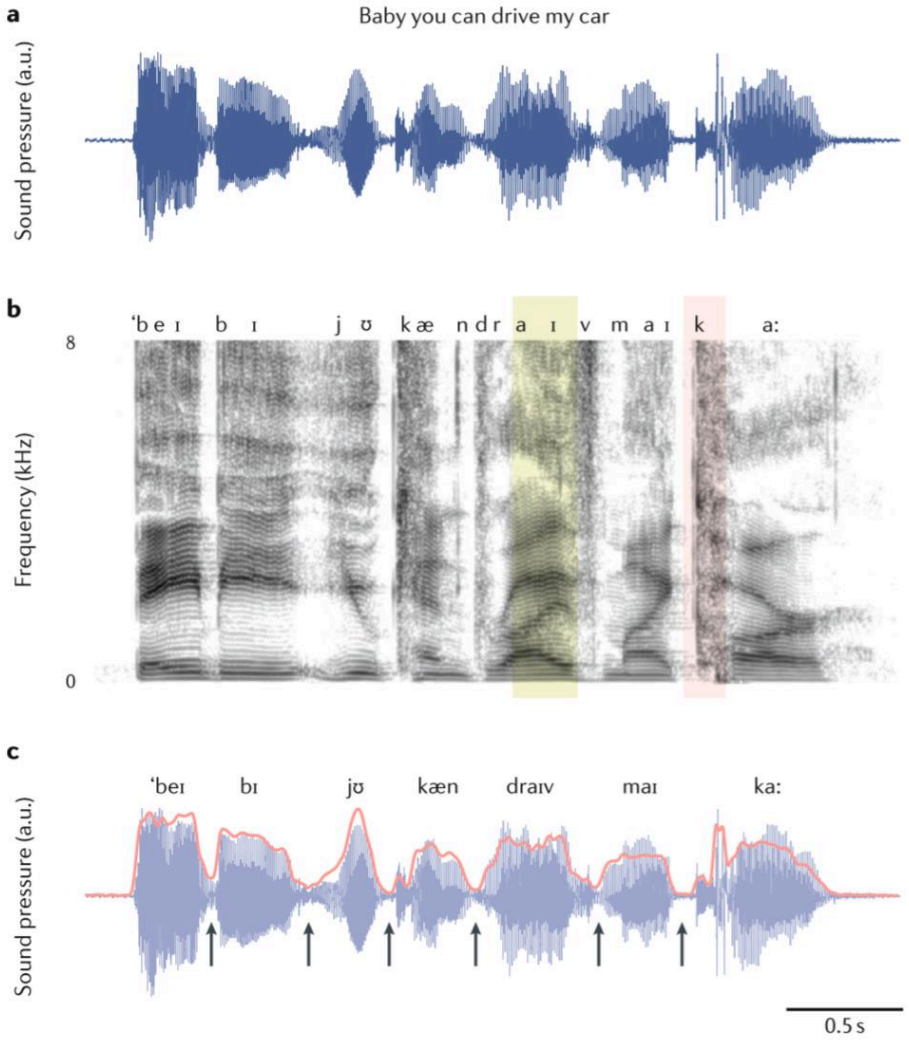
Spontaneous synchronization to speech reveals neural mechanisms facilitating language learning

M. Florencia Assaneo[1,7*], Pablo Ripollés[1,7], Joan Orpella[2,3,4,7], Wy Ming Lin[1], Ruth de Diego-Balaguer[2,3,4,5,8] and David Poeppel[1,6,8]



Rhythms in the Speech

Speech production exhibits rhythmicity

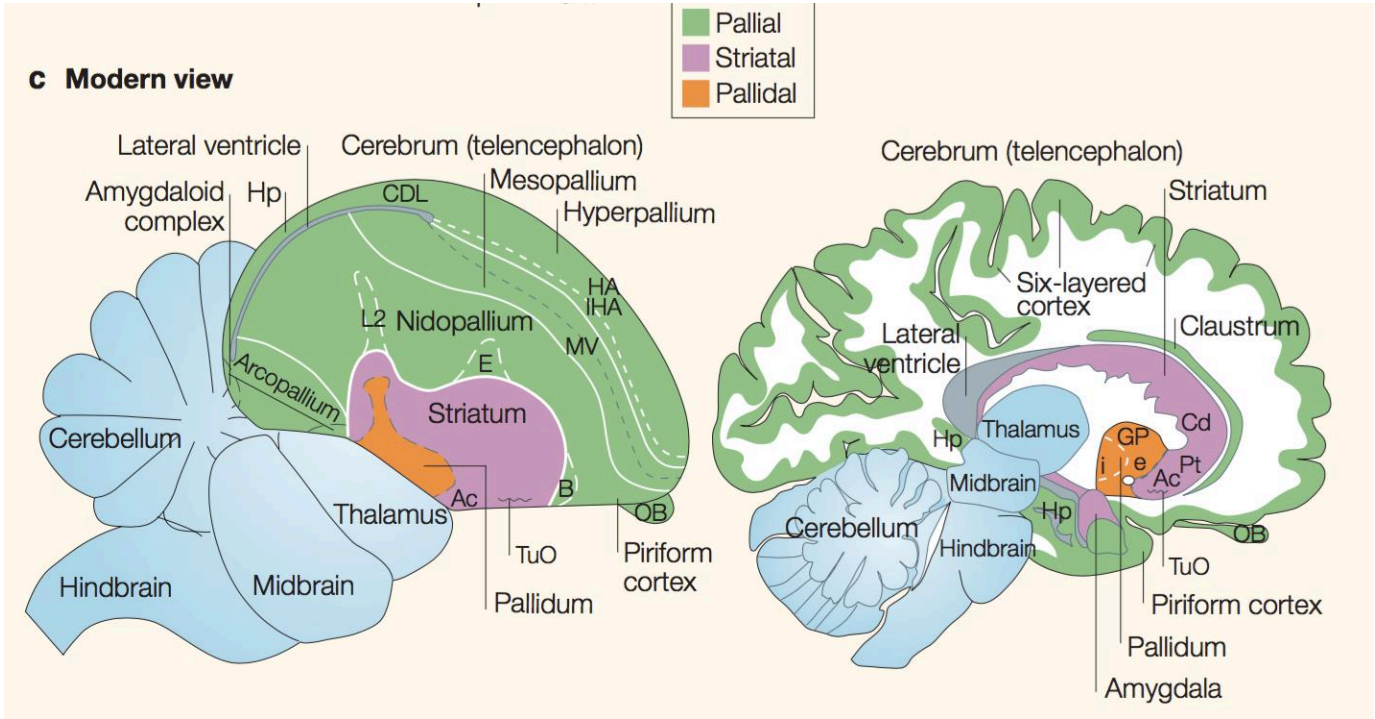


Speech rhythms and their neural foundations

David Poeppel[1,2]✉ and M. Florencia Assaneo[2,3]

NATURE REVIEWS | NEUROSCIENCE

Rhythms in the Brain of a Songbird?



Similar structures mean similar properties?

nature neuroscience
ARTICLES
https://doi.org/10.1038/s41593-019-0353-z

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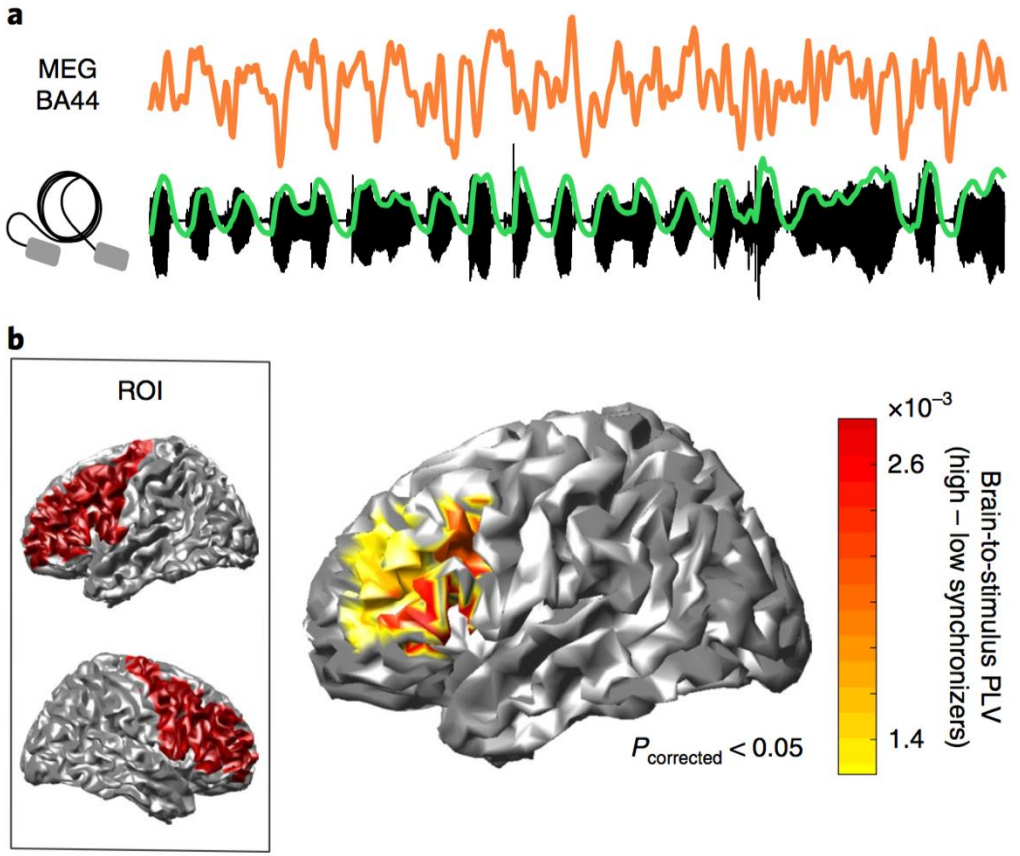
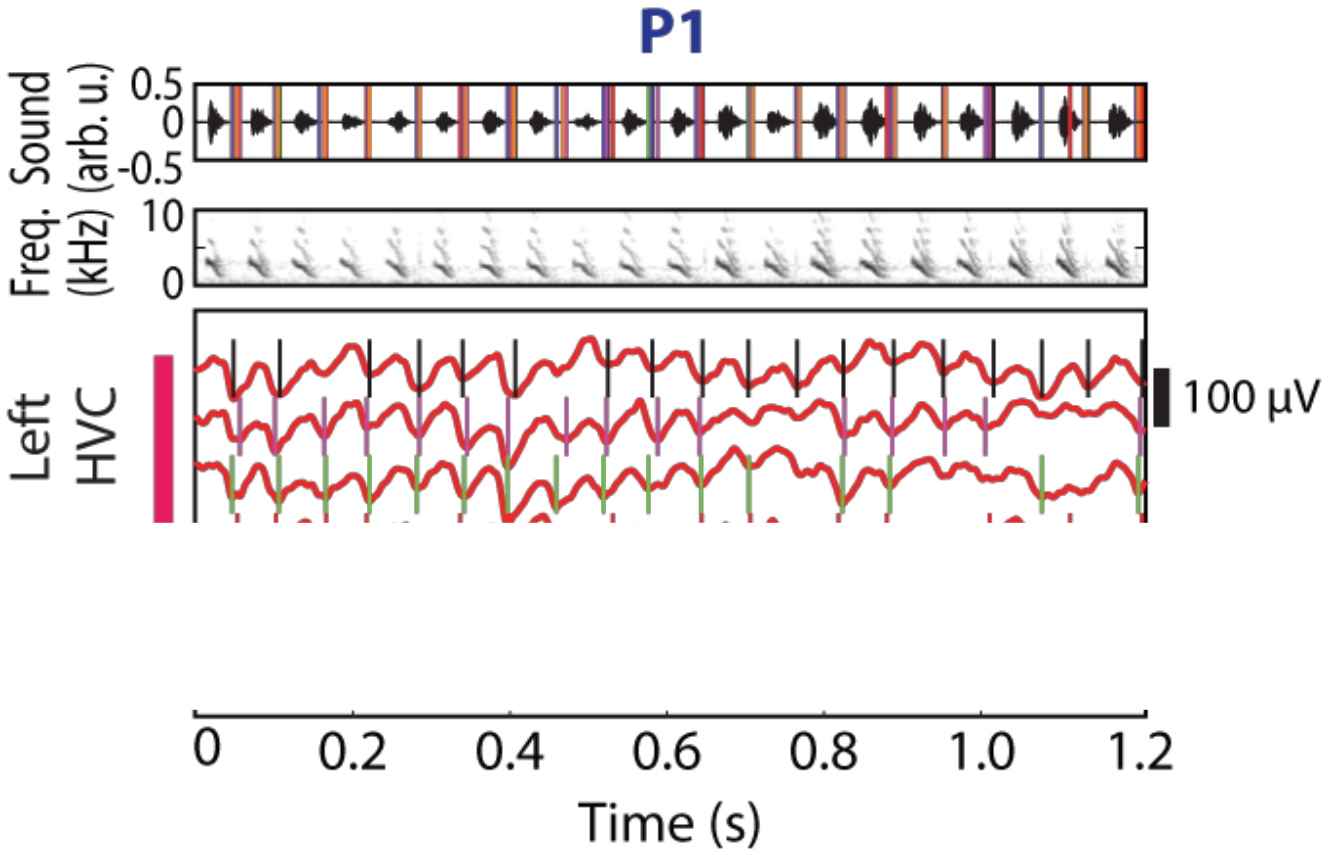


Rhythms in the Brain of a Songbird !



LFP oscillations are phase-locked (synchronization)

nature neuroscience
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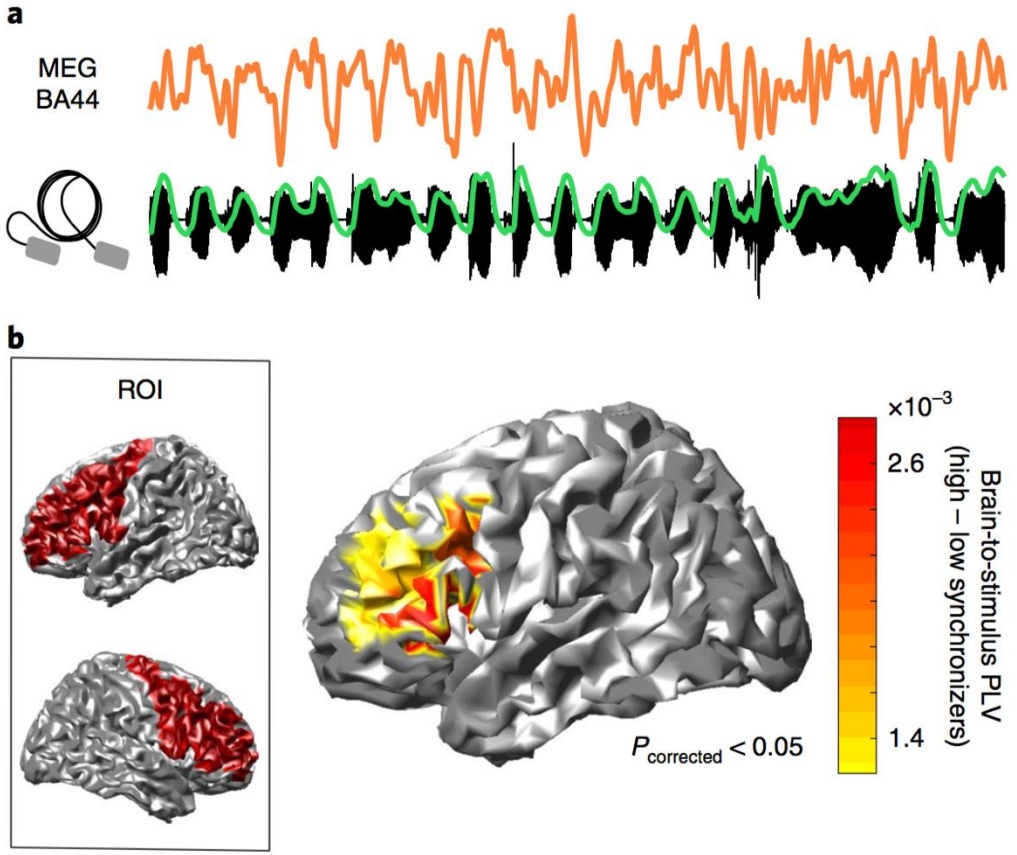

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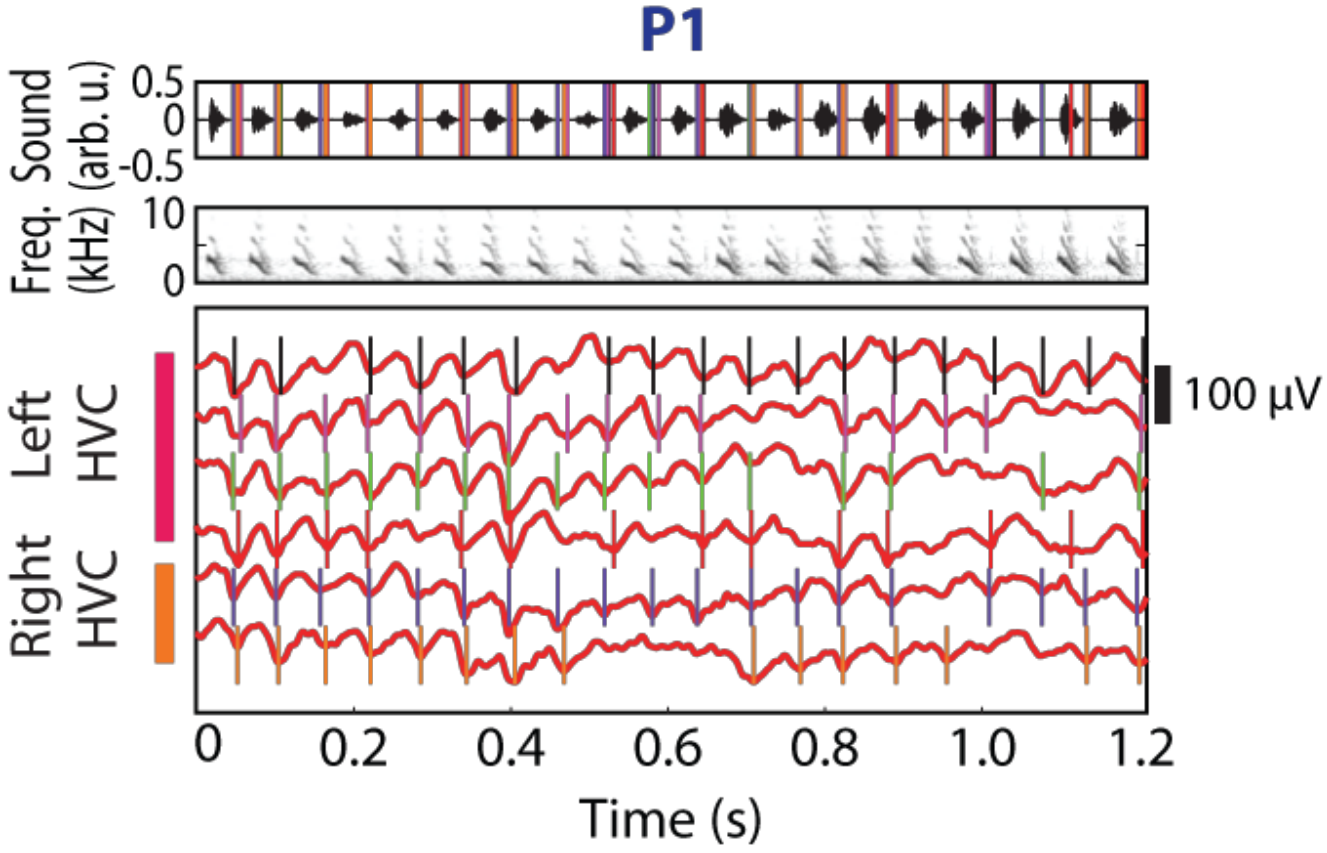

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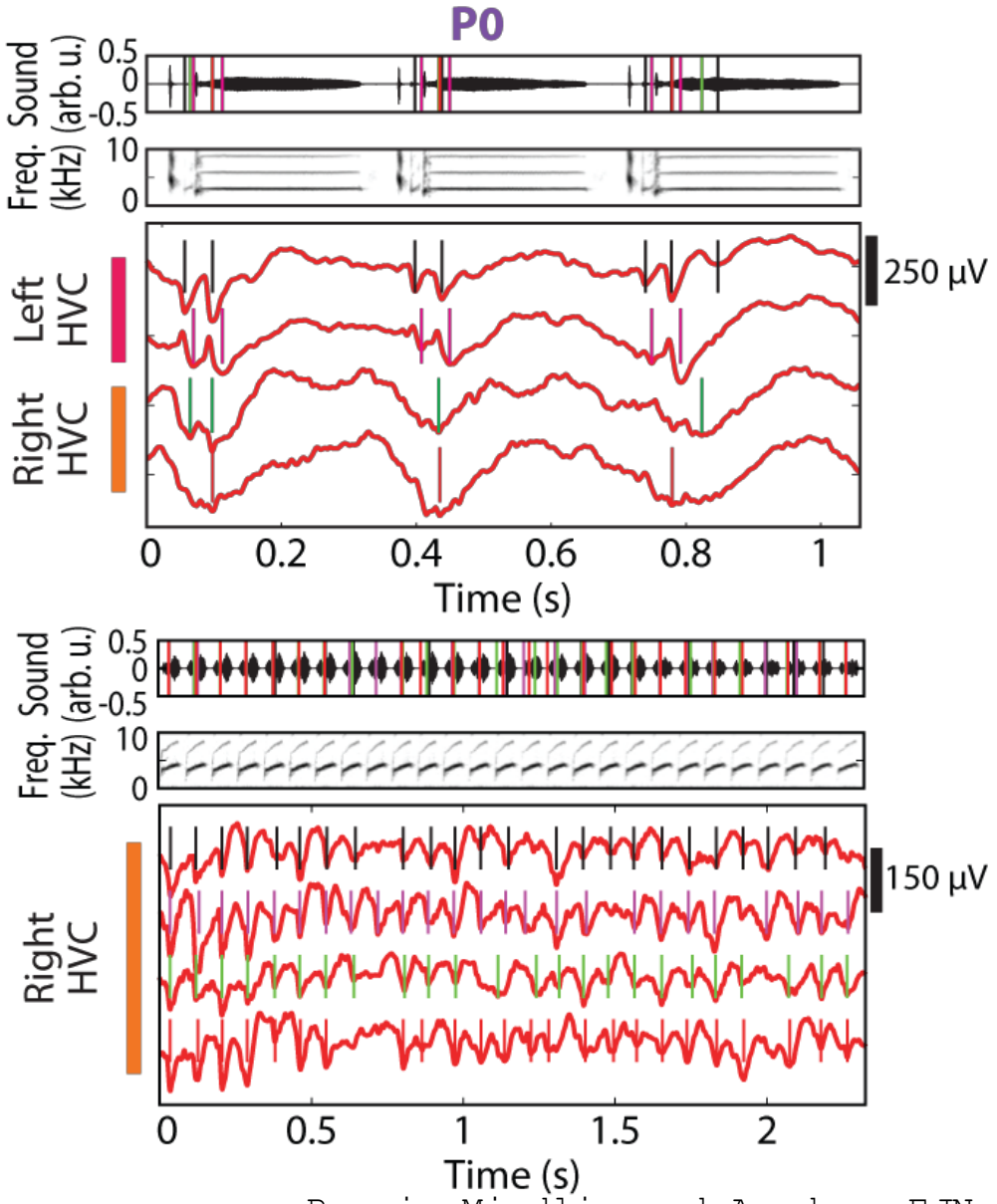
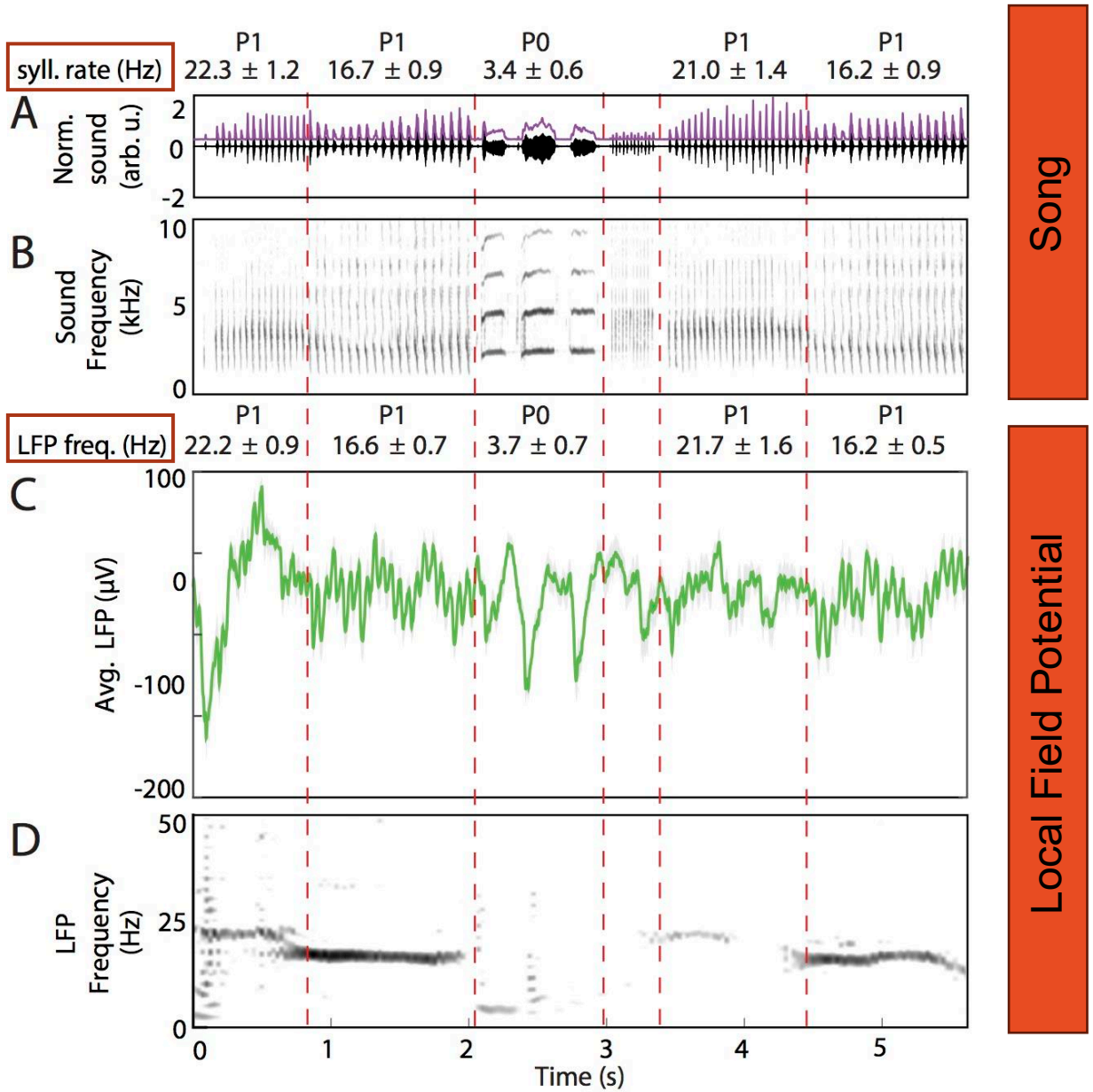
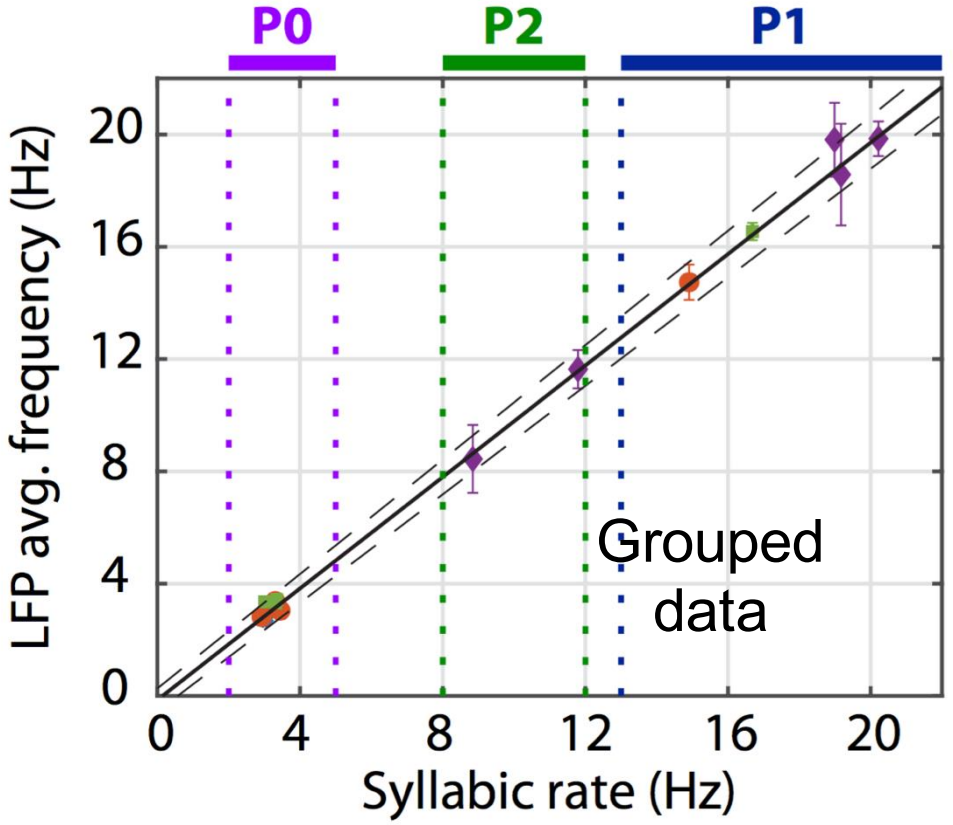


Boari, Mindlin and Amador, EJN 2021

LFP and coding of behavior (birdsong)



LFP oscillations occur at the song syllabic rate



$$LFP_{freq} = a + b\, s_r$$

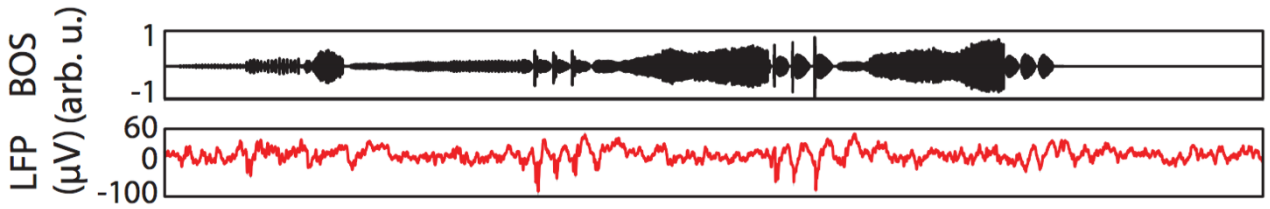
$a = -0.2 \pm 0.4\ Hz$

$b = 0.99 \pm 0.03$

Boari, Mindlin and Amador, EJN 2021

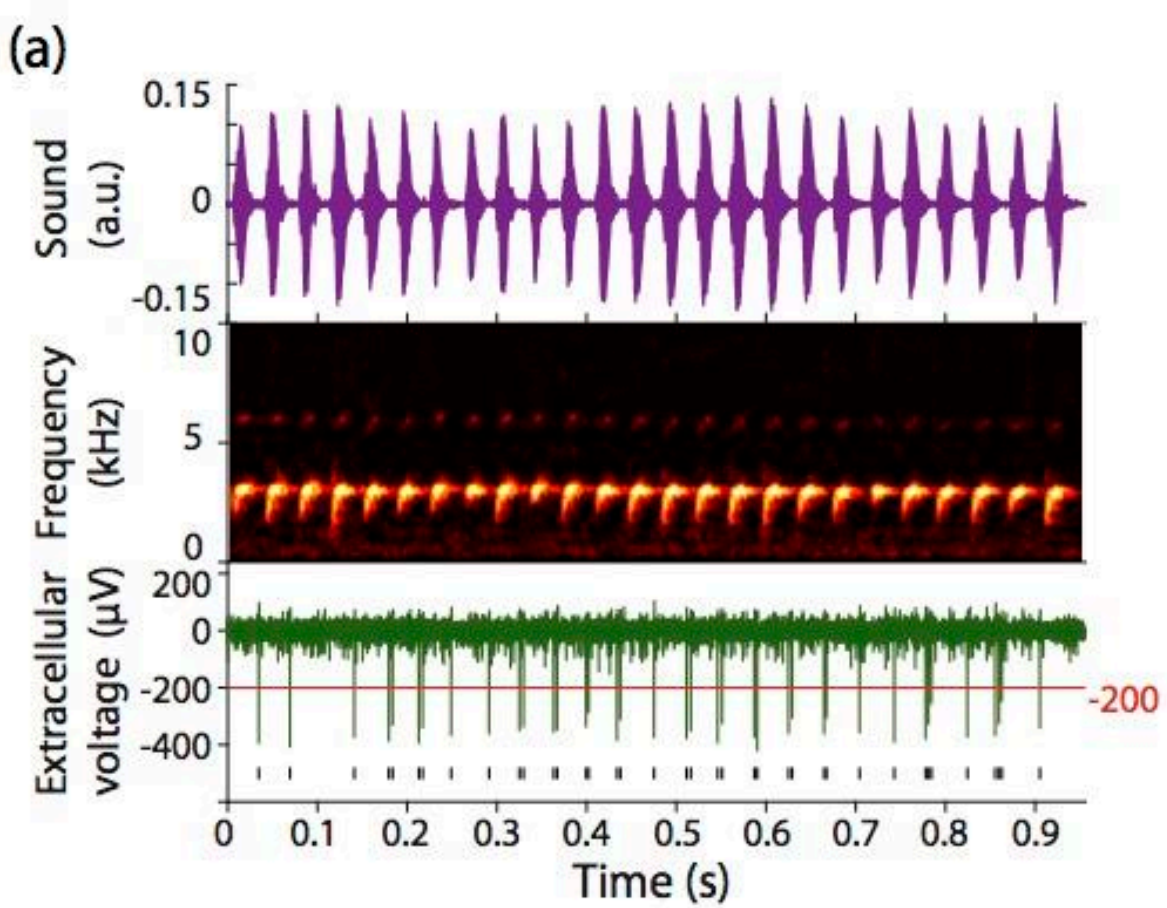
LFP vs. MUA vs. SUA

Extracellular recordings in canaries while hearing song (BOS)

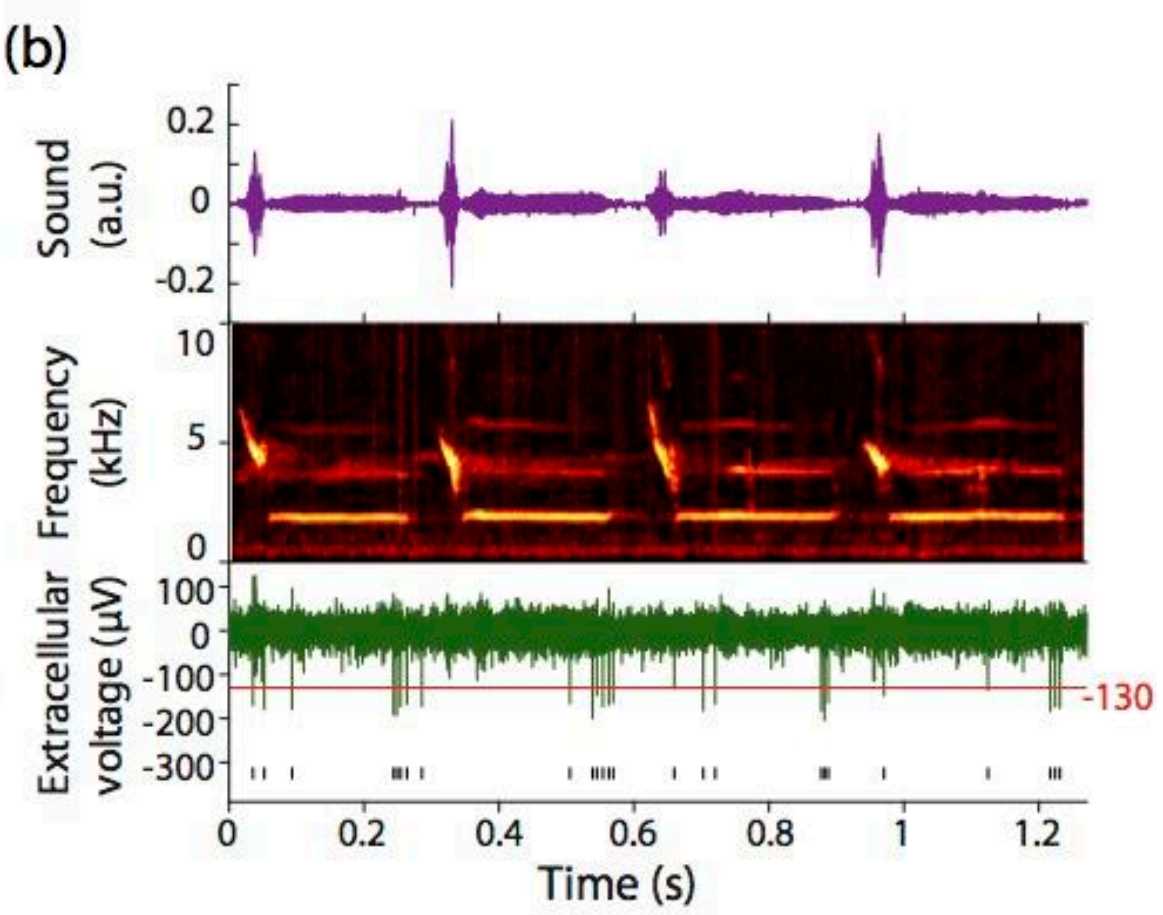


Neural recordings in singing canaries

Sparse neural activity and complex behavior



P1 syllables



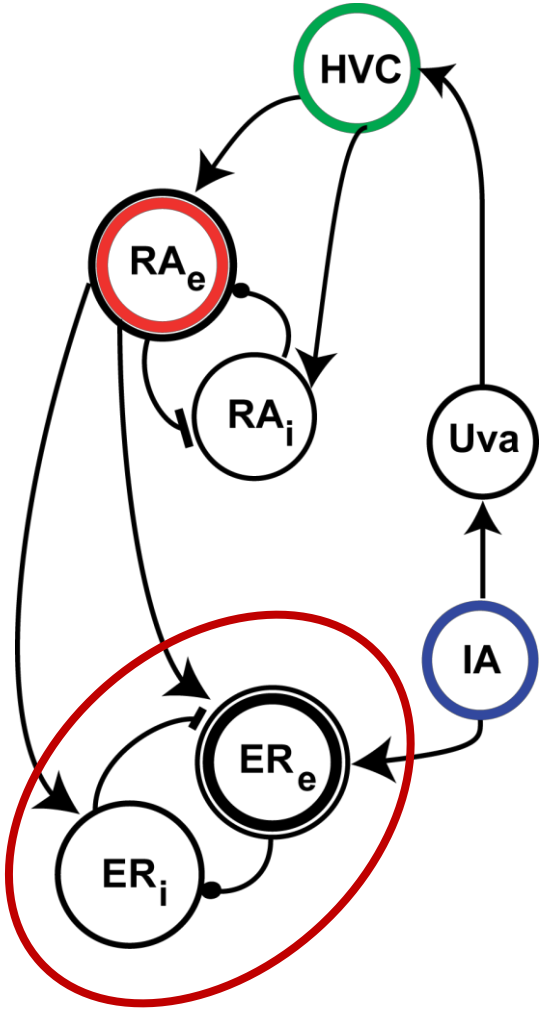
P0 syllables

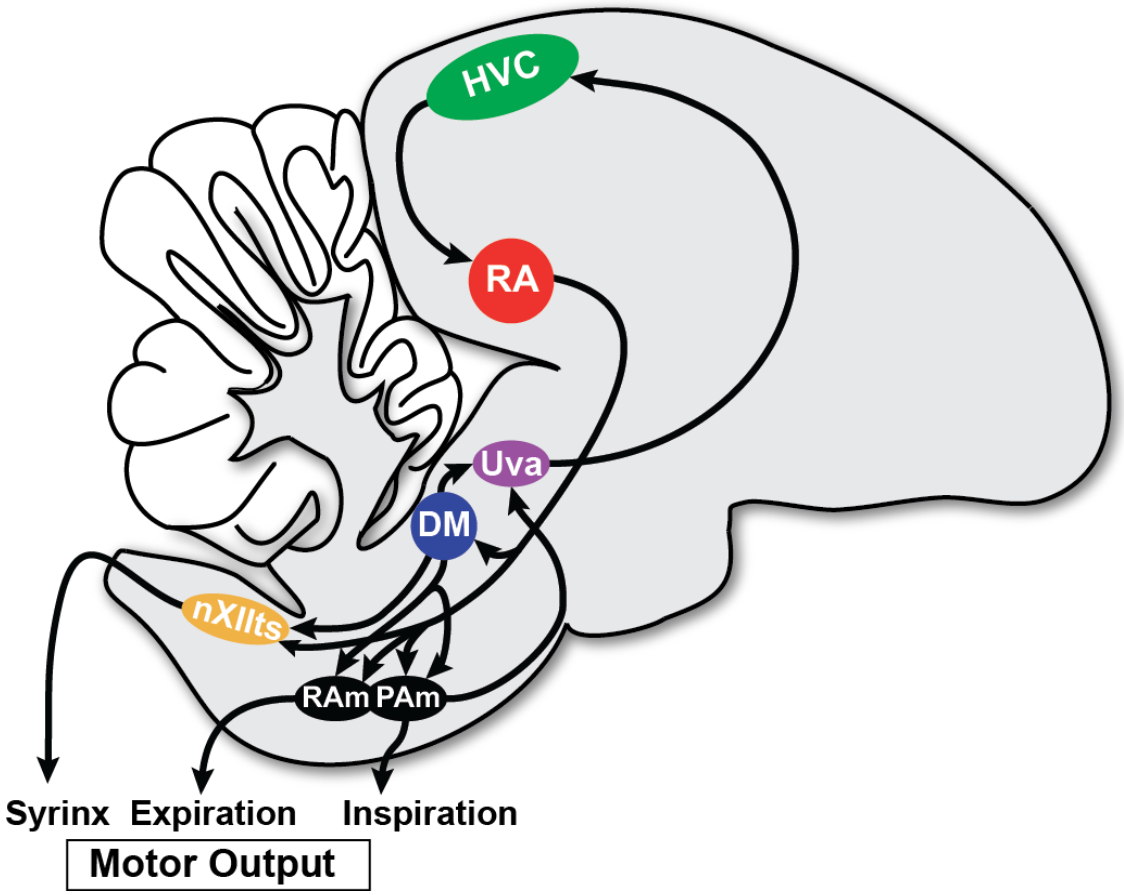
Sparse neural activity and complex behavior

We build a neural model that can generate a complex behavior (song) with minimum ingredients

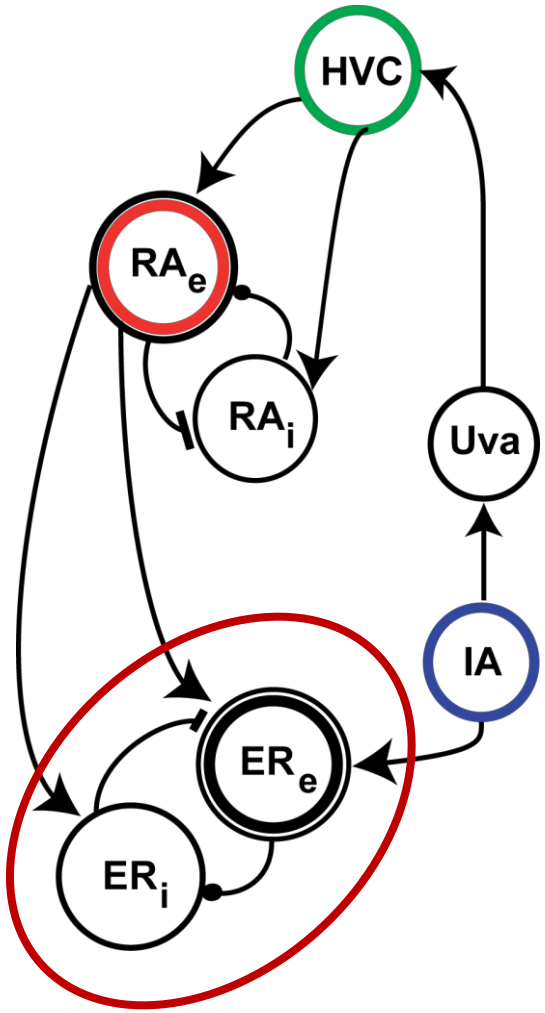
Building a neural model

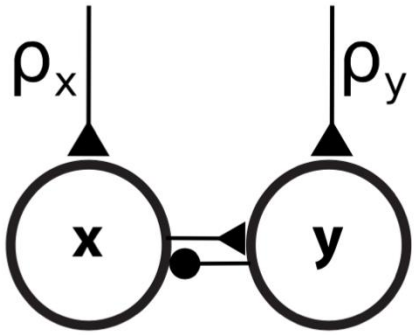
How are these motor gestures generated



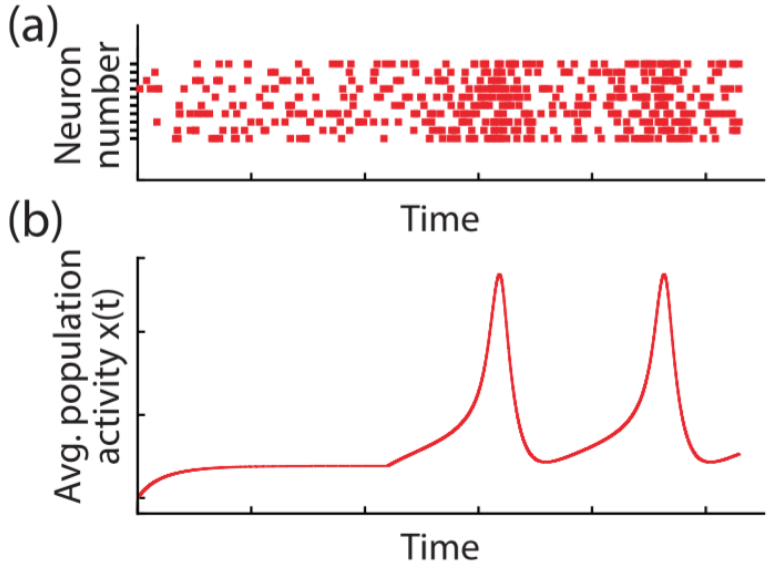


Building a neural model





Additive model



$$\dot{x} = -x + S\left(\rho_x + a\,x - b\,y\right)$$

$$\dot{y} = -y + S\left(\rho_y + c\,x - d\,y\right)$$

with $S(x) = (1 + e^{-x})^{-1}$

x (y) : activity of a population of excitatory (inhibitory) units

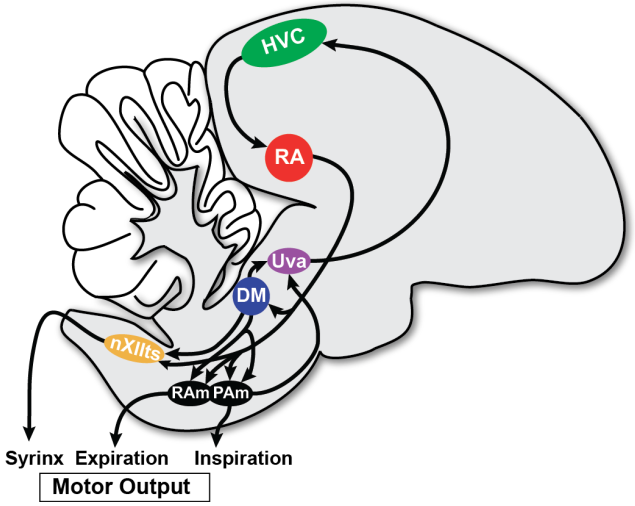
Circular model

Chaos

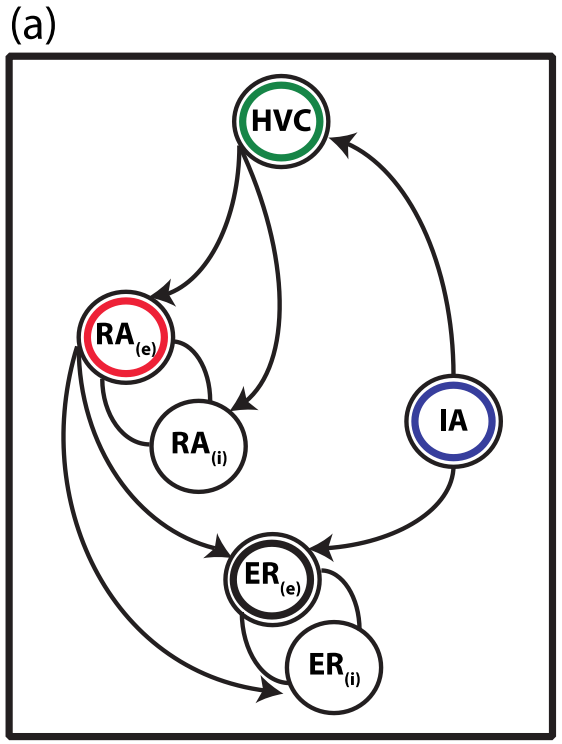
Dynamical model for the neural activity of singing *Serinus canaria*

Cite as: Chaos 30, 053134 (2020); https://doi.org/10.1063/1.5145093
Submitted: 14 January 2020 . Accepted: 27 April 2020 . Published Online: 18 May 2020

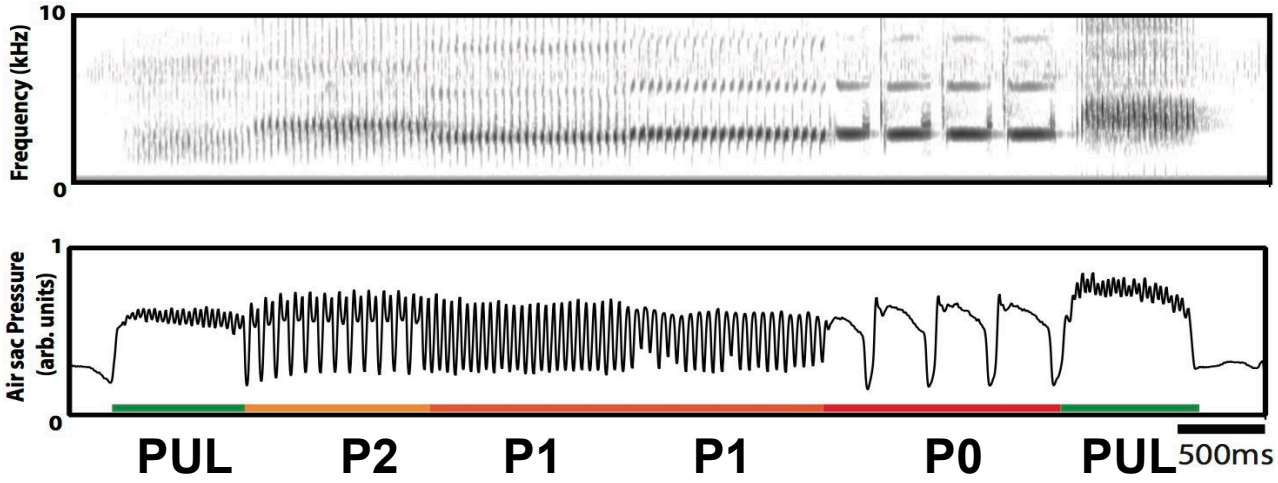
Cecilia T. Herbert, Santiago Boari, Gabriel B. Mindlin, and Ana Amador



Mindlin et al.



Behavior and motor gestures



Alonso et al. 2015
Herbert et al. 2020

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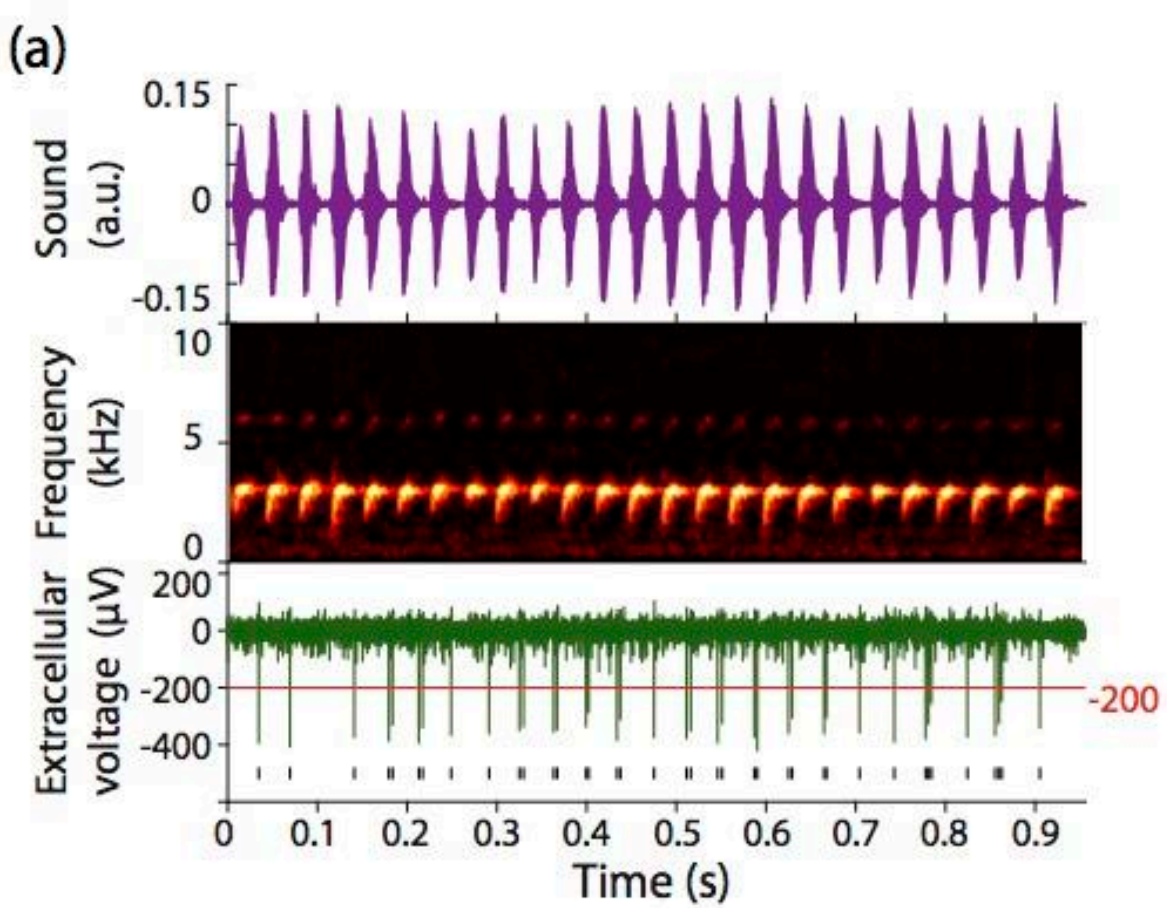
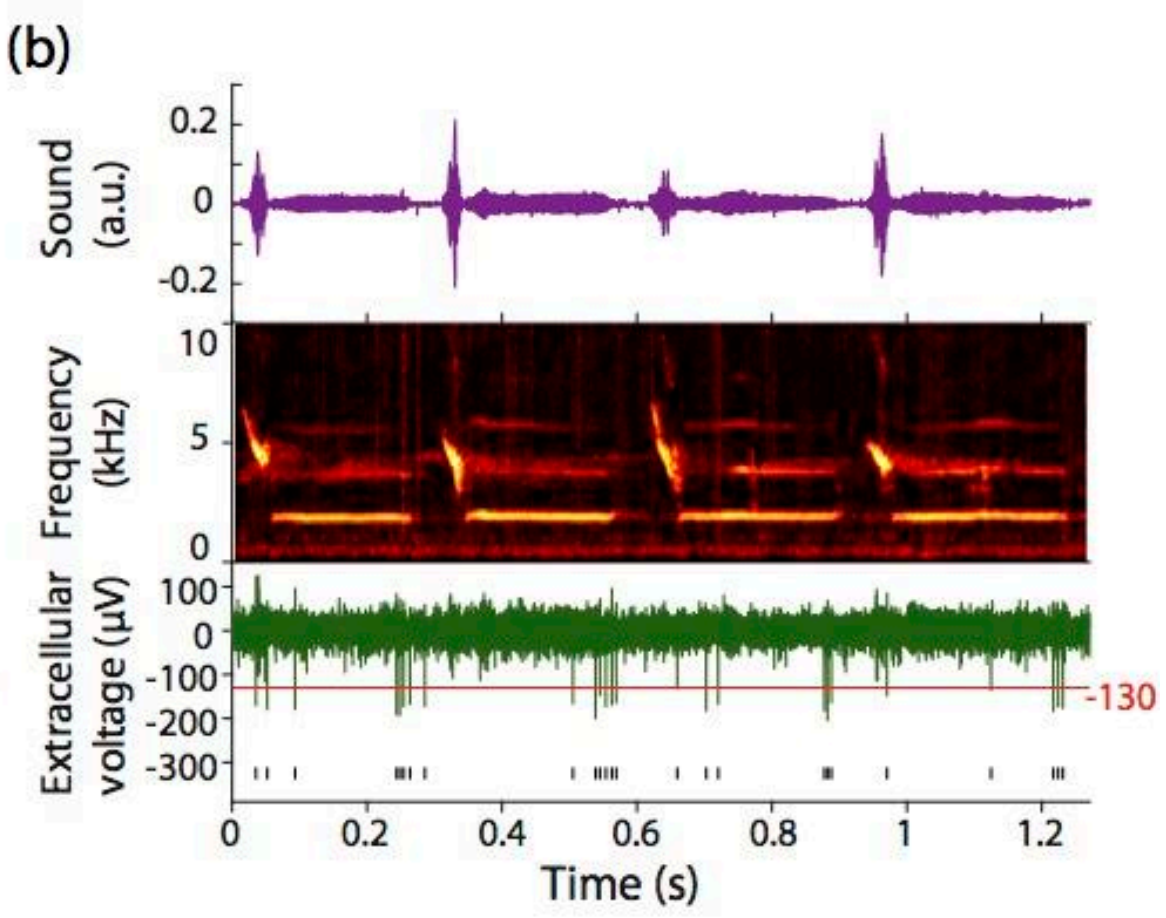
Sparse neural activity and complex behavior



P1 syllables

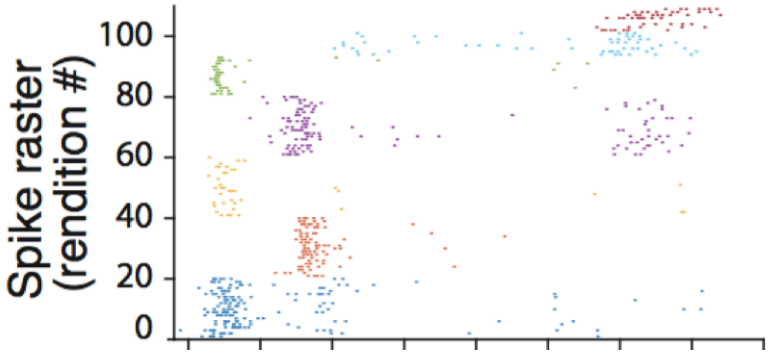


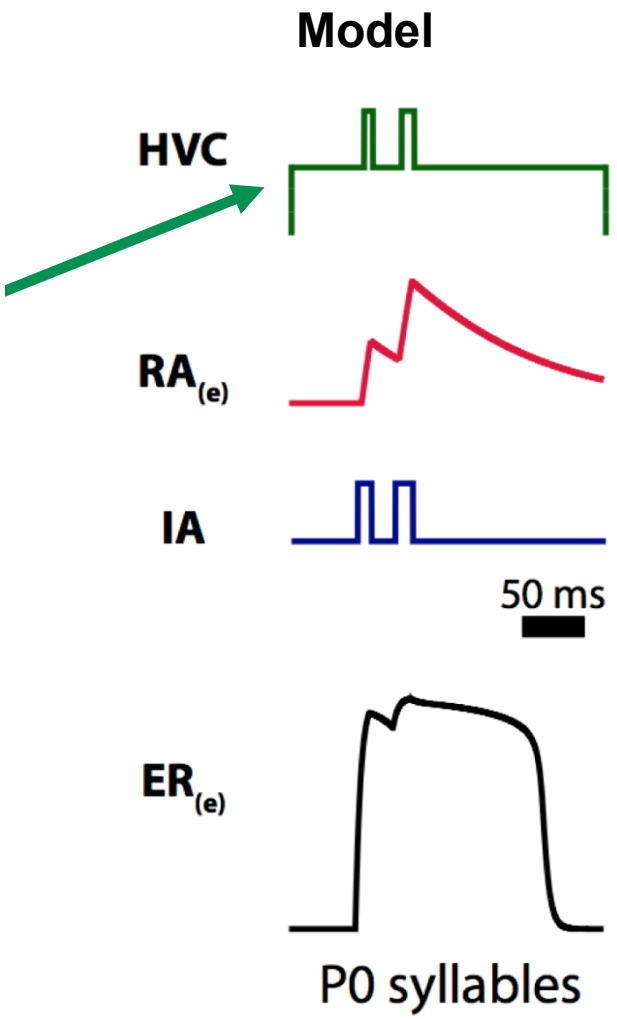
P0 syllables

Neural recordings vs. model

Grouped data : P0 syllables

Spikes per syllable
One colour per neuron





HVC extracellular recordings in singing canaries

Neurons fire at specific instances of P0 syllables

See Herbert, Boari, Mindlin & Amador 2020

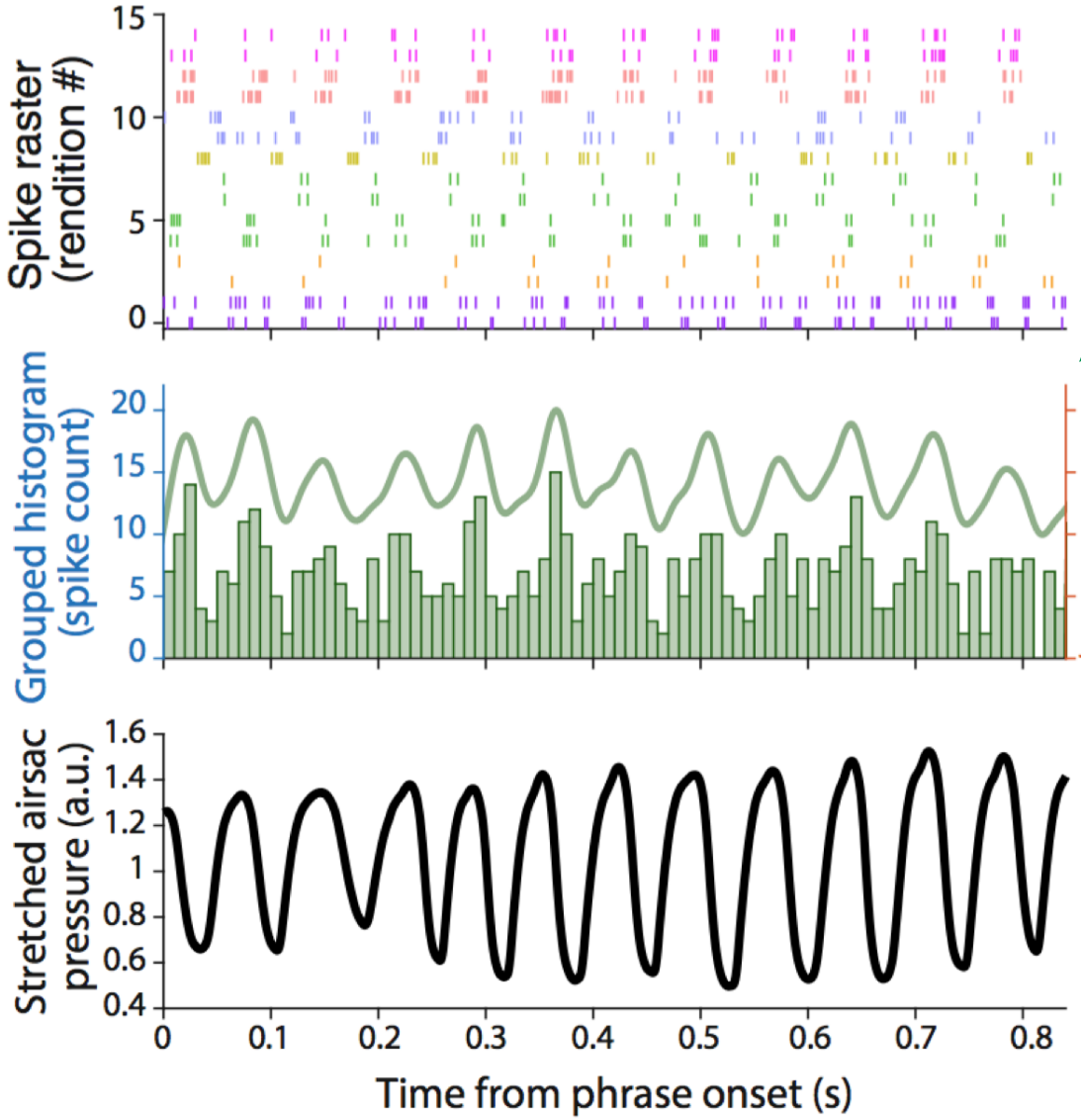
Neural recordings vs. model

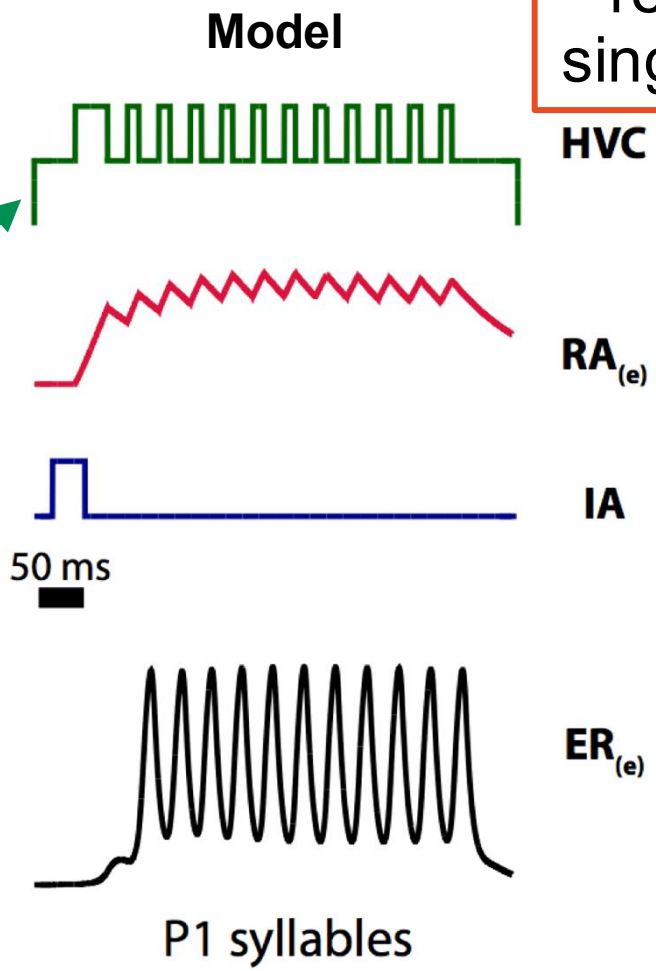
Grouped data

Spikes per phrase (12 syll)
One colour per neuron

Population neural activity

Air sac Pressure





Extracellular recordings in singing canaries

Neurons fire rhythmically during P1 phrases

See Herbert, Boari, Mindlin & Amador 2020

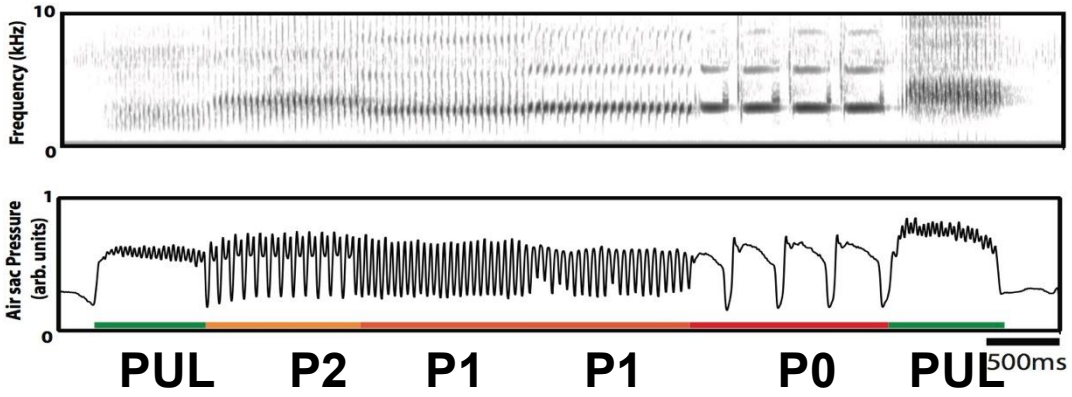
Circular model

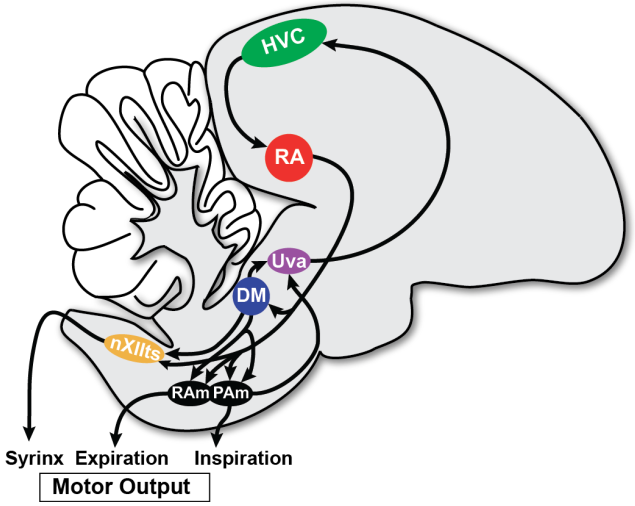
Chaos

Dynamical model for the neural activity of singing *Serinus canaria*

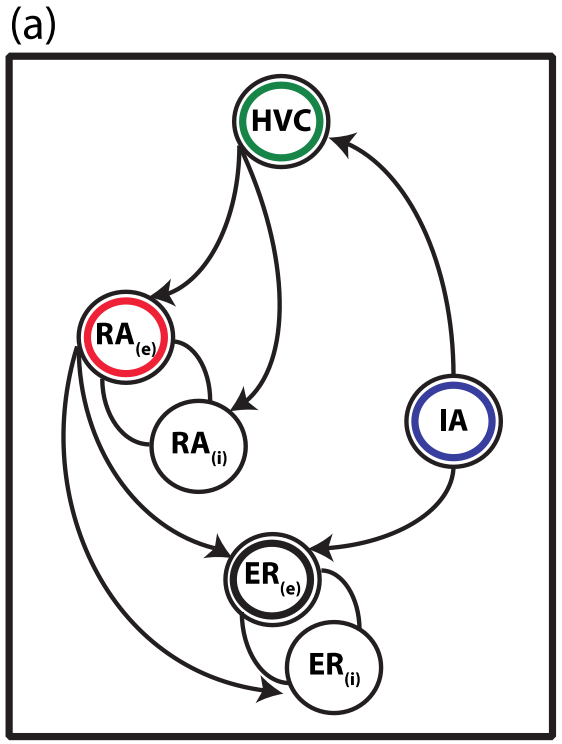
Cite as: Chaos **30**, 053134 (2020); https://doi.org/10.1063/1.5145093
Submitted: 14 January 2020 . Accepted: 27 April 2020 . Published Online: 18 May 2020

Cecilia T. Herbert, Santiago Boari, Gabriel B. Mindlin, and Ana Amador





Mindlin et al.



Sparse input

Specific predictions of HVC activity

Complex output

Alonso et al. 2015
Herbert et al. 2020

Conclusions

- Rhythms in a songbird brain are synchronized with behavior (song).
- Low dimensional model allows to study motor control and neural coding in songbirds.
- A distributed neuronal code is proposed for the motor control in the song system.
- Experimental measurements (neural recordings) suggest a motor gesture related neural code.

Gracias por su atención!

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- ✧ Fiamma L. Leites (UBA, Biology)

Postdocs

- ✧ Santiago Boari (UBA, Physics)

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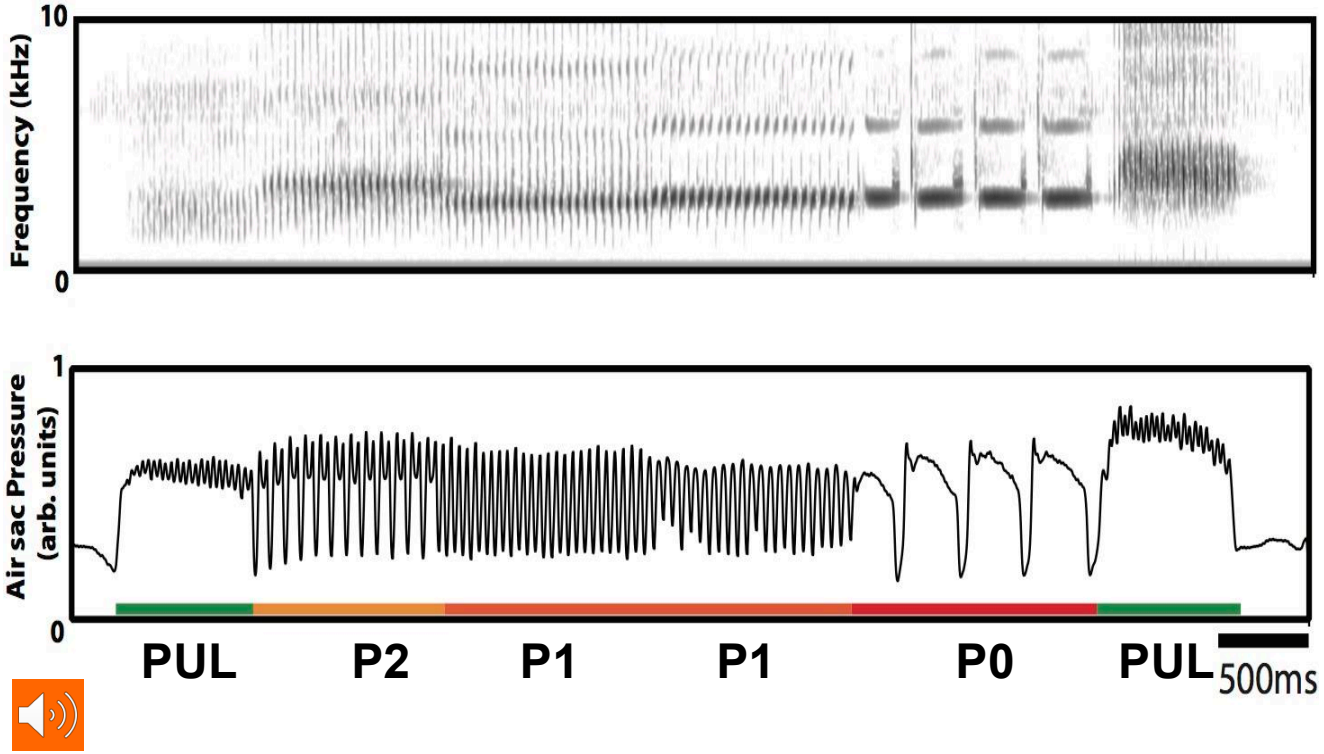
- ✧ Agencia Nac. de Promoción Científica y Tecnológica (ANPCyT, Argentina)

Rhythms in a canary song

Canary song

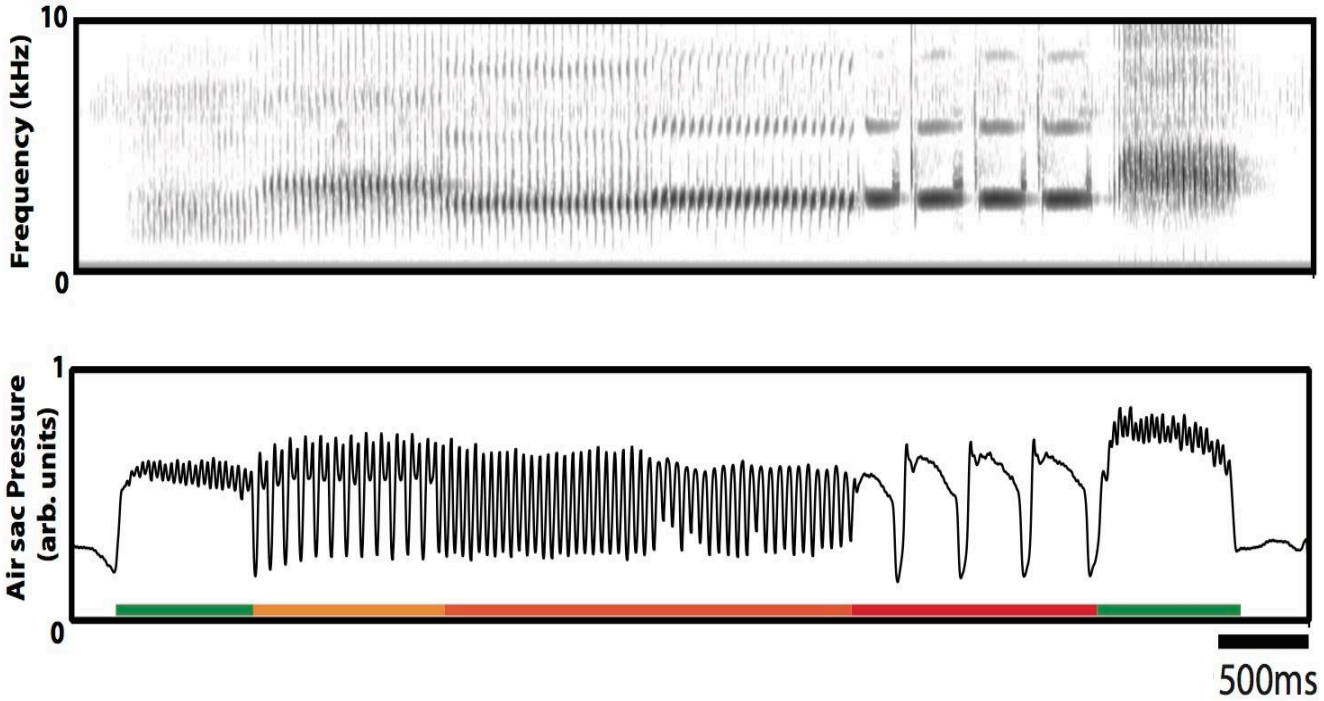


Air sac pressure: Motor gestures

Mindlin & collaborators, e.g. Alliende et al, 2010

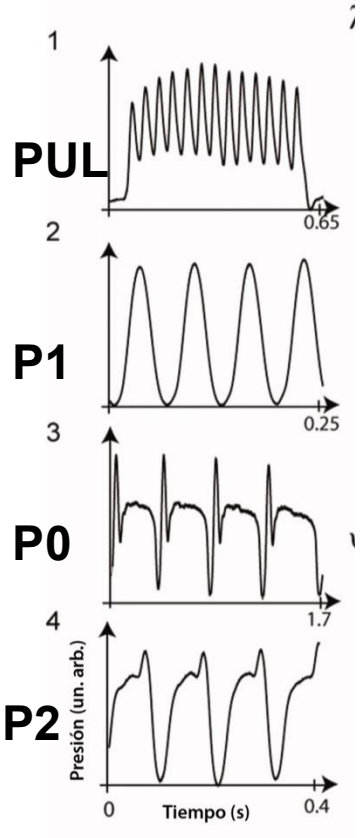
Looking carefully at the behavior

Canary song



Air sac pressure: Motor gestures

Classifying using motor gestures

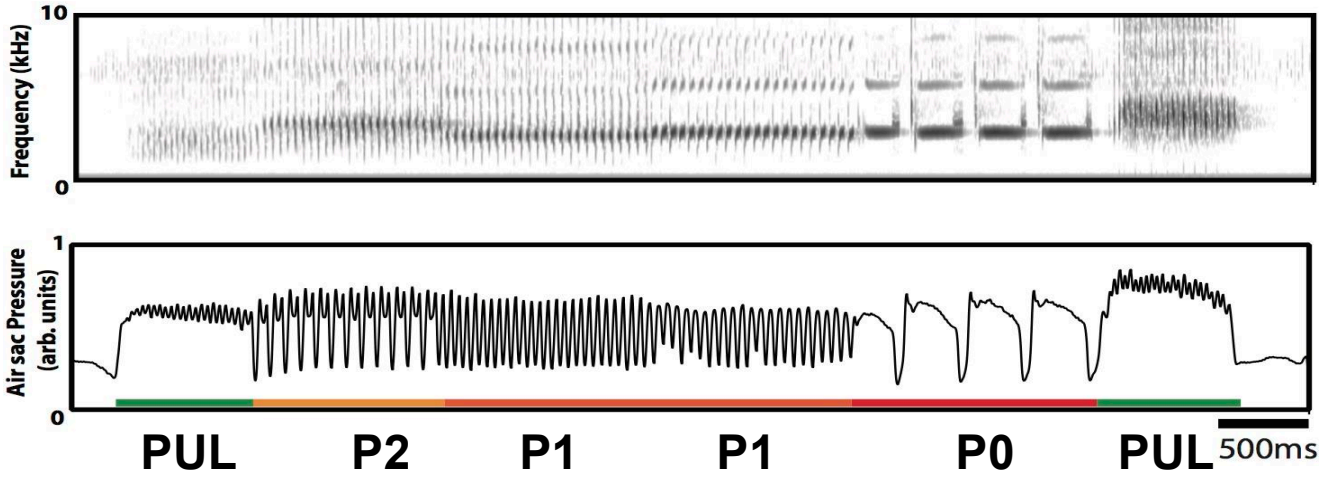


Canary syllables can be grouped in **4 categories** using motor gestures

Mindlin & collaborators, e.g. Alliende et al, 2010

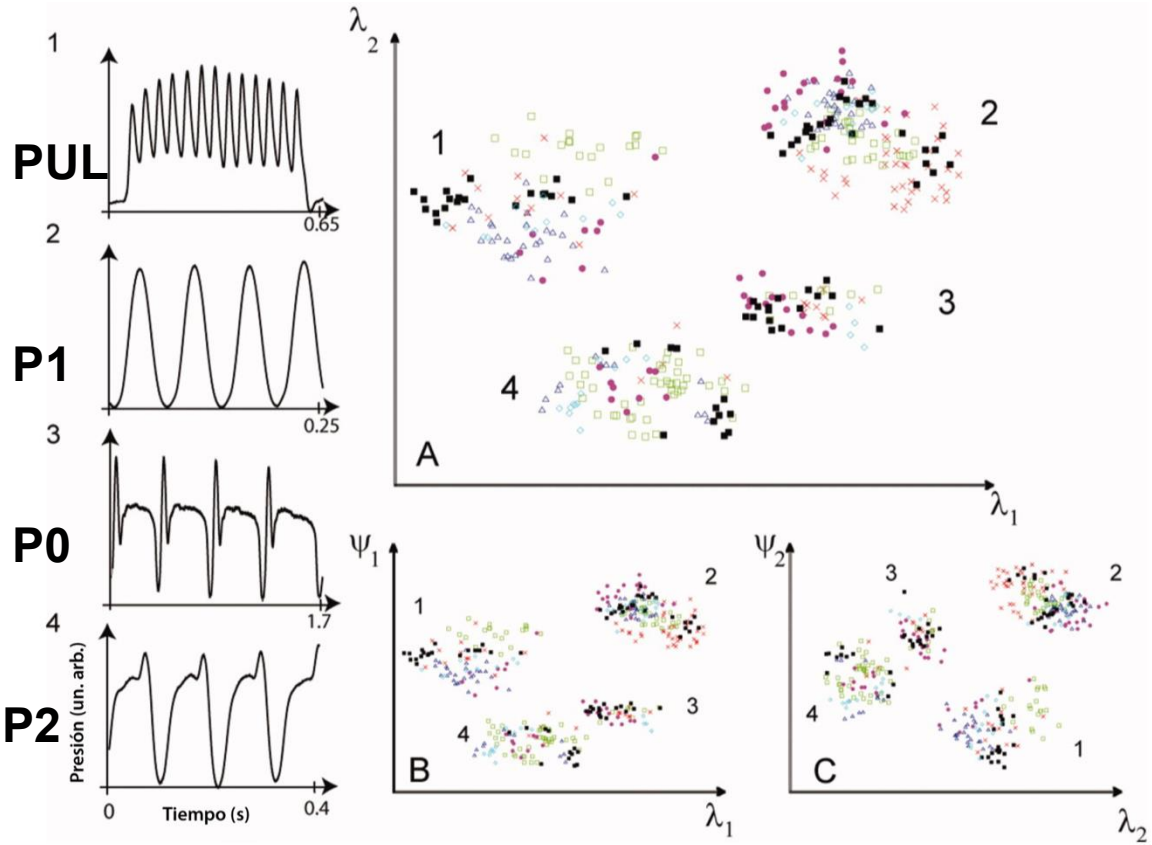
Looking carefully at the behavior

Canary song



4 rhythms classified
by motor gestures
4 groups of syllable rates

Classifying using motor gestures

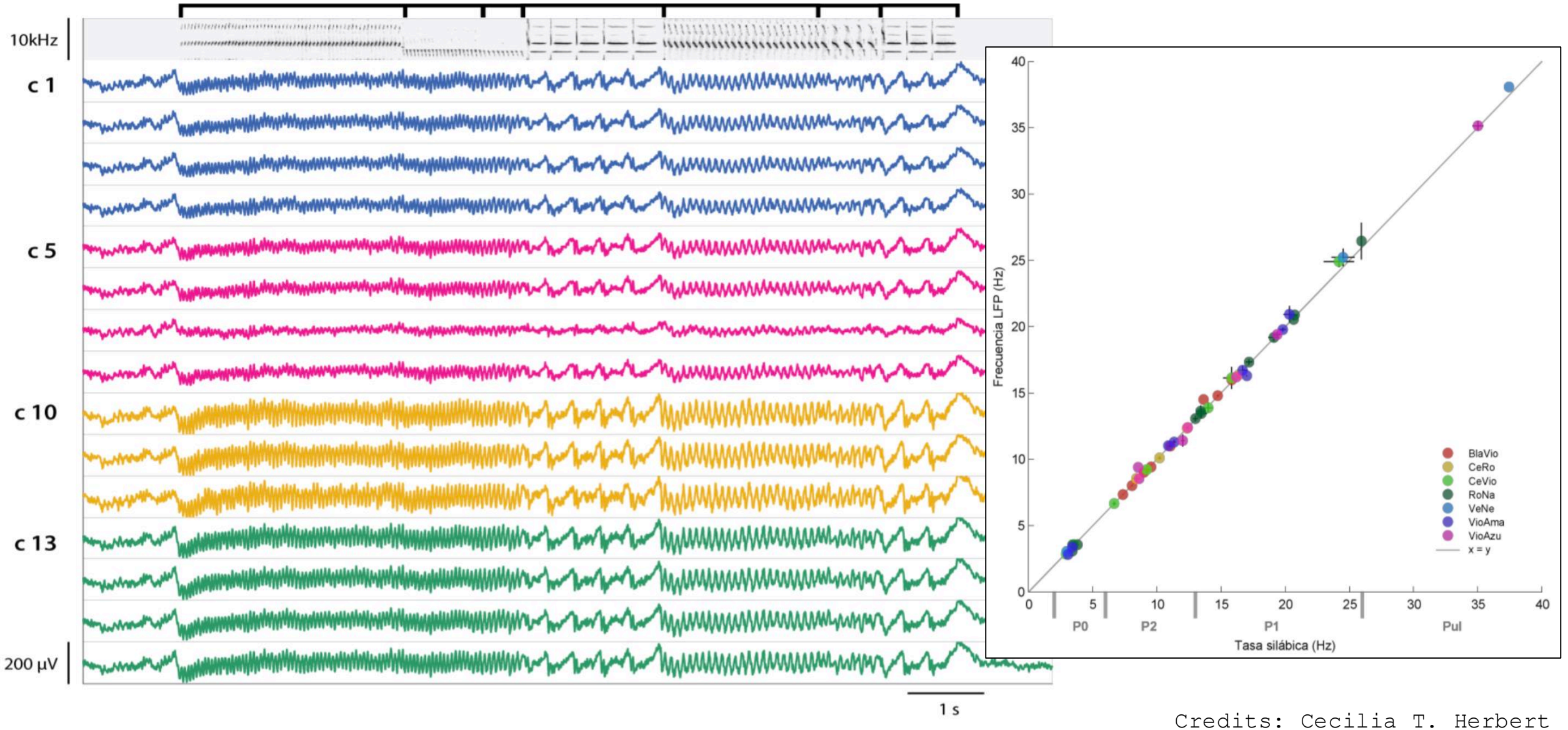


Canary syllables can be grouped in **4 categories** using motor gestures

Mindlin & collaborators, e.g. Alliende et al, 2010

Singing canaries

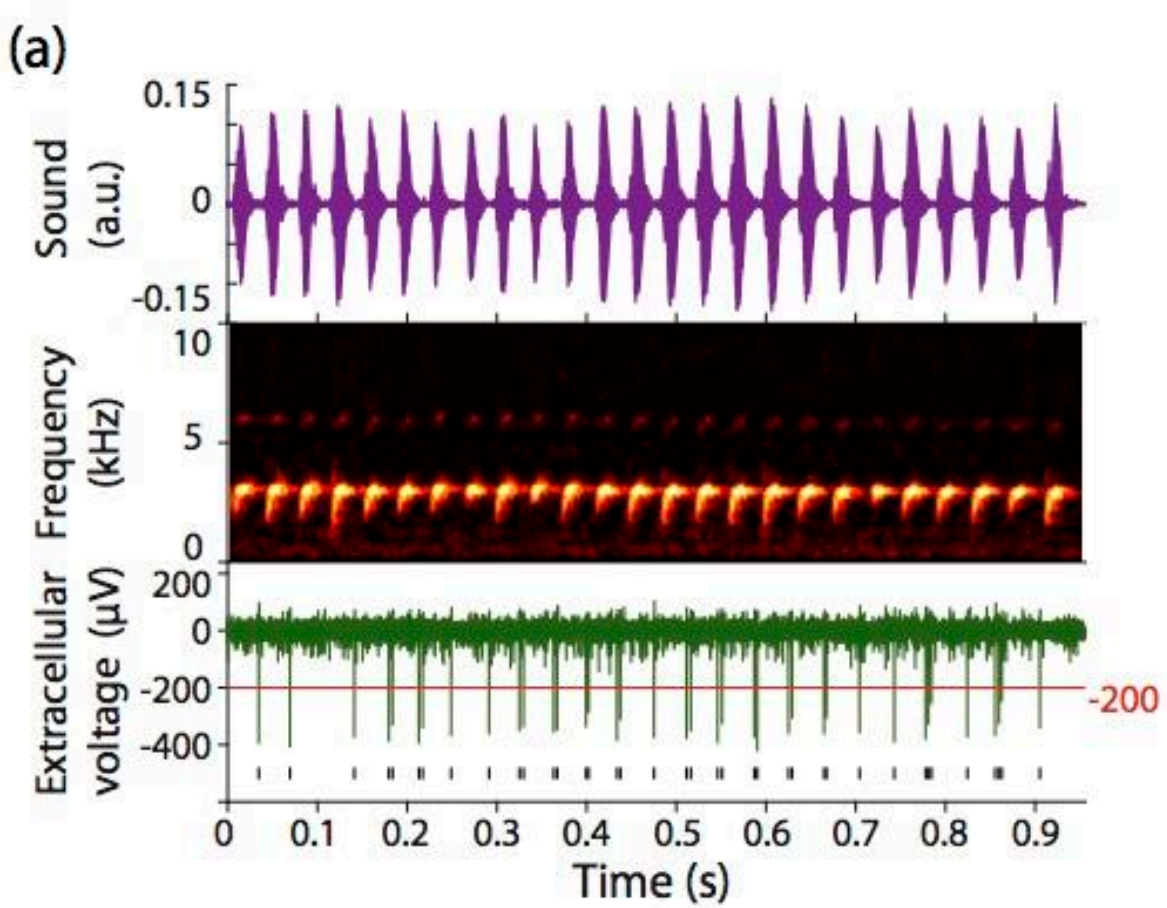
Singing canaries: LFP



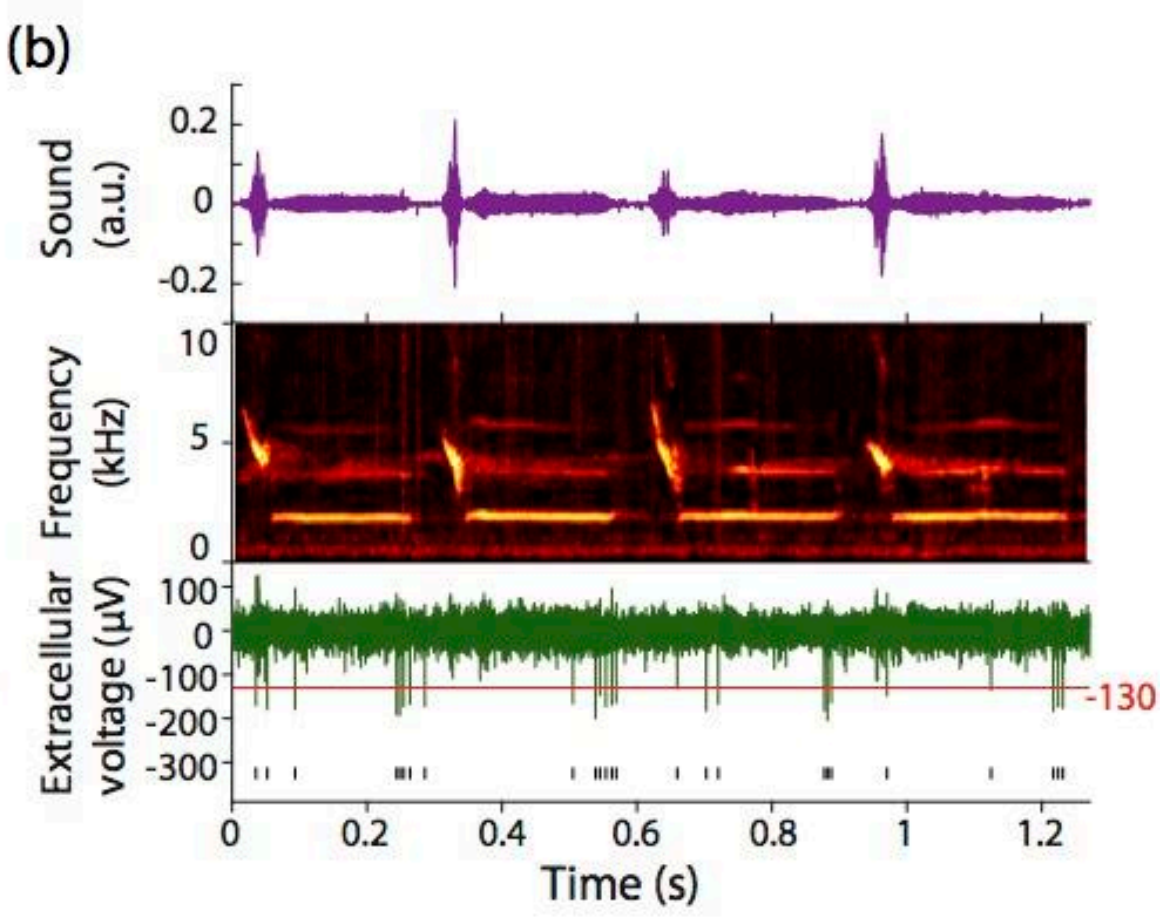
Credits: Cecilia T. Herbert

Neural recordings in singing canaries

Sparse neural activity and complex behavior



P1 syllables



P0 syllables

Rhythms in the Brain of a Songbird

Local Field Potentials are locked to behavior

LFP frequencies ~ syllable repetition rate

✓ in auditory responses
(presentation of the Bird´s own song)

✓ during song production