TAs: Salomon Muller, Marjorie Xie, Matteo Alleman, Dan Biderman, Amin Nejatbakhshesfahani

Meetings: Tuesdays & Thursdays, Lecture 2:00-3:30

W**ebpage** - https://ctn.zuckermaninstitute.columbia.edu/courses

January

21 (Larry) Introduction to the Course and to Theoretical Neuroscience

23 (Larry) Mathematics Review

28 (Larry) Electrical Properties of Neurons, Integrate-and-Fire Model (Assignment 1)

30 (Larry) Adaptation, Synapses, Spiking Networks

February

4 (Larry) Numerical Methods, Filtering (Assignment 2)

5 Assignment 1 Due

6 (Larry) The Hodgkin-Huxley Model

11 (Larry) Types of Neuron Models and Networks (Assignment 3)

12 Assignment 2 Due

February

13 (Ken) Linear Algebra I
18 (Ken) Linear Algebra II (Assignment 4)
19 Assignment 3 Due
20 (Ken) Linear Algebra III
25 (Ken) PCA and Dimensionality Reduction (Assignment 5)
26 Assignment 4 Due
27 COSYNE

March

3 COSYNE
5 (Ken) Rate Networks/E-I networks I
10 (Ken) Rate Networks/E-I networks II (Assignment 6)
11 Assignment 5 Due
12 (Ken) Unsupervised/Hebbian Learning, Developmental Models
17 Spring Break
19 Spring Break

March

24 (Ashok) – Introduction to Probability, Encoding, Decoding
25 Assignment 6 Due
26 (Ashok) – GLMs
31 (Ashok) – Decoding, Fisher Information (Assignment 7)

April

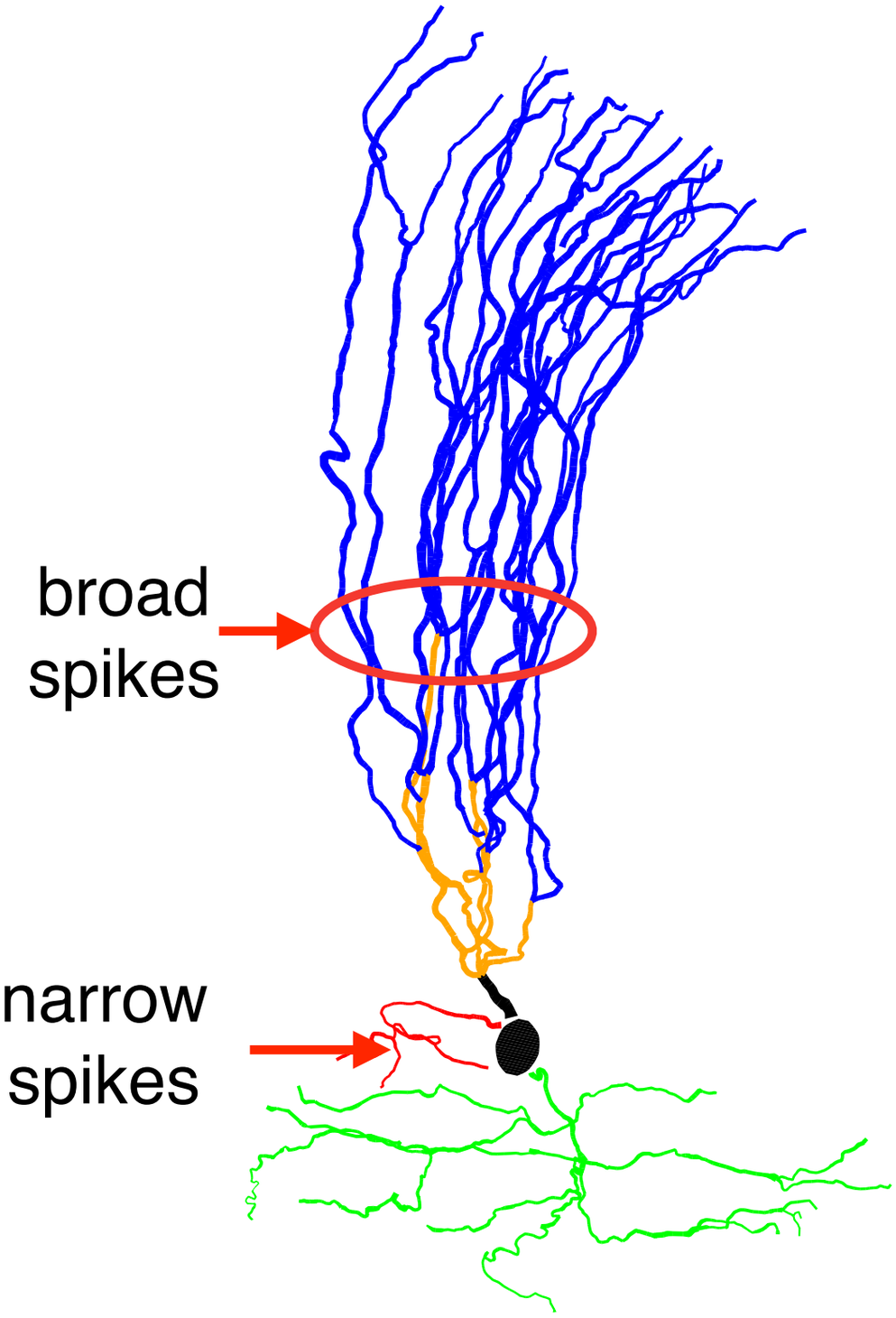
2 (Ashok) – Decoding, Fisher Information II
7 (Ashok) – Information Theory (Assignment 8)
8 Assignment 7 Due
9 (Ashok) – Optimization
14 (Ashok) – Optimization II (Assignment 9)
15 Assignment 8 Due
16 Research Topic

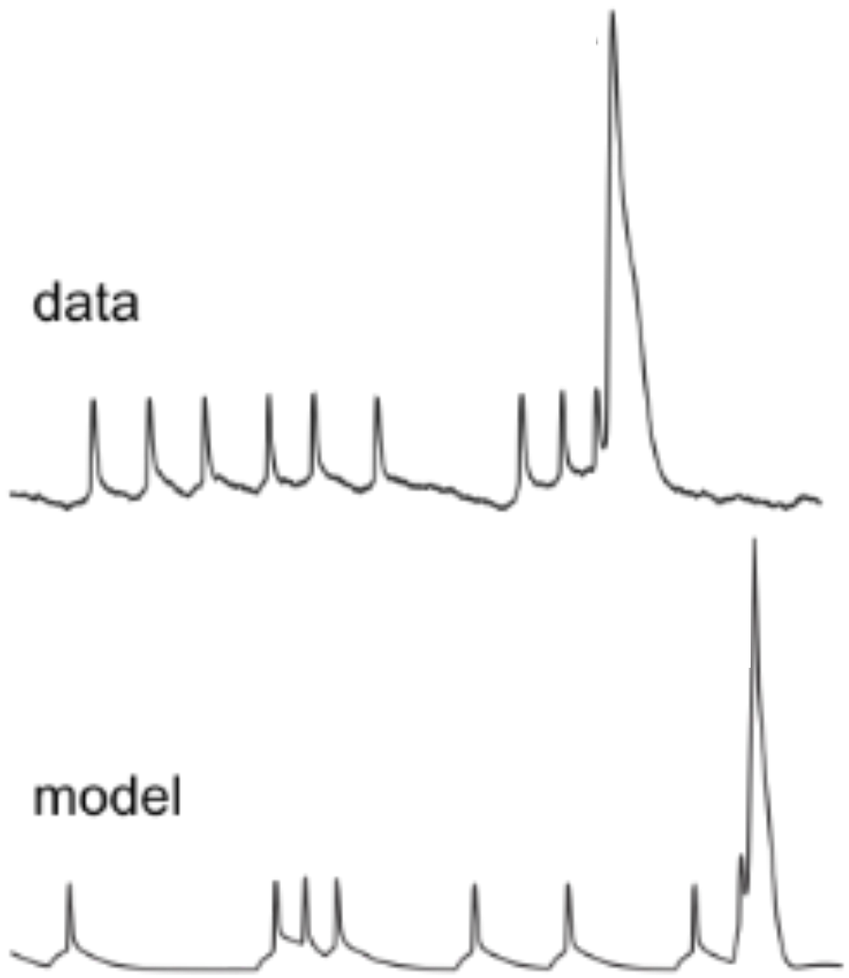
April

21 (Stefano) Perceptron (Assignment 10)
22 Assignment 9 Due
23 (Stefano) Multilayer Perceptrons and Mixed Selectivity
28 (Stefano) – Deep Learning I (backpropagation) (Assignment 11)
29 Assignment 10 Due
30 (Stefano) – Deep Learning II (convolutional networks)

May

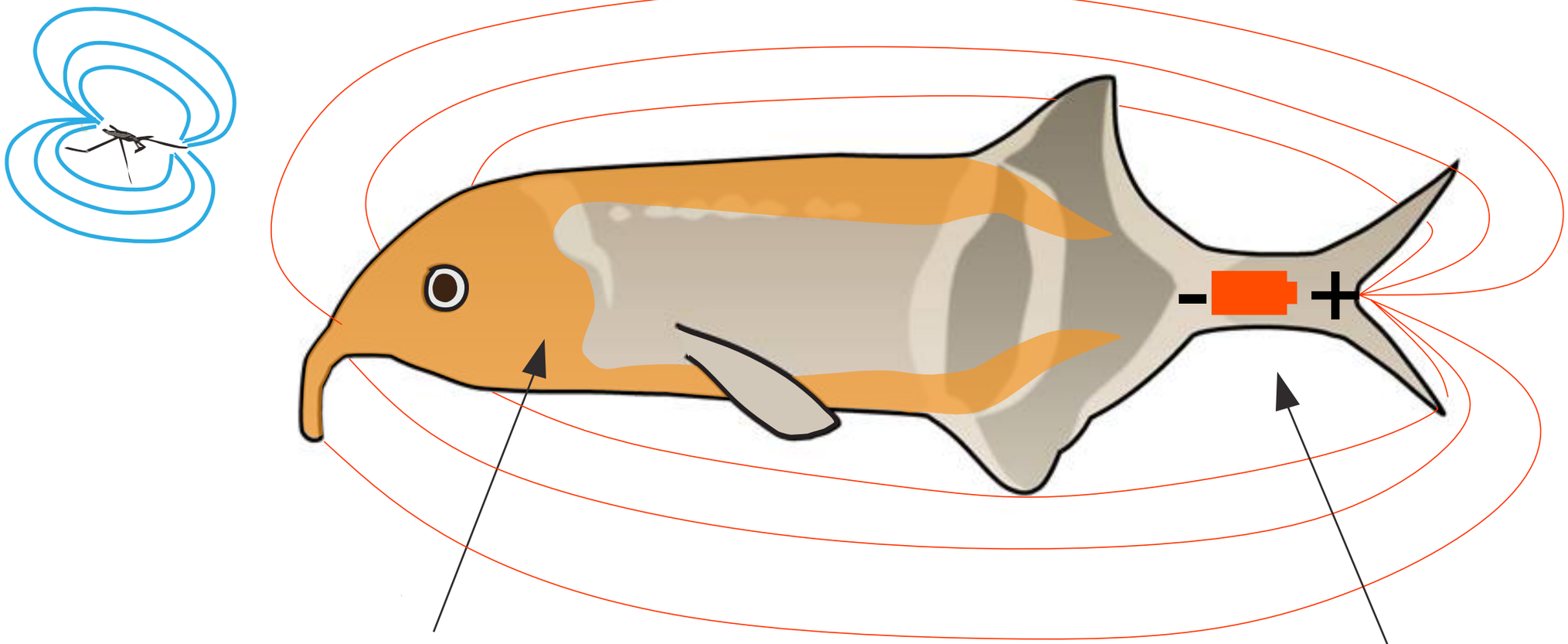
5 (Stefano) Learning in Recurrent Networks (Assignment 12)
6 Assignment 11 Due
7 (Stefano) Continual Learning and Catastrophic Forgetting
12 (Stefano) Reinforcement Learning
13 Assignment 12 Due
14 Research Topic





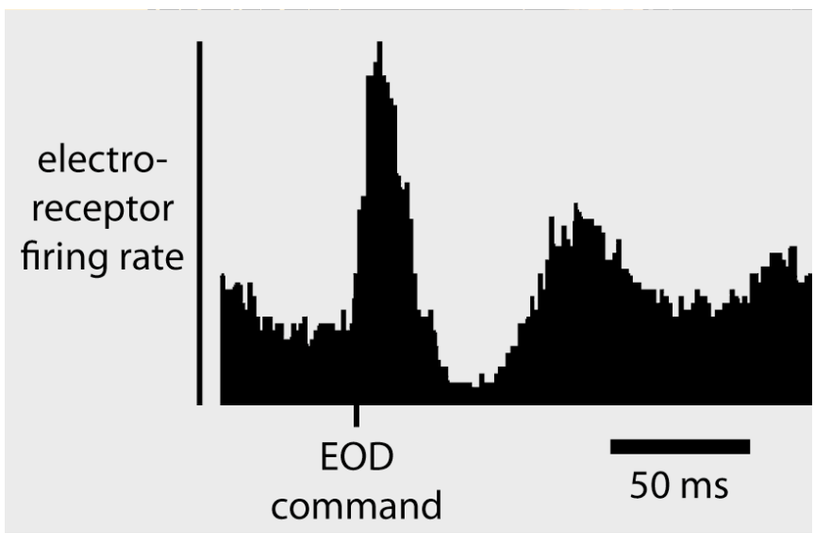
Salomon Muller - Abbott, Sawtell

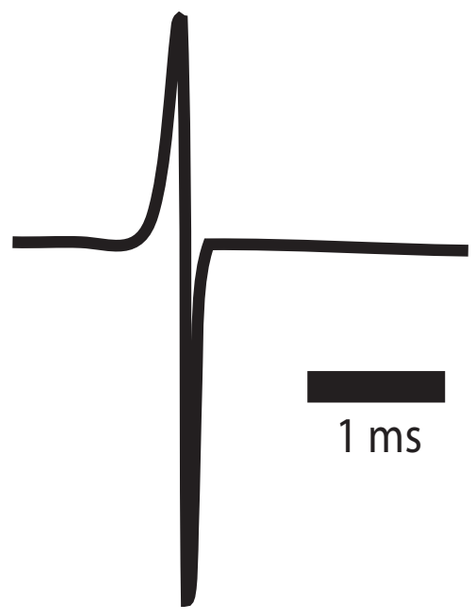
Elephant Nose Fish



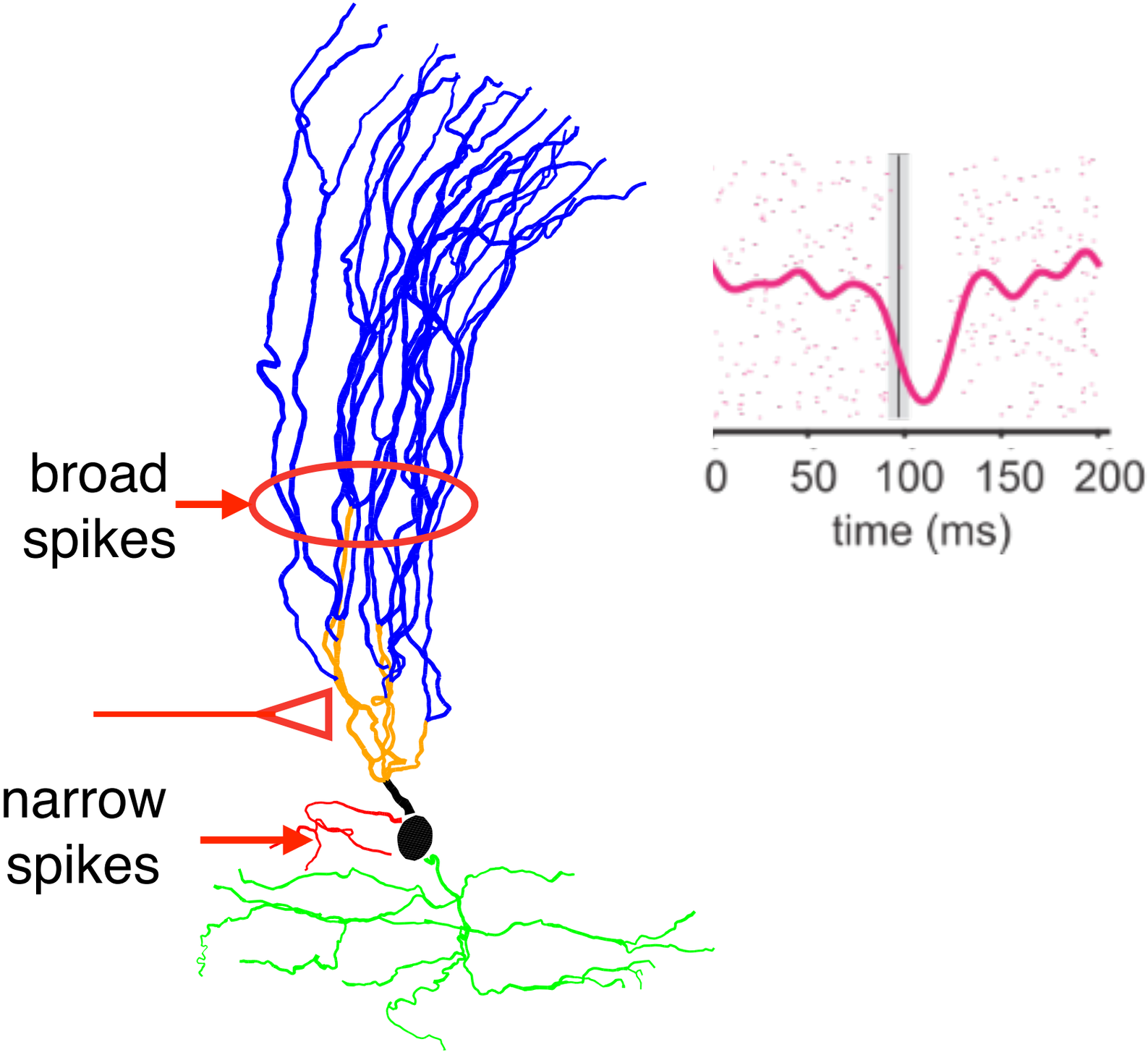
electroreceptors
(passive electrolocation)

electric organ





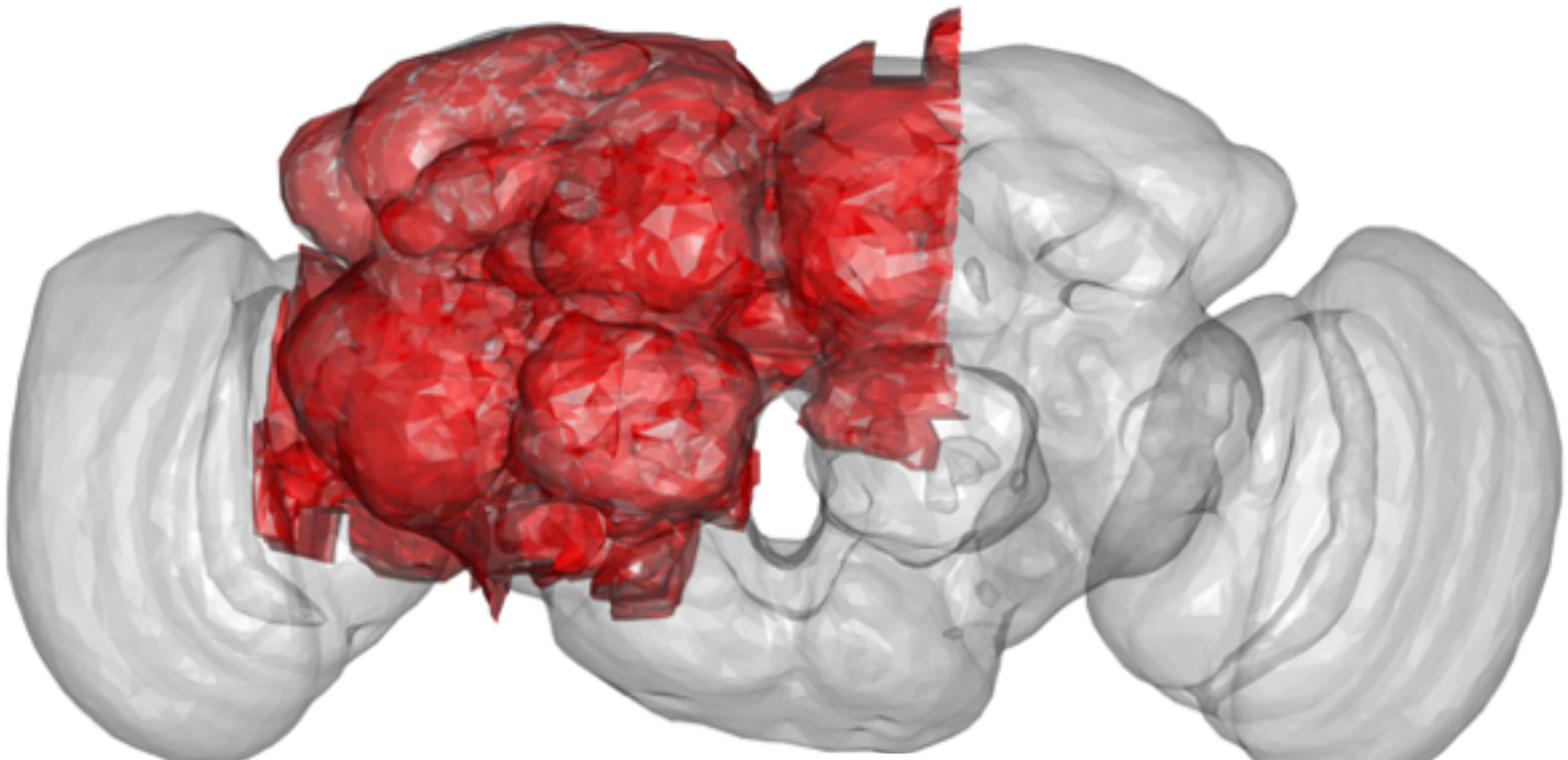
electric organ
discharge
(EOD)


broad
spikes
narrow
spikes

0
50
100
150
200
time (ms)

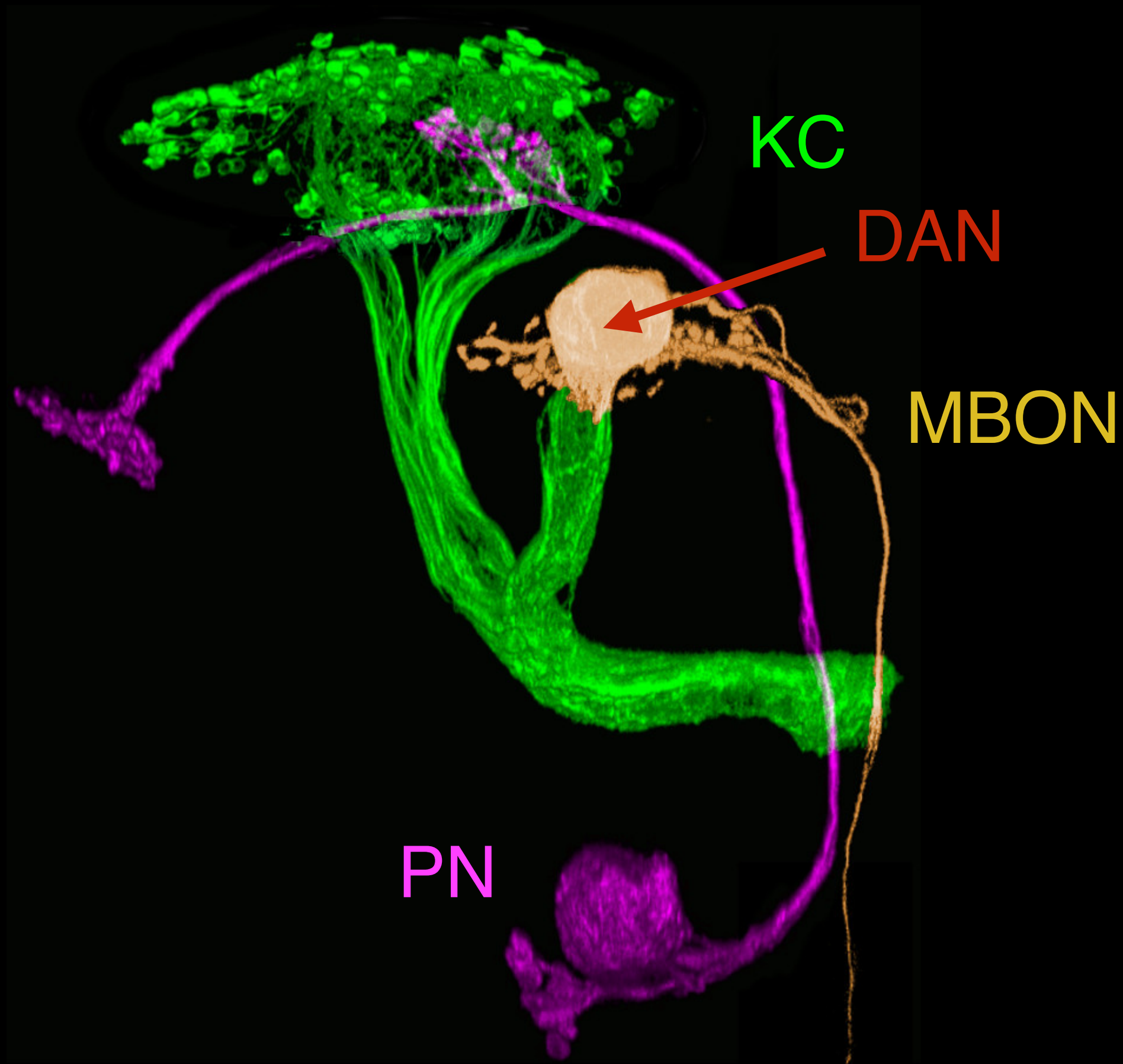
Complete Fly Brain EM Connectome

Ashok Litwin-Kumar, Larry Abbott, Jack Lindsey, Gerry Rubin + ~ 40



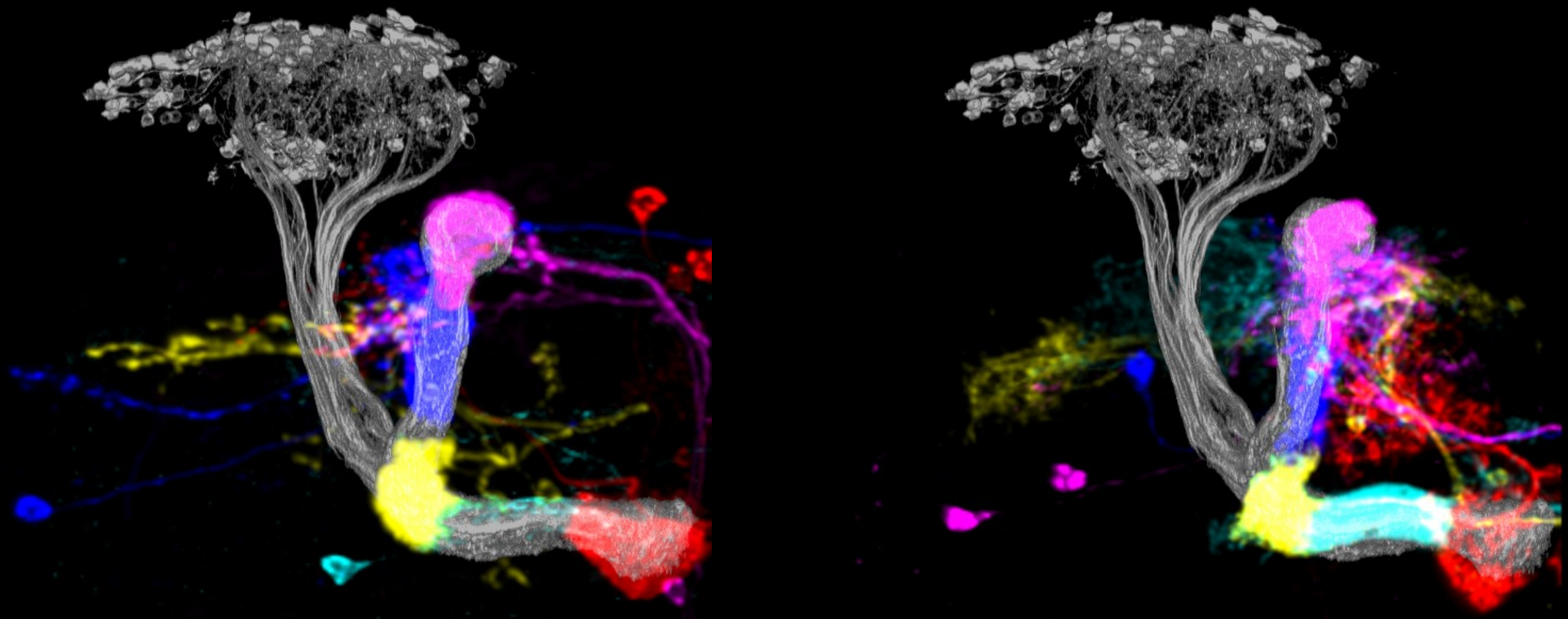
hemibrain janelia flyEM Google

Matthias Christenson, Sarah Heath, Jacob Portes, Jessie Kohn - Rudy Behnia


KC
DAN
MBON
PN

Mushroom body output neurons

Dopaminergic neurons



5 of 16 compartments

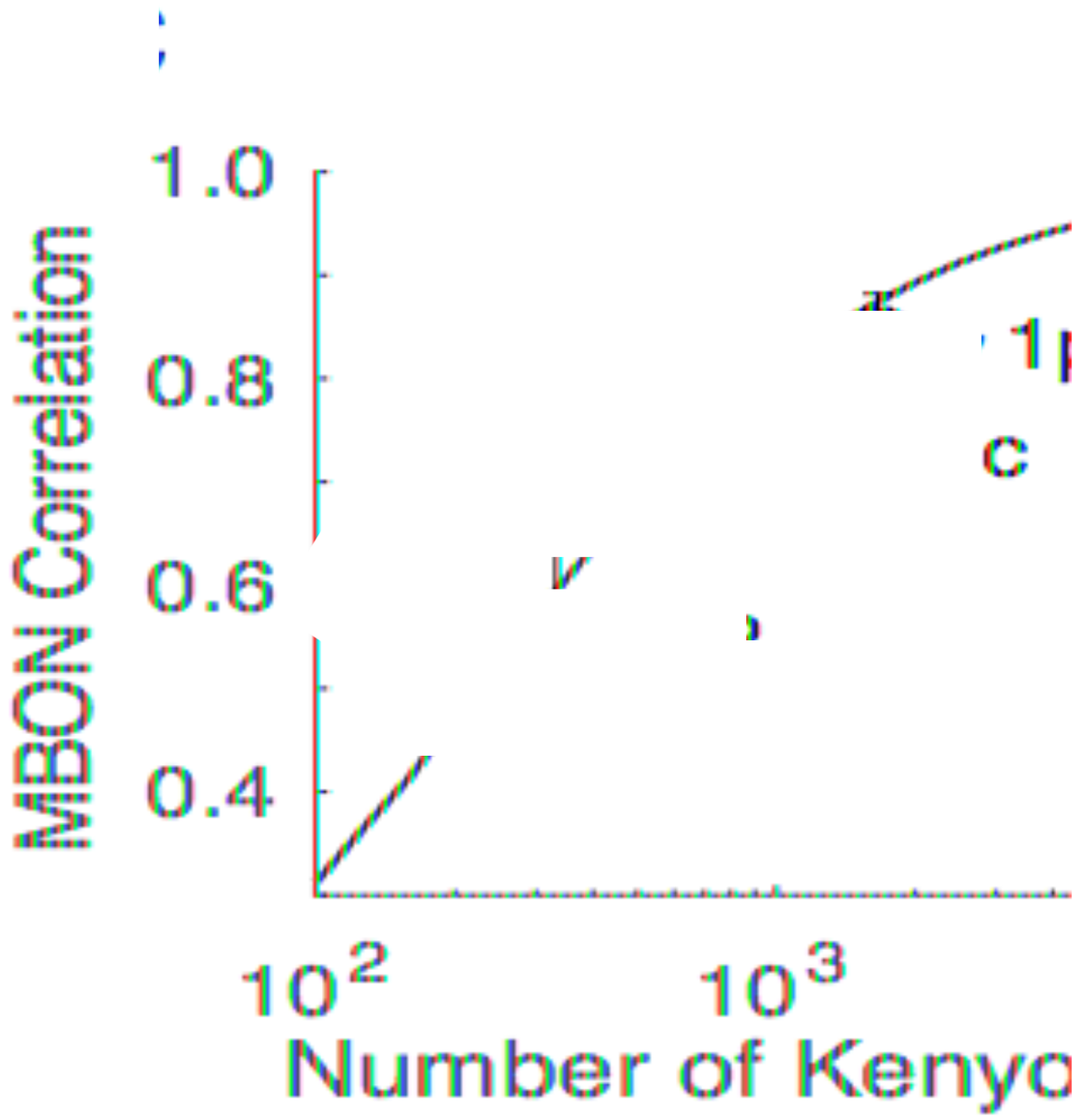
Random

Learned

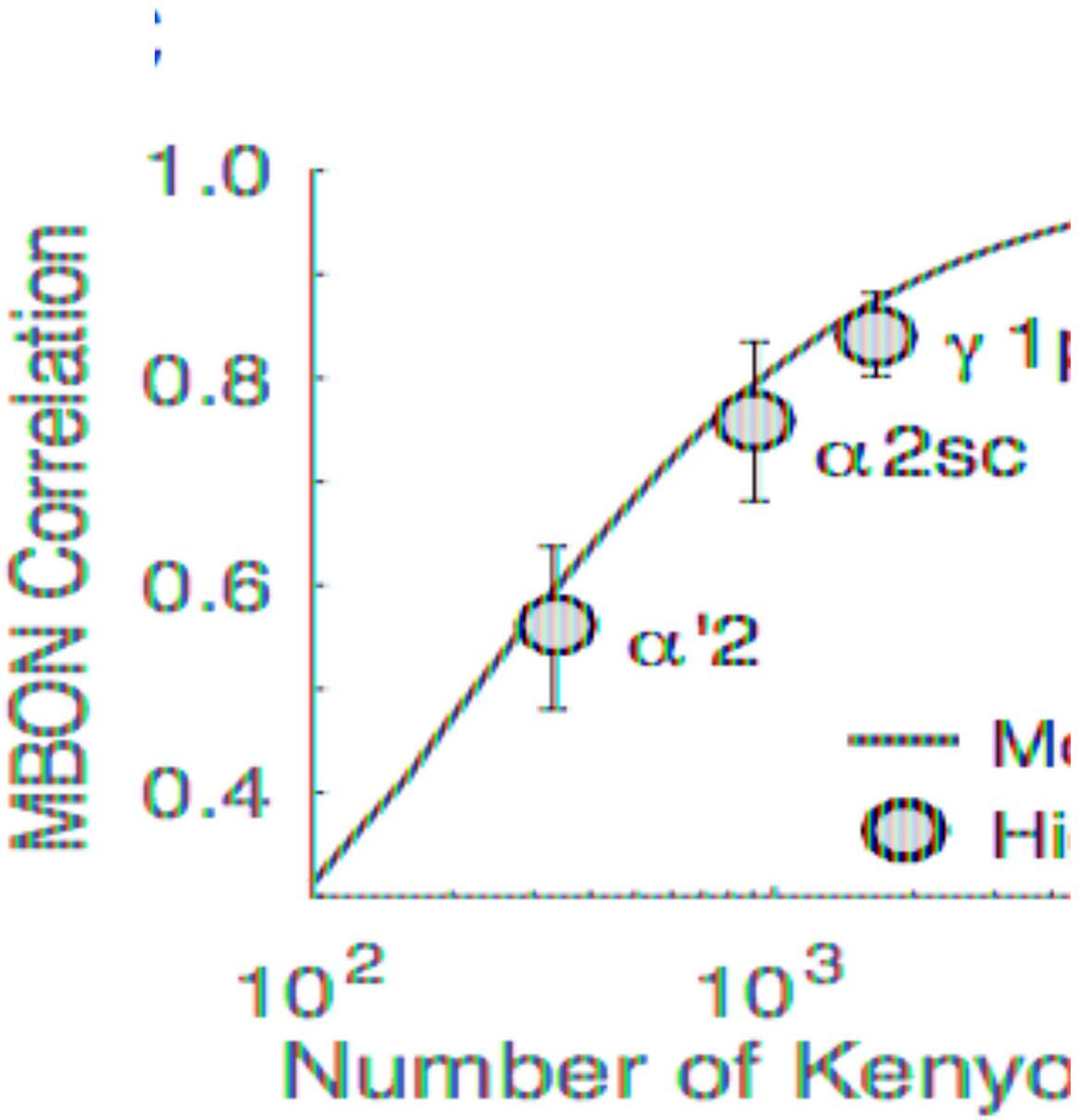
Random

Learned

Same?

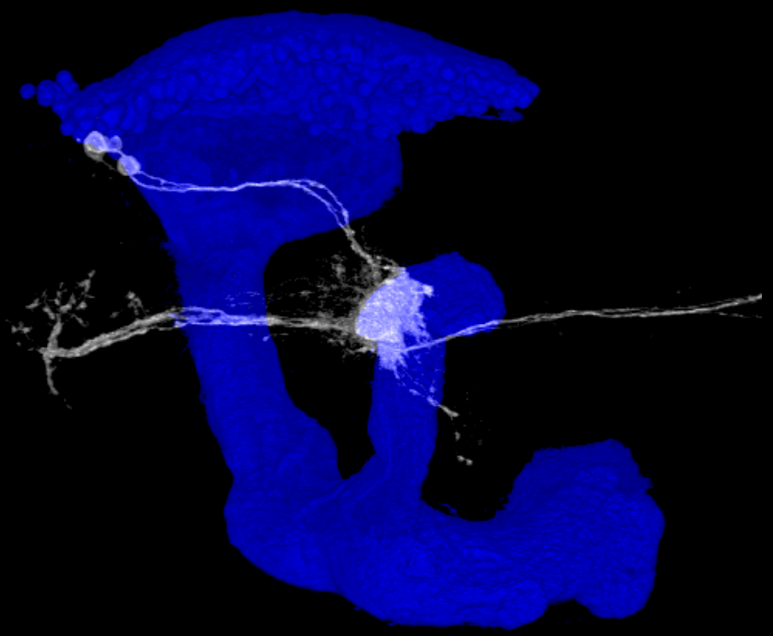


Evan Schaffer, Dan Stettler, Larry Abbott, Richard Axel

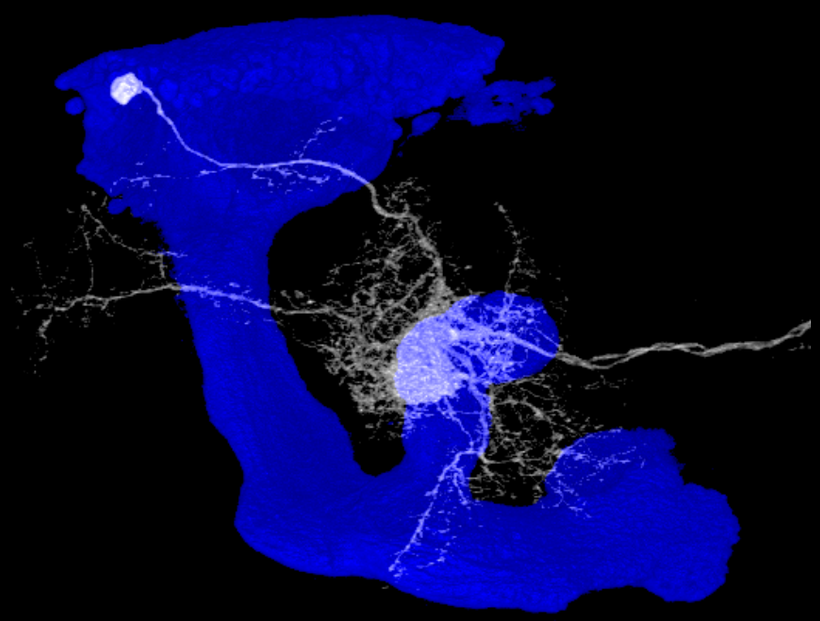

1.0
0.8
0.6
0.4
MBON Correlation
α'2
α2sc
γ 1
10^2
10^3
Number of Kenyo

The α'3 compartment represents novelty and familiarity

MBON-α'3

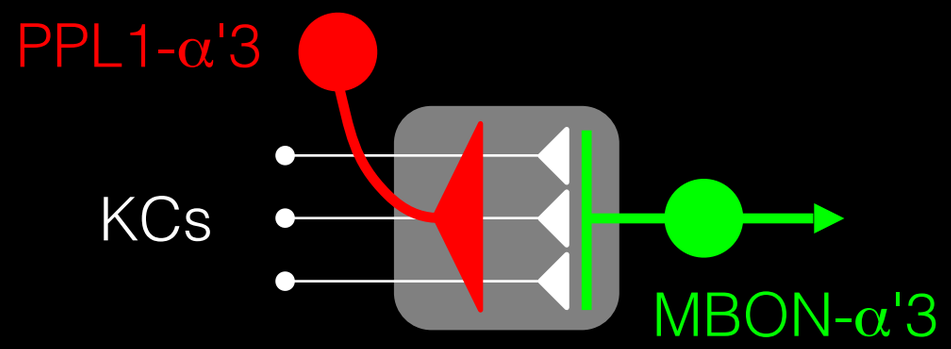


PPL1-α'3

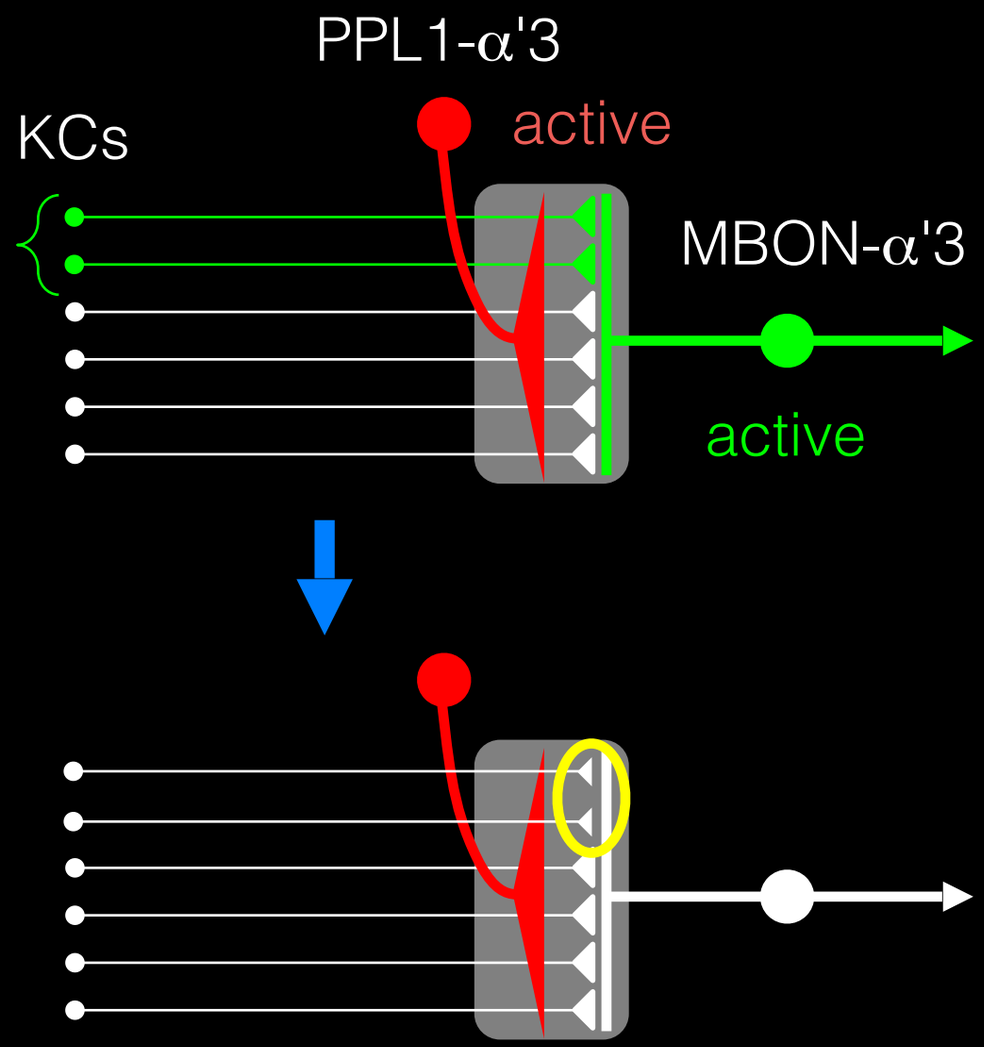


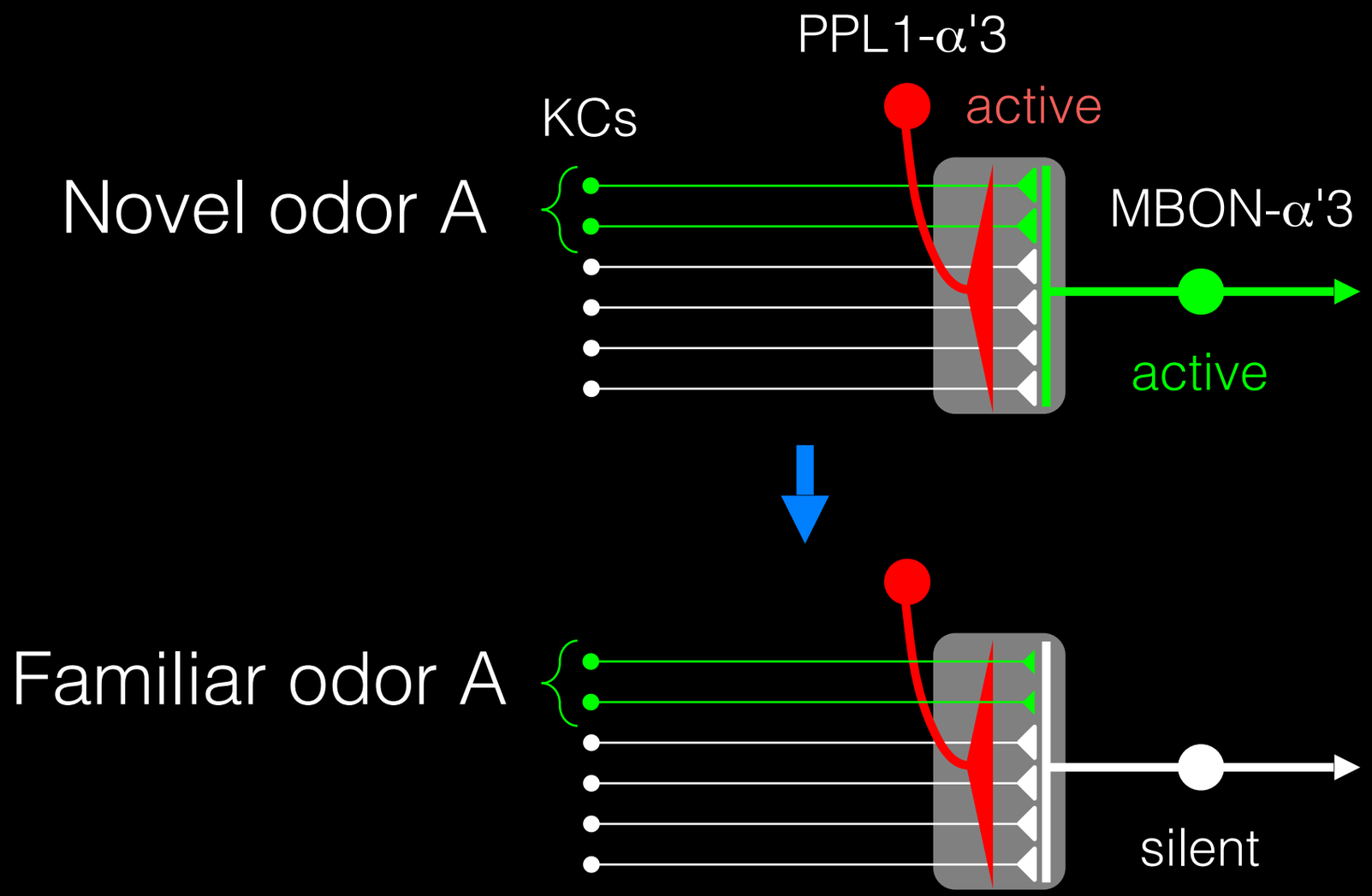
MBON excitation: novelty

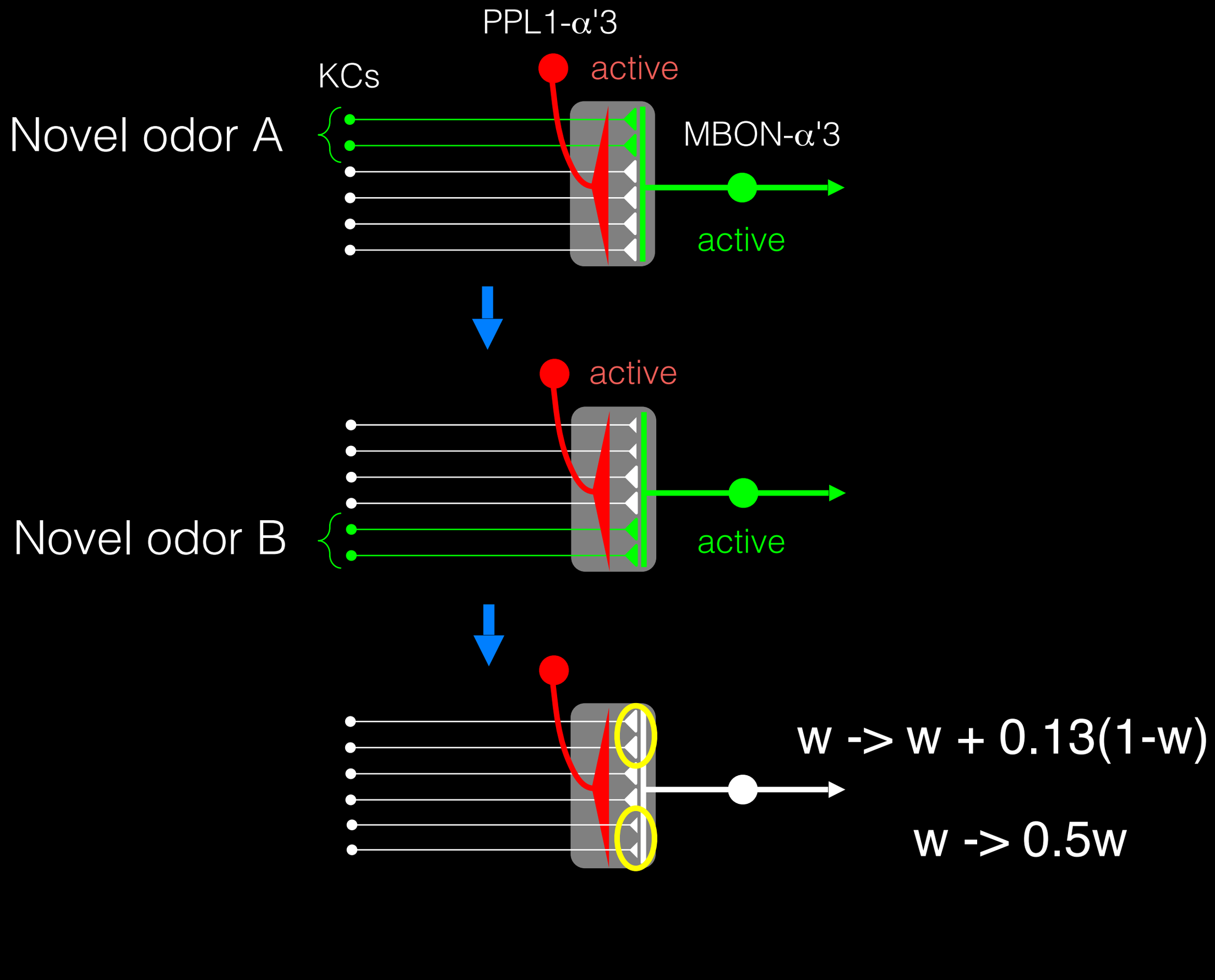
MBON suppression: familiarity



Novel odor A




PPL1-α'3
KCs
active
Novel odor A
MBON-α'3
active
Familiar odor A
silent


PPL1-α'3
KCs
active
Novel odor A
MBON-α'3
active
active
Novel odor B
active
w -> w + 0.13(1-w)
w -> 0.5w

$$\text{MBON input} = \sum_{i=1}^{N} w_i R_i^{\text{KC}}$$

when odor is presented (fraction f of KCs active)

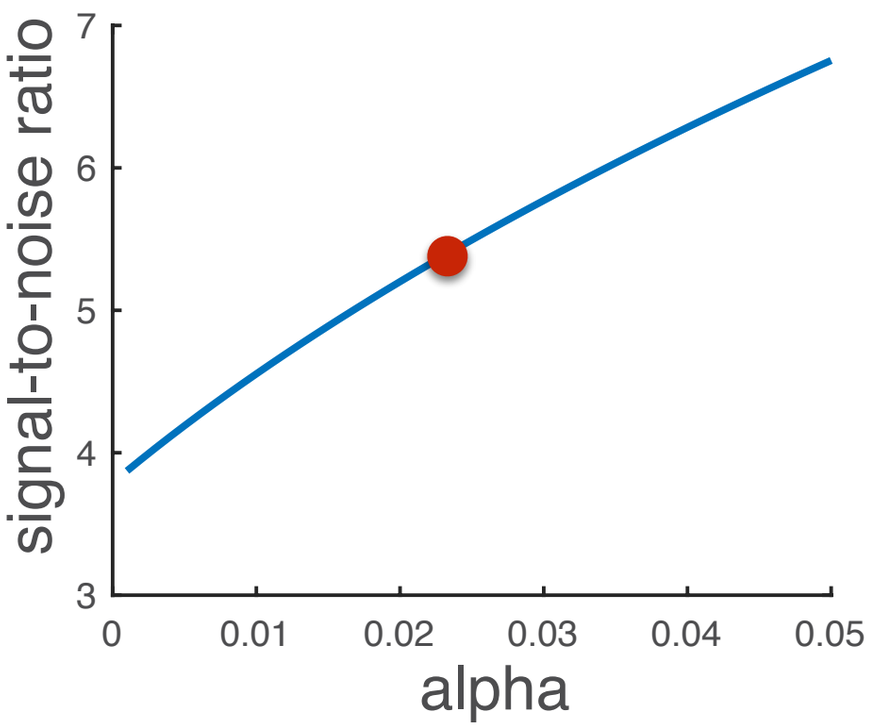
$$\text{if KC}_i \text{ active} \quad w_i \to 0$$

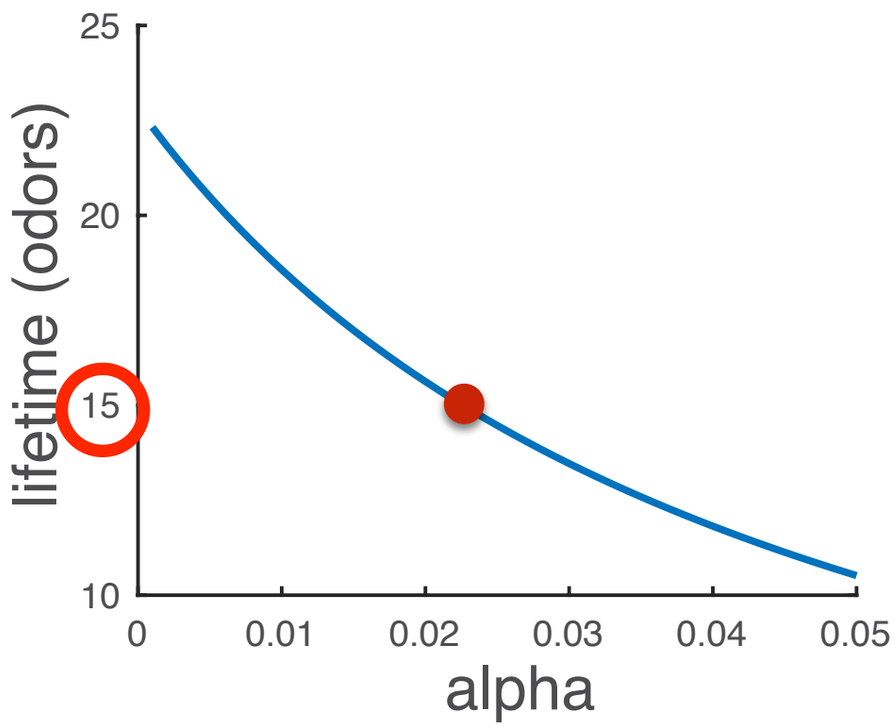
$$\text{if KC}_i \text{ inactive} \quad w_i \to w_i + \alpha(1 - w_i)$$

$$\overline{w} = 1 - \frac{f}{1 - (1 - f)(1 - \alpha)} \qquad \tau = \frac{-1}{\ln\left((1 - f)(1 - \alpha)\right)}$$

$$\sigma_w^2 = 1 - \frac{f}{1 - (1 - f)(1 - \alpha)^2} - \left(\frac{f}{1 - (1 - f)(1 - \alpha)}\right)^2$$

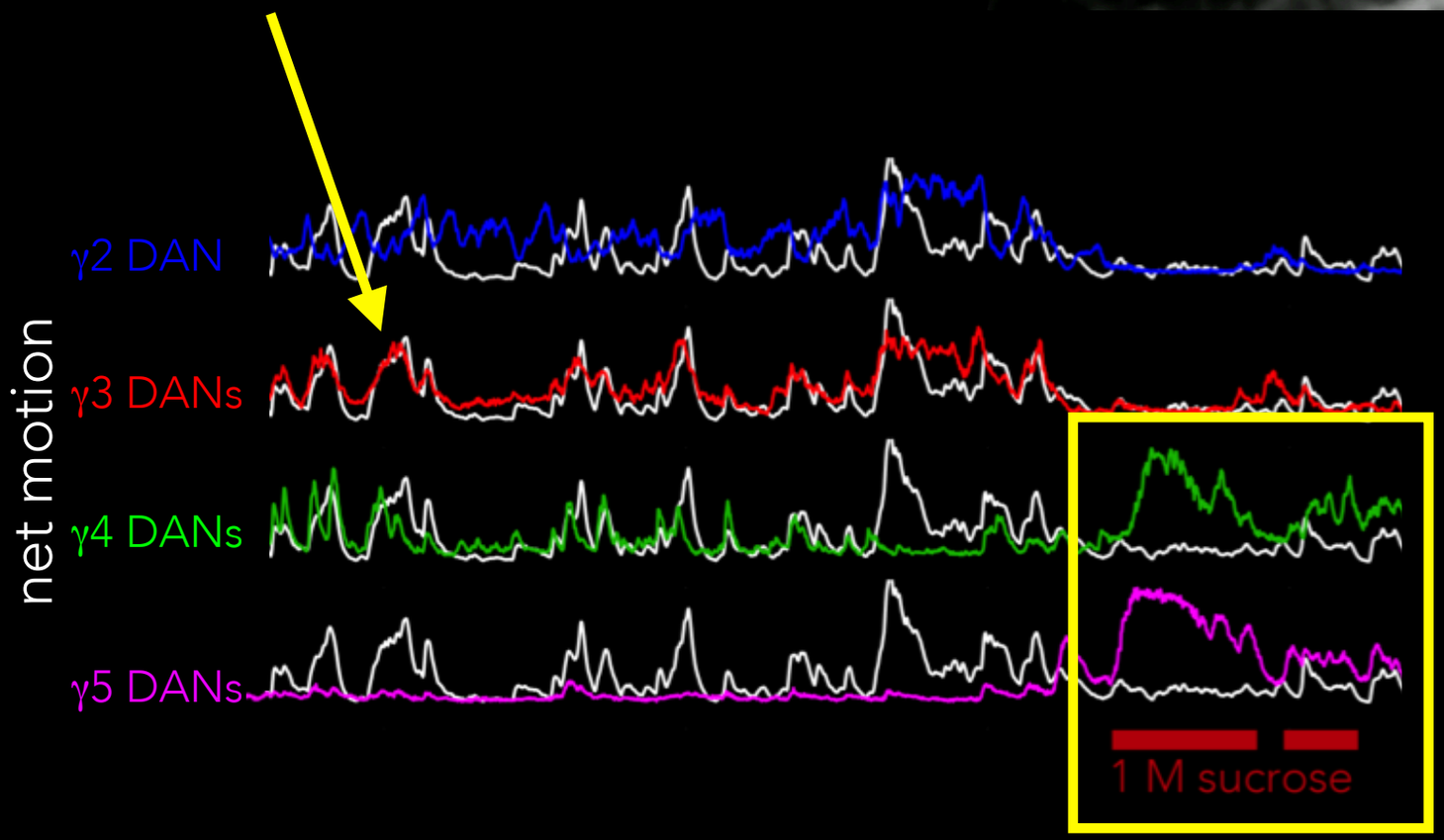
$$\text{SNR} = \frac{\overline{w}}{\sigma_w}$$

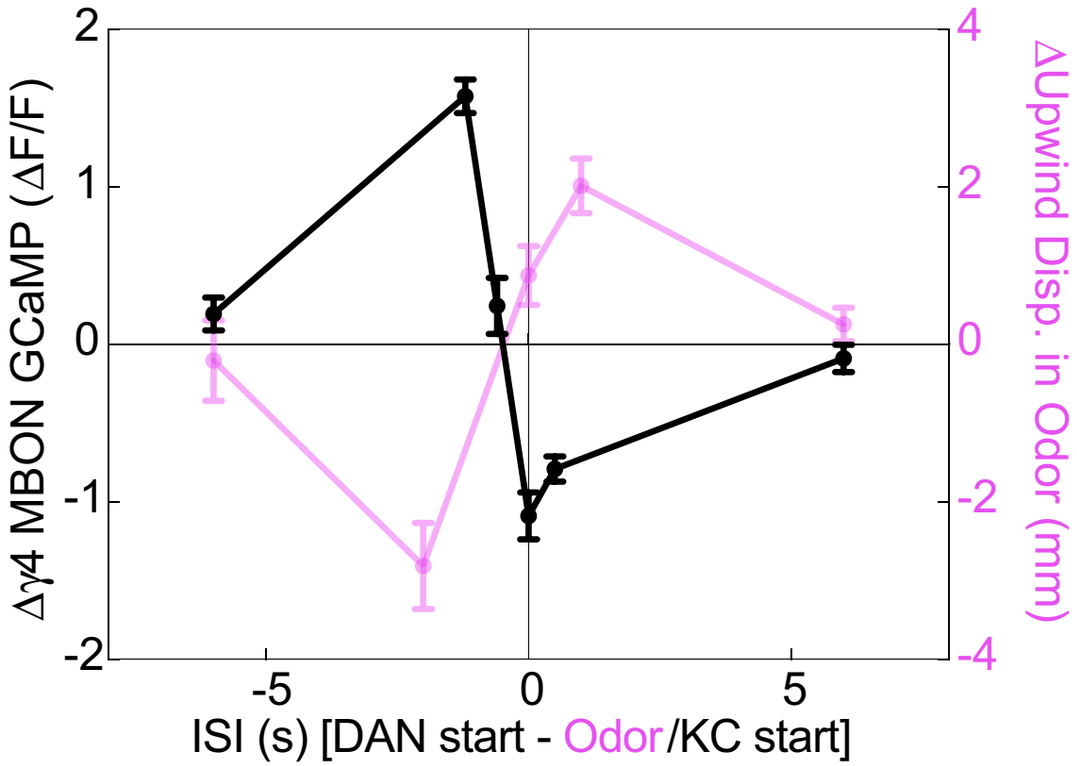

signal-to-noise ratio
7
6
5
4
3
0
0.01
0.02
0.03
0.04
0.05
alpha


lifetime (odors)
25
20
15
10
0
0.01
0.02
0.03
0.04
0.05
alpha

Mushroom Body Dopaminergic Neurons Correlate with Both Reward and Locomotion

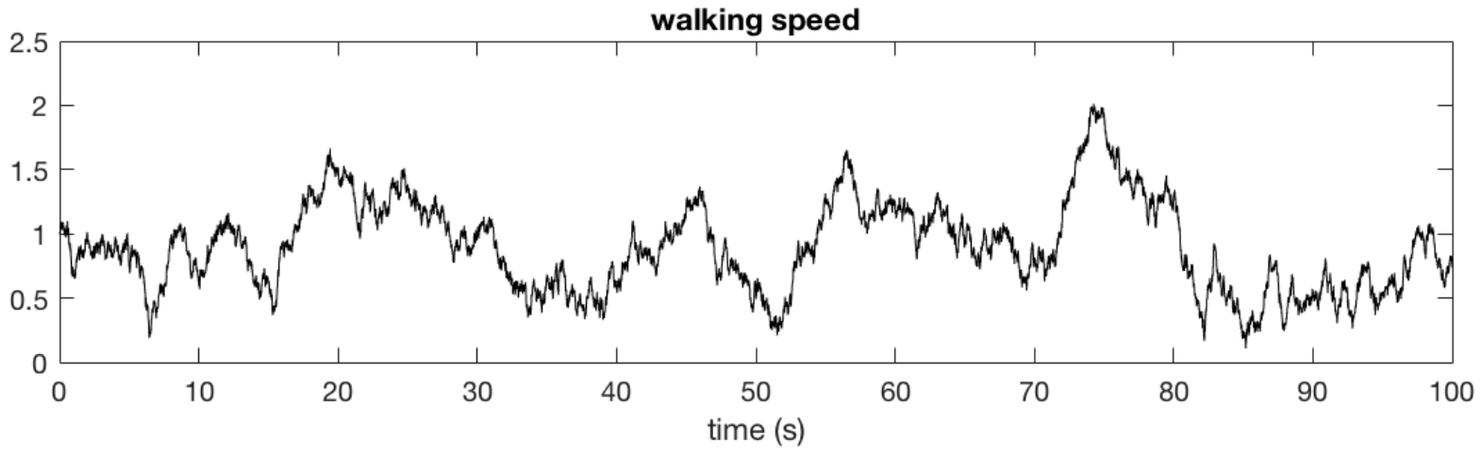
Raphael Cohn, Andrew Siliciano, Vanessa Ruta

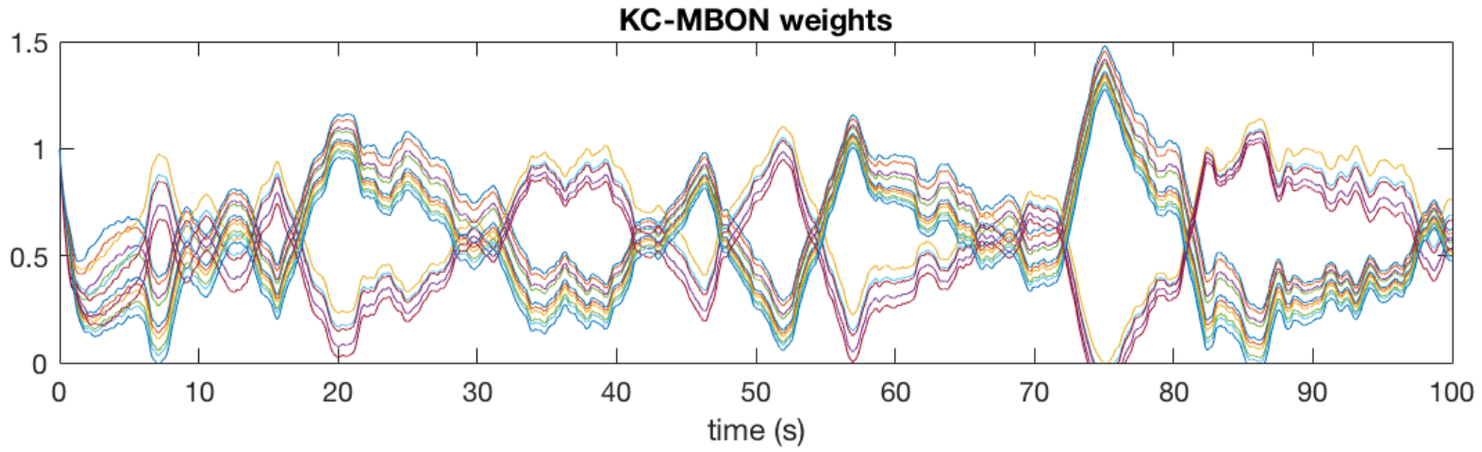


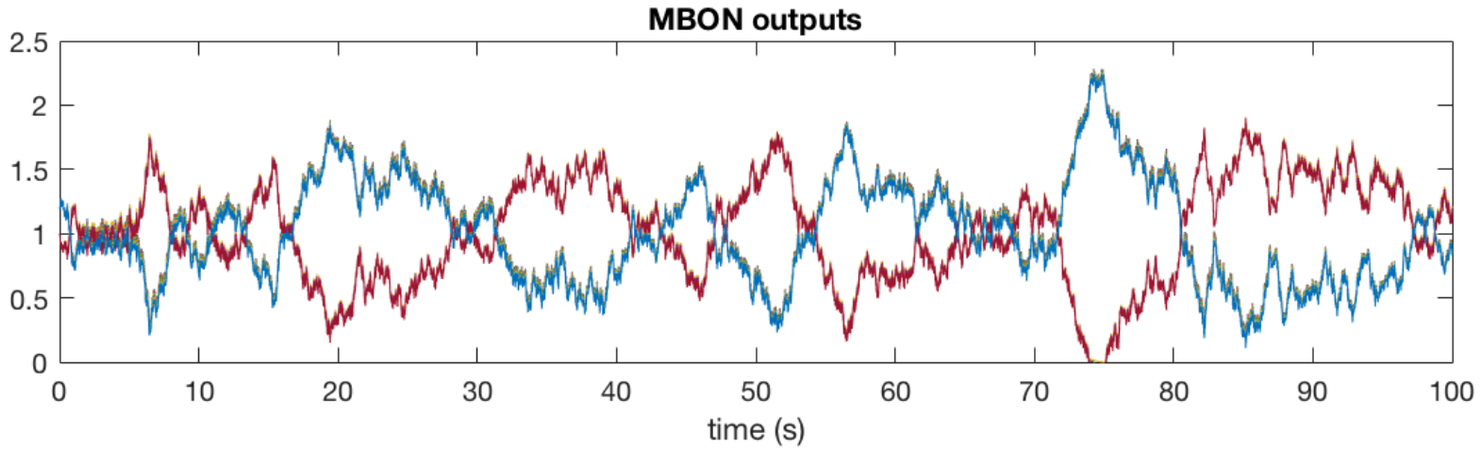


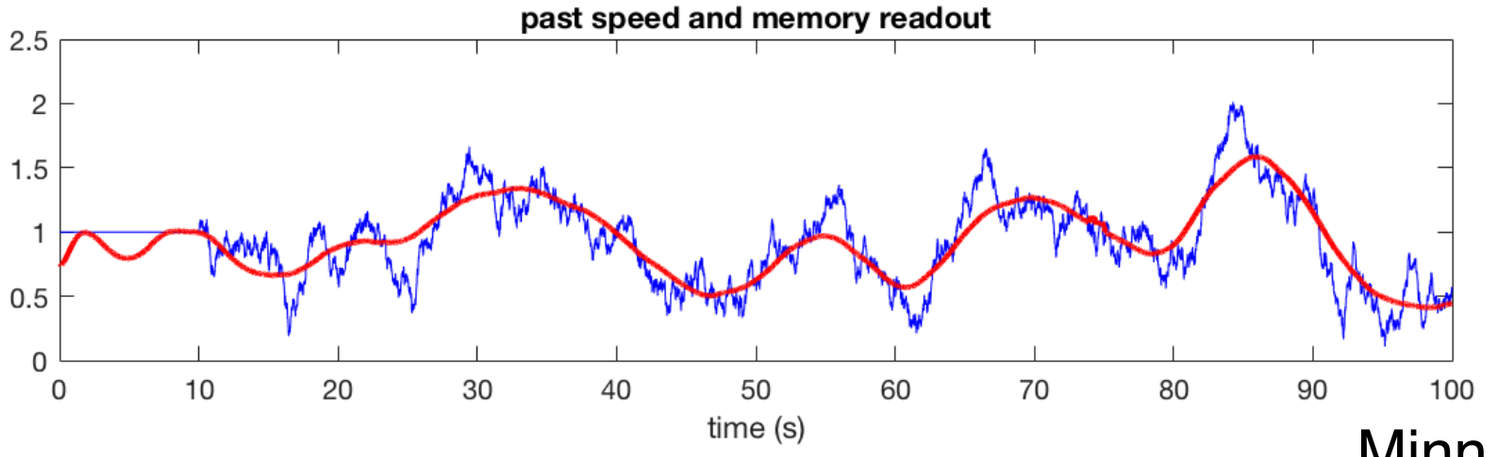
Annie Handler, Thomas G.W. Graham, Raphael Cohn, Ianessa Morantte,

Andrew F. Siliciano, Jianzhi Zeng, Yulong Li, and Vanessa Ruta



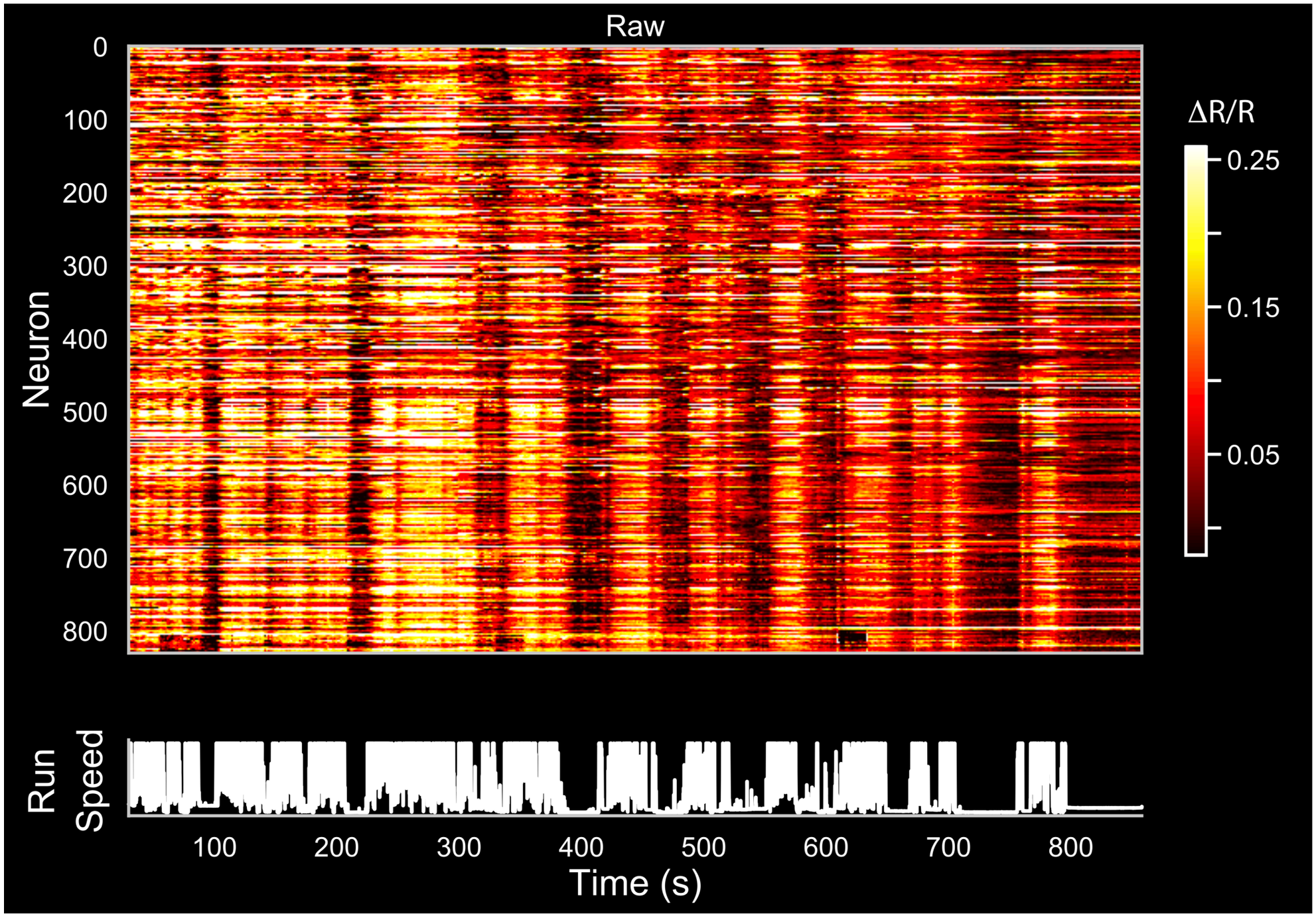






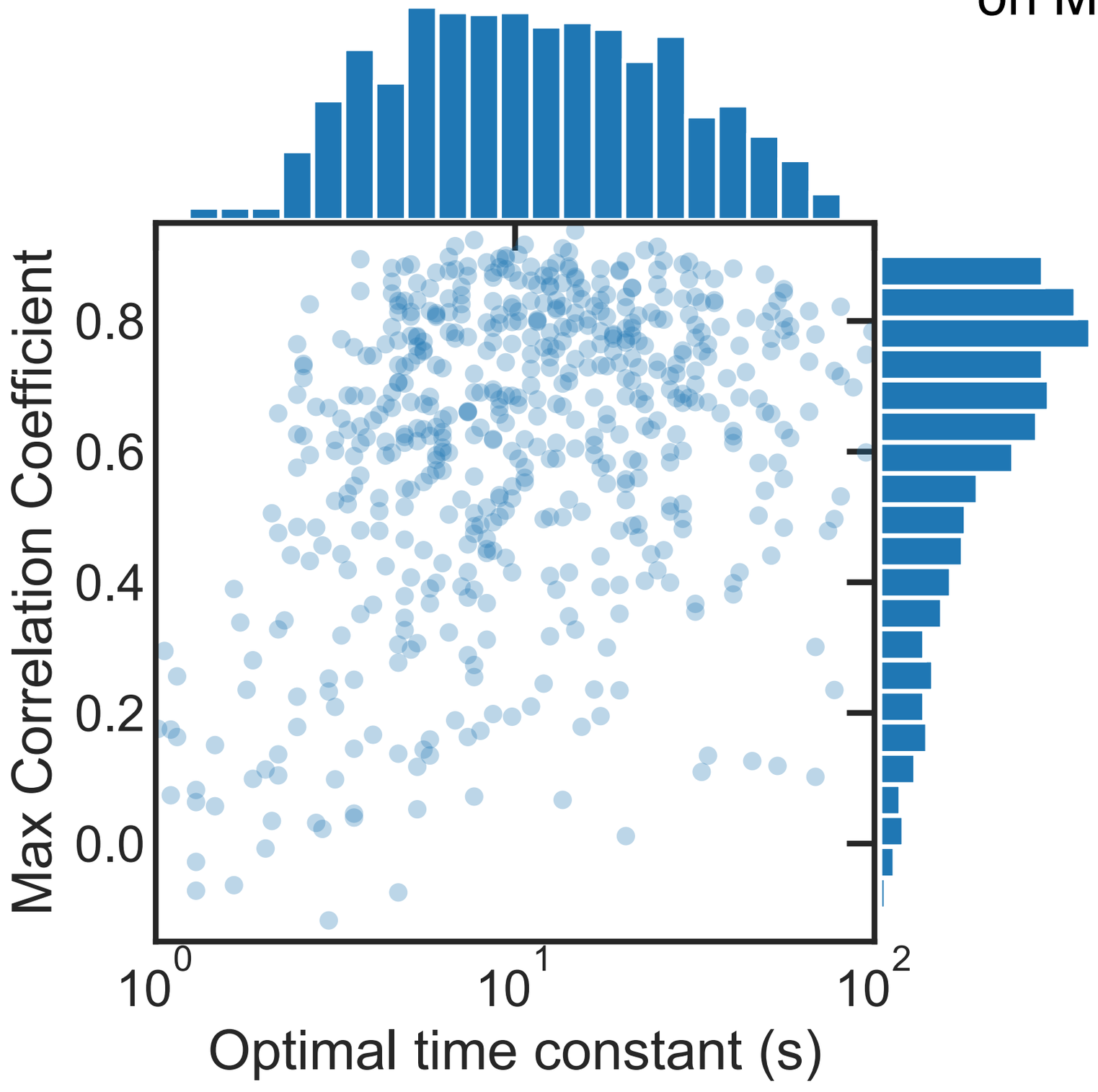
Minni Sun, Larry Abbott

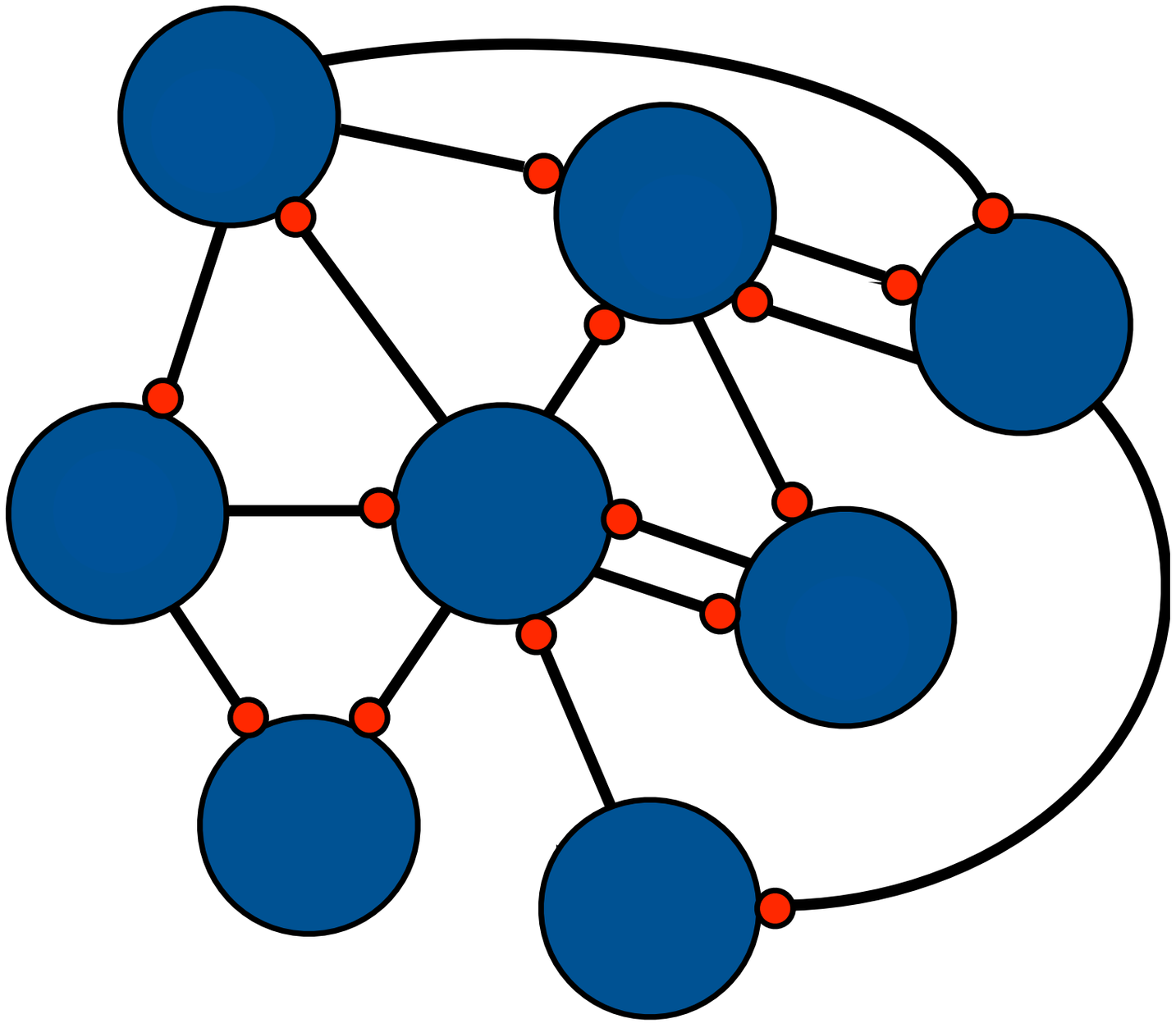
Global neural activity strongly correlates with running speed

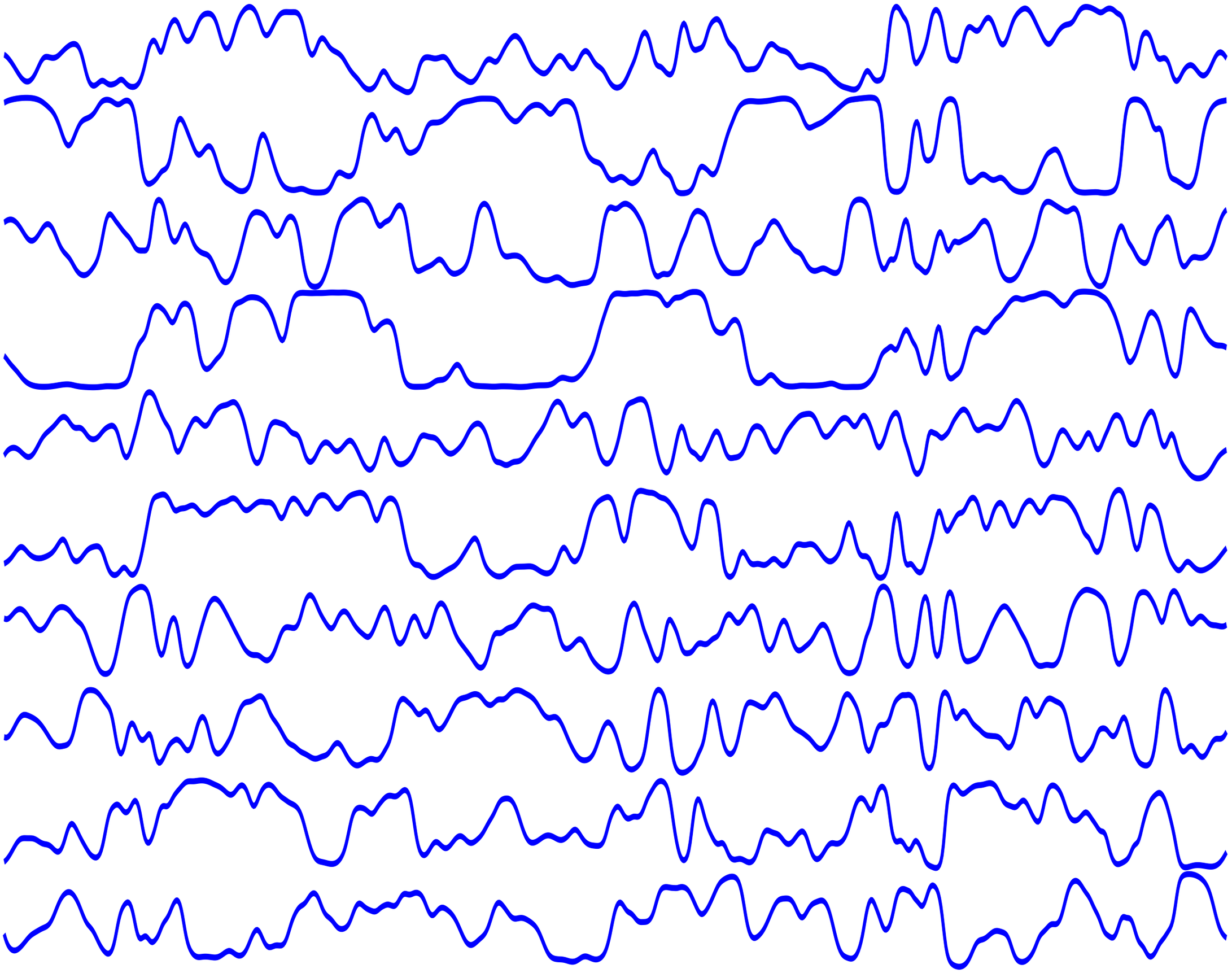


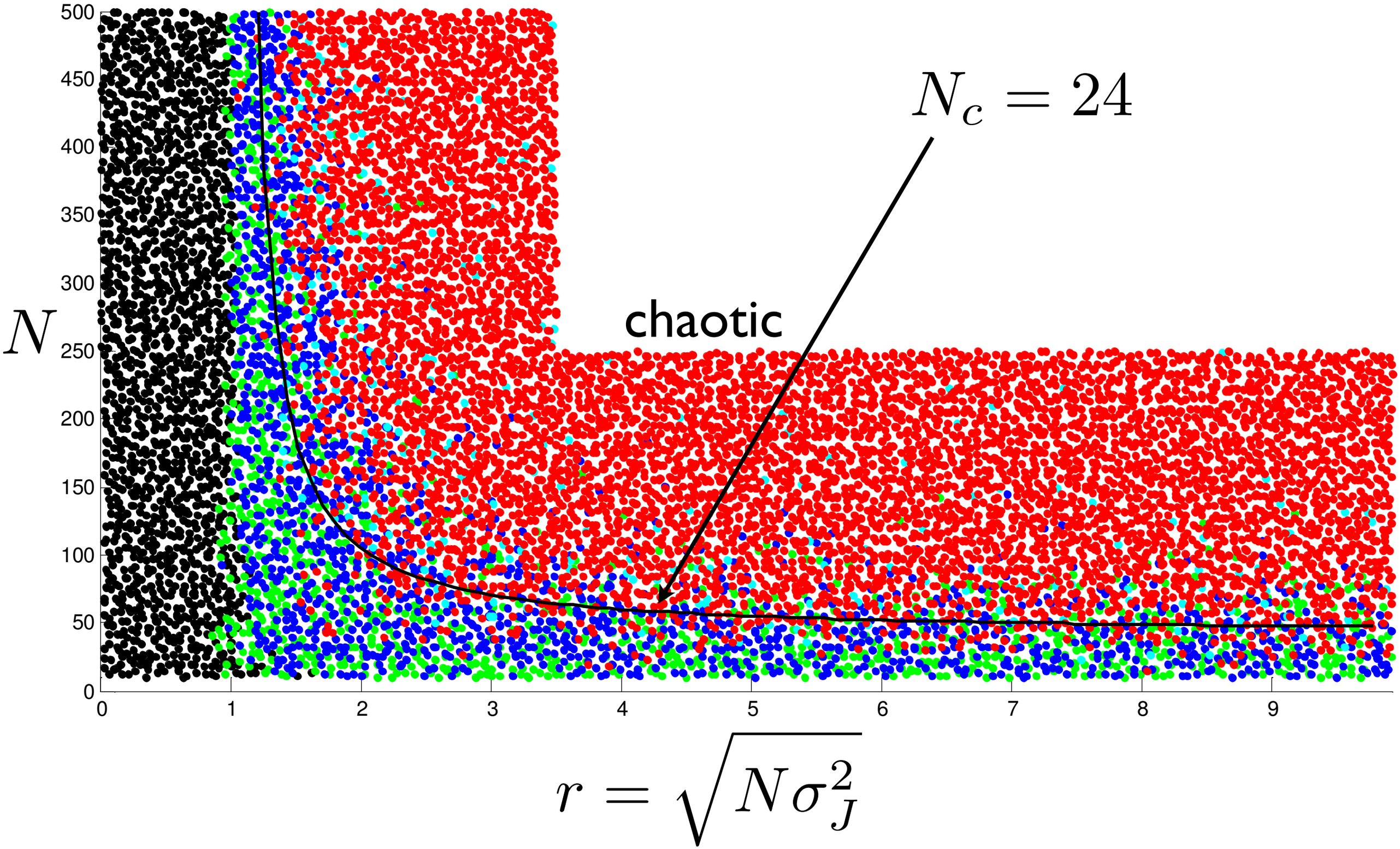
Evan Schaffer, Neeli Mishra - Hillman and Axel Labs

Neuron Correlate with Running on Multiple Timescales



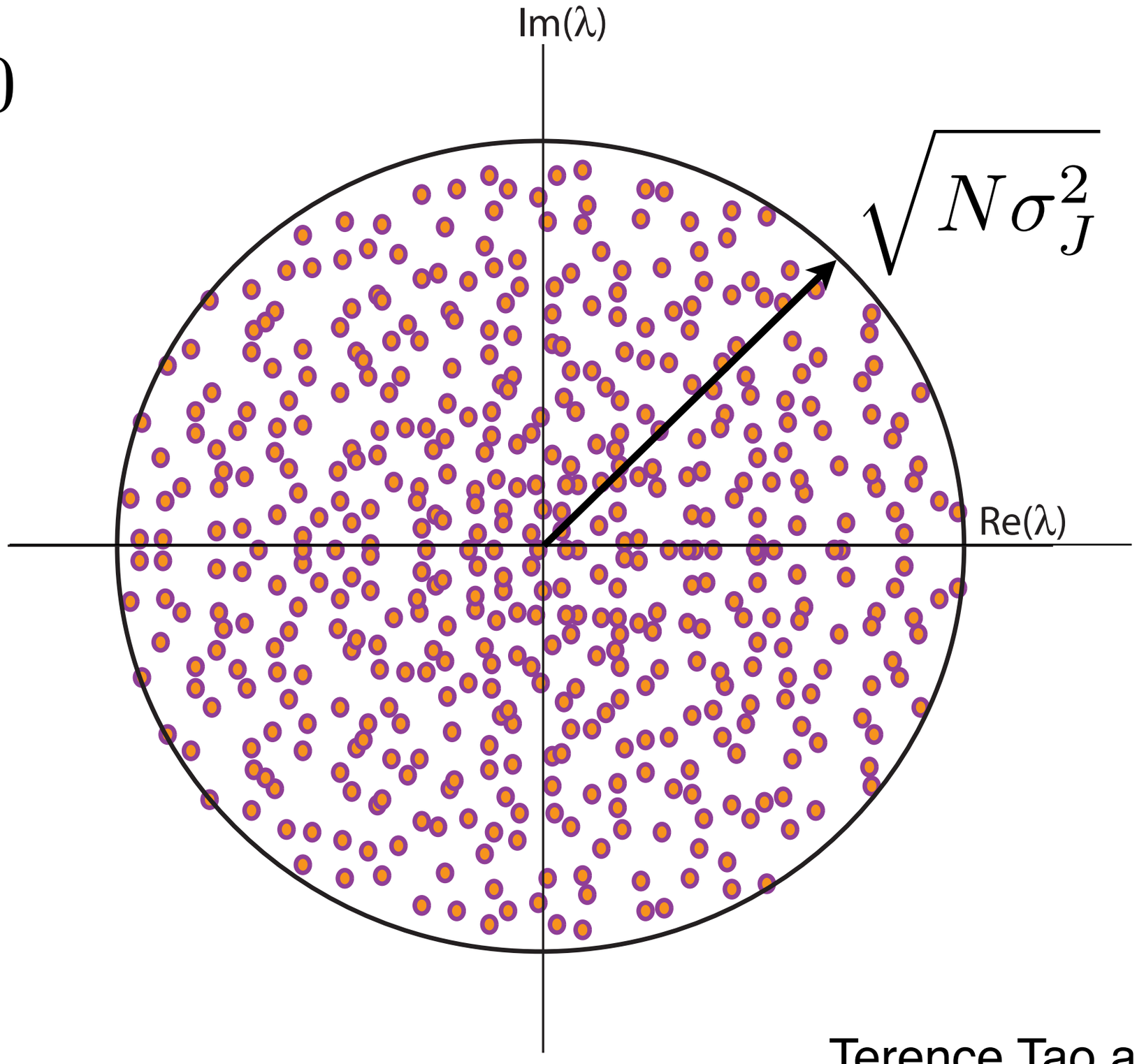






$$r = \sqrt{N\sigma_J^2}$$

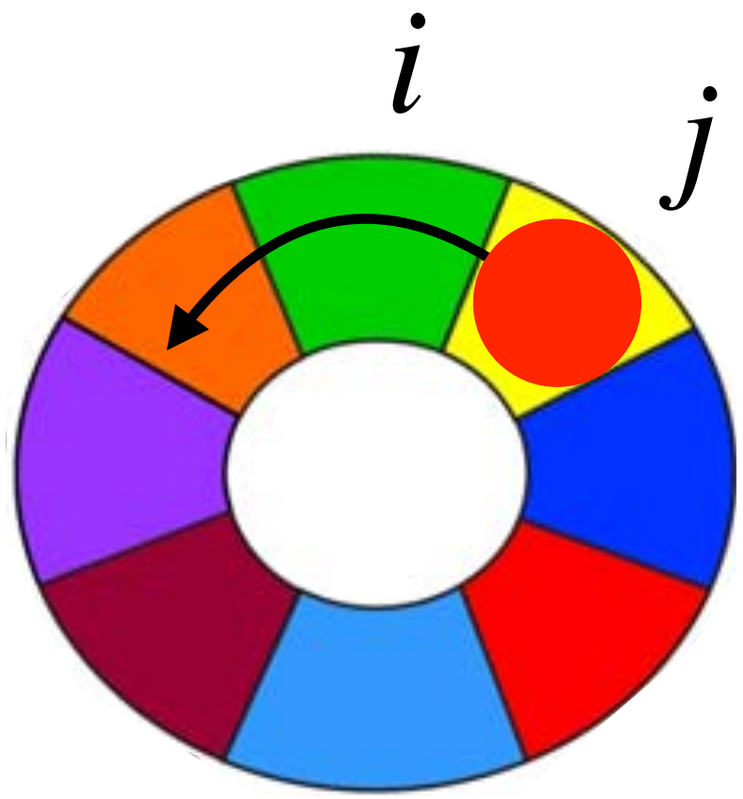
$$\mu_J = 0$$



Terence Tao and Van Vu

Kanaka Rajan, Merav Stern - Abbott; Miller

Ring Model



$$J_{ij} = \cos(\theta_i - \theta_j) - C$$

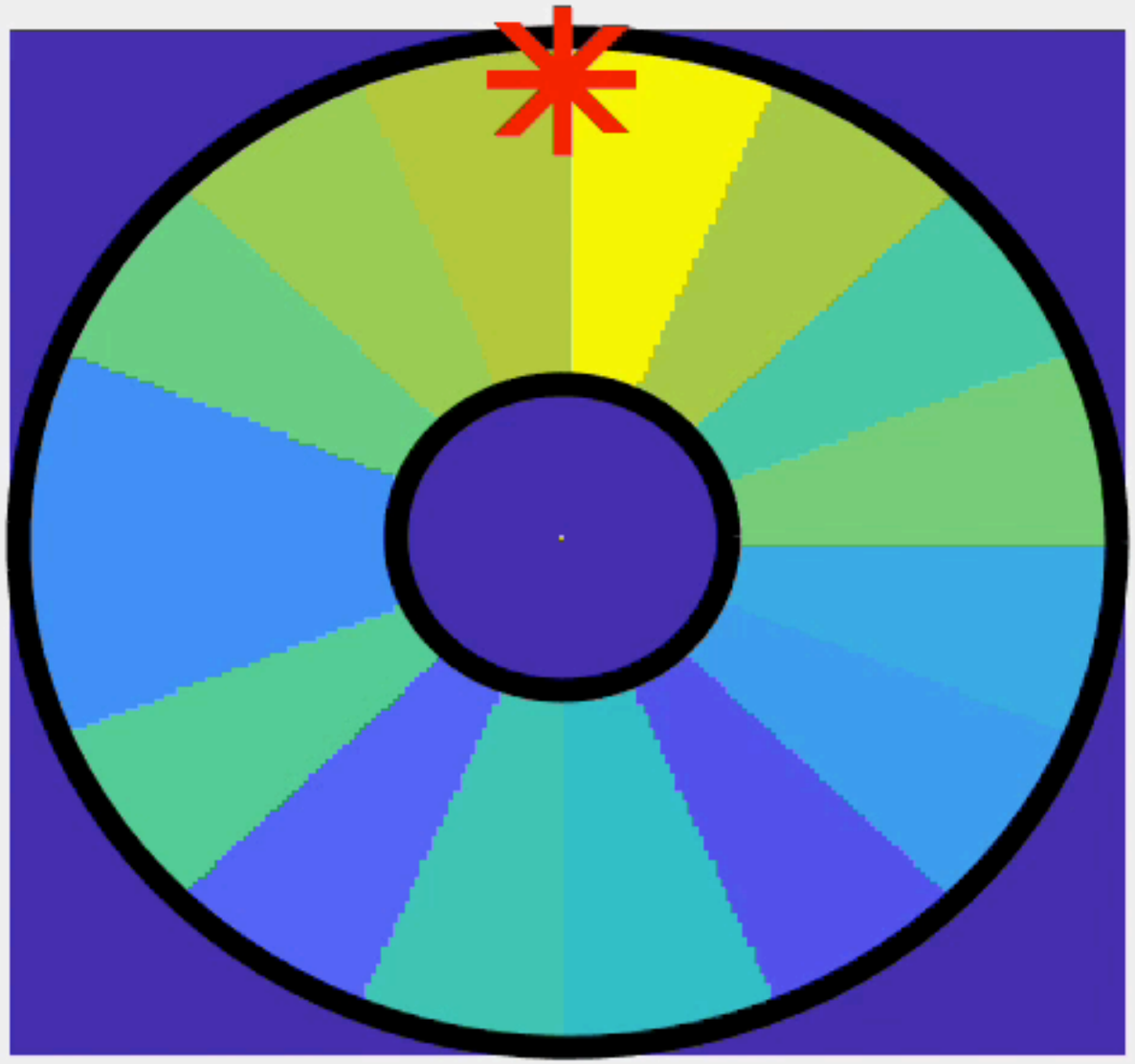
$$\Delta J_{ij} = v\cos(\theta_i - \theta_j \pm \Delta)$$

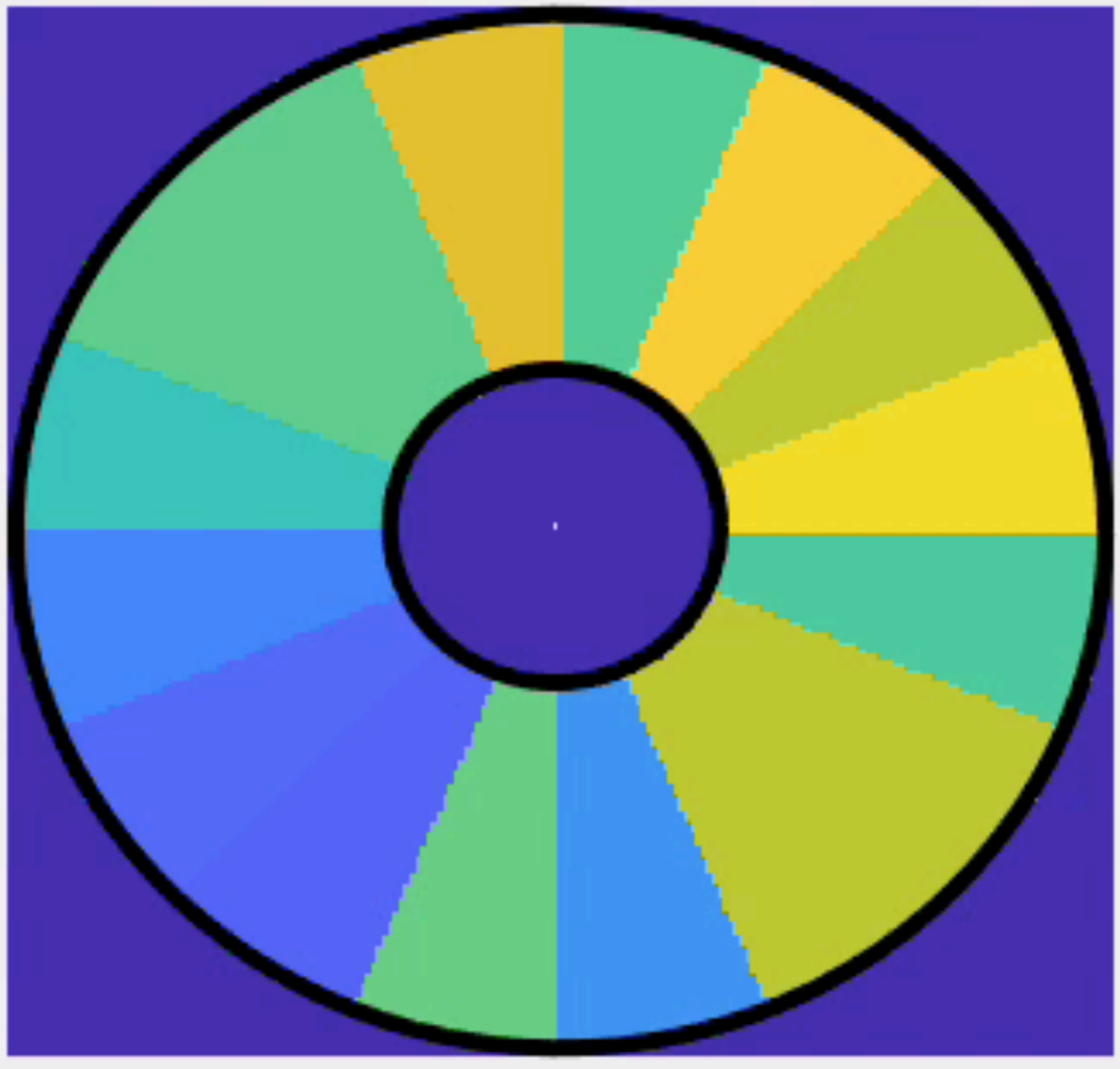
$$I_i = \cos(V - \theta_i)$$

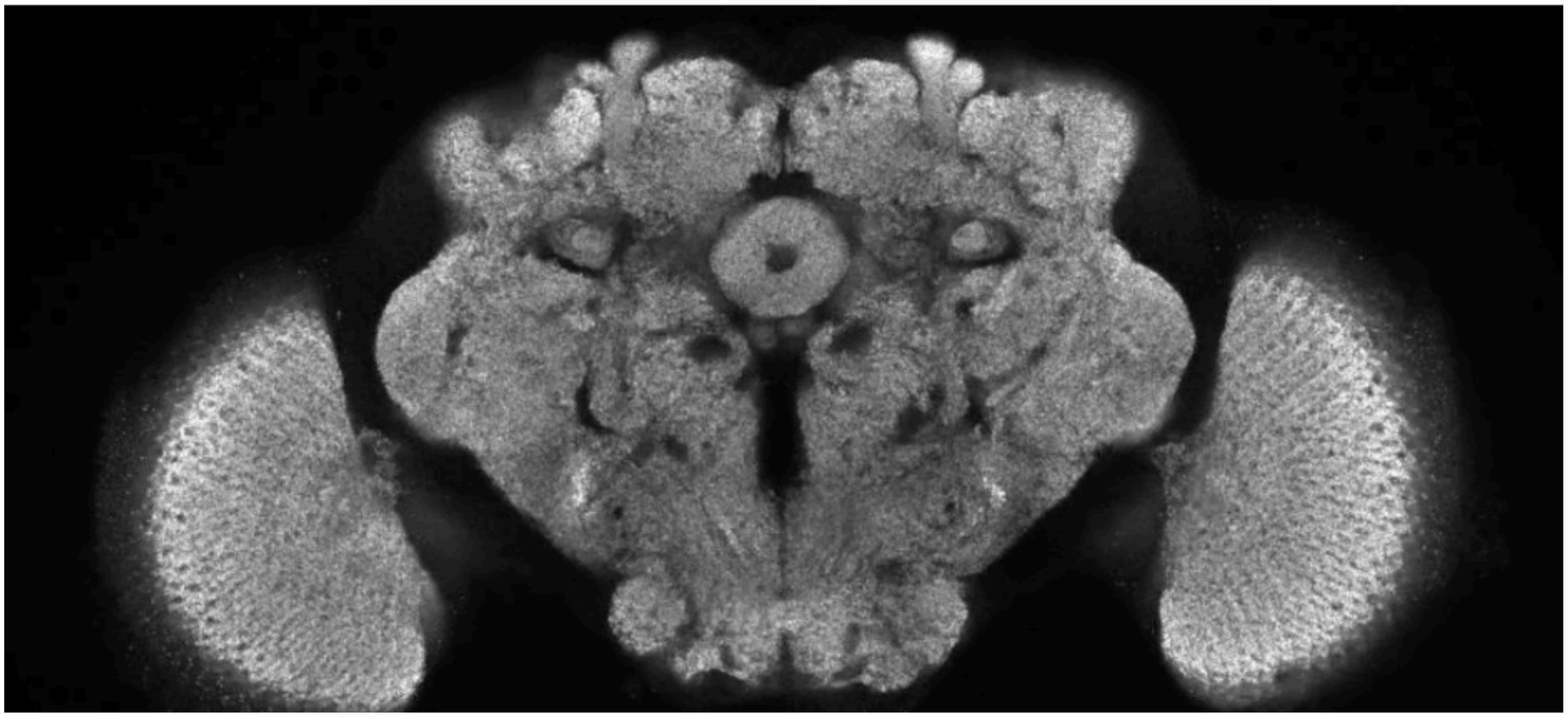
Ben-Yishai, Bar-Or, Sompolinsky (1995)

Skaggs, Knierim, Kudrimoti, McNaughton (1995)

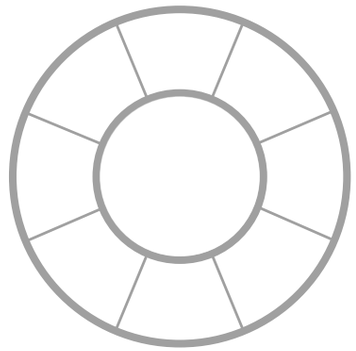
Zhang (1996)



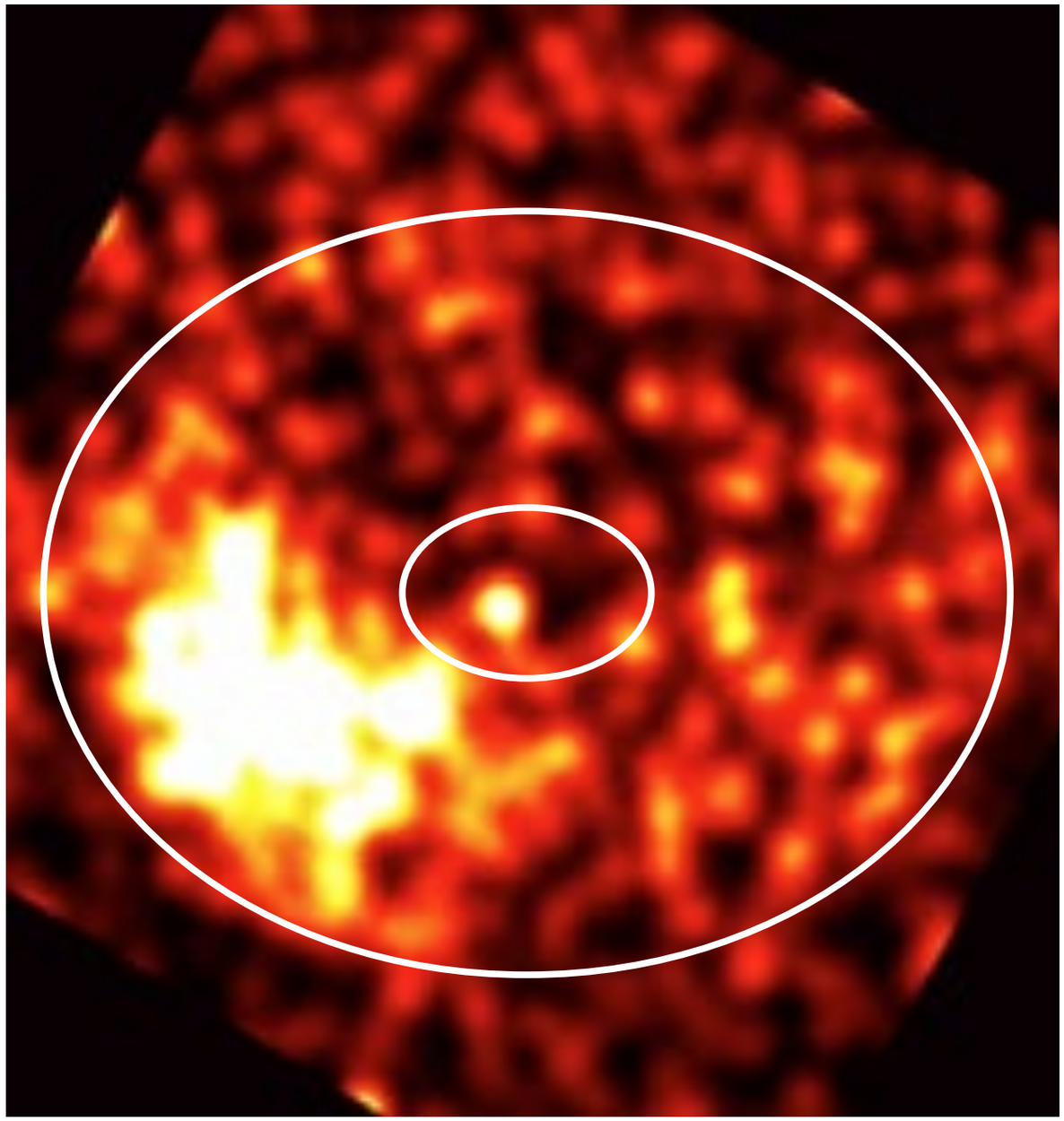




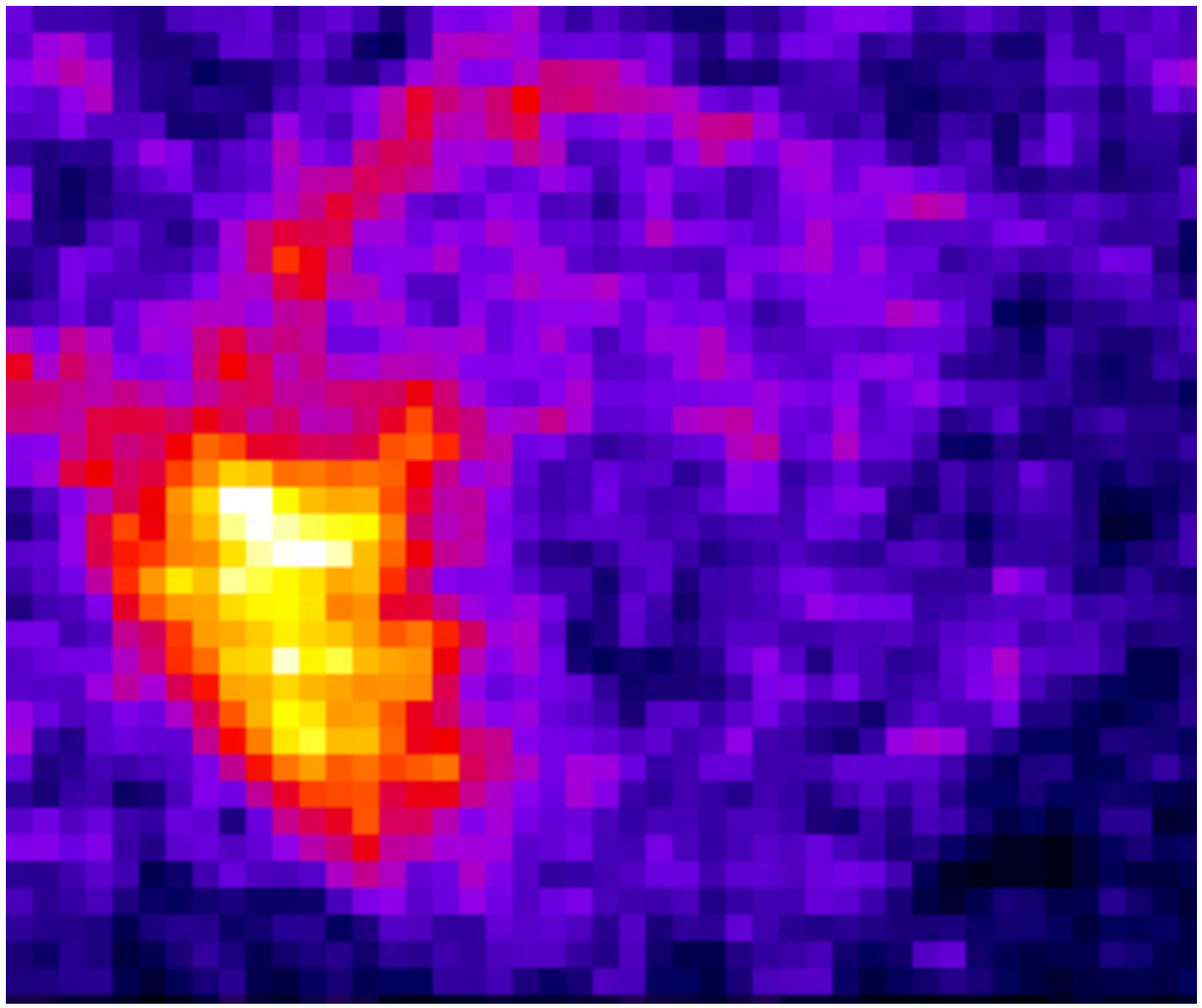
ellipsoid body



http://flybrain.mrc-lmb.cam.ac.uk/si/bridging/www/brains/

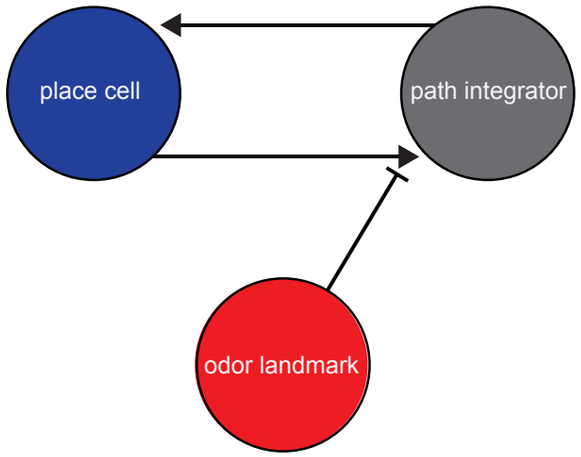


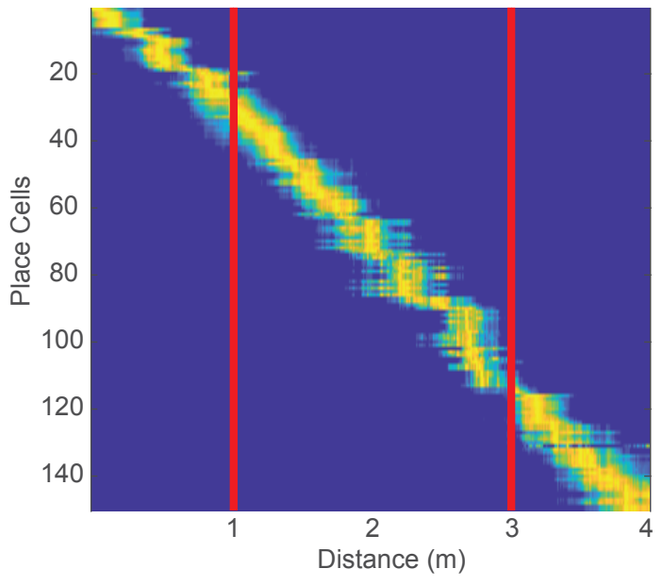
Seelig, Jayaraman (2015)

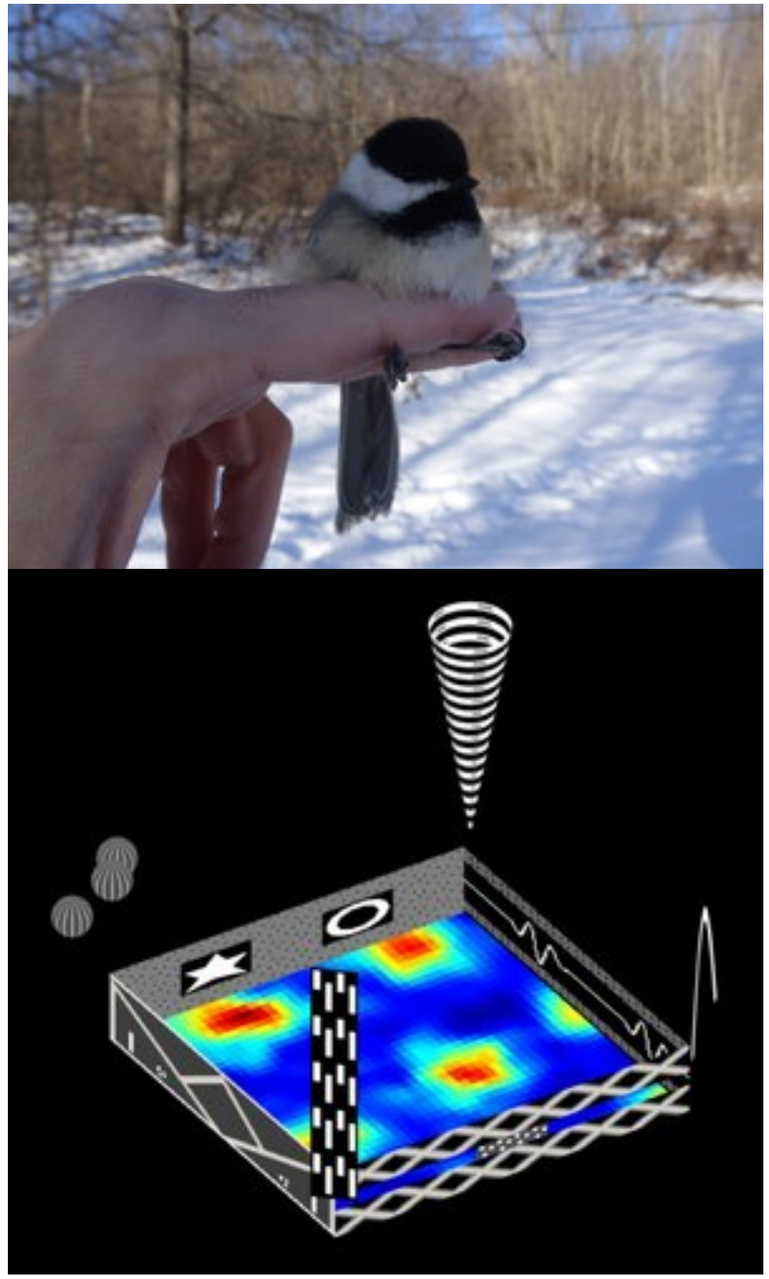


Green, Adachi, Shah, Hirokawa,
Magani, Maimon (2017)

Hippocampus of Mouse and Bird







Walter Fishler, David Clark, - Axel Lab

Emily Mackevicius, Ching Fang - Ahranov Lab

Two-target pedaling task

Abbey Russo, Sean Bittner, Ramin Khajeh,
John Cunningham, Larry Abbott, Mark Churchland

M1/PMd

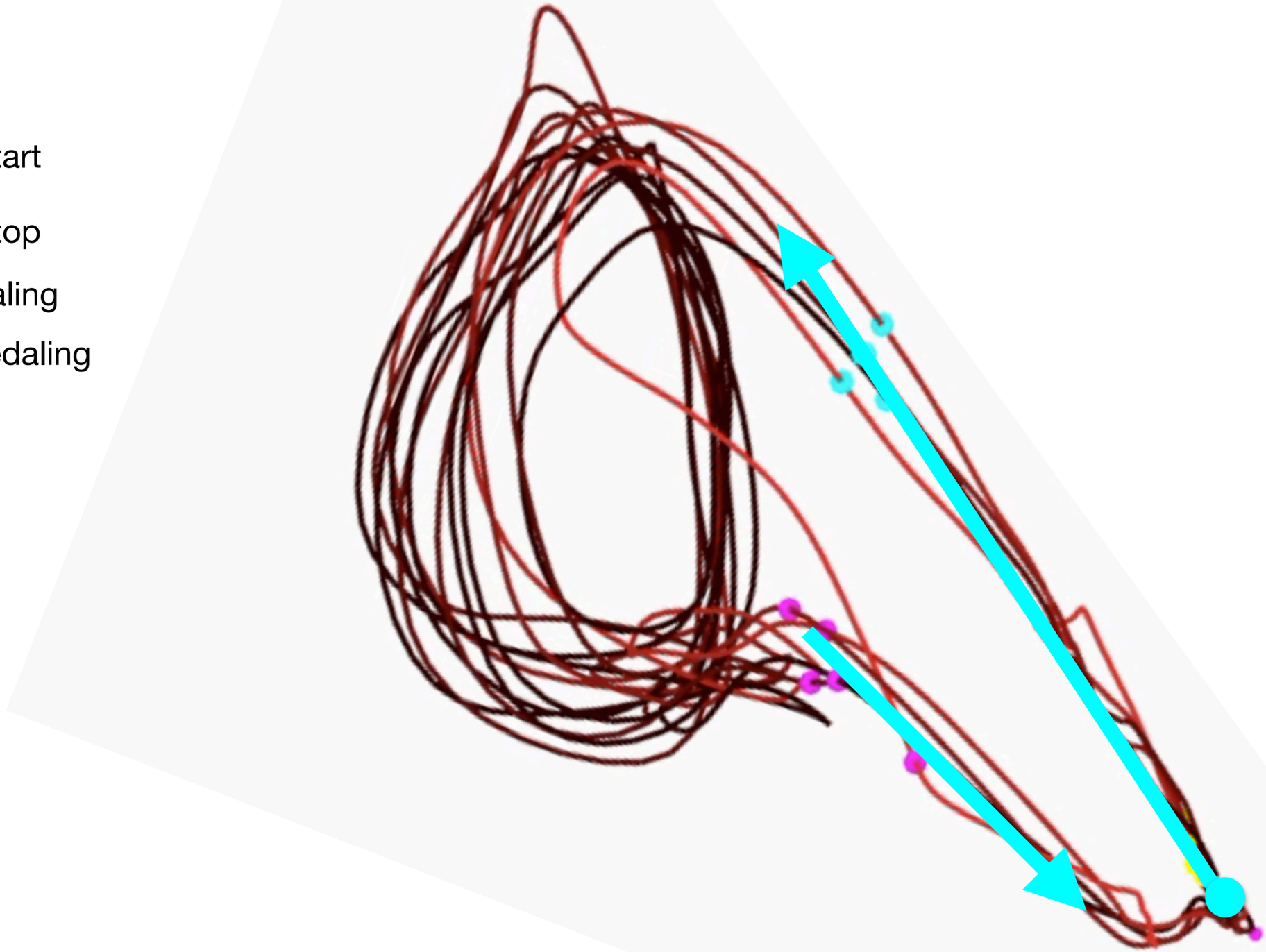
target on

movement start

movement stop

forward pedaling

backward pedaling



M1/PMd:

target on

movement start

movement stop

forward pedaling

backward pedaling

SMA

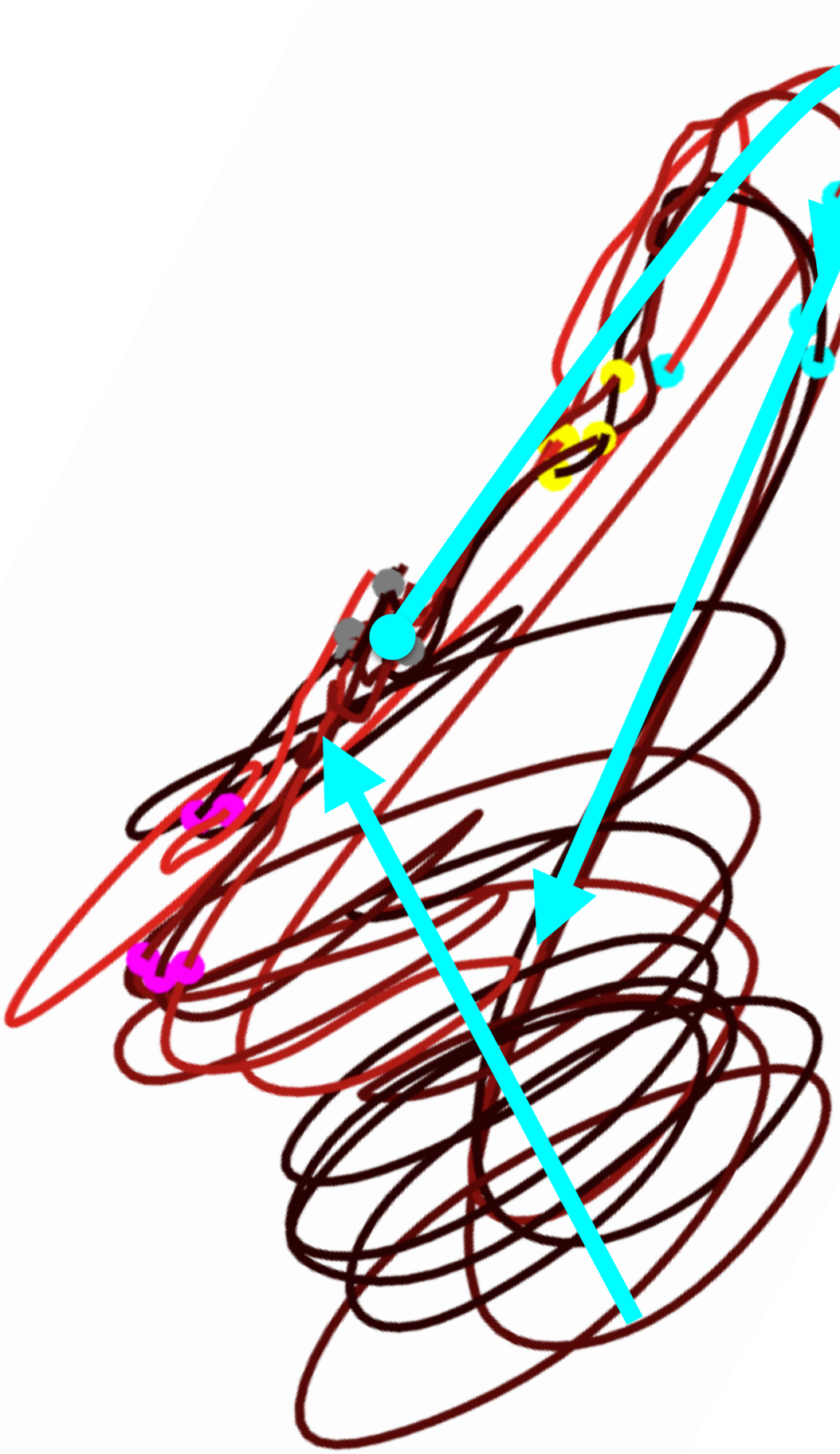
target on

movement start

movement stop

forward pedaling

backward pedaling



SMA

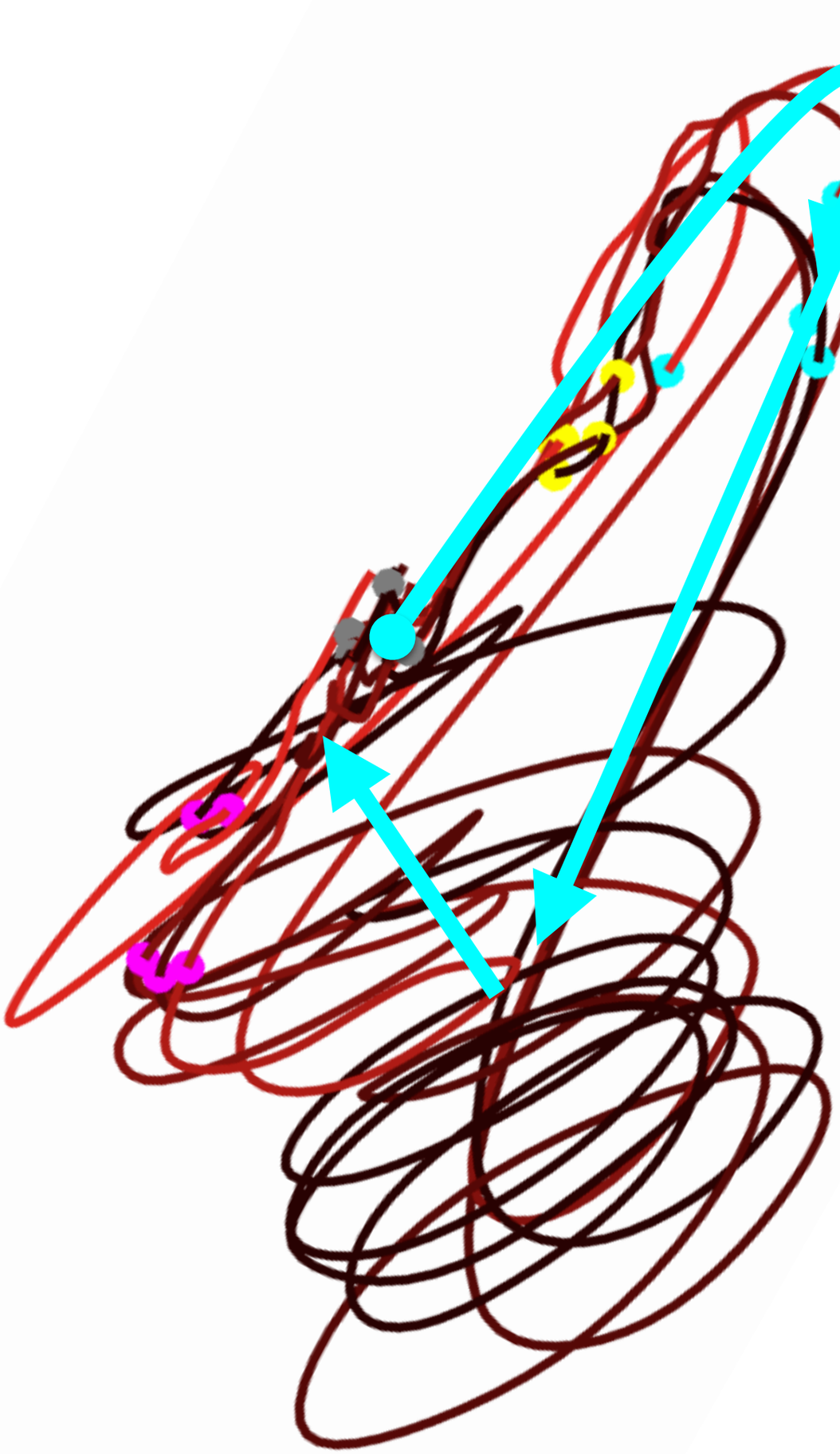
target on

movement start

movement stop

forward pedaling

backward pedaling



SMA: Cousteau, smoothed

target on

movement start

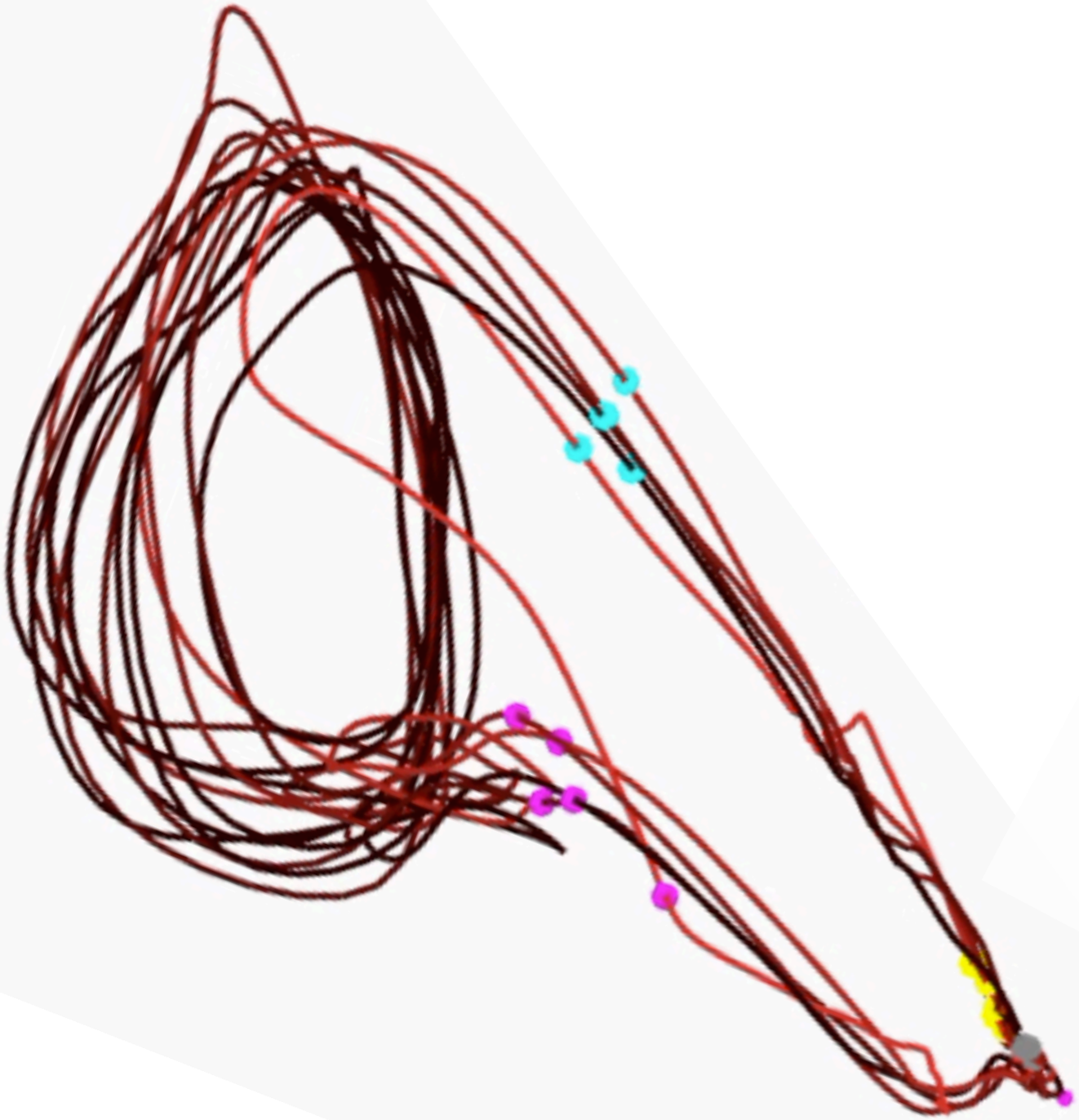
movement stop

forward pedaling

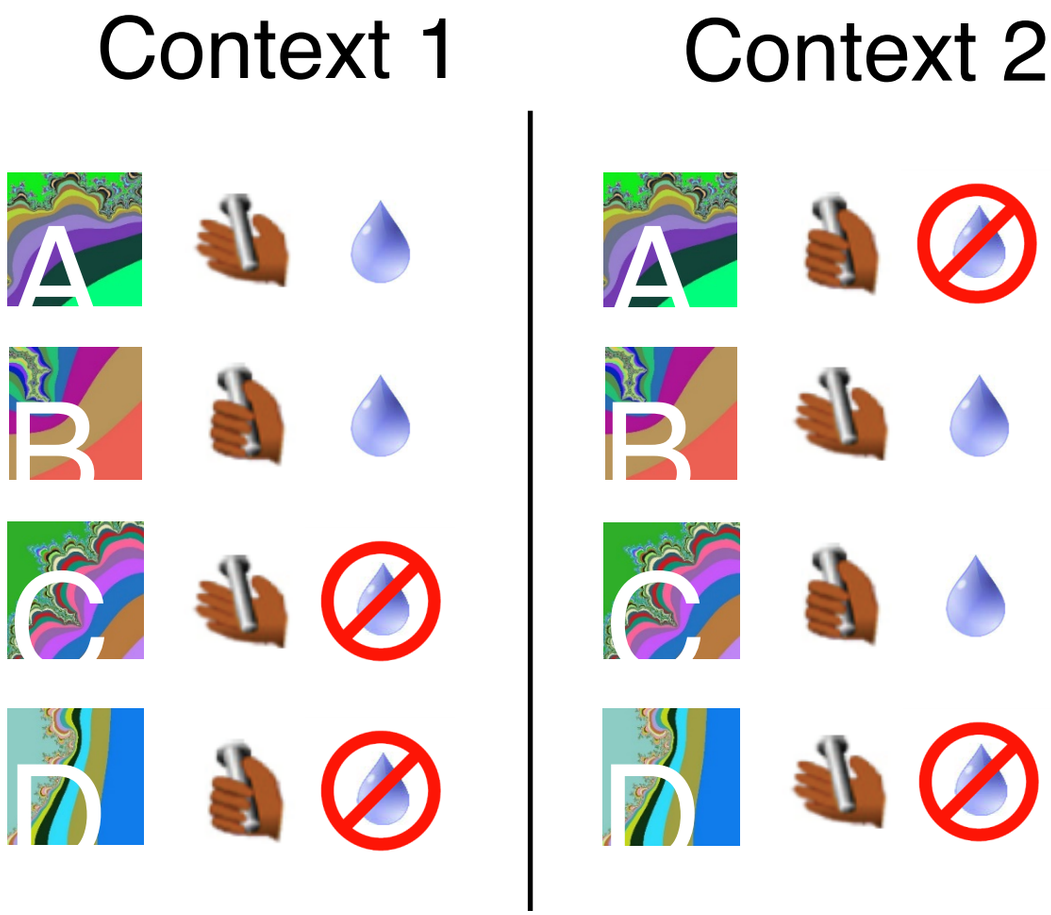
backward pedaling

M1/PMd

SMA

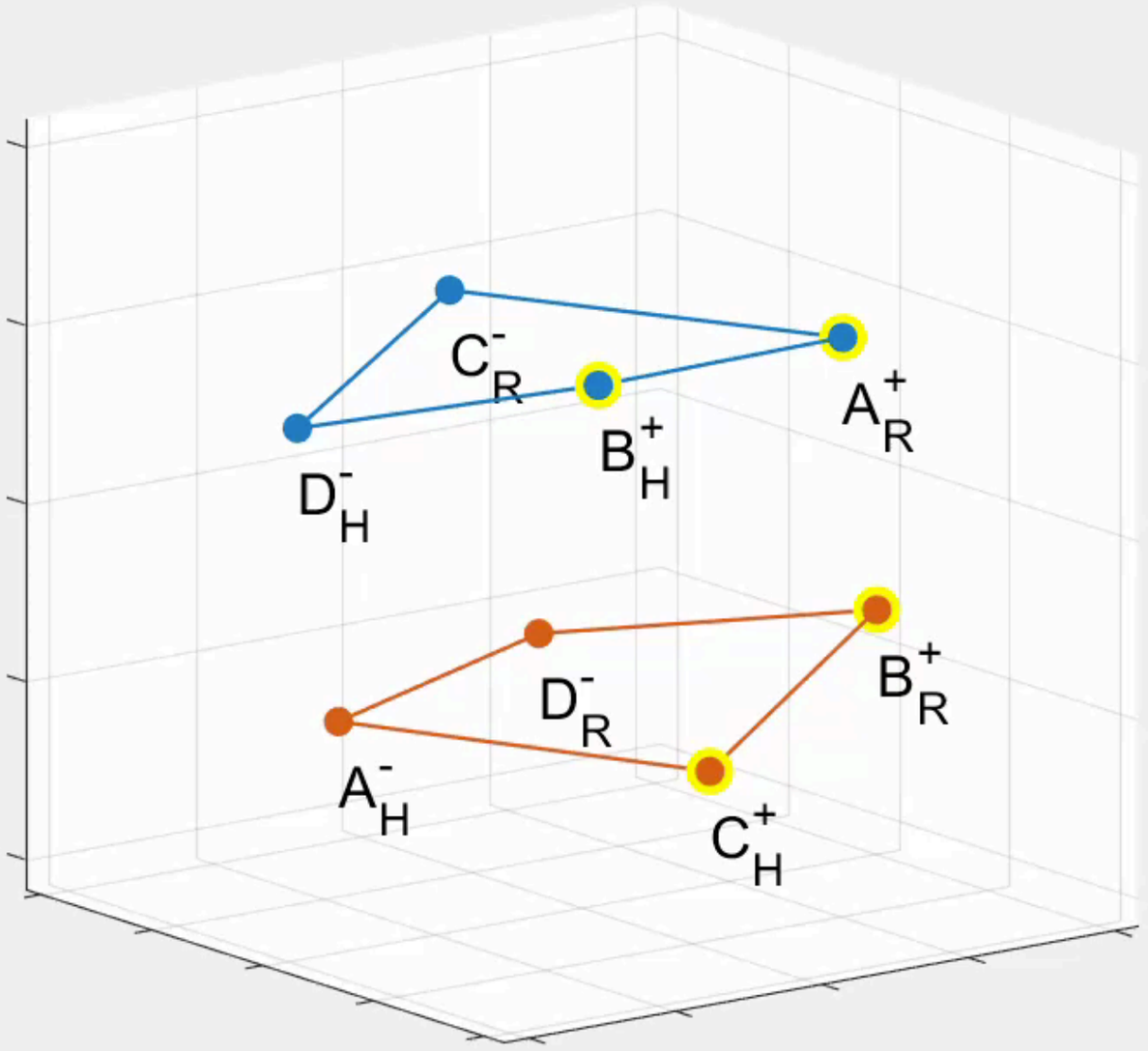


Elom Amematsro, Najja Marshall, Mark Churchland



Silvia Bernardi, Marcus Benna,
Mattia Rigotti, Jerome Munuera,
Stefano Fusi, Daniel Salzman

ACC



t

1
0.8
0.6
0.4
0.2
0

HPC
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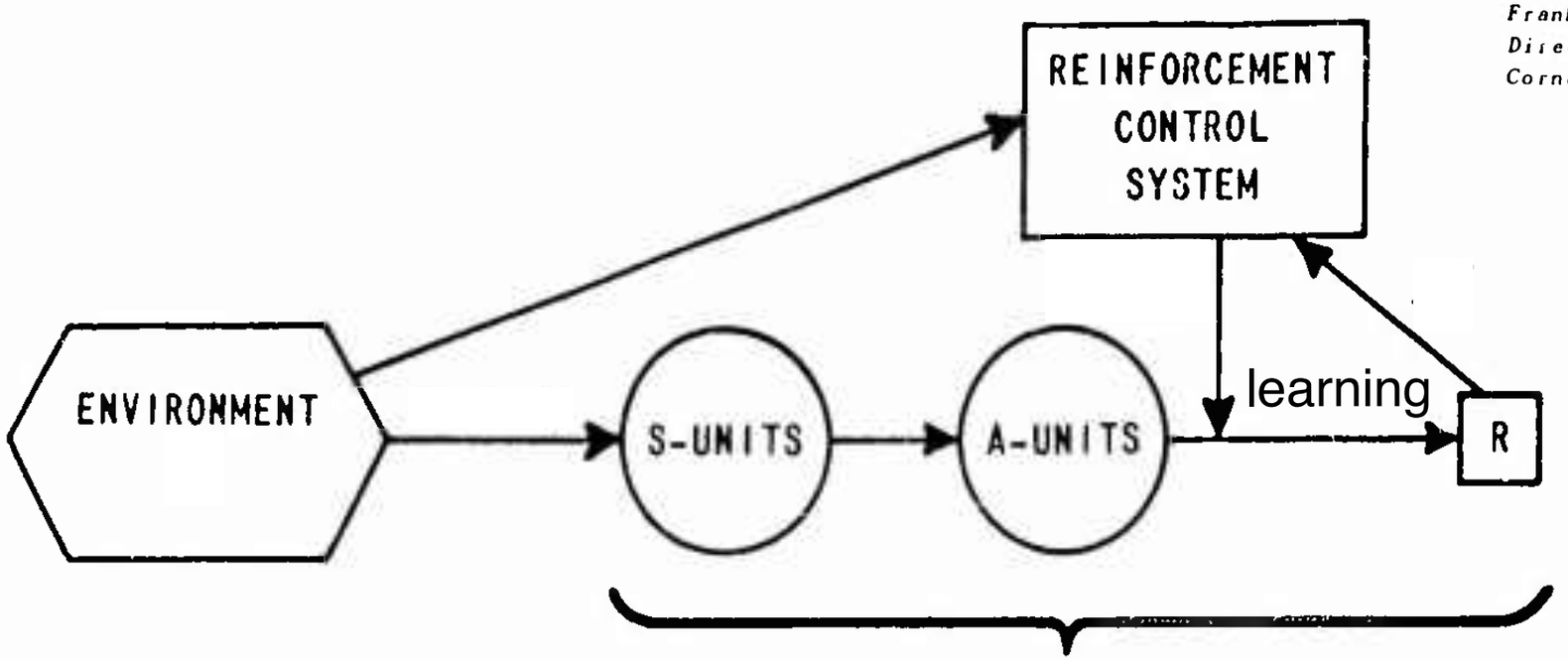
PRINCIPLES OF NEURODYNAMICS

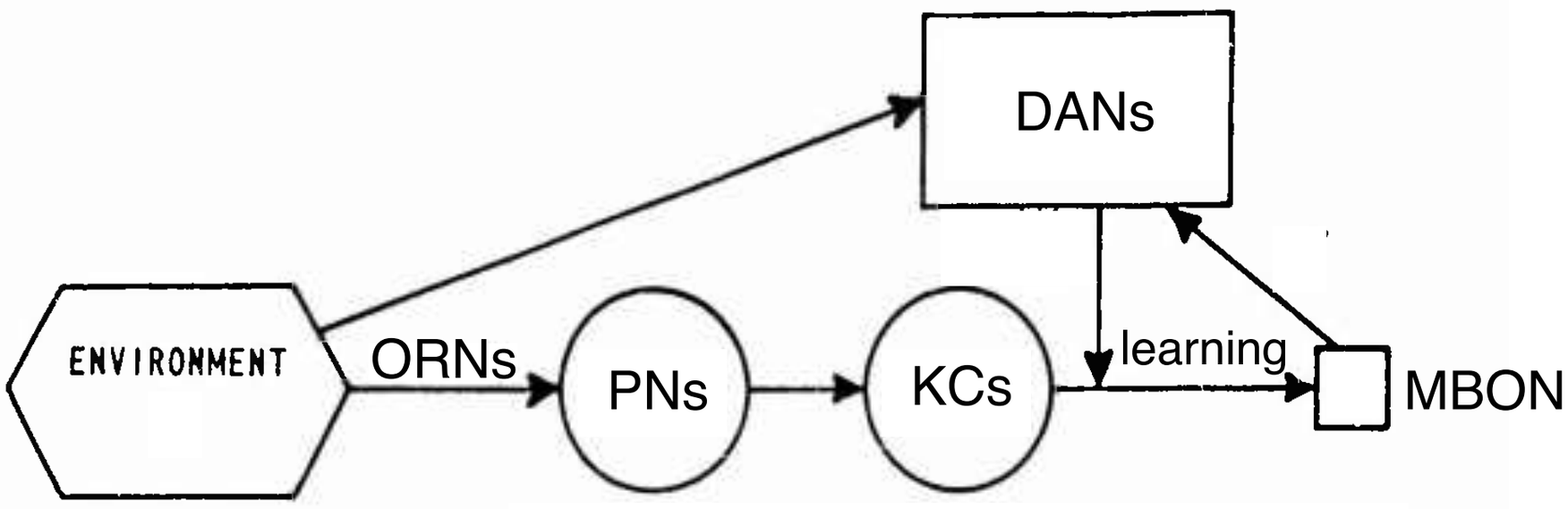
PERCEPTRONS AND THE THEORY OF BRAIN MECHANISMS

BY: Frank Rosenblatt

Frank Rosenblatt
Director, Cognitive Systems Research Program
Cornell University, Ithaca, N. Y.

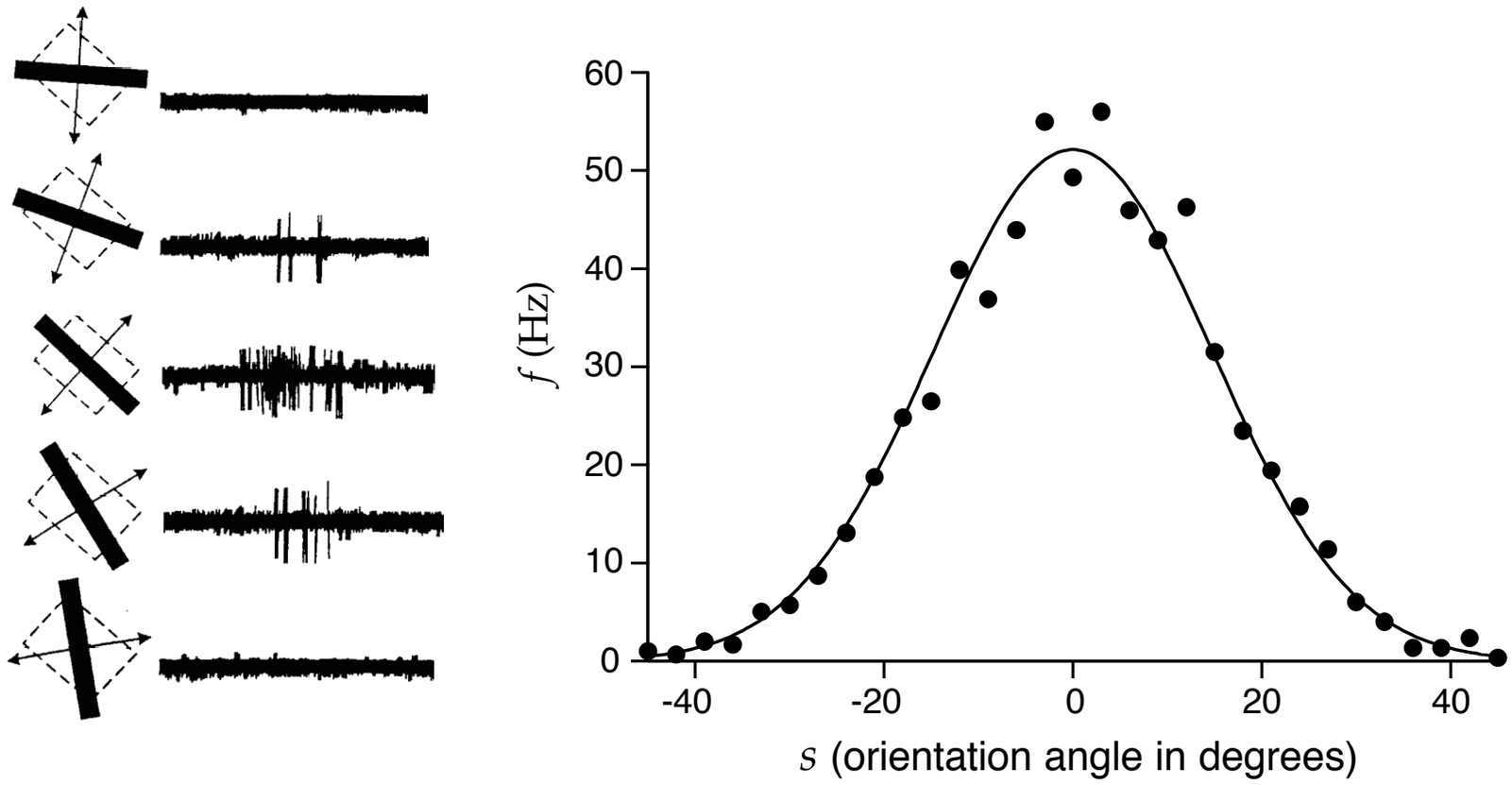
15 MARCH 1961





perceptrons may eventually be able to learn, make decisions, and translate languages

M. Minsky and S. Papert, 1969


60
50
40
30
20
10
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f (Hz)
-40
-20
0
20
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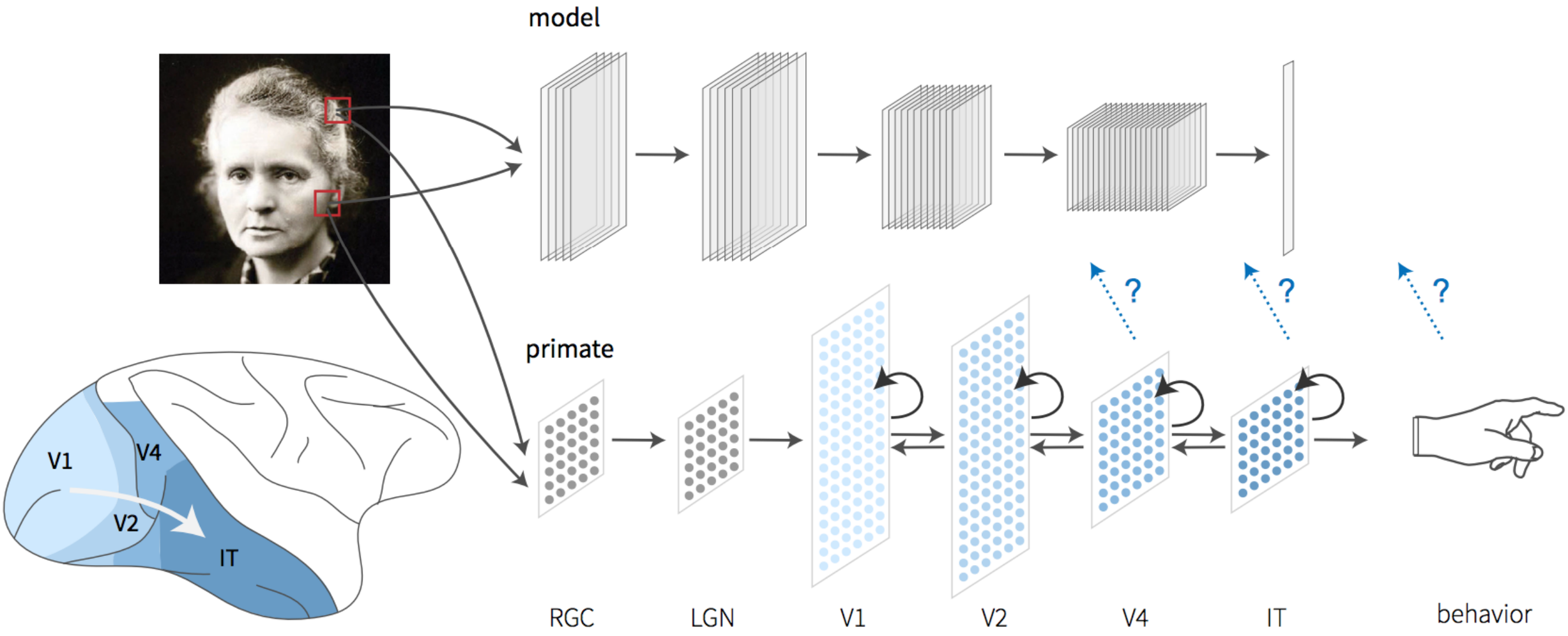
s (orientation angle in degrees)



Elia Issa, Niko Kriegeskorte

A Biological Auto-Encoder

Tessa Montague, Erica Shook - Axel Lab