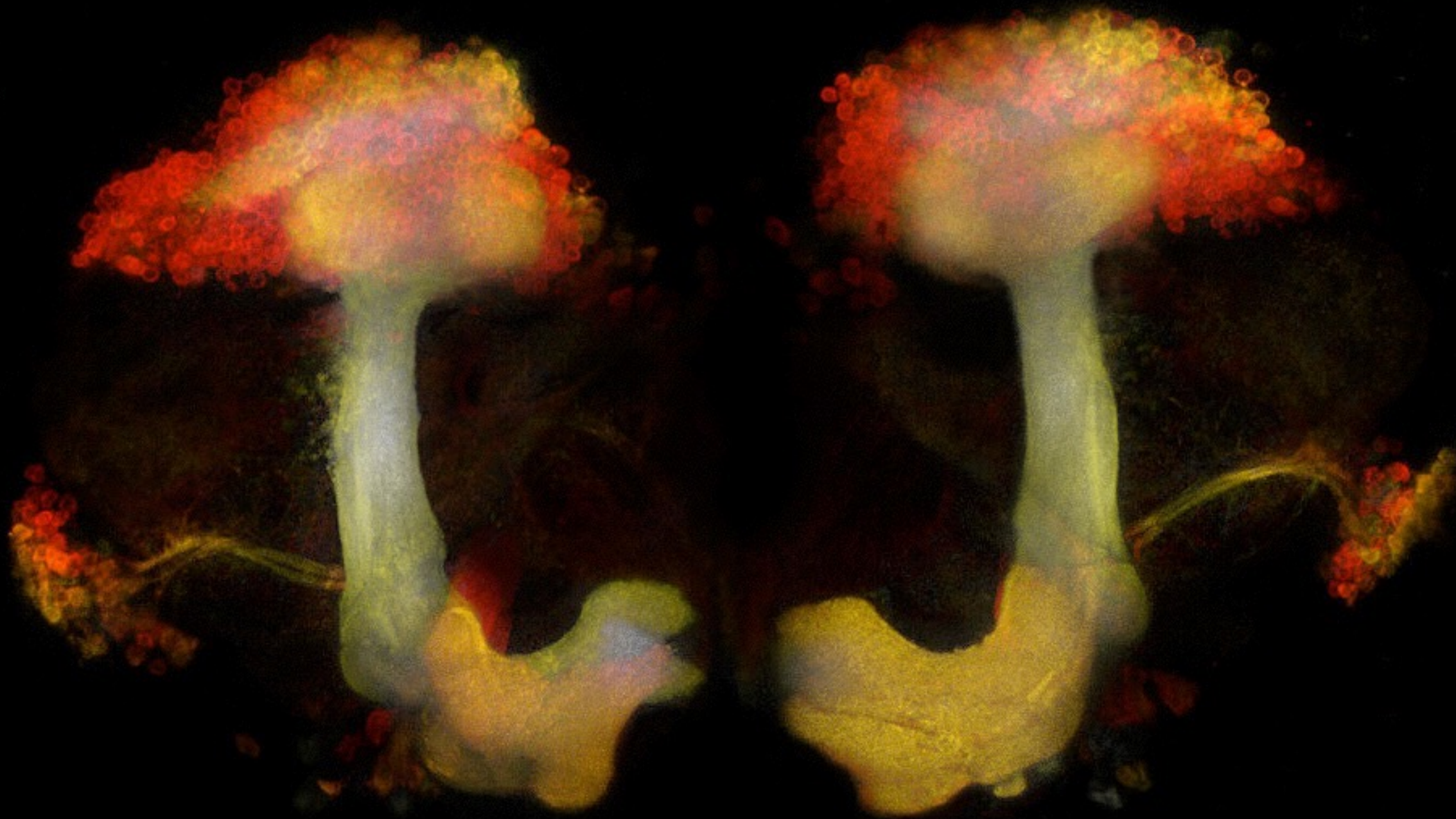
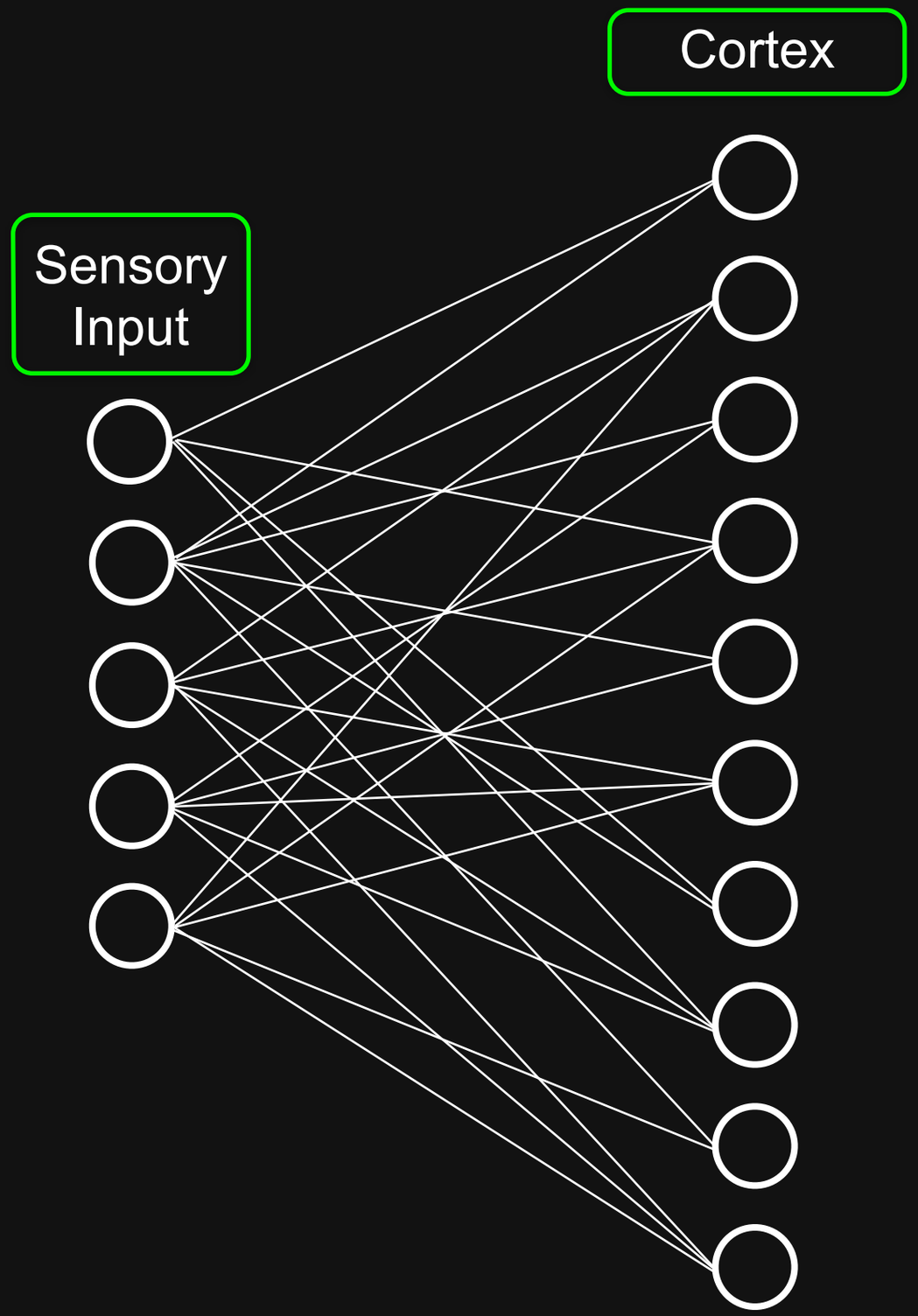
Olfactory Signaling in Mushroom Body Output Neurons
Neural coding as a Circuit Converges

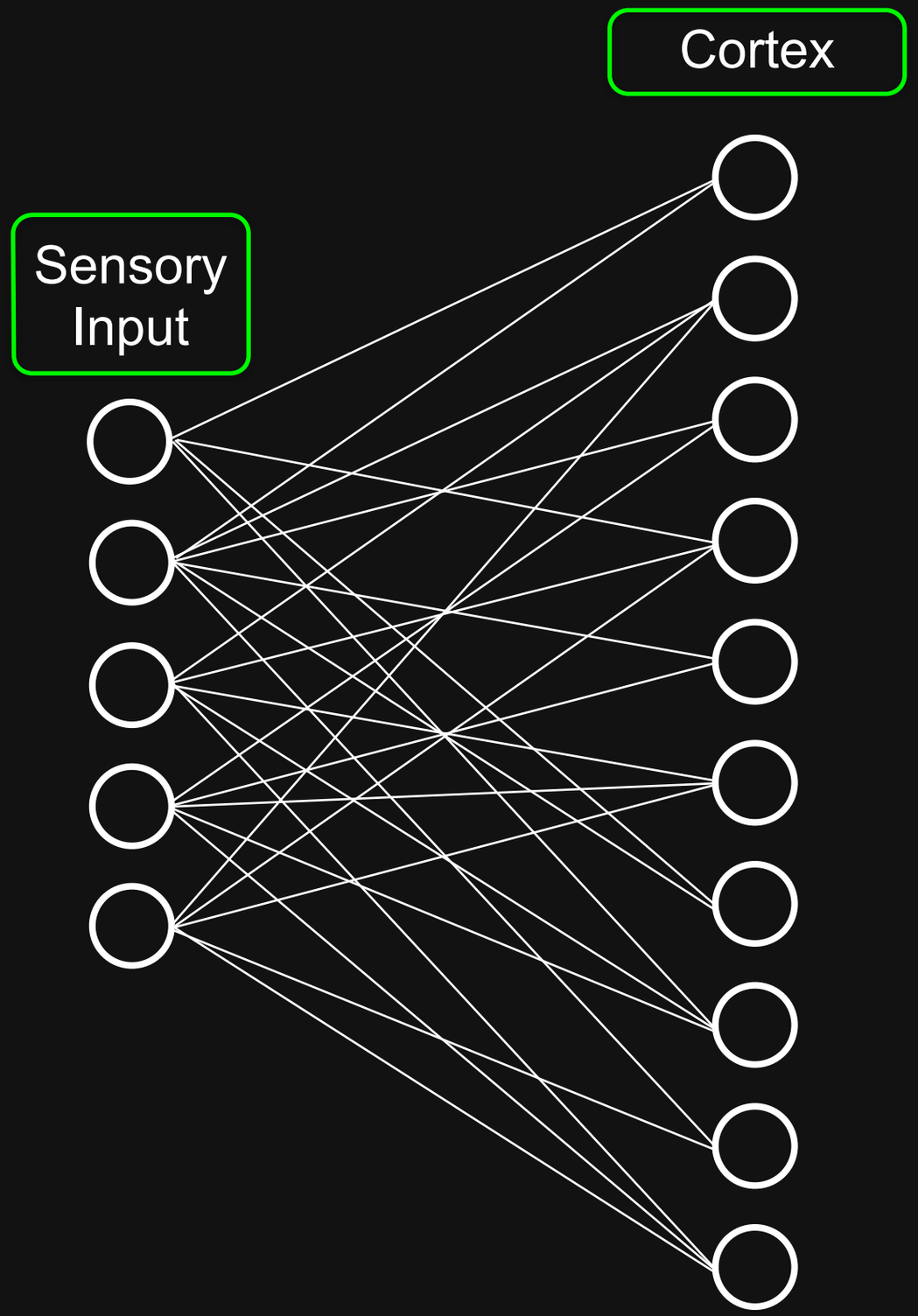


Expanding structure of neural circuits



Expanding structure of neural circuits

Center-Surround



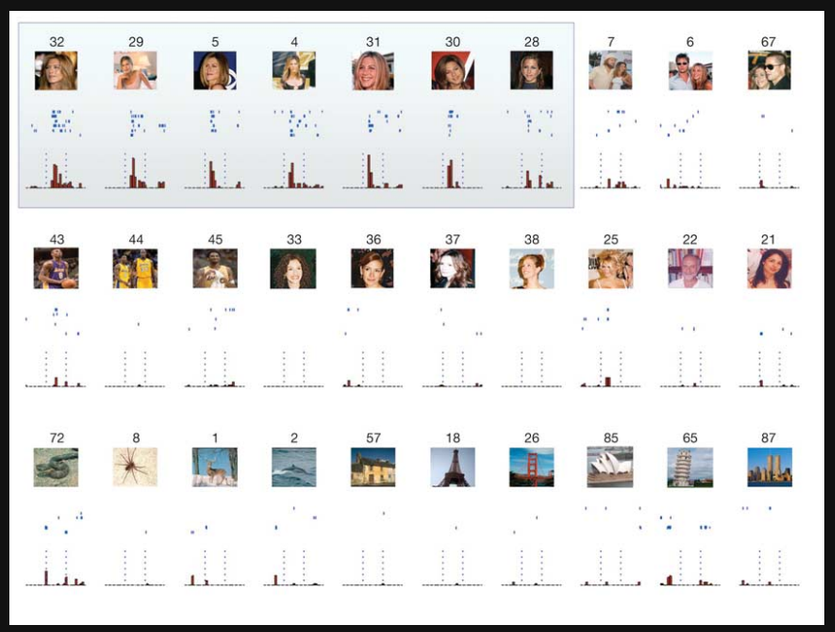
Expanding structure of neural circuits

Cortex

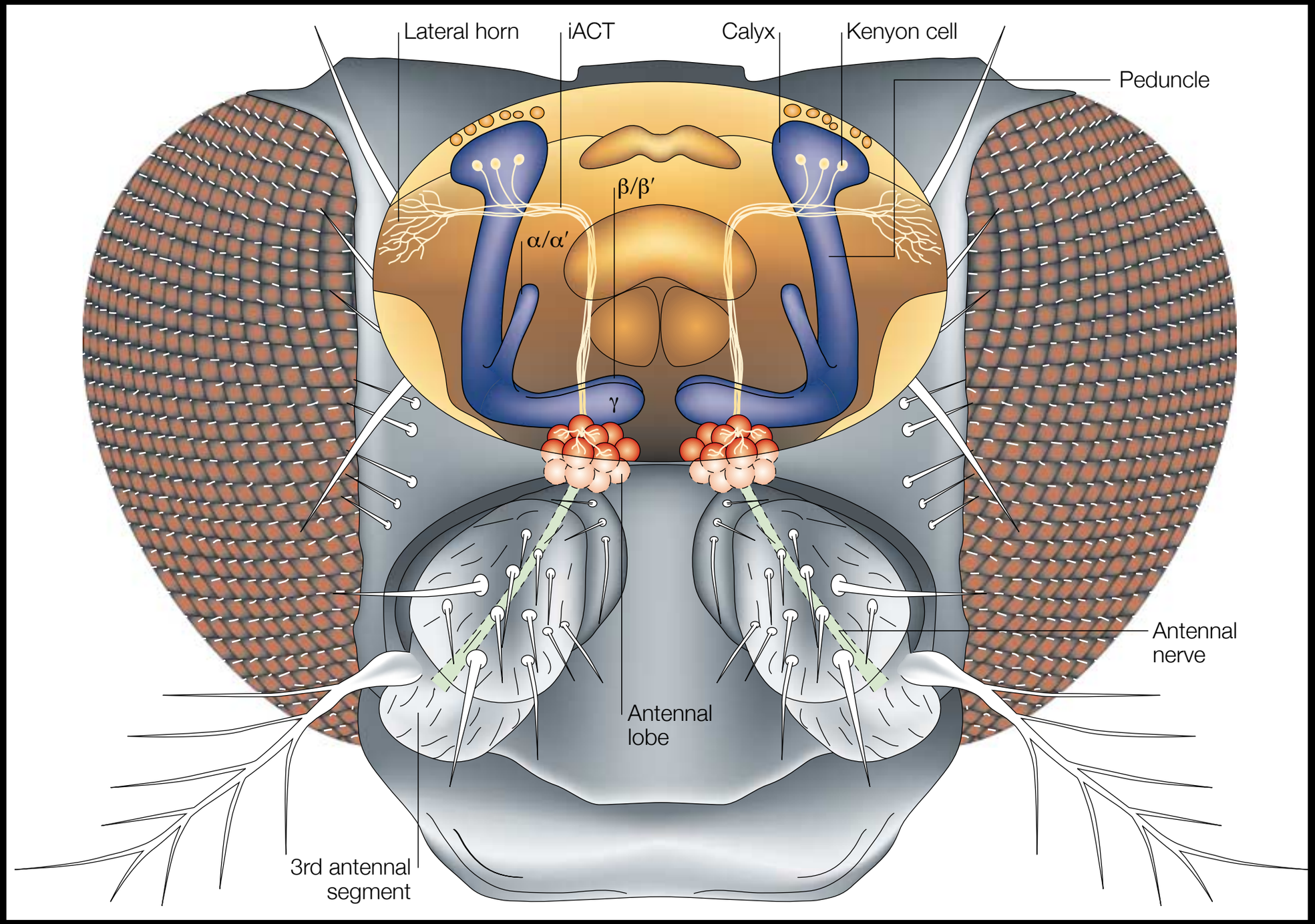
Sensory Input

Center-Surround

Jennifer Anniston

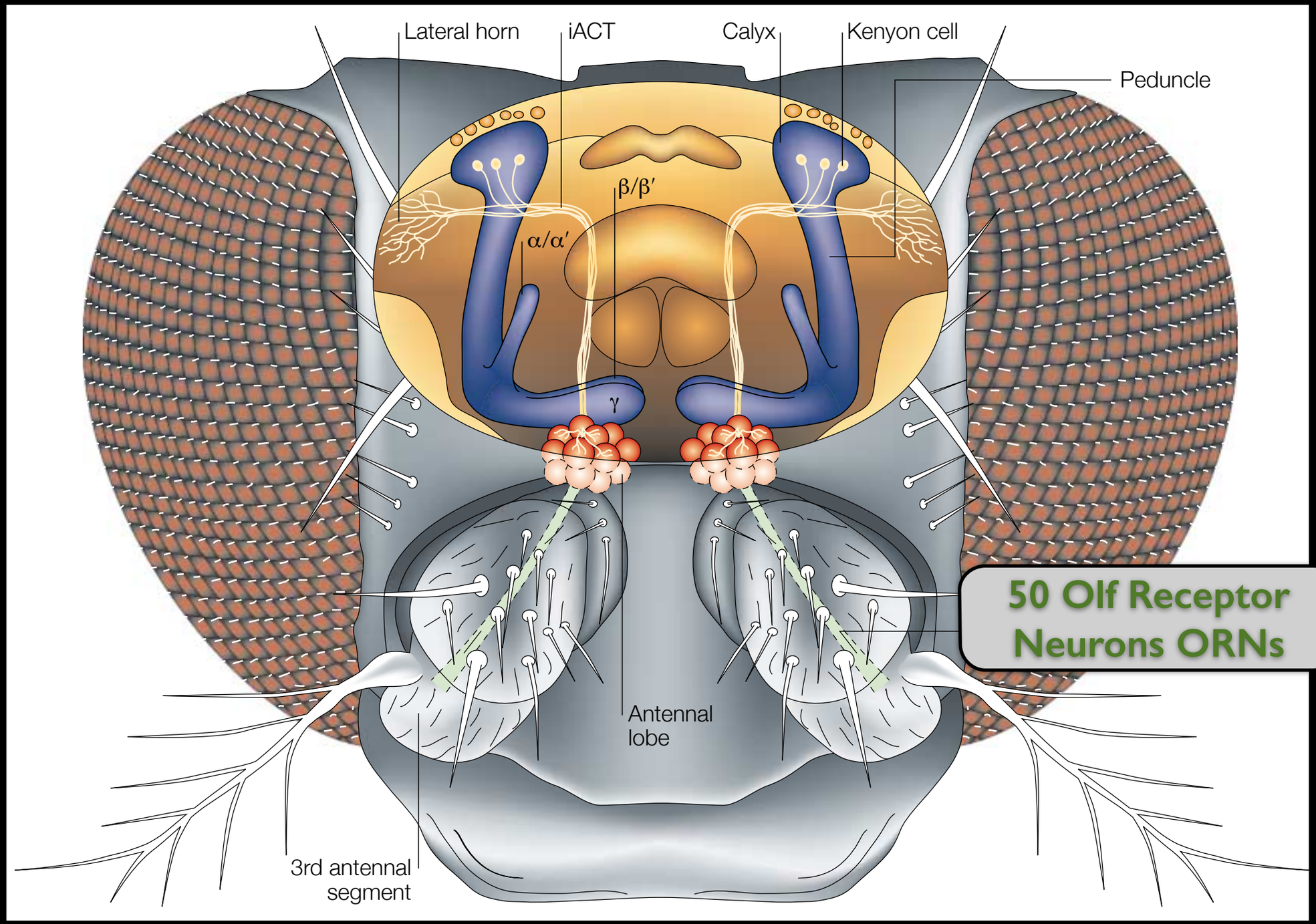


The Olfactory Circuit



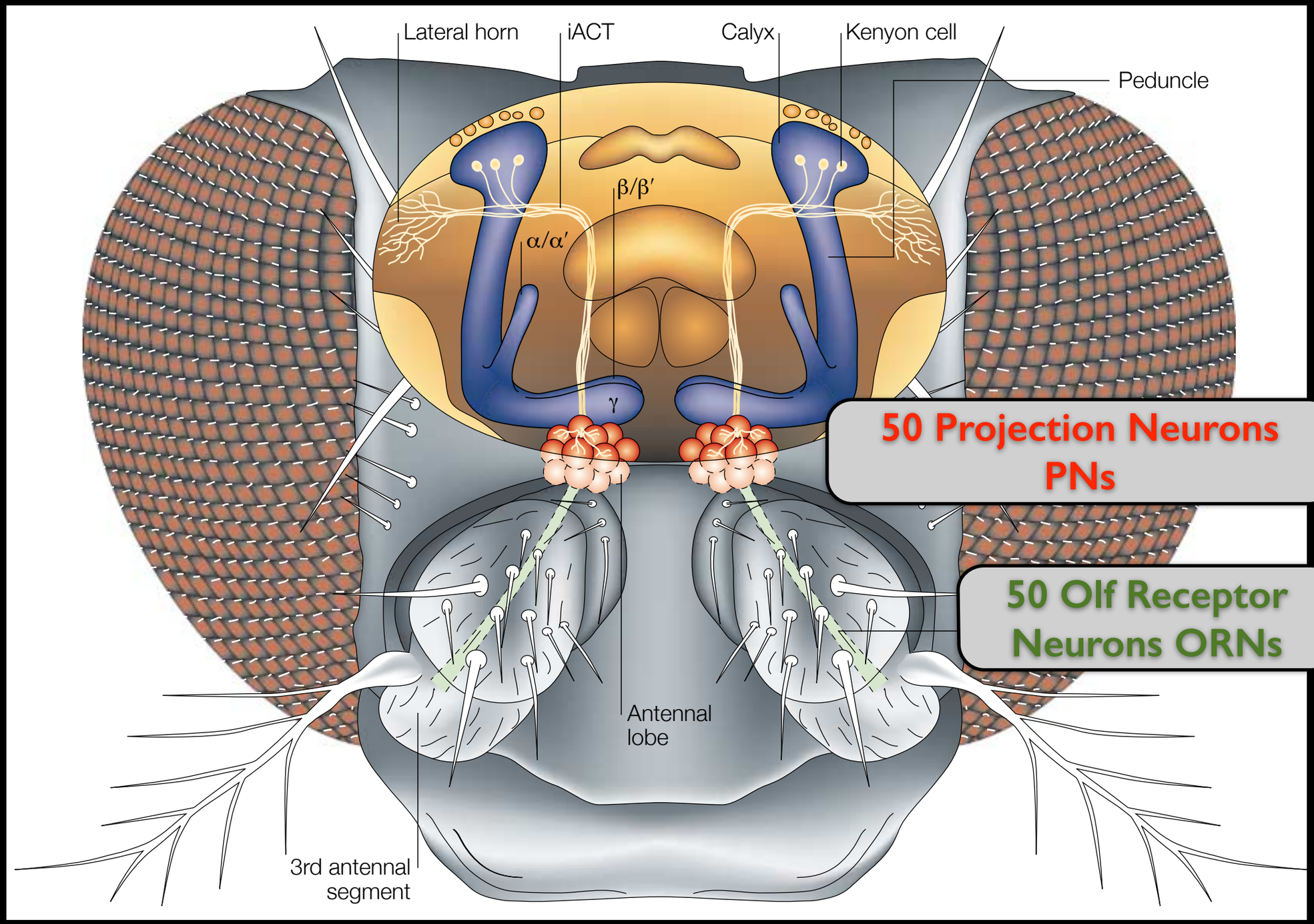
Heisenberg Nat Rev Neuro 2003

The Olfactory Circuit



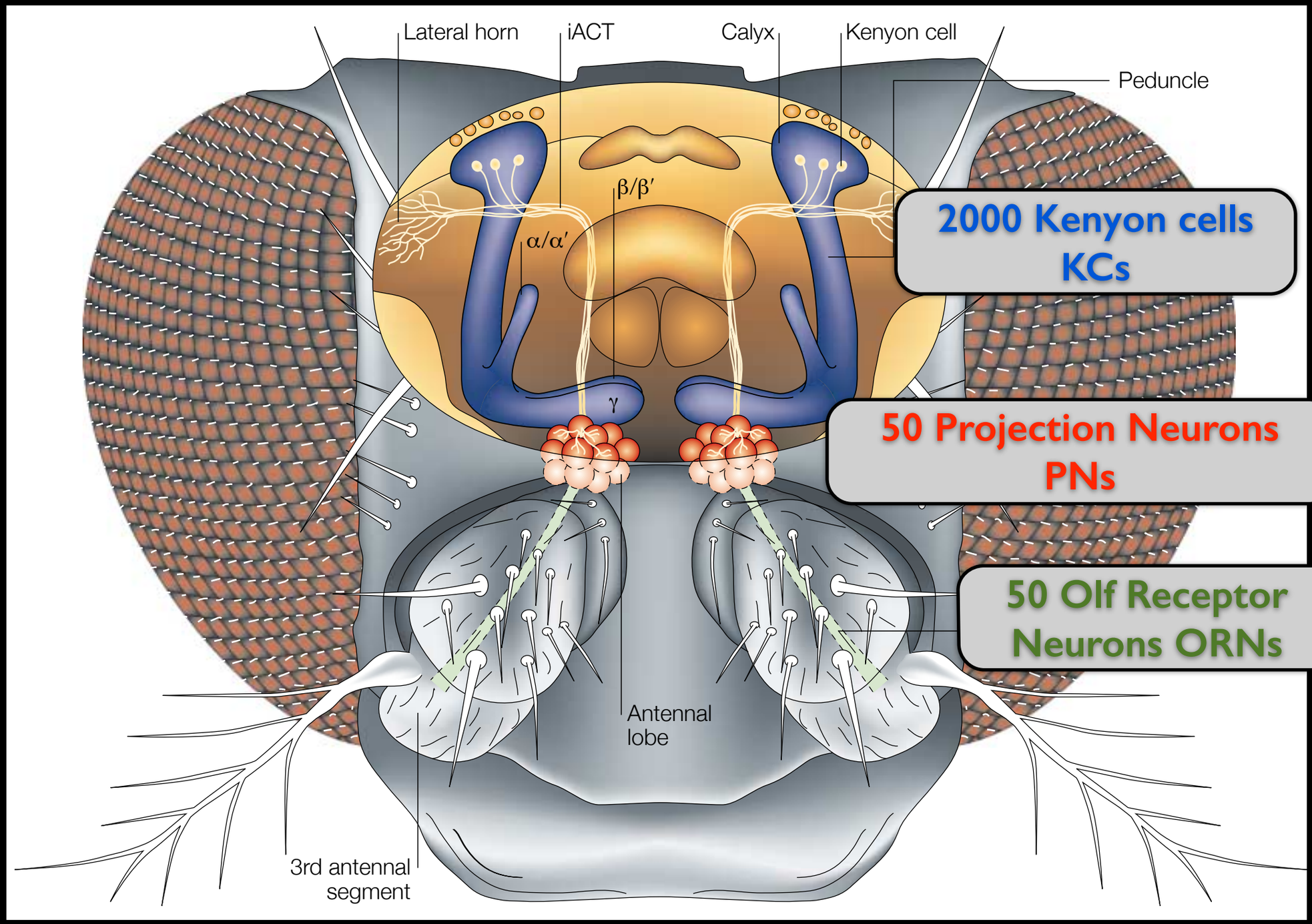
Heisenberg Nat Rev Neuro 2003

The Olfactory Circuit



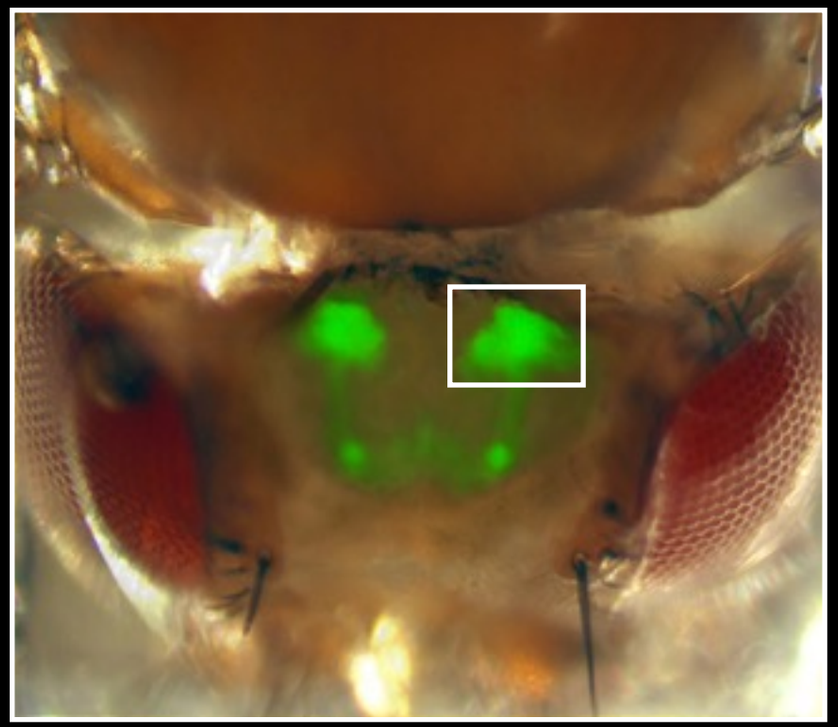
Heisenberg Nat Rev Neuro 2003

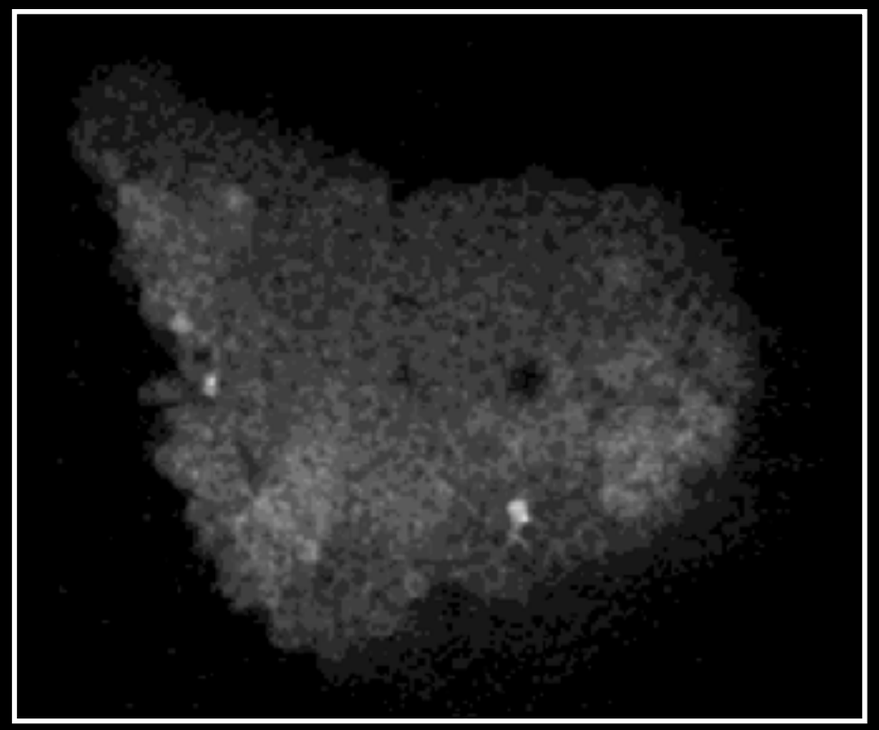
The Olfactory Circuit



Heisenberg Nat Rev Neuro 2003

Visualising neural activity:
GFP-based calcium sensor GCaMP





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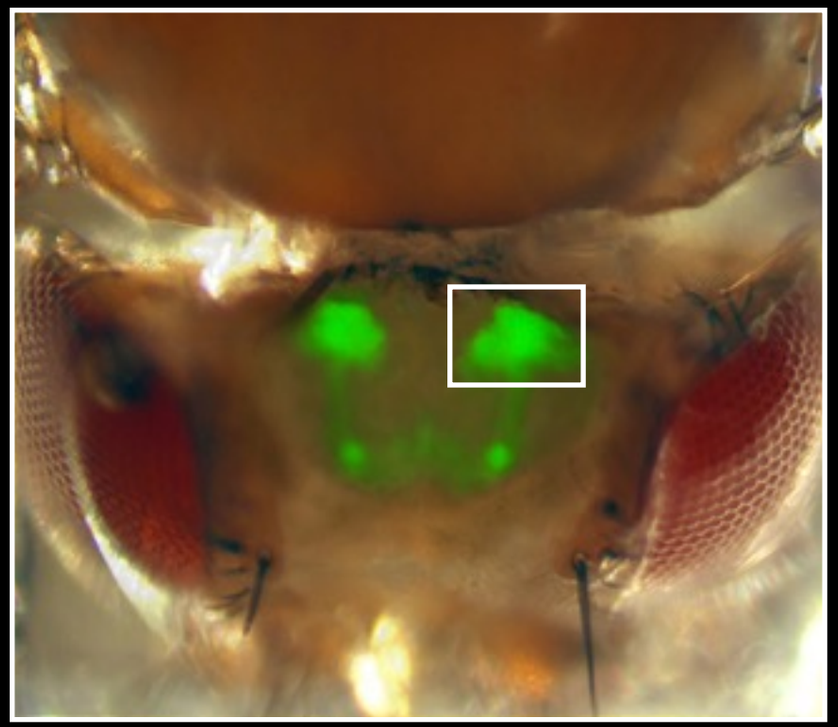

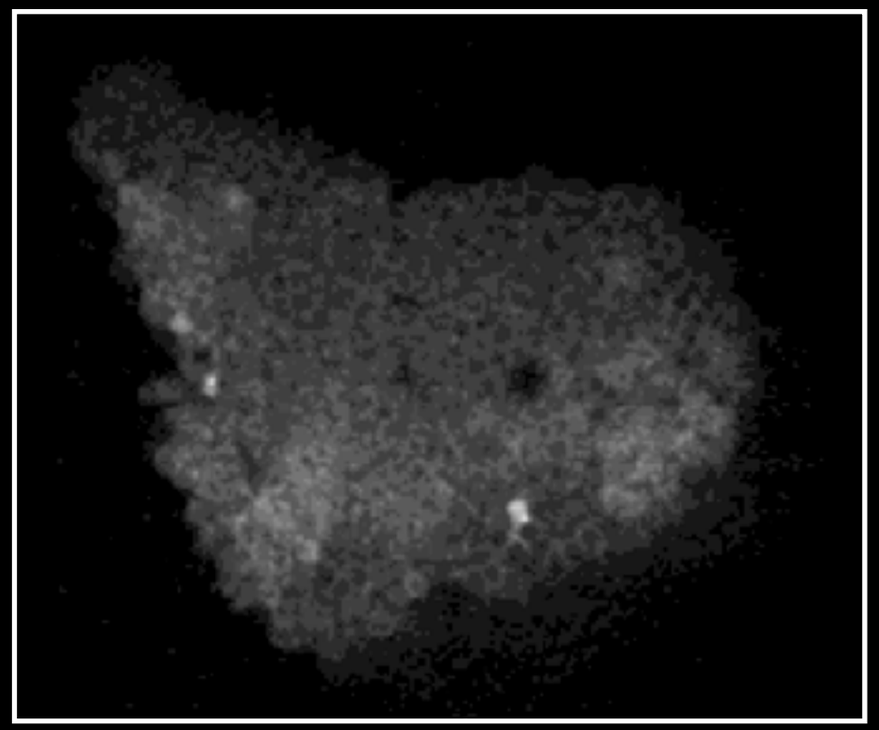

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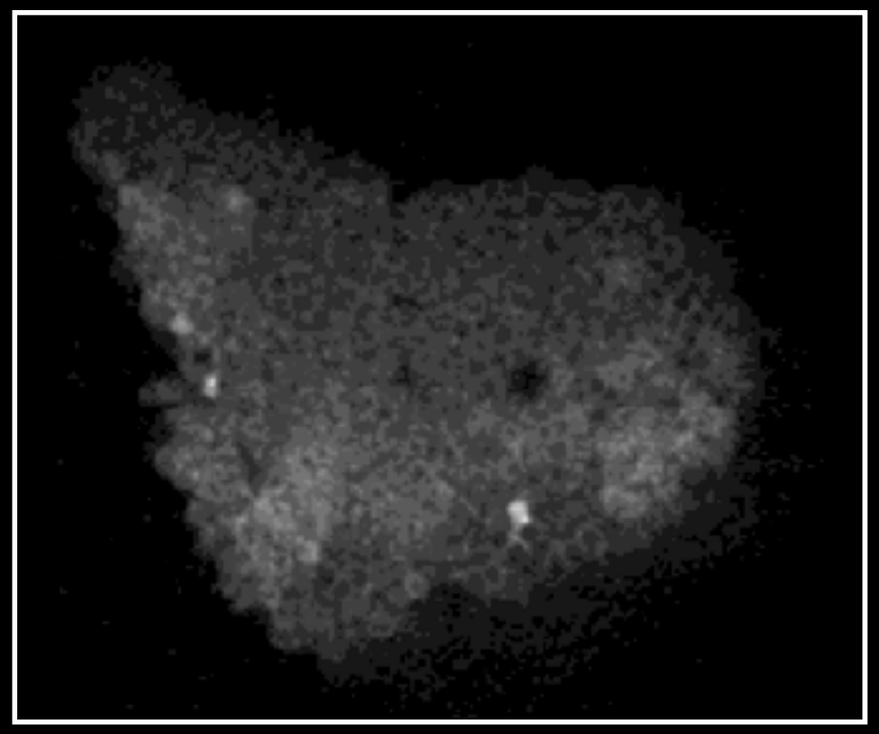

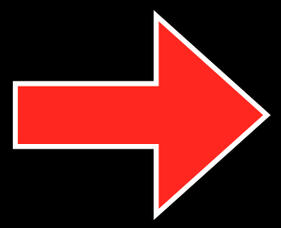

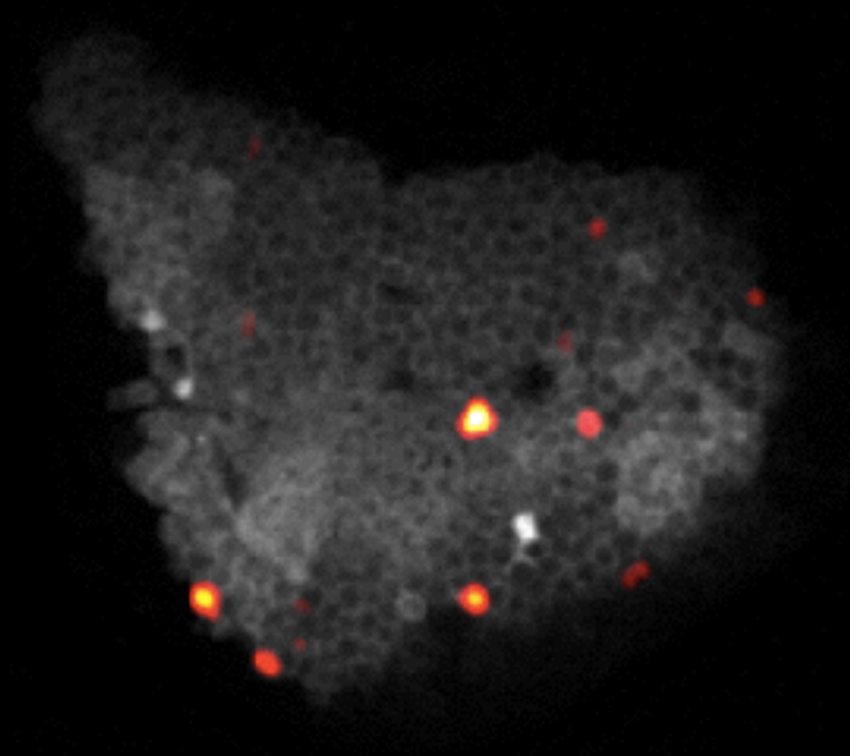

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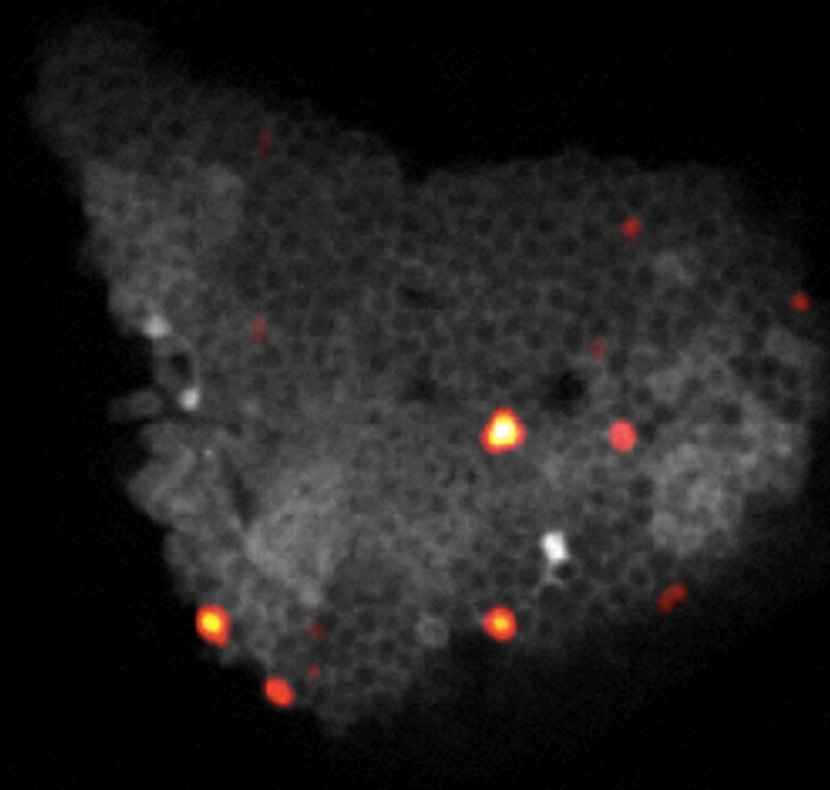
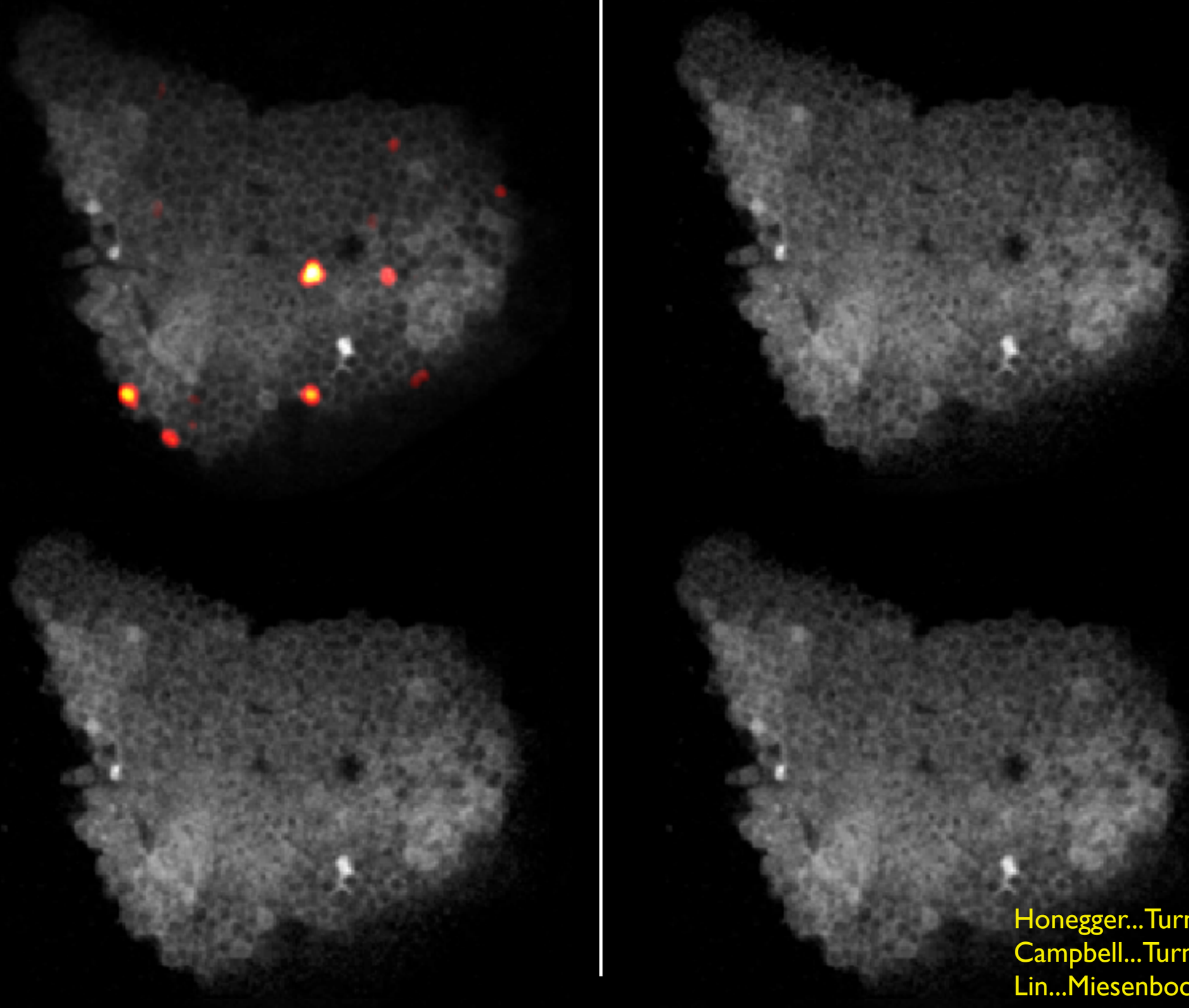


Odor A

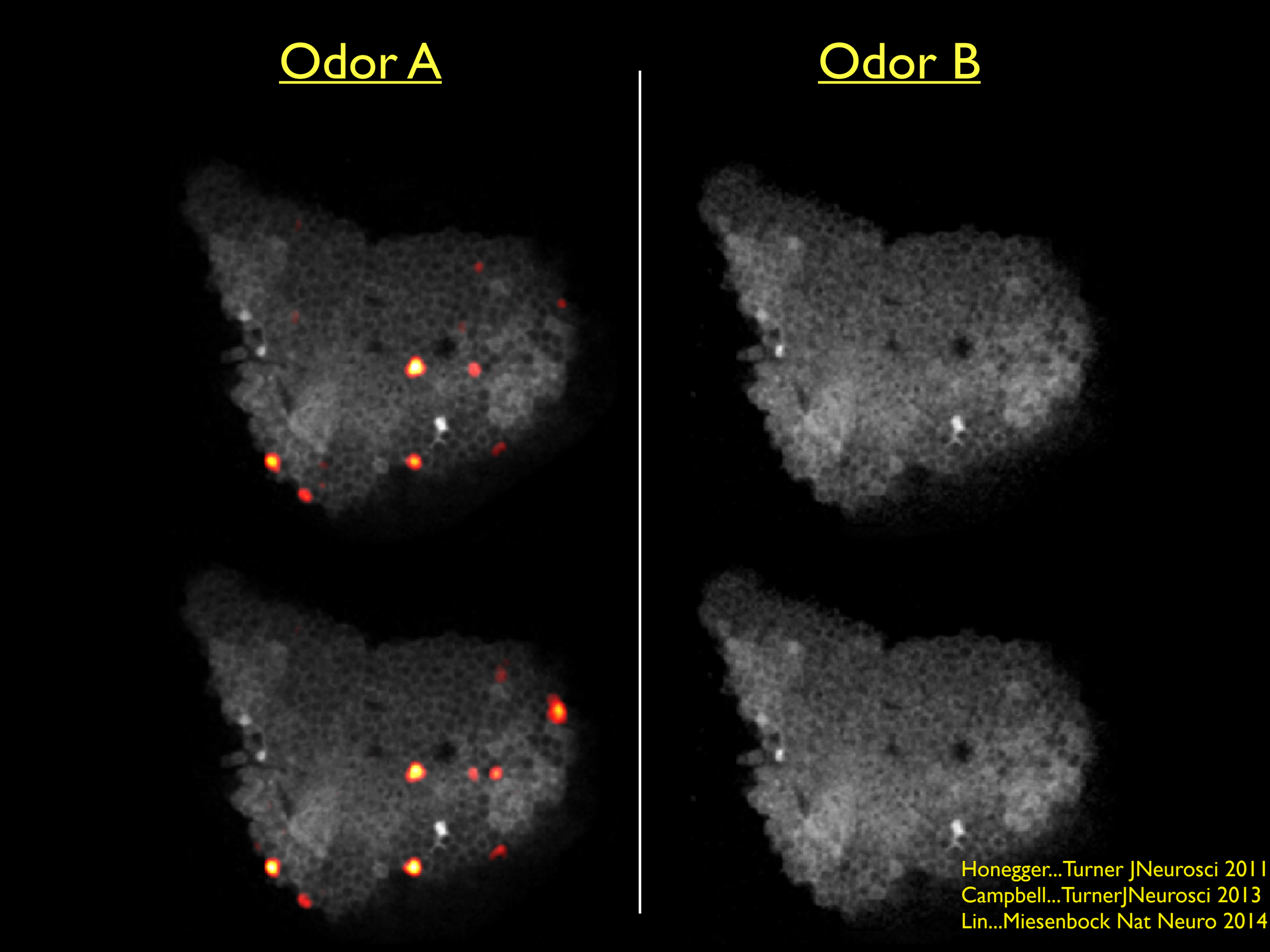
Odor B



Honegger...Turner JNeurosci 2011
Campbell...TurnerJNeurosci 2013
Lin...Miesenbock Nat Neuro 2014

Odor A

Odor B



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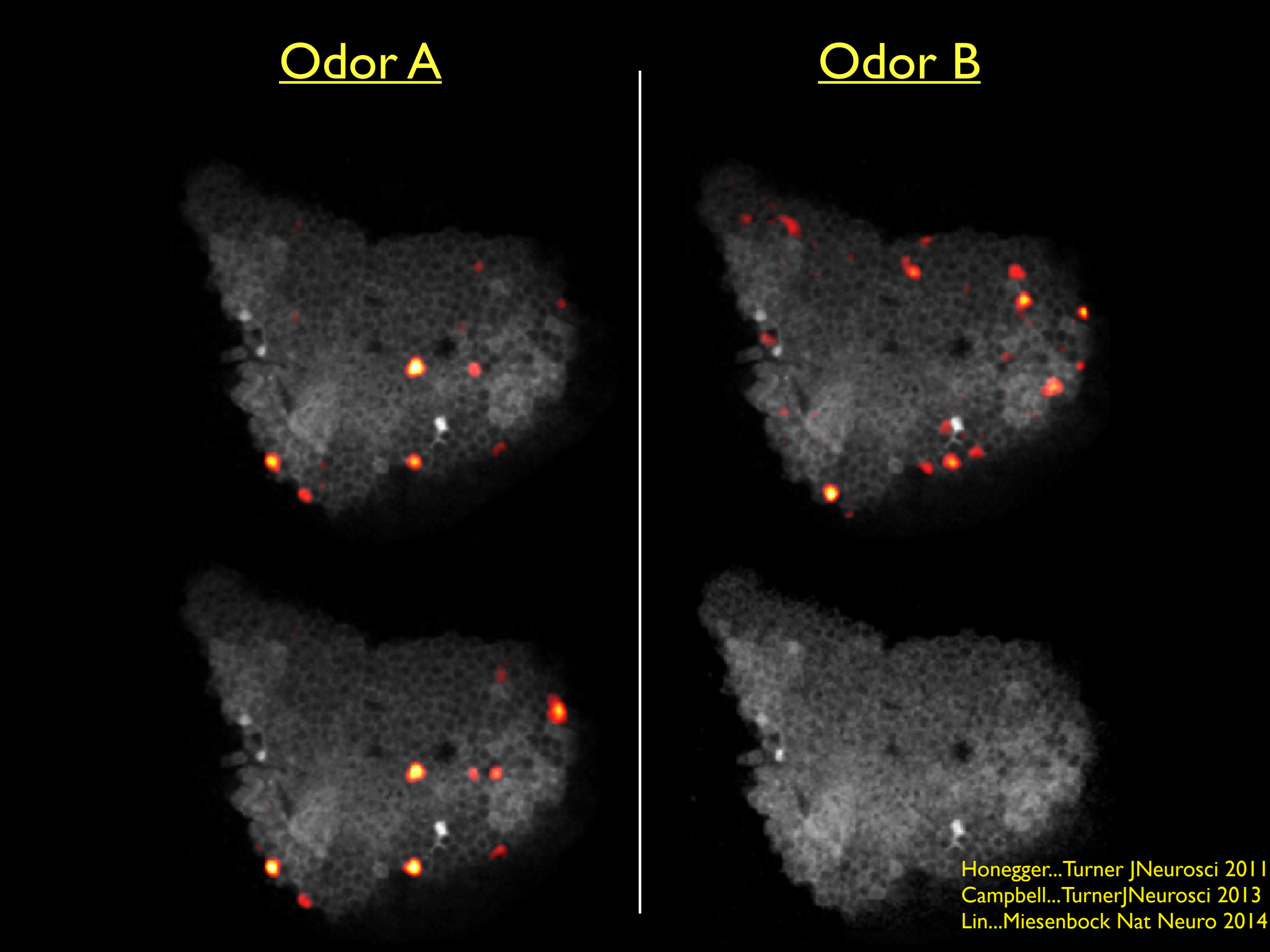

Honegger...Turner JNeurosci 2011
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Odor A

Odor B

Honegger...Turner JNeurosci 2011
Campbell...TurnerJNeurosci 2013
Lin...Miesenbock Nat Neuro 2014

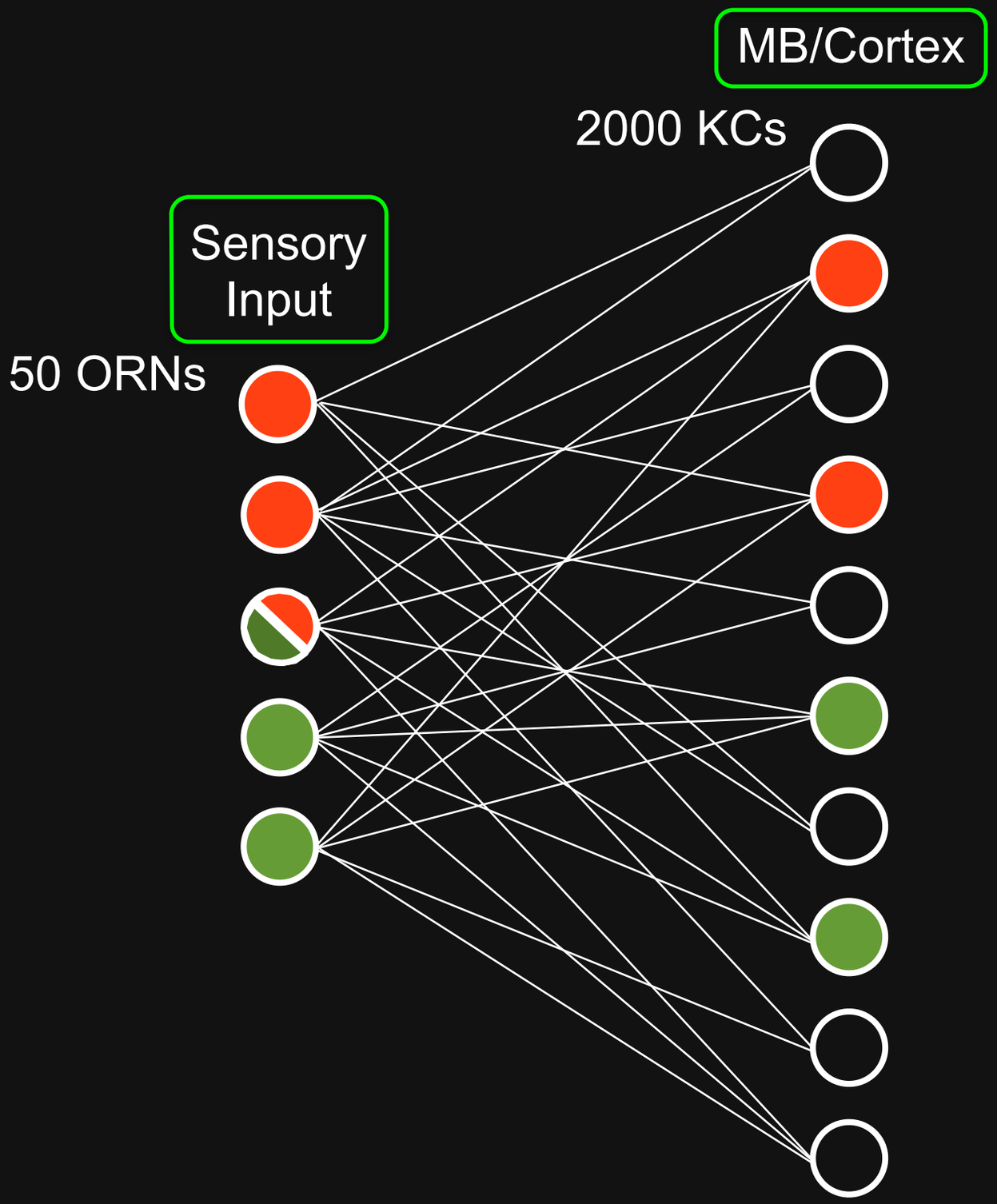
Odor A

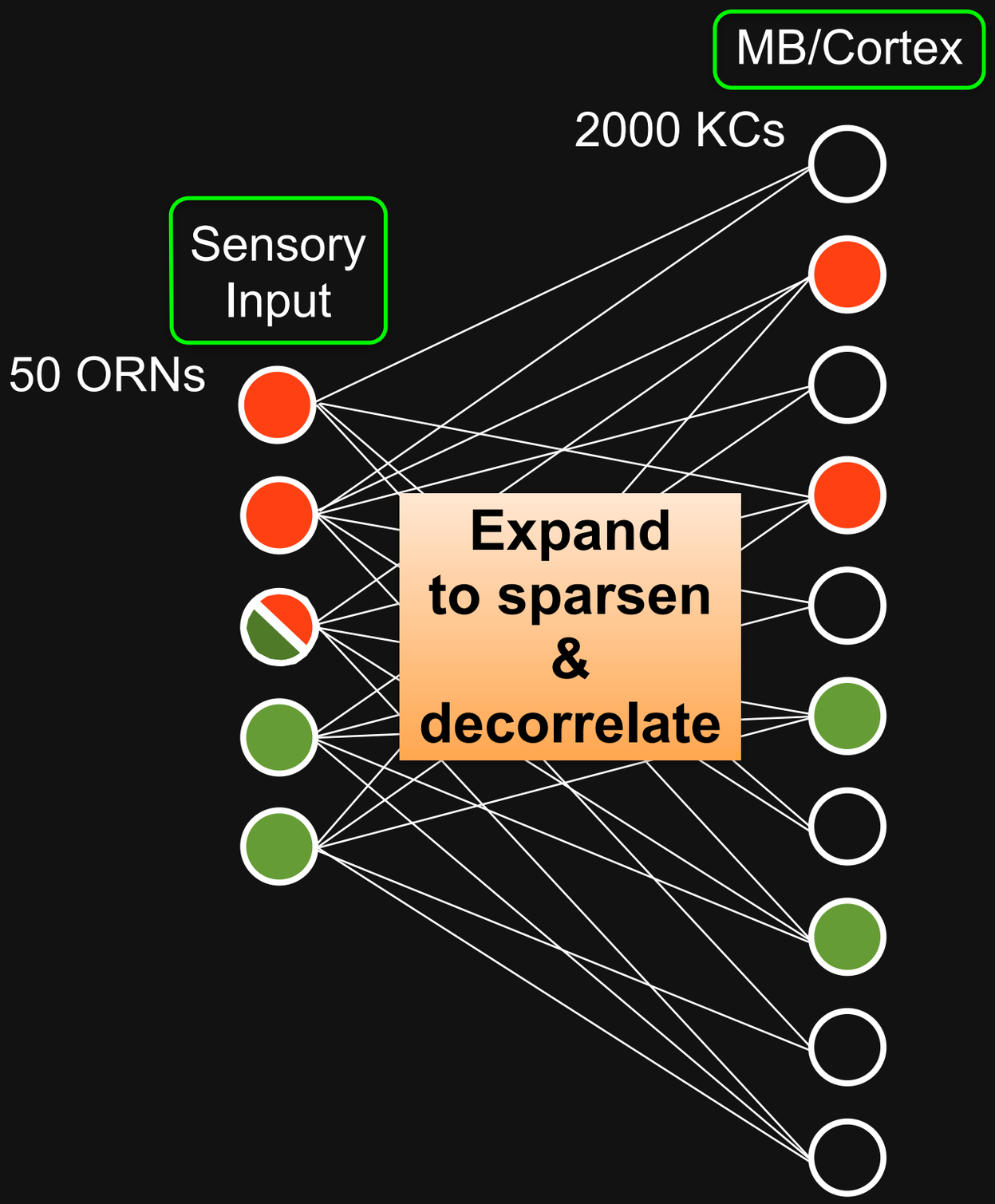
Odor B

Sparse response patterns: ~5% of cells respond

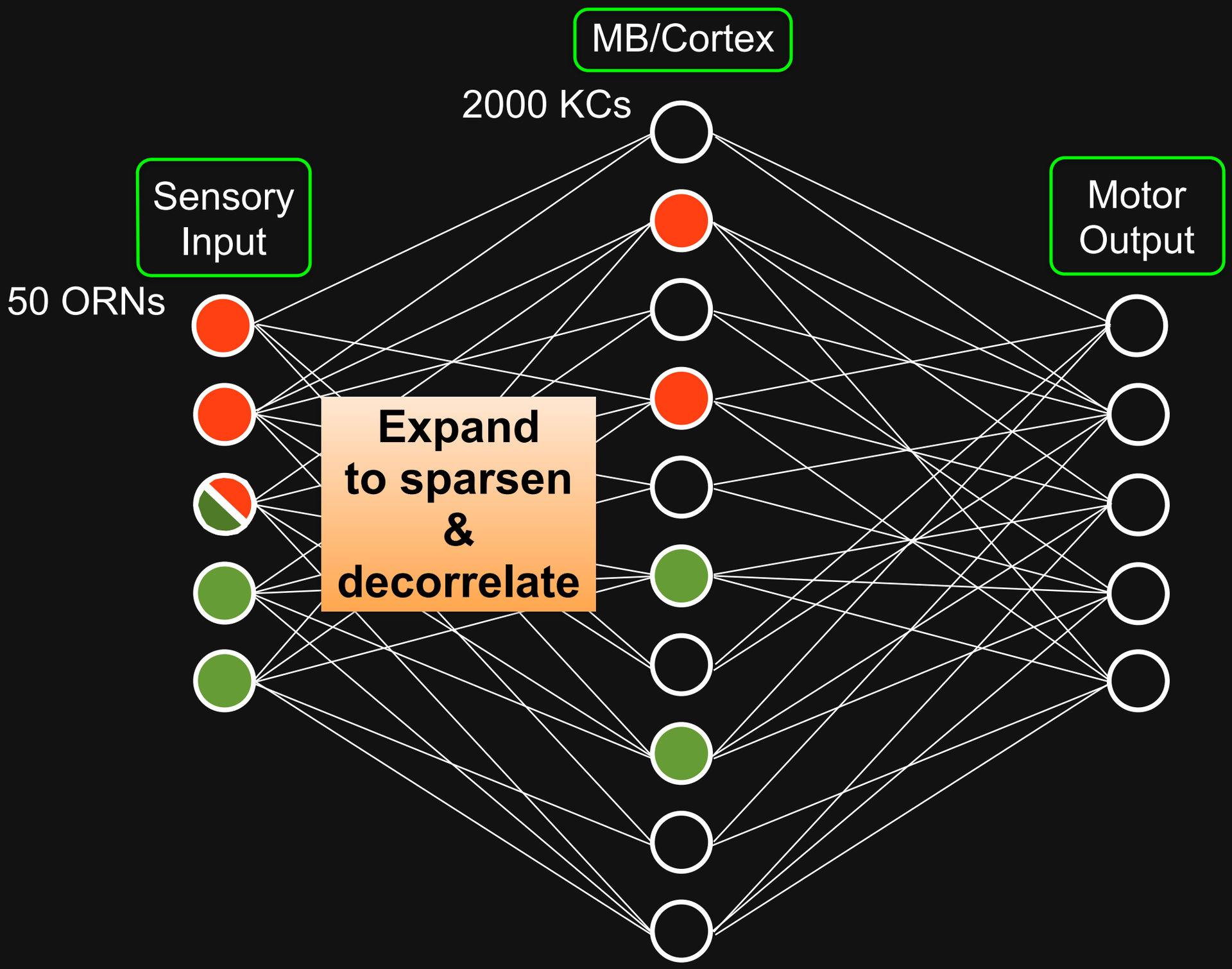
☞ Overlap predicts accuracy of memory formation

Honegger...Turner JNeurosci 2011
Campbell...TurnerJNeurosci 2013
Lin...Miesenbock Nat Neuro 2014

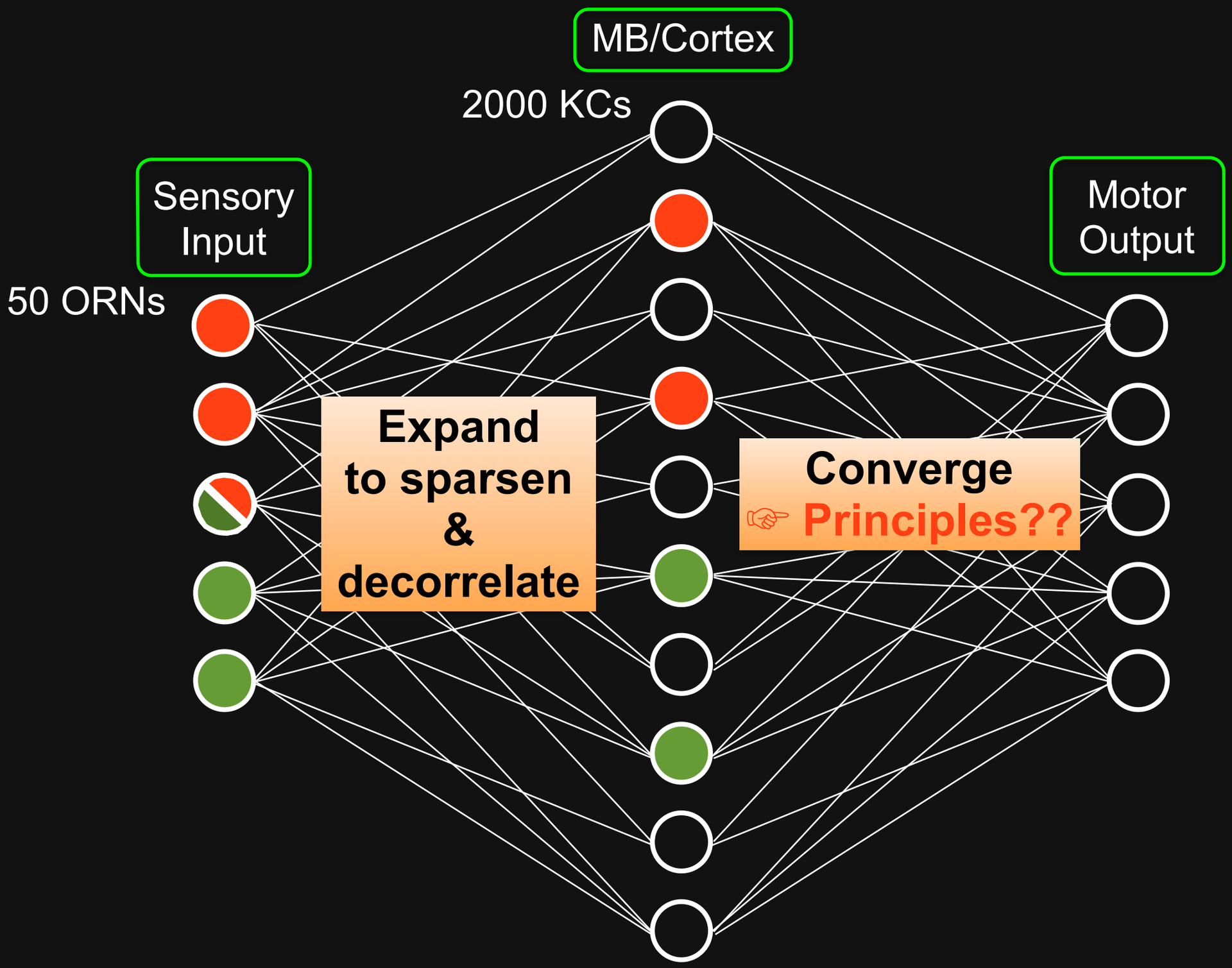

MB/Cortex
2000 KCs
Sensory
Input
50 ORNs


MB/Cortex
2000 KCs
Sensory Input
50 ORNs
Expand to sparsen & decorrelate

Expand-Converge structure of neural circuits



Expand-Converge structure of neural circuits

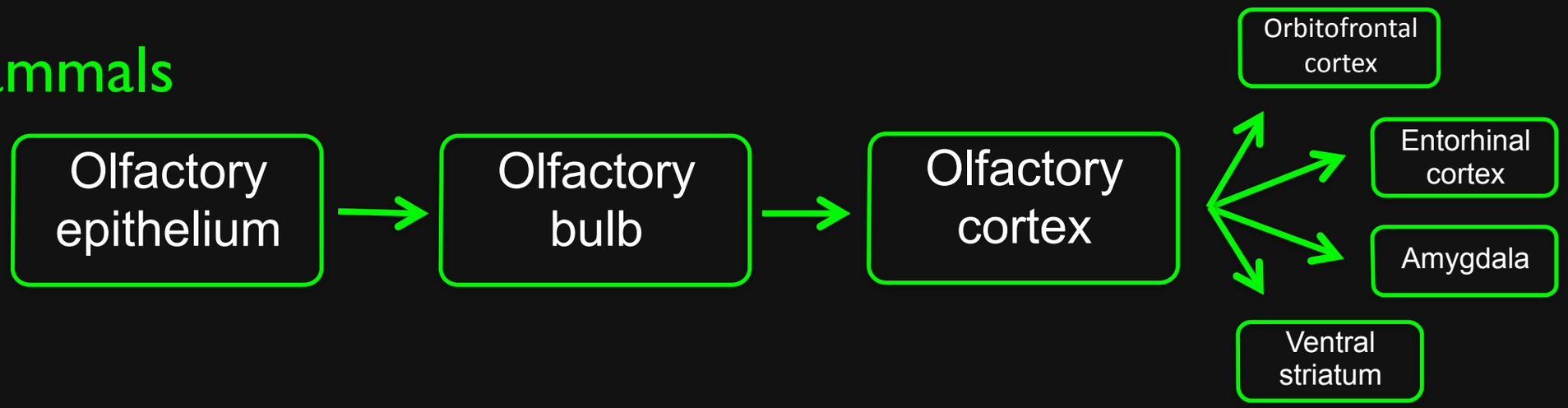


Olfactory circuits

Mammals

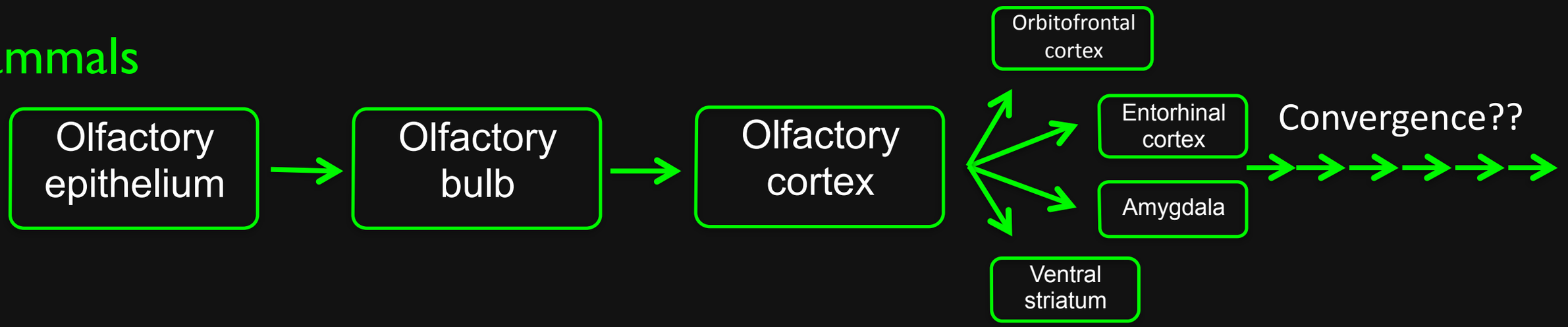
Olfactory circuits

Mammals

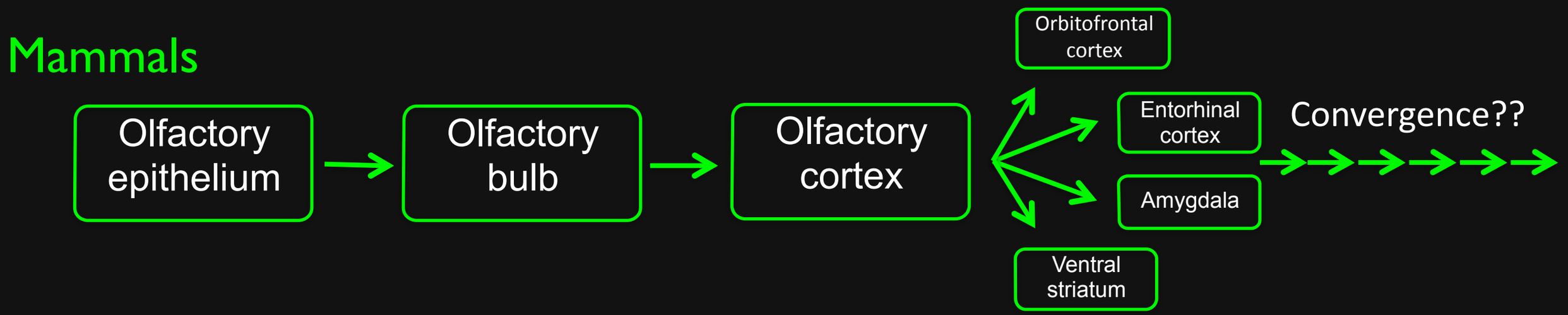


Olfactory circuits

Mammals

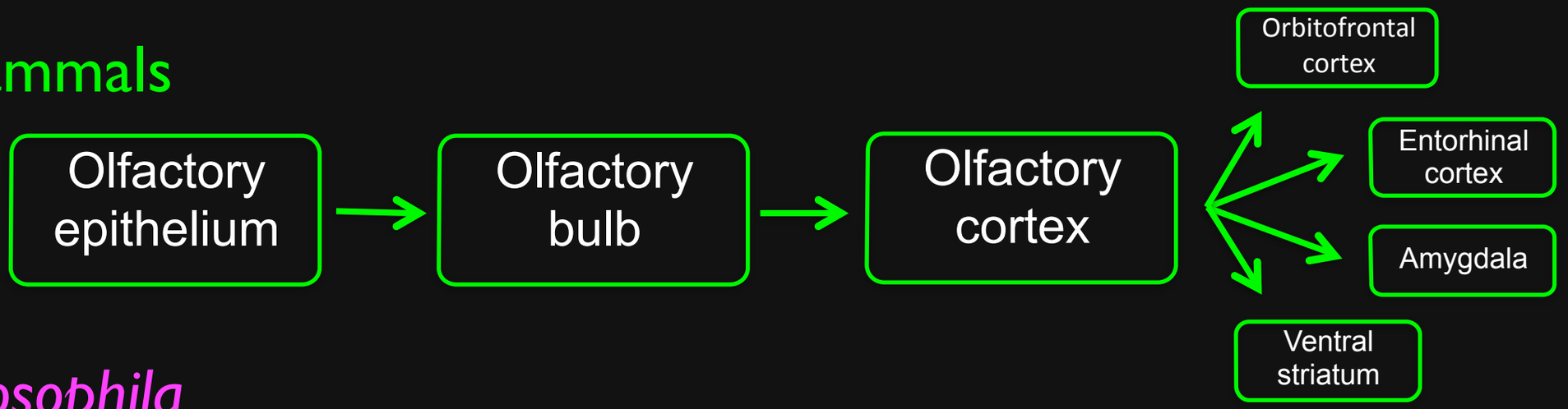


Olfactory circuits



Olfactory circuits

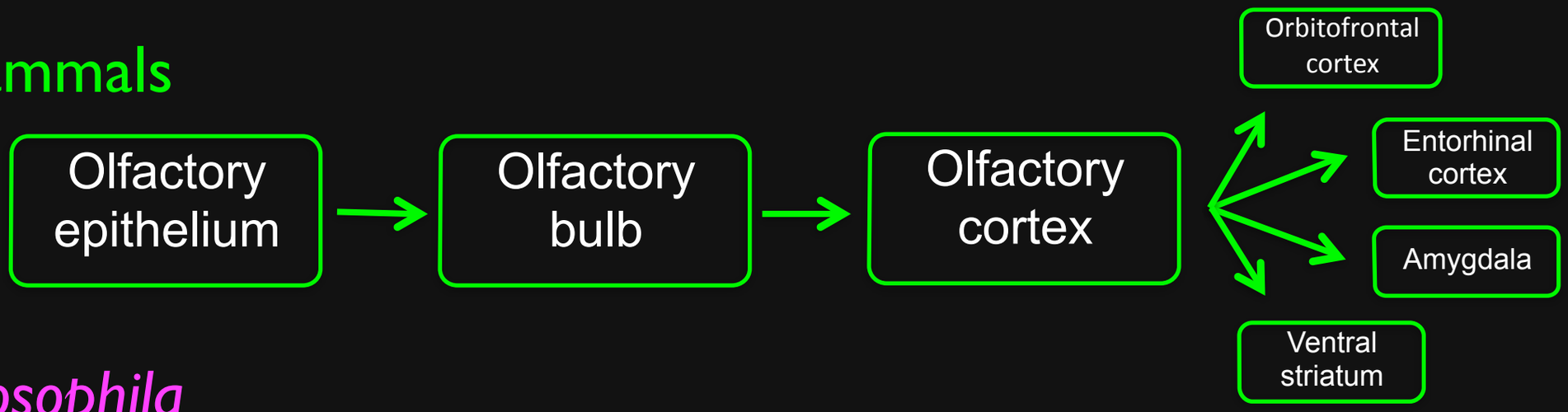
Mammals



Drosophila

Olfactory circuits

Mammals



Drosophila

2000 KCs

Olfactory circuits

Mammals

Olfactory epithelium → Olfactory bulb → Olfactory cortex → Orbitofrontal cortex, Entorhinal cortex, Amygdala, Ventral striatum

Drosophila

Antenna → Antennal lobe → Mushroom body → **34 Output Neurons**

2000 KCs

Aso...Rubin eLife 2014a & 2014b

Olfactory circuits

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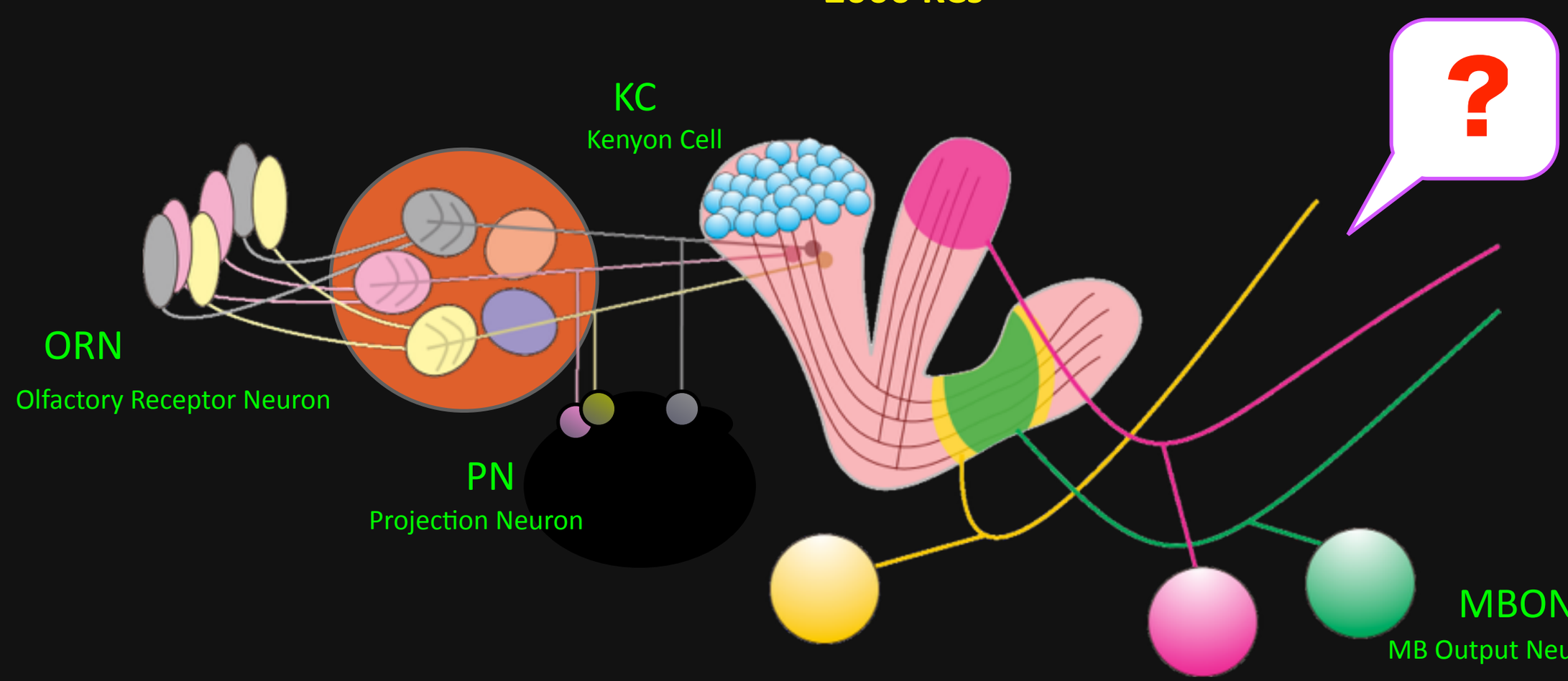

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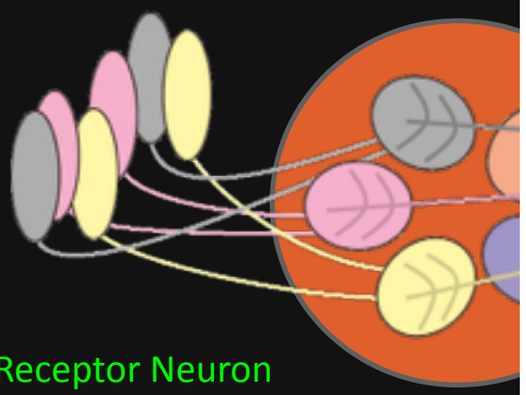


ORN

Olfactory Receptor Neuron

PN

Projection Neuron

KC

Yoshi Aso

Rubin lab

@ Janelia

Toshihide Hige

Turner lab

@ CSHL

?

MBON

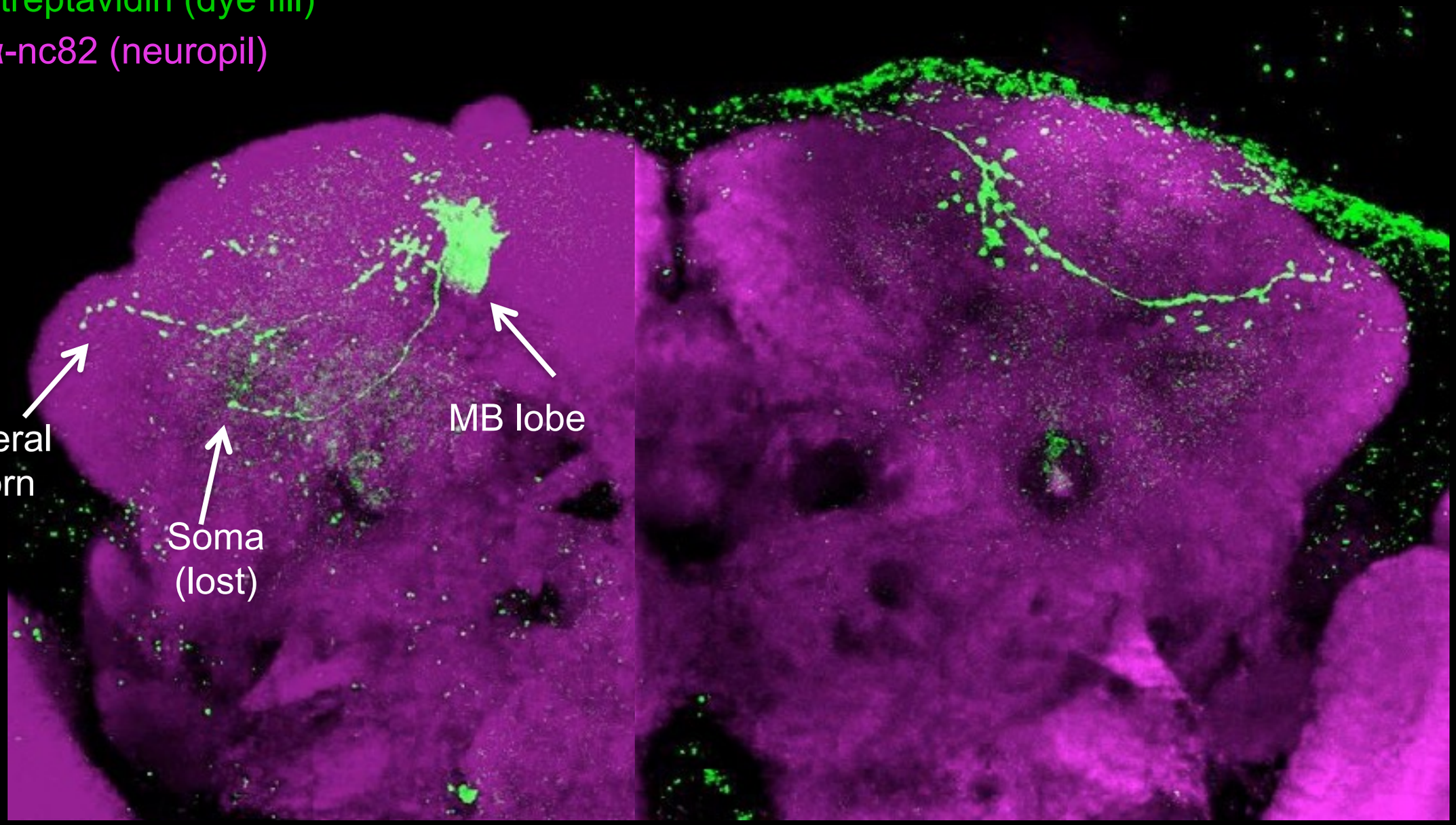
MB Output Neuron

MB Output Neuron
V2α2sc

MB Output Neuron
V2α2sc

MB Output Neuron
V2α2sc

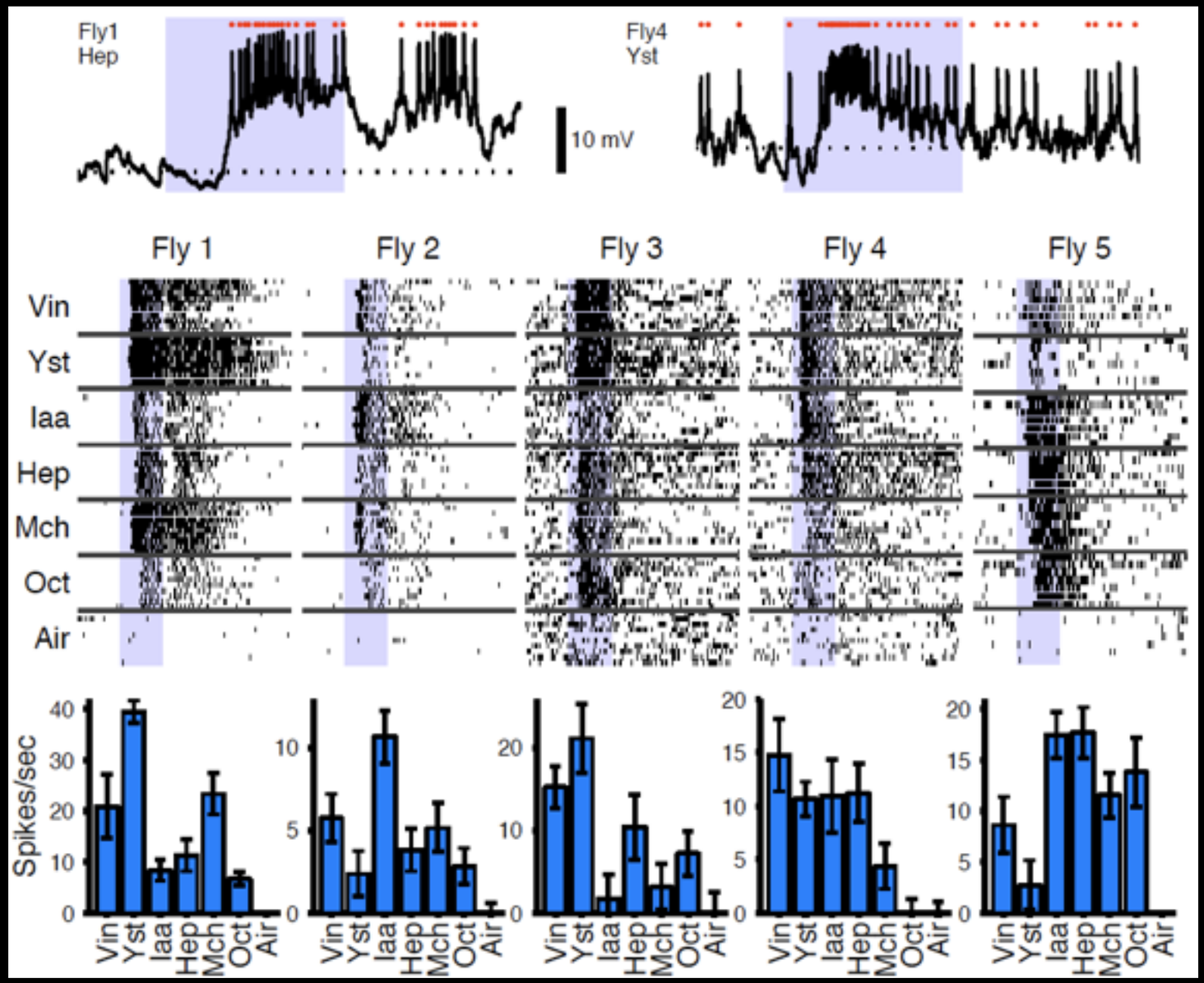
Streptavidin (dye fill)
α-nc82 (neuropil)



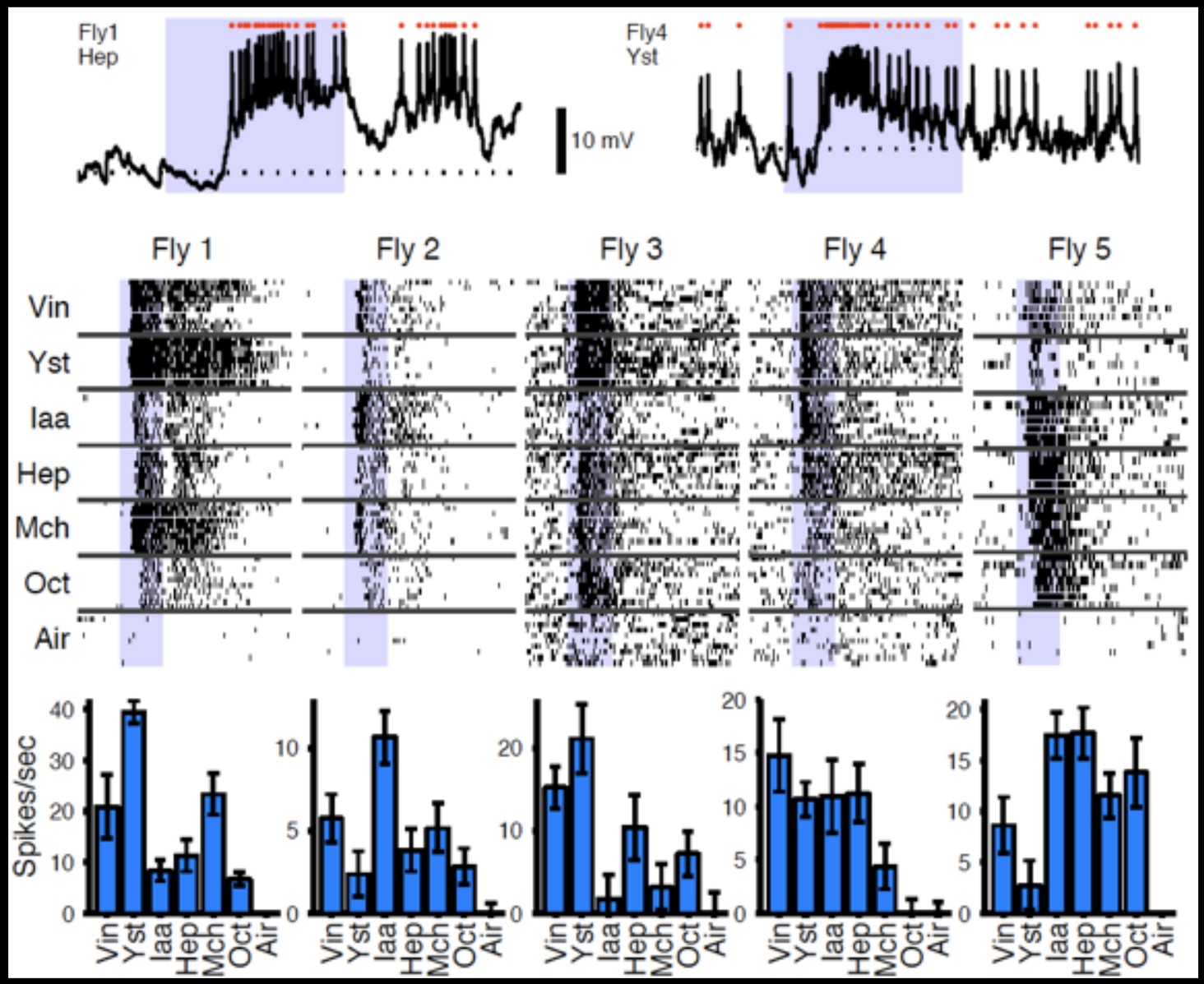
ipsilateral

contralateral

V2α2sc MBON Odor Responses

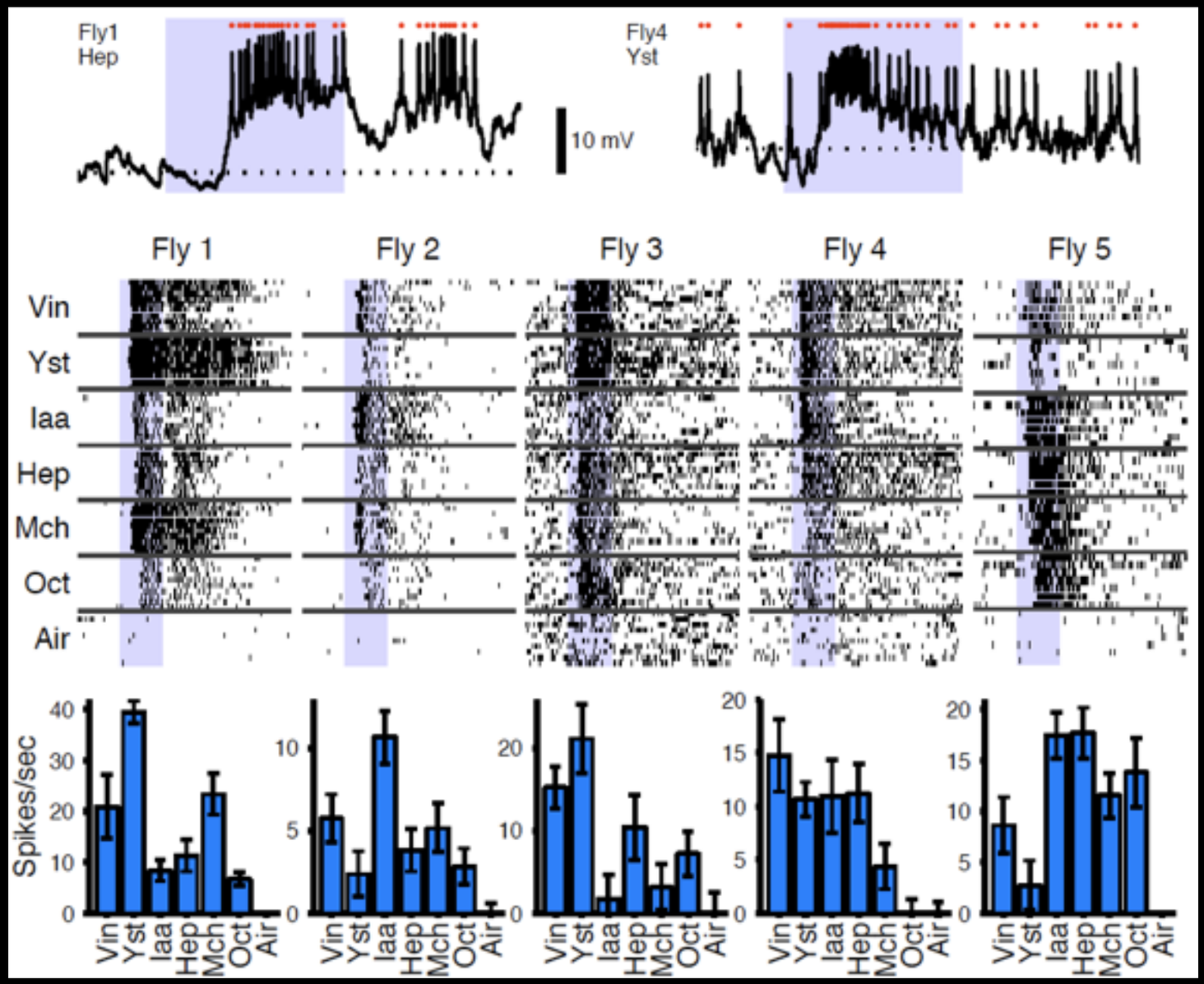


V2α2sc MBON Odor Responses



?Same neuron - different response?

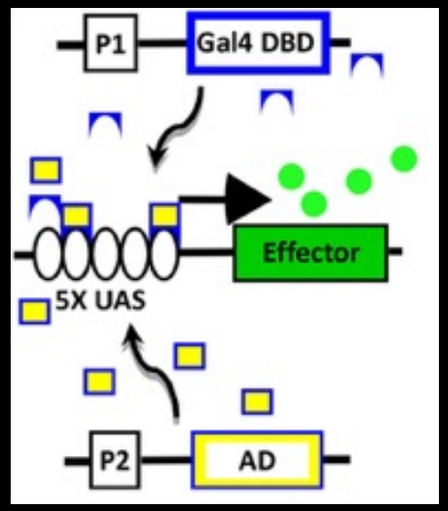
V2α2sc MBON Odor Responses

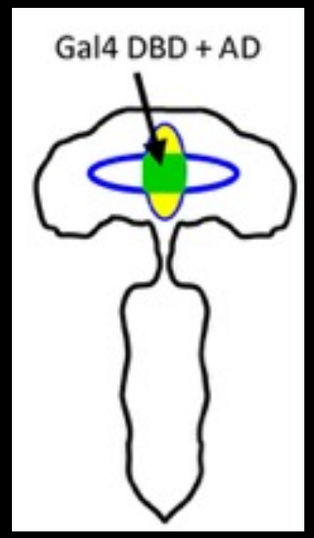


?Same neuron - different response?

Are we recording a different cell each time?
Does intracellular recording perturb the cell?

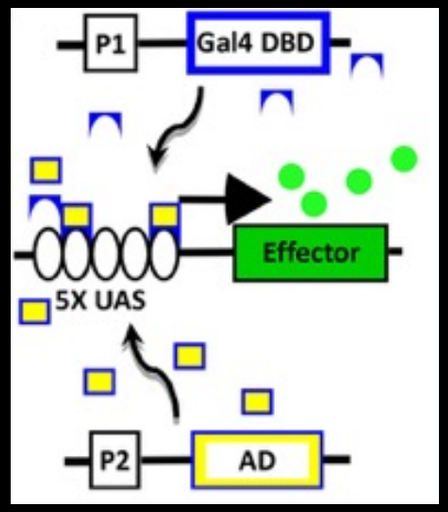
Increasing Driver Specificity with Split Gal4

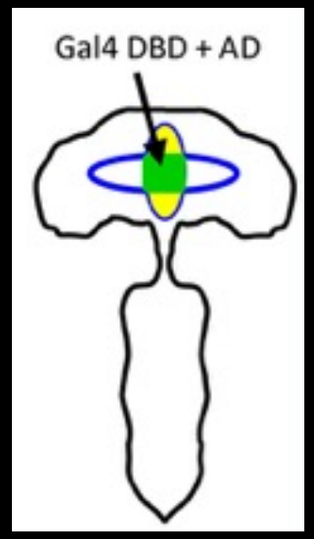




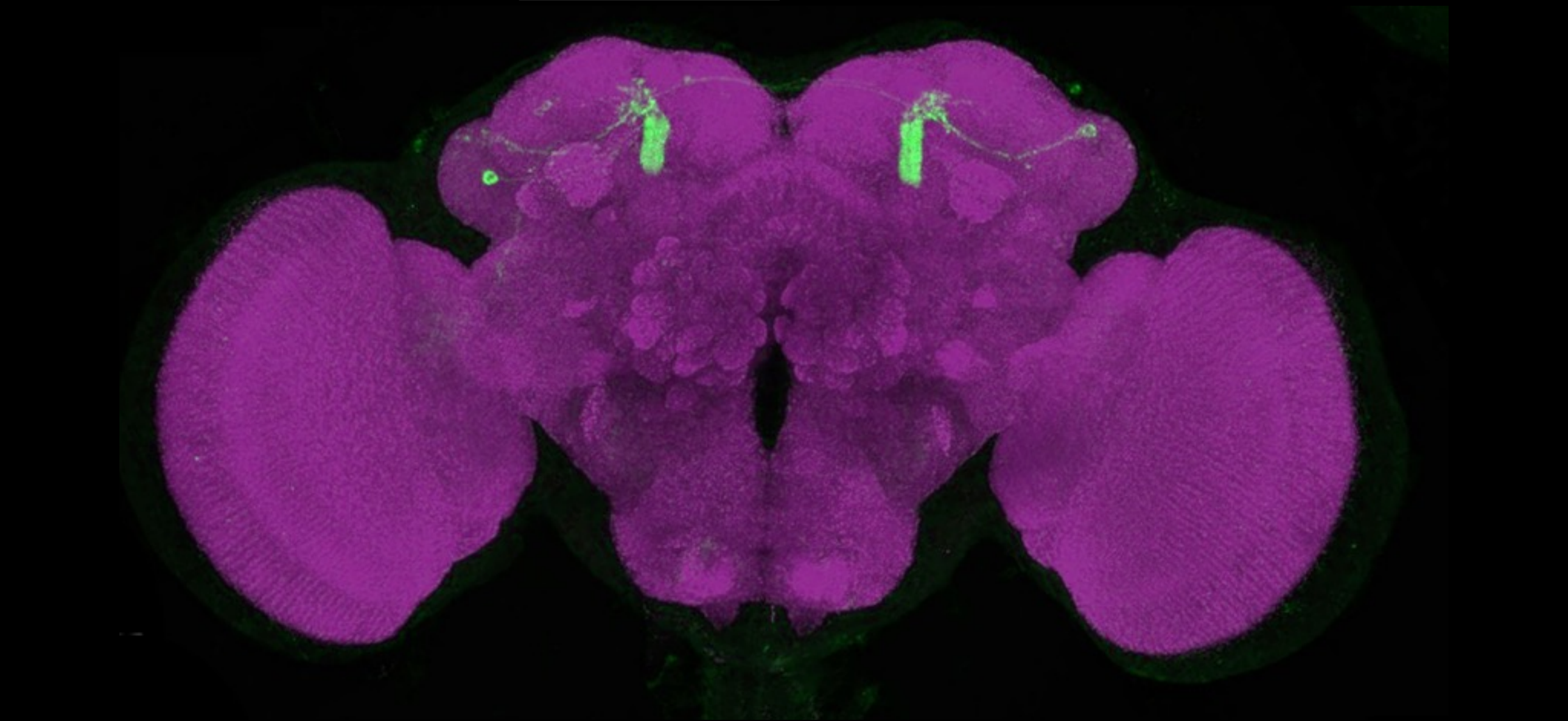
Y. Aso & G. Rubin

Increasing Driver Specificity with Split Gal4



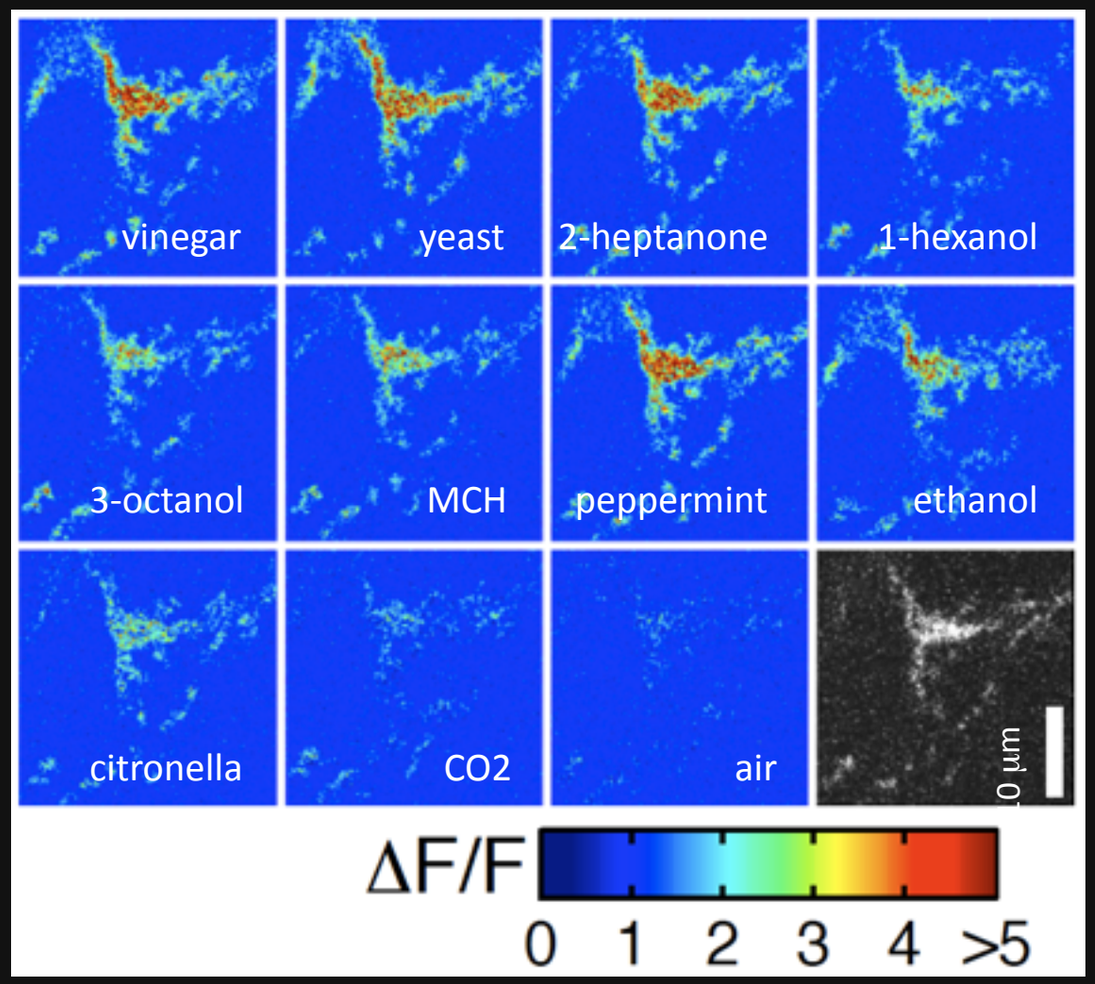


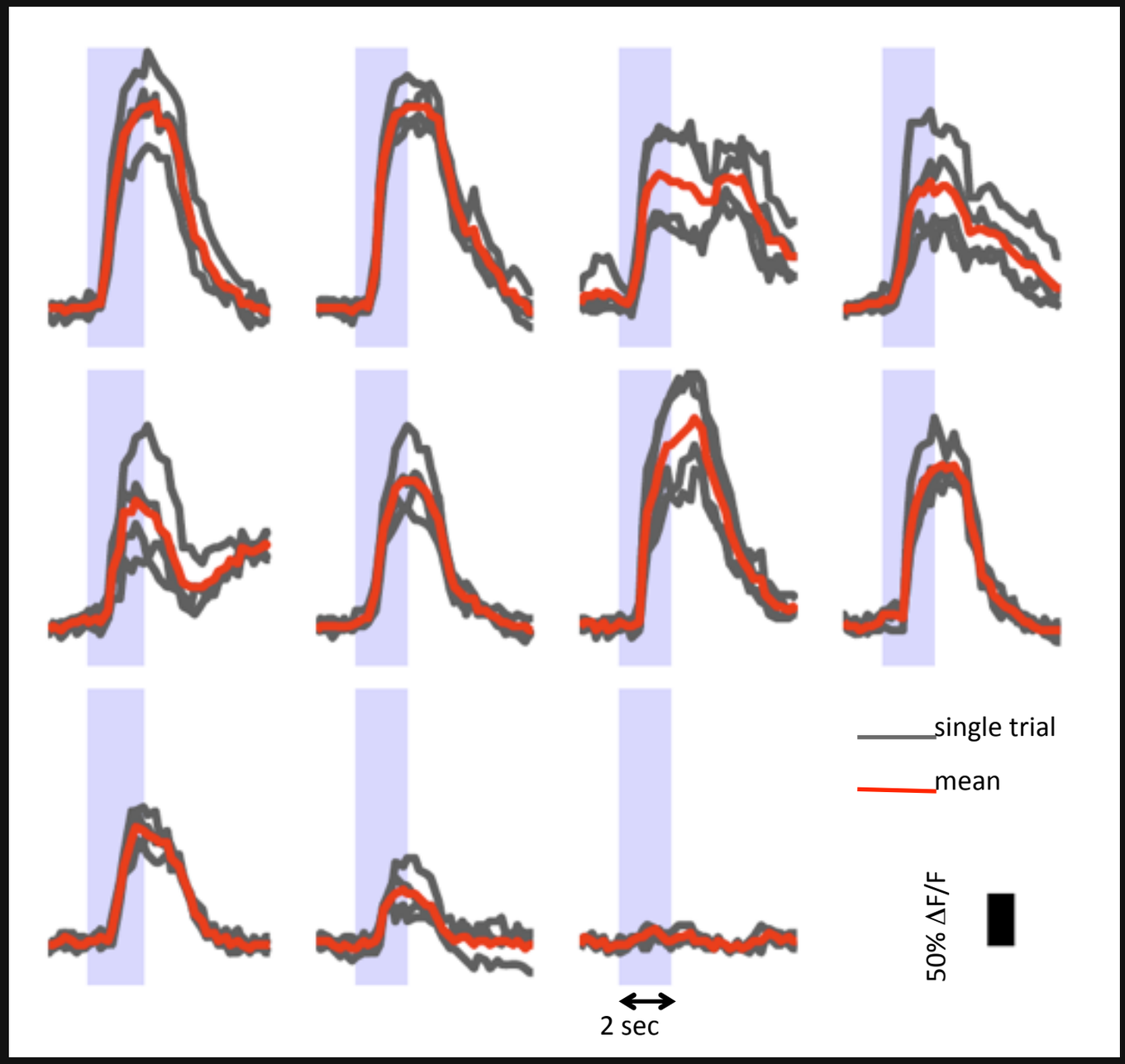
Y. Aso & G. Rubin



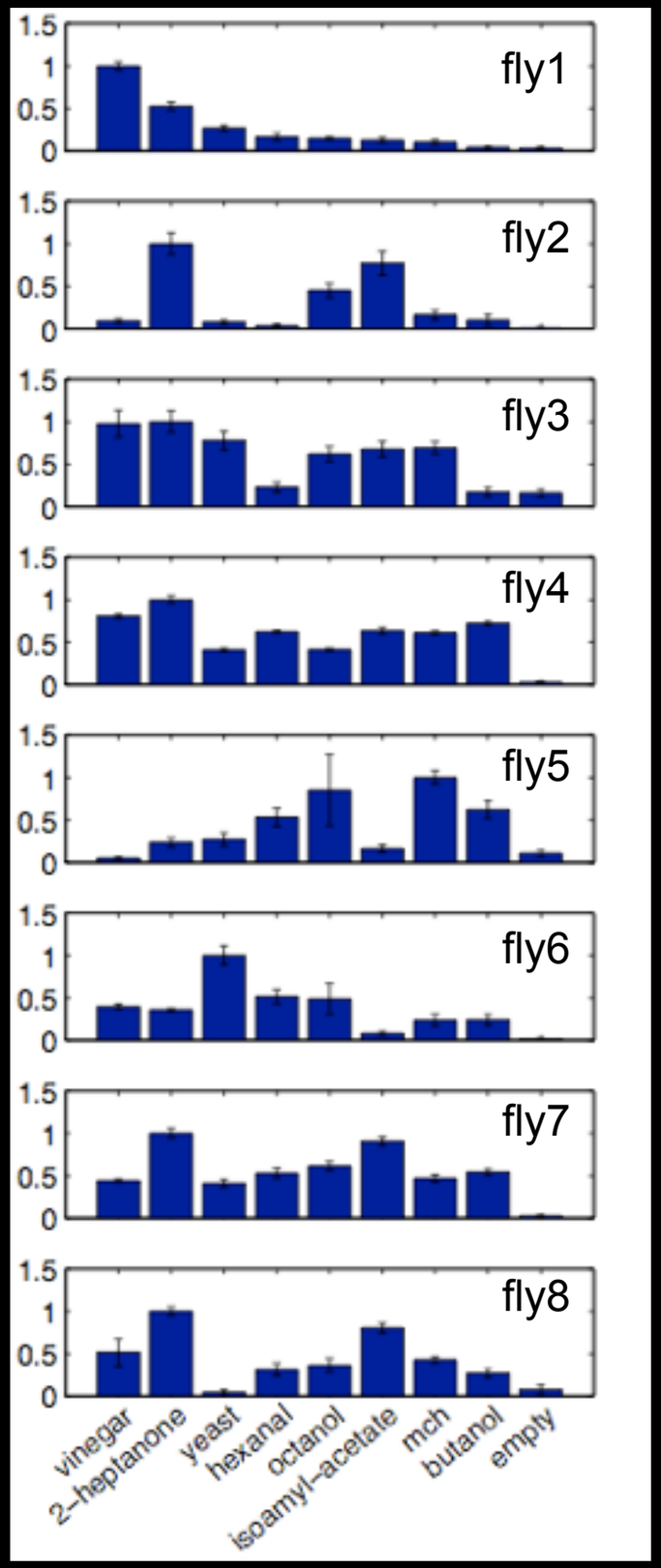
Ca^{2+} imaging in a single MBON

MB-V4 (axonal arbor)

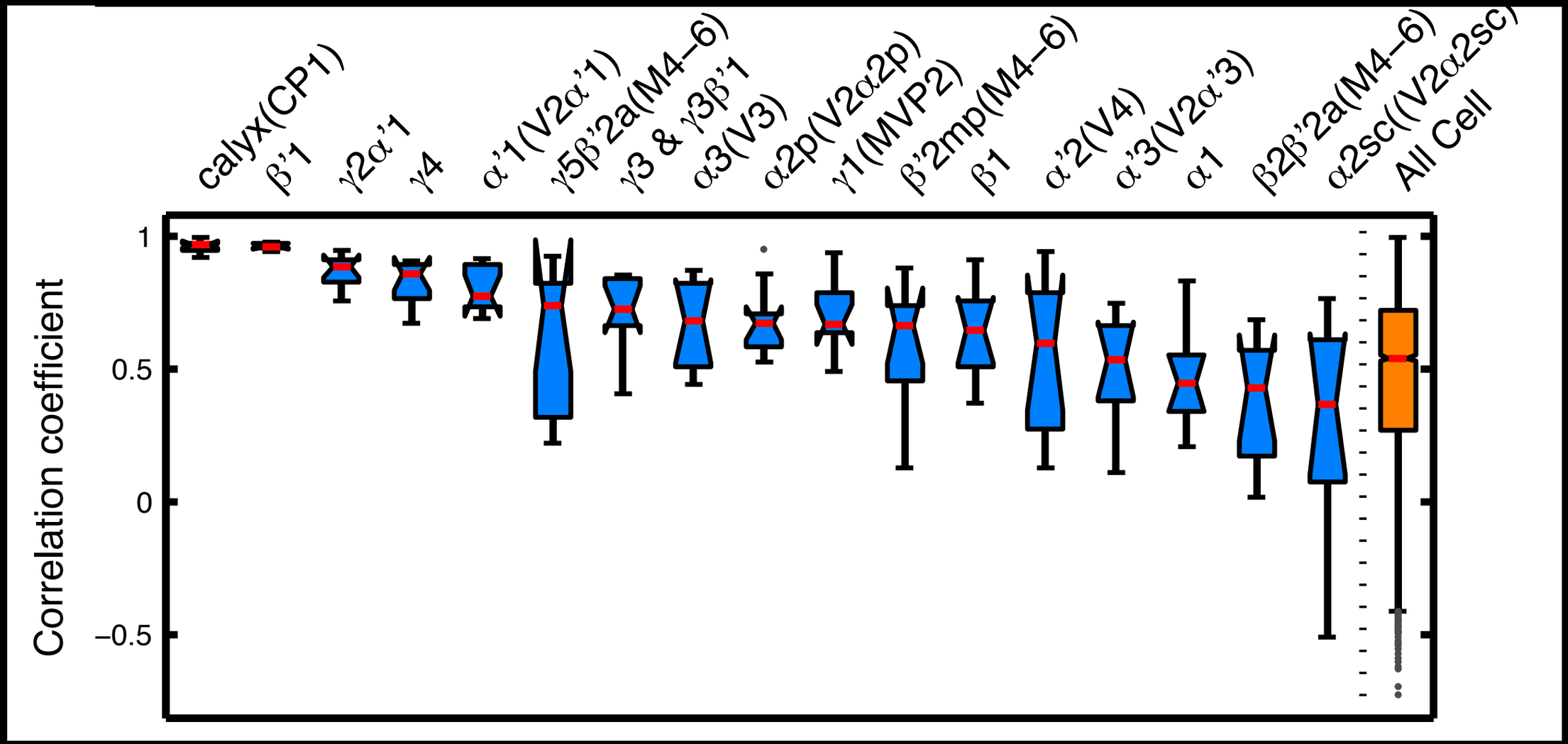




V2α2sc MBON Still Variable



Cross-fly variability of MBON odor tuning



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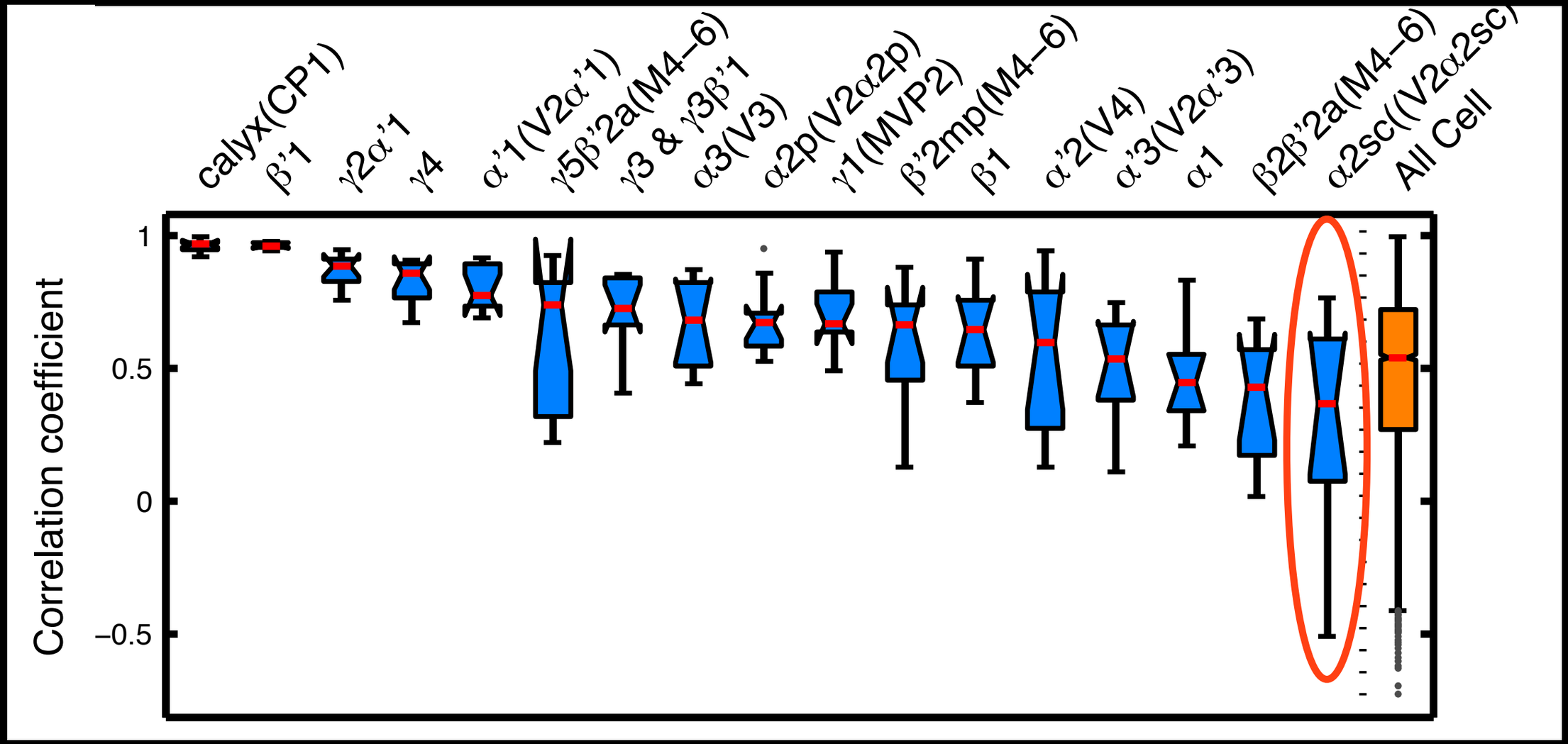
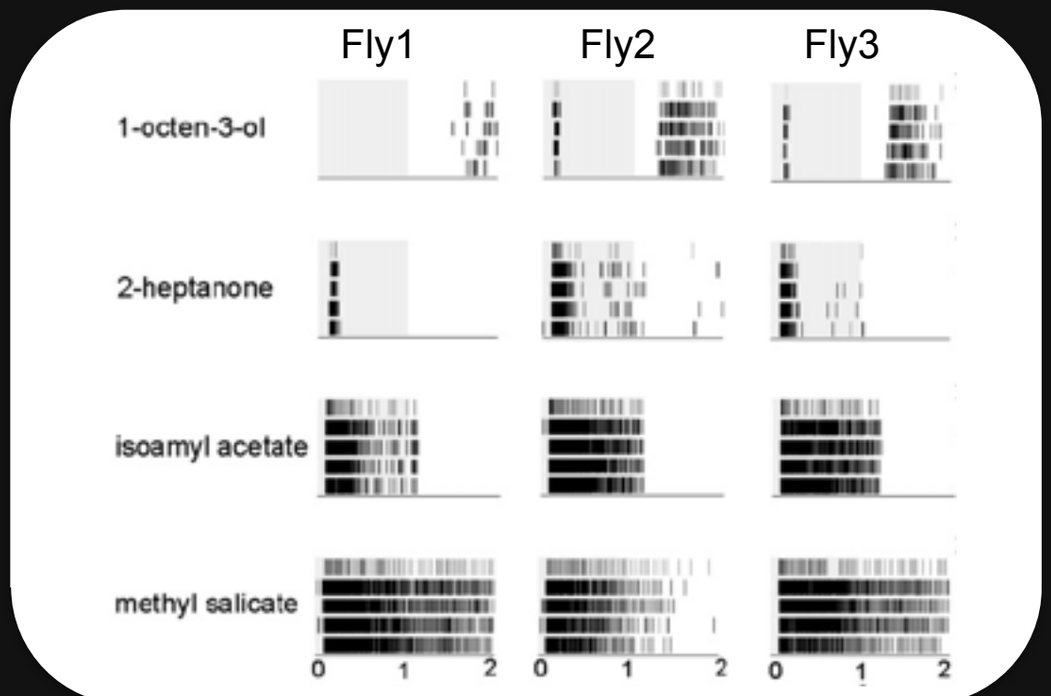
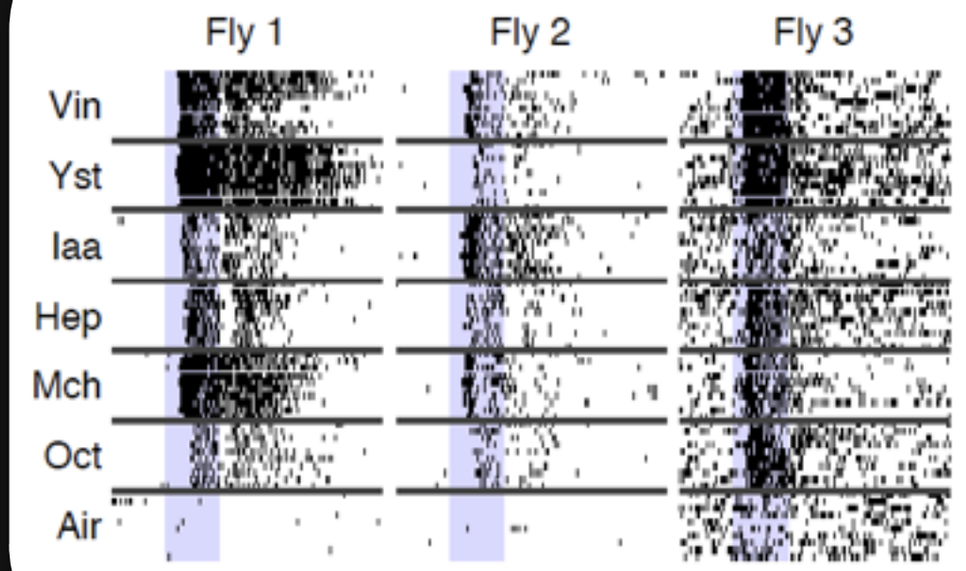


Cross-fly variability - a feature of deeper layers

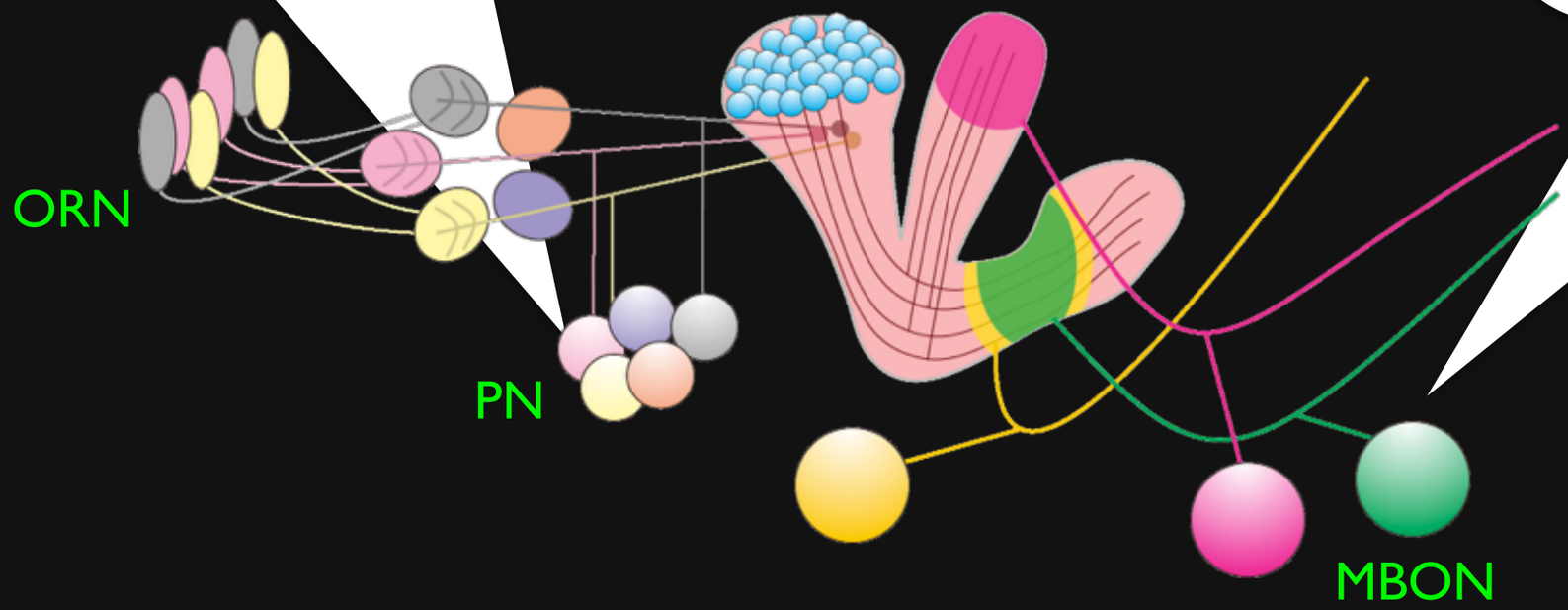
Stereotyped



Non-stereotyped



Murthy Fiete Laurent Neuron 2008



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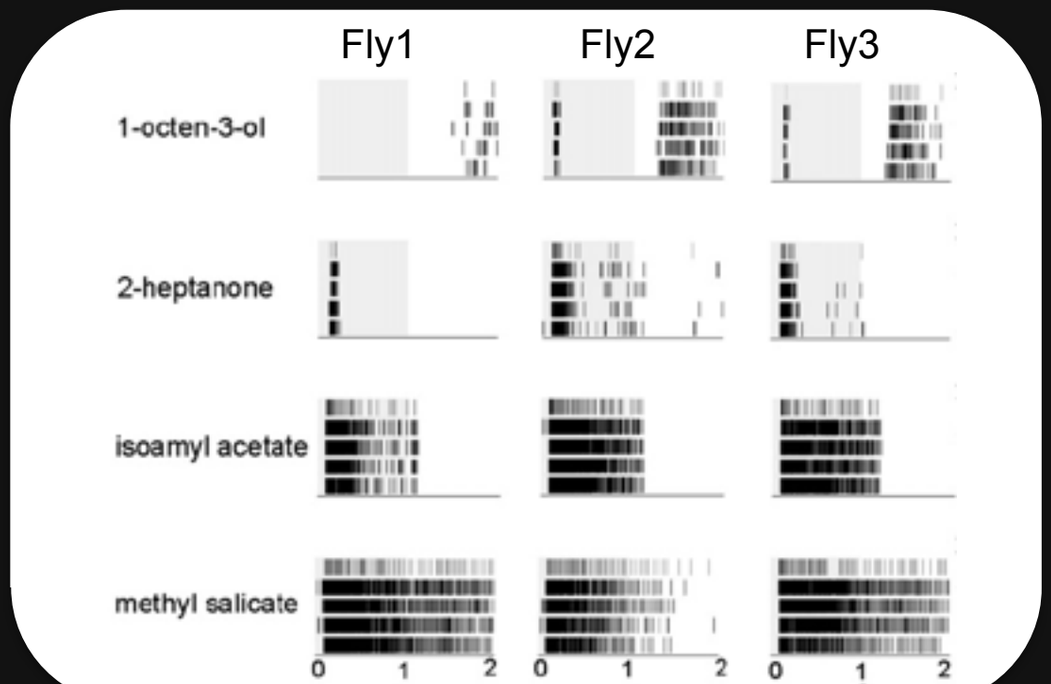
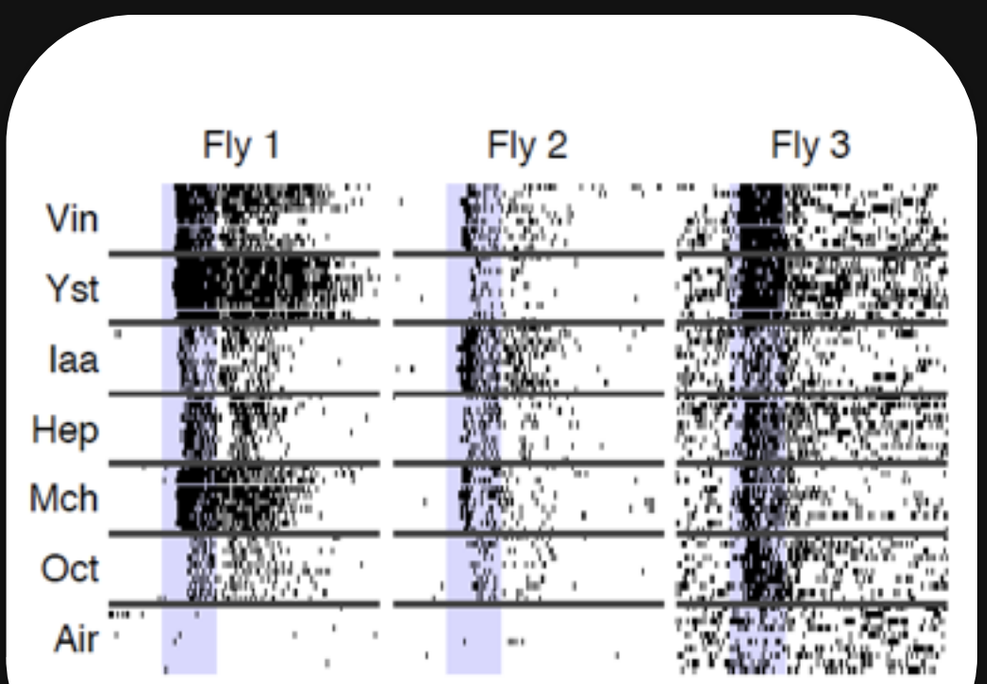
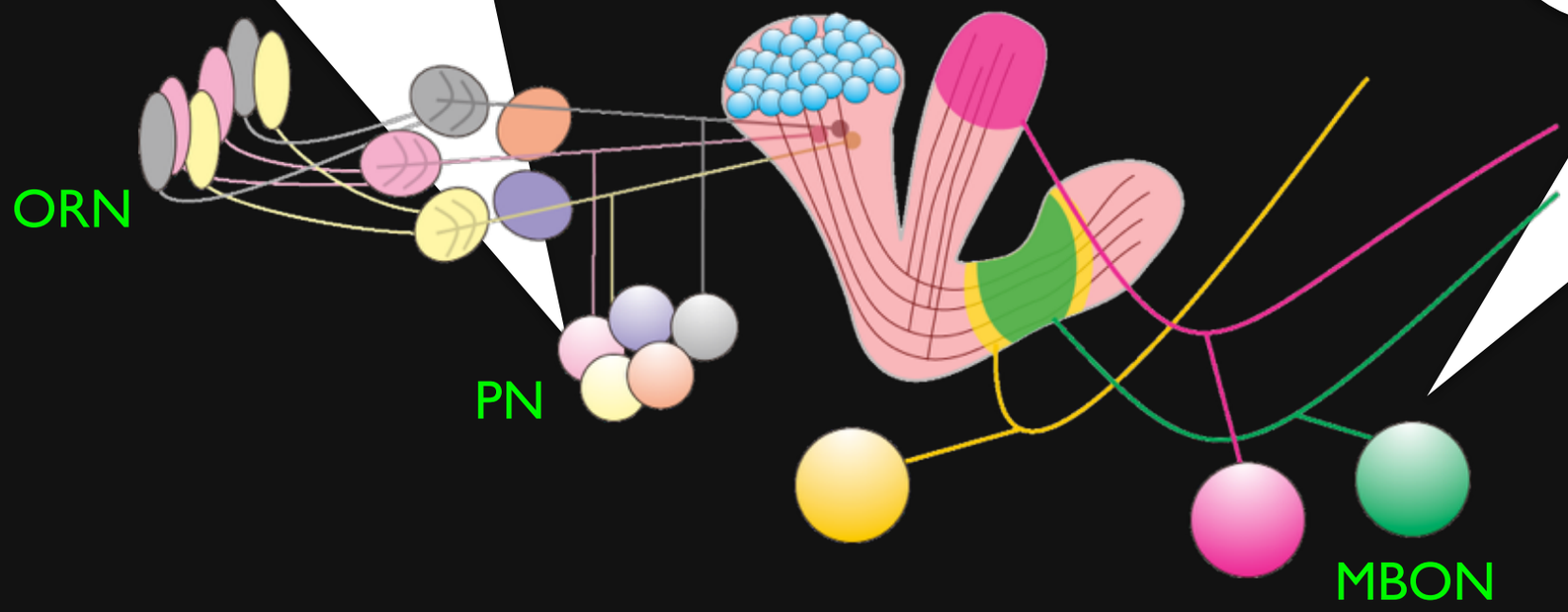


Murthy Fiete Laurent Neuron 2008

Non-stereotyped





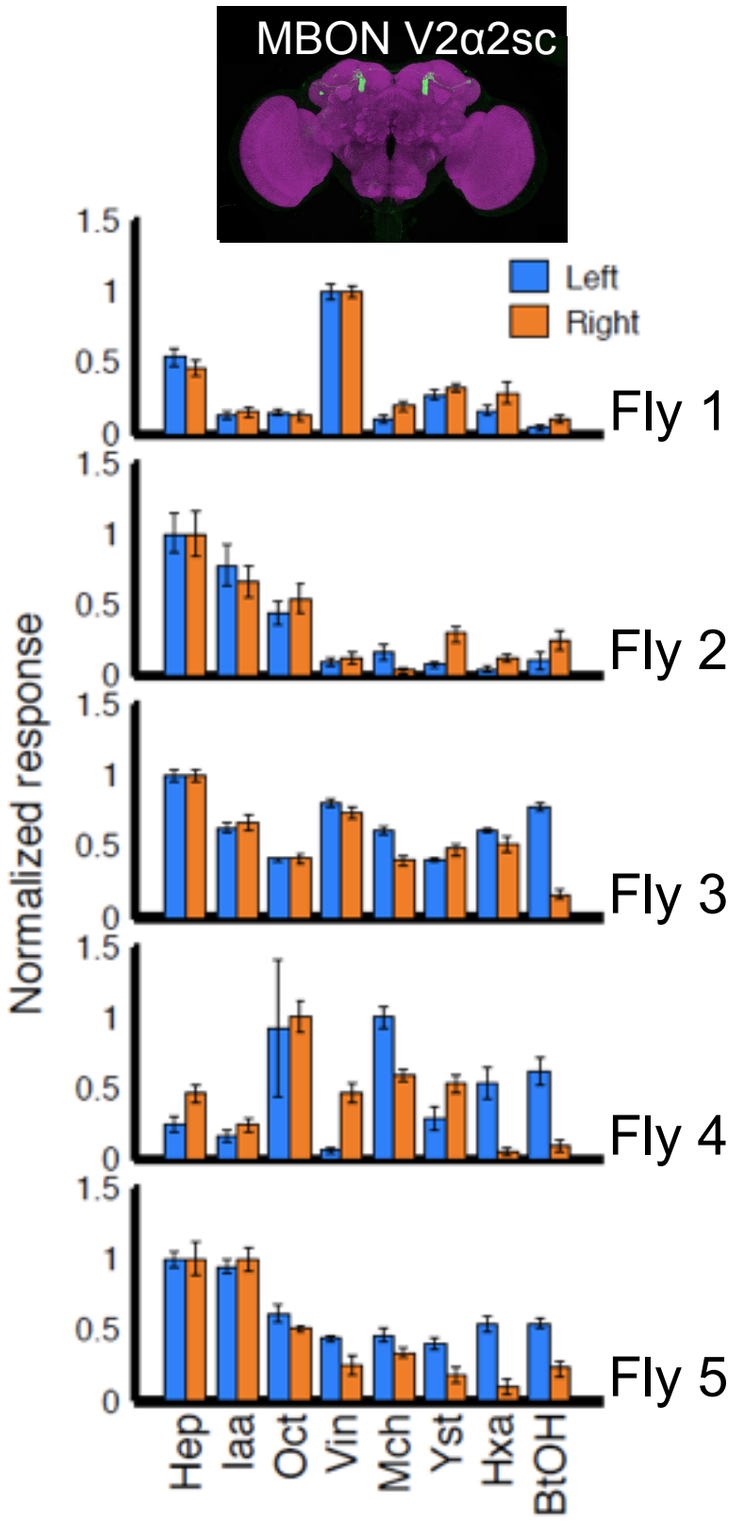
What controls the tuning pattern?

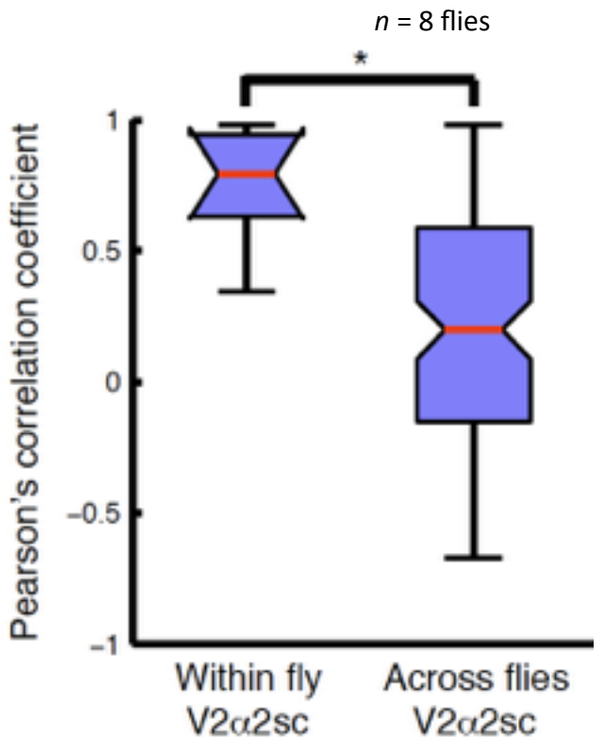
Experience-dependent plasticity?

If variability is the result of experience-dependent plasticity

Prediction: *A pair of identical neurons in the same animal should be more correlated than across different animals.*

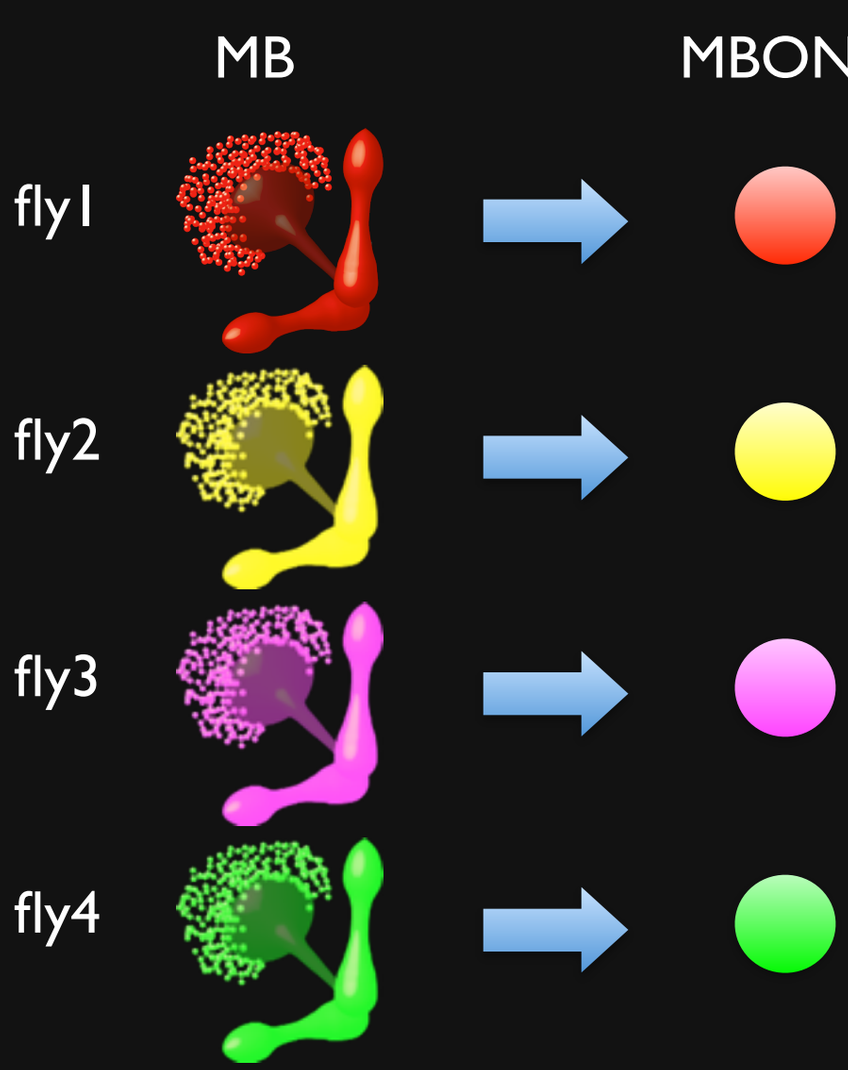
Similar MBON tuning in both hemispheres





How does variability arise?

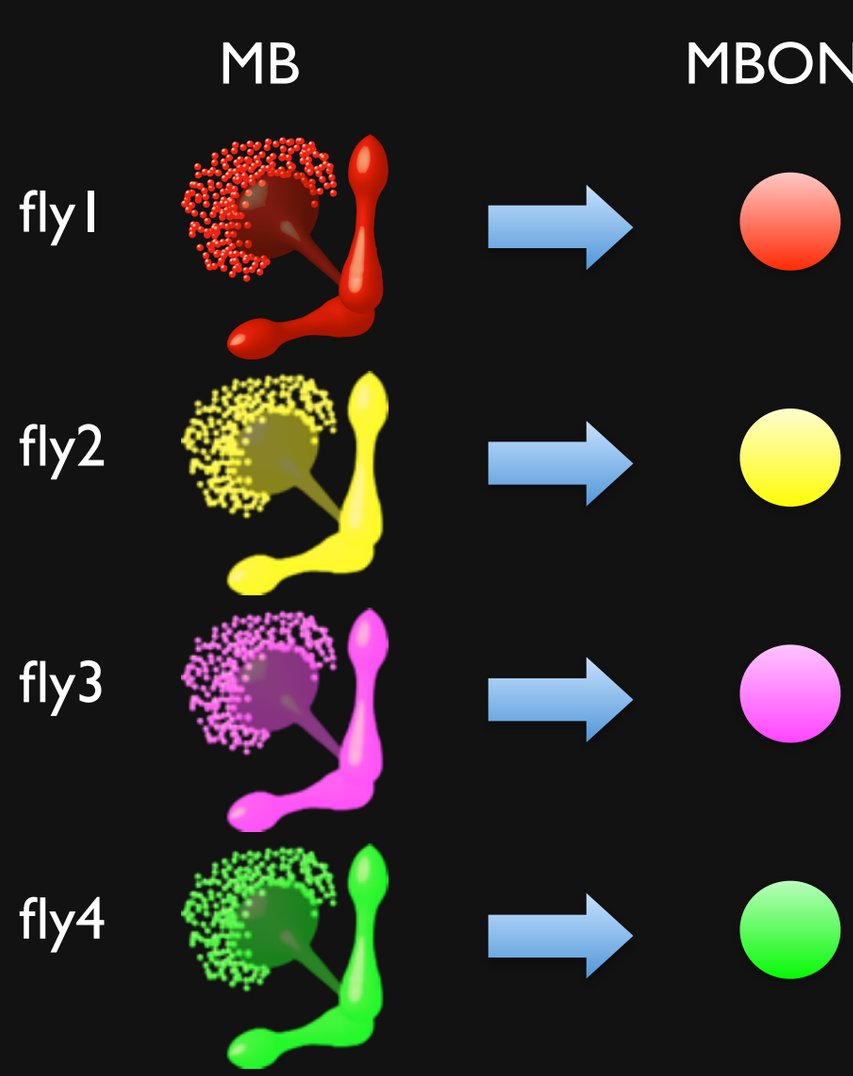
1. Variability inherited from KCs



Prediction:
KC population responses vary across flies

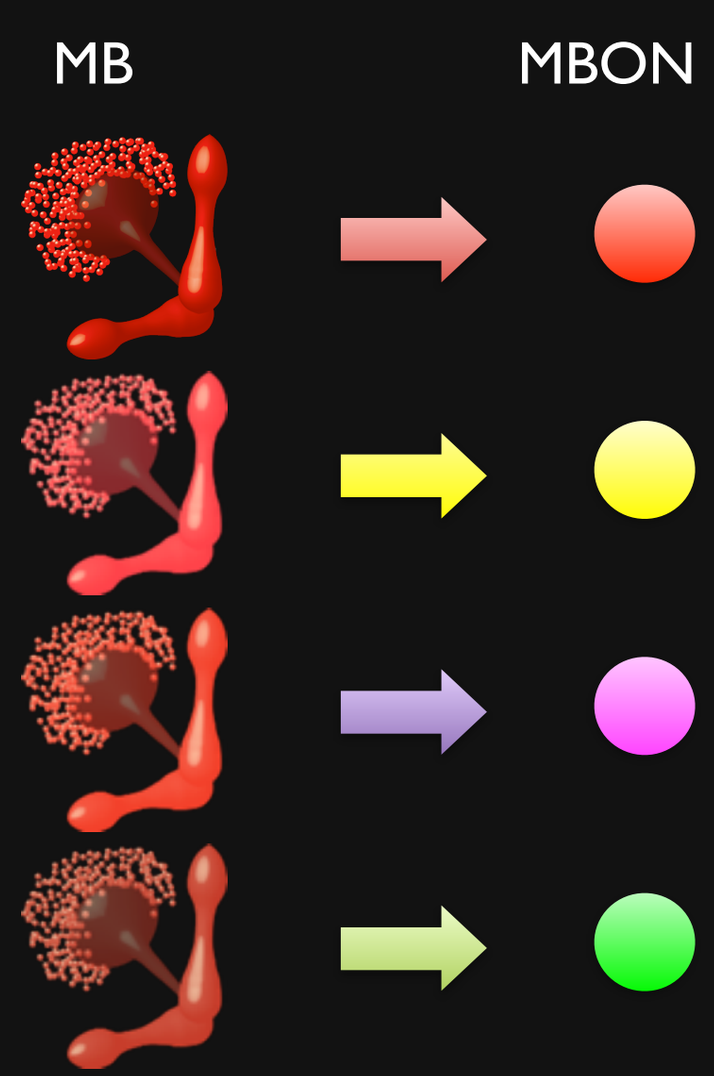
How does variability arise?

1. Variability inherited from KCs



Prediction:
KC population responses vary across flies

2. Variable KC-MBON connectivity

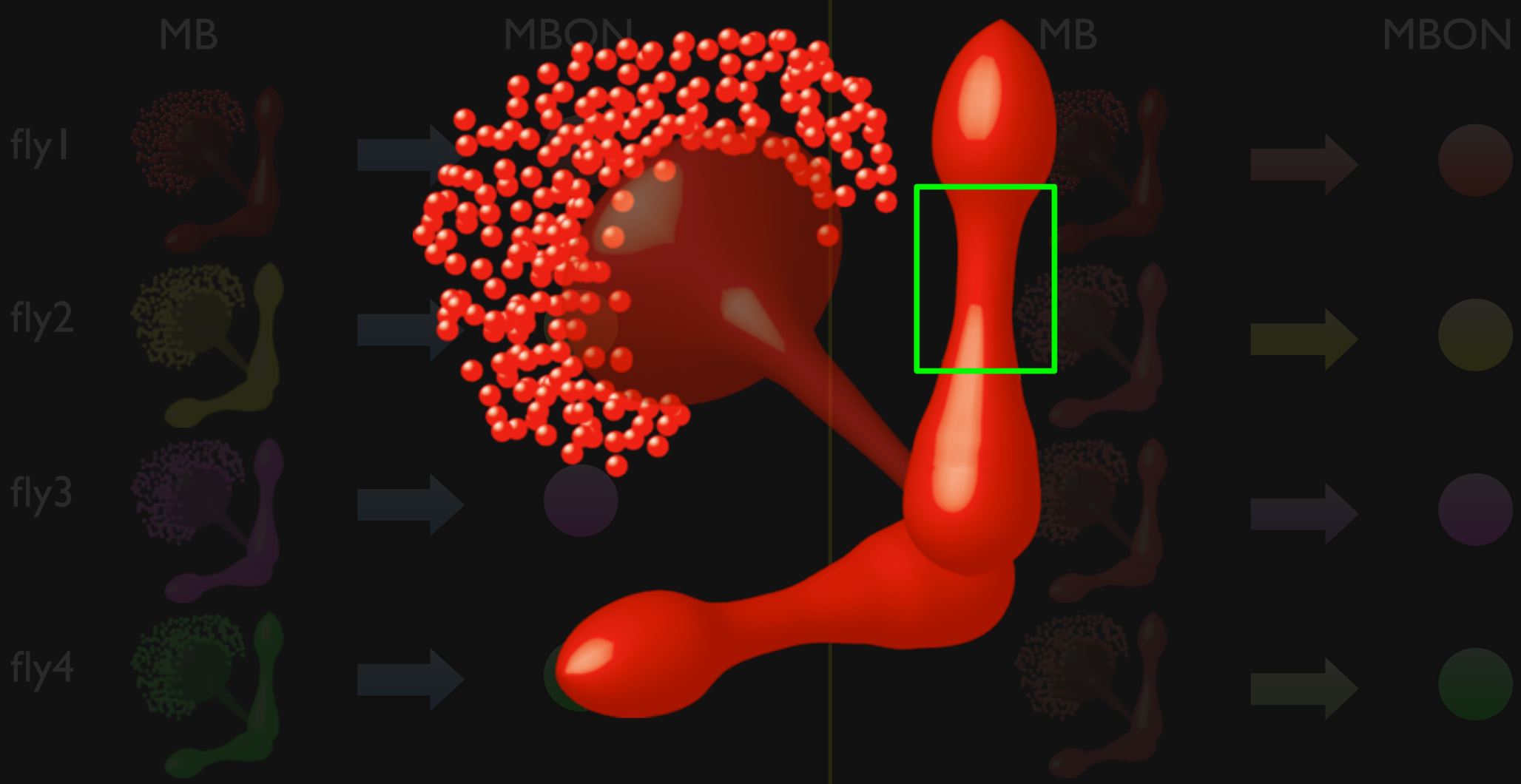


Prediction:
KC population responses can be similar

How does variability arise?

1. Variability inherited from KCs

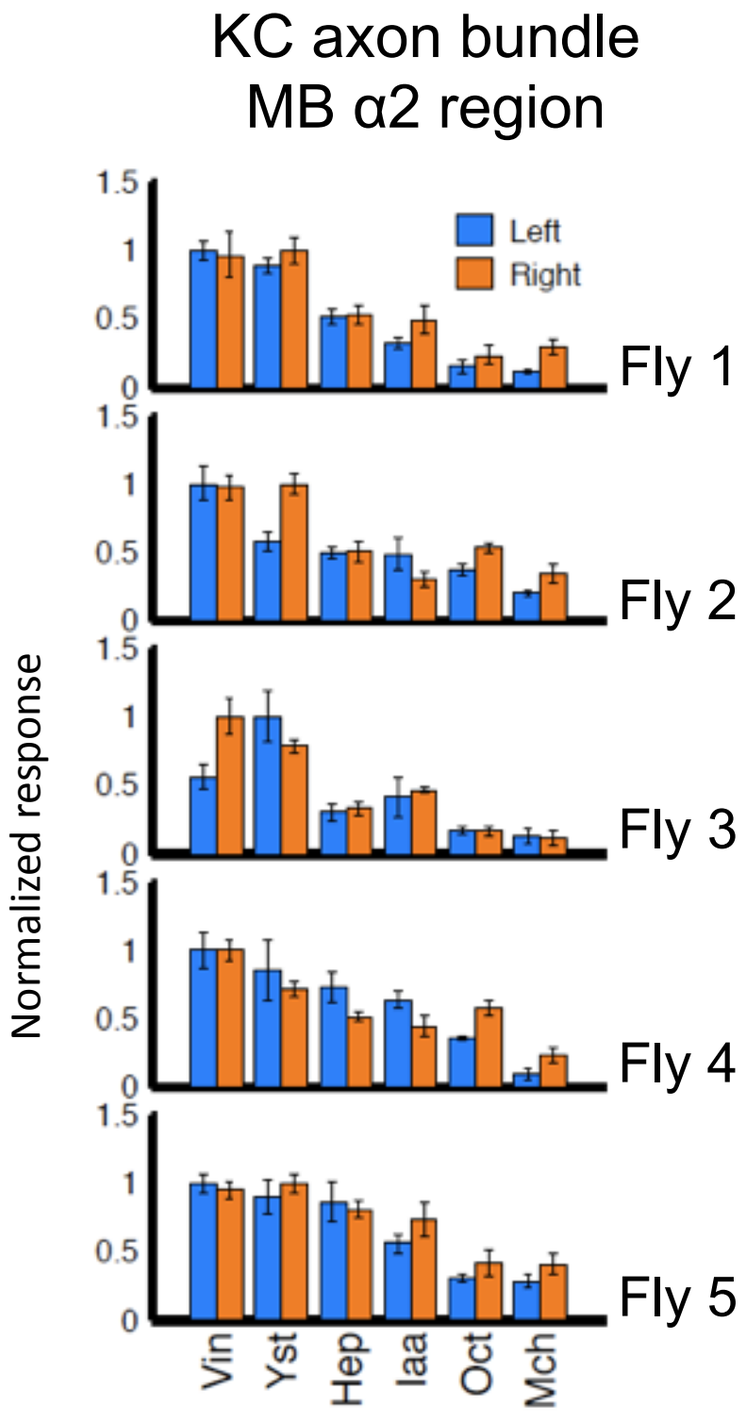
2. Variable KC-MBON connectivity

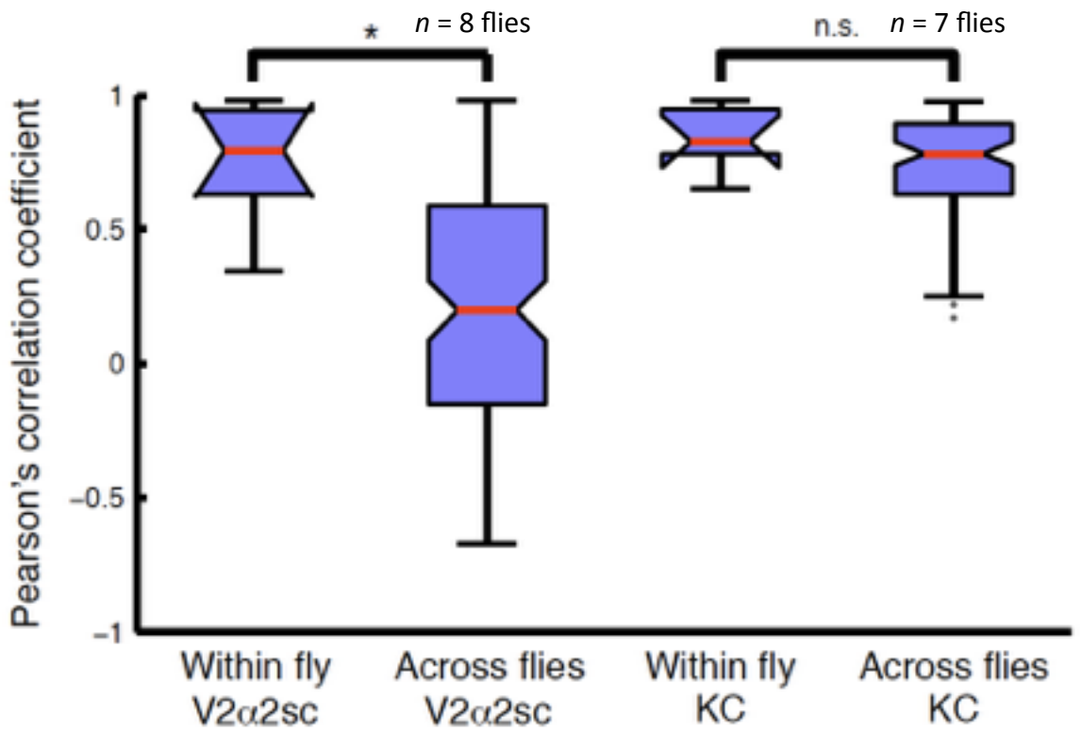


Prediction:
KC population responses vary across flies

Prediction:
KC population responses can be similar

KC population responses are consistent across flies

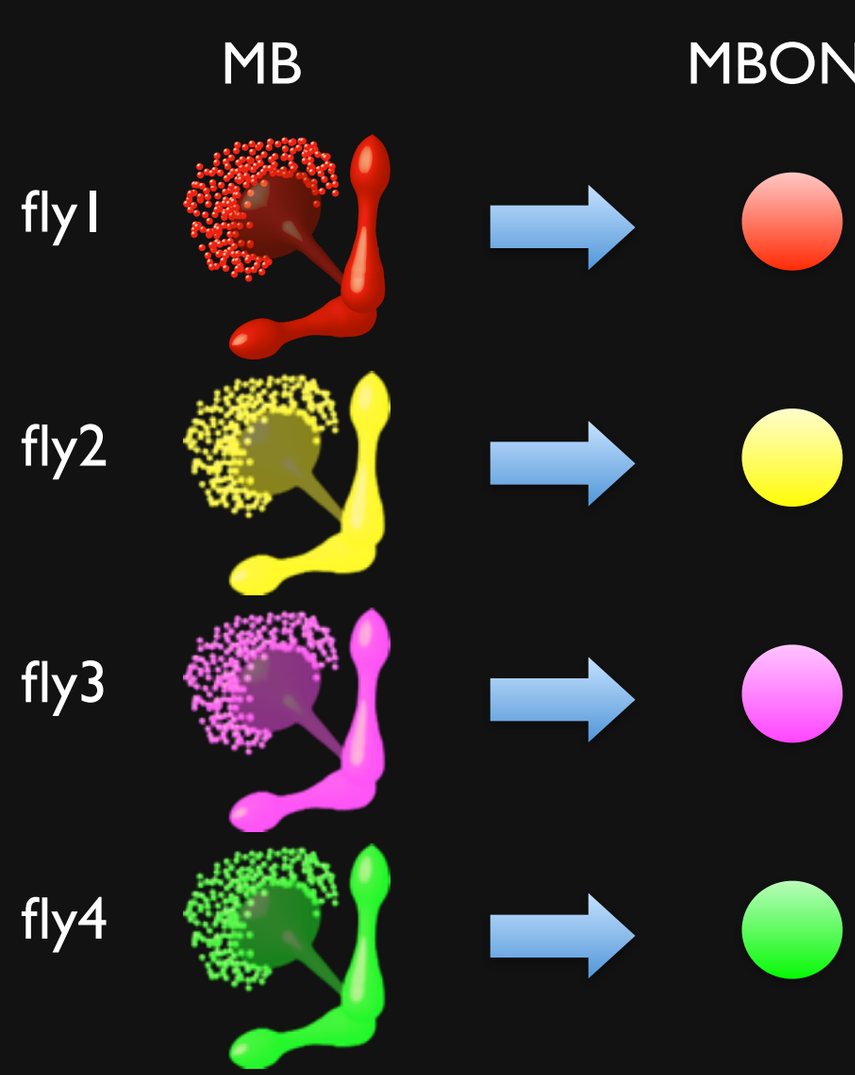




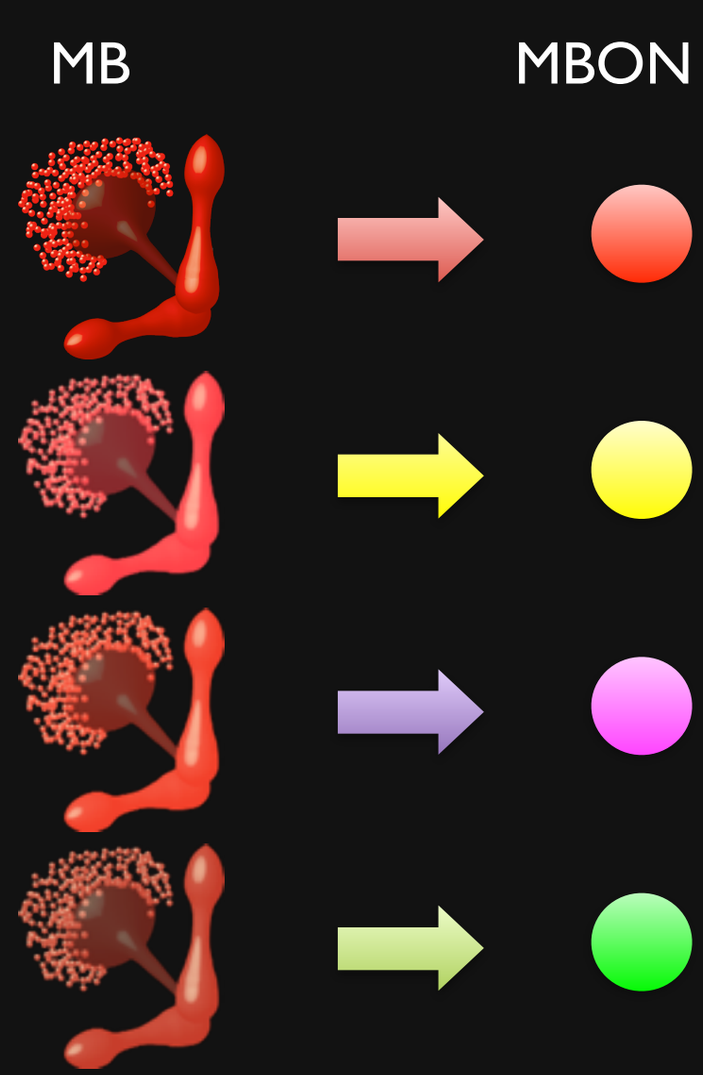
MBON variability is not inherited from the KCs

How does variability arise?

Hypothesis 1: Variability inherited from KCs

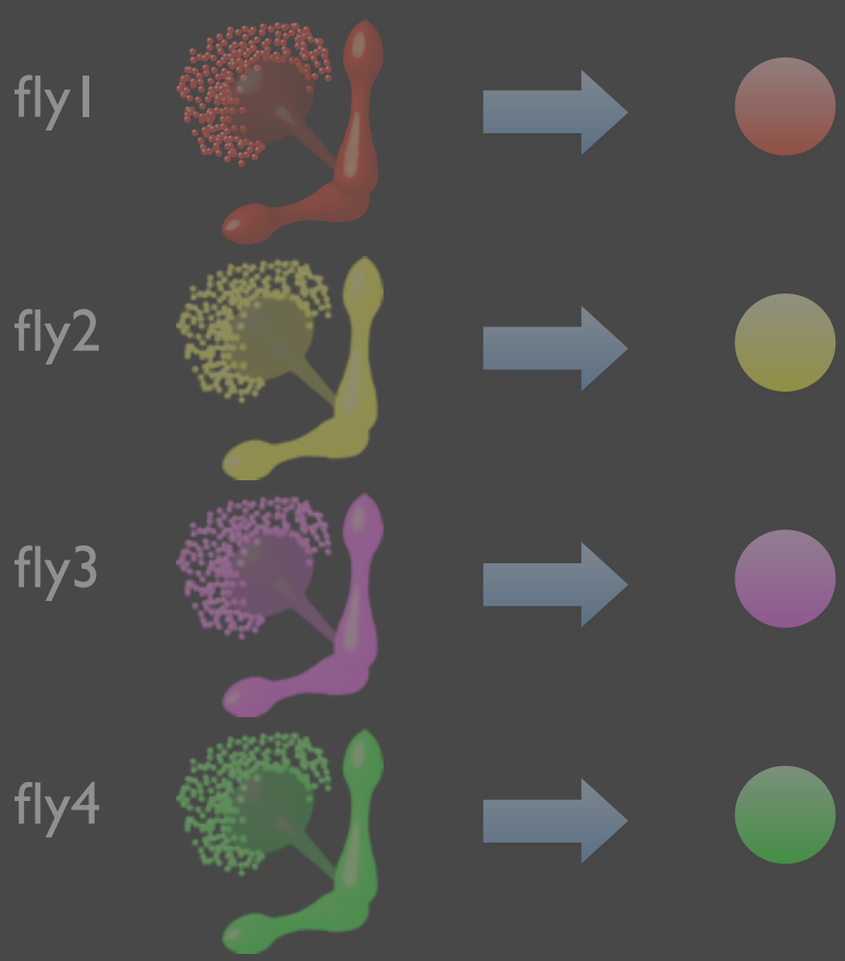


Hypothesis 2: Variable KC-MBON connectivity

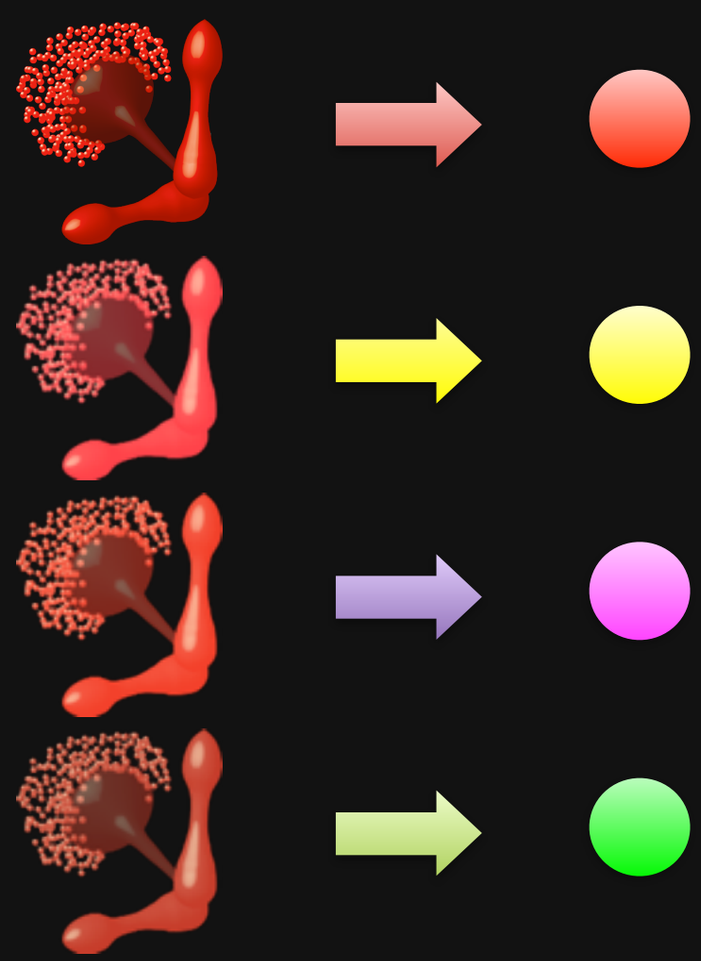


How does variability arise?

Hypothesis 1: Variability inherited from KCs



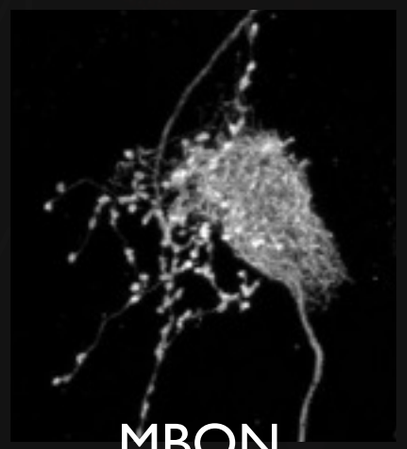
Hypothesis 2: Variable KC-MBON connectivity



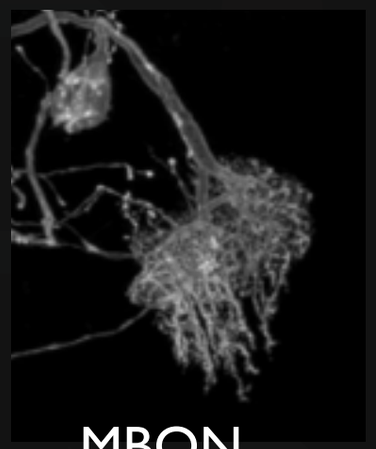
How does variability arise?

Hypothesis 1: Variability inherited from KCs

Dendrite structures



MBON
V2α2sc

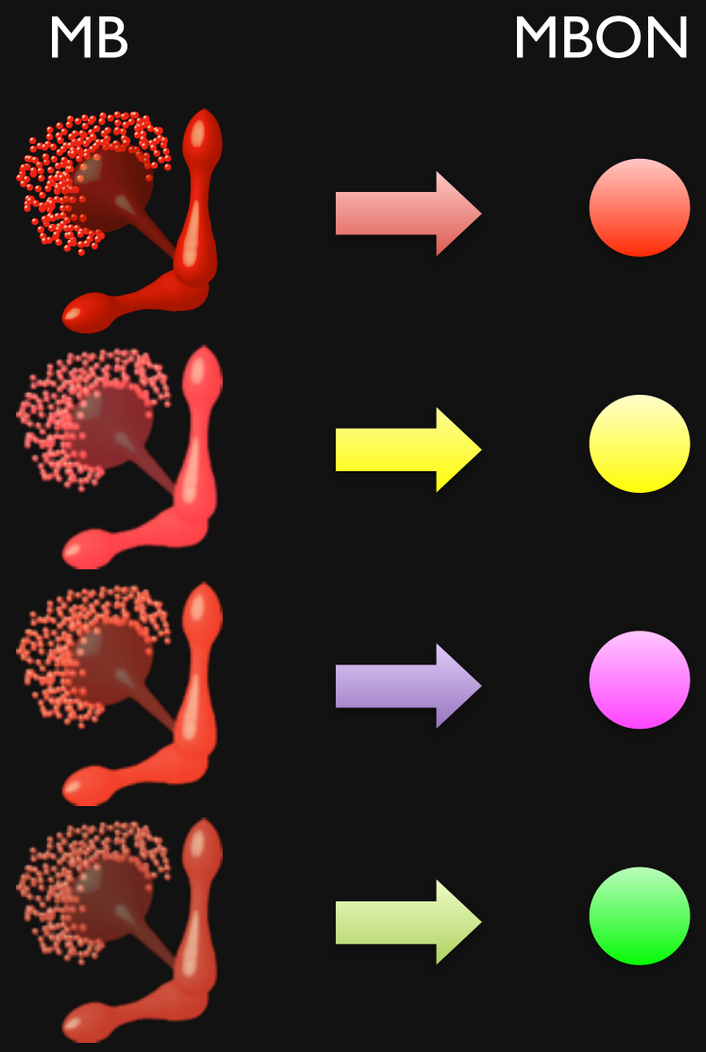


MBON
MV2

Expect very high connectivity

fly4

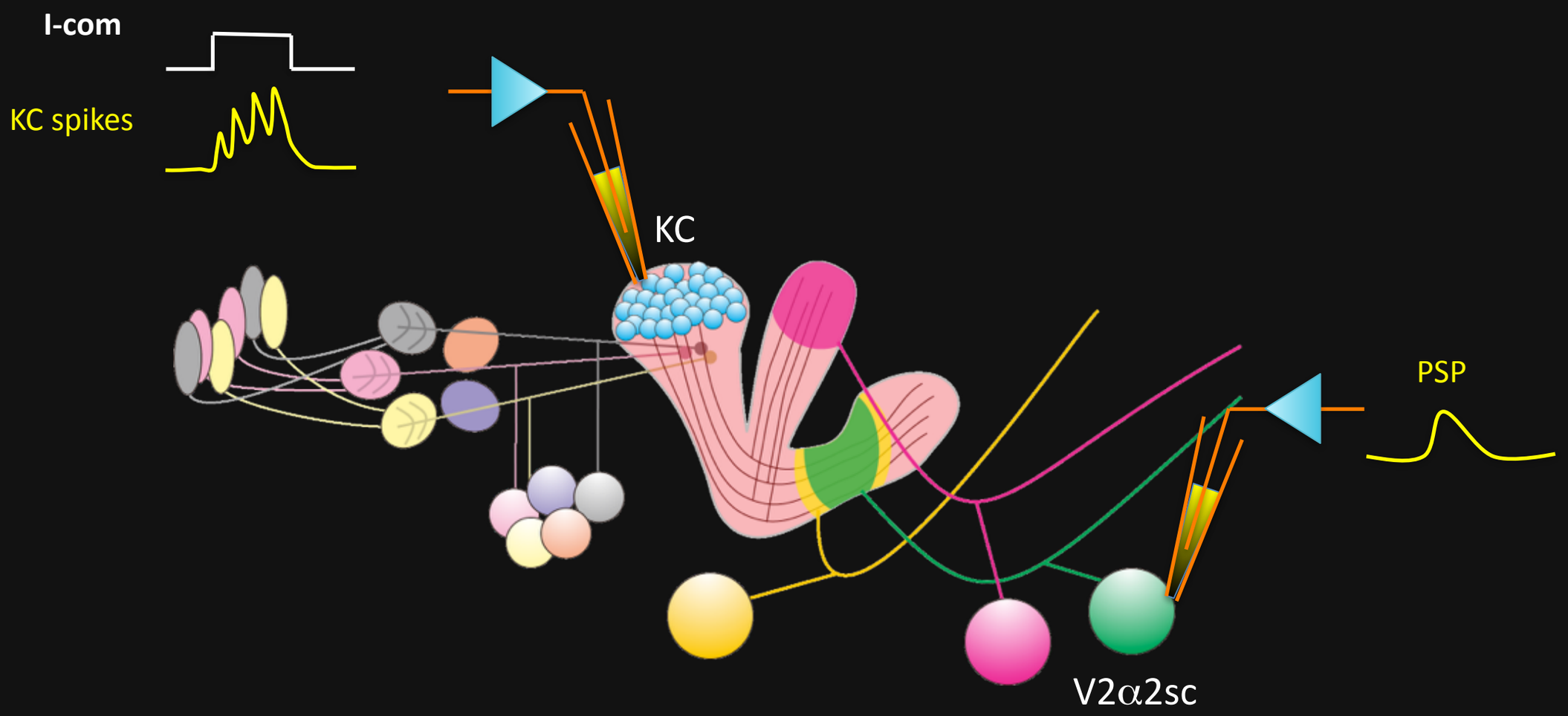
Hypothesis 2: Variable KC-MBON connectivity



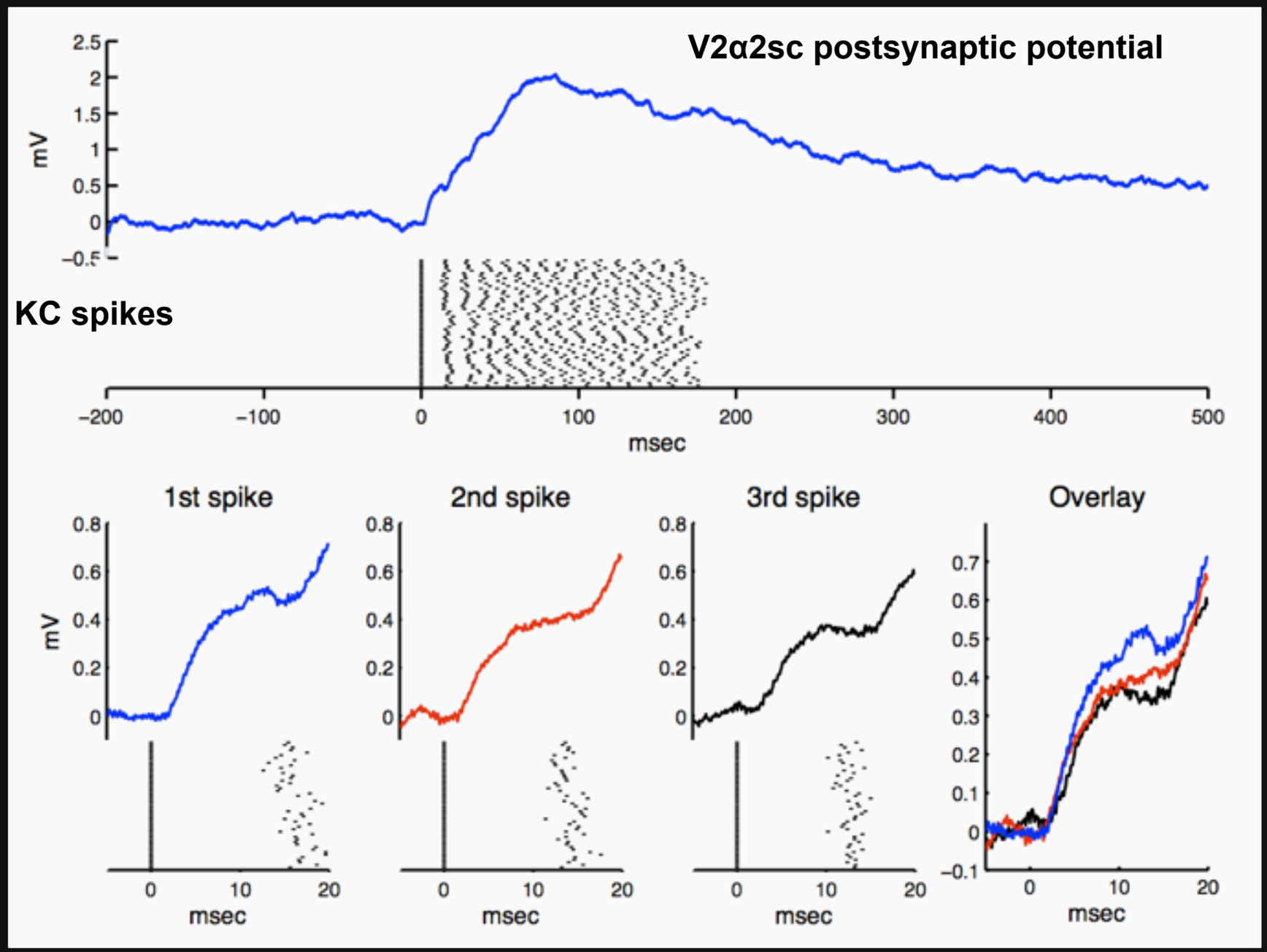
All-to-one connectivity or selective?

All-to-one connectivity or selective?

Paired intracellular recordings from α/β KCs and V2α2sc to determine KC-MBON connectivity levels

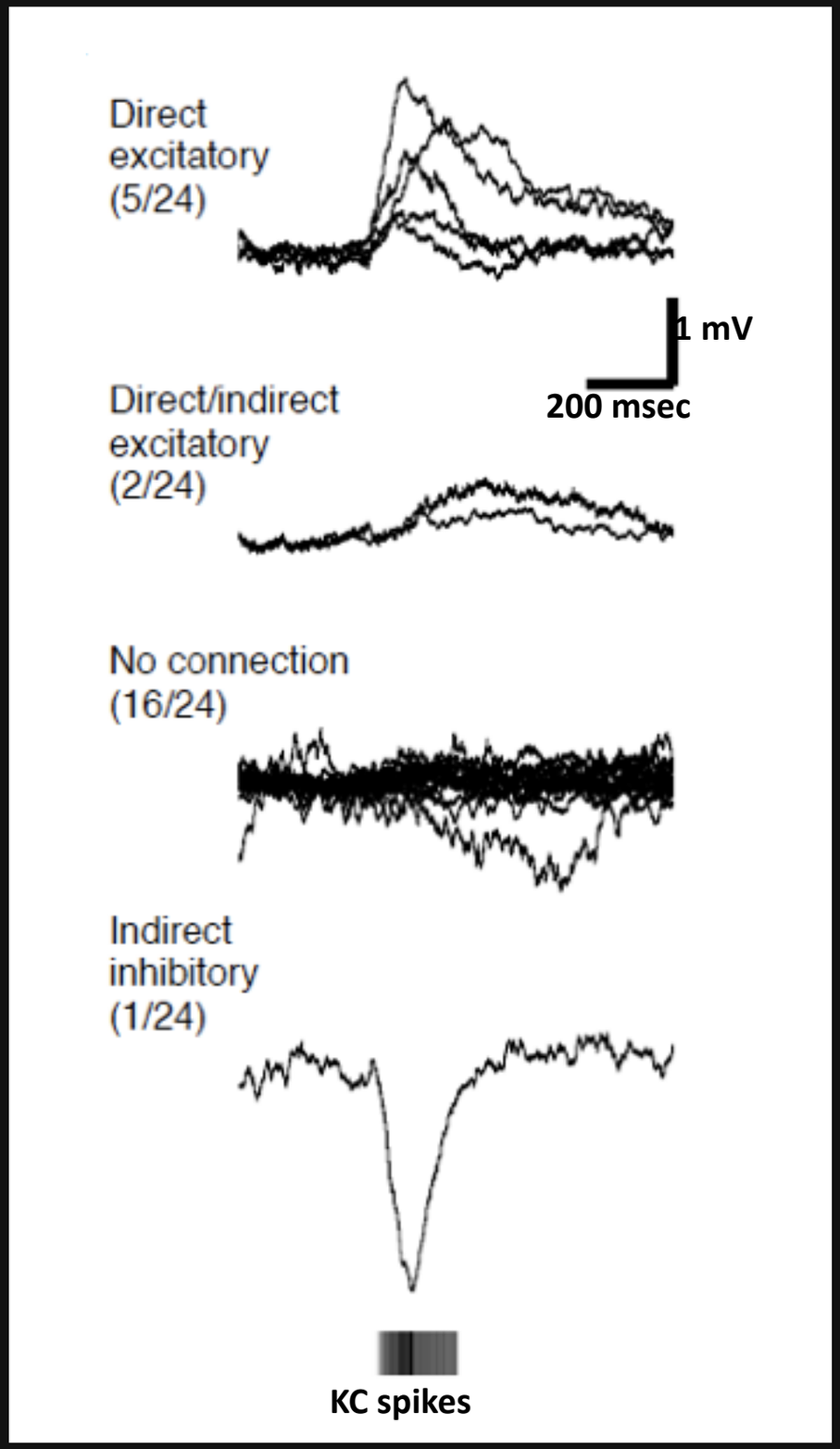


Functional connectivity between α/β KC & V2α2sc



In 100µM Mecamylamine (nAchR blocker)

Functional connection rate is low



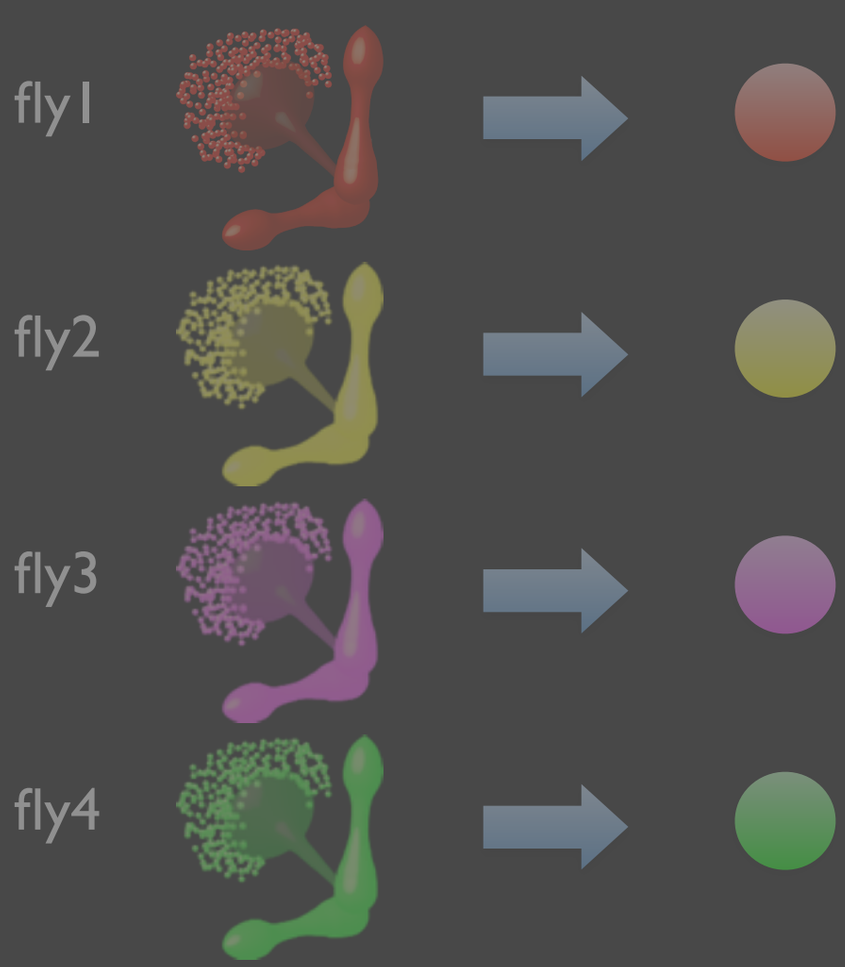
7 out of 24 pairs

Anatomical contact: ≈ 90 %

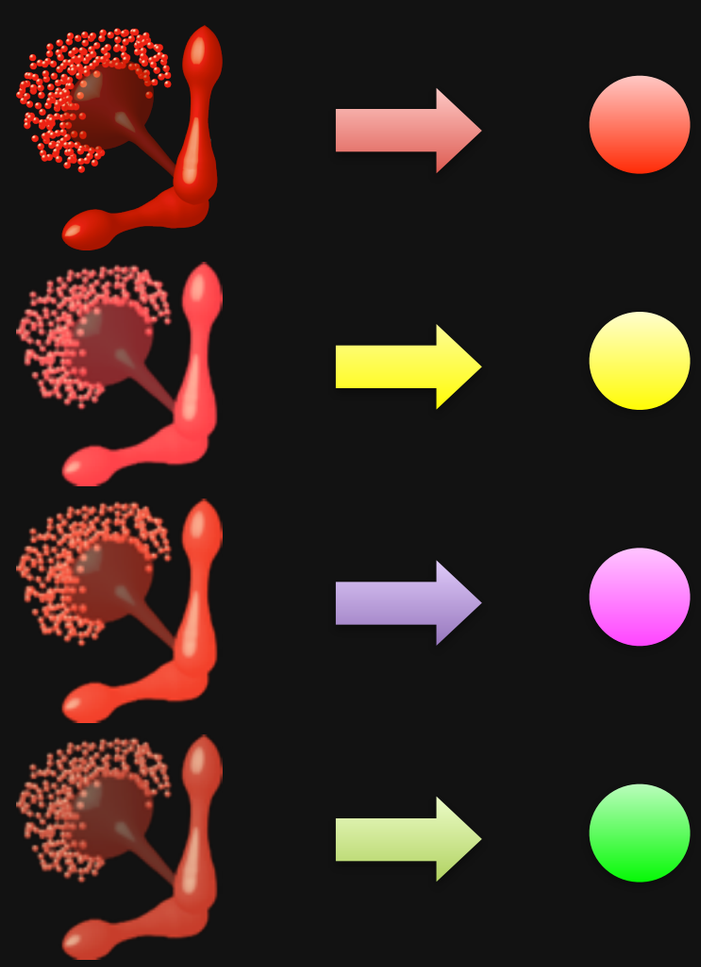
Only ≈ 30 % of α/β KCs are functionally connected to MB-V2α2sc

How does variability arise?

Hypothesis 1: Variability inherited from KCs



Hypothesis 2: Variable KC-MBON connectivity



How does variability arise?

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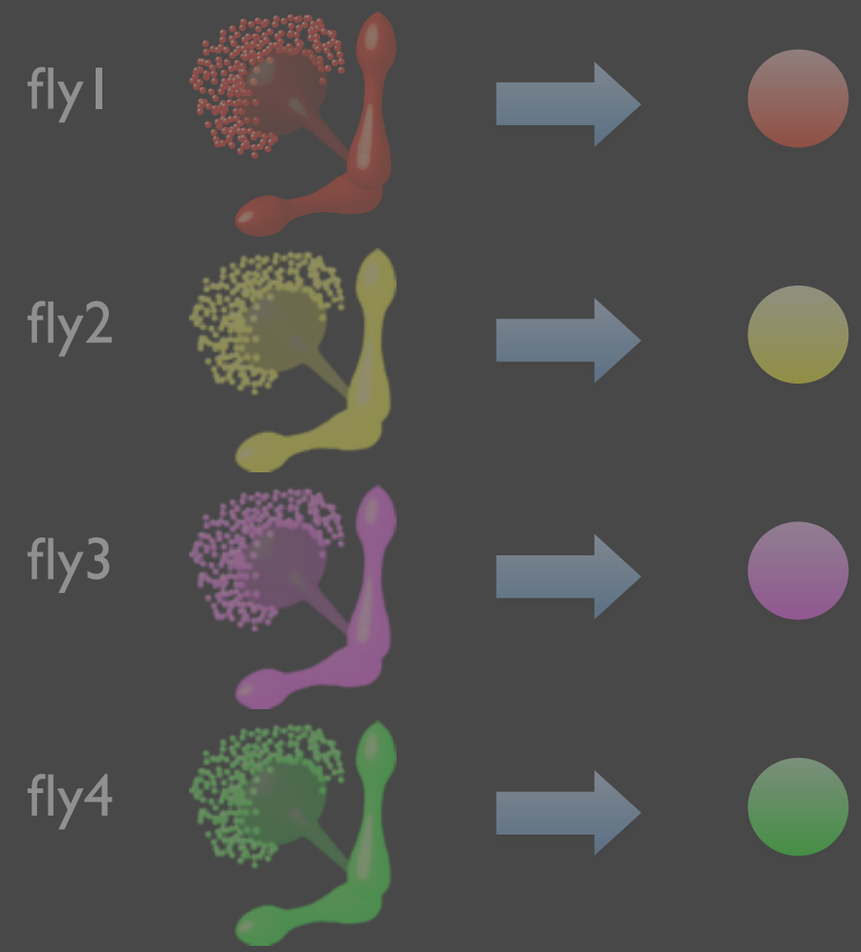
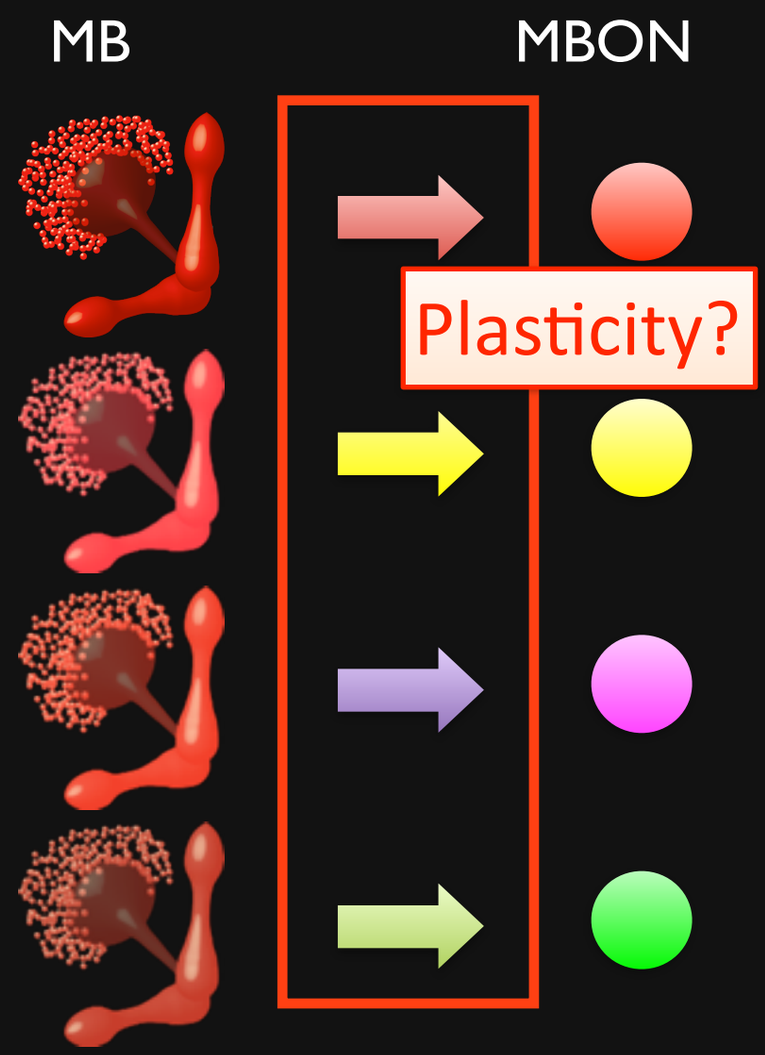
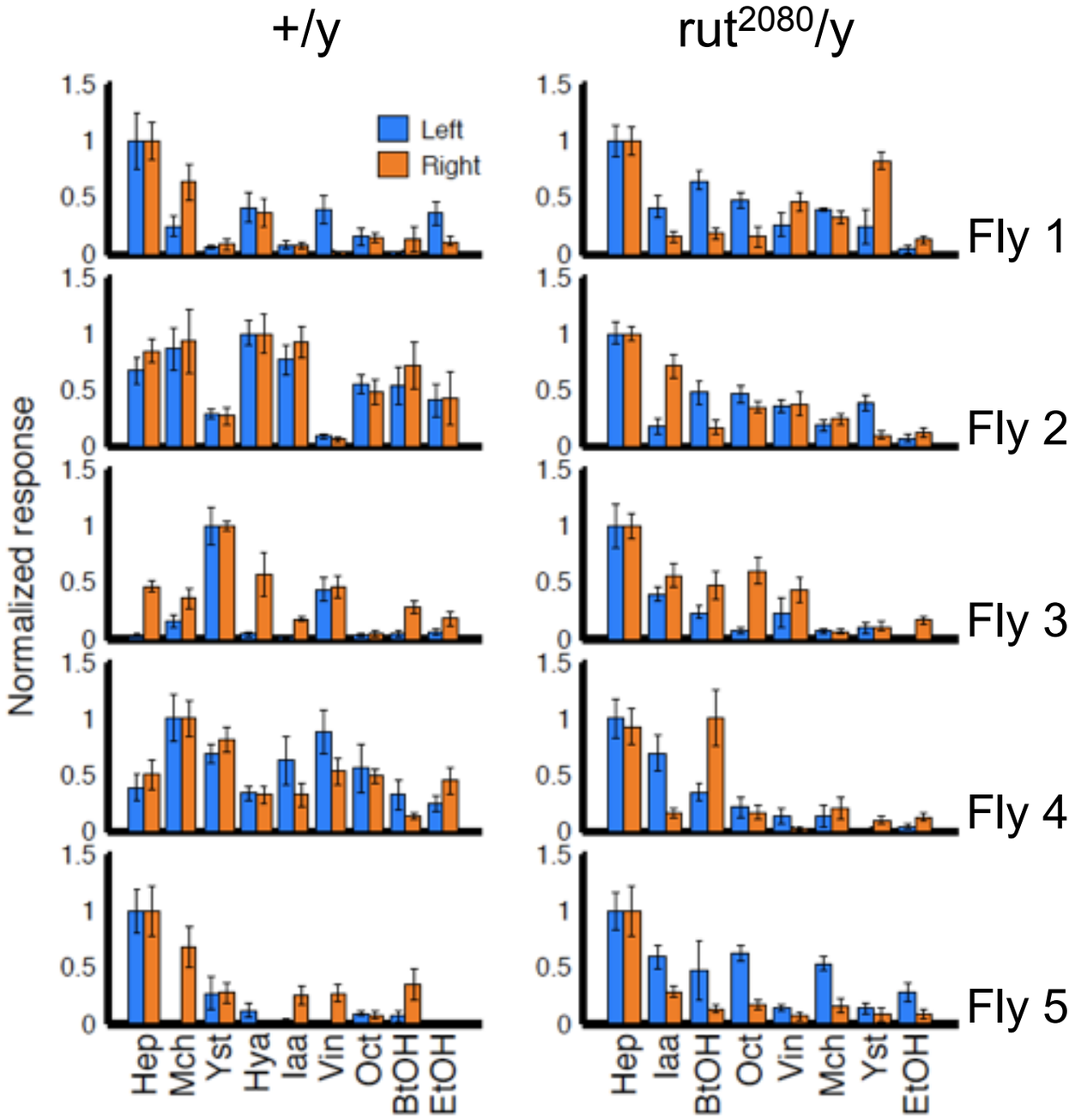
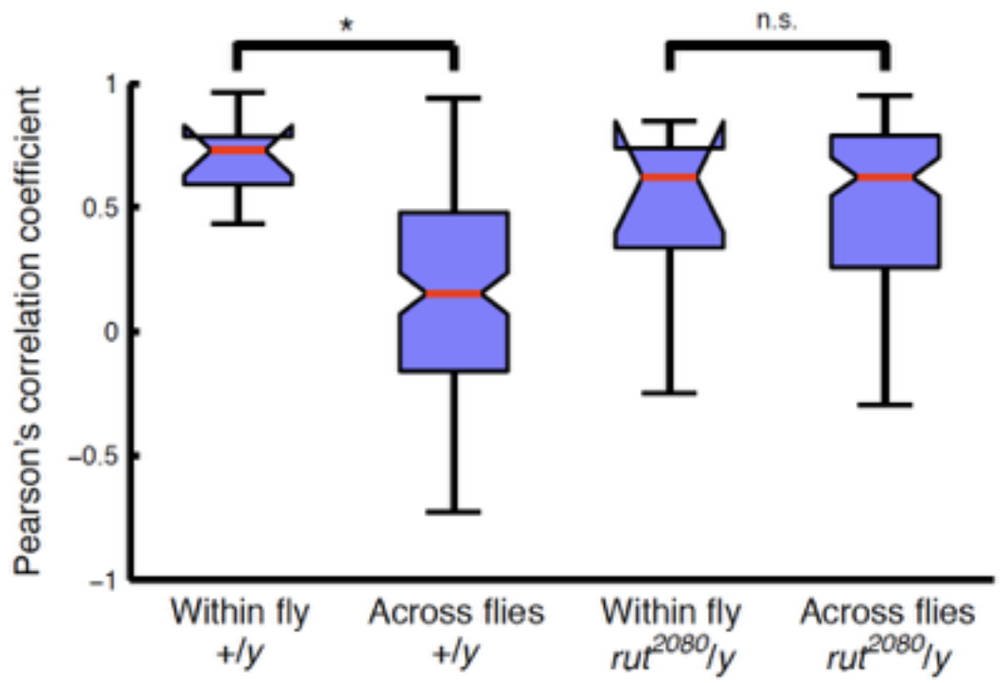


Hypothesis 2: Variable KC-MBON connectivity



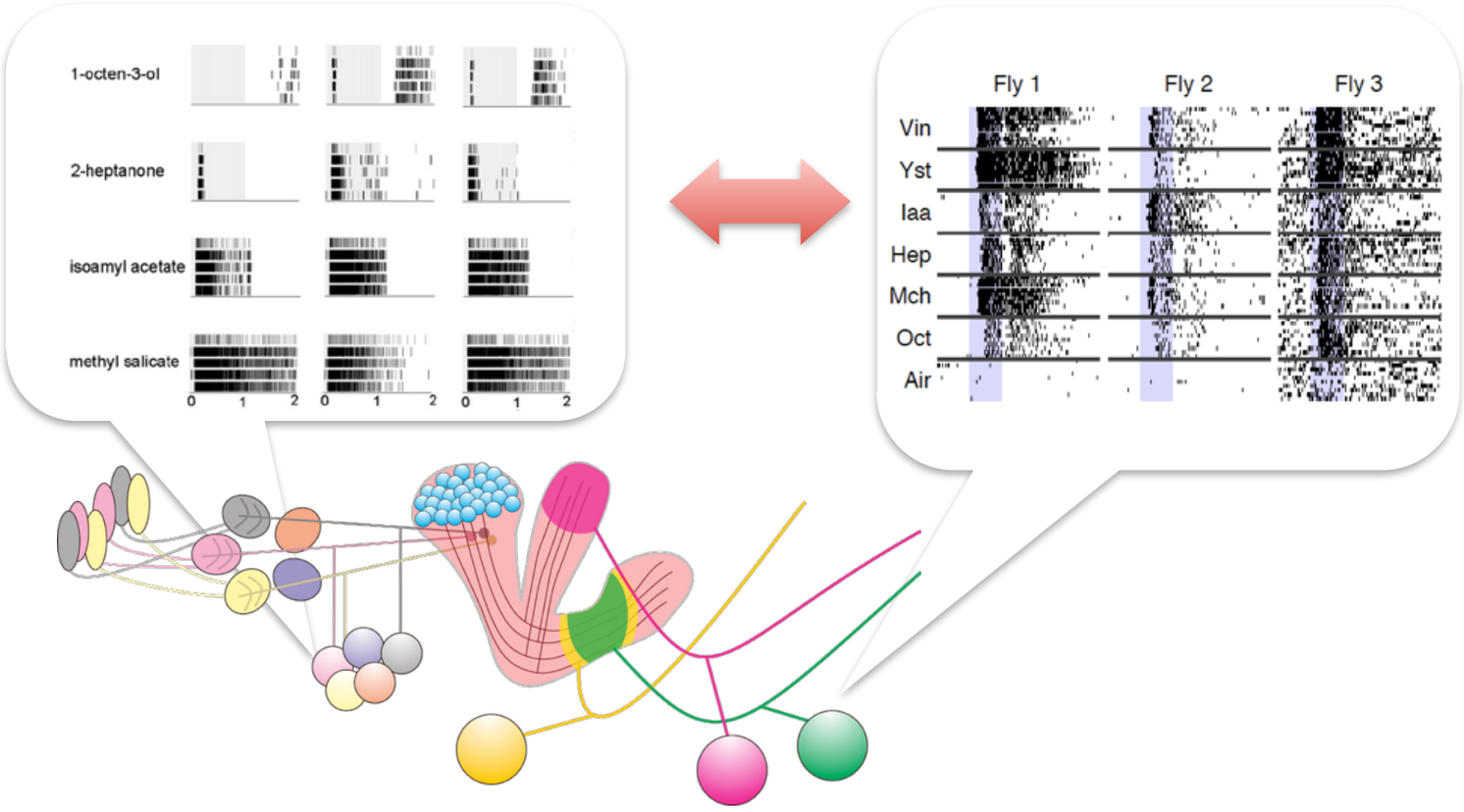
MBON variability lost in rutabaga mutants





Rutabaga required for MBON variability

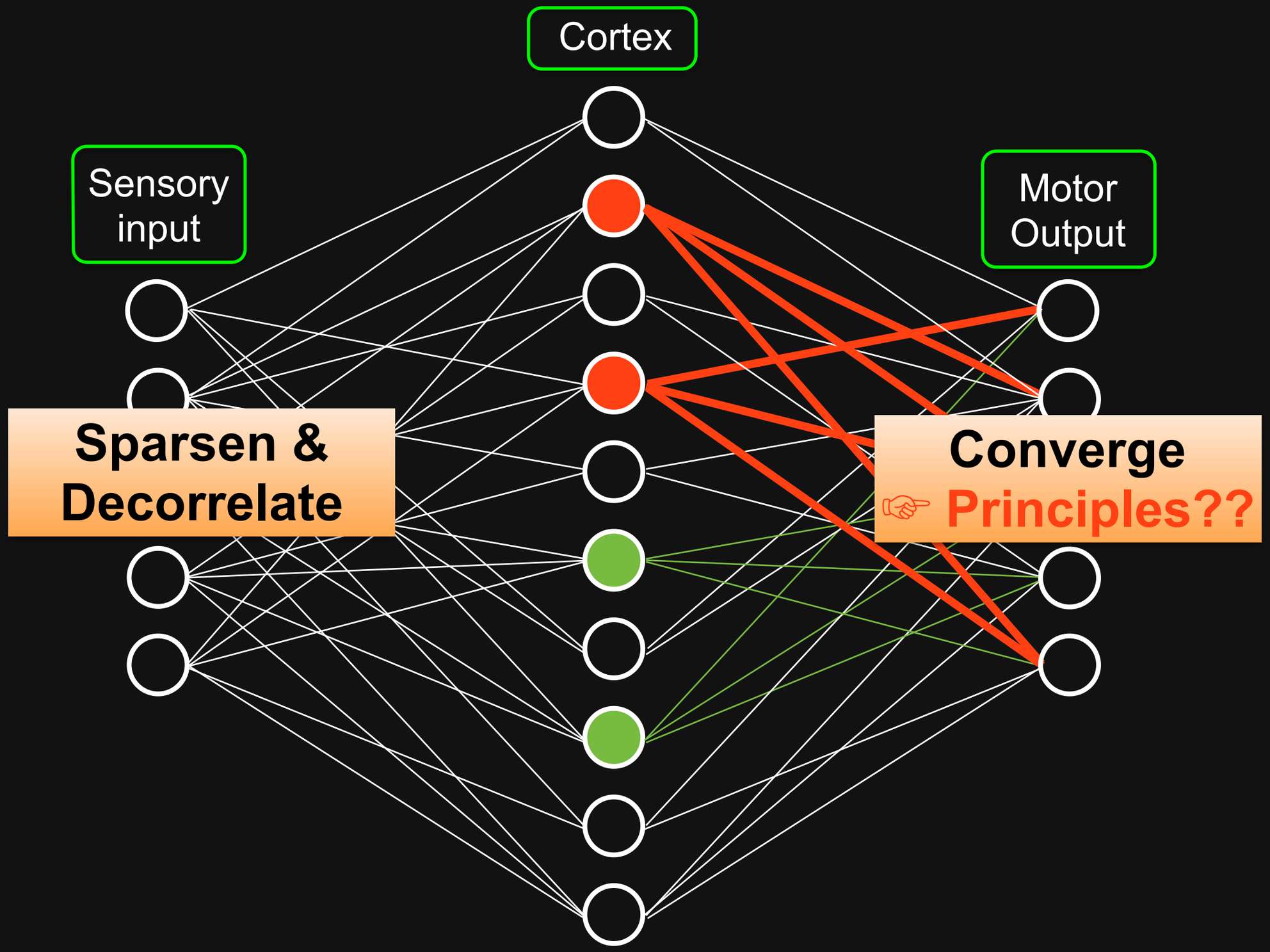
Cross-Individual variability: a plastic process



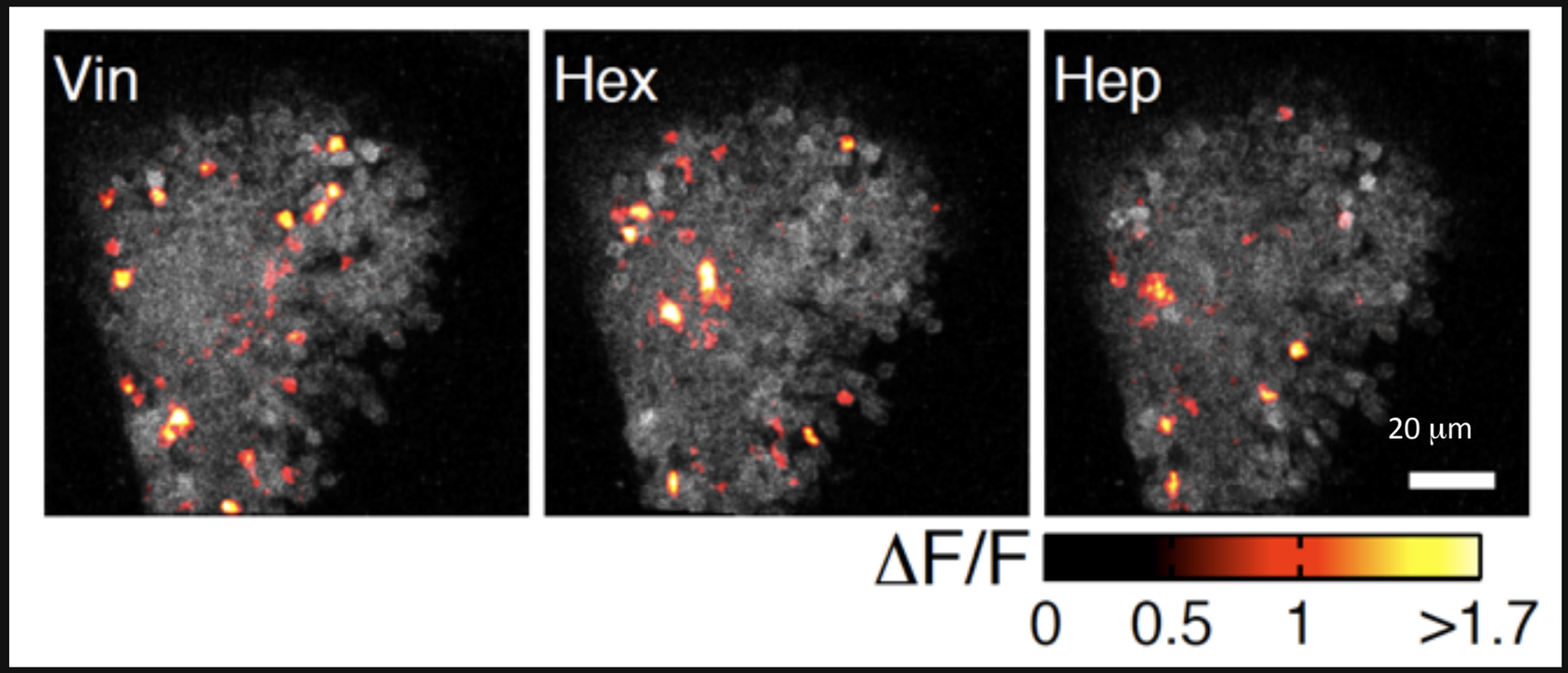
- Variable across individual flies - Consistent within one fly
- Not inherited from KCs - Selective KC-MBON connections
- Active process of diversification - requires rutabaga

MBON tuning curves shaped by plasticity

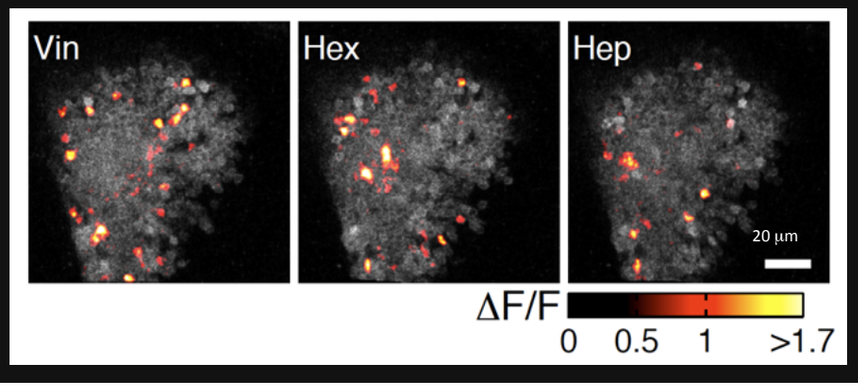
Transformation in converging phase?

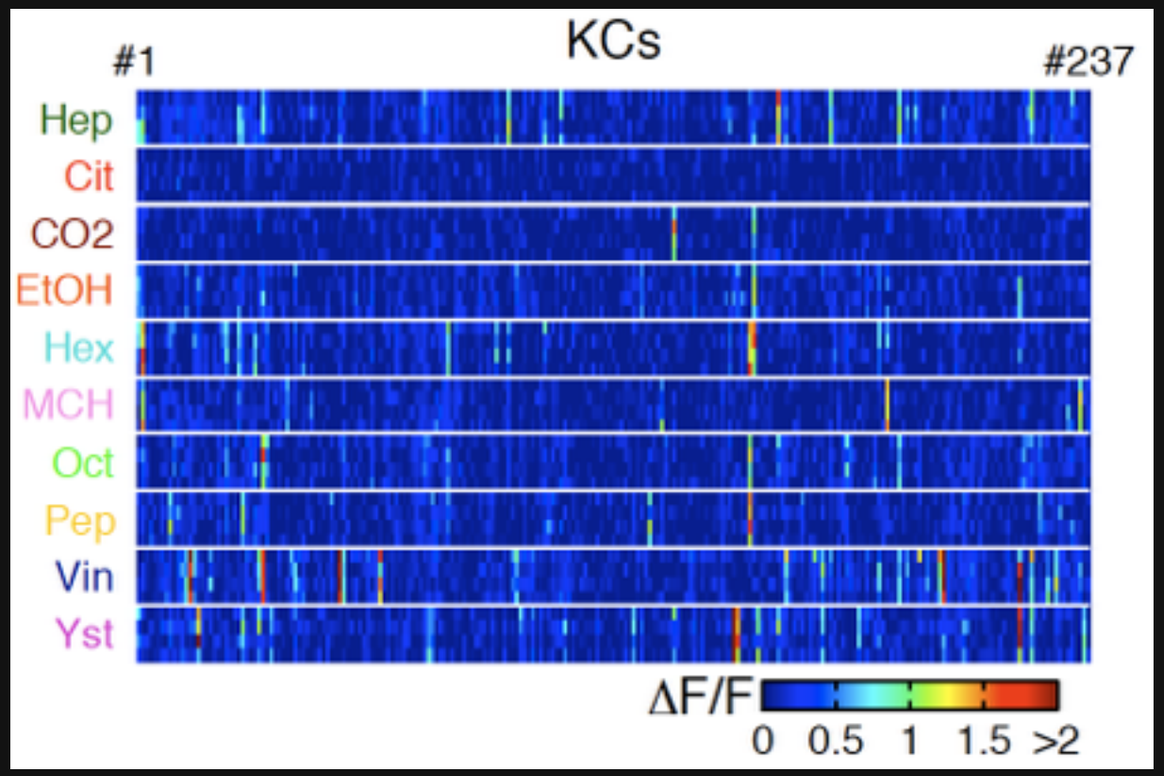


Population coding in KCs

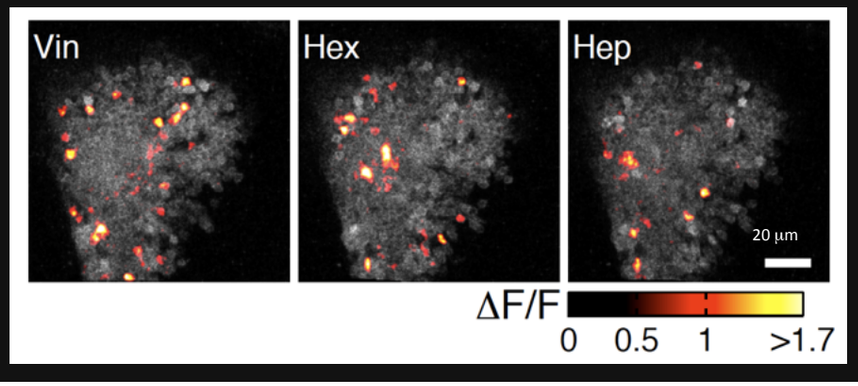


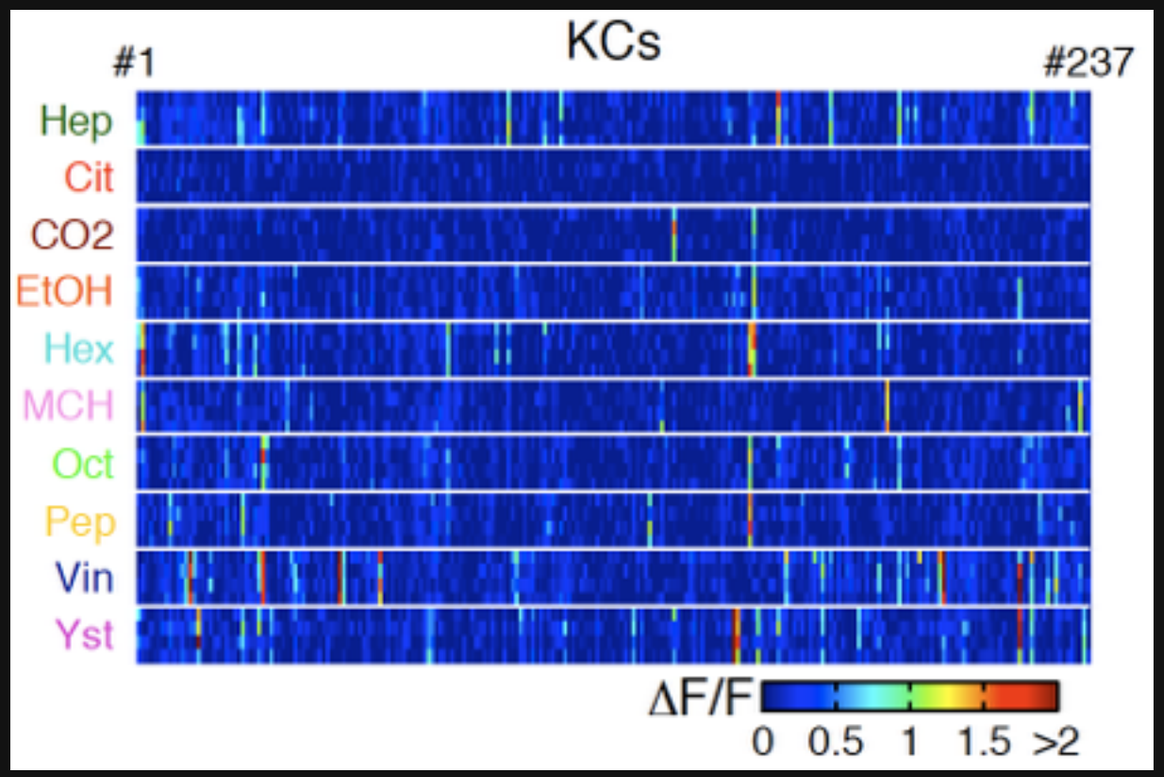
Population coding in KCs



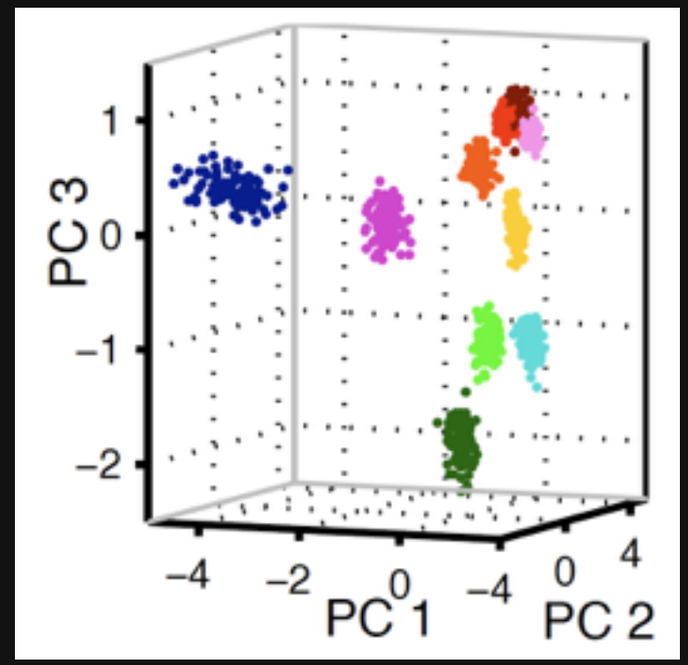


Population coding in KCs

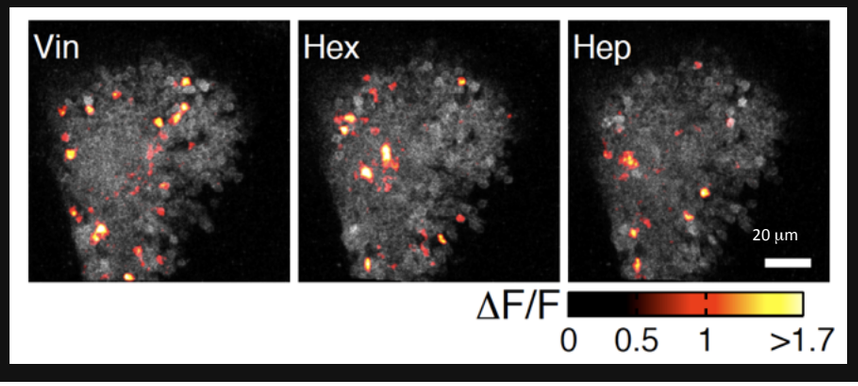


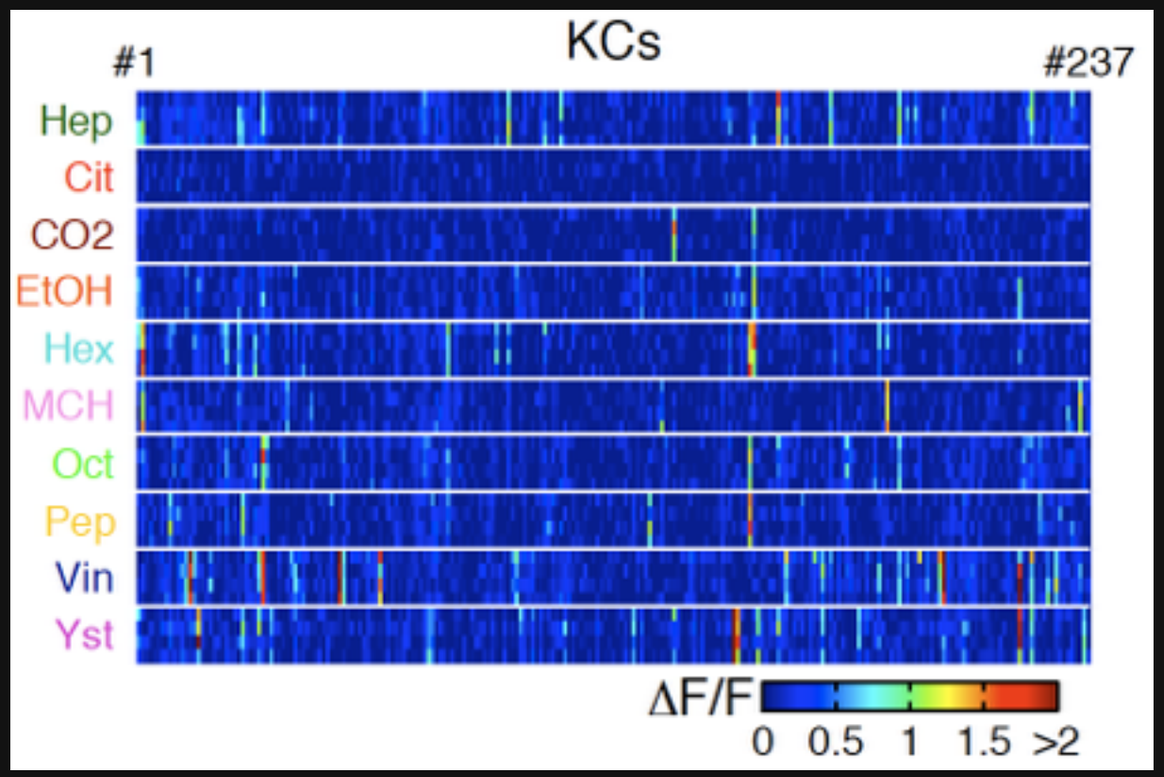


PCA



Population coding in KCs





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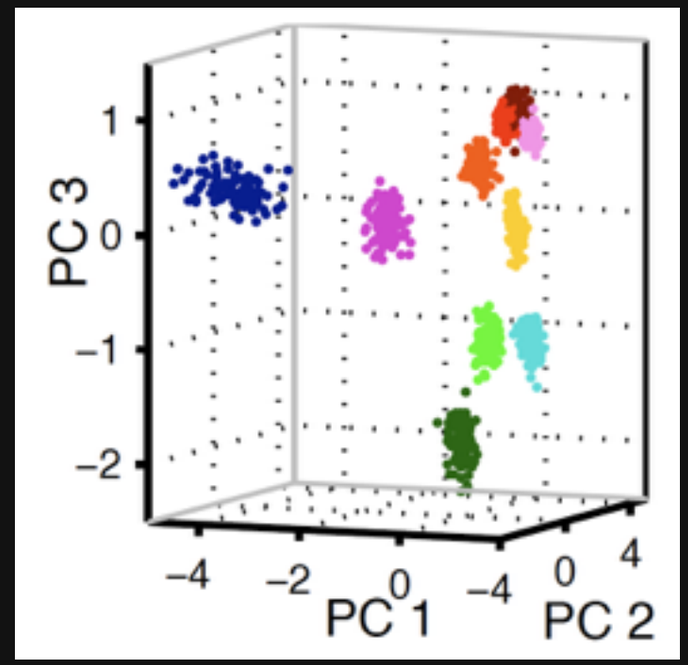
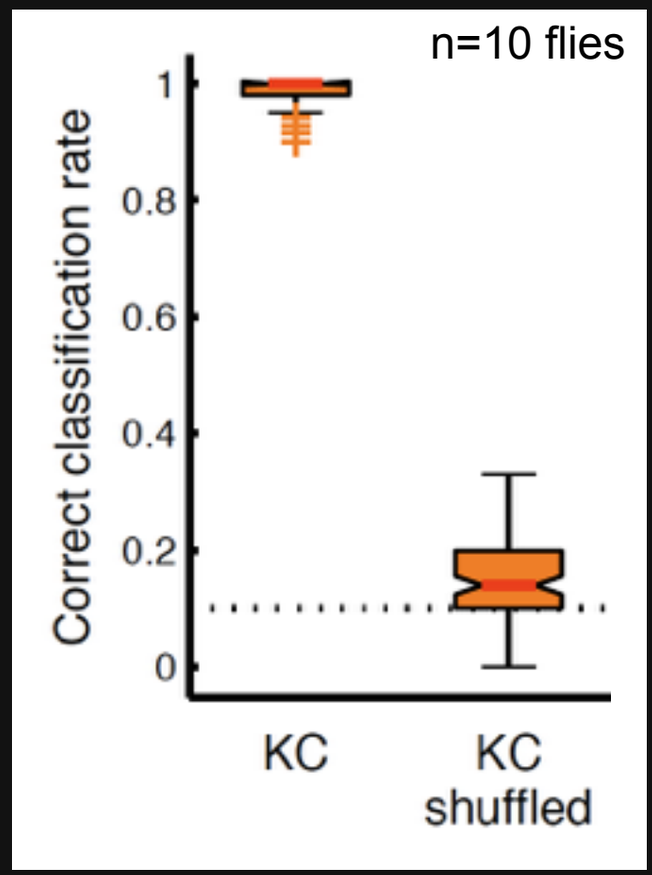
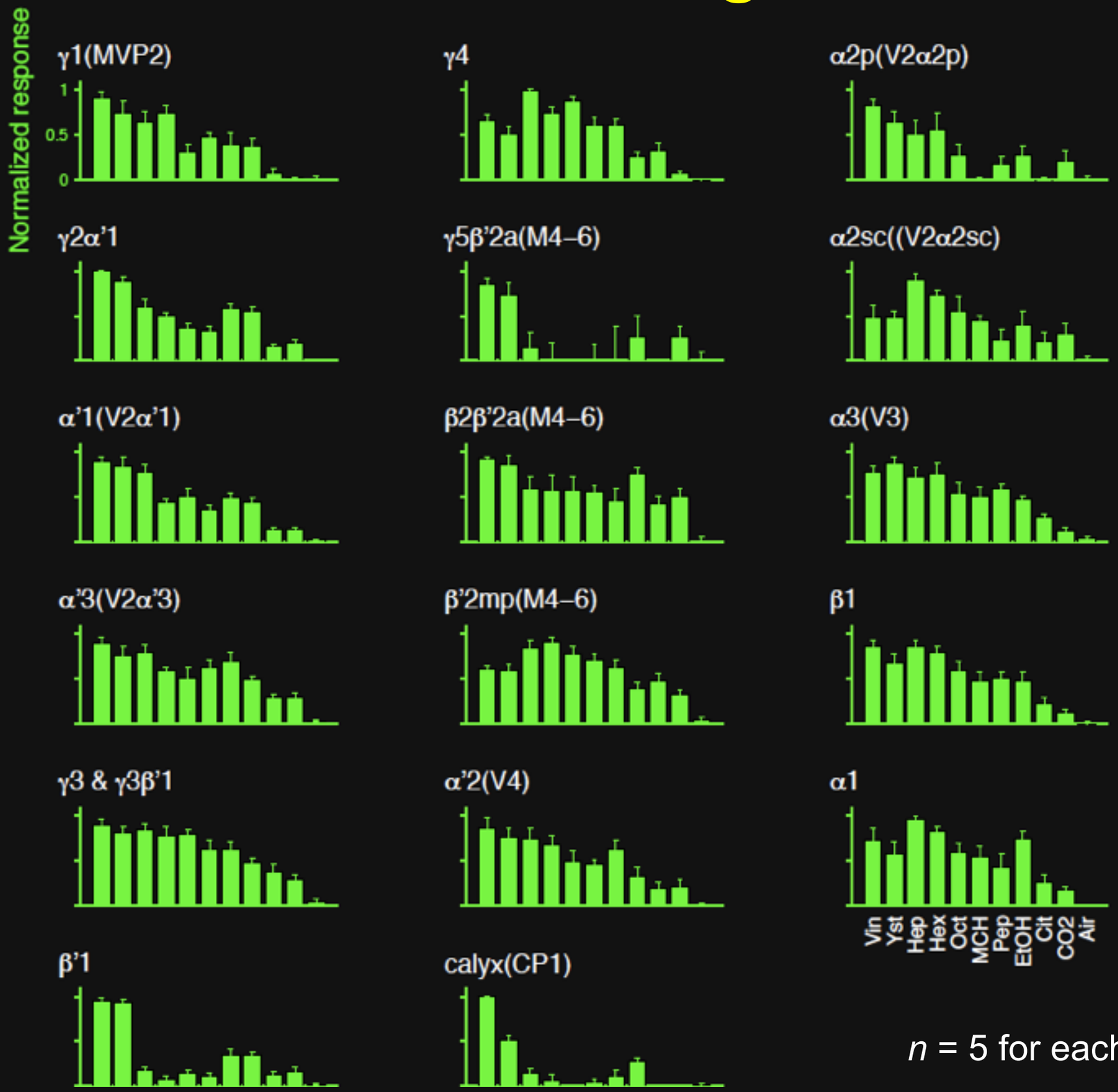


Odor Classification

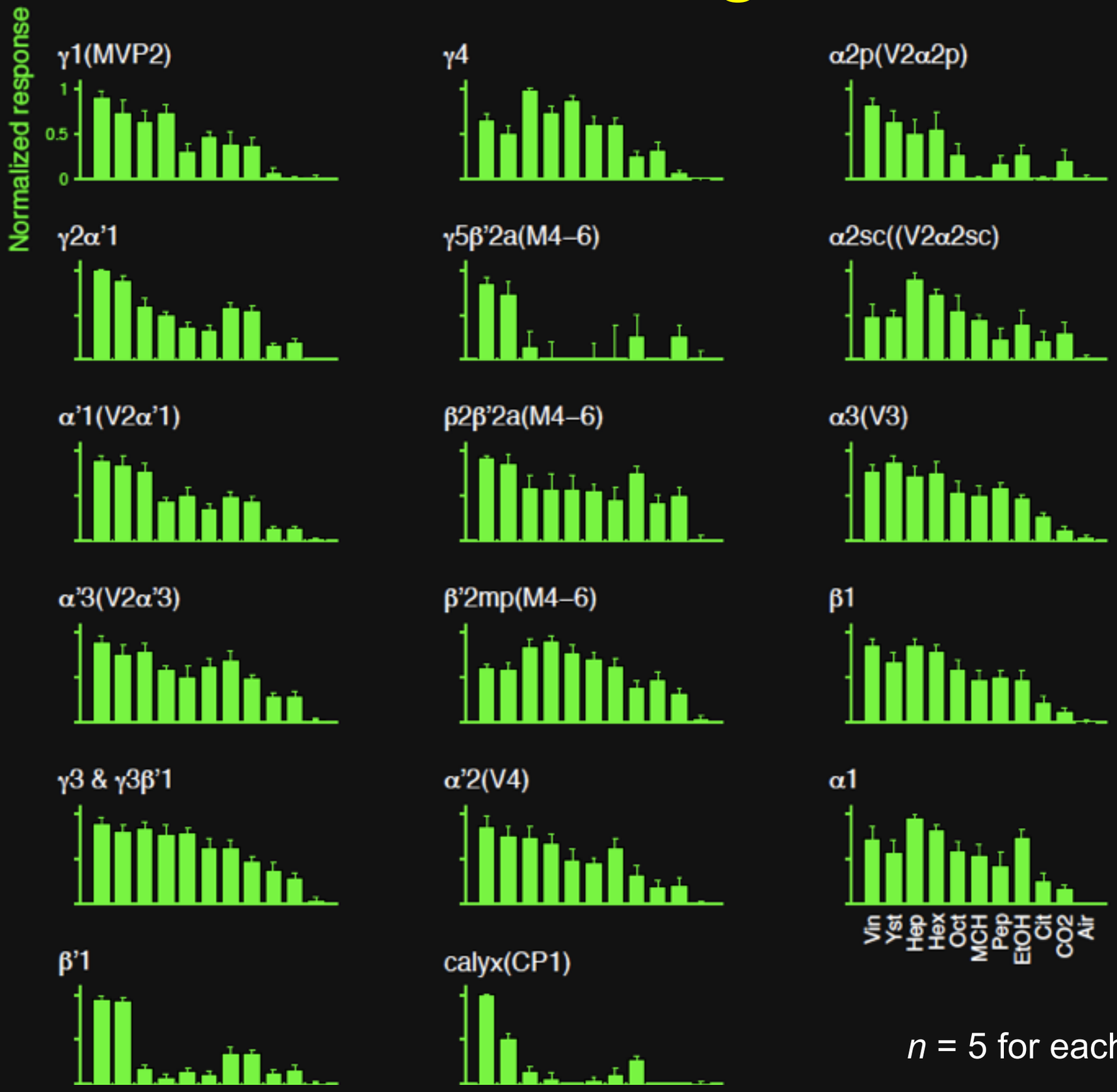


Odor tuning of MBONs



n = 5 for each cell type

Odor tuning of MBONs

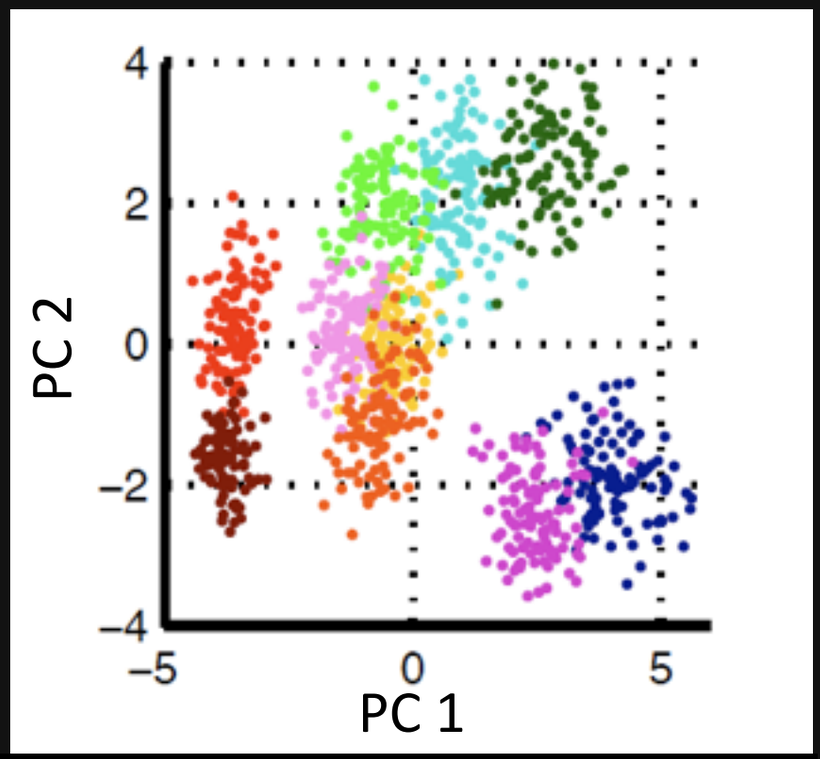


Population Activity

n = 5 for each cell type

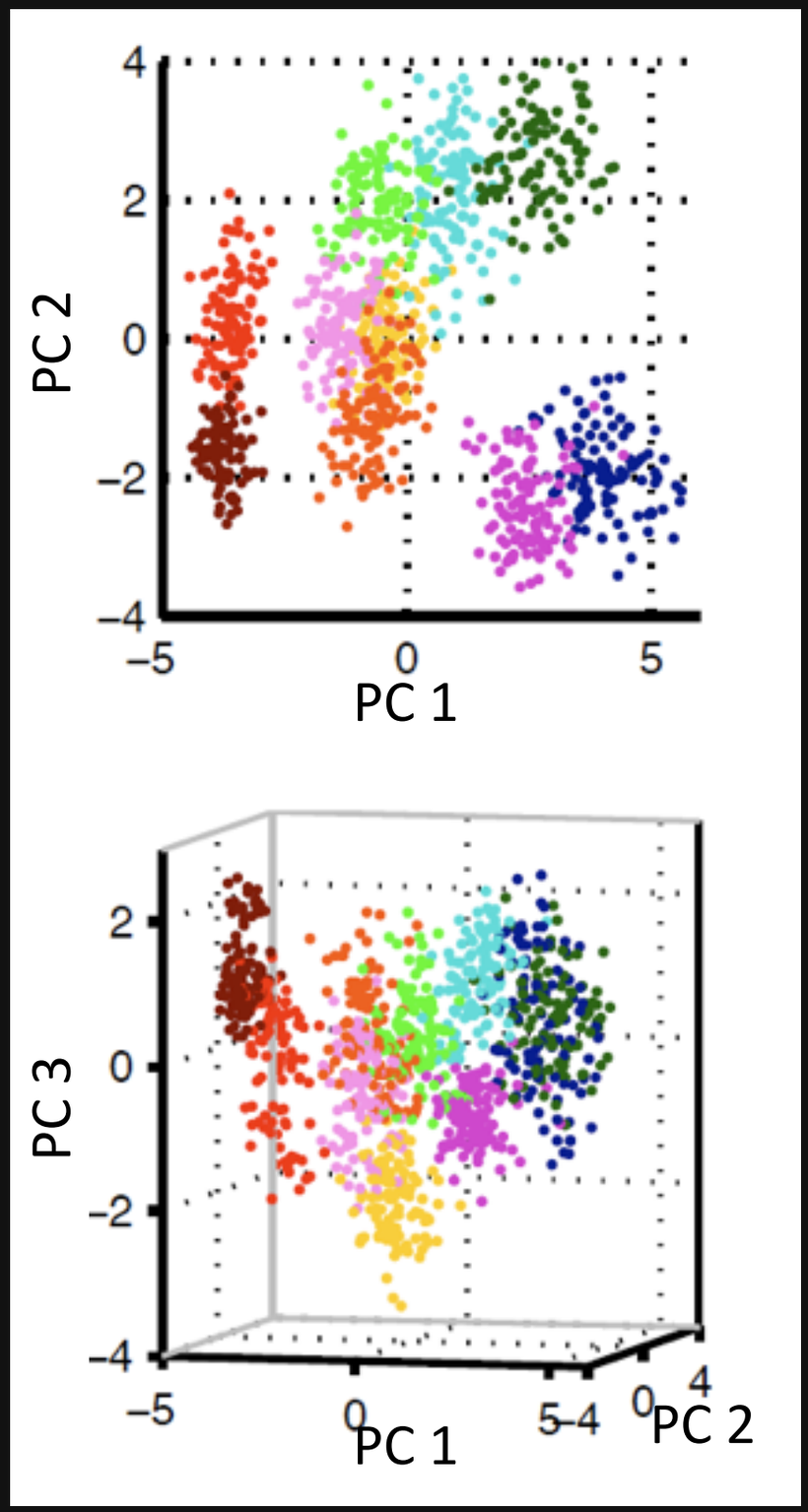
Population representations of odors

MBONs



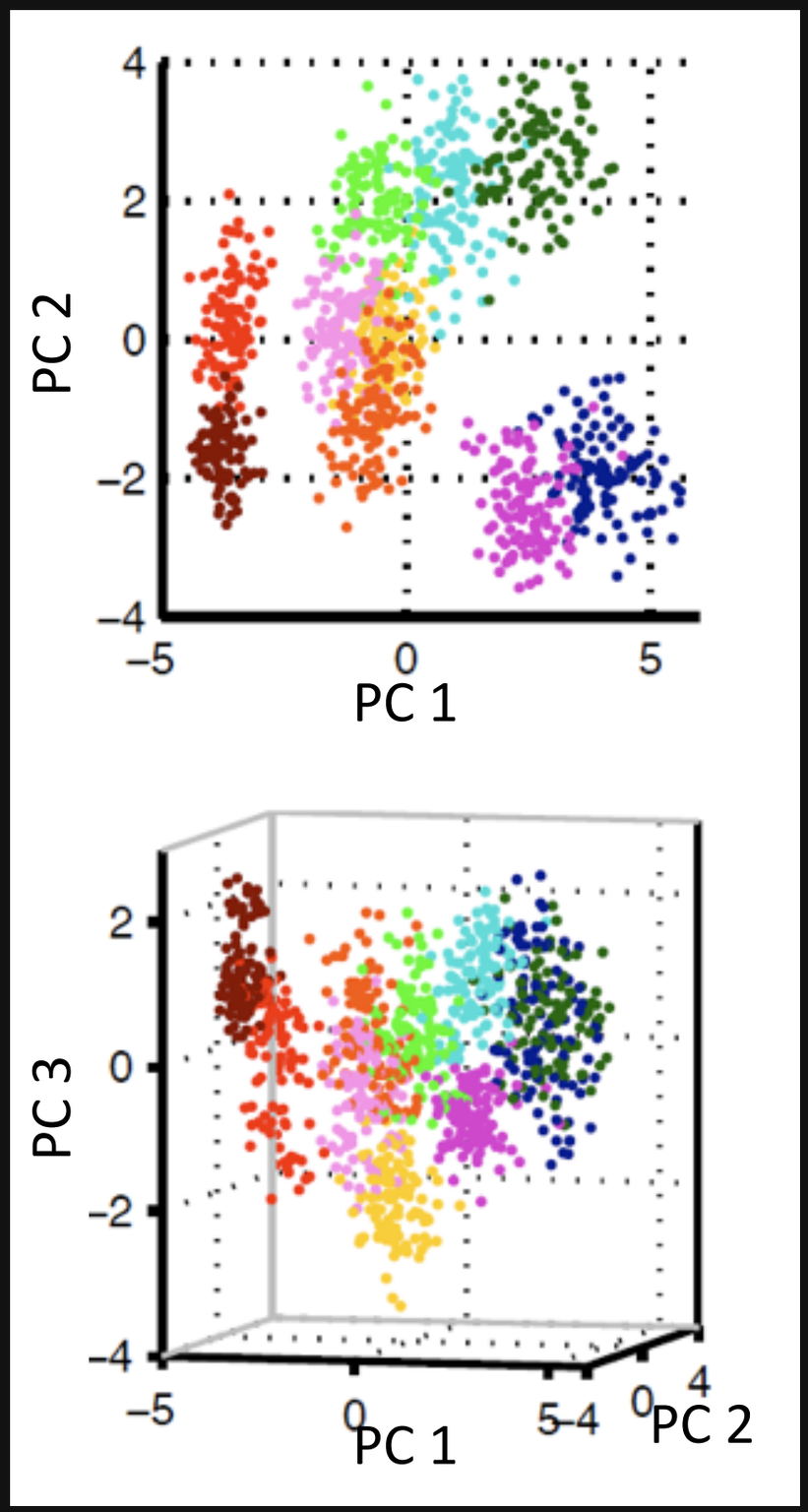
Population representations of odors

MBONs

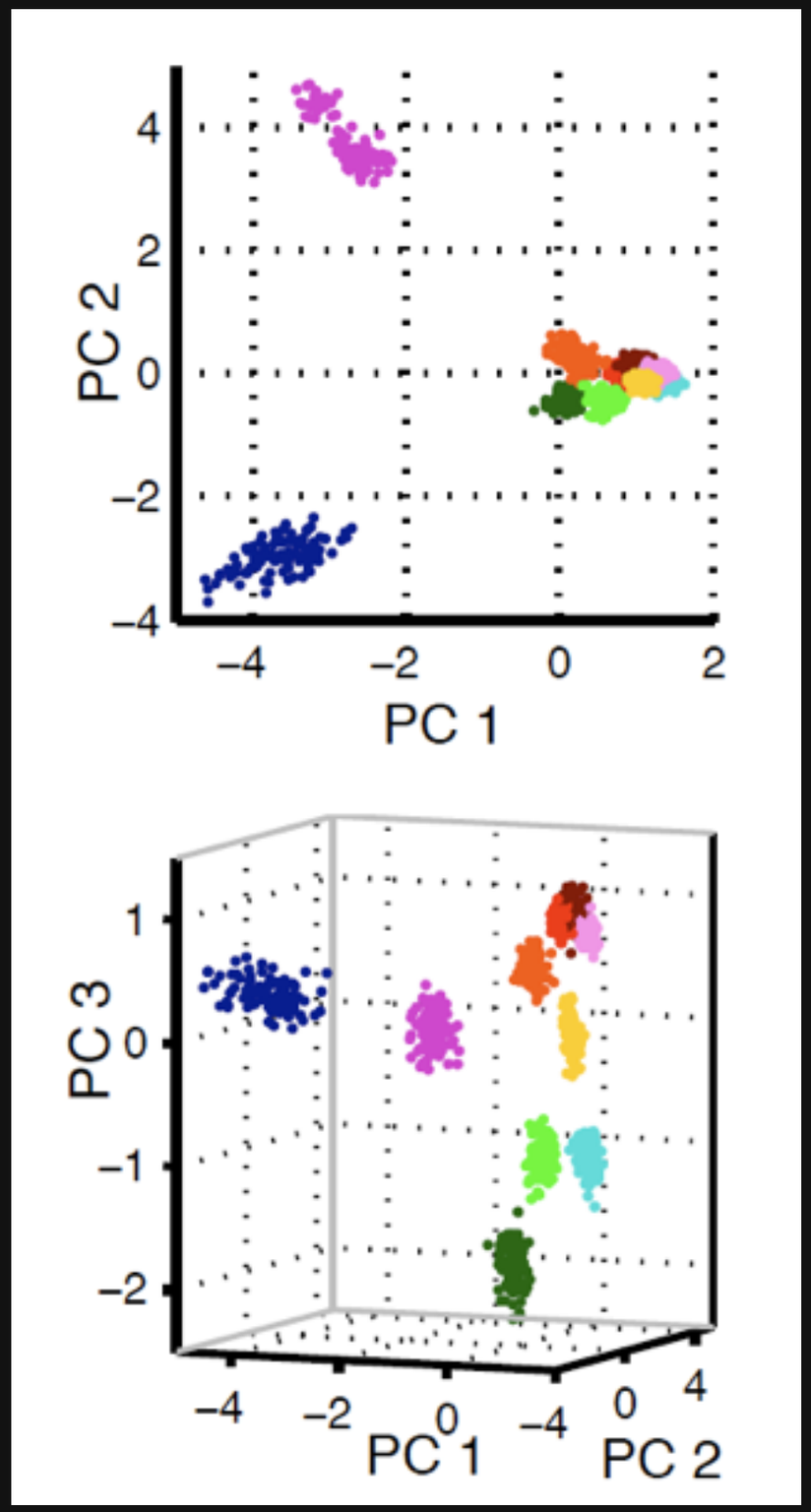


Population representations of odors

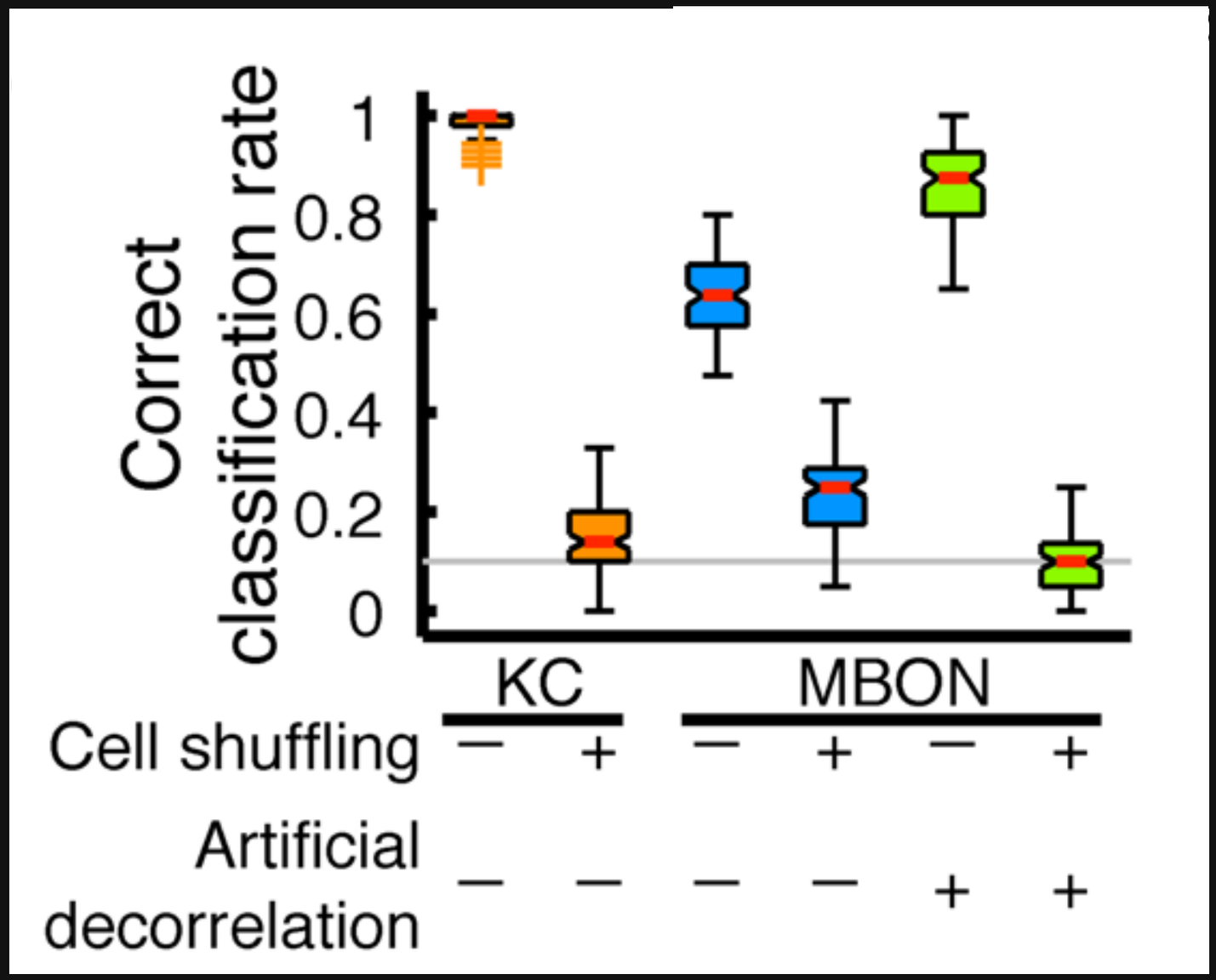
MBONs



KCs

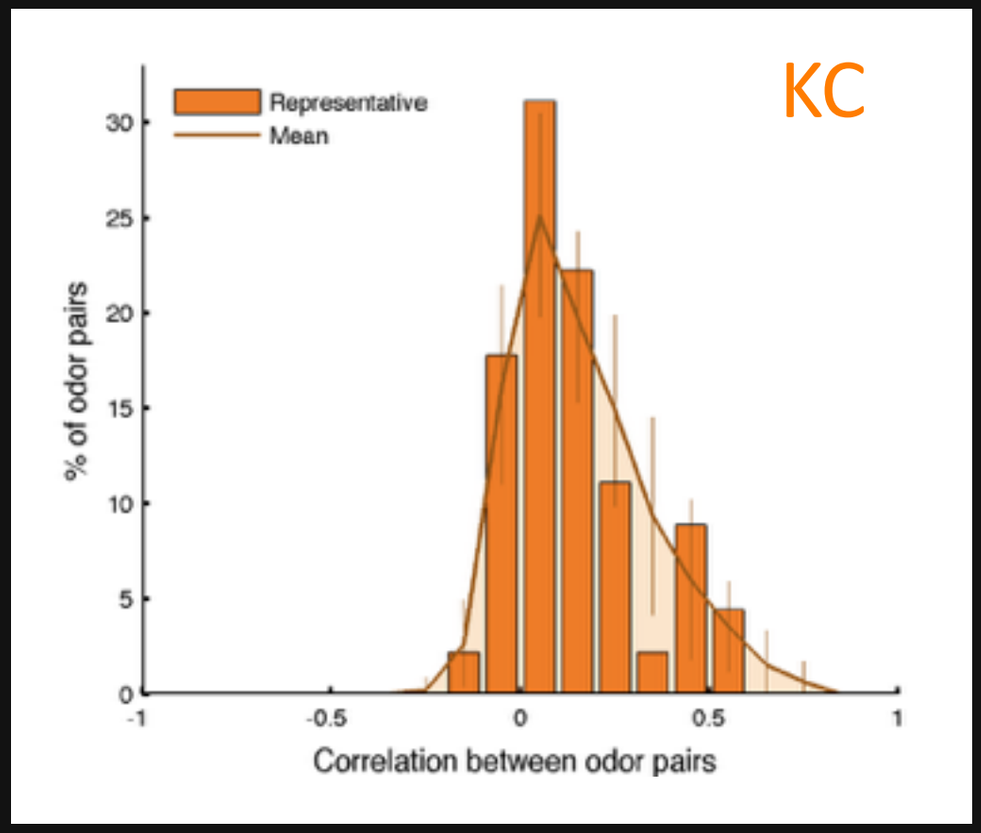


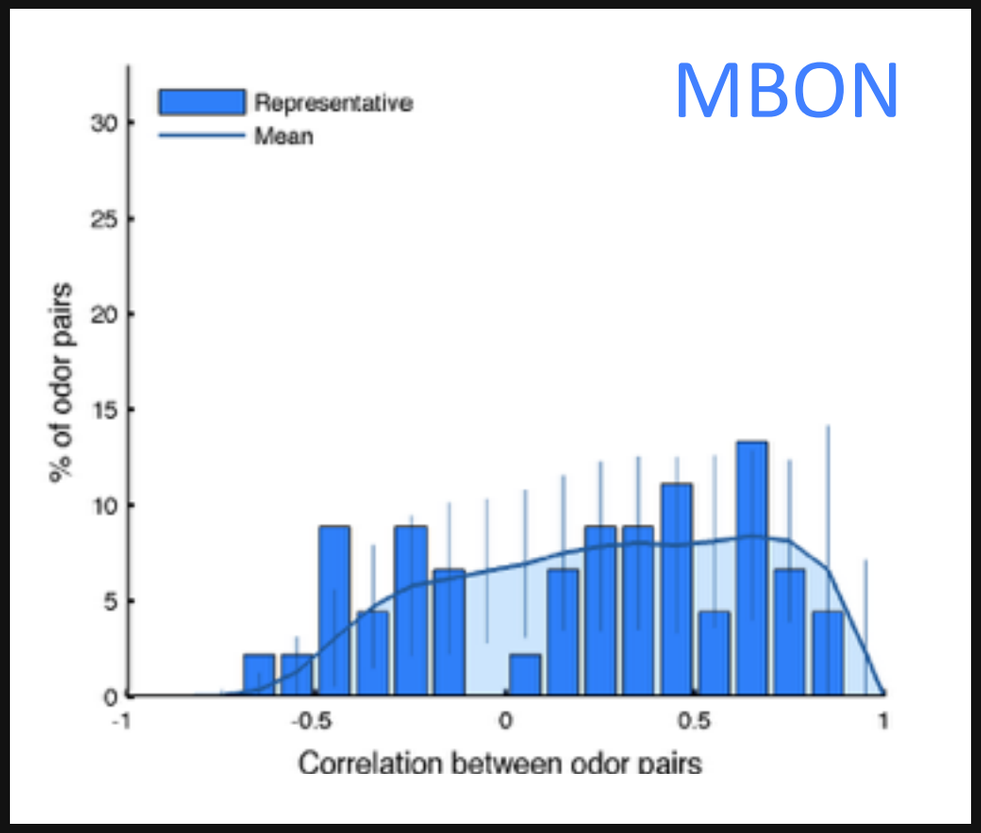
Poor representation of odor identity in MBONs

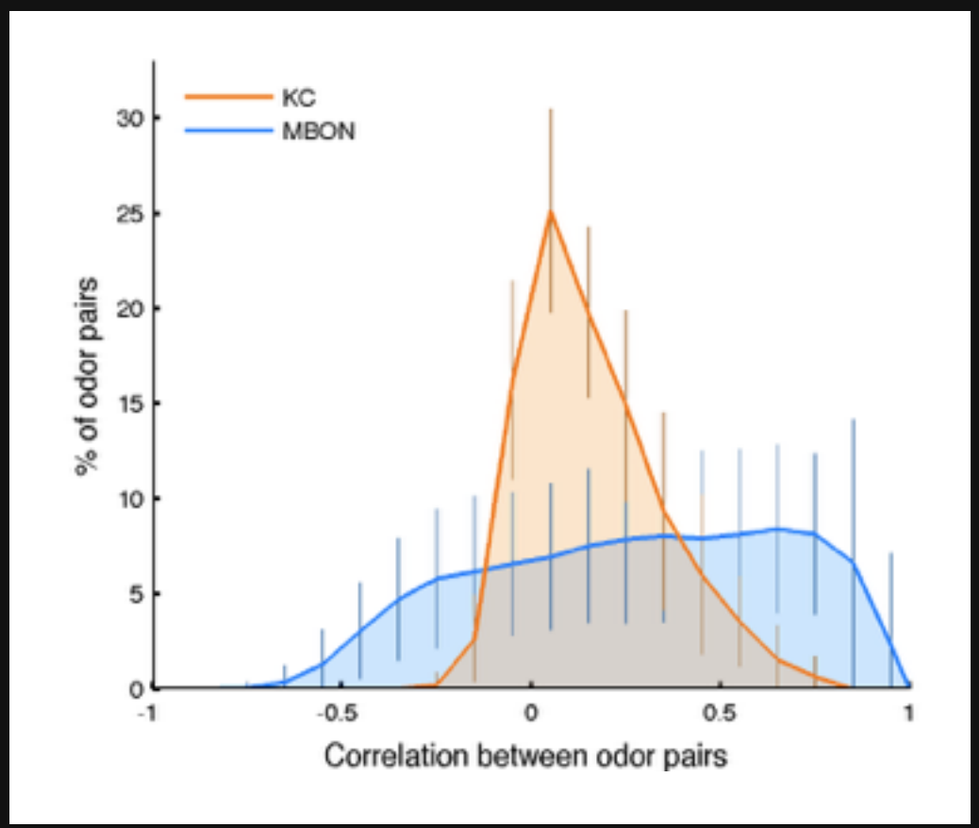


Representing something other than identity?

Reshaping odor representations in MBONs

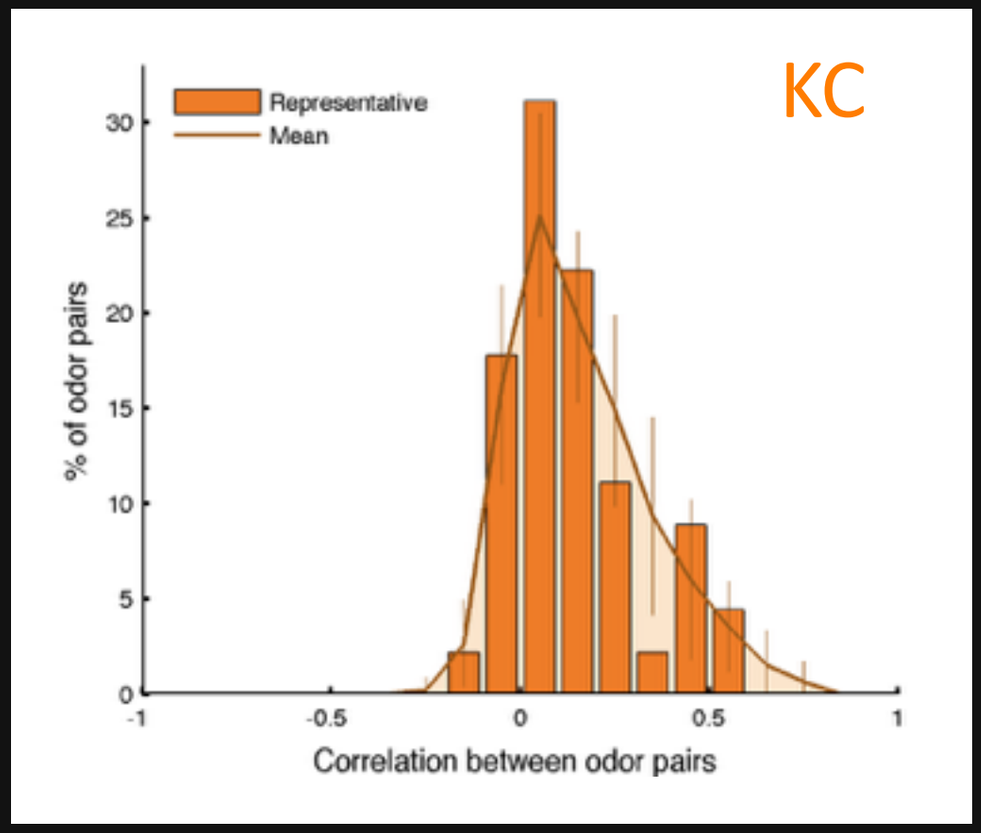


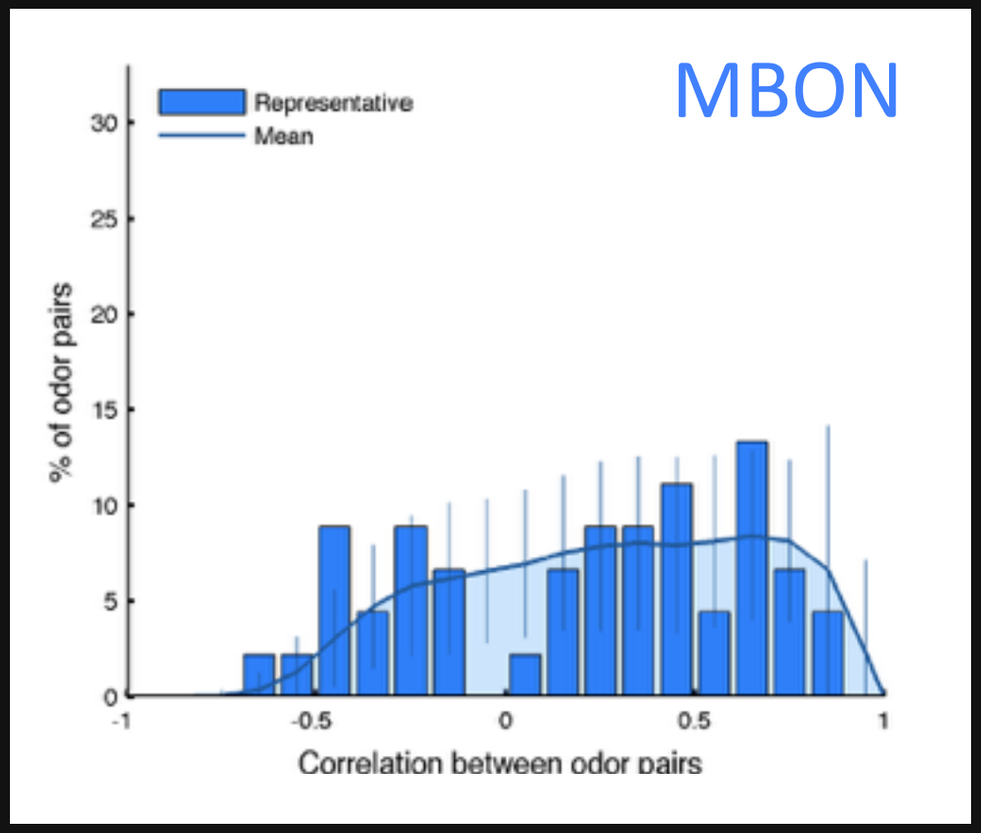


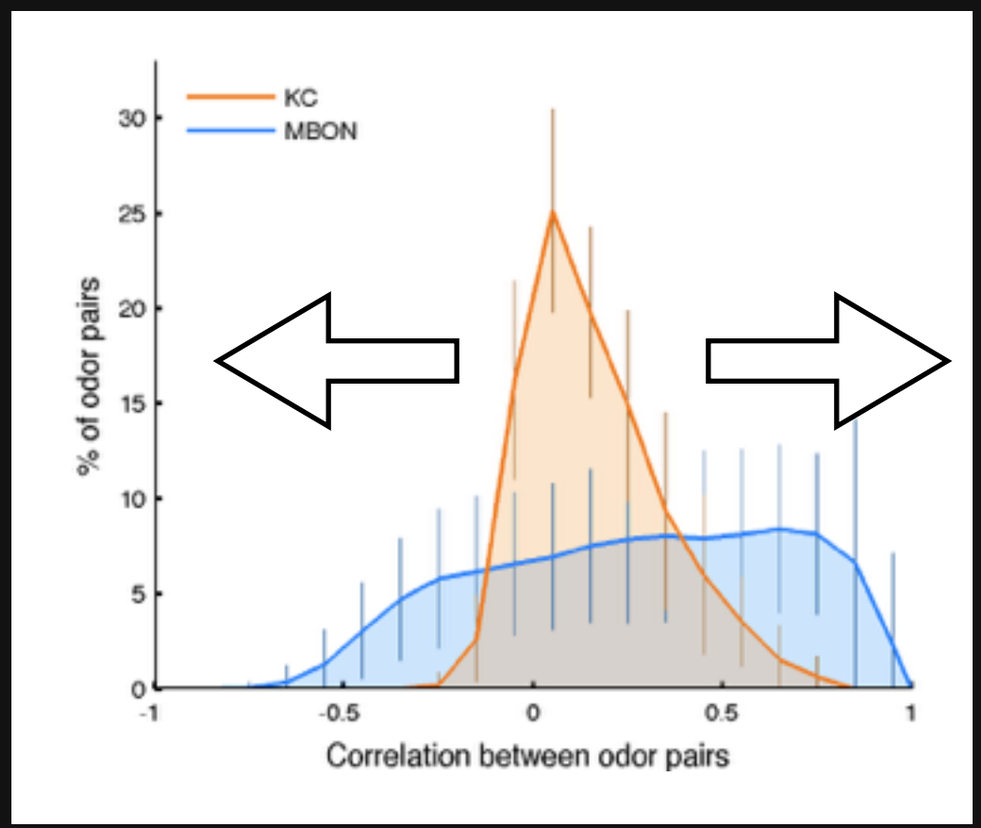


Odors pushed into positively and negatively correlated groups

Reshaping odor representations in MBONs

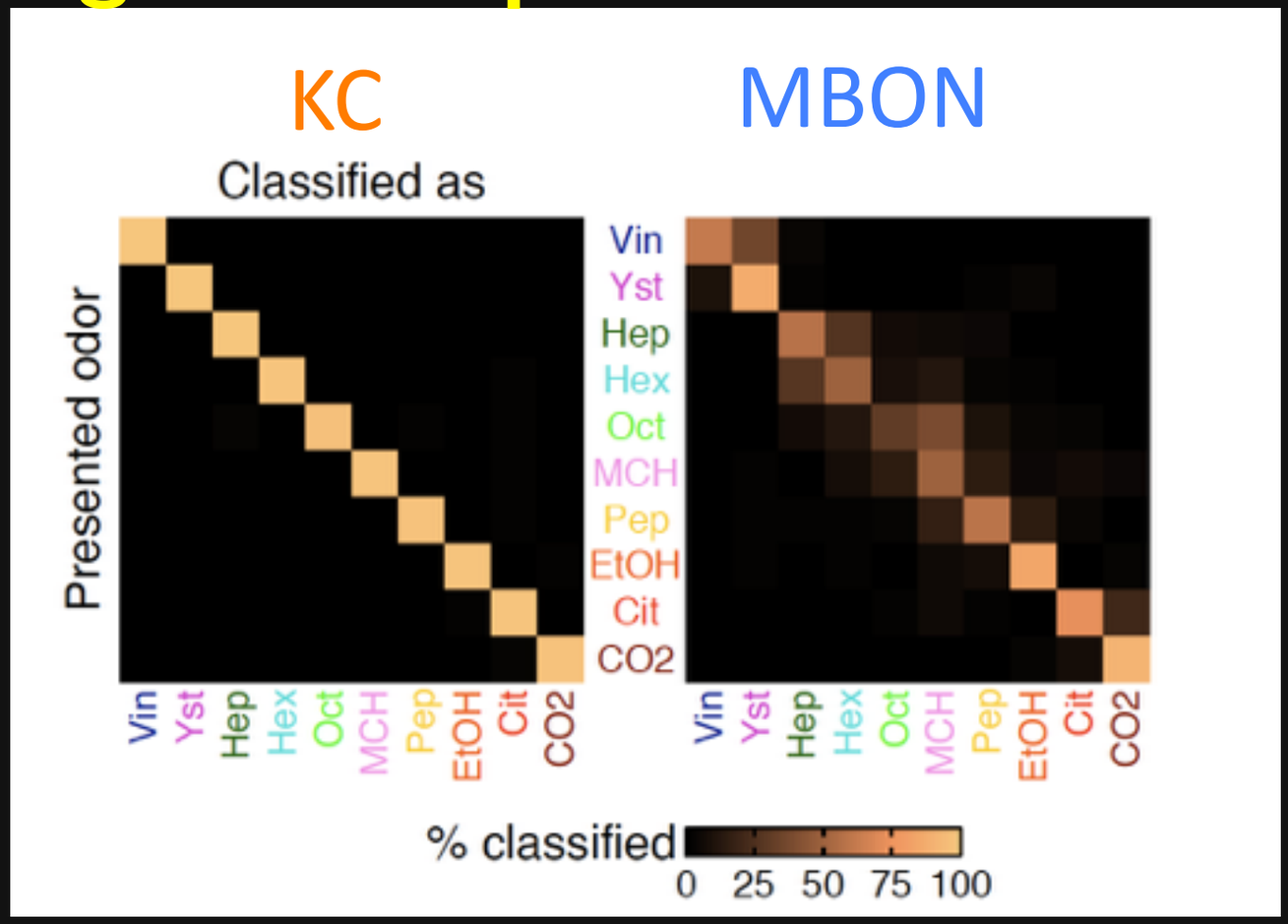


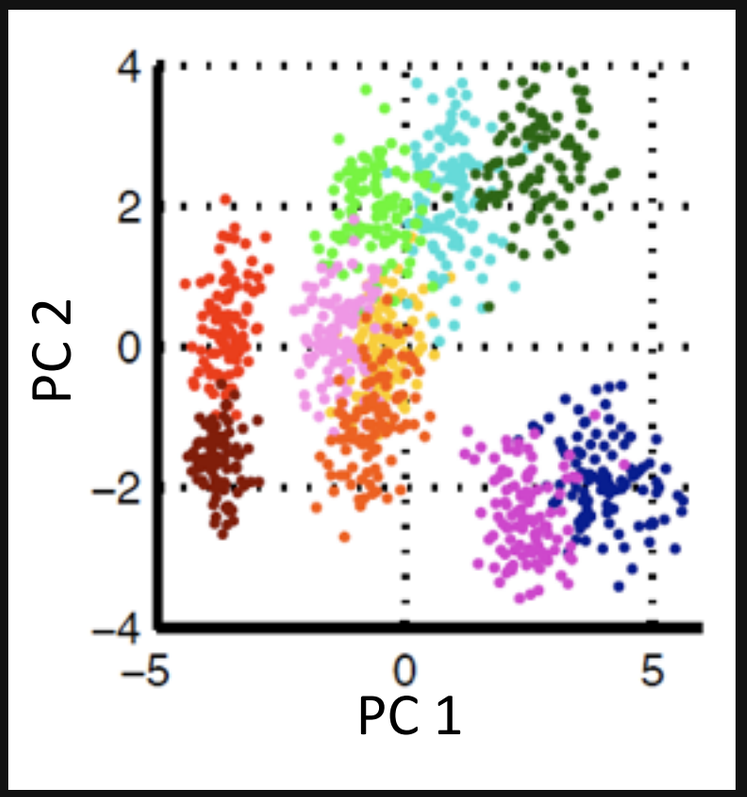




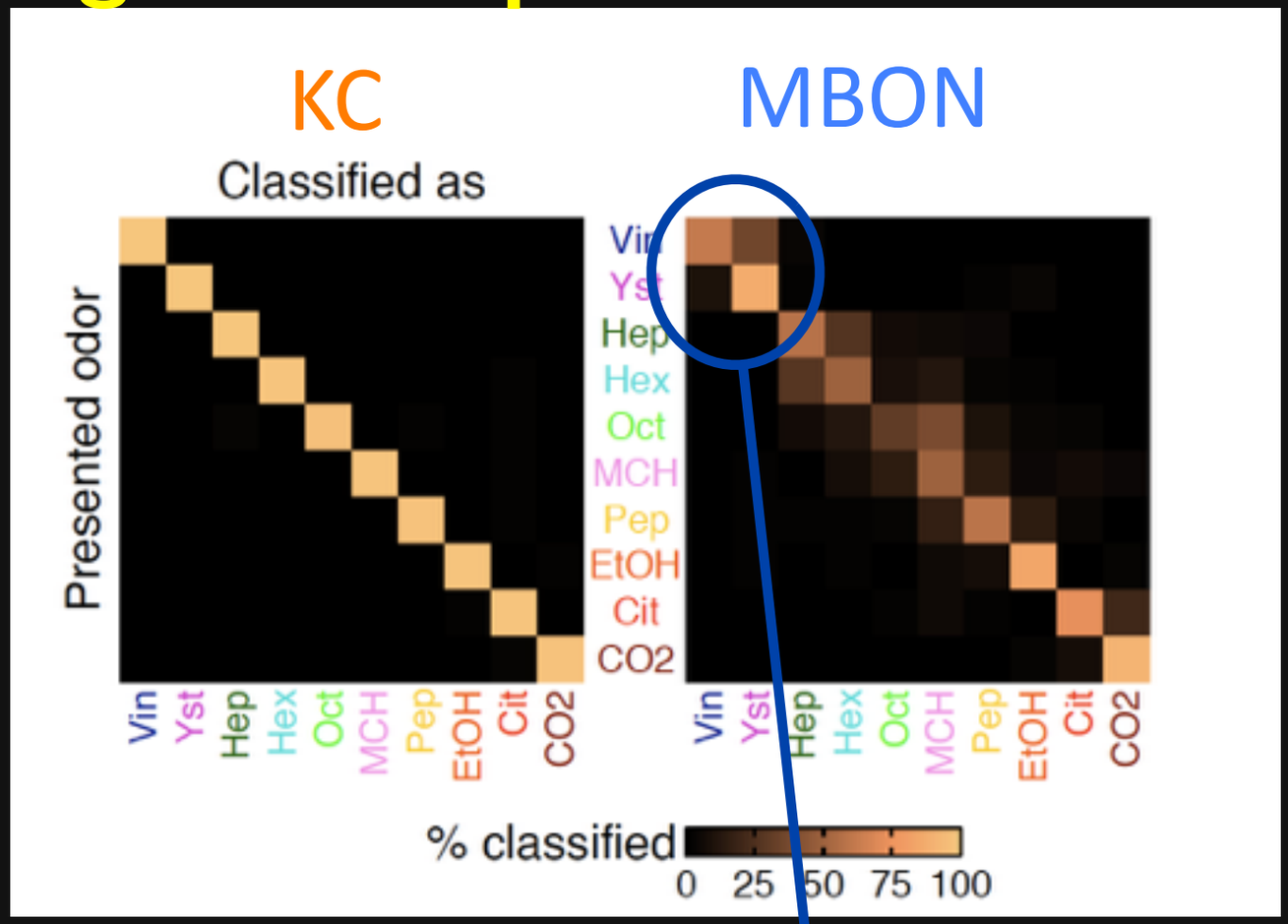
Odors pushed into positively and negatively correlated groups

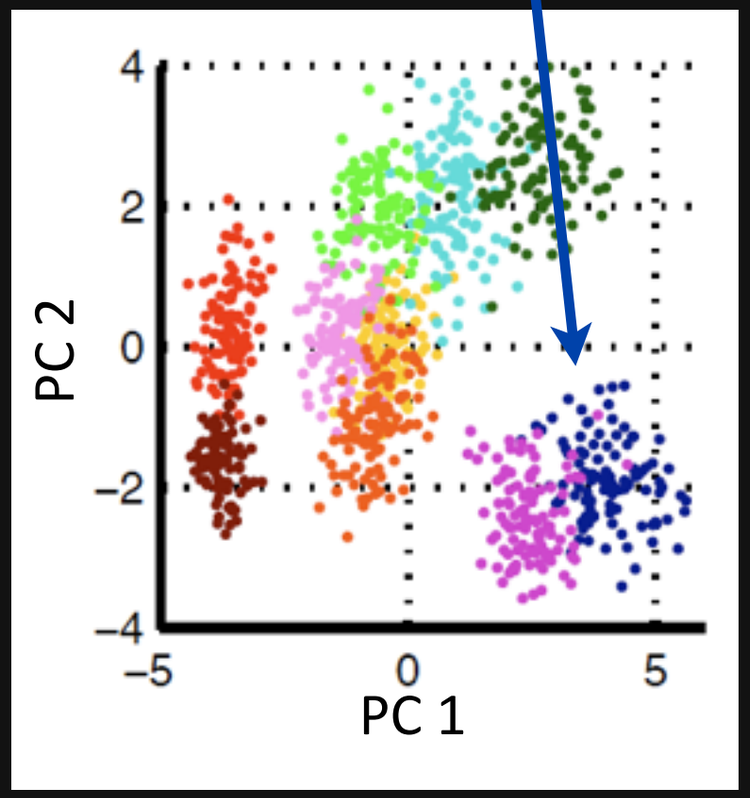
Reshaping odor representations in MBONs





Reshaping odor representations in MBONs



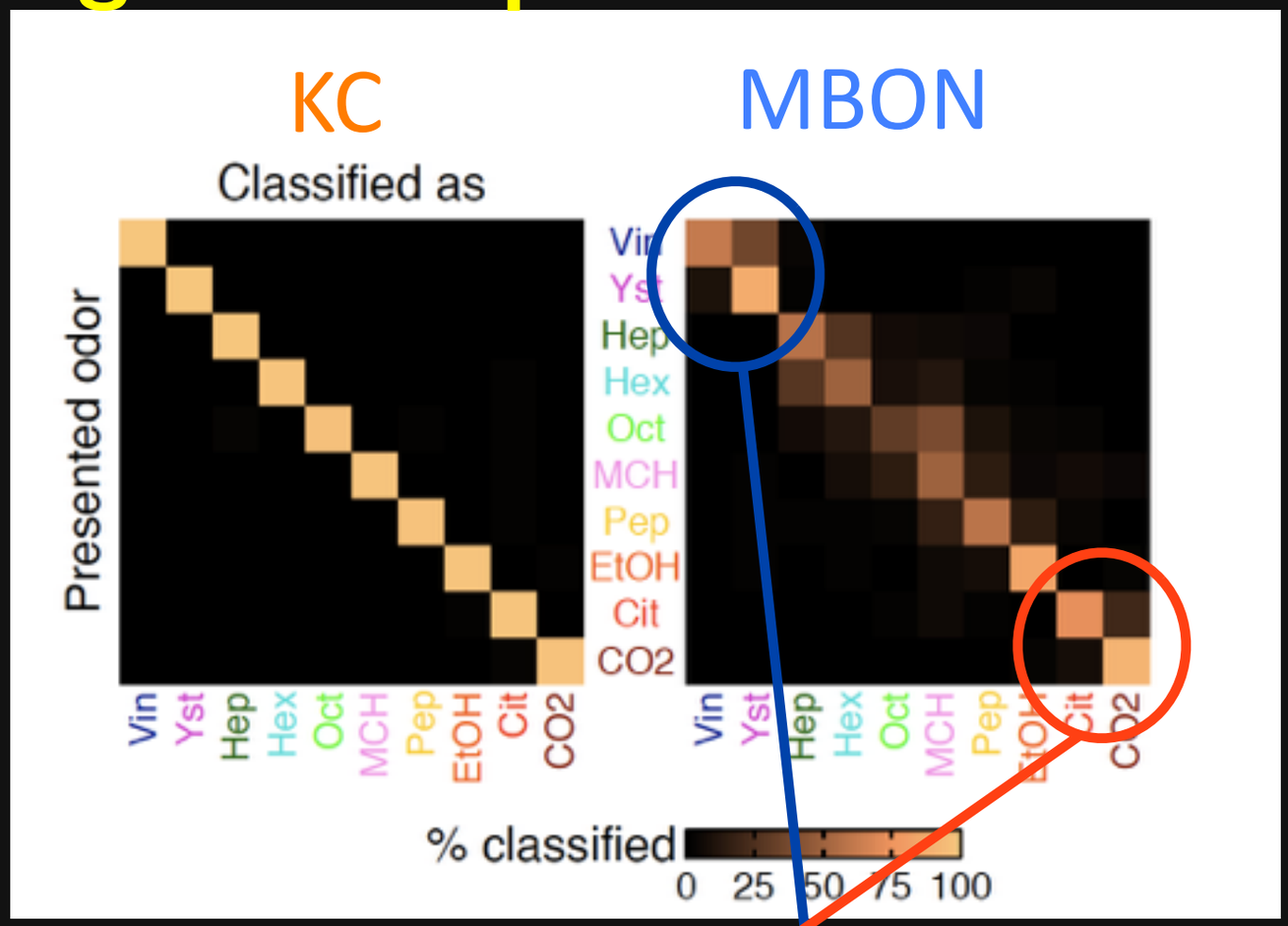


Vinegar

Yeast

Food

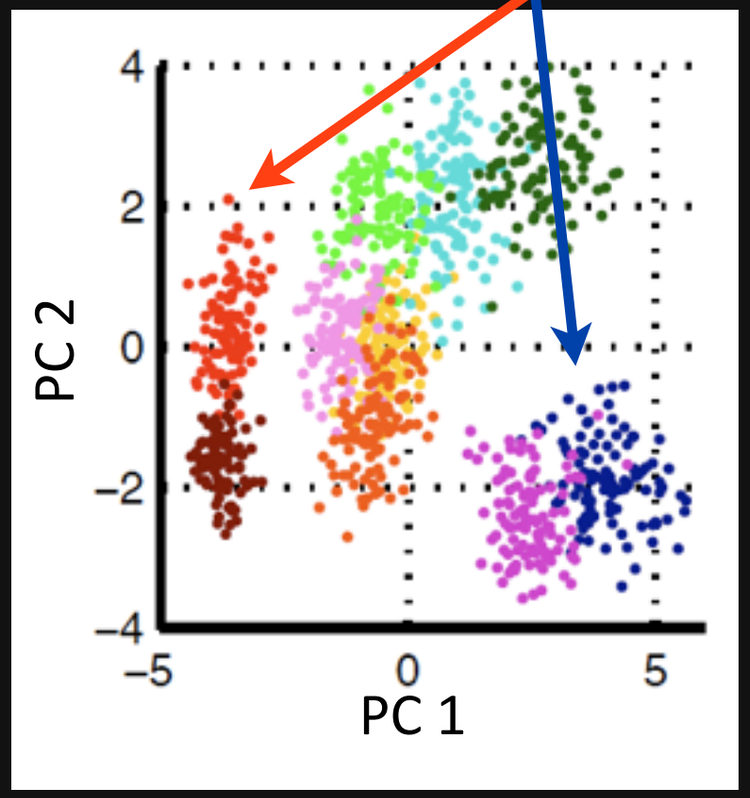
Reshaping odor representations in MBONs



Citronella

CO2

Repellent

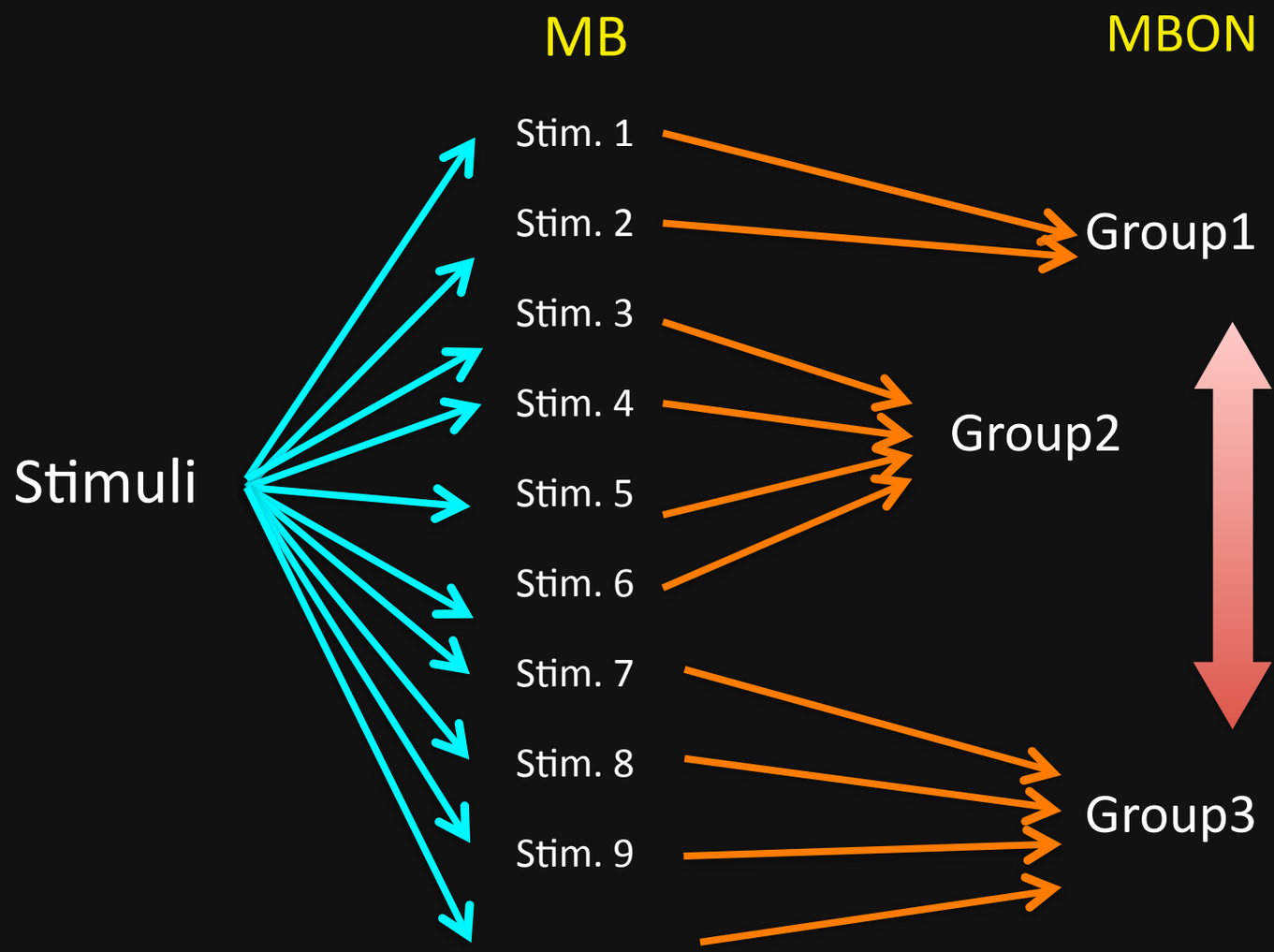


Vinegar

Yeast

Food

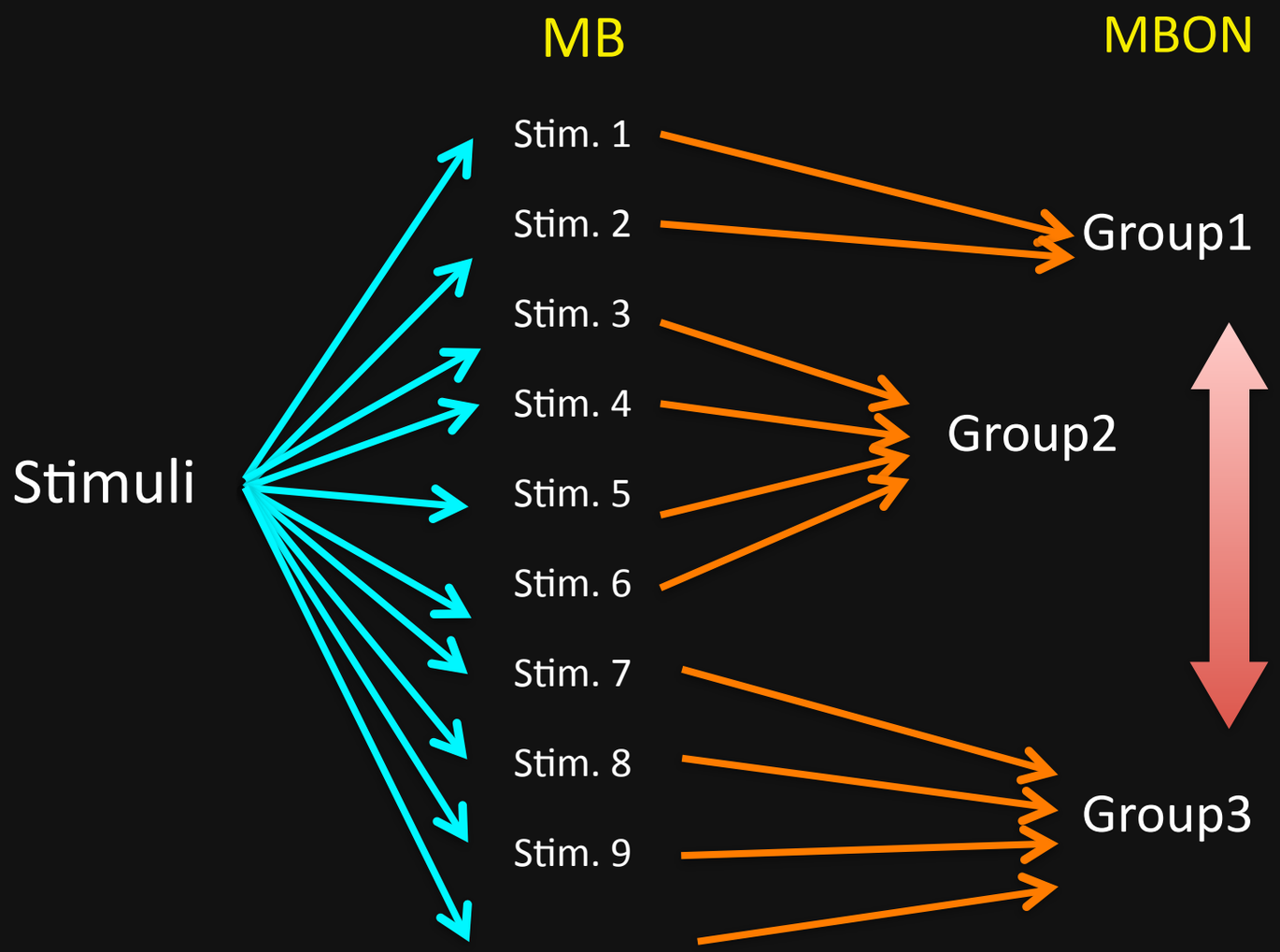
Push-Pull Transformation in MBONs

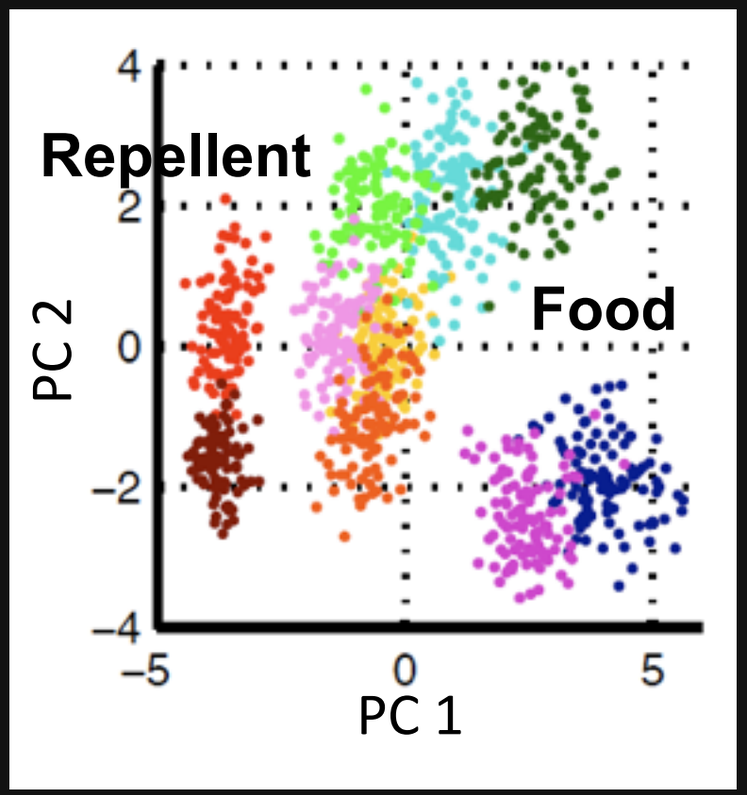


Many-to-few sensory to motor mapping

Experience dependent?

Push-Pull Transformation in MBONs





Many-to-few sensory to motor mapping

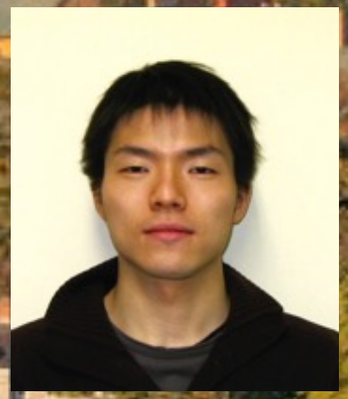
Experience dependent?

CSH Cold Spring Harbor Laboratory

Cold Spring Harbor Laboratory

Thanks to:

Yoshi Aso
Janelia



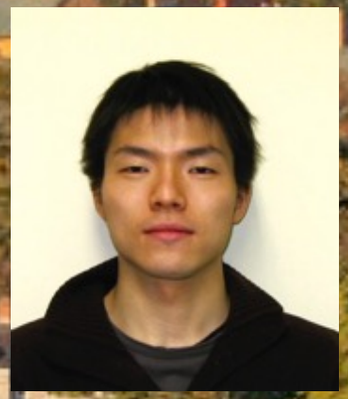
Toshihide Hige
MB Output Neurons
Postdoc

Gerry Rubin
Janelia

Cold Spring Harbor Laboratory

Thanks to:

Yoshi Aso
Janelia

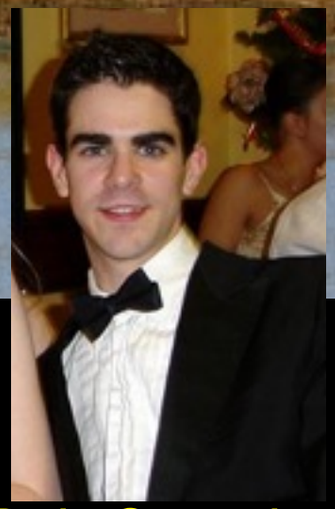


Toshihide Hige
MB Output Neurons
Postdoc

Gerry Rubin
Janelia

Eyal Gruntman
Dendritic Claws
WSBS

Kyle Honegger
MB population activity
WSBS



Rob Campbell
MB population activity
Postdoc

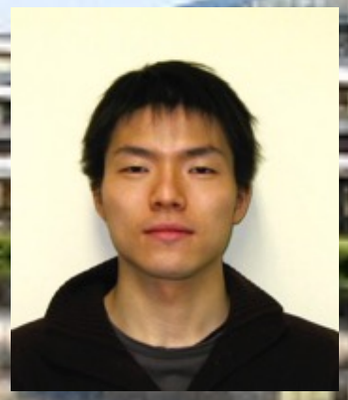
Mehrab Modi
Learning in MB
Postdoc

Martin Bill
Olfactory Coding
Postdoc

hhmi | janelia

Thanks to:

Yoshi Aso
Janelia



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