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**SEMMELWEIS  
UNIVERSITY**



**Development of Complex Curricula for Molecular Bionics and Infobionics Programs within a consortial\* framework\*\***

Consortium leader

**PETER PAZMANY CATHOLIC UNIVERSITY**

Consortium members

**SEMMELWEIS UNIVERSITY, DIALOG CAMPUS PUBLISHER**

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# BEVEZETÉS A FUNKCIONÁLIS NEUROBIOLÓGIÁBA

## INTRODUCTION TO FUNCTIONAL NEUROBIOLOGY

By Imre Kalló

Contributed by: Tamás Freund, Zsolt Liposits, Zoltán Nusser, László Acsády, Szabolcs Káli, József Haller, Zsófia Maglóczky, Nórbert Hájos, Emilia Madarász, György Karmos, Miklós Palkovits, Anita Kamondi, Lóránd Eröss, Róbert Gábrriel, Kisvárdai Zoltán

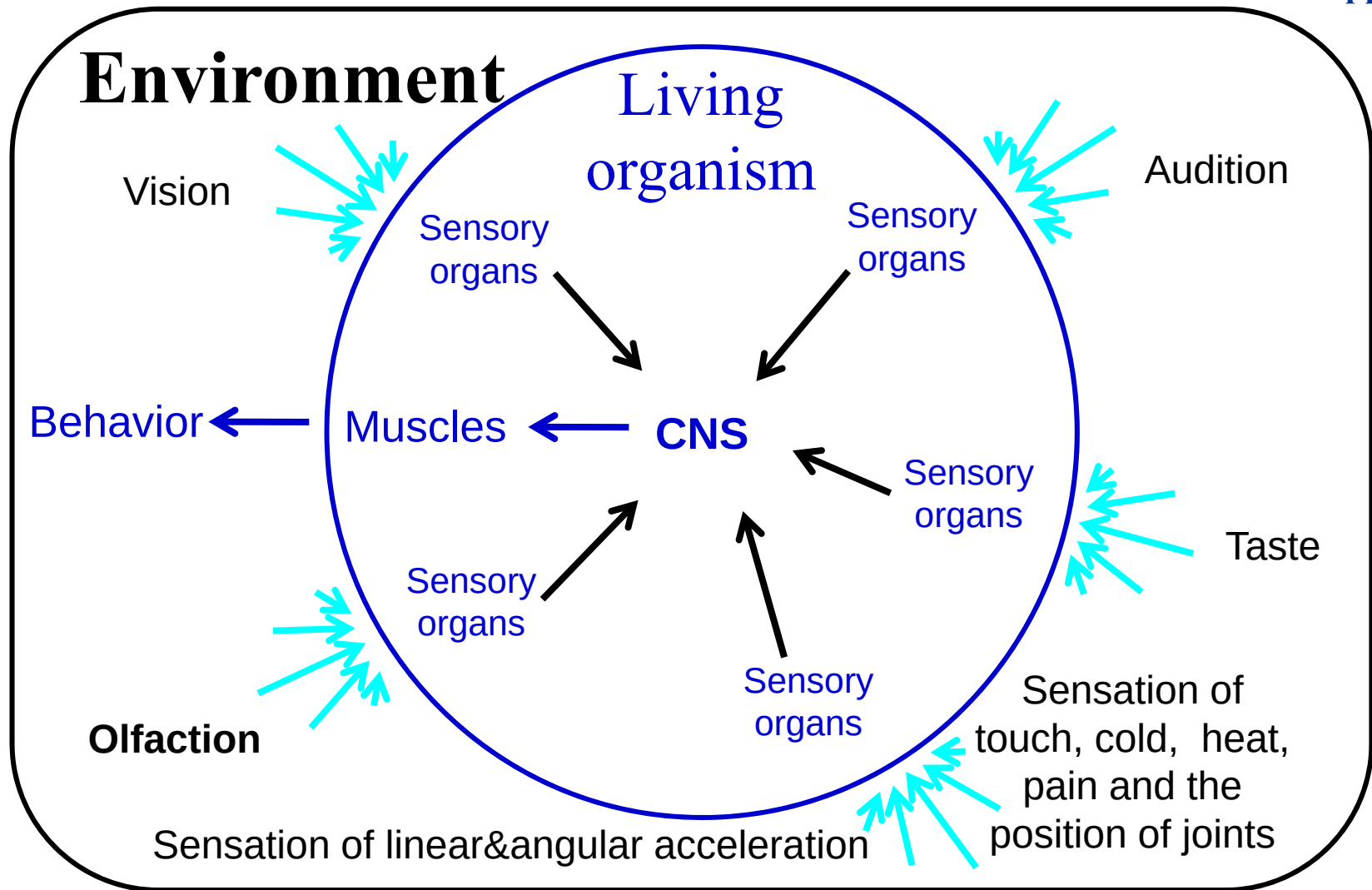
# Olfaction:

## Determining the chemical constituents (odorants) of the environment and encoding it in the CNS

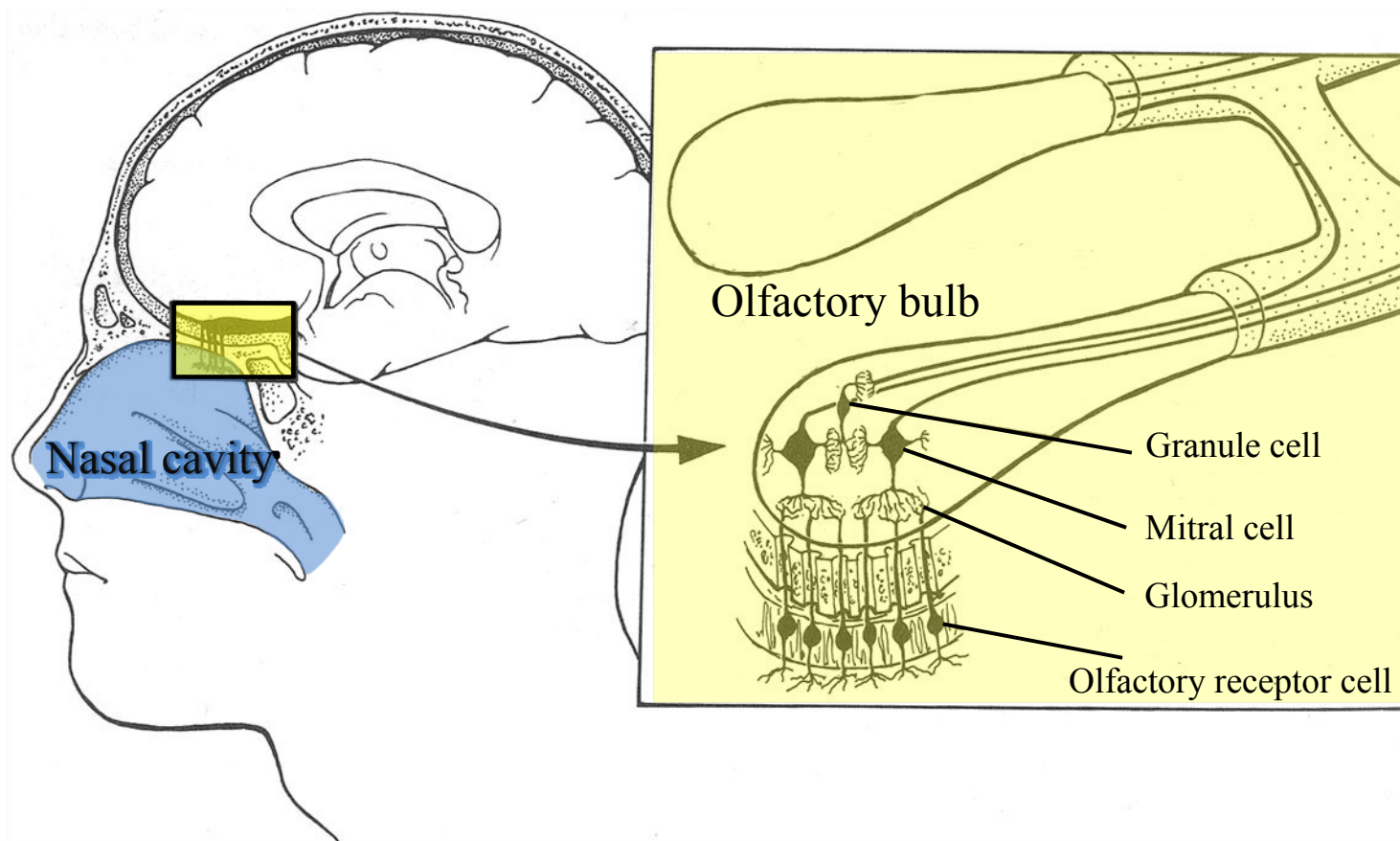
**Imre Kalló & Zoltán Nusser**

*Pázmány Péter Catholic University, Faculty of Information Technology*

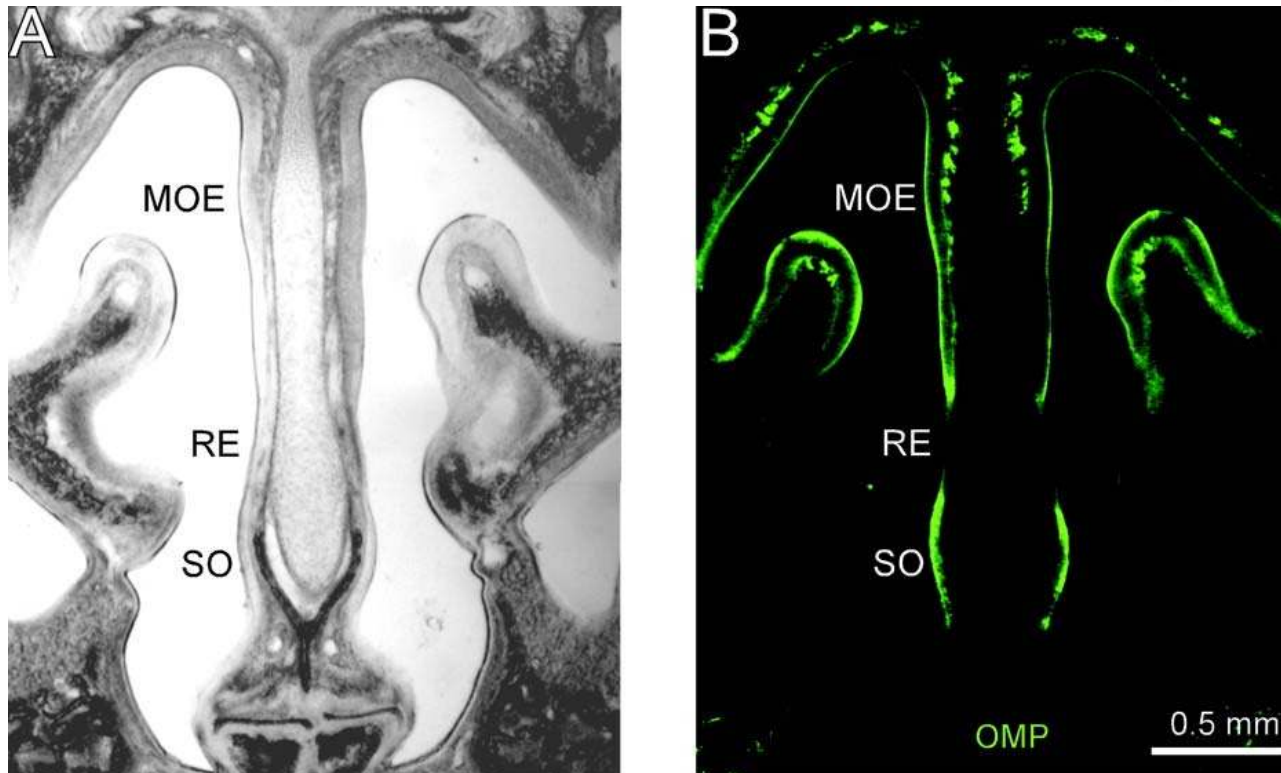
- I. Olfactory receptors.
- II. Cells and synaptic connections of the olfactory bulb.
- III. Network activity (rhythms and oscillations) and encoding of information in the olfactory bulb.



## Location of the olfactory sensory organ in humans



## Location of the olfactory epithelium (OE; containing olfactory receptor cells) in the mouse nasal cavity



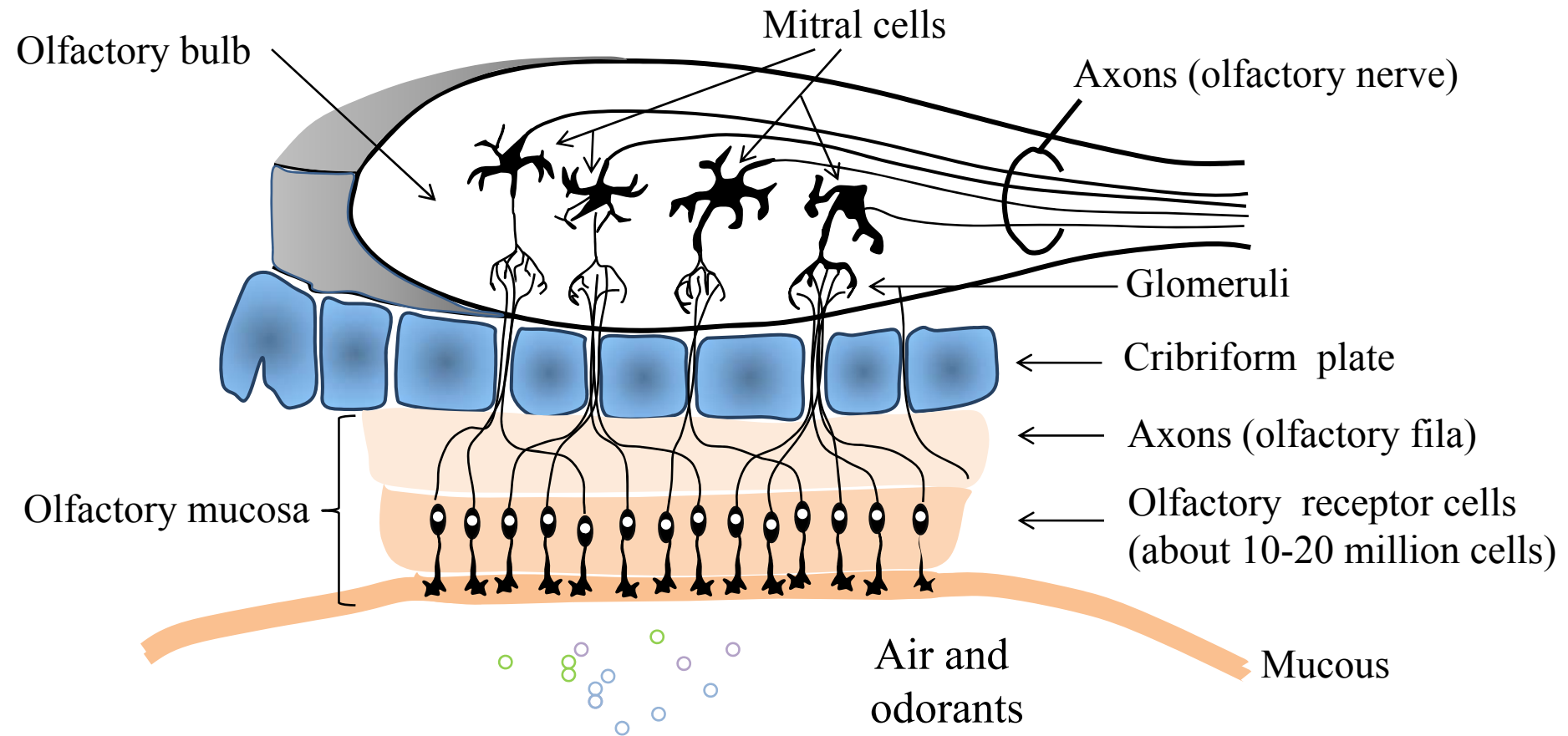
**Ref:** Ma M, Grosmaître X, Iwema CL, Baker H, Greer CA, Shepherd GM. Olfactory signal transduction in the mouse septal organ. *J Neurosci.* 2003 Jan 1;23(1):317-24.

## Location of the olfactory epithelium (OE; containing olfactory receptor cells) in the mouse nasal cavity

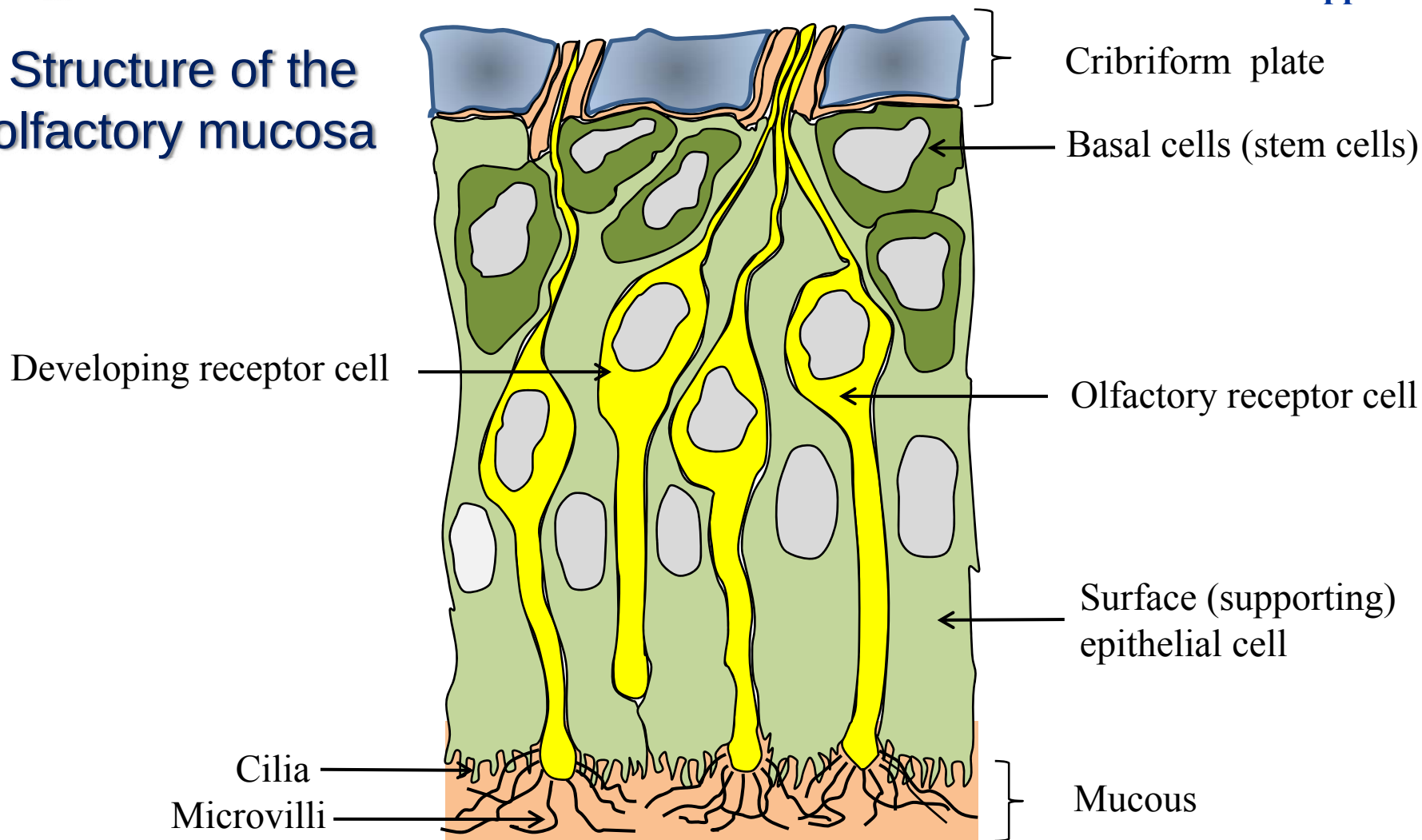
**Exp:** Immunohistochemical studies visualising the olfactory marker protein were employed to demonstrate the distribution of receptor cells in the nasal mucosa, which allows targeting of these cells specifically in morphological and functional studies. Frontal sections of the mouse nasal cavity were cut and investigated in bright field and fluorescent microscopes. Comparison of the images revealed that the receptor cells are distributed on large surfaces of the nasal cavity involving the roof, the septum as well as the conchae.

**Ref:** Ma M, Grosmaître X, Iwema CL, Baker H, Greer CA, Shepherd GM. Olfactory signal transduction in the mouse septal organ. *J Neurosci.* 2003 Jan 1;23(1):317-24.

## Structure of the olfactory bulb and mucosa

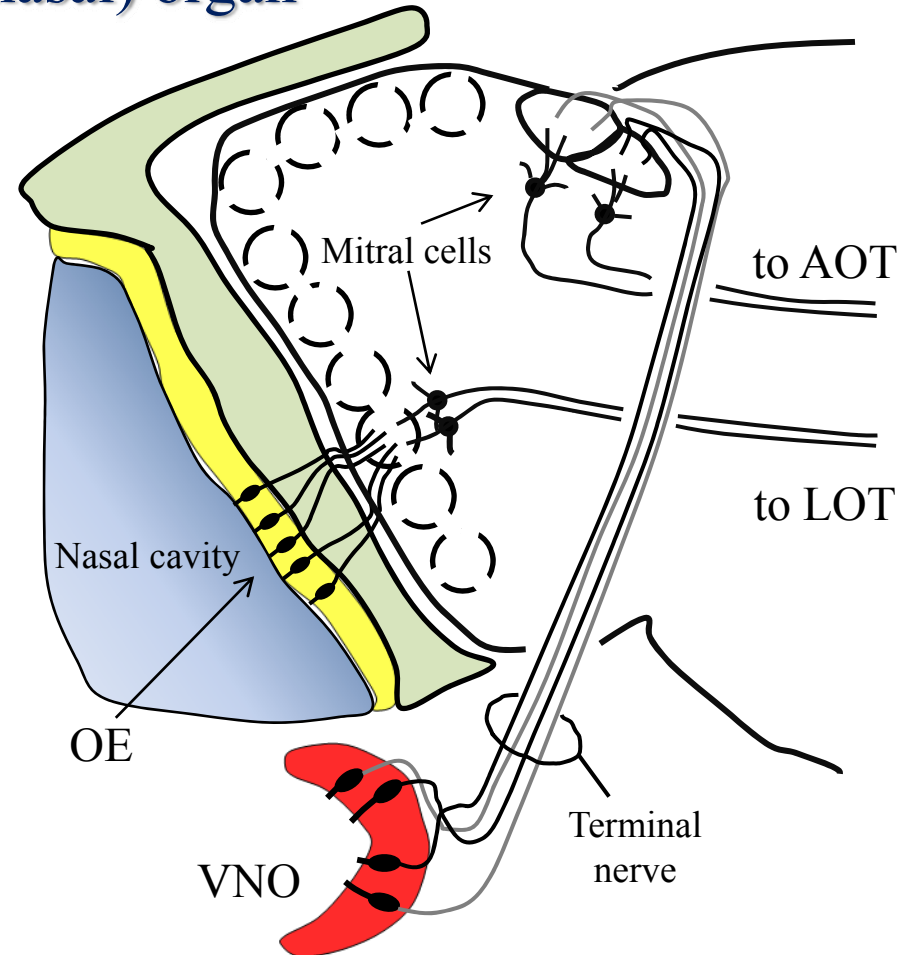
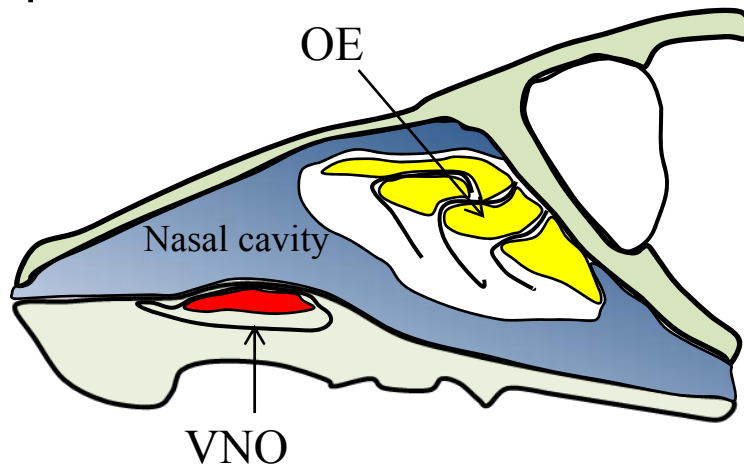


## Structure of the olfactory mucosa



## Location of the Jacobson's (vomeronasal) organ

Jacobson's vomeronasal organ (VNO) is the site of sensation for pheromones. This organ is absent in humans, but has important role in animals to find mates, territorial borders and to determine sexual responsiveness etc.



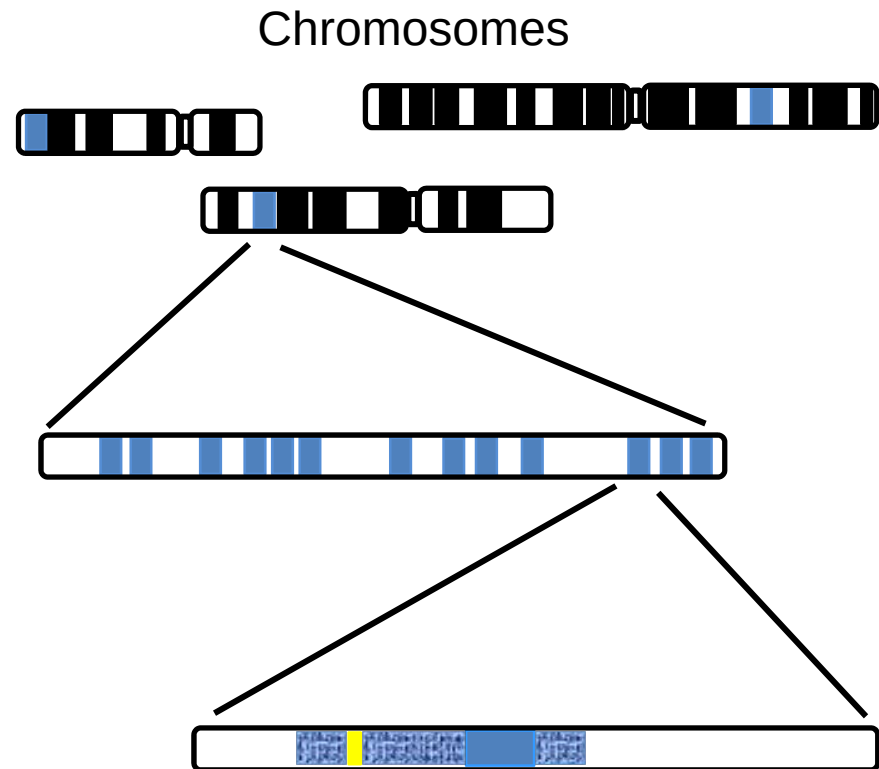
## The superfamily of olfactory receptor genes

Olfactory genes are in large clusters at more than 25 different locations

5-30 genes in the clusters

Coding regions  
(no introns present)

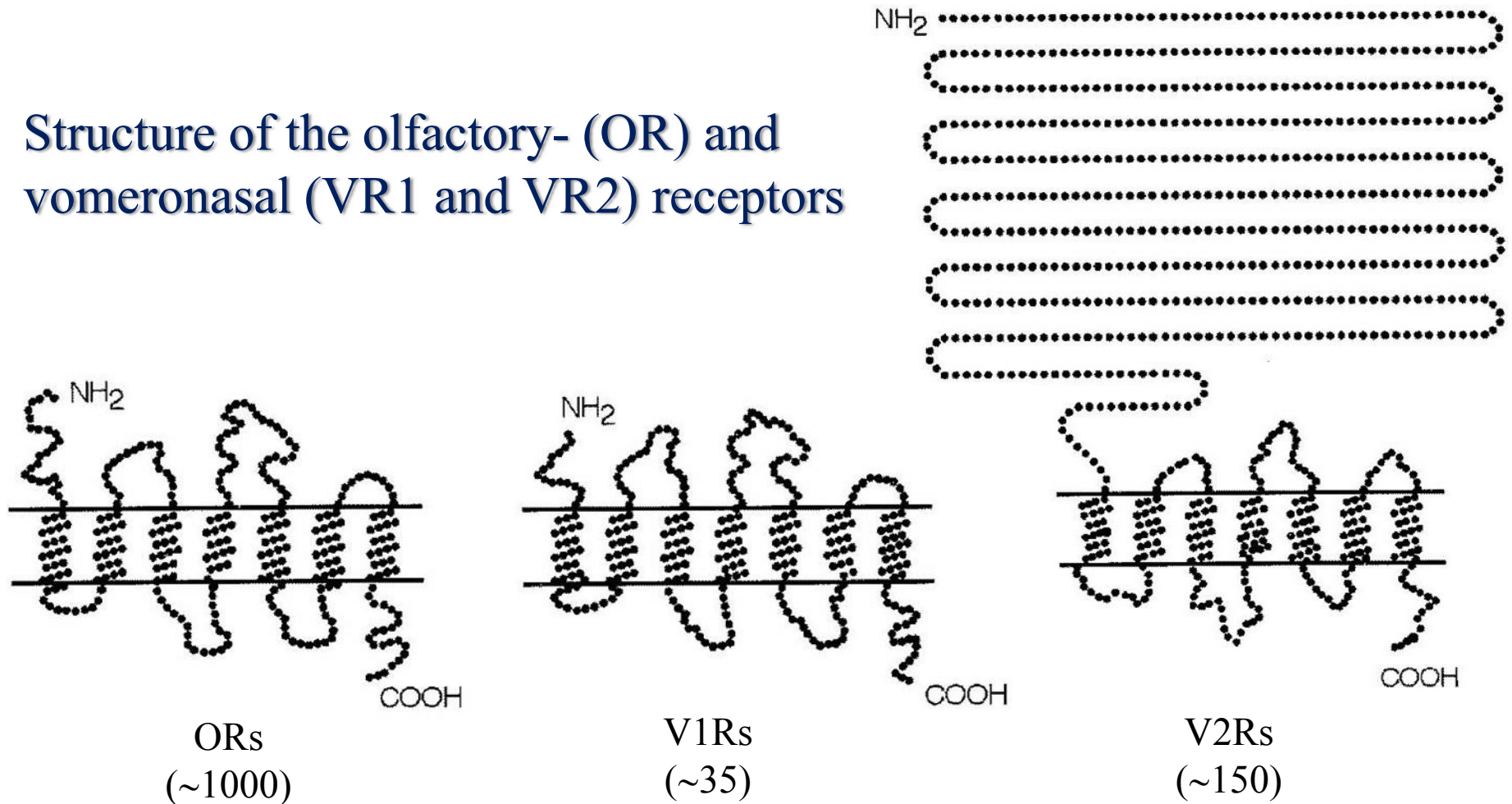
Non-coding regions



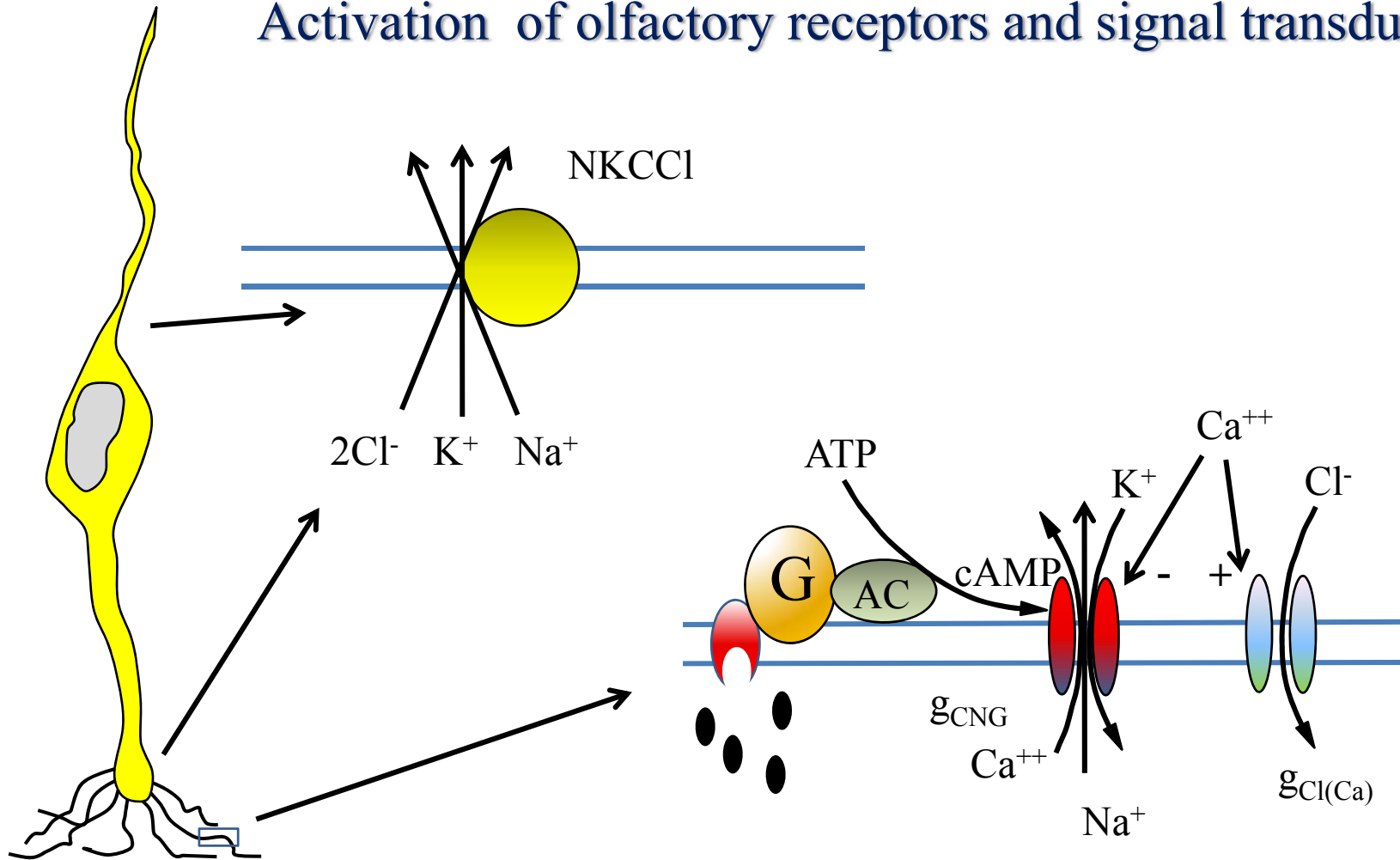
There are more than 1000 genes (gene homology is about 40-90%). 3% of all human genes.

**Ref:** Buck L, Axel R (1991) A novel multigene family may encode odorant receptors: a molecular basis for odor recognition. *Cell* 65:175-187.10

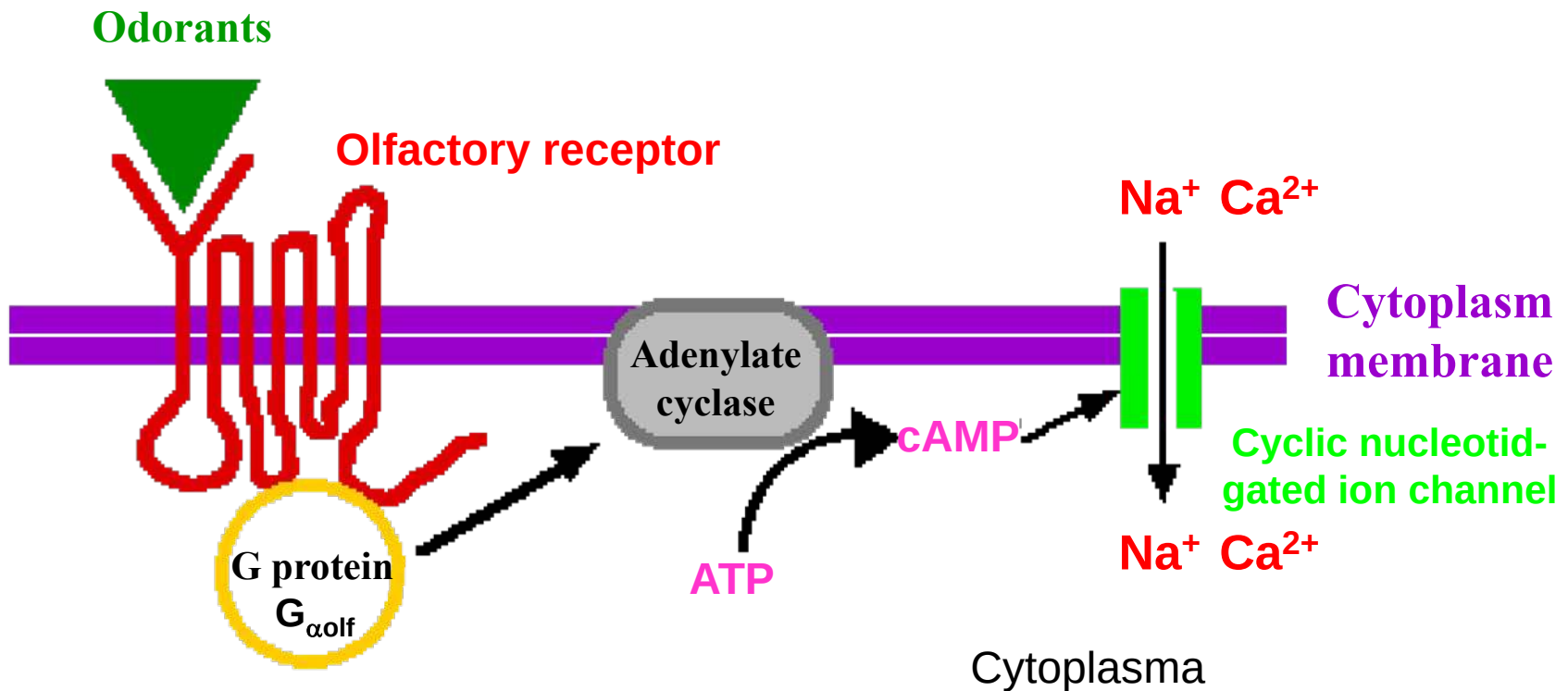
## Structure of the olfactory- (OR) and vomeronasal (VR1 and VR2) receptors



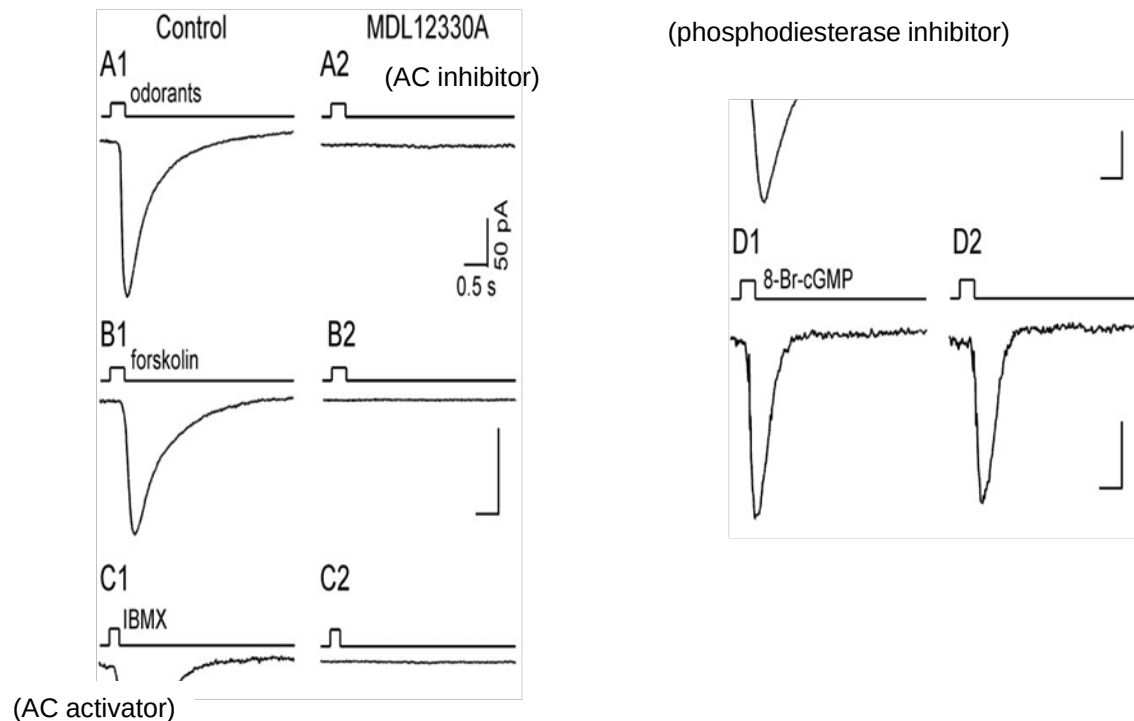
## Activation of olfactory receptors and signal transduction



## Activation of olfactory receptors and signal transduction



## Cyclic AMP mediated signal transduction in the olfactory epithelial cells



**Ref:** Ma M, Grosmaître X, Iwema CL, Baker H, Greer CA, Shepherd GM. Olfactory signal transduction in the mouse septal organ. *J Neurosci.* 2003 Jan 1;23(1):317-24.

## Cyclic AMP mediated signal transduction in the olfactory epithelial cells

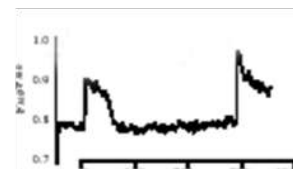
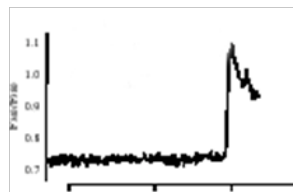
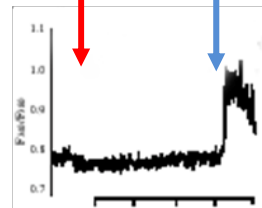
**Exp:** Intact olfactory epithelium was prepared and exposed to odorants. Perforated patch-clamp recordings were performed on the dendritic knobs of individual olfactory epithelial cells (OEC) to study the currents generated by odorants and compounds influencing signal transduction. Odorants, and compounds elevating cyclic nucleotide levels induced inward currents in the neurons under voltage-clamp mode. In contrast, a blocker of the adenylate cyclase inhibited this current supporting the crucial role of cAMP in the signal transduction of OECs.

**Ref:** Ma M, Grosmaître X, Iwema CL, Baker H, Greer CA, Shepherd GM. Olfactory signal transduction in the mouse septal organ. *J Neurosci.* 2003 Jan 1;23(1):317-24.

## Studies on the specificity of olfactory receptors in a gene expression model

**Exp:** HEK293 cells were transfected *in vitro* with constructs of genes normally not expressed in this cell line, i.e. genes coding mouse olfactory receptors (mOR912-93) and/or G protein subunits ( $G\alpha_{15}$ ,  $Gq_0G\gamma$ ). Changes of intracellular  $Ca^{2+}$  concentration was measured in response to a single odorant and to an ubiquitous activator of the CNG channels by using FURA-2 calcium indicator.

2-heptanon ATP



Expressed genes:

mOR912-93: -  
 $G\alpha_{15}$ ,  $Gq_0G\gamma$ : -

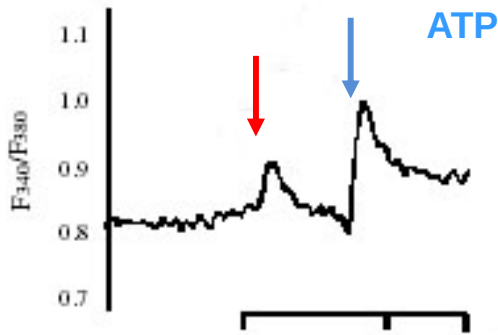
mOR912-93: -  
 $G\alpha_{15}$ ,  $Gq_0G\gamma$ : +

mOR912-93: +  
 $G\alpha_{15}$ ,  $Gq_0G\gamma$ : -

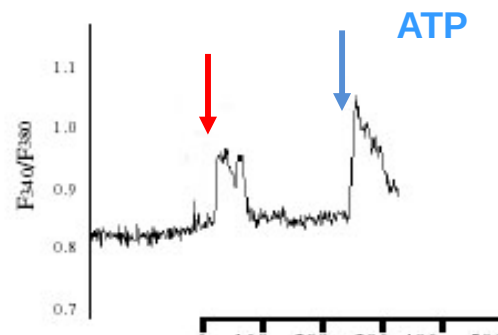
mOR912-93: +  
 $G\alpha_{15}$ ,  $Gq_0G\gamma$ : +

## Studies on the specificity of olfactory receptors in a gene expression model : Ca responses to aliphatic ketones with slightly different carbon numbers

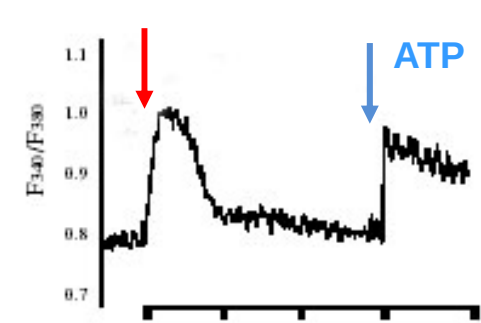
2-butanon 



2-heptanon 



2-dekanon 

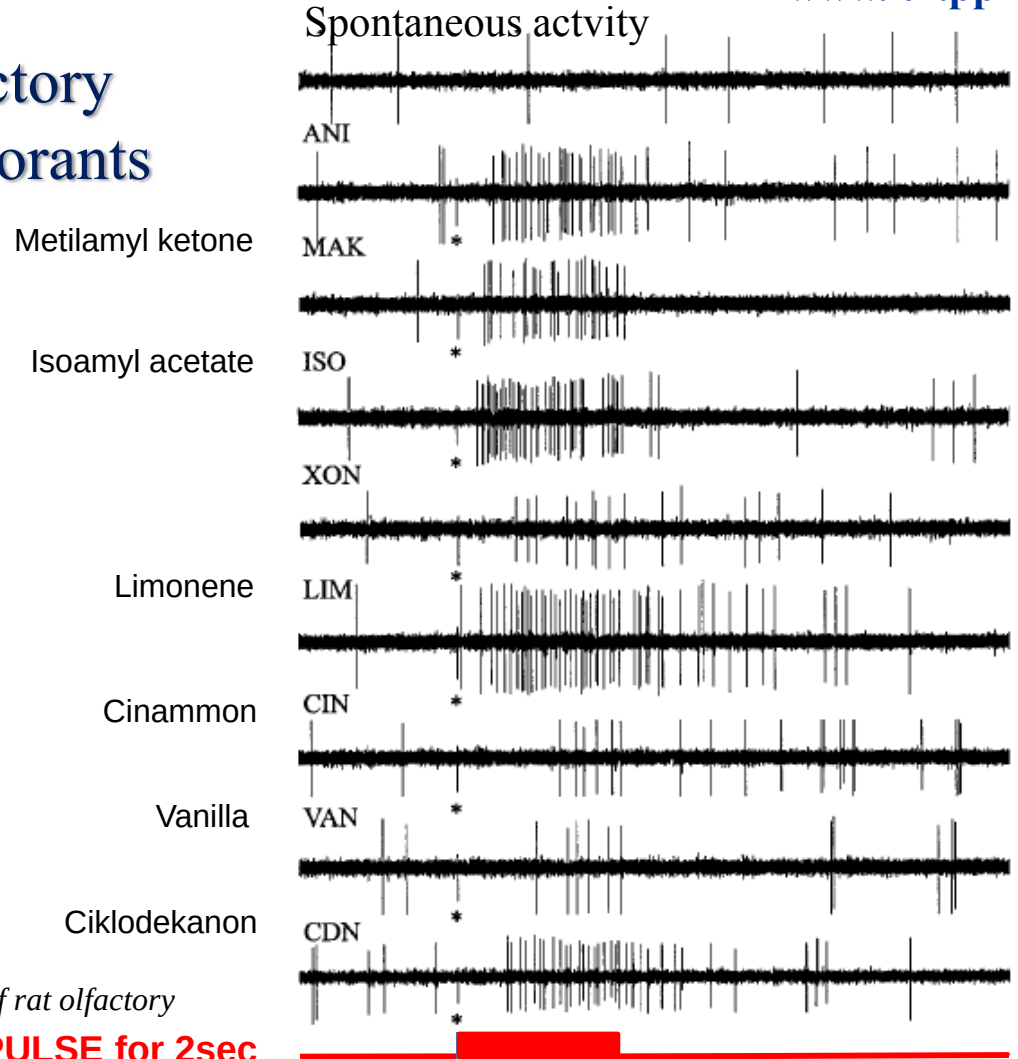


**Exp:** Changes of intracellular  $\text{Ca}^{2+}$  concentration was measured in response to slightly different odorants and to an ubiquitous activator of the CNG channels by using FURA-2 calcium indicator. .

## Response of a single olfactory epithelial cell to various odorants

**Exp:** The activity of single olfactory receptor neurons was recorded *in vivo* from a rat and exposed to various odorants. Single unit (extracellular) recordings were performed on an olfactory epithelial cell to study its firing activity changes evoked by various odorants.

**Ref:** Duchamp-Viret et al., Odor response properties of rat olfactory receptor neurons. *Science*. 1999, 284:2171-4. **ODOR PULSE for 2sec**

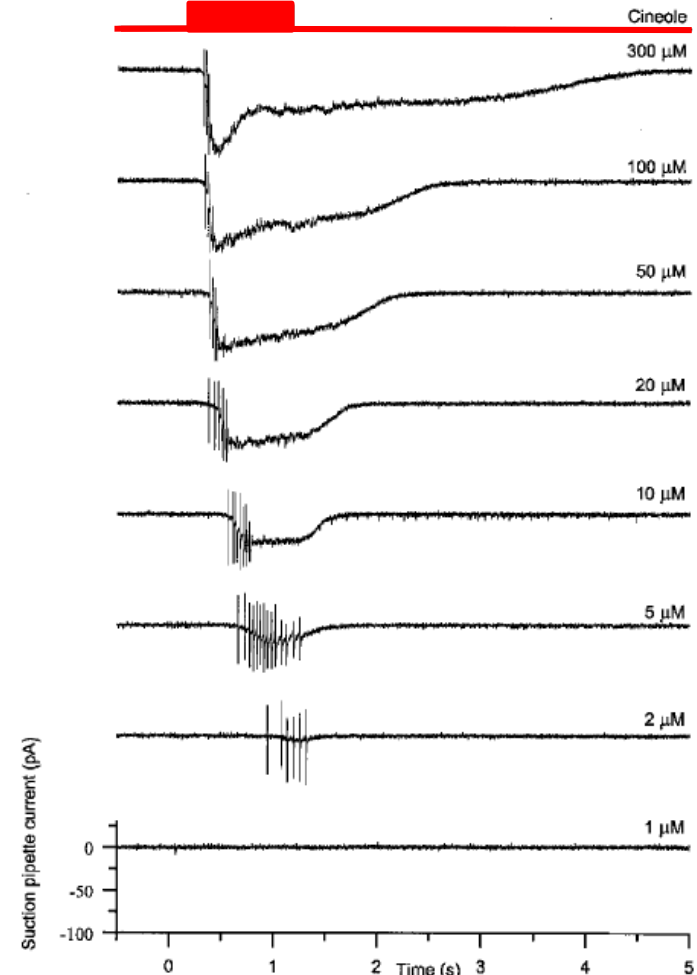


## Response of a single olfactory epithelial cell to exposure of various concentrations of cineole

**Exp:** Olfactory epithelial cells were isolated from a frog. Receptor currents and spike trains were recorded by the suction-pipette recording technique. The cell body was drawn into a suction pipette, leaving the cilia exposed to the superfusing solution, within the concentration of the odorant cineole was raised gradually.

**Ref:** Reisert J, Matthews HR. Adaptation of the odor-induced response in frog olfactory receptor cells. *J Physiol (London)*. 1999, 519:801-813.

ODOR PULSE for 1 sec

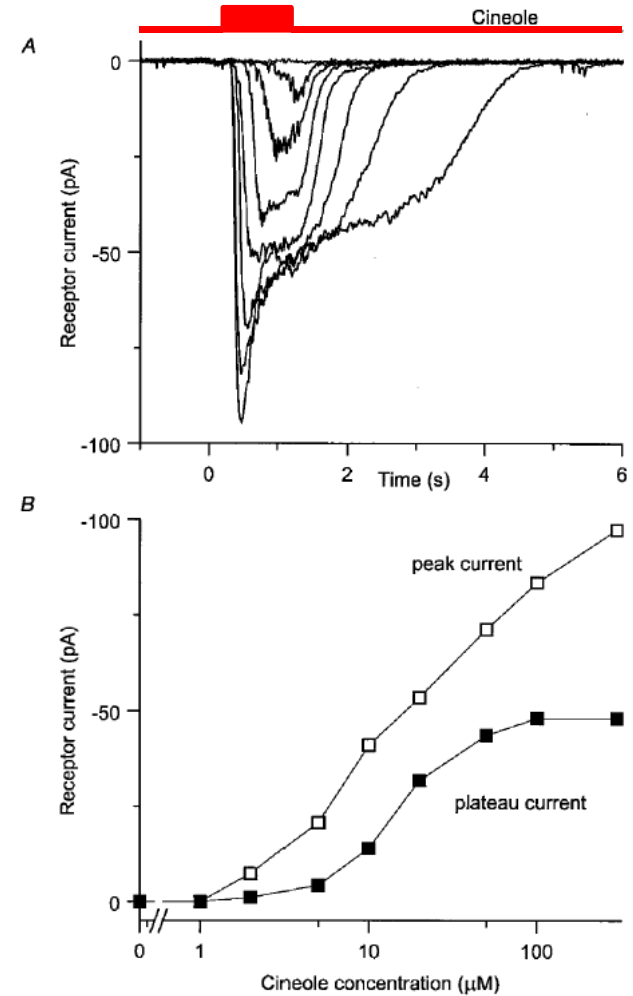


## Response of a single olfactory epithelial cell to exposure of various concentrations of cineole

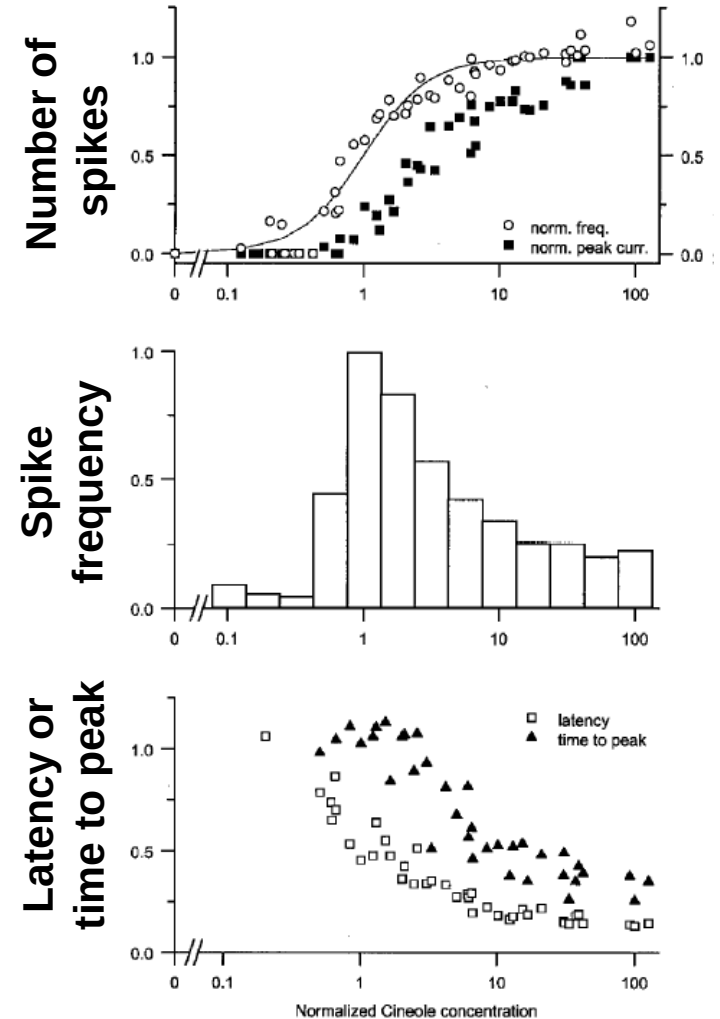
**Exp:** Olfactory epithelial cells were isolated from a frog. Receptor currents and spike trains were recorded by the suction-pipette recording technique. The cell body was drawn into a suction pipette, leaving the cilia exposed to the superfusing solution, within the concentration of the odorant cineole was raised gradually.

**Ref:** Reisert J, Matthews HR. Adaptation of the odor-induced response in frog olfactory receptor cells. *J Physiol (London)*. 1999, 519:801-813.

### ODOR PULSE



## Response of a single olfactory epithelial cell to exposure of various concentrations of cineole

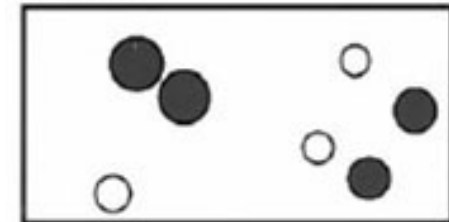


**Ref:** Reisert J, Matthews HR. Adaptation of the odor-induced response in frog olfactory receptor cells. *J Physiol (London)*. 1999, 519:801-813.

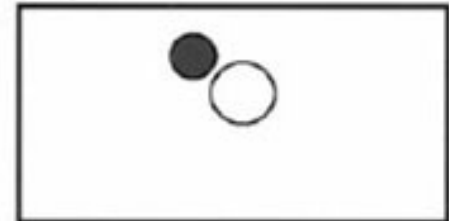
## Activity patterns evoked by different chemical compounds in the OECs

|                | ORs |   |   |   |   |   |   |   |   |    |    |    |    |    |                                                            |
|----------------|-----|---|---|---|---|---|---|---|---|----|----|----|----|----|------------------------------------------------------------|
|                | 1   | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |                                                            |
| hexanoic acid  |     |   |   |   |   |   |   |   |   |    |    |    |    |    | rancid, sweaty, sour<br>goat-like, fatty                   |
| hexanol        |     |   |   |   |   |   |   |   |   |    |    |    |    |    | sweet, herbal, woody<br>Cognac, Scotch whiskey             |
| heptanoic acid |     |   |   |   |   |   |   |   |   |    |    |    |    |    | rancid, sweaty, sour<br>fatty                              |
| heptanol       |     |   |   |   |   |   |   |   |   |    |    |    |    |    | violet, sweet, woody<br>herbal, fresh, fatty               |
| octanoic acid  |     |   |   |   |   |   |   |   |   |    |    |    |    |    | rancid, sour, repulsive<br>sweaty, fatty                   |
| octanol        |     |   |   |   |   |   |   |   |   |    |    |    |    |    | sweet, orange, rose, fatty<br>fresh, powerful, waxy        |
| nonanoic acid  |     |   |   |   |   |   |   |   |   |    |    |    |    |    | waxy, cheese,<br>nut-like, fatty                           |
| nonanol        |     |   |   |   |   |   |   |   |   |    |    |    |    |    | fresh, rose, oily, floral<br>odor of citronella oil, fatty |

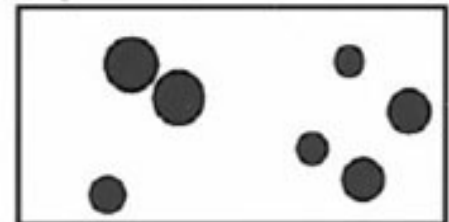
octanal



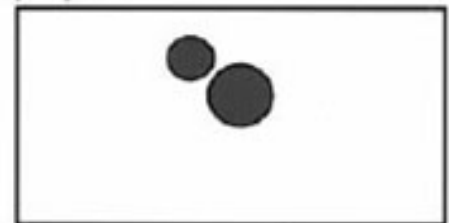
propionic acid



amyl acetate



propanal

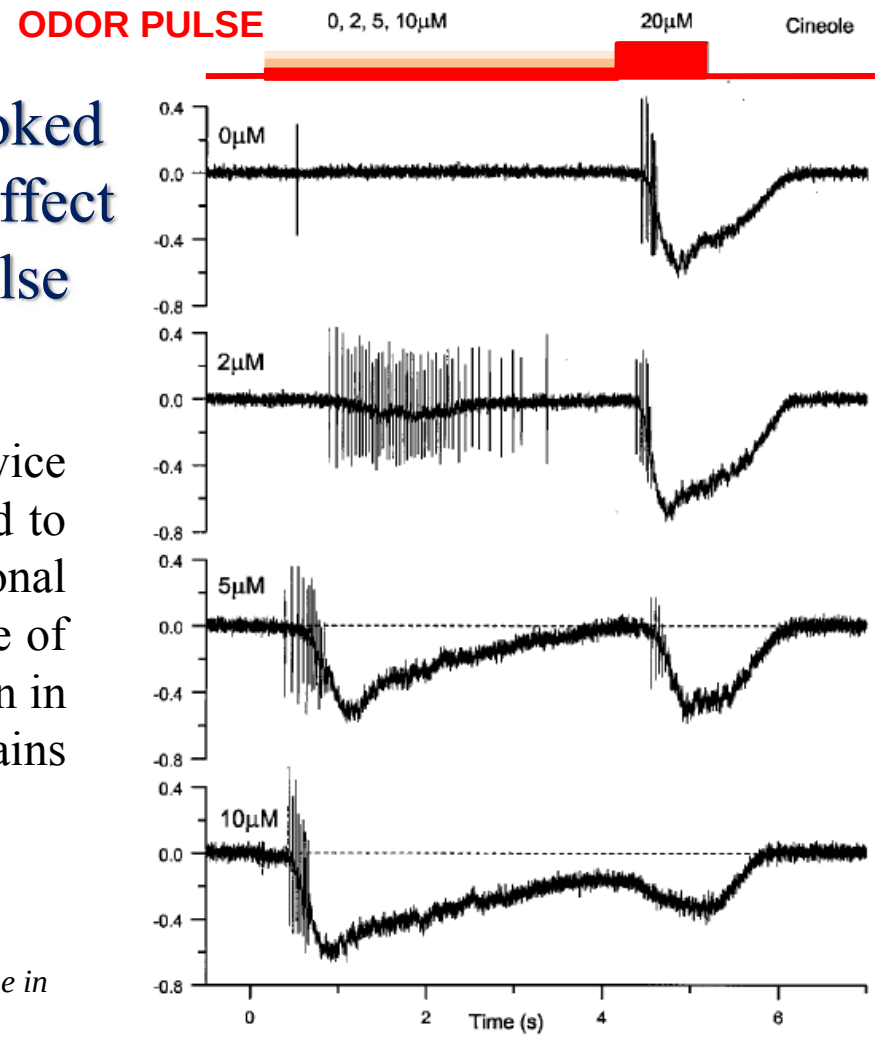


**Ref:** Buck, The Molecular Architecture of Odor and Pheromone Sensing in Mammals *Cell*, 2000, 100, 611-618

## Adaptation of receptor currents evoked by repeated exposure to odorants: effect of concentration at conditional pulse

**Exp:** Olfactory epithelial cells were exposed twice to cineole. First the recorded cell was exposed to increasing concentration of cineole (a conditional pulse), which was followed by a second pulse of cineole (test pulse; using the same concentration in each trial). Receptor currents and spike trains generated by the test pulse were analysed.

**Ref:** Reisert J, Matthews HR. Adaptation of the odor-induced response in frog olfactory receptor cells. *J Physiol (London)*. 1999, 519:801-813.

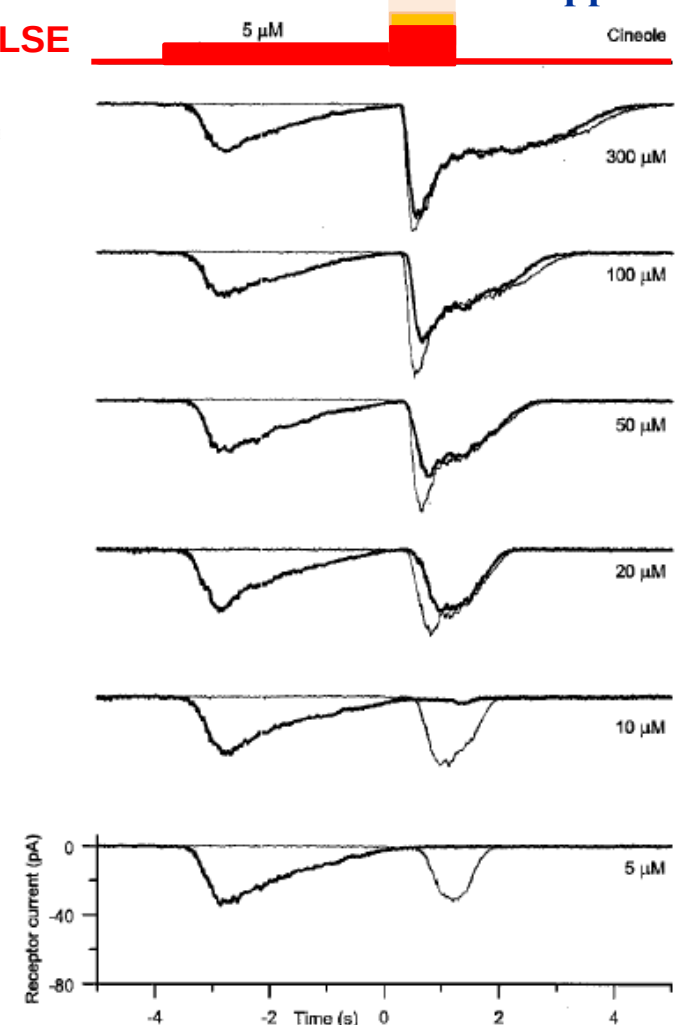


## Adaptation of receptor currents evoked by repeated exposure to odorants: effect of concentration at test pulse

**Exp:** Olfactory epithelial cells were exposed twice to cineole. First the recorded cell was exposed to stable concentration of cineole (a conditional pulse), which was followed by a second pulse of cineole (test pulse; using this time an increasing concentration in each trial). Receptor currents and spike trains generated by the test pulse were analysed.

**Ref:** Reisert J, Matthews HR. Adaptation of the odor-induced response in frog olfactory receptor cells. *J Physiol (London)*. 1999, 519:801-813.

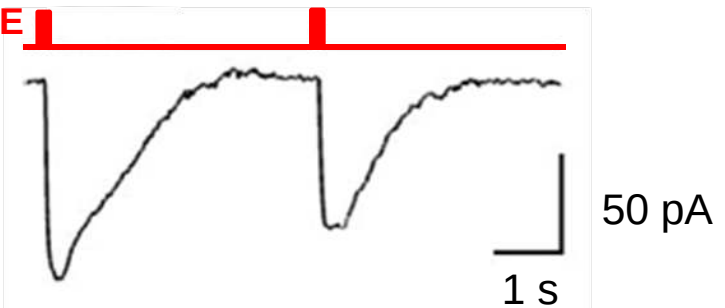
ODOR PULSE



## Adaptation of receptor currents evoked by repeated exposure to odorants: effect of inter-pulse time

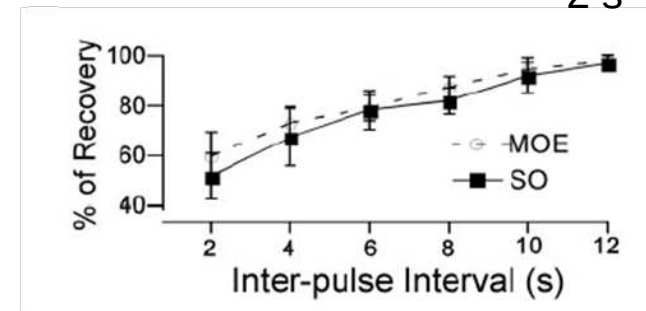
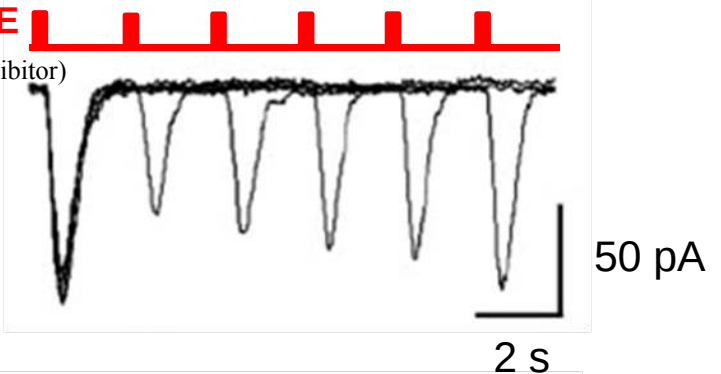
**Exp:** Olfactory epithelial cells were exposed to odorants or the phosphodiesterase inhibitor IBMX with different inter-pulse intervals.

ODOR PULSE



IBMX PULSE

(phosphodiesterase inhibitor)



## Summary: OECs

The olfactory mucosa is a special area of the nasal mucosa, which is about 5 cm<sup>2</sup> in humans (150 cm<sup>2</sup> in dogs!), and covers the dorsal and posterior part of the nasal cavity. Structurally it contains olfactory epithelial cells (OECs; 10-20 million in humans, 200 millions in dogs), supporting cells and basal cells.

OECs are produced throughout life (every 60 days they are renewed) from the basal precursor cells. They recognise a great diversity of odorants with special olfactory receptor proteins.

The olfactory receptor proteins are seven transmembrane region-containing receptors coupled to G protein ( $G_{\alpha\text{olf}}$ ). By activating the adenylate cyclase, they increase the intracellular level of cAMP, which in turn open cyclic nucleotide-gated ion channels, and consequently depolarise OECs and cause  $\text{Ca}^{2+}$  influx.  $\text{Ca}^{2+}$  activates  $\text{Ca}^{2+}$  dependent  $\text{Cl}^-$  channels, through which the  $\text{Cl}^-$  efflux results in further depolarization.

A single OEC express only a single olfactory receptor protein, which suggest its high specificity.

## Summary: OECs

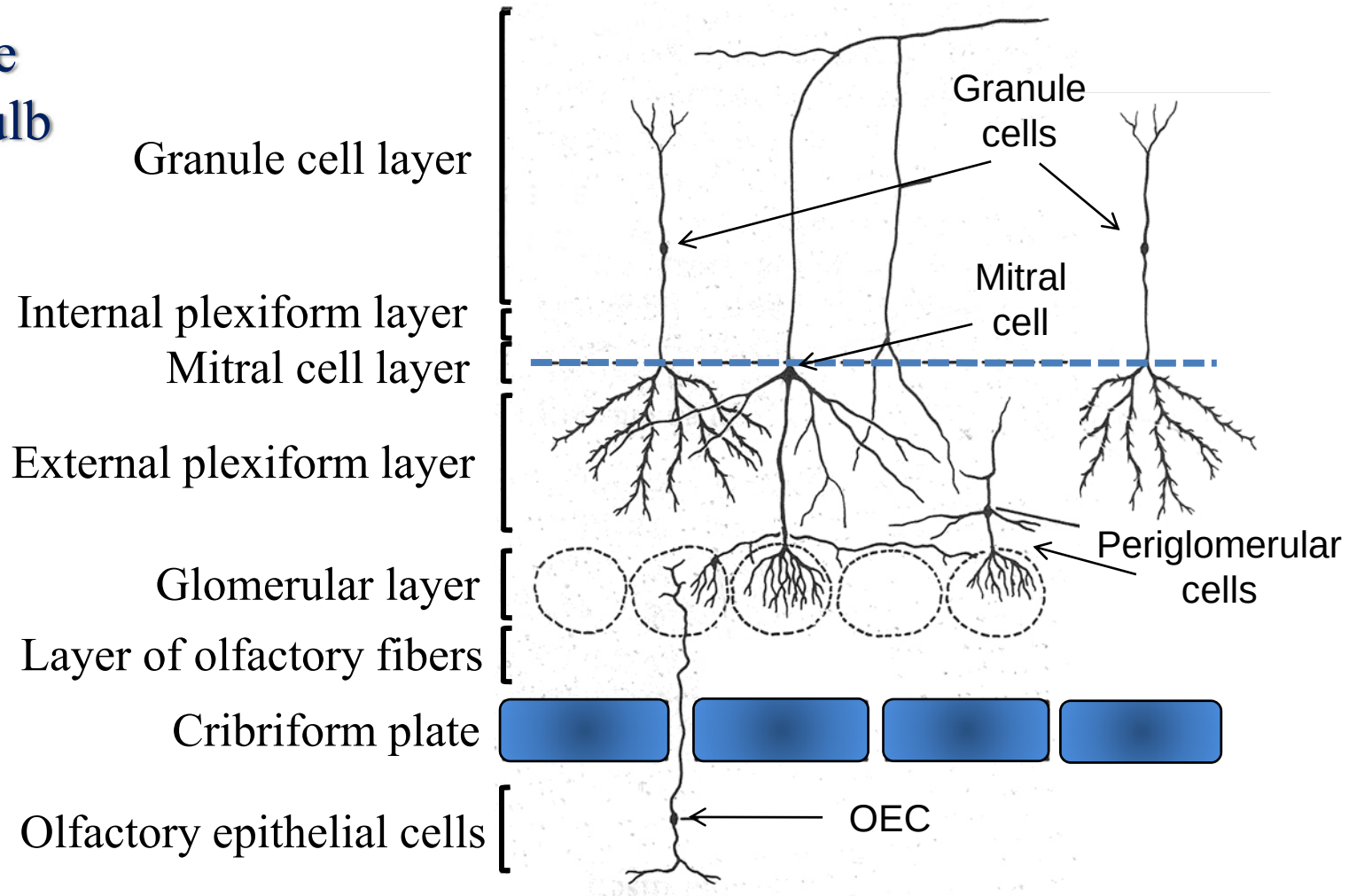
A single receptor protein is able to bind several chemical molecules/odorants and a single chemical molecule can bind to several receptor proteins. Different chemical molecules are capable to increase (stimulatory) or decrease (inhibitory) the activity of OECs. Taken together, the olfactory receptors, and hereby the OECs show a low specificity for the molecules (several odorants stimulate them).

Every molecule induces their own characteristic activity pattern (in space and time) in the olfactory glomeruli. Different molecules induce partially overlapping, but not identical activity patterns.

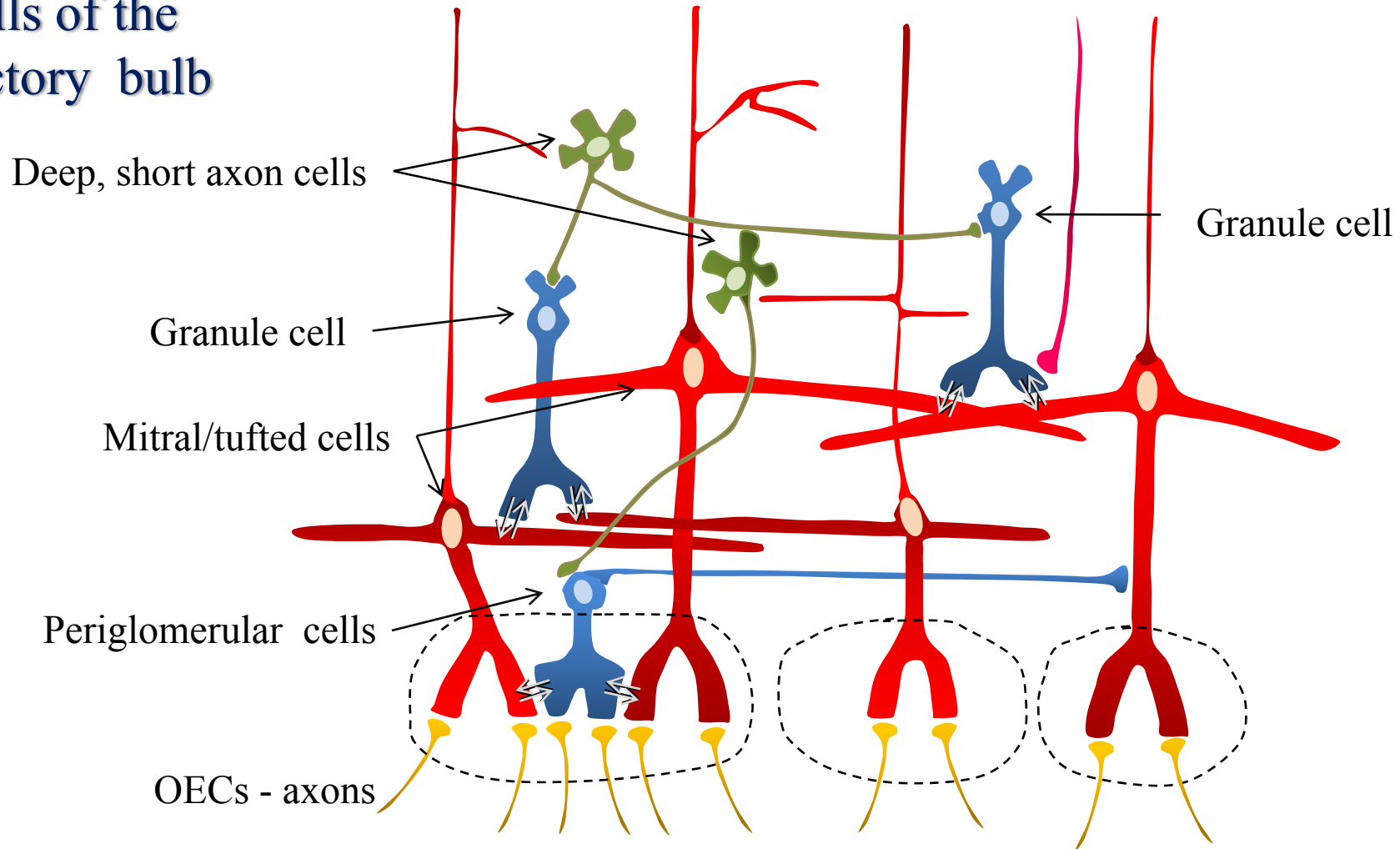
The odorant induced electrical responses of OECs (number, latency and the frequency of action potentials) show adaptation. The adaptation is manifested in the size (amplitude and duration) of receptor currents. A conditional stimulus with a certain concentration of odorants reduce the extent of the response to the test stimulus. Larger the concentration of odorants during the conditional stimulus, the stronger the adaptation recorded at the test stimulus (shift in the dose-response curve)

## Olfaction: Cellular elements and synaptic connections of the olfactory bulb

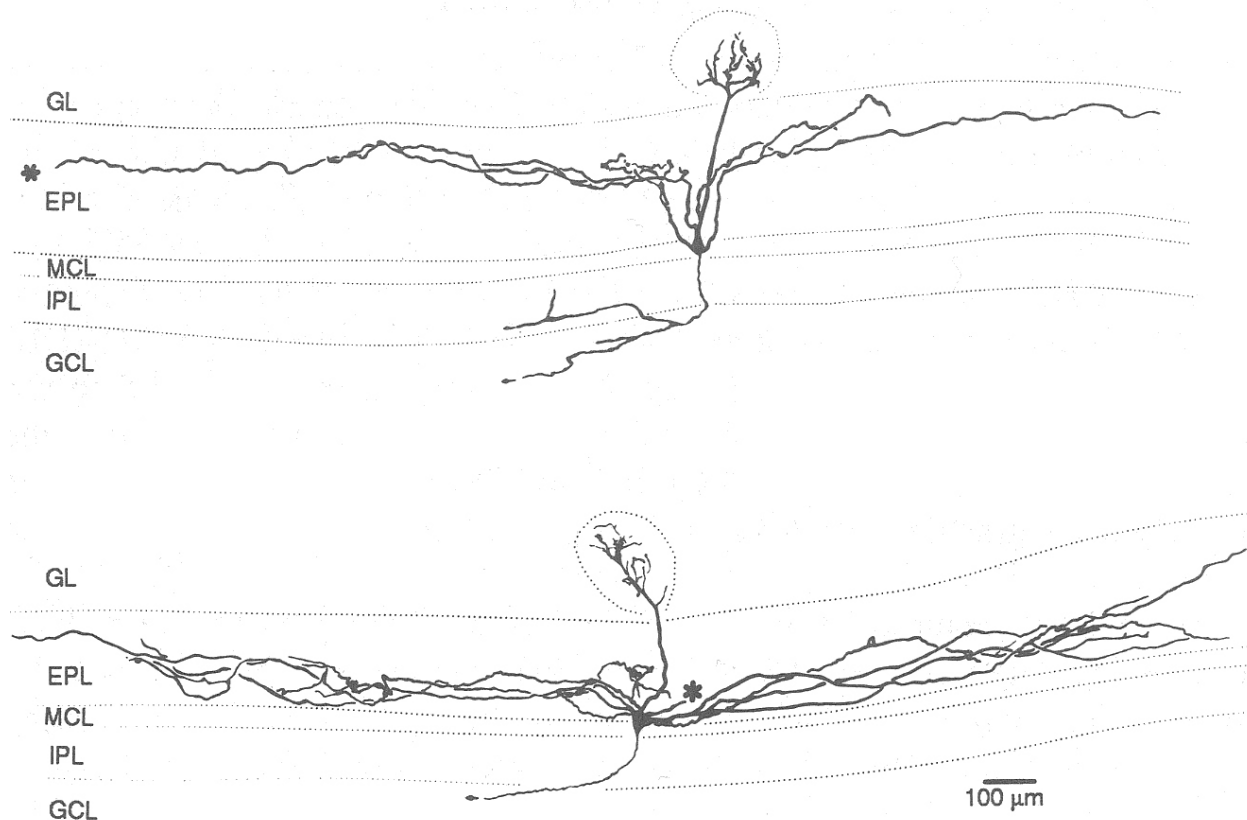
## Layers of the olfactory bulb

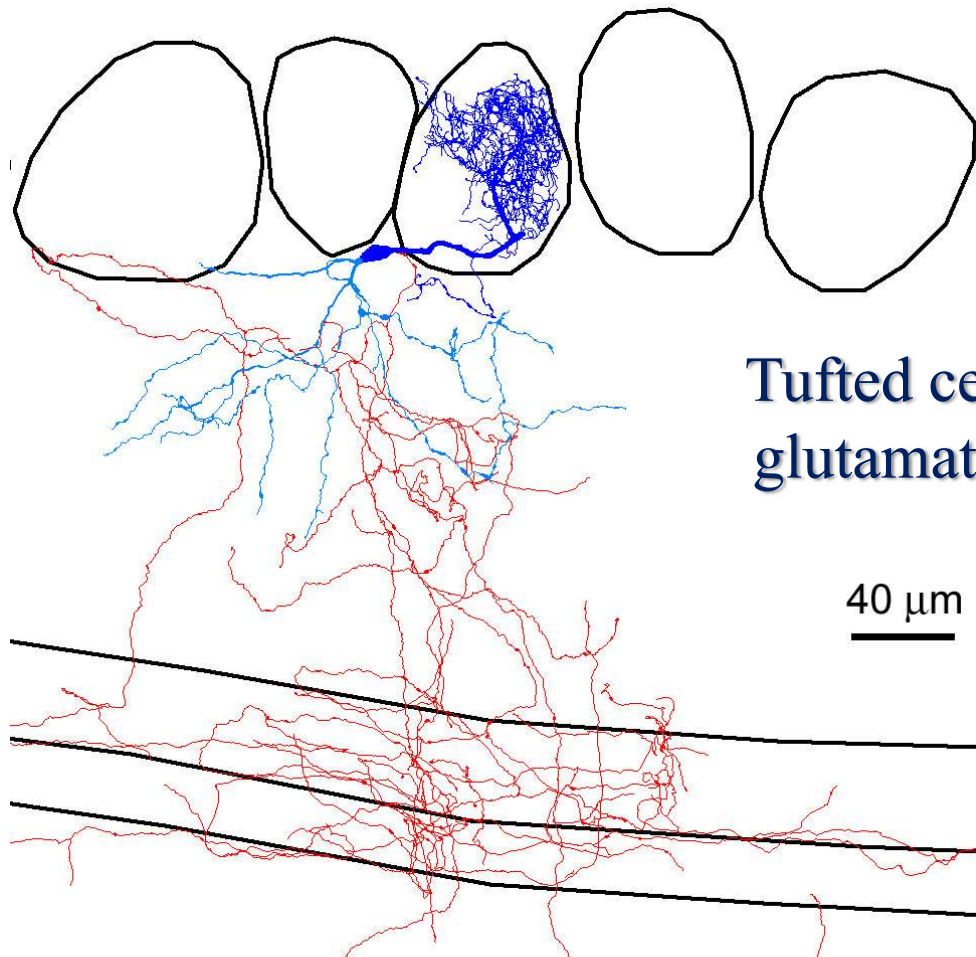


## Cells of the olfactory bulb



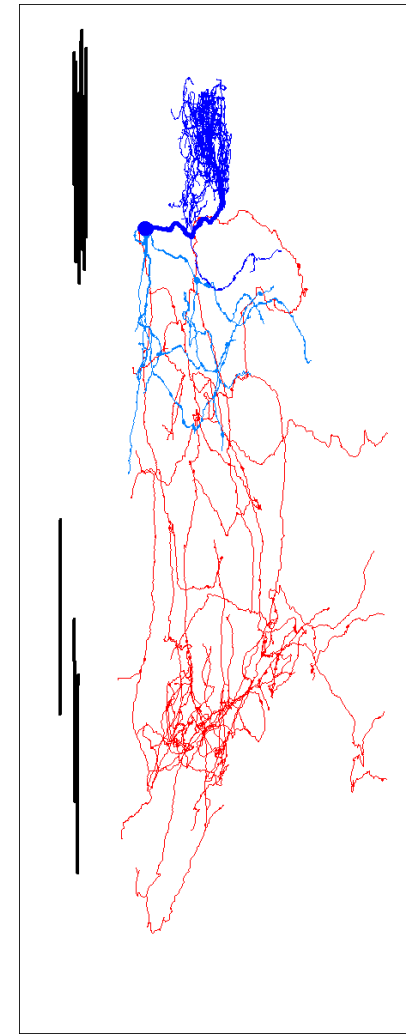
## Mitral cells (excitatory, glutamatergic neurons)



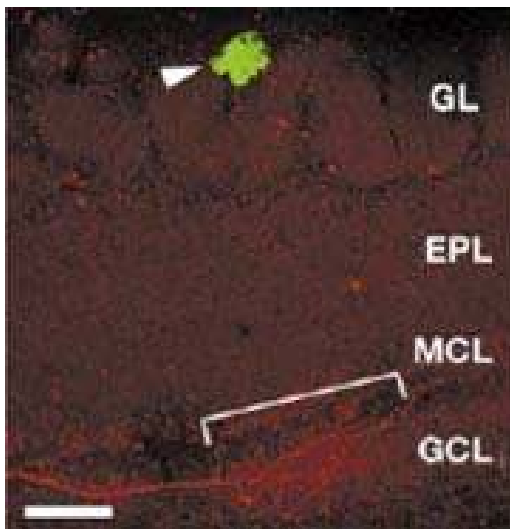
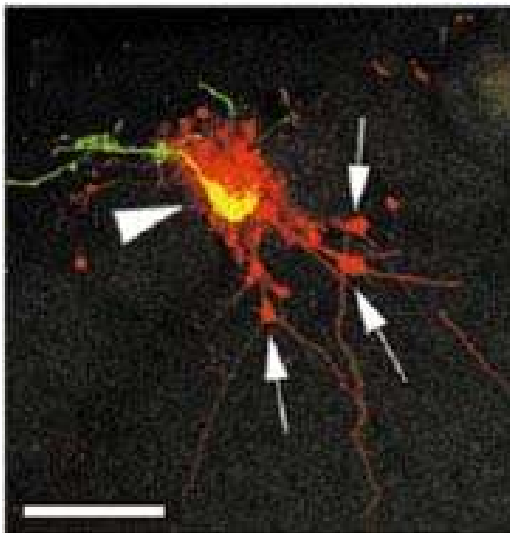


Tufted cells (excitatory,  
glutamatergic neurons)

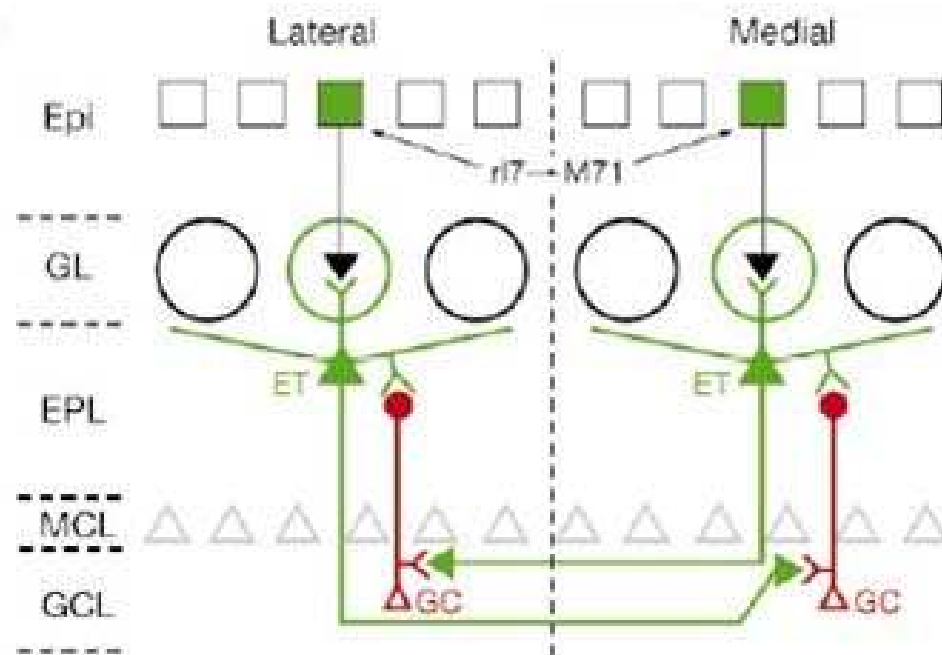
40 μm



**Ref:** Antal M, Eyre M, Finklea B, Nusser Z. External tufted cells in the main olfactory bulb form two distinct subpopulations. *Eur J Neurosci.* 2006 Aug;24(4):1124-36.

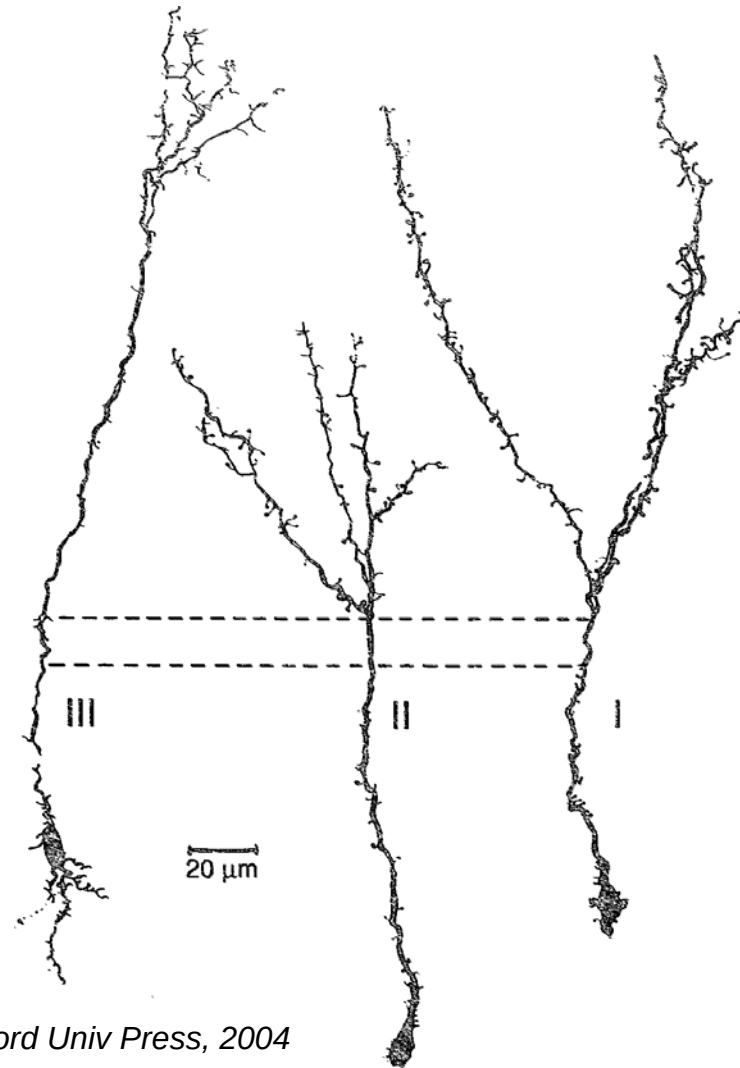


## Intrabulbar, topographic projection of tufted cells



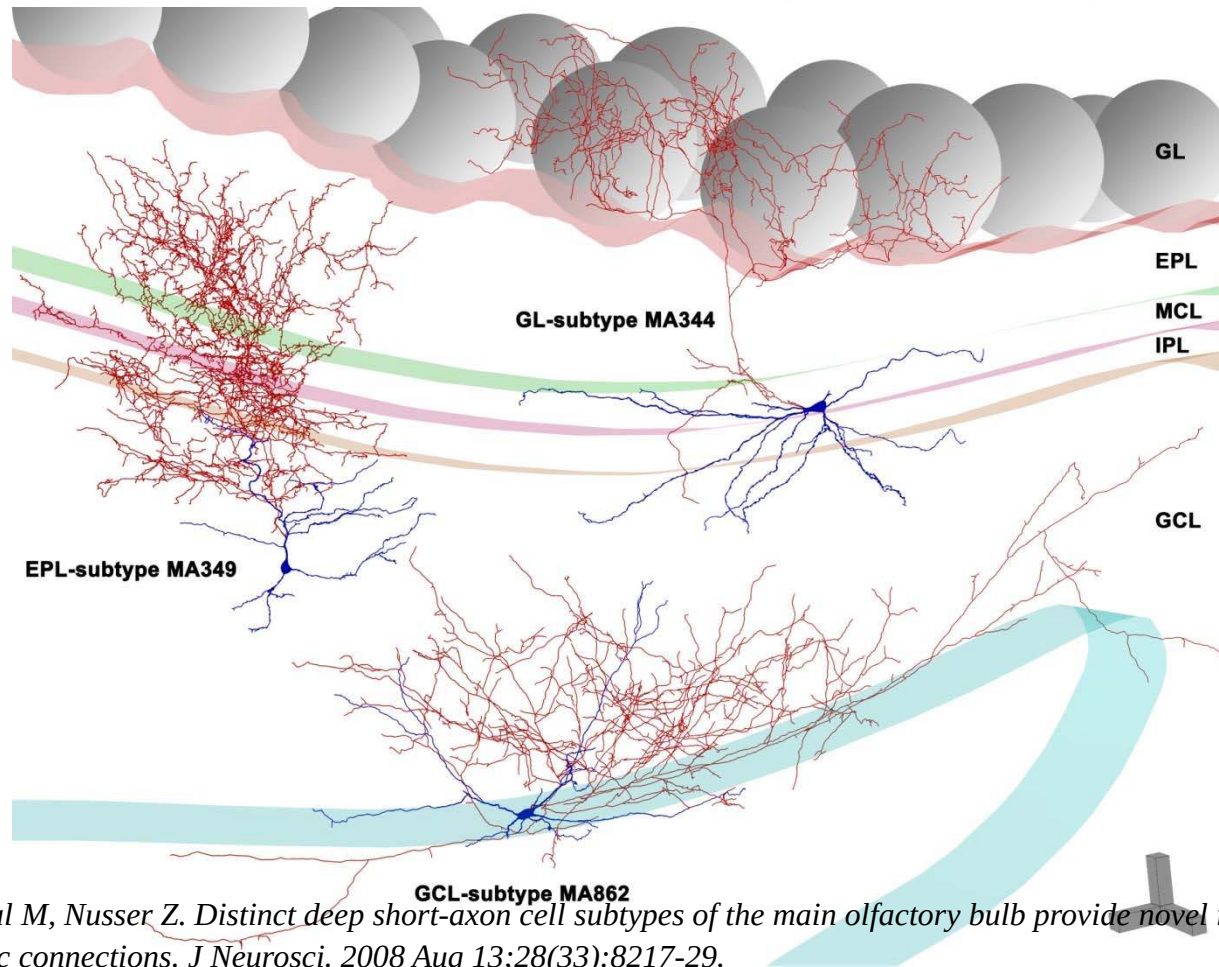
**Ref:** Belluscio et al., Odorant receptors instruct functional circuitry in the mouse olfactory bulb, *Nature*, 419, 296-300.

## Granule cells (inhibitory, GABAergic neurons)



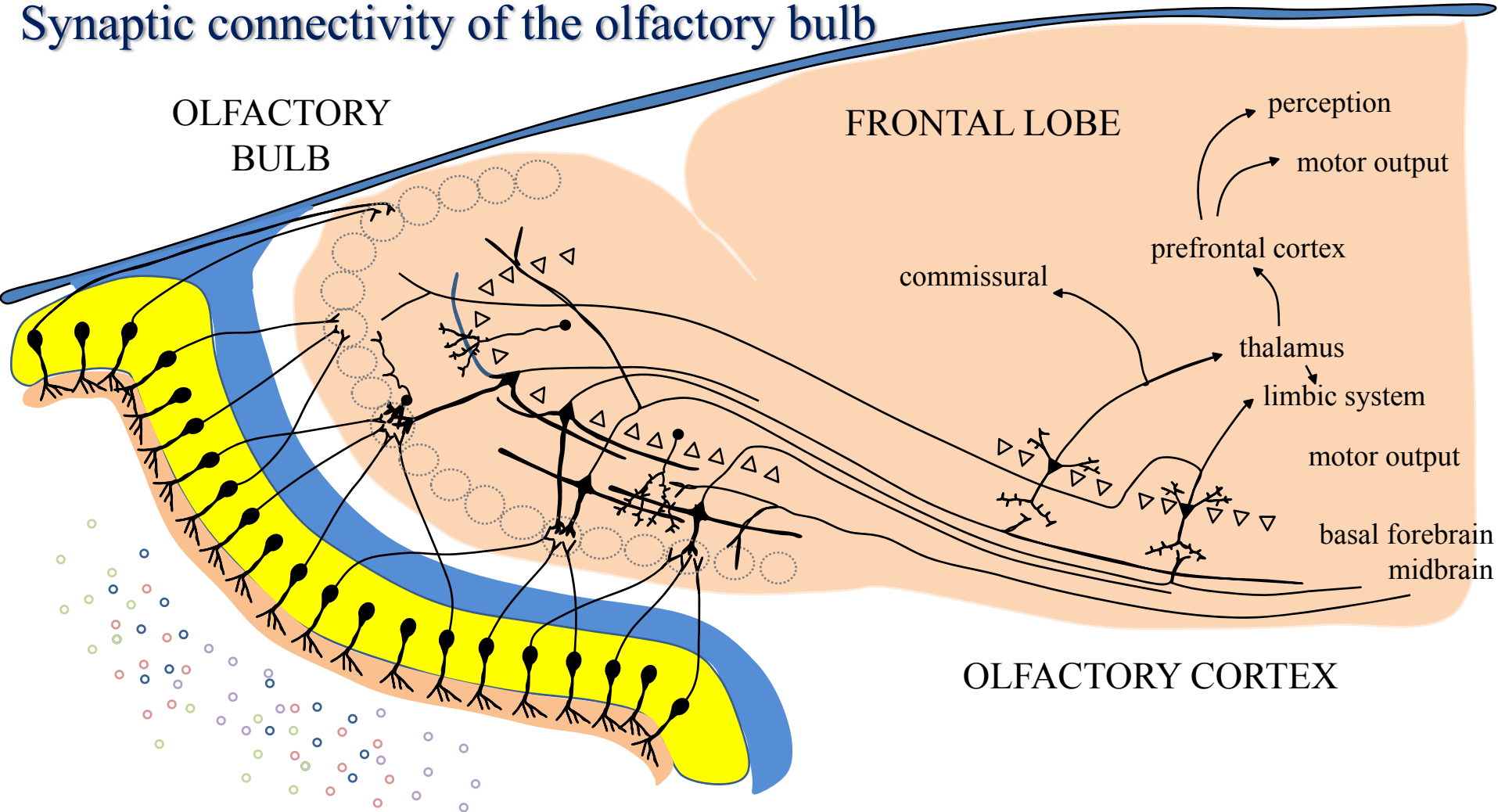
**Ref:** Sheperd, *Synaptic Organization of the Brain*, Oxford Univ Press, 2004

## Deep, short-axon neurons (inhibitory, GABAergic neurons)

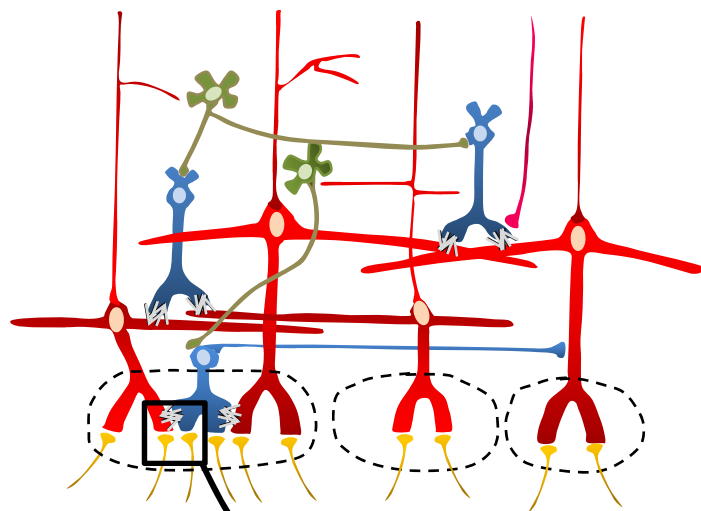


**Ref:** Eyre MD, Antal M, Nusser Z. Distinct deep short-axon cell subtypes of the main olfactory bulb provide novel intrabulbar and extrabulbar GABAergic connections. *J Neurosci*. 2008 Aug 13;28(33):8217-29.

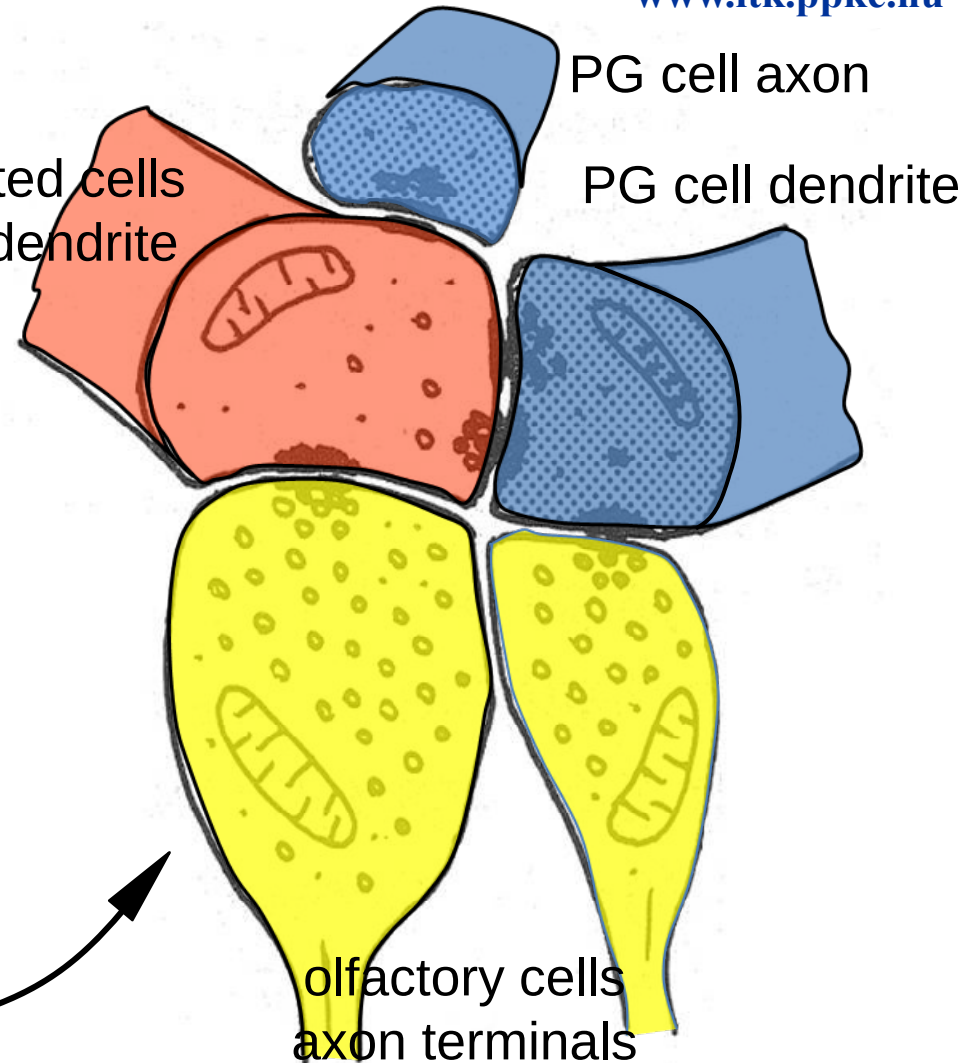
## Synaptic connectivity of the olfactory bulb



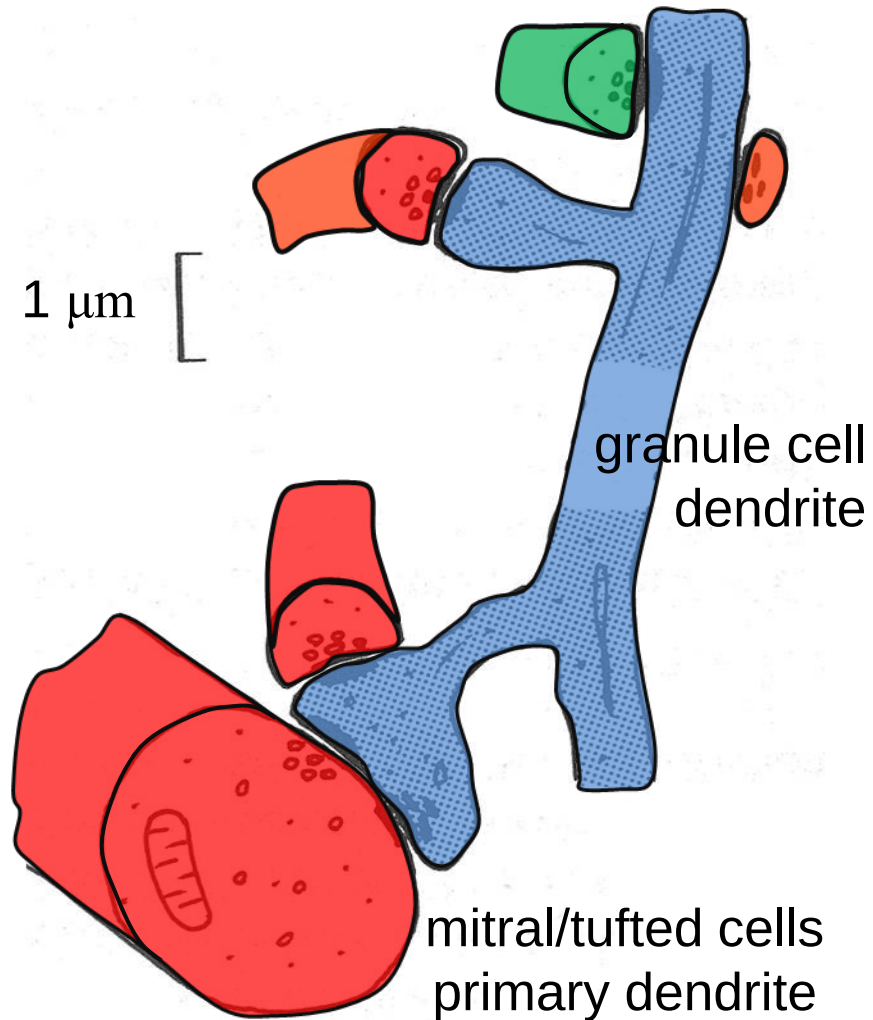
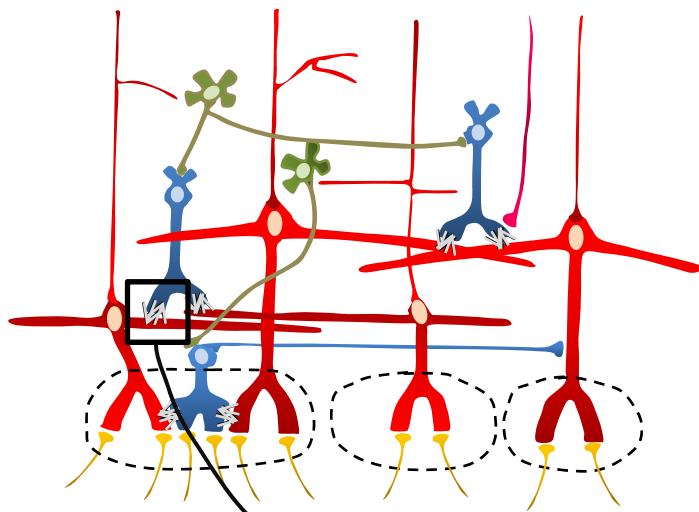
## Intrabulbar synaptic connections: Glomerulus



mitral/tufted cells  
primary dendrite



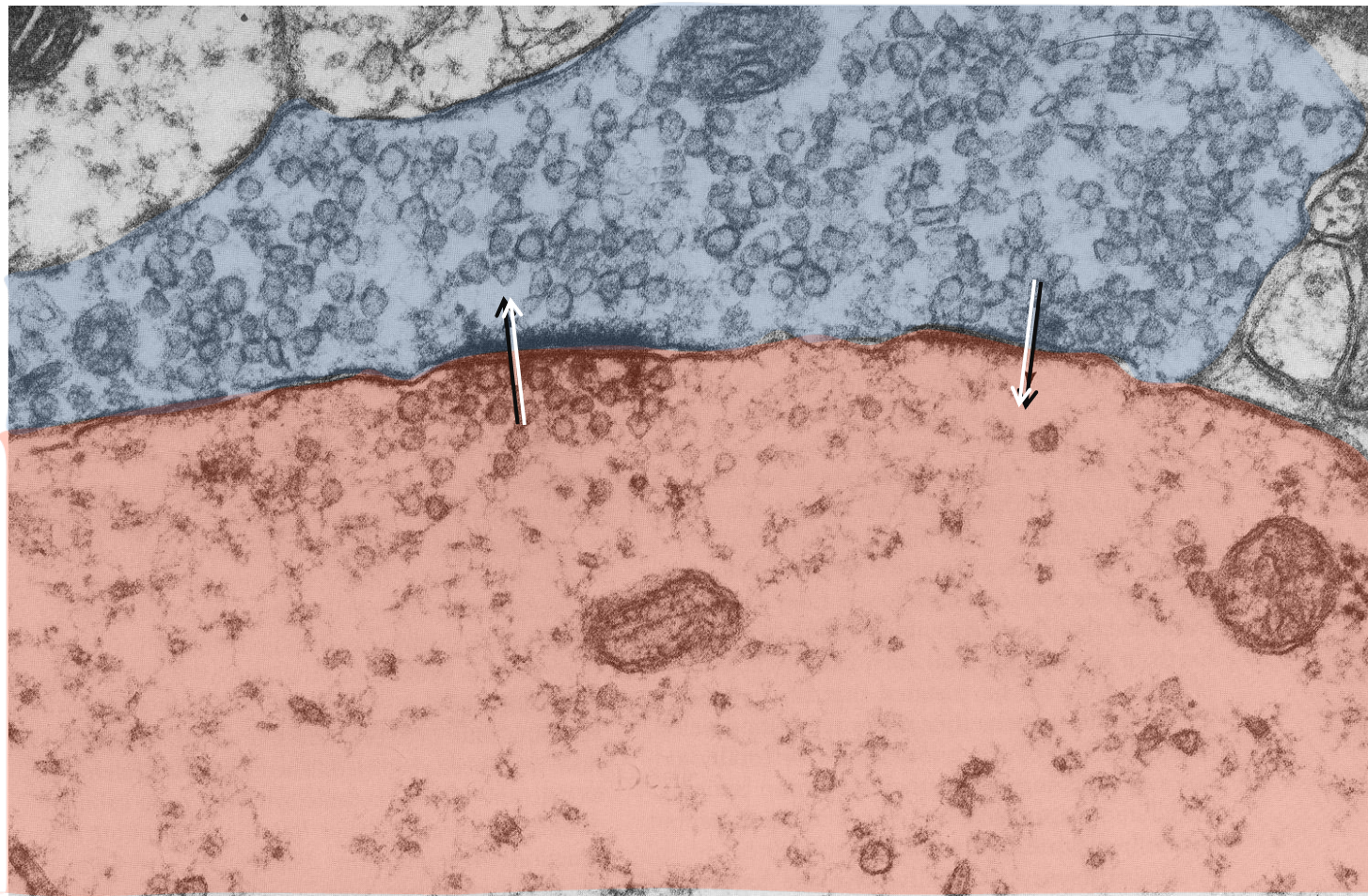
## Intrabulbar synaptic connections: External plexiform layer

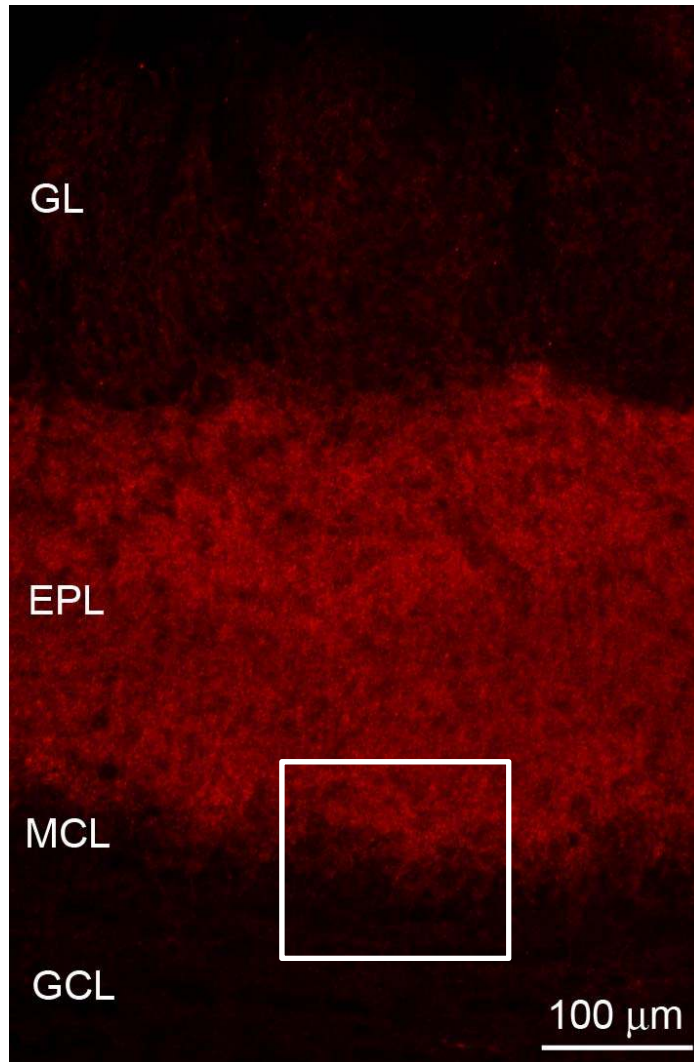


## Dendro-dendritic reciprocal synapses in the external plexiform layer

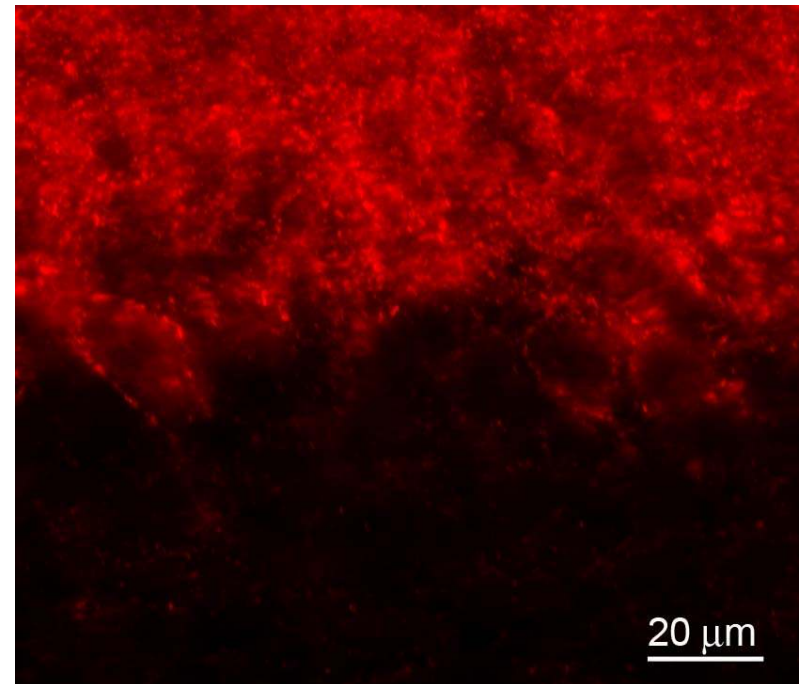
granule cell  
dendrite

mitral/tufted  
cells dendrite

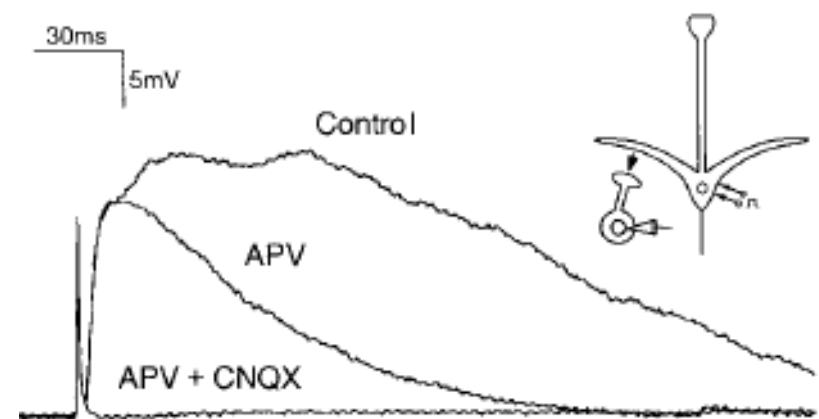
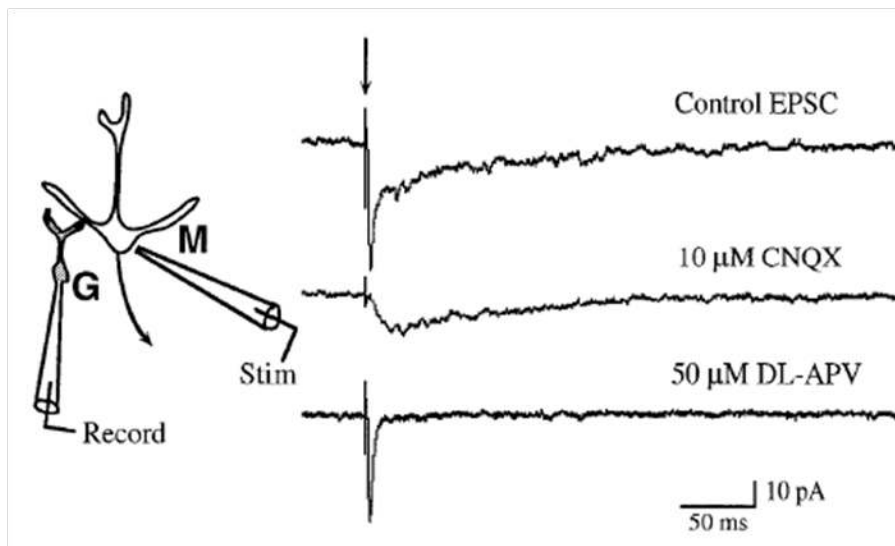




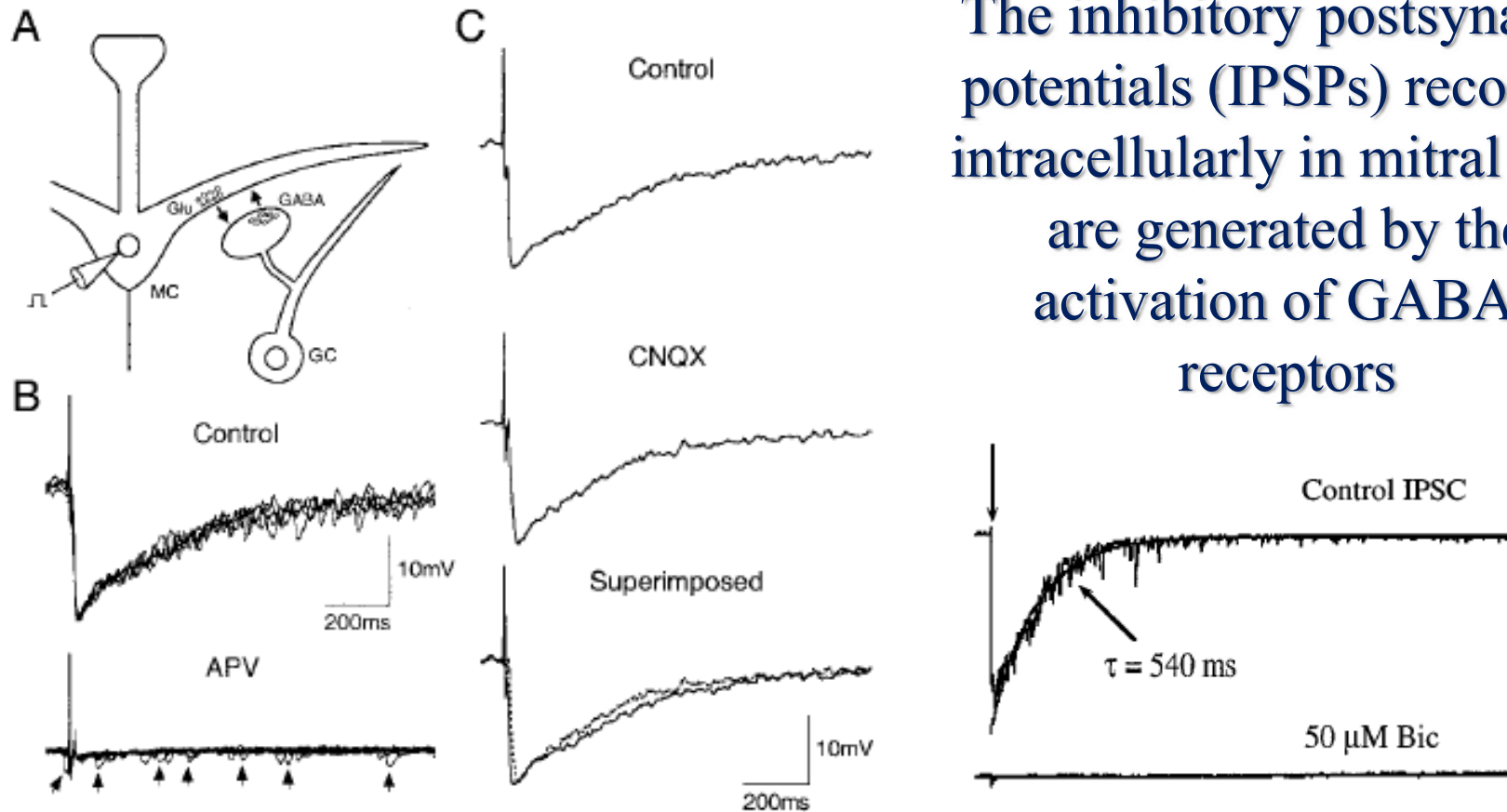
A high density of GABAergic synapses is present in the external plexiform layer



## The excitatory postsynaptic potentials (EPSPs) recorded intracellularly in granule cells are generated by the activation of AMPA and NMDA receptors



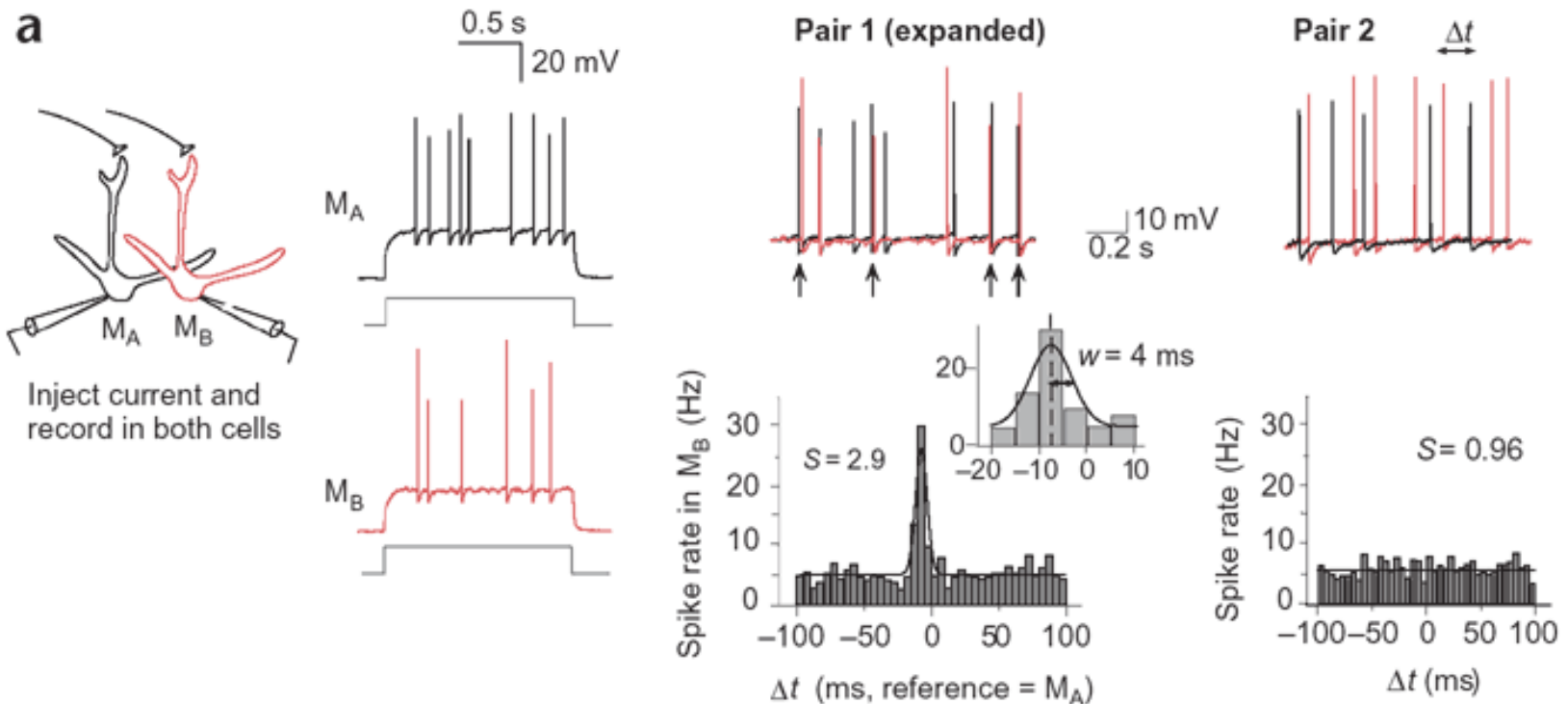
**Ref:** Chen et al., Analysis of relations between NMDA receptors and GABA release at olfactory bulb reciprocal synapses. 2000, 25, 625-33.



The inhibitory postsynaptic potentials (IPSPs) recorded intracellularly in mitral cells are generated by the activation of GABA<sub>A</sub> receptors

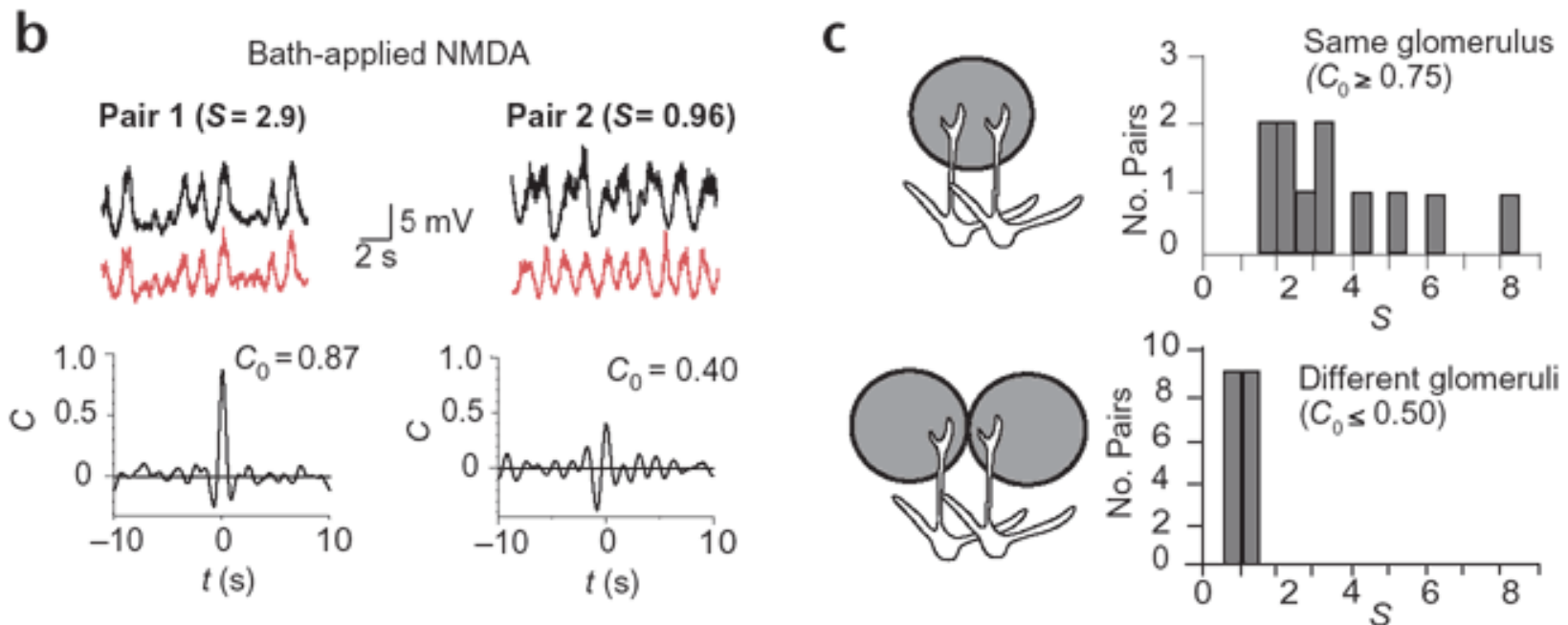
**Ref:** Chen et al., Analysis of relations between NMDA receptors and GABA release at olfactory bulb reciprocal synapses. 2000, 25, 625-33.

## Synchronous activation of mitral cells projecting to the same glomerulus



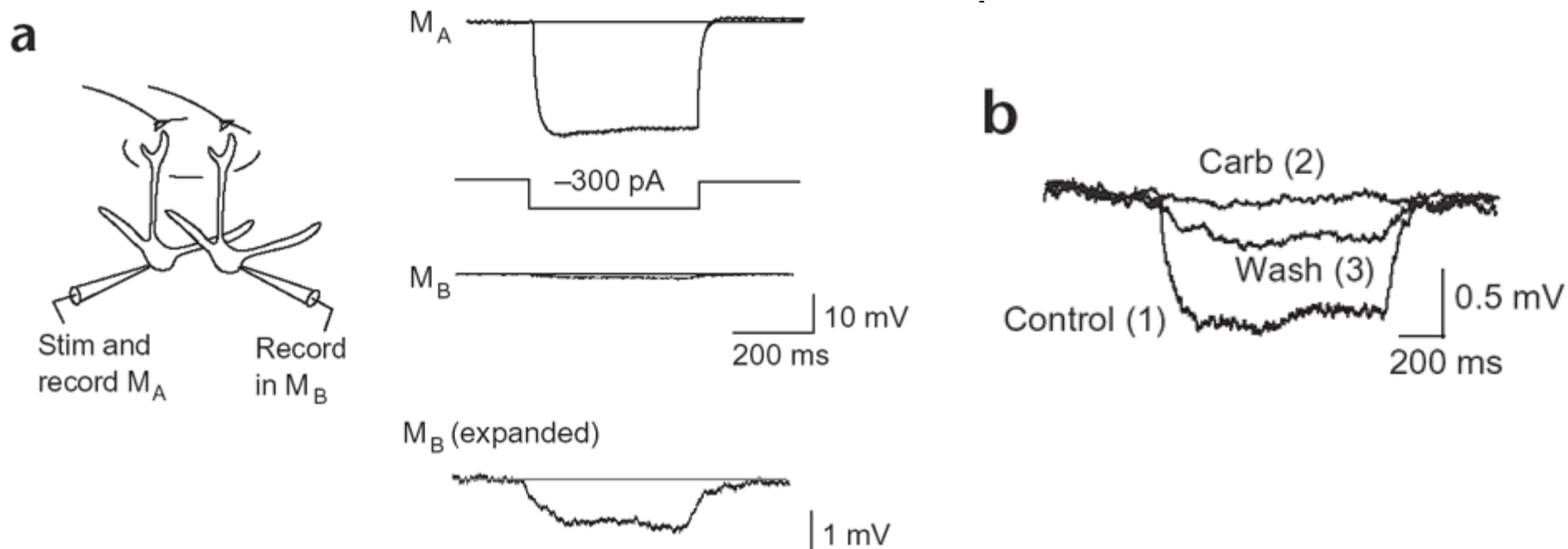
**Ref:** Schoppa NE, Westbrook GL. AMPA autoreceptors drive correlated spiking in olfactory bulb glomeruli. *Nat Neurosci.* 2000, 5:1194-202.

## Synchronous activation of mitral cells projecting to the same glomerulus

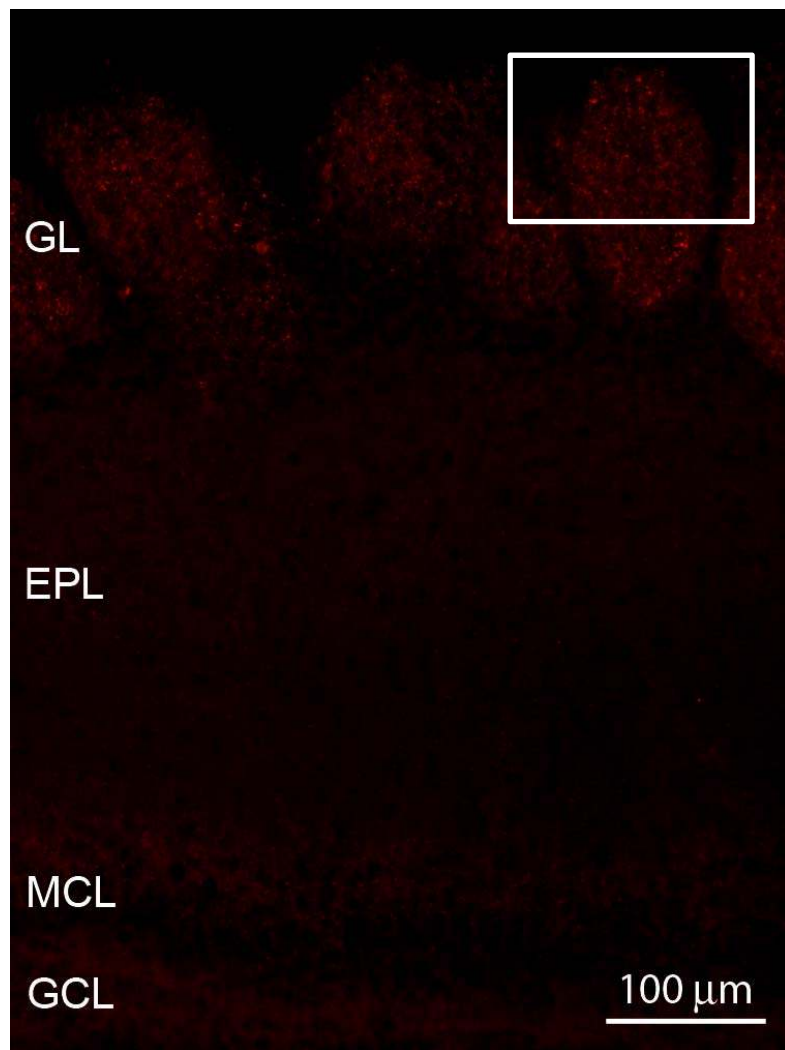


**Ref:** Schoppa NE, Westbrook GL. AMPA autoreceptors drive correlated spiking in olfactory bulb glomeruli. *NatNeurosci.* 2002 Nov;5(11):1194-202.

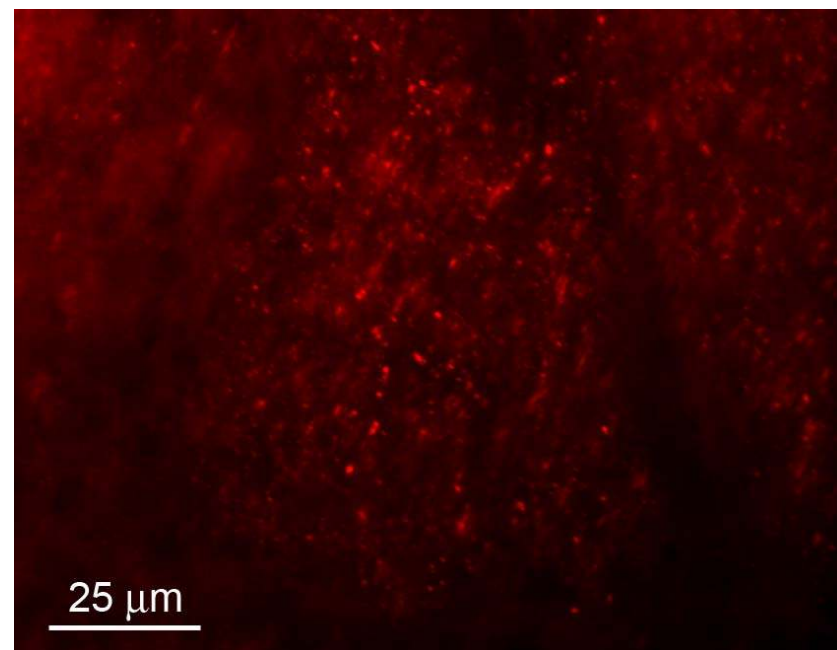
## Dendritic electric synapses (gap junctions) are responsible for the synchronous activation of mitral cells projecting to the same glomerulus



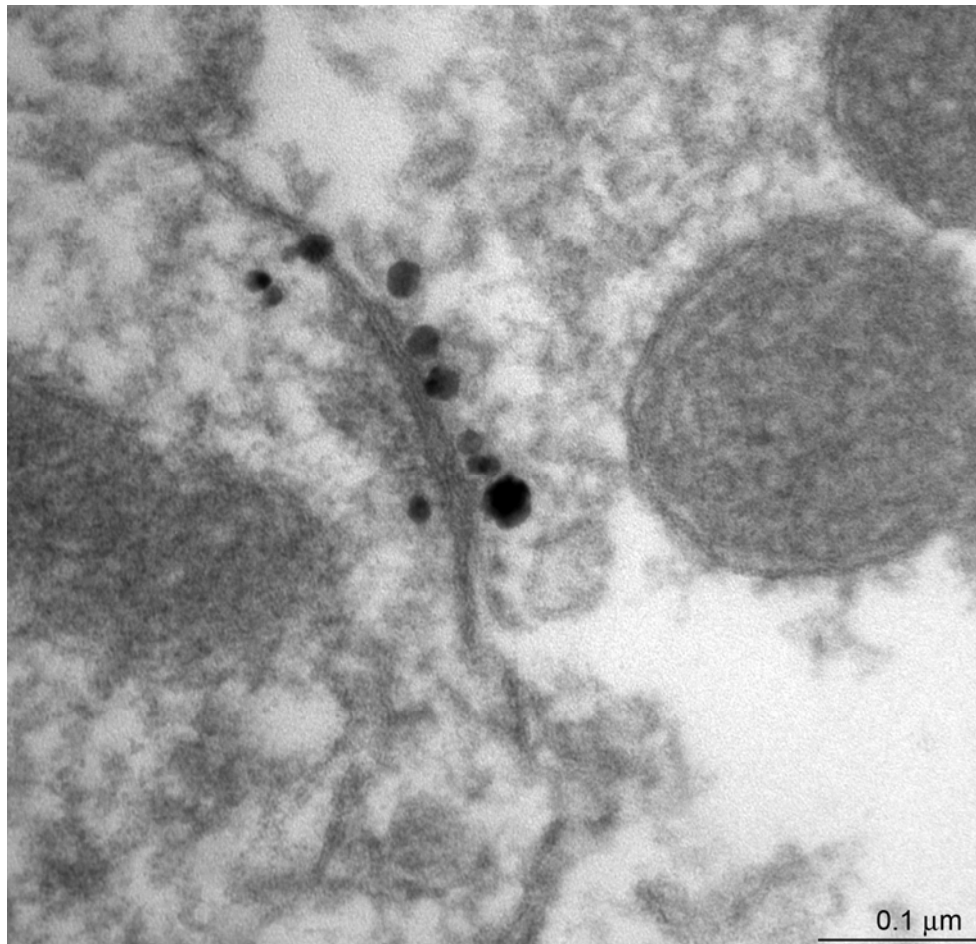
**Ref:** Schoppa NE, Westbrook GL. AMPA autoreceptors drive correlated spiking in olfactory bulb glomeruli. *NatNeurosci.* 2002 Nov;5(11):1194-202.



## Distribution of connexin36 proteins establishing gap junctions in the olfactory bulb



## Electron microscopic localization of connexin36



## Summary: layers and cells

**Layers of the olfactory bulb:** Layer of olfactory fila, glomerular layer, external plexiform layer, layer of mitral cells, internal plexiform layer, layer of granule

**Cellular elements of the olfactory bulb:** Juxtglomerular cells (external tufted and periglomerular cells), middle and internal tufted cells, mitral cells, granule cells and short-axon cells

**Mitral cells:** They are the principal cells of the olfactory bulb providing excitatory projections to other parts of the brain. Their cell bodies are 15-30  $\mu\text{m}$  with one primary dendrite ramifying in a single glomerulus, where they receive their main excitatory input from the axons of OECs. They have several secondary or lateral dendrites, which are several millimeters long and establish reciprocal dendro-dendritic connections.

**Tufted cells:** They are also principal cells of the olfactory bulb. Excitatory, glutamergic cells with synaptic connections very similar to those established by mitral cells. They have, however, more extensive, wide-spread local collaterals in the internal plexiform layer.

**Granule cells:** GABAergic, inhibitory interneurons, with no axons! Their cell bodies are 6-8  $\mu\text{m}$ , and the dendrites are 200-400  $\mu\text{m}$ . The dendrites receive the input (mainly excitatory from mitral cells), as well as provide the output (inhibitory, onto the lateral dendrites of mitral cells).

**Periglomerular cells:** GABAergic inhibitory interneurons. Some of those are dopaminergic. They have small cell bodies, and a single, short dendrite ramifying in the glomerulus. They receive excitatory input from the axons of OECs and the dendrites of mitral/tufted cells. They provide a GABAergic output to the dendrites of mitral/tufted cells and to other periglomerular cells.

**Short-axon cells:** GABAergic inhibitory interneurons, which can be found in almost all layers.

## Summary: synaptic connections

**Sensory input:** Excitatory, glutamatergic input from the OECs in the glomeruli.

**Central (centrifugal) inputs:** From the pyramidal cells of the olfactory cortex (glutamatergic), from the anterior olfactory nucleus (glutamatergic), the DBB (cholinergic), the locus coeruleus (noradrenergic) and the raphe nuclei (serotonergic). Most of the centrifugal fibers terminate in the granule cell layer.

**Central (centripetal) outputs :** Mitral- and tufted cells project to the primary olfactory cortex, the anterior olfactory nucleus, the taenia tectae, the dorsal peduncular nucleus, the anterior cortical amygdaloid nucleus and the lateral olfactory tract nucleus. The olfactory cortex projects also to several other brain regions including the thalamus, limbic system, prefrontal cortex etc.

### **Intrabulbar synaptic connections:**

**In the glomeruli:** Axon terminals of the OECs provide excitatory (glutamatergic) input to the primary dendrites of mitral/tufted cells and to the dendrites of certain periglomerular cells. The periglomerular cells establish dendro-dendritic synapses with the primary dendrites of mitral/tufted cells, and vice versa receive excitatory dendro-dendritic inputs. The periglomerular cells establish inhibitory dendro-dendritic synapses and axo-dendritic synapses with each others' dendrites. Dendritic gap junctions are responsible for the synchronous activity of mitral cells projecting to the same glomeruli.

**External plexiform layer:** Lateral dendrites of mitral/tufted cells establish dendro-dendritic reciprocal synapses with the dendrites of granule cells. The mitral/tufted cells provides excitatory (via glutamatergic synapses) input to the dendrites of granule cells, and vice versa receive inhibitory, GABAergic input.

**Internal plexiform layer:** Local collaterals of mitral/tufted cells establish excitatory axo-dendritic synapses with the dendrites of granule cells and deep, short-axon cells.

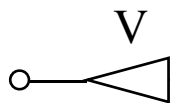
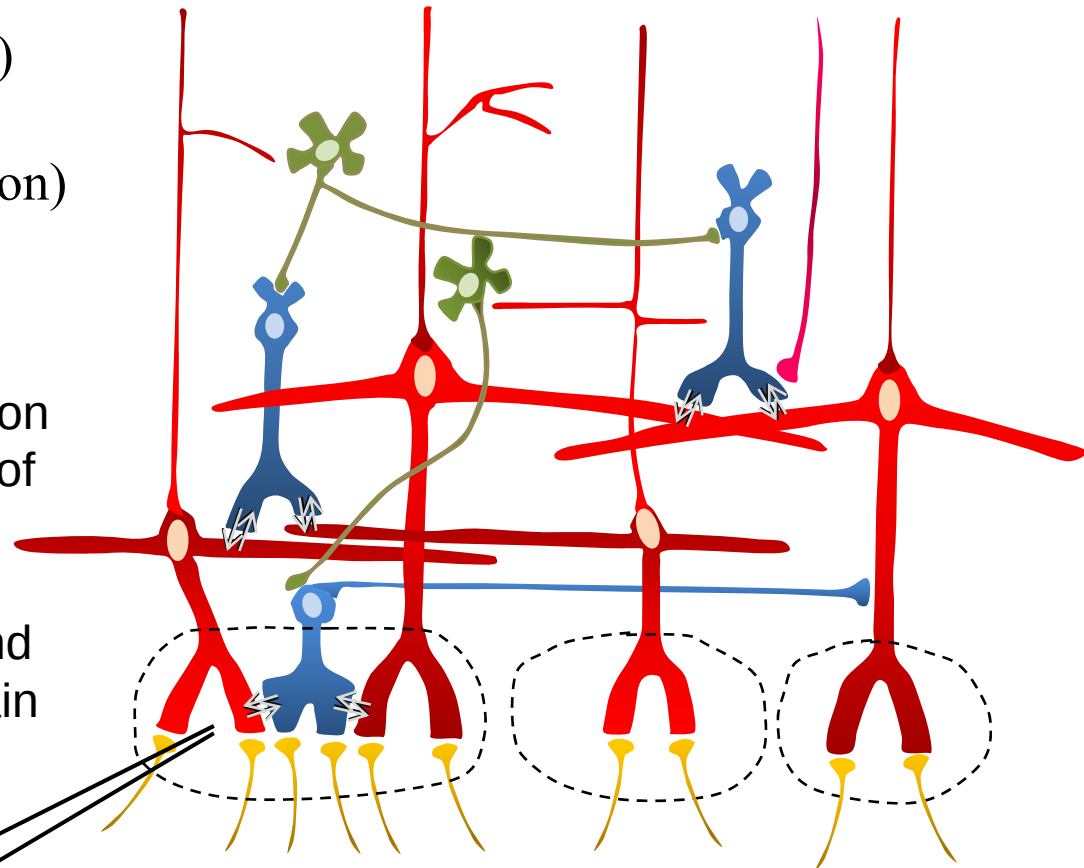
## Olfaction:

Network phenomena (rhythmic phenomena, oscillations)  
and encoding the information

## Measuring field potentials

- From the surface of the skull (EEG)
- From the surface of the brain
- From the brain (a certain brain region)

**The field potential** is the summation of spatial and temporal alterations of synaptic and voltage-dependent currents in a defined region of the brain. Consequently, it refers to and characterizes the activity of a certain cell or afferent **population**.



**Oscillation: rhythmic change in the field potential**

**The prerequisite of development of oscillation is the periodic and synchronous activity of a certain cell population.**

Periodic, but asynchronous activity of cells

Synchronous, but non-periodic activity of cells

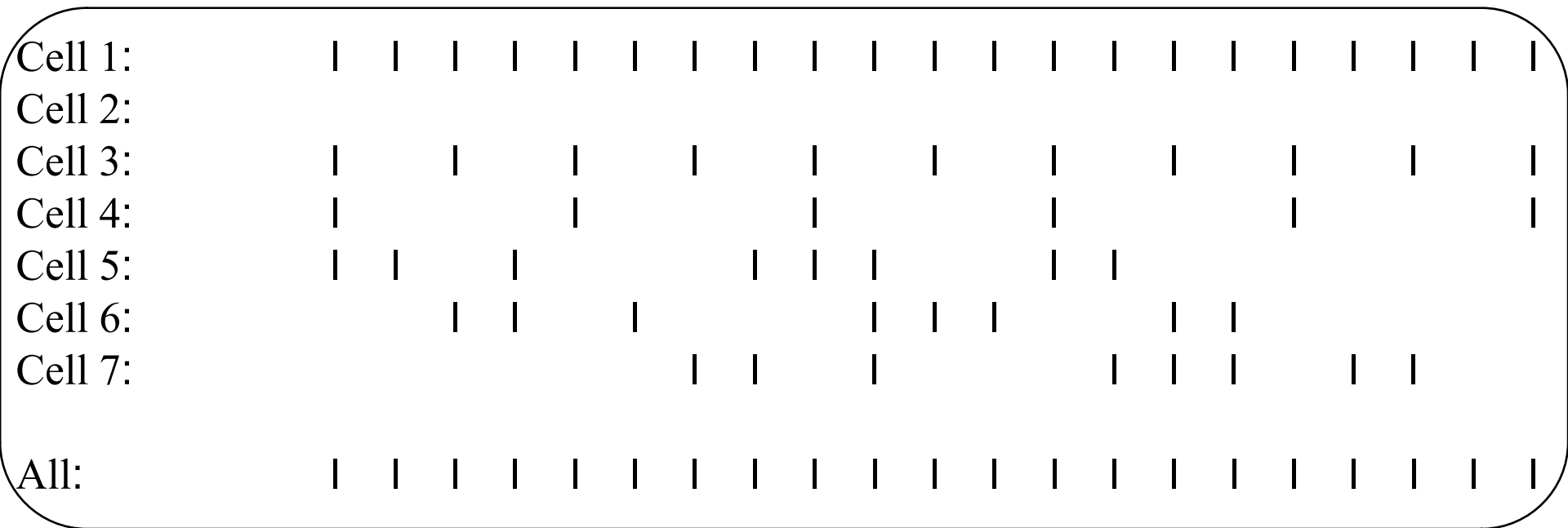
|         |  |
|---------|--|
| Cell 1: |  |
| Cell 2: |  |
| Cell 3: |  |
| Cell 4: |  |
| All:    |  |

|         |  |
|---------|--|
| Cell 1: |  |
| Cell 2: |  |
| Cell 3: |  |
| Cell 4: |  |
| All:    |  |

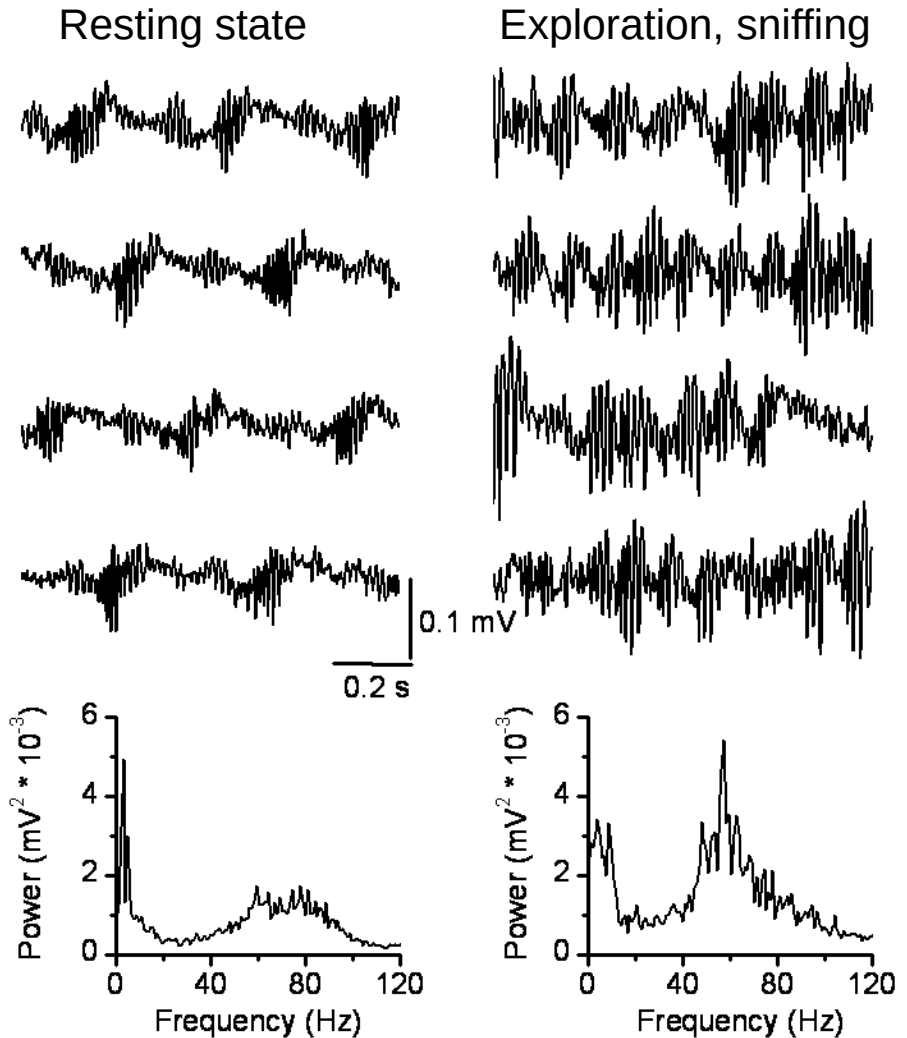
**Oscillation: rhythmic change in the field potential**

**The prerequisite of development of oscillation is the periodic and synchronous activity of a certain cell population.**

Synchronous and periodic activity of cells



## Field potential recorded from behaving mice



**Ref:** Nusser Z, Kay LM, Laurent G, Homanics GE, Mody I. Disruption of GABA(A) receptors on GABAergic interneurons leads to increased oscillatory power in the olfactory bulb network.

*J Neurophysiol.* 2001 Dec;86(6):2823-33.

*Am Physiol Soc*, used with permission

No information is carried solely by the oscillation of field potential; it marks simply, that a population of cells exhibits synchronous and periodic activity in a defined brain region.

An examiner, however, can use the field potential as a timekeeper (time reference frame), i.e. can compare the activity of a single cell to it (to the activity of the rest of cells).

## Brain map or encoding information in the brain

**Brain map:** It is part of the nervous system, where the distribution of neurons represents a sort of physico-chemical parameter of the environment (e.g. olfactory bulb).

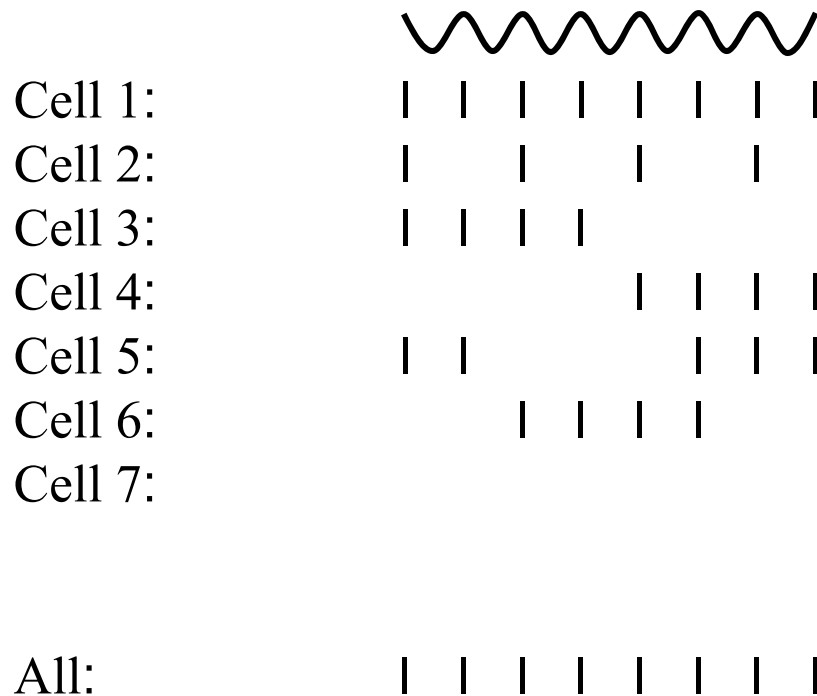
**Topographic brain map:** It is a sort of brain map, where the spatial distribution of neurons represents a defined parameter (neighborship) in the environment (e.g. in the visual field – retina).

**Code:** Signs, symbols, system of rules, through which information can be transferred and regained into its original form.

If brain map is part of the neuronal code, it means, that encoding and decoding of the information take by necessity in consideration the spatial distribution of the neurons. If the identity of the neurons (their own characteristic electric properties) counts, and not their regional distribution, then we talk about the identity coding. (An example, by which the physical arrangement is part of the code, is the genetic code, the DNA. Another example, by which the physical arrangement is surely not part of the code, is the encoding of the momentary location of the animal by the hippocampal place-cells.)

## Dynamically developing activity pattern in a population of cells

Odorant “A”

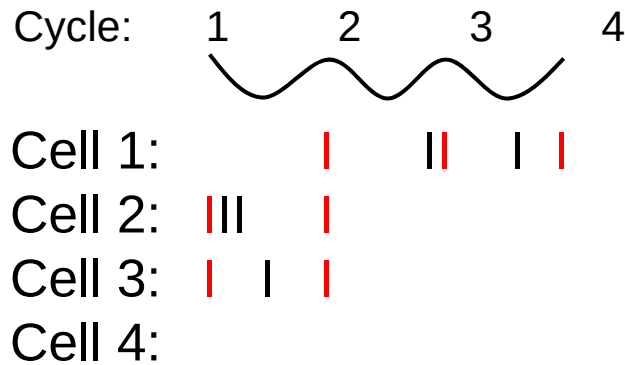


All: | | | | | | | |

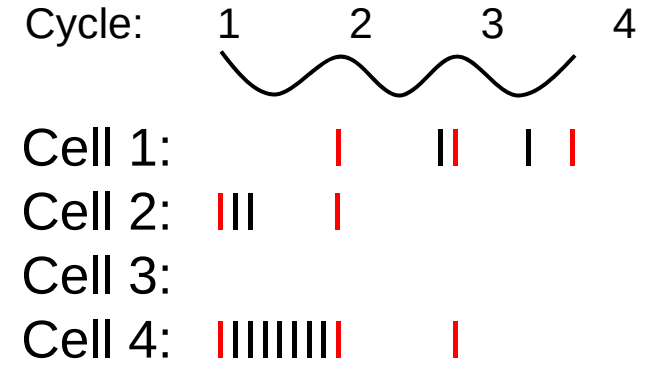
## Information coding with a dynamically developing activity pattern in a population of cells

‘population’, ‘temporal’ and ‘identity’ code (theory)

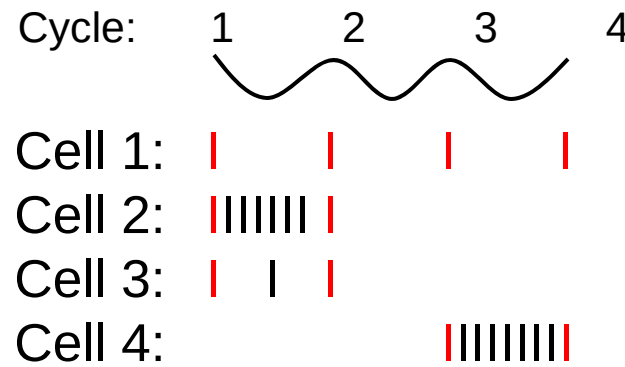
**Odorant “A”**



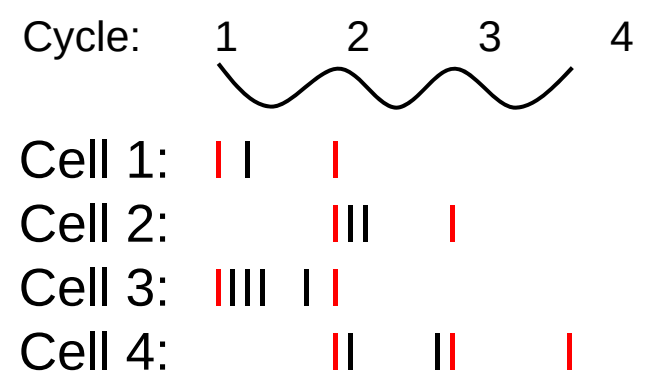
**Odorant “B”**



**Odorant “C”**



**Odorant “D”**



## Information coding with a dynamically developing activity pattern in a population of cells

### 'population', 'temporal' and 'identity' code (theory)

Parallel recording of two  
'projection' cells (corresponding  
to mitral cells) responding to 6  
different odorant mixture in locust

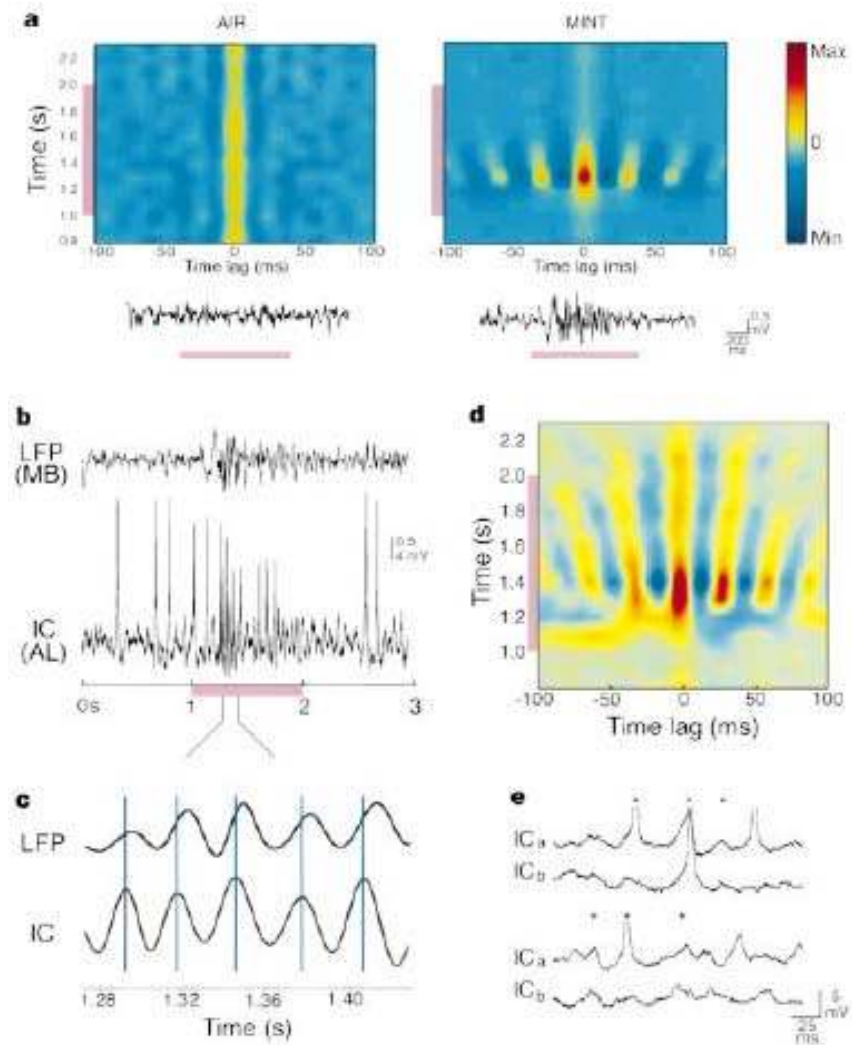
Cell 1:

Cell 2:



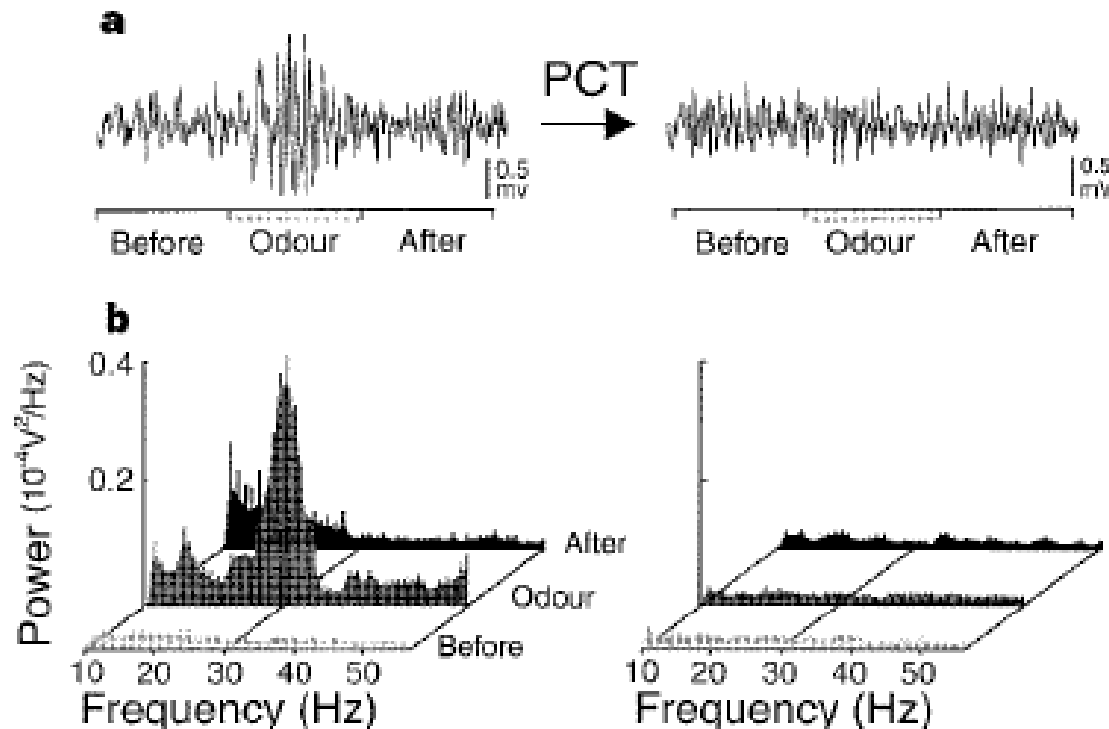
**Ref:** Stopfer et al., Impaired odour discrimination on desynchronization of odour-encoding neural assemblies. *Nature*, 1997, 390, 70-4.

## Odorant evoked 30 Hz oscillation of field potential in the „mushroom body”



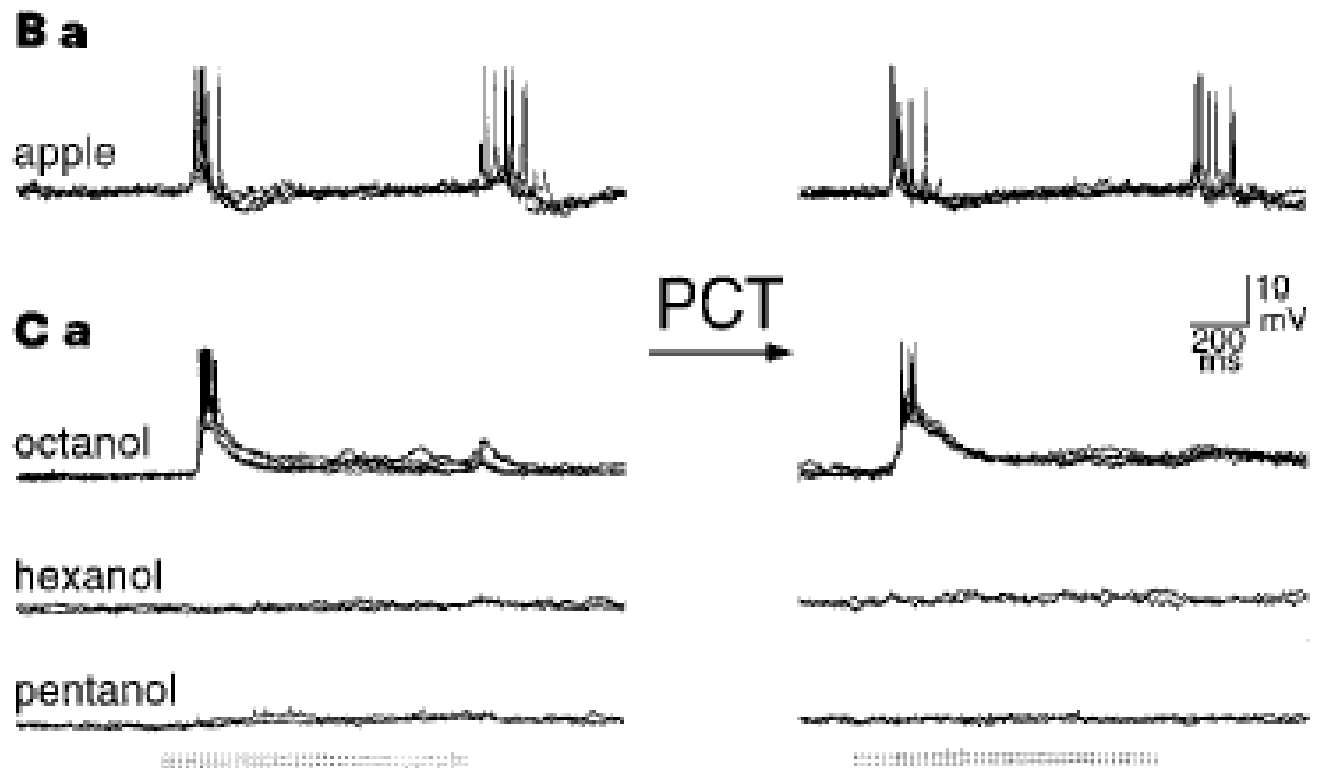
**Ref:** Stopfer M, Bhagavan S, Smith BH, Laurent G. Impaired odour discrimination on desynchronization of odour-encoding neural assemblies. *Nature*. 1997 Nov 6;390(6655):70-4.

## The GABA<sub>A</sub> receptor blocker picrotoxin removes the odorant-evoked oscillation of field potential in the „mushroom body”



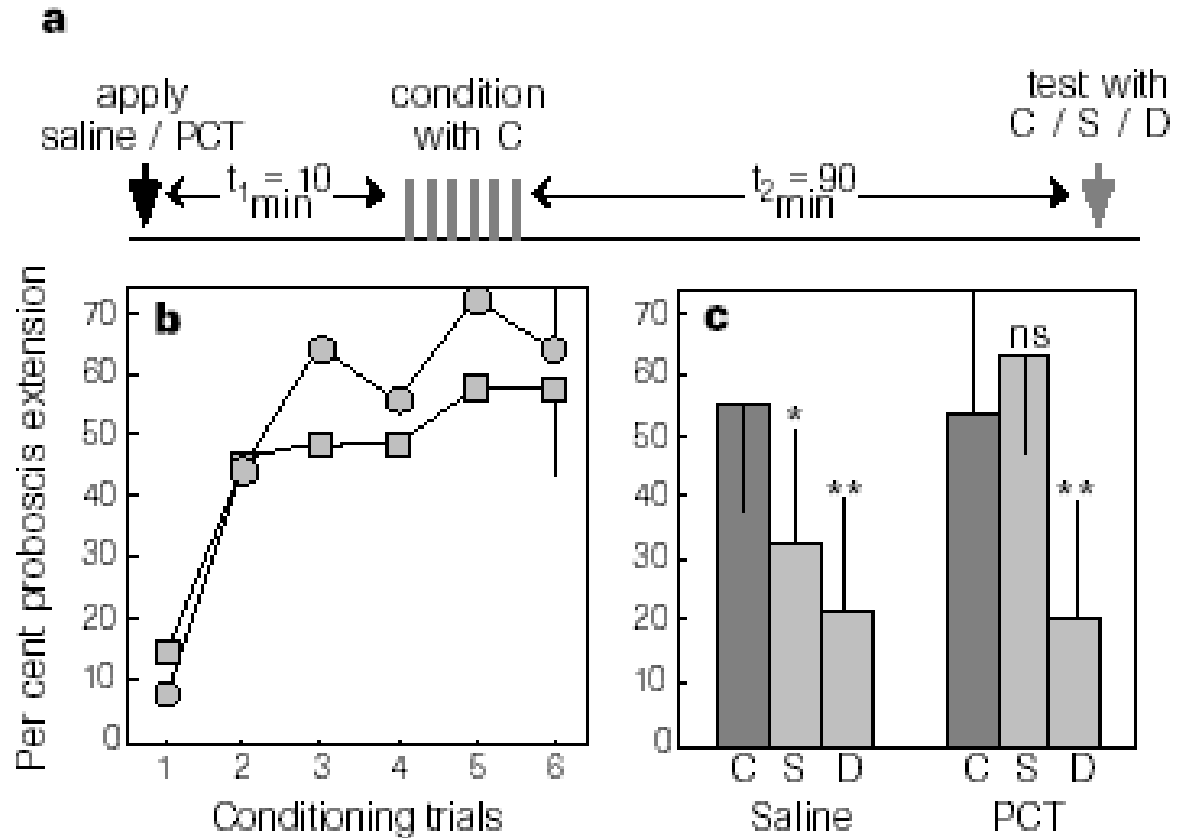
**Ref:** Stopfer M, Bhagavan S, Smith BH, Laurent G. Impaired odour discrimination on desynchronization of odour-encoding neural assemblies. *Nature*. 1997 Nov 6;390(6655):70-4.

The GABA<sub>A</sub> receptor blocker picrotoxin does not influence the specificity and the strength of the cellular response evoked by the odorants



**Ref:** Stopfer M, Bhagavan S, Smith BH, Laurent G. Impaired odour discrimination on desynchronization of odour-encoding neural assemblies. *Nature*. 1997 Nov 6;390(6655):70-4.

The temporal synchronization of the firing of “projection” cells is necessary to distinguish molecules with similar chemical structure



**Ref:** Stopfer M, Bhagavan S, Smith BH, Laurent G. Impaired odour discrimination on desynchronization of odour-encoding neural assemblies. *Nature*. 1997 Nov 6;390(6655):70-4.

## Summary: information coding

An odor stimulus evokes a temporally changing, complex, odor-specific response. The response pattern is similar from test to test. A different odor stimulus evokes a different response pattern in the same neuron, and the same odor stimulus generates different response patterns in other cells. Taken together, the odor evoked activity pattern is specific for the stimulus and also for the cells, where it is generated.

To understand information-coding in the olfactory system it is necessary to learn about the identity of cells, the temporal pattern of their activity and their synchrony related to each other. It is suggested that in the olfactory system information is encoded by a dynamically developing activity pattern (with temporal and identity code) in a population of cells (in a neuronal ensemble).