

# Optical Imaging of Wave Dynamics in Neocortical Local Network

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# Introduction

I Optical Recording and voltage-sensitive dye

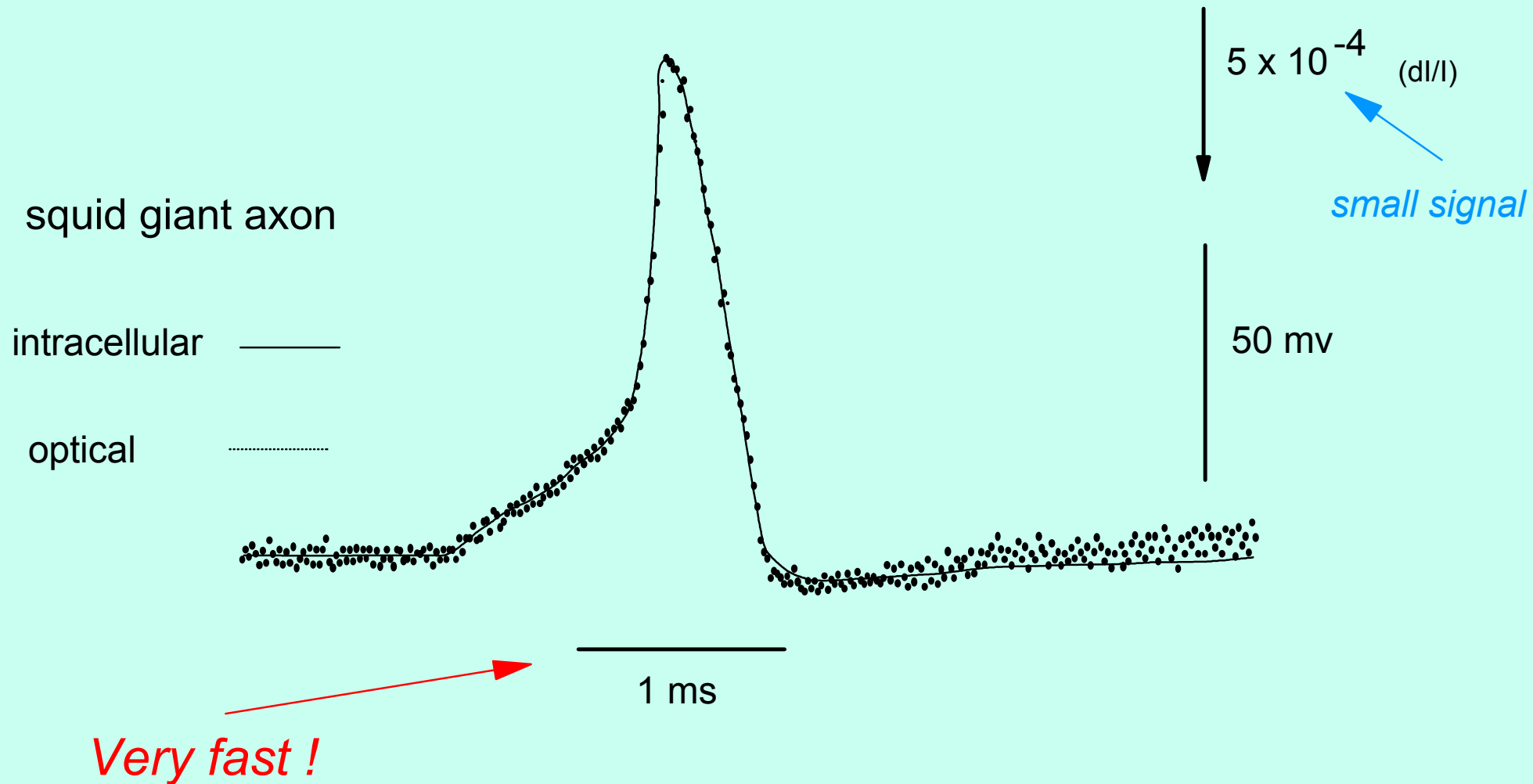
Optical signals in cortical slices

II Traveling waves of theta oscillations

Rotating waves during theta oscillation

III Gamma oscillation and slow waves

# Optical recording with voltage-sensitive dye

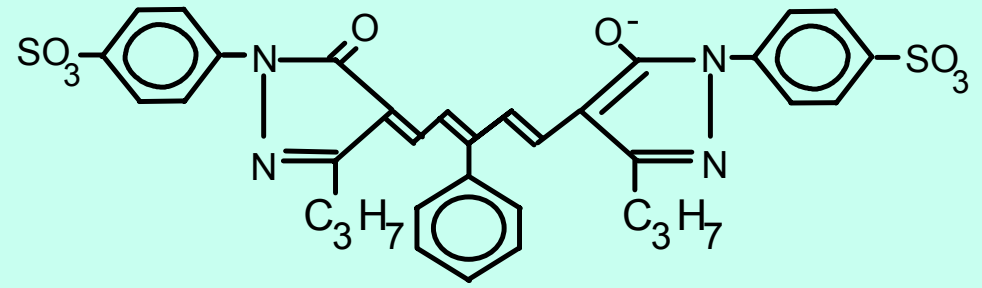
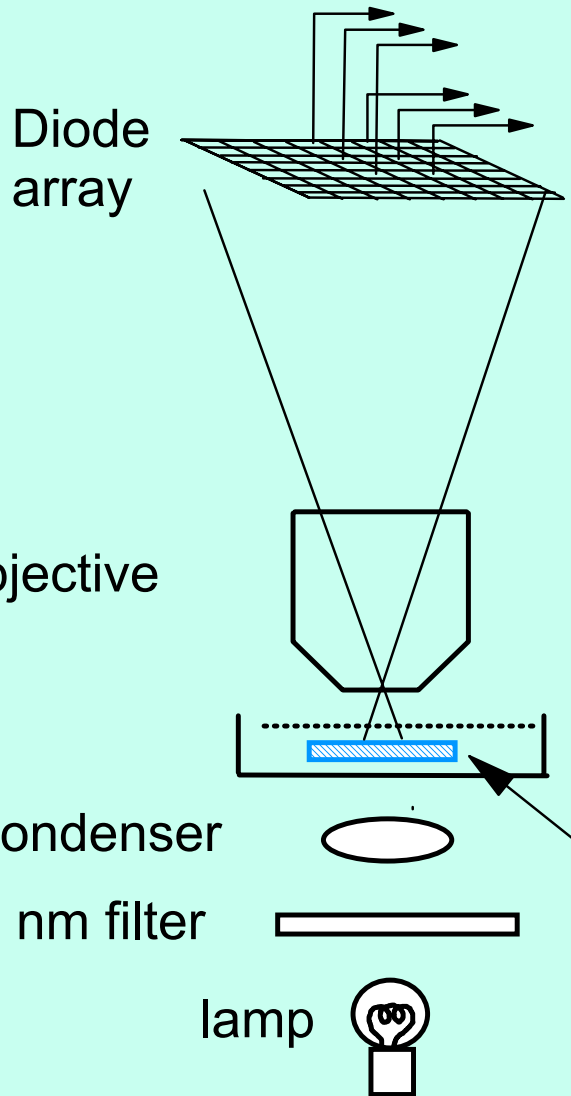


(Redrawn from Ross et al., 1977)

The Cohen Gang, early 1980s

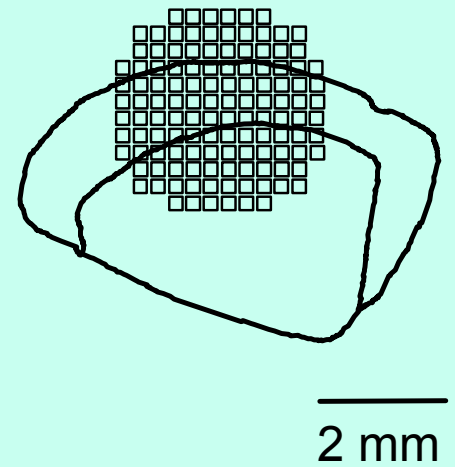


# Optical recording from brain slice



RH 482

Pixel size 330 x 330 um -- 5x lens

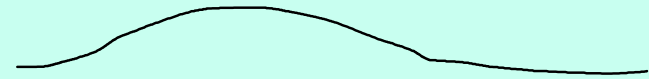
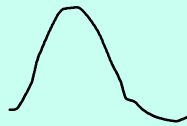


# Optical signal and population activity

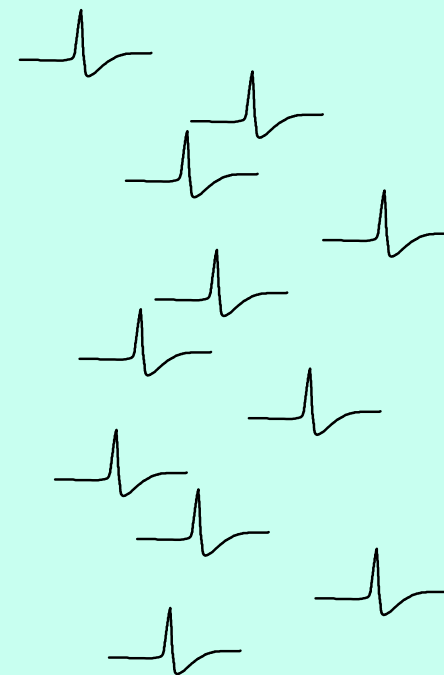
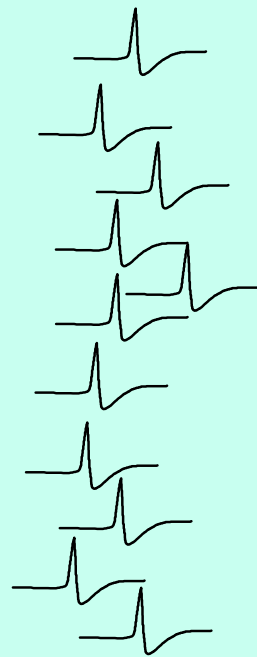
Higher population firing rate

Lower population firing rate

Dye signal



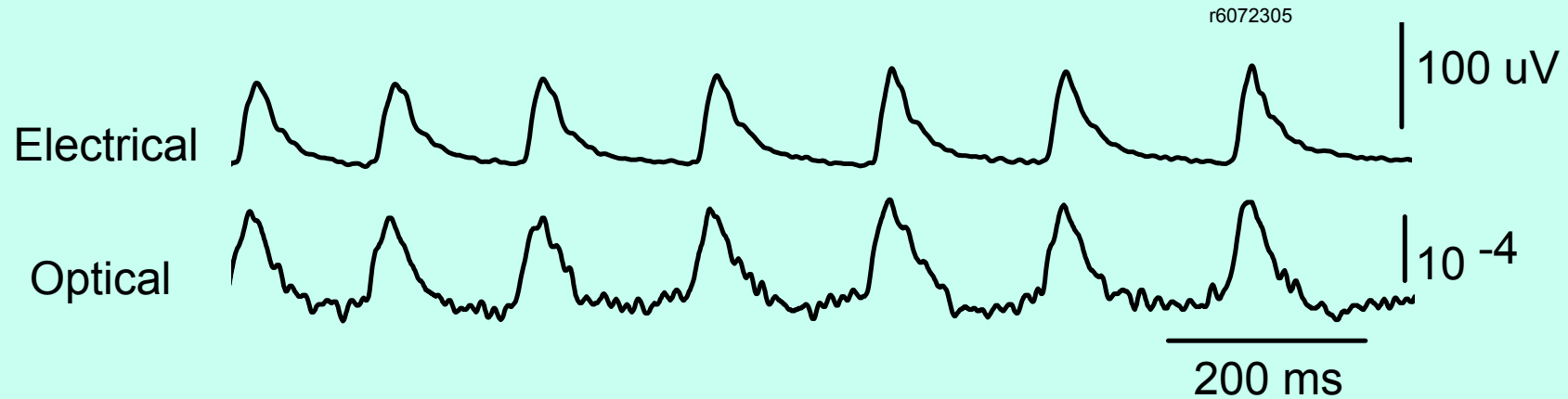
(spikes and synaptic activity)



~ 5,000 neurons / detector

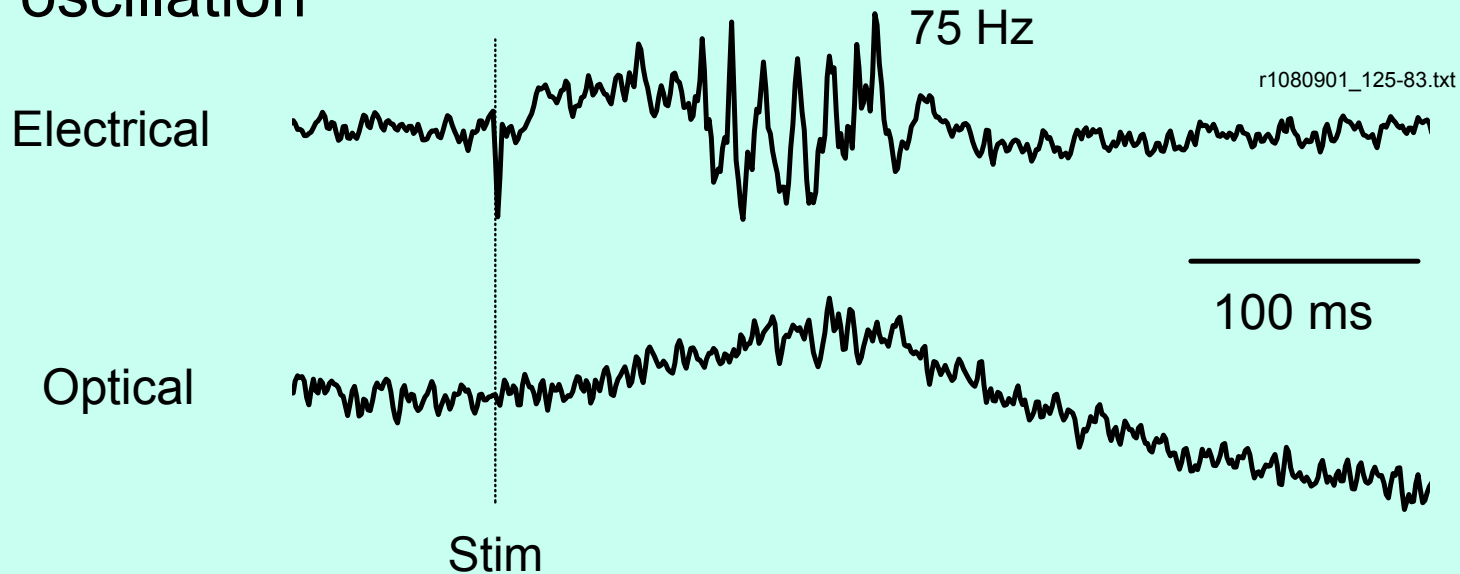
# Two kinds of oscillations

## I. Oscillation can be seen optically: Theta oscillation



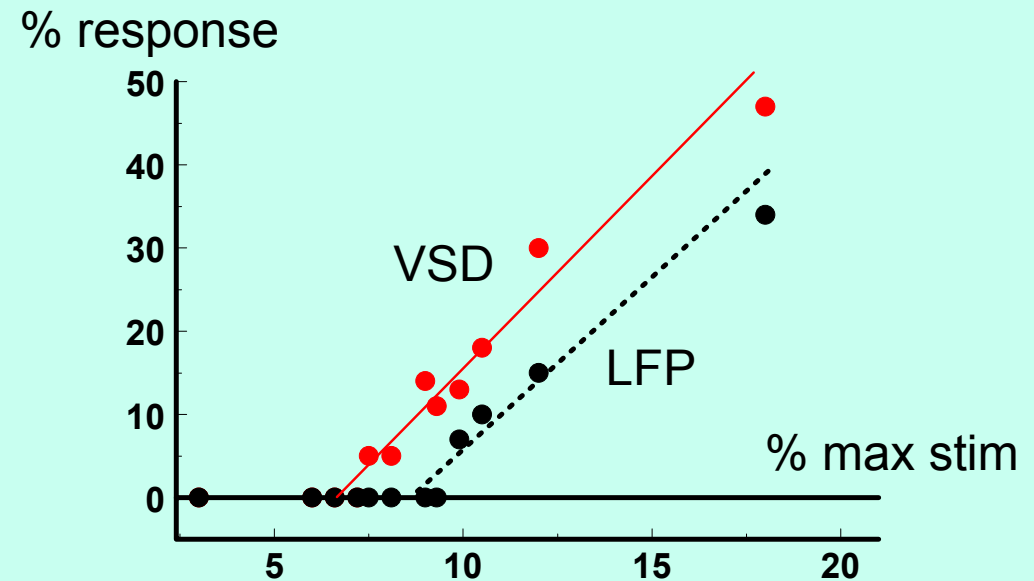
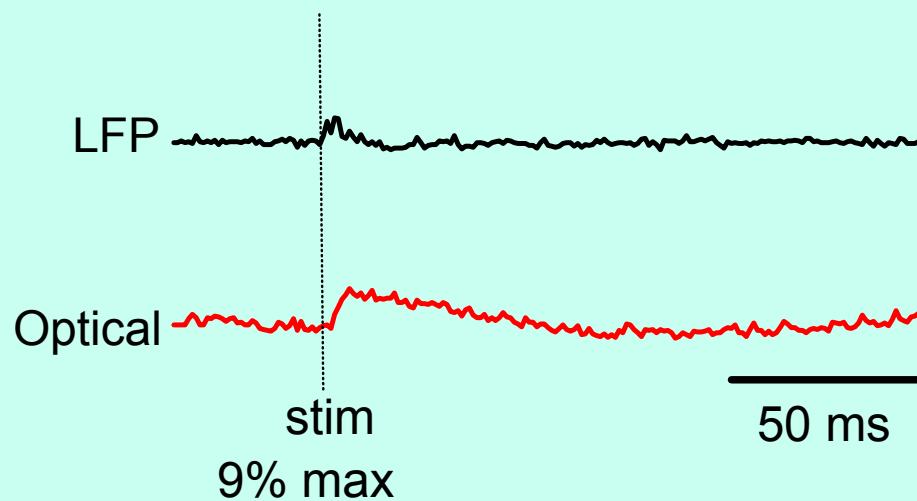
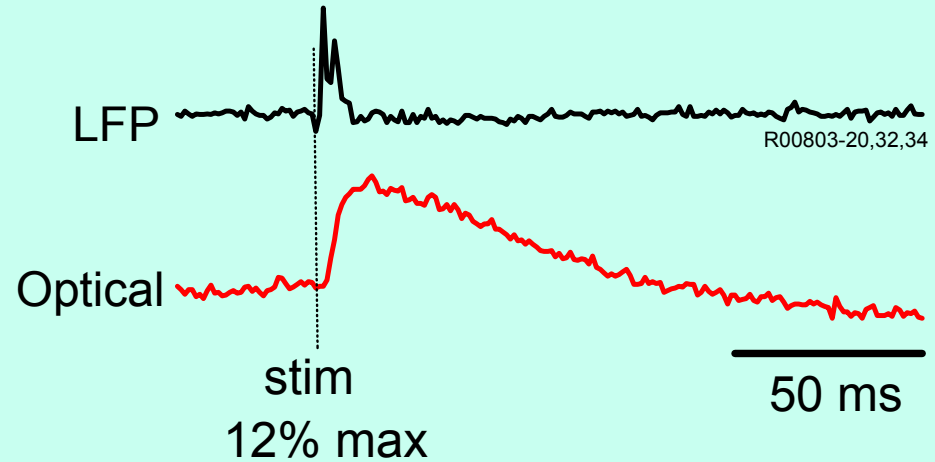
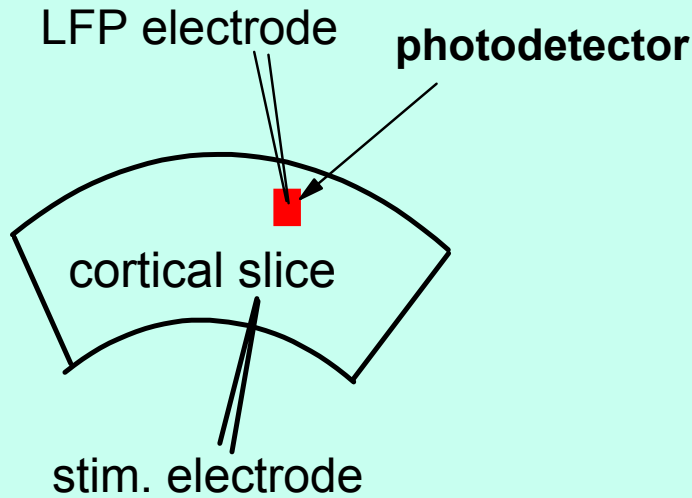
(Wu et al., 1999, J. Neurosci, 19:5005)

## II. Oscillation does not show optically: Gamma oscillation



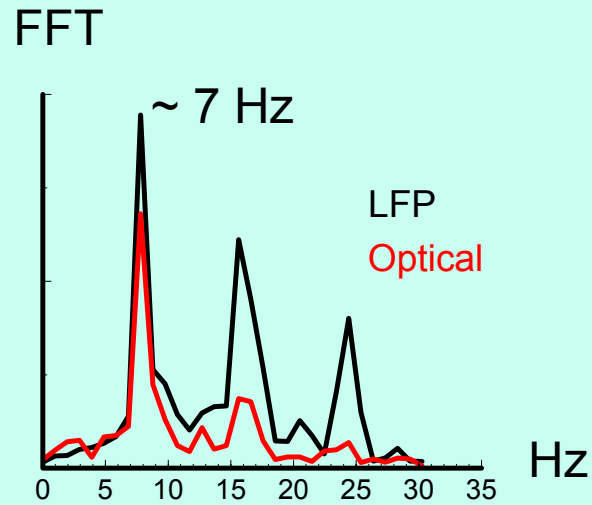
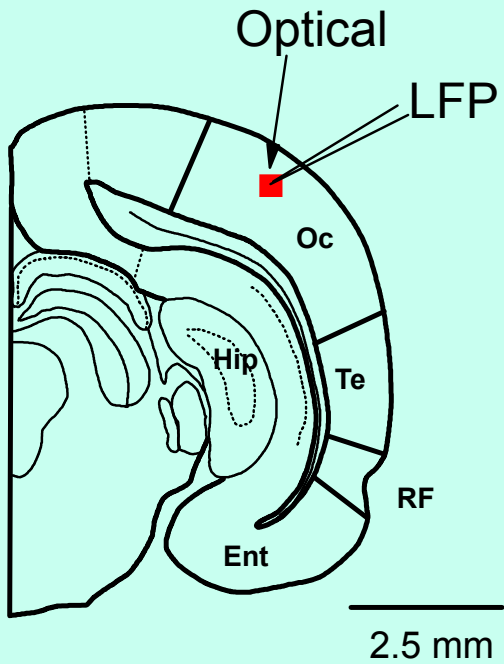
(Wu et al., 2001, J. Neurophysiol, 86:2461)

# Sensitivity of the optical recording



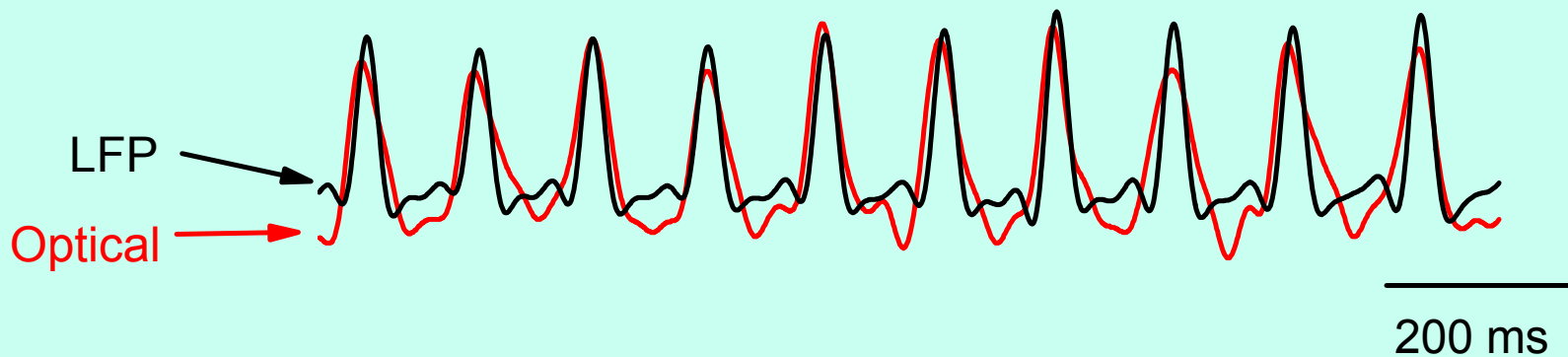


# Cholinergic theta oscillation

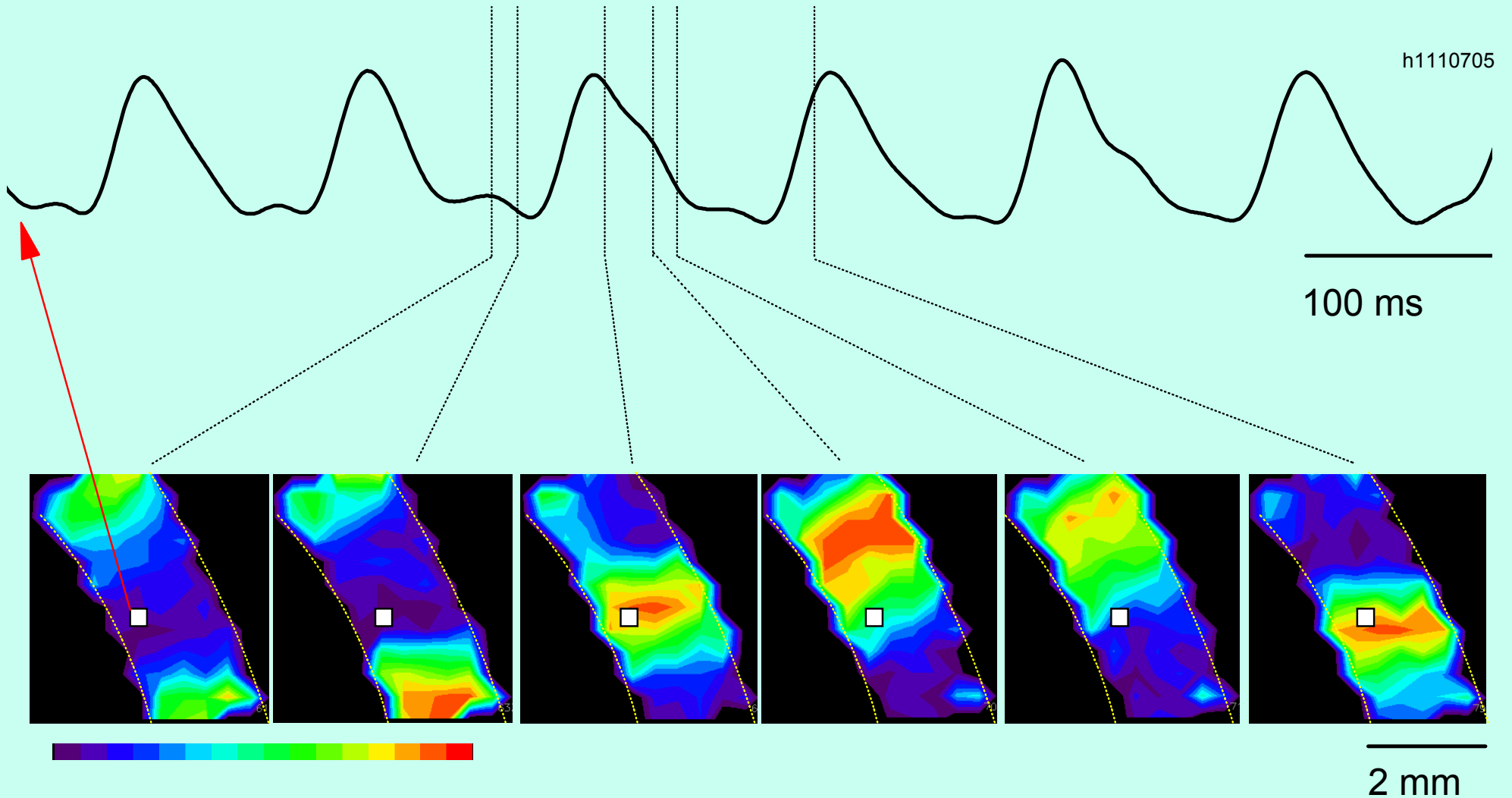


100  $\mu$ M carbachol  
10  $\mu$ M bicucullin  
visual cortex

Same location: LFP and optical

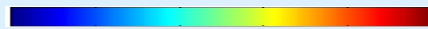
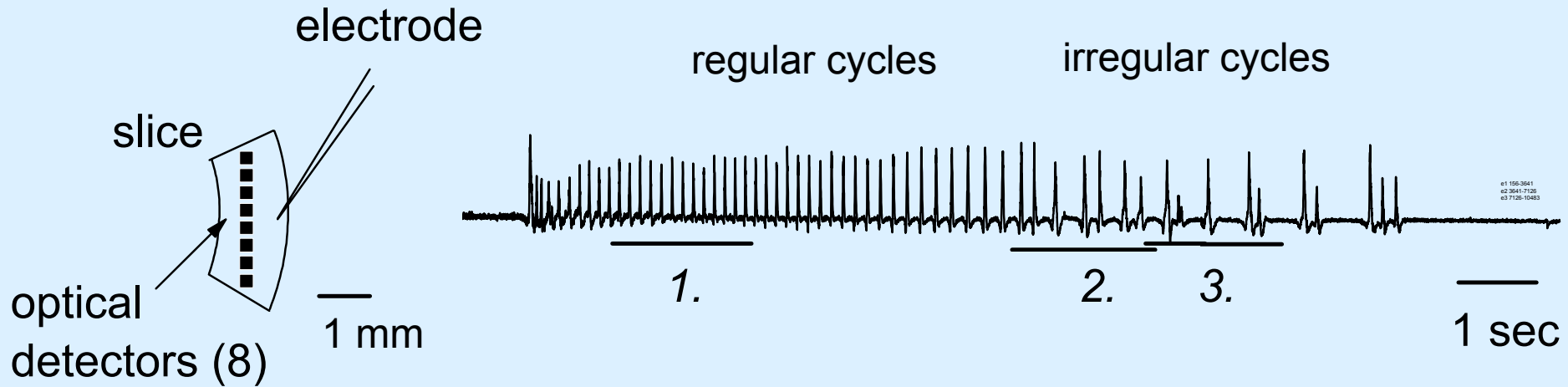


# Propagating wave

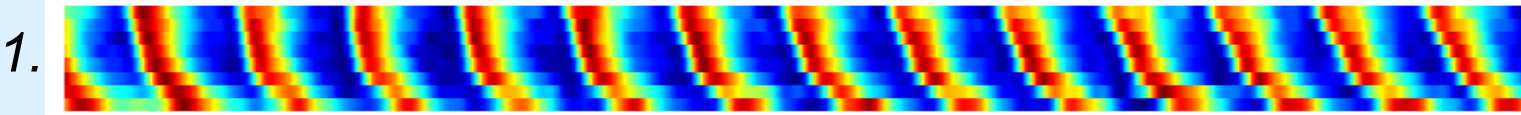


movie 1

# Oscillation and propagating waves

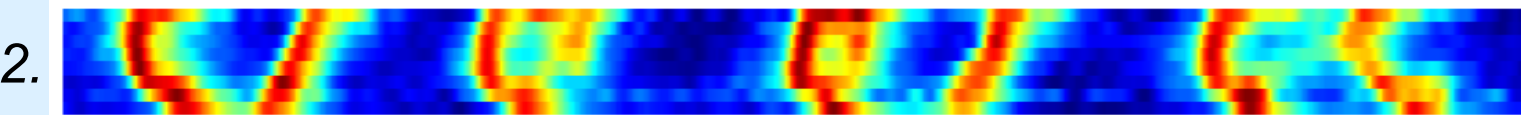


h1110201ub 1567-2876



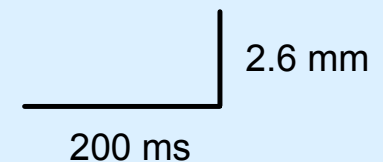
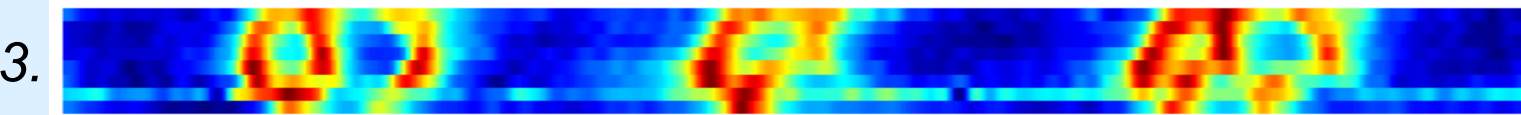
Plane waves

h1110201ue 5328-6673



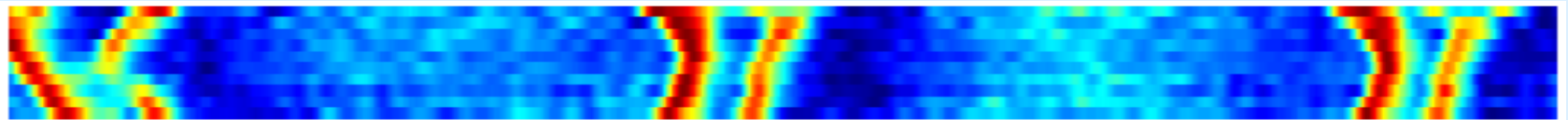
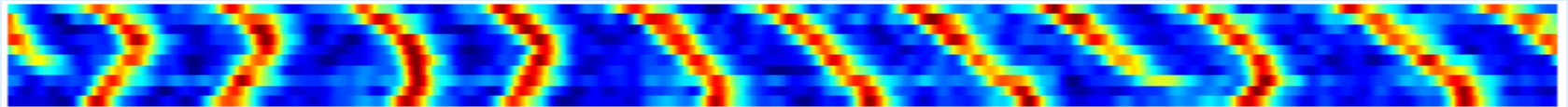
Irregular patterns

h1110201uf 6581-7890

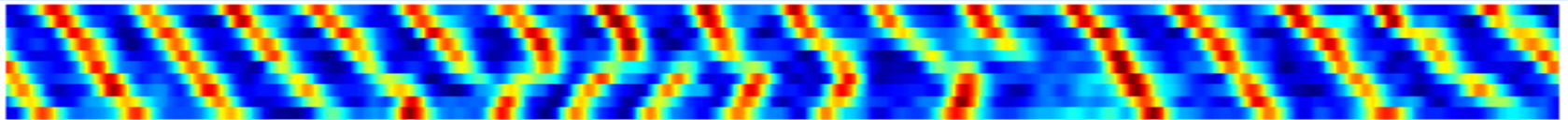


# Irregular waves

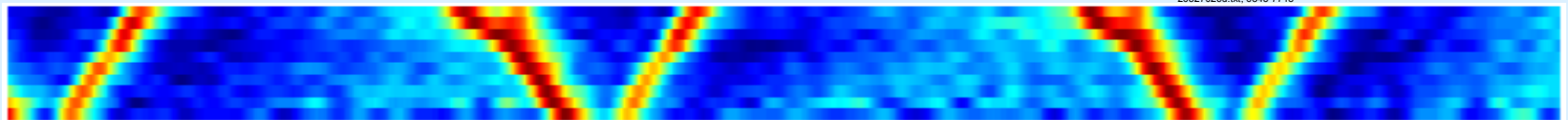
Collisions



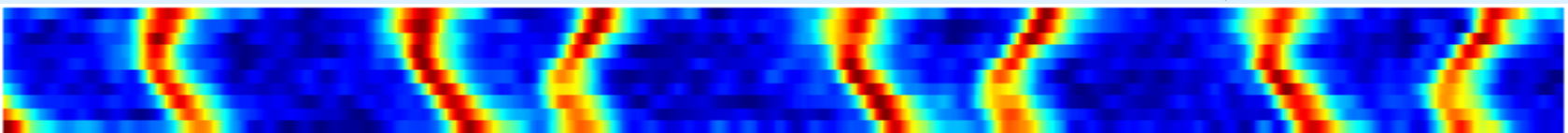
Broken waves



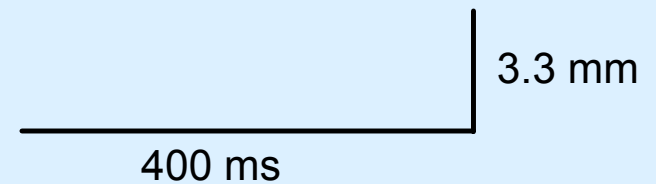
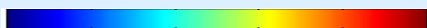
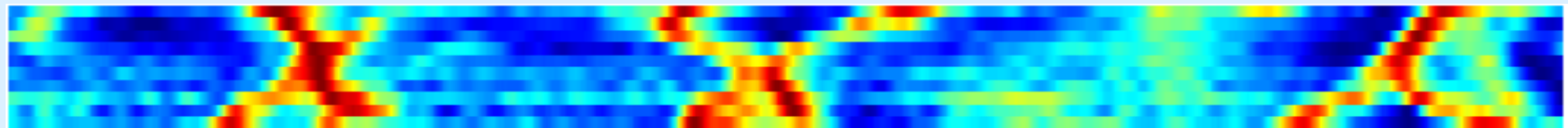
Edge effect?



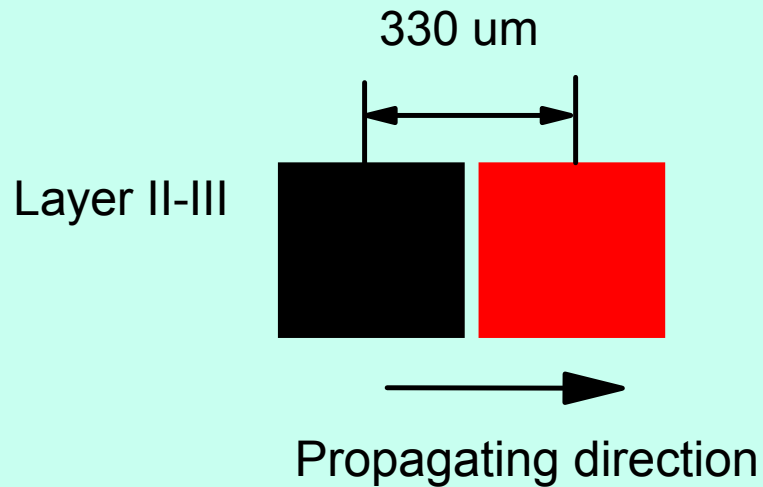
Center initiation



Collisions + new center

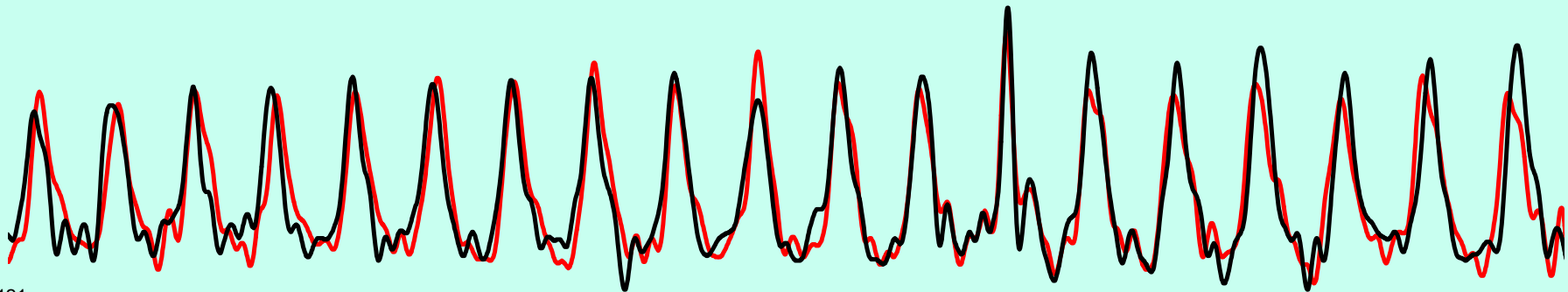


# Local frequency variation: Coupled Oscillators?

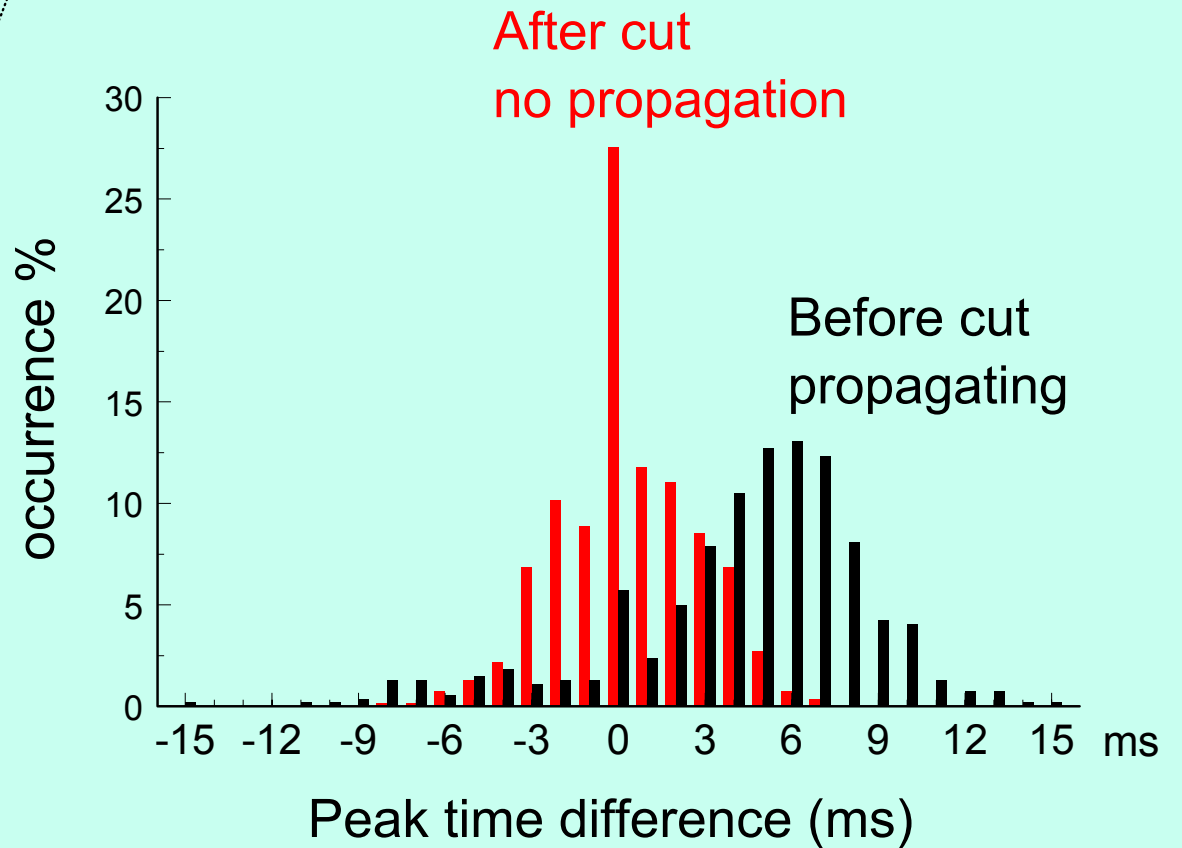
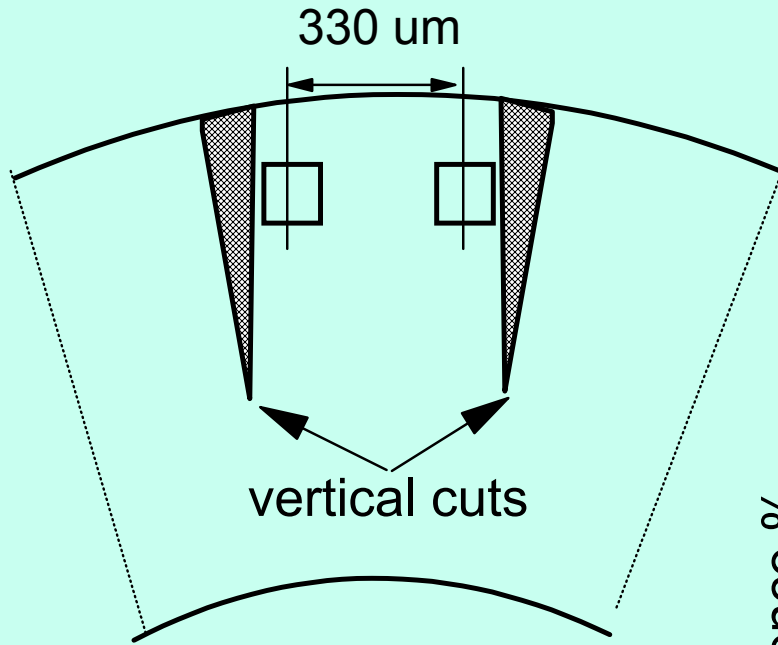


Peak time difference (ms)

8 10 3 9 4 8 4 4 2 0 -2 -5 -2 -4 -5 -6 -5 -11 -12



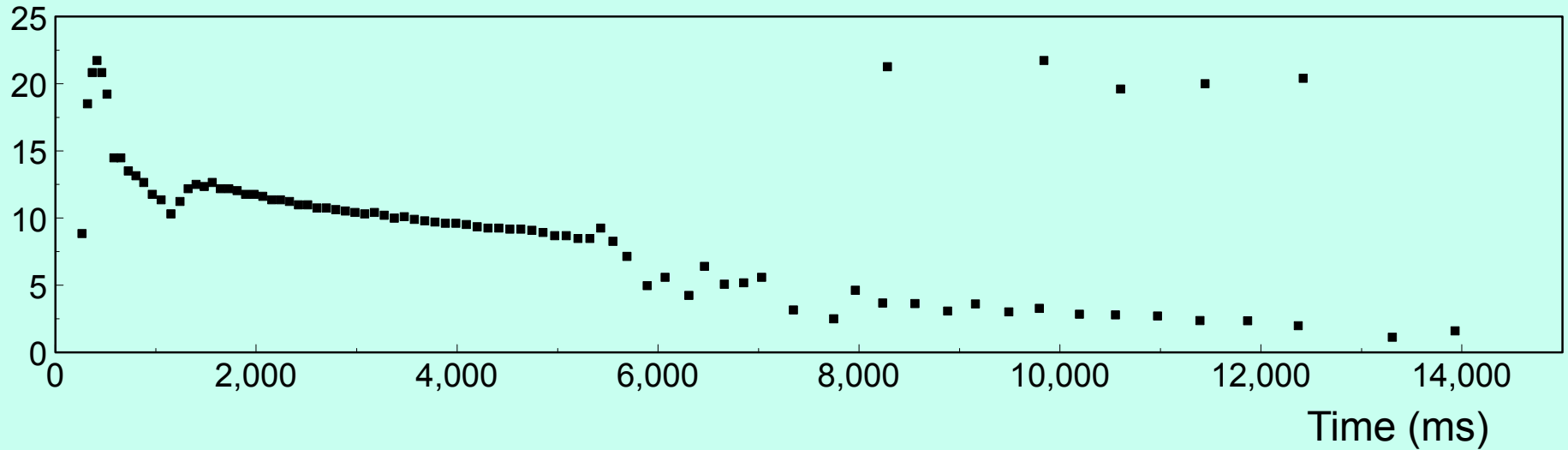
# More evidence: I: Single oscillator in mini slice



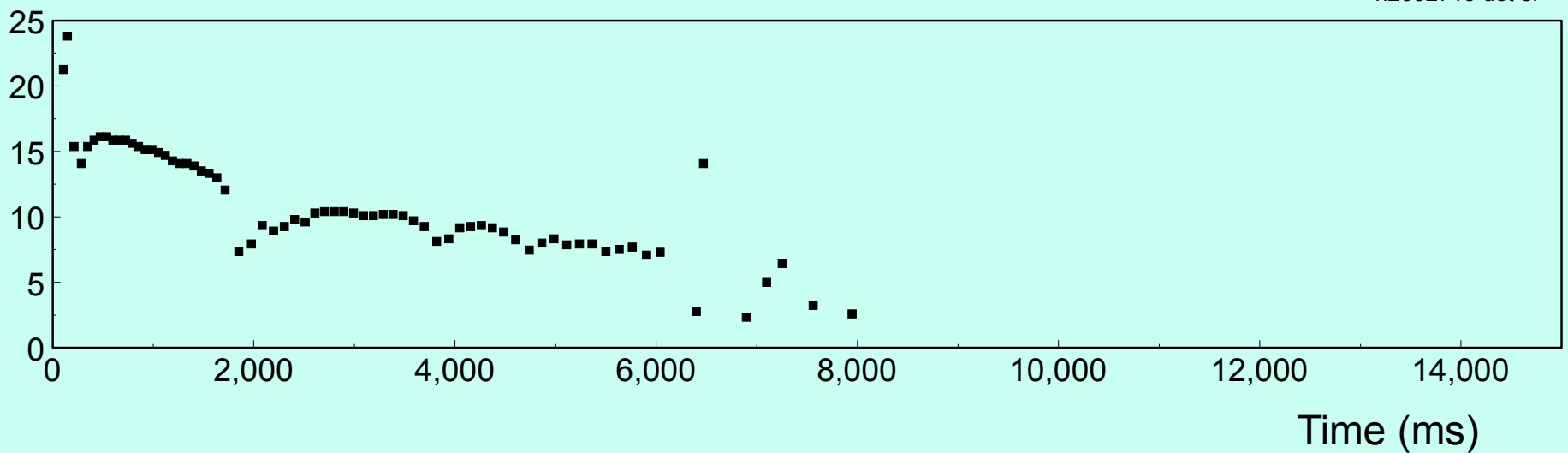
whole slice, h20326,05(95 c),06(88 c), three pairs  
mini slice, h20406, 01(31 c), 02(44 c), 03(38 c), 05(36 c), 07(37 c))

# II Break up of coupling

Frequency (Hz)

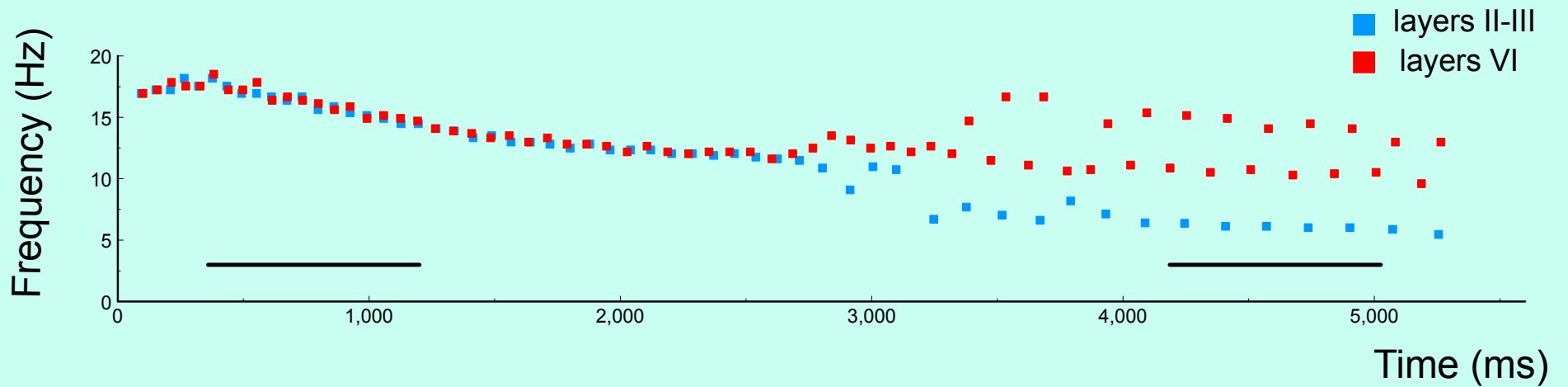


Hz

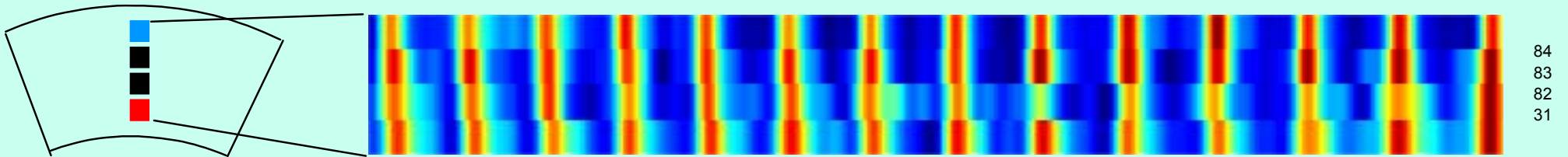




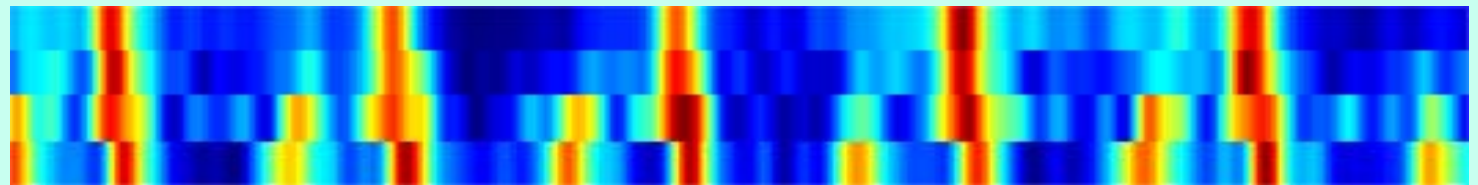
# Columnar de-synchronization



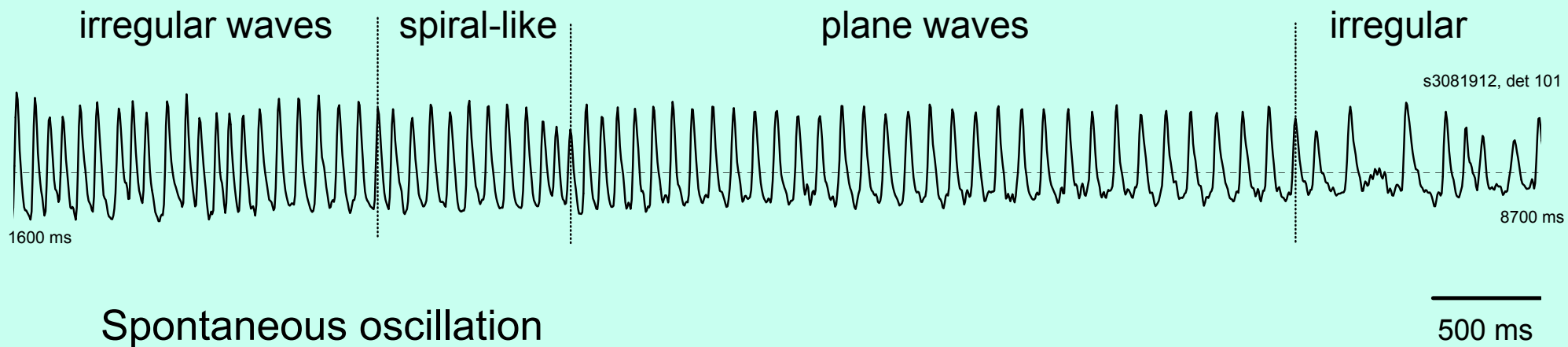
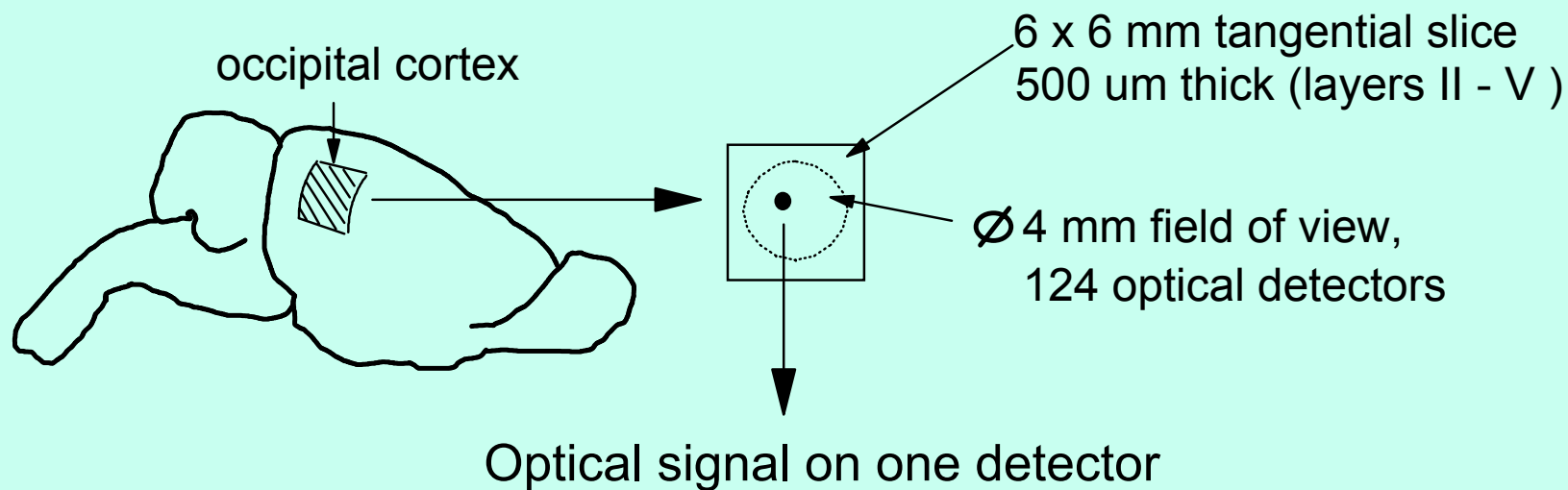
Synchronized



Later, desynchronized

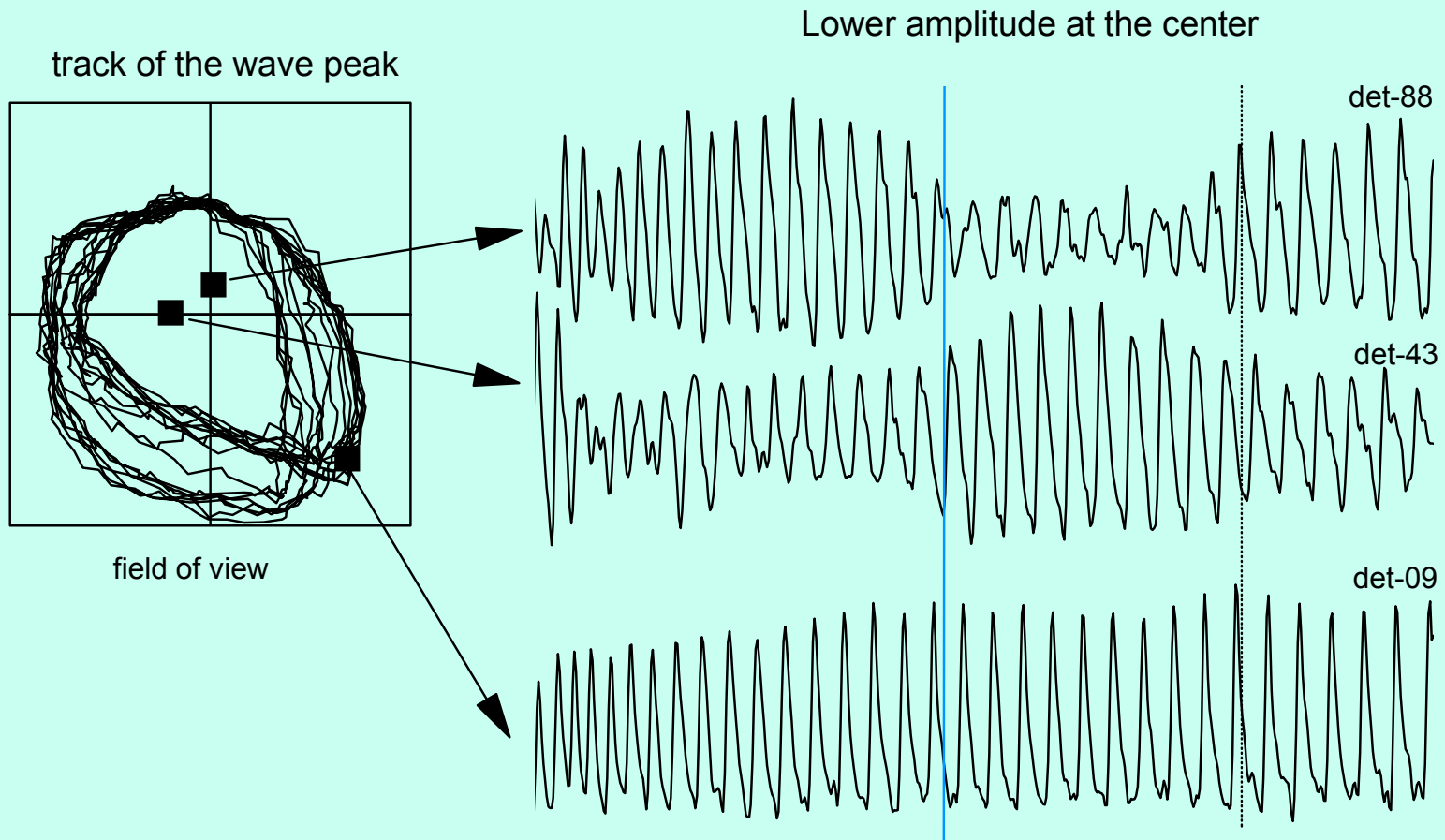


# Spiral-like waves in tangential slice



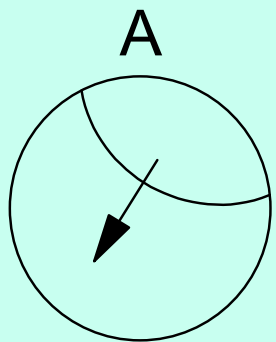
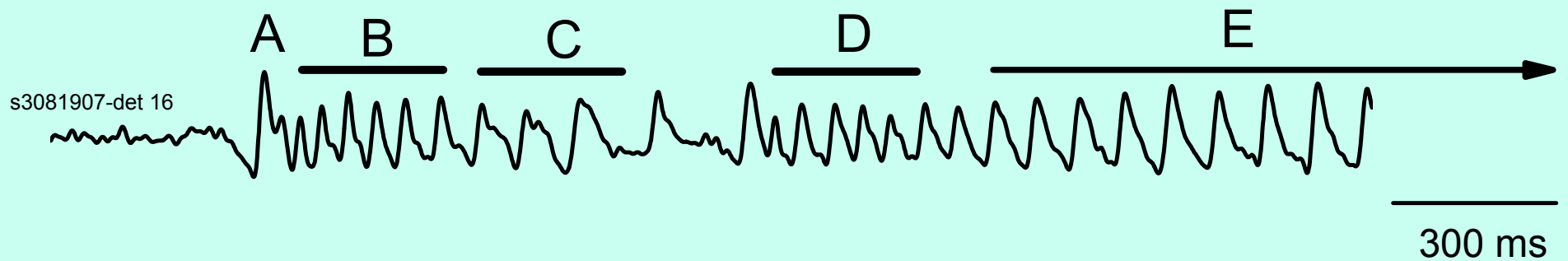
movie 2

# Drift of the spiral center

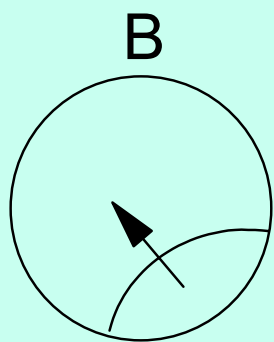


s3081907, filter 5-50,  
3500-6500, 1-2-3-2-1 resmaple

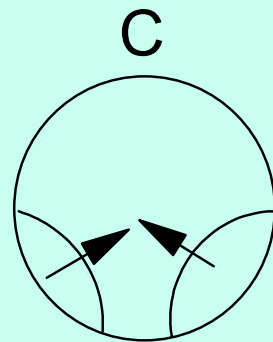
# Initiation of spiral-like waves



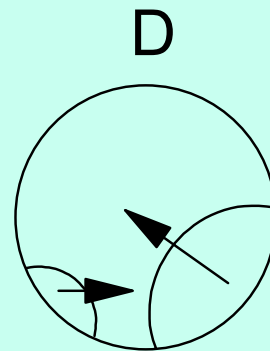
A large wave



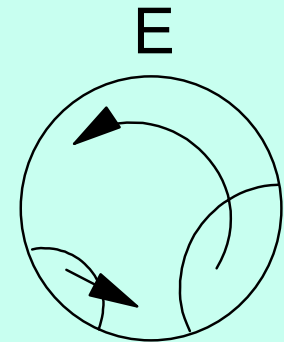
small fast waves,  
6 cycles



collisions,  
3 cycles



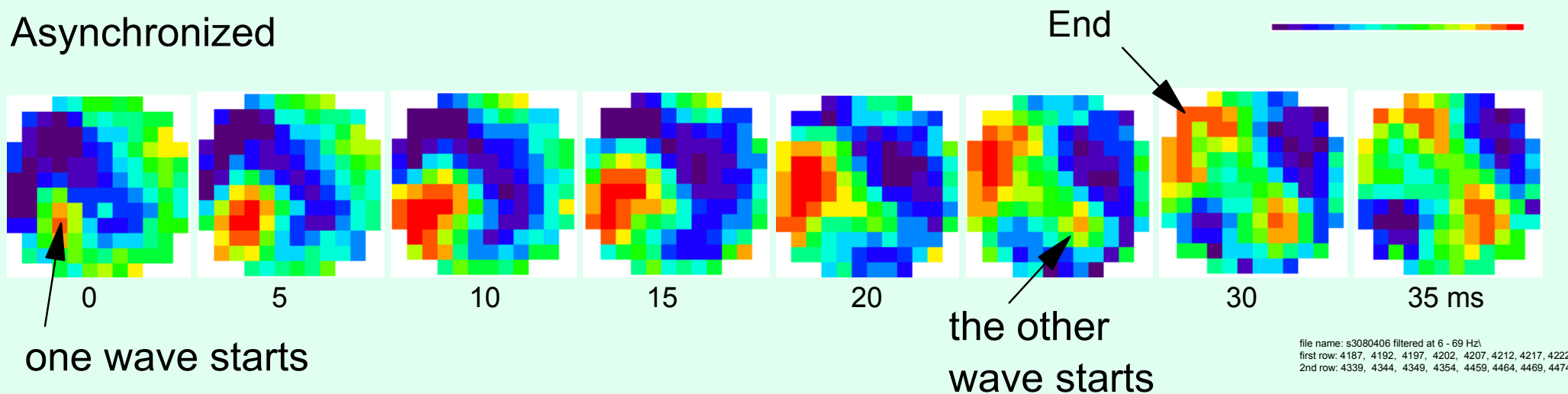
fast waves  
6 cycles



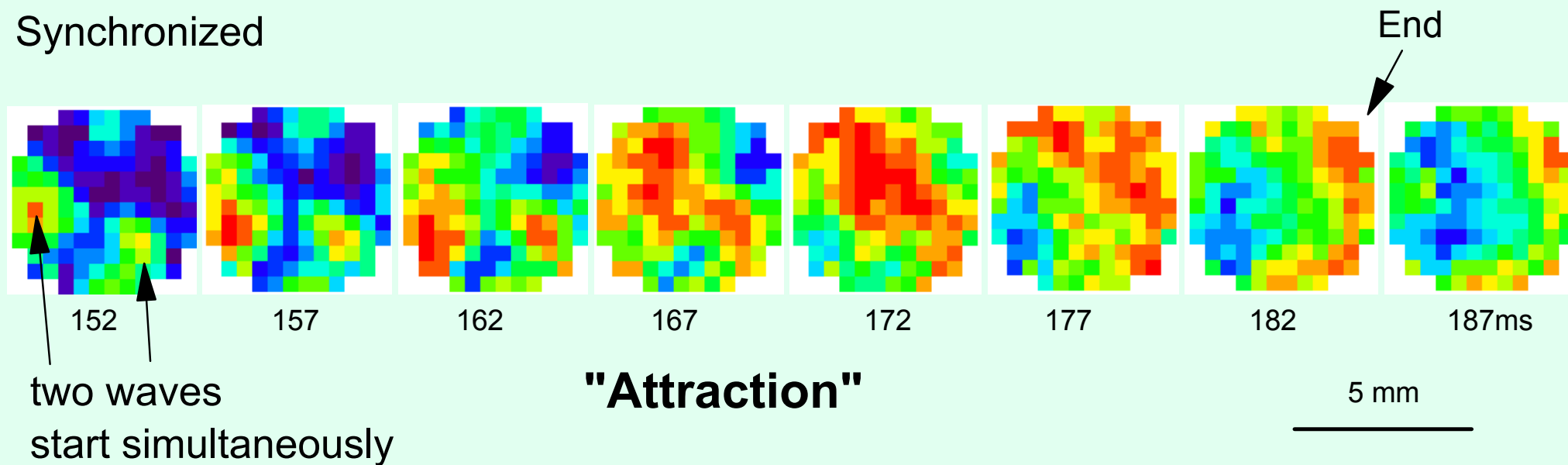
spiral-like,  
30 cycles

# Interaction of two waves

Asynchronized



Synchronized



# Theta oscillations

## Propagating Waves

NMDA theta ( ~ 7 Hz)

Cholinergic theta ( ~ 7 Hz )

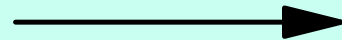
## Local oscillators:

~300 x 300 um,

5000 neurons.

10% synchronized

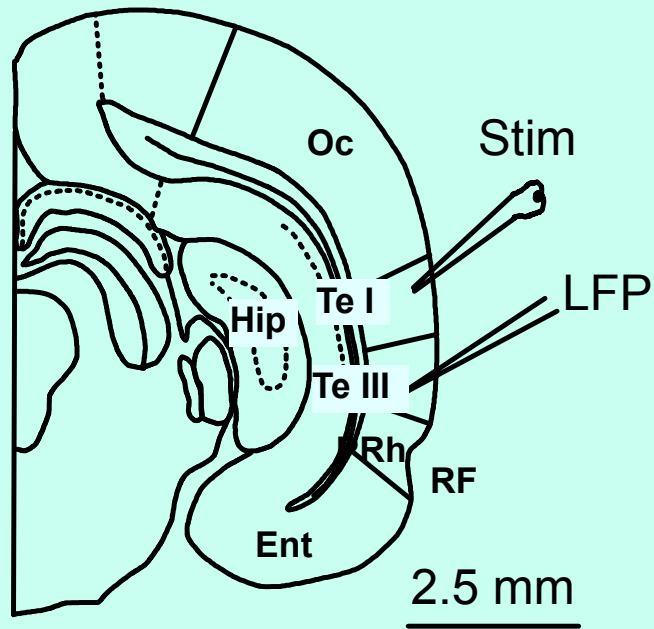
Coupled local  
oscillators



Propagating waves

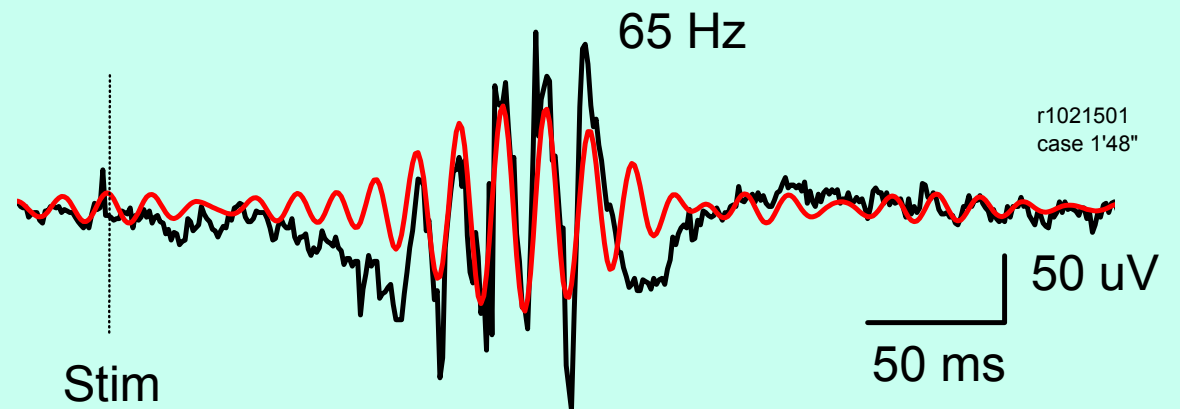
Wave-to-wave "attraction" is a possible  
mechanism for controlling truns

# Evoked gamma oscillations



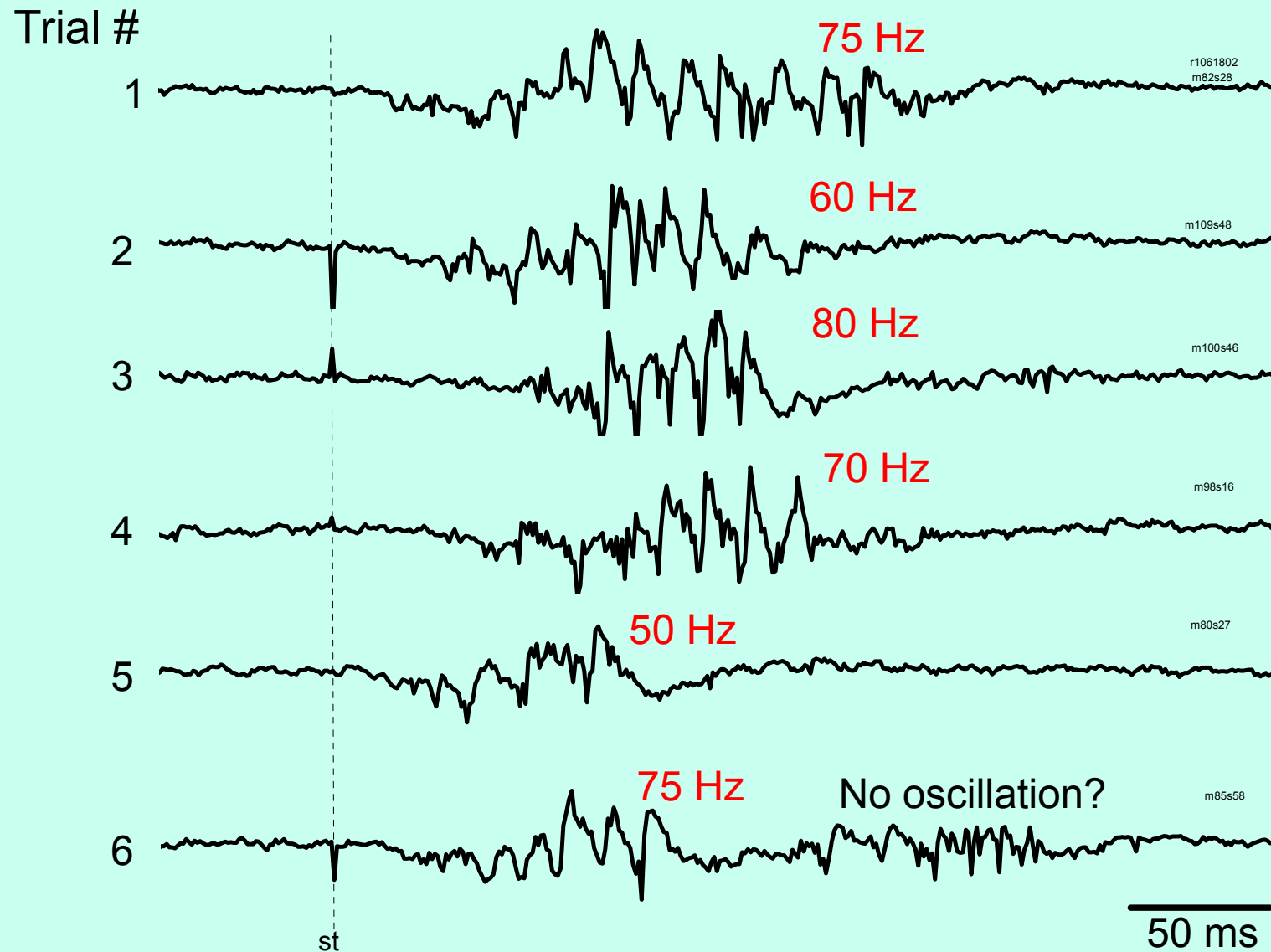
Coronal slice  
bregma -6.2 mm

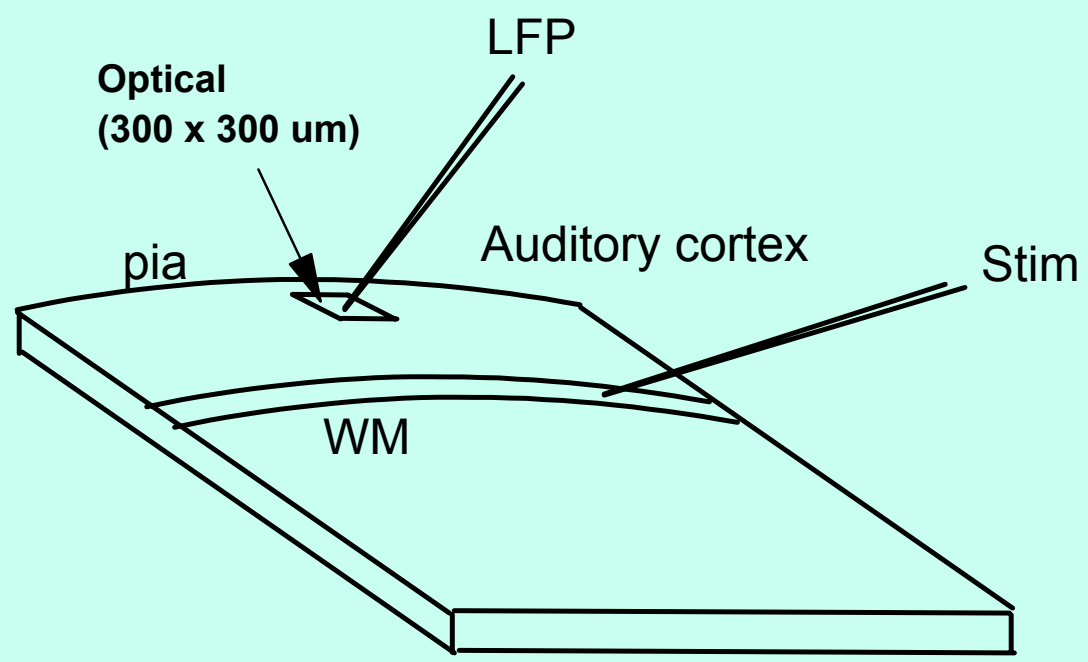
— 2-300 Hz  
— 58-71 Hz



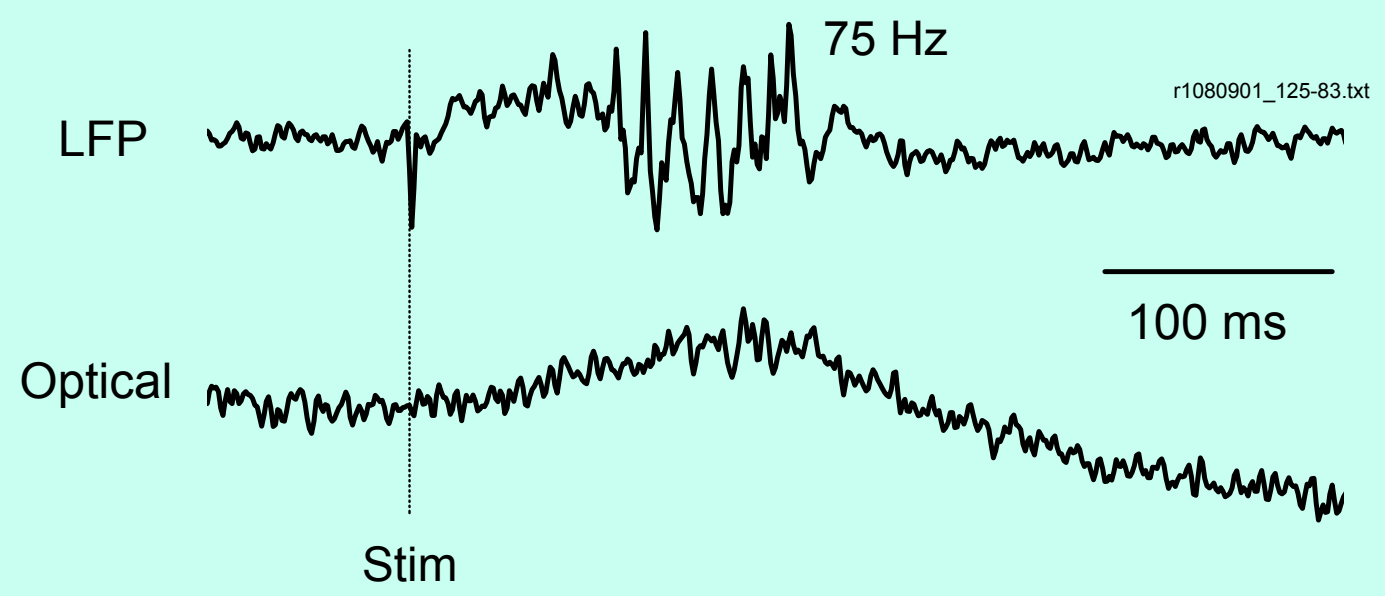


# Dynamically organized: trial-to-trial variations



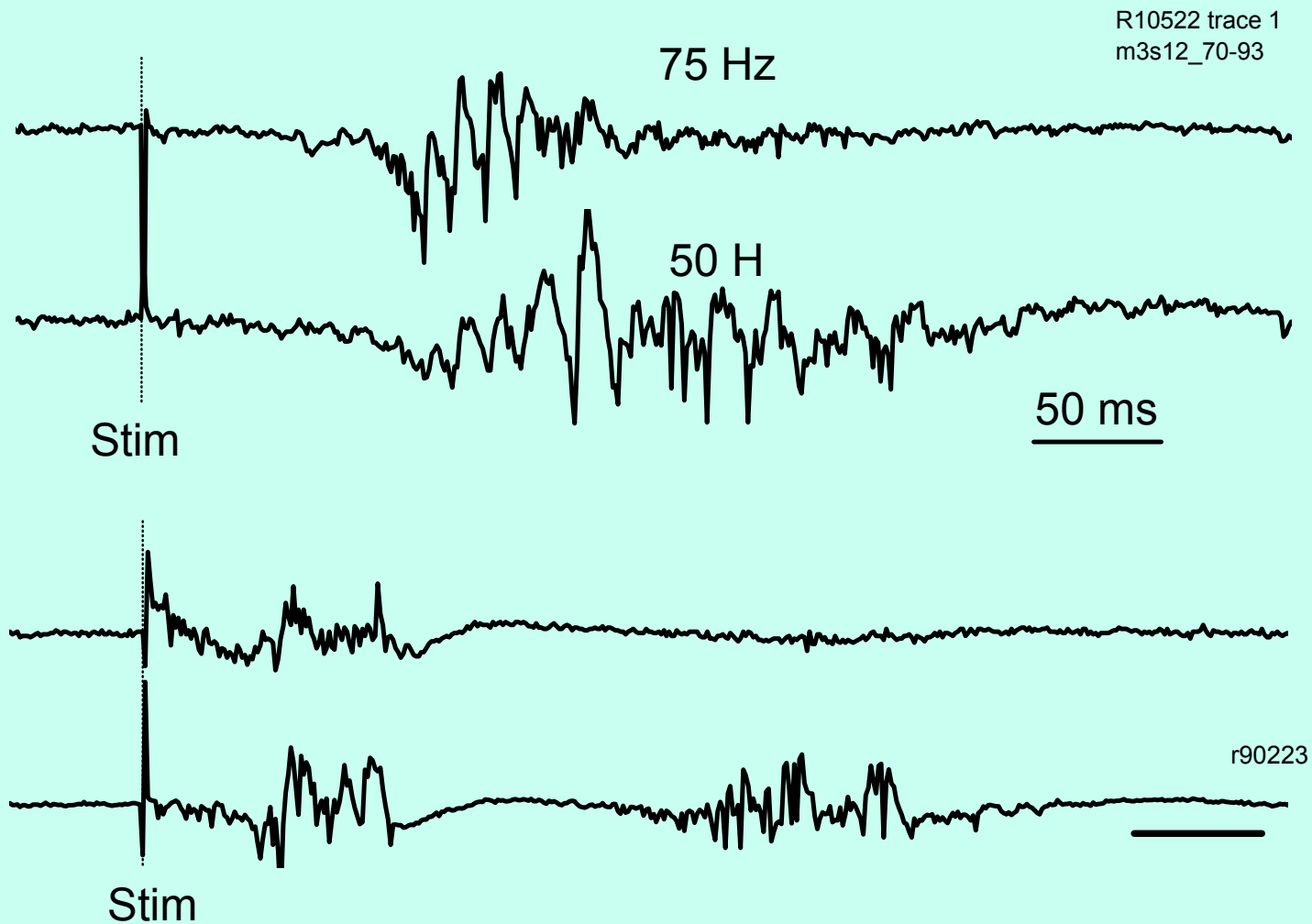


"neural bump"  
(movie 3)



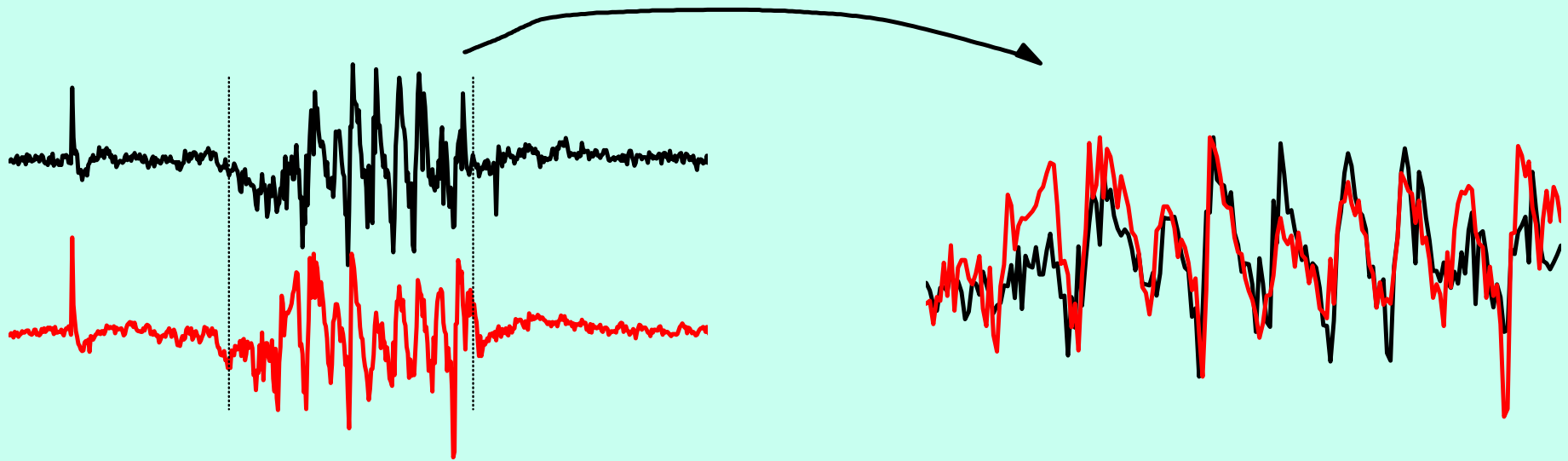
# Local oscillator smaller than 200 $\mu\text{m}$

Electrode, 200  $\mu\text{m}$  apart , two oscillations

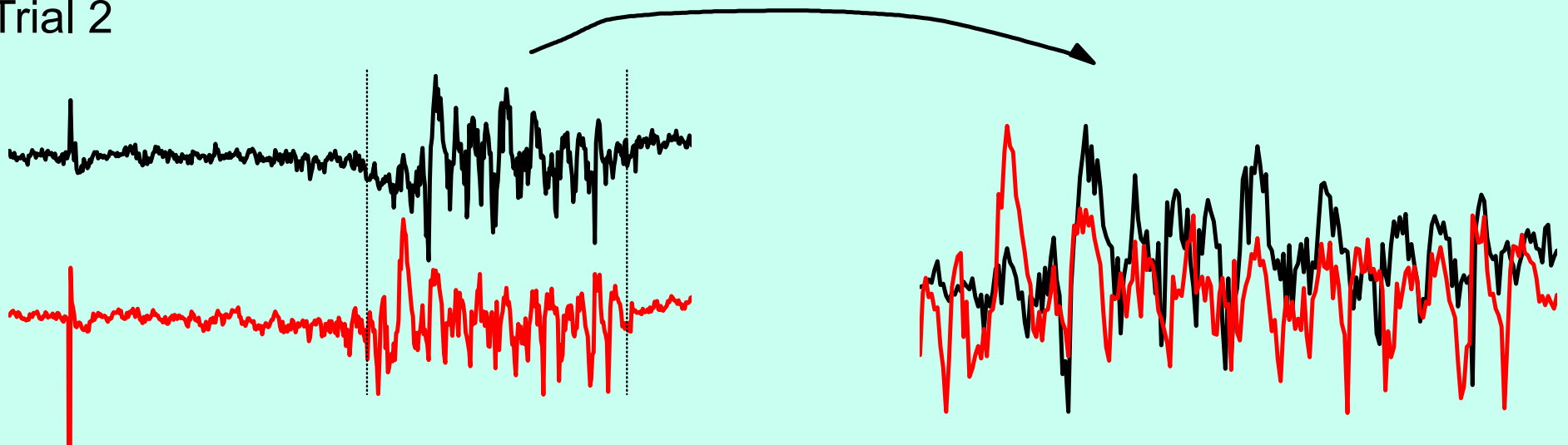


# Electrodes 50 um apart, better correlation

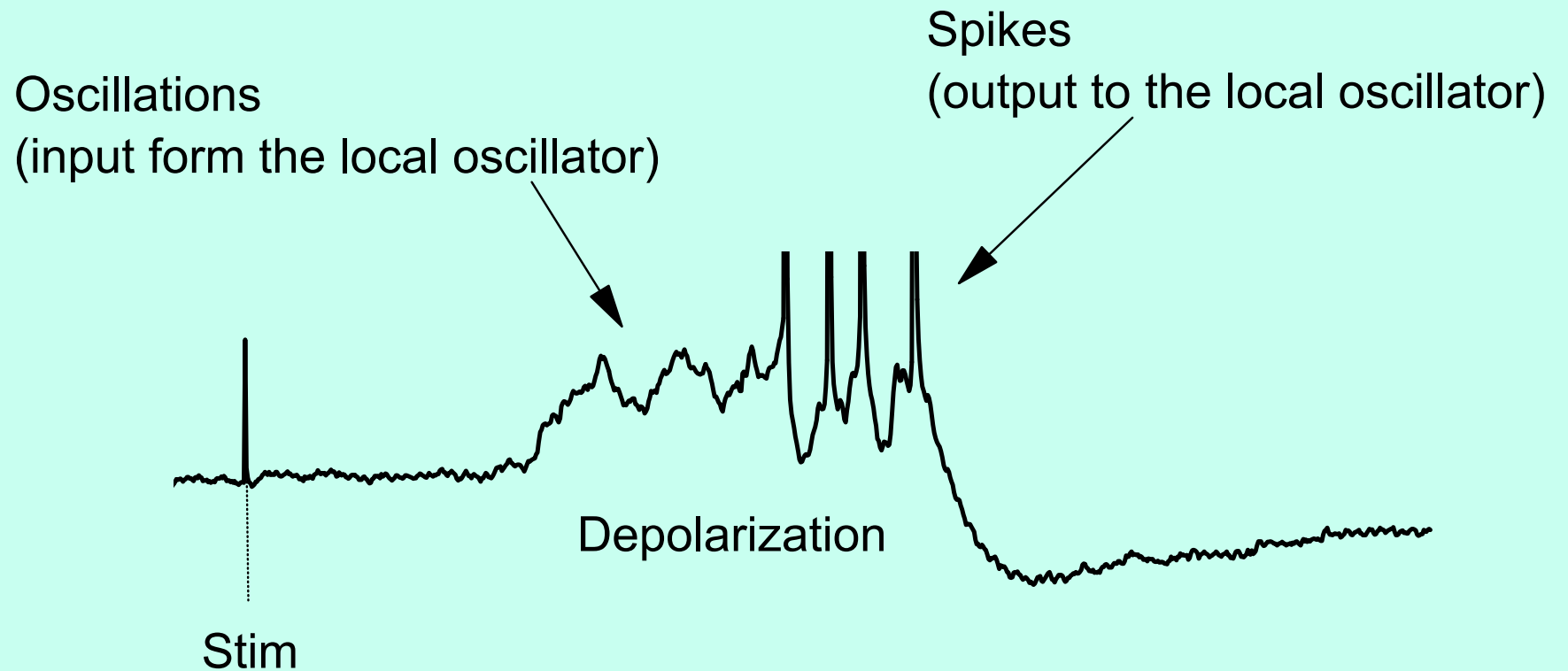
Trial 1



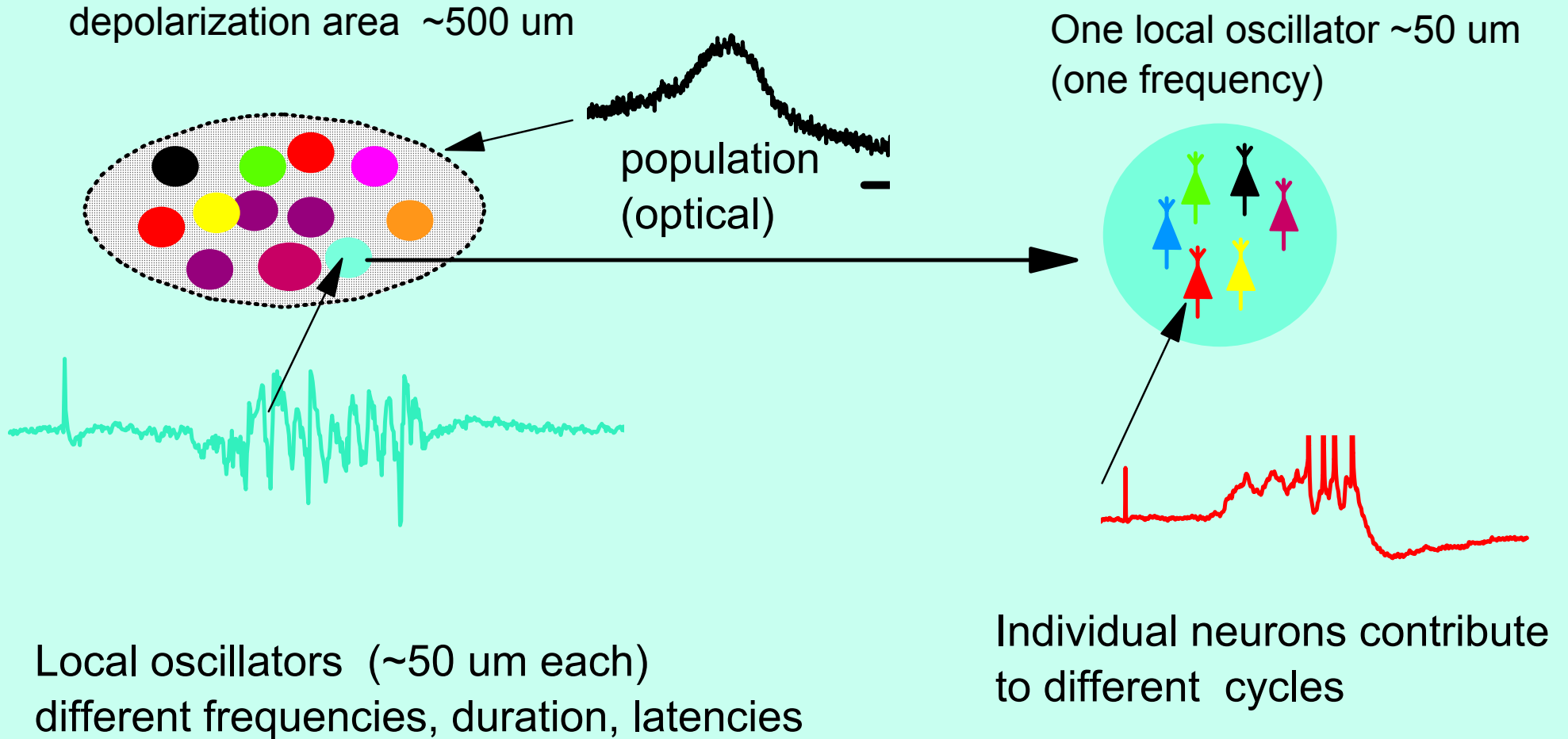
Trial 2



# Intracellular recording



# Organization of the gamma oscillation



# Gamma oscillation

1. Small oscillators
2. Slow waves, one wave many cycles.
3. Oscillations only occur on  $\sim 50$   $\mu\text{m}$  scale  
not on individual cells, nor on a  $500$   $\mu\text{m}$  scale

# Acknowledgment



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