# Thalamic Bursting in rats during different awake behavioral states

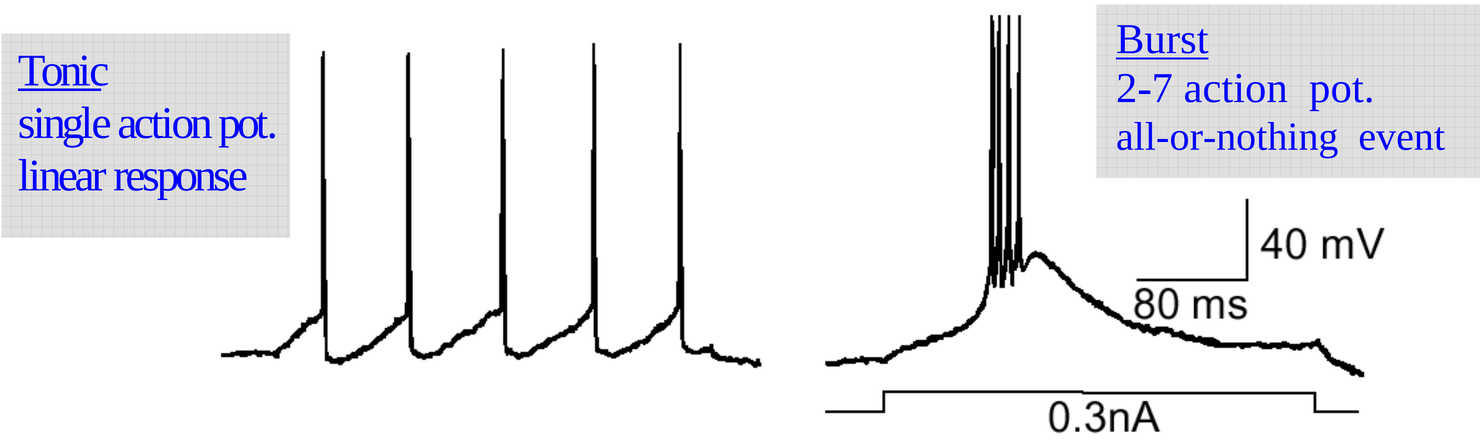
**E. Fanselow, K. Sameshima, L. Baccala & M.A.L Nicolelis**

*Duke University Medical Center*

**PNAS : December 2001**.

## Scope

- To investigate the functional role of ***bursting firing mode*** of thalamic relay neurons




- to study the interaction between **primary somatosensory cortex** and **thalamus** in awake, freely moving rats during different behaviors:
  immobility, whisker twitching (7-12 Hz whisker mov.) , exploratory whisking

- to understand the signal detection process
  that involves a thalamocortical loop
  and is mediated via oscillatory neural activity.

# METHODS

**Implantation of recording electrodes in 3 rats:**

in ventroposterior medial thalamic nucleus (**VPM**) and **SI**

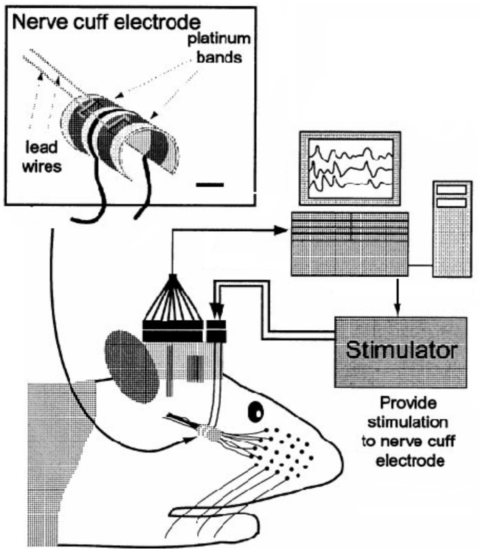
63 / 58 single-units in VPM / SI

**Inactivation of SI-activity by Muscimol Infusion**

**Construction and Implantation of Nerve Cuff Electrode**

for infraorbital nerve stimulation

Stimuli: current pulses, 100 µs




**Behavioral Analyses** via video recordings:

(i) quiet immobility

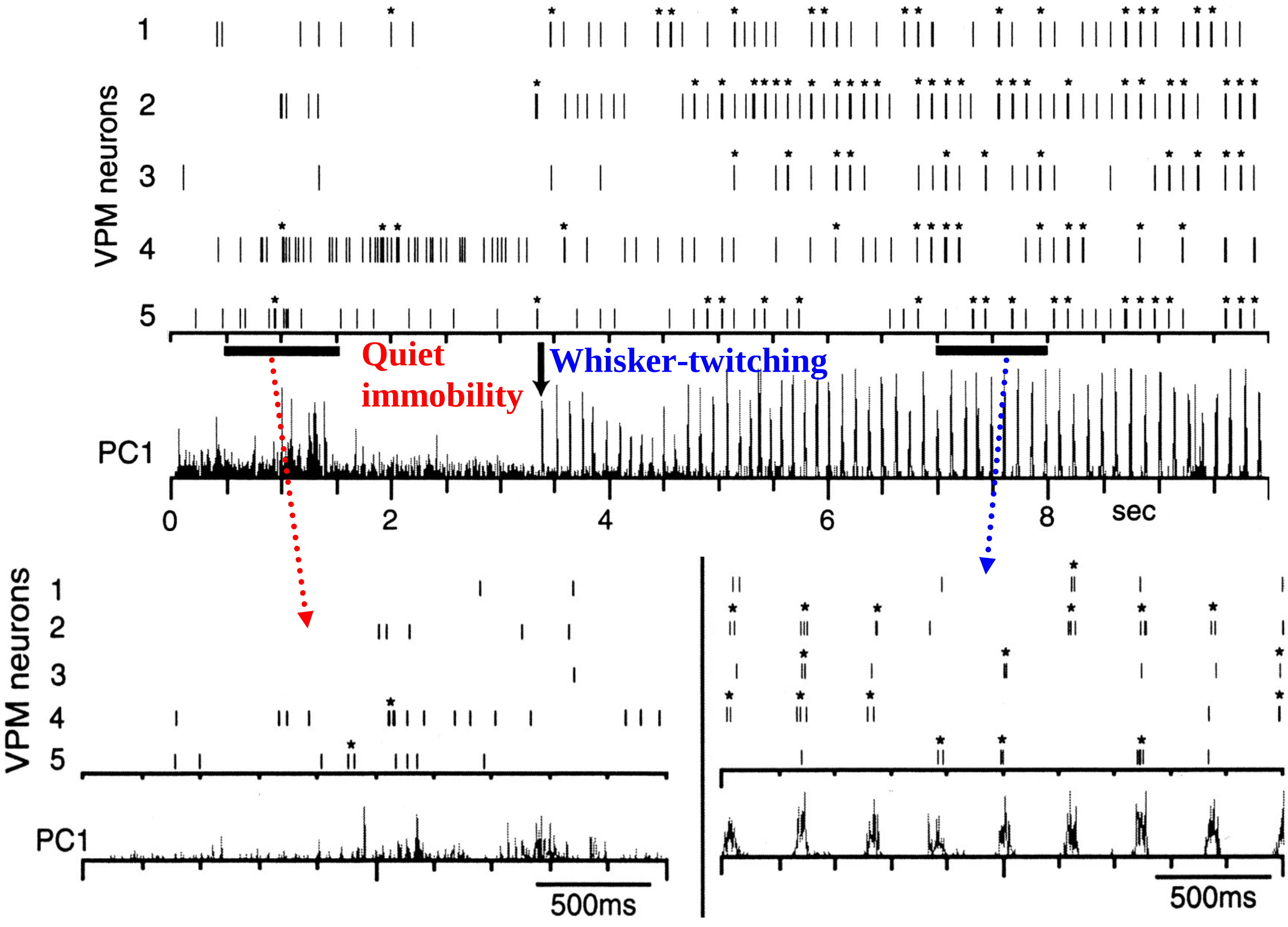
(ii) active (motor activity but no whiskers)

(iii) whisking (large whisker movements / exploratory behavior)

(iv) whisker twitching (WT): small amplitude whisker mov at 7-12 Hz accompanied by oscillatory activity in brainstem, VPM & SI

## Data Analysis

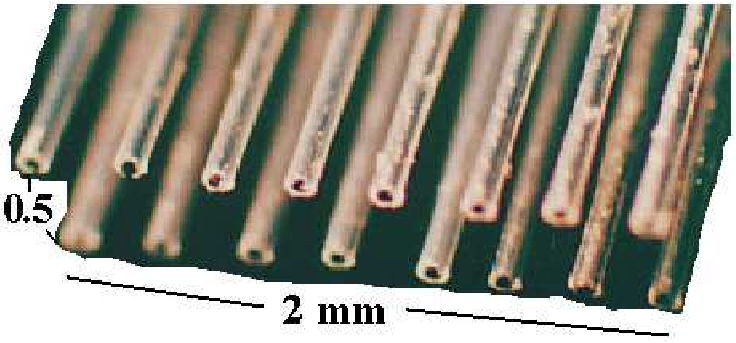
Whisker twitching periods were verified by the 1st Princ. Comp. within an area




**A burst was defined as** : minimum 2 spikes and maximum ISI: 10 msec
& minimum separation from other bursts : 100 msec

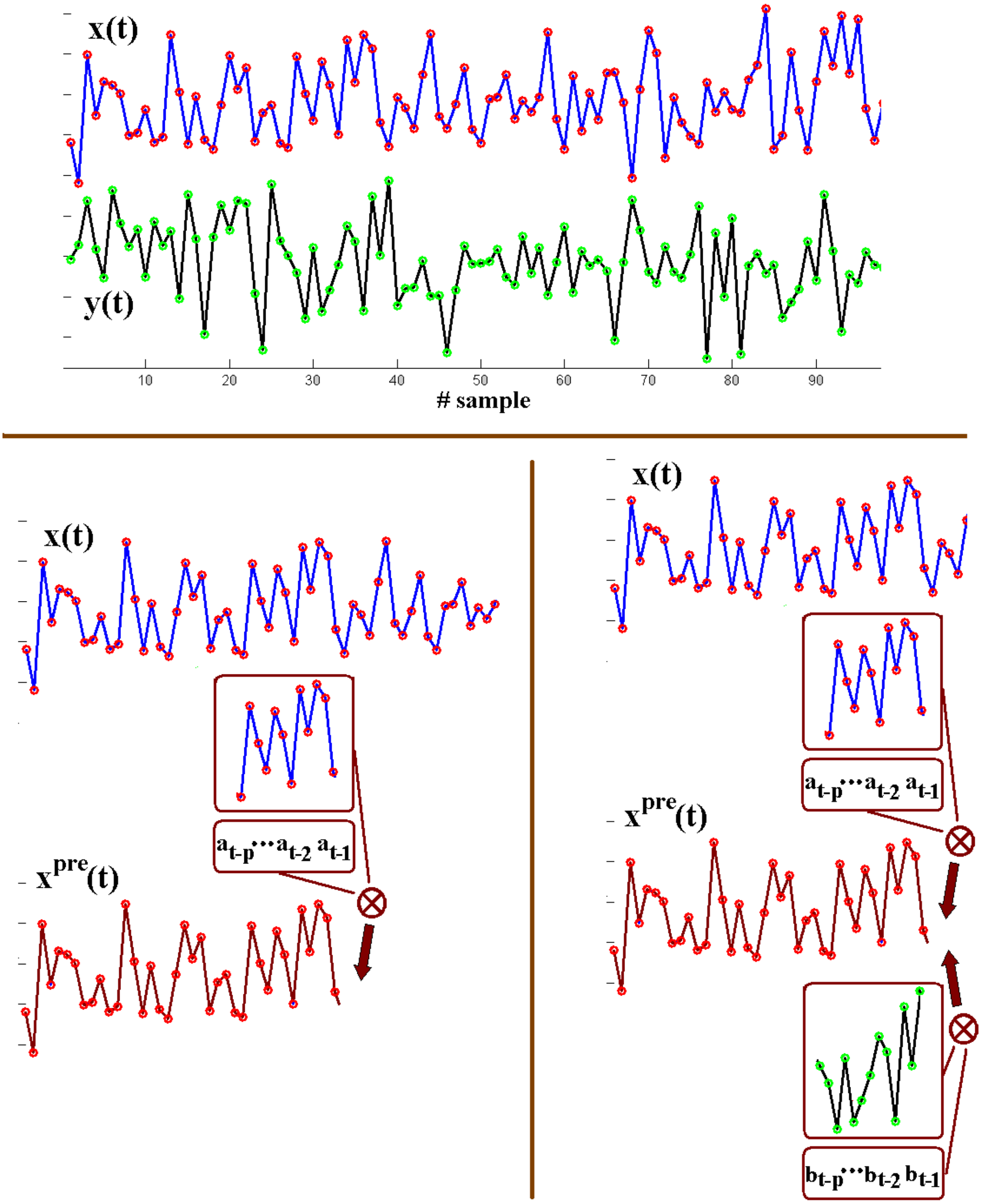
**The amount of cortical area (SI) activated due to a stimulus :**

Cumulative summation of the number of electrodes active in successive (post-stim) time bins



# Partial Directed Coherence (PDC) :

A frequency domain representation of **Granger-causality**



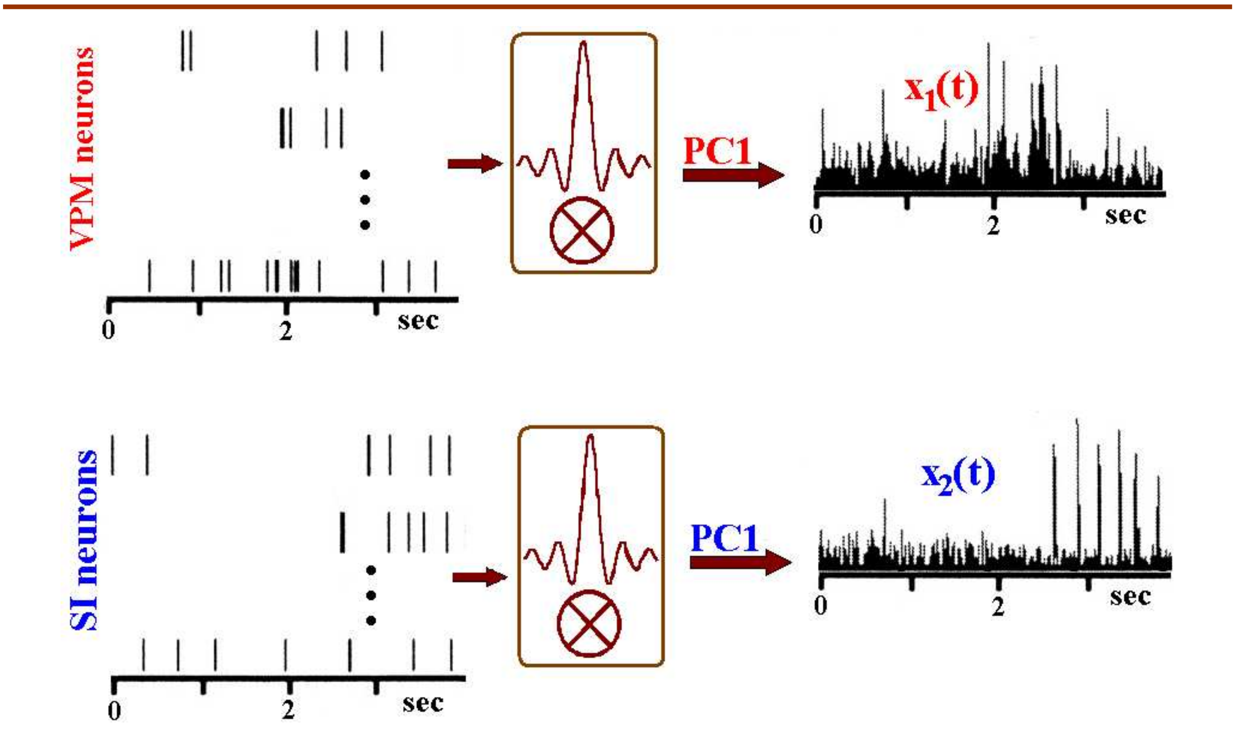
**<u>Multivariate autoregressive</u>** modeling
of the signals derived from neuronal spiking data

$$\begin{bmatrix} x_1(t) \\ \vdots \\ x_N(t) \end{bmatrix} = \sum_{r=1}^{p} \mathbf{A_r}_{[N\mathrm{x}N]} \begin{bmatrix} x_1(t-r) \\ \vdots \\ x_N(t-r) \end{bmatrix}, \qquad \mathbf{A_r} = \begin{bmatrix} a_{11}(r) & a_{12}(r) & \cdots & a_{1N}(r) \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & & a_{ij}(r) & \\ a_{N1}(r) & \cdots & \cdots & a_{NN}(r) \end{bmatrix}$$

$a_{ij}(r)$ : linear interaction effect of $x_j(n\text{-}r) \rightarrow x_i(n)$

**PDC**

$$\mathbf{A_r} \xrightarrow{\text{Z-trans.}} \mathbf{A}(f) = \sum_{r=1}^{p} \mathbf{A_r}\, z^{-r}\Big|_{z=e^{-i2\pi f}} \longrightarrow \pi_{ij}(f) = \pi_{i \leftarrow j}(f) = \frac{\bar{a}_{ij}(f)}{\text{norm. factor}}$$




e.g.
p=2

$$\begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix} = \begin{bmatrix} a_{11}(1) & a_{12}(1) \\ a_{21}(1) & a_{22}(1) \end{bmatrix} \bullet \begin{bmatrix} x_1(t-1) \\ x_2(t-1) \end{bmatrix} + \begin{bmatrix} a_{11}(2) & a_{12}(2) \\ a_{21}(2) & a_{22}(2) \end{bmatrix} \bullet \begin{bmatrix} x_1(t-2) \\ x_2(t-2) \end{bmatrix}$$

$$\mathbf{x_1(t) = a_{11}(1) \, . \, x_1(t\text{-}1) + a_{12}(1) \, . \, x_2(t\text{-}1) + a_{11}(2) \, . \, x_1(t\text{-}2) + a_{12}(2) \, . \, x_2(t\text{-}2)}$$

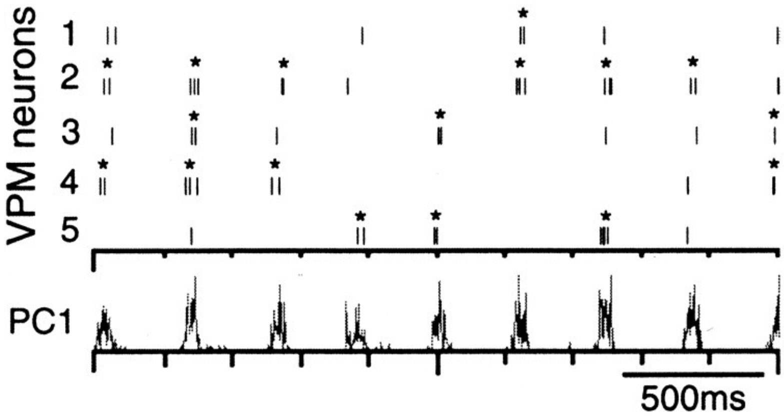
$$\pi_{1 \leftarrow 2}$$

## RESULTS

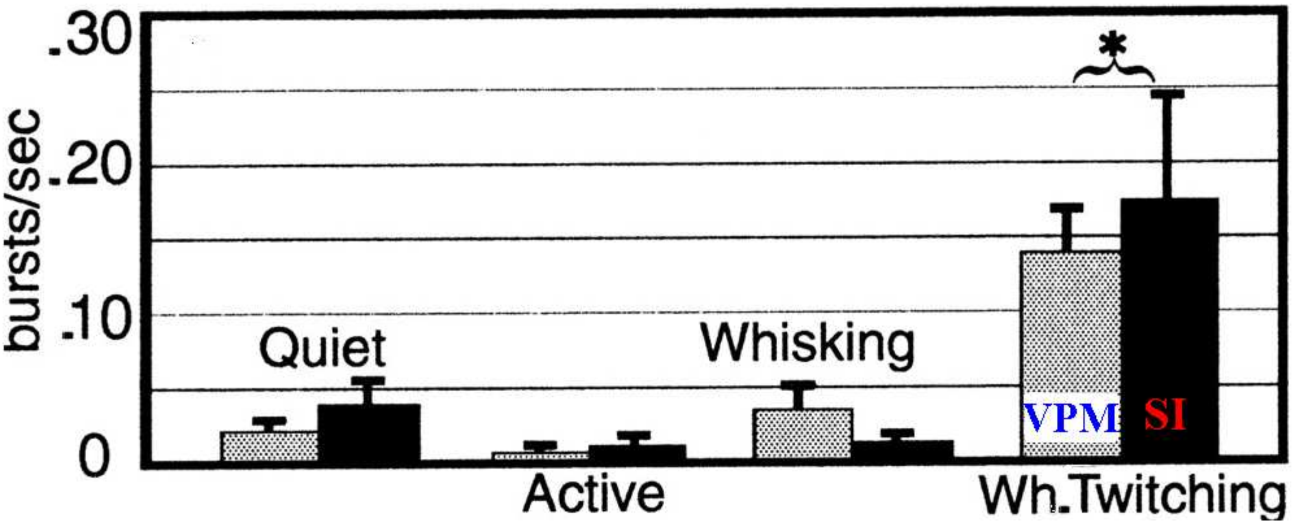
During WT behavior, robust oscillations were observed in VPM & SI.

Neurons fired bursts synchronized with these oscillations.

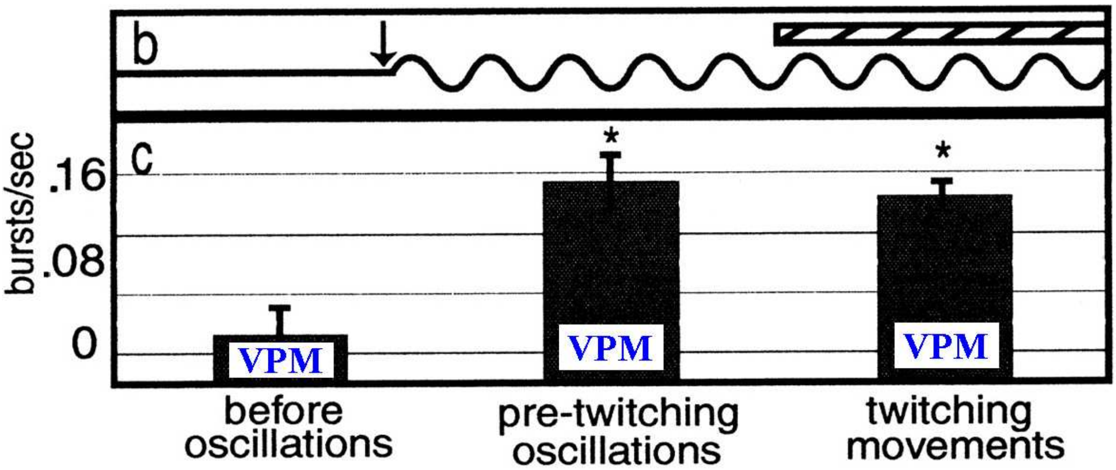
**Not** every neuron fired with every oscillatory cycle



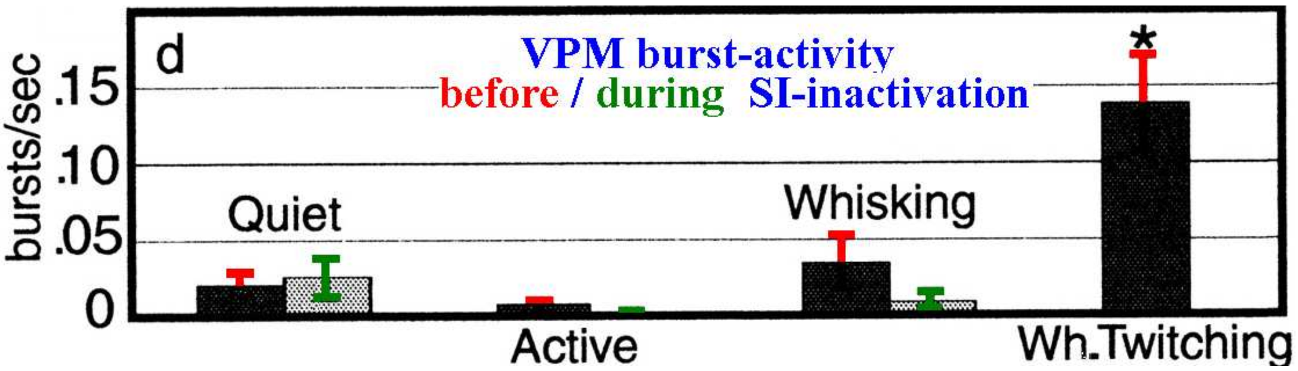

### Rhythmic burst activity was characteristic only of the WT behavior



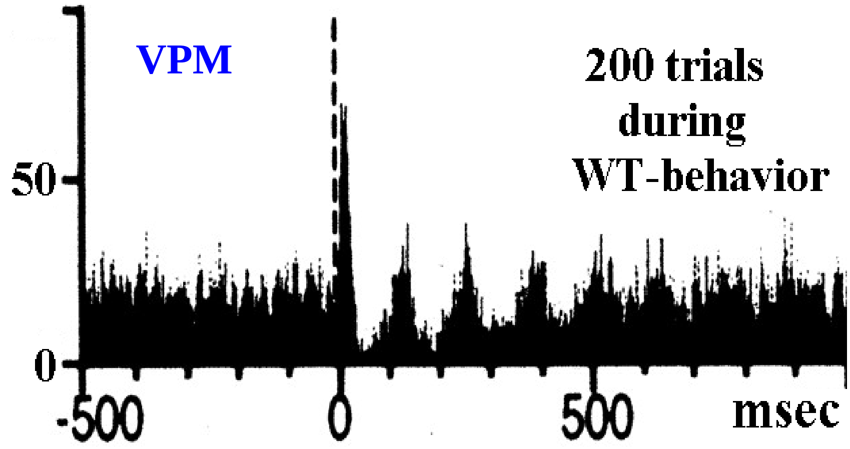

### Oscillatory activity in VPM preceded the onset of WT-movements 576 ± 28 ms



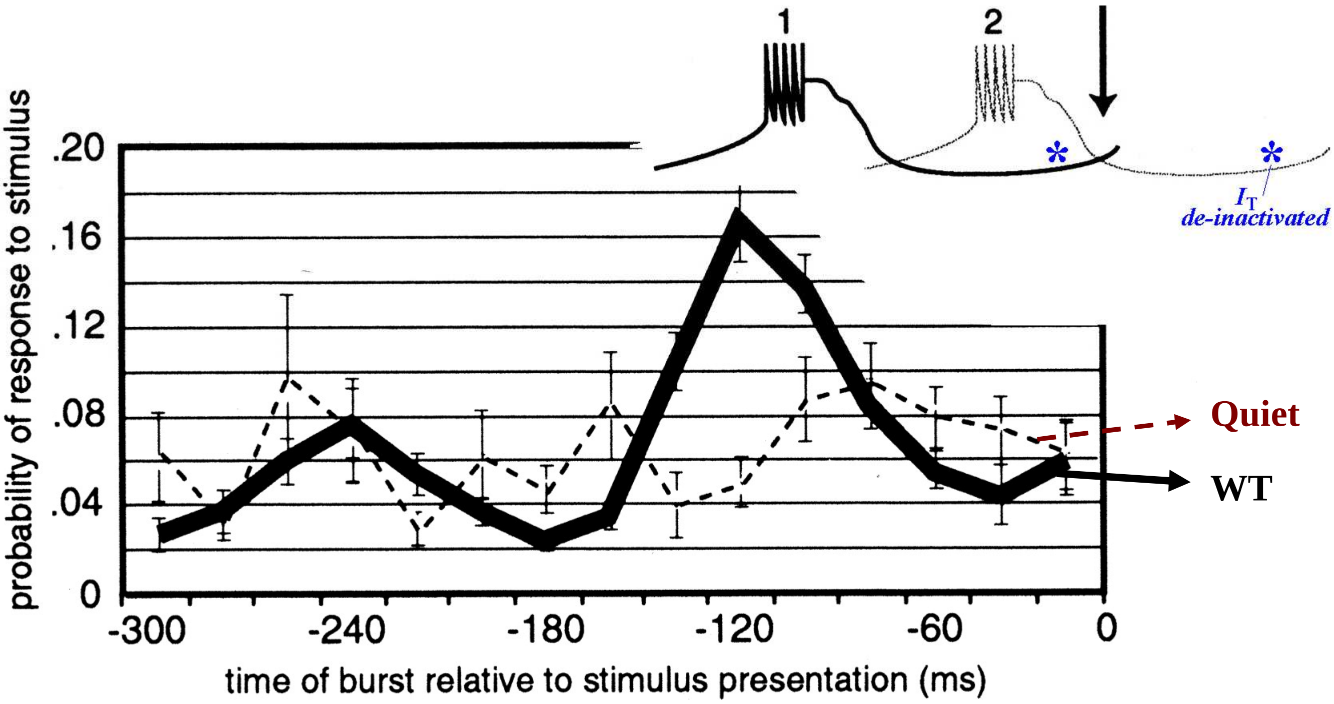
**After SI was inactivated by muscimol infusion, animals showed no WT-behavior, thalamic-oscillatory activity was blocked and burst-activity disappeared**




**Resetting of Oscillation Phase by a stimulus**



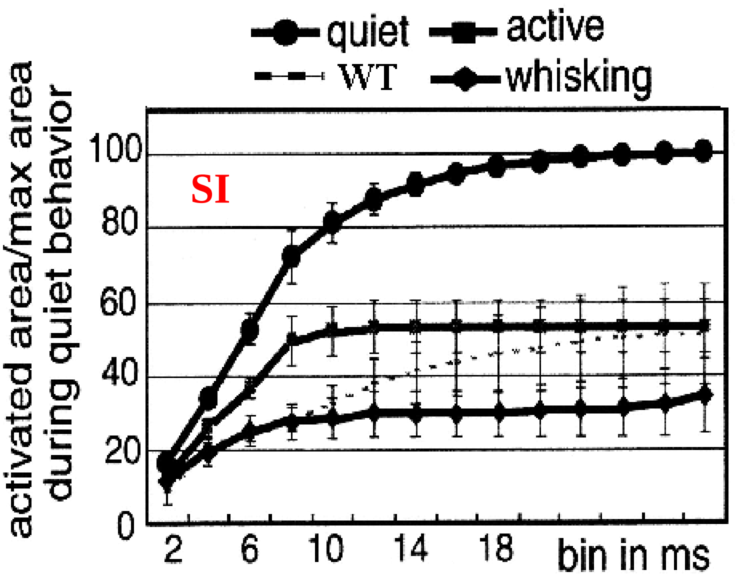

**The probability of a neuron responding to a stimulus is highest if a burst occurred 120 ms before the stimulus**



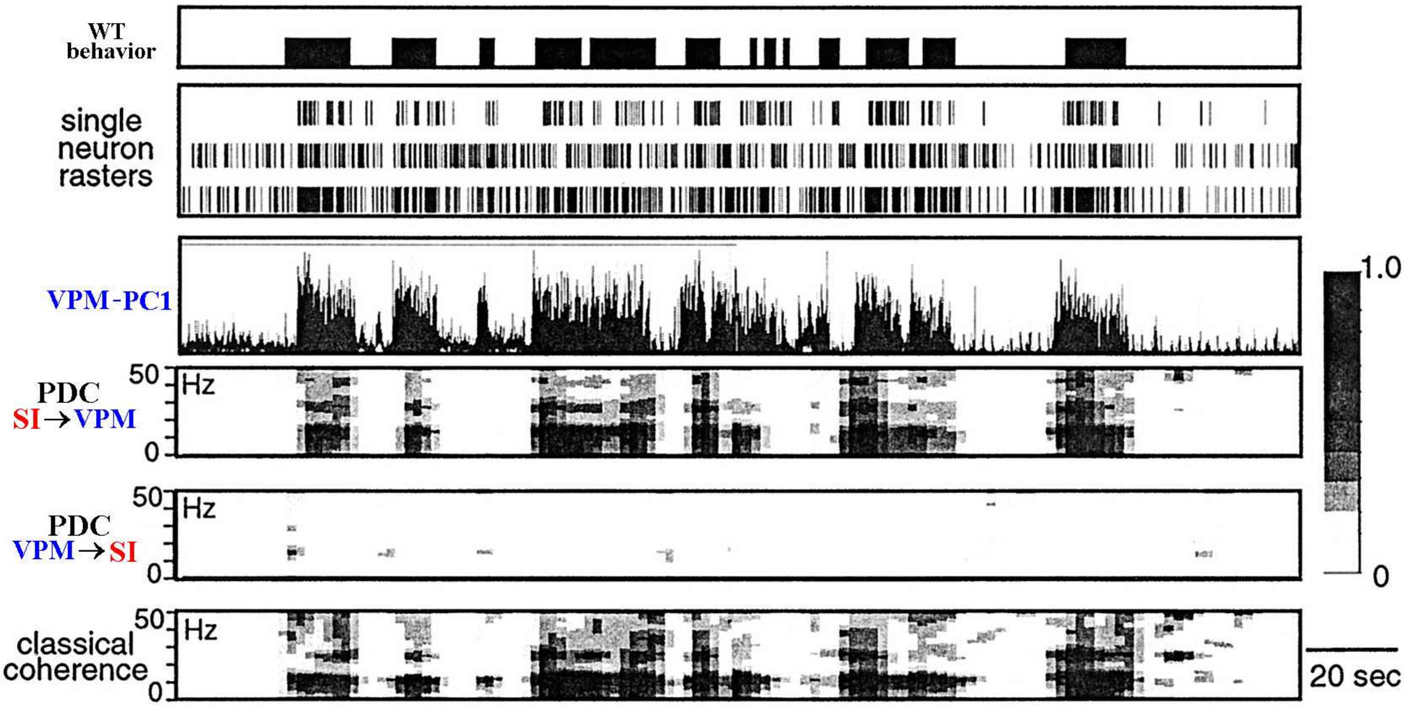
**The cortical area activated by a single stimulus**

**was much larger during the quiet state**

**and in addition this activation was developed at the fastest rate**




The direction of Information Flow was determined, via PDC-analysis , and compared for the different behavioral-states , e.g.

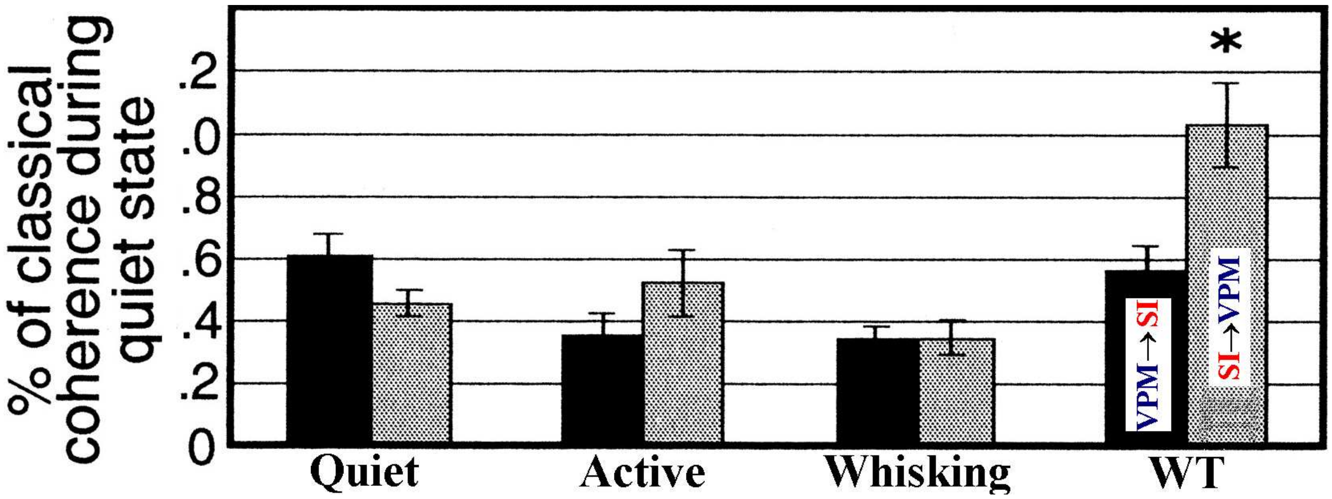


**during quiet/active/whisking states**

**(i)** there was no difference between **VPM→SI** **&** **SI→VPM**

**(ii)** and no difference between states**,** e.g. PDC(quiet)≅ PDC(active)

**(iii) but in WT-behavior:** $\mathbf{PDC_{SI\rightarrow VPM}} > \mathbf{PDC_{VPM\rightarrow SI}}$



# DISCUSSION

❶ thalamocortical neurons fire in bursting mode during WT-behavior
SI does respond to stimuli during WT-behavior

→ there is relay of sensory information

❷ the inactivation showed that WT-behavior depends on SI
PDC-analysis during WT showed more influence from SI → VPM

→ bursting can have functional role : optimal signal detection

❸ the probability of VP neuron responding to a stimulus
was highest when a burst occurred 120 ms earlier

→ during WT the vibrissal system is primed
to detect the incoming stimuli

❹ an hyperalert state during the WT-behavior
which is based on oscillatory activity

## *Conclusion*

❒ the nervous system is not a passive detector of afferent stimuli,
but it plays an active role in optimizing
the detection of potential incoming sensory information