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Université Laval Robert-Giffard

Origin of cortical slow waves

The Department of Higher nervous activity, School of Biology, Moscow State University October 6, 2011

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National Institutes of Health

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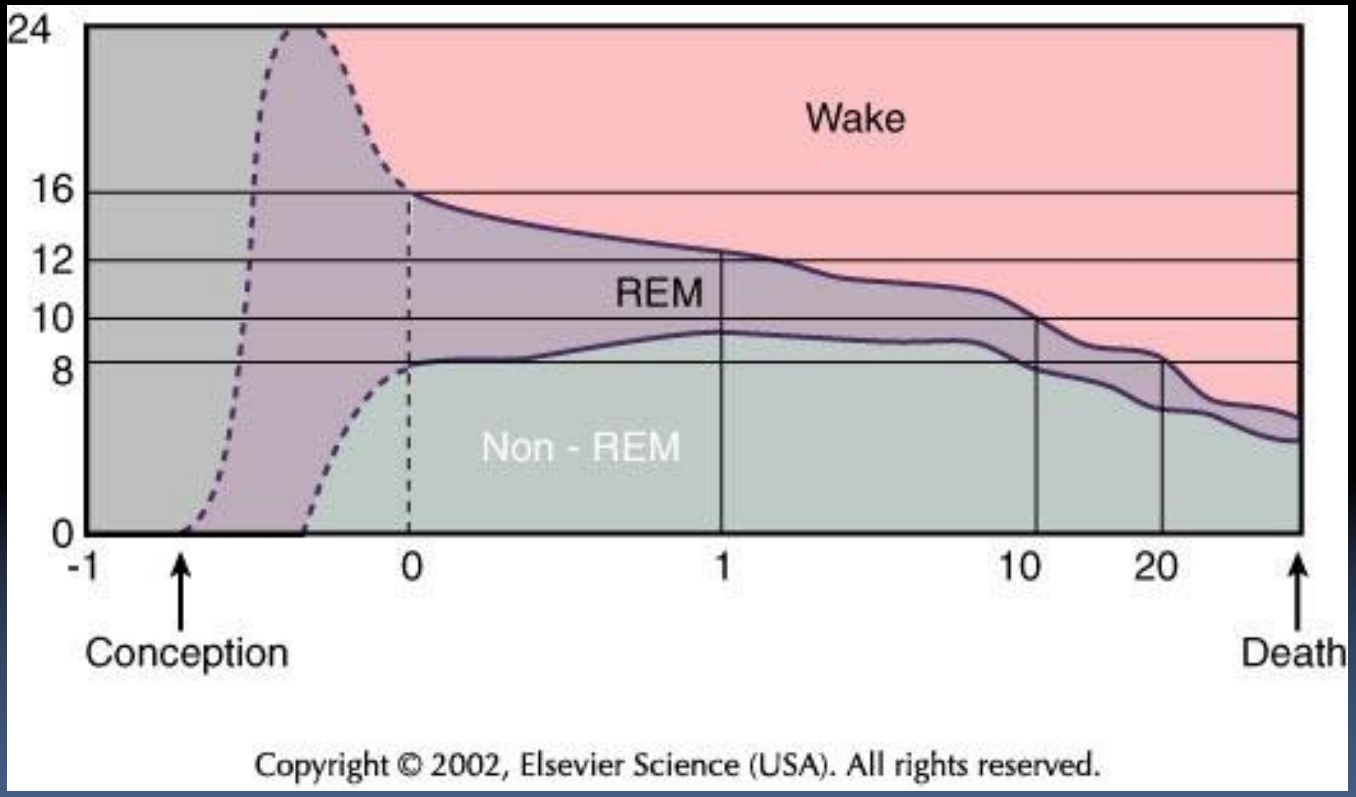
Portions of a 24-h day that are devoted to waking, REM sleep, and non-REM (NREM) sleep change over a lifetime



Brain waves during states of vigilance

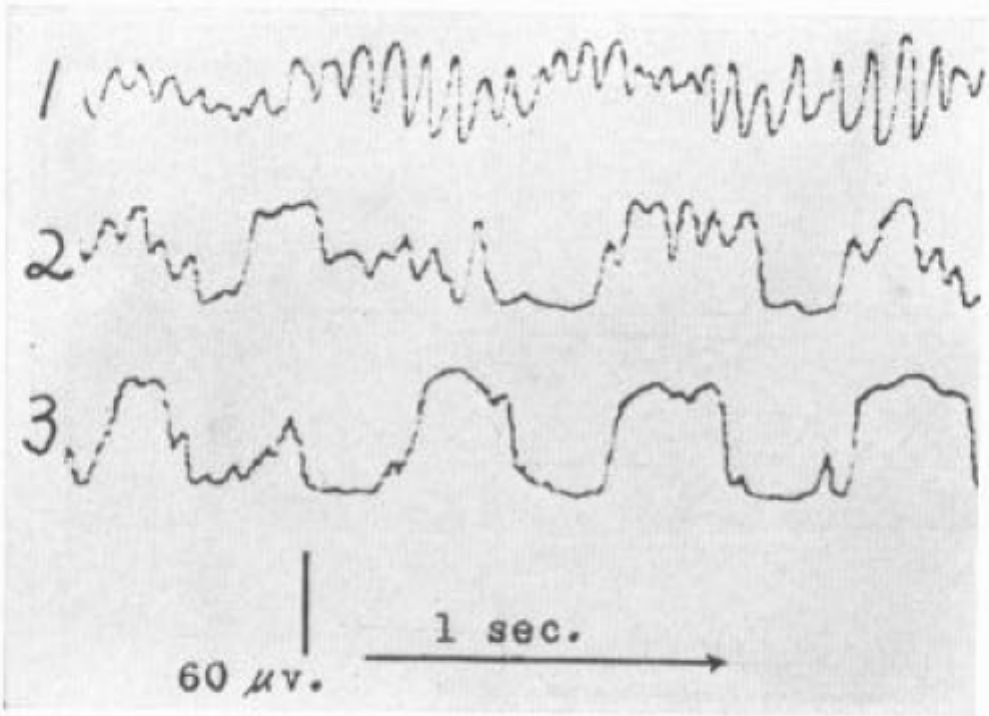
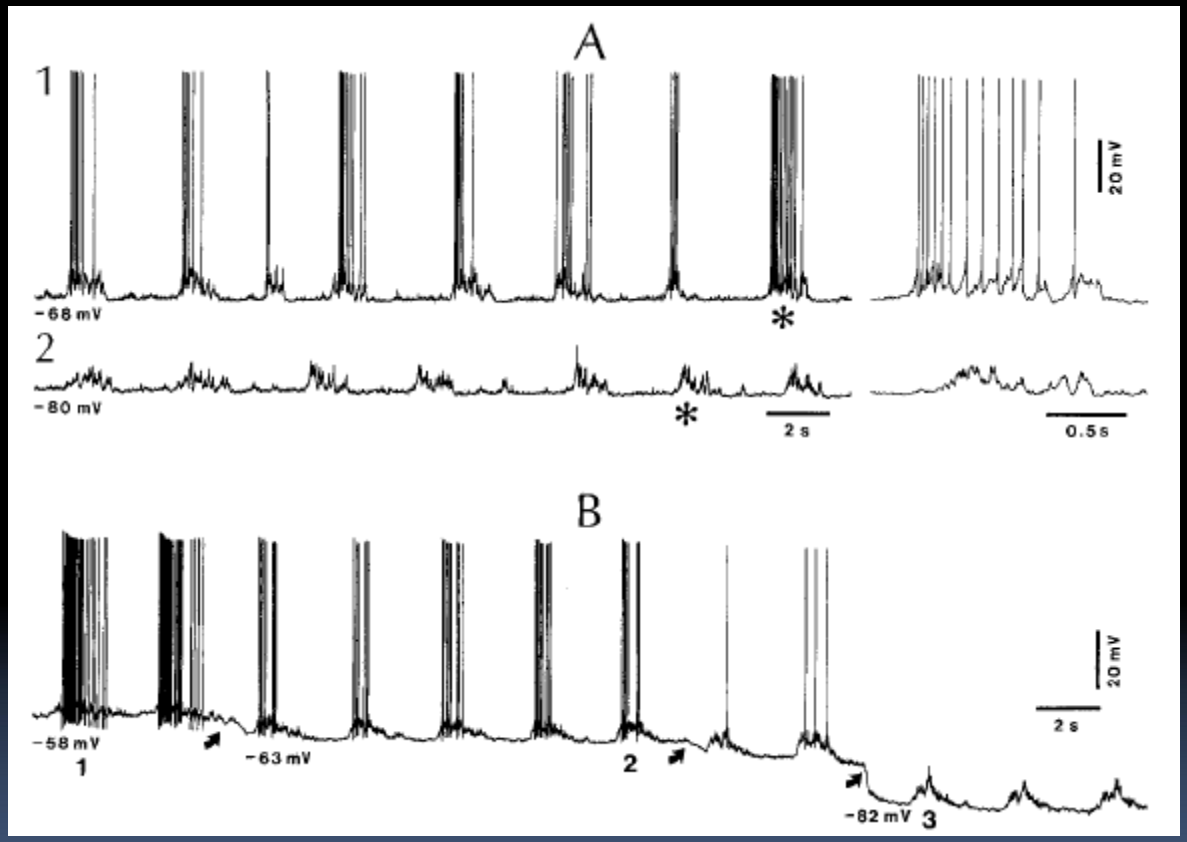


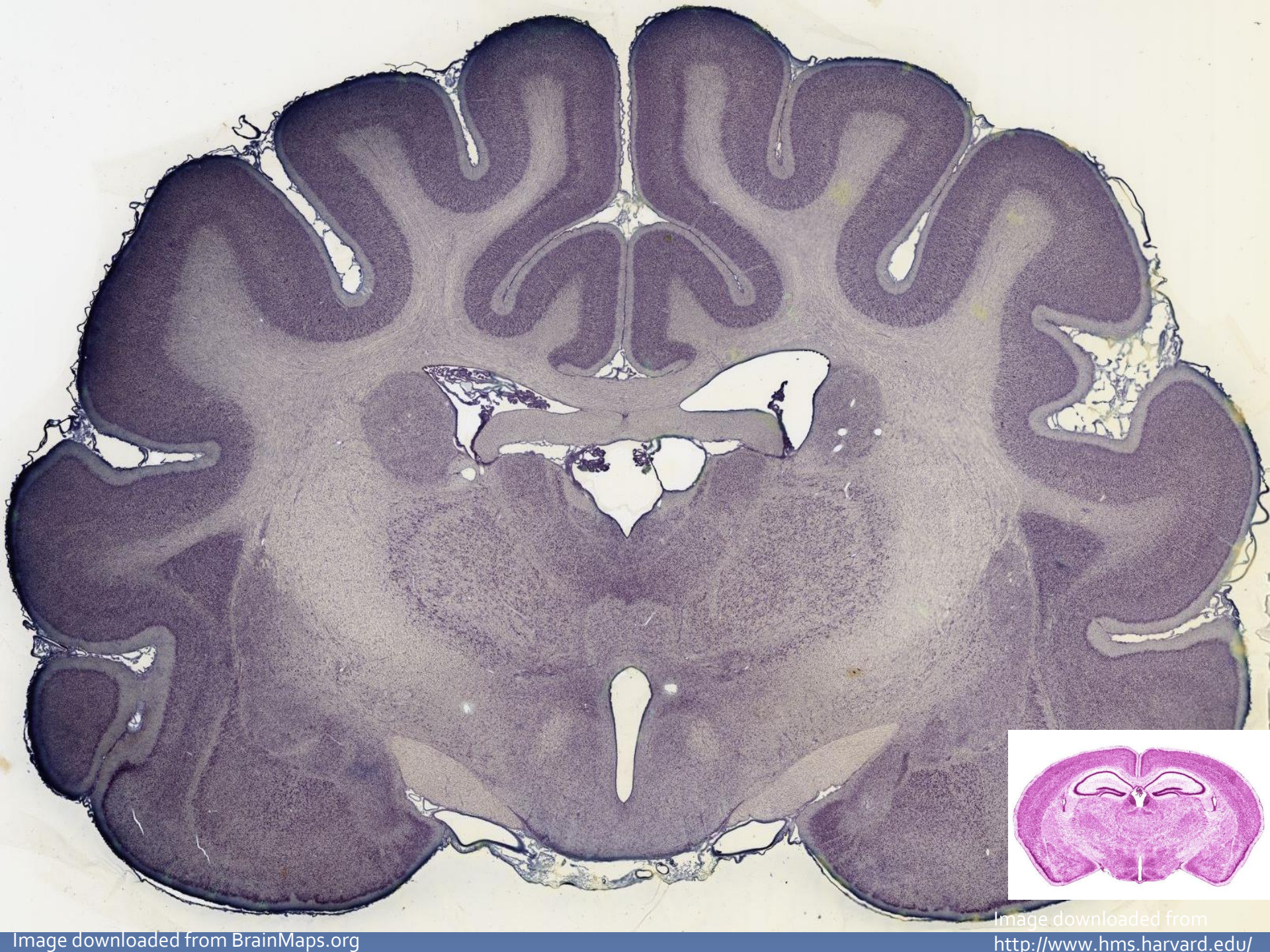
Fig. 1. Crystograph record, medium speed. *1*. Awake, 10/sec. waves marked. Modulation strong. *2*. Moderate sleep, 10/sec. waves as notches on 1/sec. ones. *3*. Deep sleep, 1/sec. waves strong (4+).

Blake H, Gerard RW. (1937) Brain potentials during sleep. *Am J Physiol 119:692-703.*

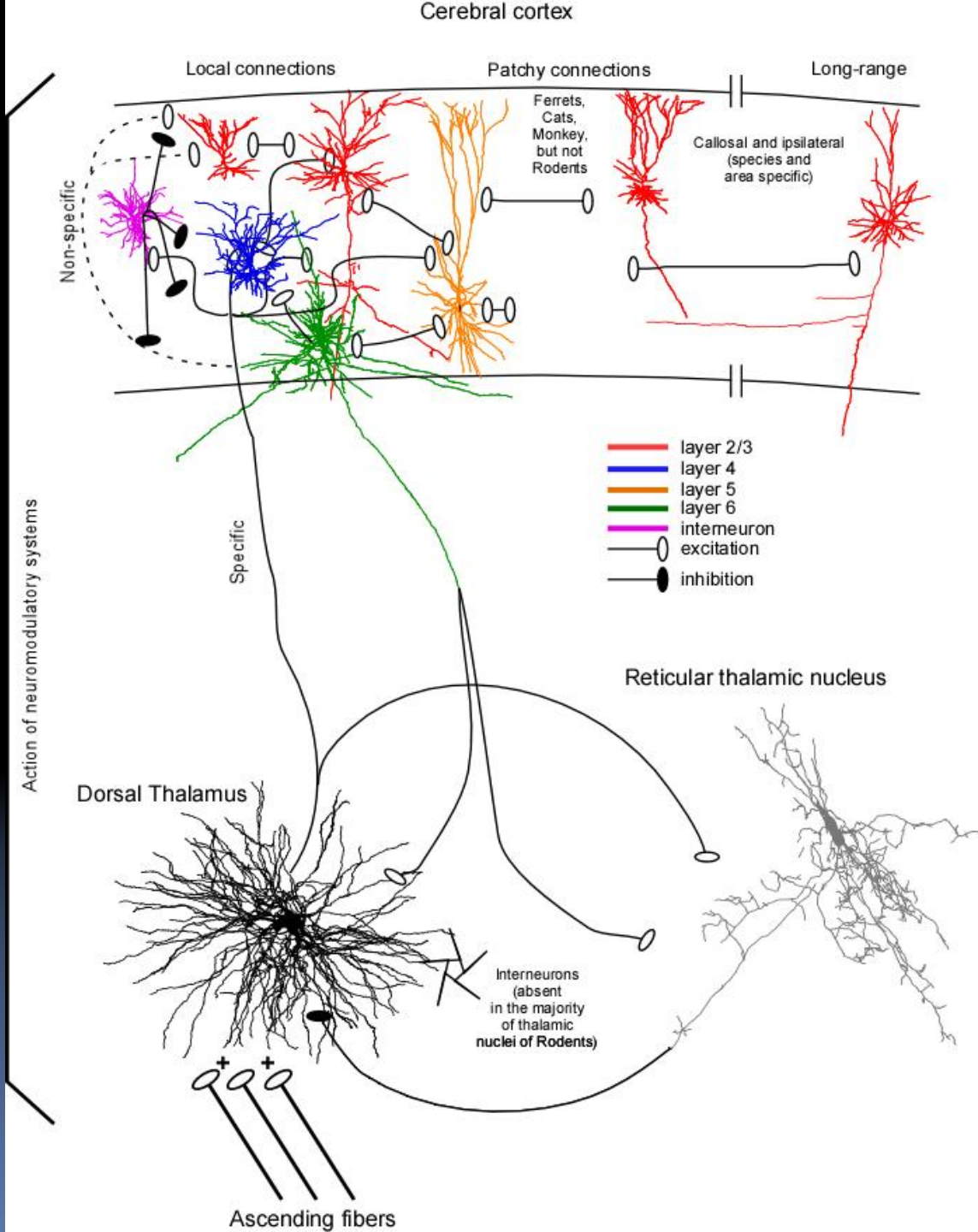
First intracellular observation of slow oscillation



Steriade M, Nuñez A, Amzica F (1993) A novel slow (<1 Hz) oscillation of neocortical neurons *in vivo : depolarizing and hyperpolarizing components. J Neurosci 13:3252-3265.*

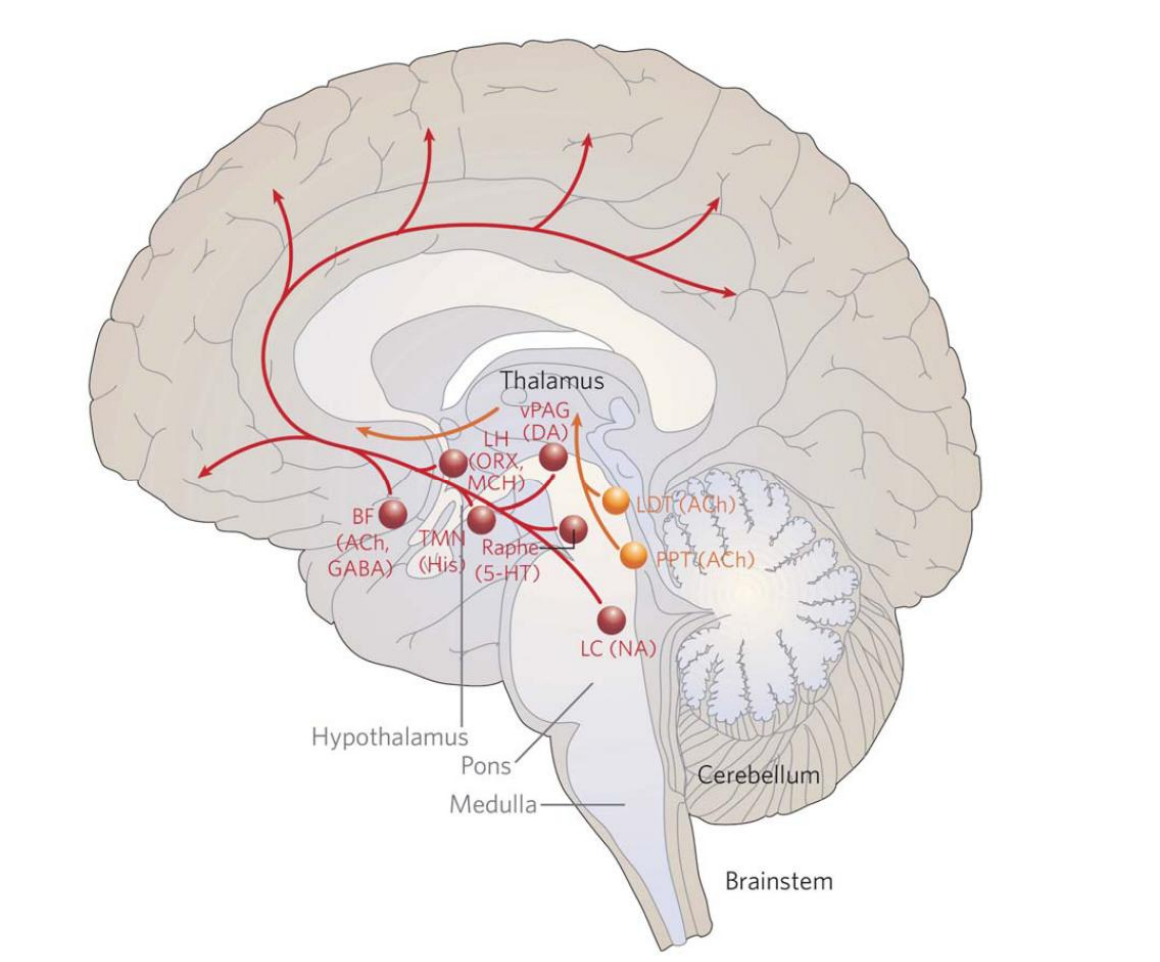


Thalamocortical system



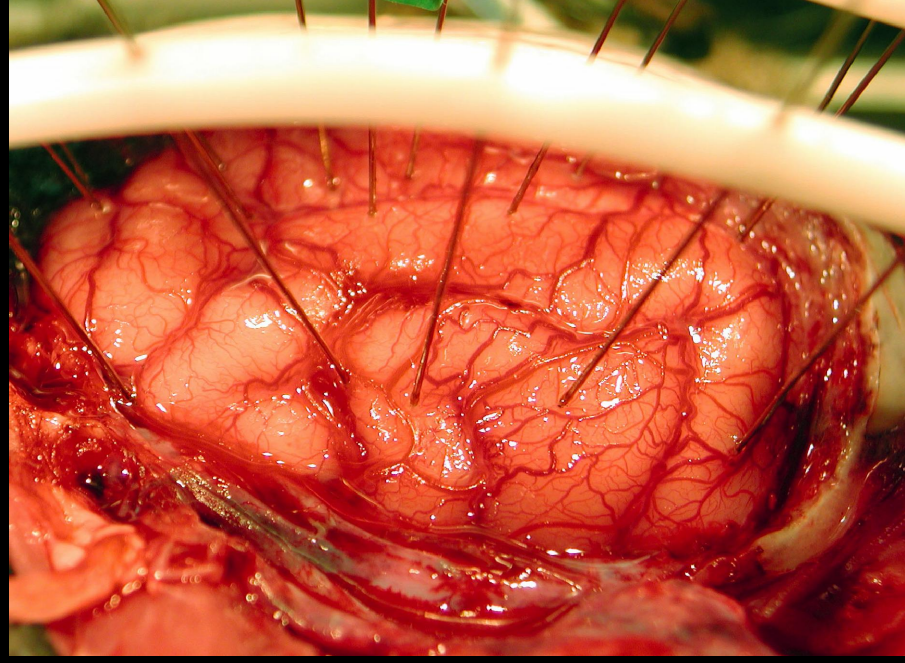
Timofeev I, Chauvette S. (2011) In: Current Topics in Medicinal Chemistry. 11, 2457-2471.

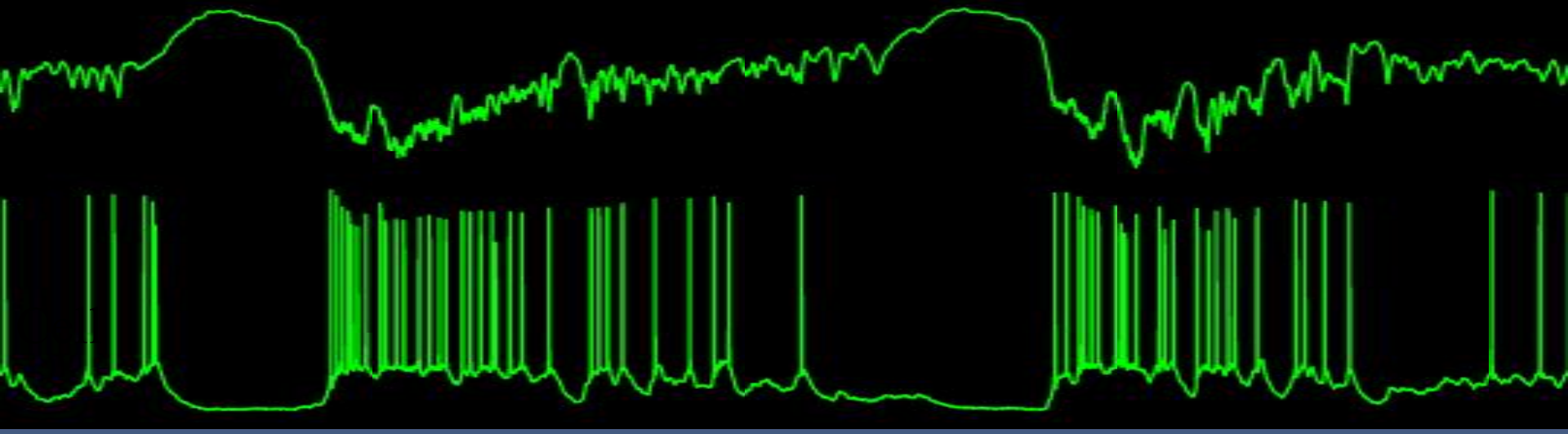
A schematic diagram of ascending arousal systems in the brain



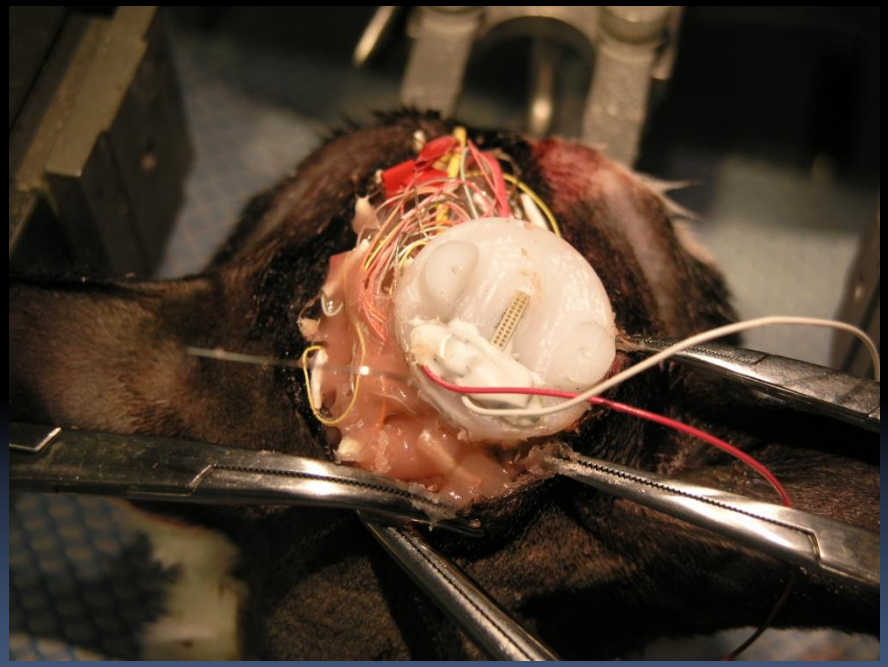
Saper CB (2006) Staying awake for dinner: hypothalamic integration of sleep, feeding, and circadian rhythms. Prog Brain Res 153:243-252.

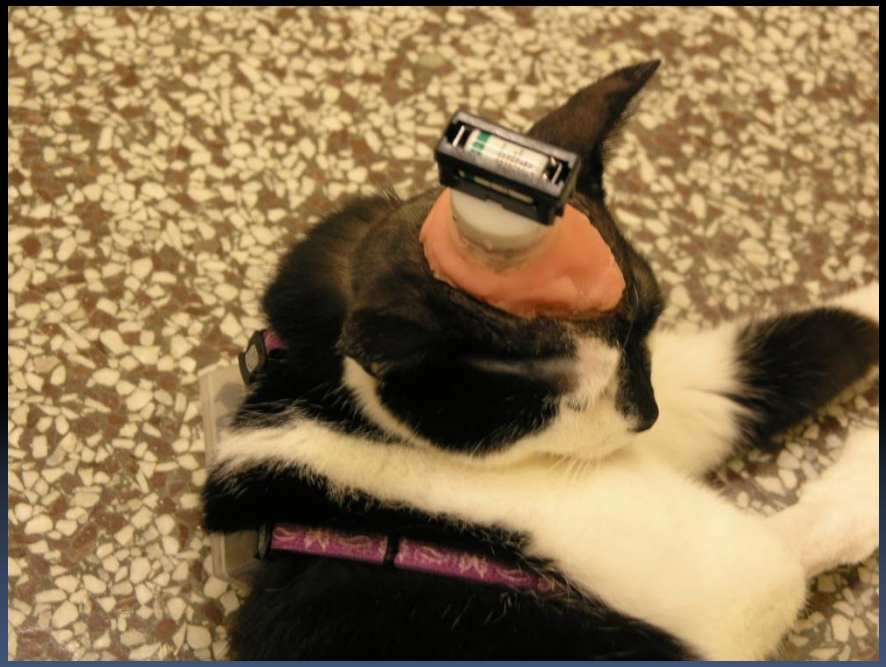
The problem



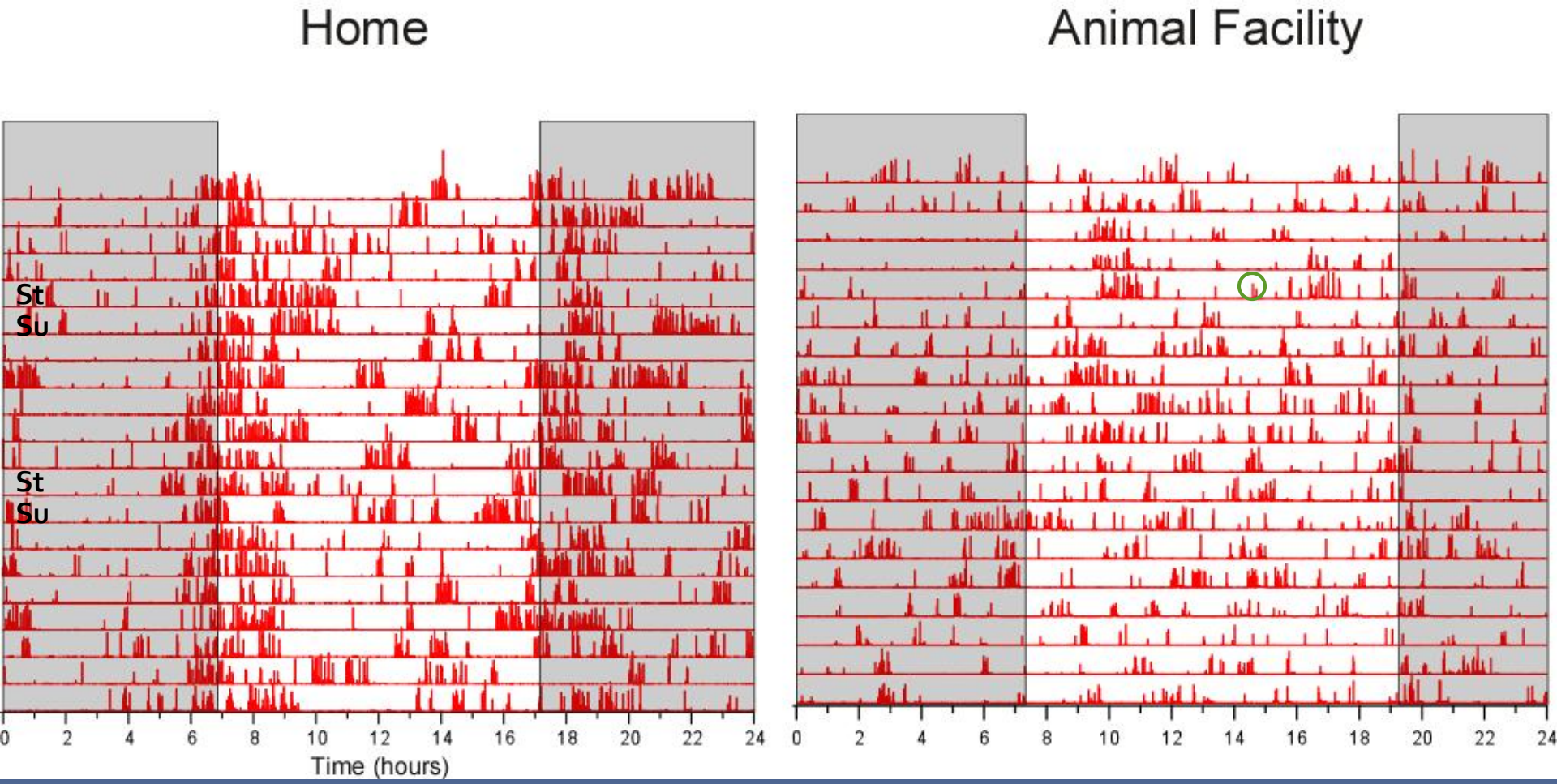


Behavioral observations



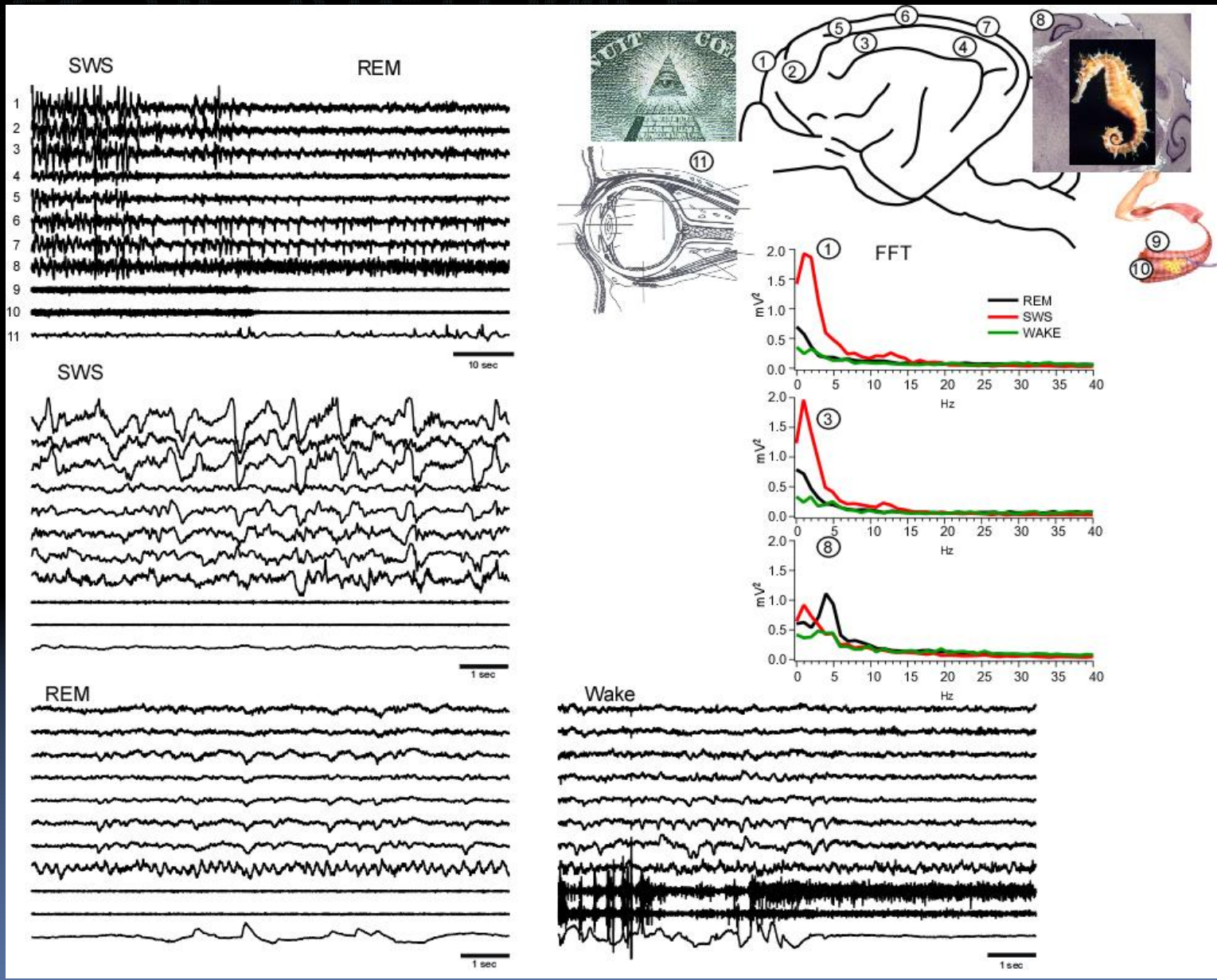


Daily activity of two cats



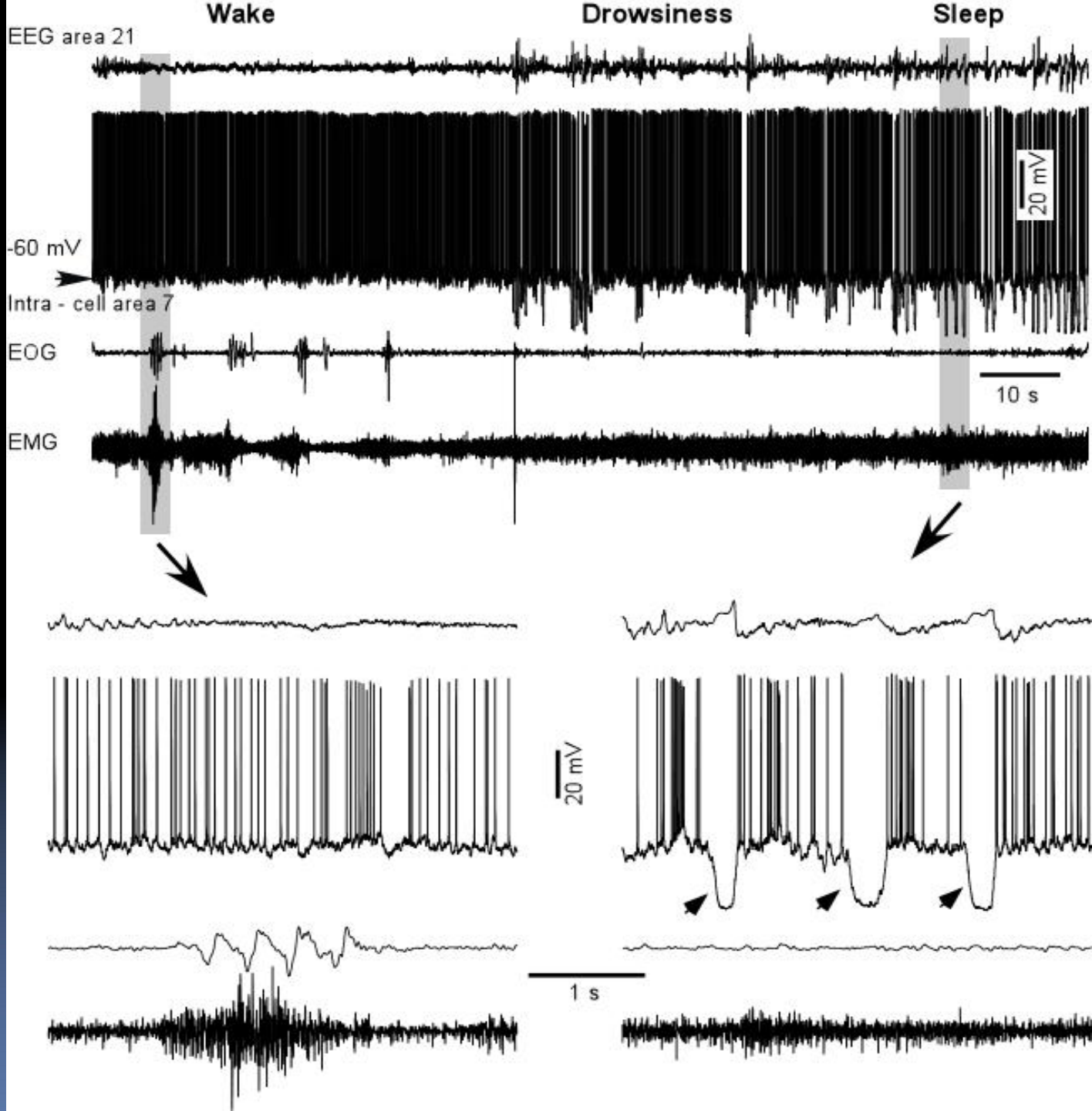
Grand, Timofeev, in preparation

STATES OF VIGILANCE



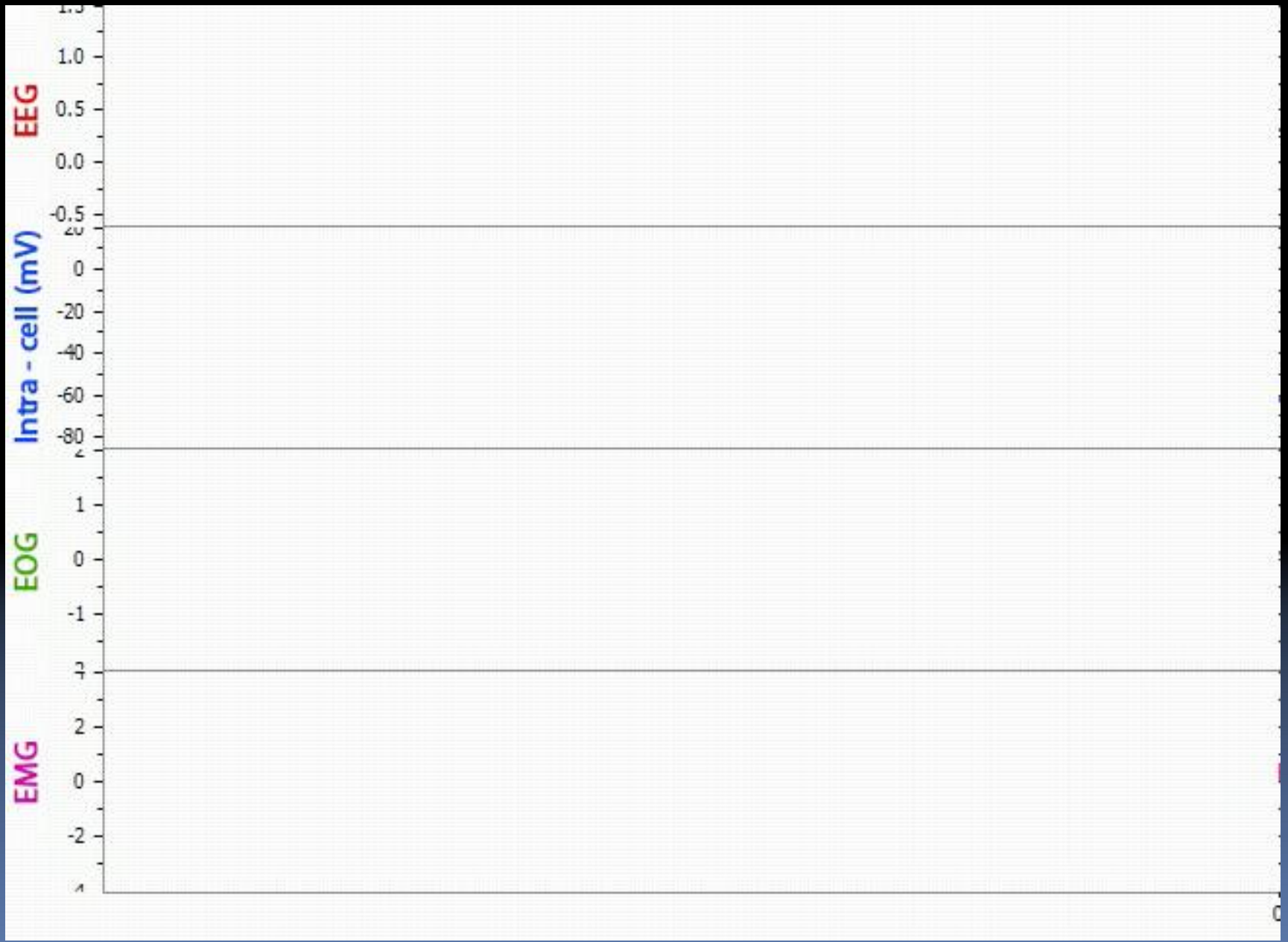
Grand, Timofeev, in preparation

Wake-sleep transition

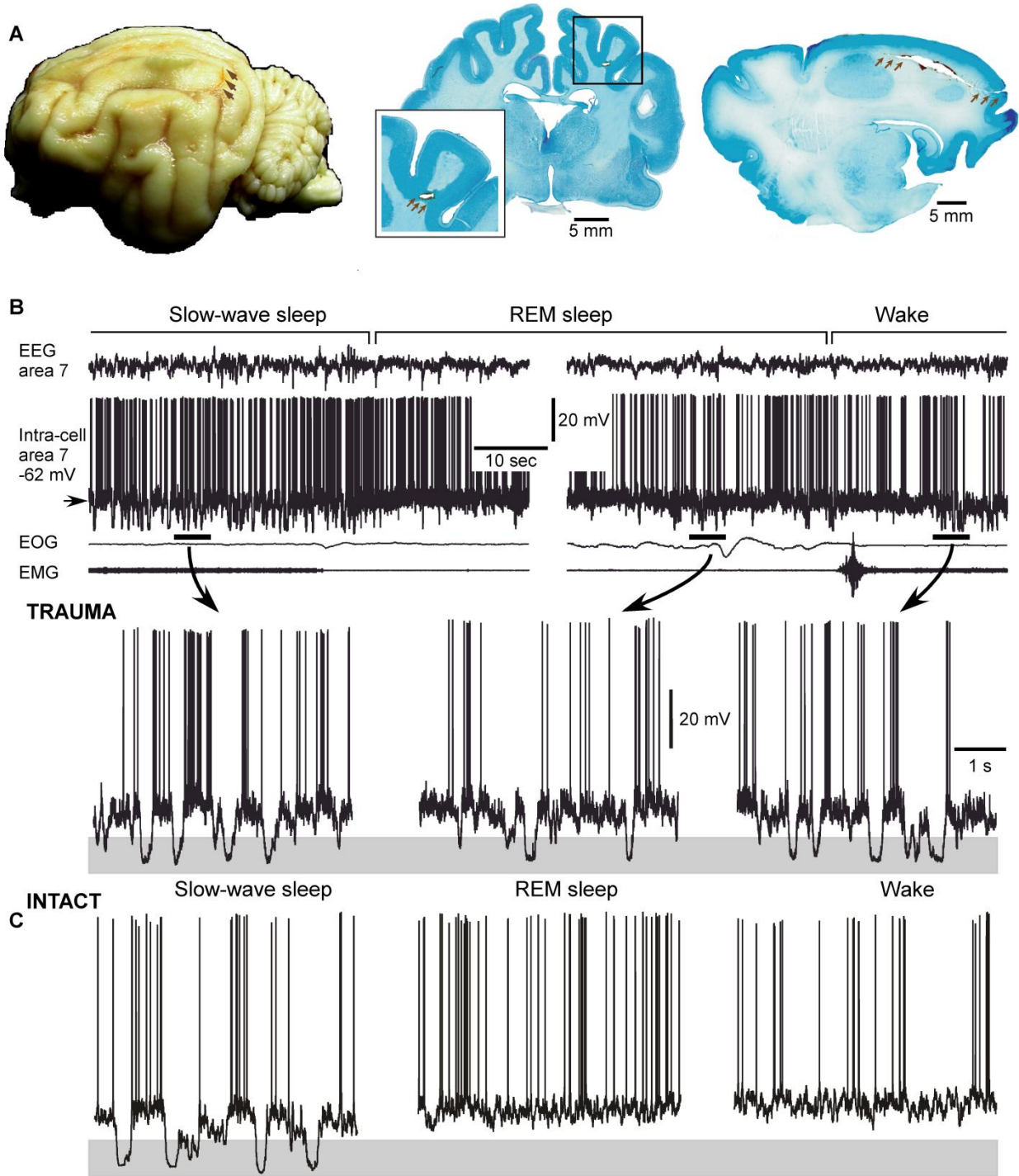


Timofeev I, Bazhenov M (2005) In: Recent Res. Devel. Physiol. (Pandalai SG, ed), pp 99-139. Kerala, India: Research Signpost.

SWS-REM-Wake intracellular

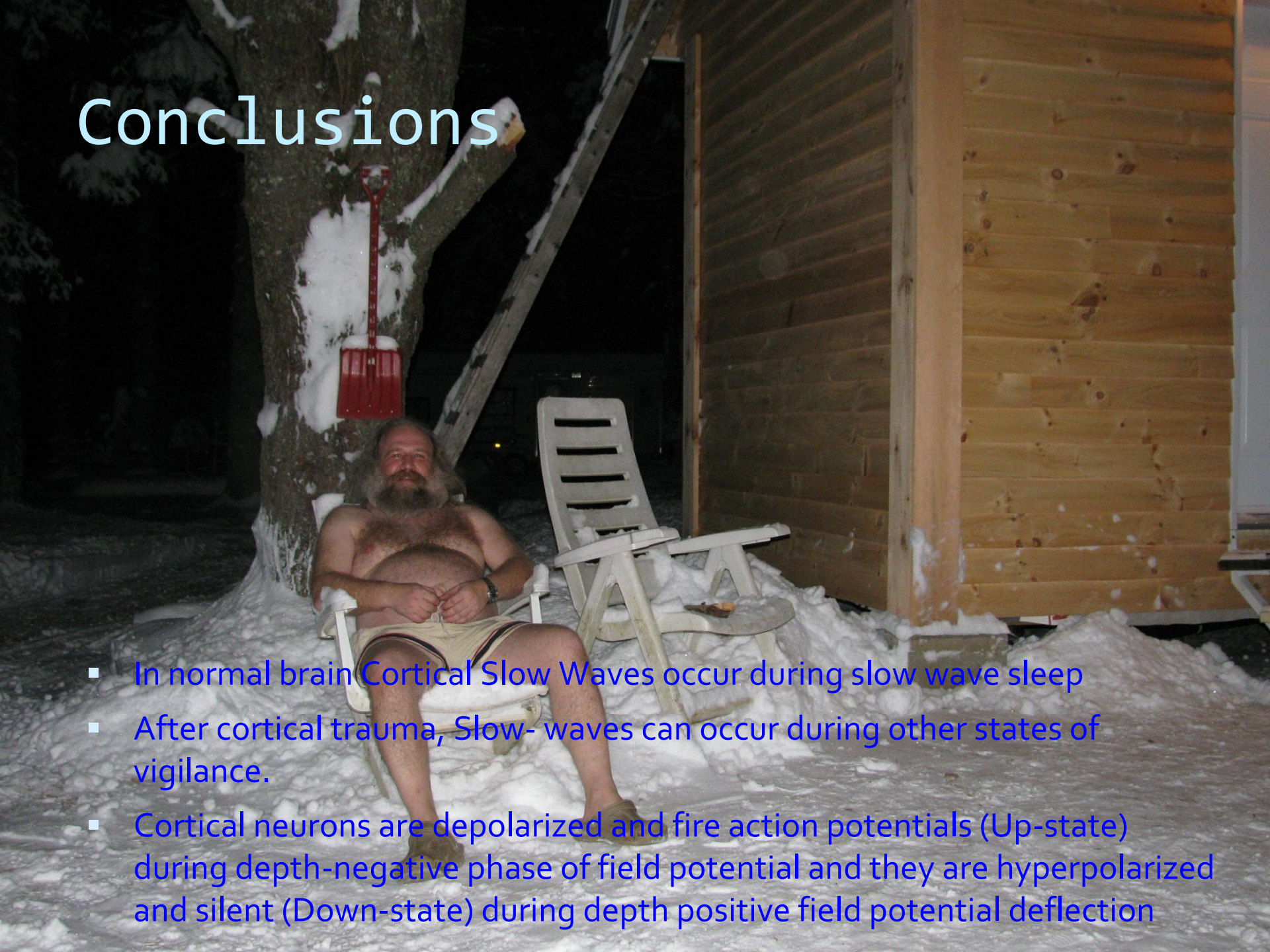


Intracellular activities in deafferented cortex



Timofeev et al, 2010, The Neuroscientist

Conclusions

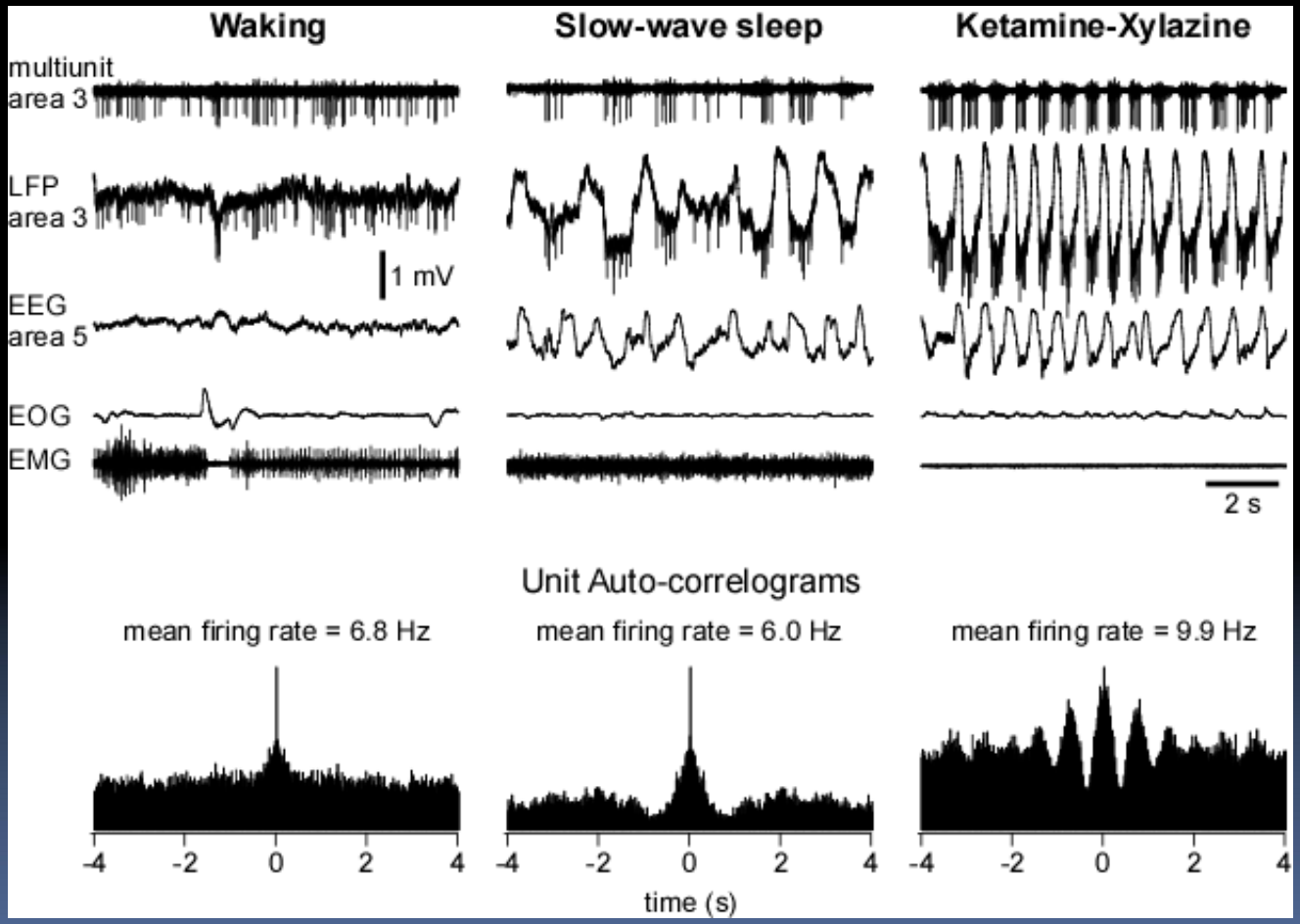


- In normal brain Cortical Slow Waves occur during slow wave sleep
- After cortical trauma, Slow- waves can occur during other states of vigilance.
- Cortical neurons are depolarized and fire action potentials (Up-state) during depth-negative phase of field potential and they are hyperpolarized and silent (Down-state) during depth positive field potential deflection

ORIGIN OF ACTIVE STATES

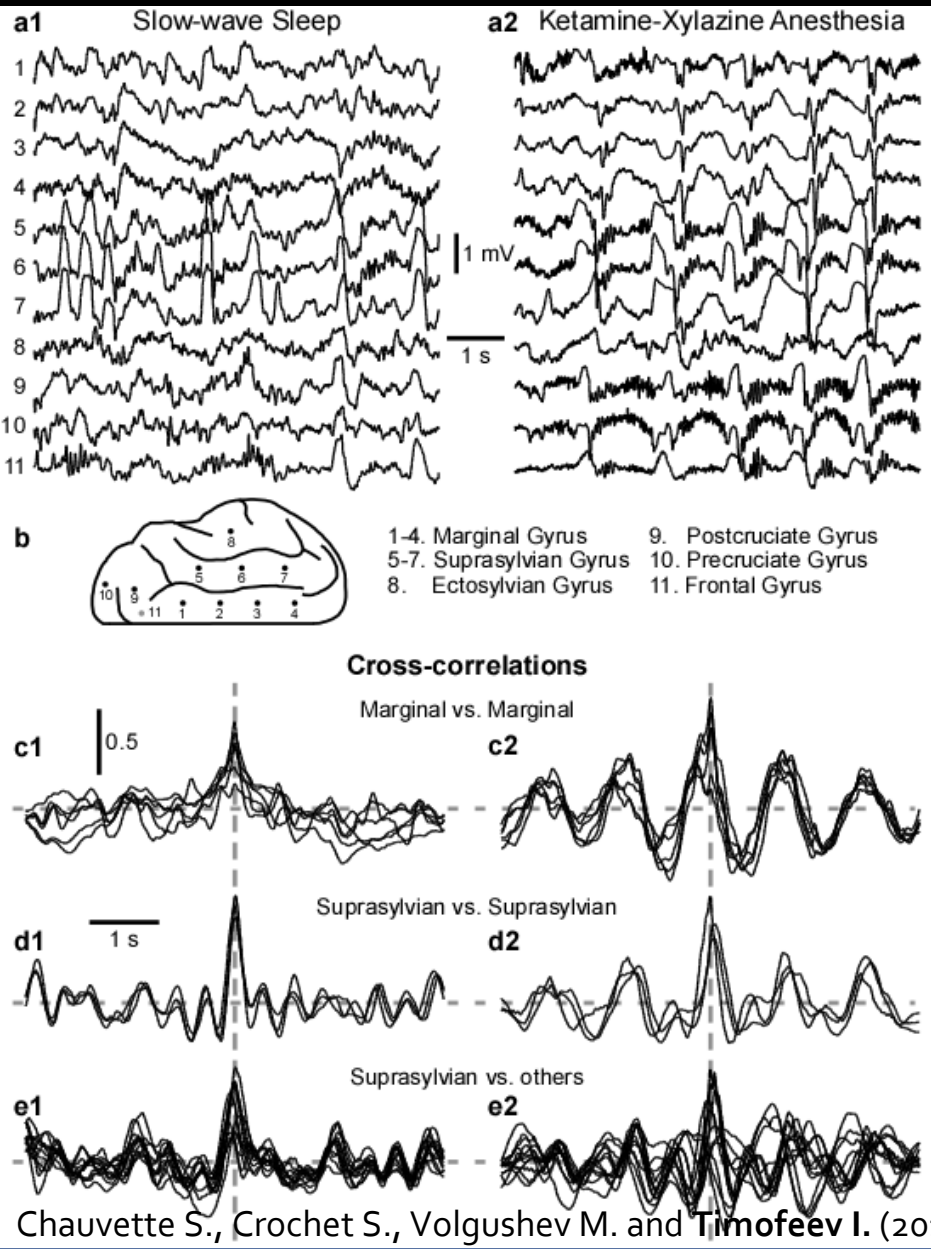
- Sleep and anesthesia
- Intracortical origin of slow waves
- Contribution of thalamus

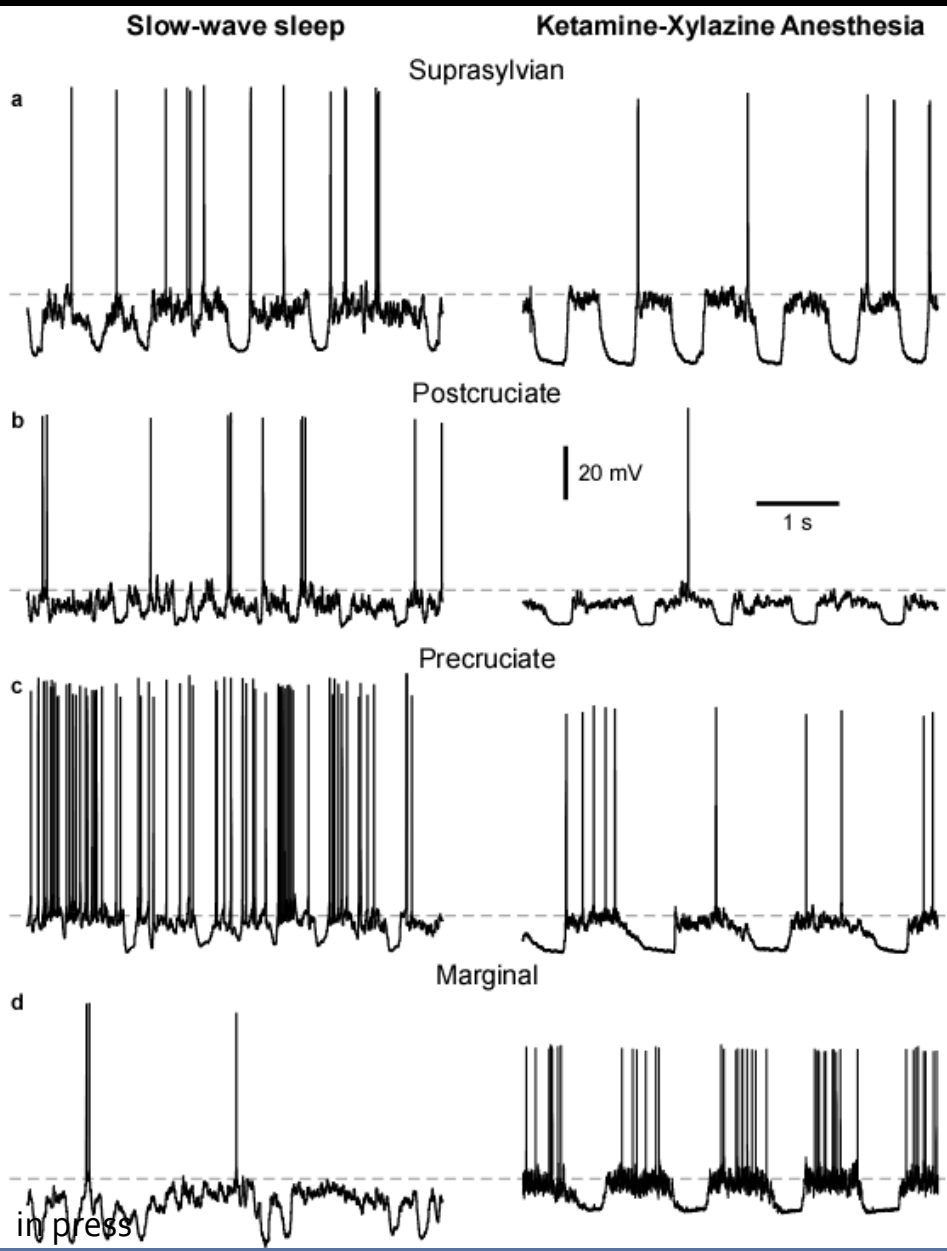
Single cell firing during wake, slow-wave sleep and anesthesia



Chauvette S., Crochet S., Volgushev M. and **Timofeev I.** (2011) in press

Qualitative differences of electrographic activities of ketamine-xylazine anesthesia with slow-wave sleep





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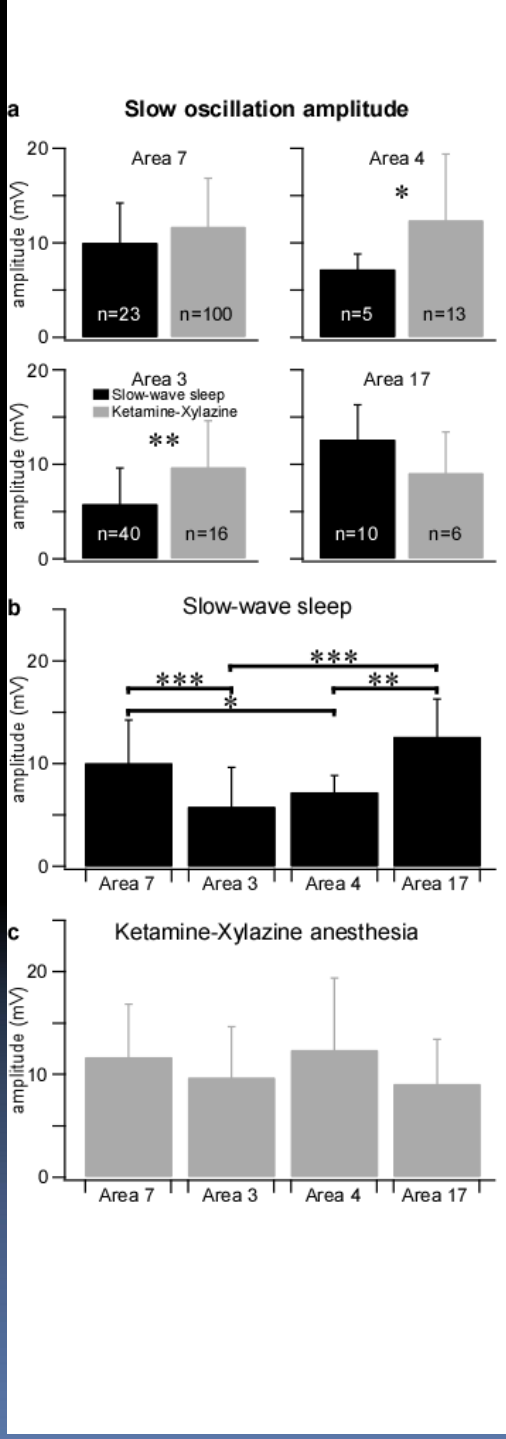
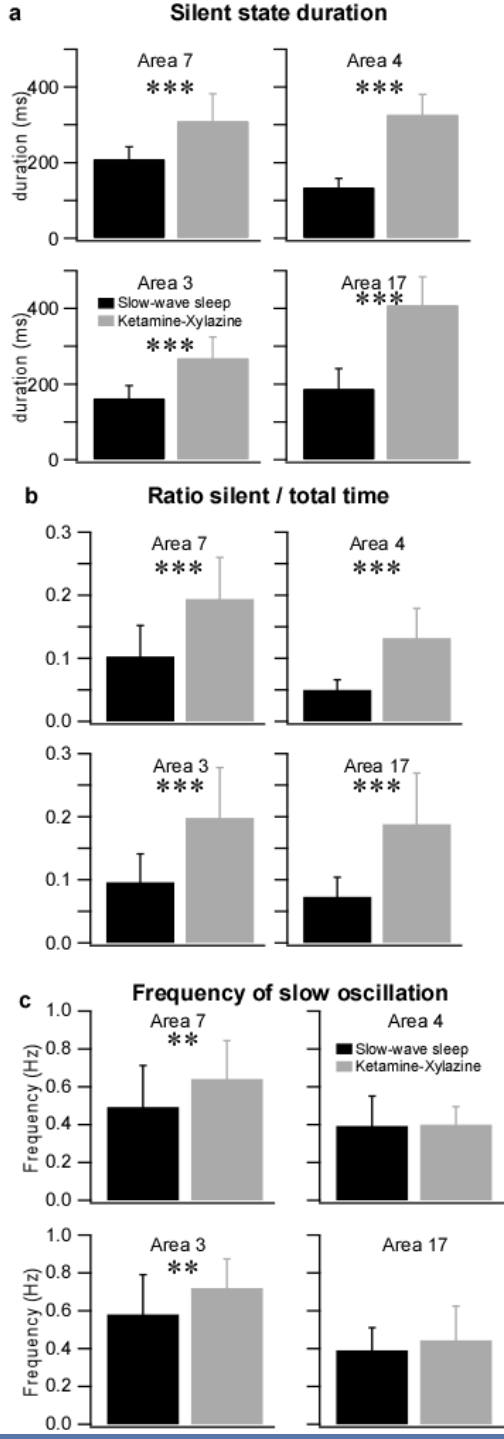
Quantitative differences of electrographic activities of ketamine-xylazine anesthesia with slow-wave sleep

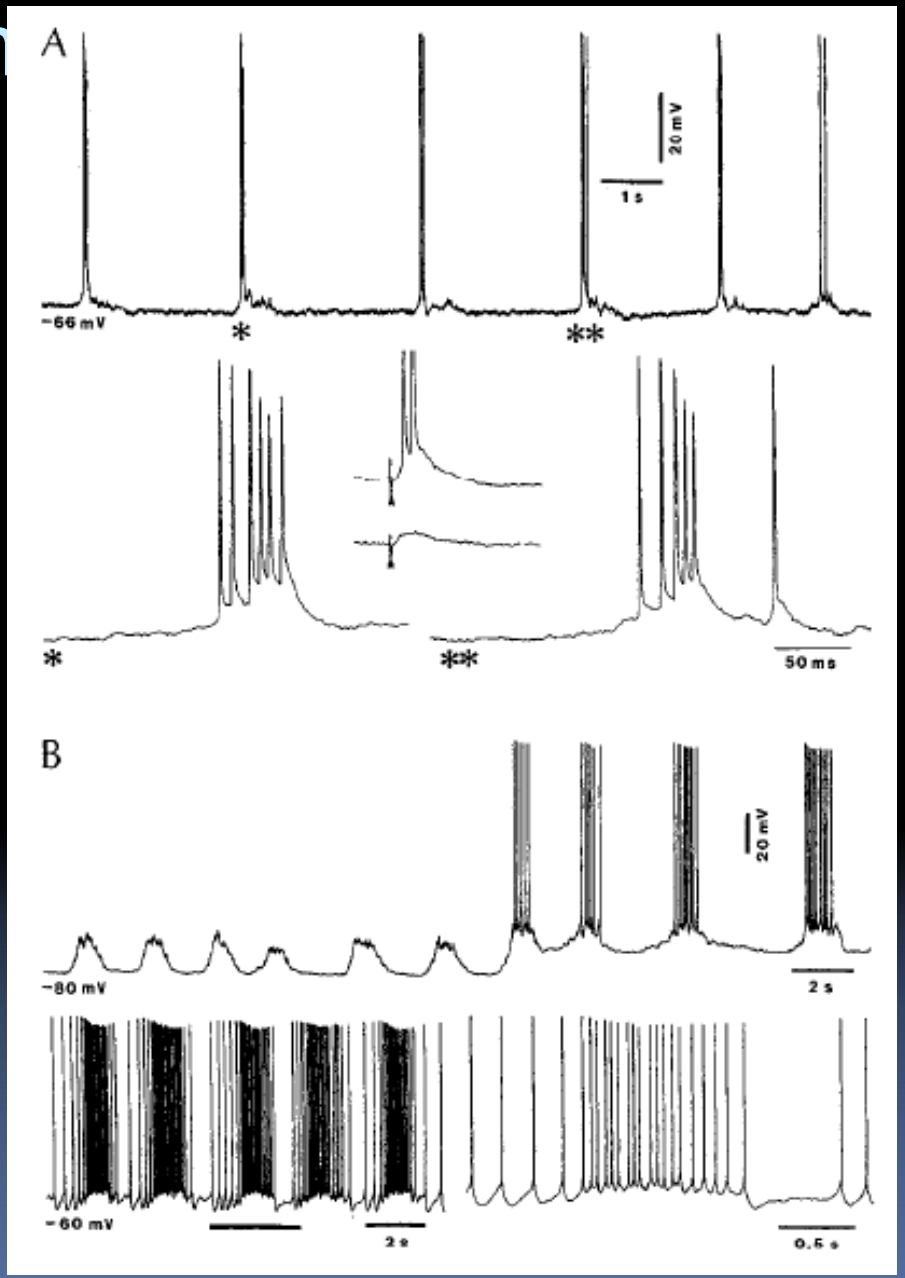




Chauvette S., Crochet S., Volgushev M. and **Timofeev I.** (2011) In press


Where?

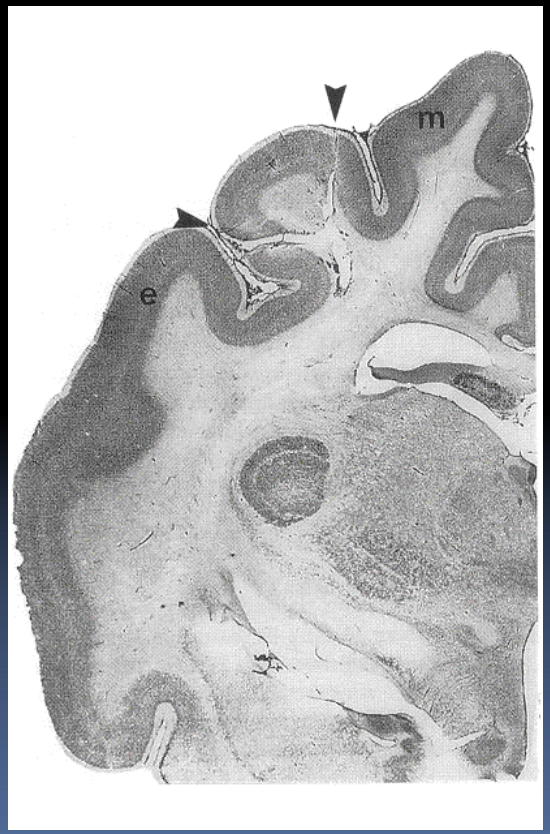
Slow oscillation after extensive lesions of thalamic inputs



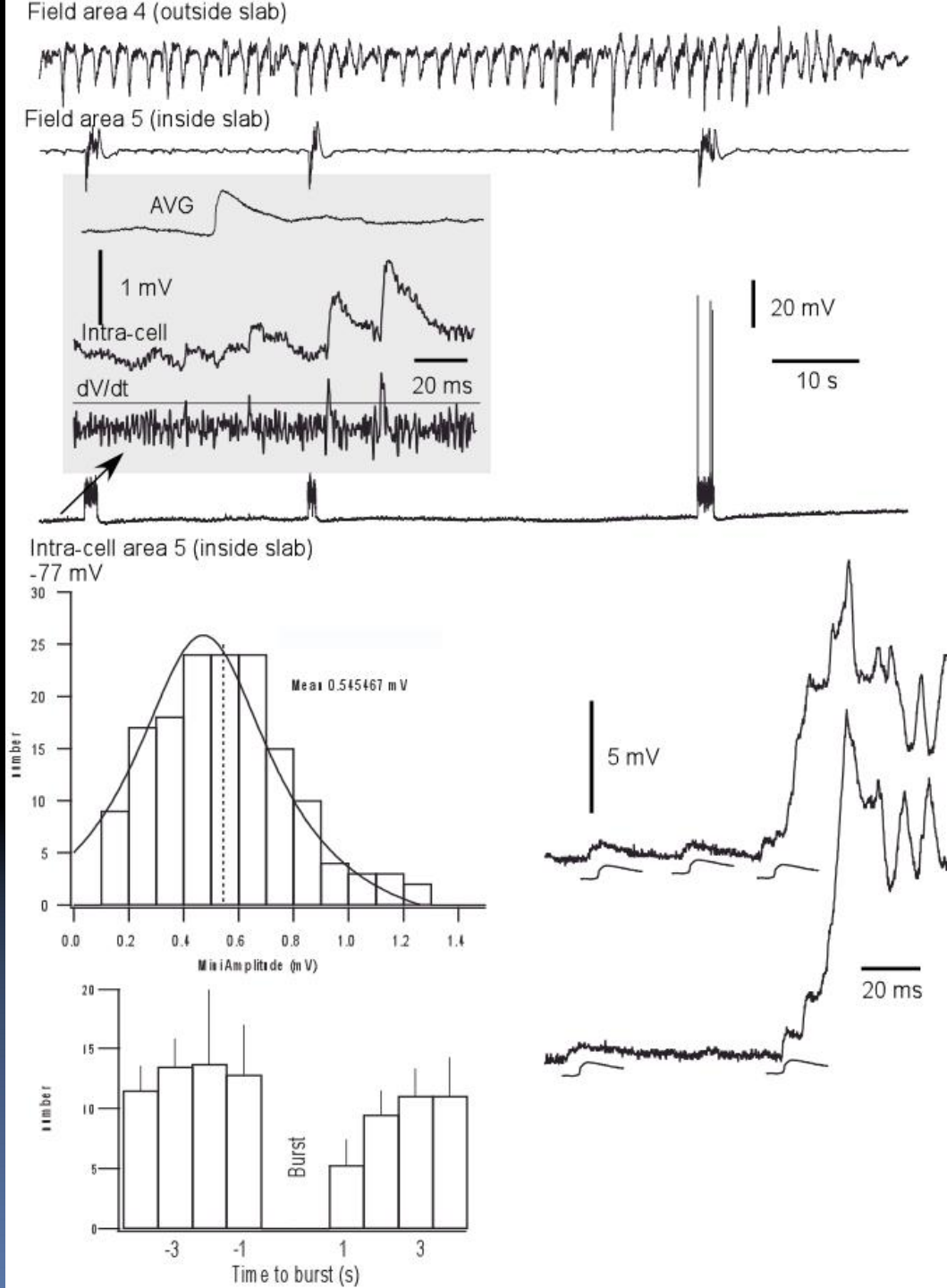
Steriade M, Nuñez A, Amzica F (1993) Intracellular analysis of relations between the slow (<1 Hz) neocortical oscillations and other sleep rhythms of electroencephalogram. J Neurosci 13:3266-3283.

Neocortical Slab

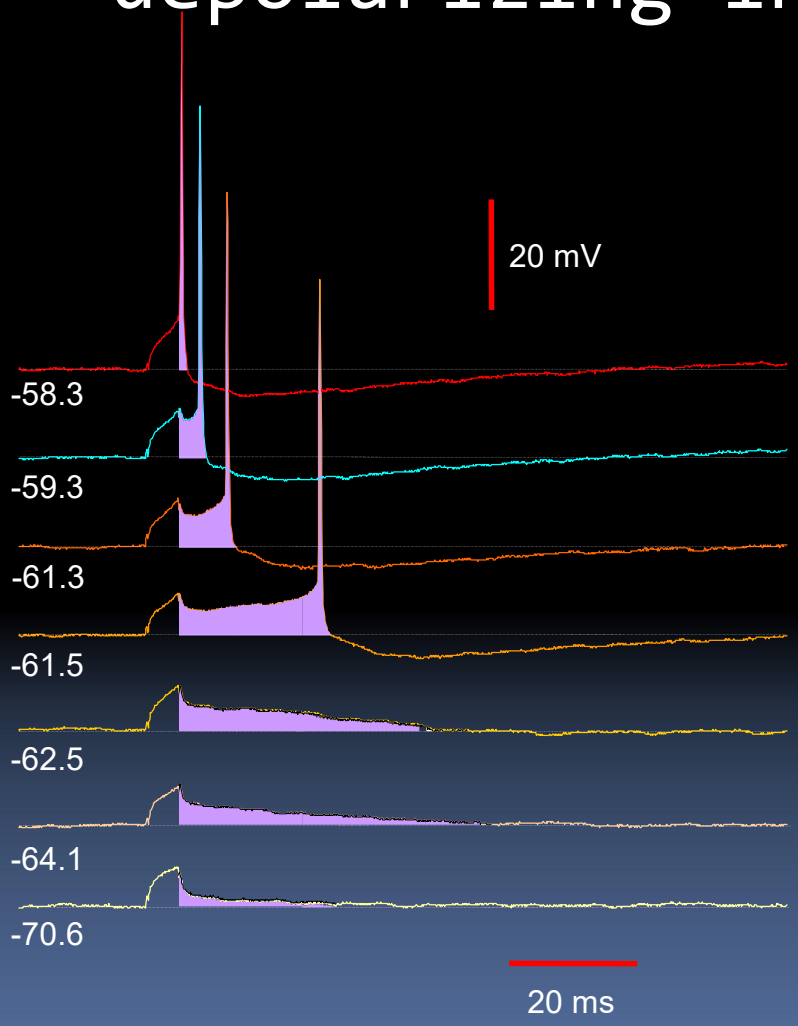
Slab: Intracellular Patterns

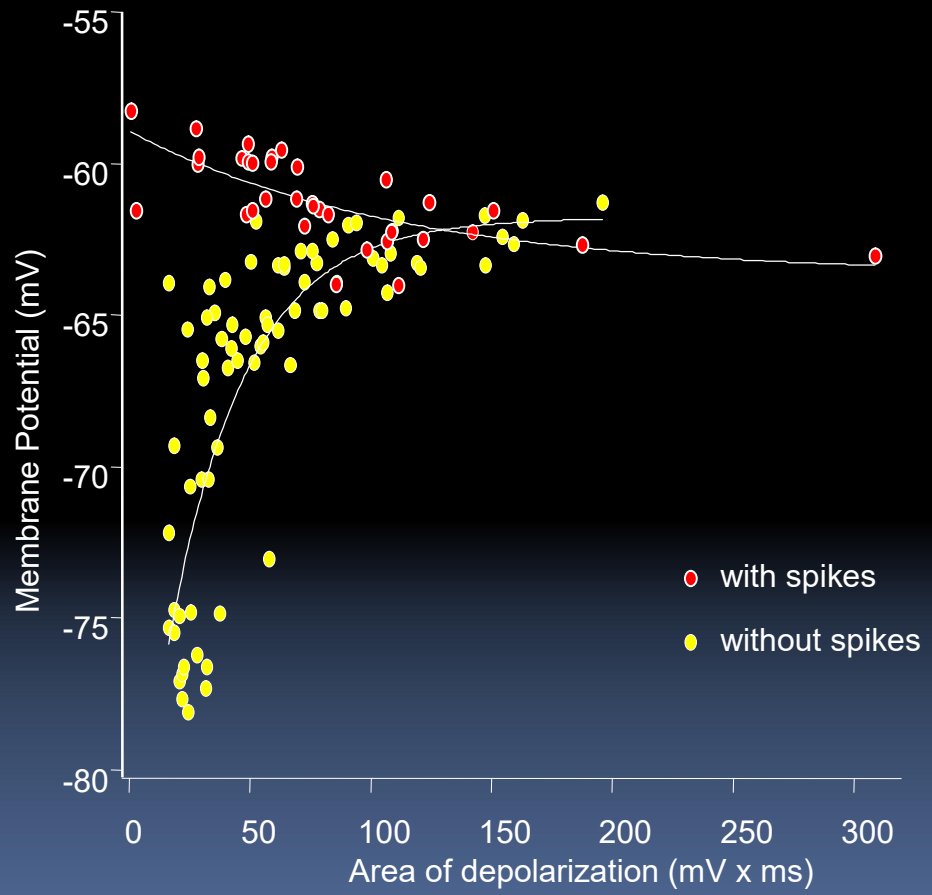


Modified from Timofeev I, et al (2000) Cereb Cortex 10:1185-1199.



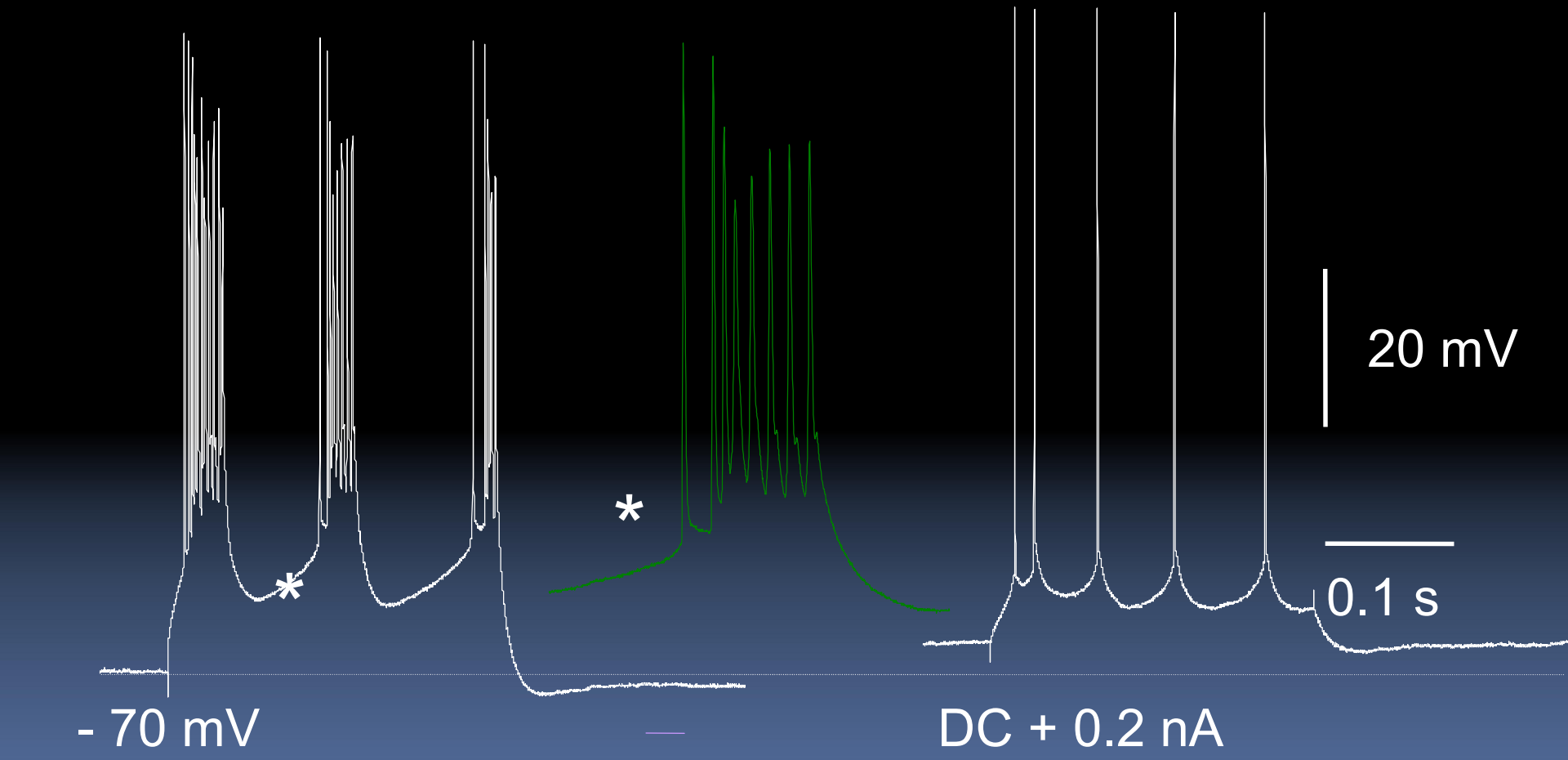
Nonlinear amplification of small depolarizing inputs *in vivo*





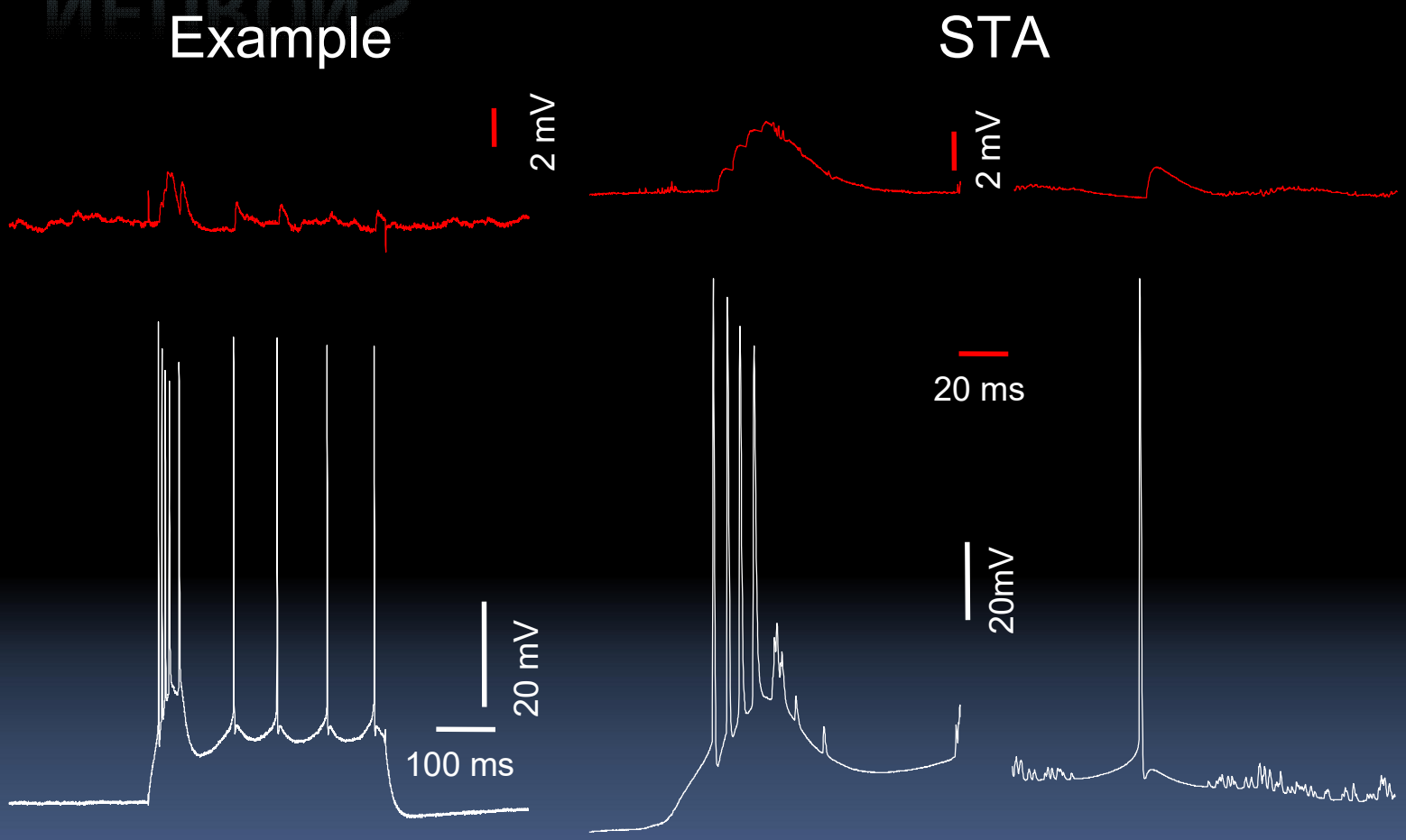
Timofeev I, Grenier F, Bazhenov M, Sejnowski TJ, Steriade M (2000) Cereb Cortex 10:1185-1199.

Intrinsically-Bursting Neuron

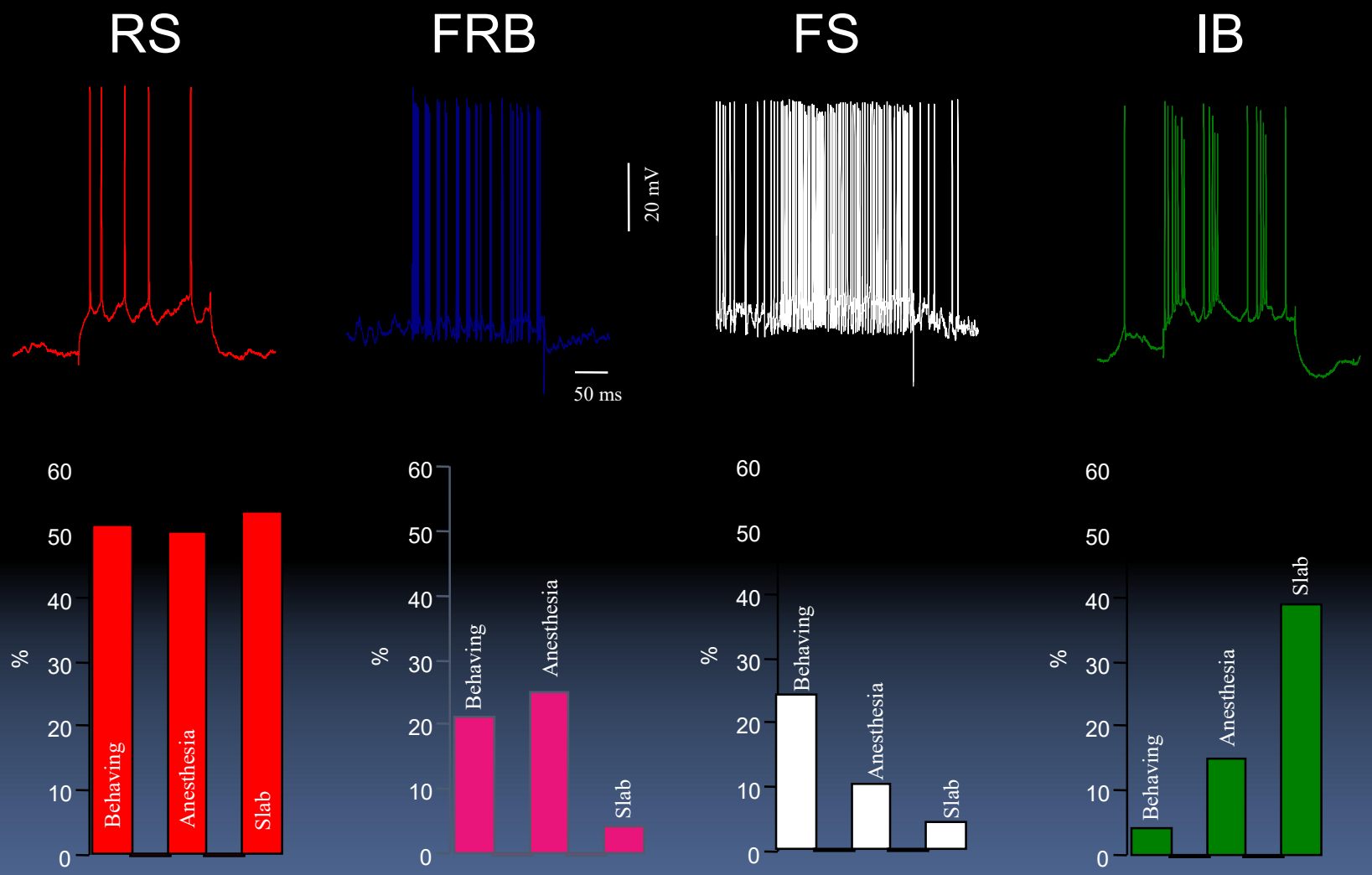


Timofeev I, Grenier F, Bazhenov M, Sejnowski TJ, Steriade M (2000) Cereb Cortex 10:1185-1199.

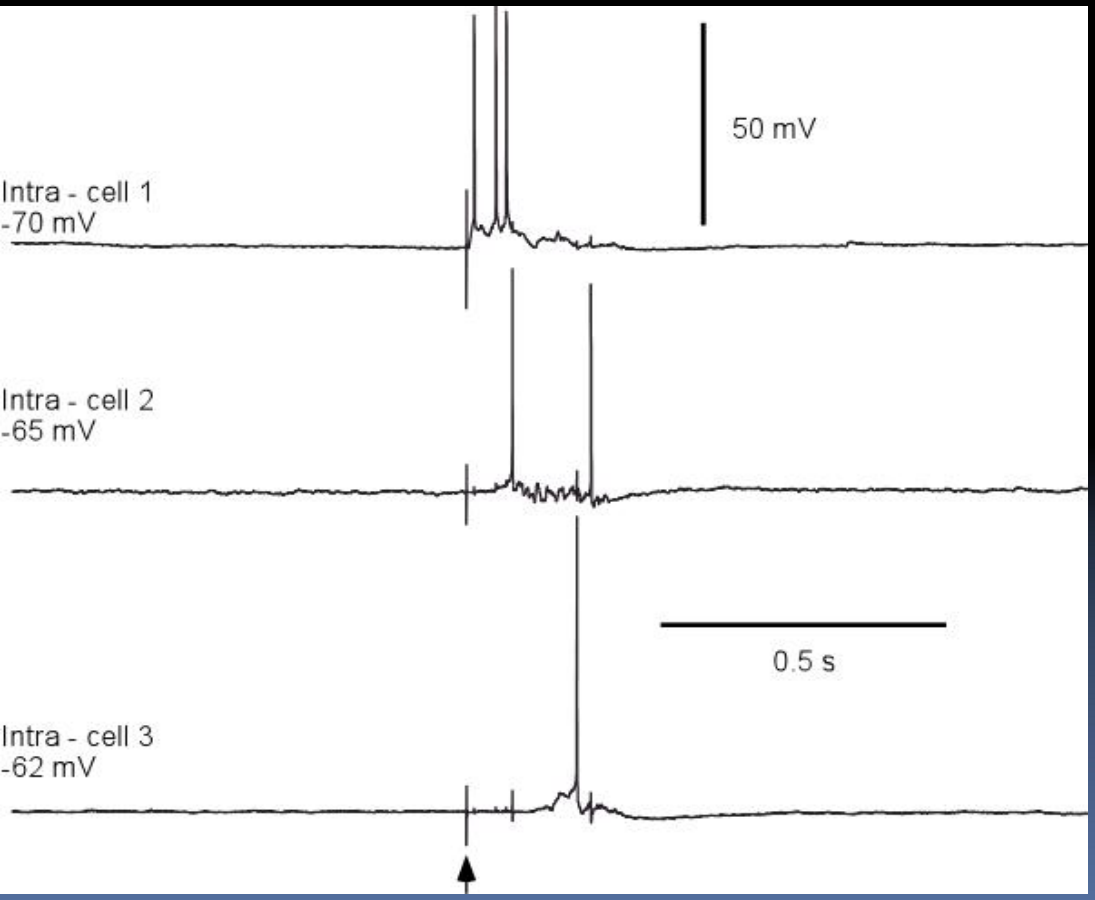
POSTSYNAPTIC IMPACT OF IB NEURONS

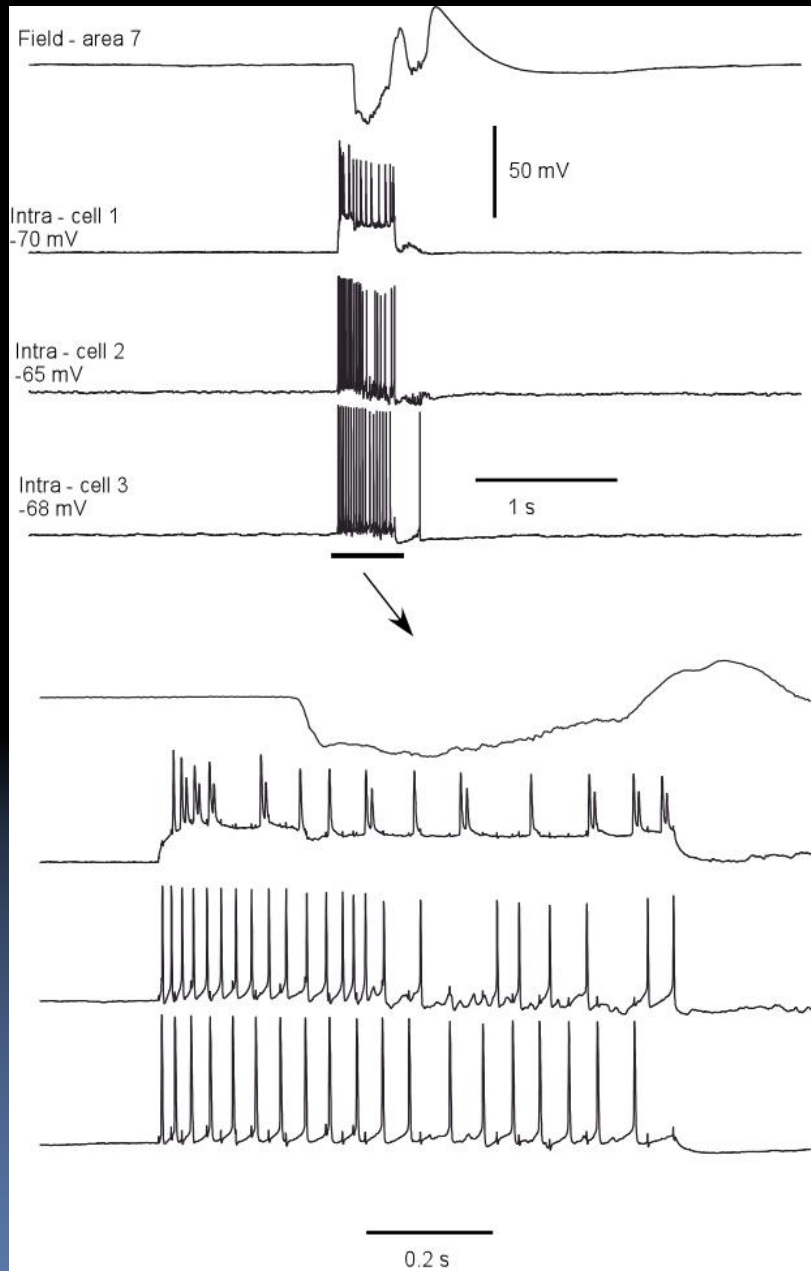


Intrinsic firing patterns



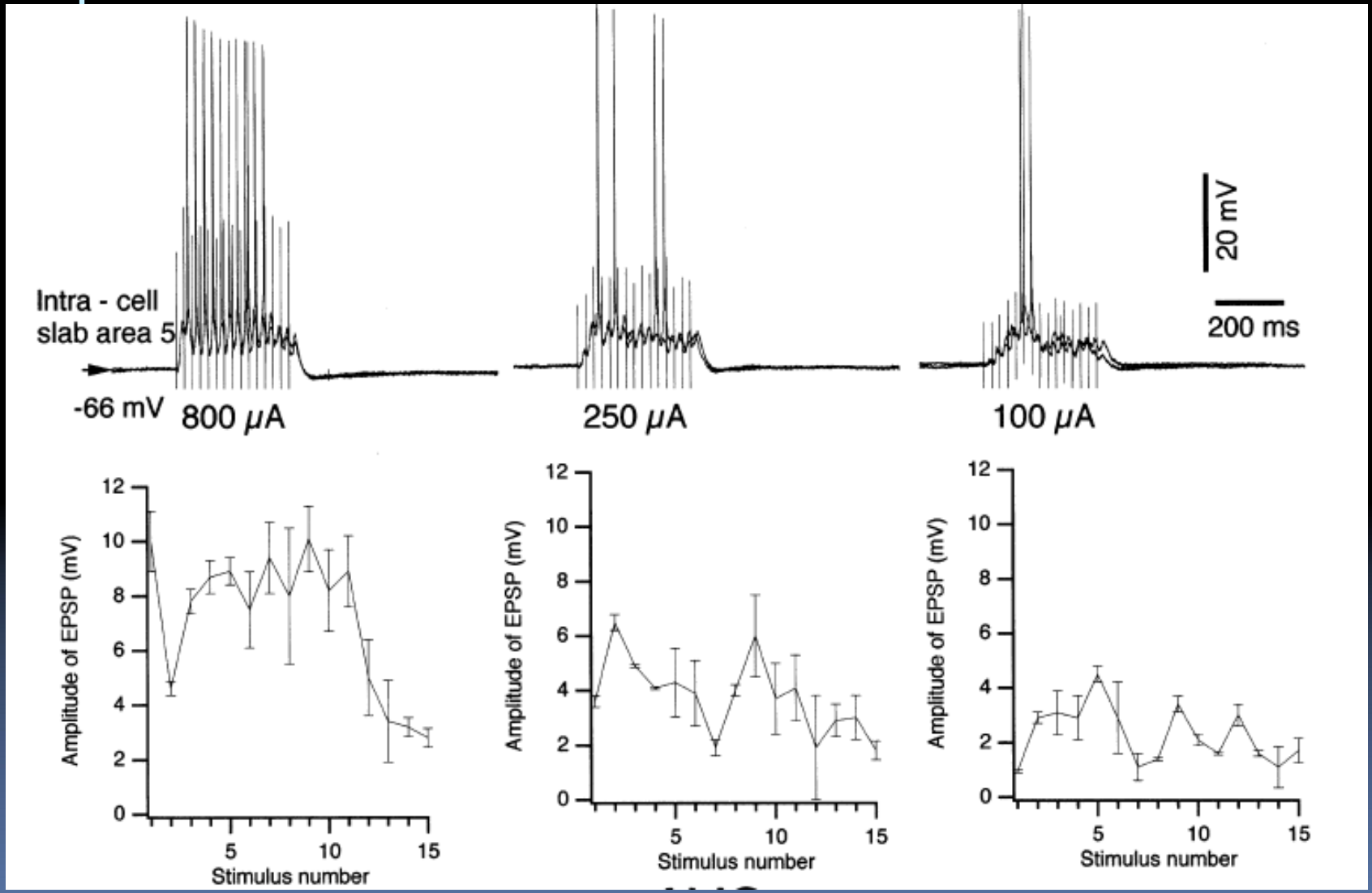
Low intensity stimuli drive active states



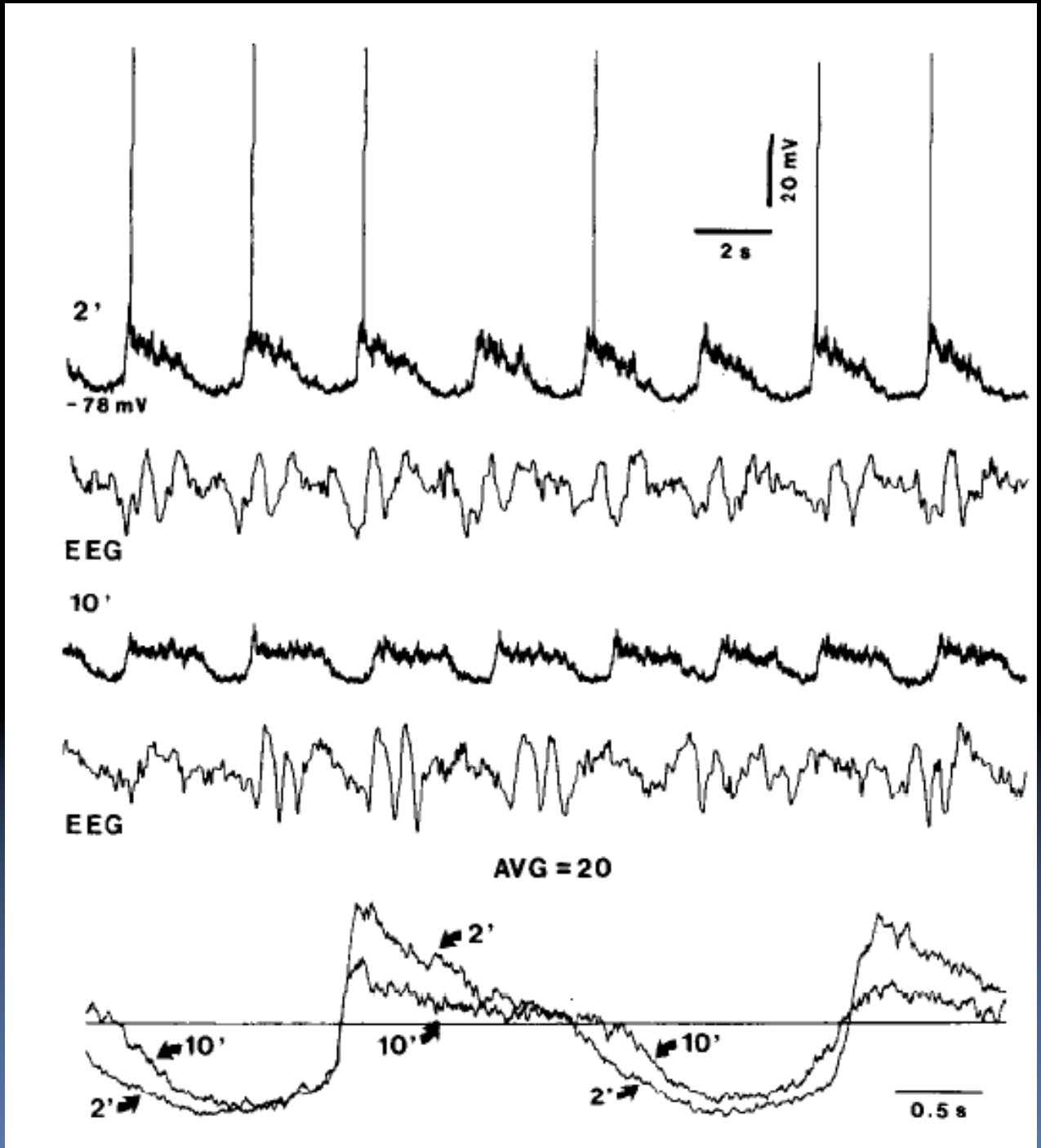


Timofeev Unpublished

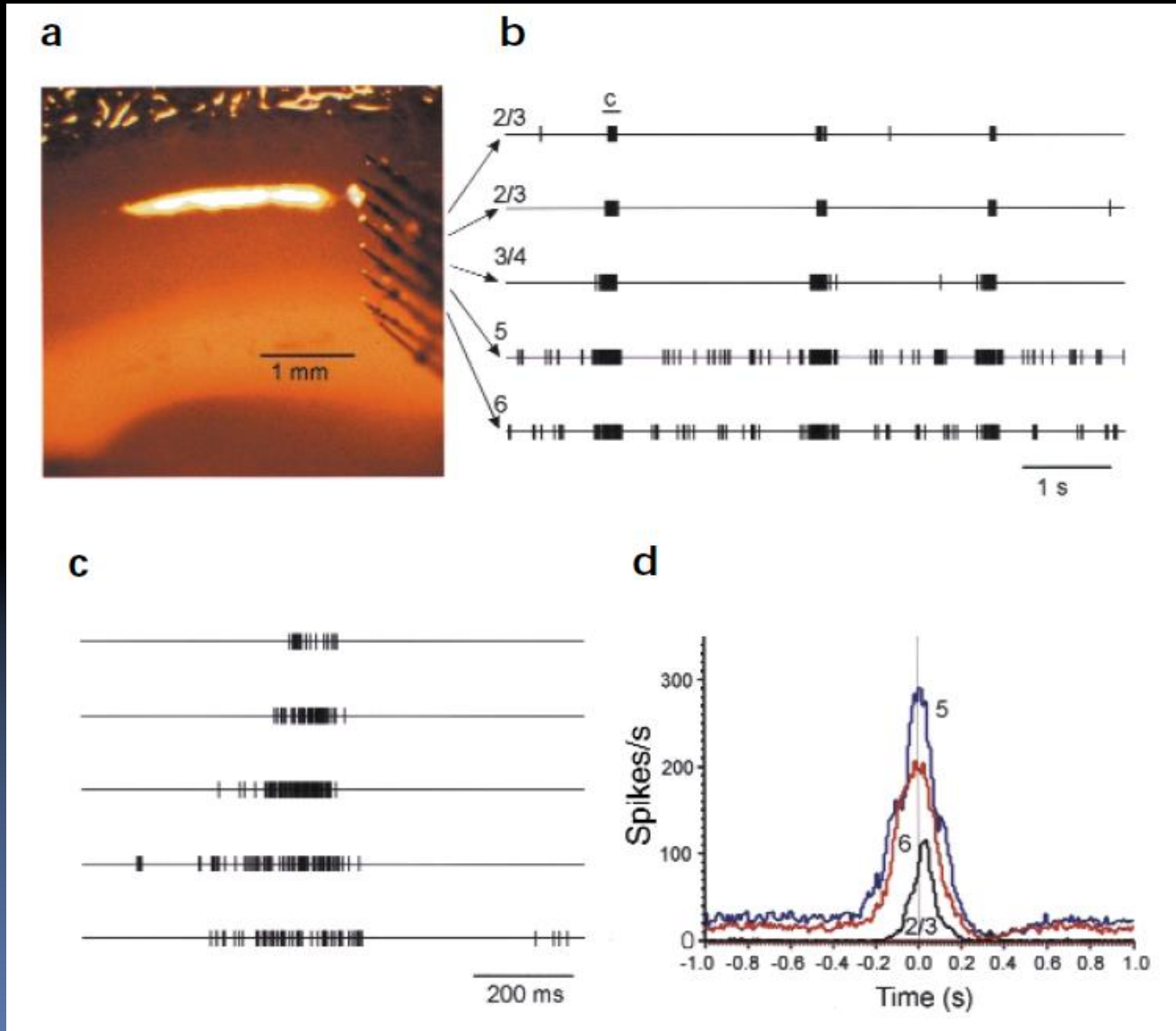
Termination of active states: synaptic depression?



Termination of active states: Active inhibition?

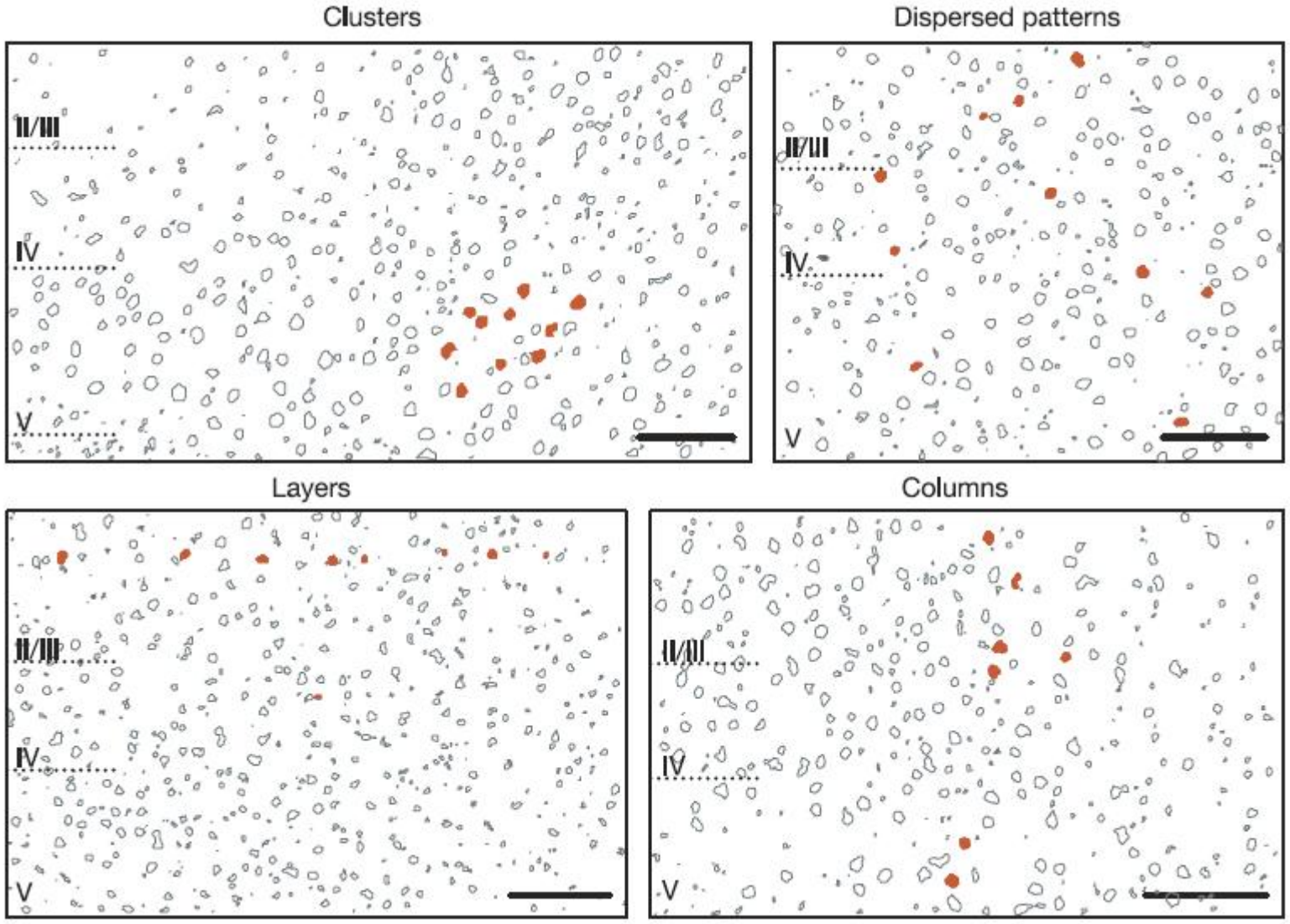


Slow oscillation in vitro



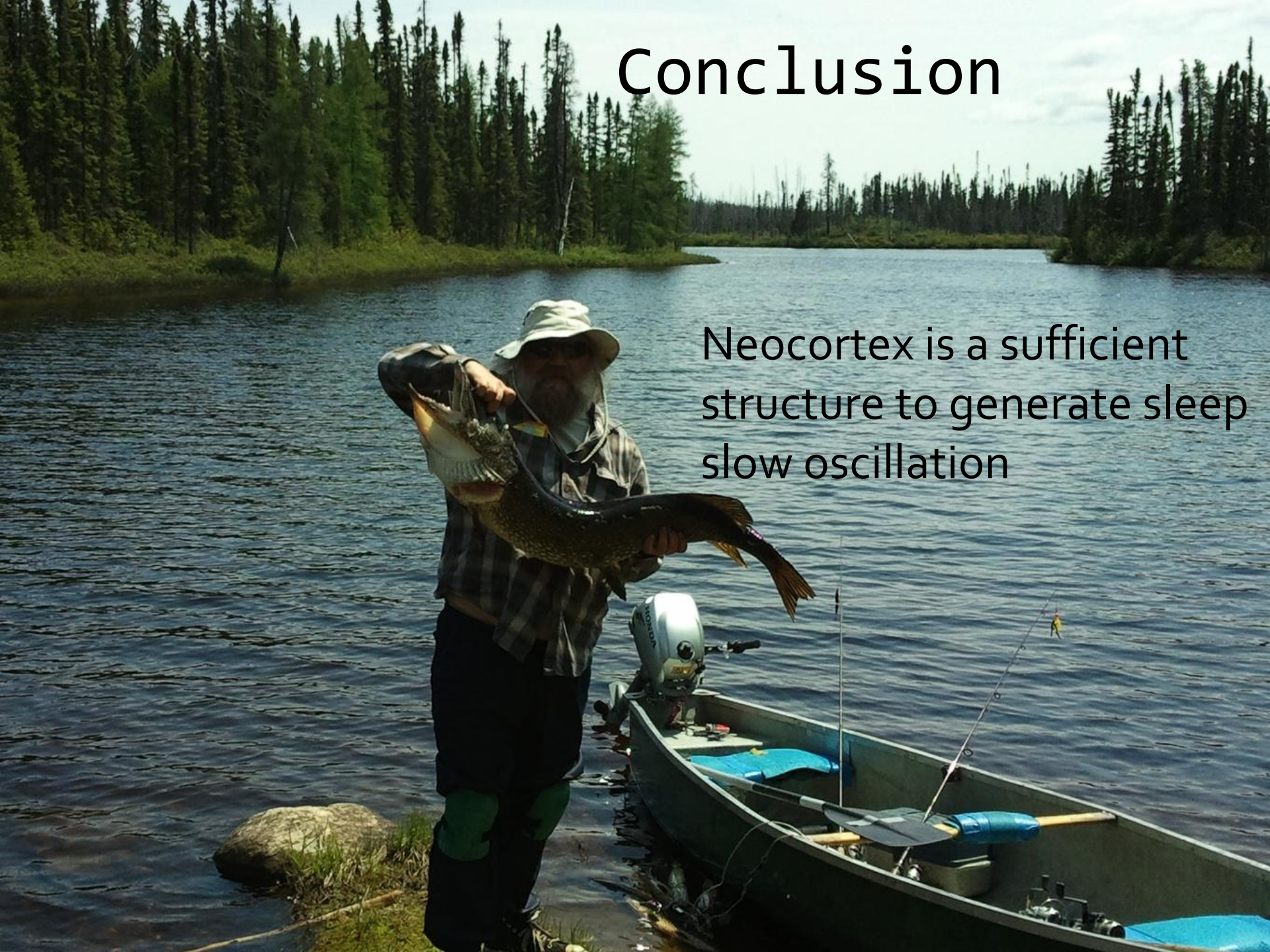
Sanchez-Vives MV, McCormick DA
Nat Neurosci 2000;3: p. 1027-34.

Spars activation of active states in vitro



Cossart R, Aronov D, Yuste R *Nature 2003;423: p. 283-8.*

Conclusion



Neocortex is a sufficient structure to generate sleep slow oscillation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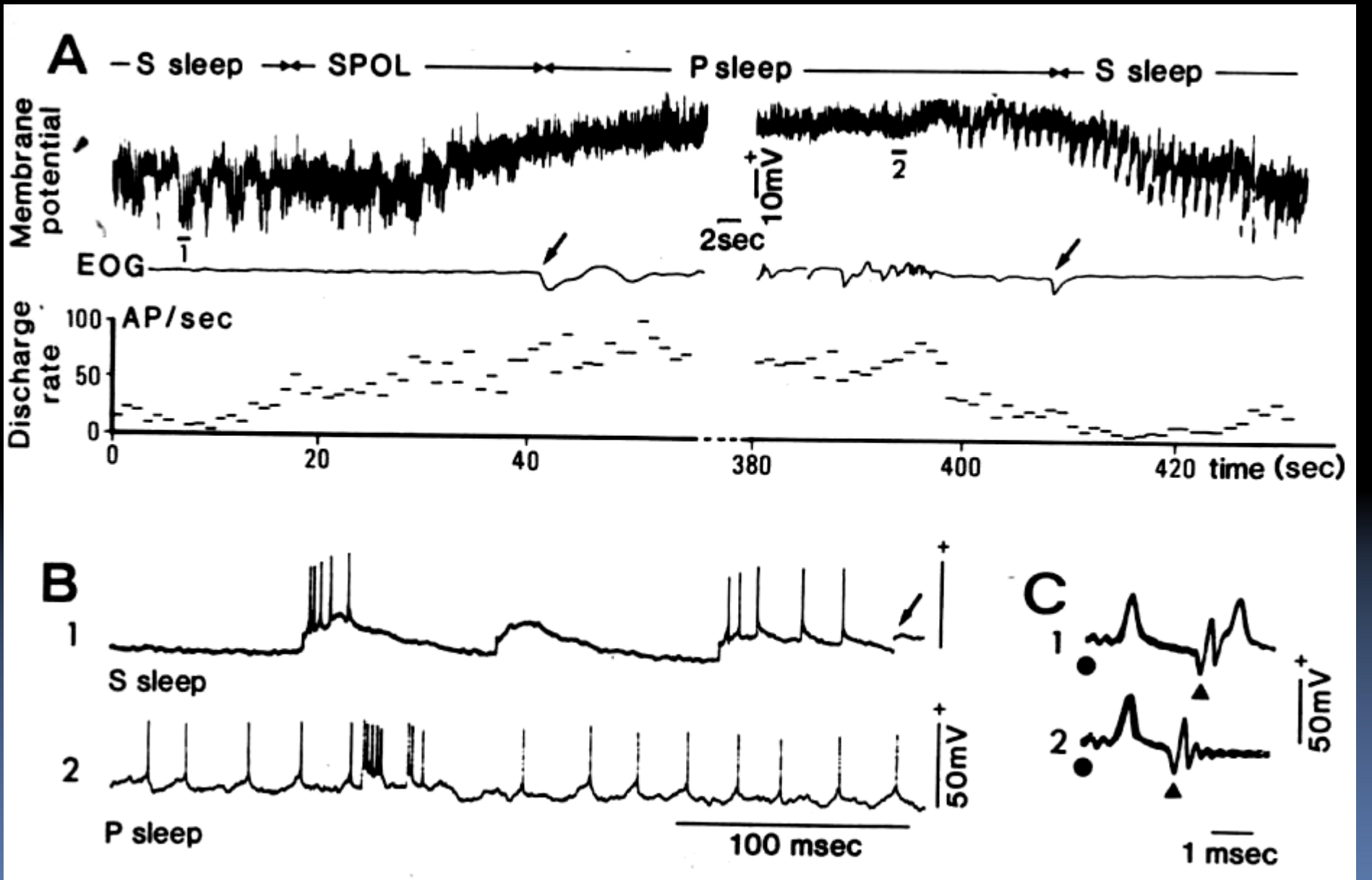
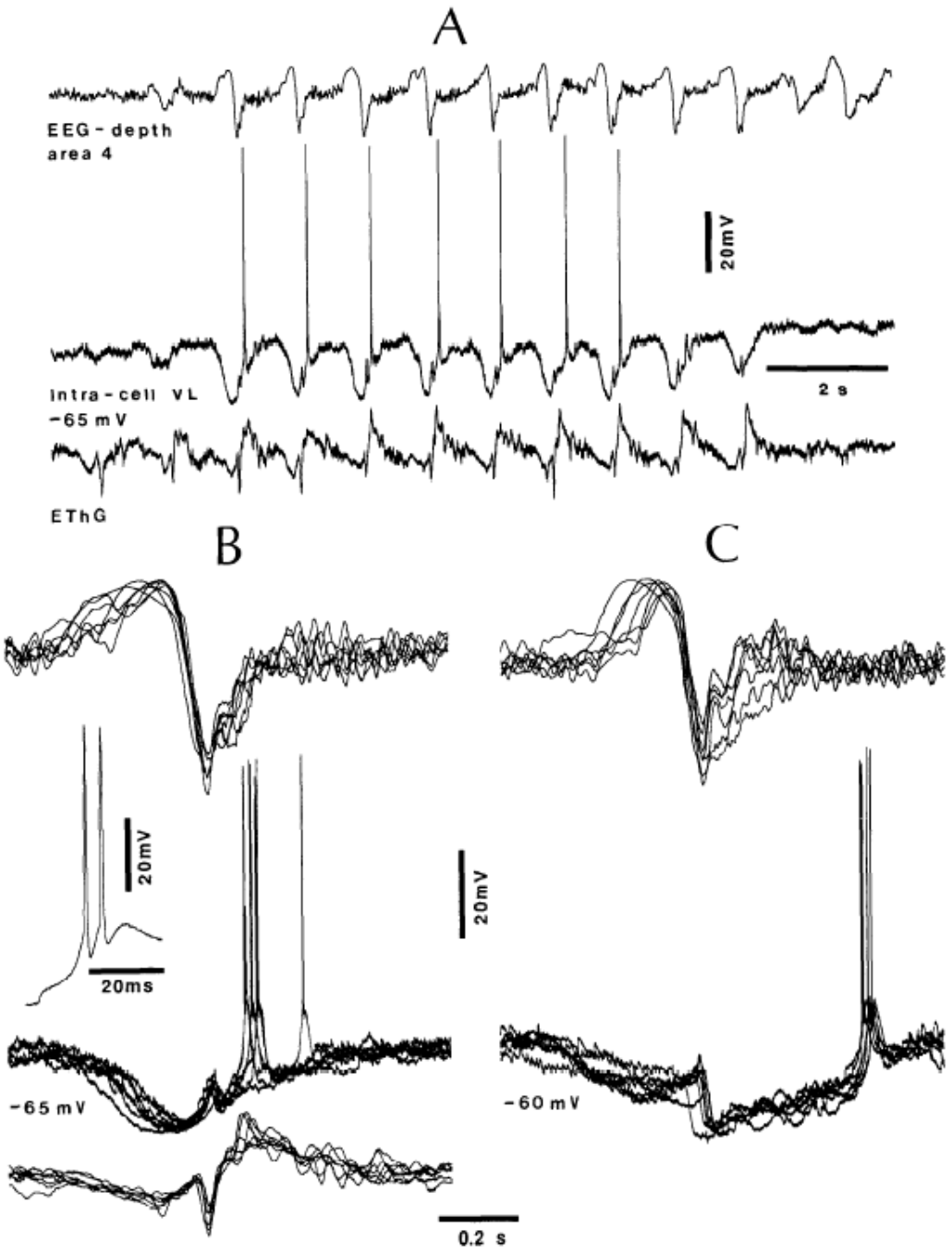
Tonic depolarization of LGB neuron during paradoxical sleep (Hirsch et al., 1983).

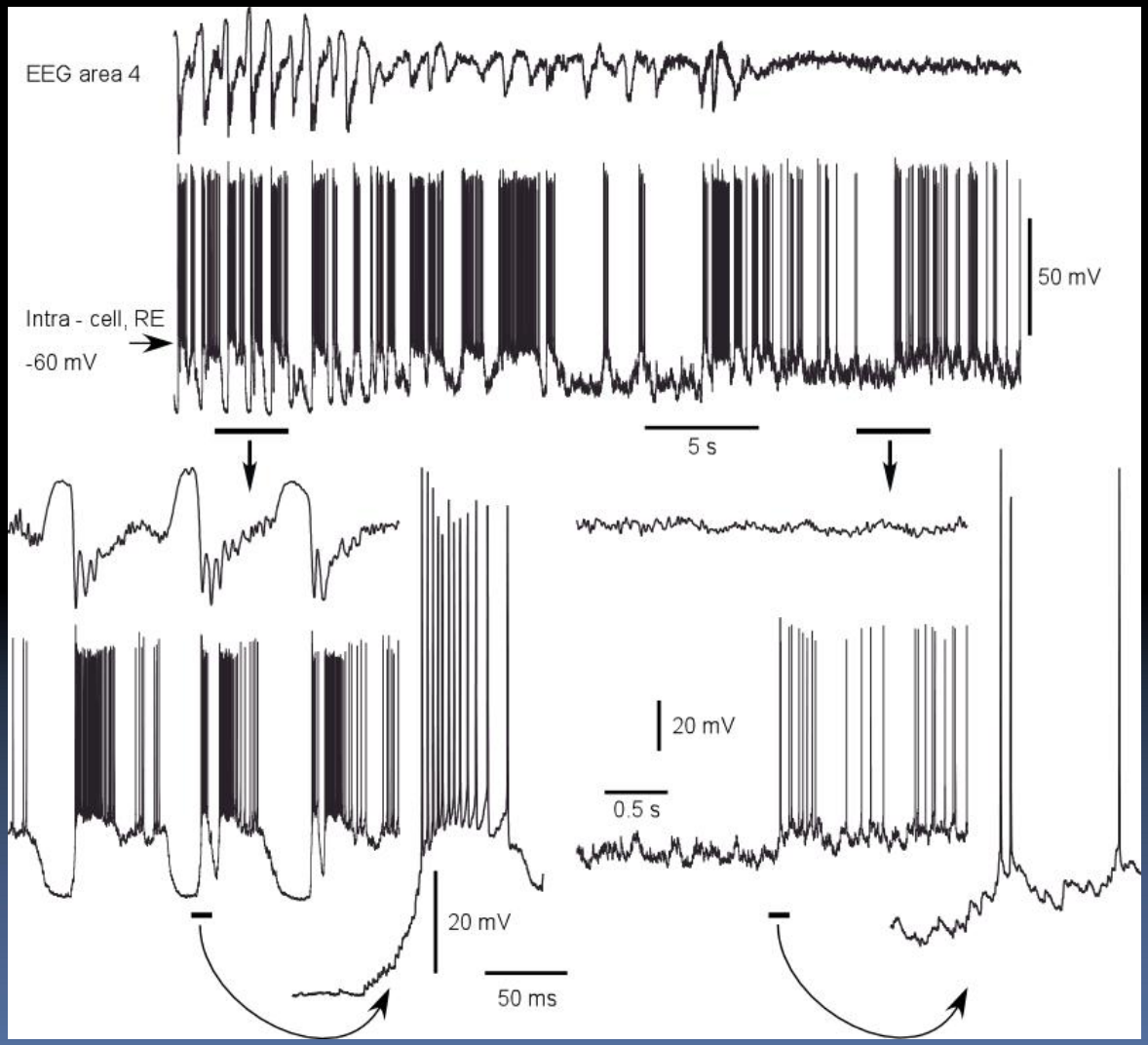


Expression of slow oscillation in thalamus vivo



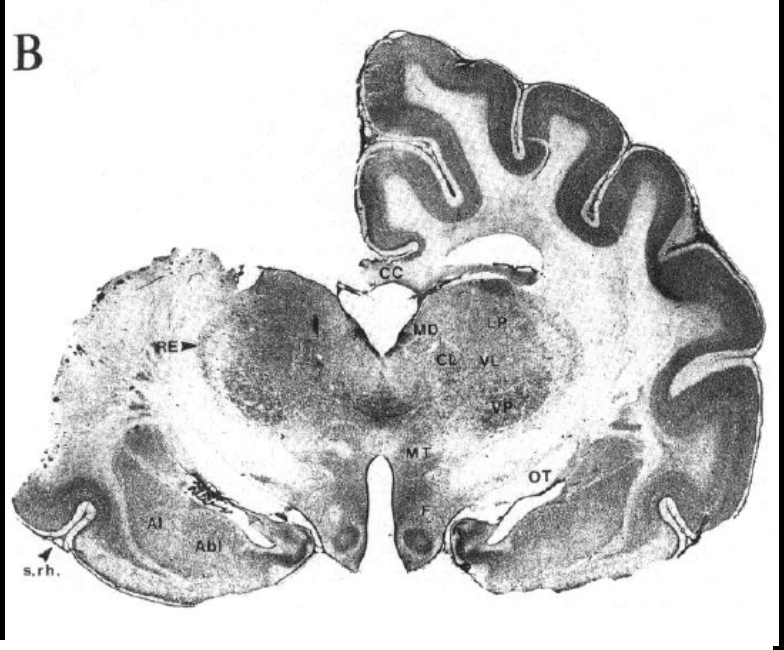
Contreras D, Steriade M. *J Neurosci 1995;15: p. 604-22.*

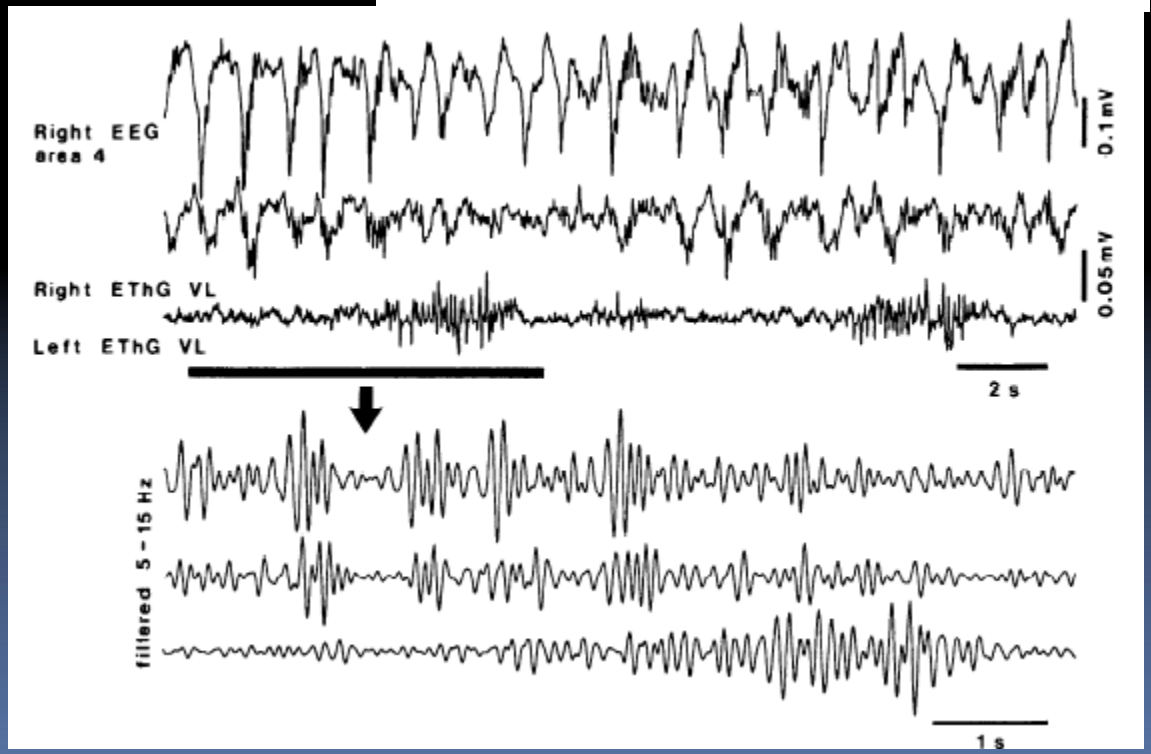
Reticular thalamic neurons during slow oscillation and EEG activation



Timofeev I., unpublished

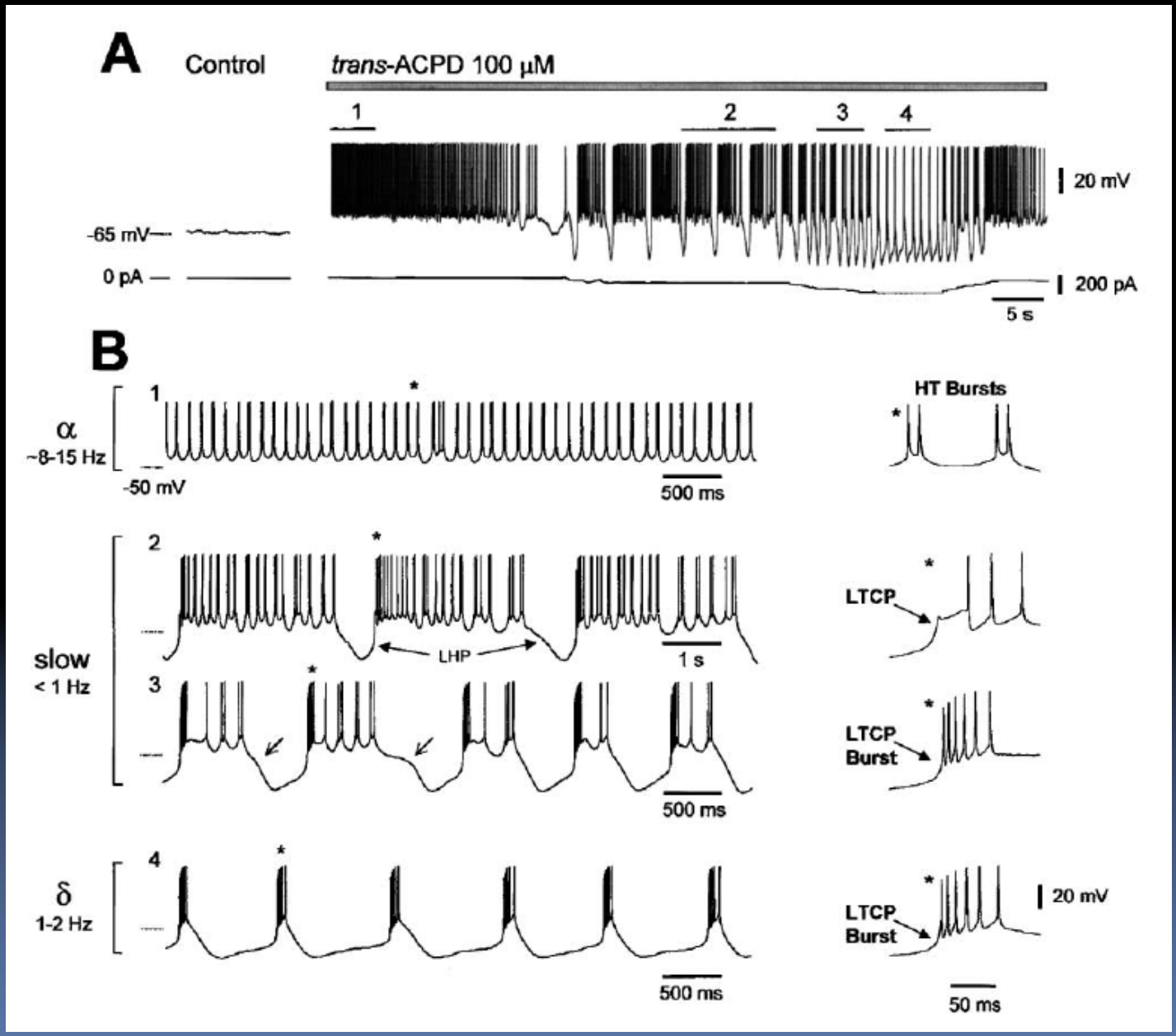
Absence of slow oscillation in thalamus of decorticated cats



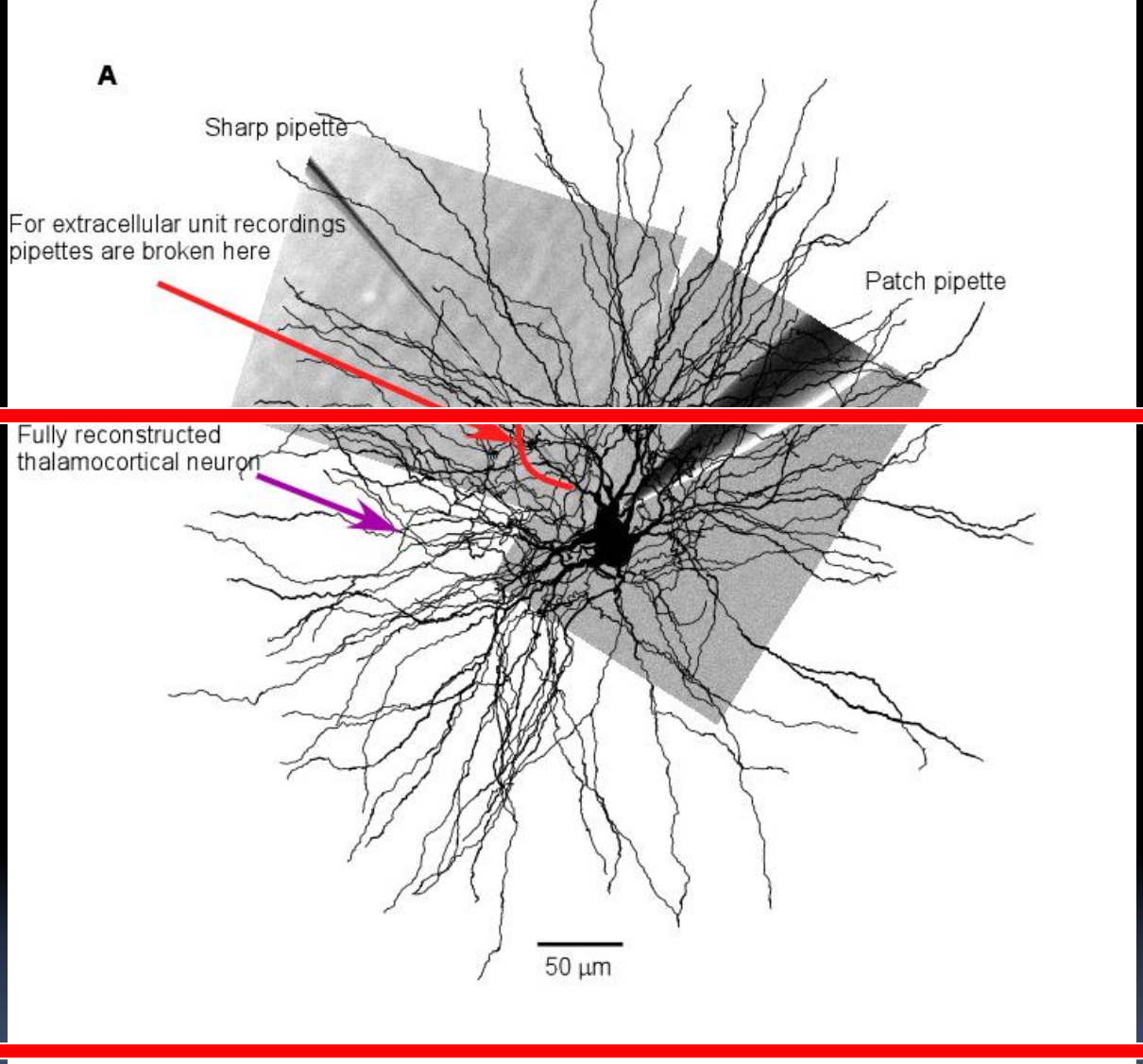


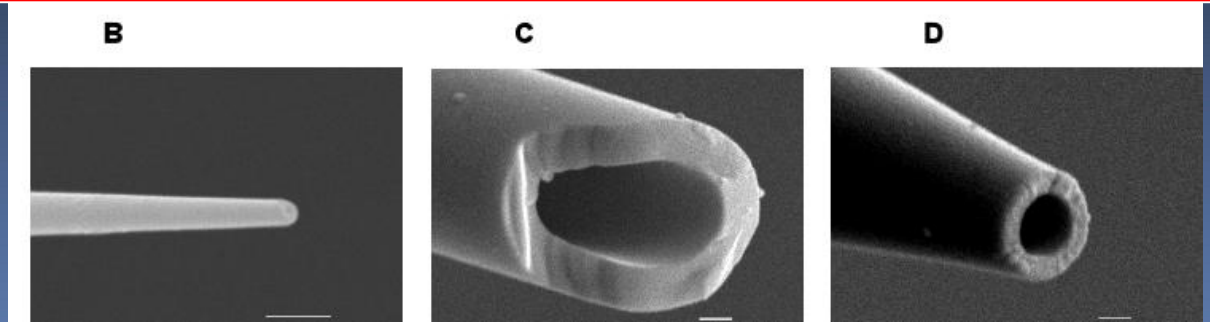
Timofeev I, Steriade M (1996) Low-frequency rhythms in the thalamus of intact-cortex and decorticated cats. J Neurophysiol 76:4152-4168.

Slow oscillation in thalamus in vitro

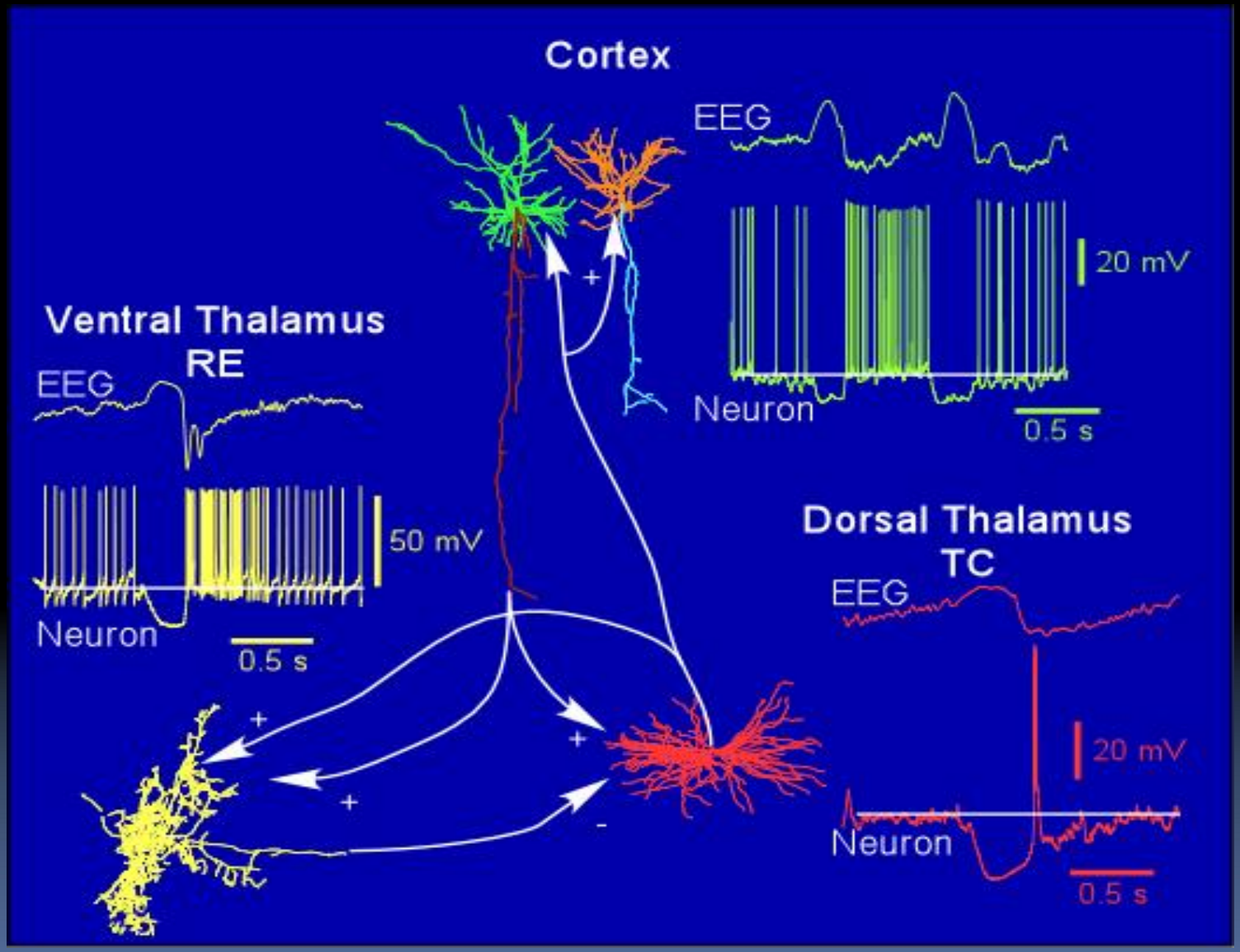


Hughes SW, Cope DW, Blethyn KL, Crunelli V
Neuron 2002;33: p. 947-58.


A
Sharp pipette
For extracellular unit recordings
pipettes are broken here
Patch pipette
Fully reconstructed
thalamocortical neuron
50 µm


B
C
D

Thalamocortical system

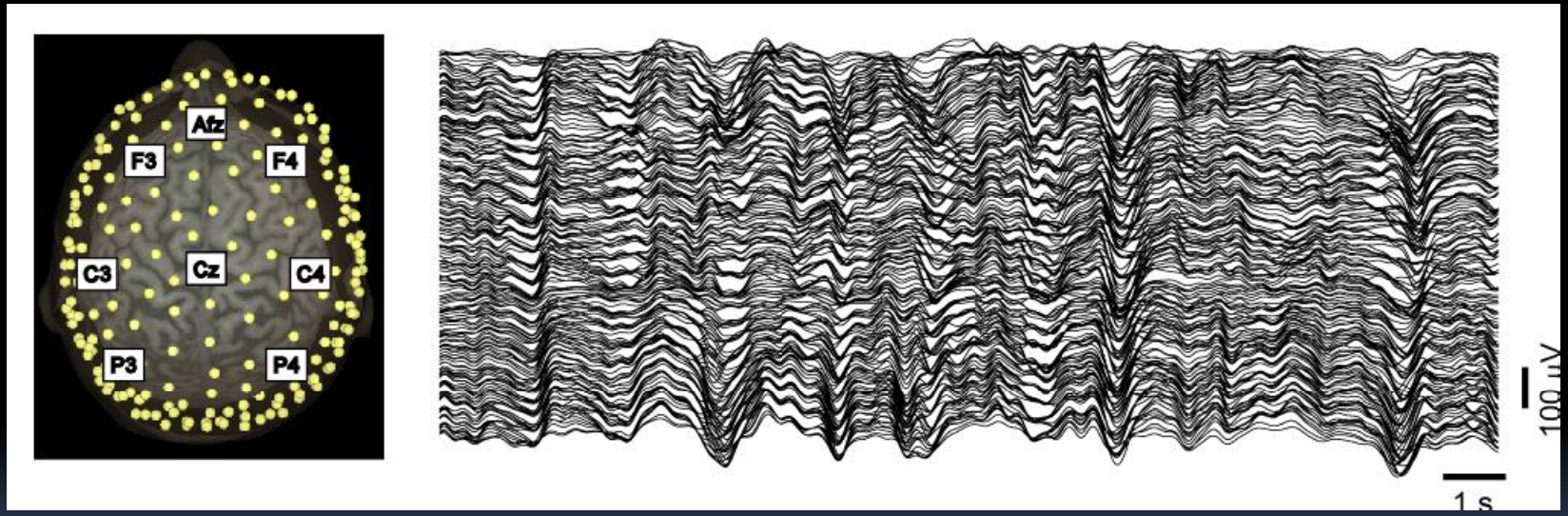


Timofeev I, Bazhenov M (2005) In: Trends in chronobiology research (Columbus F, ed), pp 1-47. New York: Nova Science Publishers.

Conclusions

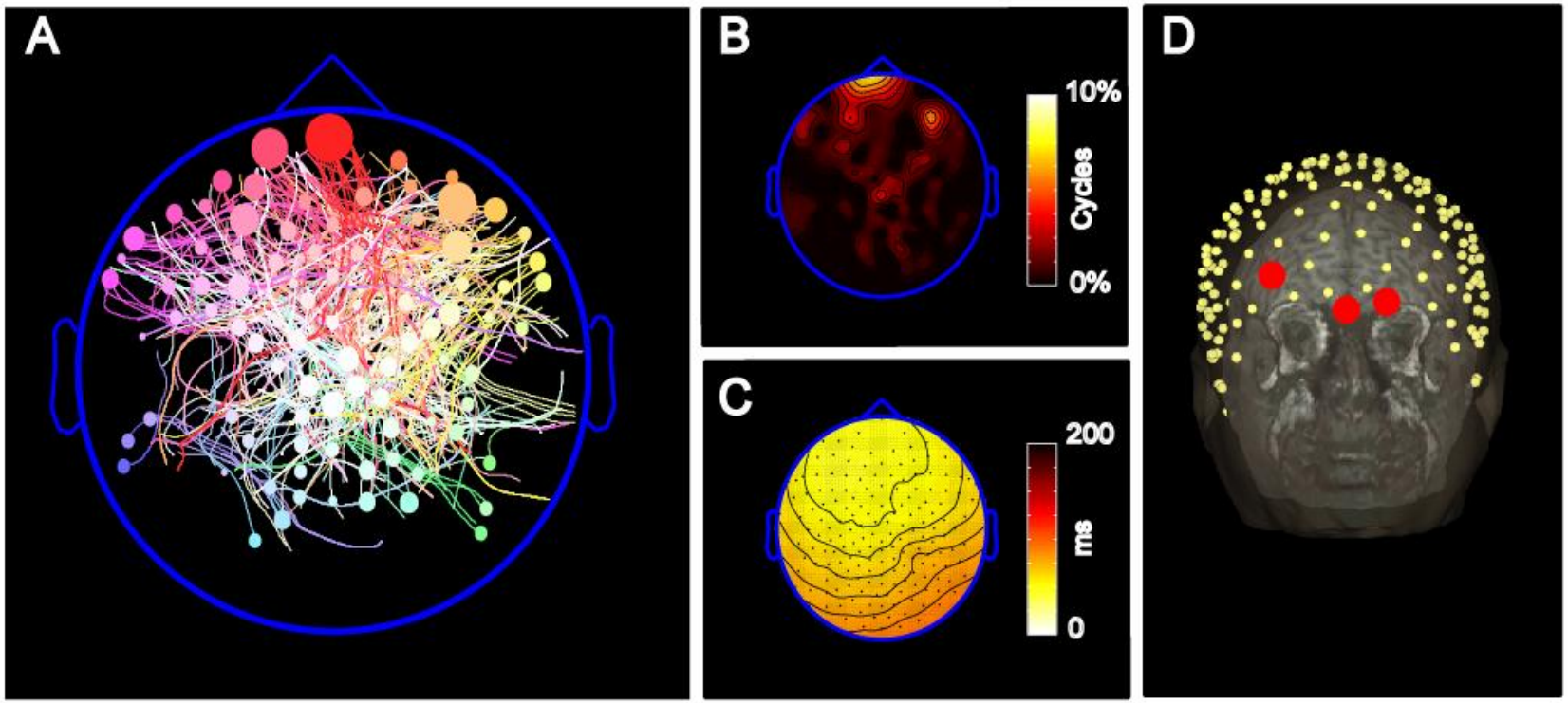
Local origin of active states

High density human EEG



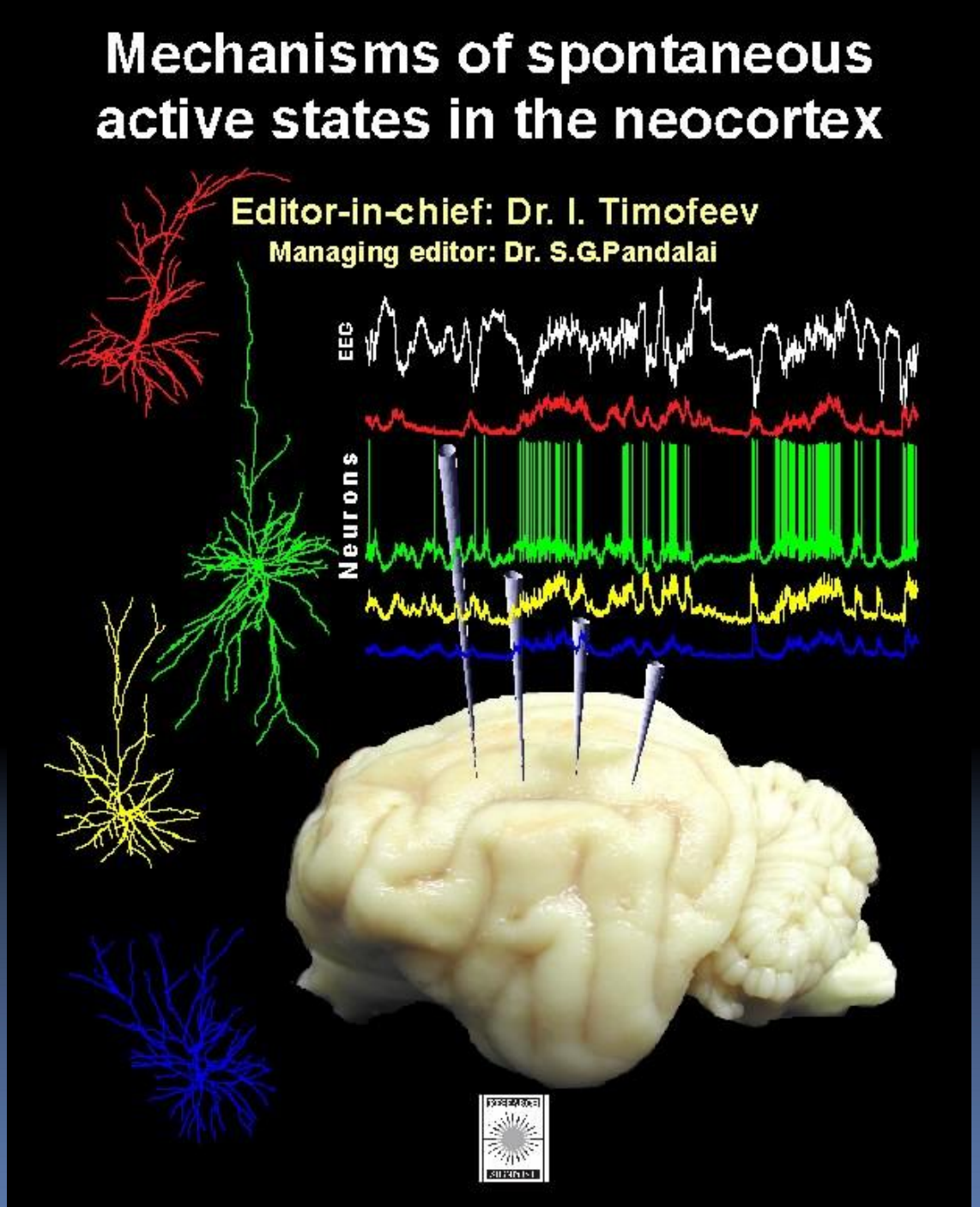
Massimini M, Huber R, Ferrarelli F, Hill S, Tononi G (2004) J Neurosci 24:6862-6870.

High density human EEG

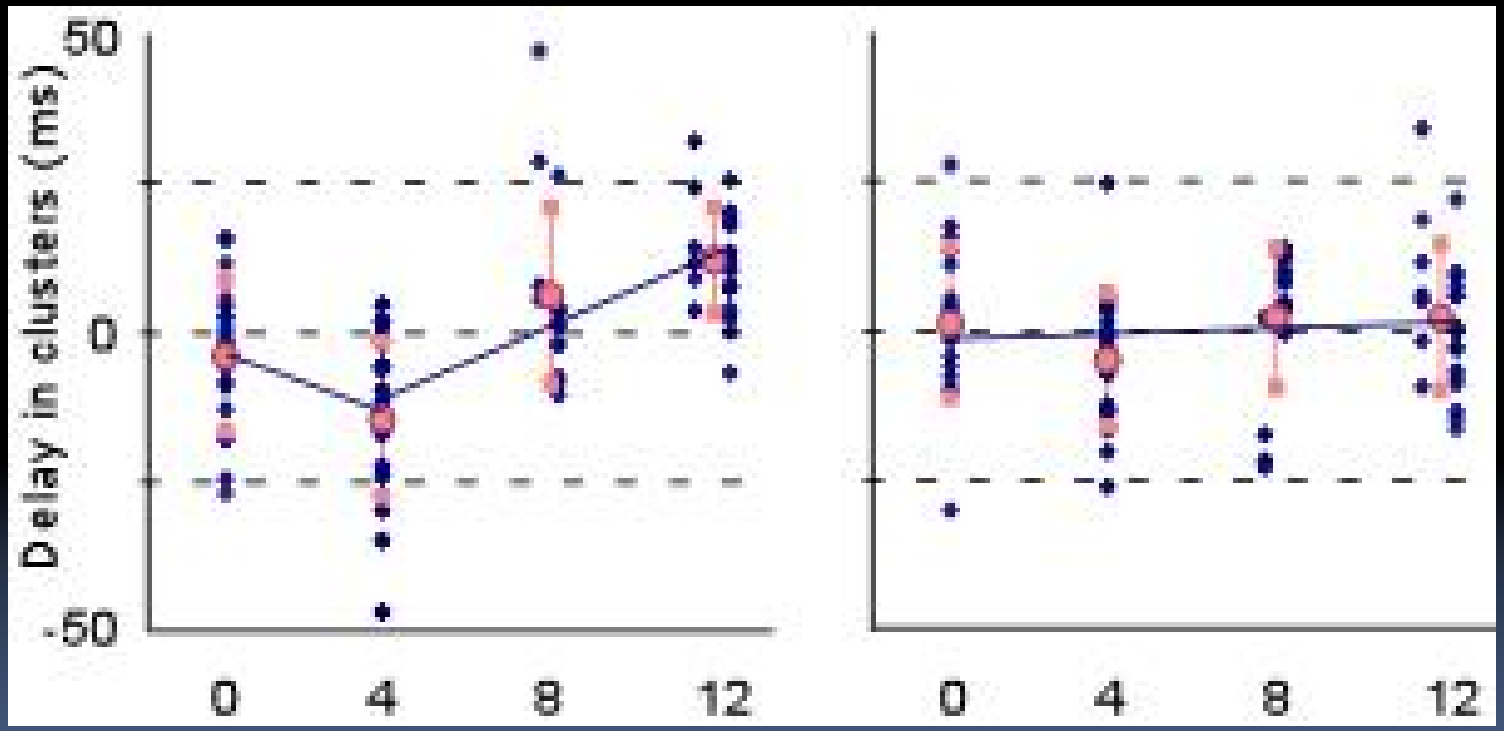


Massimini M, Huber R, Ferrarelli F, Hill S, Tononi G (2004) J Neurosci 24:6862-6870.

Active and silent states in 4 simultaneously recorded neurons and in the EEG

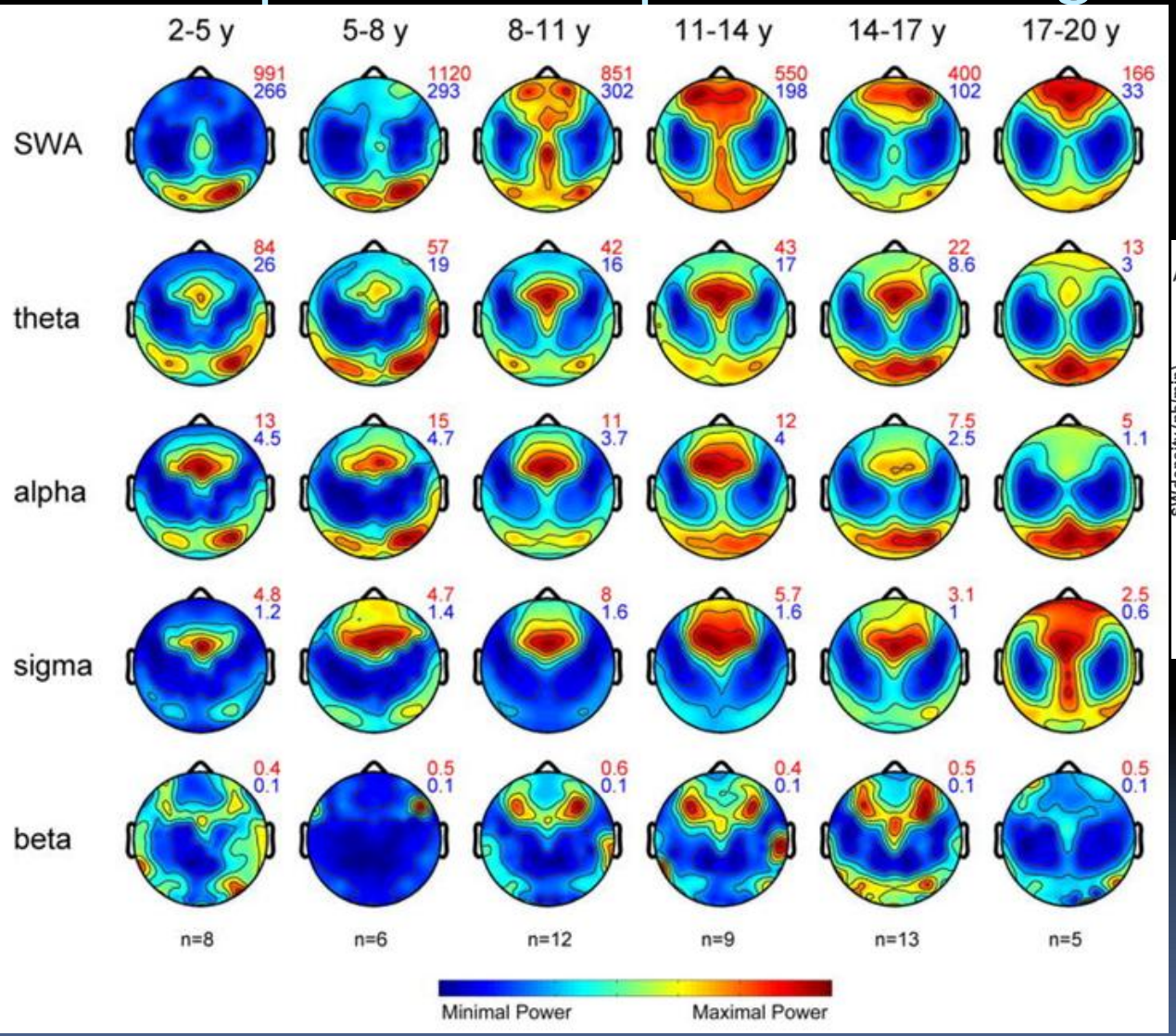


Mean delay of active and silent states onsets plotted against the antero-posterior position of recorded cells



Volgushev et al (2006) J Neurosci 26:5665-5672.

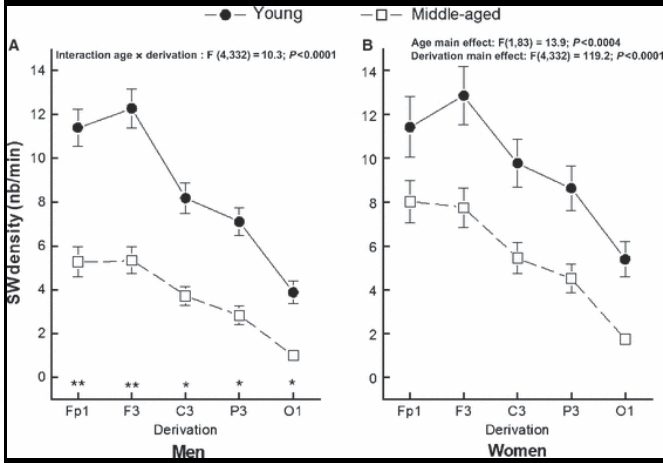
Maps of EEG power during NREM sleep



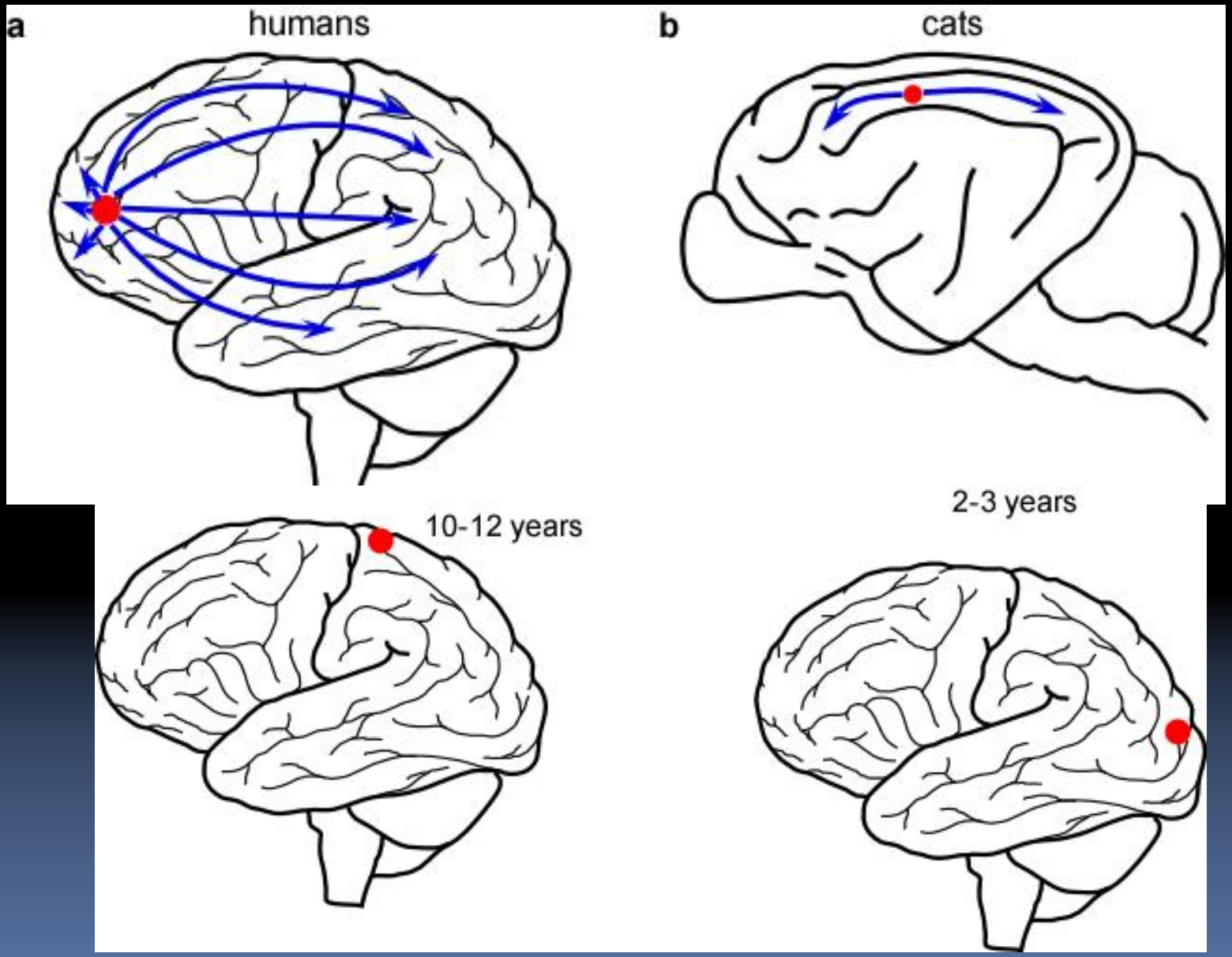
Kurth S, Ringli M, Geiger A, LeBourgeois M, Jenni OG, Huber R *J Neurosci 2010;30: p. 13211-9.*

20-30 y

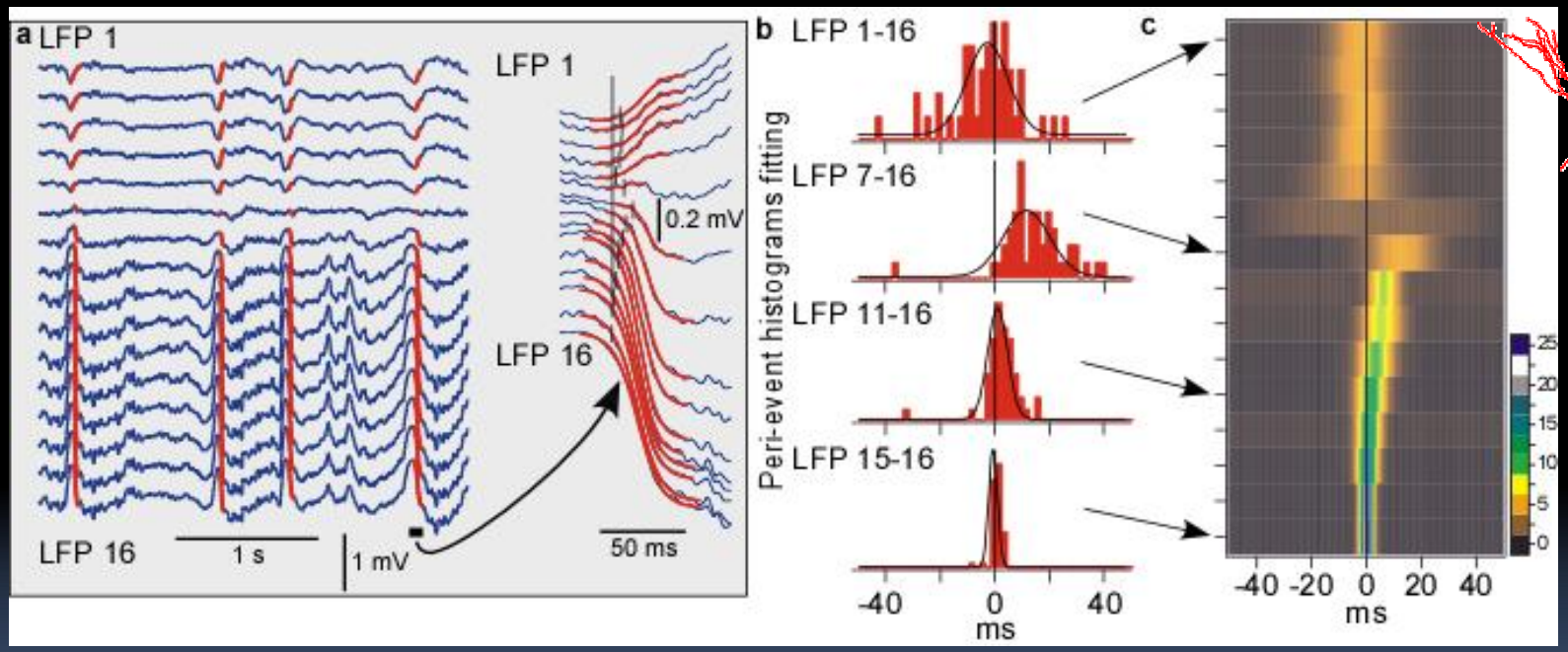
41-60 y

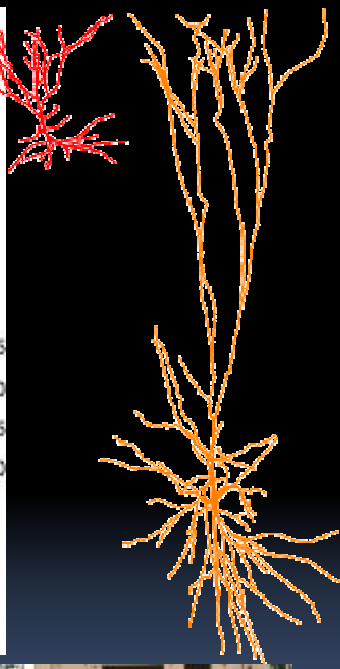


Carrier J, Viens I, Poirier G, Robillard R, Lafortune M, Vandewalle G, Martin N, Barakat M, Paquet J, Filipini D *European Journal of Neuroscience 2011;33: p. 758-766.*


a
humans
b
cats
10-12 years
2-3 years

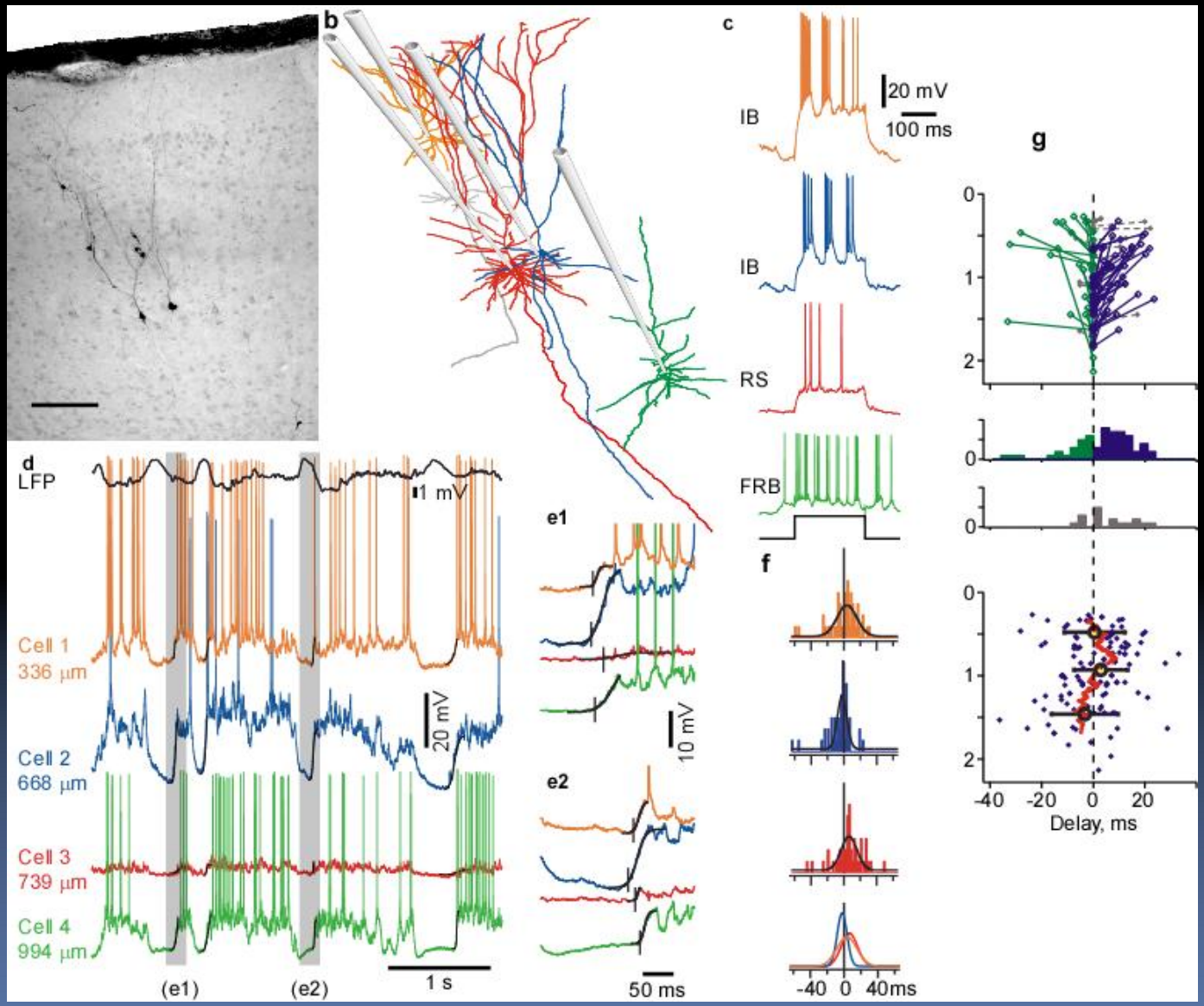
Depth profile of the LFP during slow-wave sleep





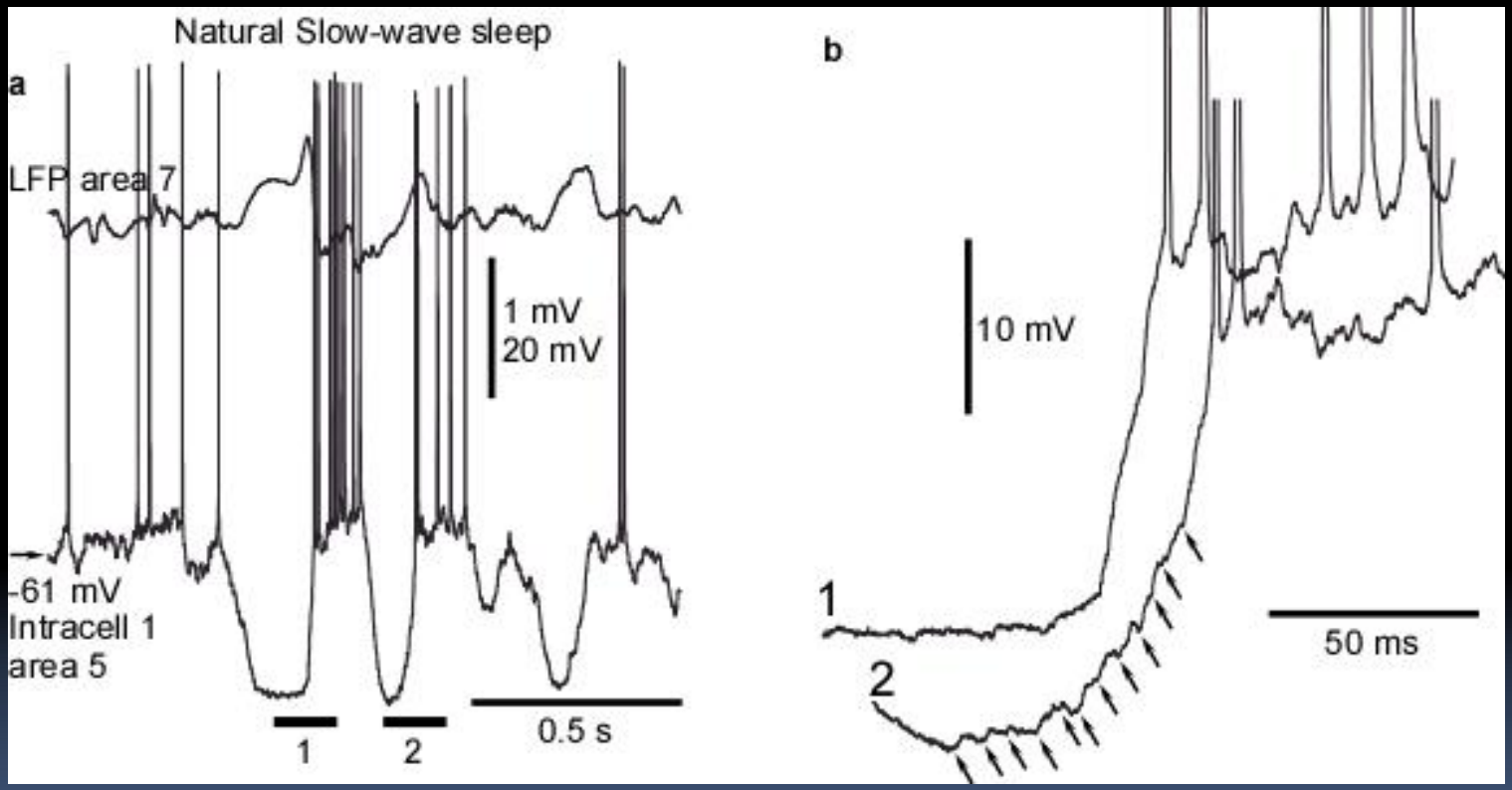
Chauvette S, Volgushev M, Timofeev I (2010) Origin of active states in local neocortical networks during slow sleep oscillation. Cereb Cortex 20:2660-2674.

Depth profile of neuronal activation in the slow-wave sleep model (ketamine-xylazine)



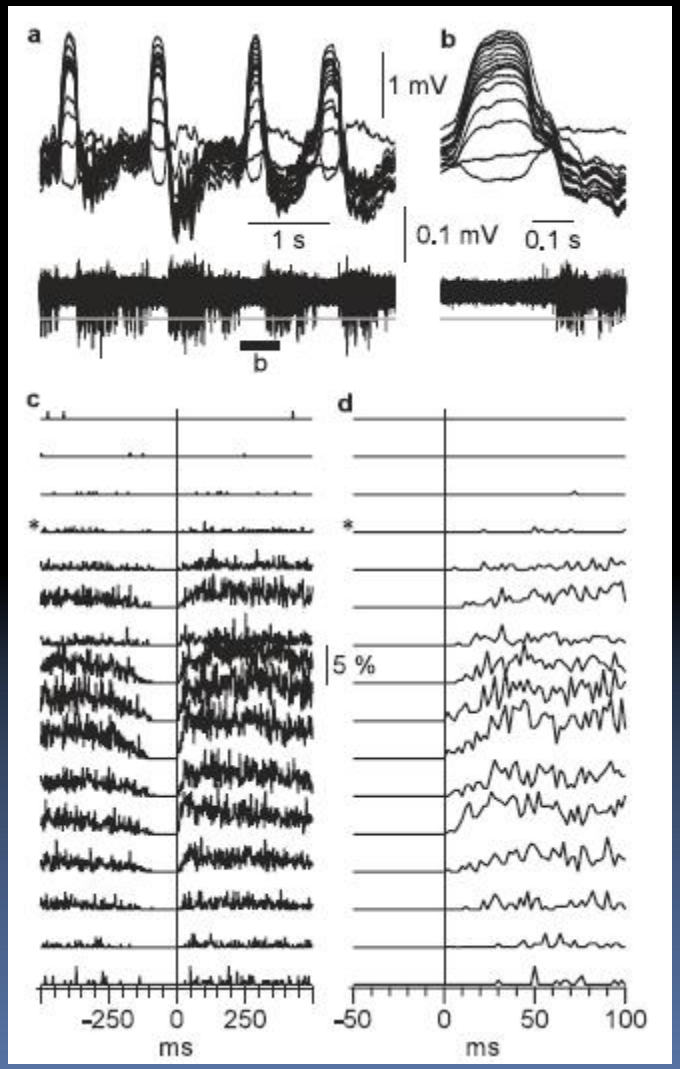
Chauvette S, Volgushev M, Timofeev I (2010) Origin of active states in local neocortical networks during slow sleep oscillation. Cereb Cortex 20:2660-2674.

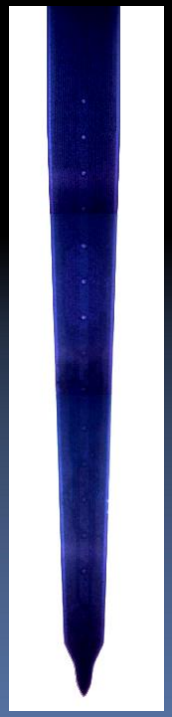
Progressive buildup versus sharp transitions from silent to active states



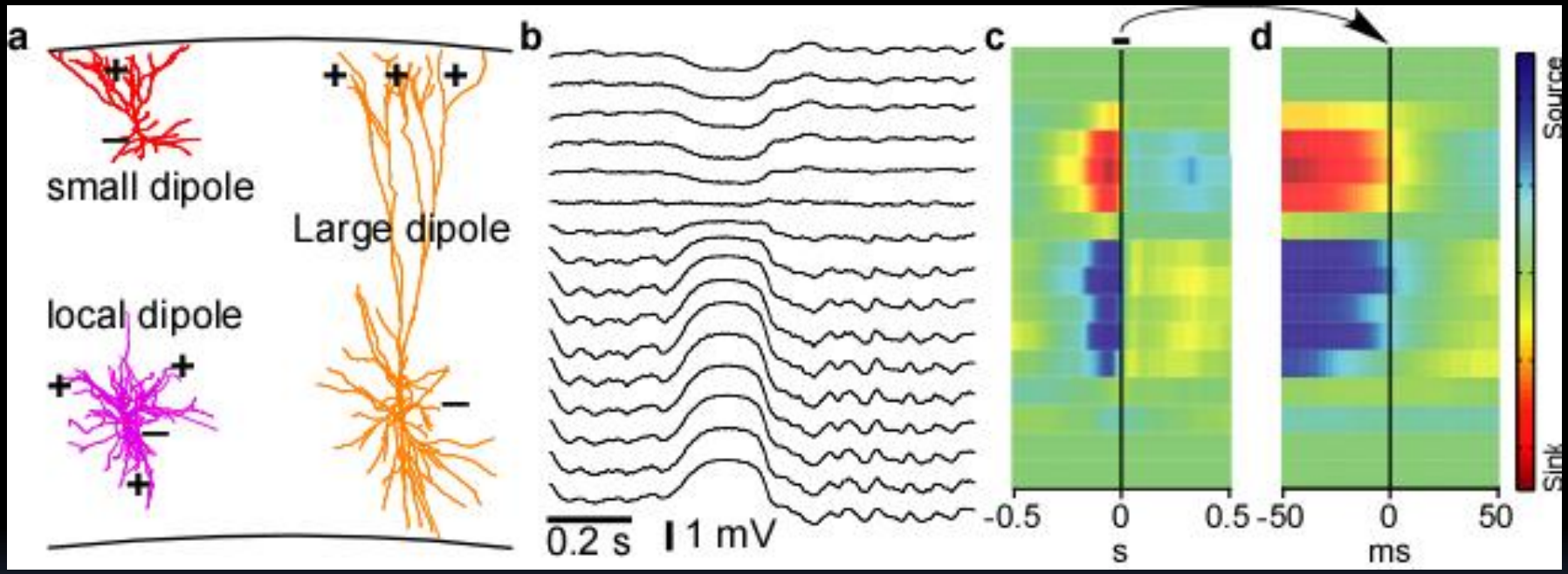
Chauvette S, Volgushev M, Timofeev I (2010) Origin of active states in local neocortical networks during slow sleep oscillation. Cereb Cortex 20:2660-2674.

Vertical ditribution of neuronal firing during slow oscillation



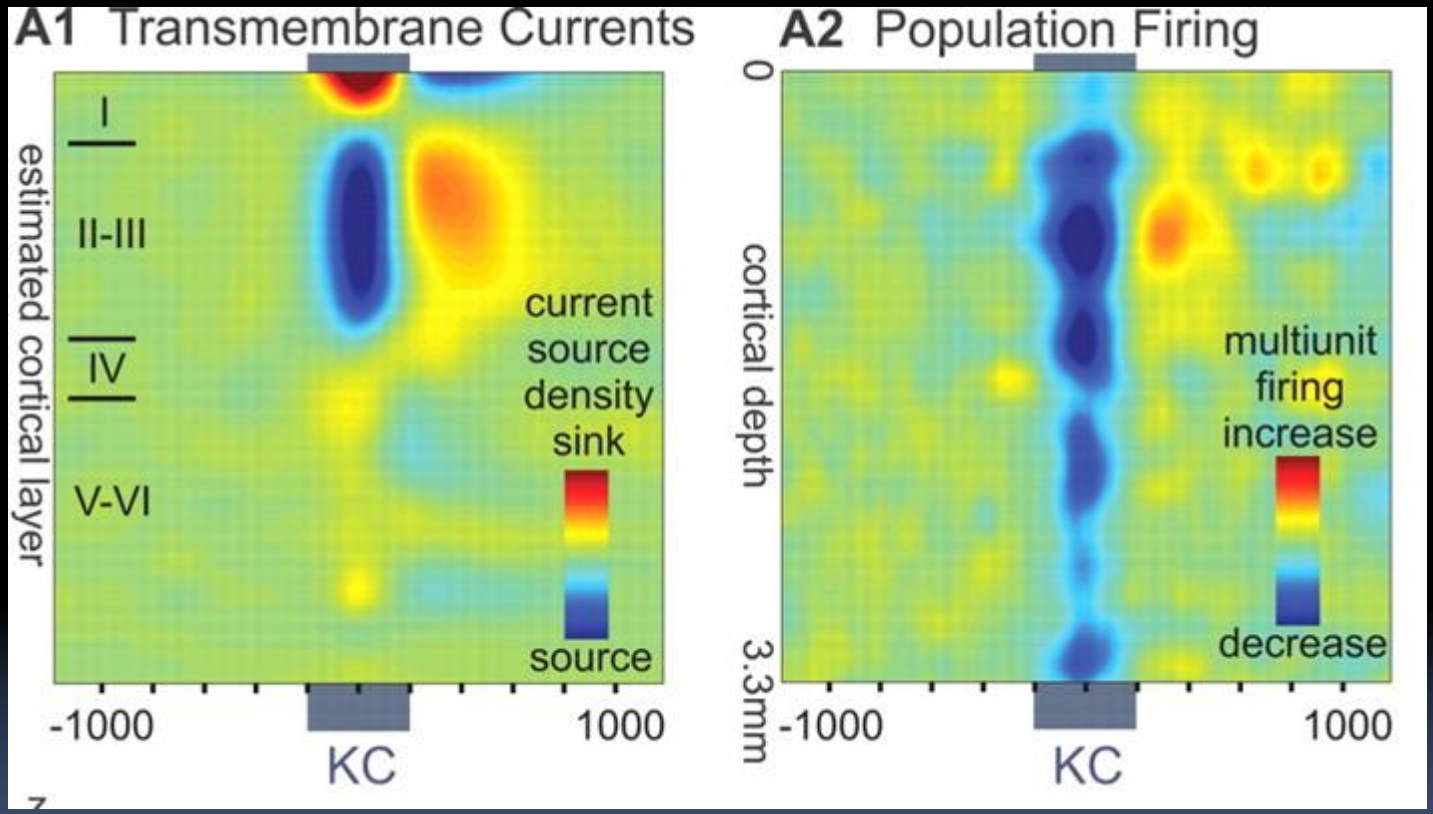


Chauvette S, Volgushev M, Timofeev I (2010) Origin of active states in local neocortical networks during slow sleep oscillation. Cereb Cortex 20:2660-2674.

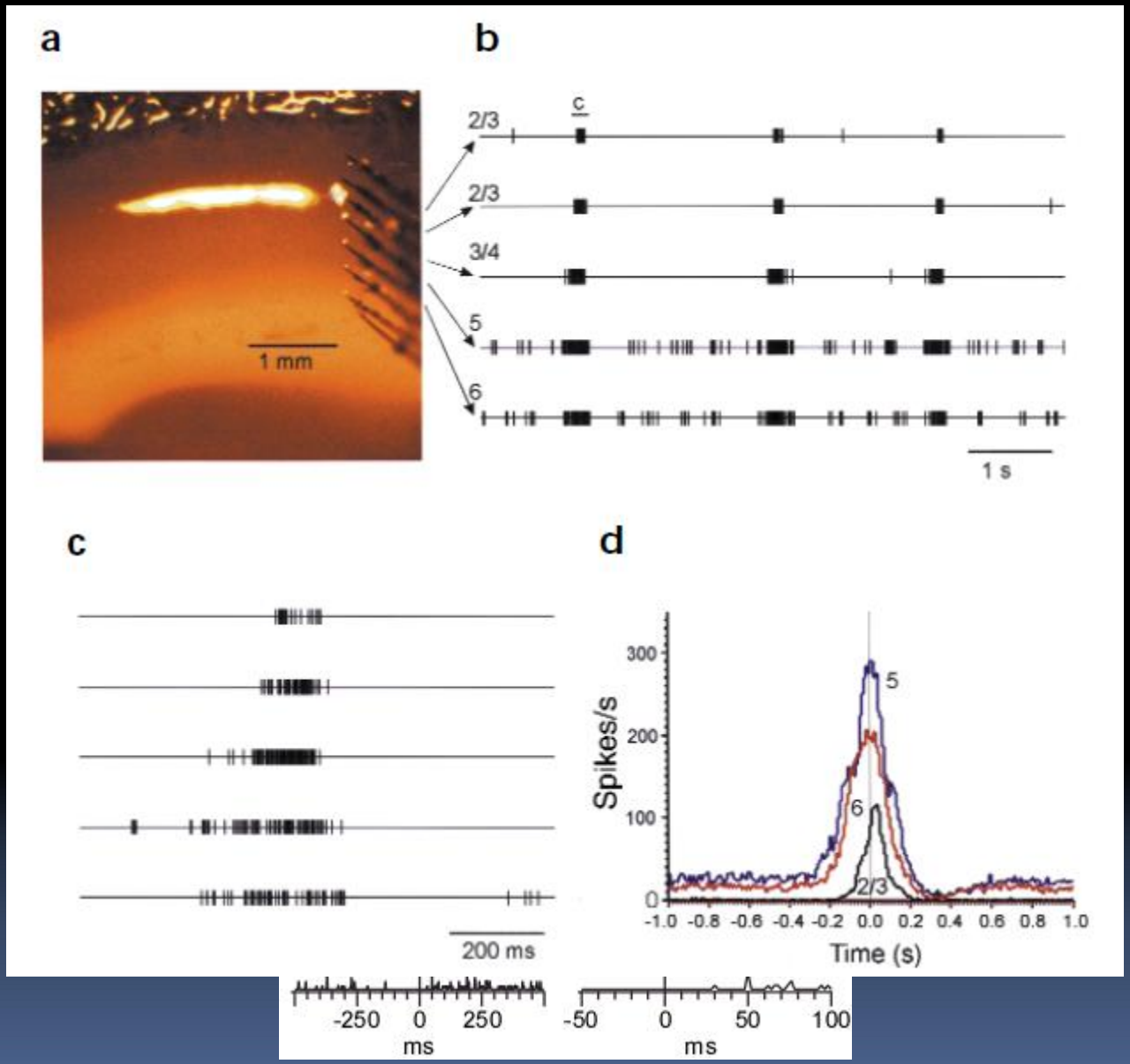


Panels A and B Timofeev, Chauvette, in press; panels C and D from Chauvette S, Volgushev M, Timofeev I (2010) Origin of Active States in Local Neocortical Networks during Slow Sleep Oscillation. Cereb Cortex.

Fig. 3 Decrement in population firing and high-frequency membrane oscillations during KC.



Cash SS, Halgren E, Dehghani N, Rossetti AO, Thesen T, Wang C, Devinsky O, Kuzniecky R, Doyle W, Madsen JR, Bromfield E, Eross L, Halasz P, Karmos G, Csercsa R, Wittner L, Ulbert I. *Science 2009;324: p. 1084-1087.*


a
b
1 mm
c
2/3
2/3
3/4
5
6
1 s
c
200 ms
d
Spikes/s
300
200
100
0
5
6
2/3
-1.0 -0.8 -0.6 -0.4 -0.2 0.0 0.2 0.4 0.6 0.8 1.0
Time (s)
-250 0 250
ms
-50 0 50 100
ms

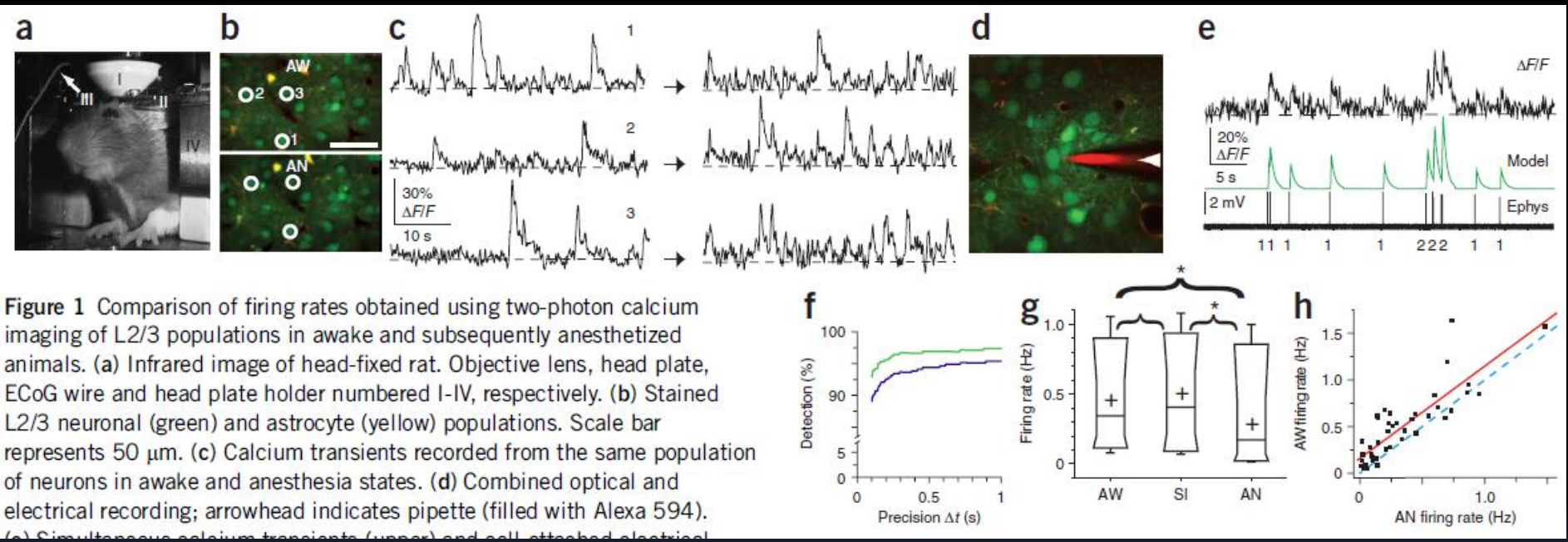
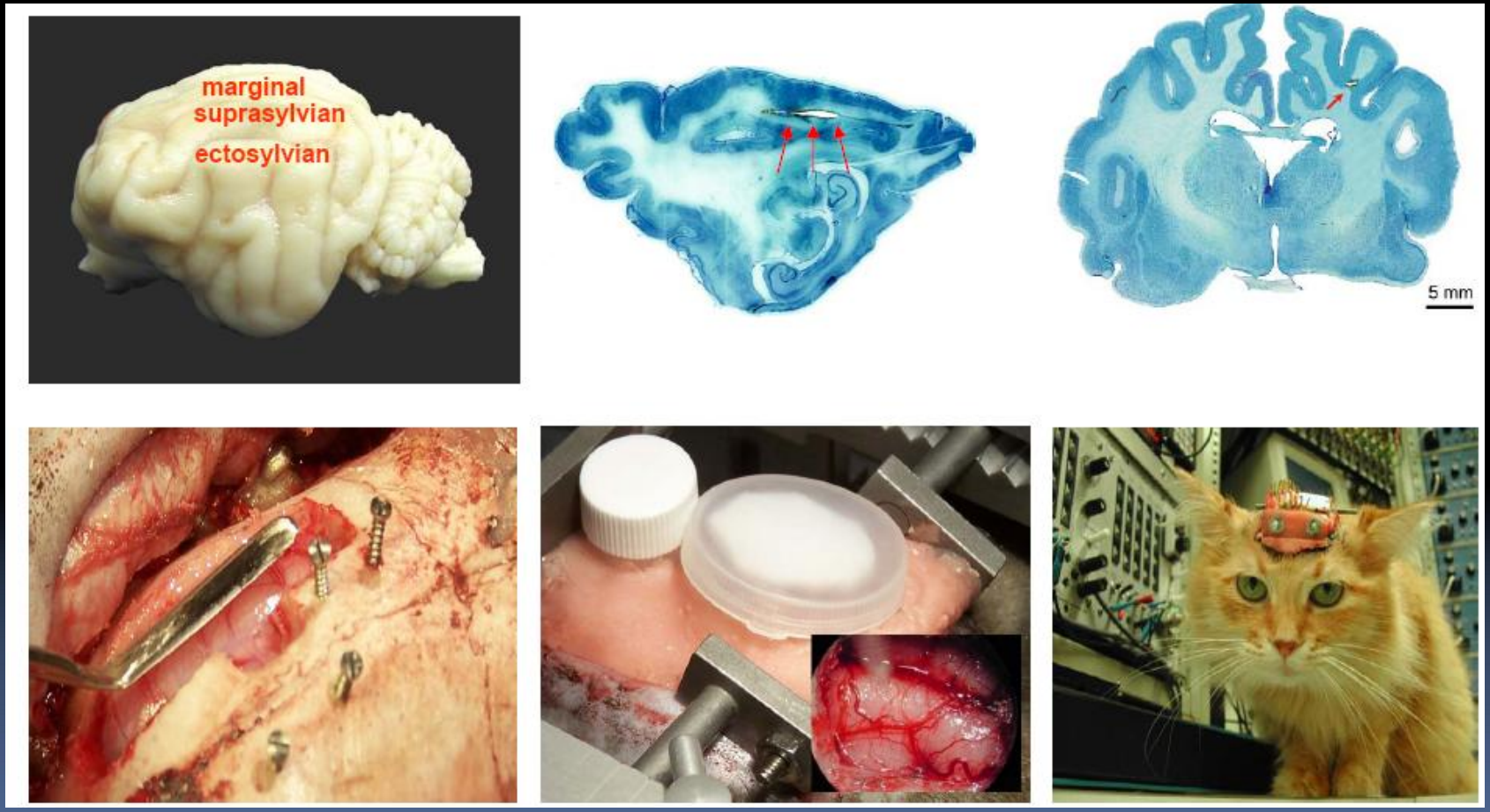


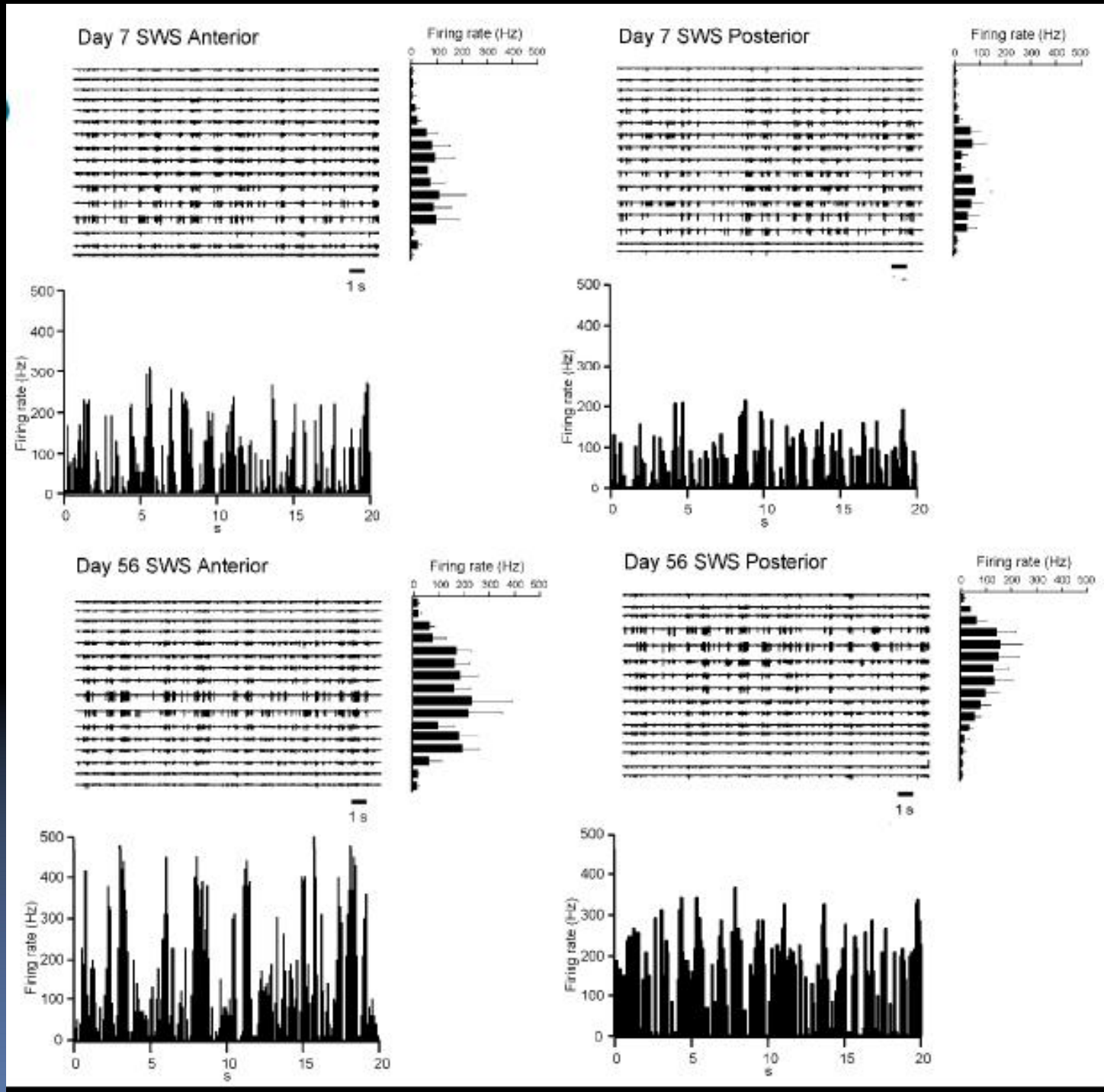
Figure 1 Comparison of firing rates obtained using two-photon calcium imaging of L2/3 populations in awake and subsequently anesthetized animals. (**a**) Infrared image of head-fixed rat. Objective lens, head plate, ECoG wire and head plate holder numbered I-IV, respectively. (**b**) Stained L2/3 neuronal (green) and astrocyte (yellow) populations. Scale bar represents 50 μm. (**c**) Calcium transients recorded from the same population of neurons in awake and anesthesia states. (**d**) Combined optical and electrical recording; arrowhead indicates pipette (filled with Alexa 594).

Greenberg DS, Houweling AR, Kerr JND (2008) Population imaging of ongoing neuronal activity in the visual cortex of awake rats. Nat Neurosci 11:749-751.

Experimental approach



Laminar distribution of neuronal firing in the undercut cortex



Avramescu, Timofeev, Unpublished

Conclusions

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