# Neuronal population activity involved in motor patterns of the spinal cord:

# Spiking regimes and skewed involvement

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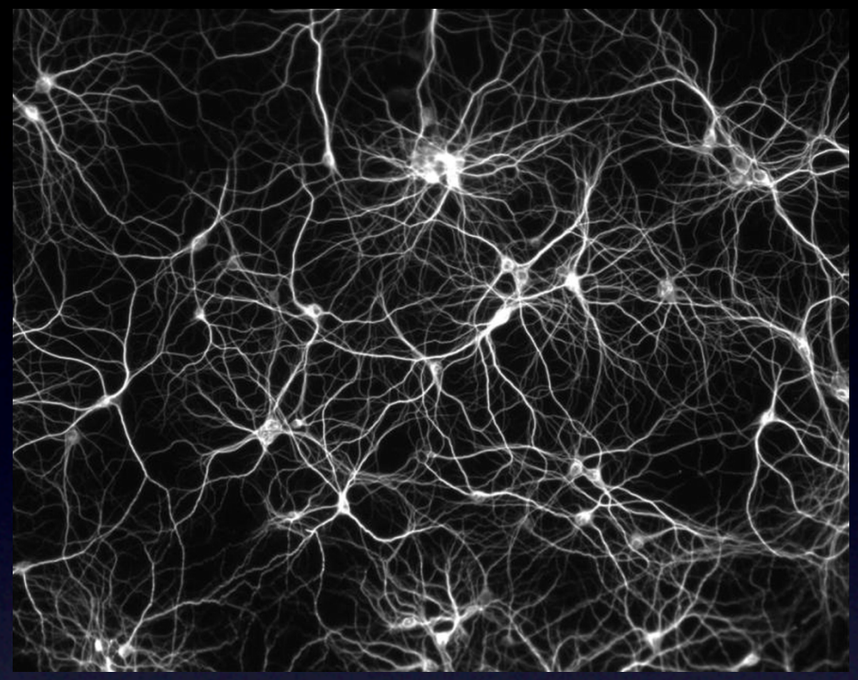
DET FRIE FORSKNINGSRÅD
DANISH COUNCIL FOR
INDEPENDENT RESEARCH

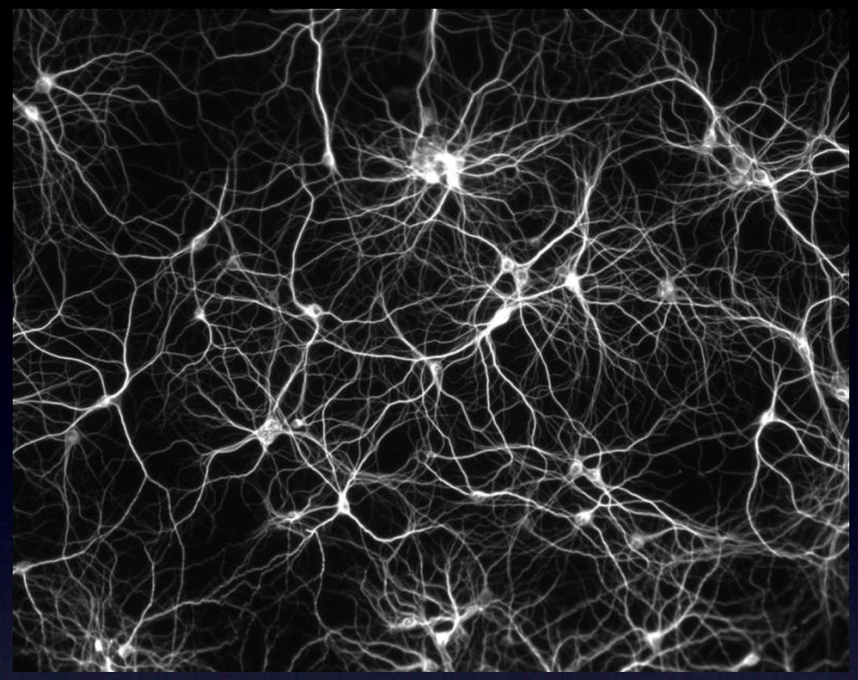
Funding:
Danish Research council
Novo Nordisk Foundation

- Participation of neuron in behaviors
- Mechanism and Spiking regimes
- Connectivity of spinal networks

# Understanding networks ?

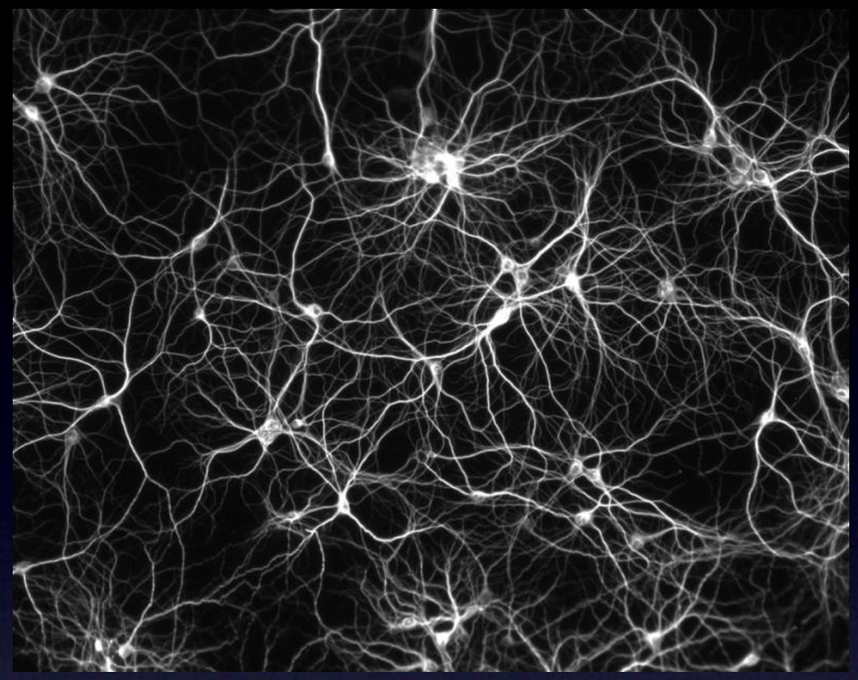


# Understanding networks ?



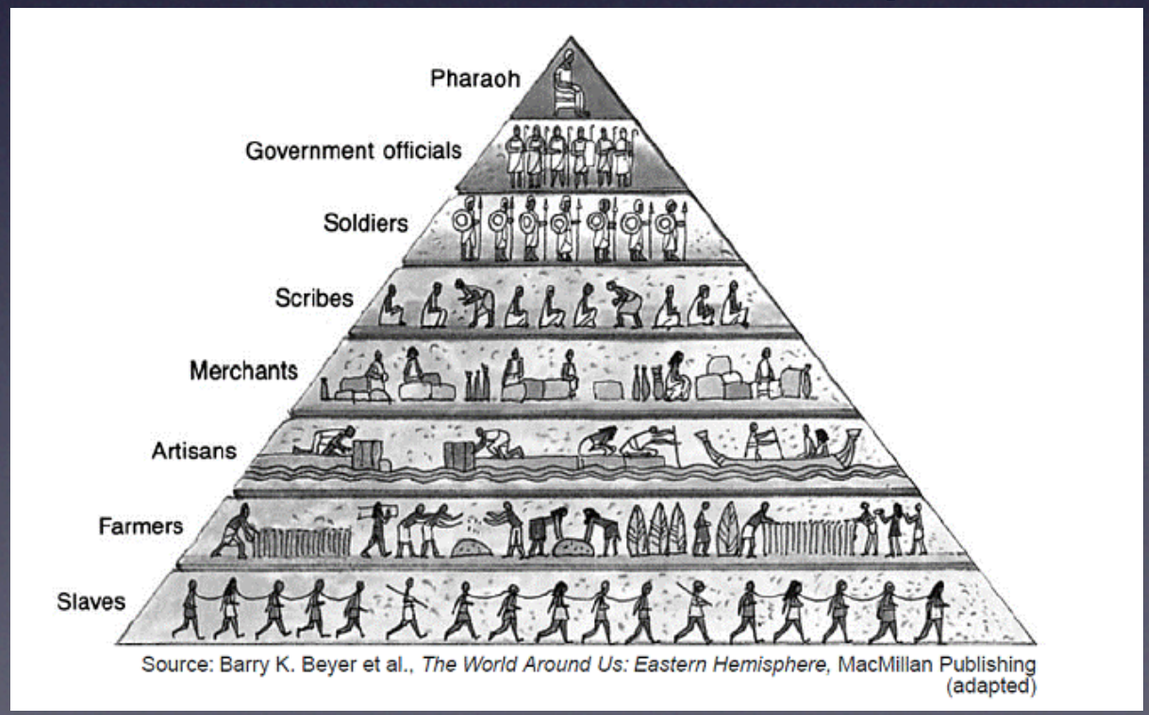
## Division of labor

# Understanding networks ?



## Division of labor

## Skewed distribution of power



# Central Pattern Generators

Chewing, Swimming, scratching, breathing and walking



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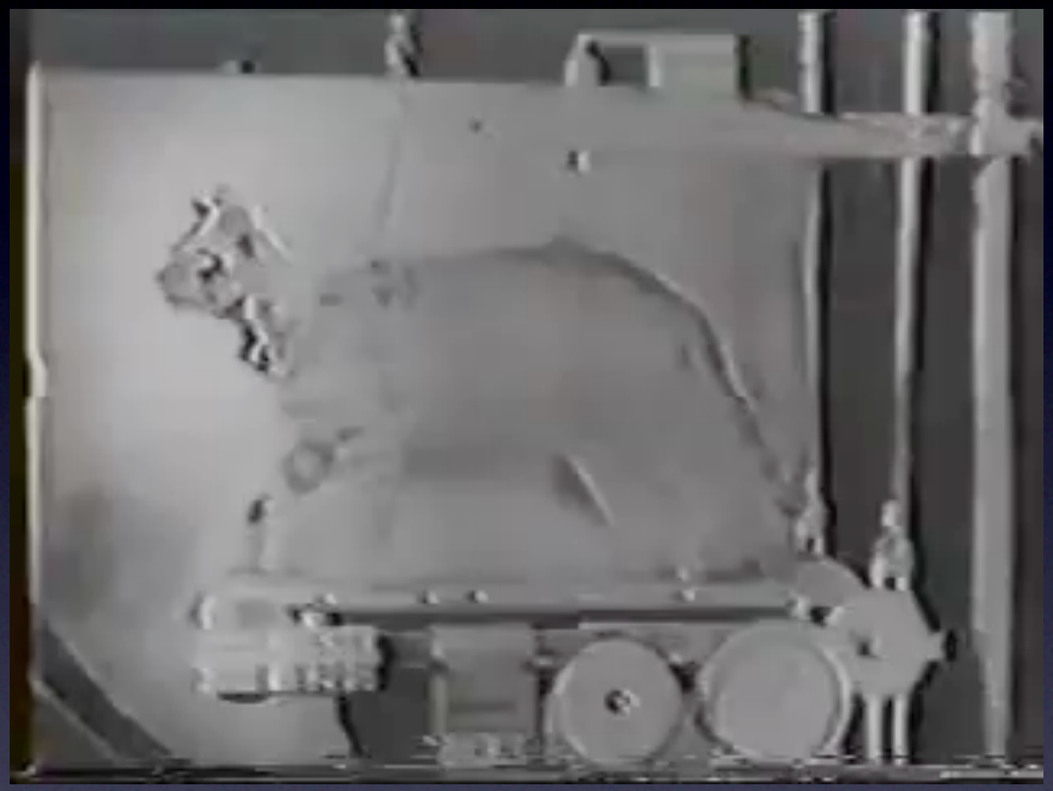
# Decerebrate cat:



Whelan, *Prog. Neurobiol* 1996
MacKay-Lyons, *Phys. Therap.* 2002



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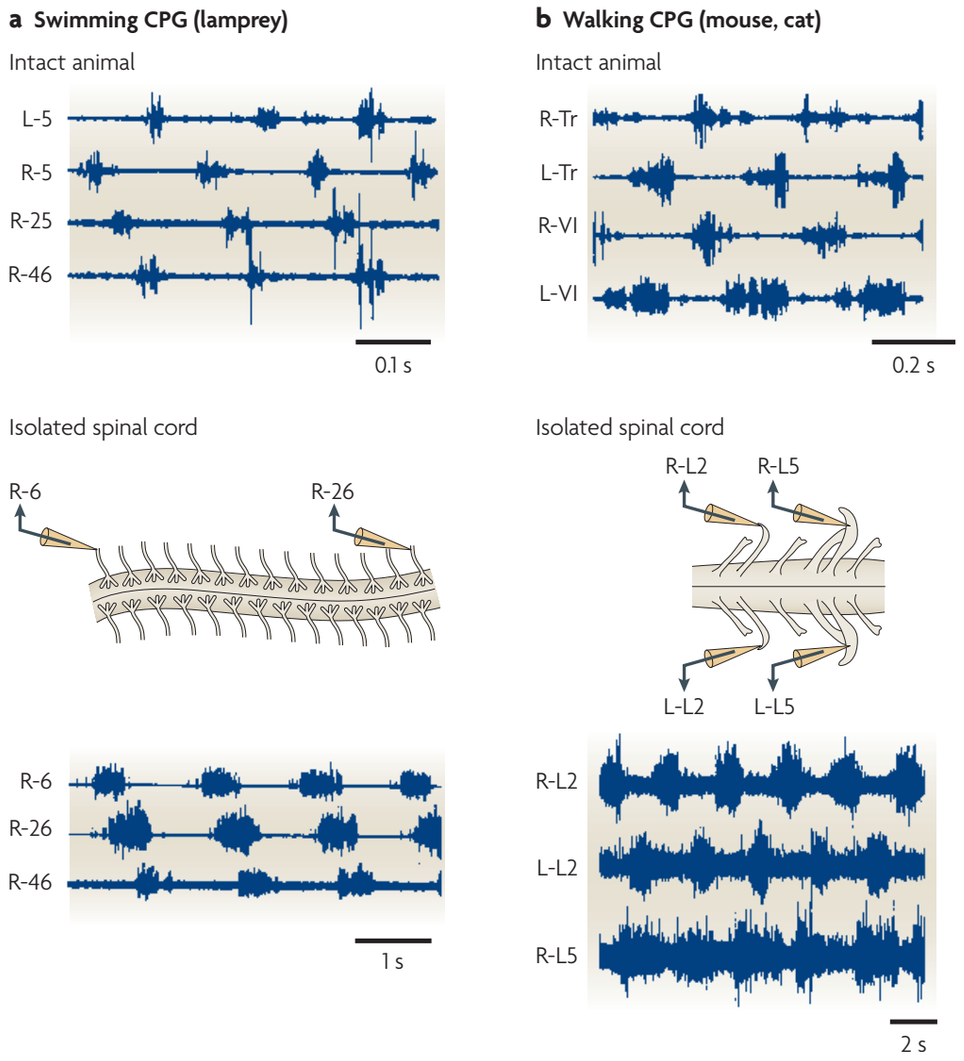
# "Fictive locomotion"

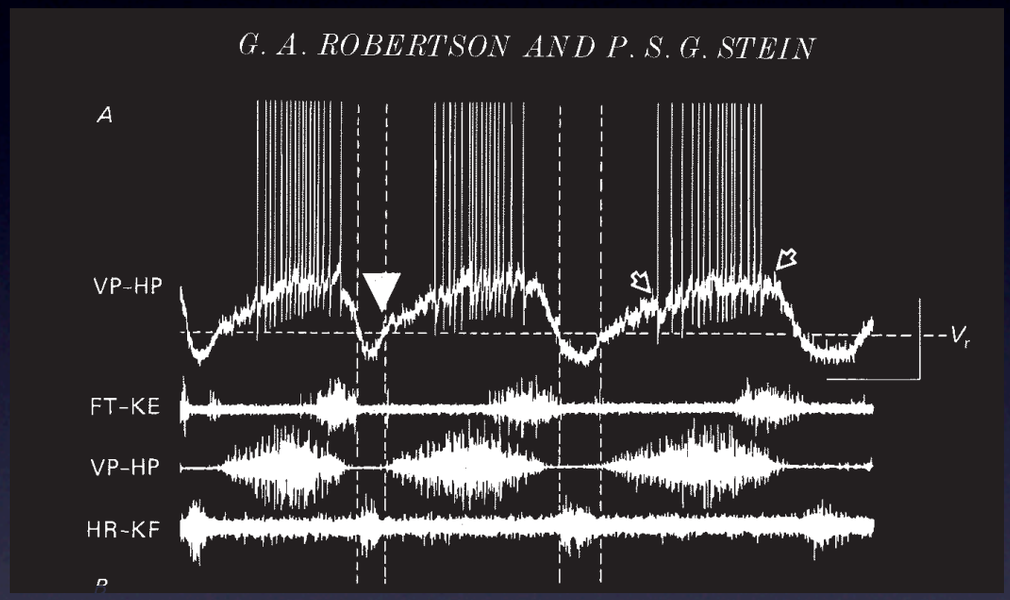
## by adding neuro-chemicals



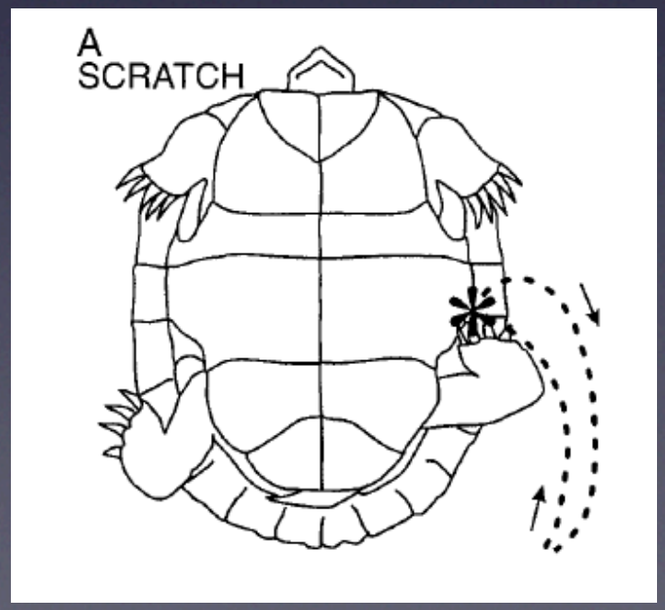

Goulding, *Nat Rev Neurosci* 2009

# Model for motor pattern generation:

## Turtle scratch reflex




Robertson & Stein, J. Physiol. 1988



# Sensory-specific scratching

Turtle is upside-down performing hindlimb scratching

# Recording Population activity



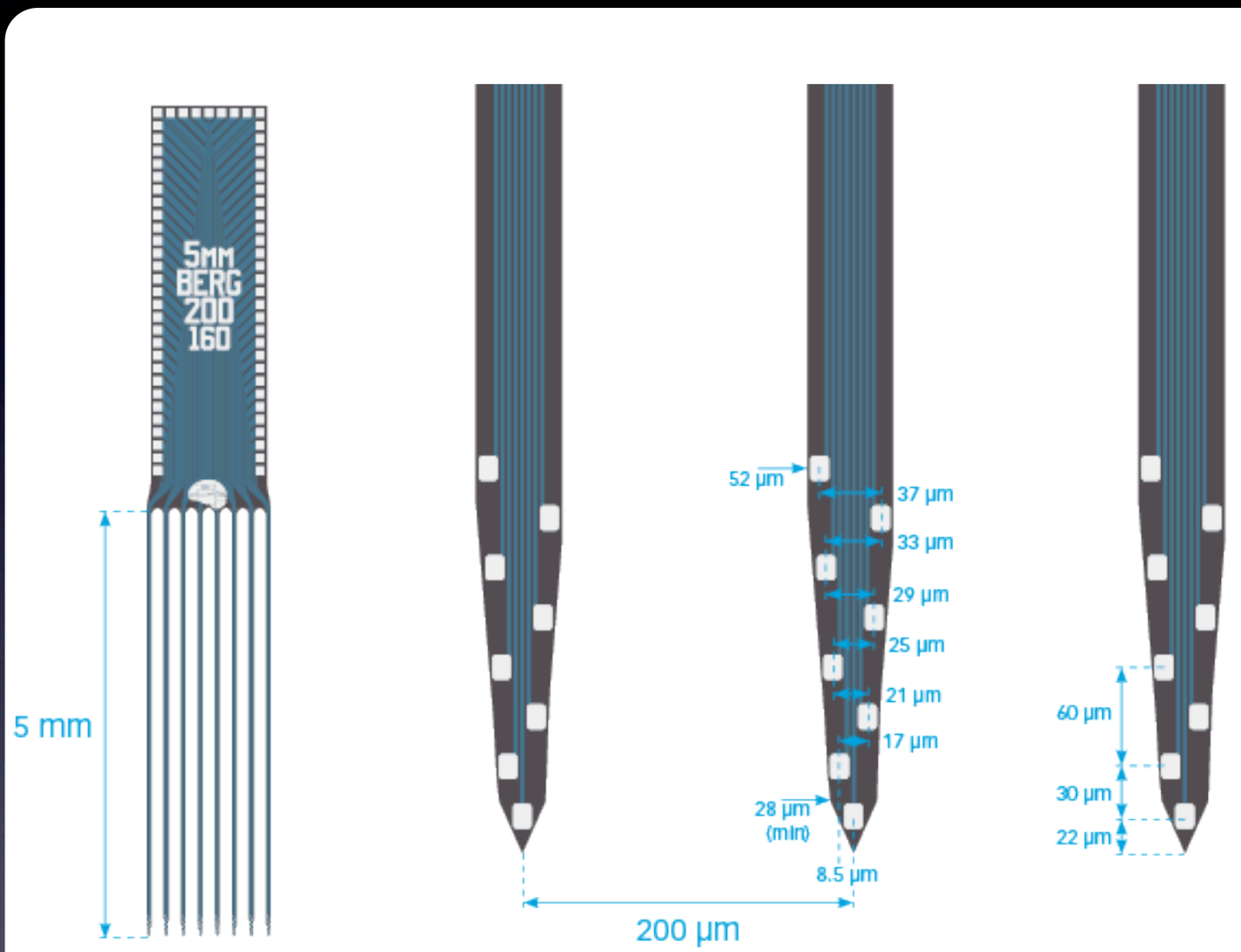
www.berg-lab.net ©

Peter Petersen

# Recording Population activity

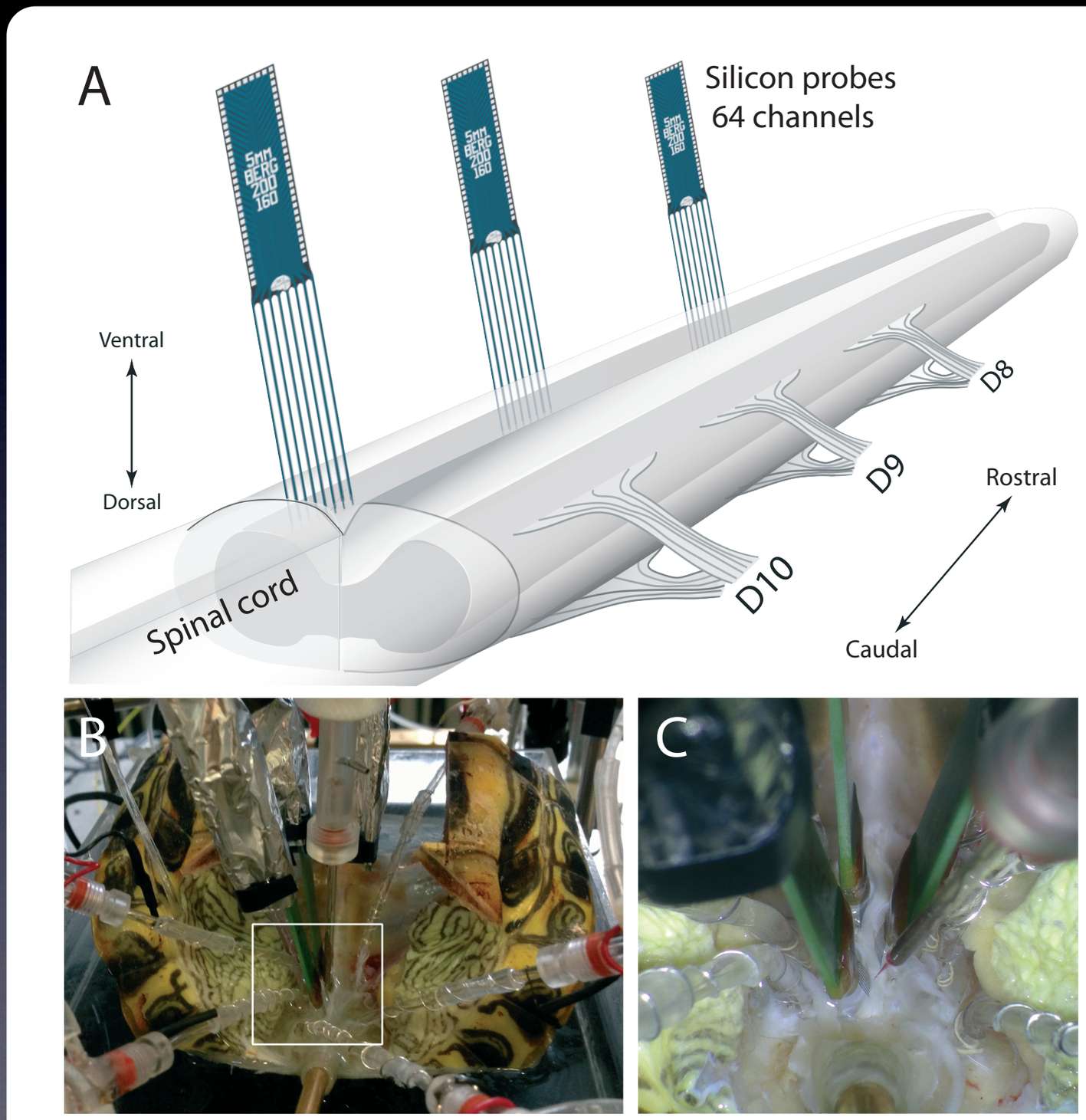
# Berg64-Probe by Neuronexus

www.neuronexus.com

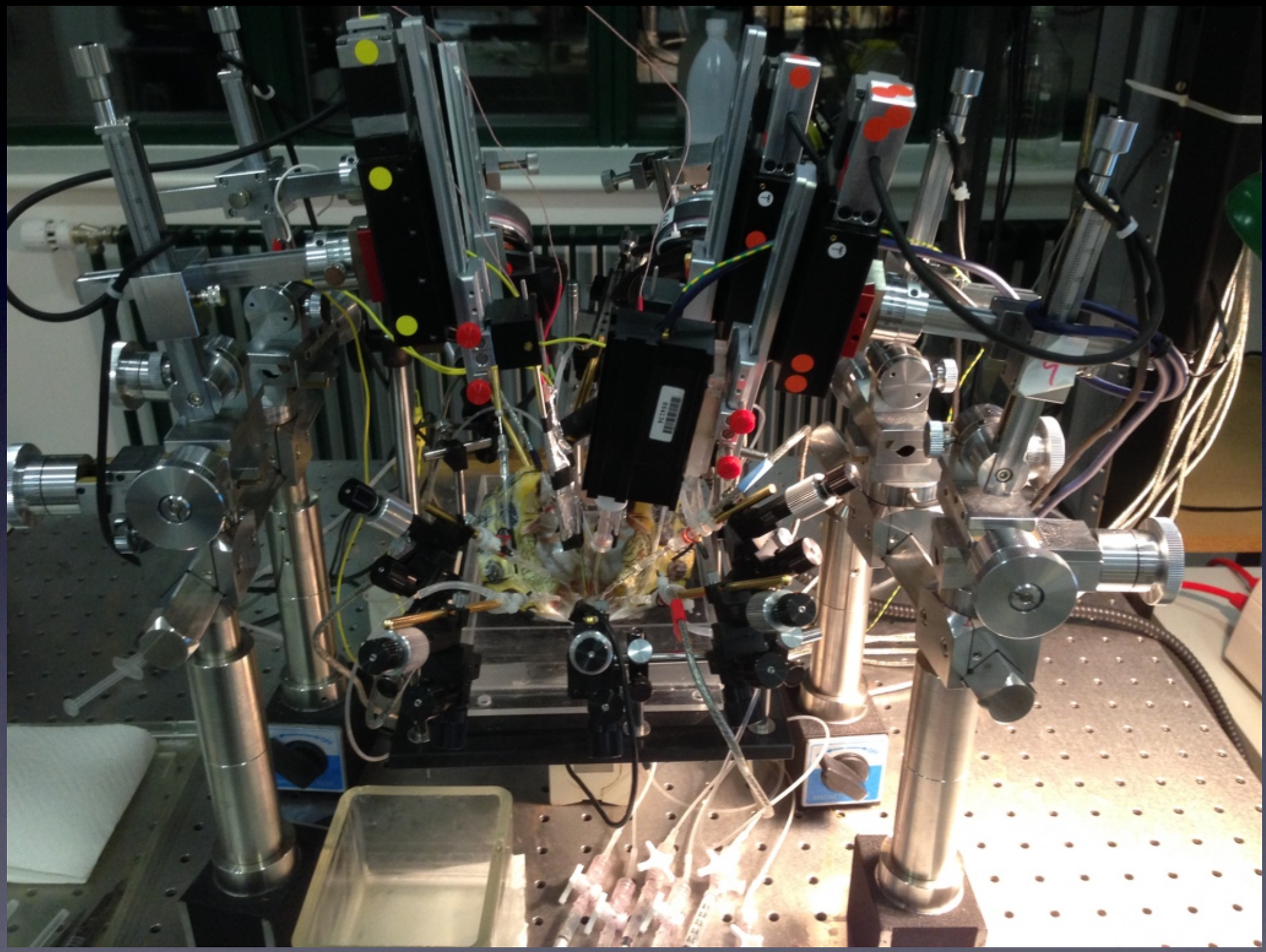



8 shanks with 8 leads = 64 ch

# Electrophysiology: Multichannel recording

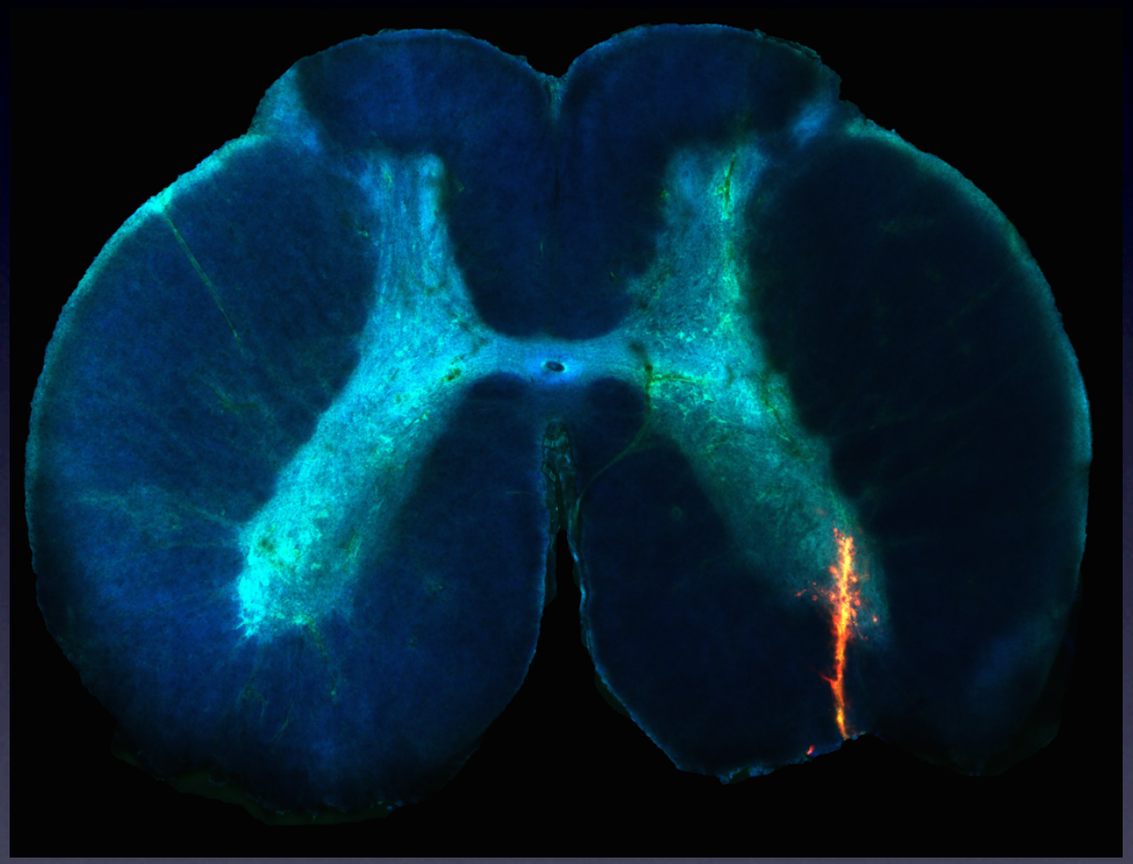


# Experimental Setup

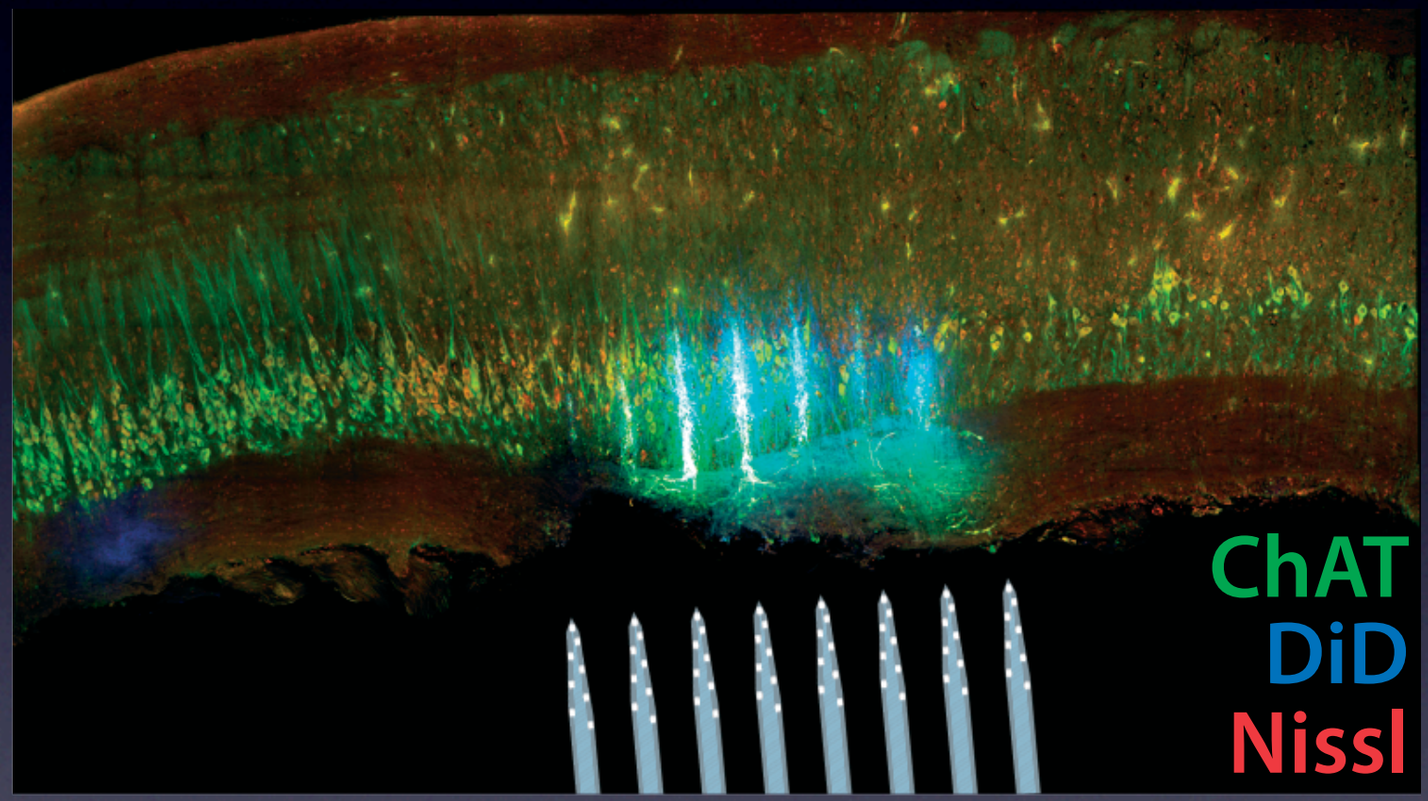


# Experimental Setup

# Histology
# DiD-labeling and Nissle



Transverse section




Sagittal section

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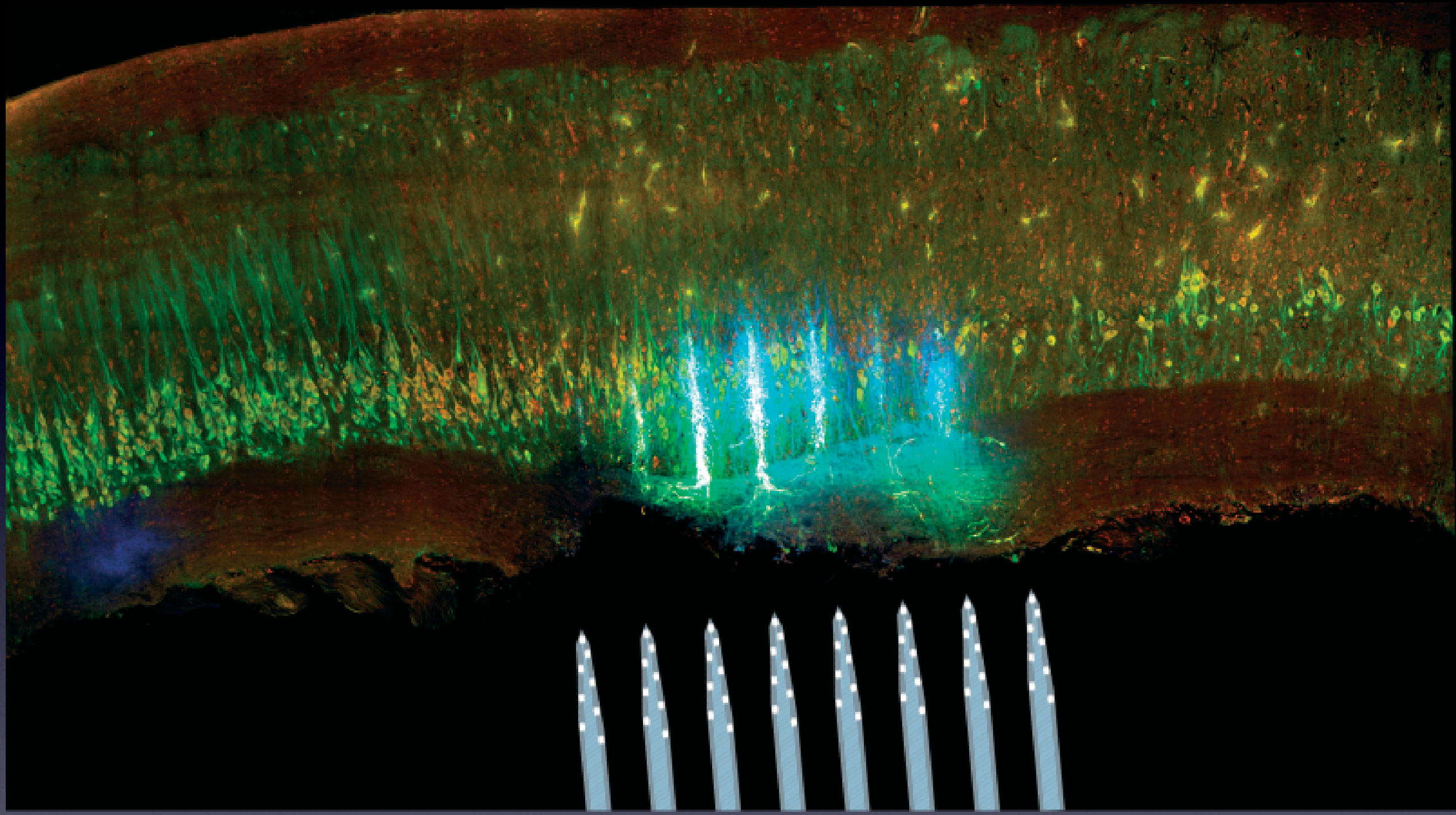
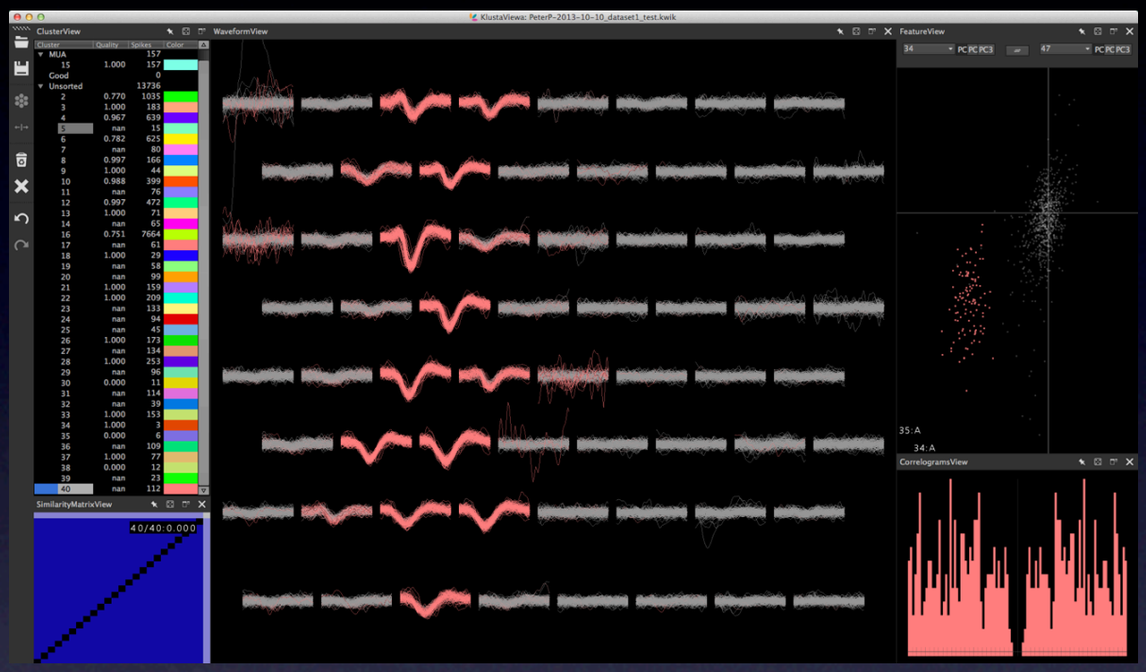
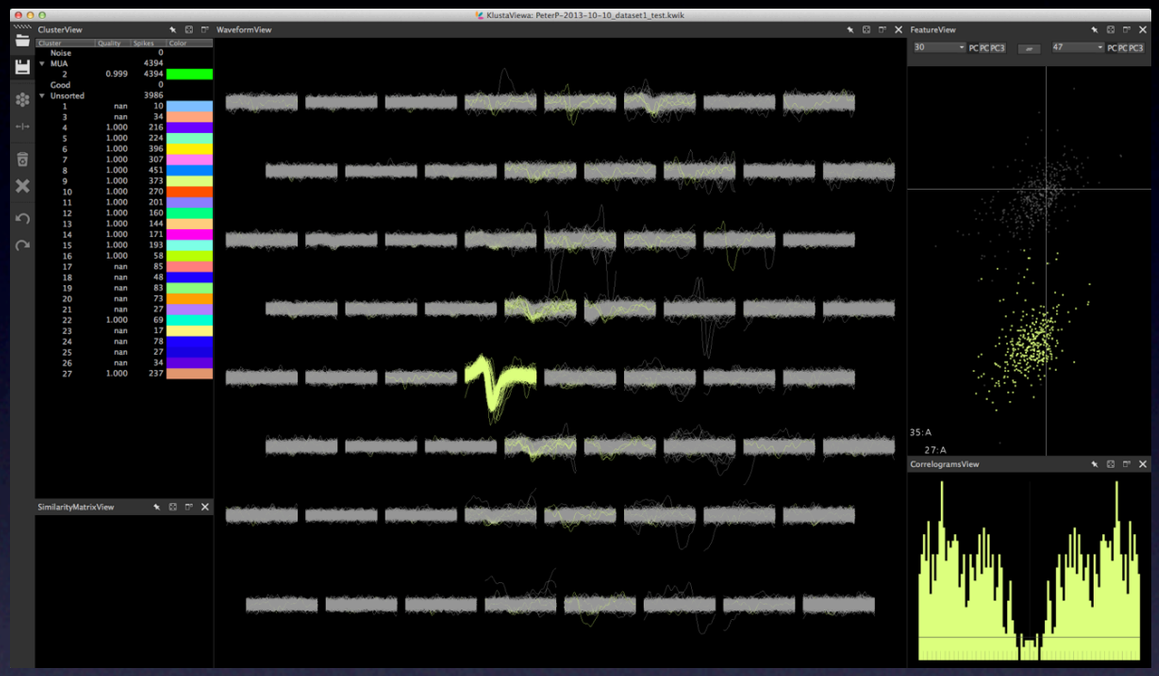
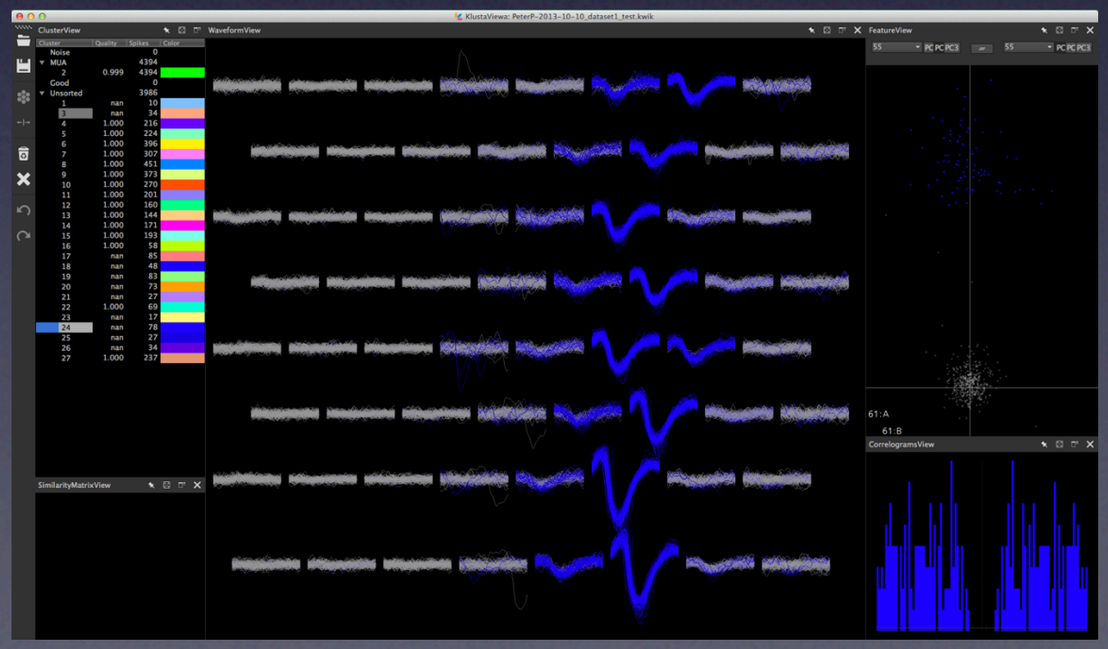


# Spike sorting

## Different units on same probe

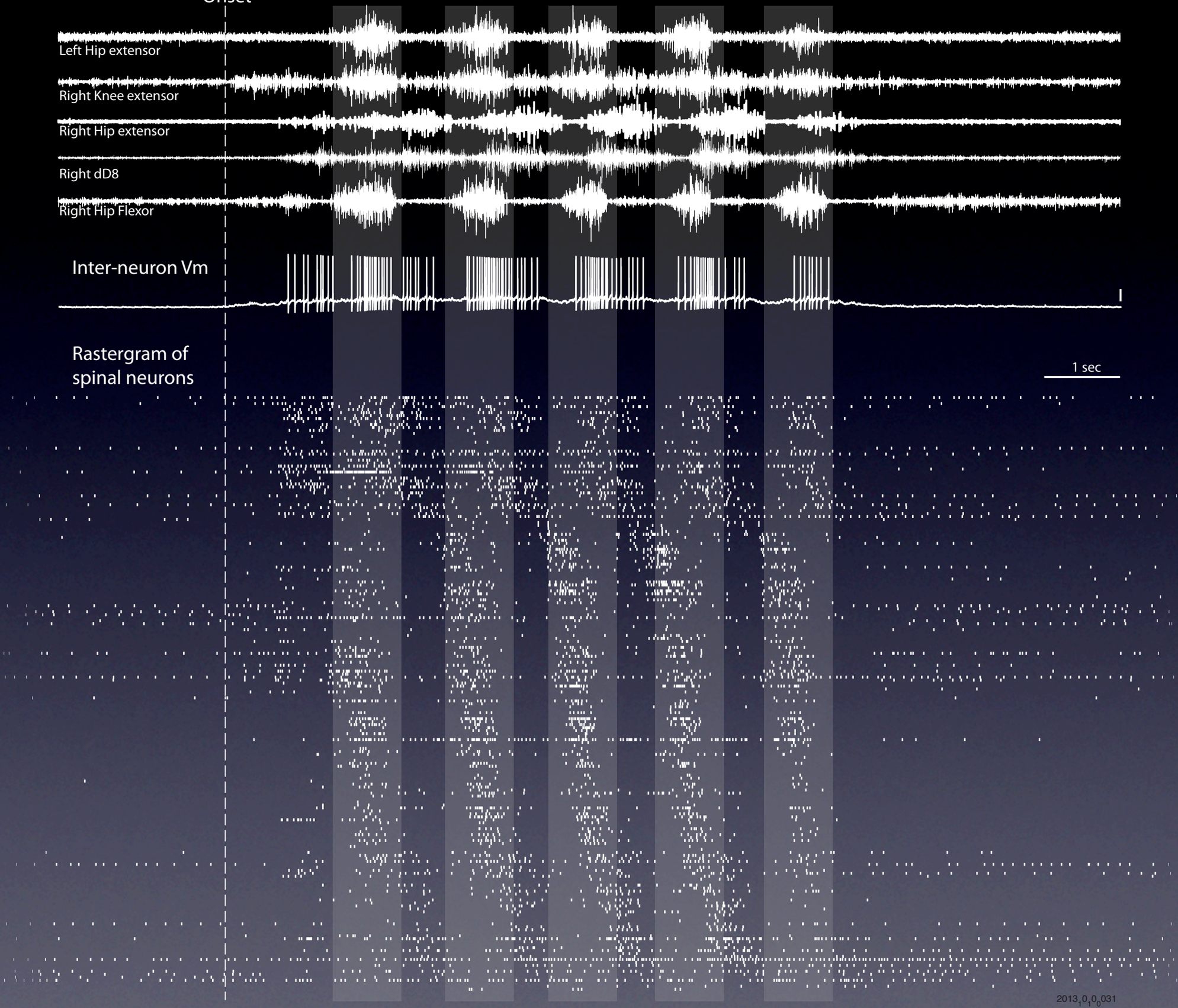






# Results

# Right Pocket scracth




2013$_1$0$_1$0$_0$031

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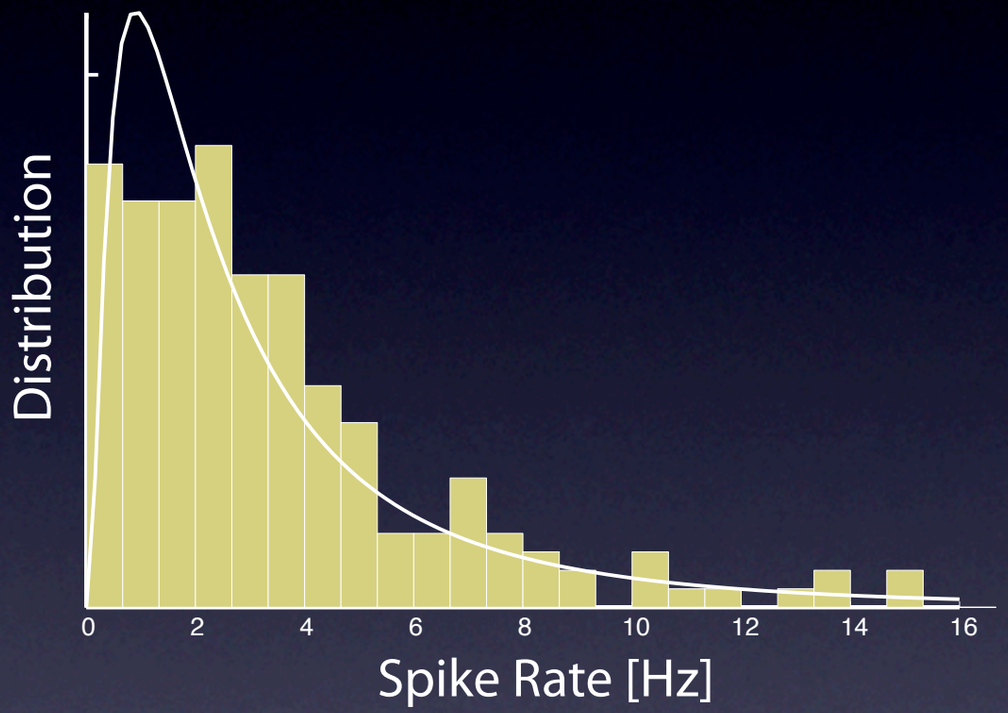
# Population Distribution of Spike Rates




Petersen and Berg, ***eLife 2016***

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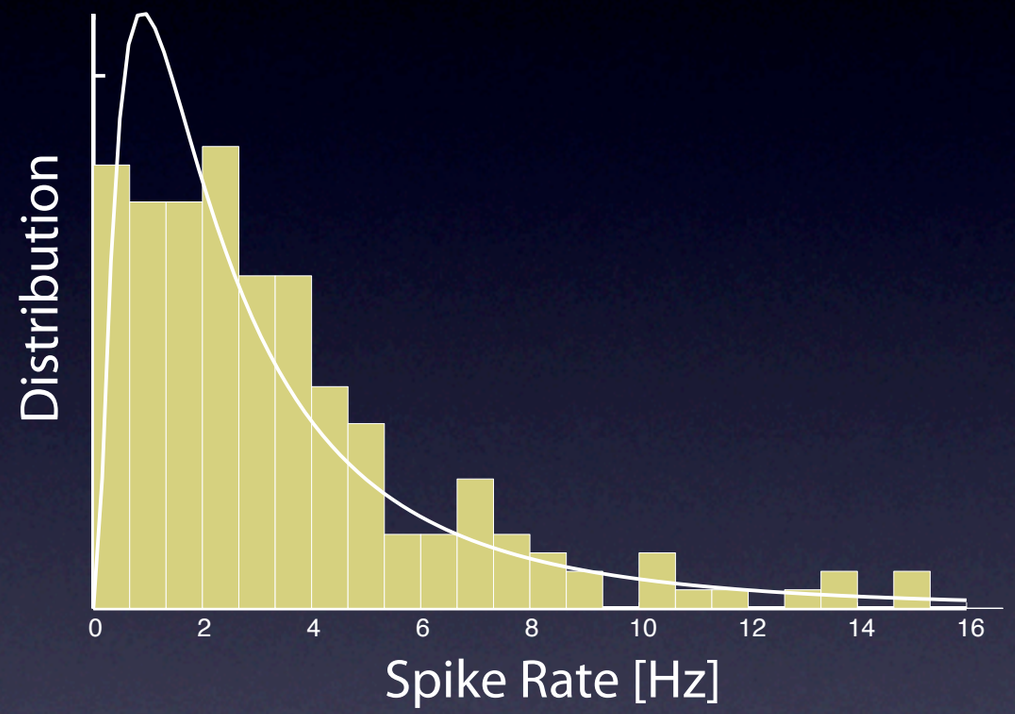
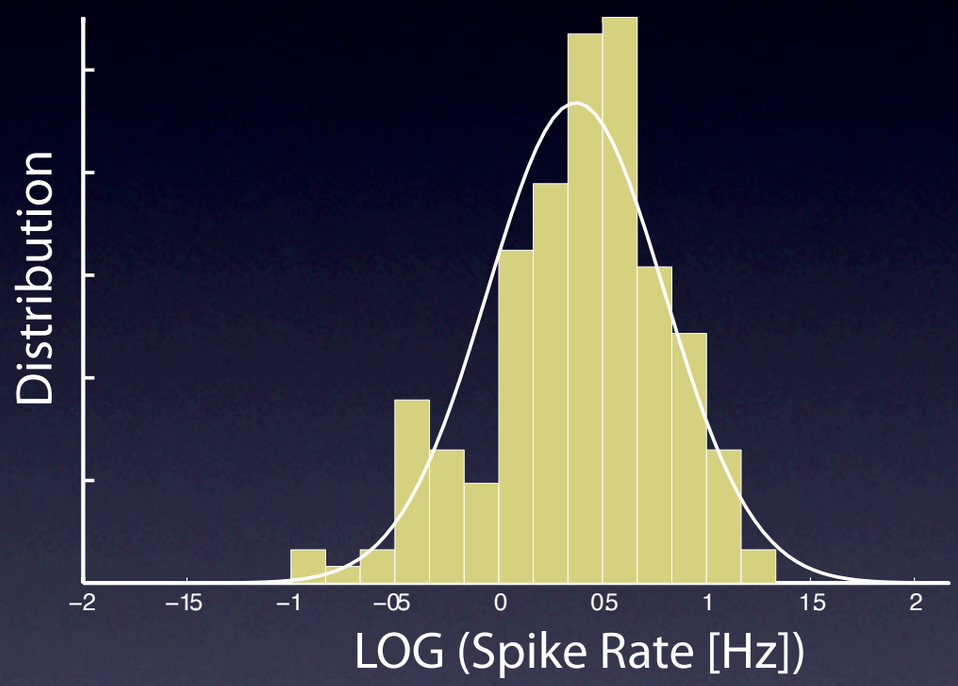
# Population Distribution of Spike Rates



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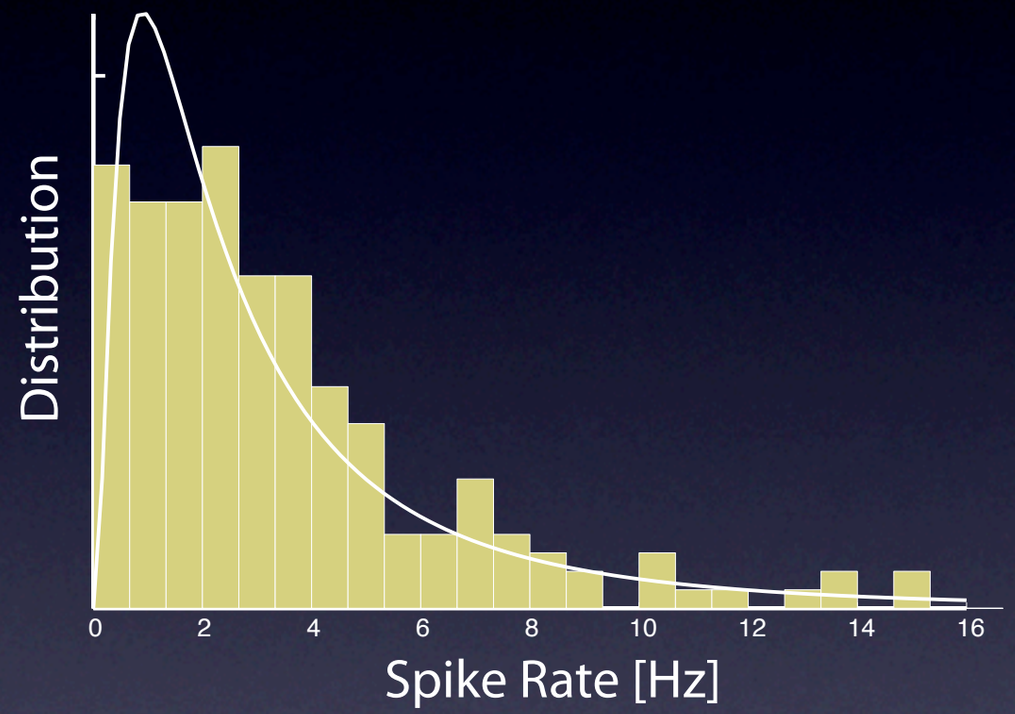
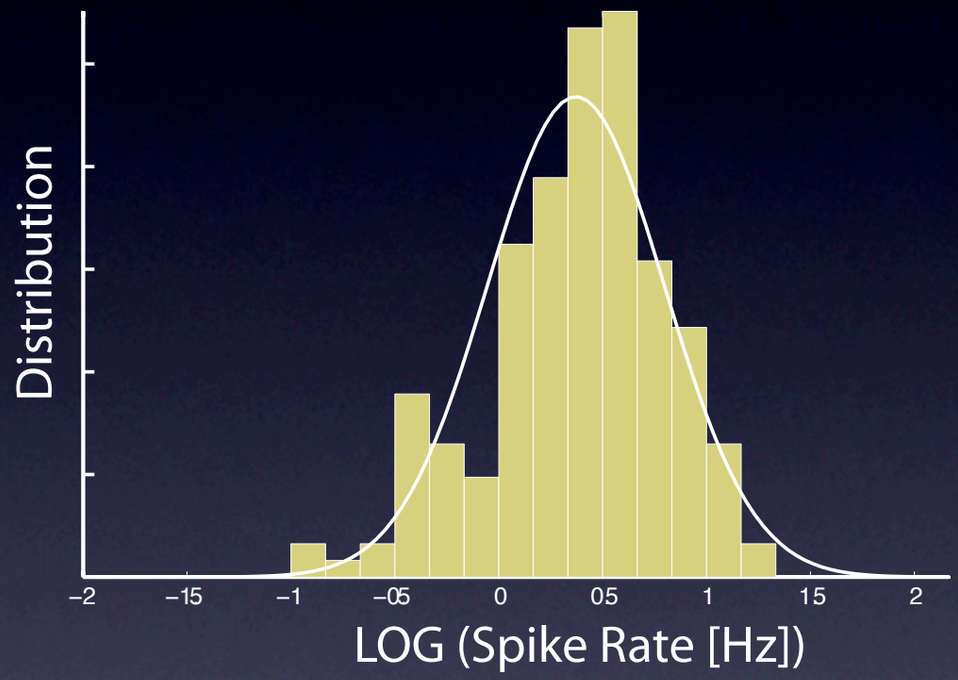
# Population Distribution of Spike Rates




## "Lognormal"

Buzsaki & Mizuseki 2014

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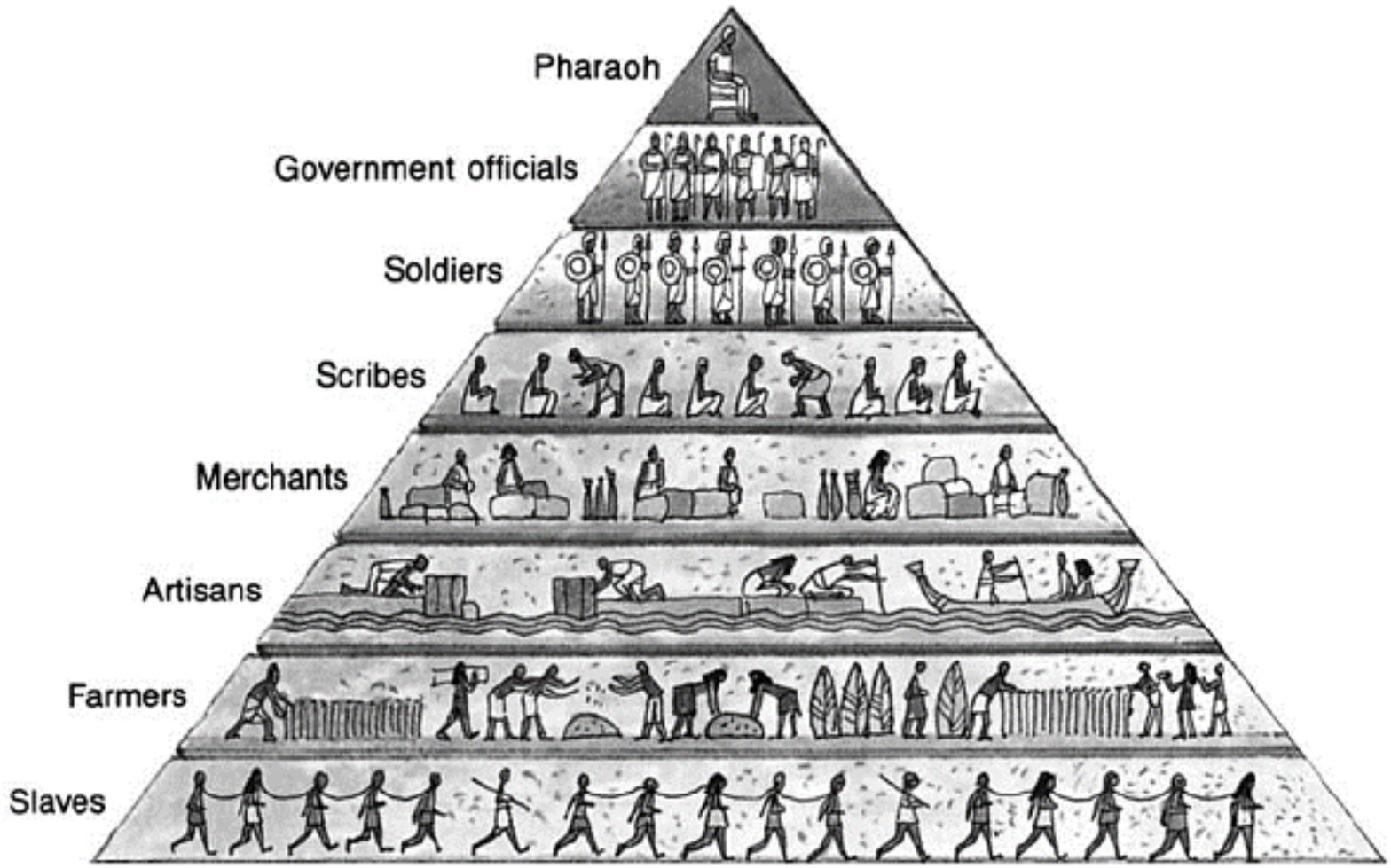
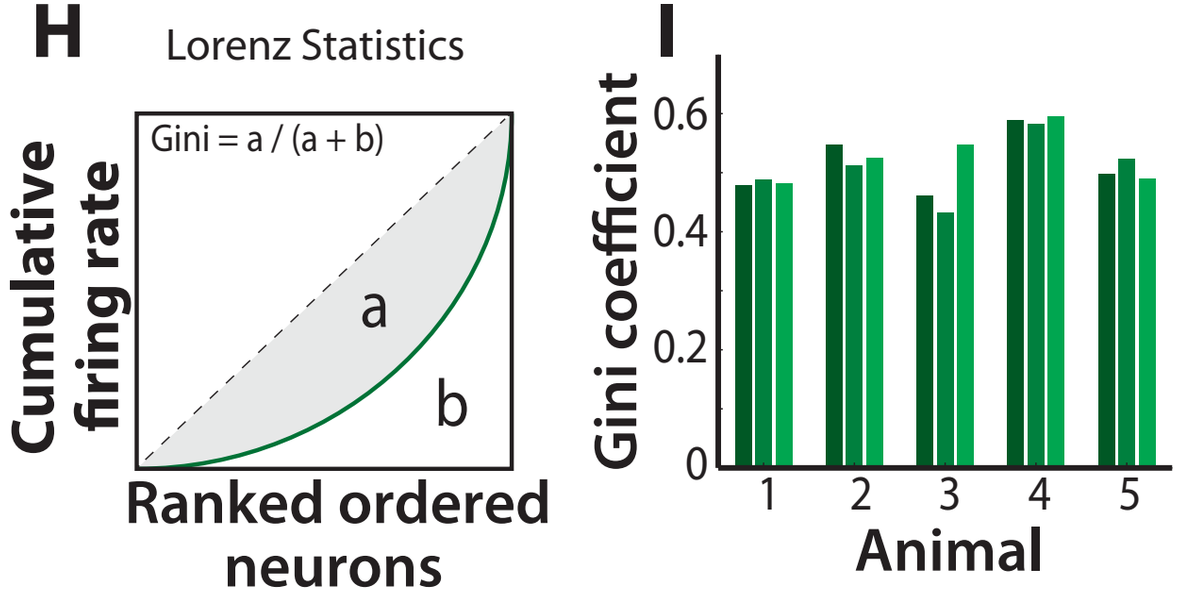
# Skewed distribution of power




Source: Barry K. Beyer et al., *The World Around Us: Eastern Hemisphere*, MacMillan Publishing (adapted)

# Gini coefficient (measure of wealth inequality)

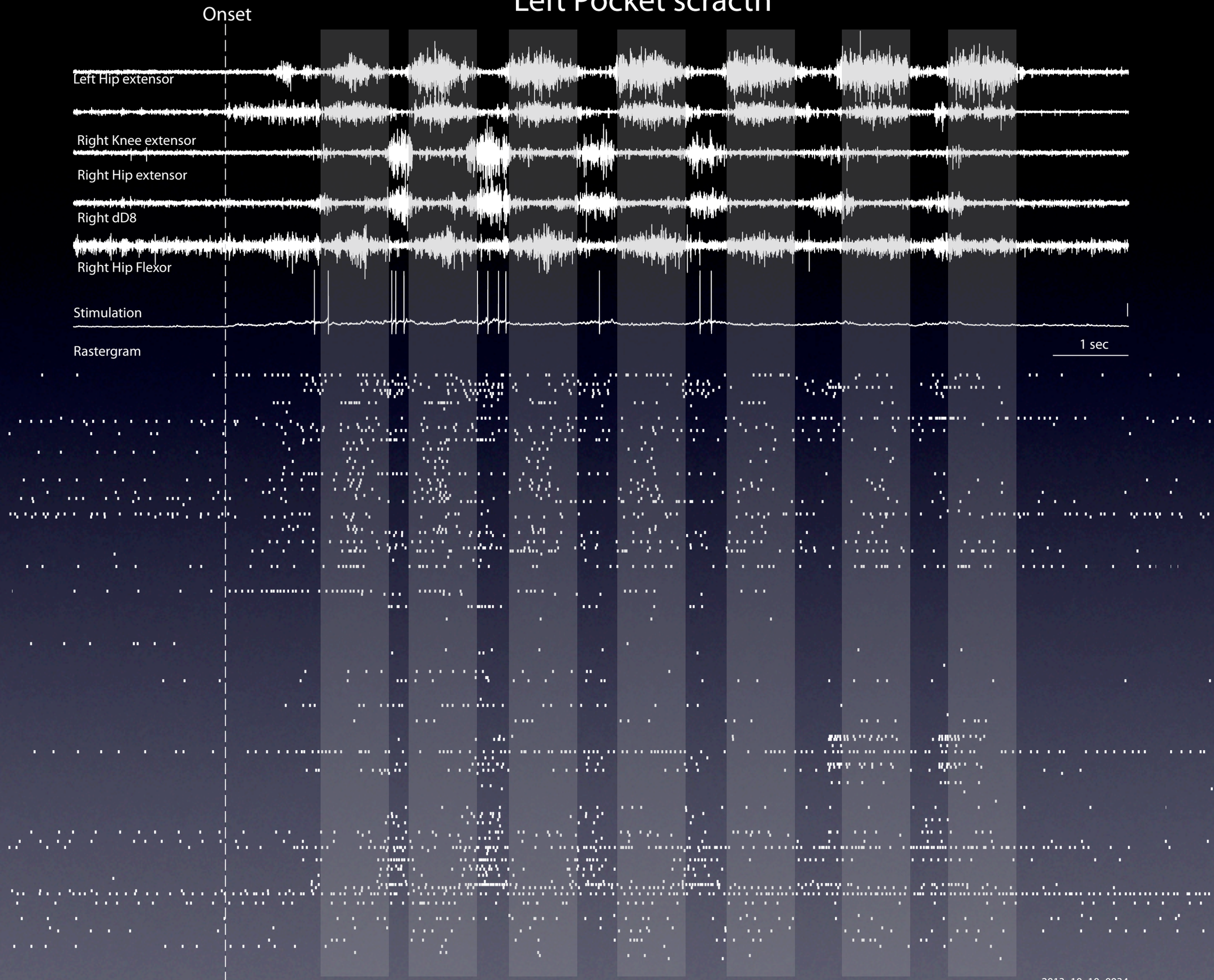



Most countries:
Gini = 0.3-0.4

World:
Gini = 0.7

Petersen and Berg, *in preparation*

# Left Pocket scracth




2013_10_10_0034

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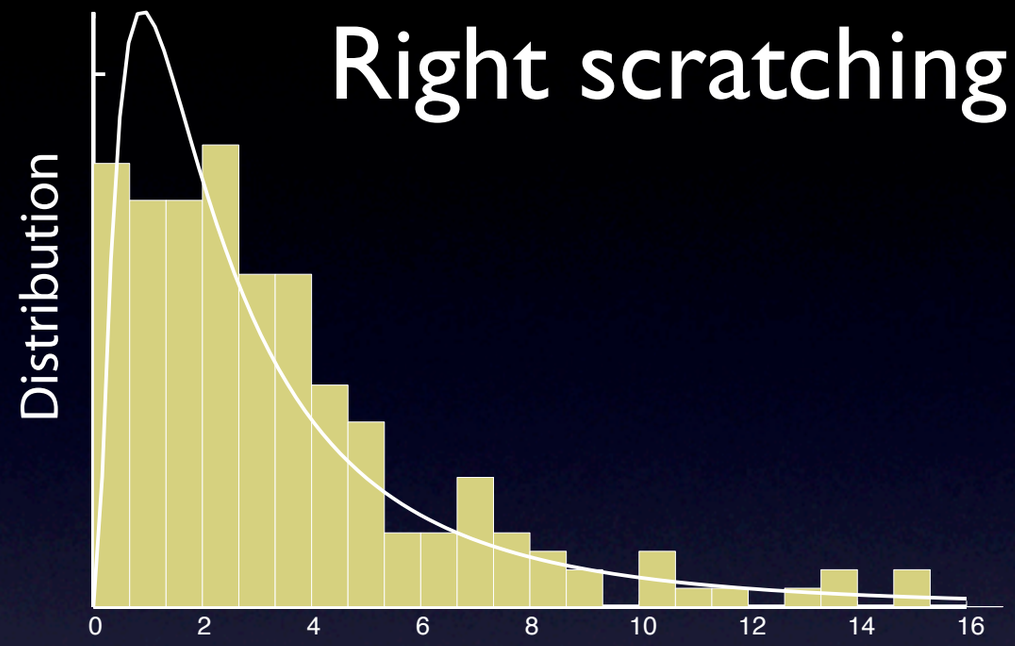
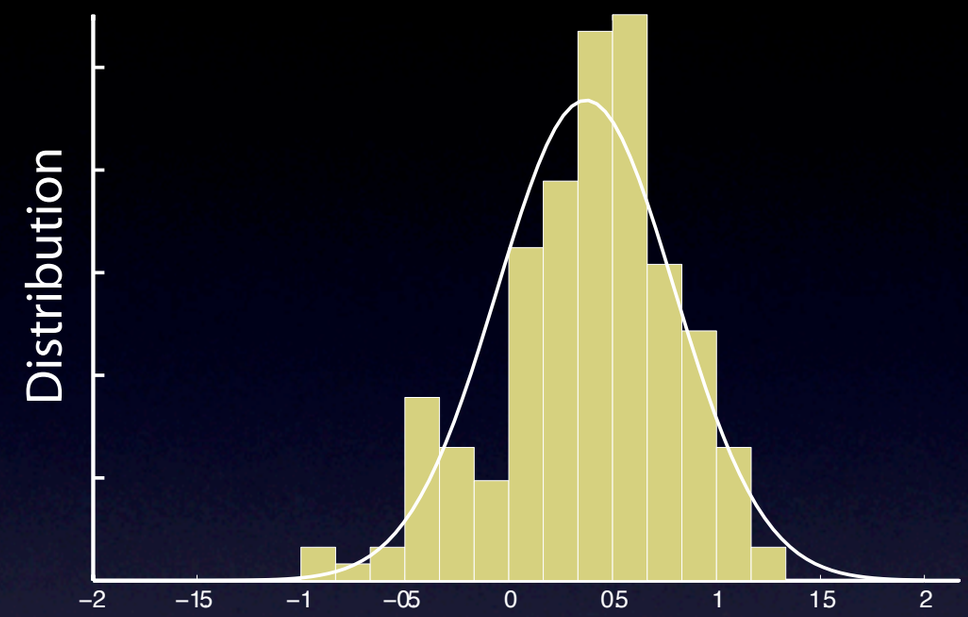
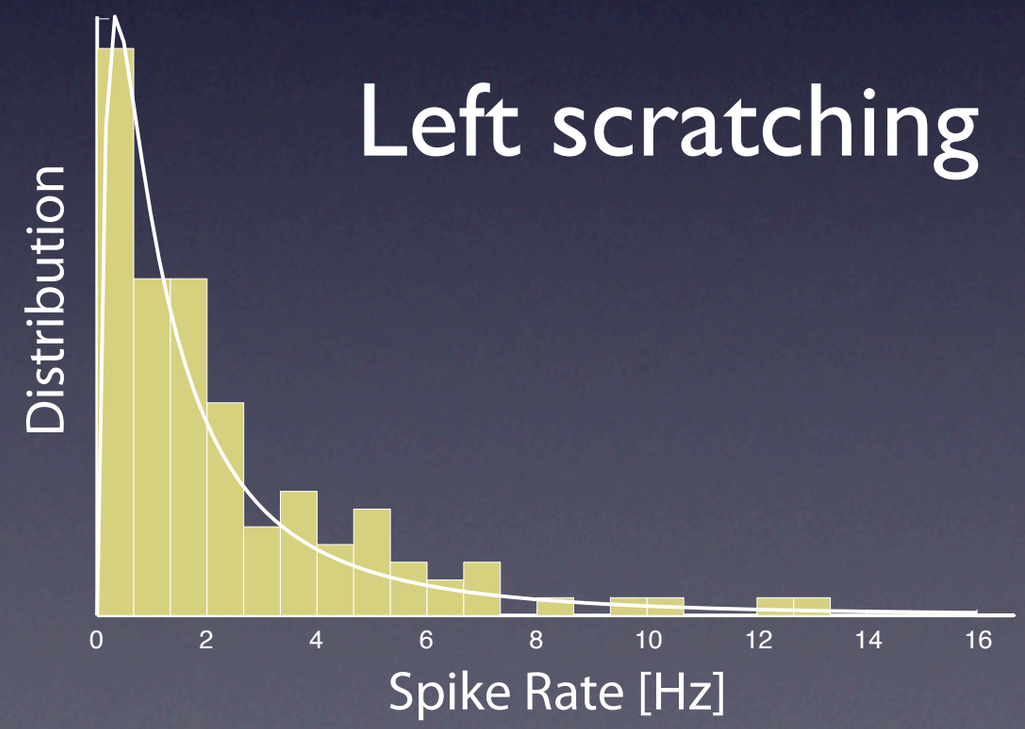
# Distribution of Spike Rates

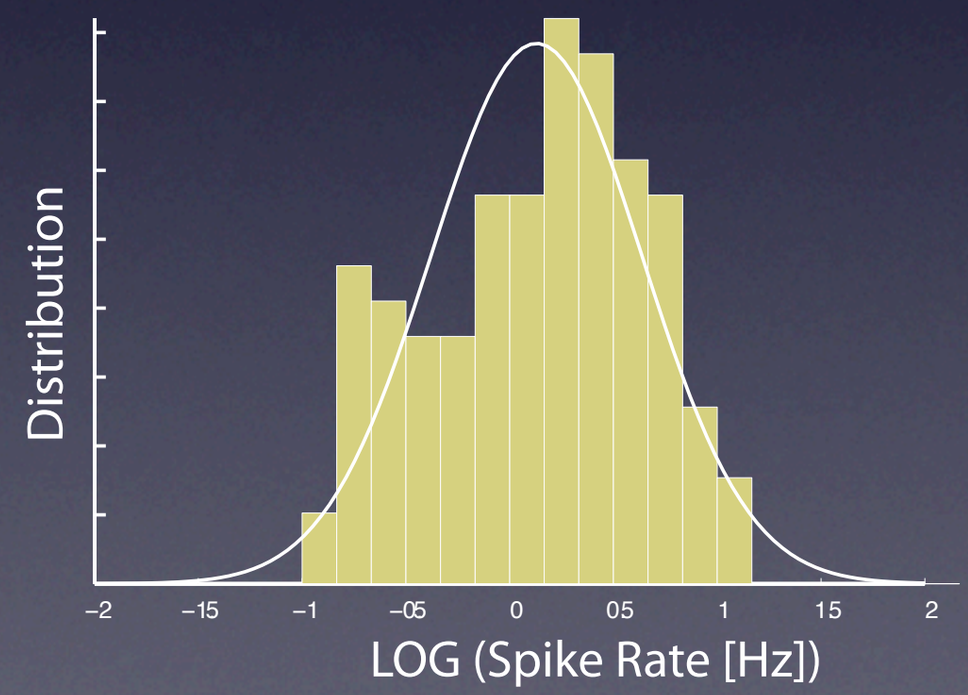
## Right scratching




## Left scratching




Petersen and Berg, ***eLife 2016***

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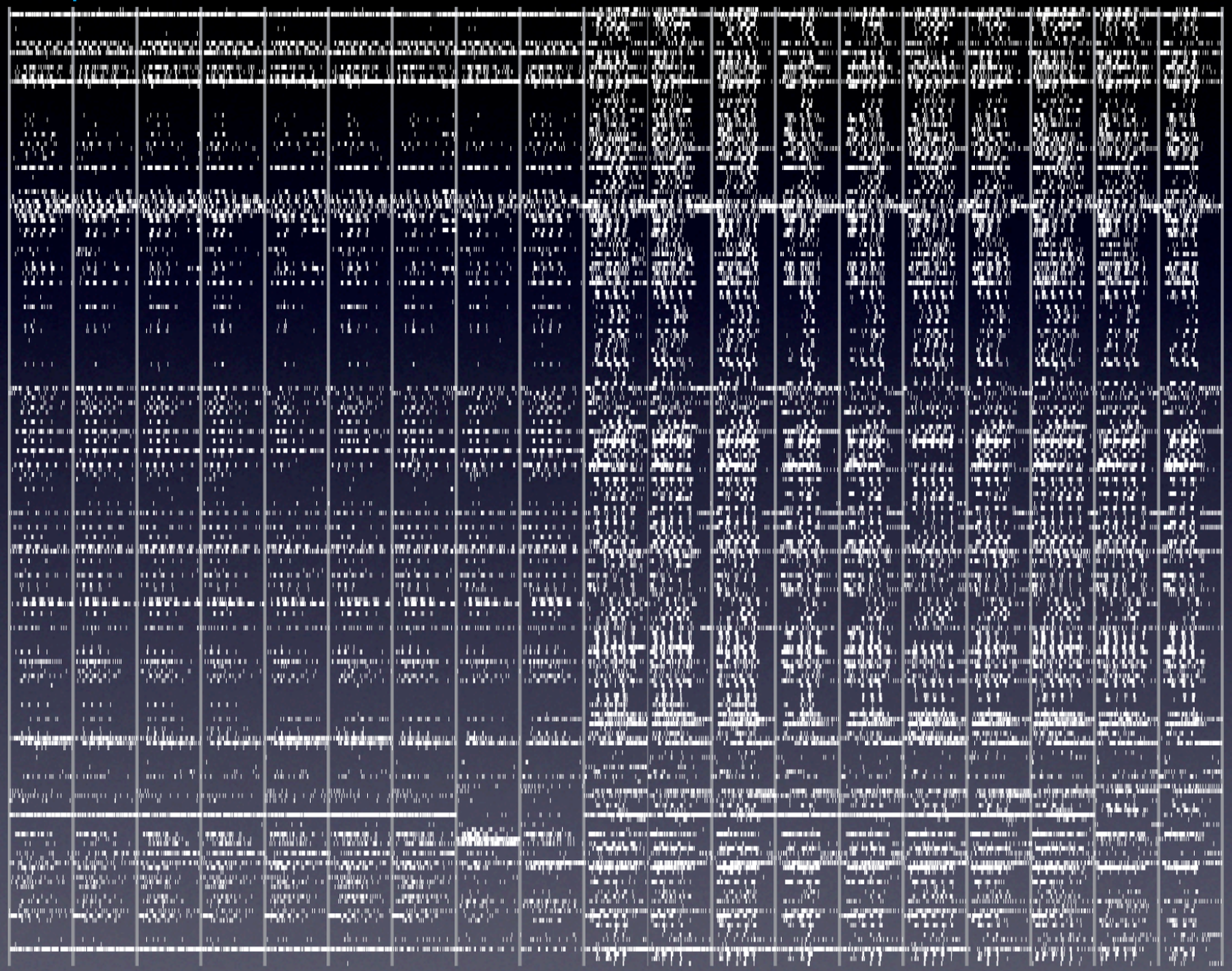
# Reproducibility

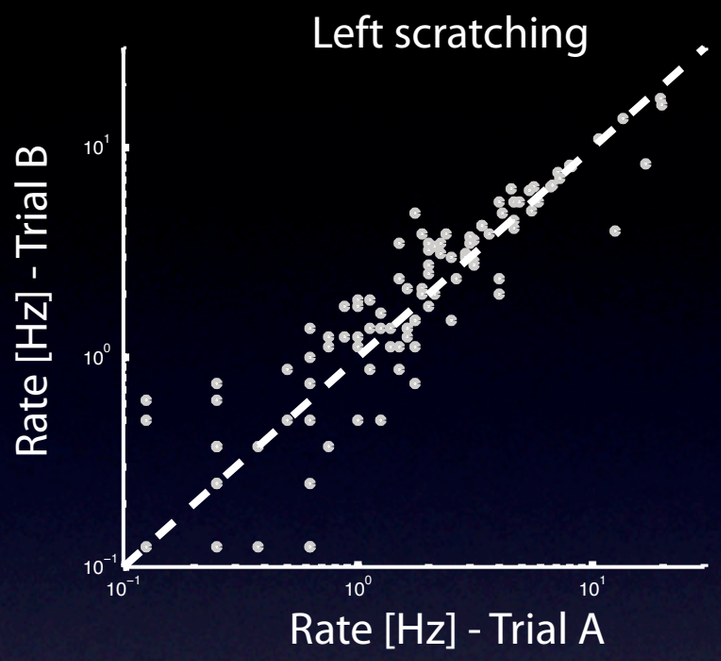
Left pocket scratch

Right pocket scratch

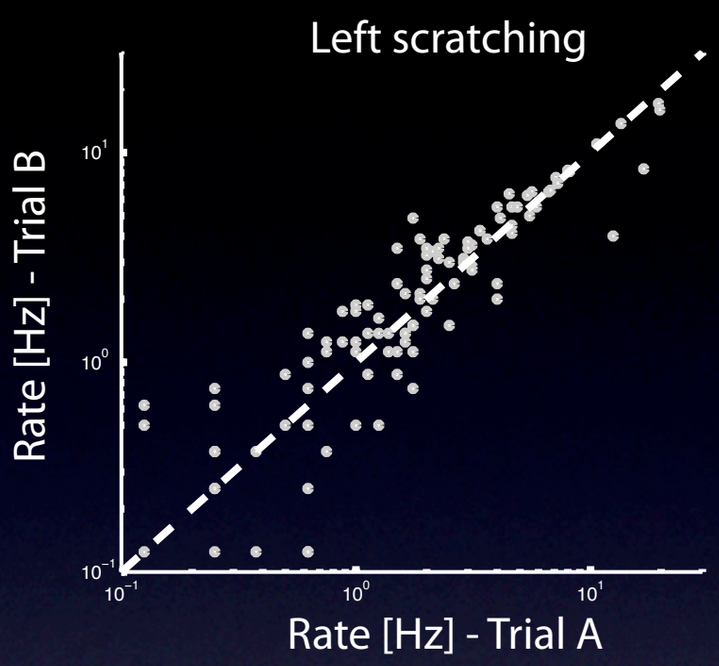


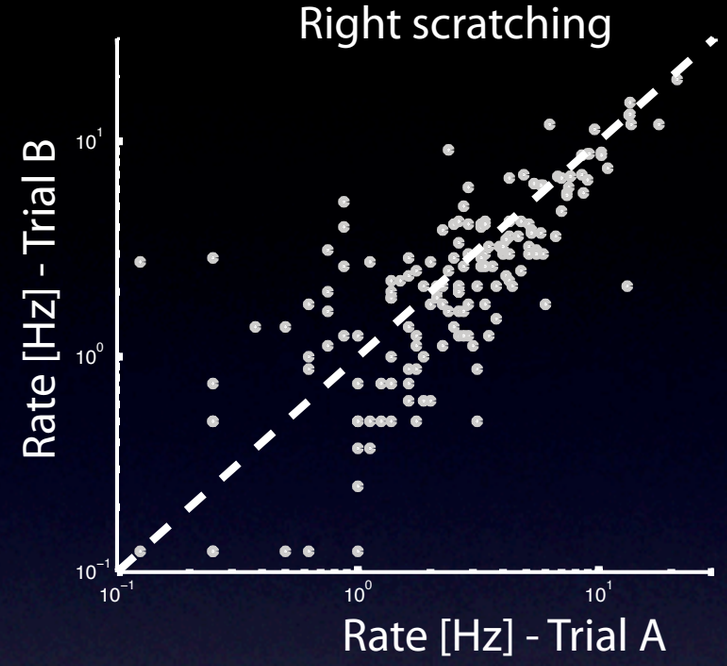
20 sec

Petersen and Berg, *in preparation*

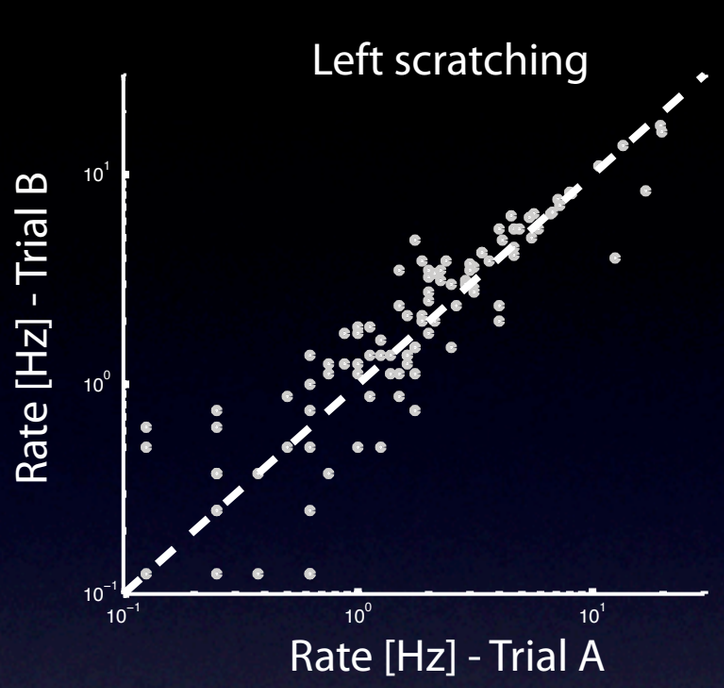


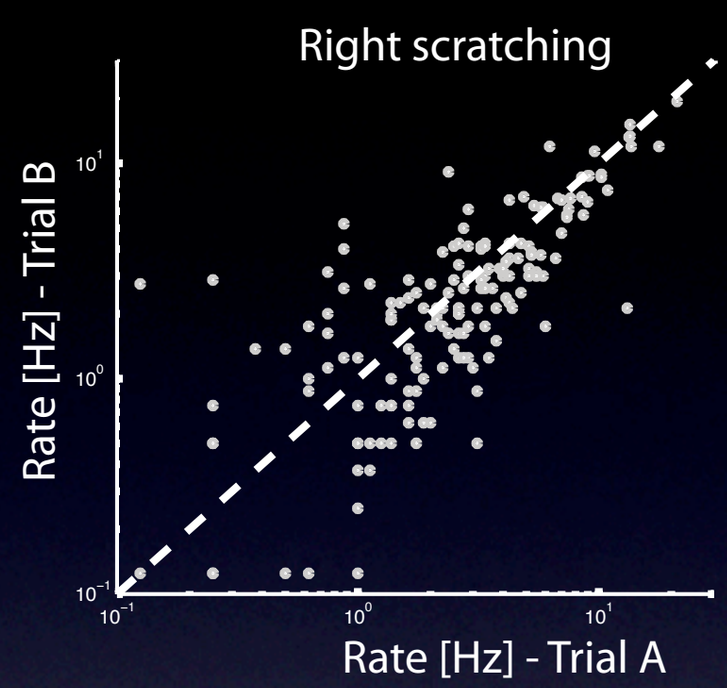

Petersen and Berg, *in preparation*

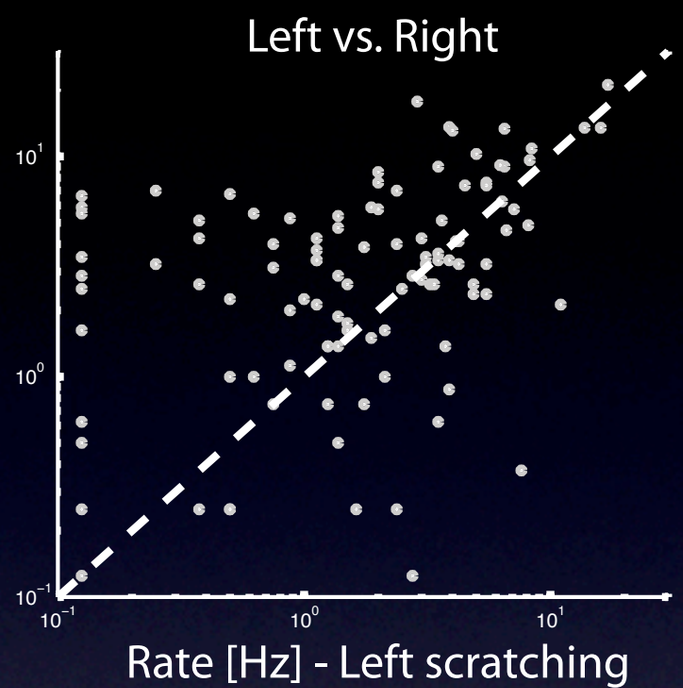


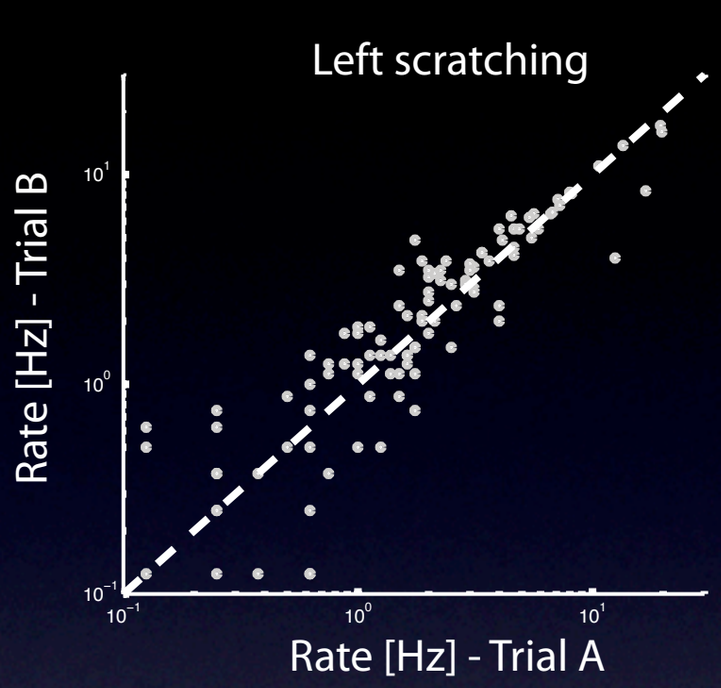

Petersen and Berg, *in preparation*

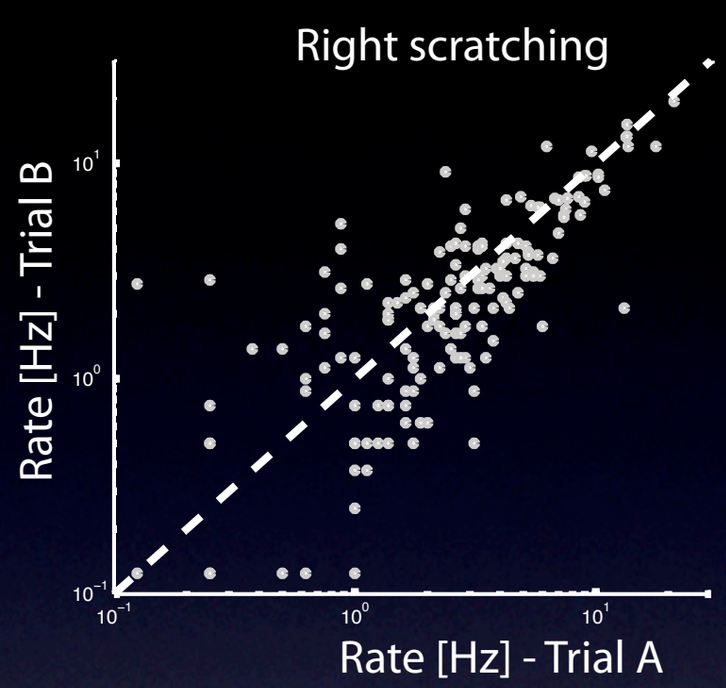


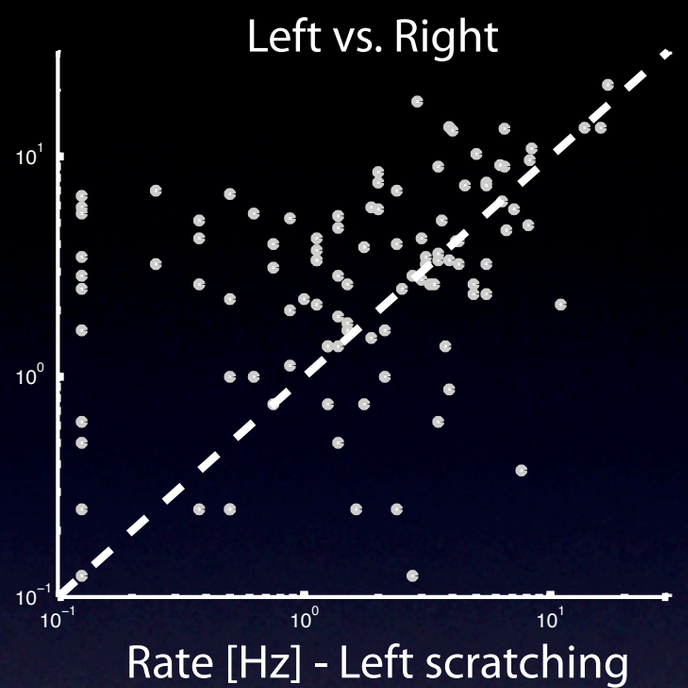



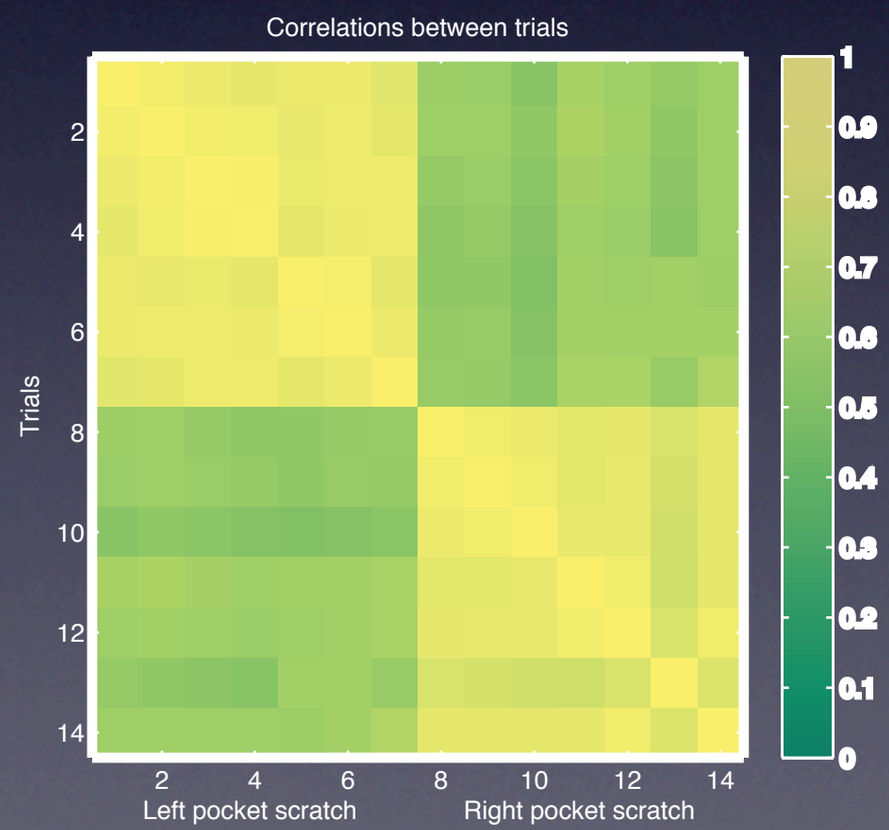




Petersen and Berg, *in preparation*




Petersen and Berg, *in preparation*

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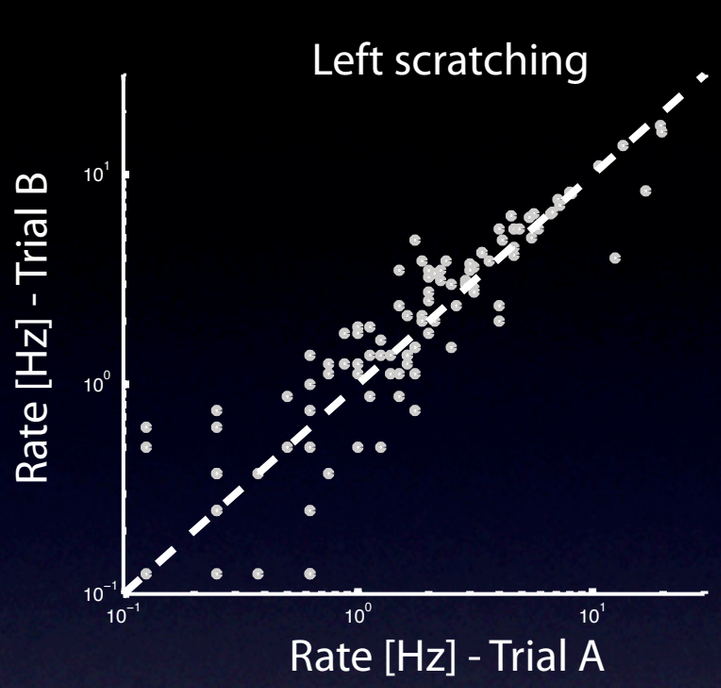
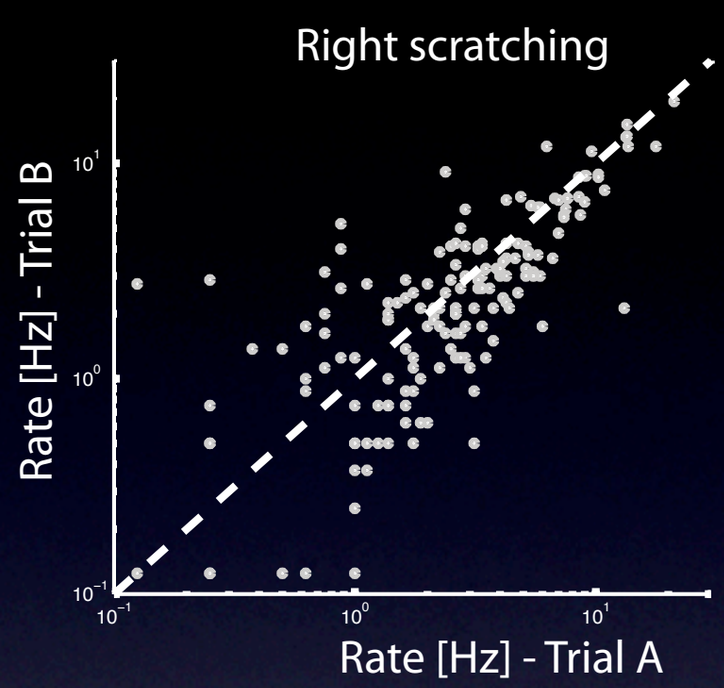
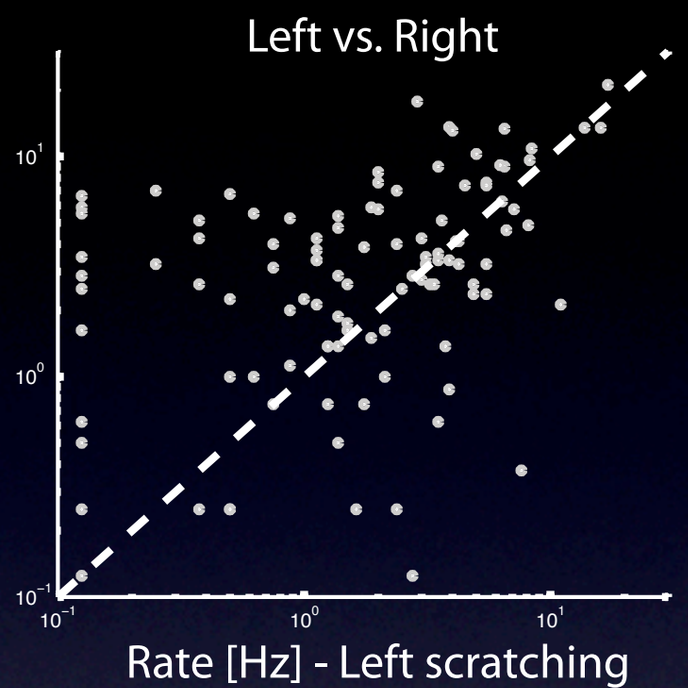
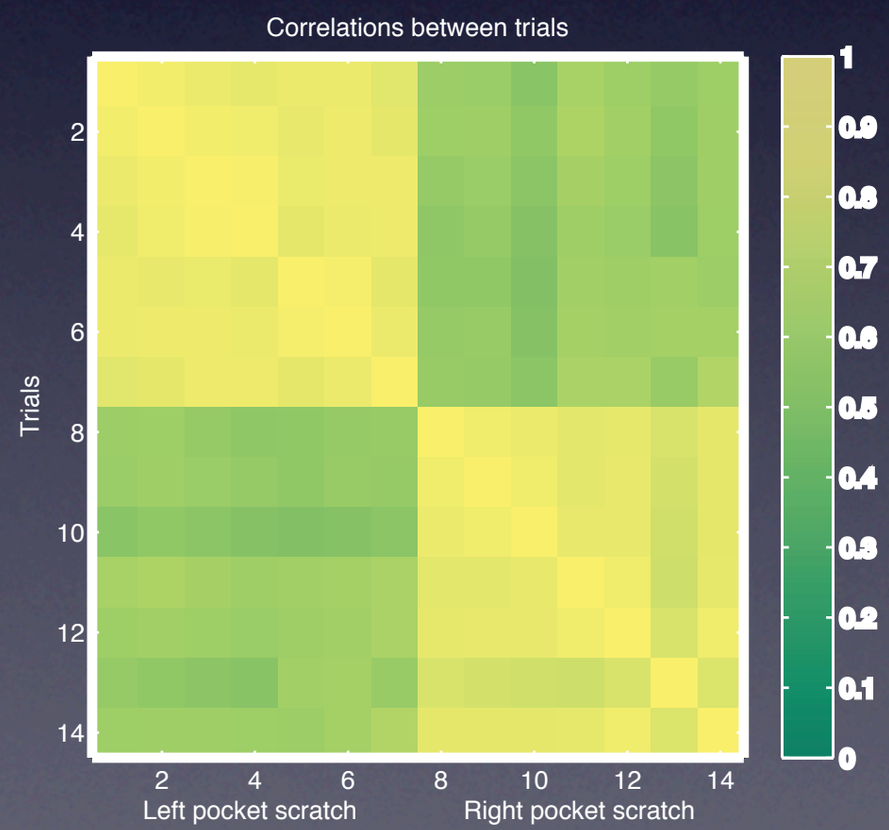
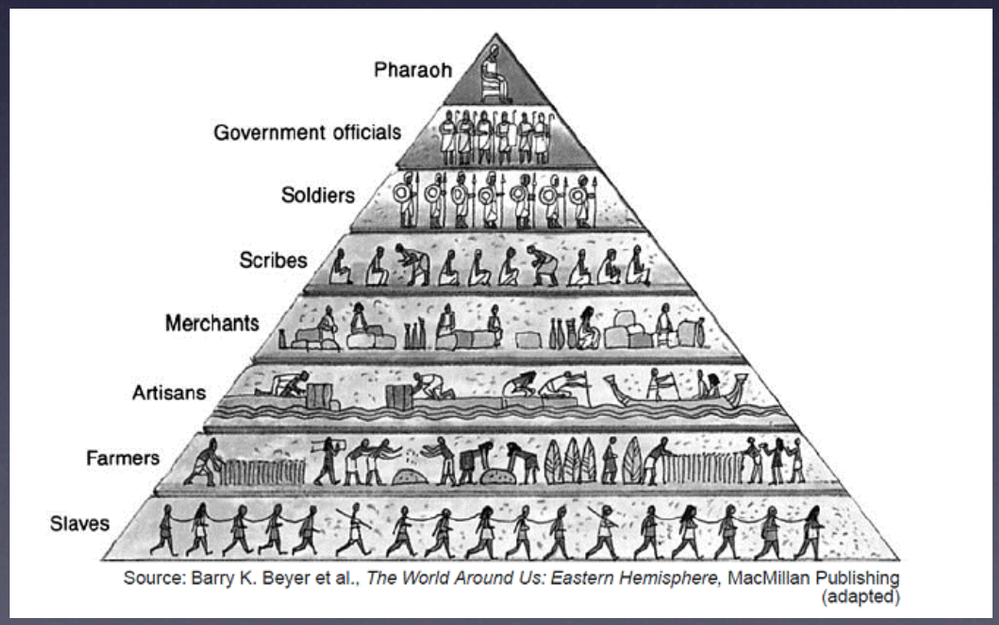



# Skewness conserved across behaviors




Petersen and Berg, *in preparation*

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# Division of labor

# Mechanism behind skewed distribution?

Behavioral/Systems/Cognitive

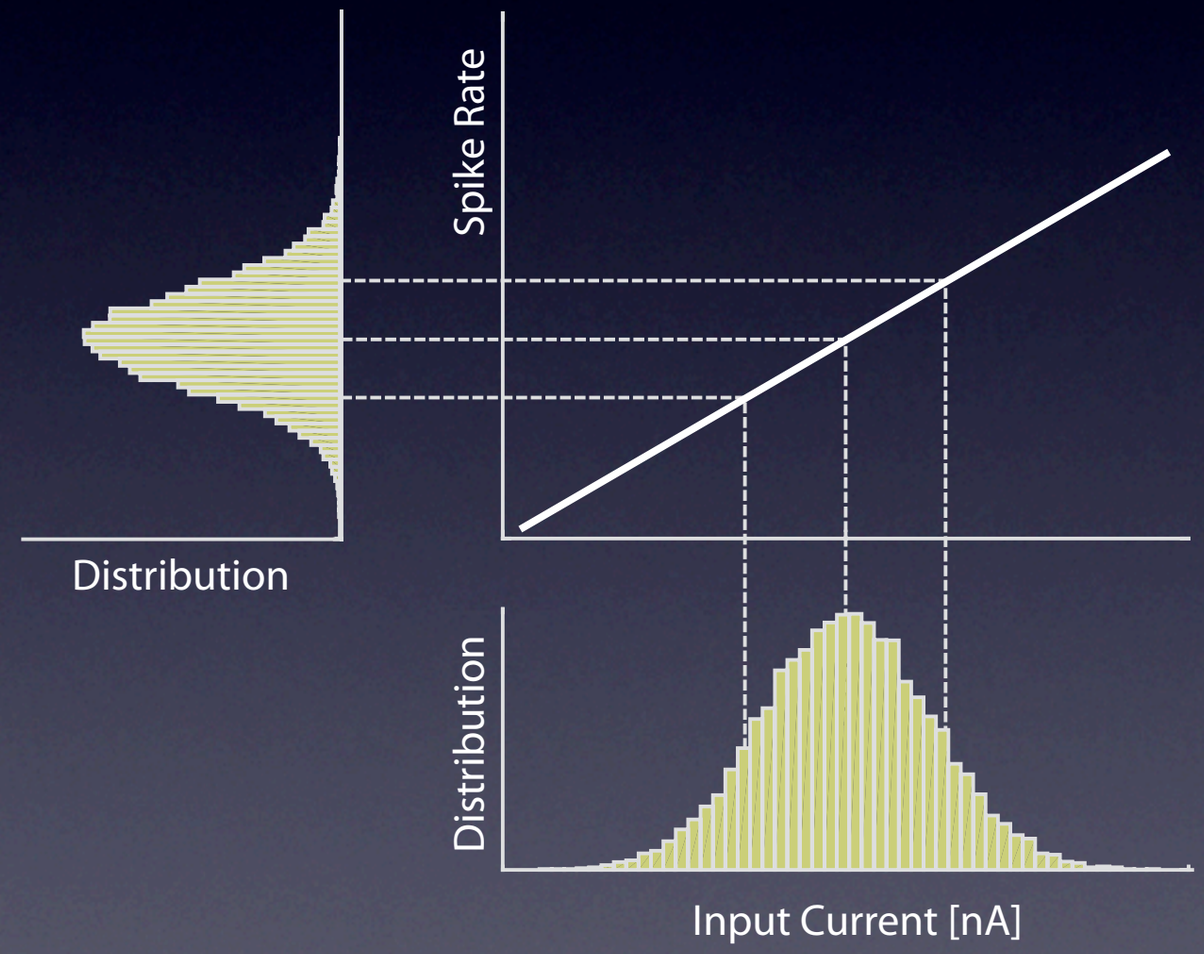
# On the Distribution of Firing Rates in Networks of Cortical Neurons

**Alex Roxin,[1,3] Nicolas Brunel,[2] David Hansel,[2,4] Gianluigi Mongillo,[2] and Carl van Vreeswijk[2]**

[1]Center for Theoretical Neuroscience, Columbia University, New York, New York 10032, [2]Centre National de la Recherche Scientifique, Unité Mixte de Recherche 8119, Université Paris Descartes, 75270 Paris, France, [3]Insitut d'Investigacions Biomèdiques August Pi i Sunyer, Barcelona 08036, Spain, and [4]Interdisciplinary Center for Neural Computation, Hebrew University, 91904 Jerusalem, Israel

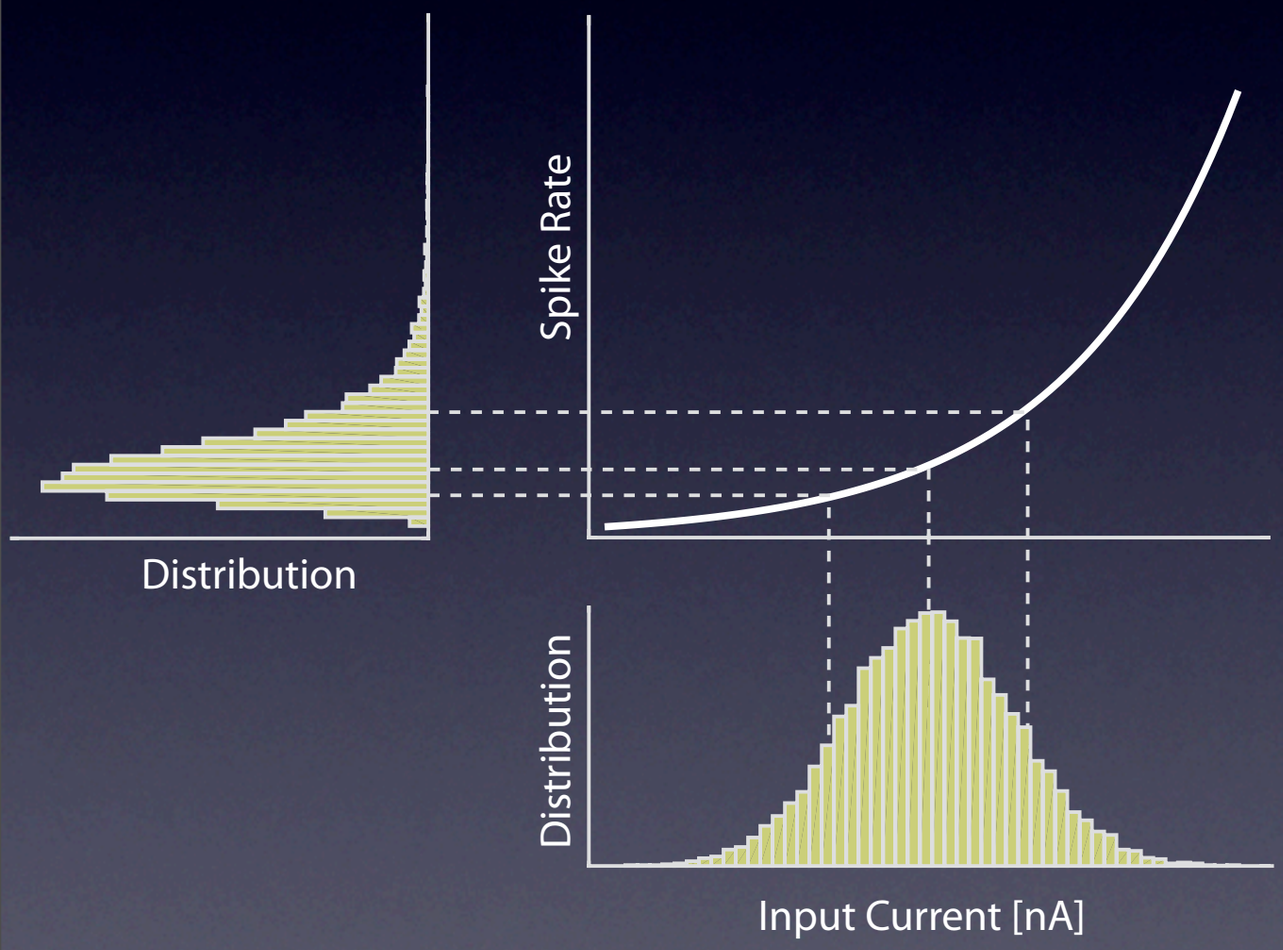
"We argue that skewed rate distributions are a signature of the nonlinearity of the in vivo F-I-curve"

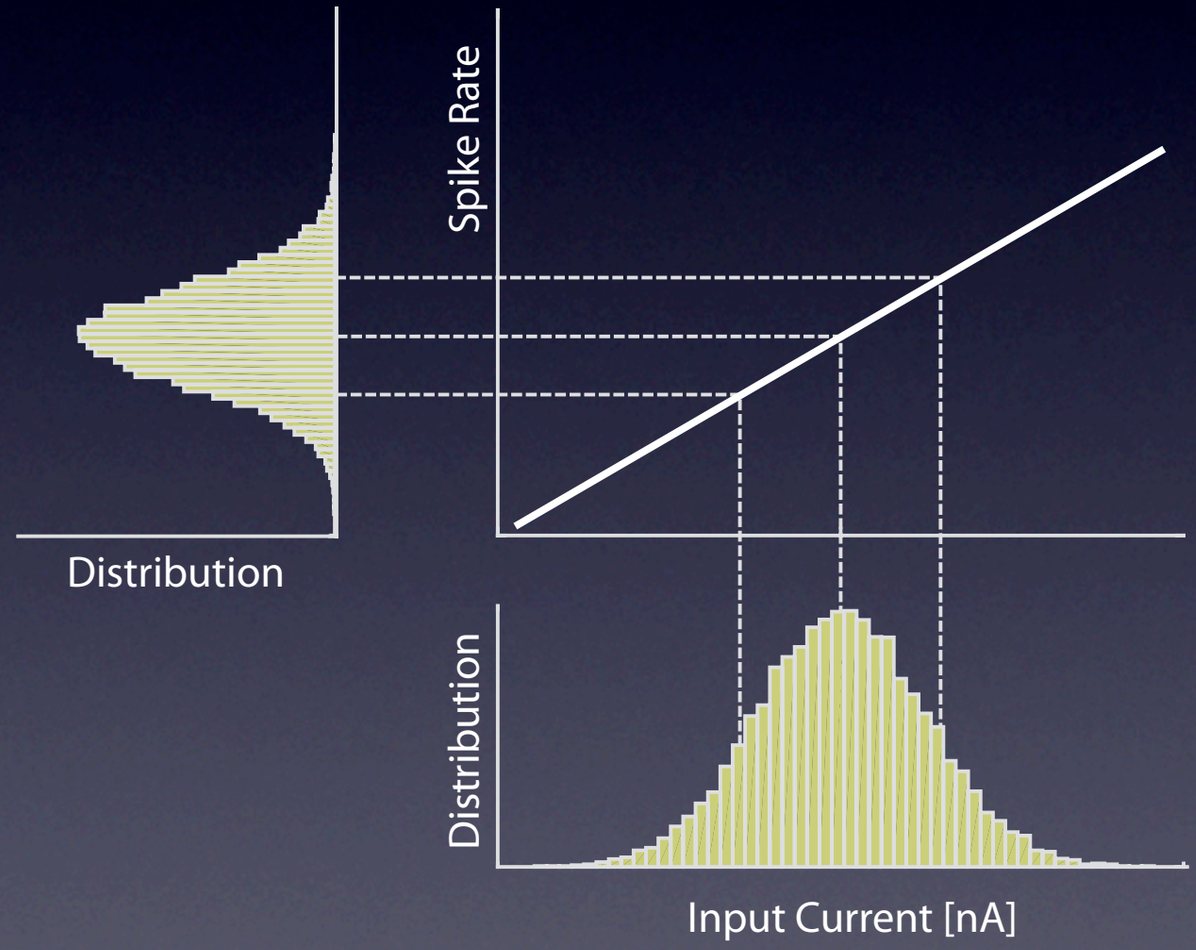
# Transformation of input-to-output



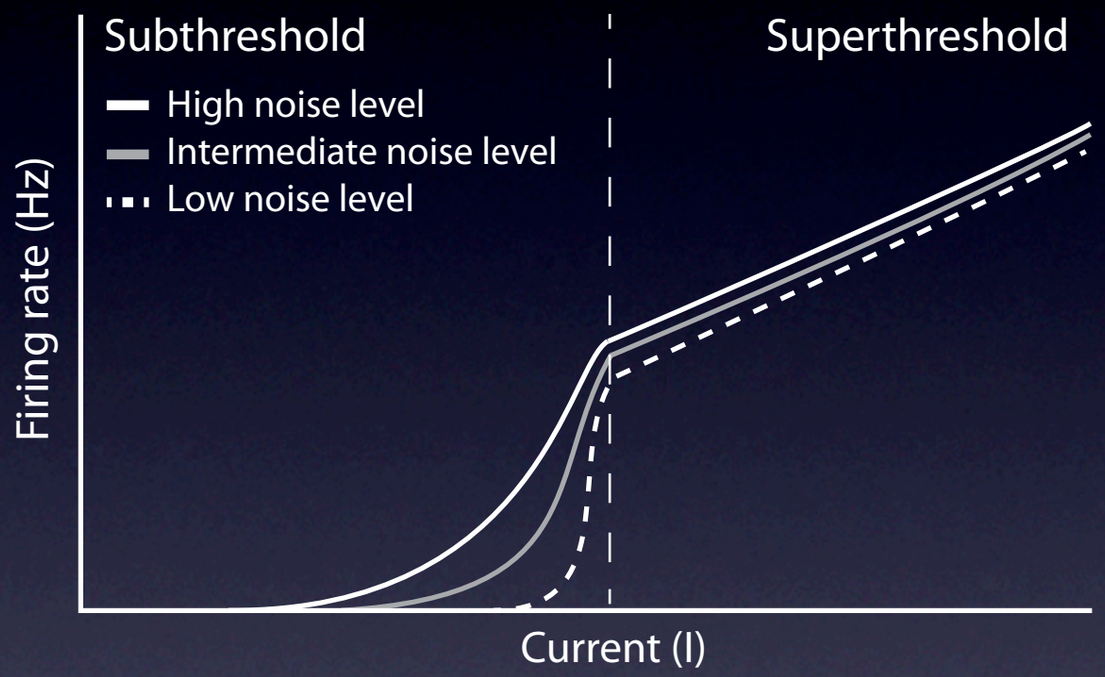

Roxin et al, *J Neurosci* 2011

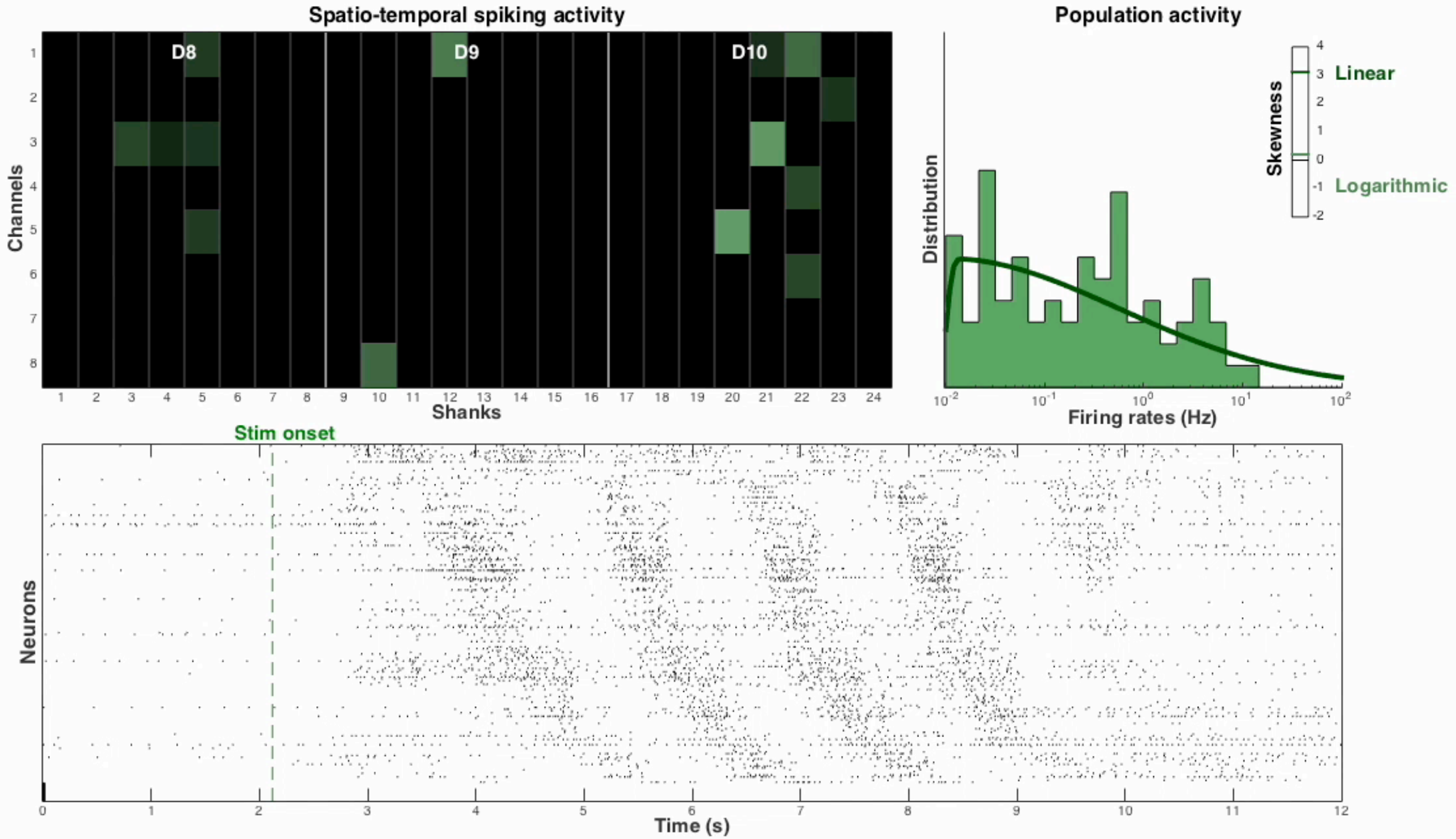
# Transformation of input-to-output



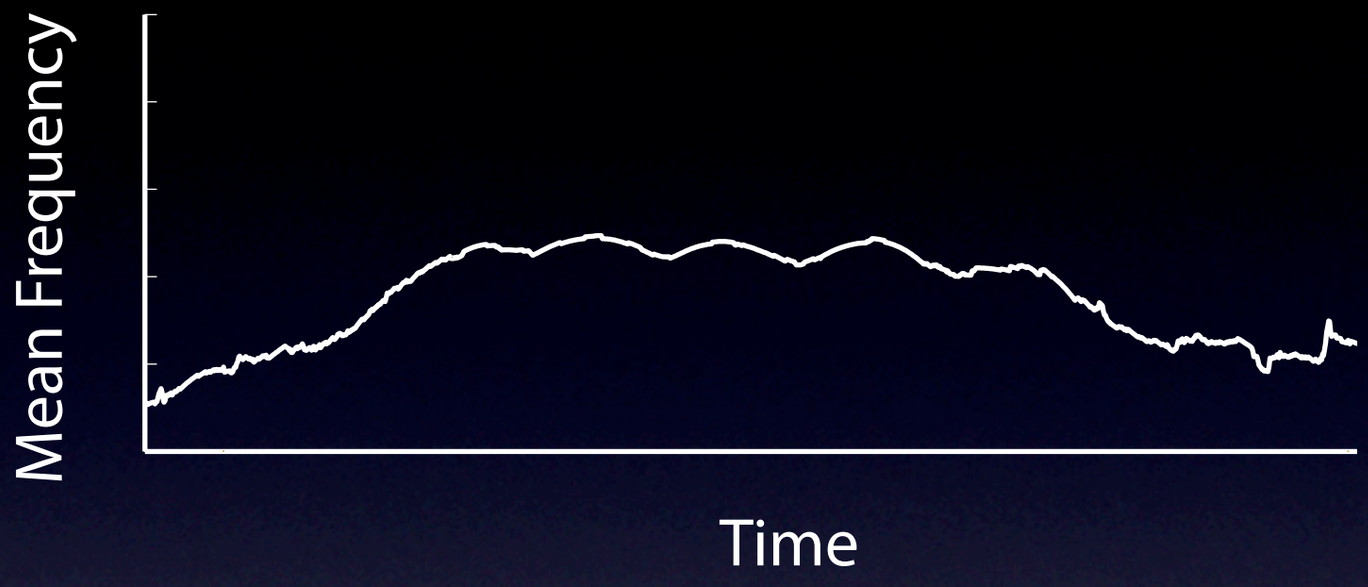



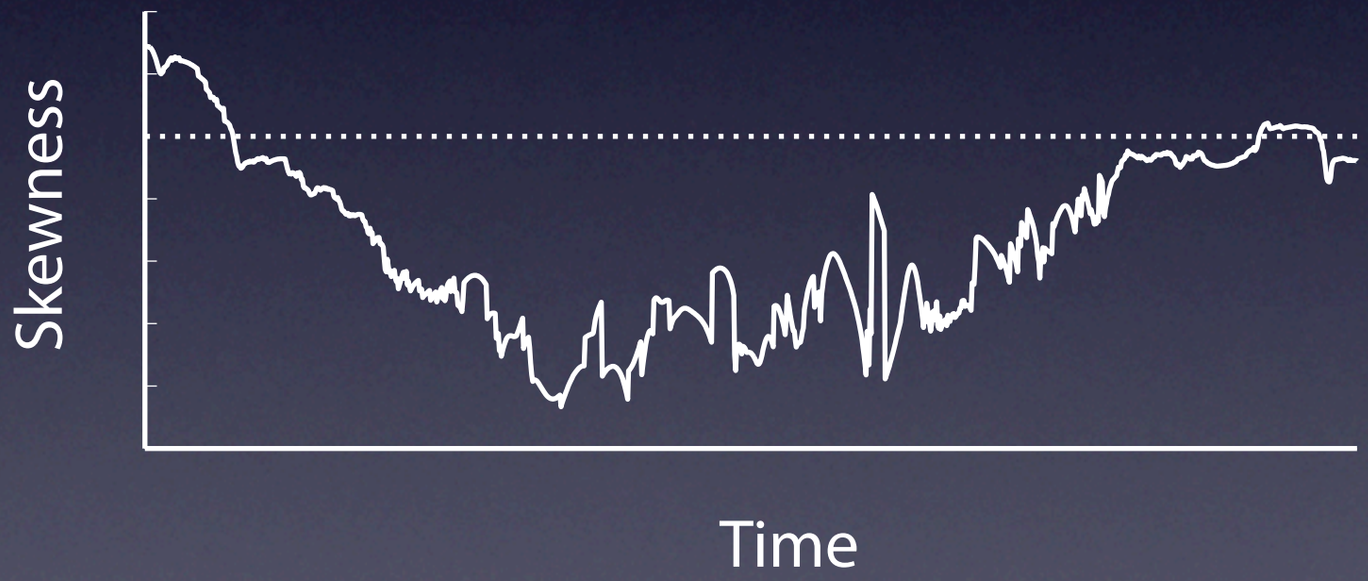

Roxin et al, *J Neurosci* 2011


Subthreshold
Superthreshold
High noise level
Intermediate noise level
Low noise level
Firing rate (Hz)
Current (I)


Spatio-temporal spiking activity
D8
D9
D10
Channels
Shanks
Population activity
Distribution
Skewness
Linear
Logarithmic
Firing rates (Hz)
Stim onset
Neurons
Time (s)

# Skewness is rate dependent




Petersen and Berg, ***eLife 2016***



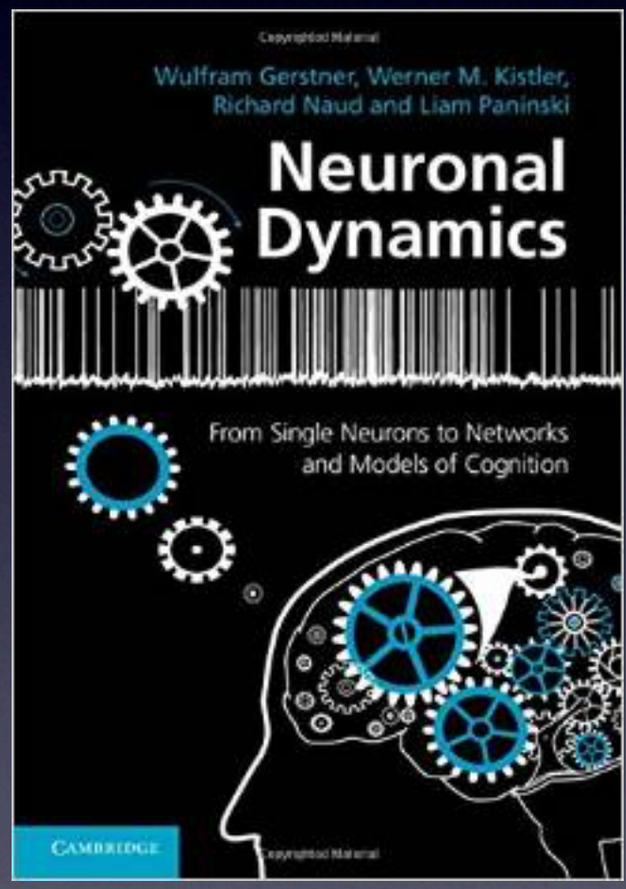
www.berg-lab.net ©

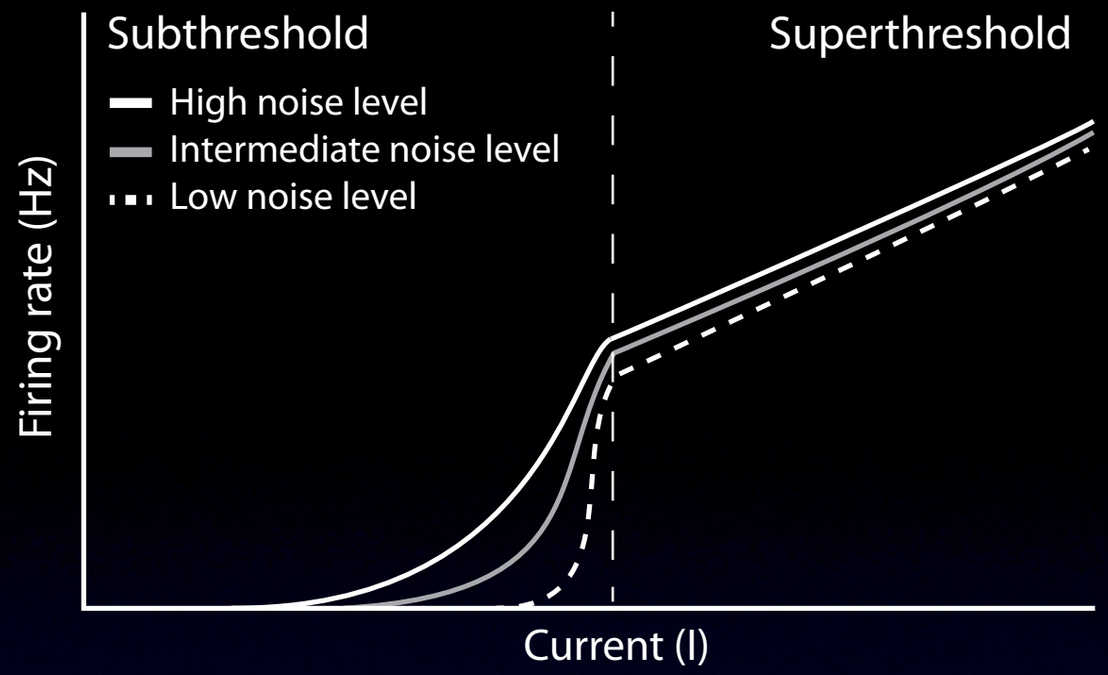
# Two regimes:

Fluctuation-driven

Mean-driven

Gerstner, Kistler, Naud and Paninski :
*"Neuronal dynamics"*





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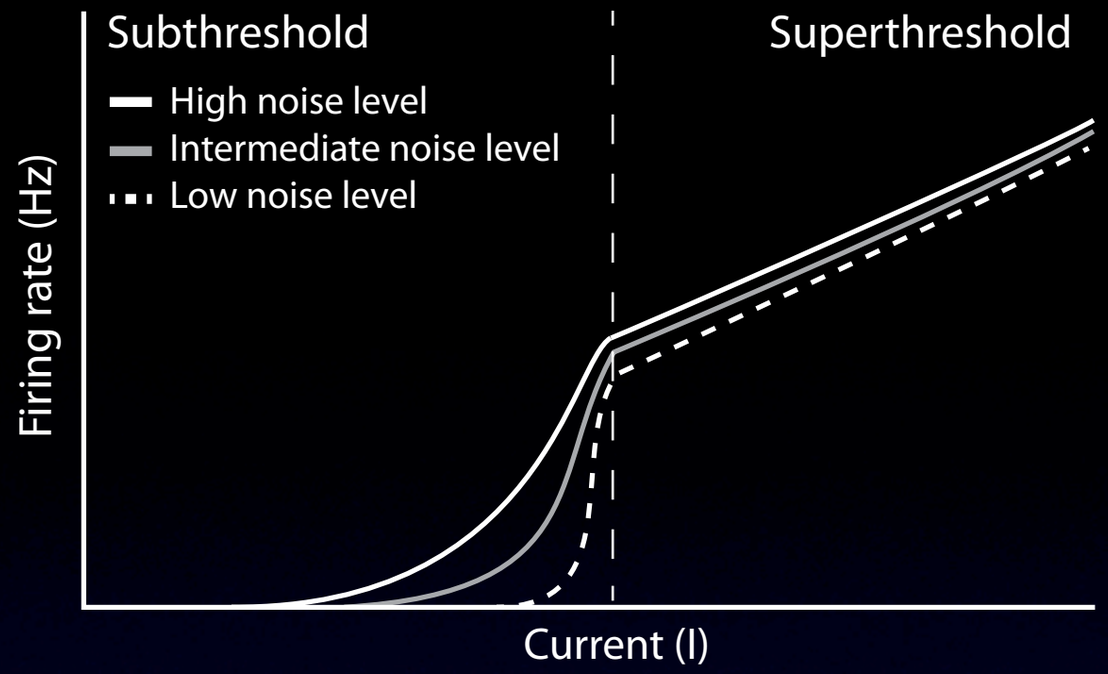
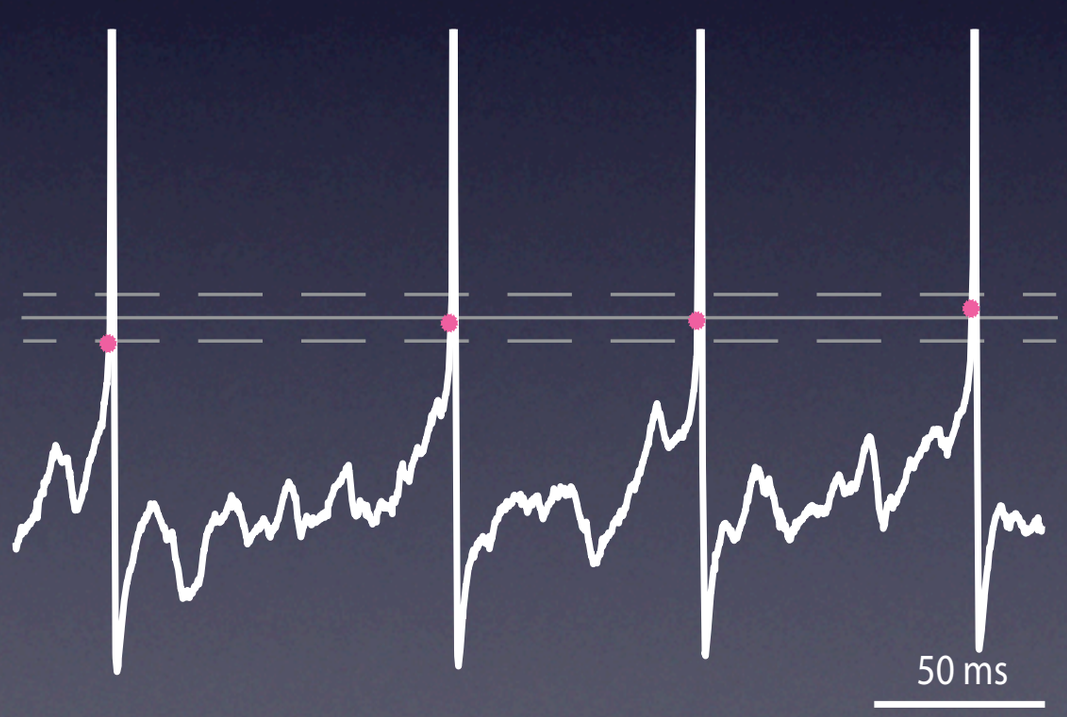
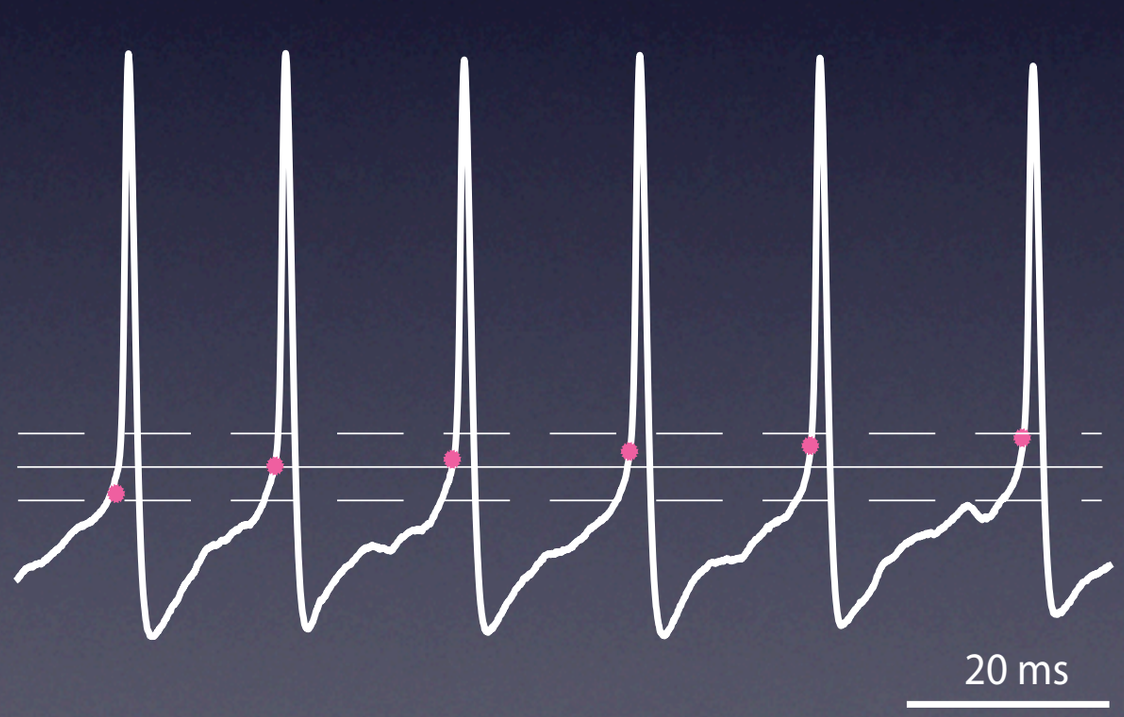



# Fluctuation driven




# Mean driven



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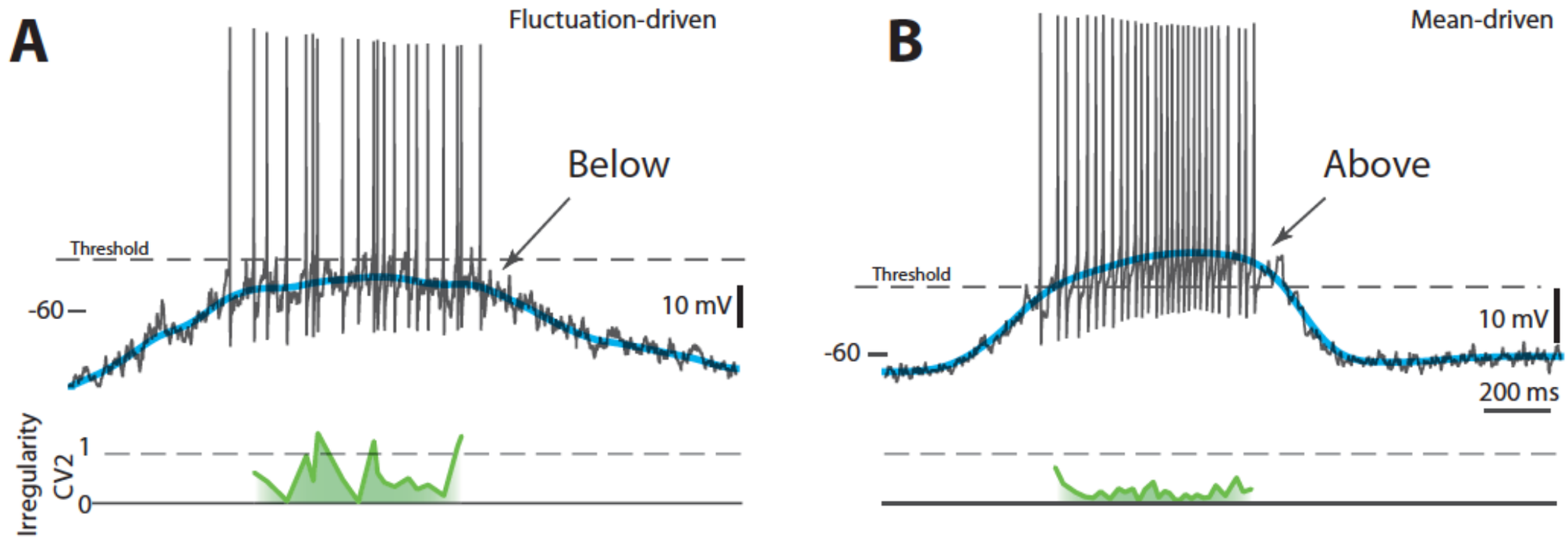
# Fluctuation- and mean-driven neurons

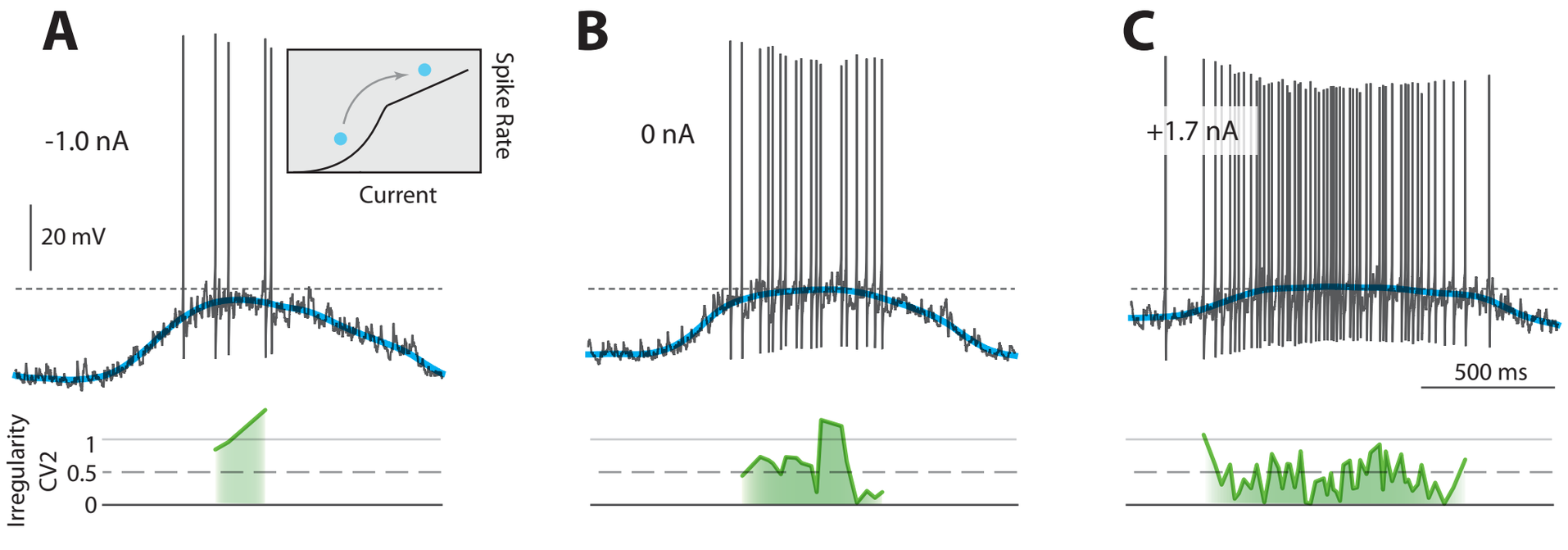





Petersen and Berg, ***eLife 2016***

www.berg-lab.net ©

# Driving a cell across regimes






Petersen and Berg, ***eLife 2016***

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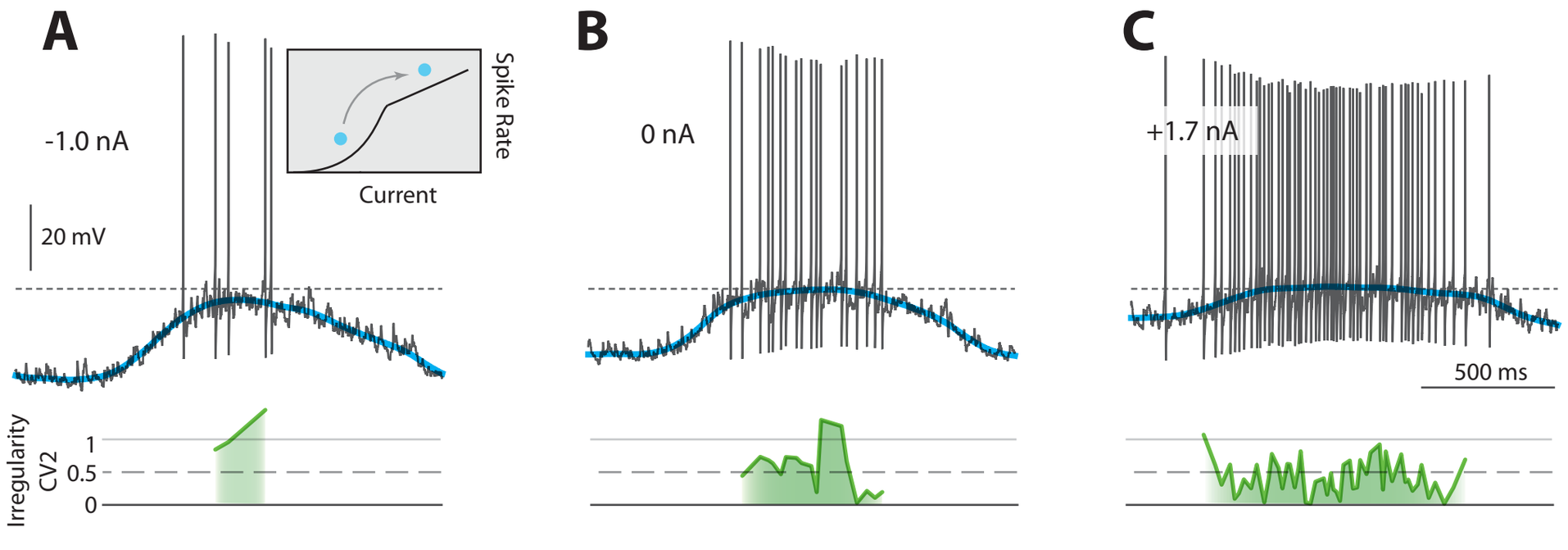
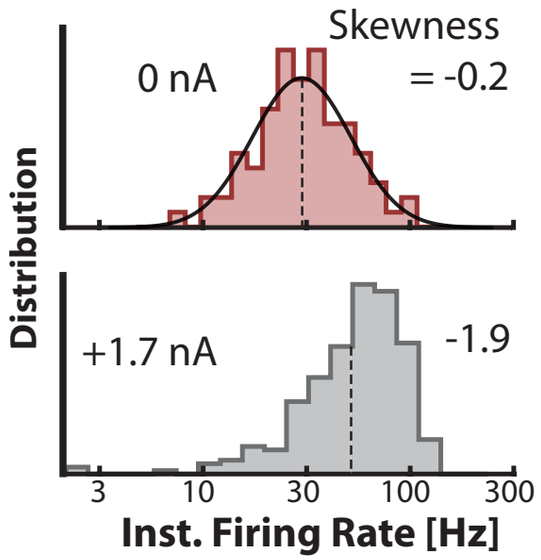
# Driving a cell across regimes






Petersen and Berg, ***eLife 2016***

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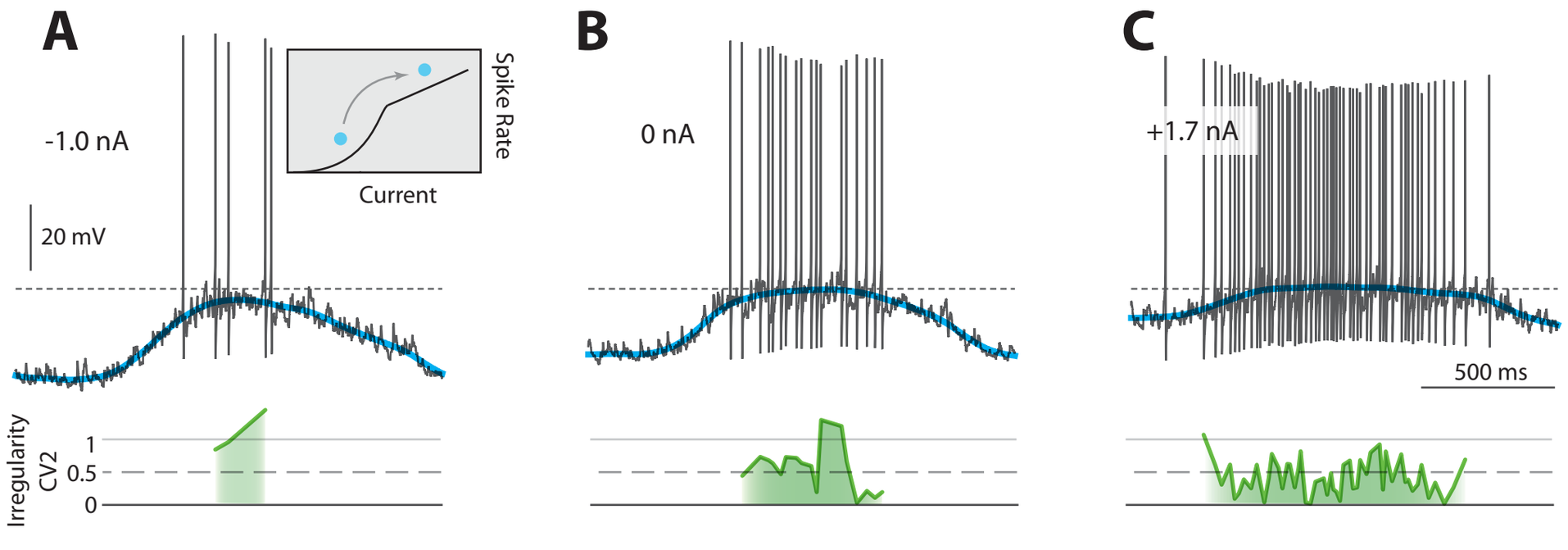
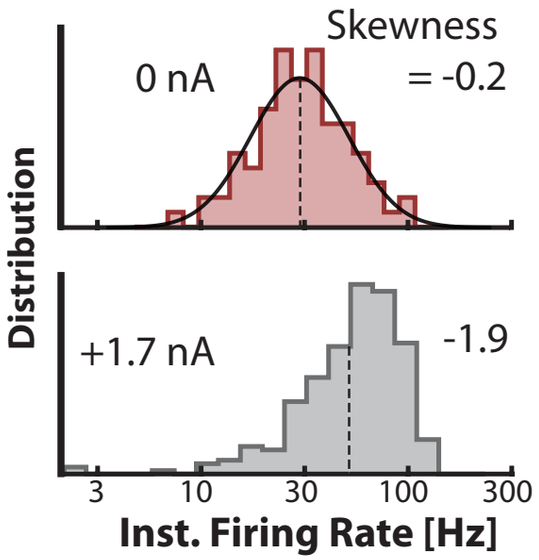
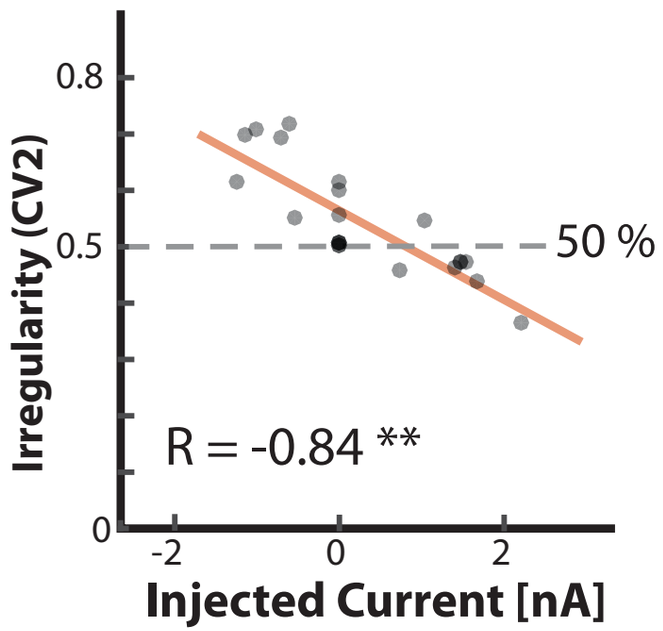
# Driving a cell across regimes



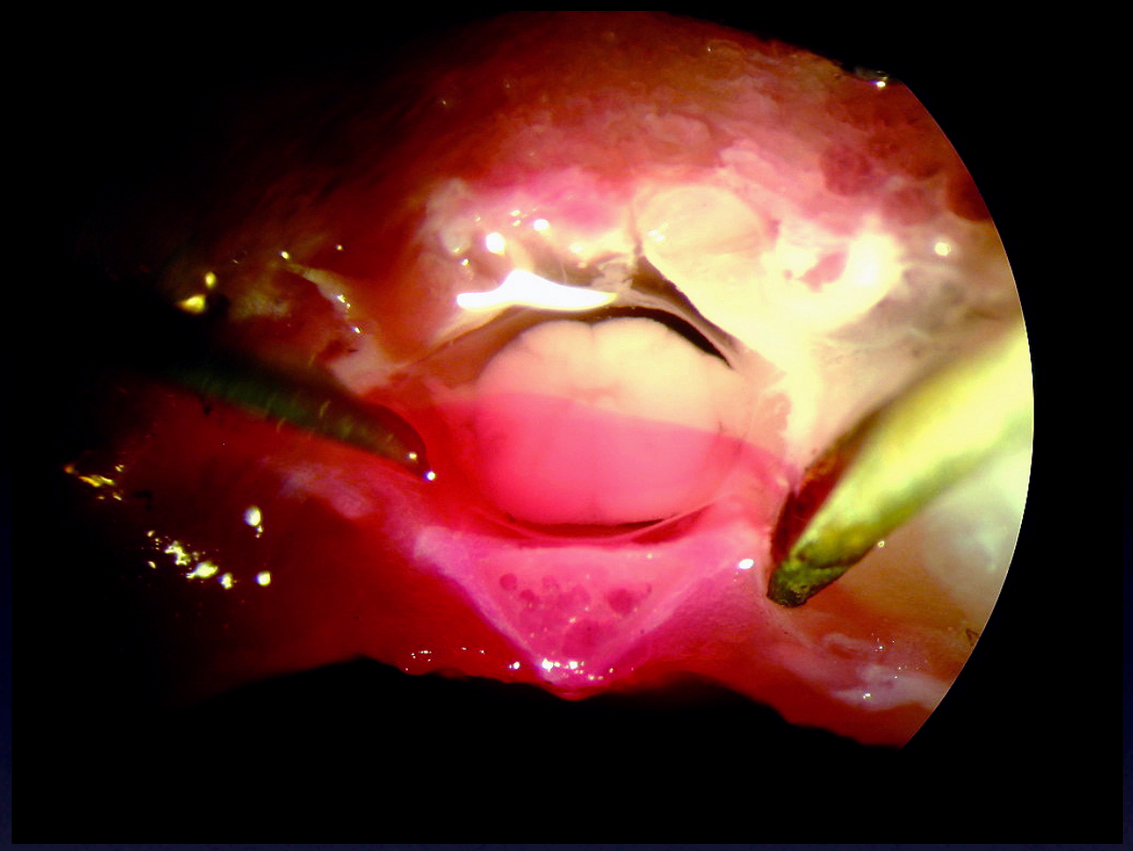



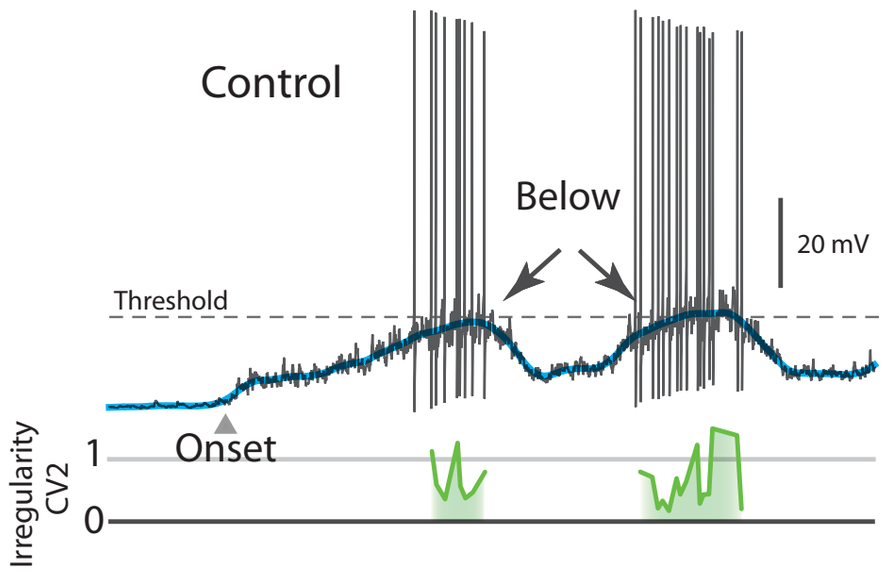


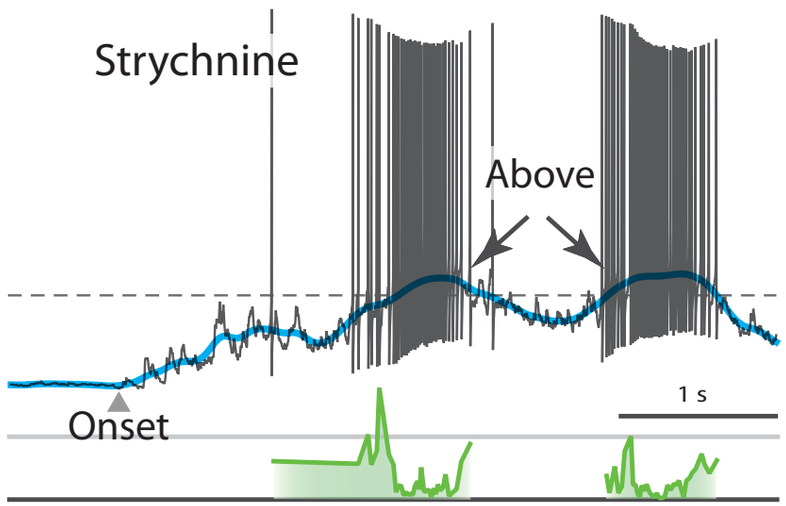

Petersen and Berg, ***eLife 2016***

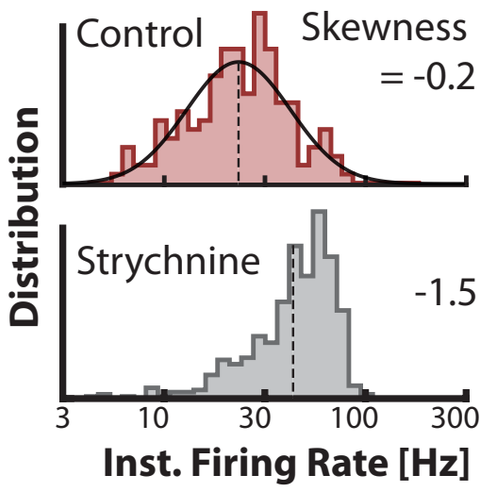
 ©

# Balanced E/I
# Unbalancing by blocking inhibition








Petersen and Berg, ***eLife 2016***

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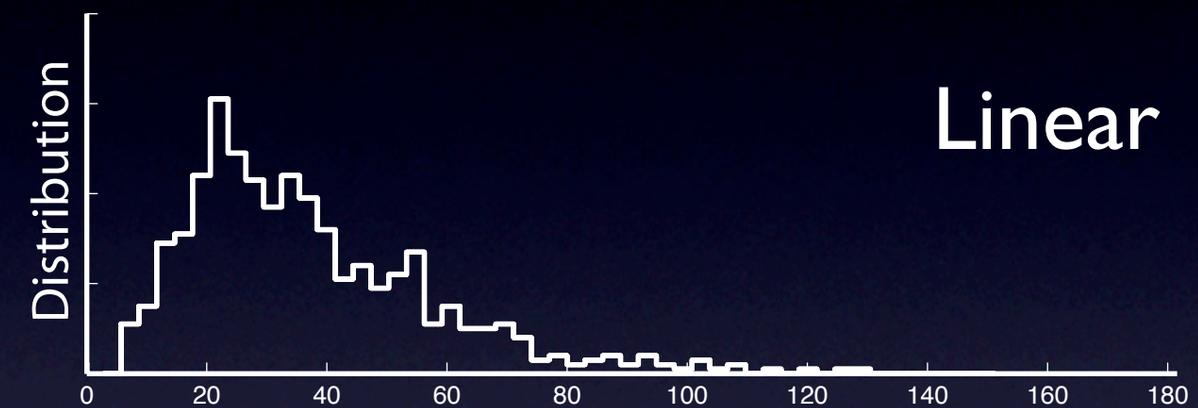
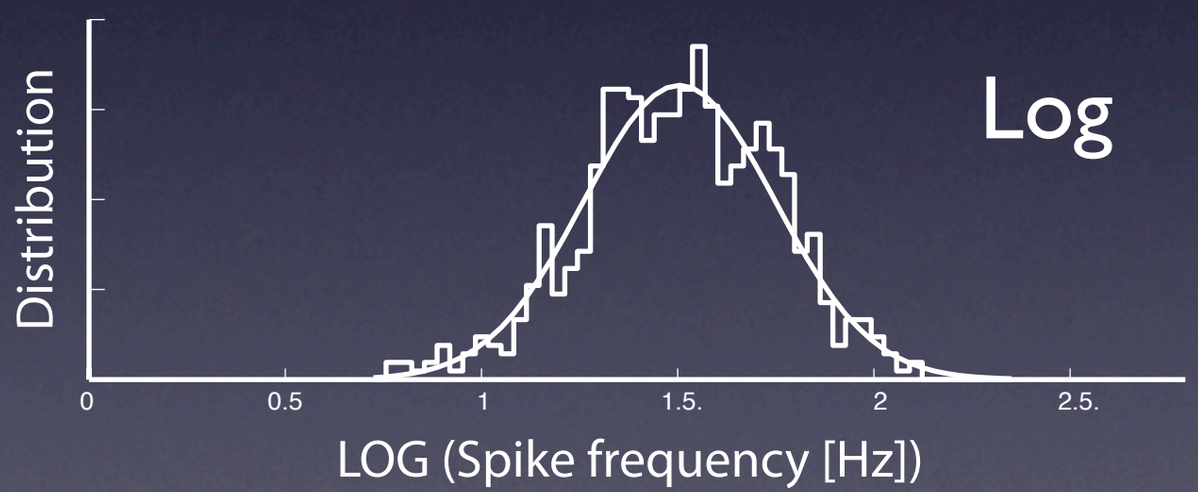
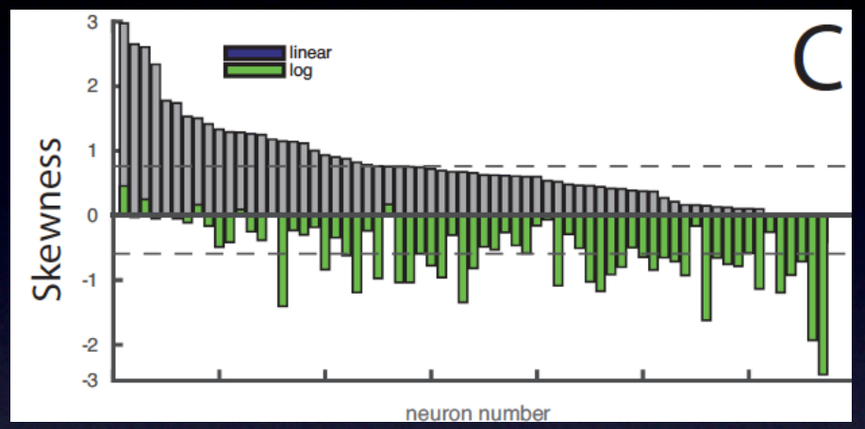
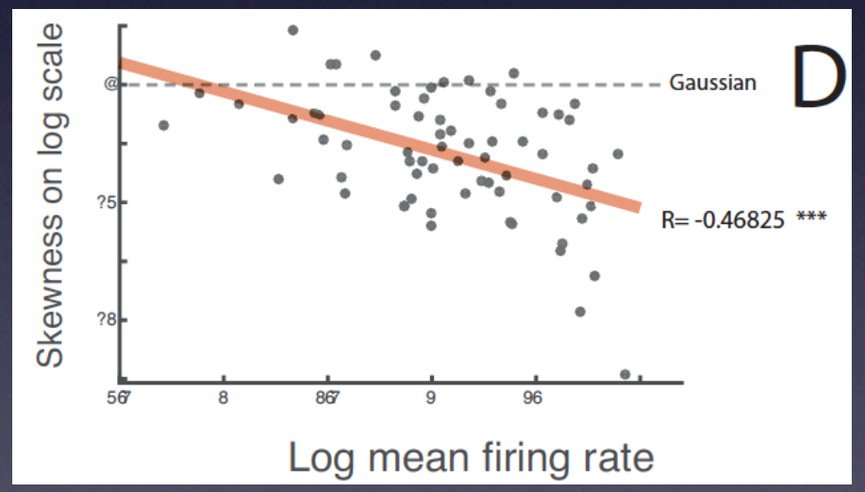
# Single cell rate distribution




Petersen and Berg, ***eLife 2016***



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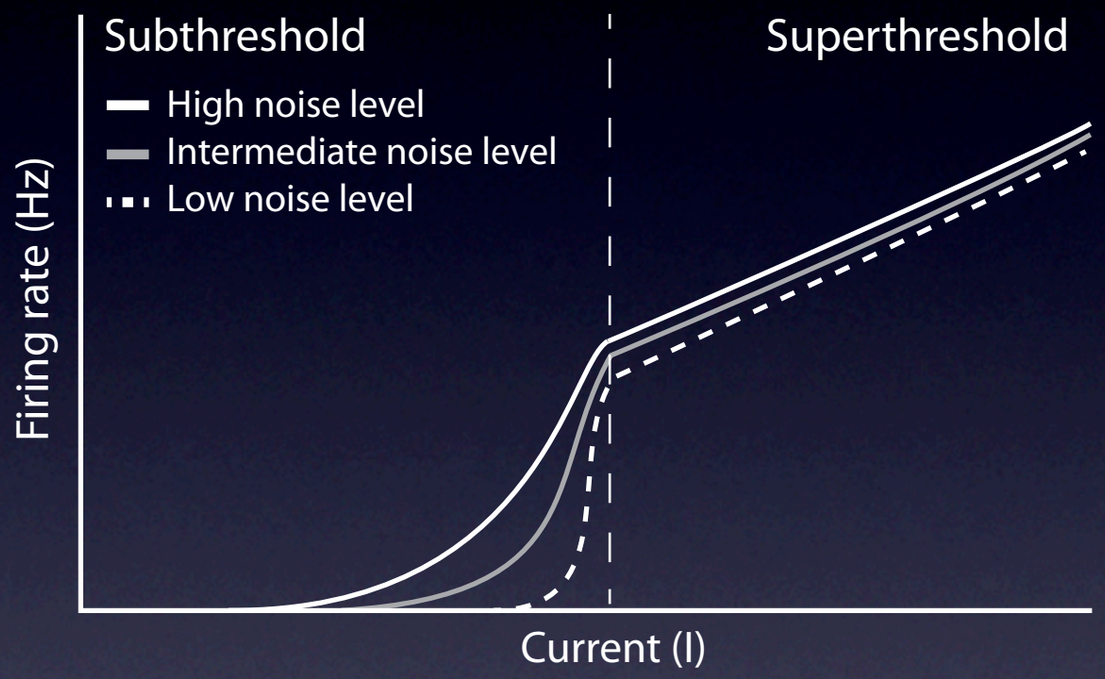
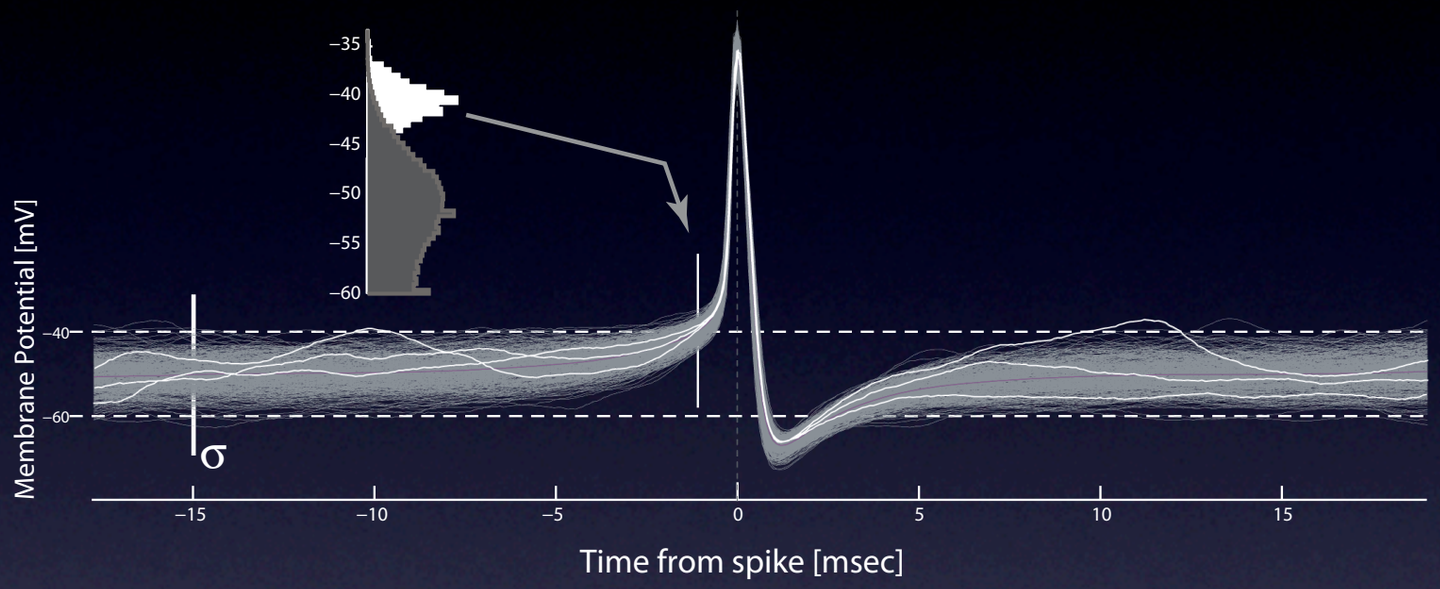
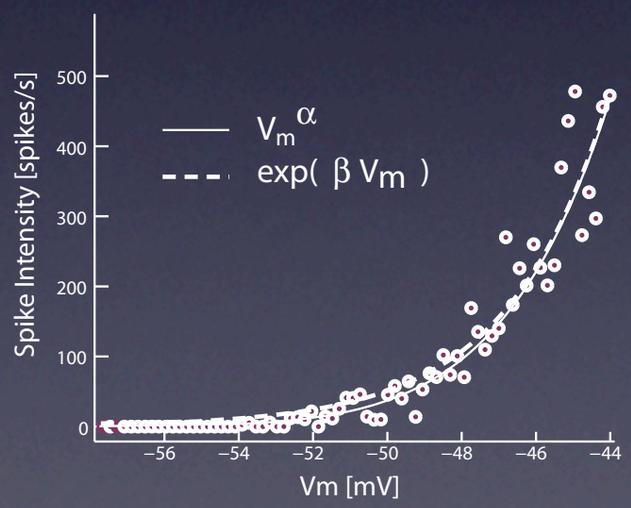
# Next step: IO-curve
# Obtaining sub-threshold IO-curve is difficult

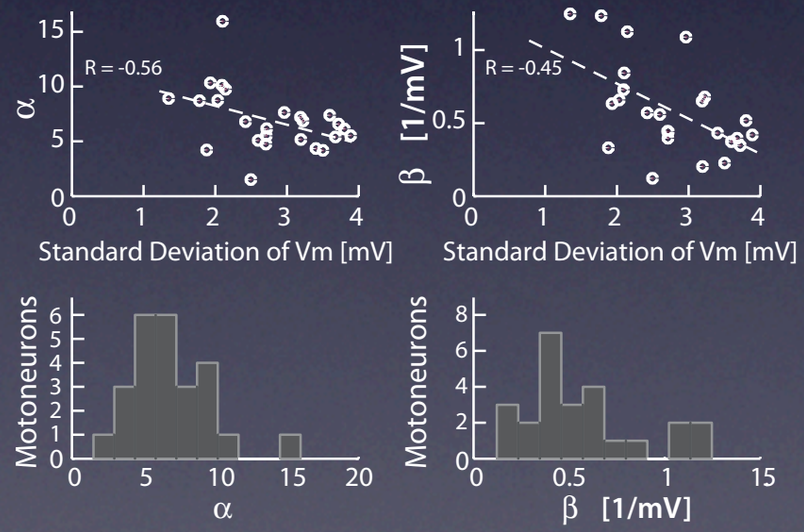


# FV-curve

## expansive nonlinearity




Patrick Jahn

Susanne Ditlevsen

Mikkel Vestergaard

Jahn et al ***J Comput Neurosci 2011***

Vestergaard and Berg, ***J Neurosci 2015***

Rune W. Berg :: INF University of Copenhagen

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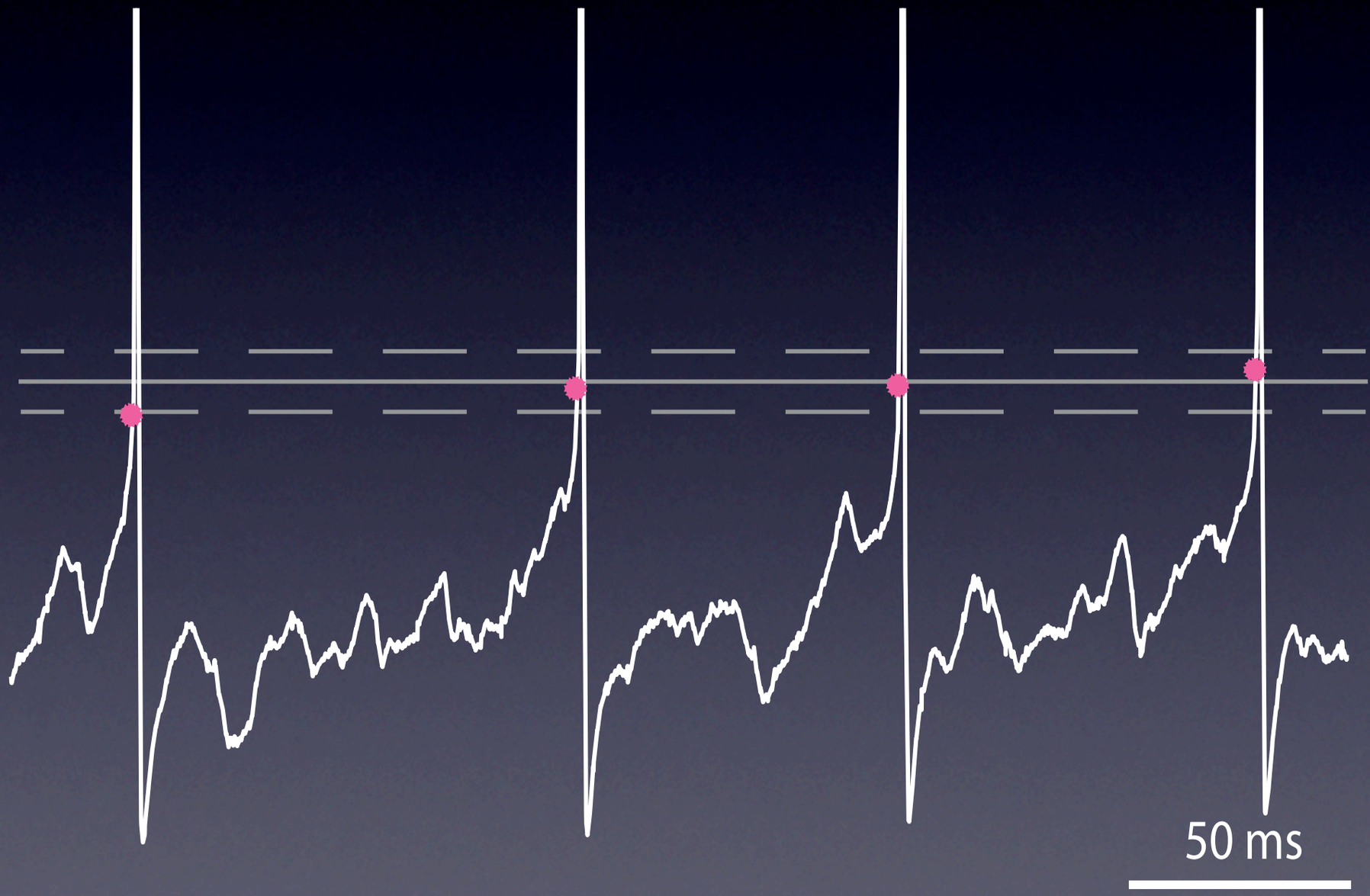
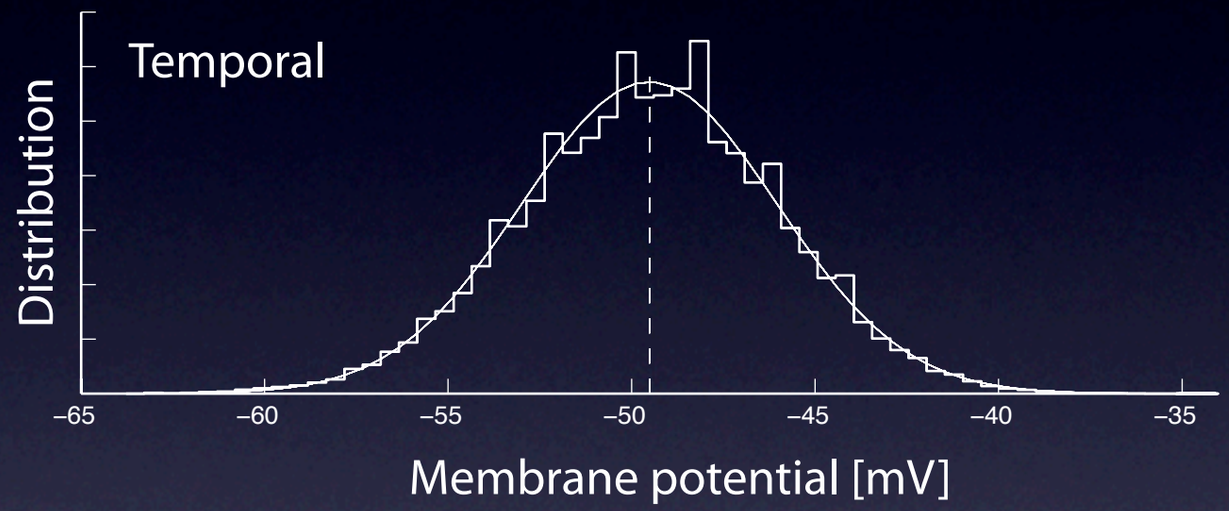
# Input distribution?

# Inter-spike-interval Vm



# Vm-distribution

## sub-threshold






Petersen and Berg, ***eLife 2016***

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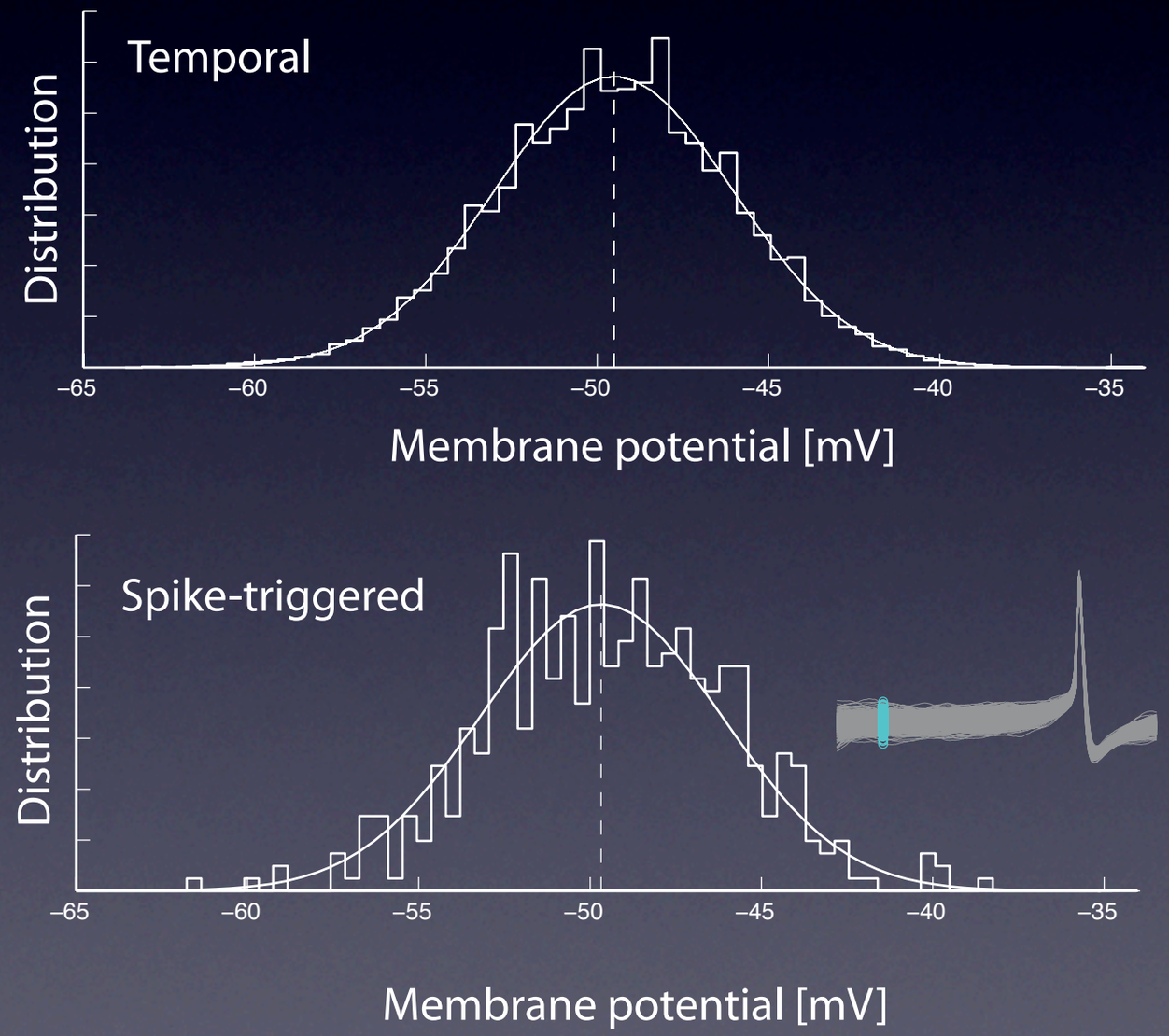
# Vm-distribution

## sub-threshold




Petersen and Berg, ***eLife 2016***



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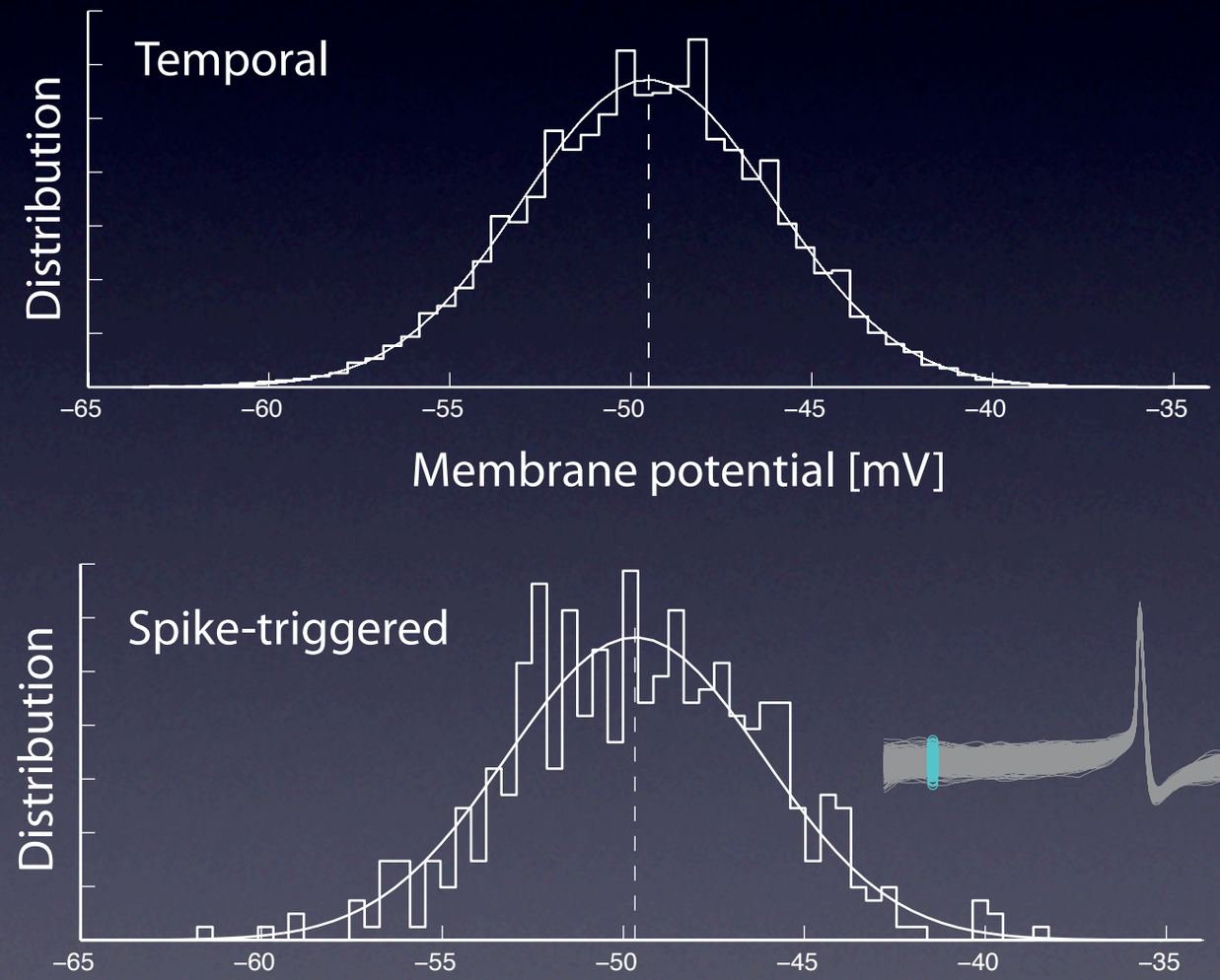
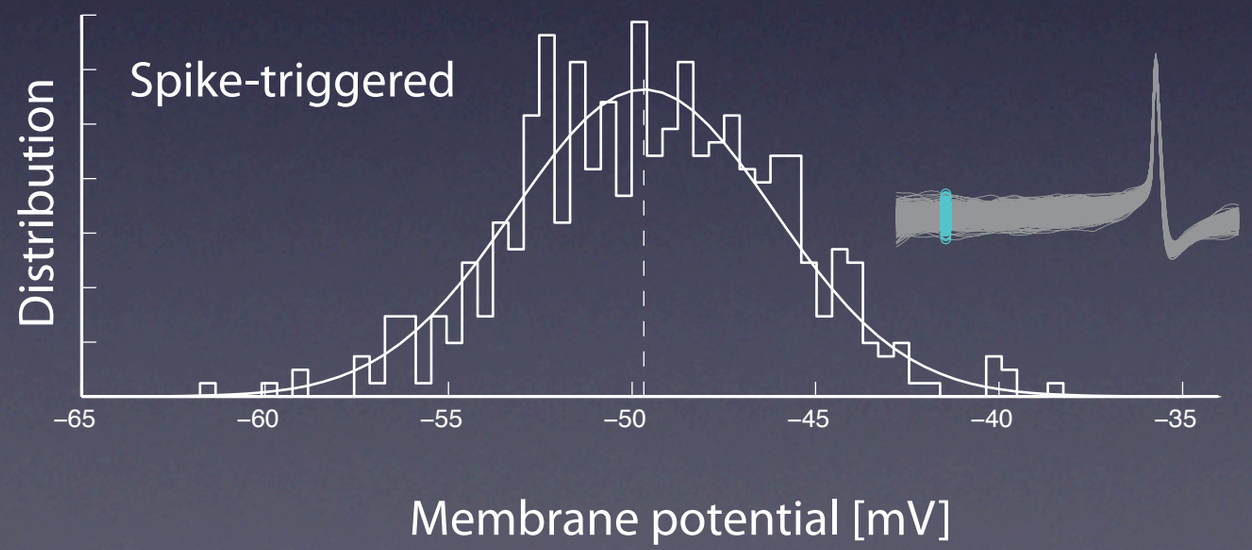
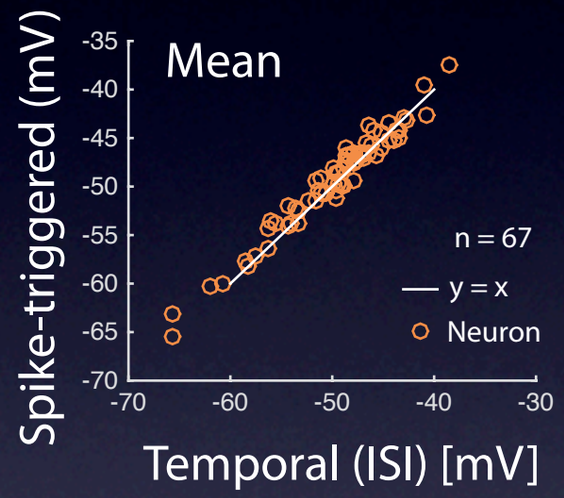
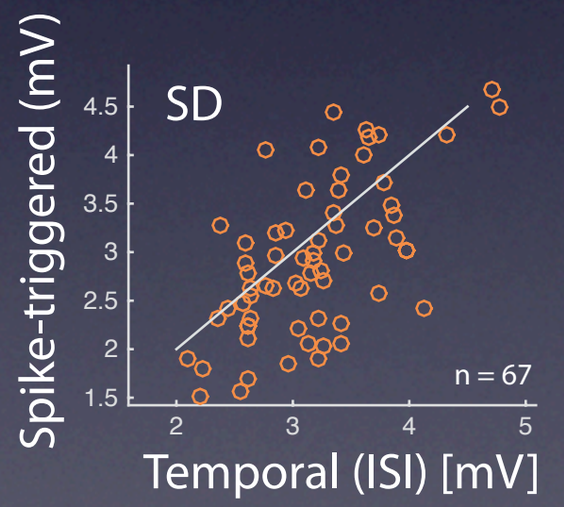
# Vm-distribution

## sub-threshold




Rune W. Berg :: INF University of Copenhagen

Petersen and Berg, ***eLife 2016***

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# Mini-conclusion

- Firing rate distribution is skewed for some neurons
- Subthreshold IO curve is non-linear
- Input distribution is Gaussian

# Spiking regime: population

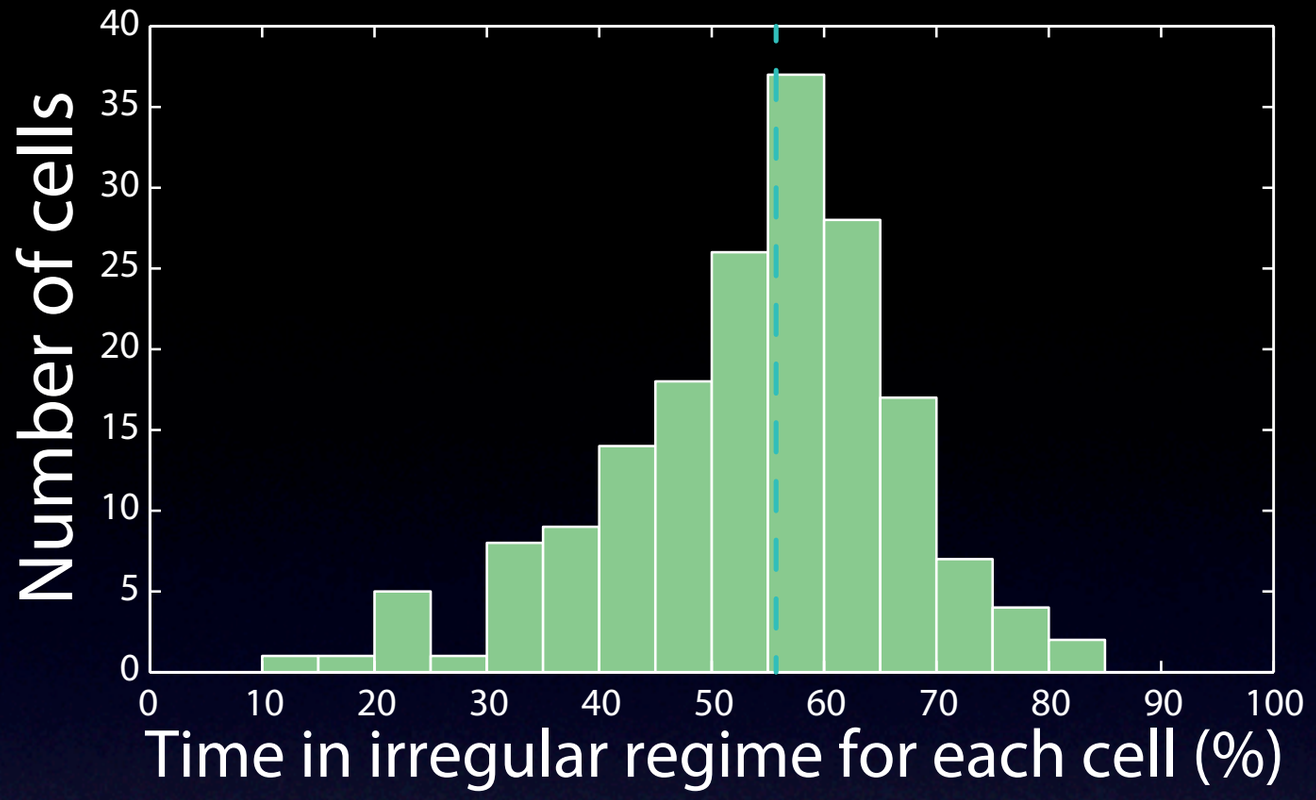
# Spiking regime: population

$CV_2 > 0.5$ “Irregular”

$CV_2 < 0.5$ “Regular”

Young et al, *J Neurophysiol* 1988

Prut and Perlmutter, *J Neurosci* 2003






Petersen and Berg, ***eLife 2016***

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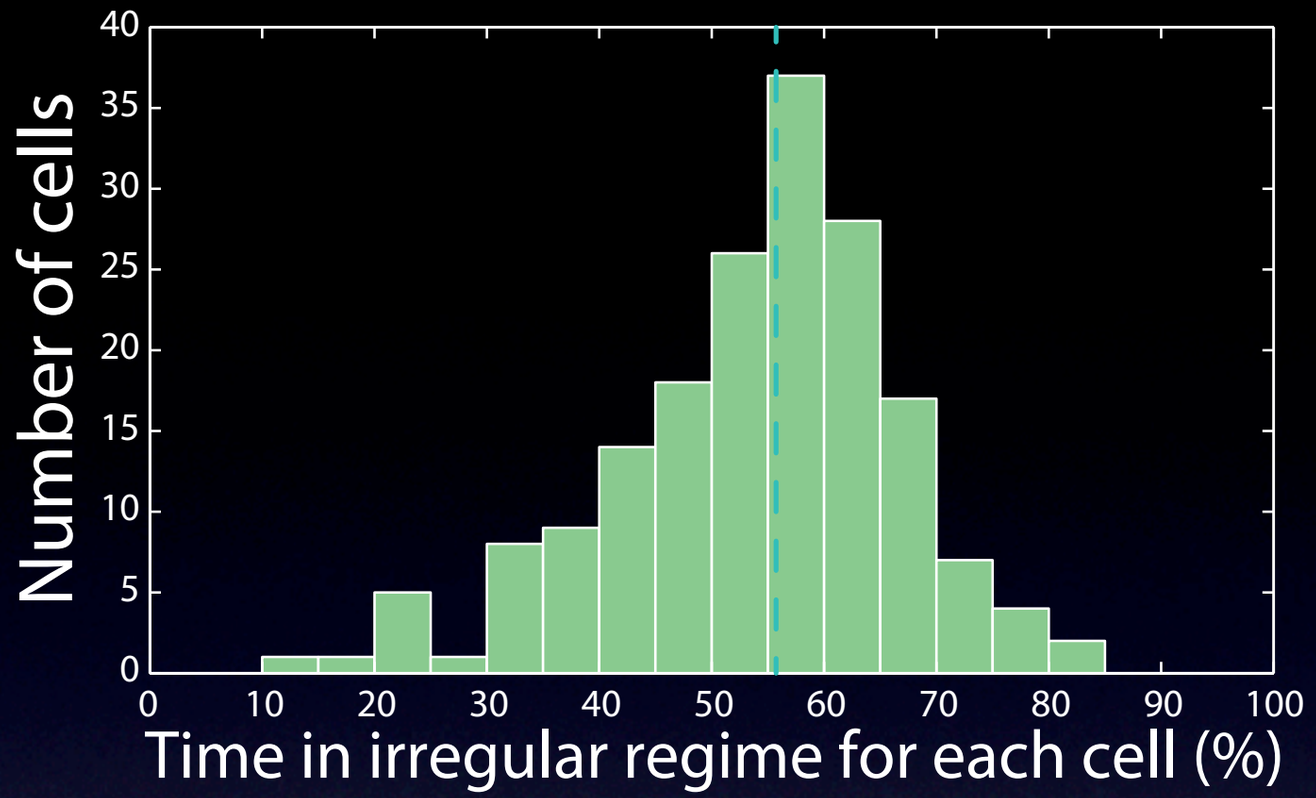


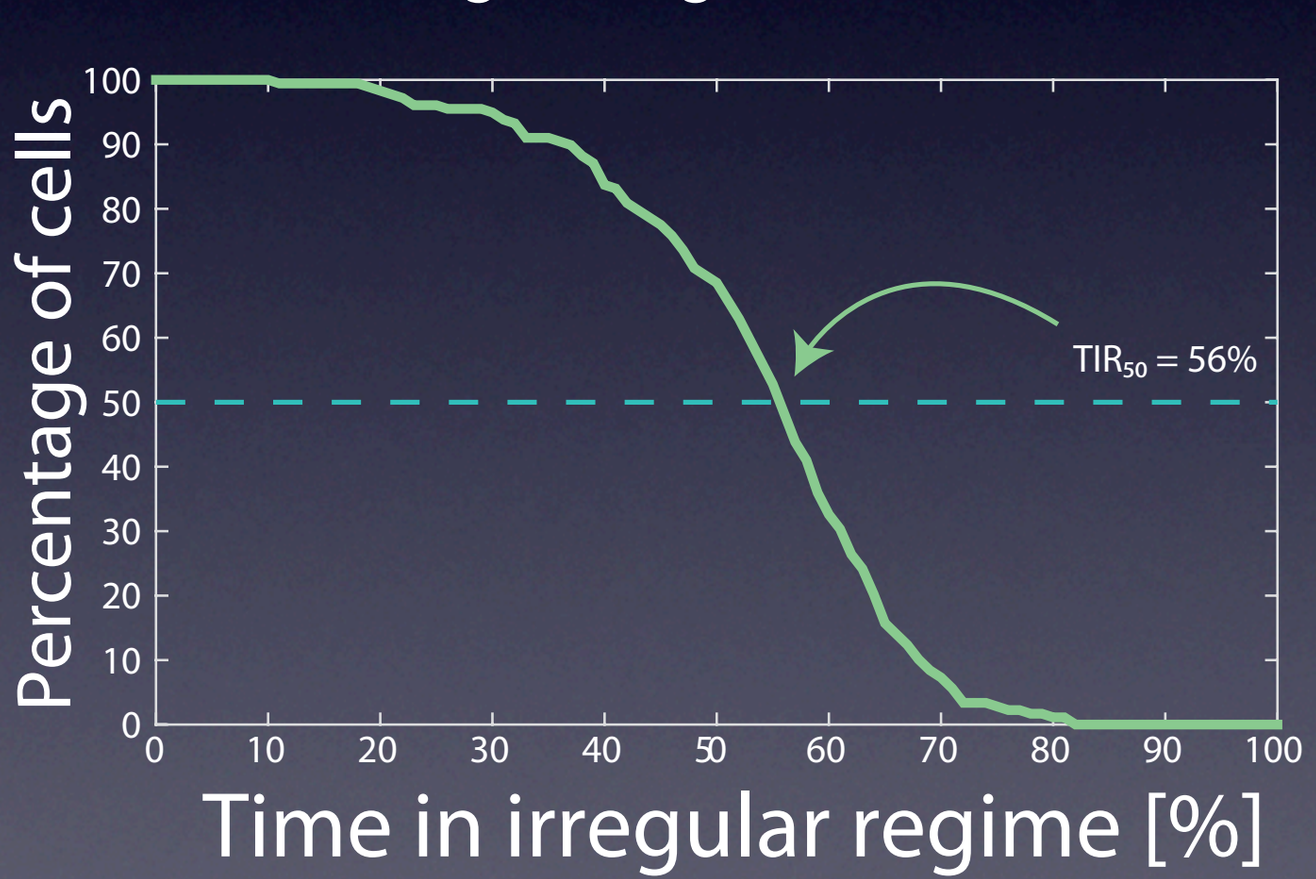


Petersen and Berg, ***eLife 2016***



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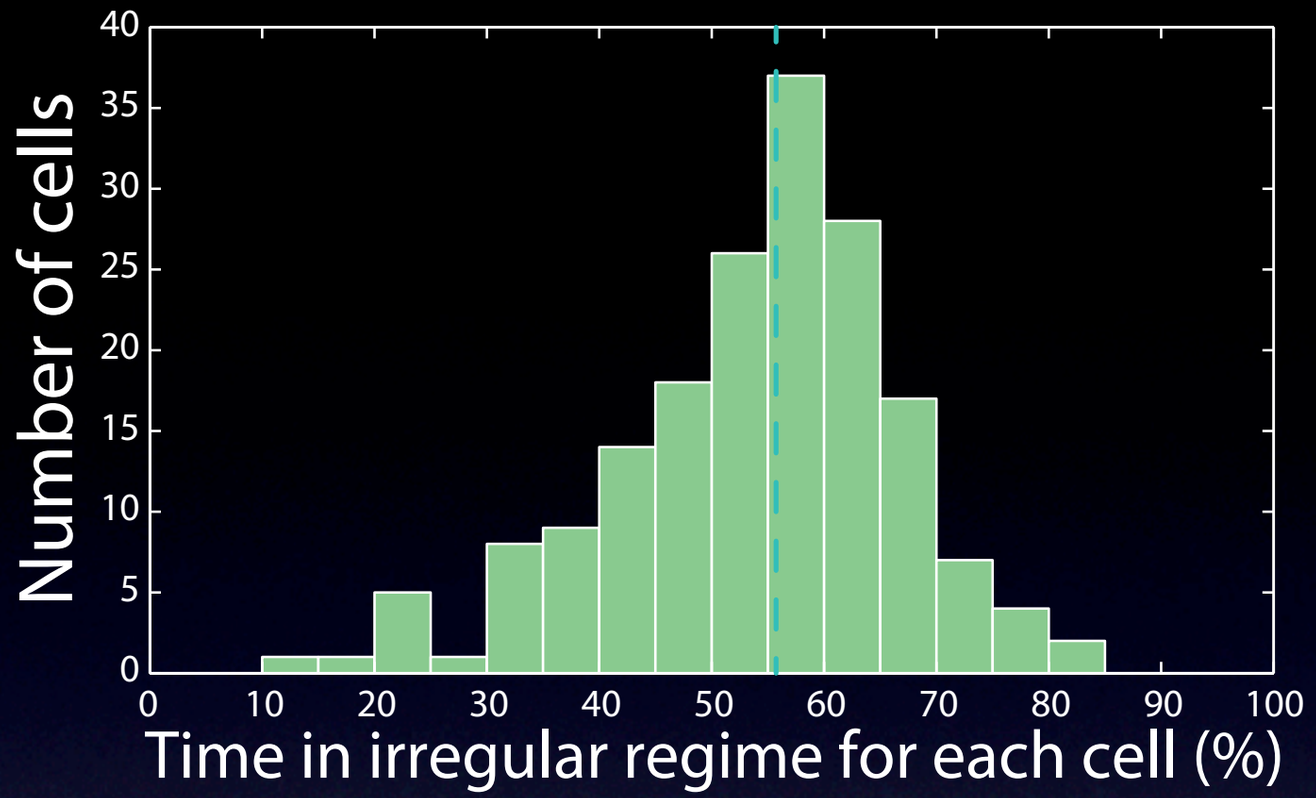
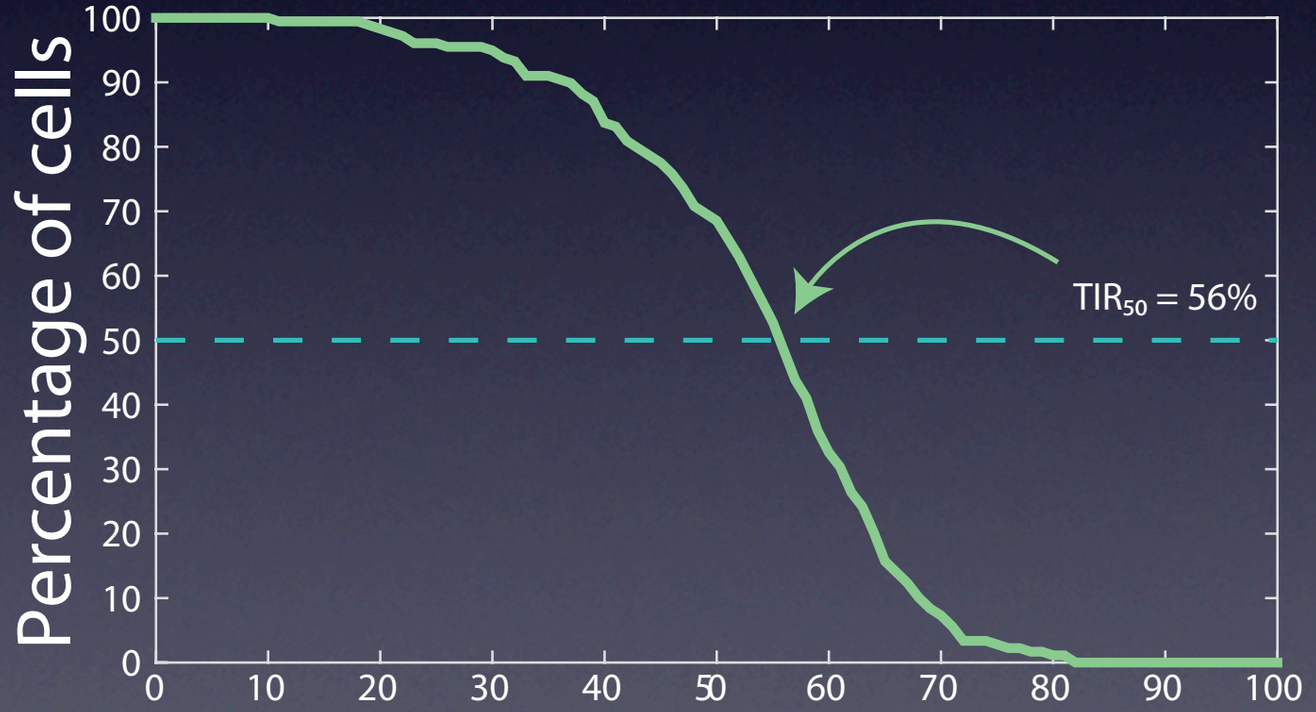
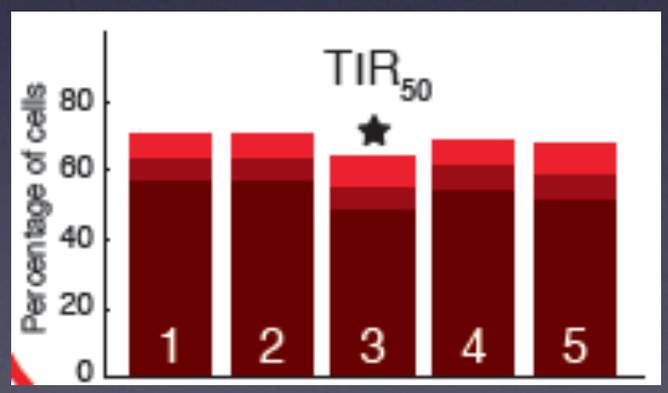


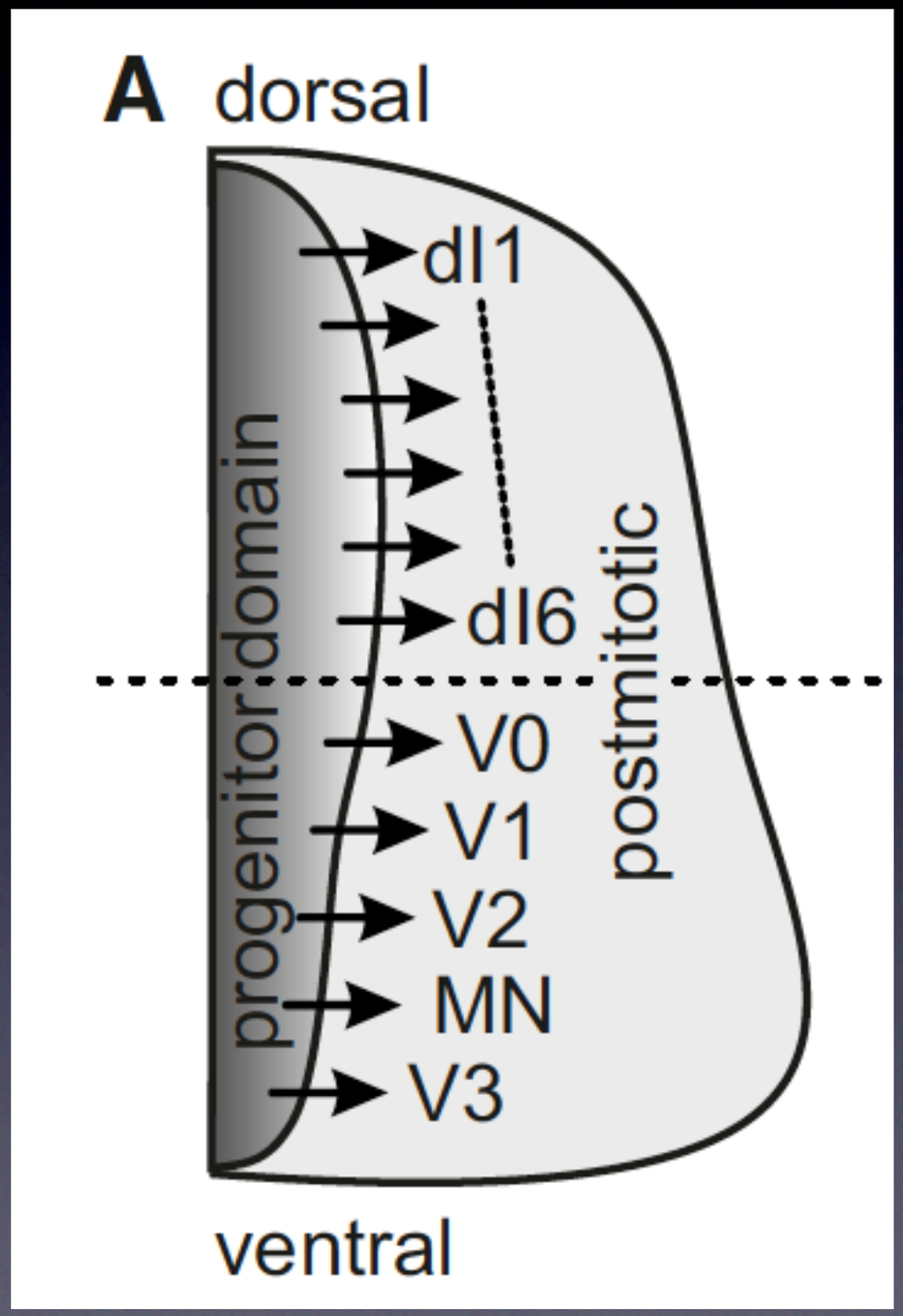

Animals:




Petersen and Berg, ***eLife 2016***

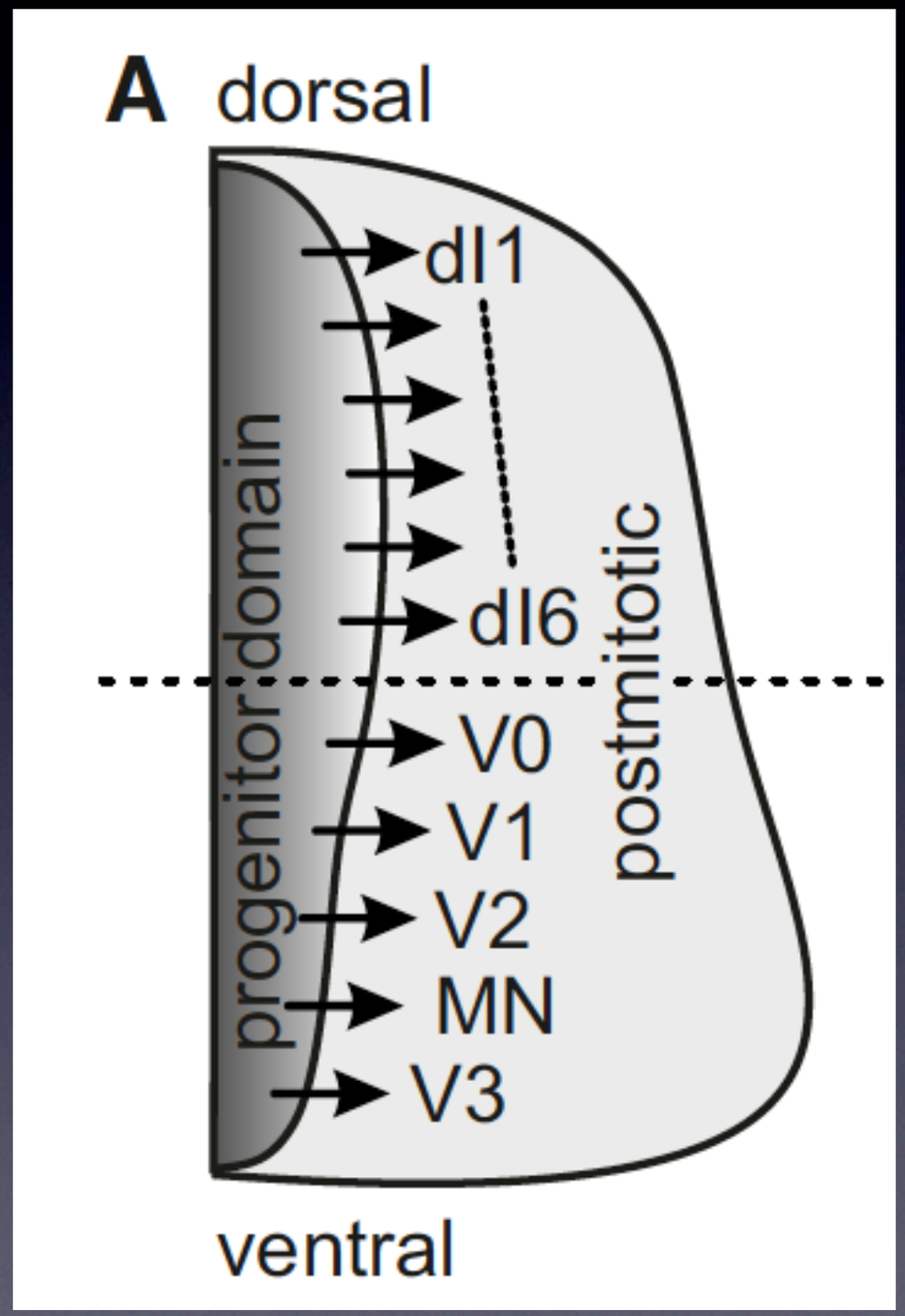
# Cell type ?

# Cell type ?

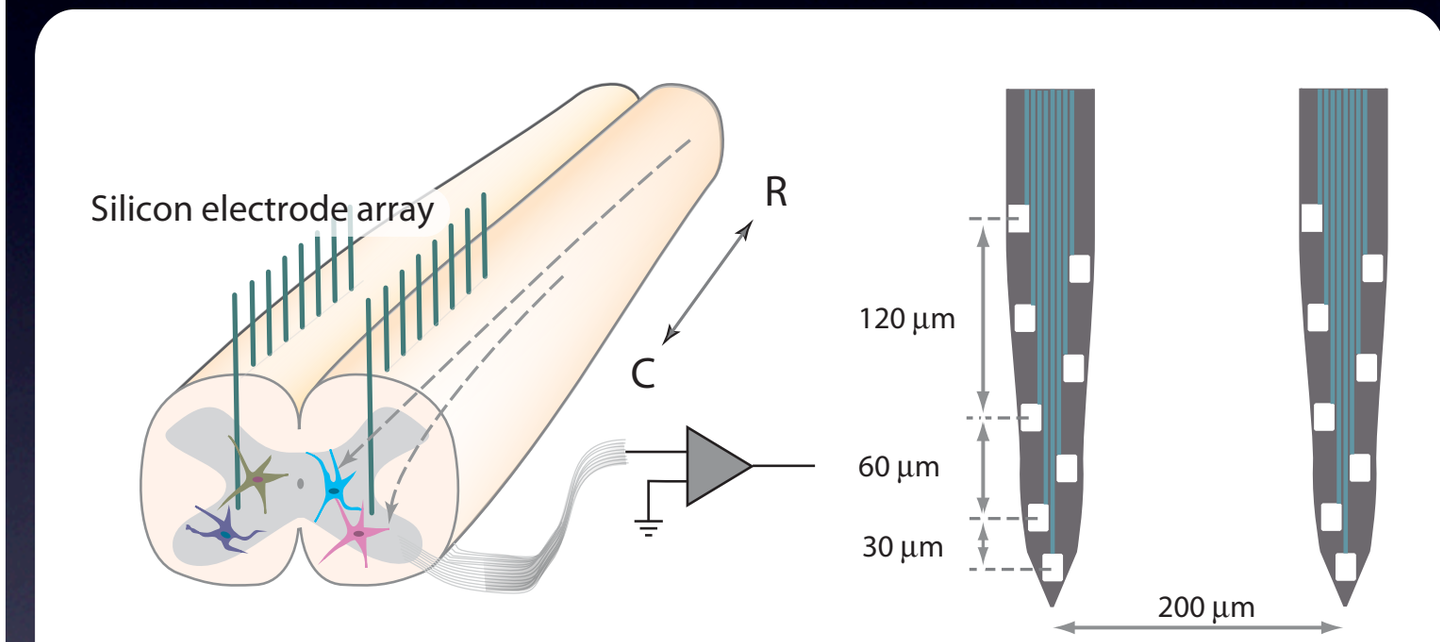



Arber ***Neuron 2012***

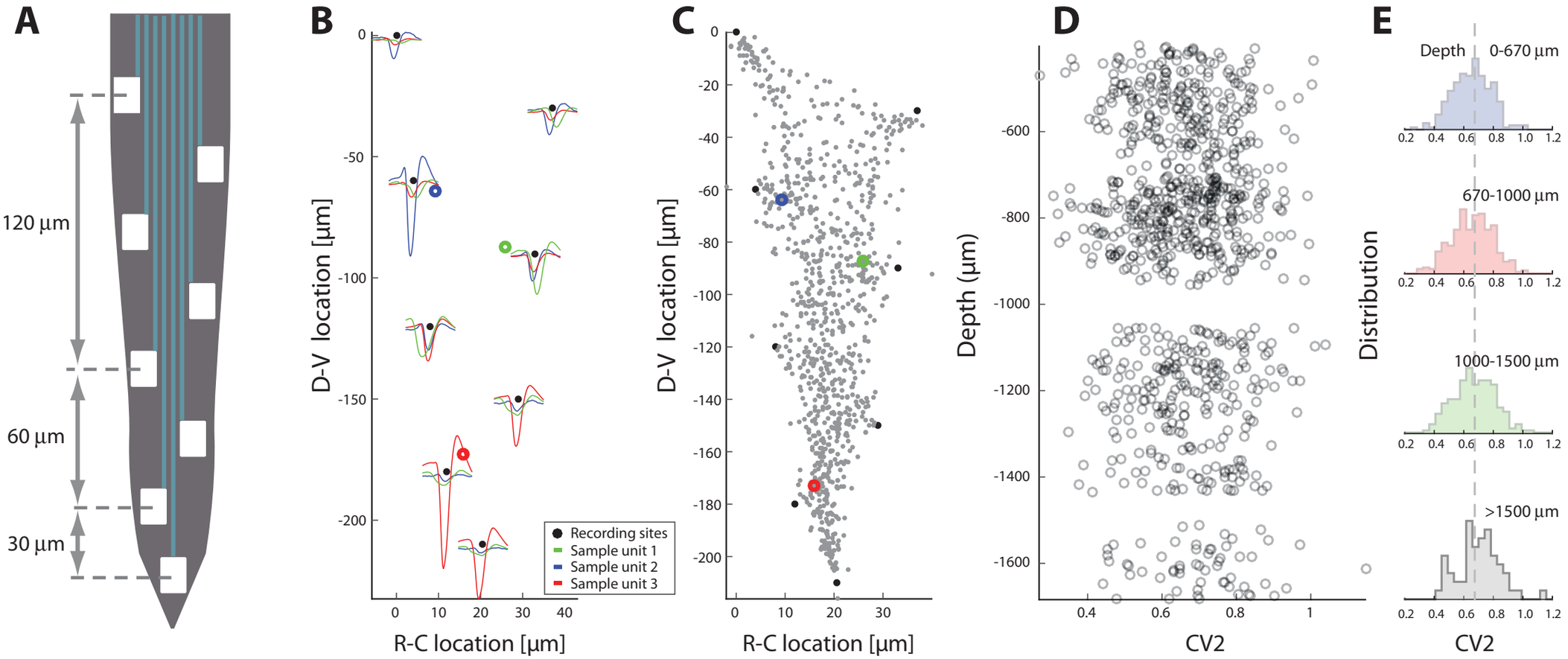
# Cell type ?




Arber ***Neuron 2012***



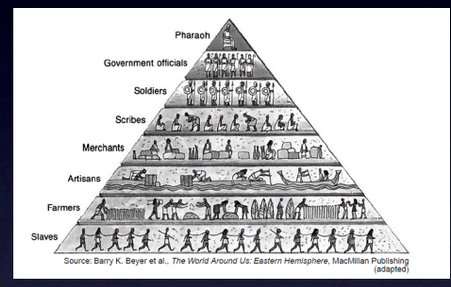
# No dependence on cell type




Petersen and Berg, ***eLife 2016***

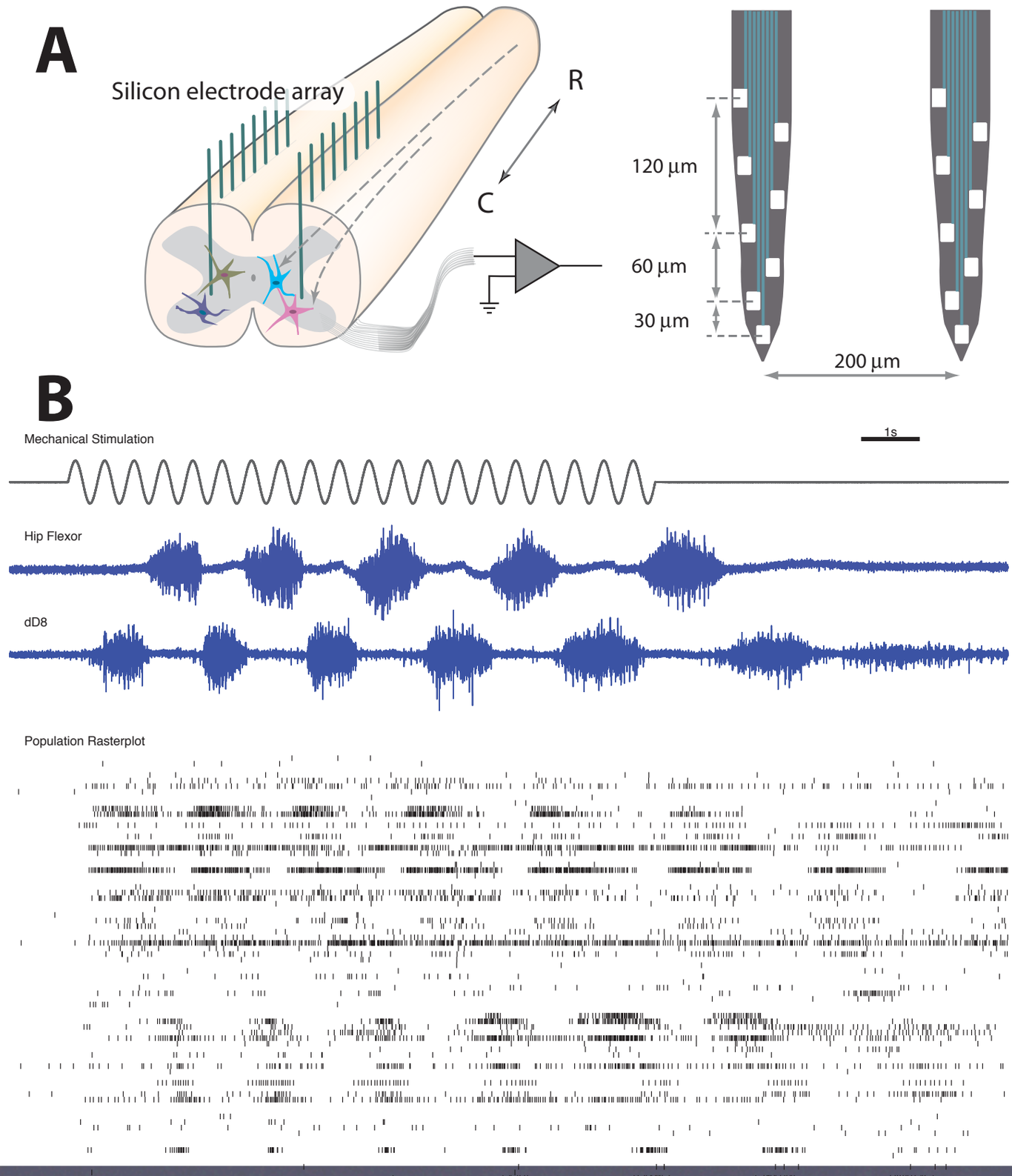
# Conclusions

- Skewed, log-normal firing rate distribution
- Conservation of position in distribution



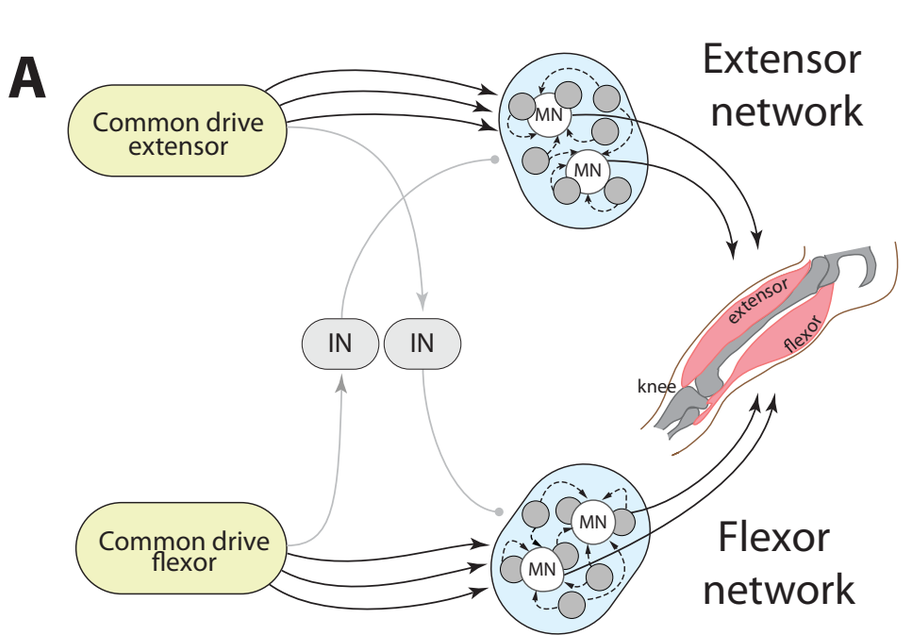

- Two regimes: fluctuation- and mean driven ~ 50%, i.e. half of cells are in irregular regime half of the time.

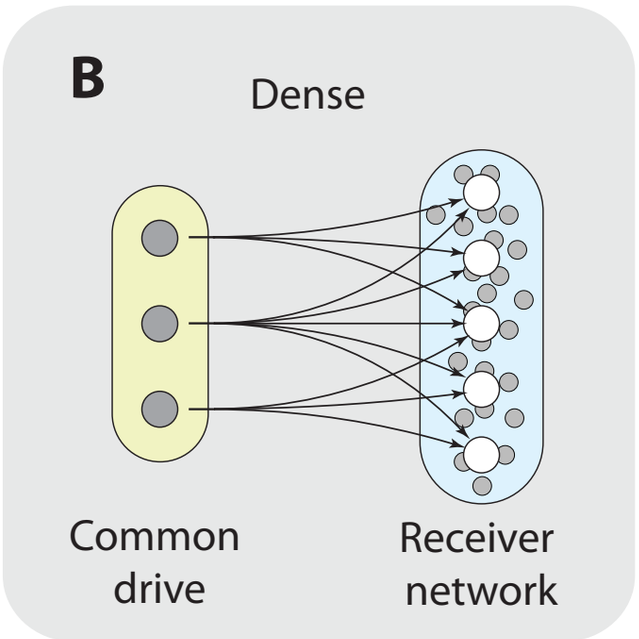
# Connectivity ?

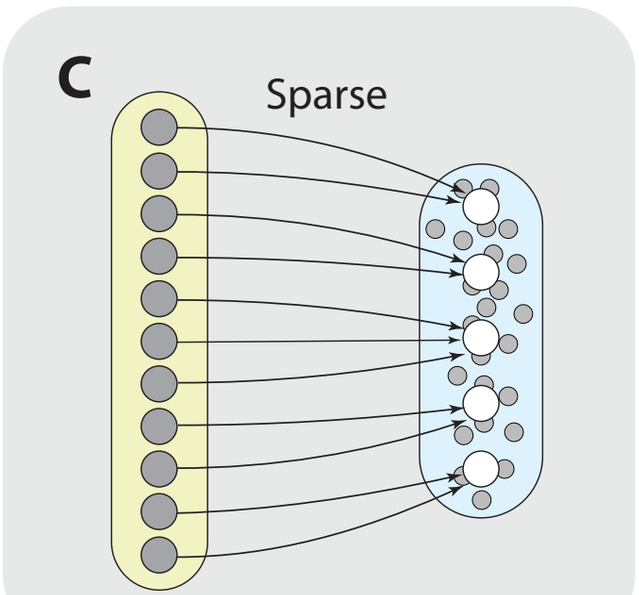



Radosevic et al, ***in preparation 2017***

# Feedforward model

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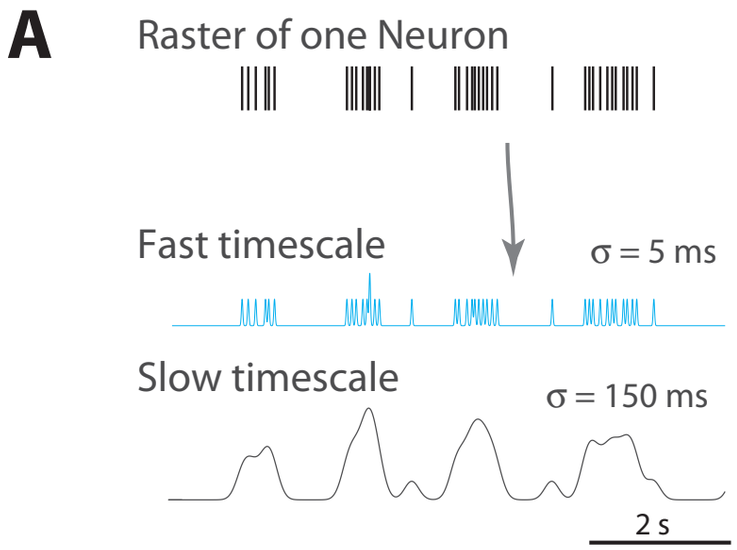
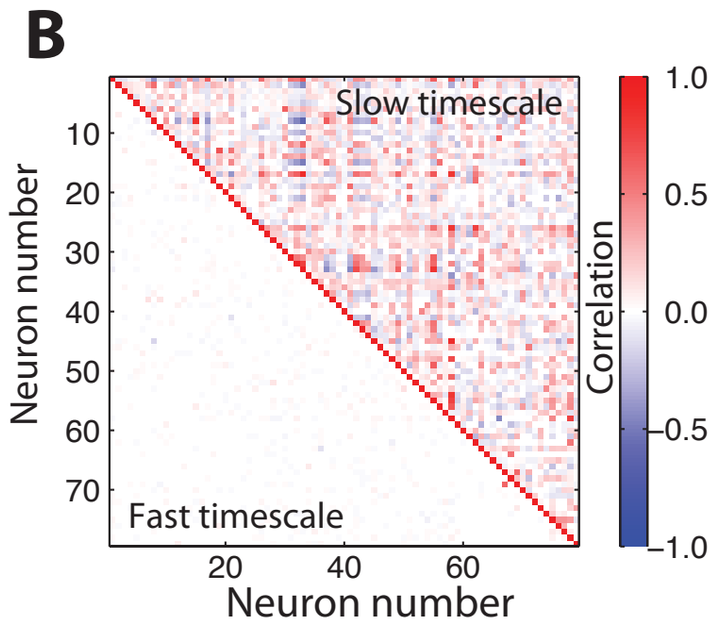
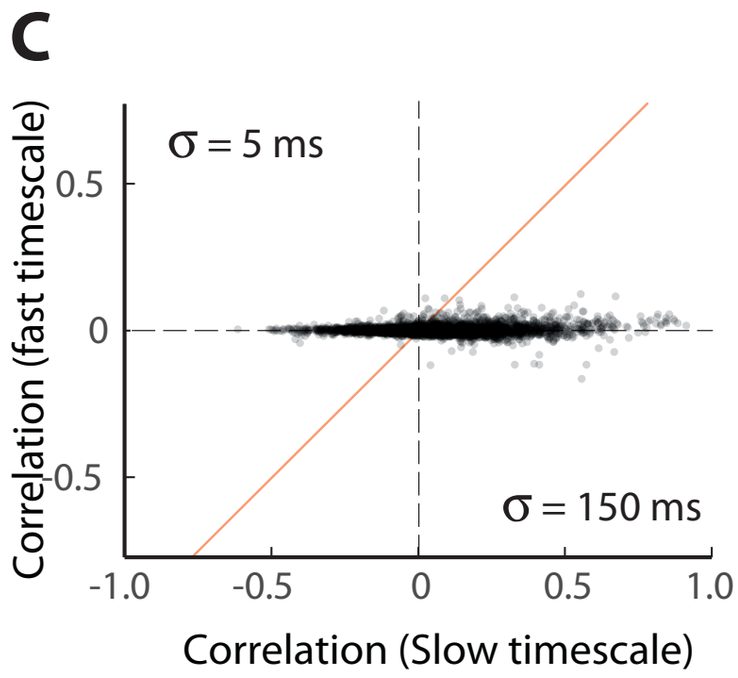
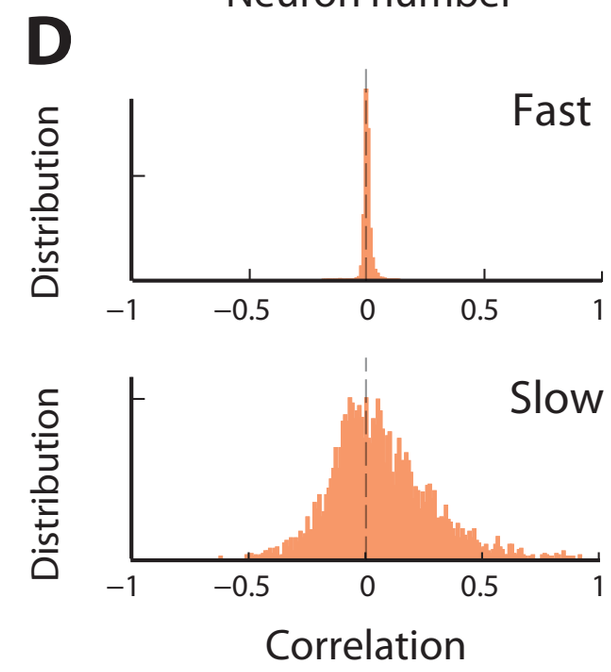
# Pairwise correlation

## slow and fast timescales

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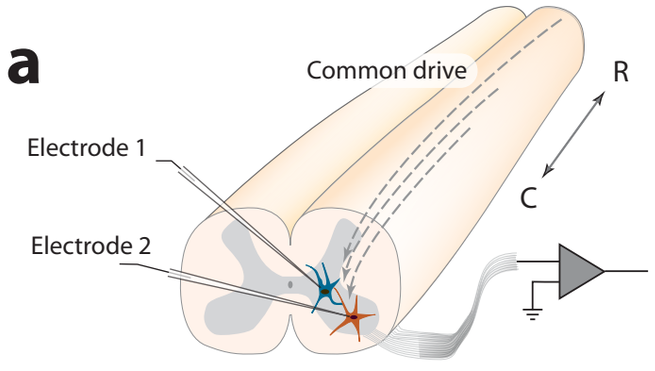
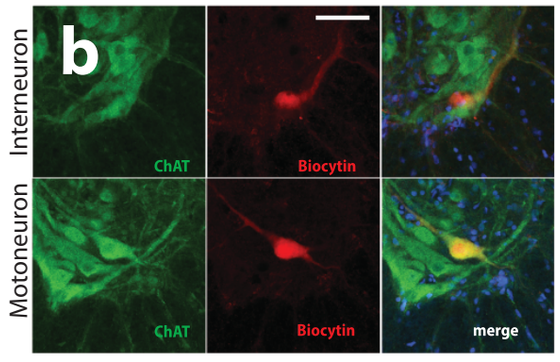
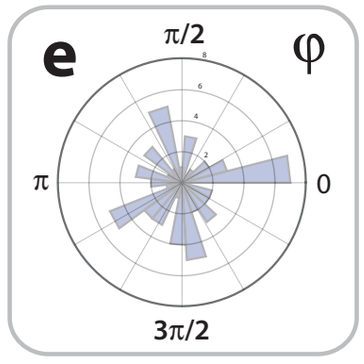
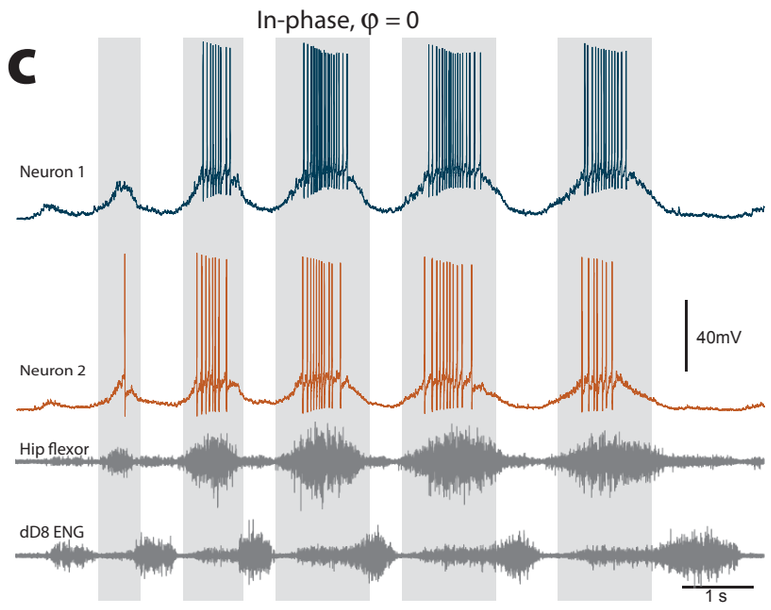
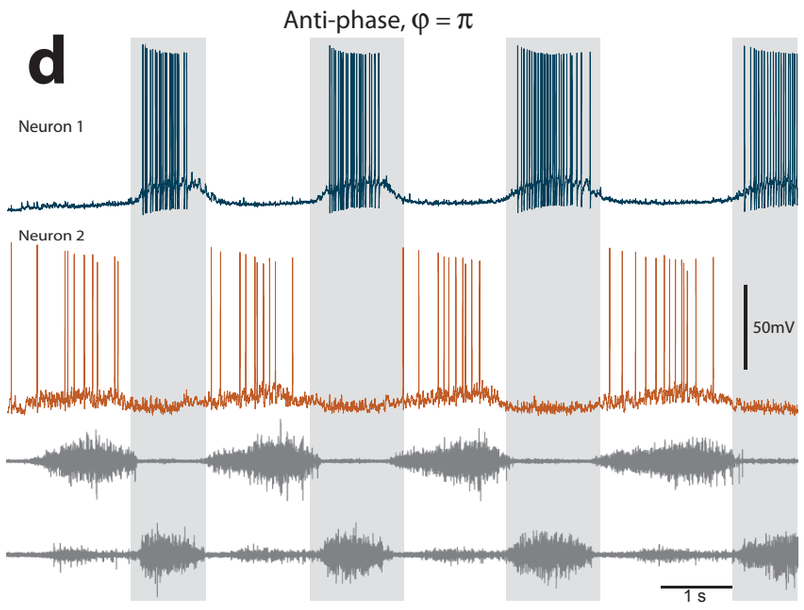
# Pairwise recording

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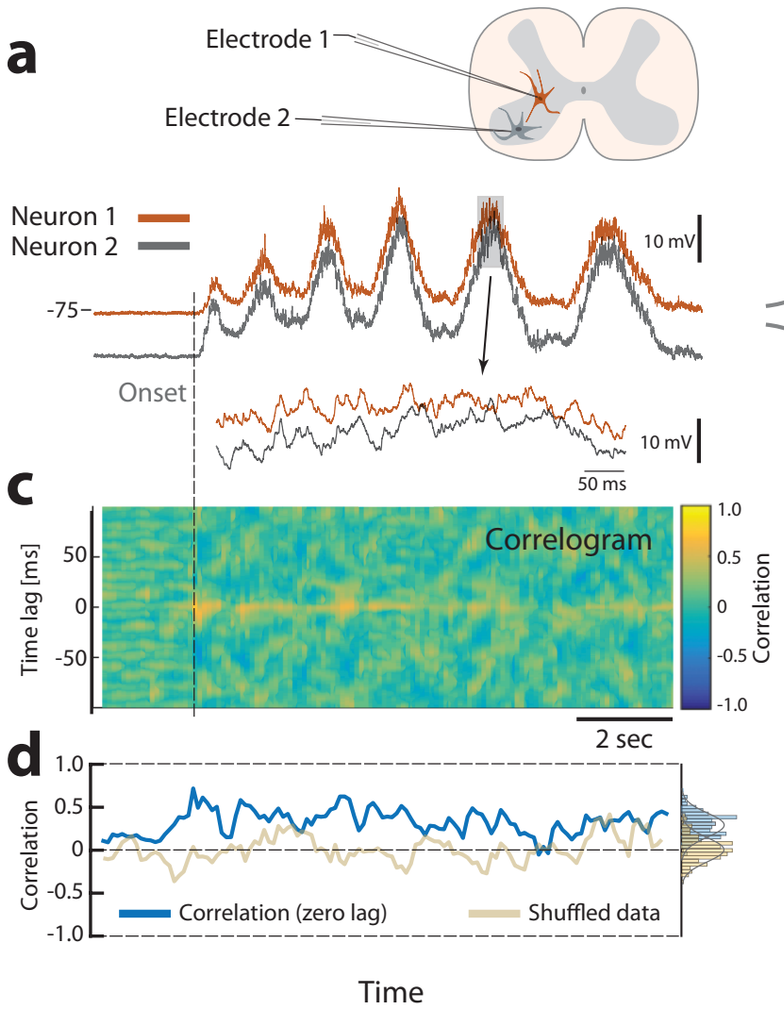
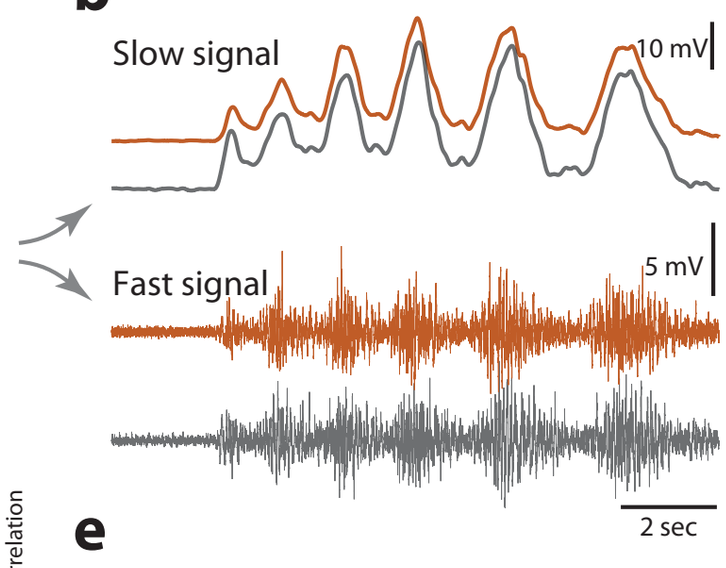
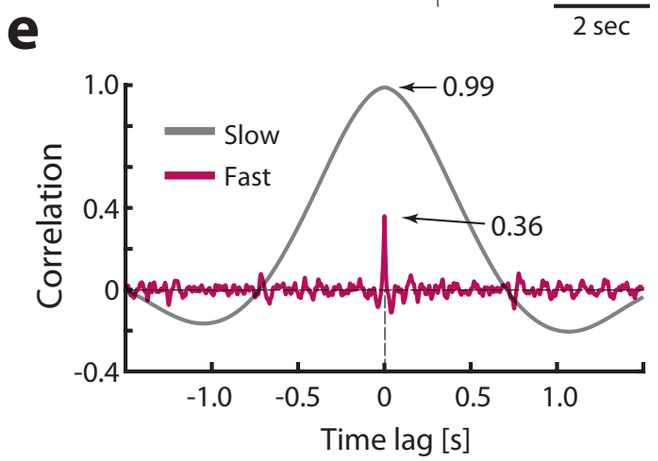
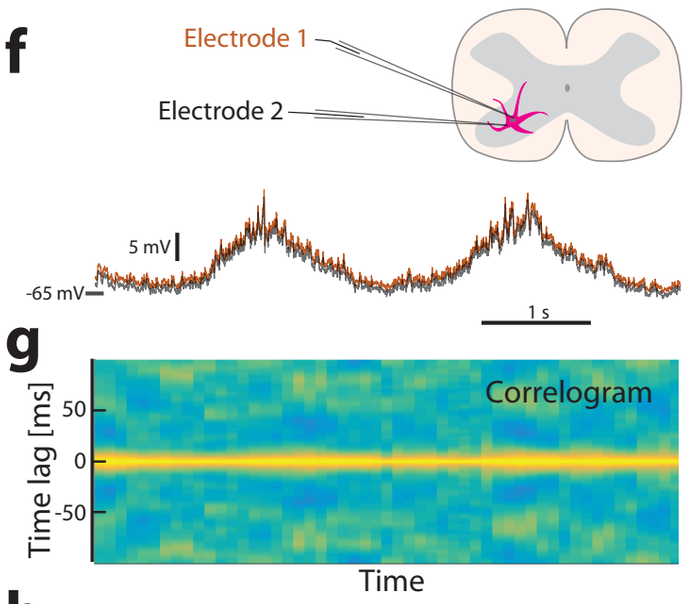
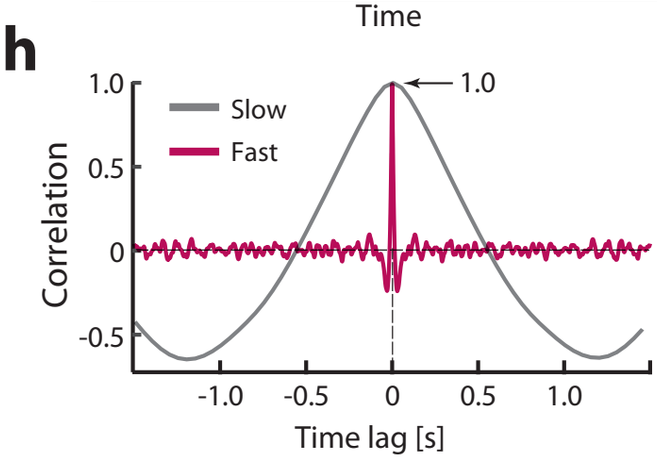
# Weak fast correlation

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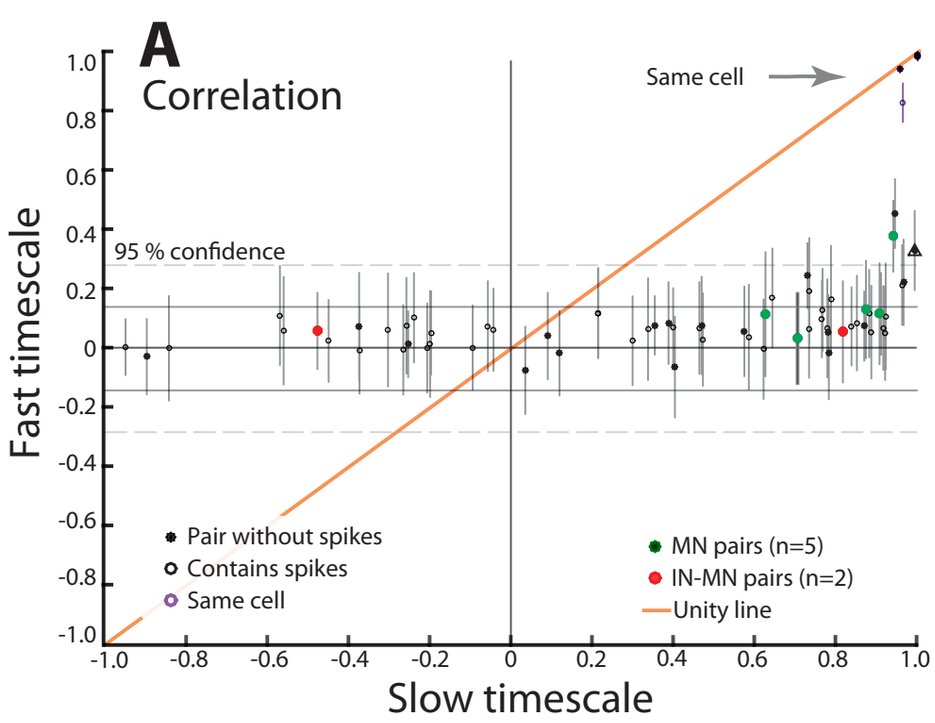
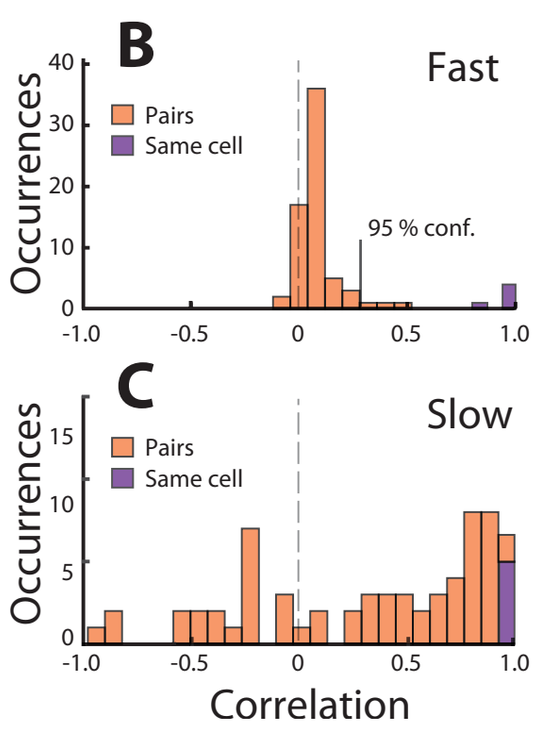
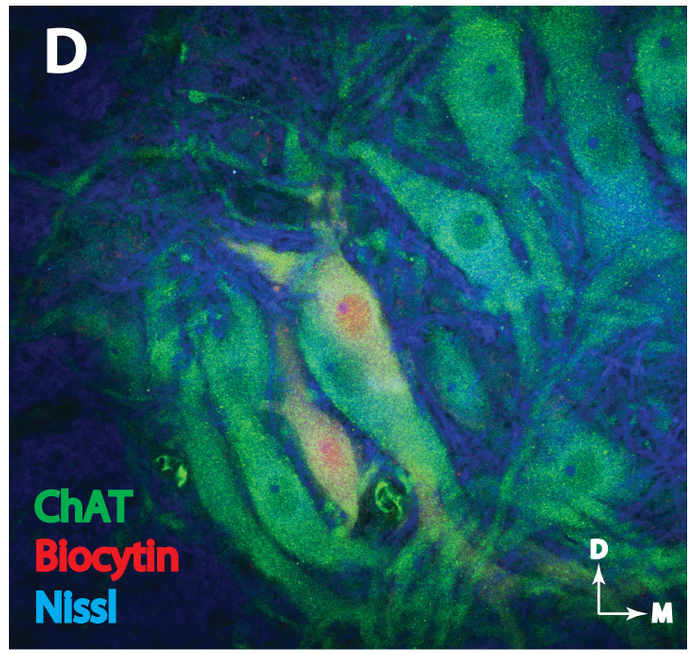
# Feedforward model

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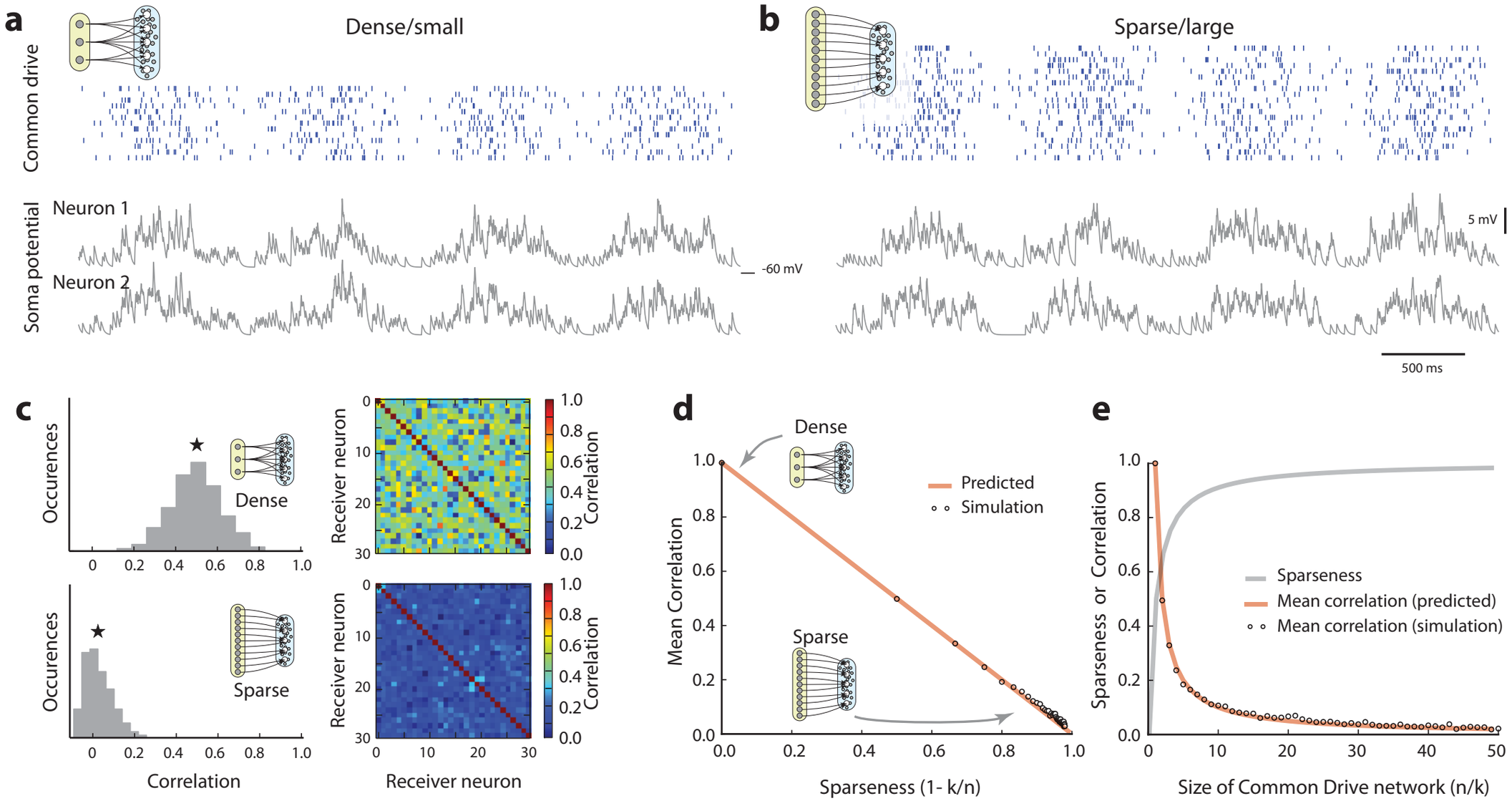
# Sparse vs. dense

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# Conclusion

Lack of correlation in synaptic input

Sparse and large network

"Active desynchronization"

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