Skewed firing rate distribution and fluctuation-driven regime

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Spinal Cord

Advantages:

- Purpose: Function is well-defined
- Morphology: Primarily a one-dimensional
- Blueprint: Phylogenetically old structure
- Complete: Contains an entire functional circuitry

Central Pattern Generators

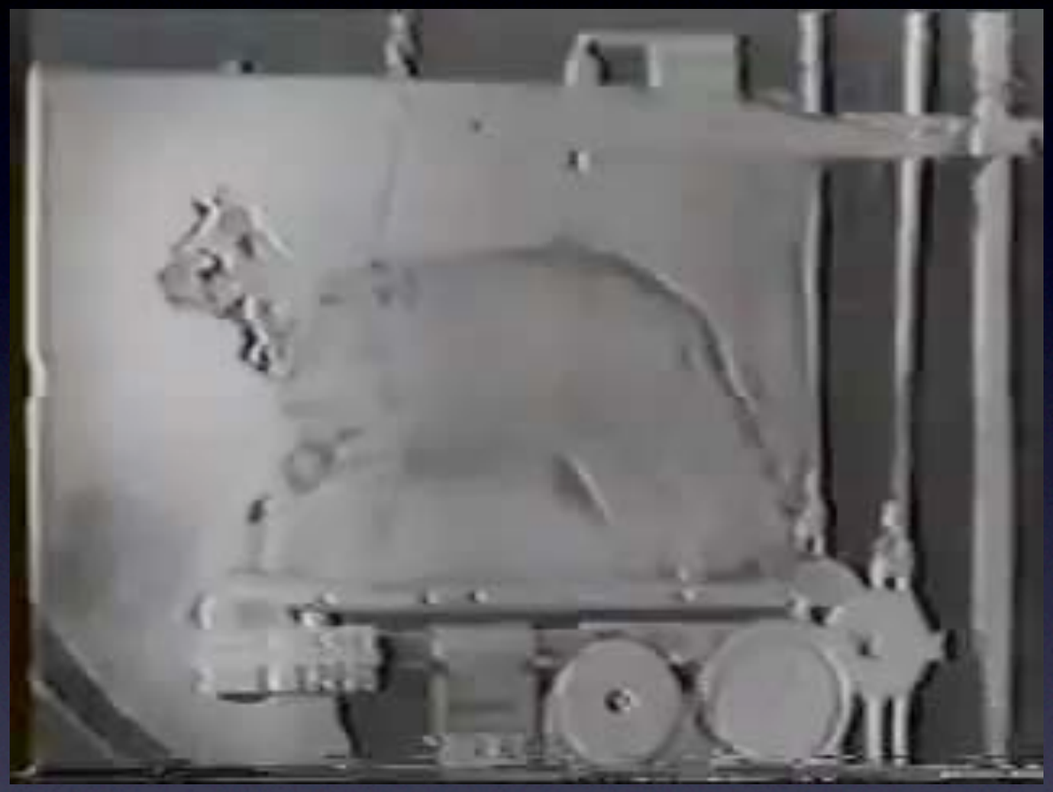
Chewing, Swimming, scratching, breathing and walking

Central Pattern Generators

Chewing, Swimming, scratching, breathing and walking

Sensory feedback not necessary, but strongly enhances movement

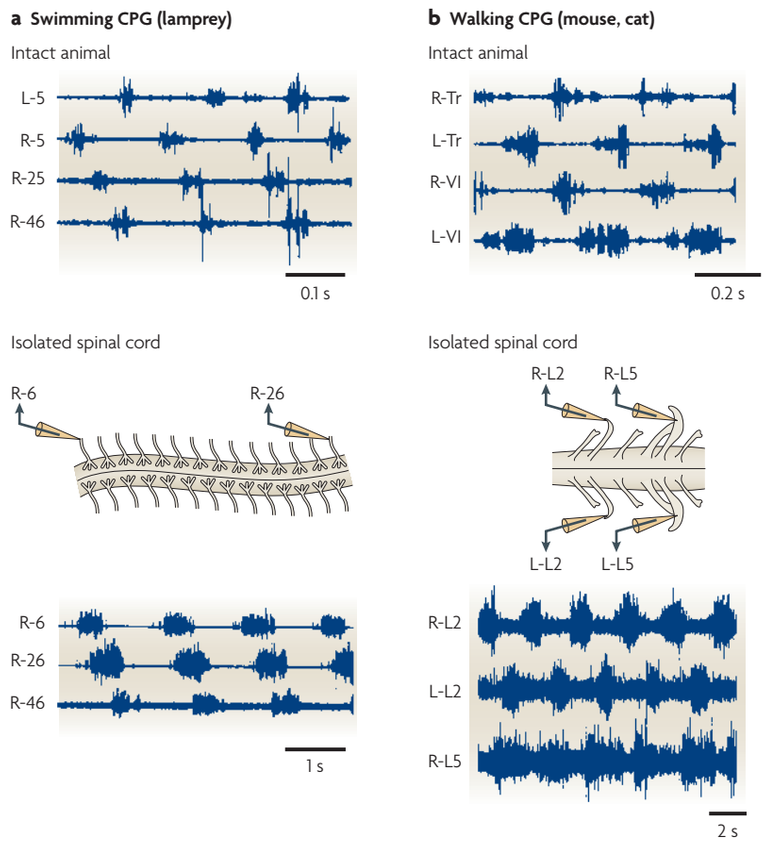
Decerebrate cat:



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

“Fictive locomotion”

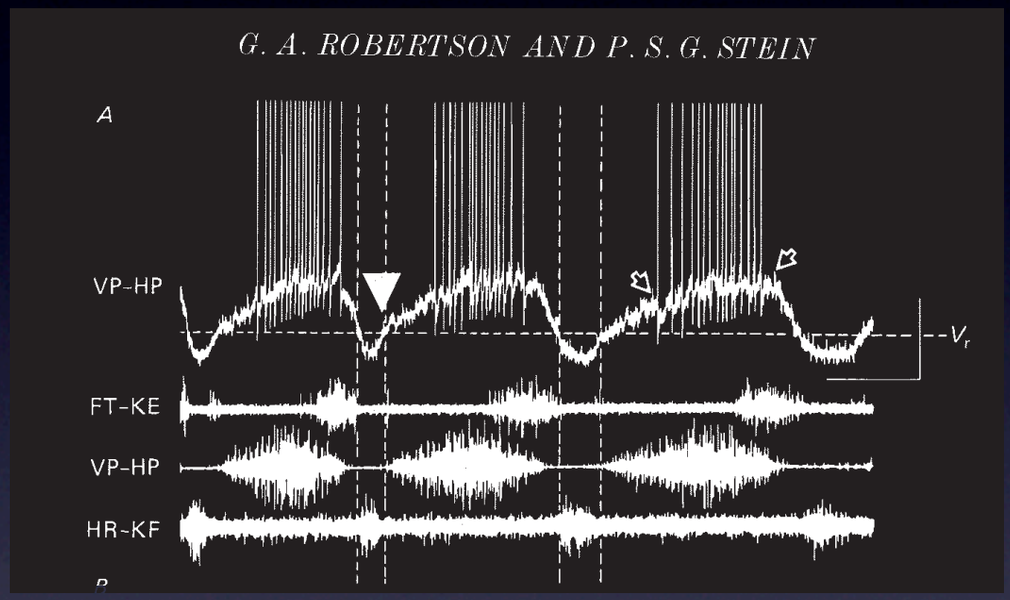
by adding neuro-chemicals



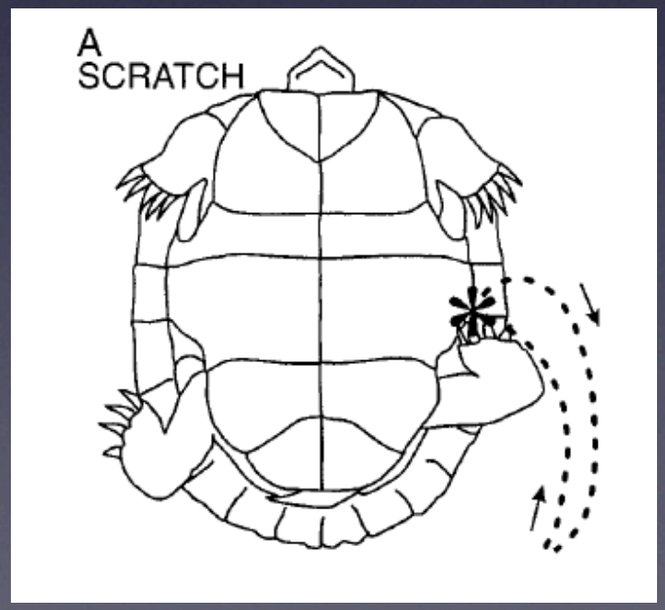
Goulding, *Nat Rev Neurosci* 2009

Model for motor pattern generation:

Turtle scratch reflex

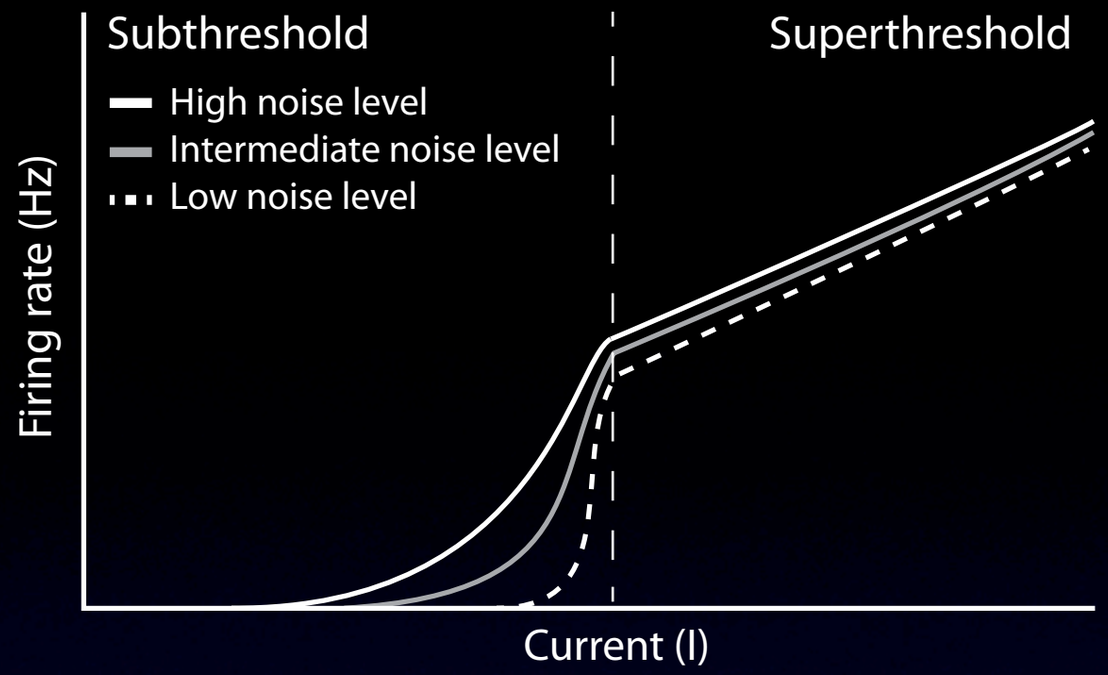


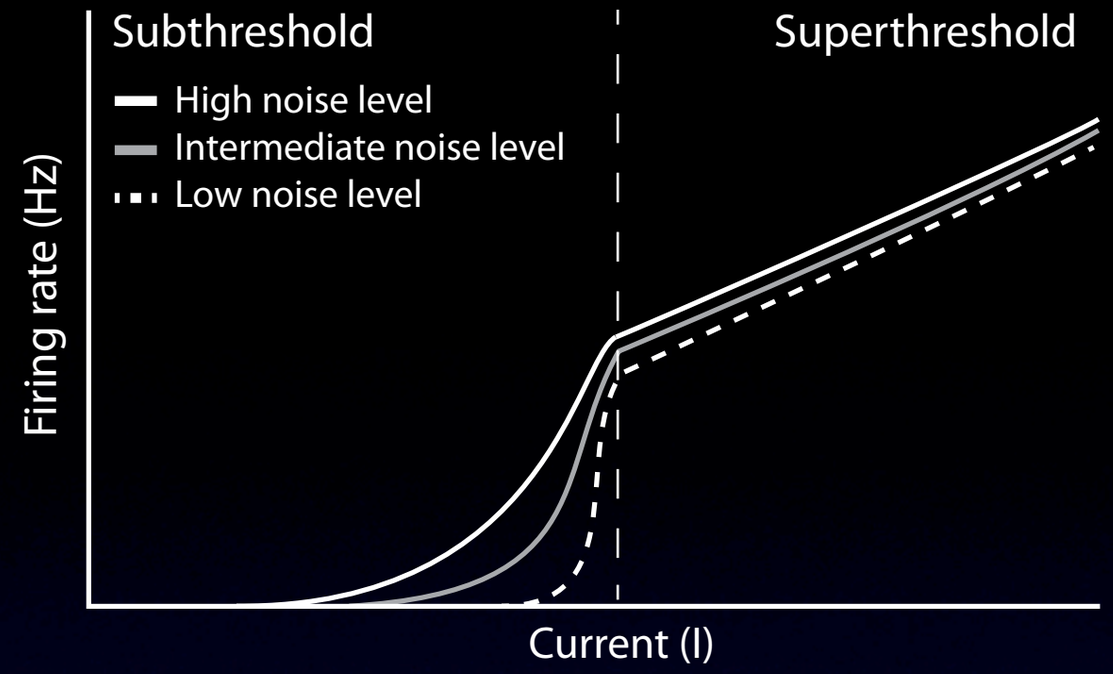
Robertson & Stein, J. Physiol. 1988



Sensory-specific spinal scratching

Turtle is upside-down performing hindlimb scratching


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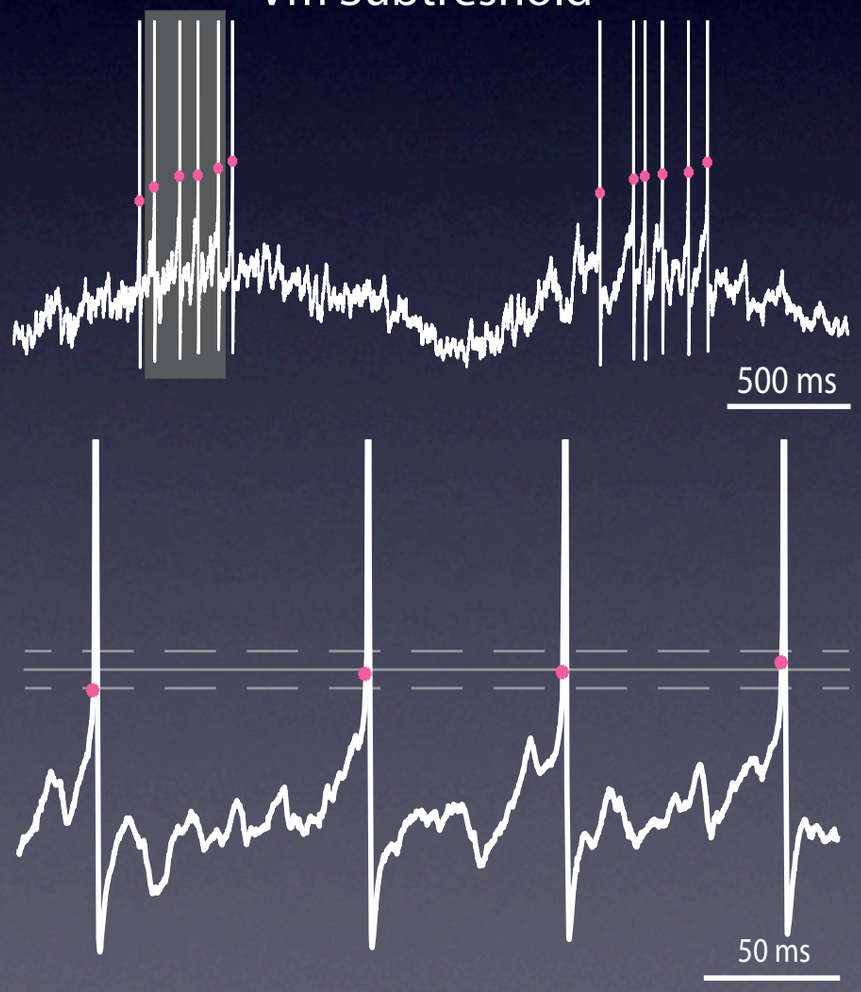
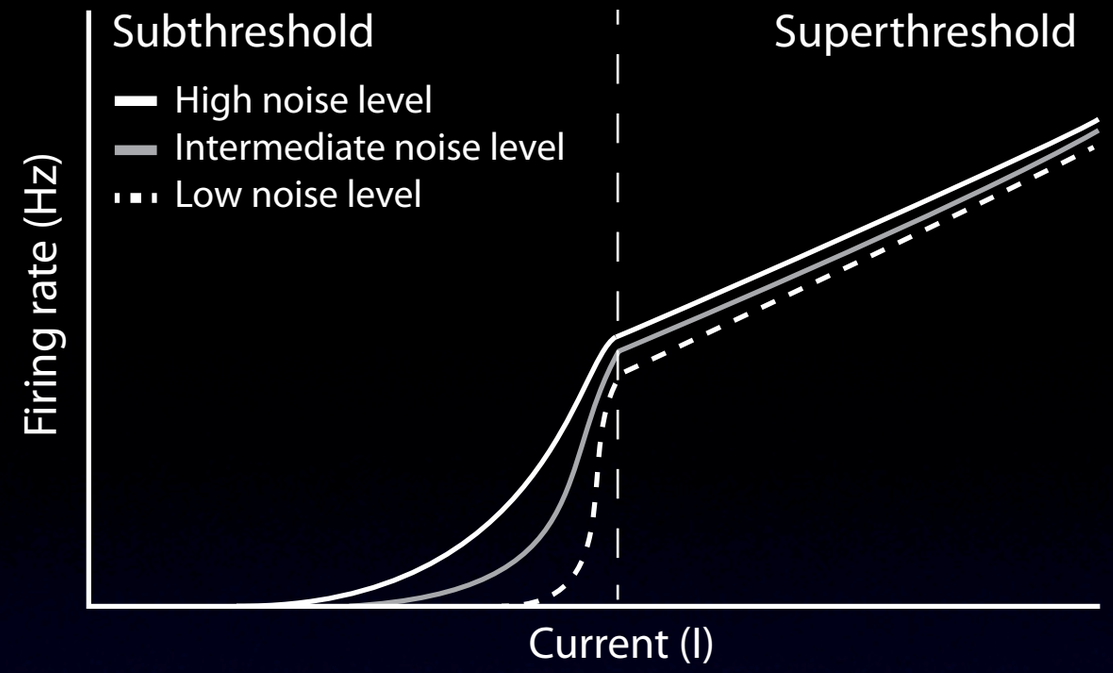
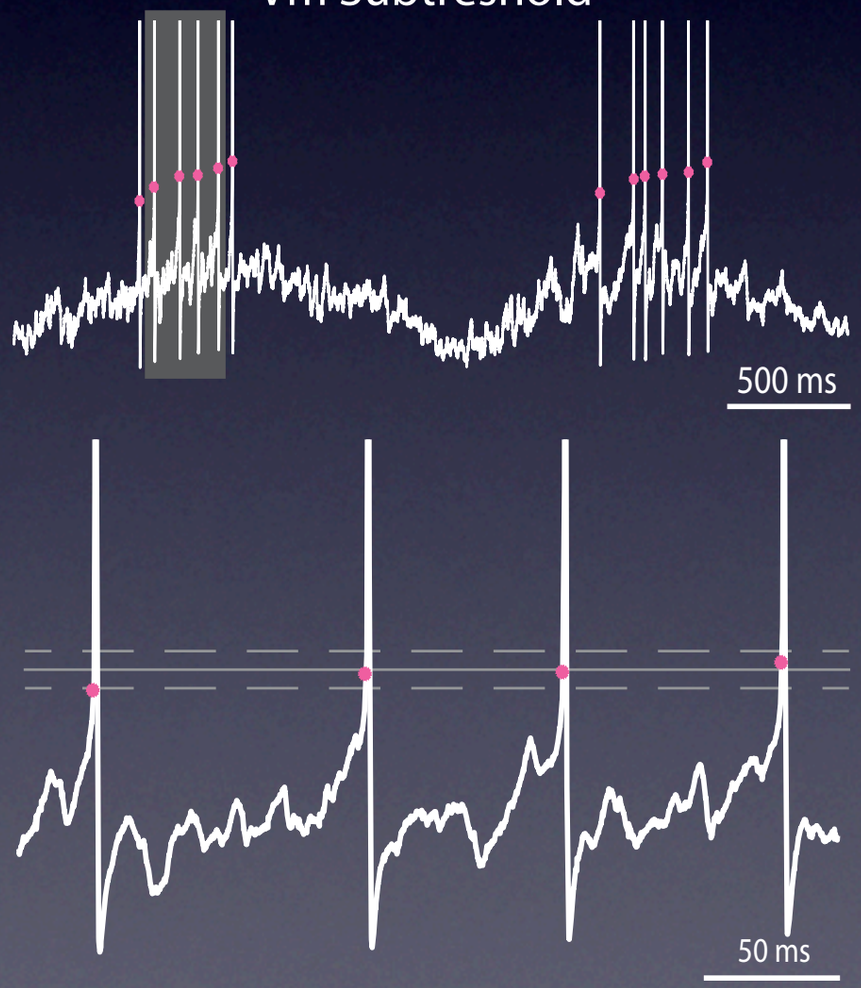
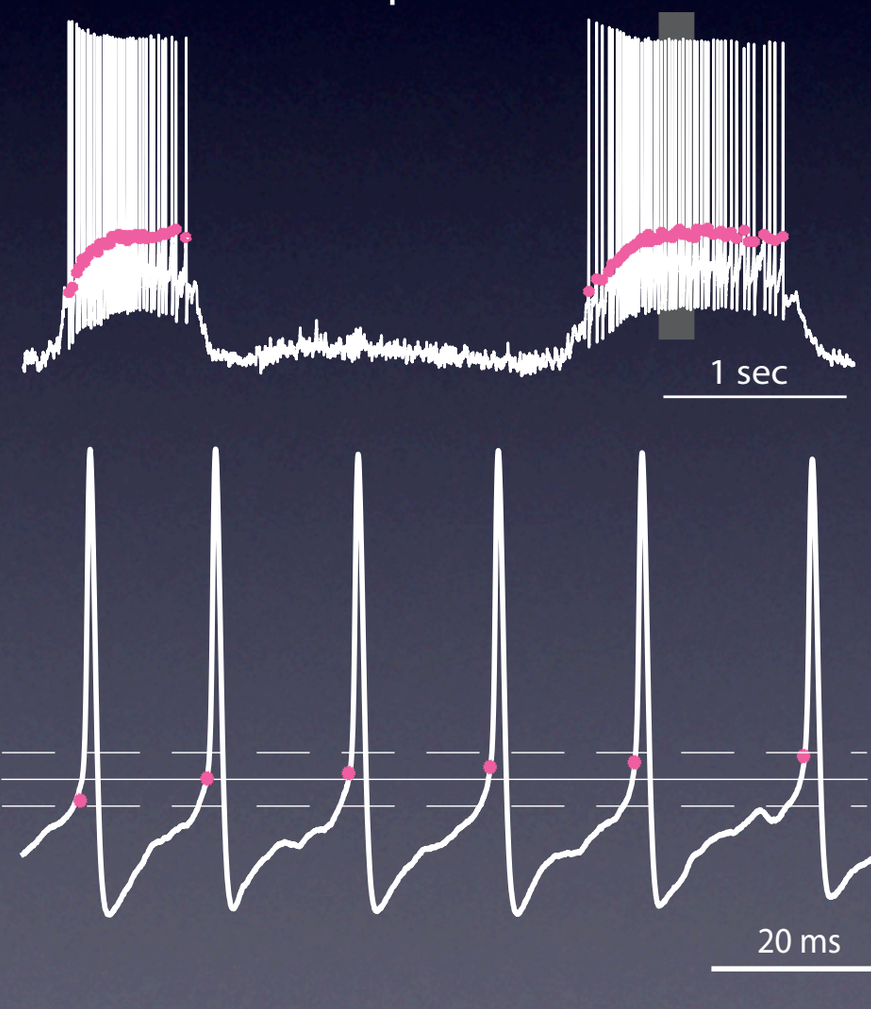

Vm Subtreshold
500 ms
50 ms



Vm Subtreshold



Vm Superthreshold

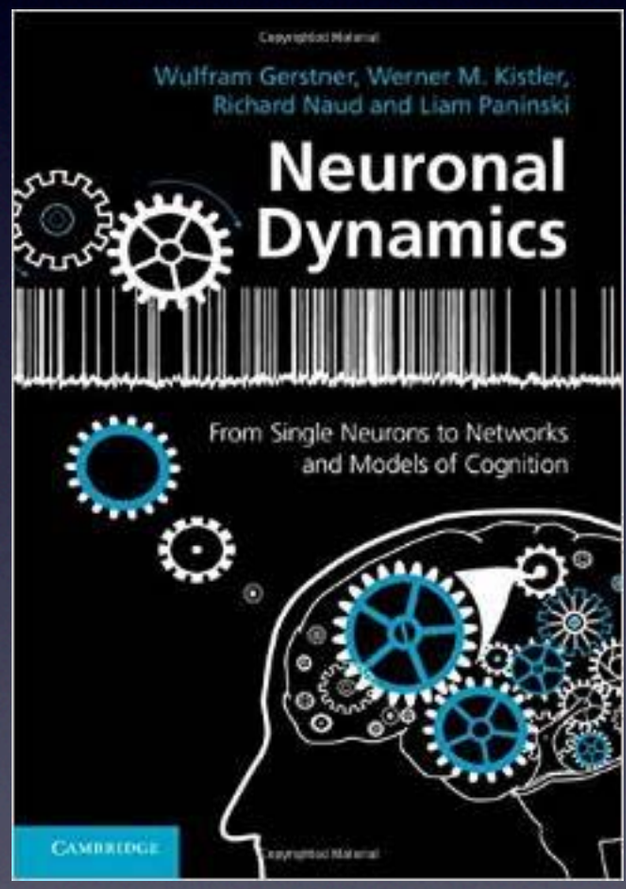


Two regimes:

Fluctuation-driven

Mean-driven

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



Two regimes:

	Fluctuation-driven	Mean-driven
Definition	$R_{in}I_{total} < V_{threshold}$	$R_{in}I_{total} > V_{threshold}$
Hallmarks		
Hallmarks		
Causes		

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

Two regimes:

	Fluctuation-driven	Mean-driven
Definition	$R_{in}I_{total} < V_{threshold}$	$R_{in}I_{total} > V_{threshold}$
Hallmarks	Low rates	High rates
Hallmarks		
Causes		

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

Two regimes:

	Fluctuation-driven	Mean-driven
Definition	$R_{in}I_{total} < V_{threshold}$	$R_{in}I_{total} > V_{threshold}$
Hallmarks	Low rates	High rates
Hallmarks	Irregular	Regular
Causes		

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

Two regimes:

	Fluctuation-driven	Mean-driven
Definition	$R_{in}I_{total} < V_{threshold}$	$R_{in}I_{total} > V_{threshold}$
Hallmarks	Low rates	High rates
Hallmarks	Irregular	Regular
Causes	Balanced E/I	Anything

Softky and Koch, *J Neurosci 1993*

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

Shape of rate distribution in the two regimes?

Shape of rate distribution is skewed

The Journal of Neuroscience, November 9, 2011 • 31(45):16217–16226 • **16217**

Behavioral/Systems/Cognitive

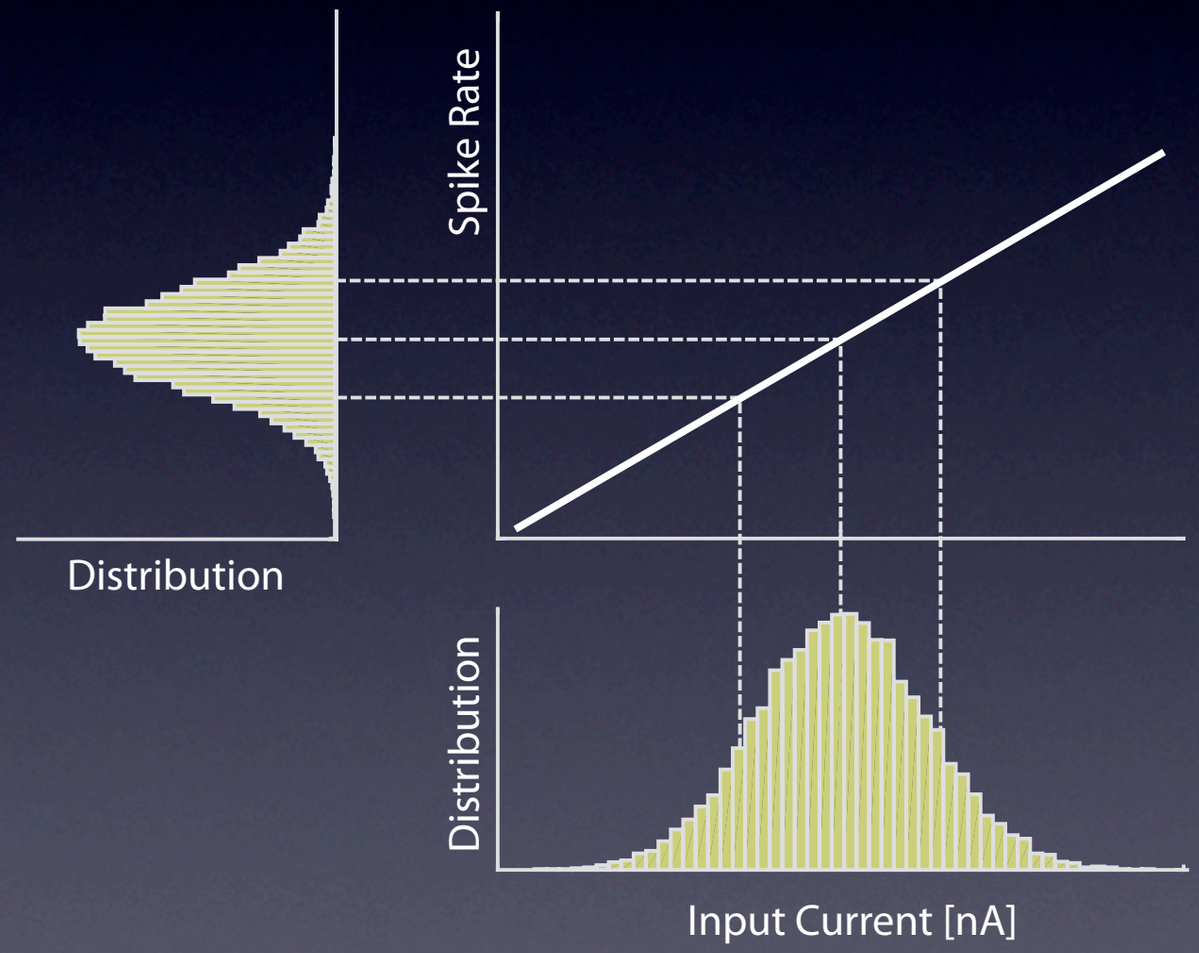
On the Distribution of Firing Rates in Networks of Cortical Neurons

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

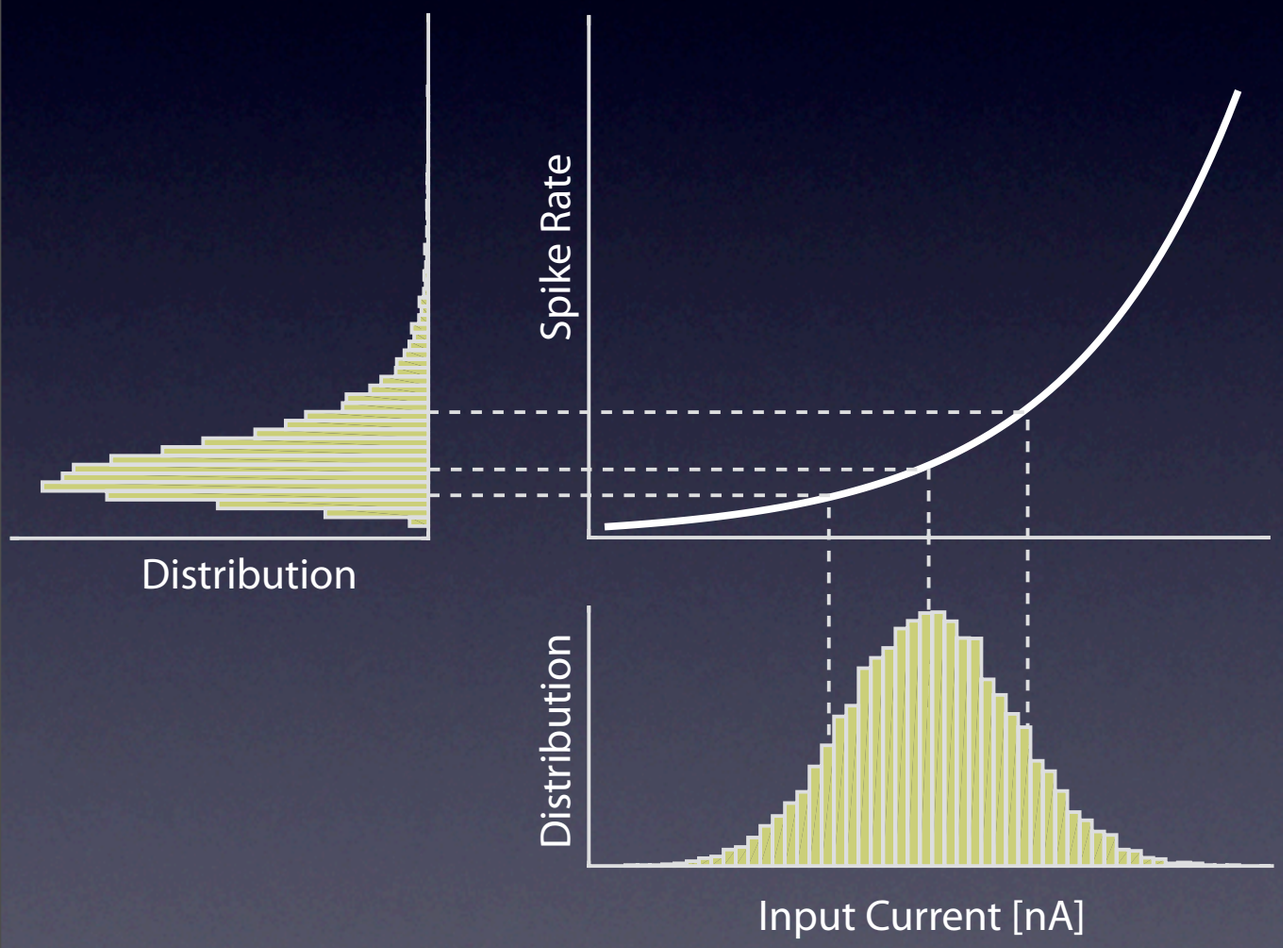
"We argue that skewed rate distributions are a signature of the nonlinearity of the in vivo F-I-curve"

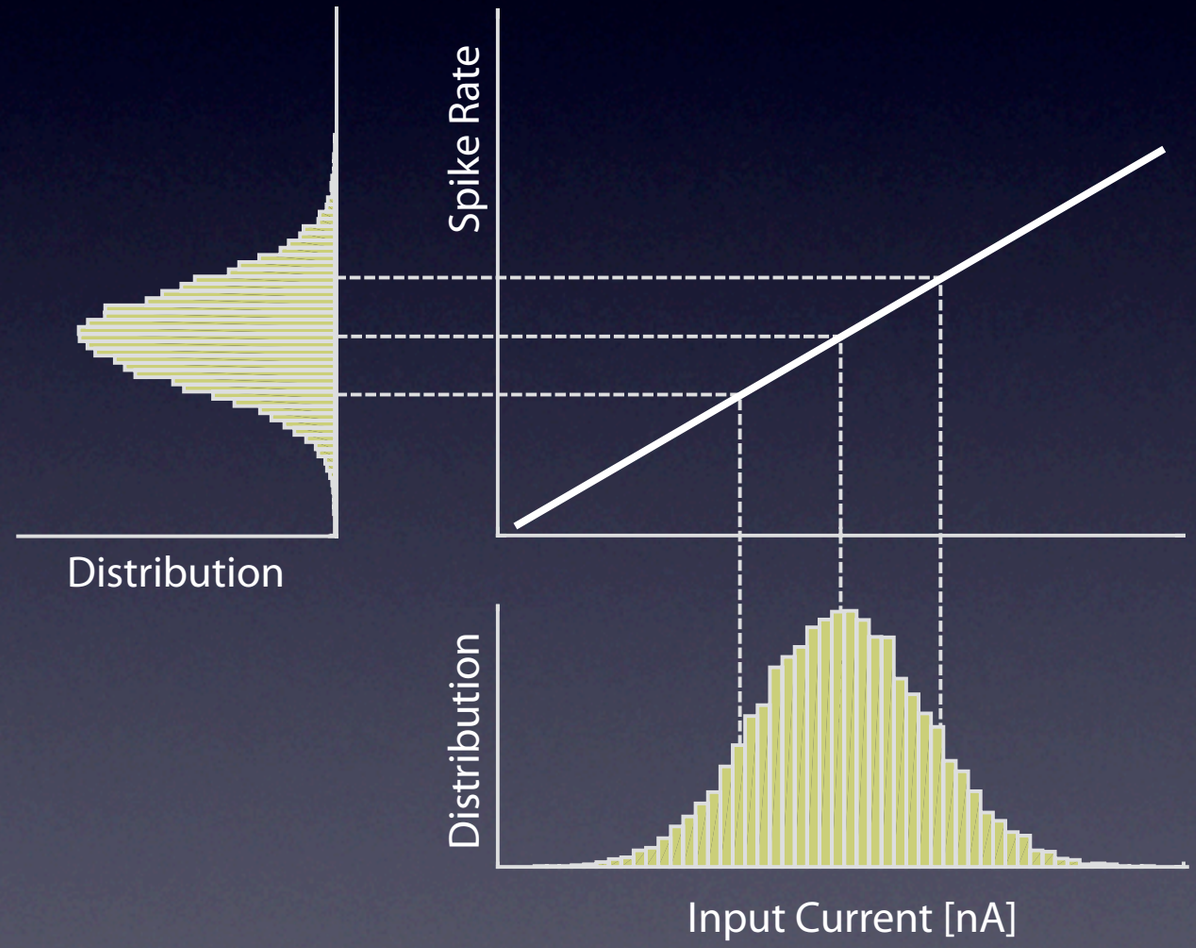
Transformation of input-to-output



Roxin et al, *J Neurosci* 2011

Transformation of input-to-output





Roxin et al, *J Neurosci* 2011

Two regimes:

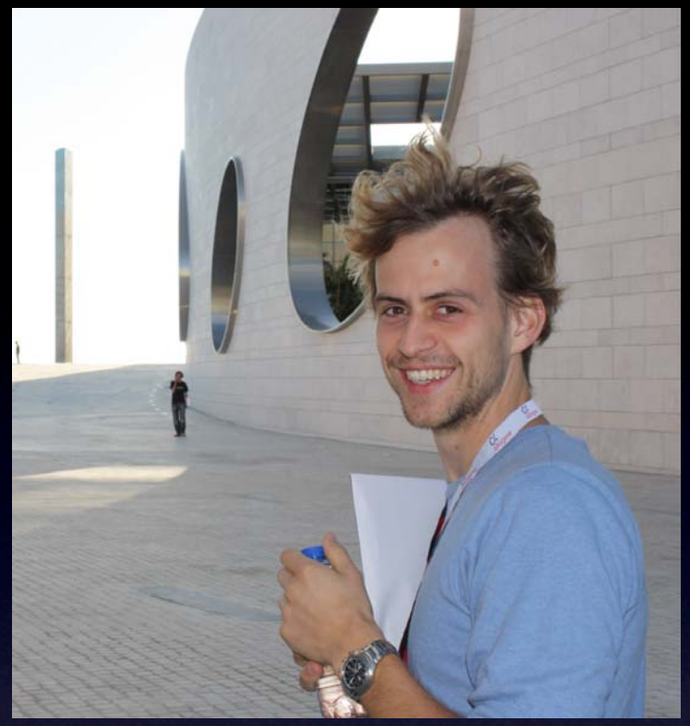
	Fluctuation-driven	Mean-driven
Definition	$R_{in}I_{total} < V_{threshold}$	$R_{in}I_{total} > V_{threshold}$
Hallmarks	Low rates	High rates
Hallmarks	Irregular	Regular
Hallmarks	**Skewed**	**Symmetric**
Causes	Balanced E/I	Anything

Lagzi and Rotter, *Front Comp Neurosci 2014*

Buzsaki and Mizuseki, *Nat Rev Neurosci 2014*

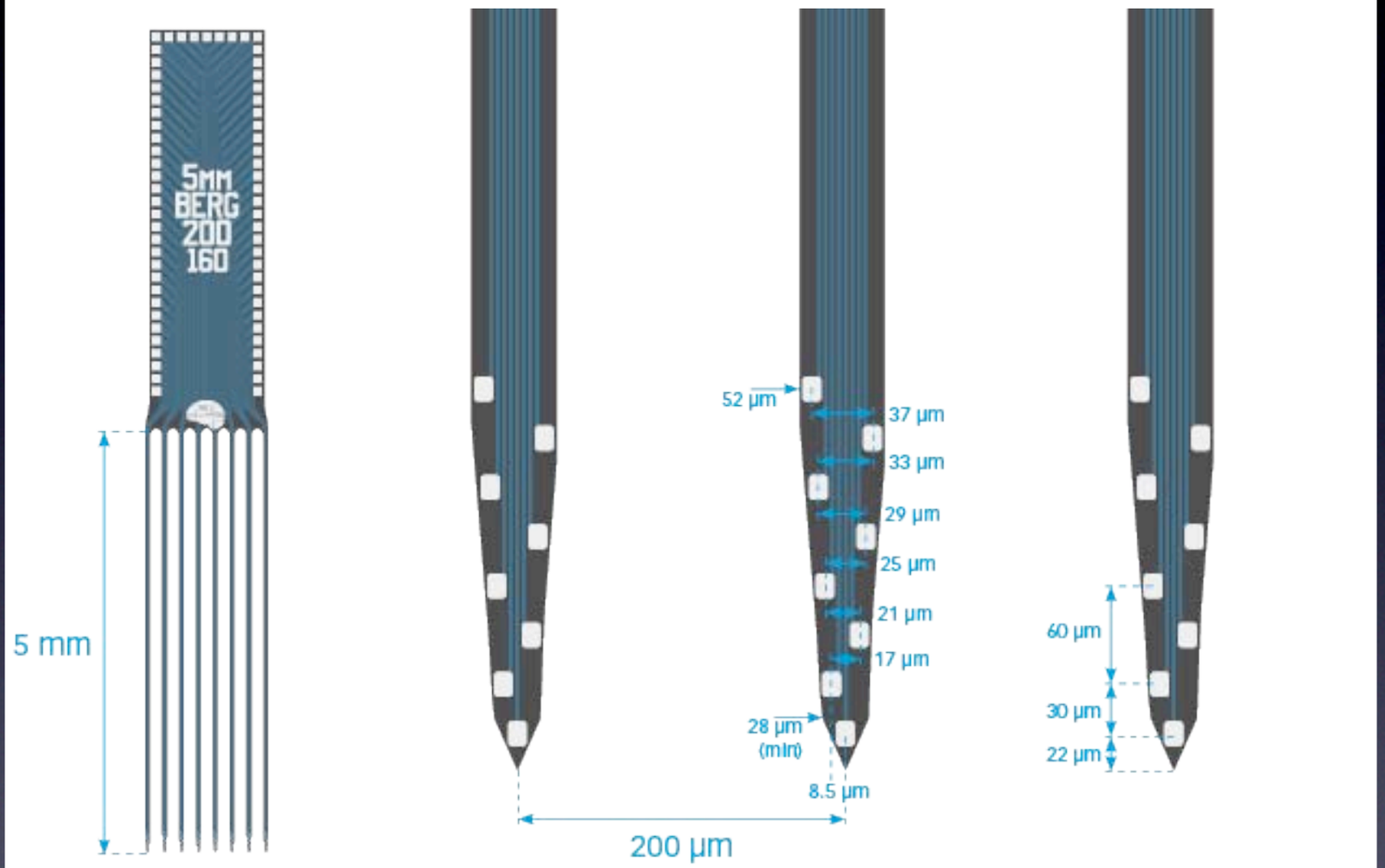
Recording Population activity

Peter Petersen



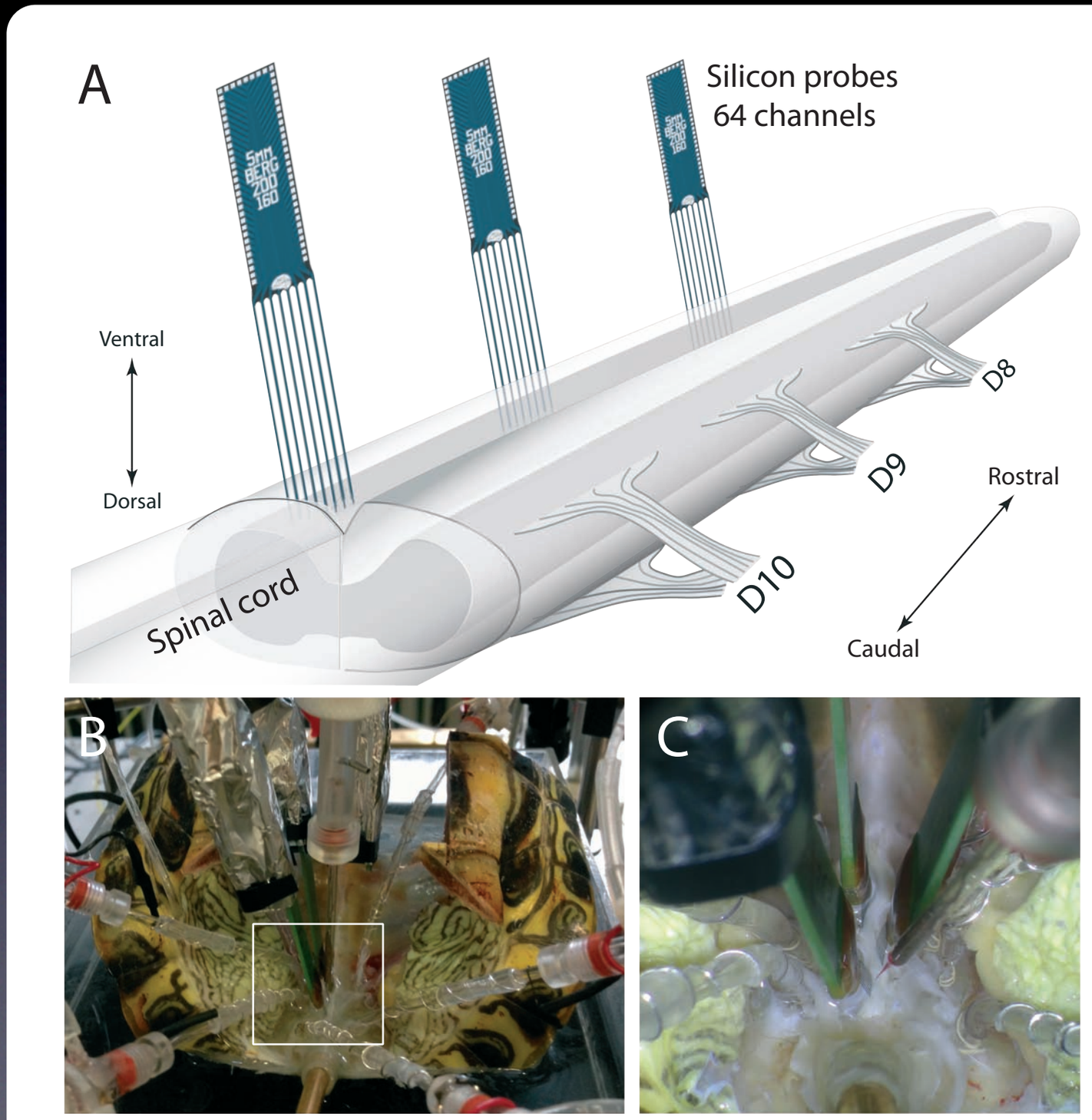
Recording Population activity

Berg64-Probe by Neuronexus

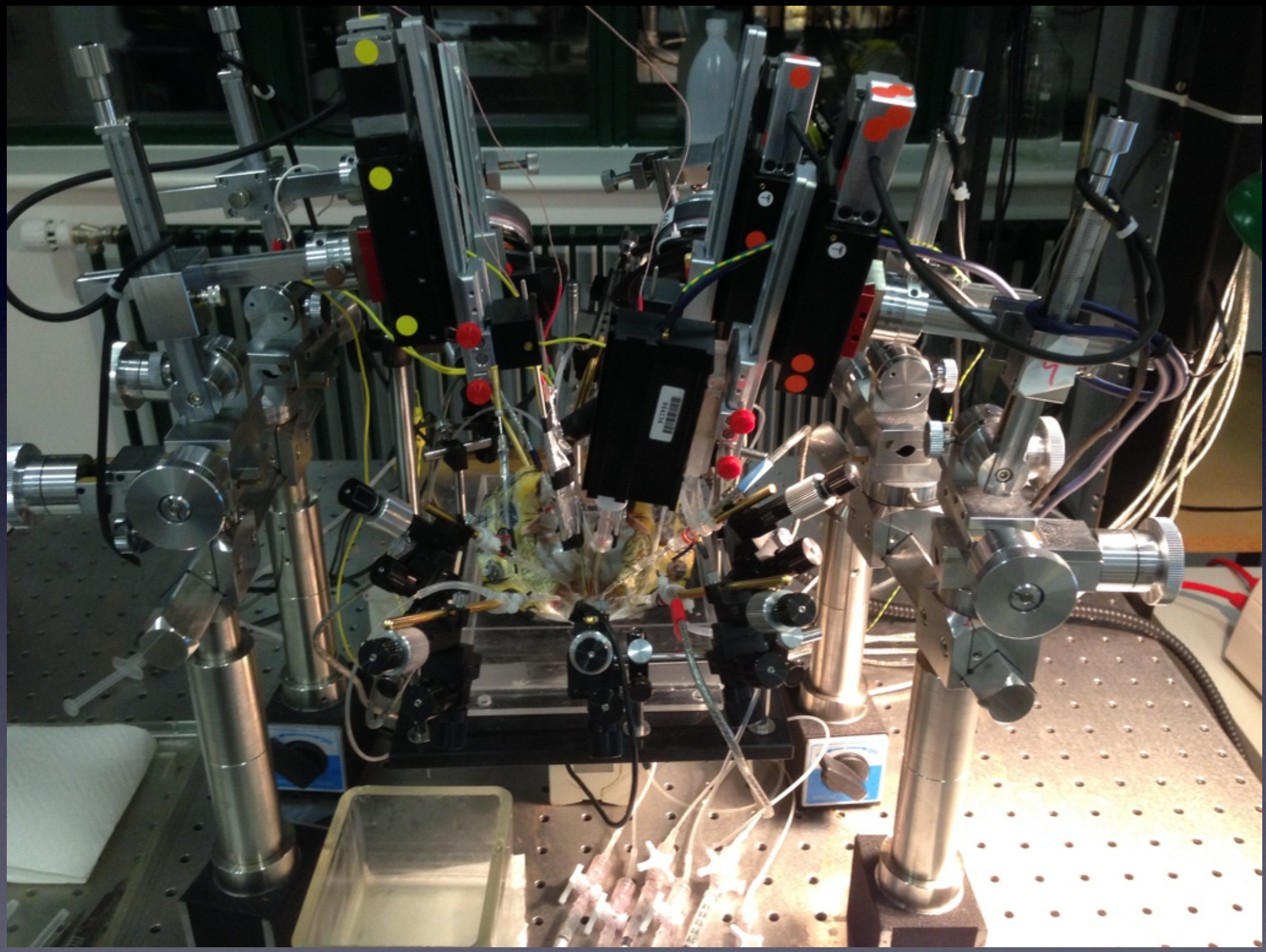


8 shanks with 8 leads = 64 ch

Electrophysiology: Multichannel recording

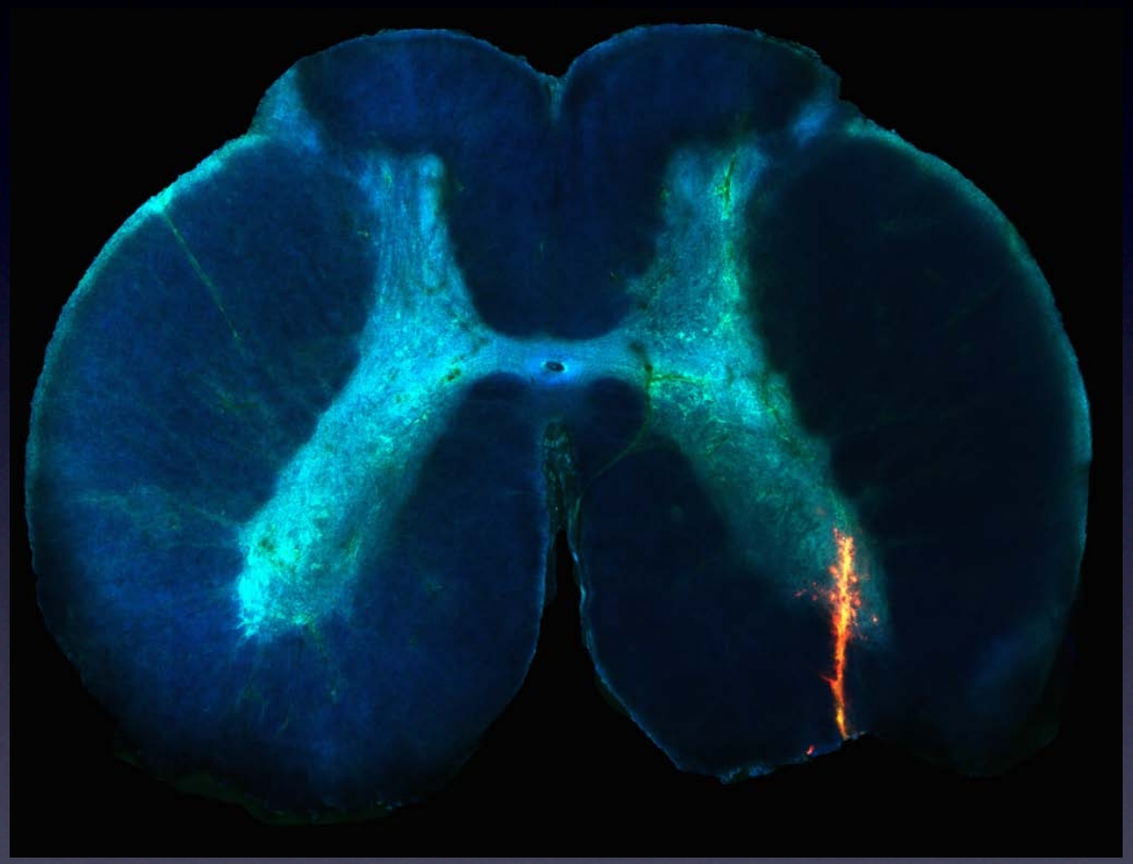


Experimental Setup

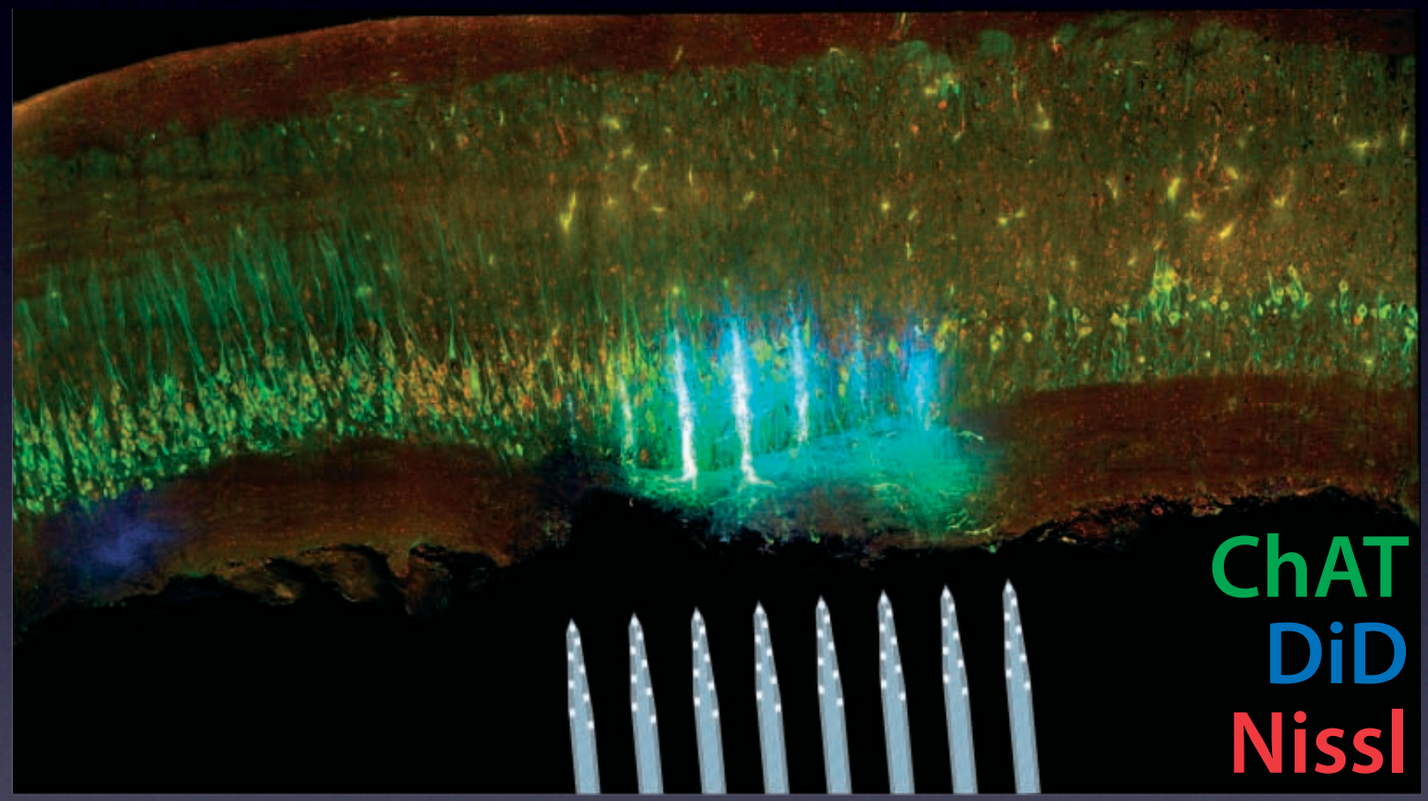


Experimental Setup

Histology
DiD-labeling and Nissle



Transverse section



Sagittal section

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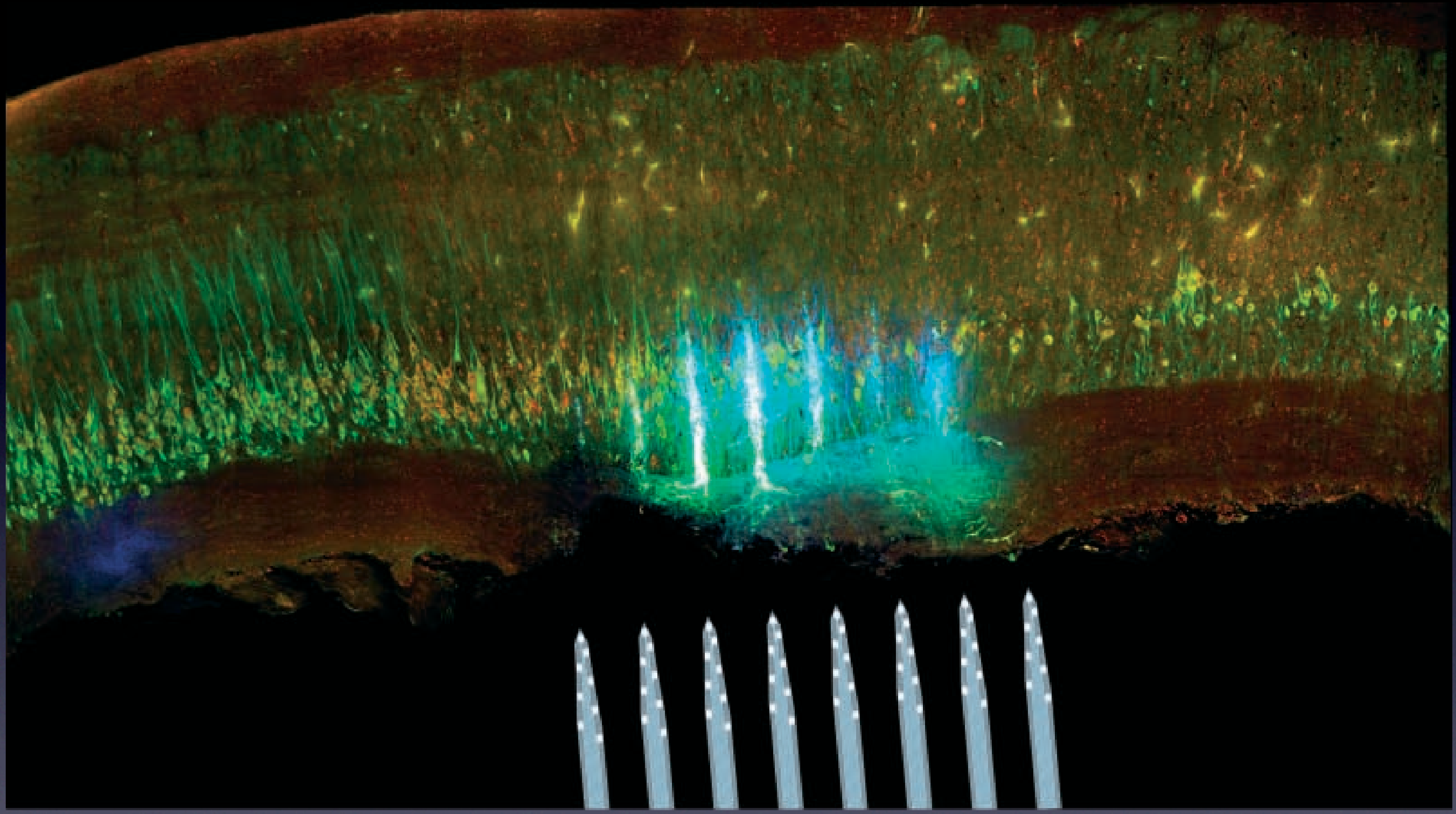
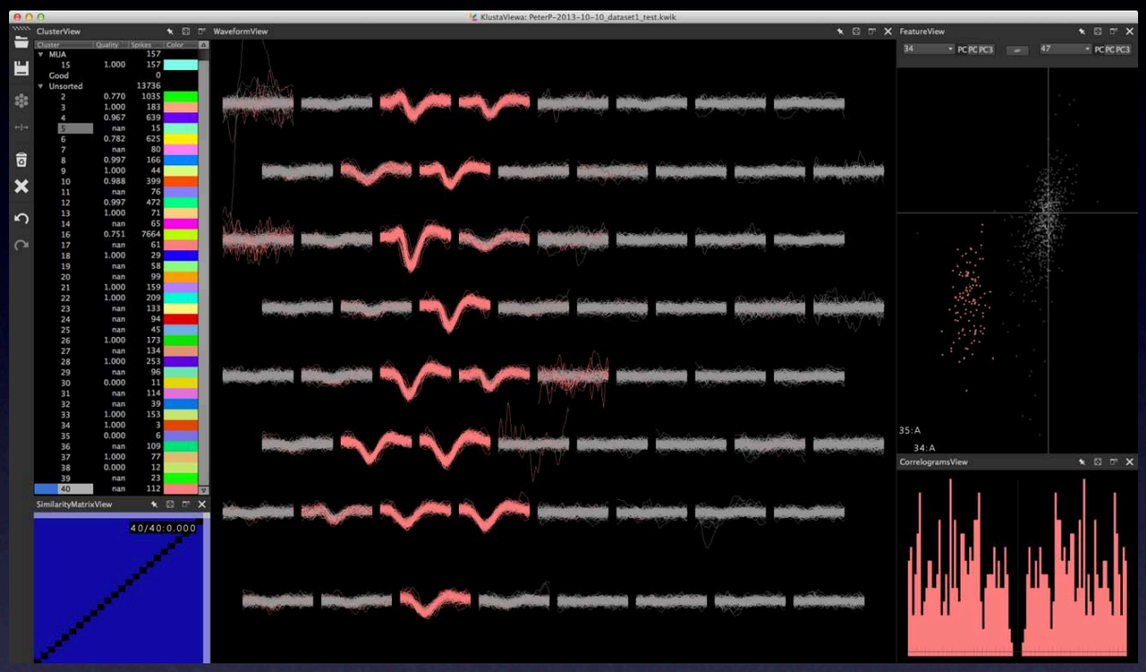
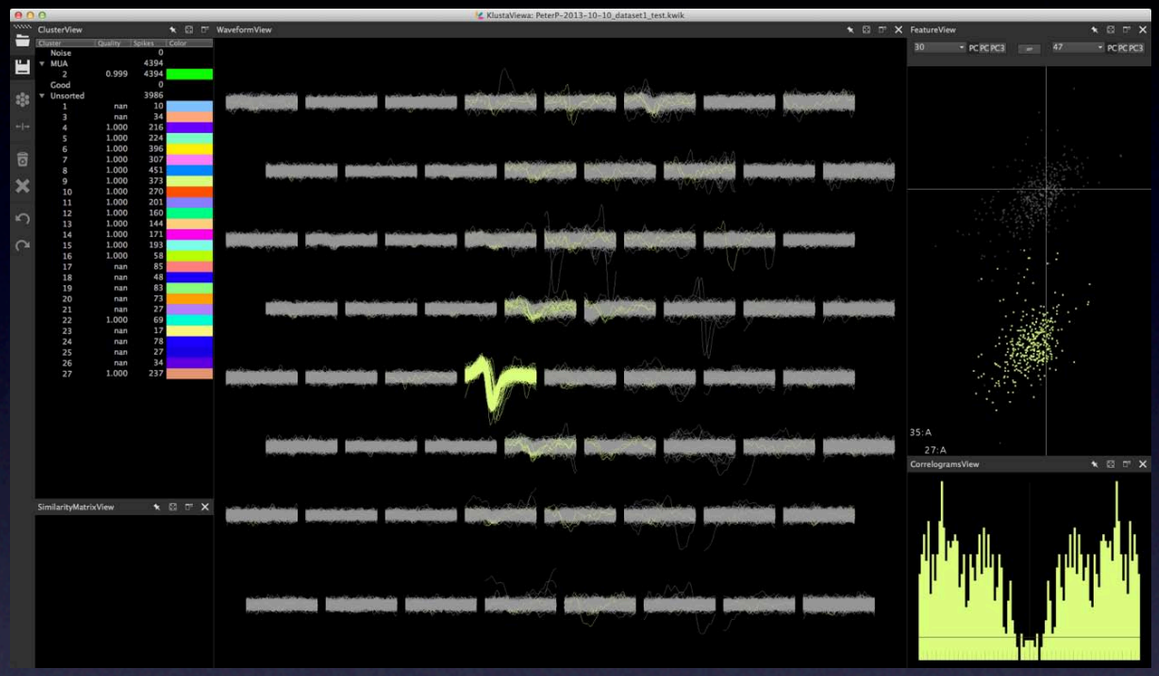
Petersen and Berg, *in preparation*

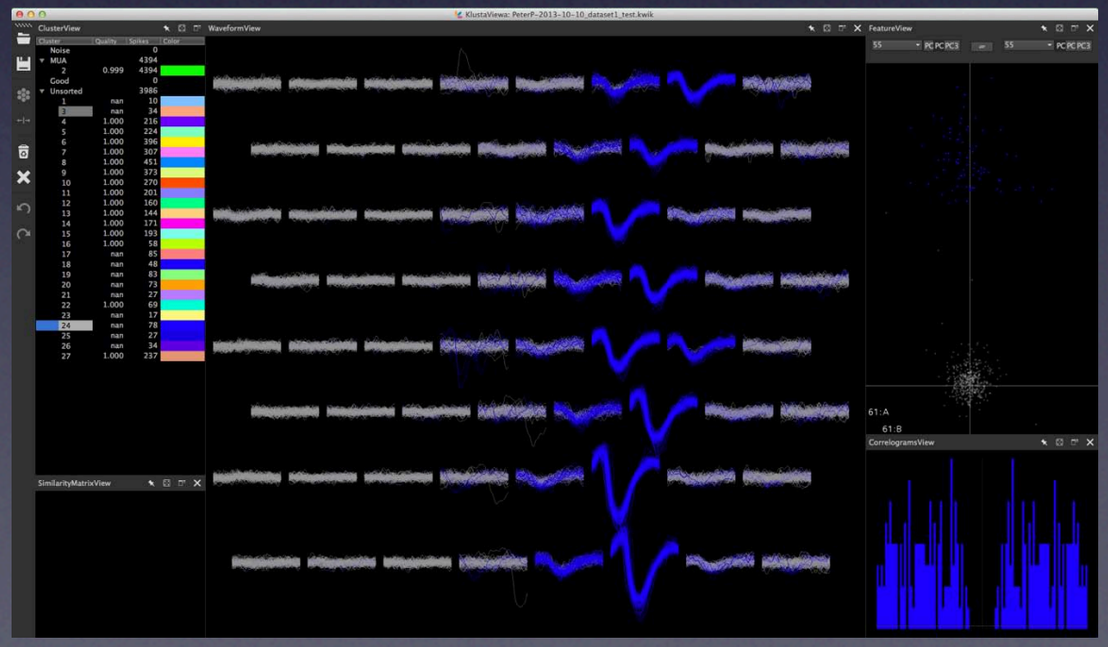


Spike sorting

Different units on same probe







Right Pocket scracth

Onset

Left Hip extensor

Right Knee extensor

Right Hip extensor

Right dD8

Right Hip Flexor

Inter-neuron Vm

Rastergram of spinal neurons

1 sec

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

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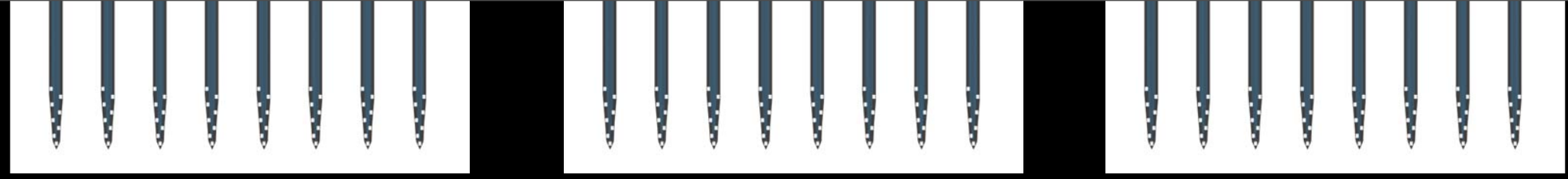
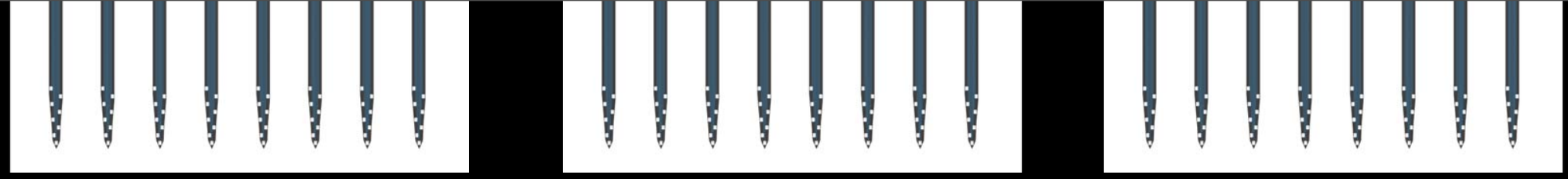
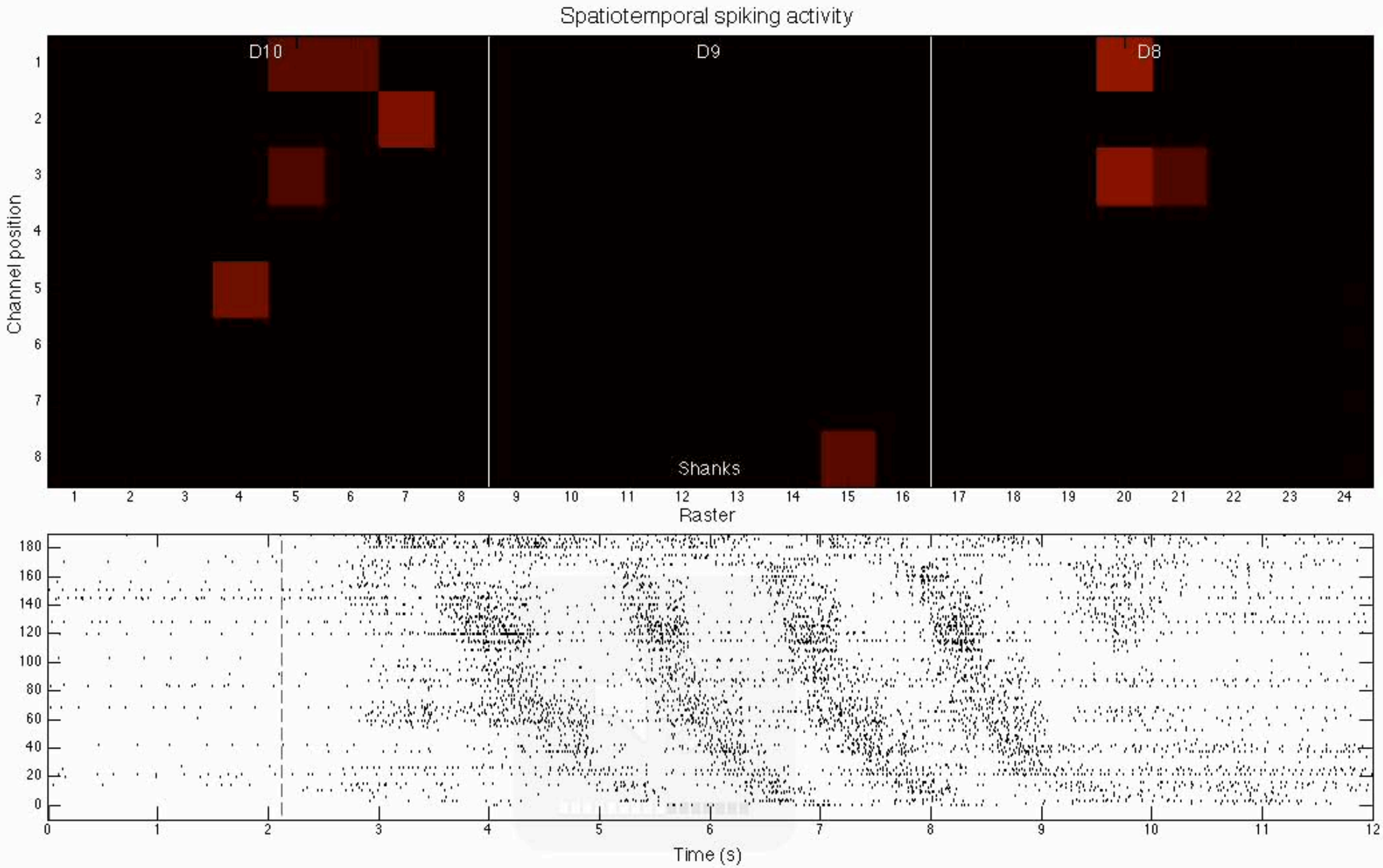


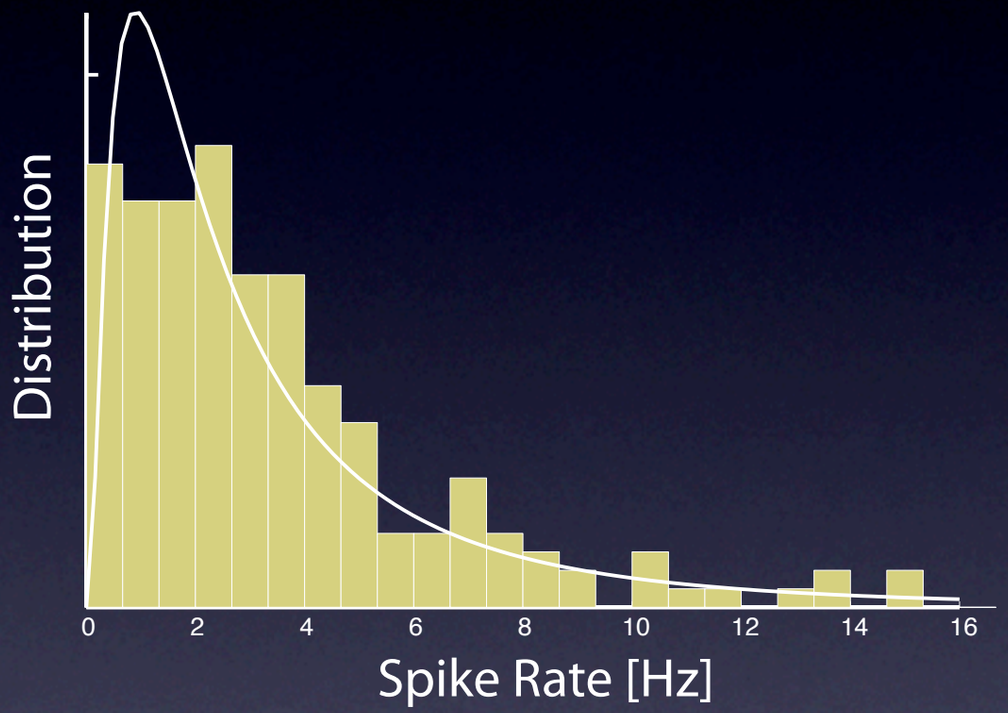
Petersen and Berg, *in preparation*





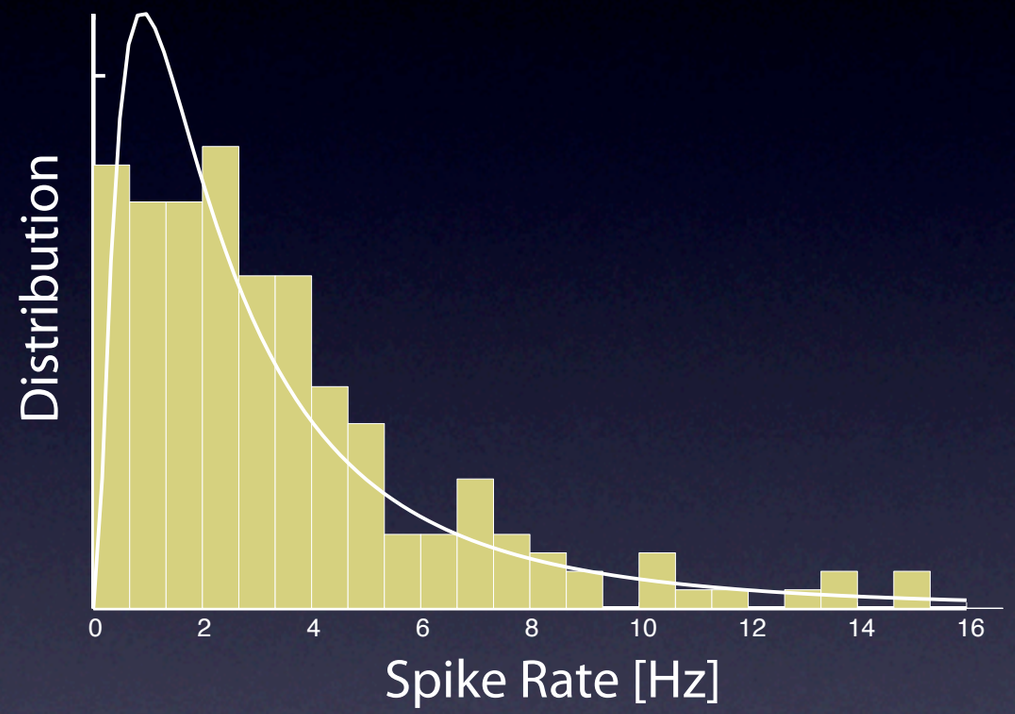
Petersen and Berg, *in preparation*

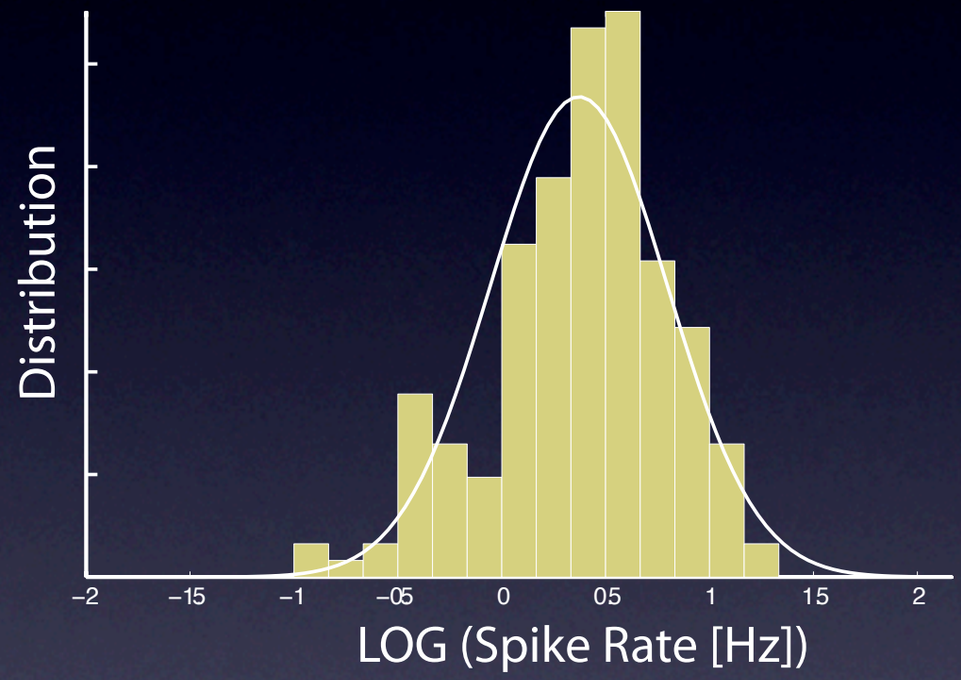
Population Distribution of Spike Rates



Petersen and Berg, *in preparation*

Population Distribution of Spike Rates

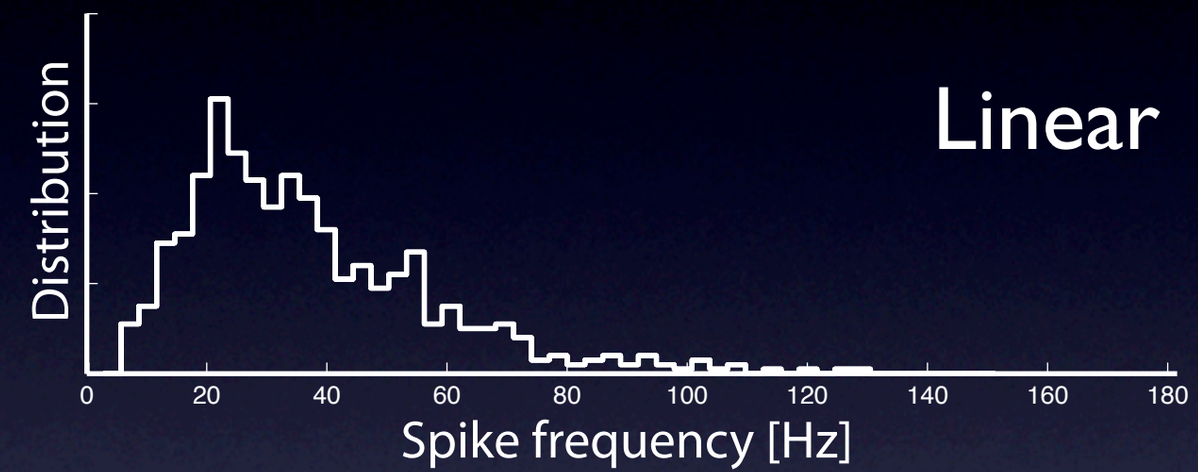




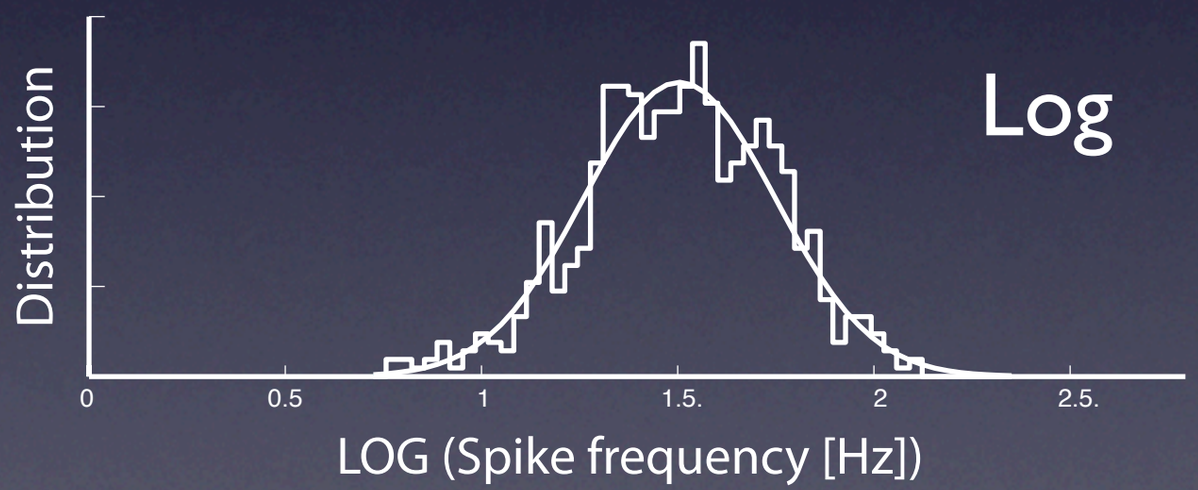
Petersen and Berg, *in preparation*

Single cell rate distribution

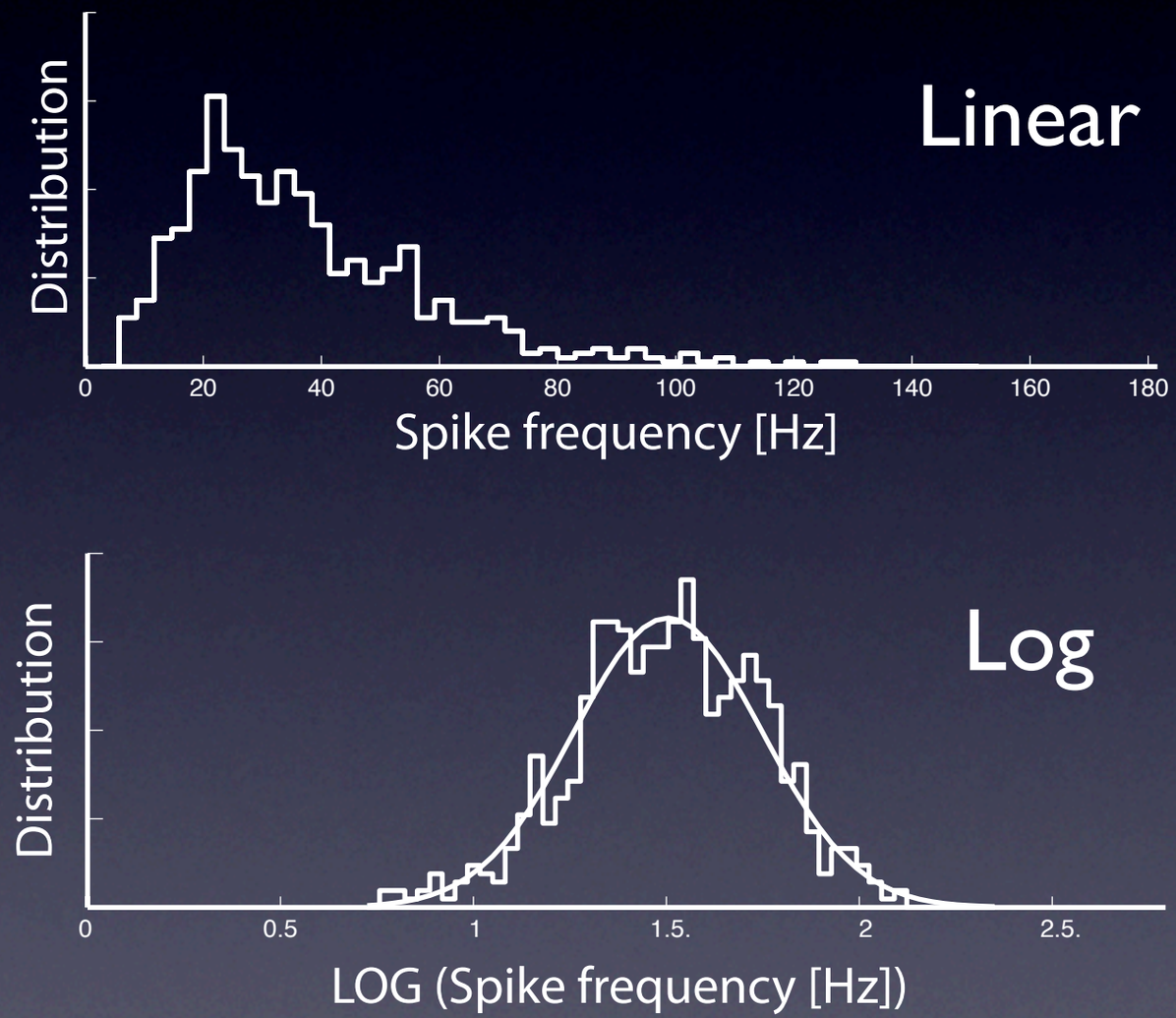
Linear

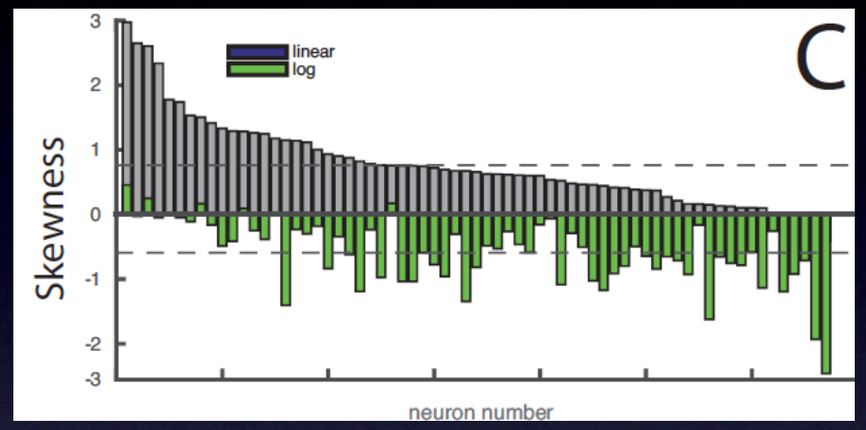


Log

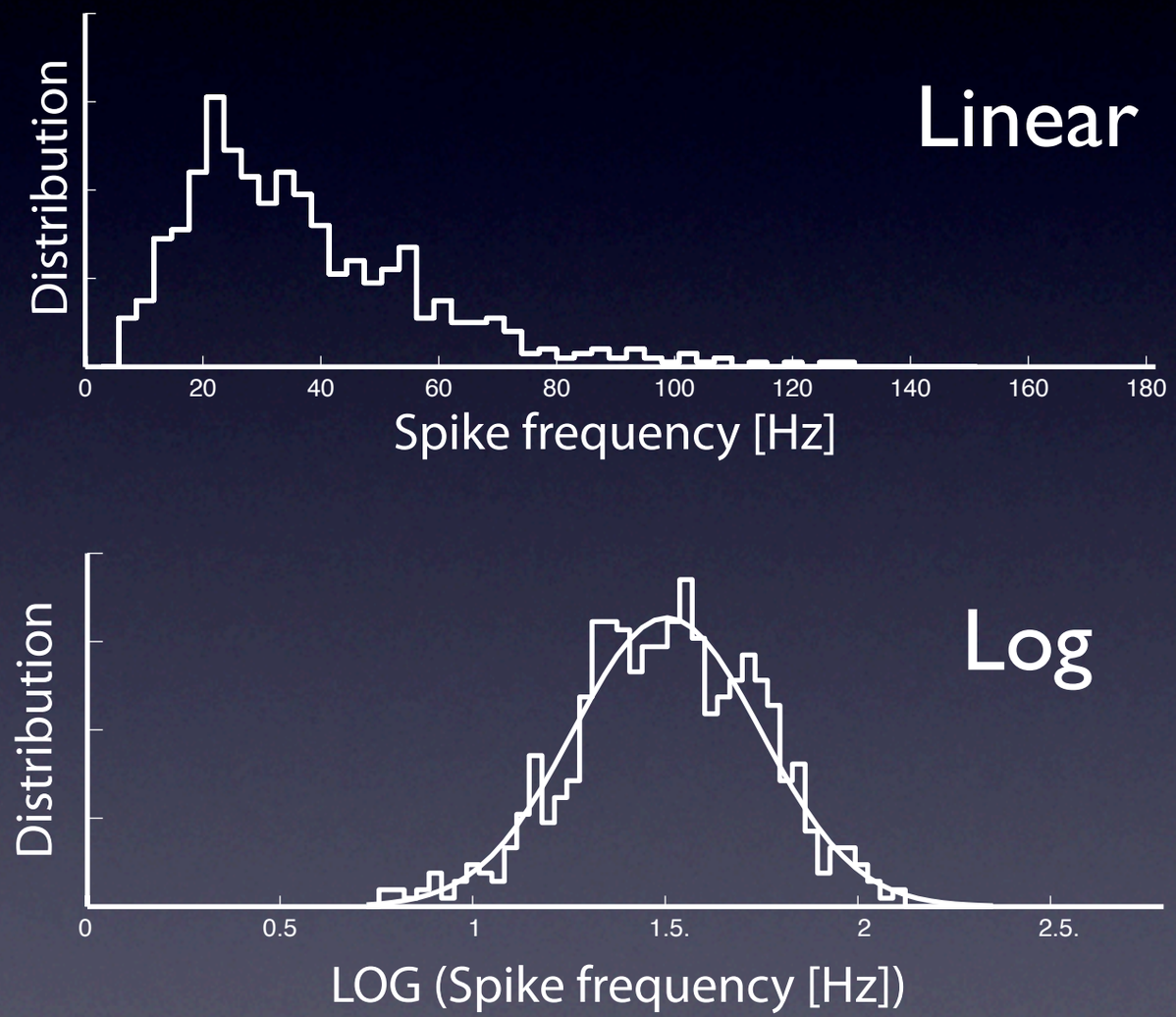


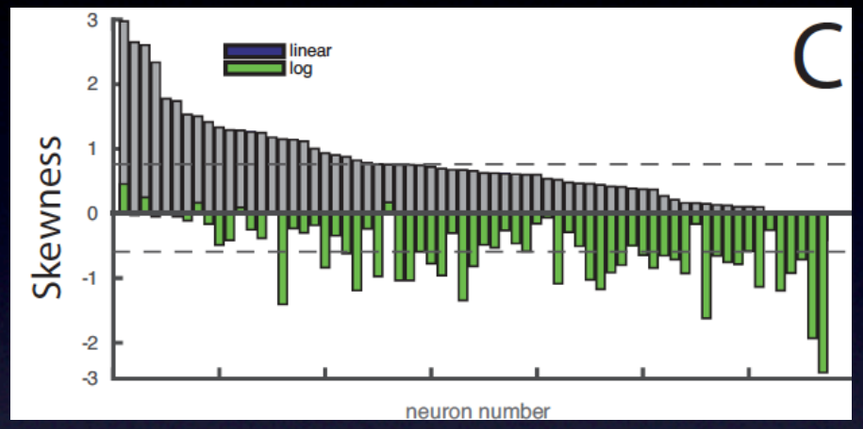
Single cell rate distribution

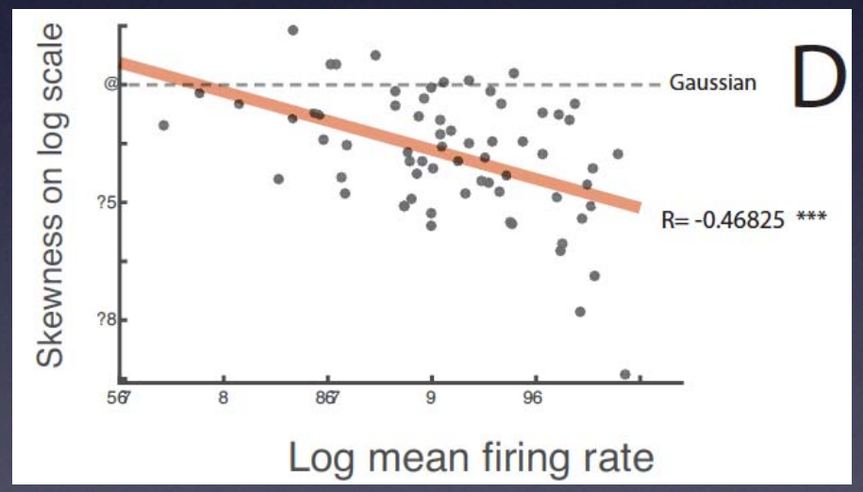




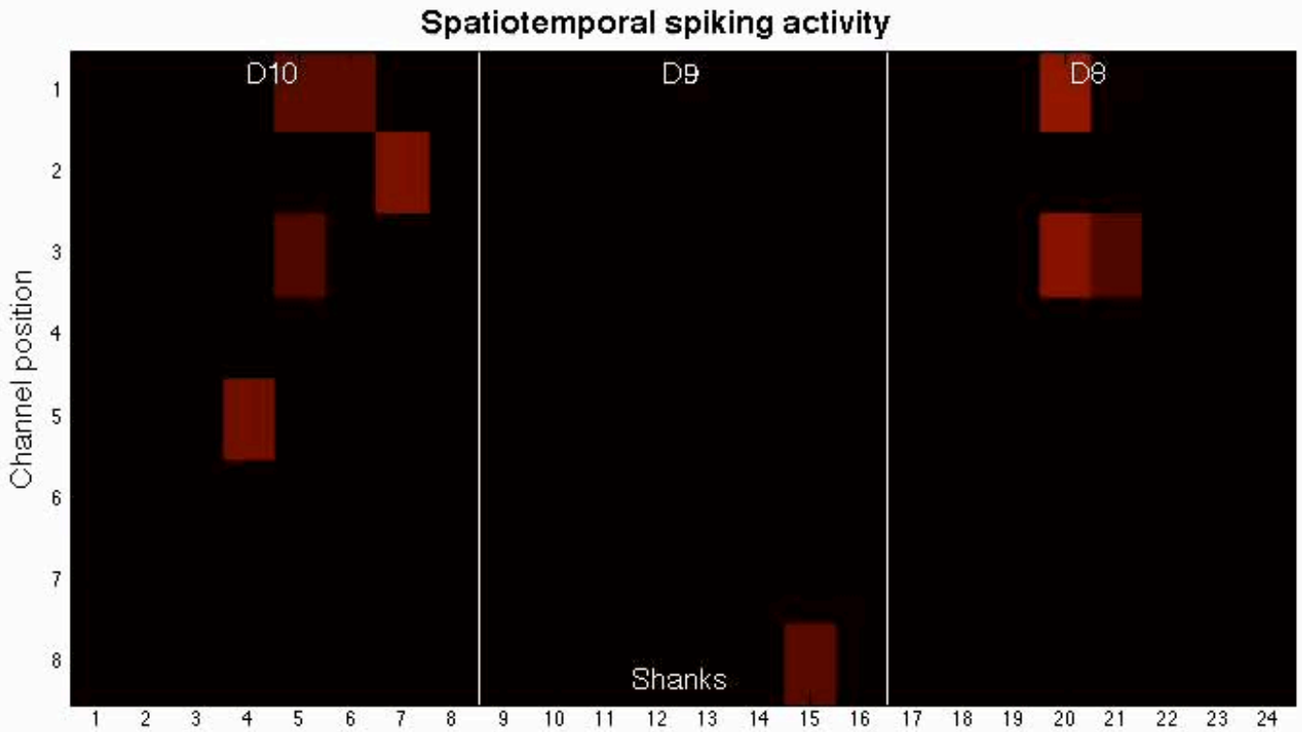
Single cell rate distribution

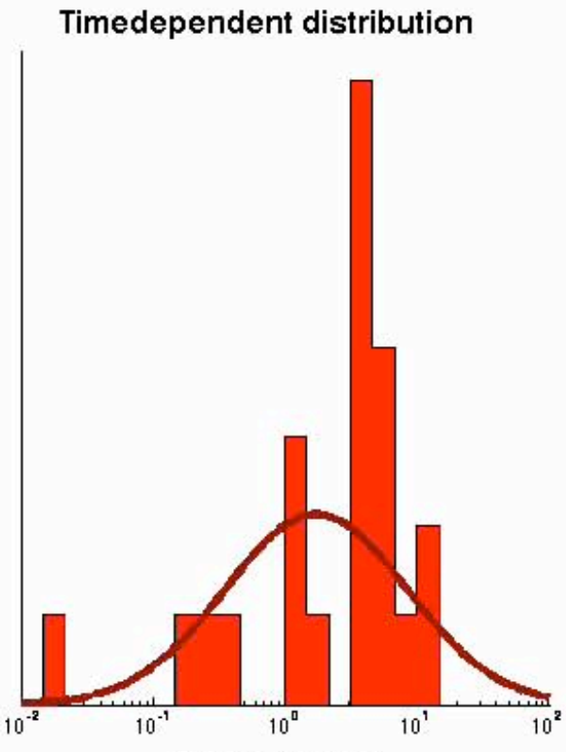


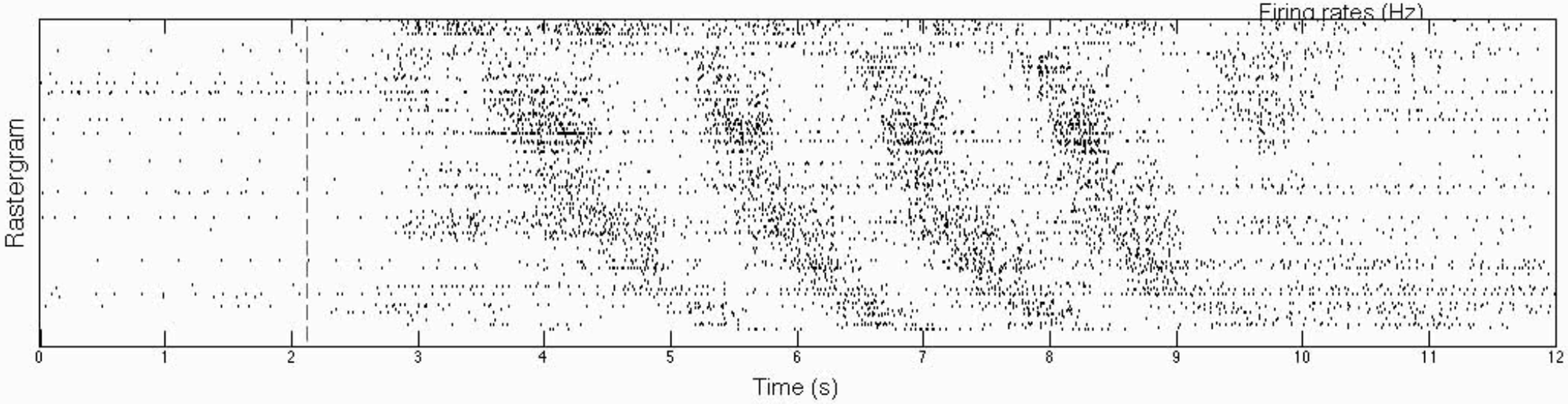




Time dependence of distribution?

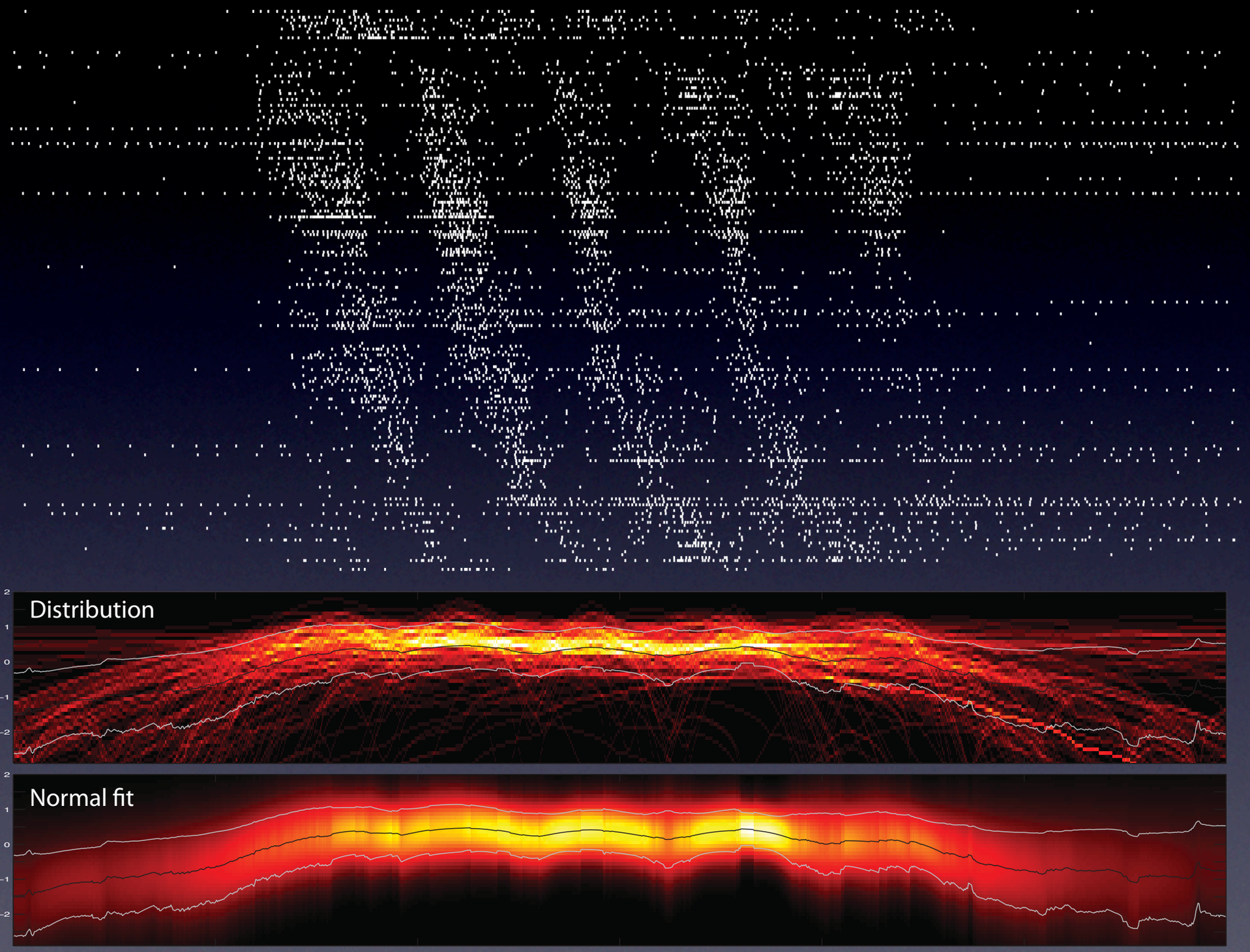






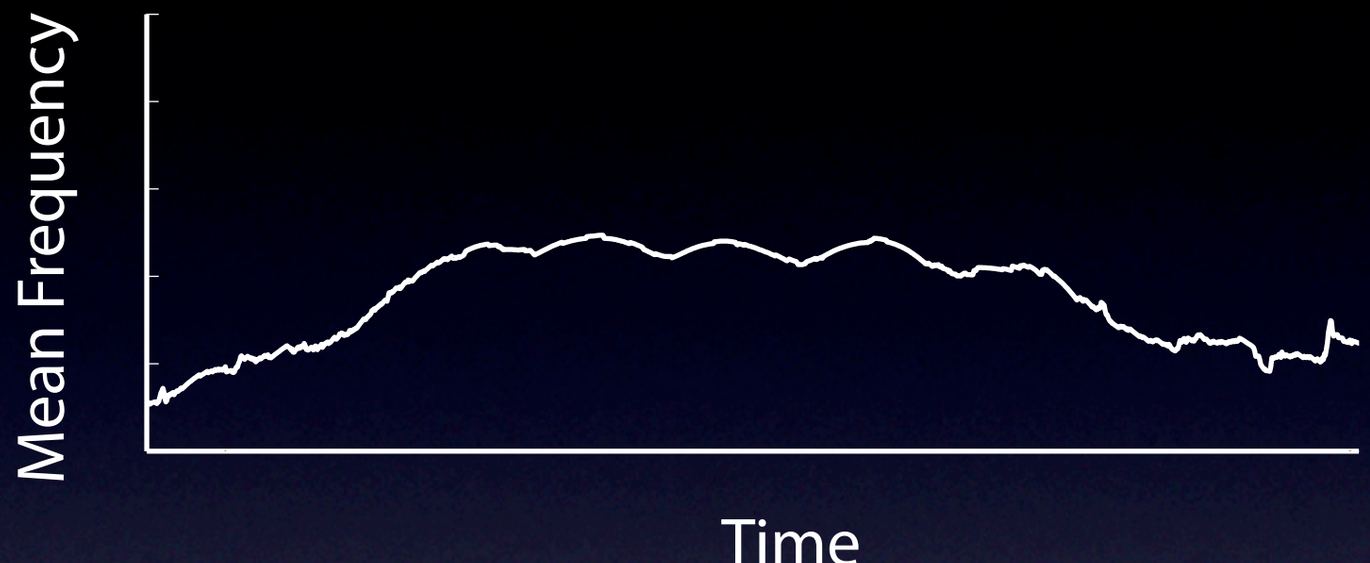
Petersen and Berg, *in preparation*

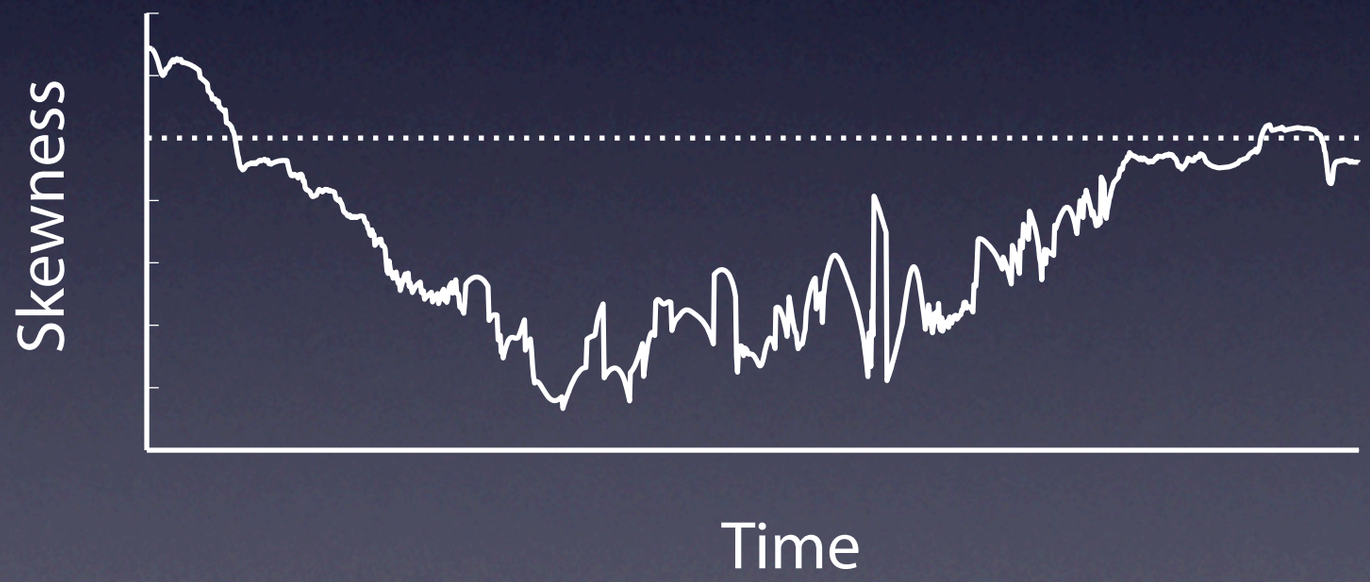
Time-dependent distribution



Petersen and Berg, *in preparation*

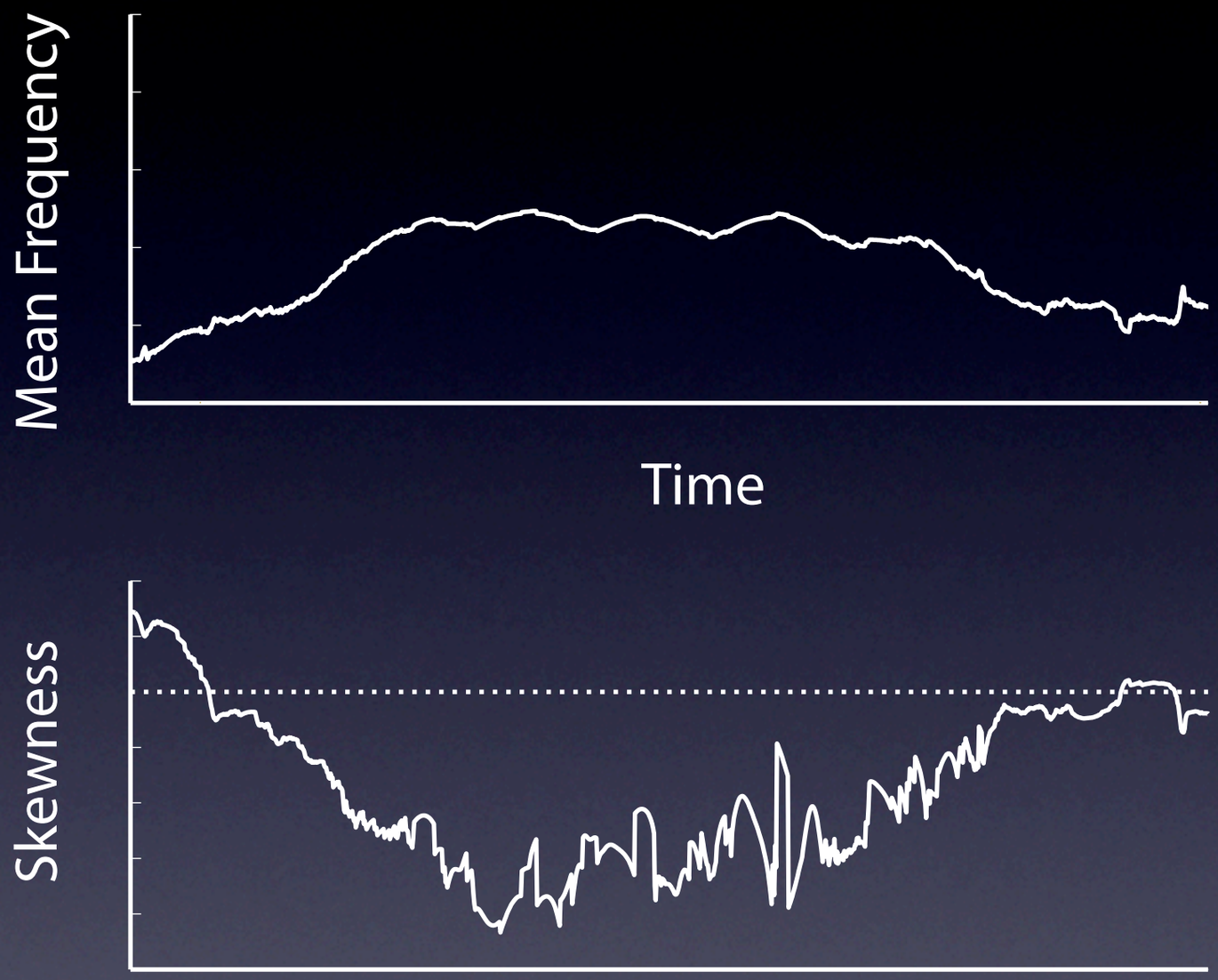
Time-dependent lognormal distribution

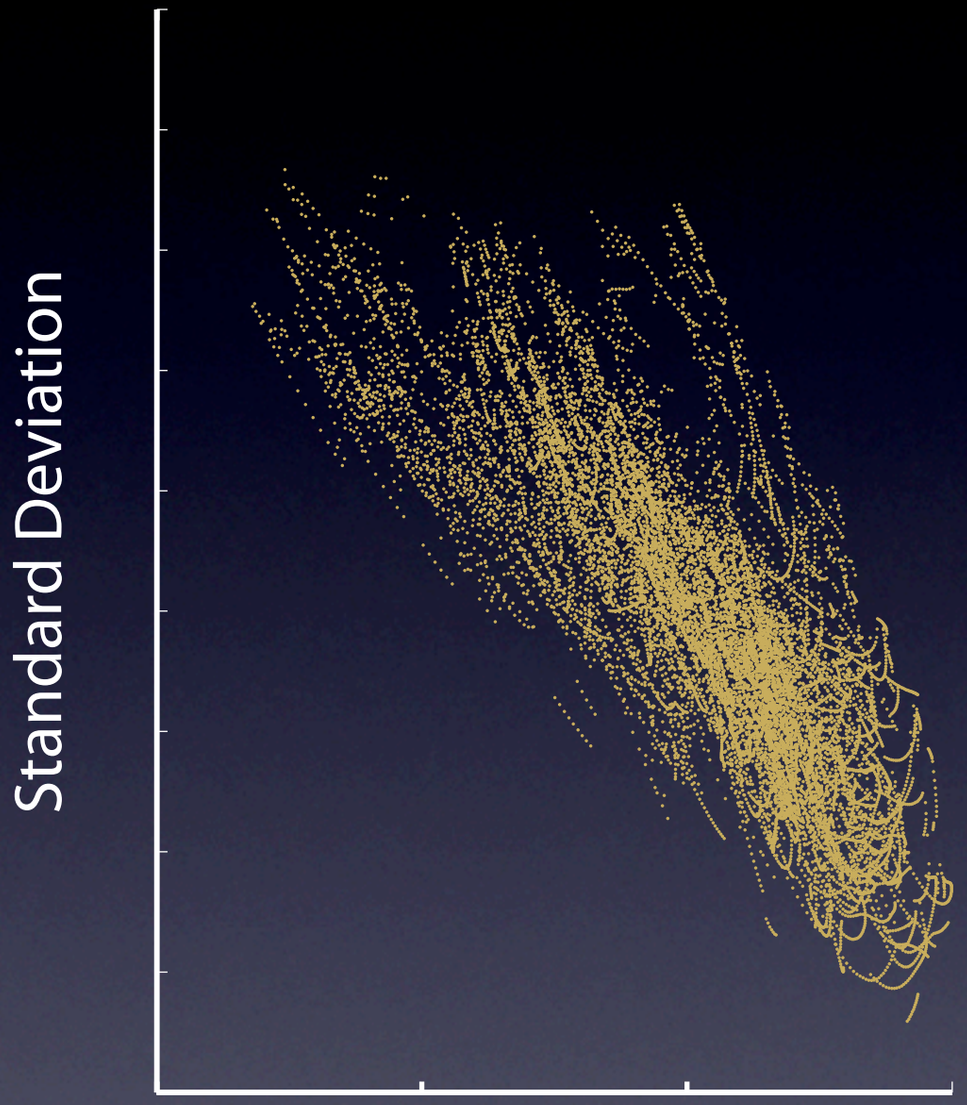




Petersen and Berg, *in preparation*

Time-dependent lognormal distribution



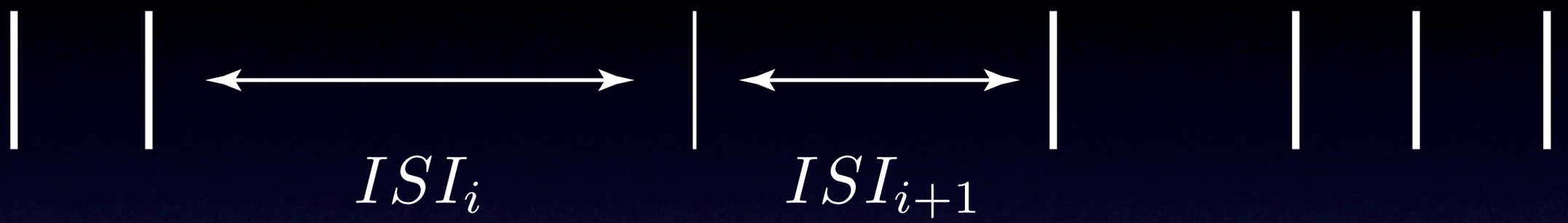


Petersen and Berg, *in preparation*

Irregularity?

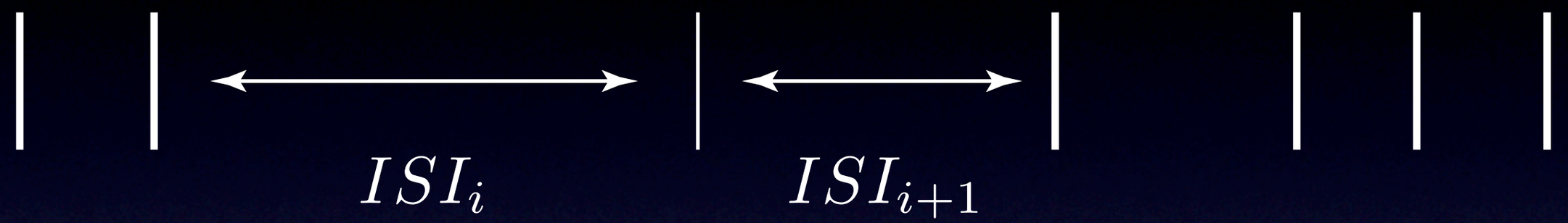
Petersen and Berg, *in preparation*

Irregularity measure



Holt et al, *J Neurophysiol* 1996

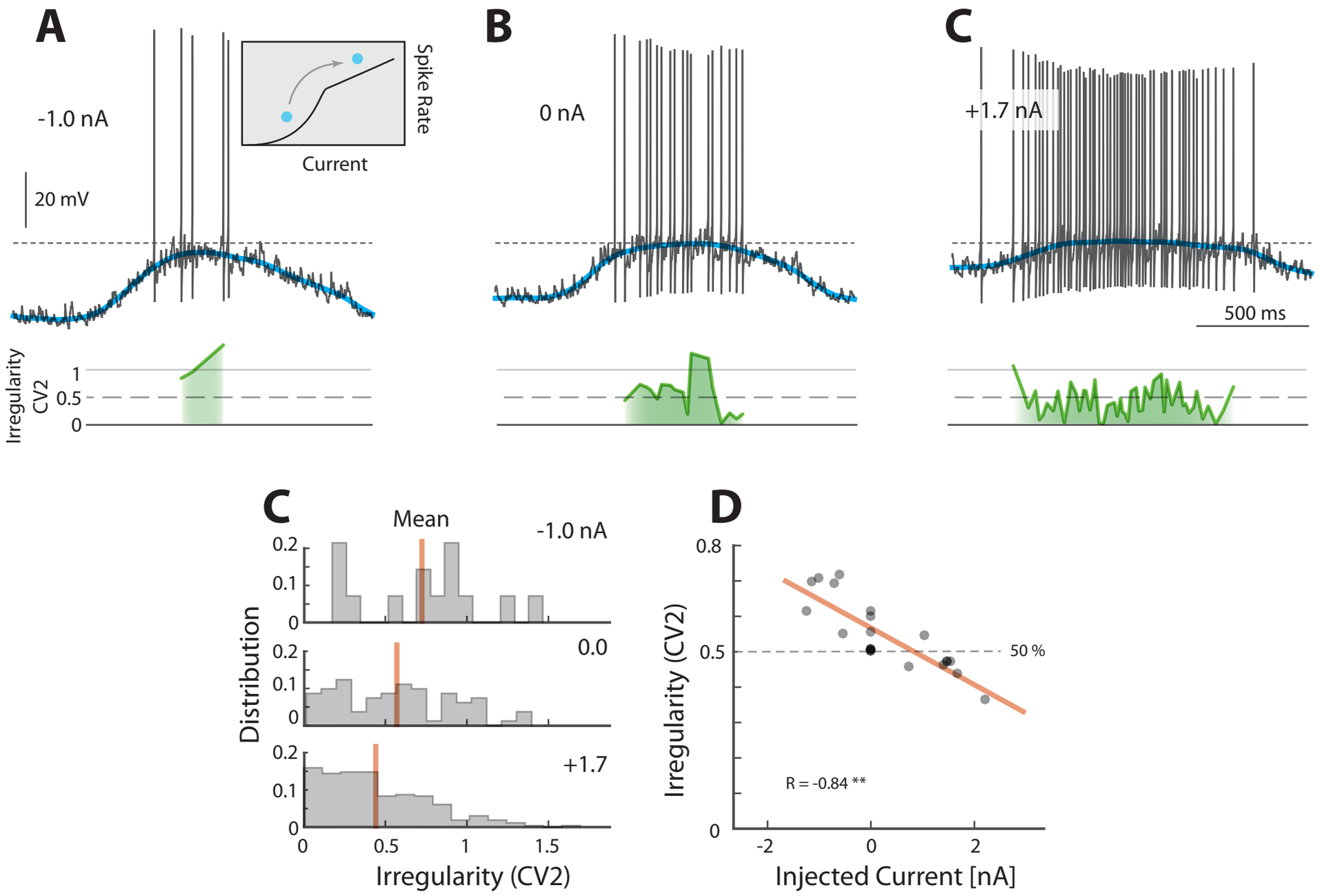
Irregularity measure



$$CV_2(i) = \frac{2|ISI_{i+1} - ISI_i|}{ISI_{i+1} + ISI_i}$$

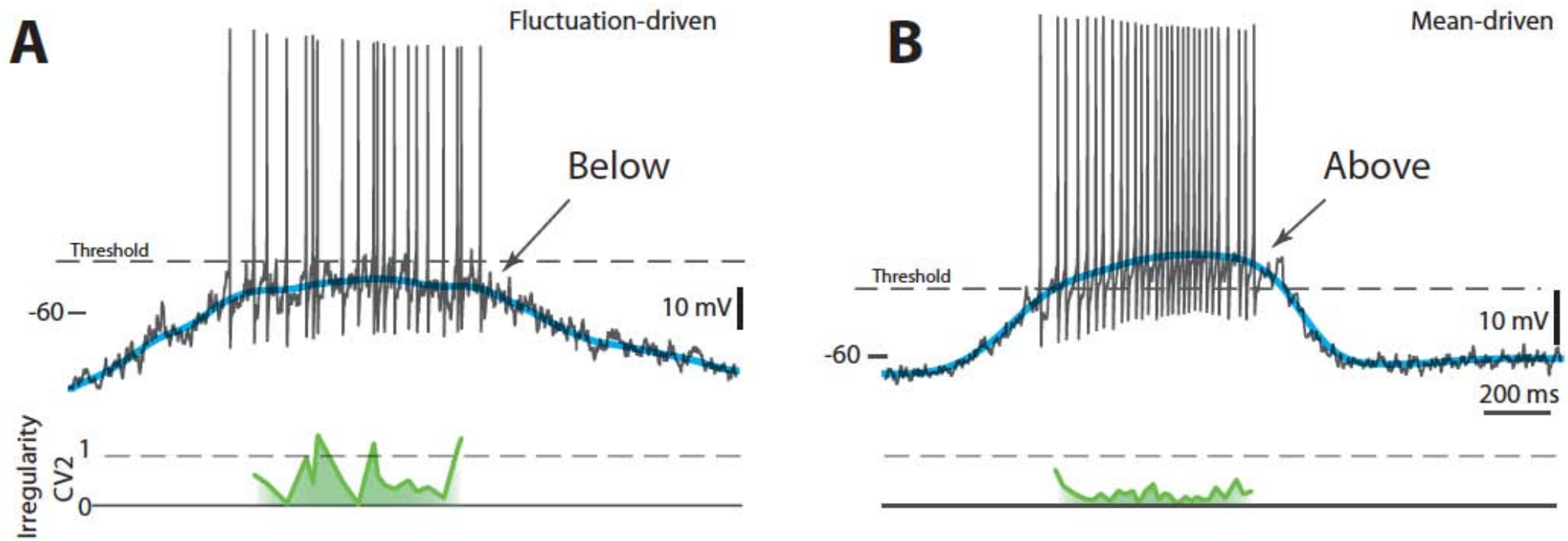
Holt et al, *J Neurophysiol* 1996

Driving a cell across regimes



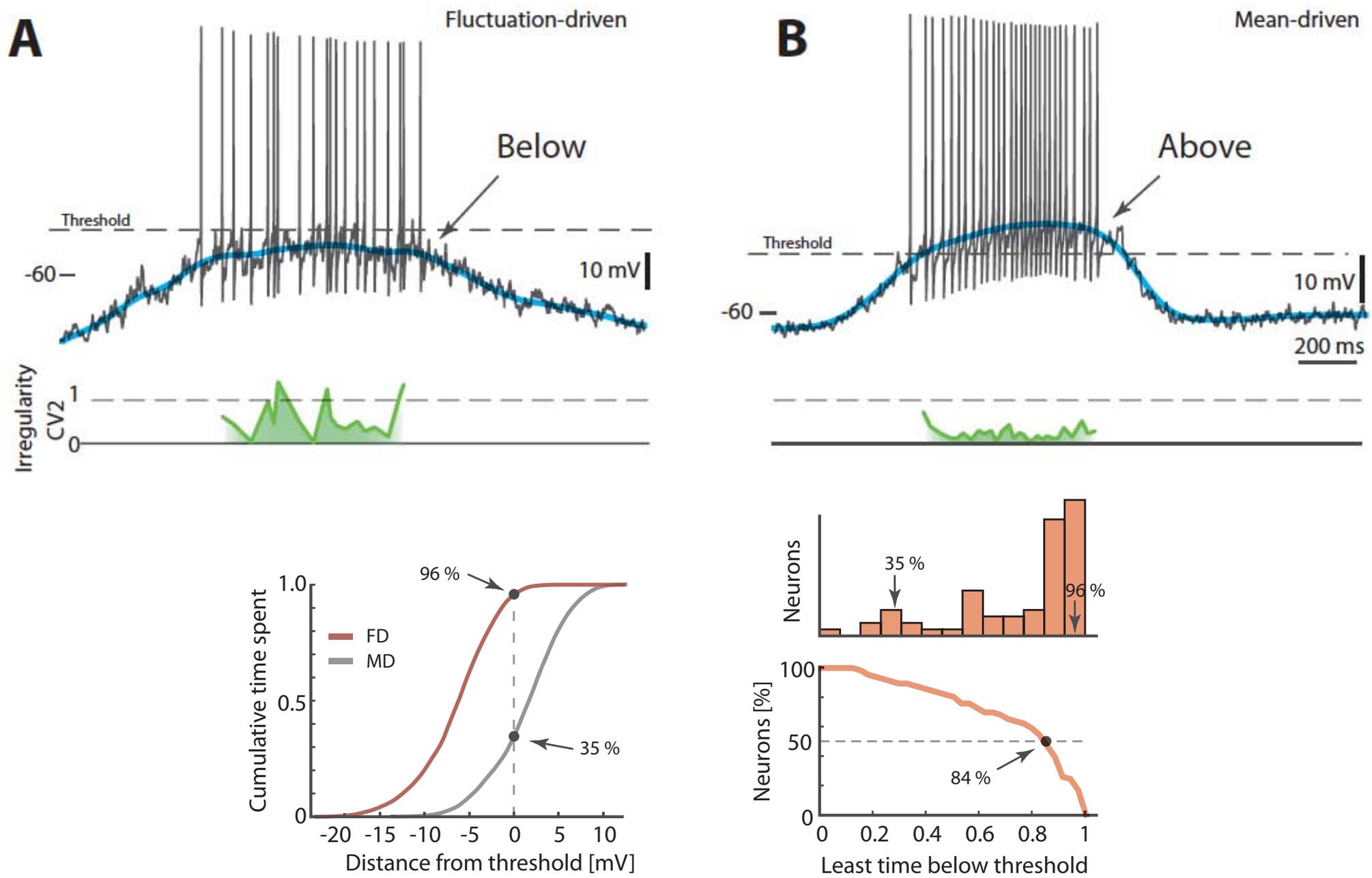
Petersen and Berg, *in preparation*

Samples: Fluctuation- and mean-driven neurons



Petersen and Berg, *in preparation*

Samples: Fluctuation- and mean-driven neurons



Petersen and Berg, *in preparation*

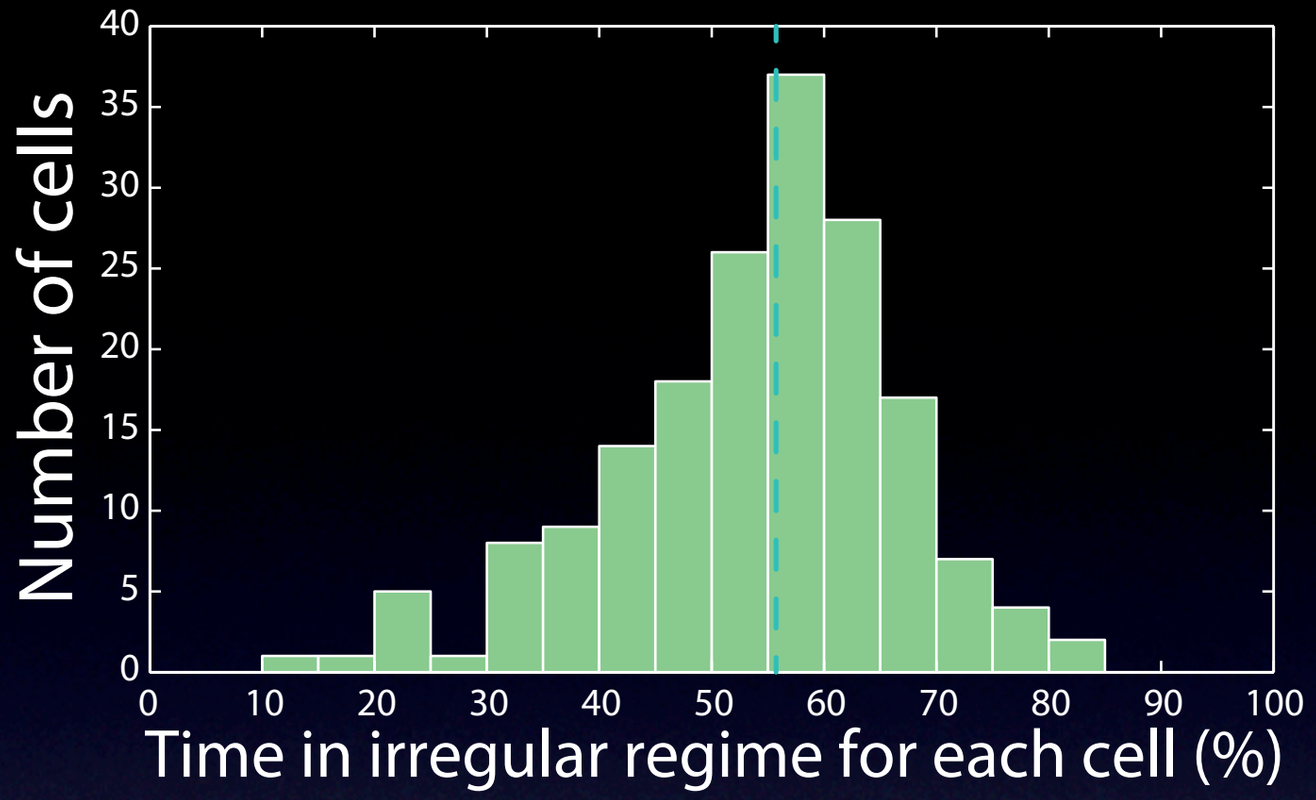
Irregularity for the population over time

$CV_2 > 0.5$ "Irregular"

$CV_2 < 0.5$ "Regular"

Young et al, *J Neurophysiol* 1988

Prut and Perlmutter, *J Neurosci* 2003



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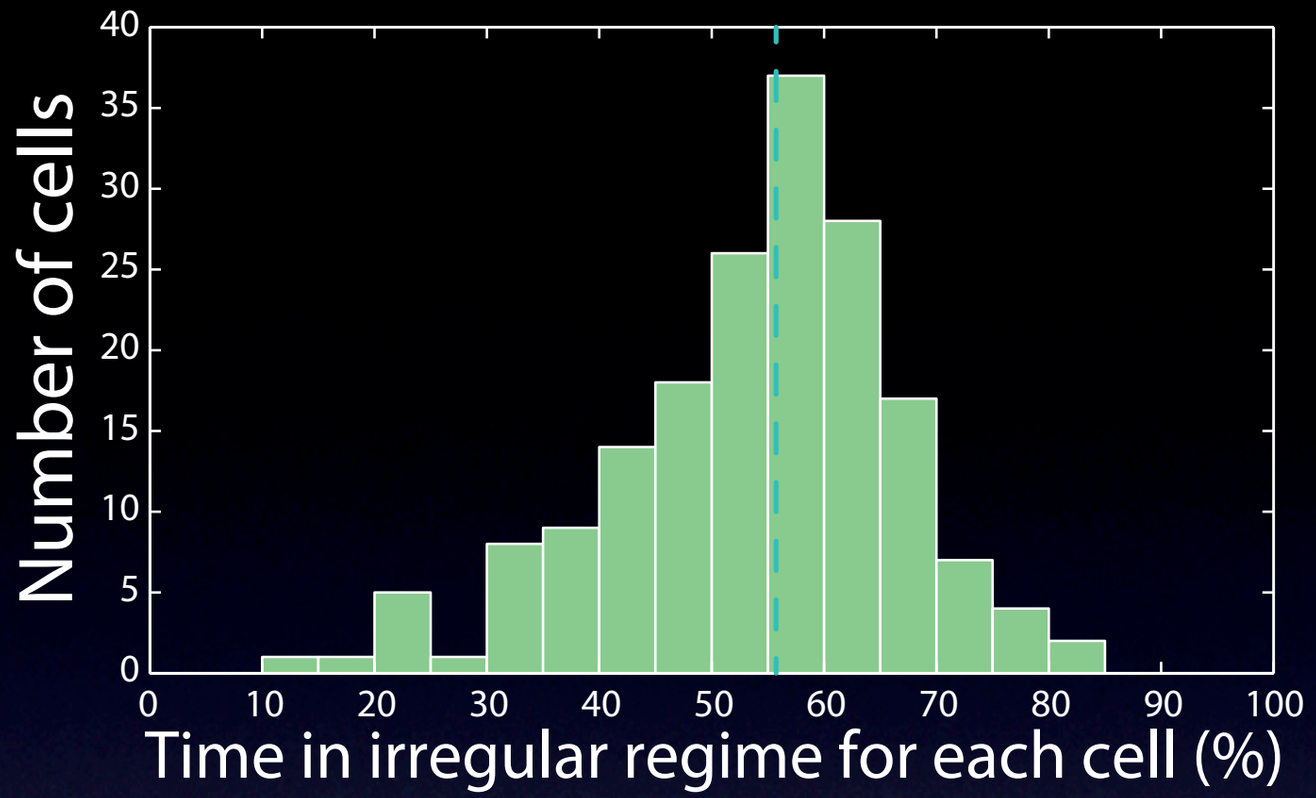
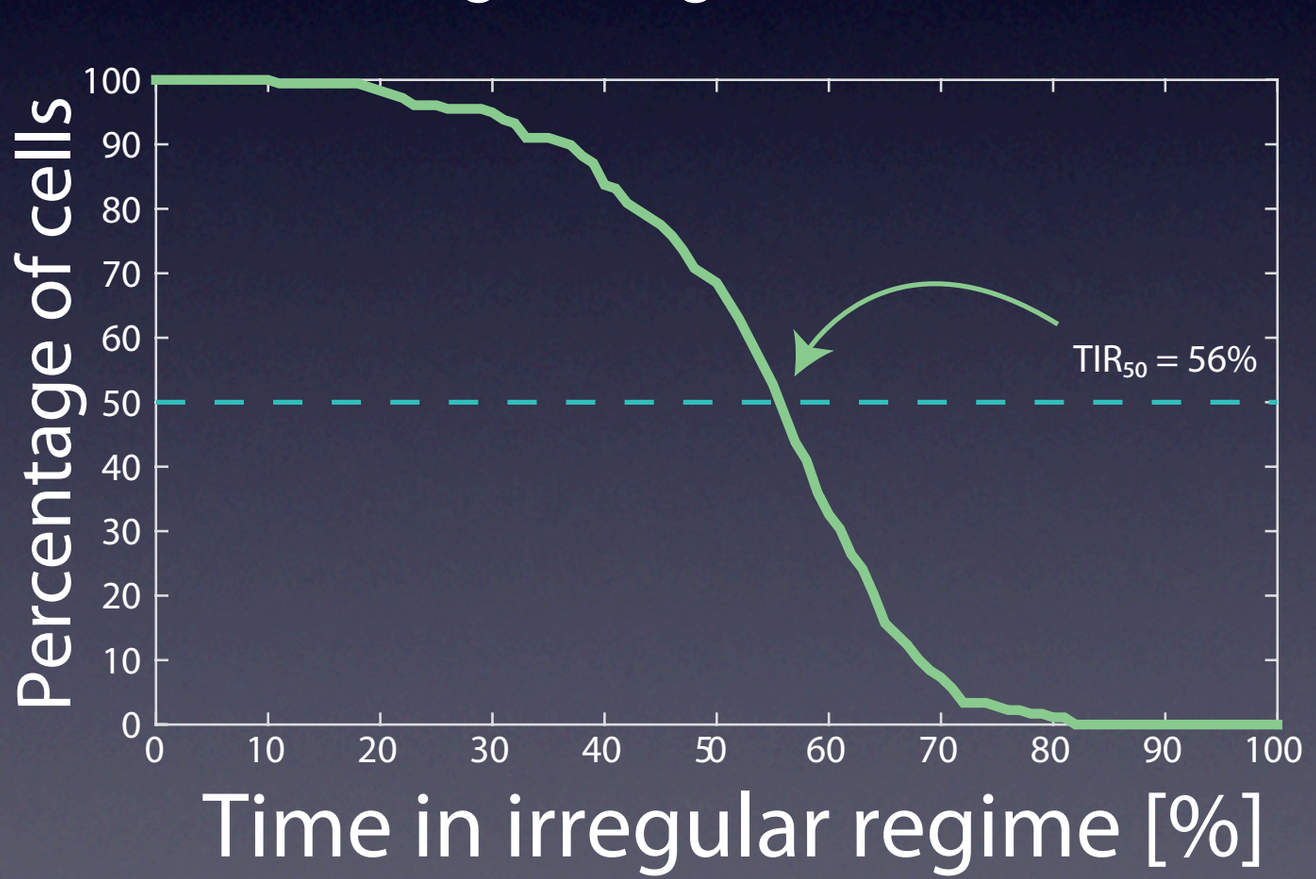
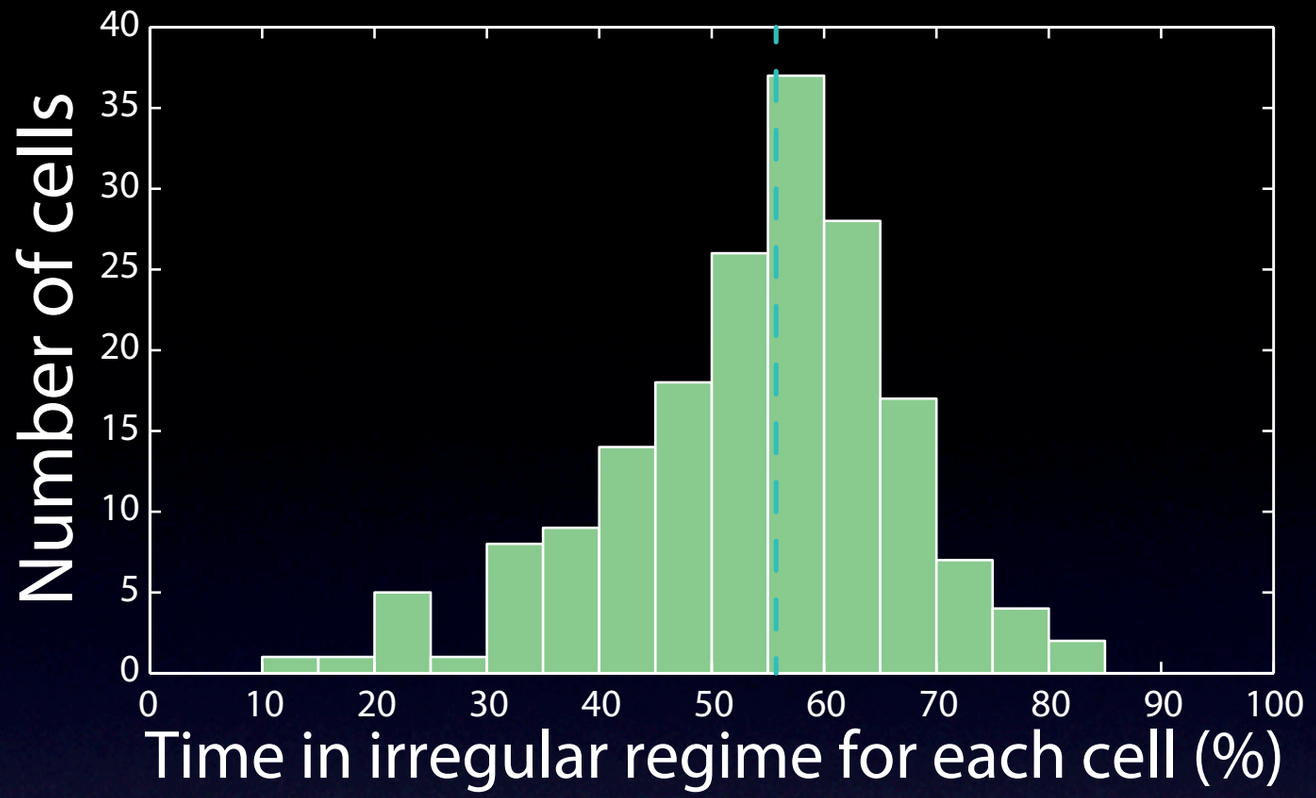
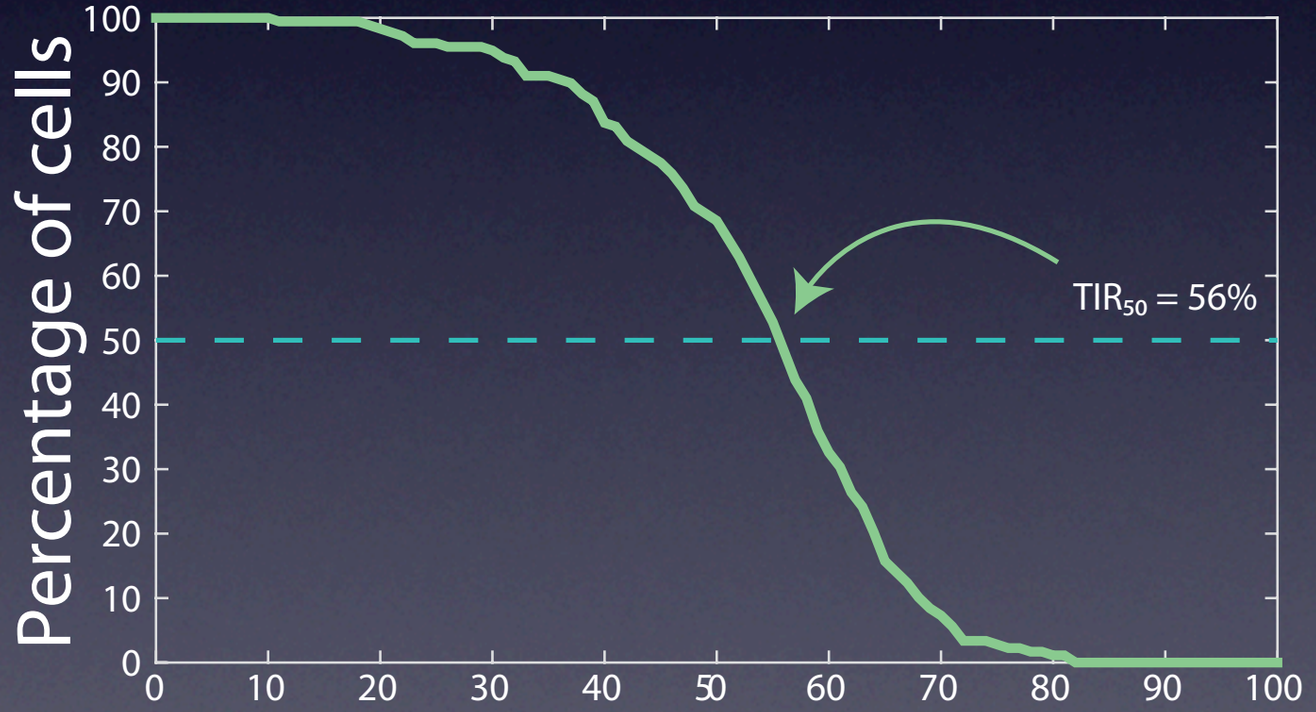


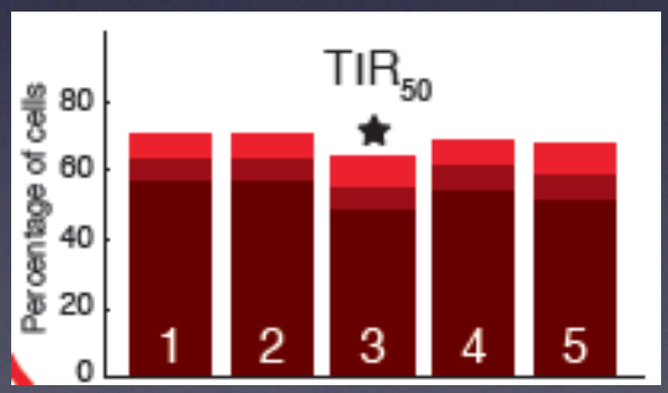


Petersen and Berg, *in preparation*





Animals:



Petersen and Berg, *in preparation*

Conclusions

- Skewed, log-normal firing rate distribution in some neurons some of the time
- Two regimes: fluctuation- and mean driven TIR50 ~ 50%, i.e. half of cells are in irregular regime half of the time.

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