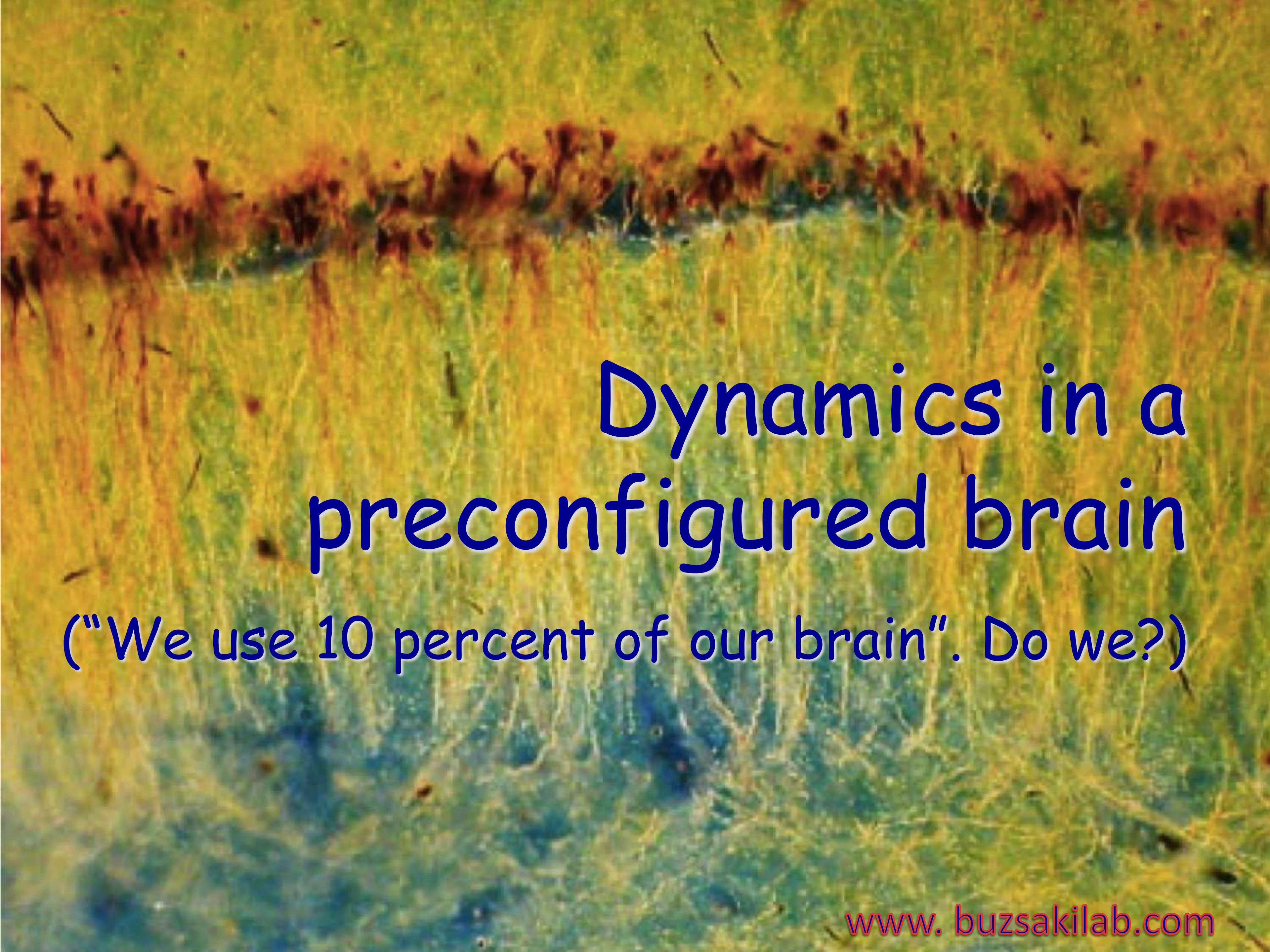


Dynamics in a preconfigured brain

("We use 10 percent of our brain". Do we?)

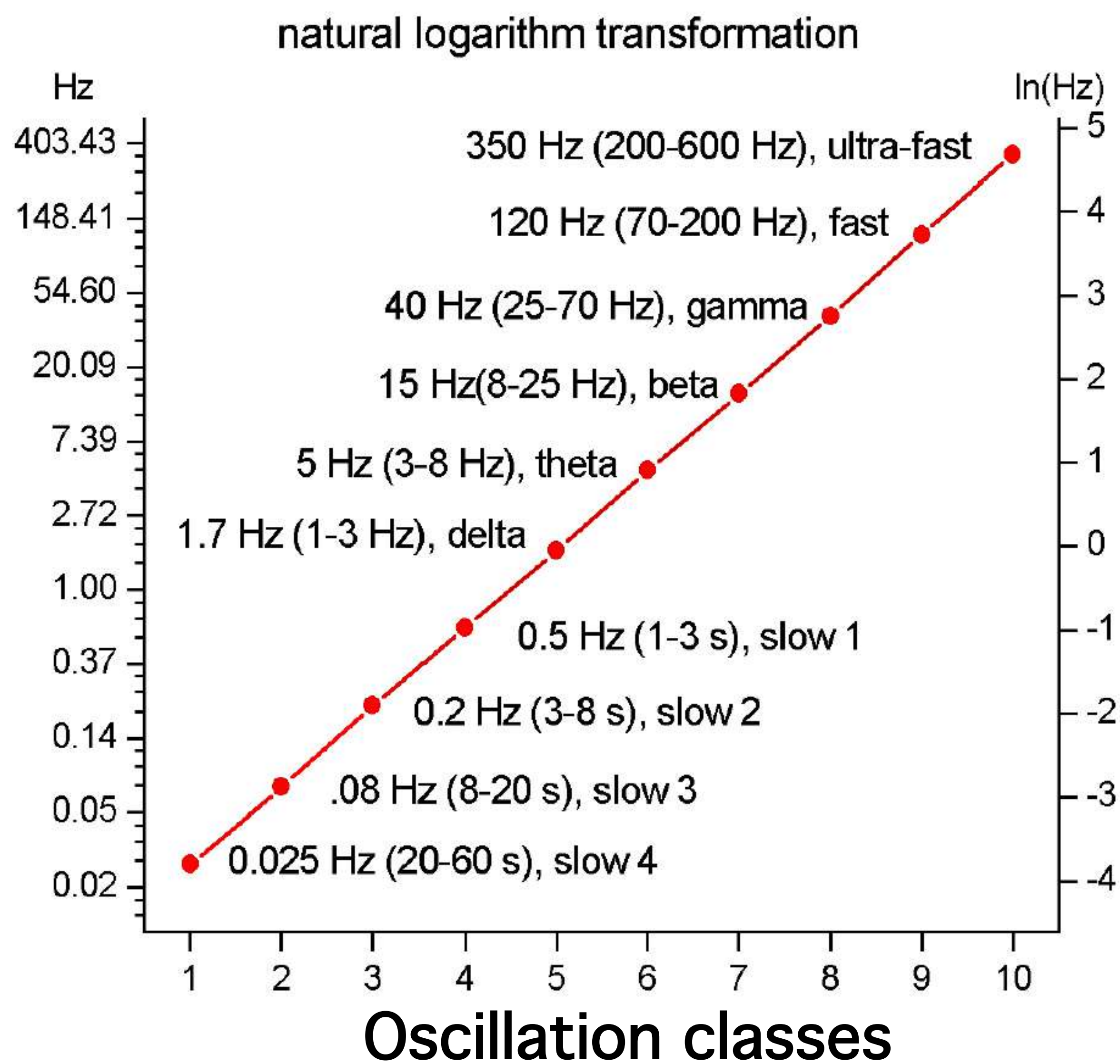
Canonical log brain rules

- A fundamental rule of psychophysics, the Weber-Fechner (log) 'law', describes subjective perception as proportional to the *logarithm* of the stimulus intensity

Canonical log brain rules

- A fundamental rule of psychophysics, the Weber-Fechner (log) 'law', describes subjective perception as proportional to the *logarithm* of the stimulus intensity
- Wide dynamic range of synaptic weights, firing rates and population synchrony (*lognormal* distribution)
- These dynamics occur on an anatomical substrate wherein the morphological connectivity within the network also displays *lognormal* distributions.

Hierarchies of oscillators (ln rule) allow brain operations at multiple temporal scales

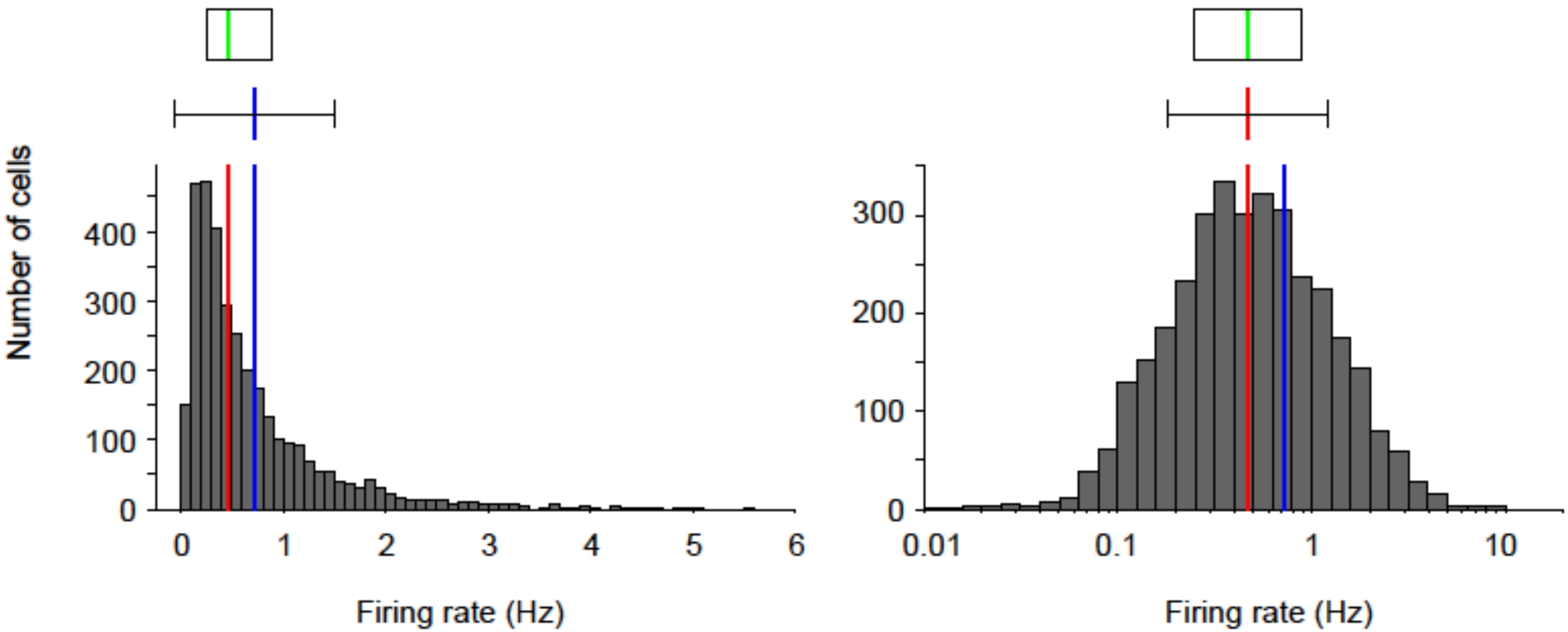


Buzsaki and Draguhn **Science** 2004

Multiple interacting rhythms are at work in the brain

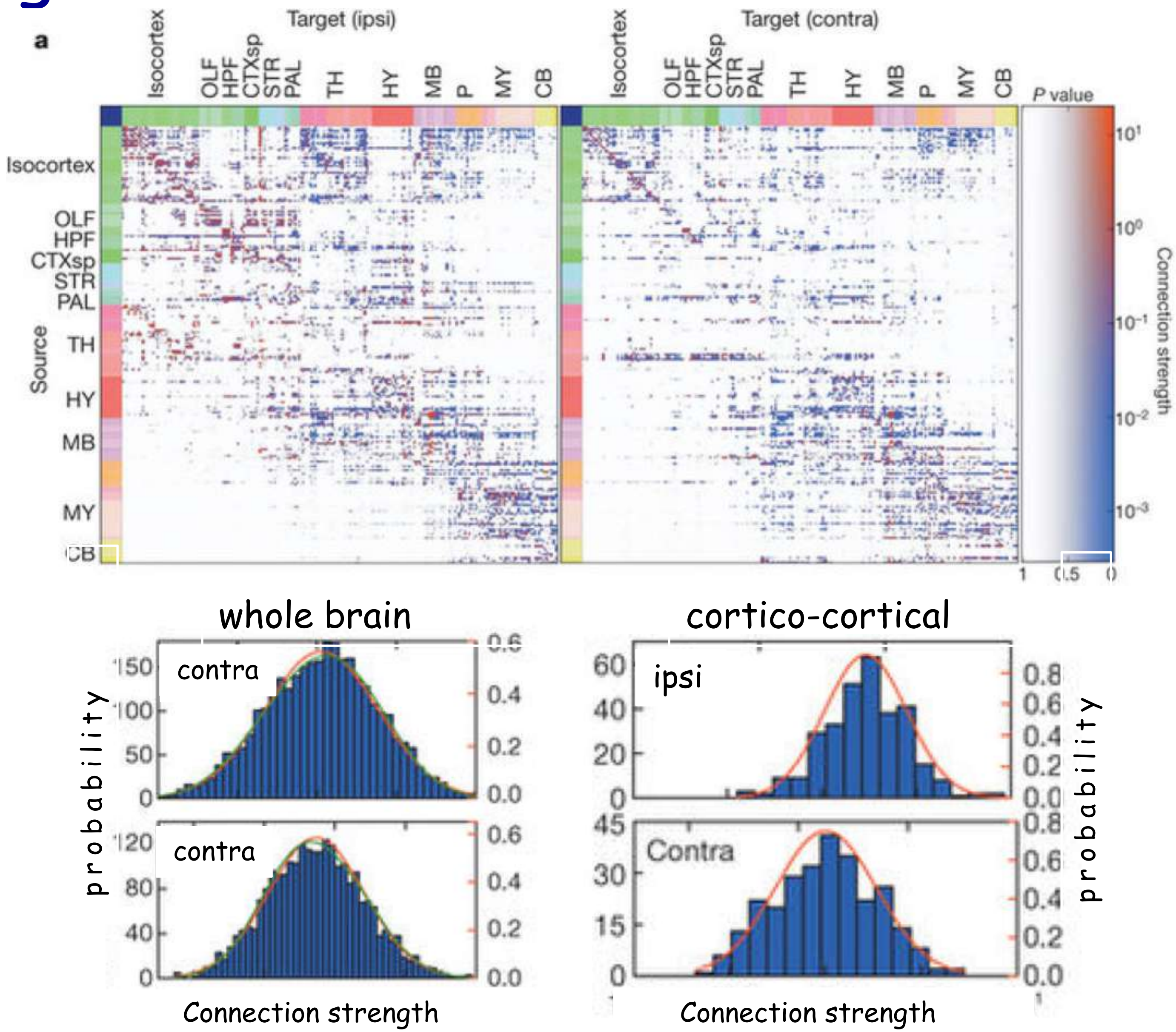
Lognormal distribution of firing rates
(CA1 pyramidal cells)

multiply/divide random numbers



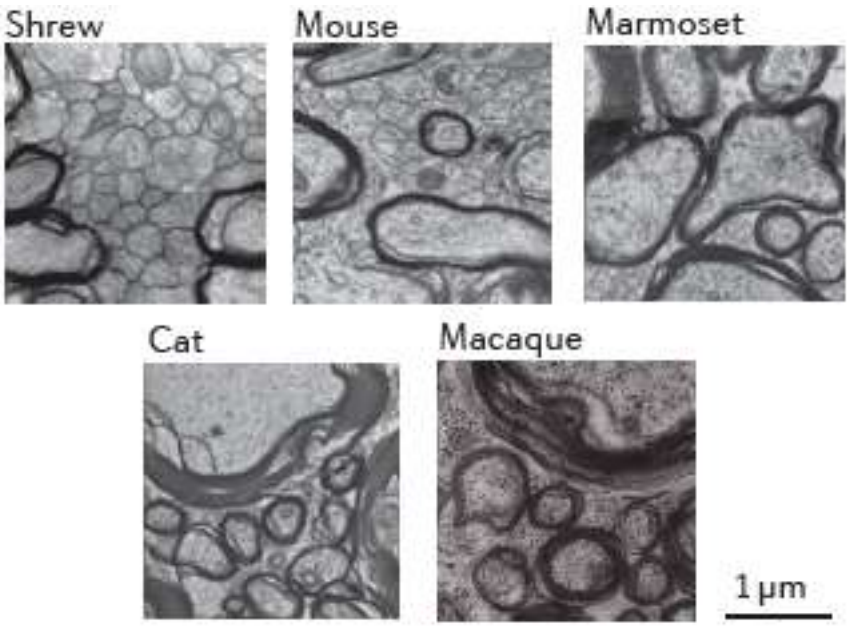
Buzsaki, Mizuseki, **Nature Rev Neurosci** 2014

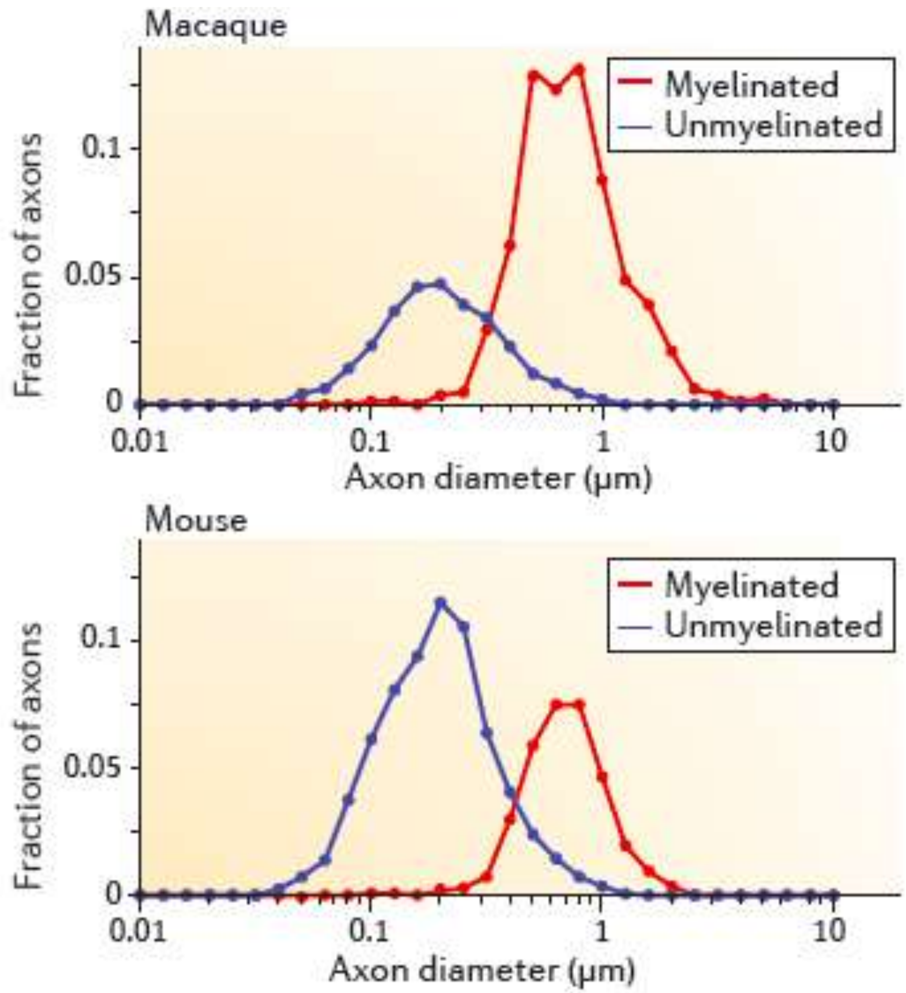
Lognormal distribution of brain connectivity



Ho et al., **Nature** 2014

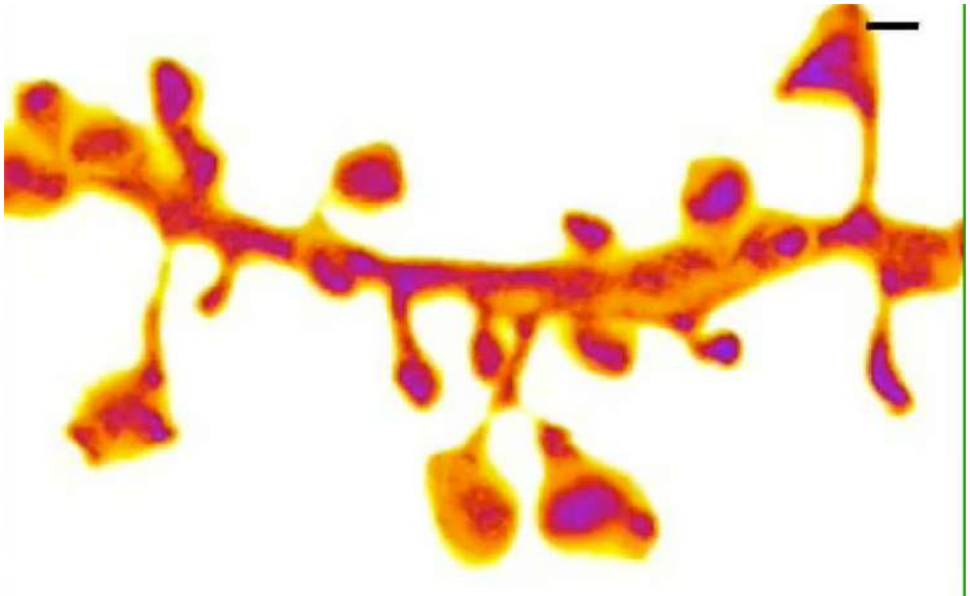
Log-normal distribution of axon diameters

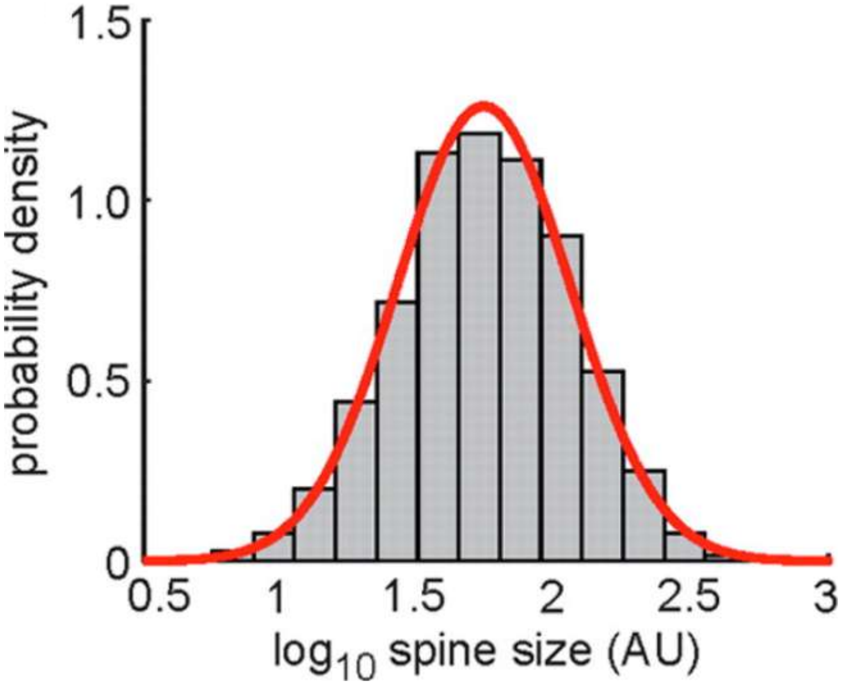




Buzsaki, Mizuseki, **Nature Rev Neurosci** 2014
Courtesy of Sam Wang

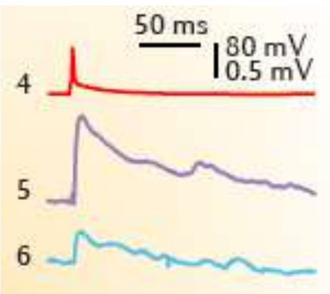
Distribution of spine sizes shows log-normal distribution

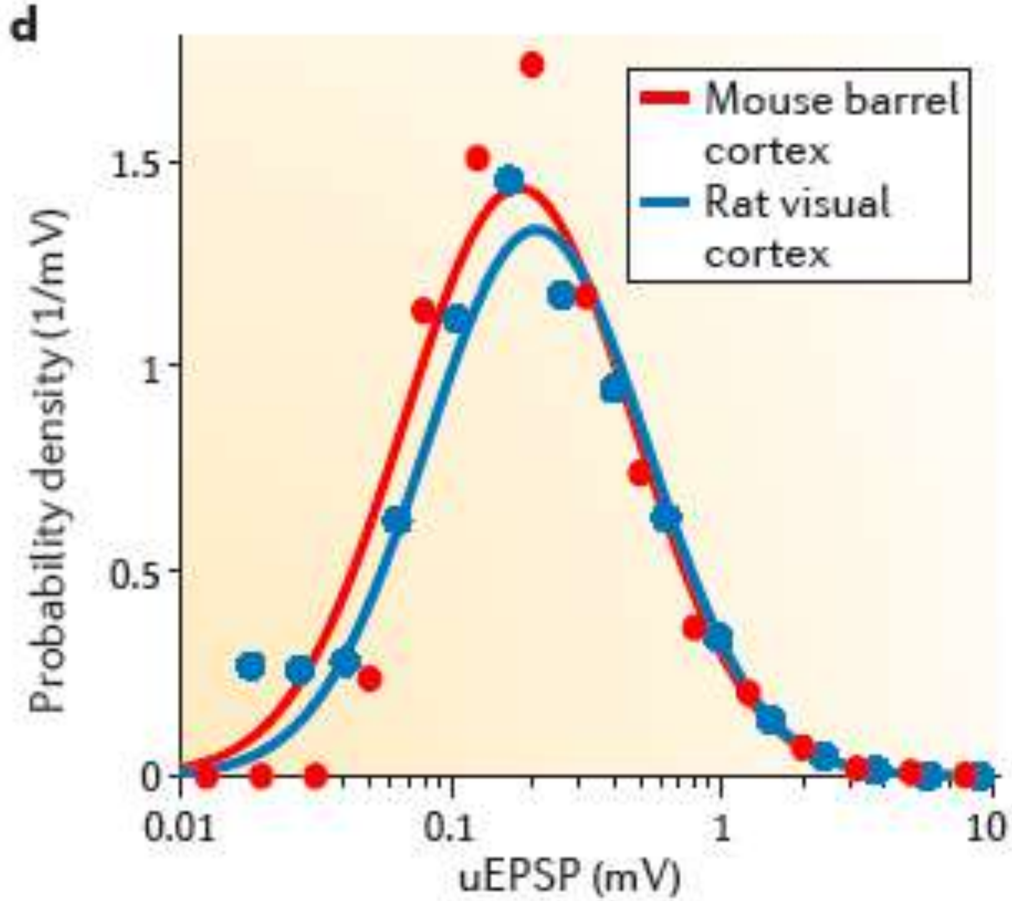




Loewenstein, Kuras, Rumpel, J Neuroscience, 2011

Distribution of synaptic strengths shows log-normal distribution (in vitro)

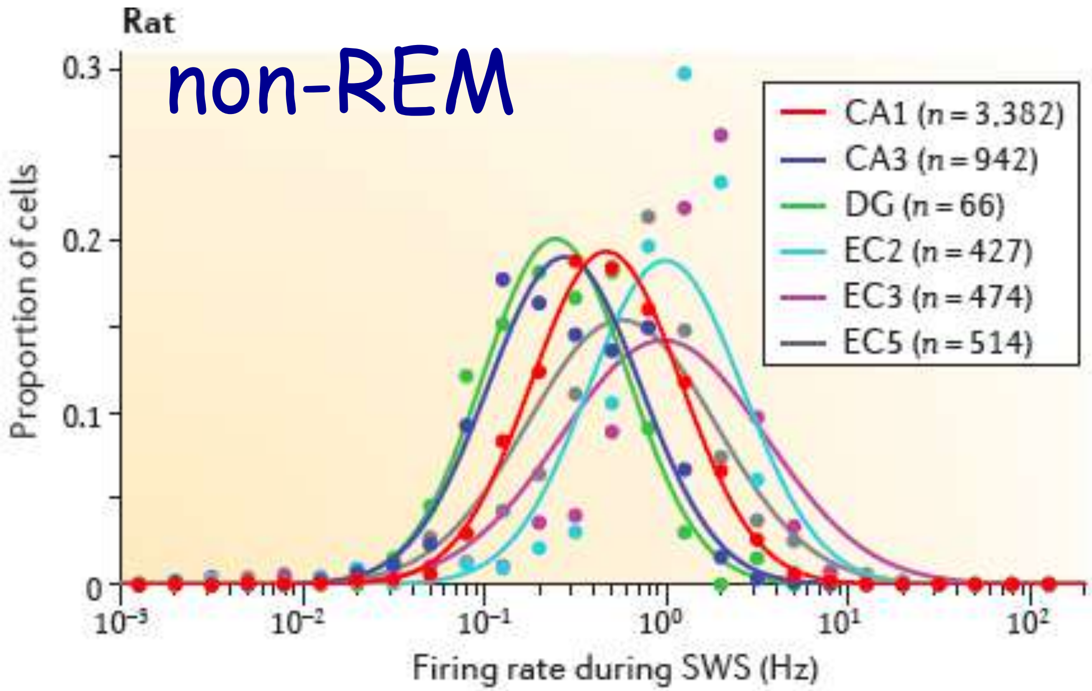




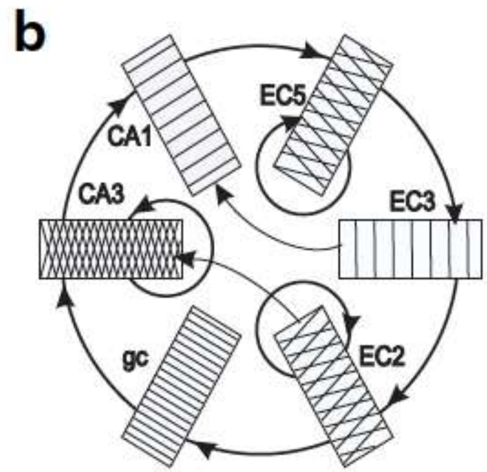
Larger synapses and multiple synapses are stronger

Buzsaki, Mizuseki, **Nature Rev Neurosci** 2014

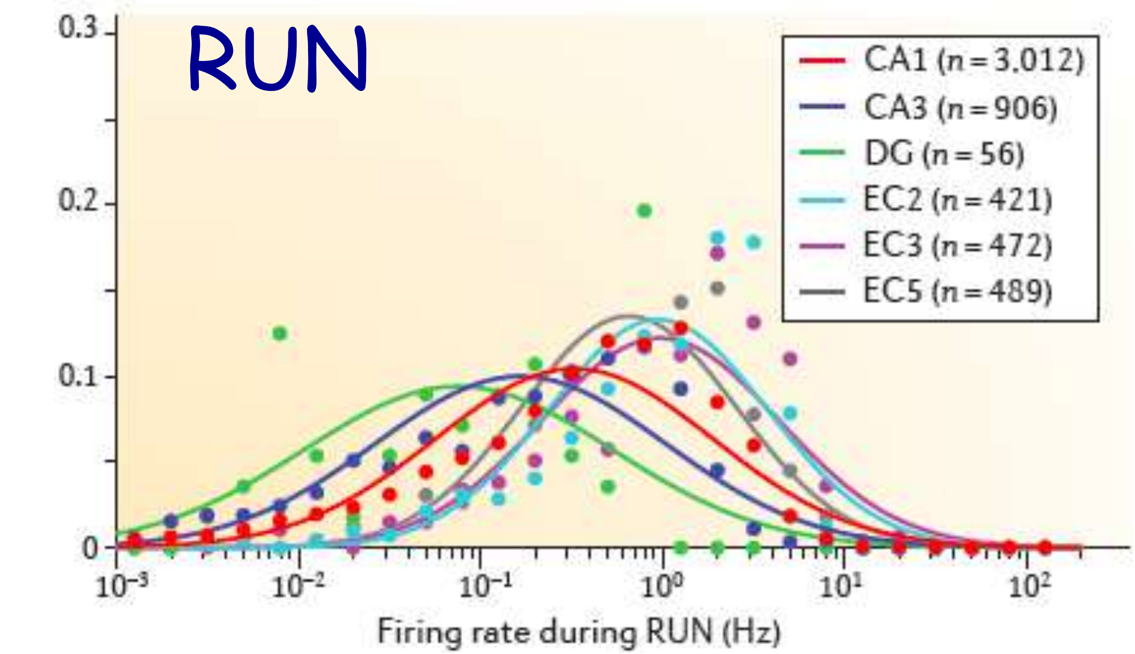
Song, Sjostrom Reigl Nelson Chklovskii PLoS Biology 2005 and courtesy of Carl Petersen



fin



Kenji Mizuseki

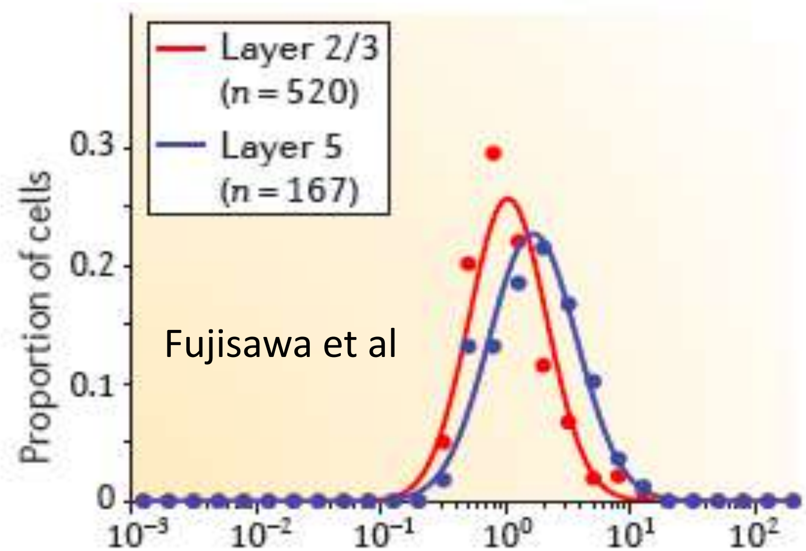


Log-normal rate distribution in each layer and region of the EC-hippocampus and brain state

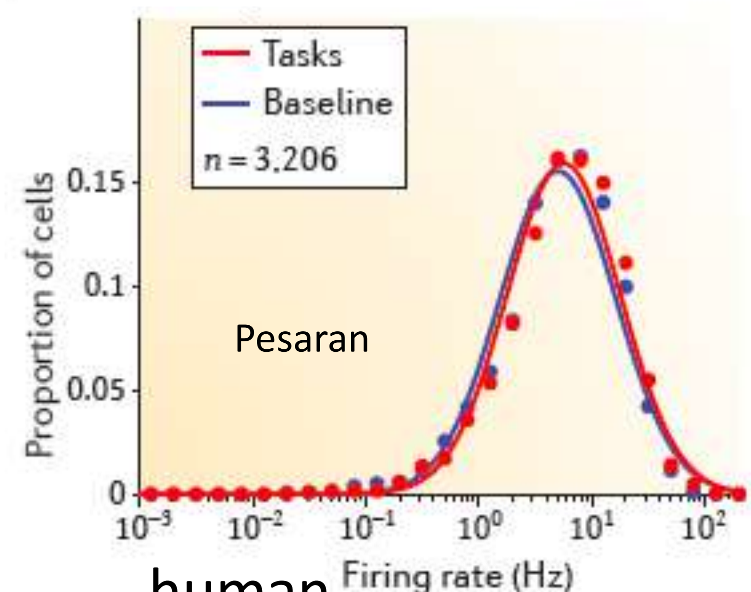
Buzsaki, Mizuseki, **Nature Rev Neurosci** 2014

Rate distributions in neocortex

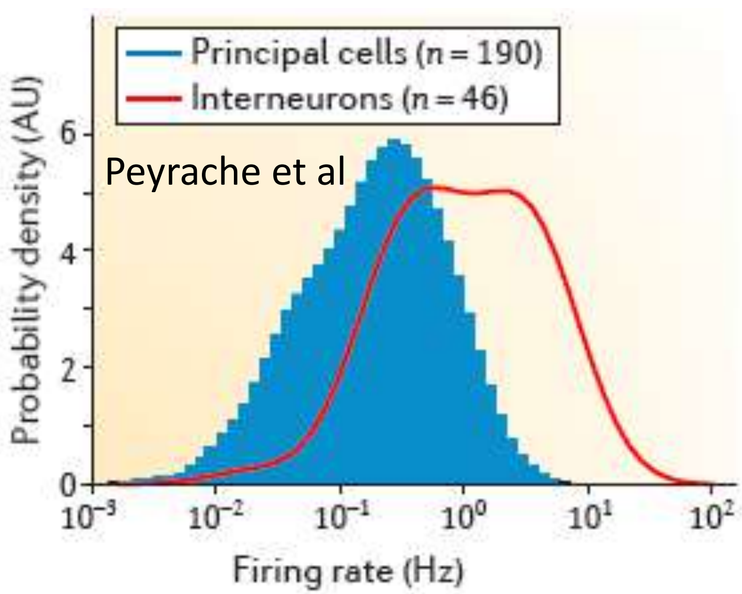
rat



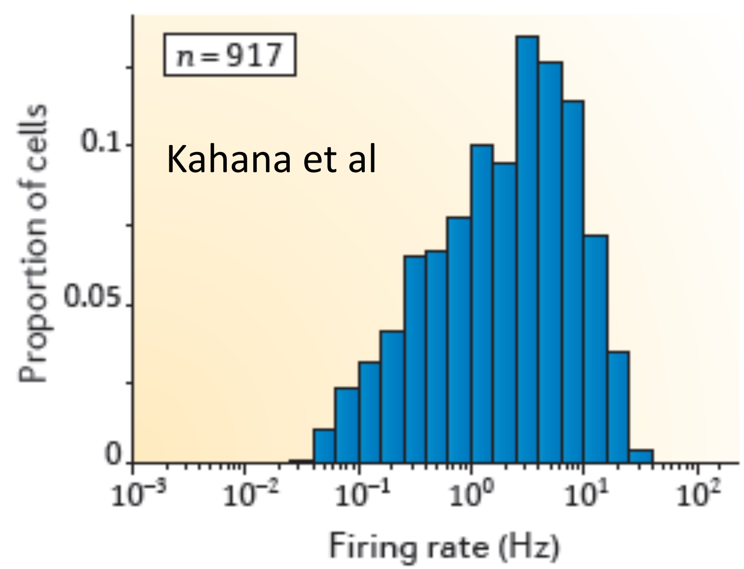
monkey



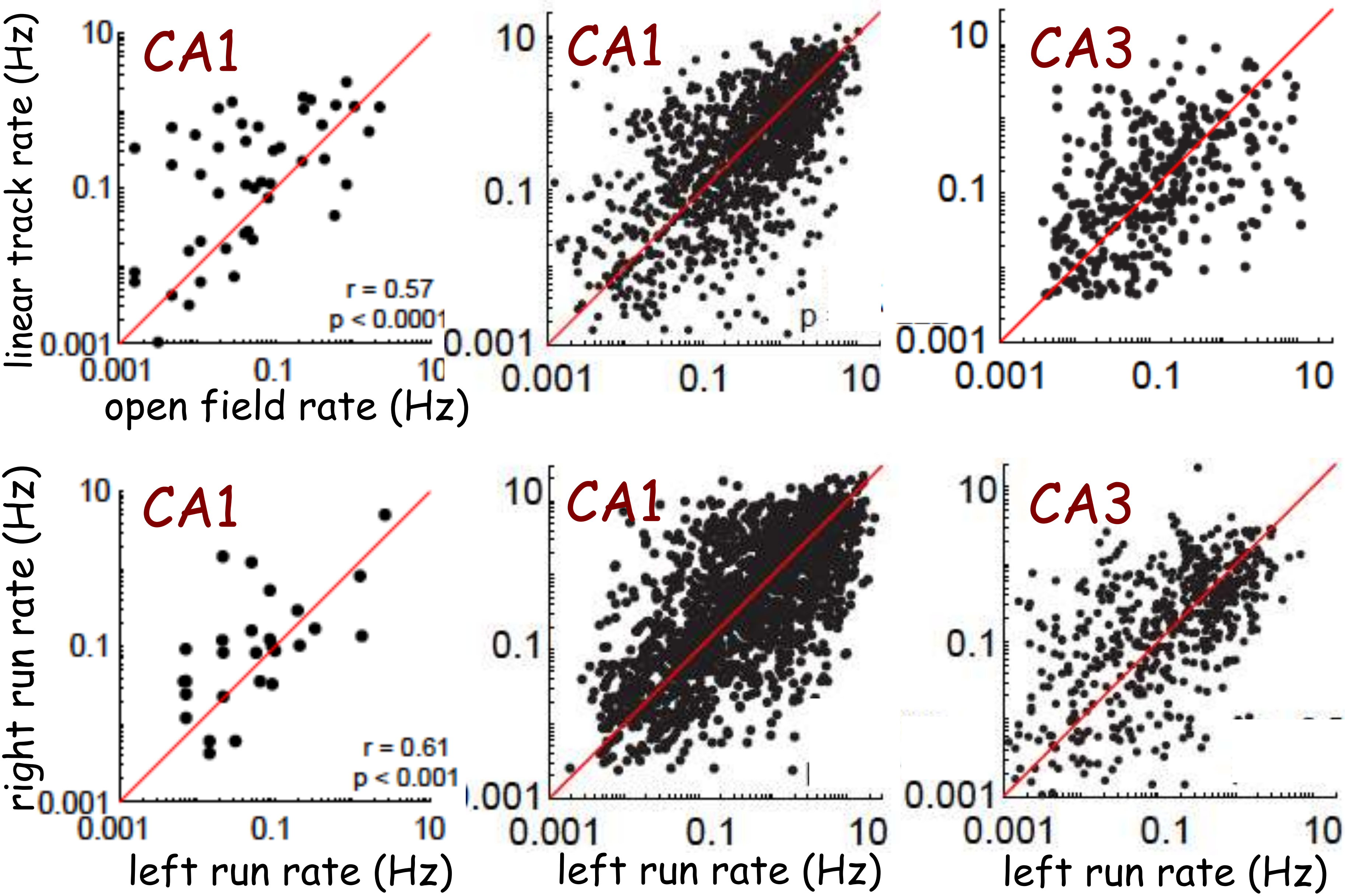
human



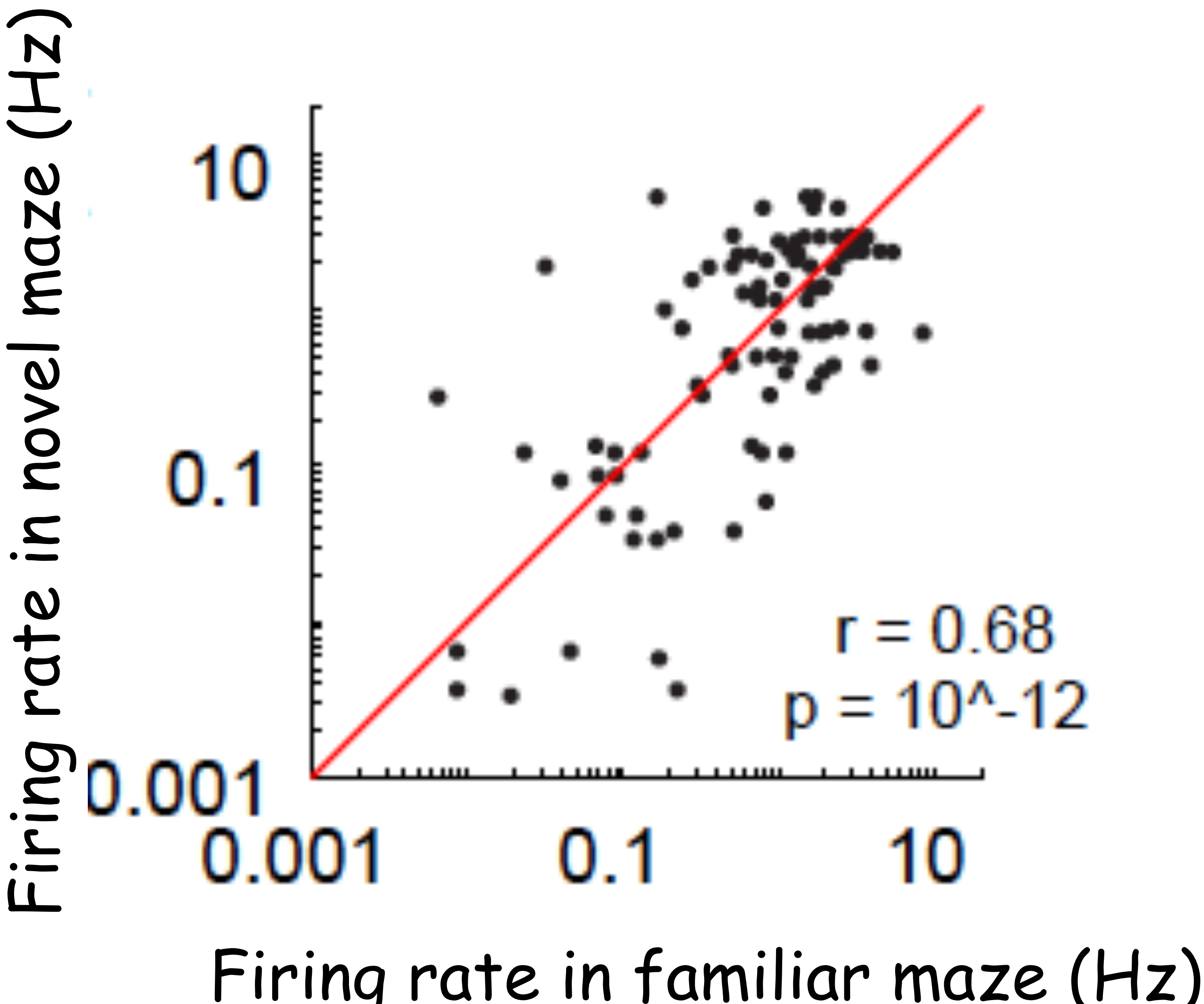
human



Log firing rate correlations across 're-mapping'

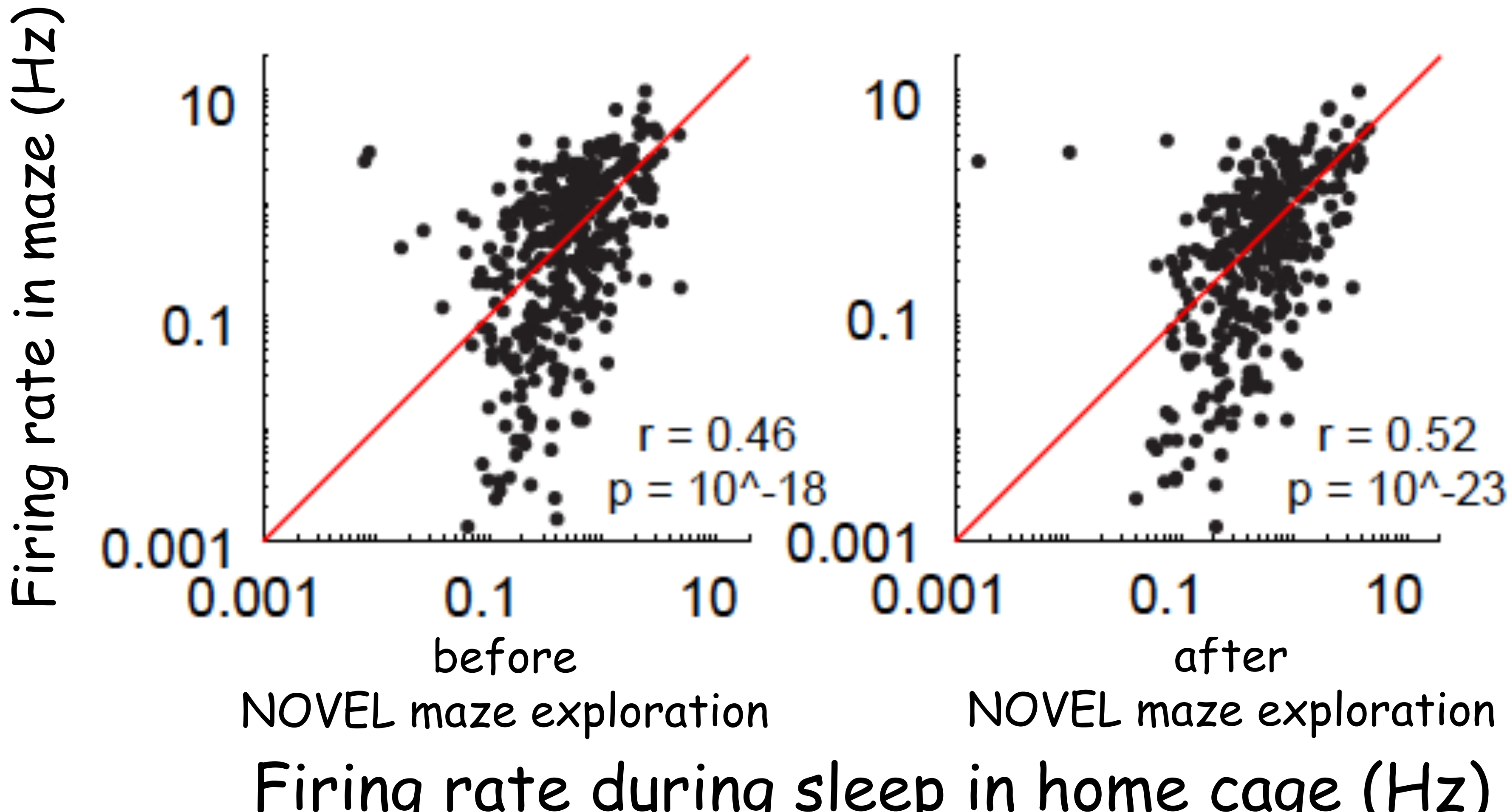


Firing rate correlations between familiar and novel environments

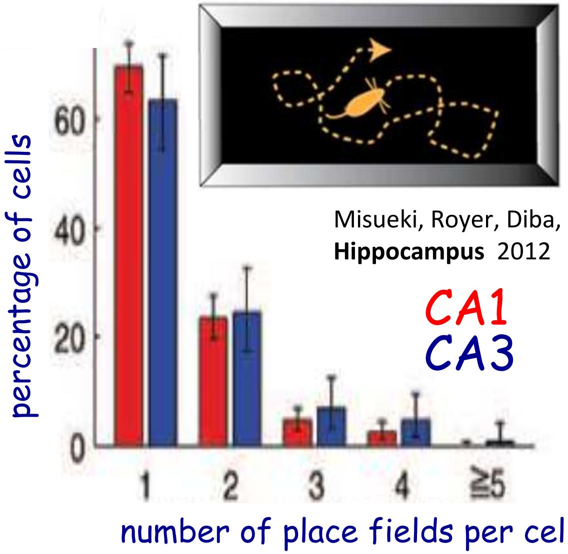


Mizuseki, Buzsaki, **Cell Rep** 2013

Firing rate correlations between novel environment and sleep

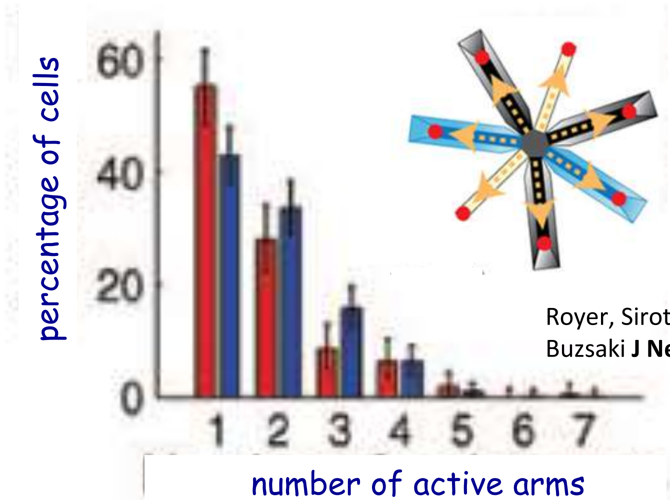


Log representation of environments

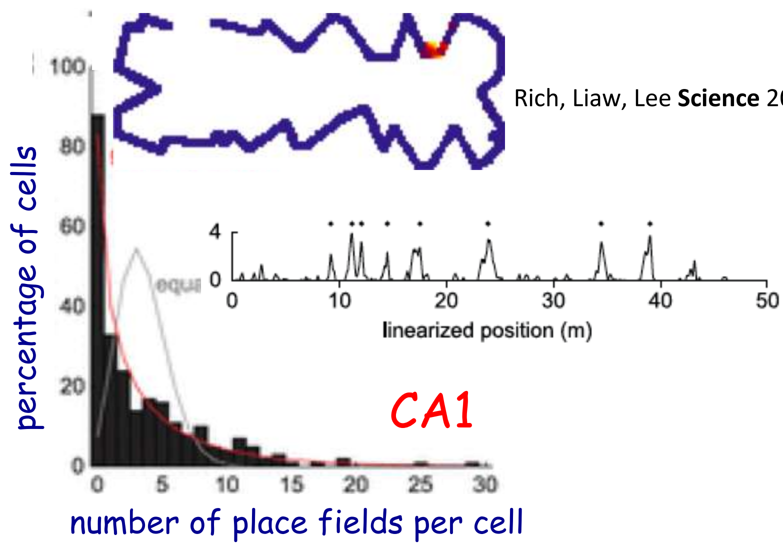


Misueki, Royer, Diba, Buzsaki
Hippocampus 2012

CA1
CA3

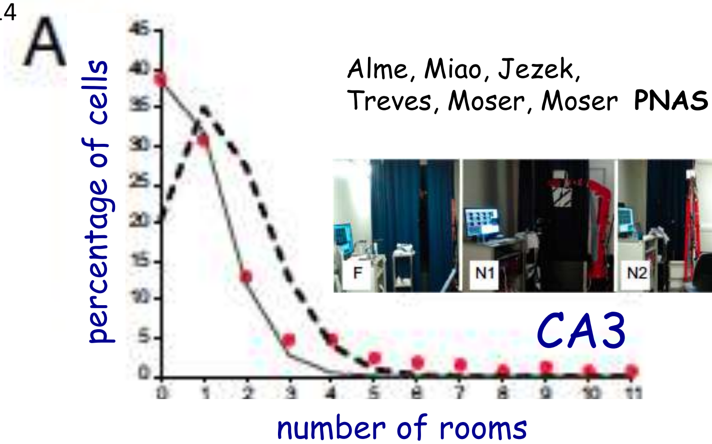


Royer, Sirota, Patel,
Buzsaki **J Neurosci** 2010



Rich, Liaw, Lee **Science** 2014

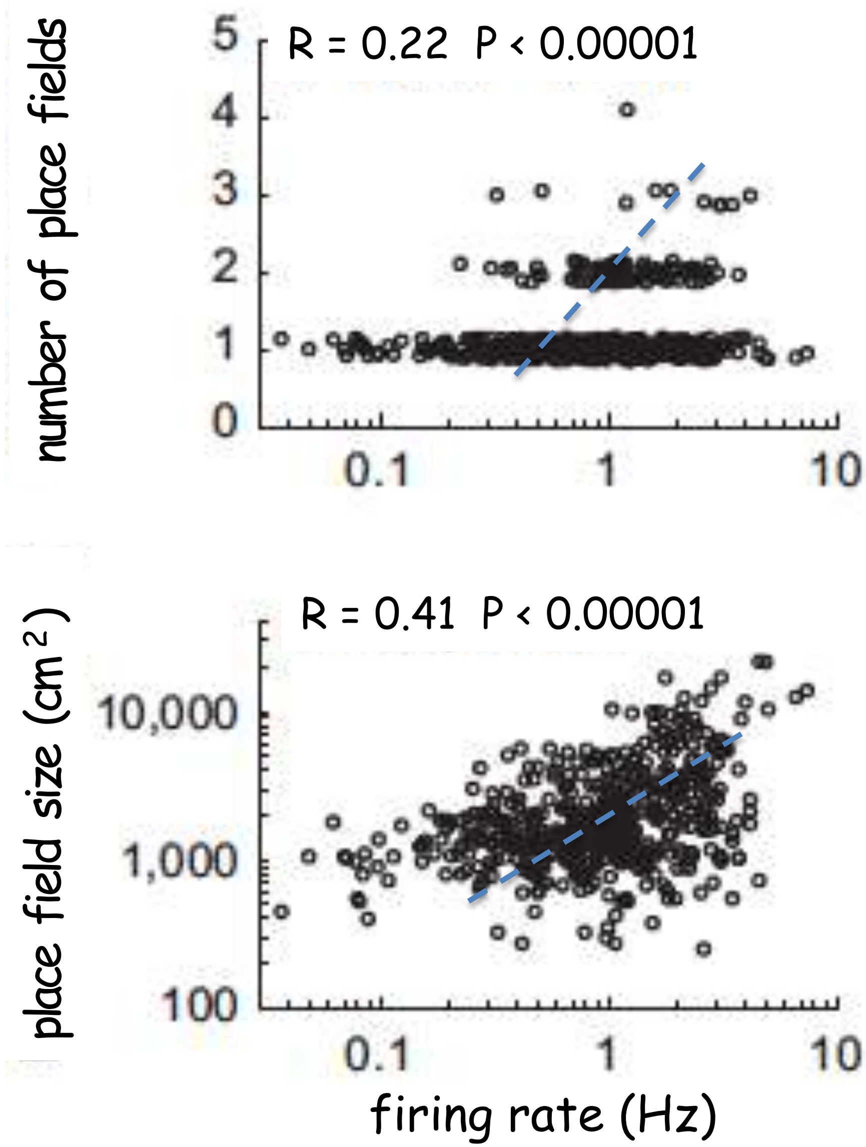
CA1



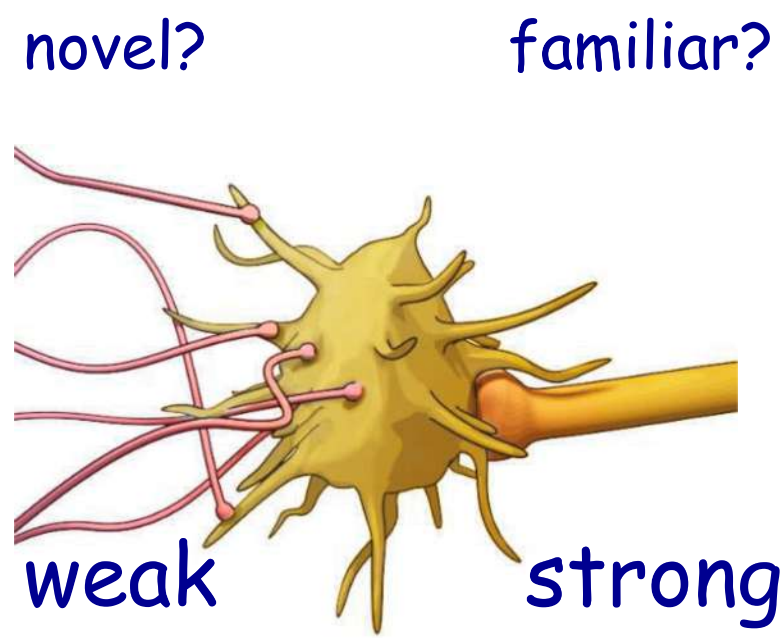
Alme, Miao, Jezek,
Treves, Moser, Moser **PNAS** 2014

CA3

Firing rates and behavioral expressions are correlated

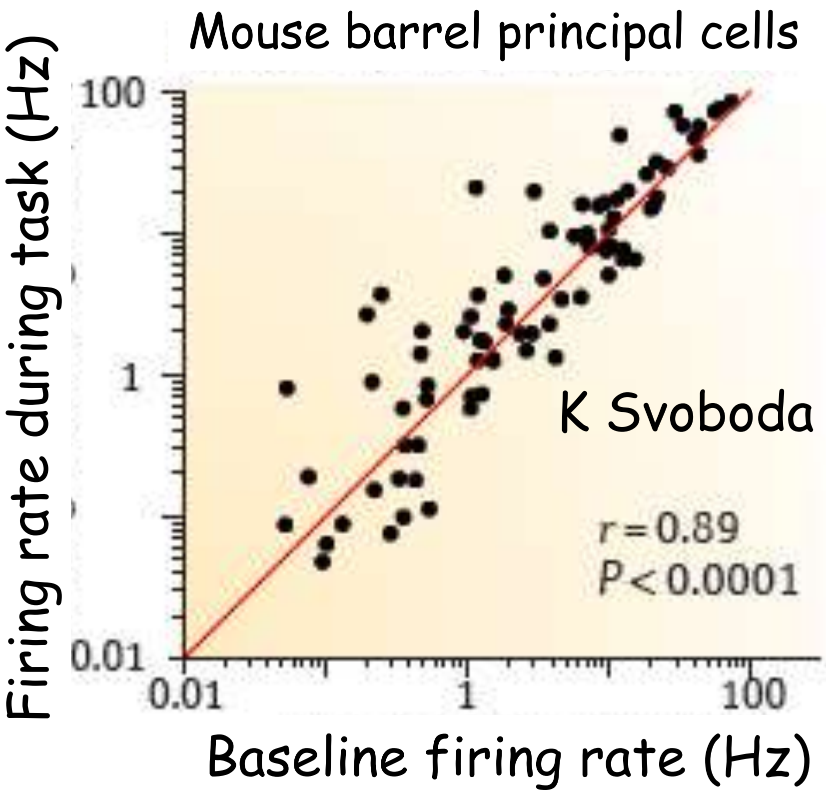


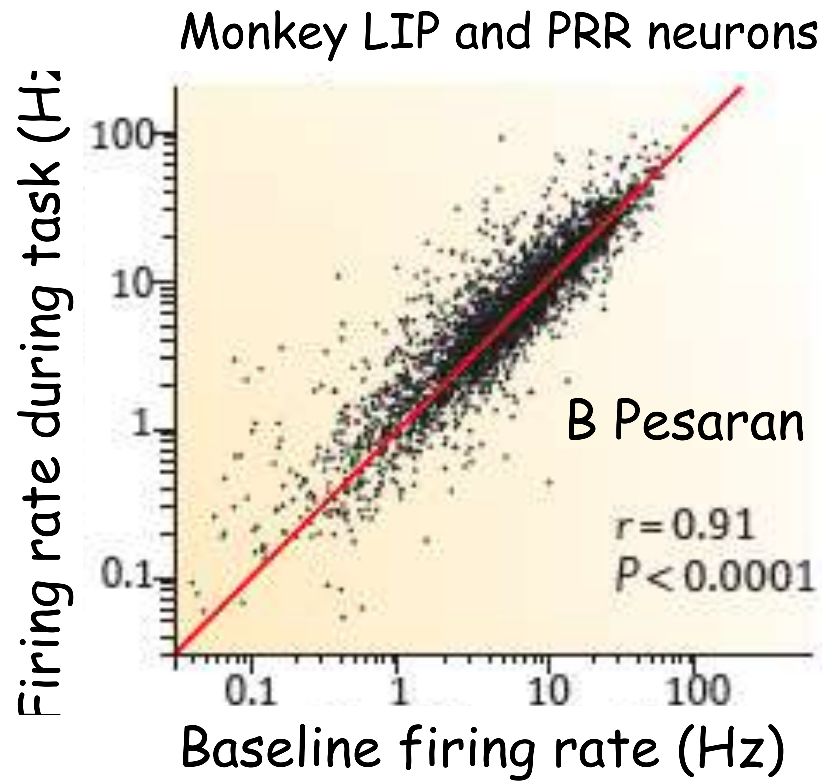
How do downstream 'readers' interpret messages sent by skewed populations?



Buzsaki **Science** 2015

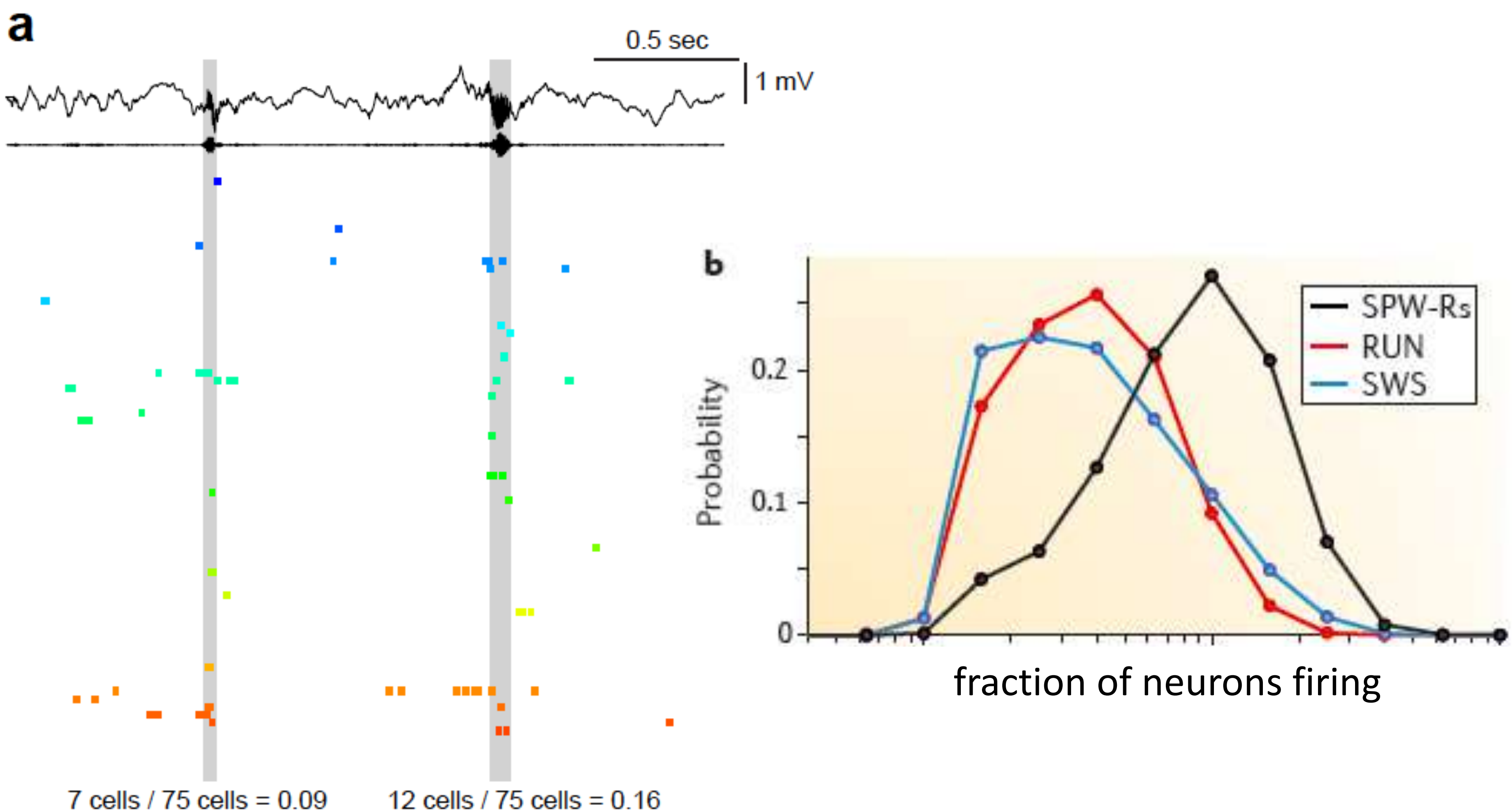
Log correlations between spontaneous and induced firing rates





Buzsaki, Mizuseki, **Nature Rev Neurosci** 2014

Population level: magnitude of neuronal synchrony follows lognormal statistics

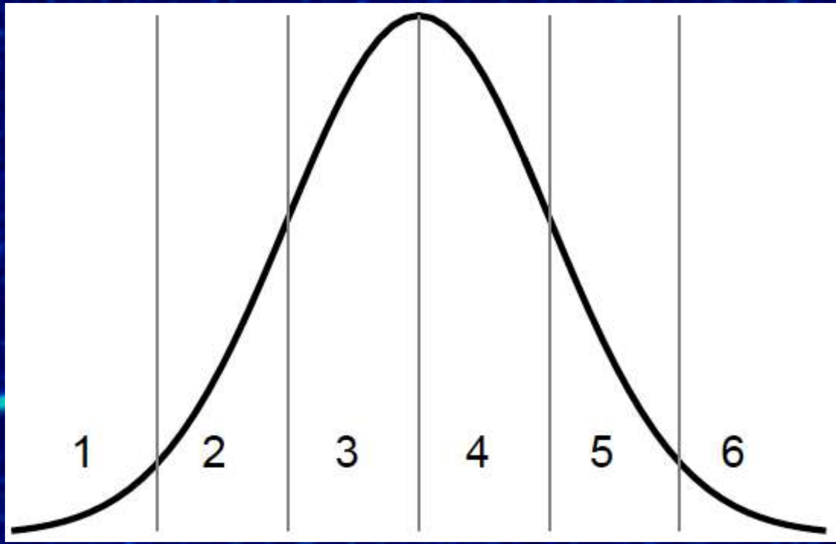


Buzsaki, Mizuseki, **Nature Rev Neurosci** 2014

- These observations are not just statistical curiosities

- The brain's attempt to reconcile conflicting demands among wide dynamic range, stability, robustness and plasticity, redundancy, resilience, degeneracy, homeostasis

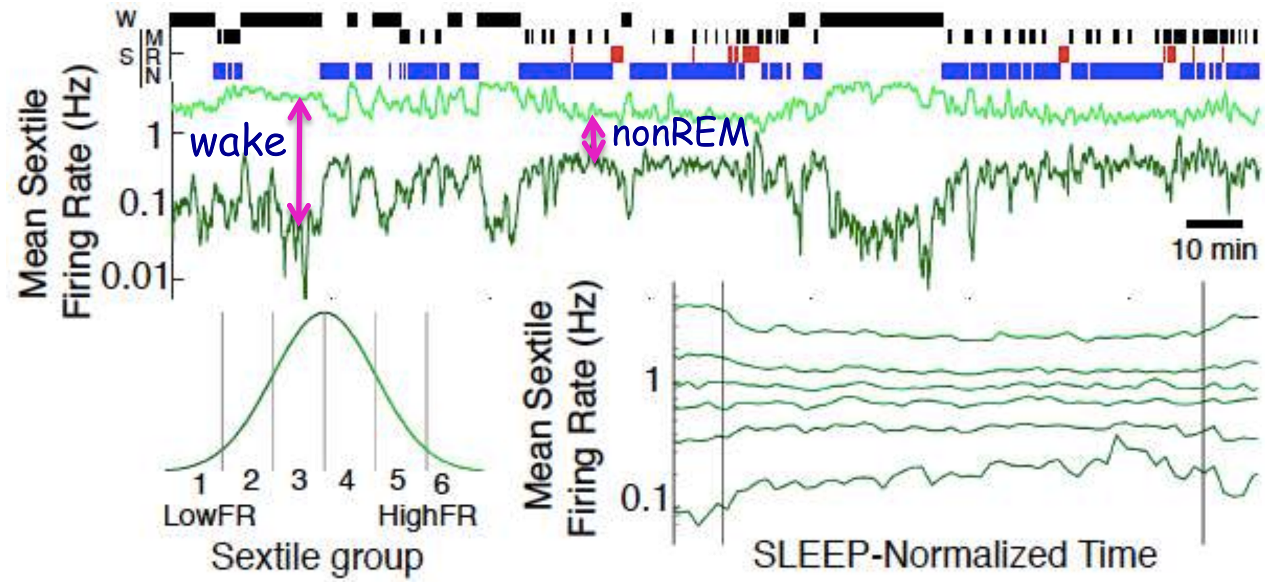
Renart, Song, Wang **Neuron** 2003　　　　Buzsaki, ***OUP*** 2019



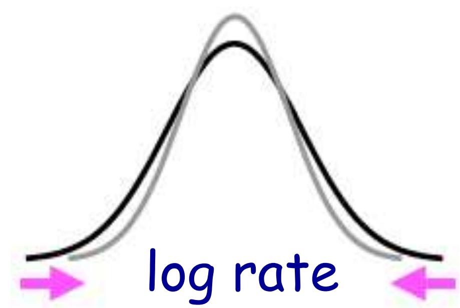
sextiles of log rates

- How are log distributions of firing rates brought about ?
- How stable are rate distributions?
- How are log distributions maintained ?
- How are log distributions exploited for function ?

Slow and fast firing neurons are differentially regulated



During nonREM SLEEP the coefficient of firing rate variation is decreased

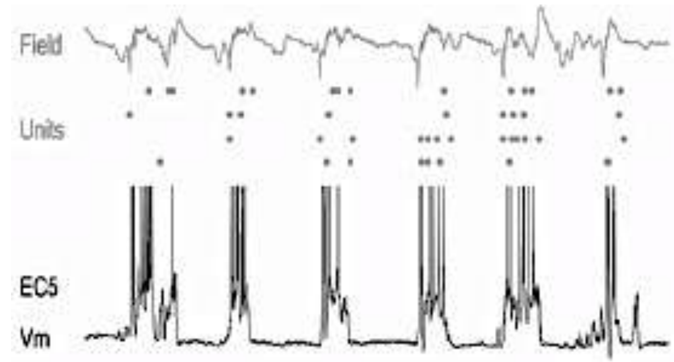


Brendon Watson

Dan Levenstein

Watson, Levenstein, Greene, Buzsaki **Neuron** (2016)

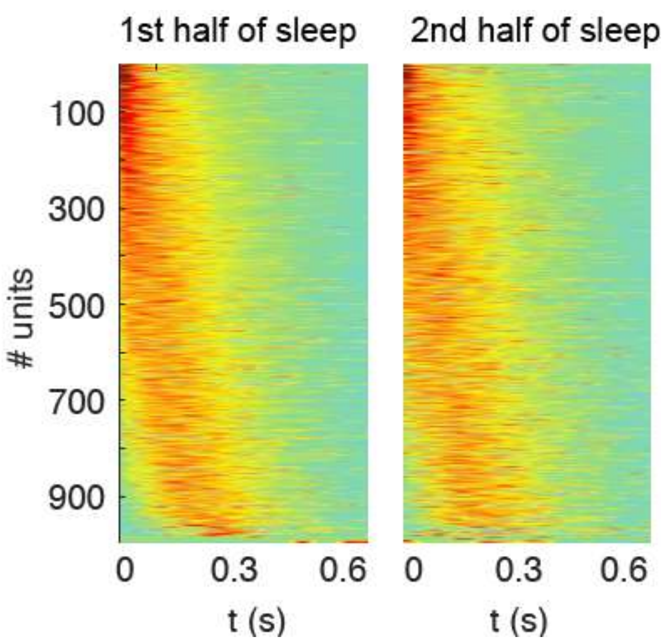
Members of the slow and fast tails of the firing rate distribution are segregated in time during sleep

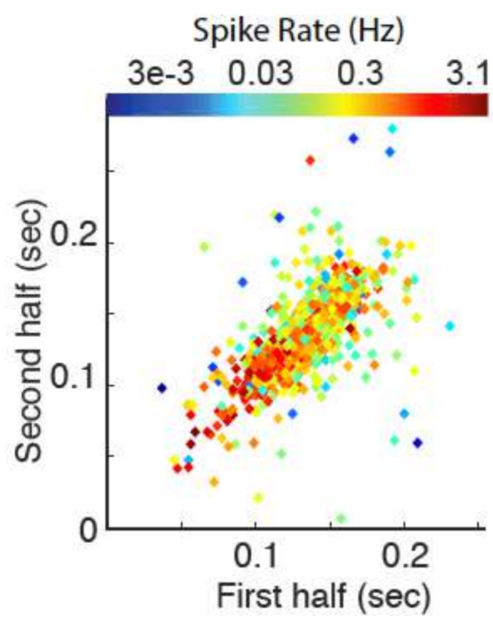


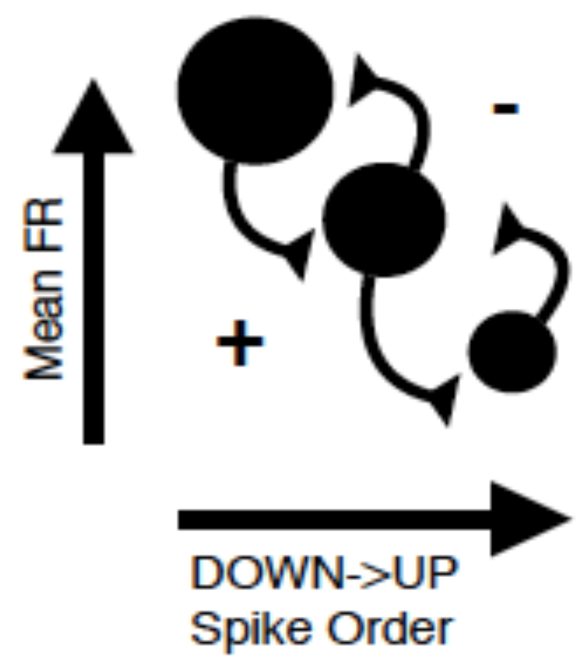
Steriade et al. **J Neurosci** (1993)

Hypothesis: slow and fast firing neurons are differentially affected by STDP

Sorted by latency



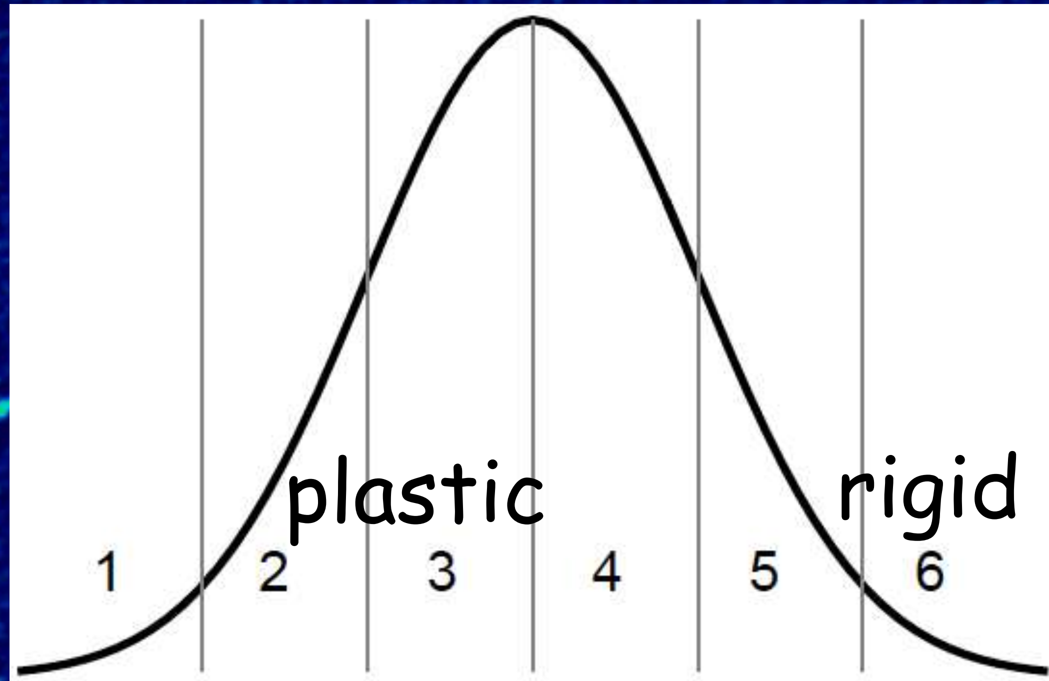




Watson, Levenstein, Greene, Buzsaki **Neuron** (2016)

Sleep Plasticity

- Fast and slow firing neurons synchronize differently – STDP – segregation
- The two tails of the distribution are regulated by different mechanisms



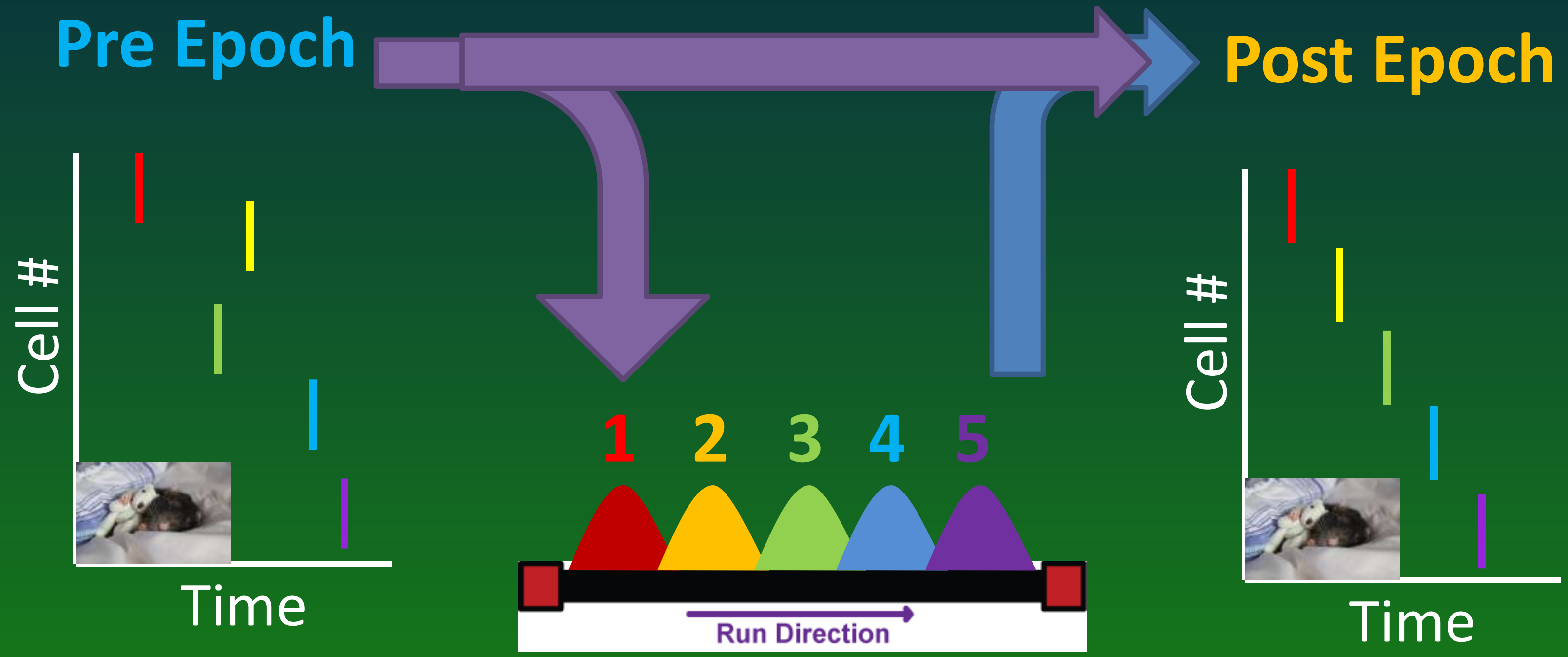
sextiles of log rates

Functions for skewed distributions

Firing rates correlate with learning-induced changes

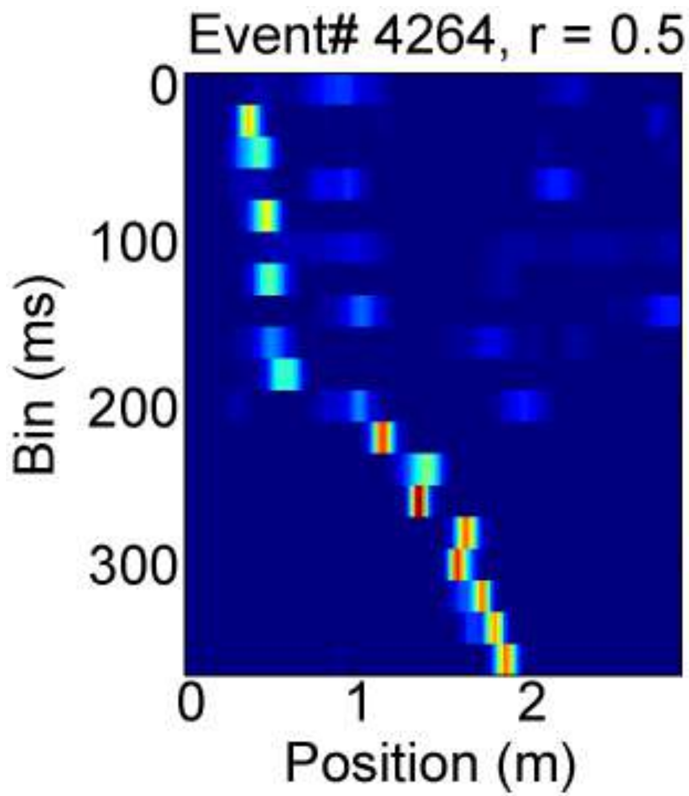
Andres Grosmark

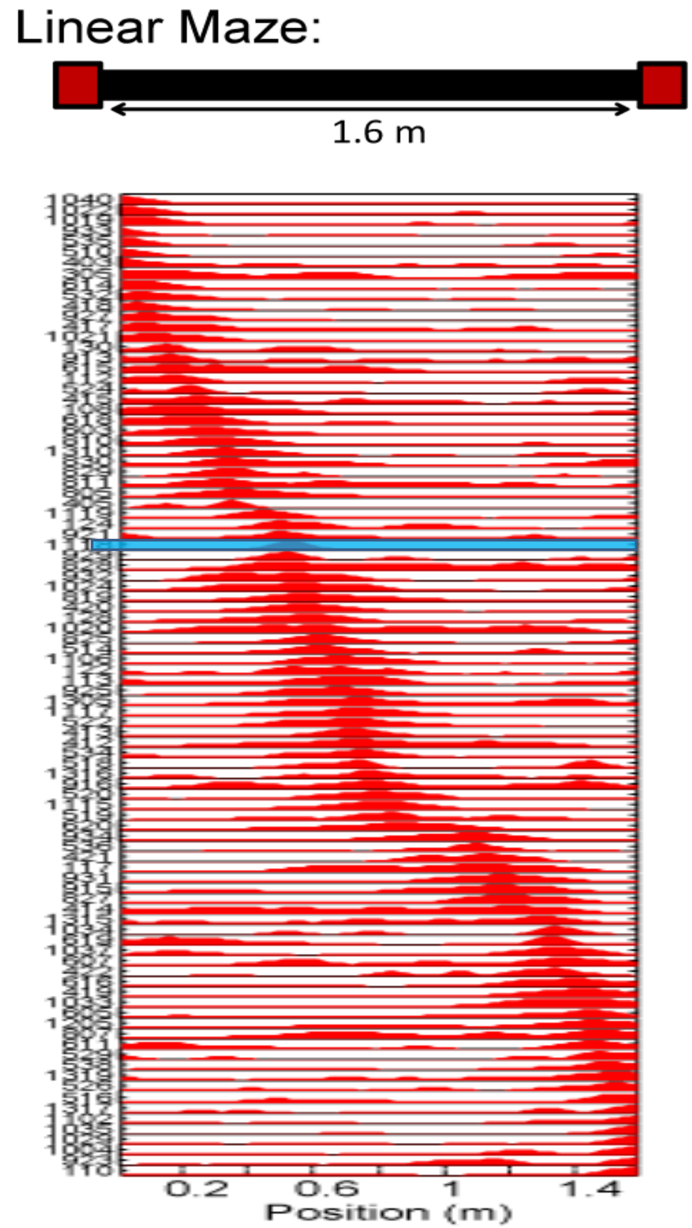
Wilson, McNaughton, **Science** 1994
Dragoi, Tonegawa, **Science** 2011



Per cell contribution (PCC) index

Bayesian decoding of position
(sequence score for each neuron)

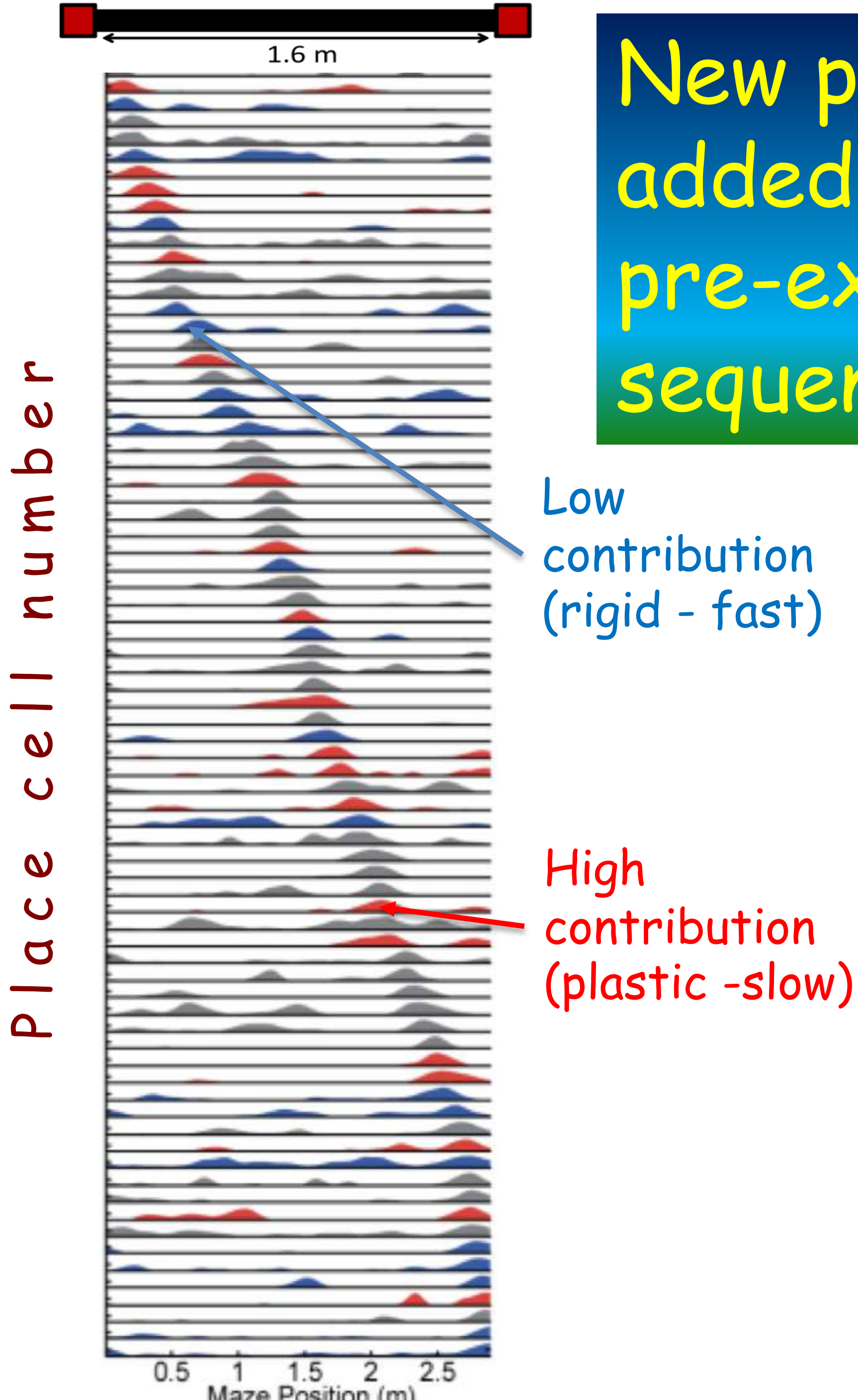


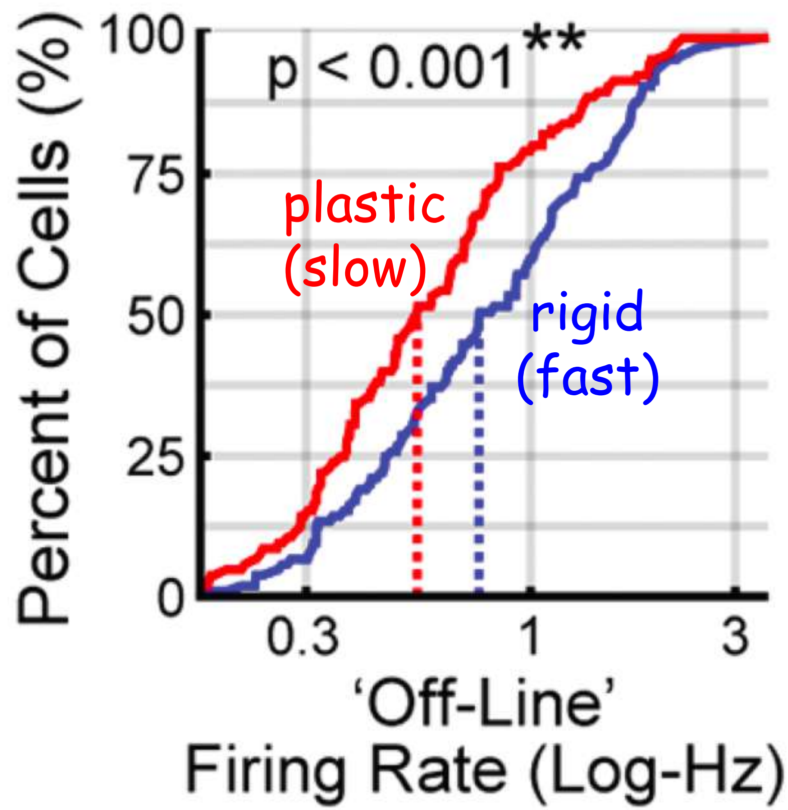


For each cell participating in each event:
P.C.C. = [*rZ(observed)* – *rZ(cell shuffle)*]xNCells

Grosmark, Buzsaki **Science** 2016

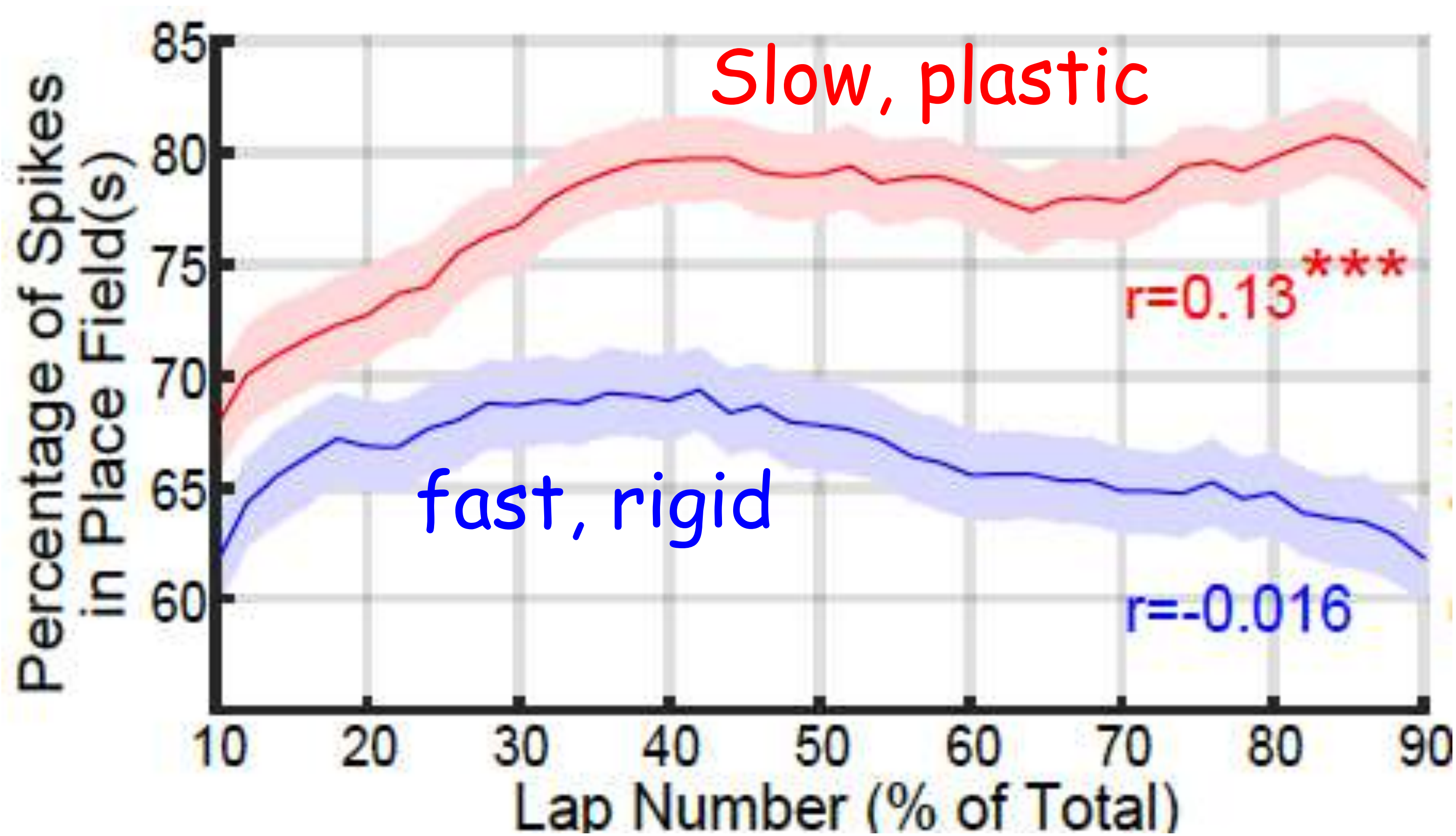
New place cells are added onto a backbone of pre-existing place cell sequence





Grosmark, Buzsaki **Science** 2016

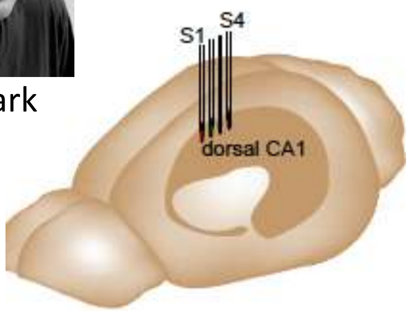
Slow firing place cells increase their spatial specificity over trials in a novel environment

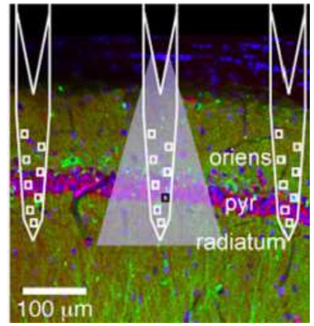


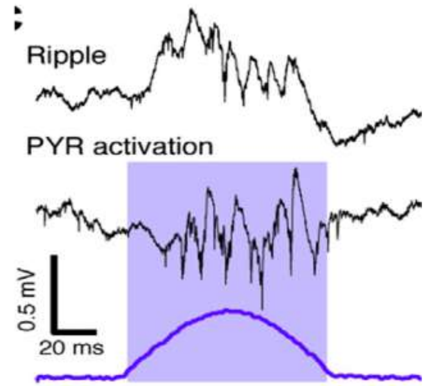
Grosmark, Buzsaki **Science** 2016

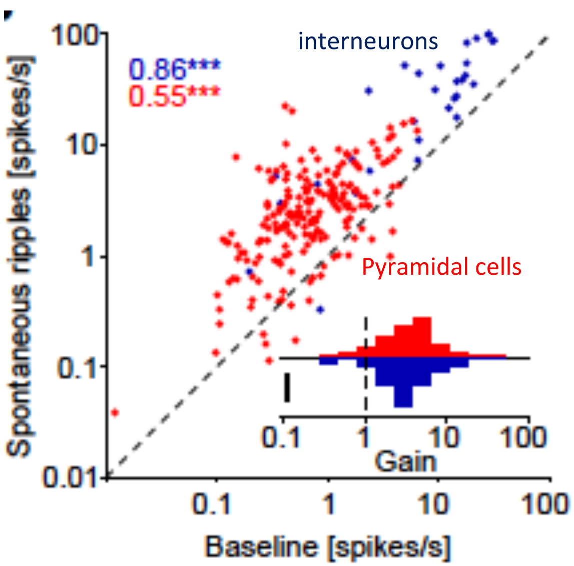
Local circuit and intrinsic properties affect firing patterns

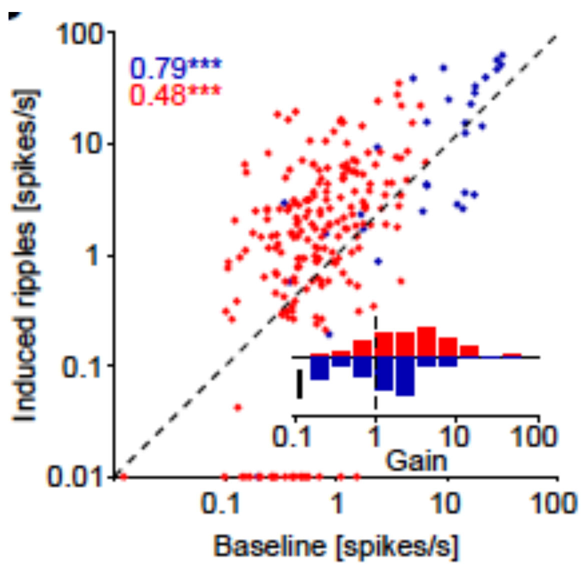
Eran Stark

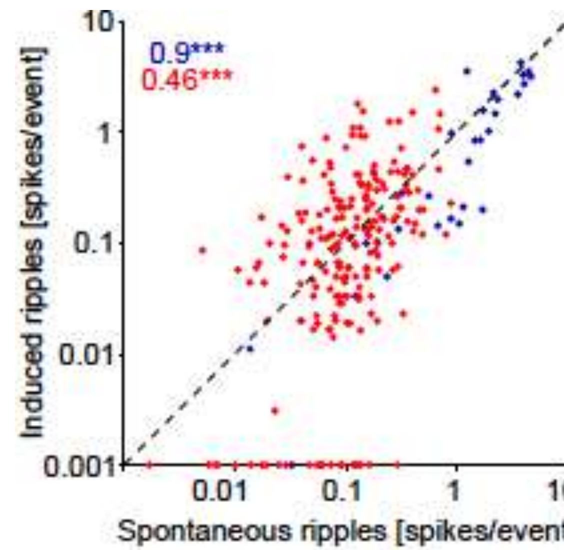










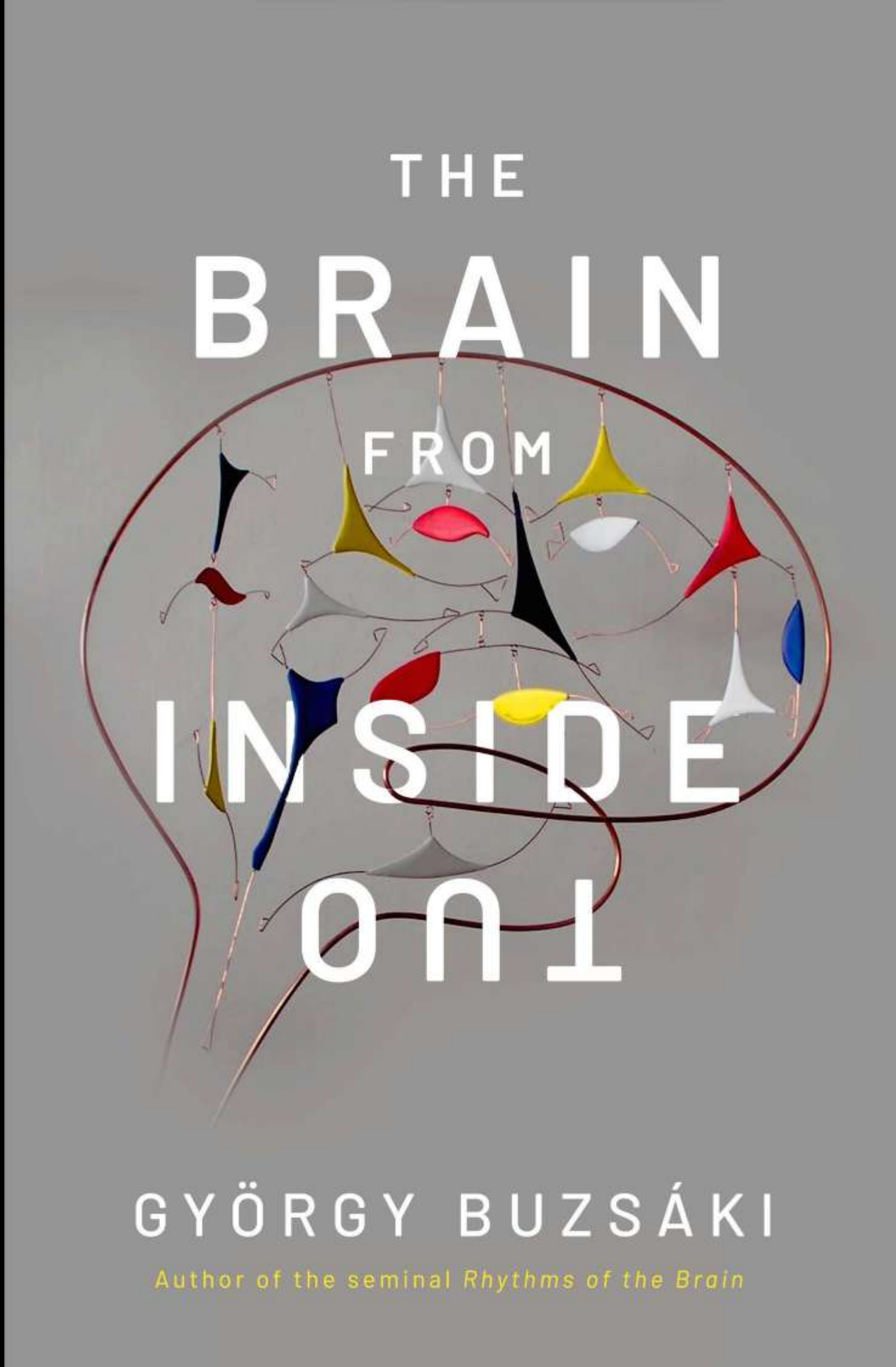


Stark, Roux, Eiler, Buzsaki **PNAS** (2015)

Simplicity is the ultimate form of sophistication

- Leo Da Vinci

- Every ready, "good enough brain" for most situations versus “careful, detail-oriented brain”
- Fast decision versus slow precision
- Rigid minority versus plastic majority
- Generalizers versus specialists



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Dion
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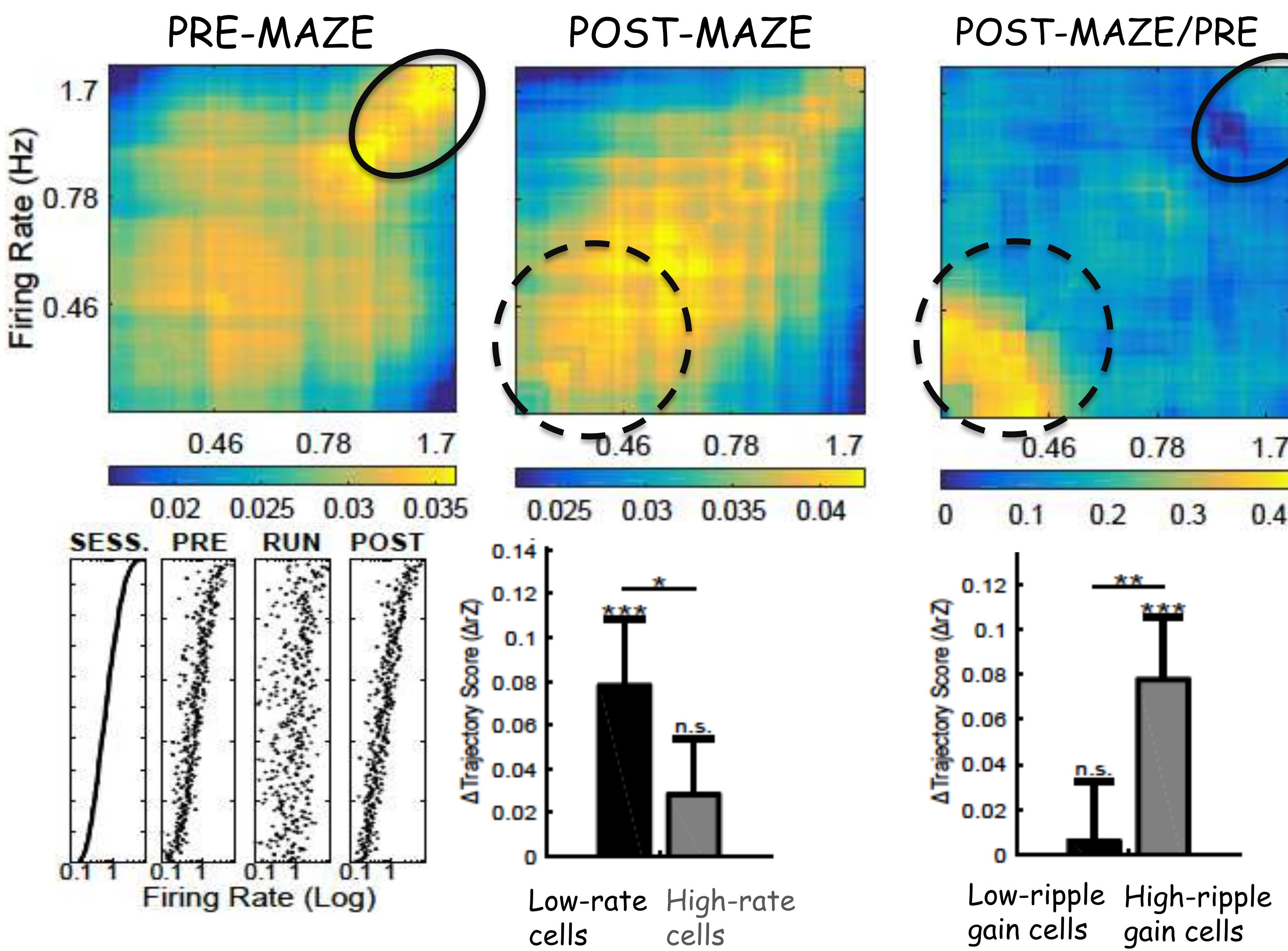
Azhara
Oliva

Bo Hu

Only low firing rate neurons are affected by learning



Grosmark, Buzsaki **Science** 2016