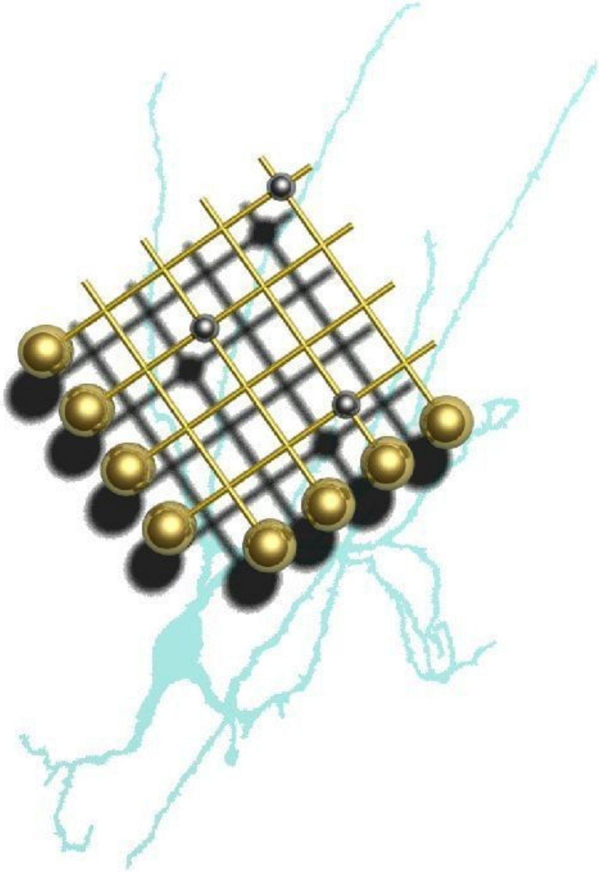
Variability and constraints in spontaneous neuronal network remodelling

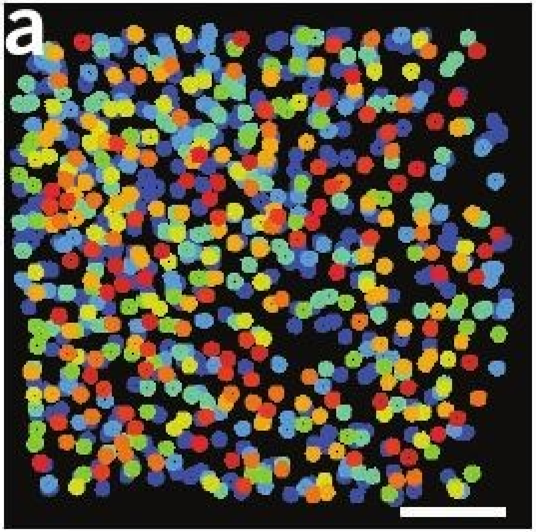
ANC, Edinburgh:
Dagmara Panas
Oliver Muthmann
Mark van Rossum

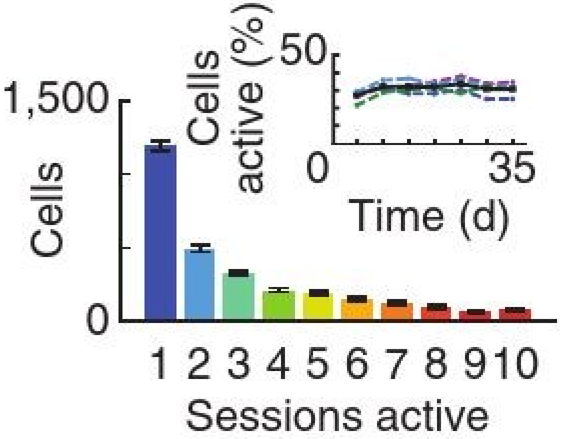
IIT, Genova:
Hayder Amin
Alessandro Maccione
Luca Berdondini

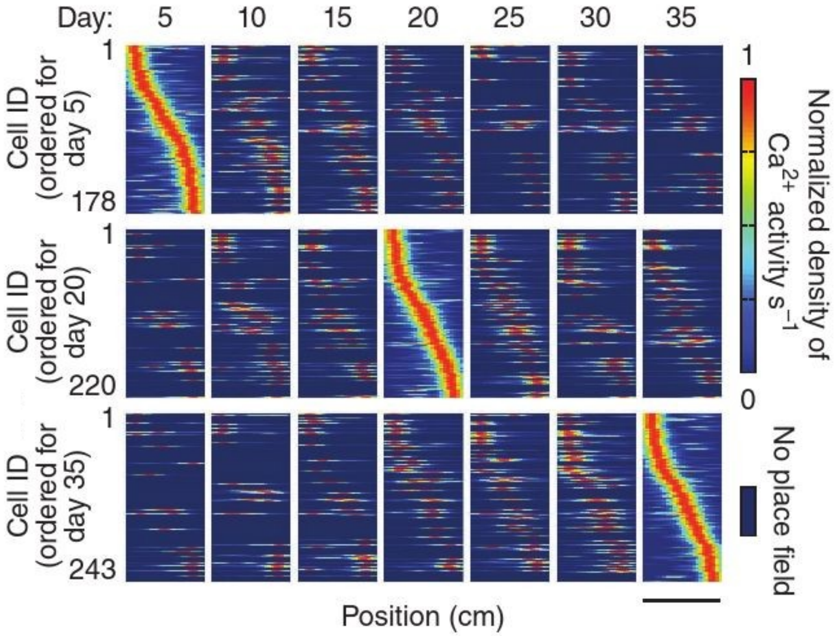


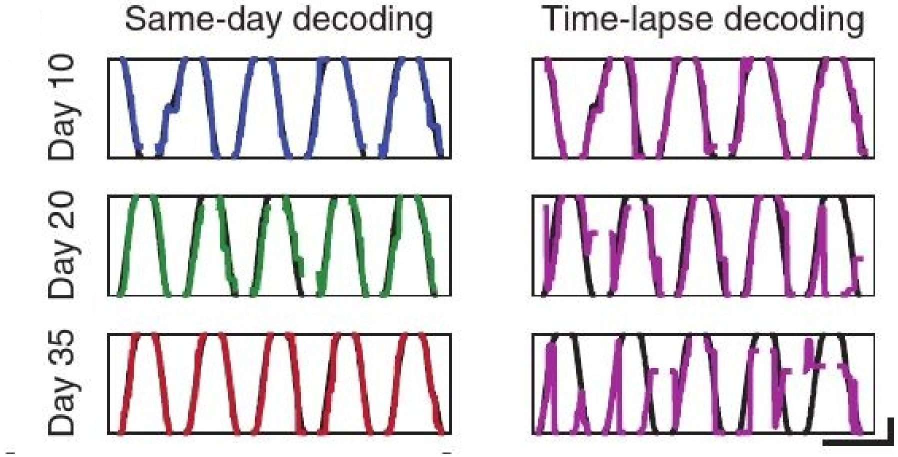
Medical Research Council

Functional stability (hippocampus)



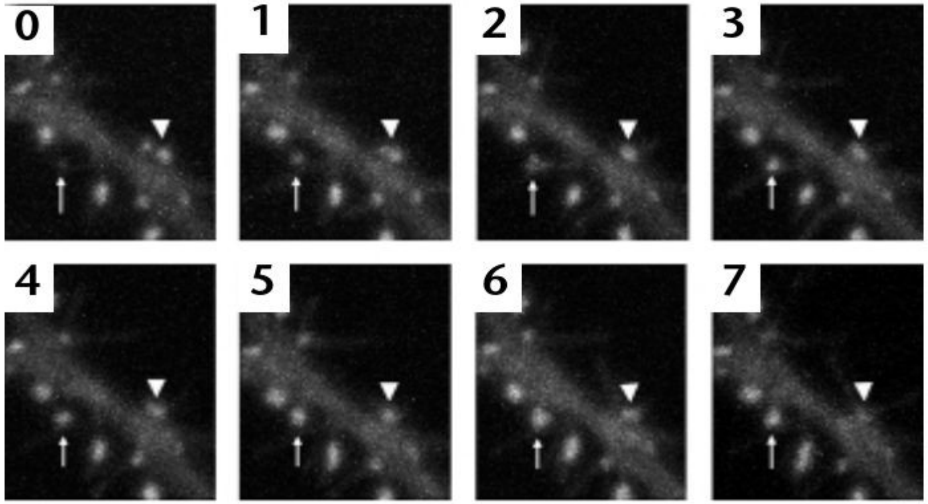




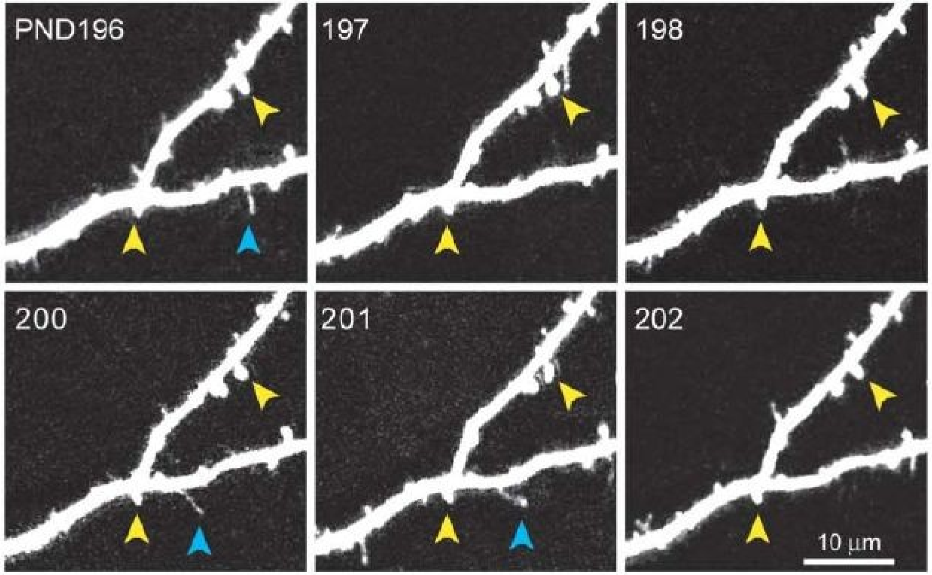


Ziv et al., Nat Neurosci, 2013; cf e.g. Chestek et al., J Neurosci, 2007

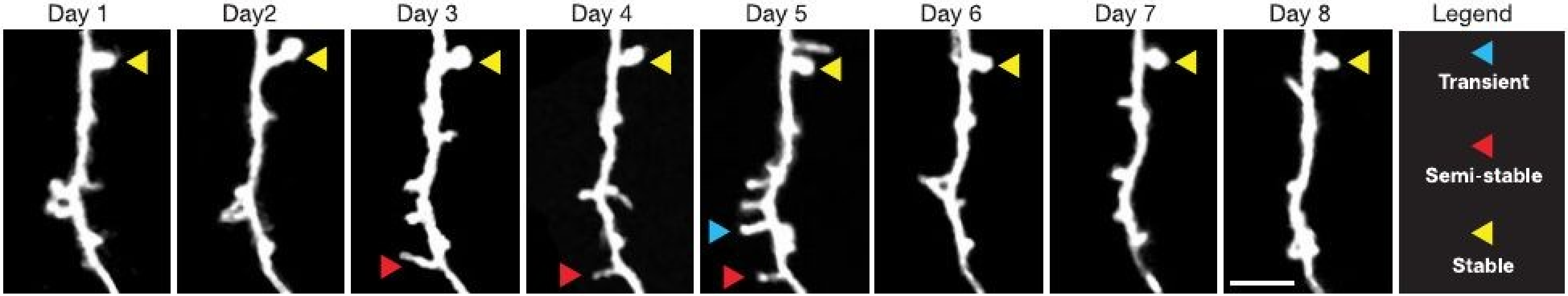
Synaptic remodeling



Okabe et al., Nat Neurosci, 1999
hippocampal culture, PSD95
>20% turnover/day

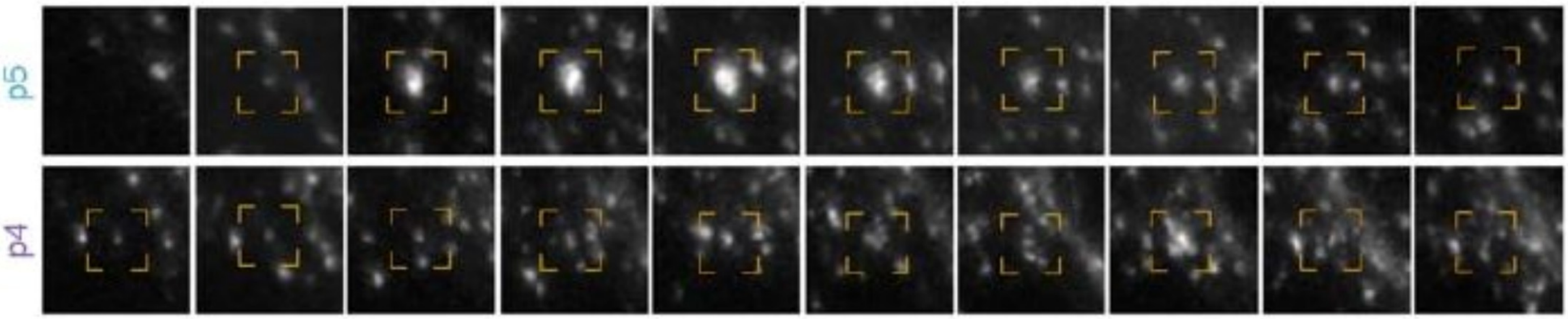


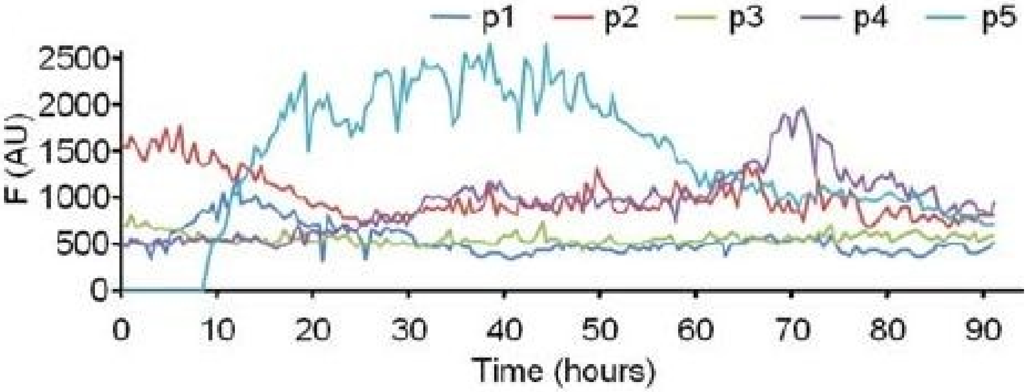
Holtmaat et al., Neuron, 2005
mouse S1 Layer 5 *in vivo*
transient vs. persistent spines

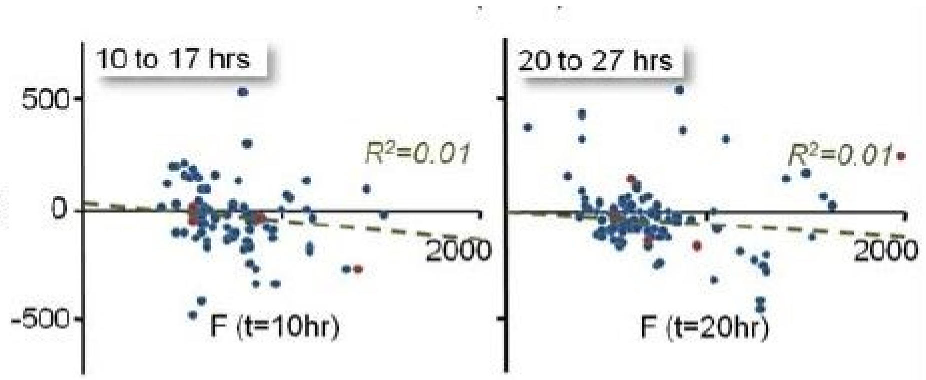


Trachtenberg et al., Nature, 2002
mouse barrel cortex, layer 5 *in vivo*, turnover depends on sensory stimulation

Spontaneous synaptic remodeling





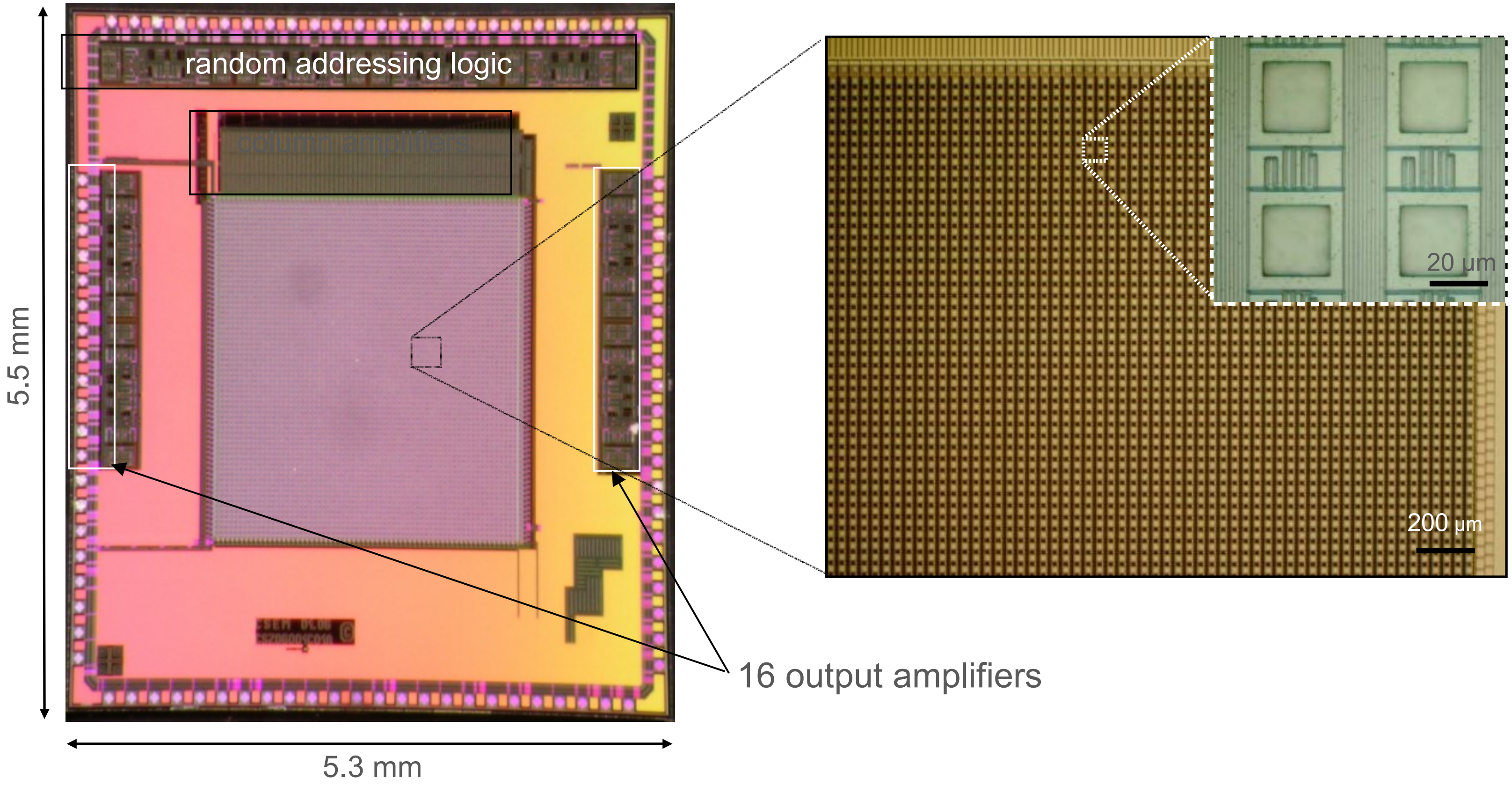


Minerbi et al, PLoS Biol, 2009

see also e.g. Loewenstein et al., J Neurosci, 2011

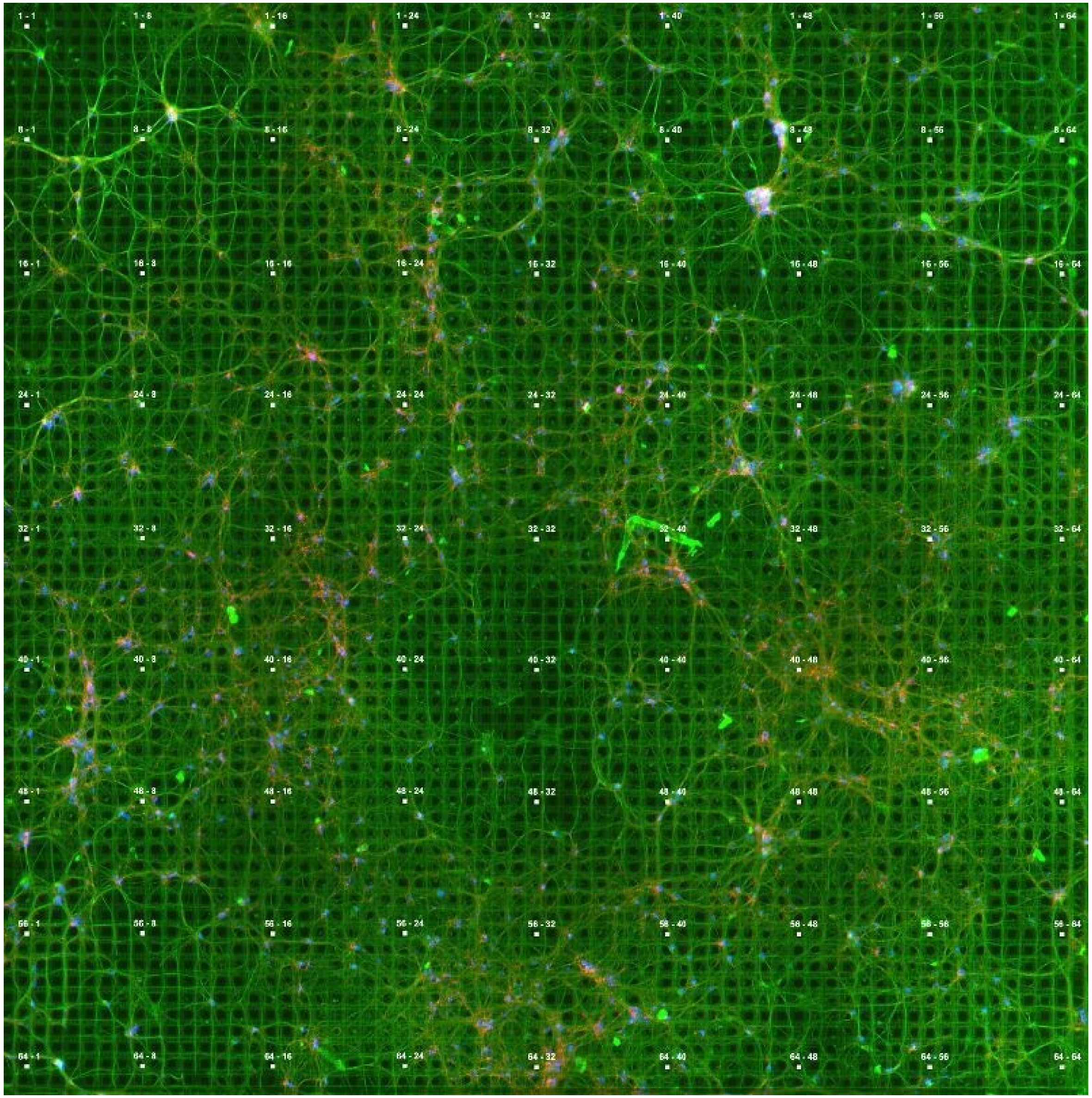
How do single neuron/synapse fluctuations co-exist with stability at the population level?

HD-MEA



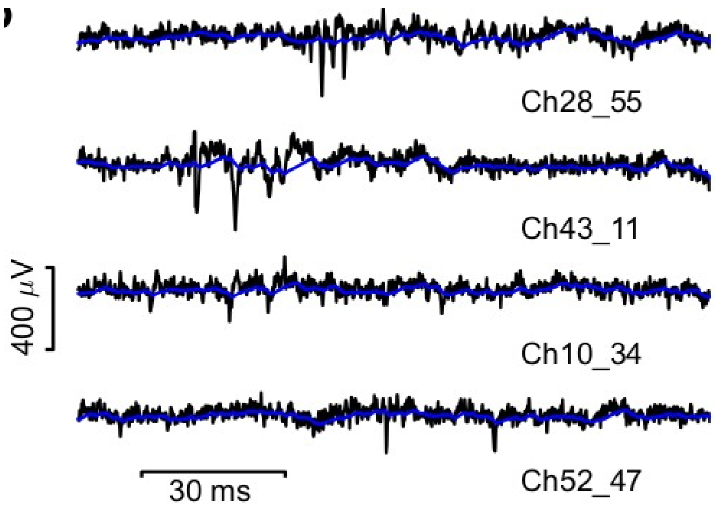
4,096 electrodes (64x64 array)
42 µm centre-to-centre
0.37 Gbit/s, ~2.8GB/minute

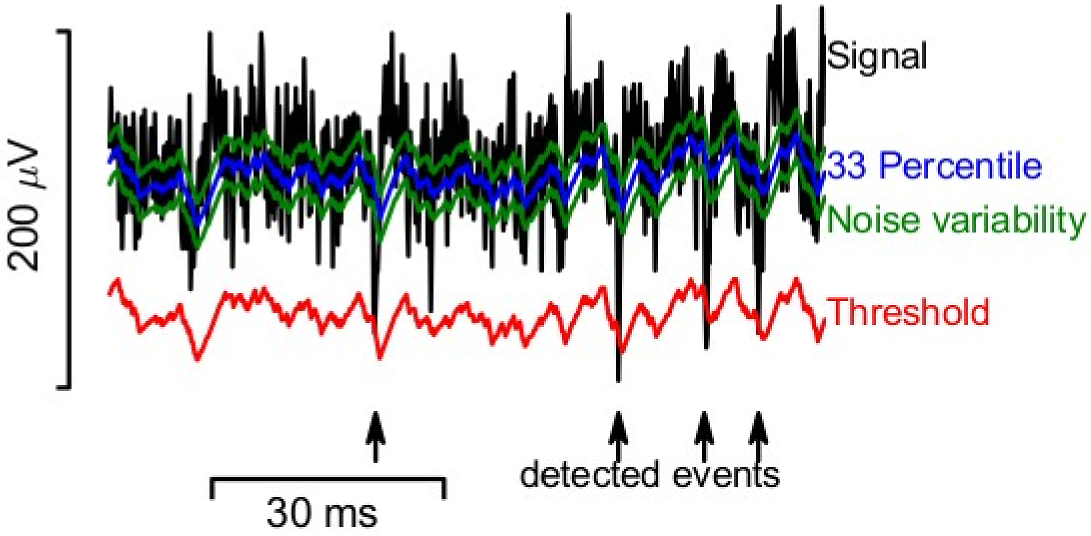
Neural cultures

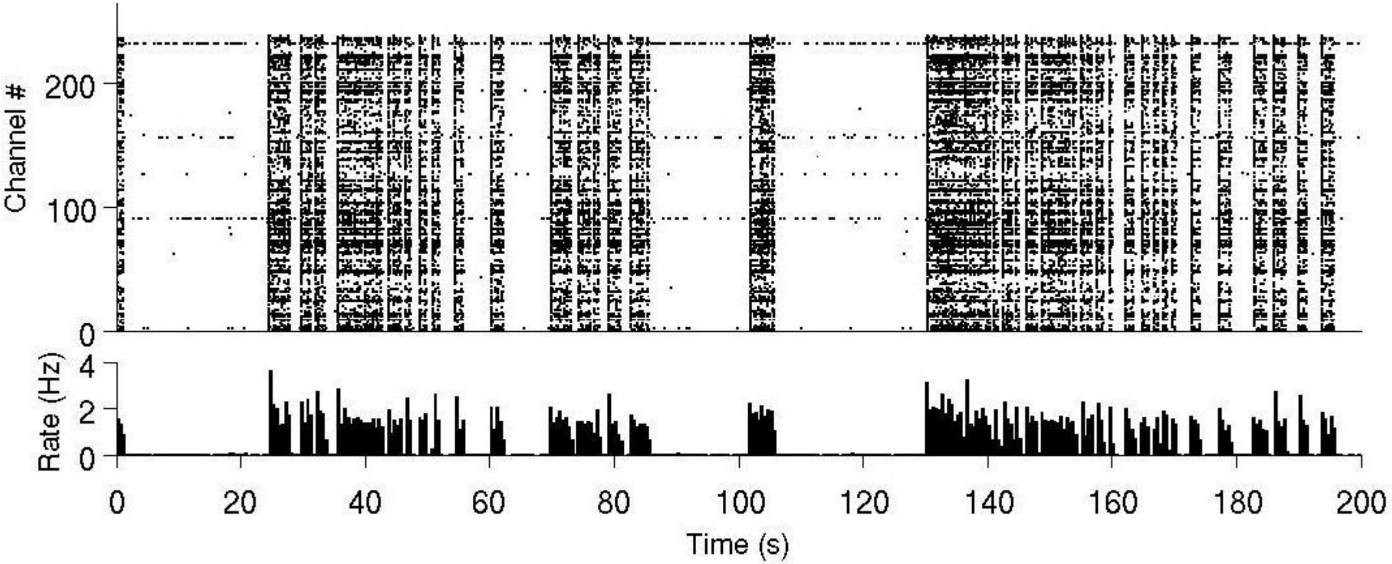


Alessandro Maccione

Event detection

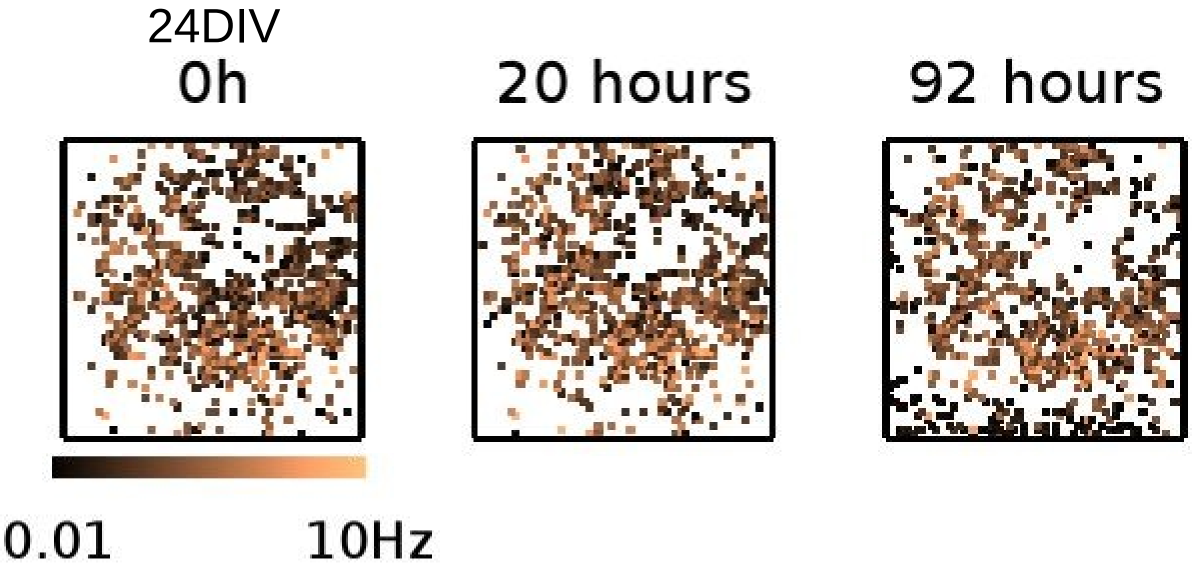


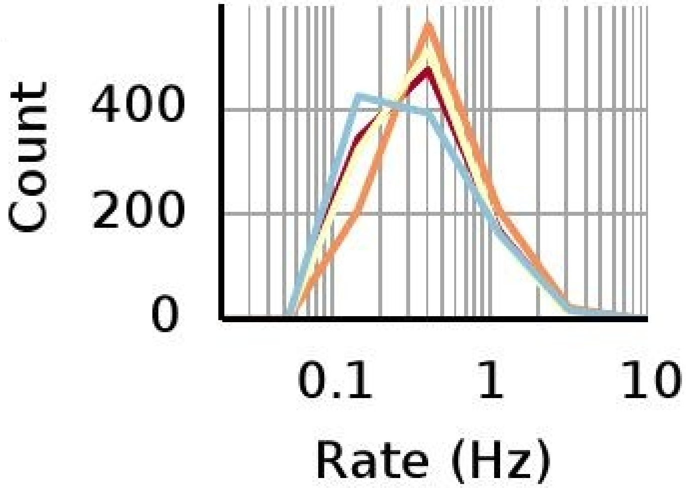


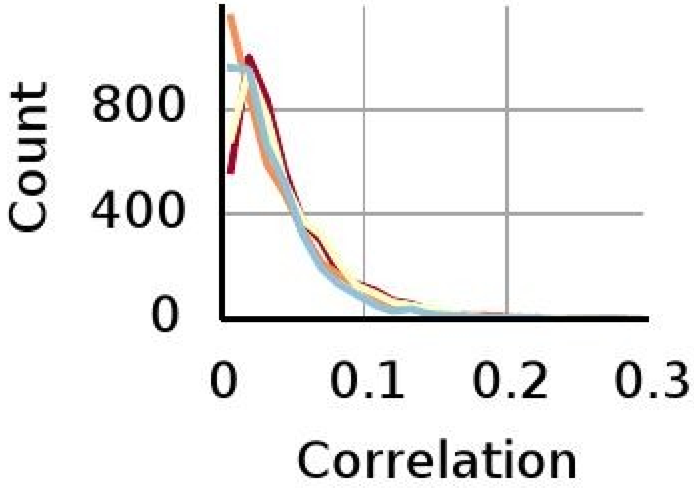


Oliver Muthmann

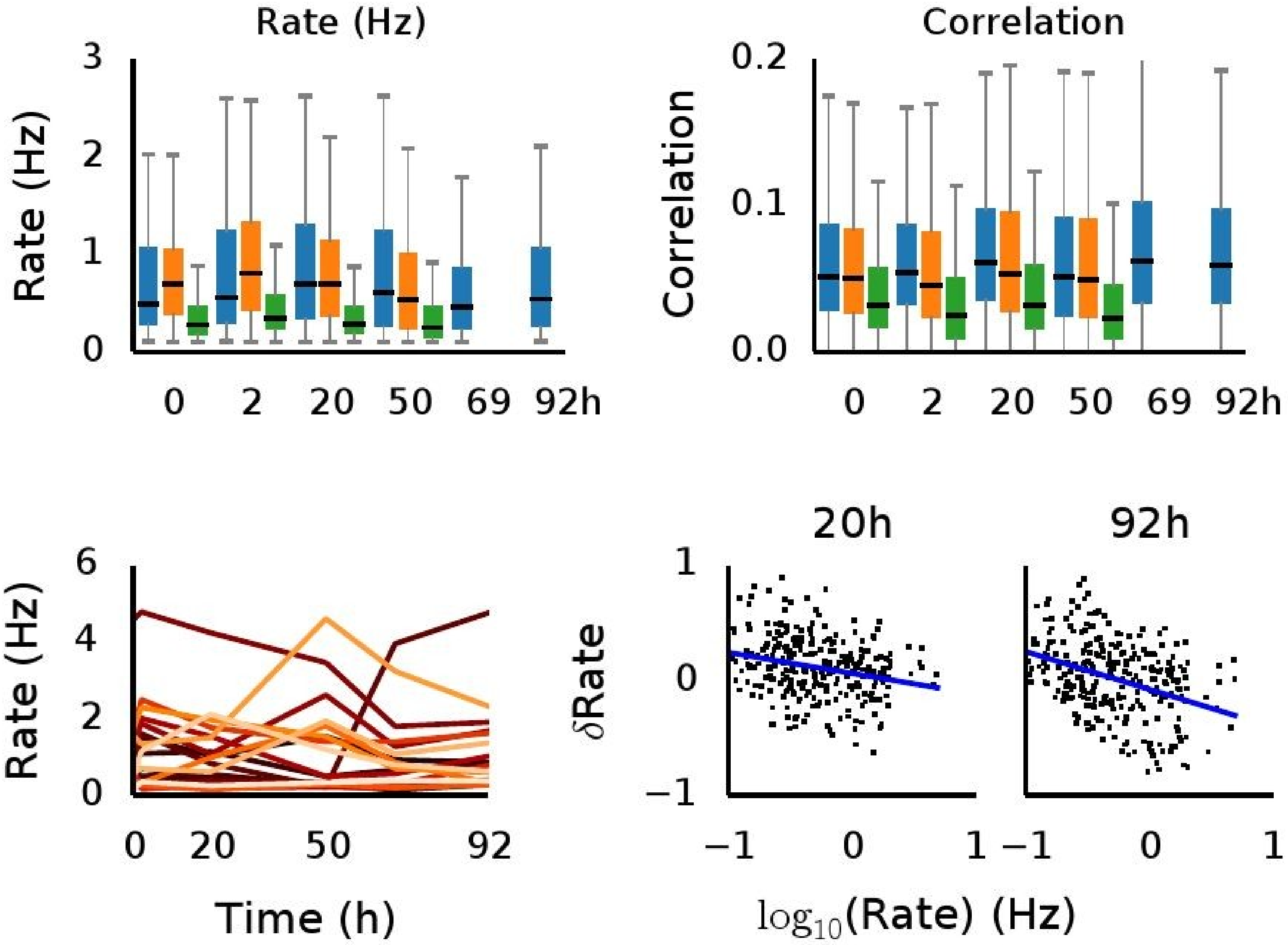
Following a culture over days



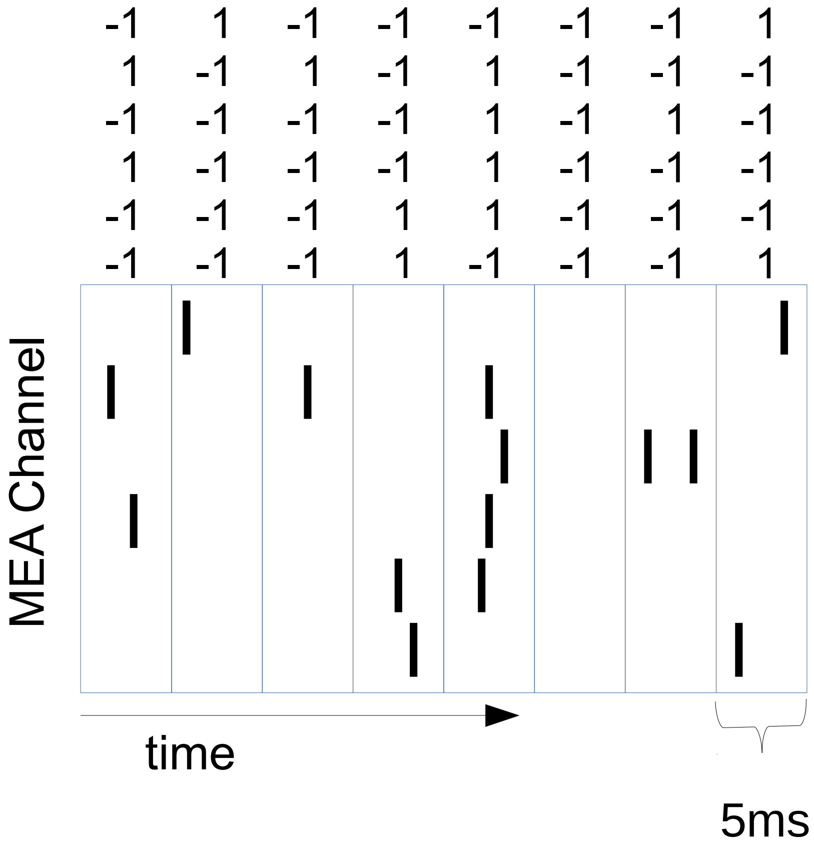


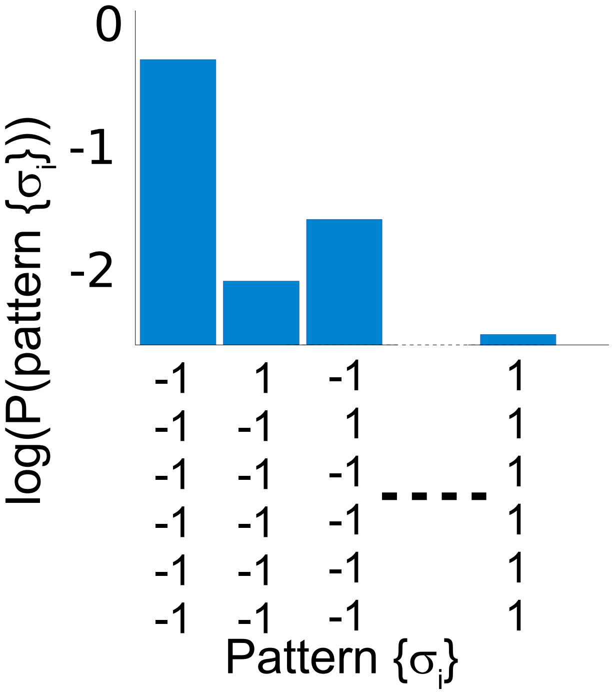


Global stability, local changes



Maximum entropy models

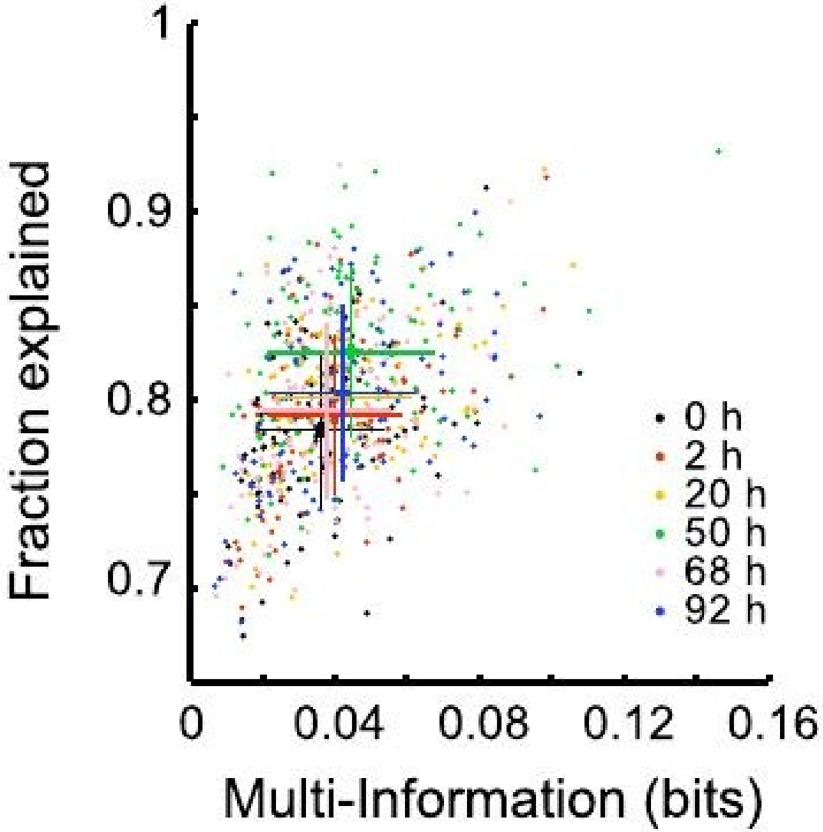




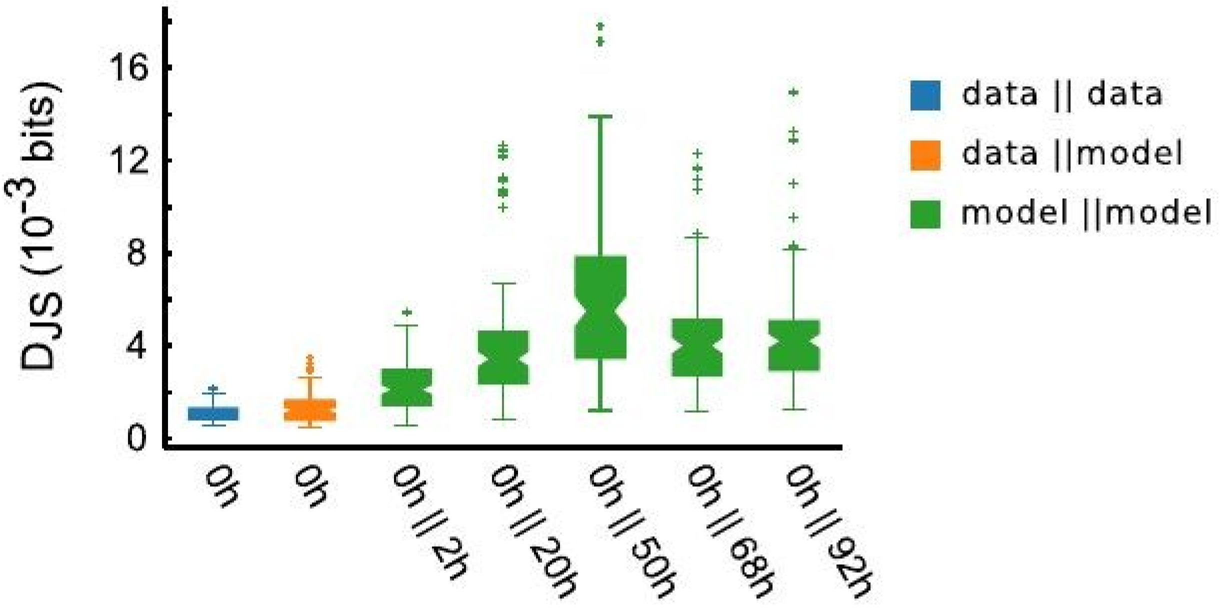
$$
\begin{aligned}
P(X) &= \frac{1}{Z}\exp\left(-H\right) \\
Z &= \sum_{\{x\}} \exp(-H) \\
H &= \sum_{j} \lambda_j x_j + \frac{1}{2}\sum_{k\neq j} \lambda_{jk} x_j x_k
\end{aligned}
$$

cf. Schneidman et al., Nature, 2006; Shlens et al., J Neurosci, 2006

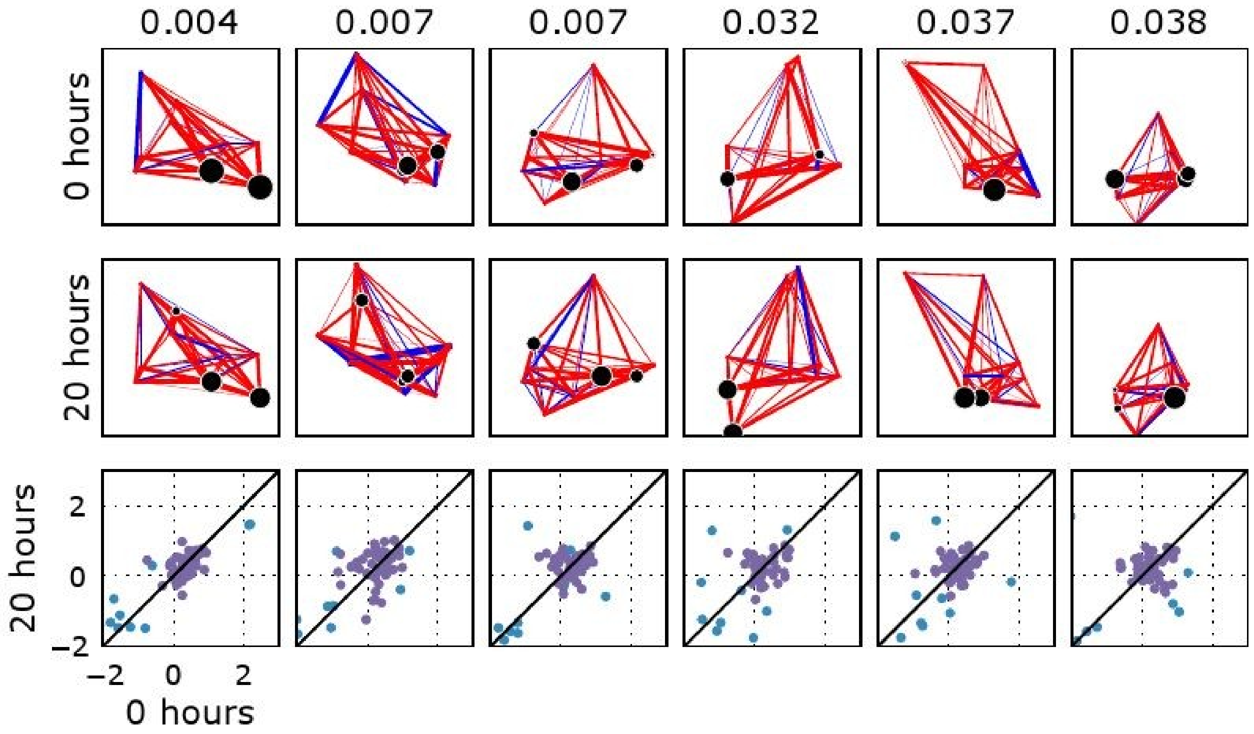
100 x 10 neuron groups

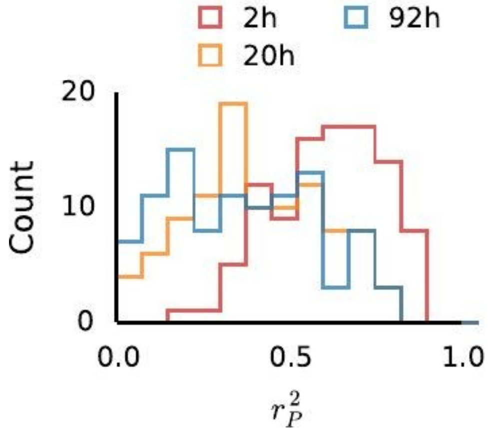


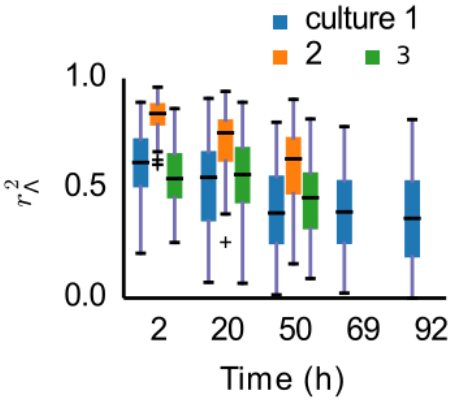
Changes over time

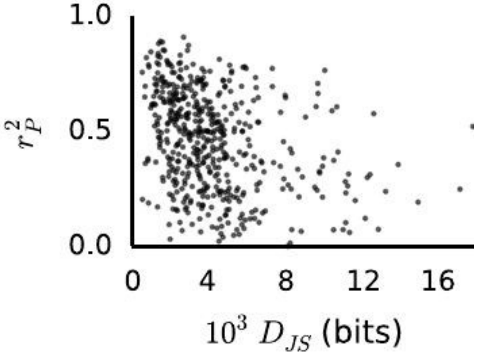


Model parameter comparison

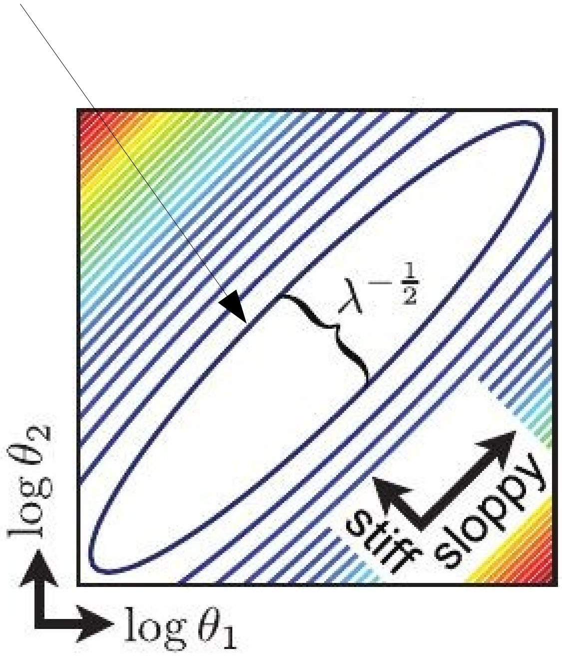






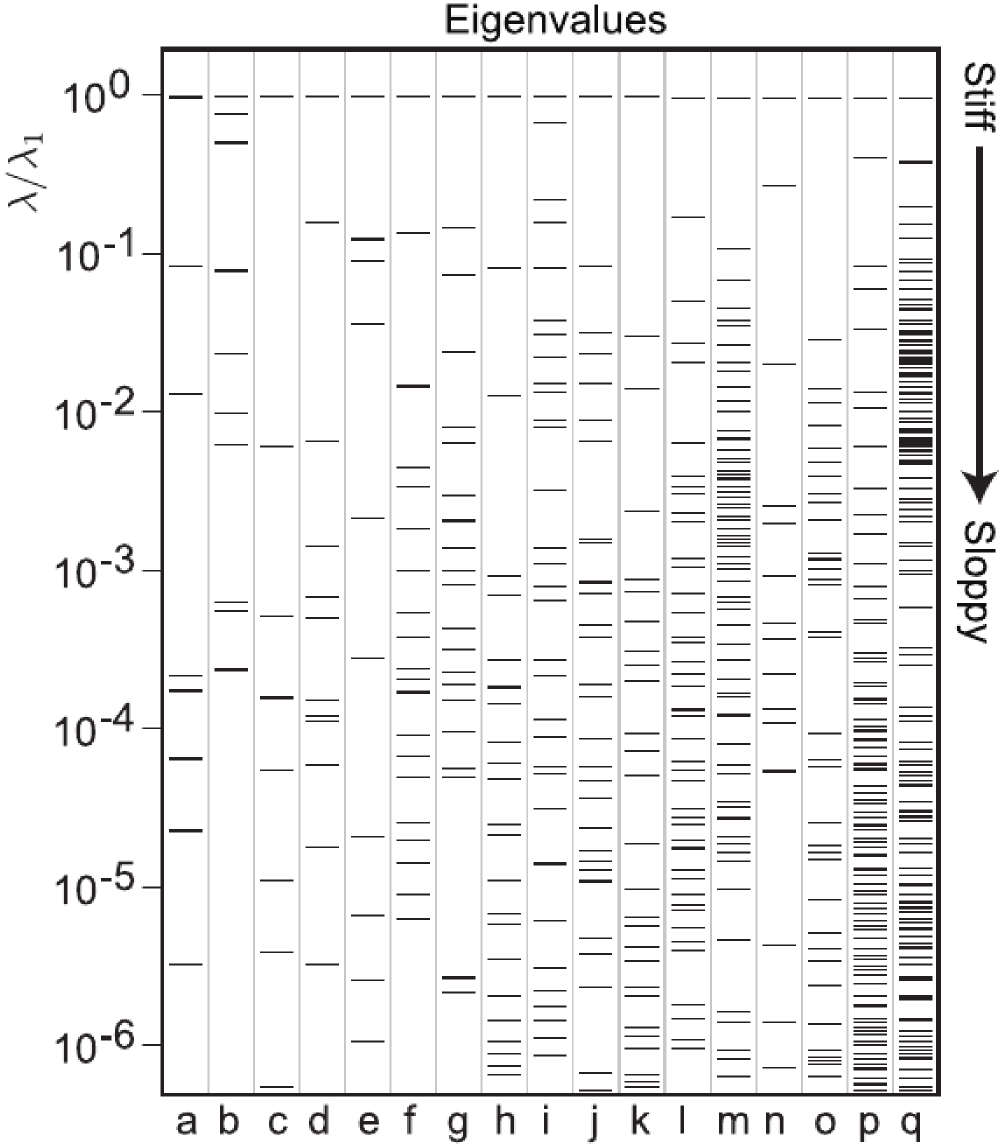


Are all parameters equally important?



constant model behaviour

$$H_{j,k}^{\chi^2} \equiv \frac{d^2\chi^2}{d\log\theta_j d\log\theta_k}$$



Gutenkunst et al., PloS Comp Biol 2007

Fisher Information Matrix

$$F_{lm}(\Lambda) = -\sum_x p(x|\Lambda) \frac{\partial \ln p(x|\Lambda)}{\partial \lambda_l} \frac{\partial \ln p(x|\Lambda)}{\partial \lambda_m}$$

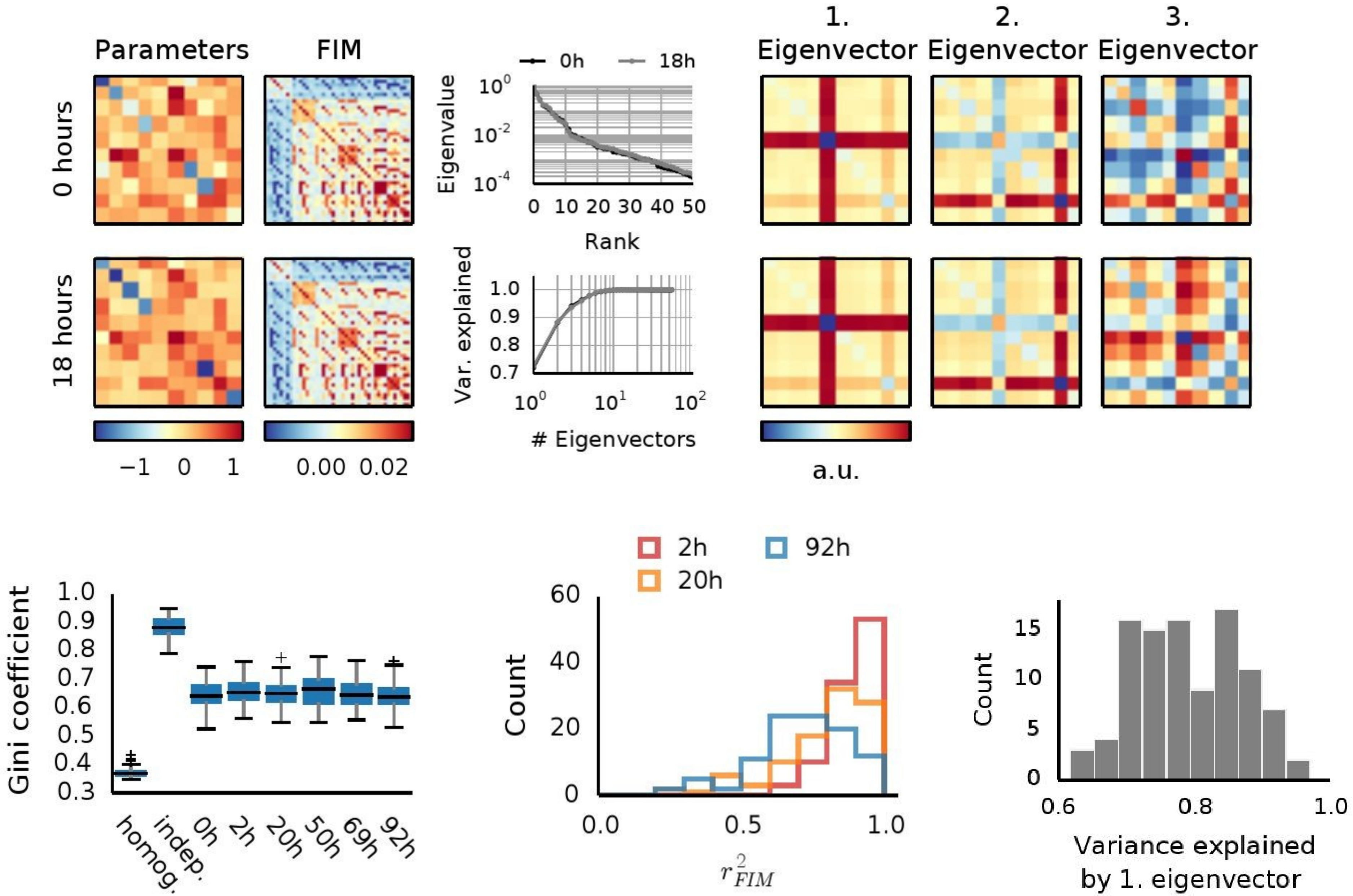
Λ : Model parameters λ_i
x : Observables

For exponential family models, this becomes:

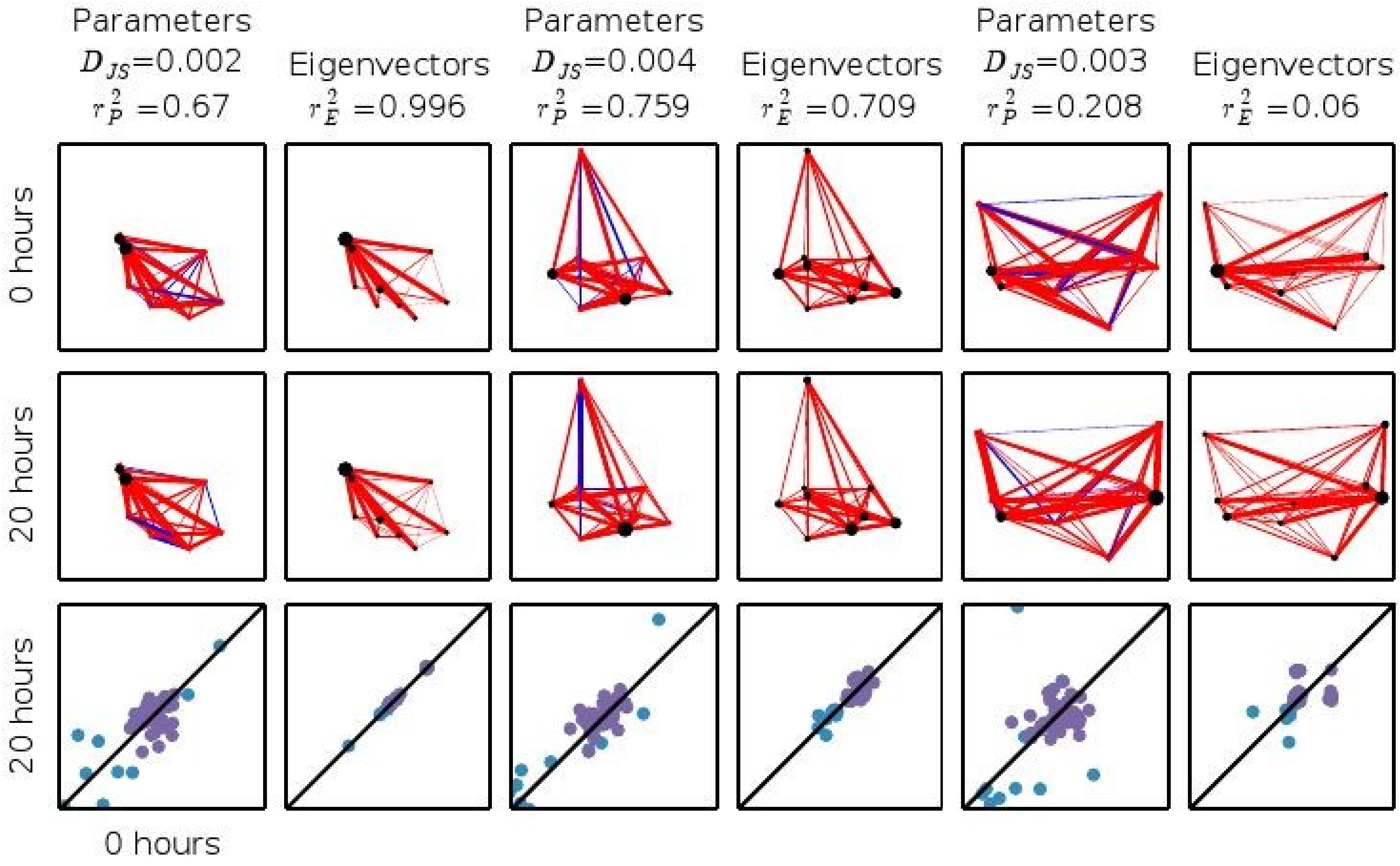
$$F_{lm}(\Lambda) = \langle X_l X_m \rangle_{mod} - \langle X_l \rangle_{mod} \langle X_m \rangle_{mod}$$

$$X_l = x_j \qquad X_m = x_j x_k$$

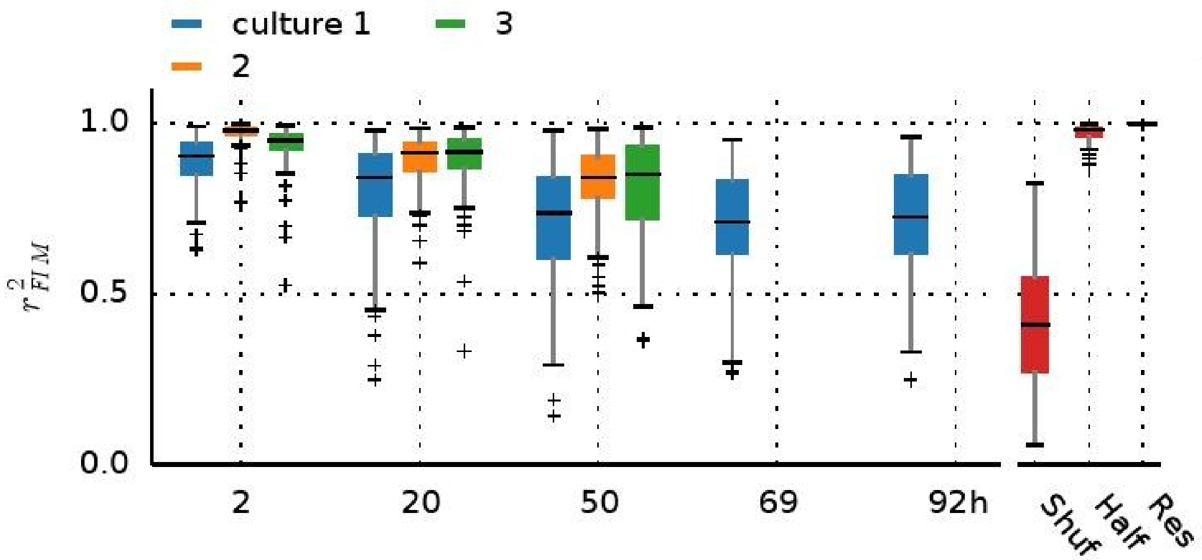
The Fisher Information Matrix

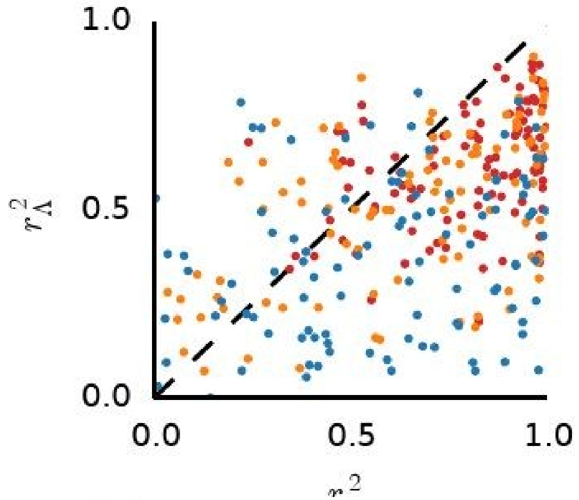


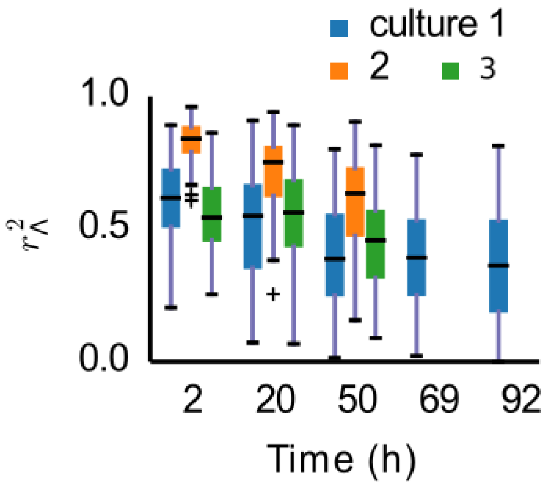
Changes in sensitivity are small

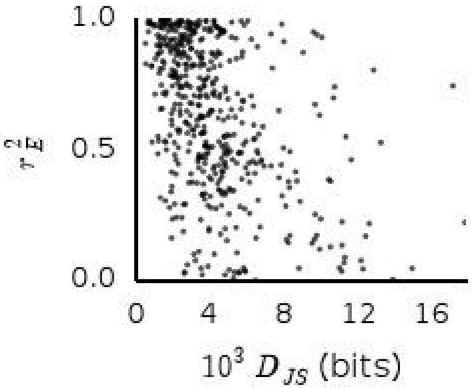


The sensitivity profile changes slowly – remodelling?

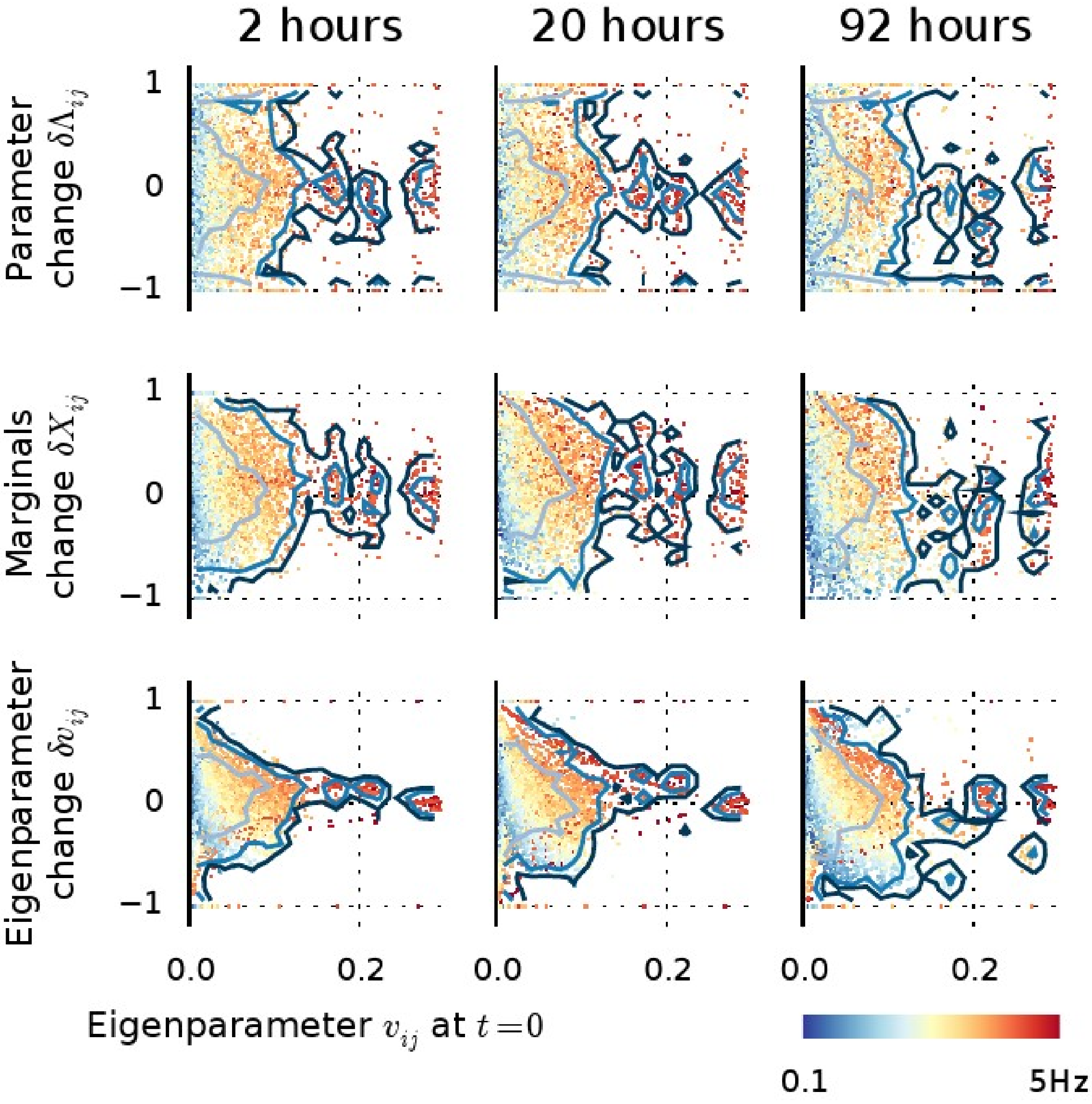


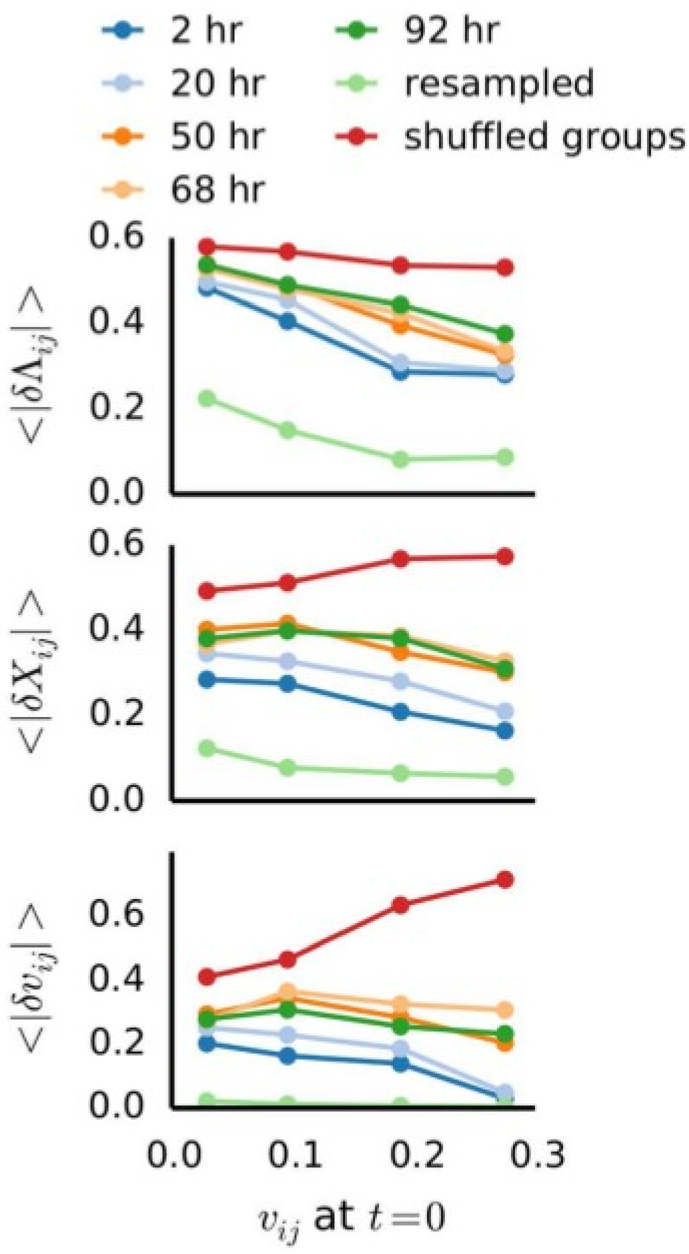




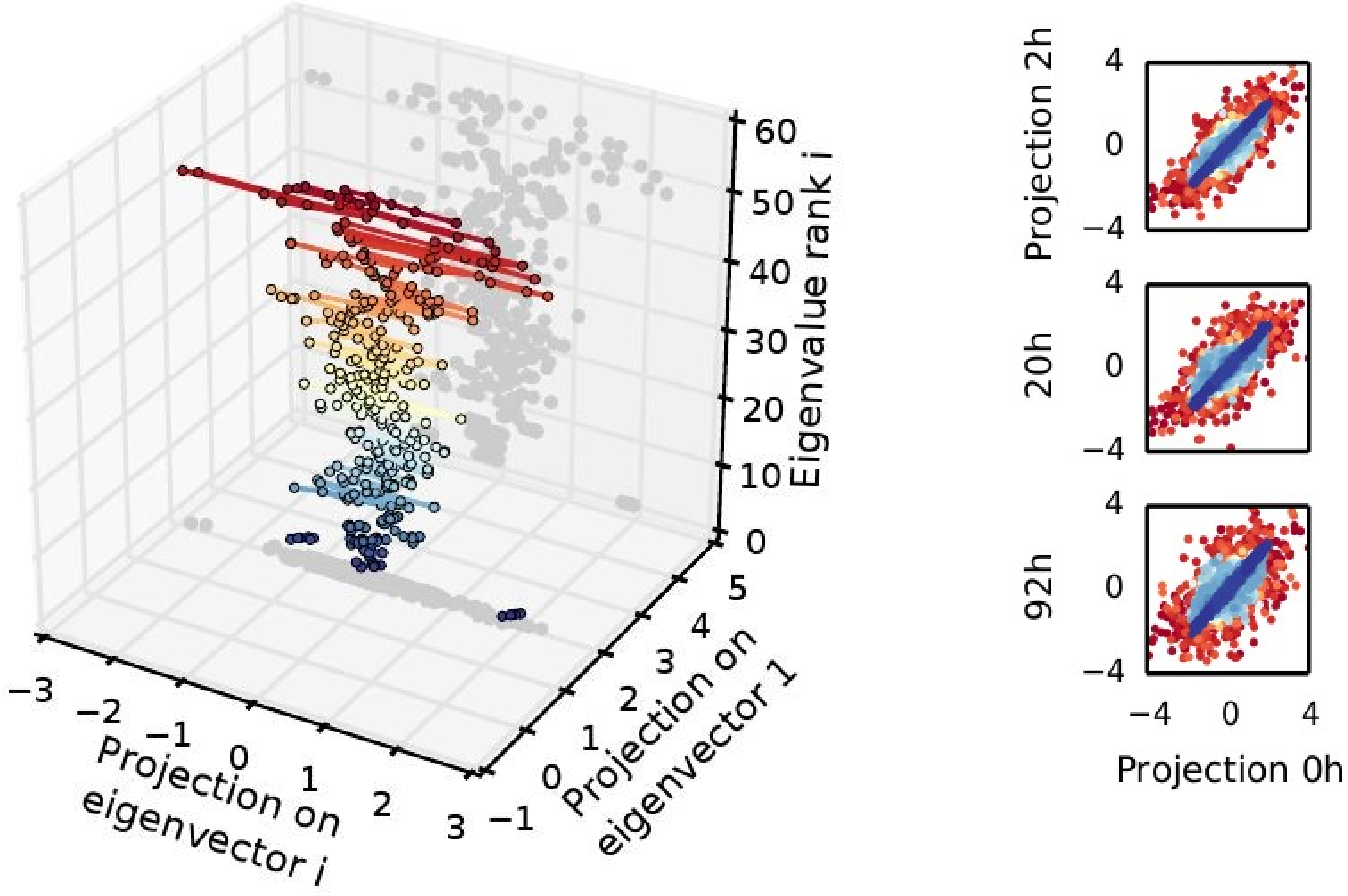


Parameter sensitivity predicts changes

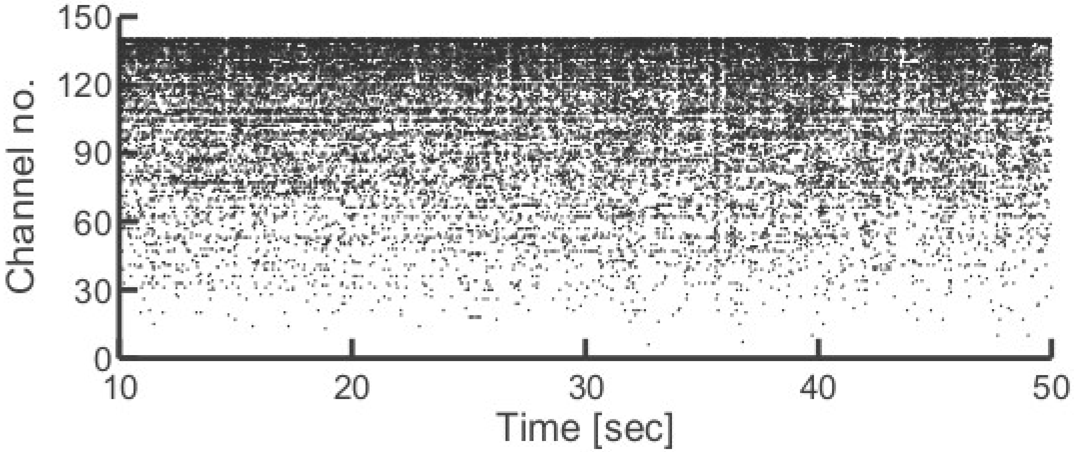


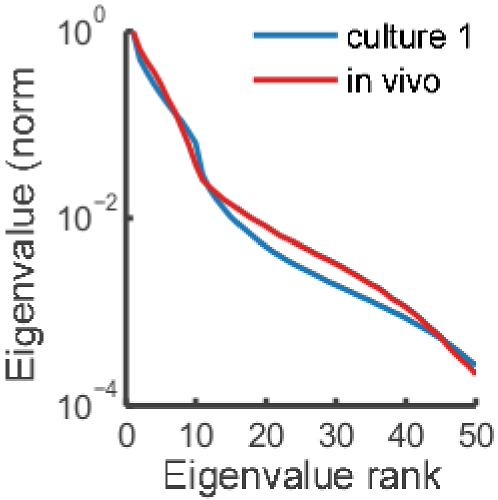


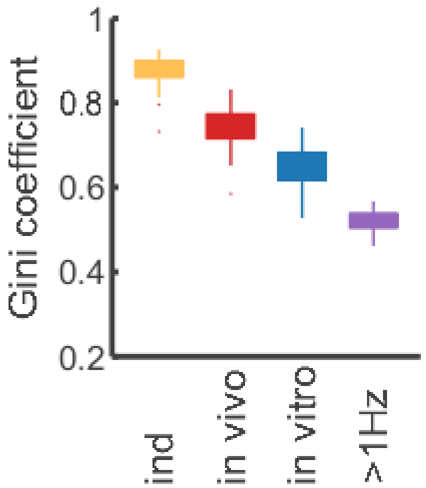
Subspace projections



Anisotropic parameter sensitivity *in vivo*

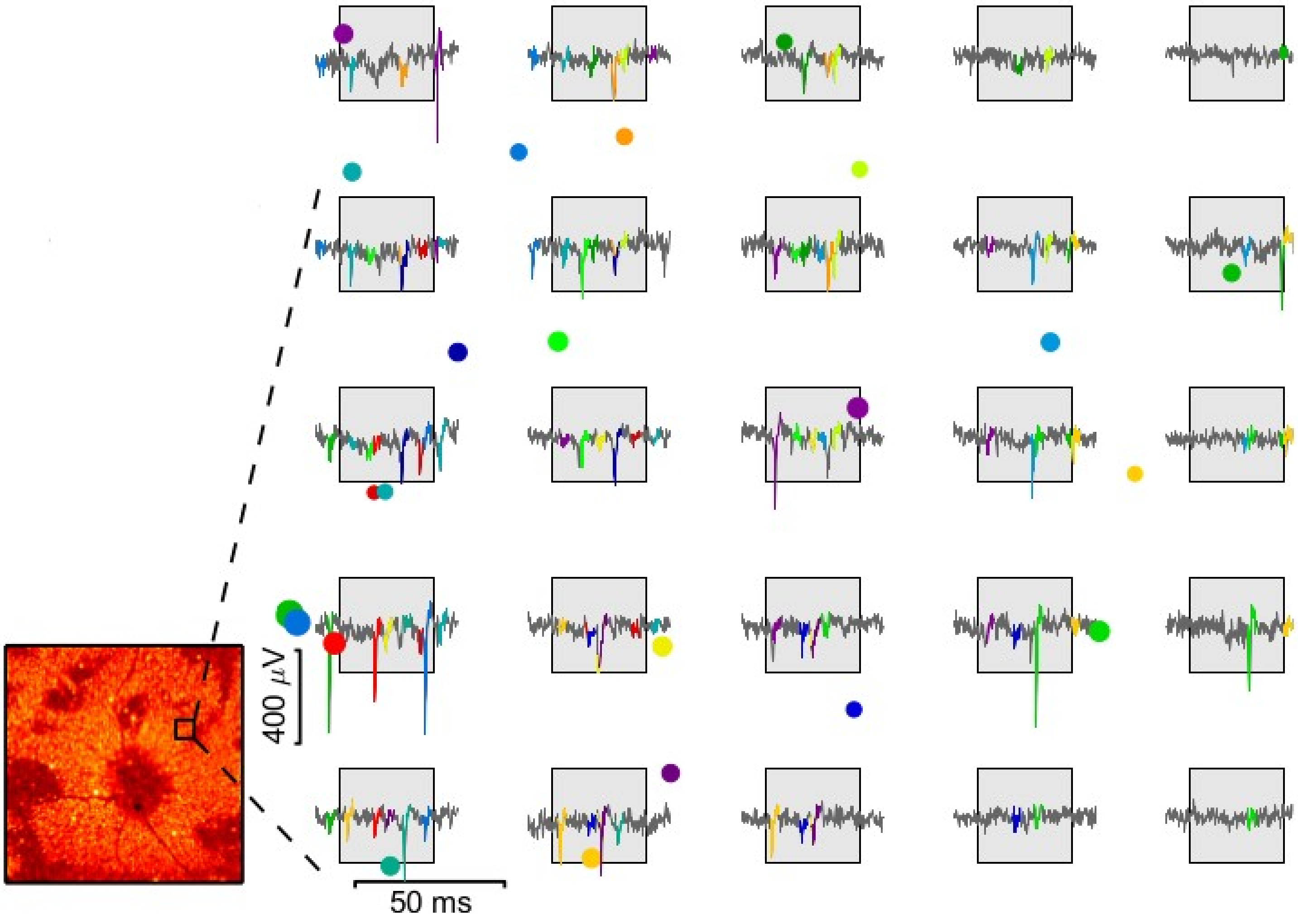






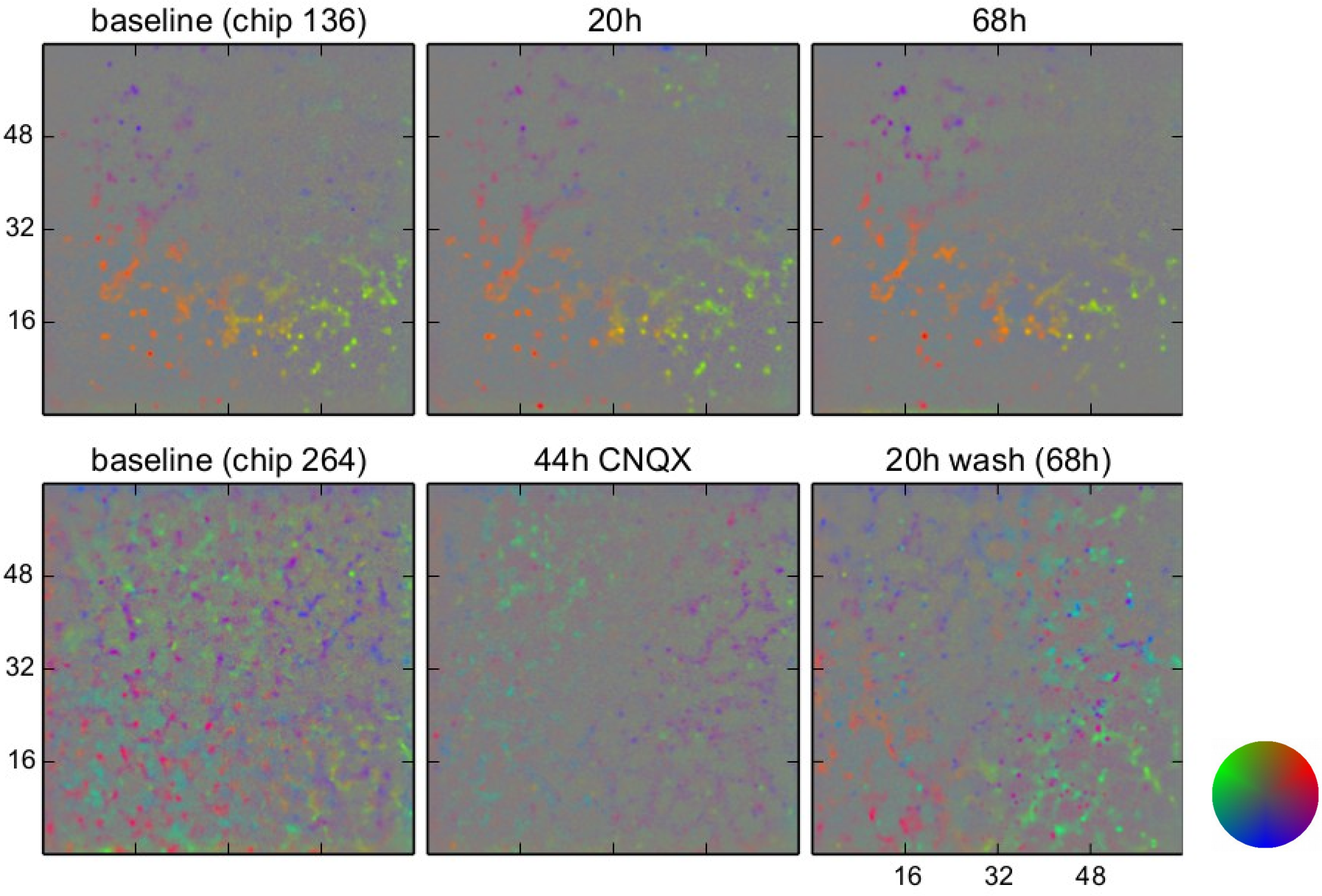
Data from: Chu C, Chien P, Hung C (2014b) Tuning dissimilarity explains short distance decline of spontaneous spike correlation in macaque V1. Vis Res 96:113–132. (CRCNS.org)

Localising spikes on the array



Oliver Muthmann

Network remodelling II



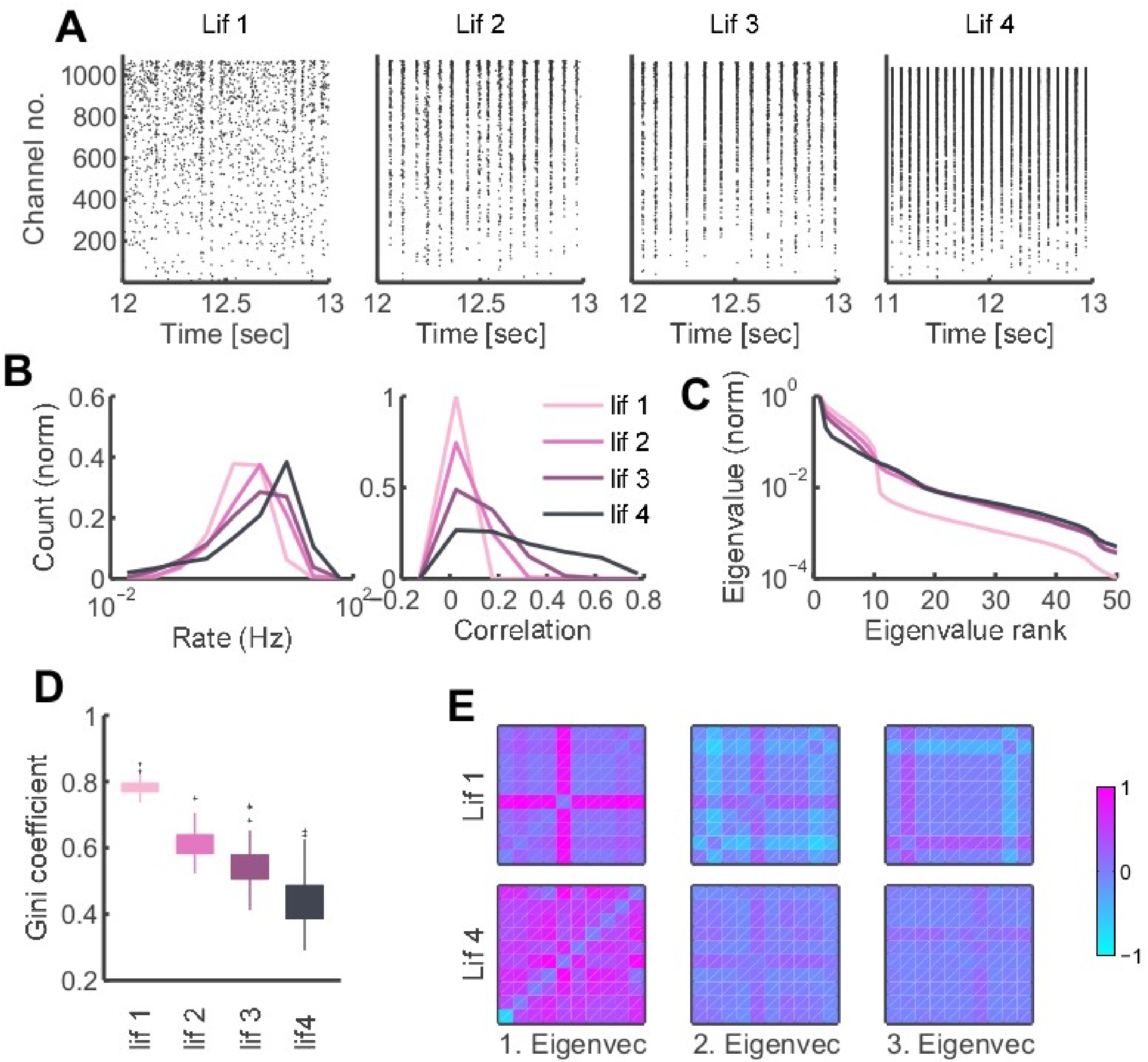
Oliver Muthmann

Summary

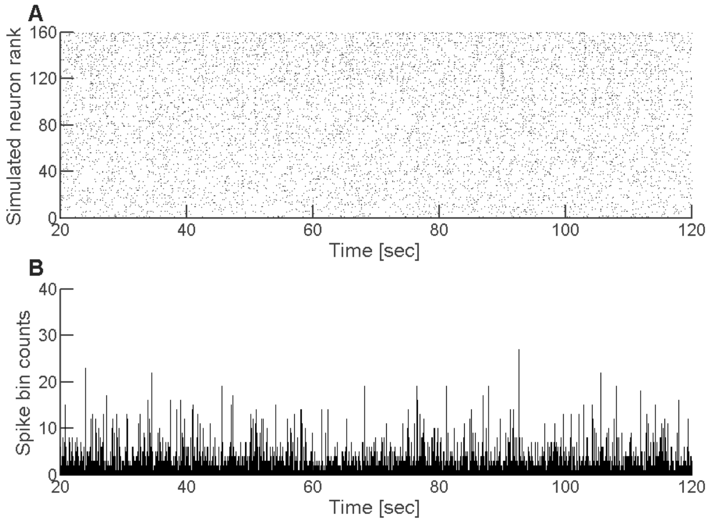
- Neuronal networks have an anisotropic parameter space
- Few neurons provide a 'stiff' scaffold (high rates)
- Faster changes are restricted to 'sloppy' dimensions
- Slower changes affect stiff dimensions

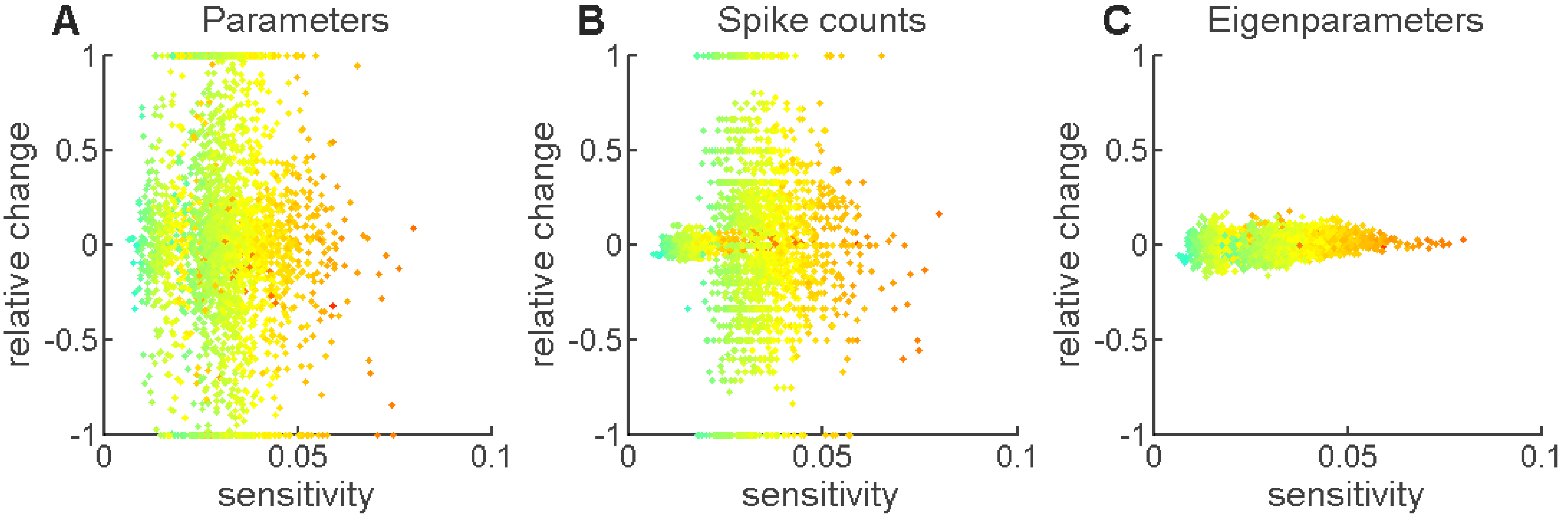
This may enable **stability** and **exploration** of the network parameter space.

Balanced LIF model

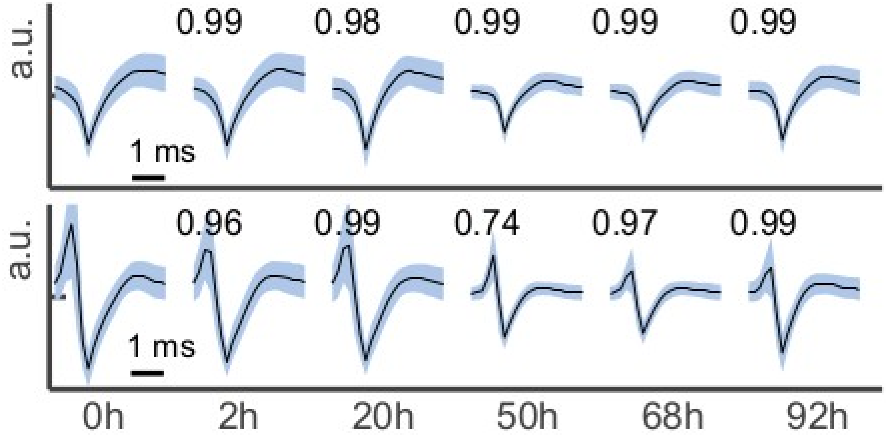


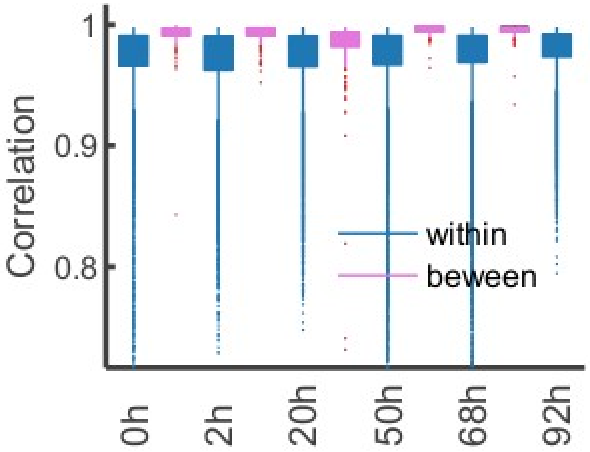
STDP


A
Simulated neuron rank
160
120
80
40
0
20
40
60
80
100
120
Time [sec]
B
Spike bin counts
40
30
20
10
0
20
40
60
80
100
120
Time [sec]

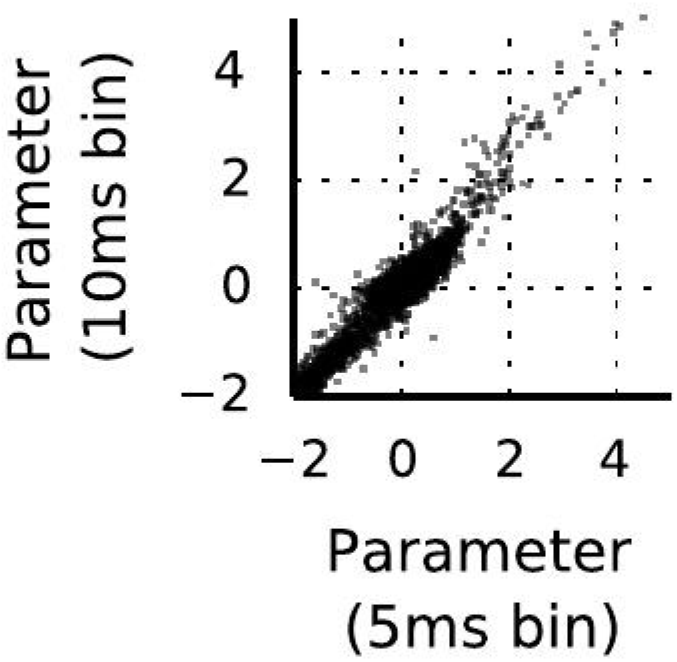

A
Parameters
B
Spike counts
C
Eigenparameters
relative change
1
0.5
0
-0.5
-1
0
0.05
0.1
sensitivity

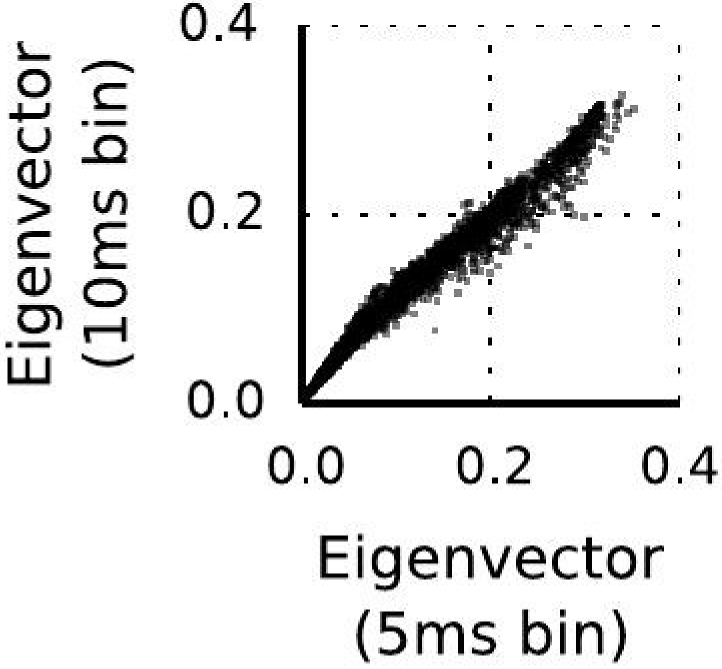
Recording stability





Does the bin size matter?





Sloppiness correlates with rate (but nothing else)